Hochschule Esslingen
University of Applied Sciences

Development of VUV-reflecting mirrors and wavelength shifting films for the CBM-RICH detector

–

Materials science for heavy ion physics

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Introduction

aim: electron identification for momenta below 8-10 GeV/c
→ high efficiency, large acceptance, 10^4 combined π-suppr. with TRD

concept: gaseous RICH detector
stable, robust
limited R&D efforts
rely to a large extend on components from industry
not too expensive

people: Pusan Natl. Univ. (I.K. Yoo et al) – gas system, RICH prototype
PNPI, St. Petersburg (V. Samsonov et al.) – mechanics
IHEP Protvino (S. Sadovsky et al.) – PMT development
HS Esslingen (M. Dürr) – mirror development/ investigations, WLS films
Wuppertal (applied for funding) – photodetector development
GSI (C. Höhne et al.) – concept, simulations, layout, coordination, photodetector + WLS films R&D, readout electronics

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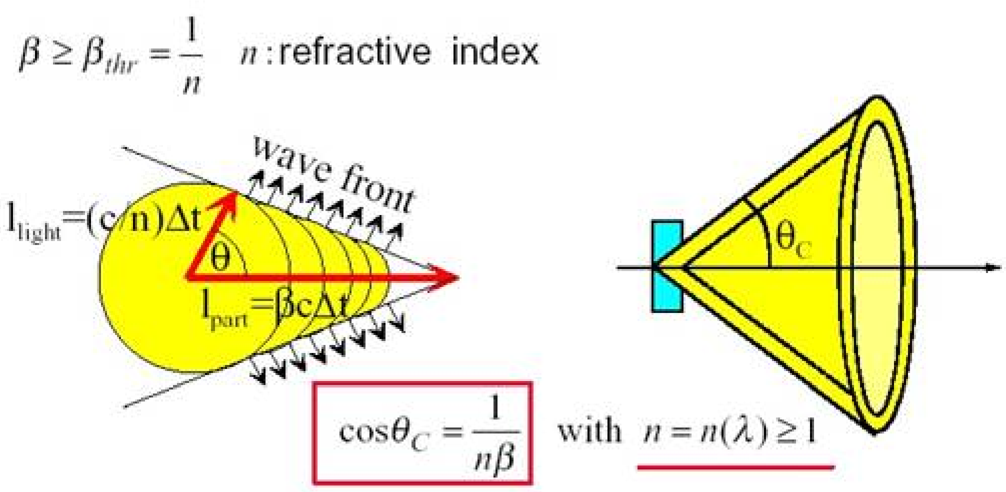
Introduction

