Testing light concentrators prototypes for the Cherenkov Telescope Array

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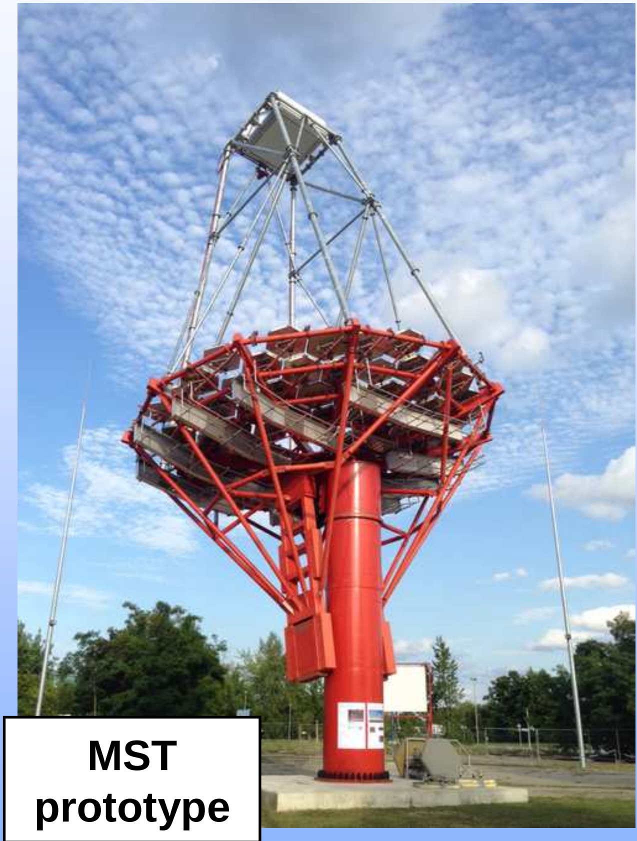
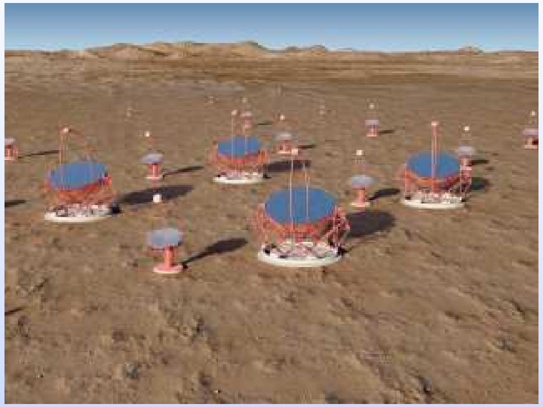
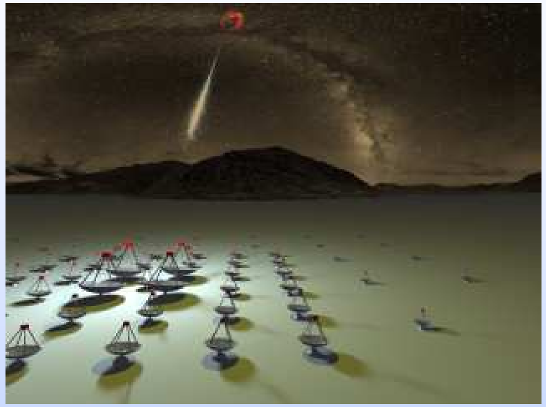
Plan of presentation

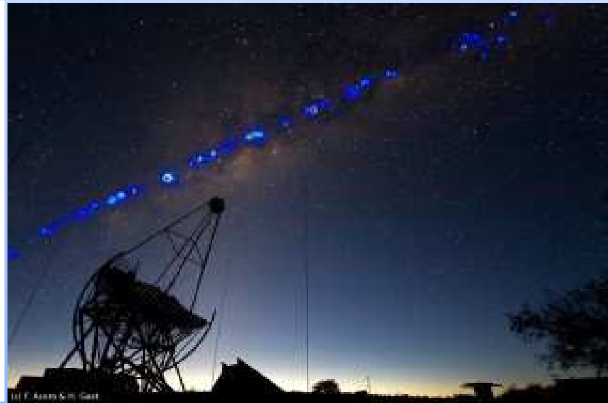
- The Cherenkov Telescope Array (CTA)
- Principle of Cherenkov telescopes
- Light Concentrator requirements
- Prototypes definition
  - Winston cones
  - Nonimaging lens
- Test bench description
  - Design
  - Error analysis
  - Measurement procedure
- Experimental results
- Conclusion

The Cherenkov Telescope Array (CTA)





