High index glass spherical targets for laser interferometry

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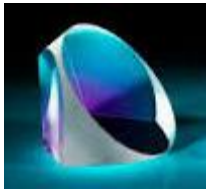
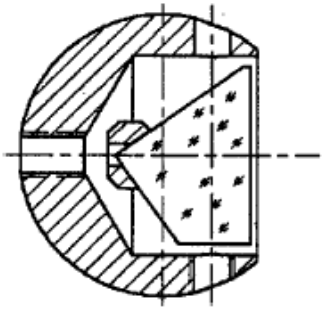
Motivation

- The targets, retroreflecting light beam, are used in interferometers, laser trackers, and alignment systems
- Ball as a target is a good reference
- It can be used both for imaging and interferometry measurements
- It can be placed anywhere with high precision

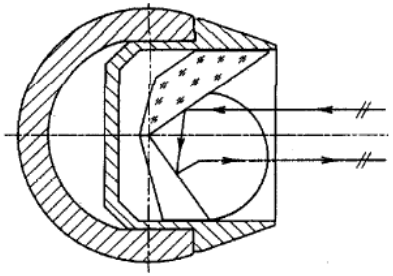
Present state of art of retro-reflective targets

corner cube glass prism





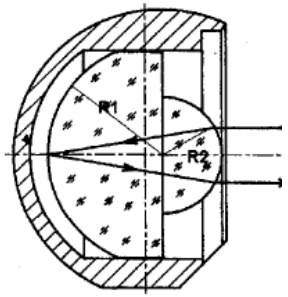
open-air hollow corner cubes



- Used for both distance and interferometry measurements
- Narrow acceptance angle for position detection (about 20°)

- Made from two hemispheres.
- Larger acceptance angles
- Never used in interferometry due to problems with complex interference pattern → complicating measurements interpretation

Cat's eye

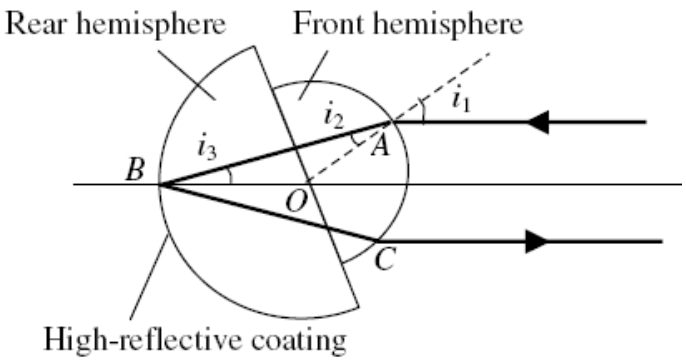


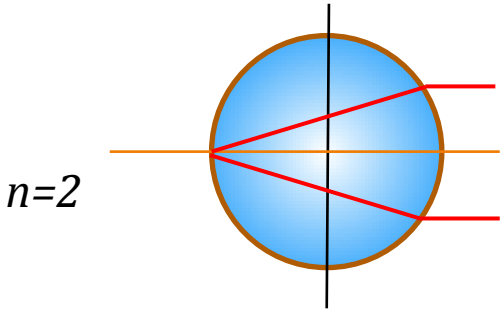
Cat's eye

- the cat's-eye retroreflector has two concentric hemispheres having different radii glued together

$$r_1 = (n-1)\, r_2$$

- An optical path analysis shows that the offset between the centres of the two hemispheres has a large influence on the measuring accuracy Aspherical cat's eye eliminates this error



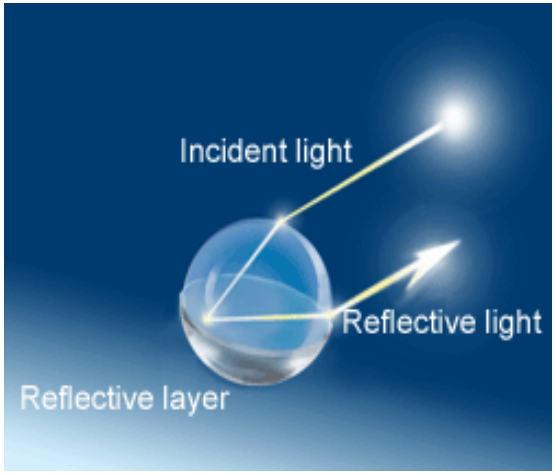


Using of hight index glas n = 2 can simplifying the process of manufacture.
The acceptance angle of a spherical cat's eye is as large as 360◦ in principle.