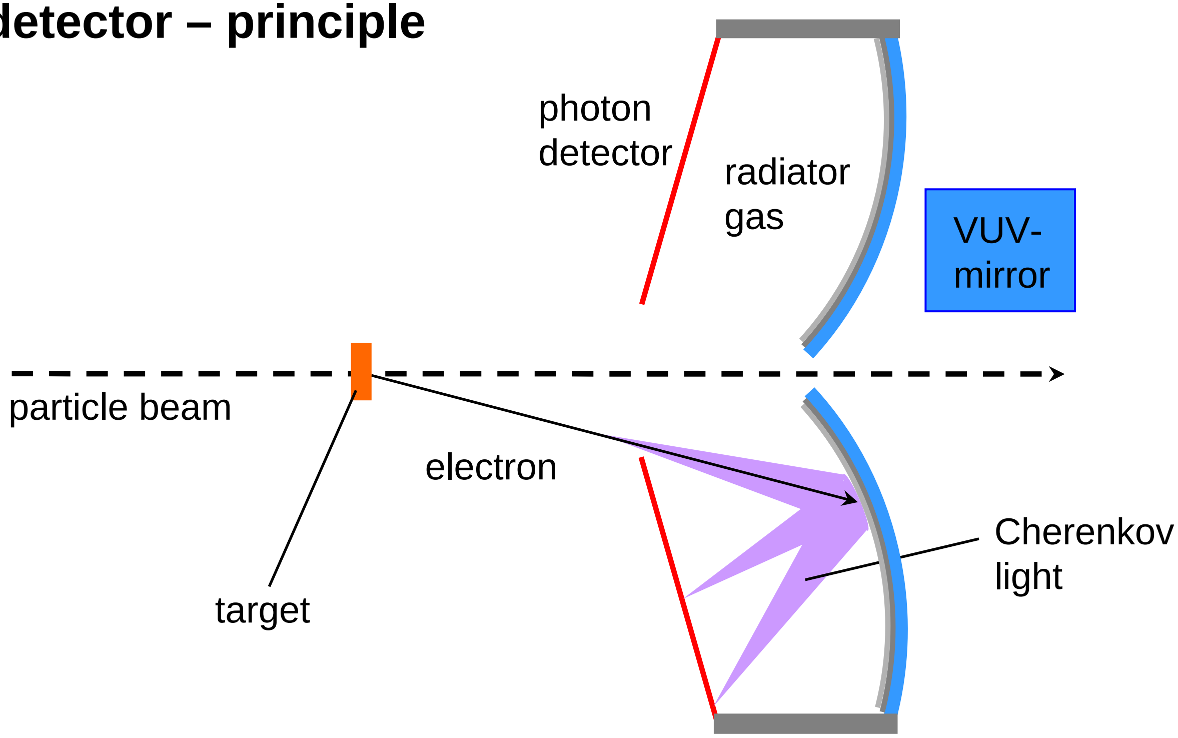
RICH detector – principle

- particles traversing matter with a velocity larger than the velocity of light in that medium (refractive index n) emit Cherenkov radiation
- opening angle of light cone $$\cos\theta = \frac{1}{n\beta}$$



Introduction

RICH detector – principle

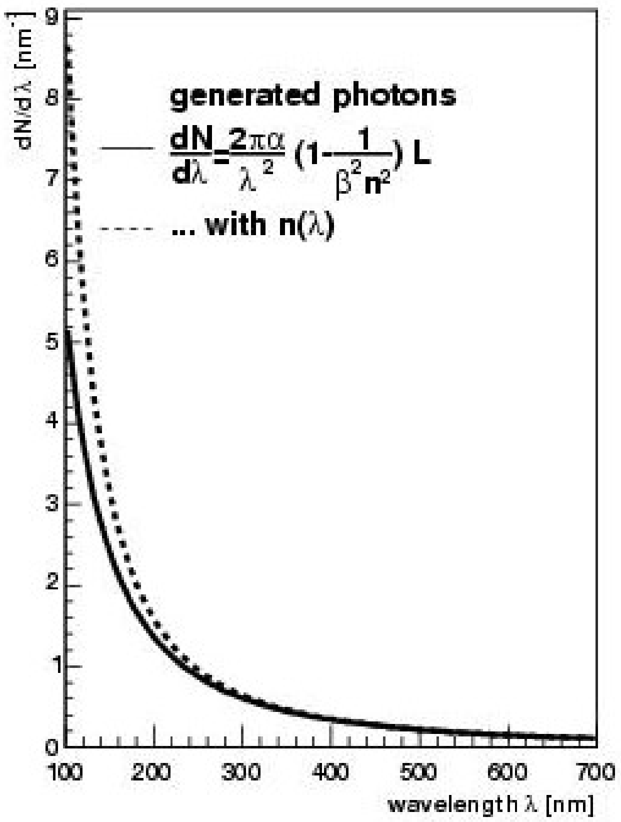


- light cone of cherenkov radiation is projected onto the focal plane where the cone is imaged as rings
- focal plane at $r_0/2$ (r_0: radius of curvature of mirror)
- ring radius depends on θ

Introduction

Cherenkov spectrum - wavelength dependence

Spectrum for nitrogen:



- number of photons per ring N_γ (full e-ring, r ≈ 5.4 cm)

$$N_\gamma = \int \frac{dN}{d\lambda} d\lambda$$

⇒ Short wavelength photons are important

Introduction

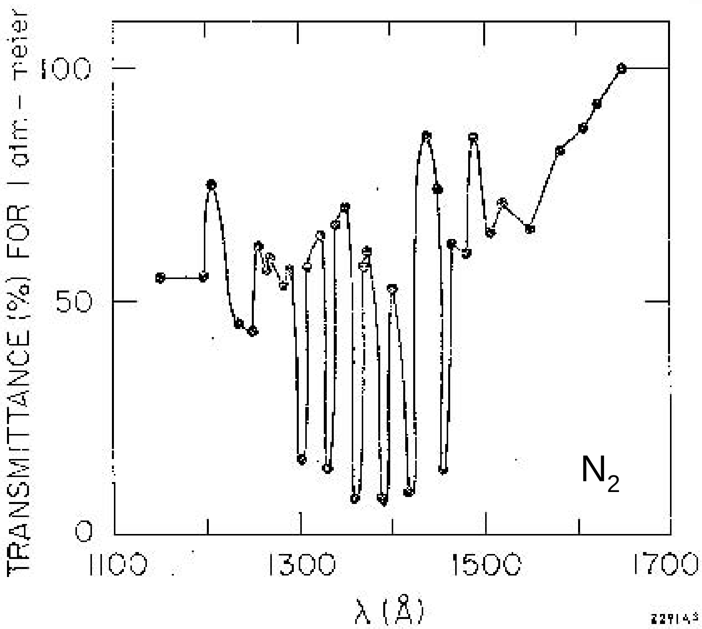
Radiator gas

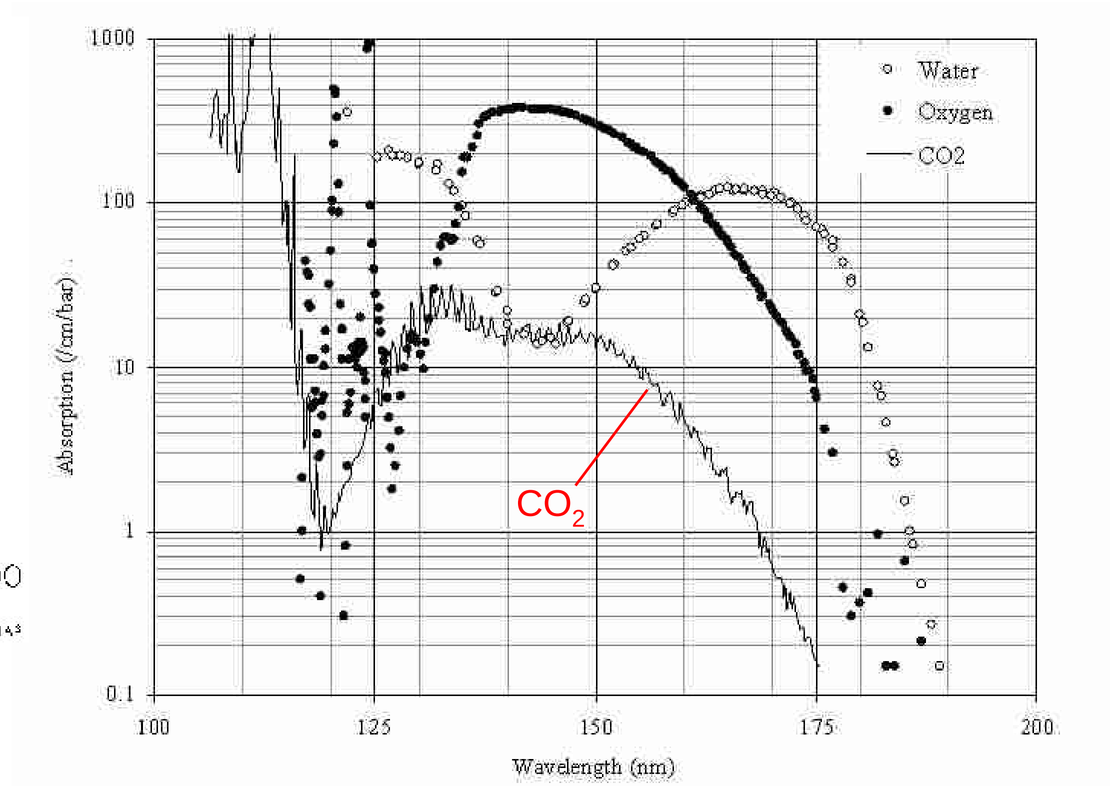
• as the RICH detector should mainly serve for electron identification, the pion threshold for emission of Cherenkov light should be sufficiently high in momentum