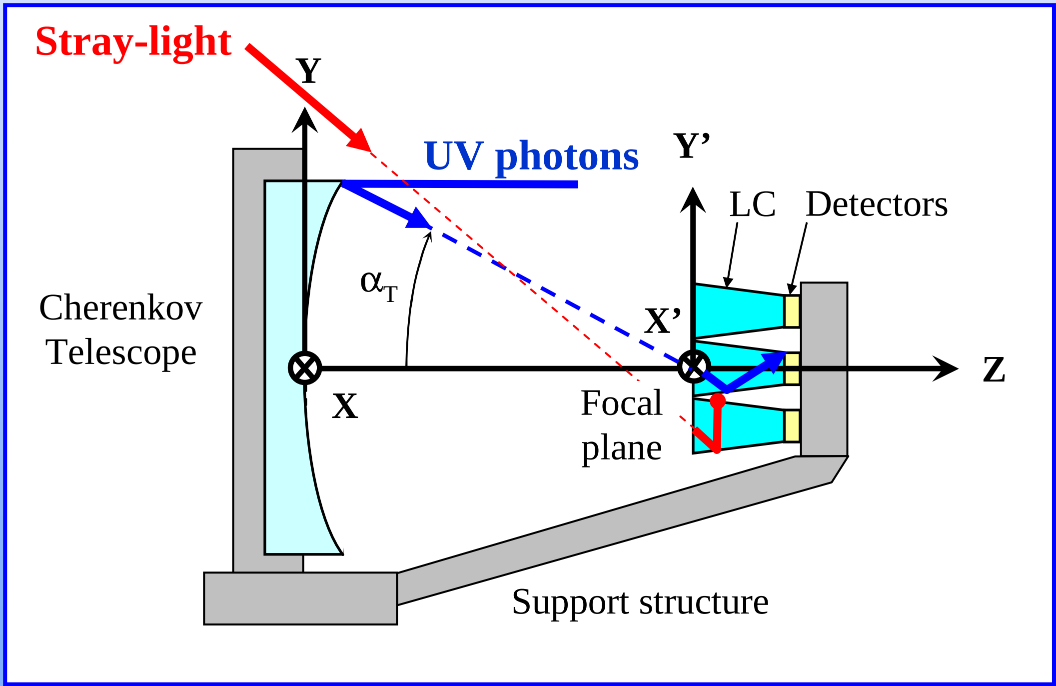




- More than 100 collecting telescopes in South and North Hemispheres (Chile and Canary Islands)
  - Including ~ 40 Medium-size telescopes (MST) of 12 m diameter

Principle of Cherenkov telescopes

- To collect very faint UV pulses at ground level, generated by high-energy cosmic Gamma-rays interacting with atmosphere
- Focal plane equipped with ~1800 photomultipliers (PM)
- Each PM equipped with a light concentrator (LC) having two main functions:
  - To maximize concentration efficiency (fill dead spaces between PMs)
  - To reject stray-light originating from terrestrial environment



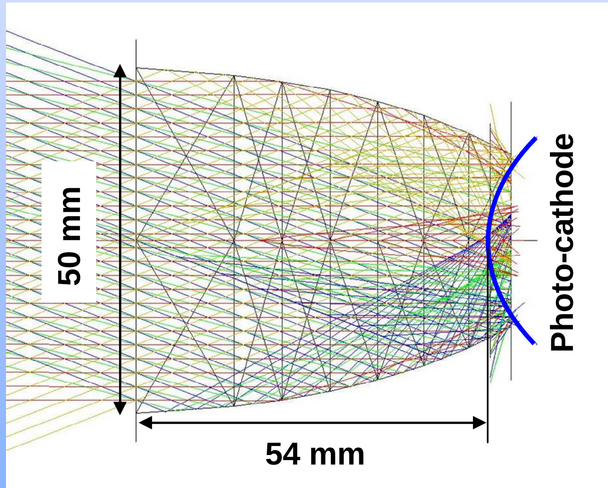
Light Concentrator requirements

- Most critical requirements: Spectral range and Optical transmission

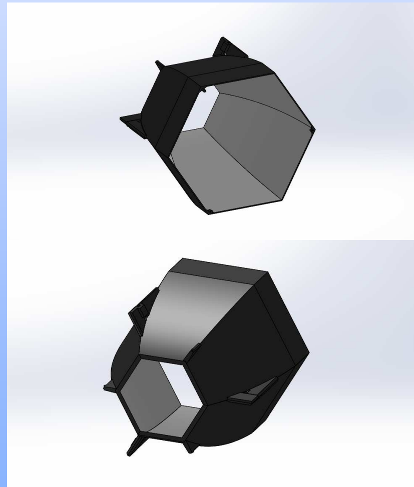
REQUIREMENTS	VALUES
Spectral range	From 300 to 600 nm
Cut-off angle α_C	Depending on the optical design $\alpha_C = 28.5 \pm 0.5$ deg. for CPC $\alpha_C = 26 \pm 0.5$ deg. for nonimaging lens
MST telescope half-angle α_T (nominal)	$\alpha_T = 21.2$ deg.
Optical transmission for all angles $0 \leq \alpha \leq \alpha_T$ and all polarization states of light	$T \geq 80$ % on the full spectral range (goal 85%)
Entrance aperture *y'*	Hexagonal of width 49 mm flat to flat
Shape error	≤ 0.1 mm
Photomultiplier Tube (PMT)	Hamamatsu R12992-100 series