Targets High Index Glass Balls

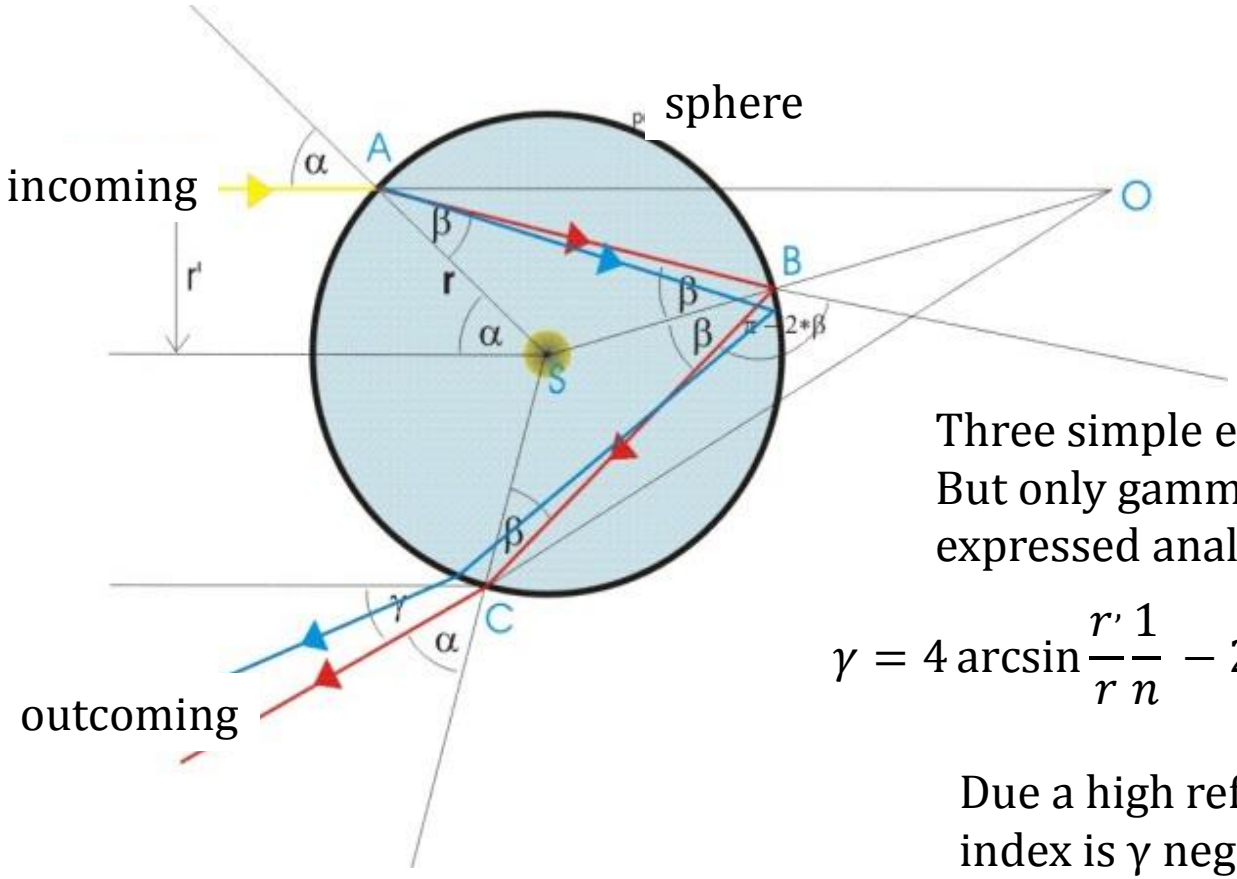
High index glass ball:

- Developed by OHARA Inc., Kanagawa, Japan
- Material : S-LAH79
- Off the shelf
- Available from diameter 1mm to 10mm
- Diameter Tolerance (µm) : 0/-3
- Sphericity (µm): 2
- Refracting index of 1.996 for He-Ne Lasers (633 nm)



Simple model with one reflection inside sphere

- Refraction / reflection / refraction



$$r' = r\ sin\alpha$$

$$4\,\beta = \gamma + 2\alpha$$

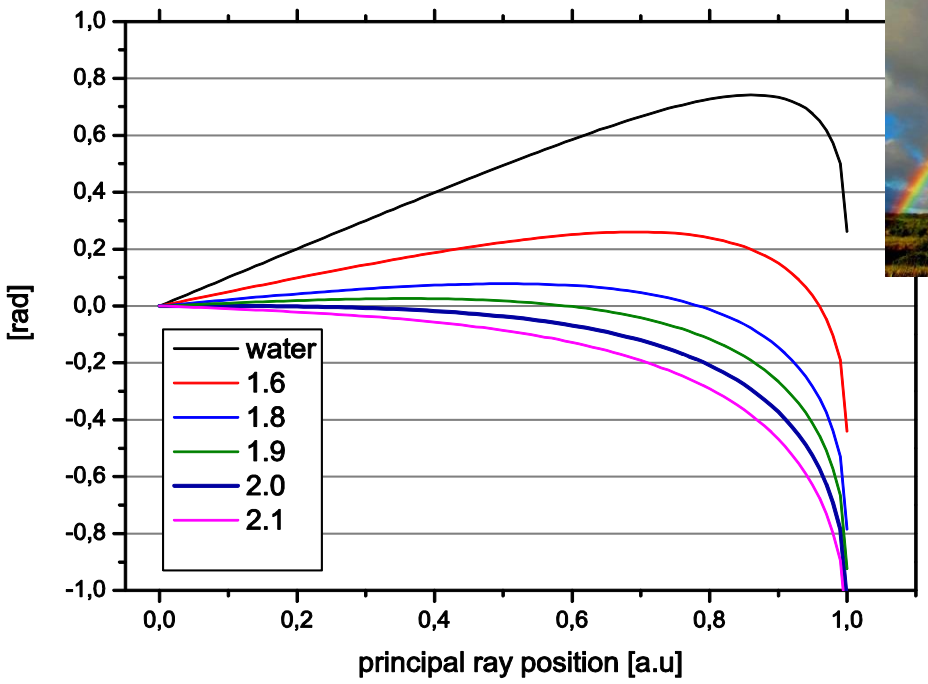
$$sin\alpha = n\ sin\beta$$

Three simple equations,
But only gamma can be
expressed analytically

$$\gamma = 4\arcsin\frac{r'}{r}\frac{1}{n} - 2\ \arcsin\frac{r'}{r}$$

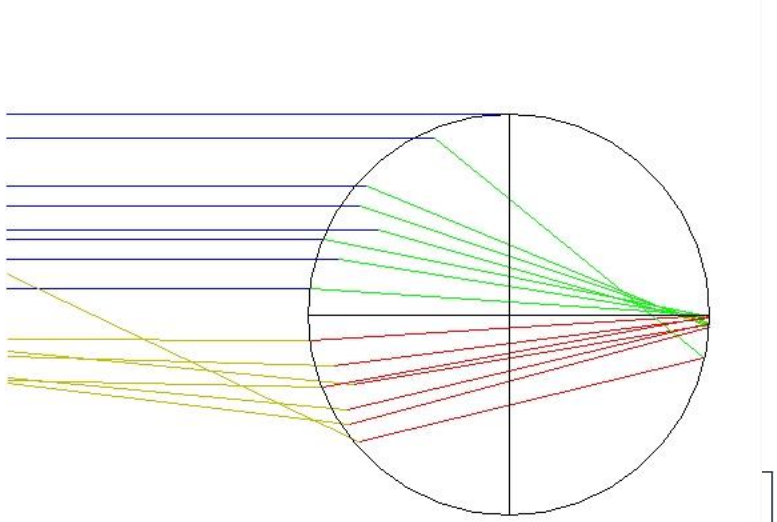
Due a high refractive
index is γ negative

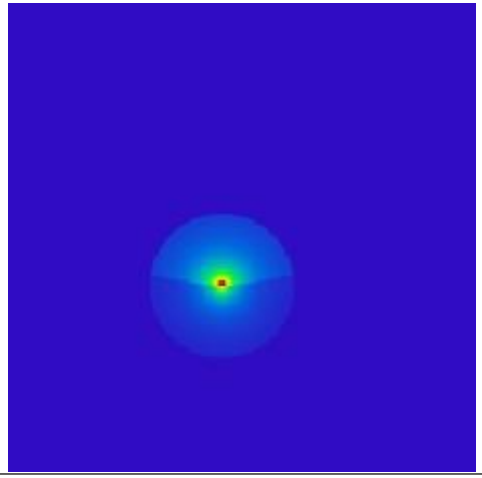
Simple model can explain rainbow, retroreflective strips etc.