radiator	n	γ_{th}	p_{th}^{π} [GeV/c]	λ_{thresh} [nm]	radiation length [m]	handling?
N_2	1.000298	41	5.6	~ 150	304	✓
CH_4	1.00044	33.6	4.7	~ [illegible]	650	☹
CO_2	1.00045	33.3	4.65	~ 175	183	✓
CF_4	1.000488	32	4.47	< 120		chemically aggressive
N_2O	1.000509	31.4	4.37			(toxic)
CH_3OH (methanol)	1.000546	30.3	4.2			flammable
C_2H_6 (ethane)	1.000706	26.6	3.71	~ 160	340	

Introduction

Radiator gas - absorption edges

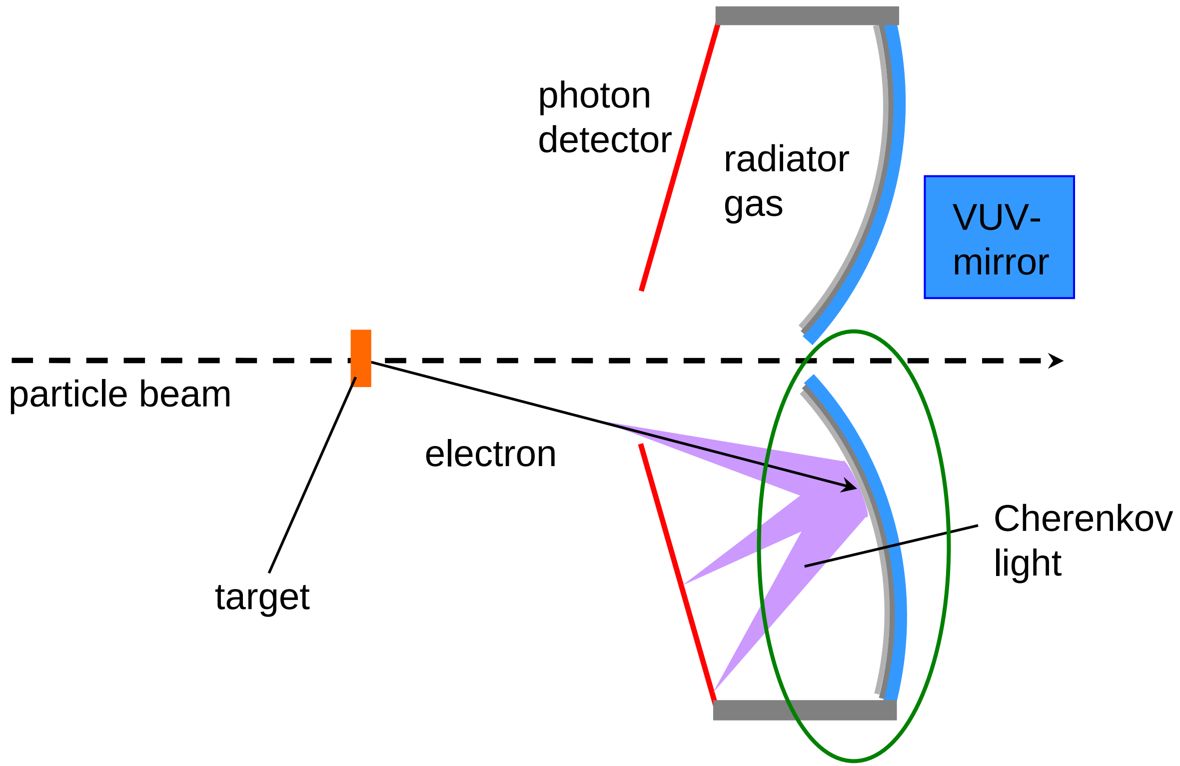




- N_2 absorption edge ~ 150 nm
- CO_2 absorption edge ~ 175 nm

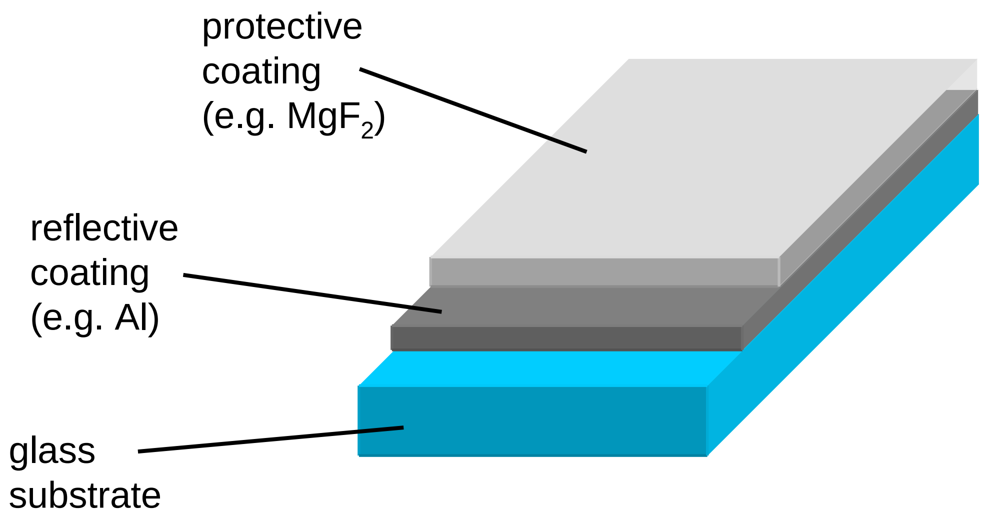
Introduction

RICH detector – principle



Introduction

RICH detector – mirror and coatings



- Al has a good reflectivity in the visible and UV spectrum
- protective coating is needed because of Al_2O_3's absorption edge in the UV

Requirements

Requirements for RICH mirrors

Physical:

- high reflectivity down to ~ 160 nm
- good surface homogeneity: small error of radius
- moderate material budget (rough number: < 2.5% X_0 including mirror support, compare to 3 mm float glass: X_0 = 2.4 %; to be investigated in detail)