Prototypes definition: Winston cones

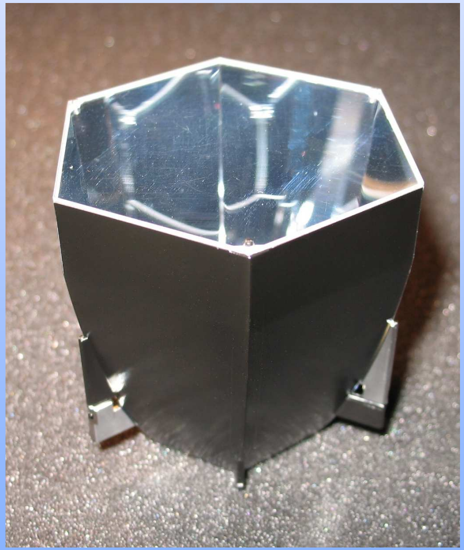
- Made of three petals of molded plastic
- Coated with high-reflective layers
- Will be protected from harmful desert environment by a large common Plexiglas window



Optical model



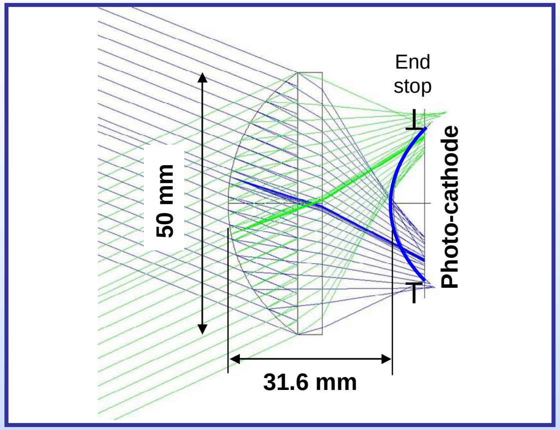
Mechanical model



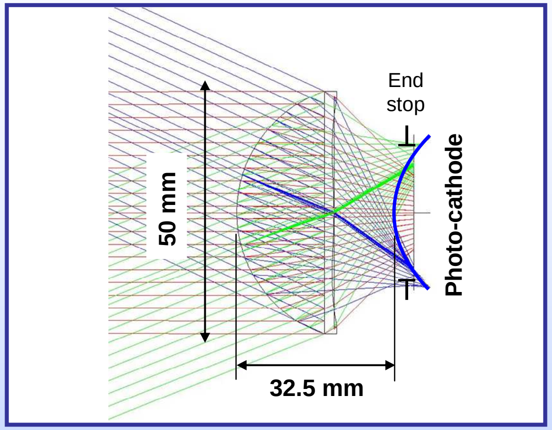
Assembled prototype

Prototypes definition: Nonimaging lenses

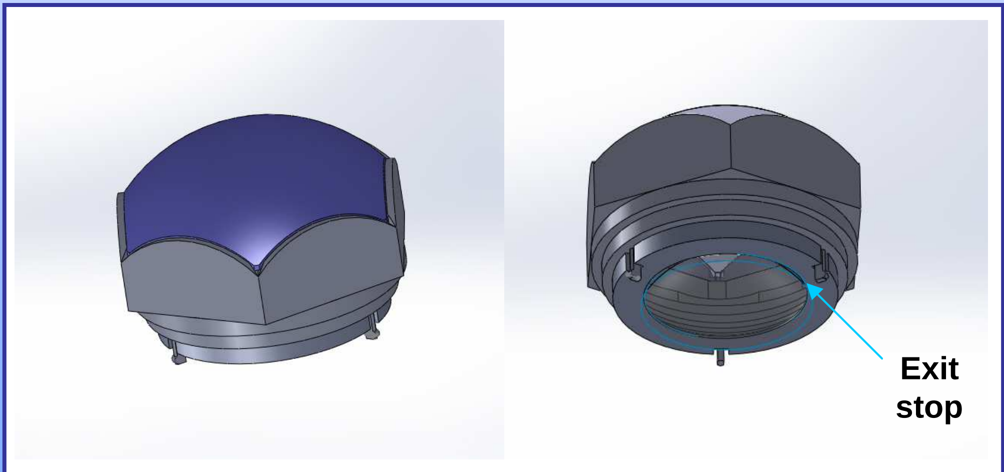
- Two different types: plano-convex and aspheric
- Made of FK5 glass (good transmission in near-UV range)
- Anti-reflection coated on both faces
- Also act as protective windows