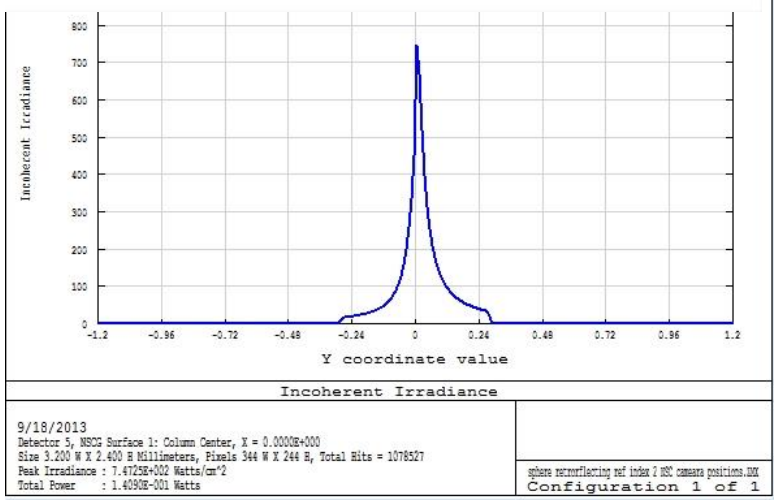


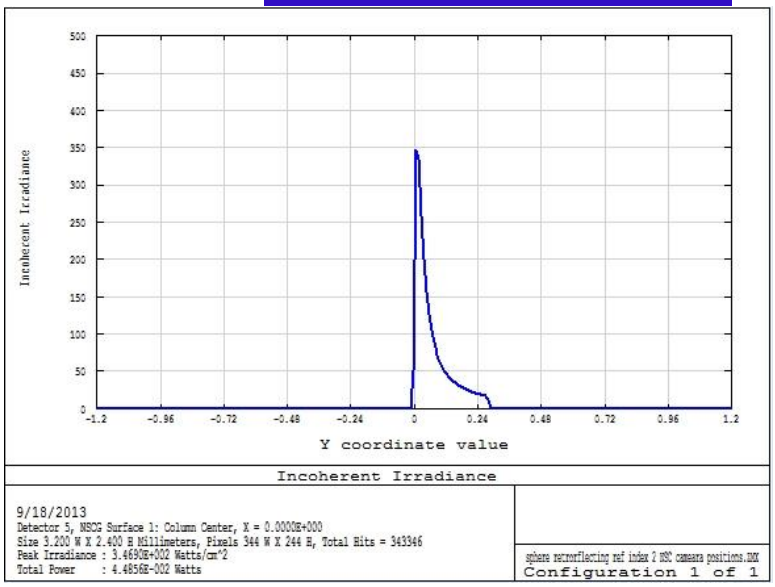
0 center, 1 edge of balll

Simulations with optical software Zemax©



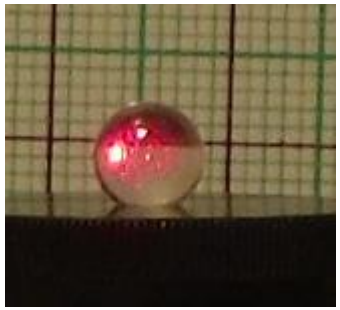






Experiments

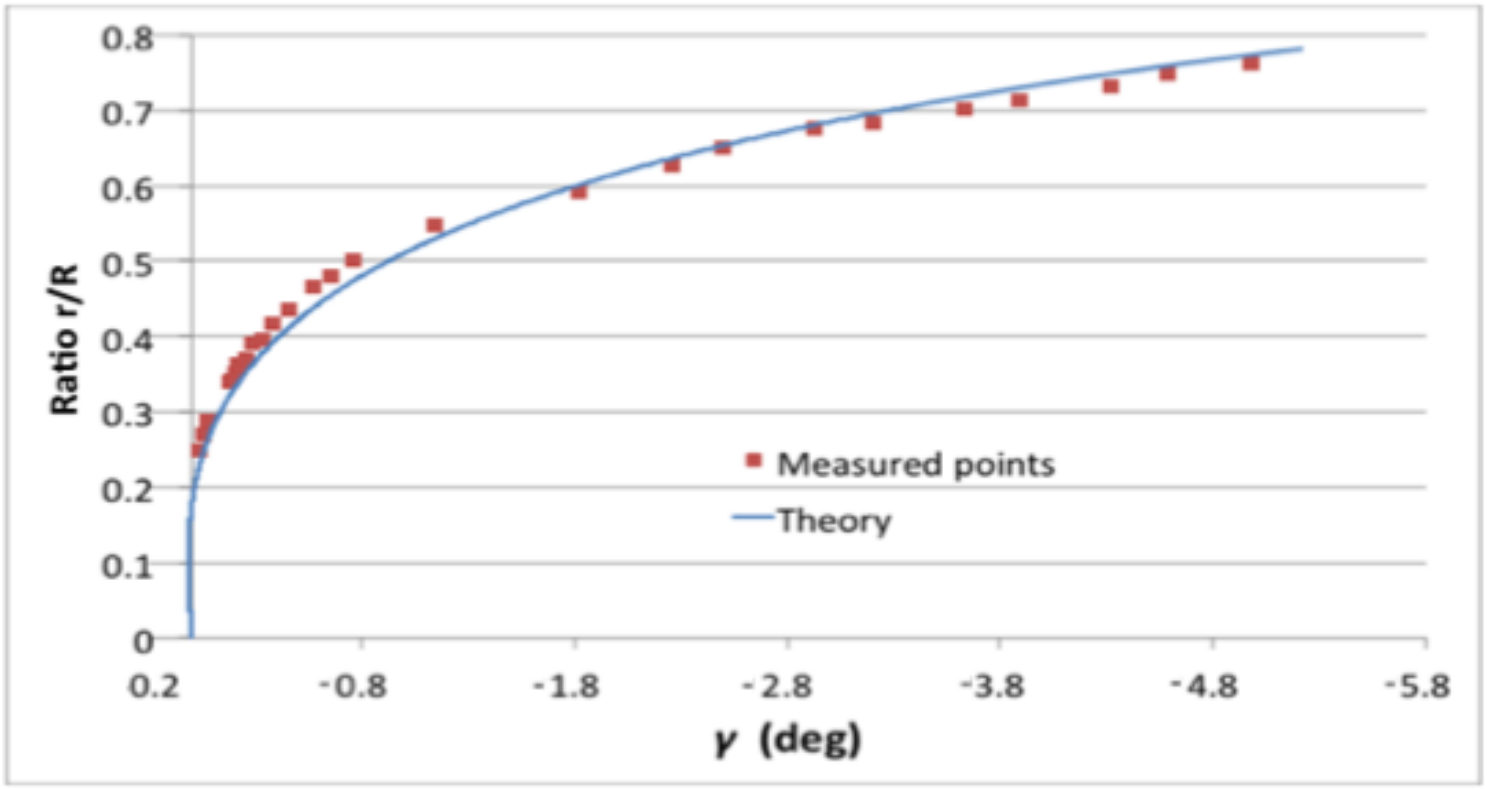
6 mm ball, roughly in axis of camera
1m distance from camera
1m distance from red laser diode