Plano-convex lens



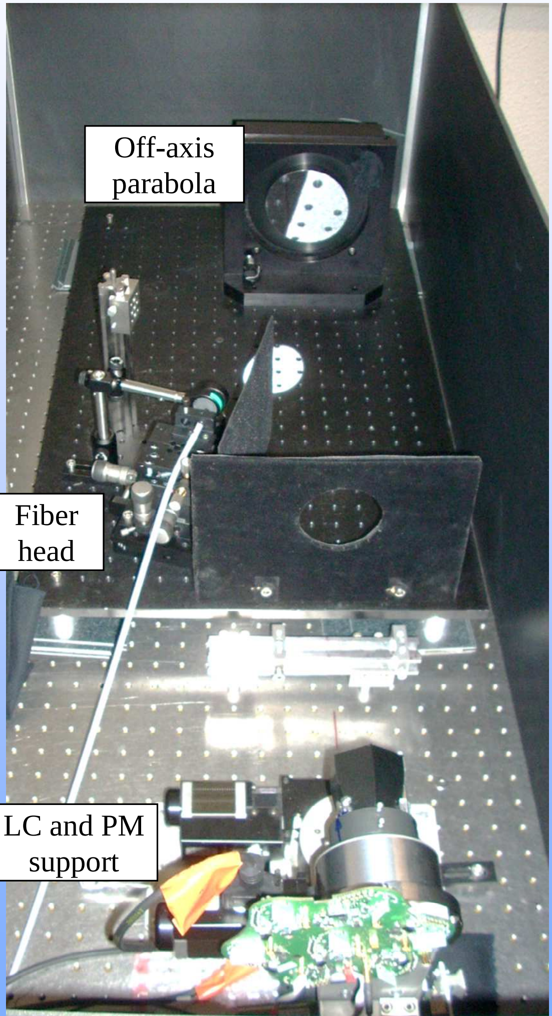
Aspheric lens

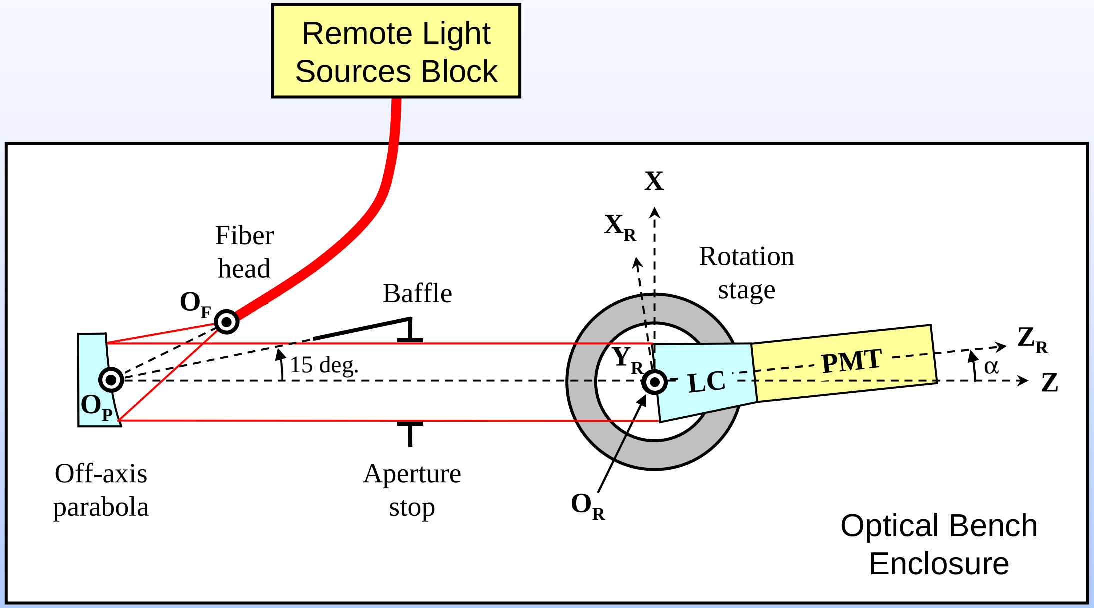


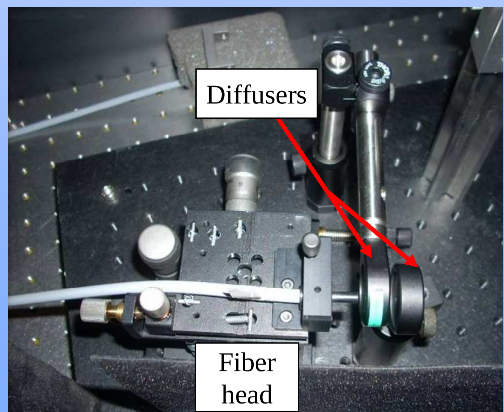
Mechanical model

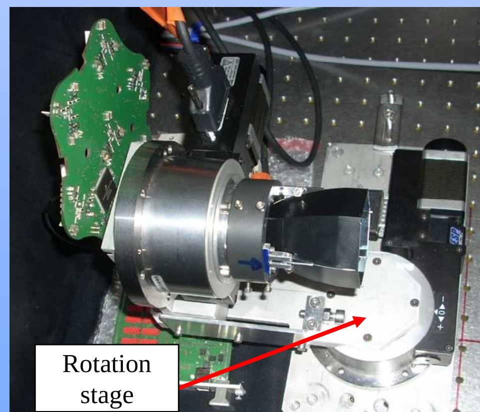
Prototype

Test bench design





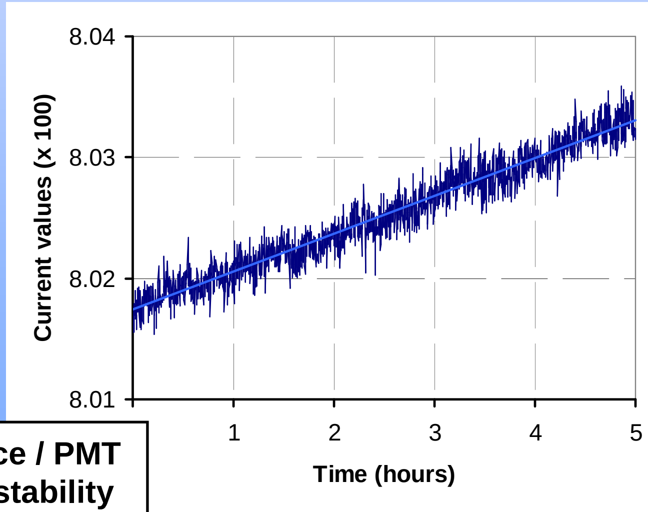




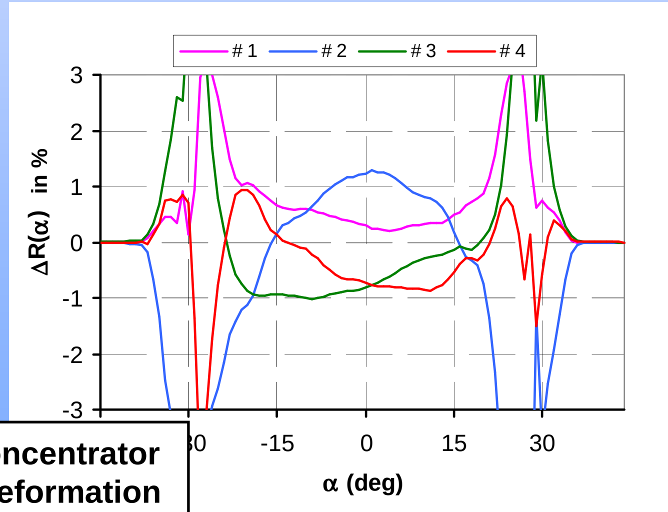
Test bench error analysis

- Typical repeatability error of **0.34 %** (worst case **1.3 %**) for rejection curves and relative transmission measurement
- Typical absolute error of **1.6 %** (worst case **2.5 %**) for spectral transmission curves

Error Source	Type	RMS Error (%)	Max. Error (%)
Beam non-uniformity	Bias	1.23	1.23
Light source and PM intensity	Drift	0.02	0.02
Light source and PM intensity	Random	0.01	0.06
PM voltage adjustment	Random	0.02	0.05
LC positioing error (XYZ)	Random	0.12	0.34
LC positioing error (roll angle)	Random	0.09	0.16
LC shape deformation	Random	0.28	0.66
Repeatability error (%)		**0.34**	**1.29**
Absolute error (%)		**1.57**	**2.52**