Small angle 35 mrad, ≈ 2°,
Illuminated from left side

Wide angle 350 mrad, ≈ 20°,
Illuminated from right side

Test results for HIE-ISOLDE



Guillaume Kautzmann EN/MEF-SU

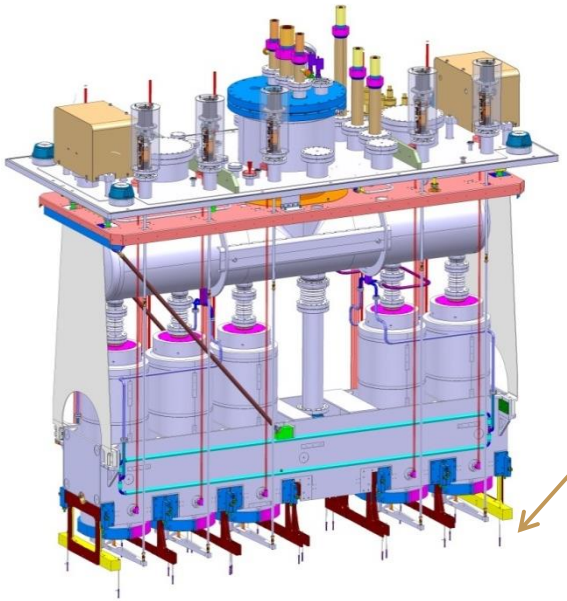
Fit well to the theory

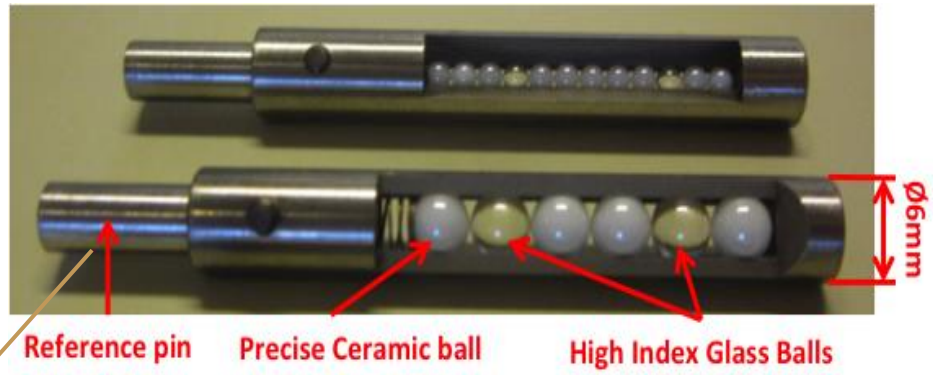
Ball retro-reflectors for HIE-ISOLDE

For the HIE-ISOLDE Monitoring (MATHILDE project)
is was necessary to develop a target :

- Visible from opposite sides;
- Spherical and of small diameter (4mm);
- Acting as a retro-reflector;
- Compatible with high vacuum and cryogenic conditions (4K).

➔ **High Index glass ball retro-reflector targets development**

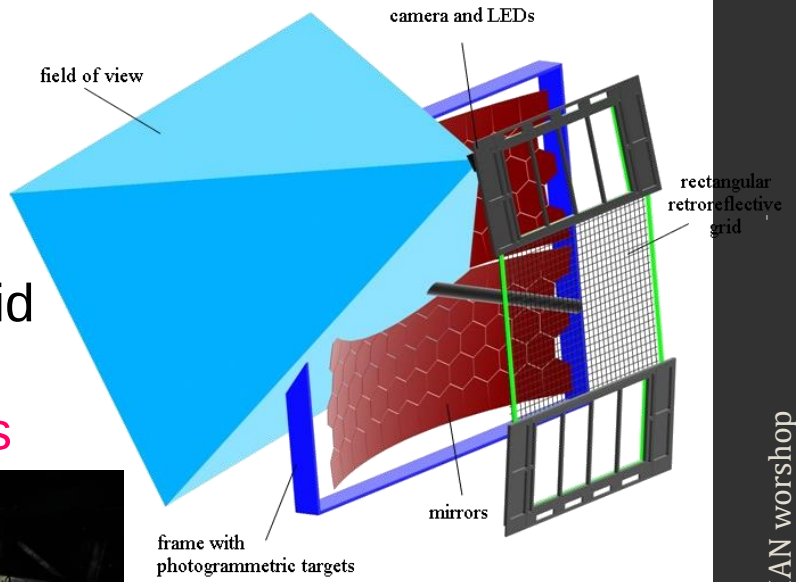


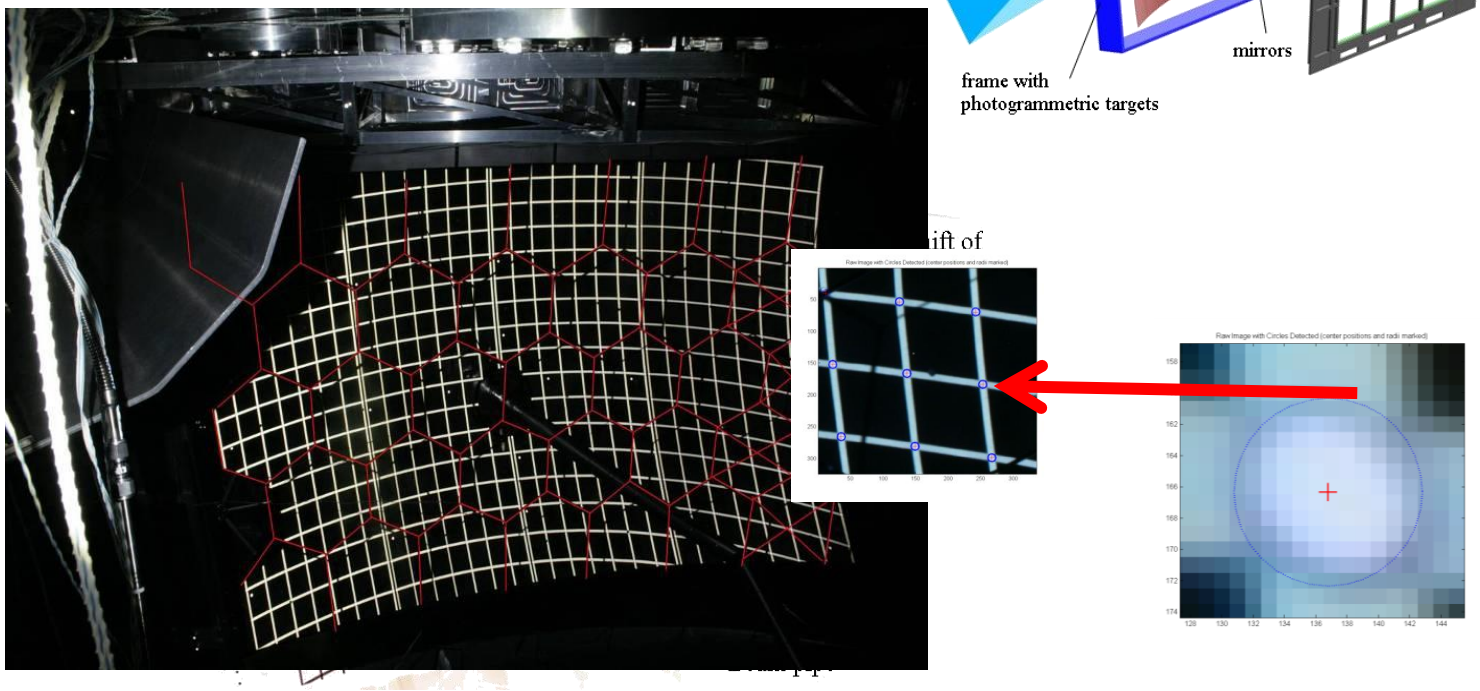


Jean-Christophe Gayde EN/MEF-SU
Guillaume Kautzmann EN/MEF-SU

Retro-reflective strips with balls used at CLAM

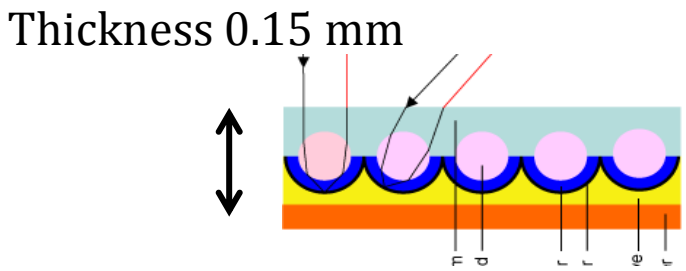
- CLAM: **C**ontinuous **L**ine **A**lignment **M**onitoring method (J.CH.Gayde)
- to observe reflection of rectangular grid on RICH mirrors - Continuous lines reflected by mirrors for aligned mirrors

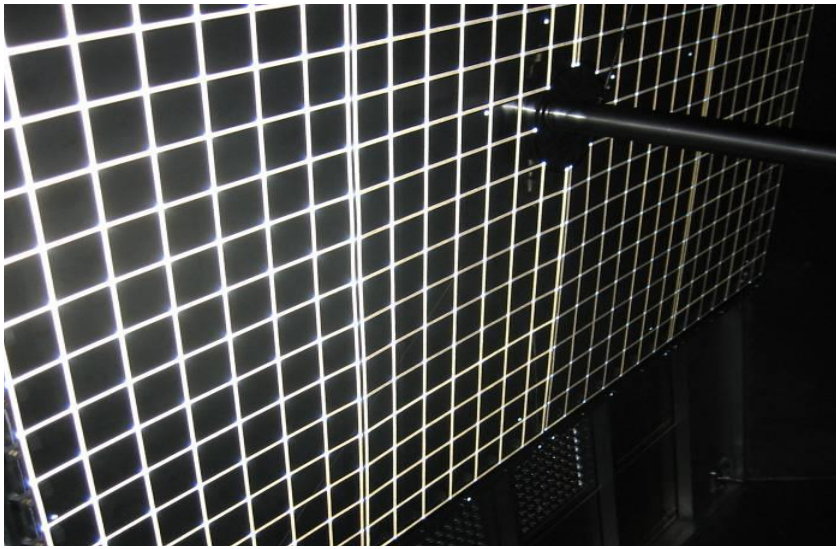


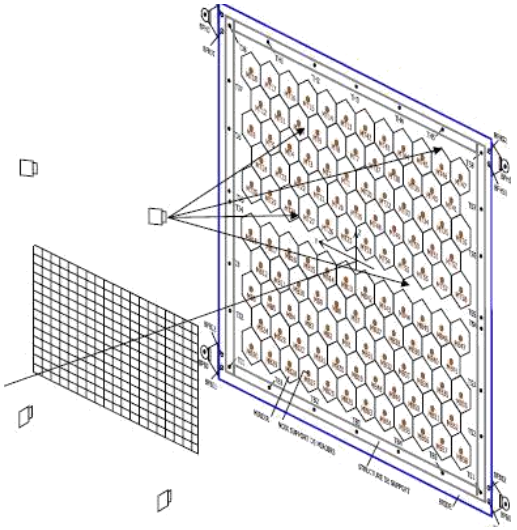


Technical Set-up

- High Luminosity LED
- Rectangular grid
- Retro-reflective material
- Strip width 1 cm
- Circular targets at crossing of strips