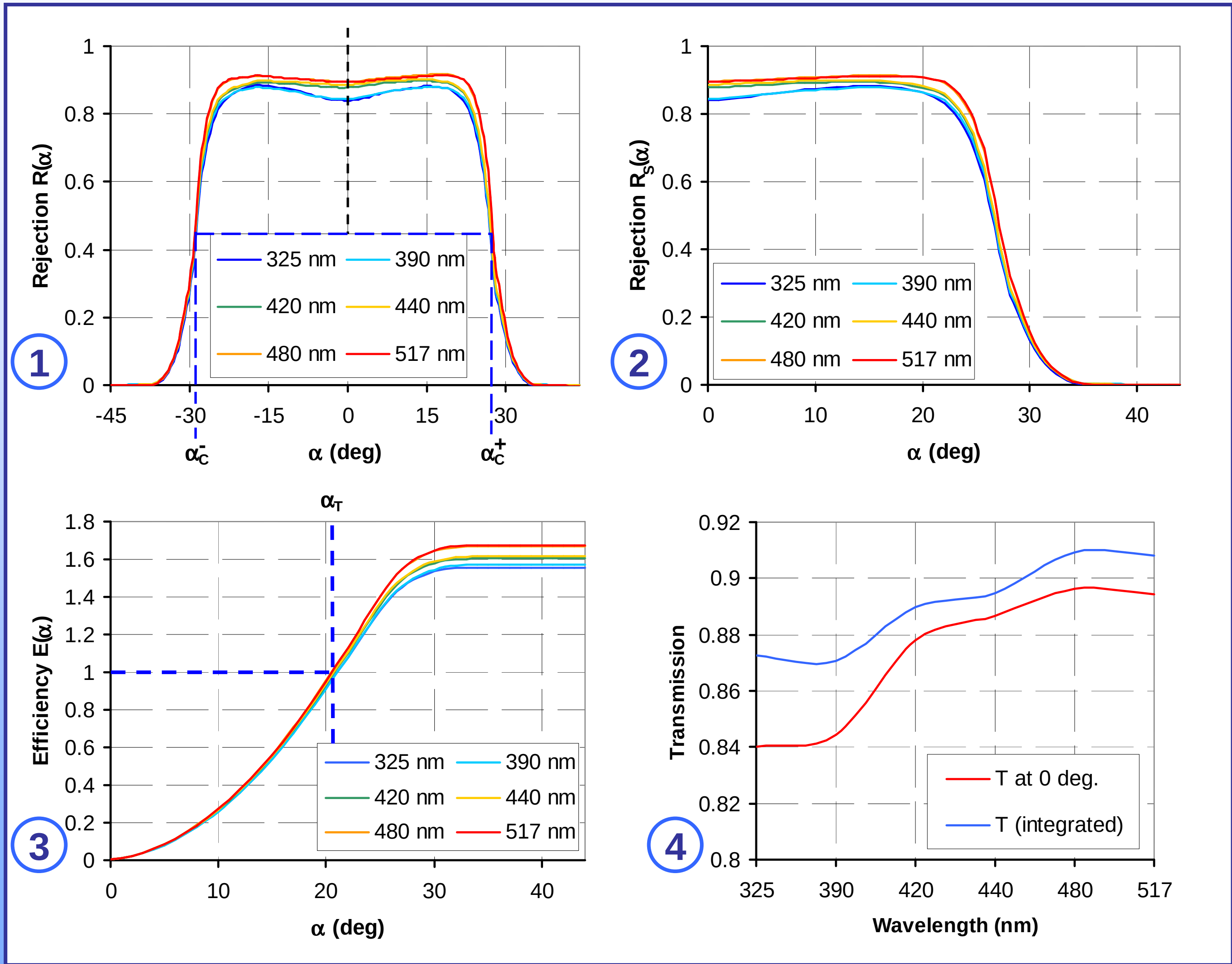
Light source / PMT response stability



Light concentrator shape deformation

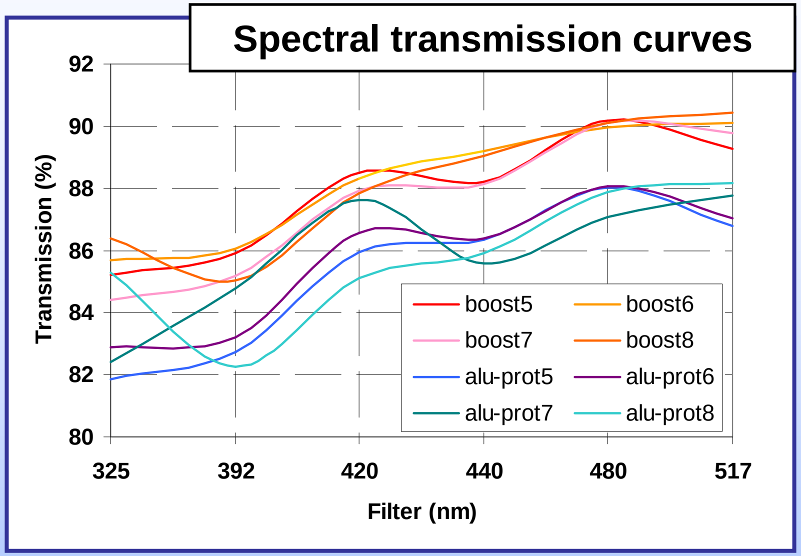
Measurement procedure

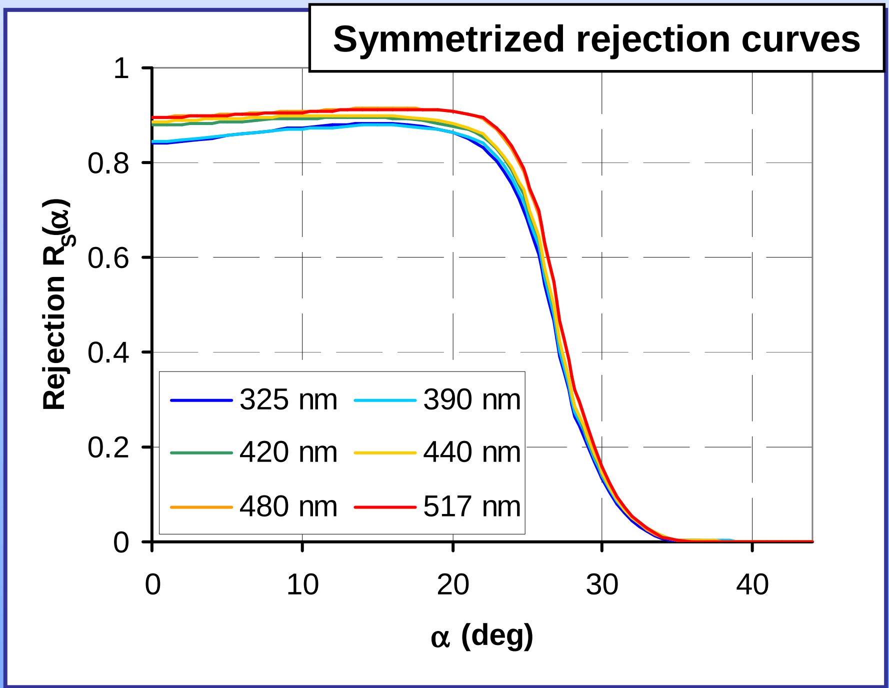
1. **Calibrated rejection curves**
2. **Symmetrized rejection curves**
3. **Radiallly integrated curves**
4. **Spectral transmission curves**