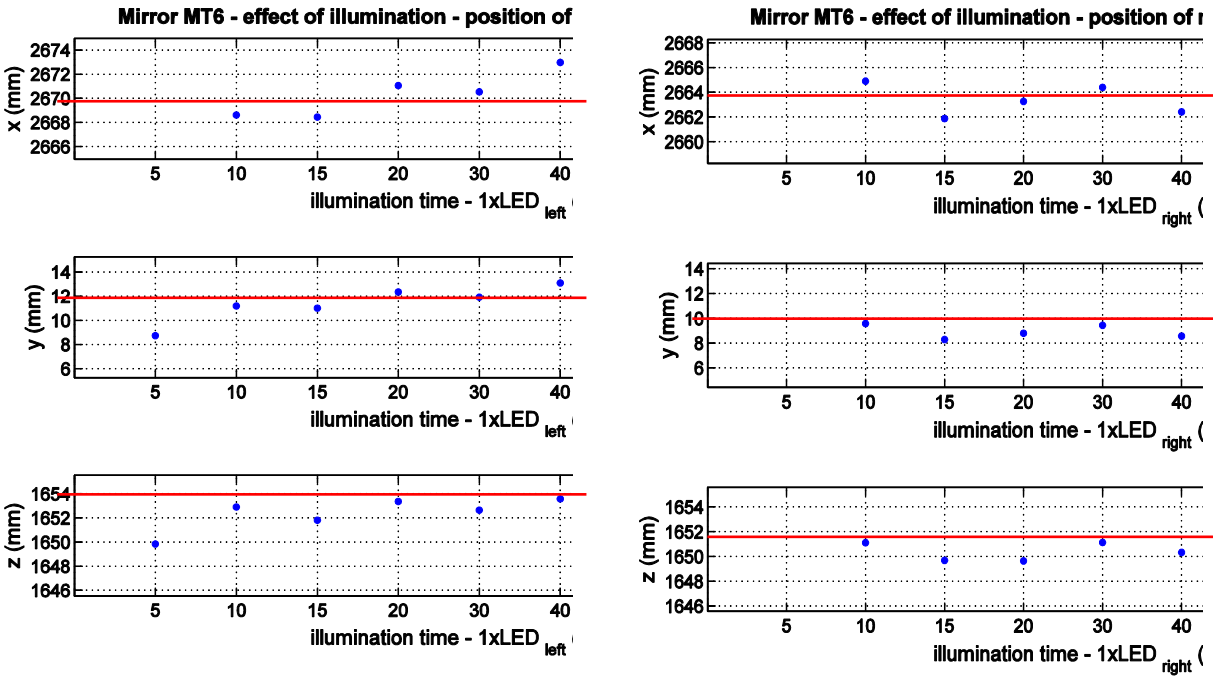


Illumination by one or two LEDs

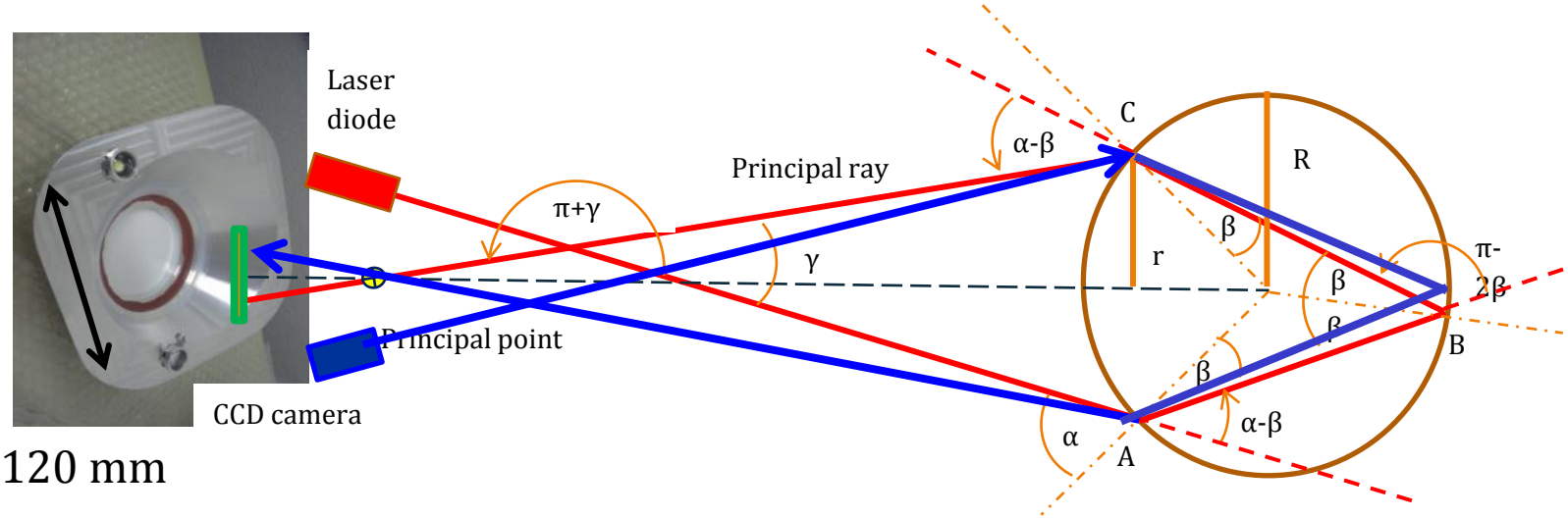
- Two LEDs are used for illuminations of retroreflective strips and PG targets
- Different results for illumination by left and right LEDs