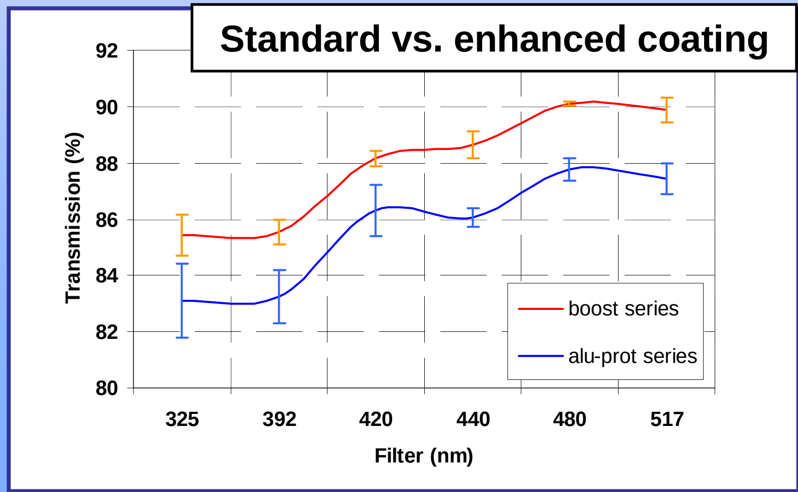


Experimental results: Winston cones

- Two different series: standard or enhanced reflective coatings
- Results are well above specification: from **85 to 90 %** for enhanced coating series

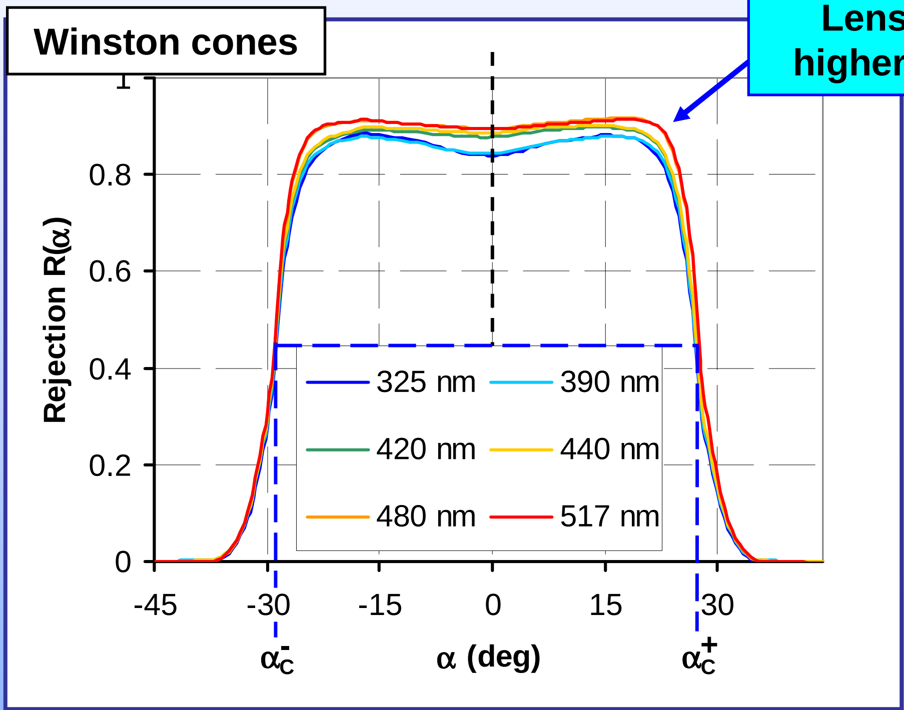


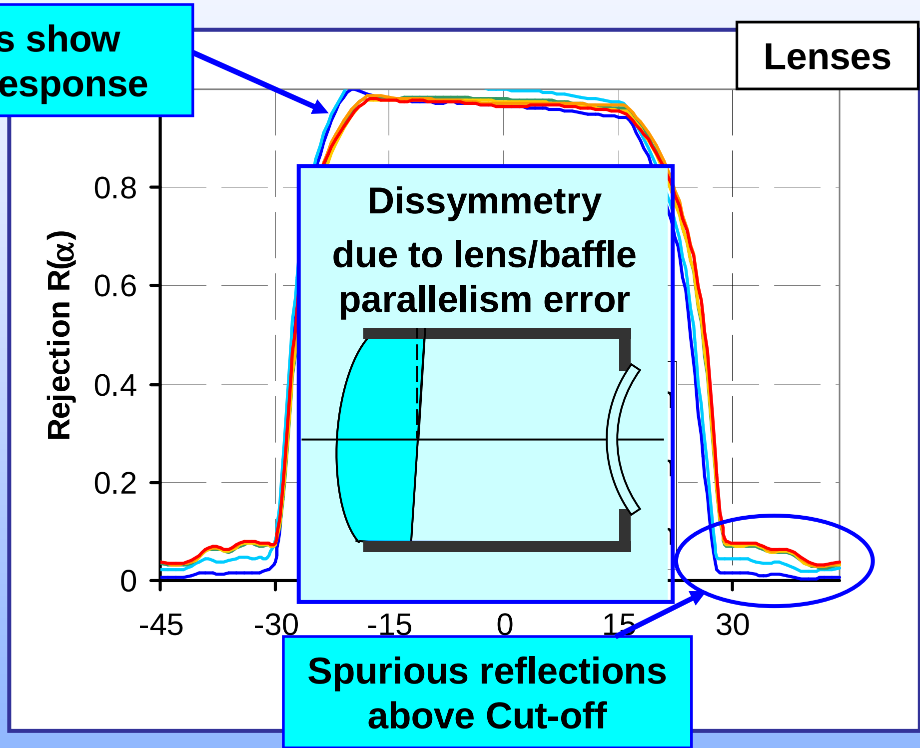




Nonimaging lenses vs. cones

- Raw rejection curves show different aspects



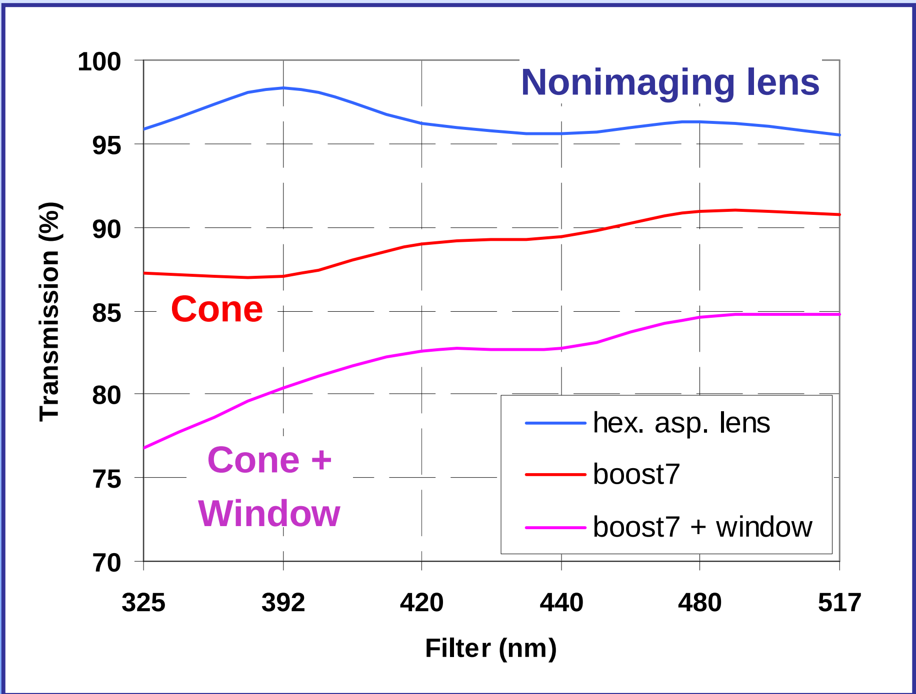


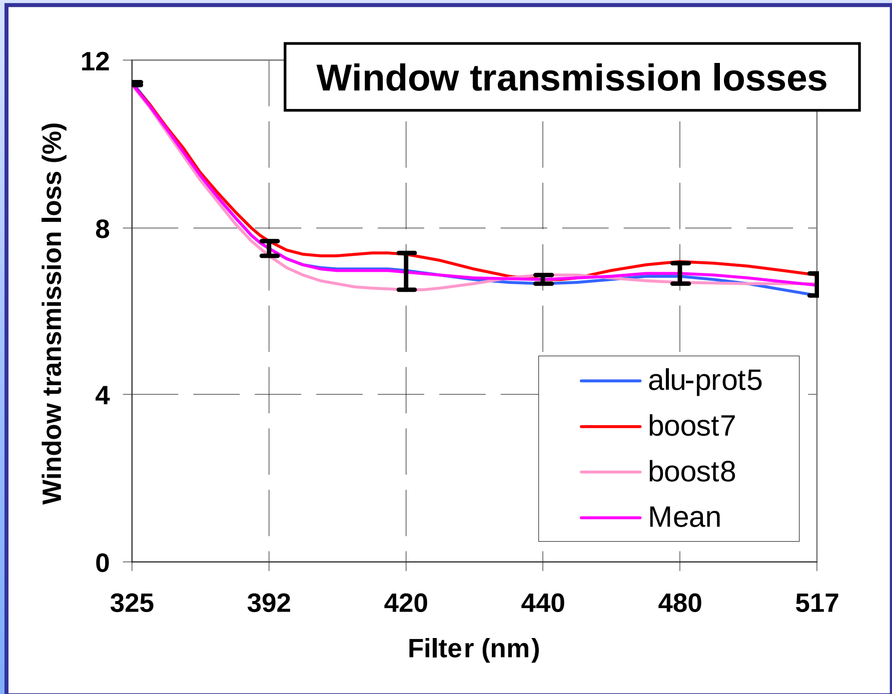
- Cut-off angles →

Cut-off angle α_C	Average (deg.)	Maximal deviation (%)	Standard deviation (%)	Requirement (deg.)
Winston cones	27.9 ($\phi = 0°$) 29.4 ($\phi = 30°$)	0.7	0.3	28.5
Nonimaging lens	26.5	1.8	1.4	25.5

Nonimaging lenses vs. cones

- Final comparison between nonimaging lenses, Winston cones, and cones + Plexiglas window
  - Lenses are more efficient than cones alone (**+5-11 %**) and cones + window (**+11-19 %**) – depending on wavelength





Conclusion

- Two different types of light concentrators have been designed for the Cherenkov Telescope Array (CTA)
  - Classical Winston cone
  - Nonimaging lens (Following Edge-ray Principle)
- Both types of concentrators have been prototyped, a test bench was developed in our laboratory
- Extensive test campaign led to the following conclusions:
  - Pure performance is in favor of nonimaging lenses. But they present some drawbacks:
    - Stray reflections above cut-off angle
    - Heavier mass
    - Higher cost
- Thus Winston cones were selected as baseline for CTA