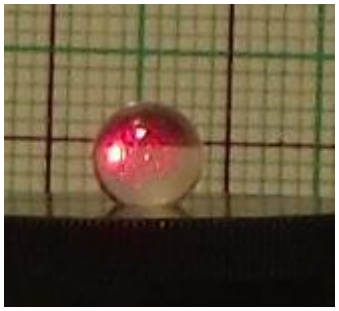
Mirror center position coordinates X, Y, Z

It corresponds to virtual target shift about 100 µm



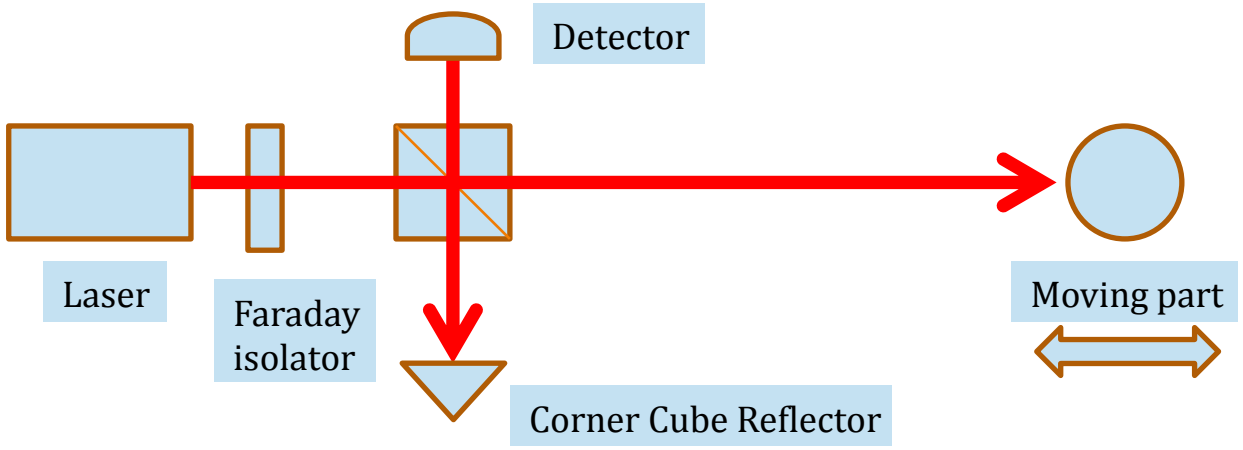
Explanation of image shift for left/right illumination





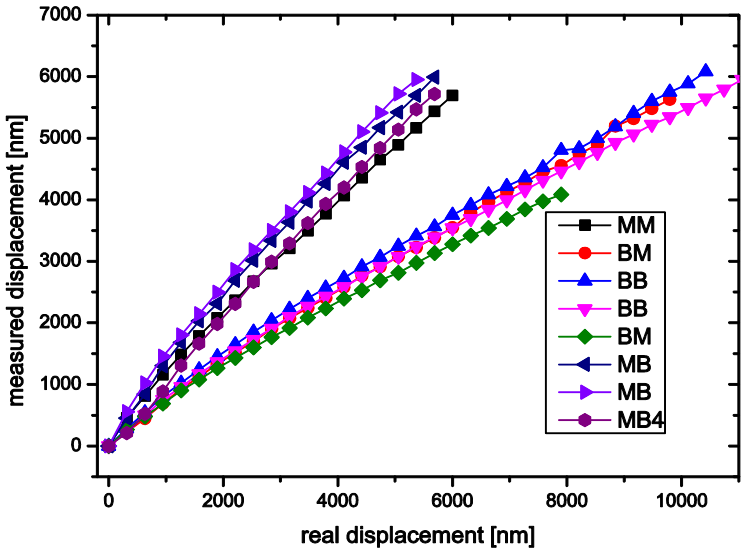
Targets are made from small diameter (around 100 µm) balls.
The reflected light is going not from sphere center, but almost from the ball edge.
There is shift between left/right illuminated target image

Laser interferometry and spherical targets

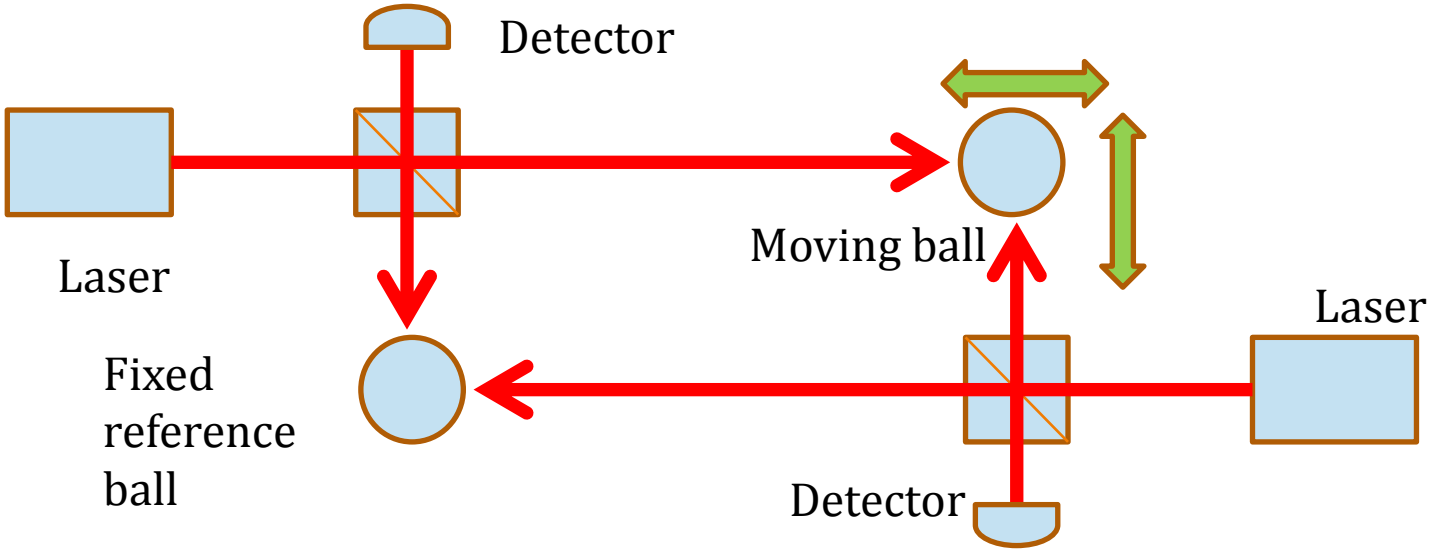


Preliminary studies and tests with configurations:

- Ref. Corner Cube / Moving Ball
- Ref. Ball / Moving Corner Cube
- Ref. Ball / Moving Ball



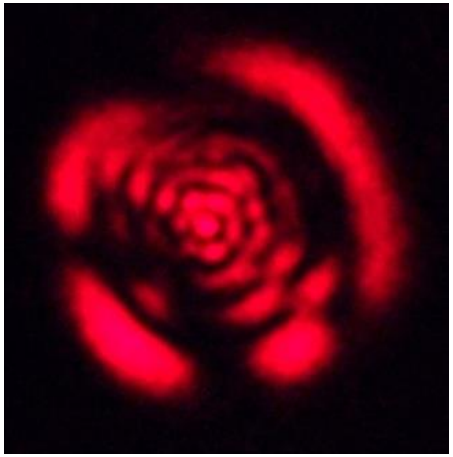
Simplified schema of interferometry measurement in 2D net



The ball retro-reflectors with the whole acceptance angle 360° can be measurable simultaneously from different locations in 3 D net

Application of ball targets for interferometry

Advantages:



- Multidirectional target … toward 3D
- Multiline interferometer
- Interferometry measurement network
- It can be used for beam aligment

Drawbacks:

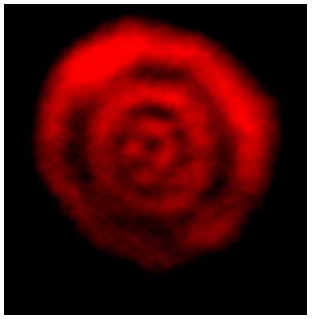
- Sensitivity to lateral alignment
- Reflected wave front is not planar → interference pattern is complicated

but …

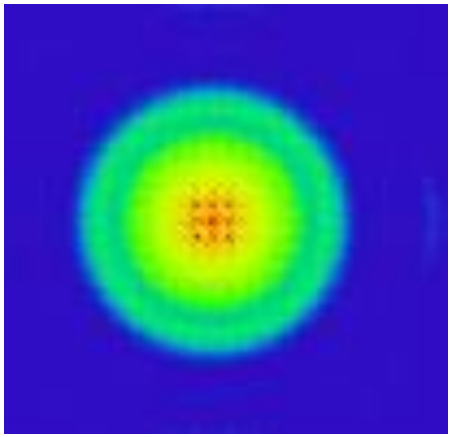
- Use of the interference pattern to measure the lateral alignment and dissociate it from the distance measurement
- Also other techniques under investigation to improve the system accuracy

Preliminary studies and tests

- Exact theory of interference of complex wave fronts

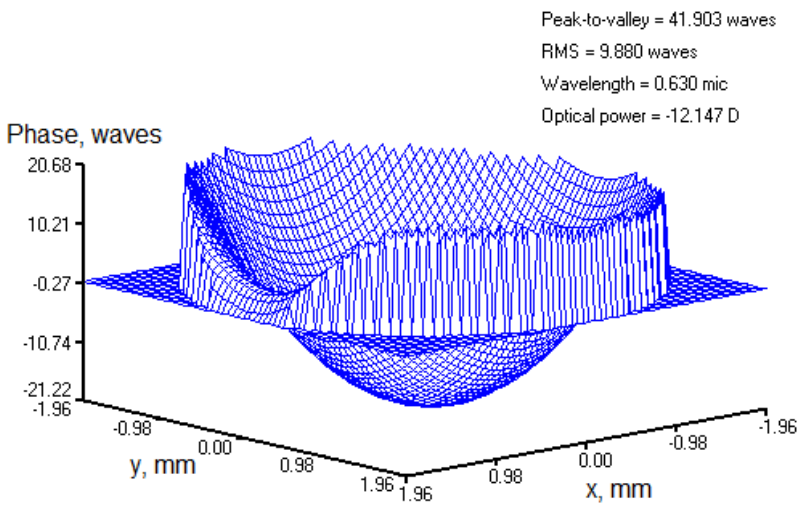


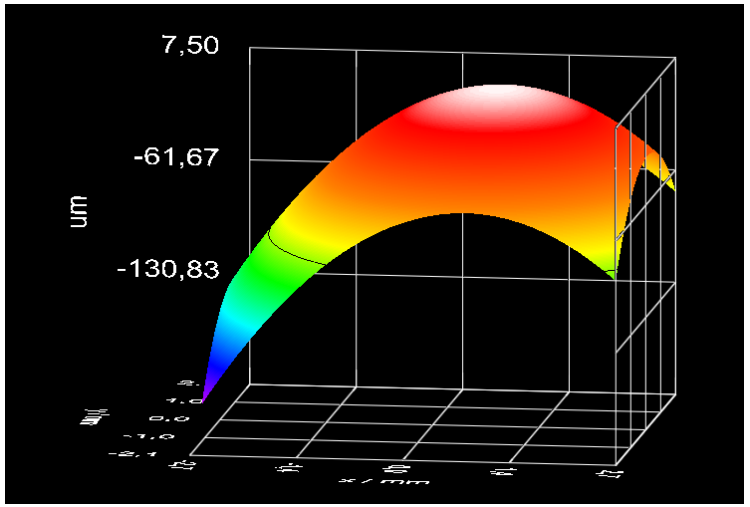
- Simulation of wave-fronts interference in optical software Zemax©



- Verification of method accuracy in 1D by Agilent HP professional interferometer, calibrated at Czech Metrology Institute
- Measurement of ball position in 3D, using Mitutoyo profilometer Legex 774 as a ball holoder

Study of wavefront by Shack - Hartmann wavefront sensor





Conclusions

- High index n = 2 glass balls with an acceptance angle of 360° are promising targets for laser beam metrology
- Simple use and interpretation for imaging technique
- Balls are promising targets for interferometers, at various configuration, for many application, but detailed studies must be still performed

Thanks for your attention