Technical:

- stiffness and precision also with support structure and in support position

Economical

- moderate costs

Options

Our approach

- minimize own R&D
- cooperate with companies as much as possible for mirror substrates and coating

Recent RICH installations and used mirror technology

- HADES: first mirrors from FLABEG, Germany, coating done at TU München
- RICH1 LHCb: carbon fiber mirrors from CMA, USA, coating at SISO, France
- RICH2 LHCb: mirrors (Pyrex) from Compas, Czech Republic, coating at CERN

Options

Companies possibly to cooperate with

- Flabeg, Germany (mirrors)
- Compas, Czech Republic (mirrors)
- Siso, France (coating)

1st trial: Flabeg

- can do now both mirrors and coating

$\Rightarrow$ test coating for reflectivity measurements

Flabeg Mirrors

Specs

photography

dimensions:

Size: $A = 400 \times 400\ mm^2$
glass: $d = 6$ mm
Radius: $r_0 = 3200$ mm

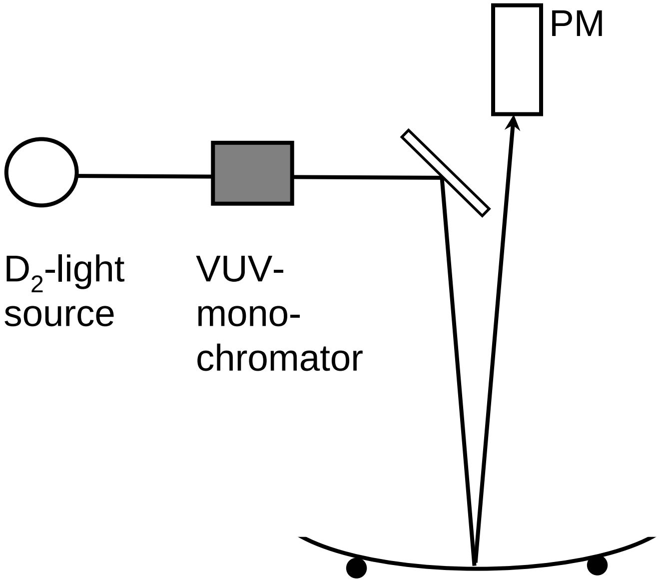
coating:

Al: $d = 70$ nm
MgF_2: $d = 90$ nm

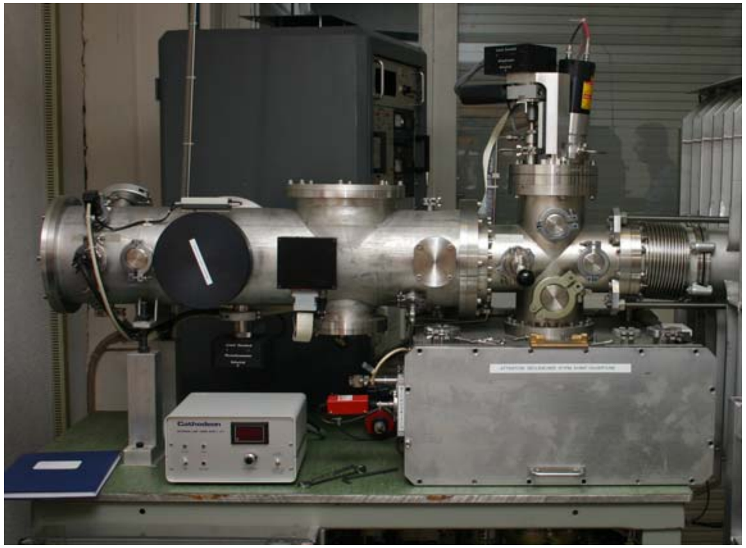
Reflectivity measurements

Set up

Schematics:

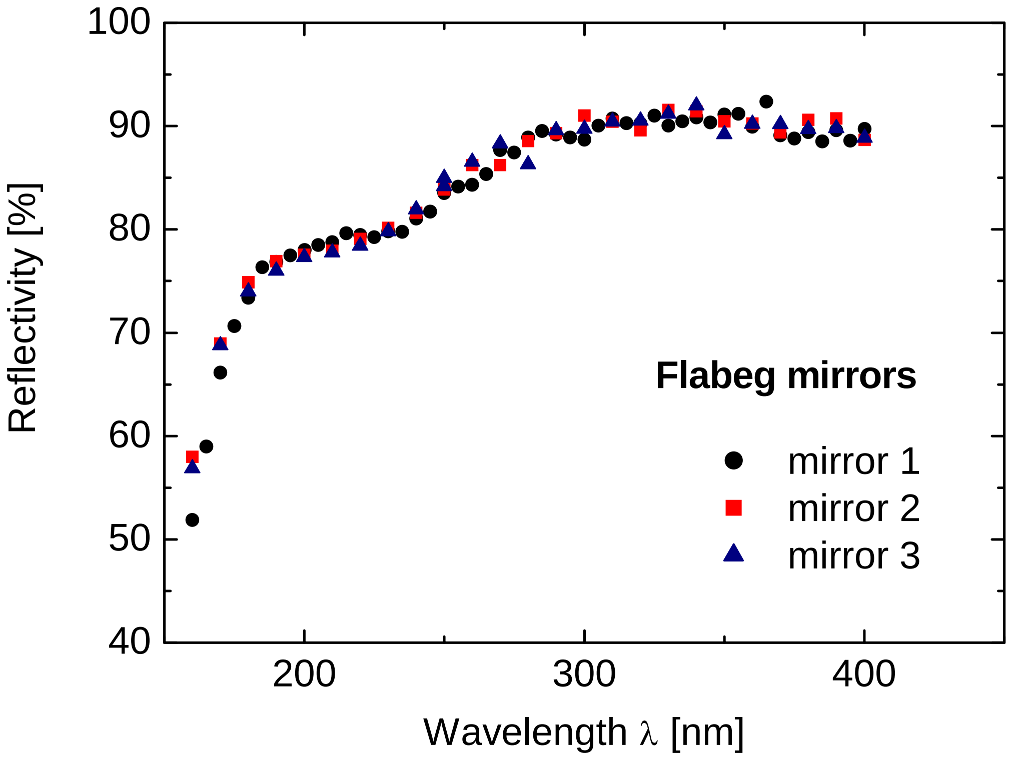


Apparatus at CERN – A.Braem:



Reflectivity measurements

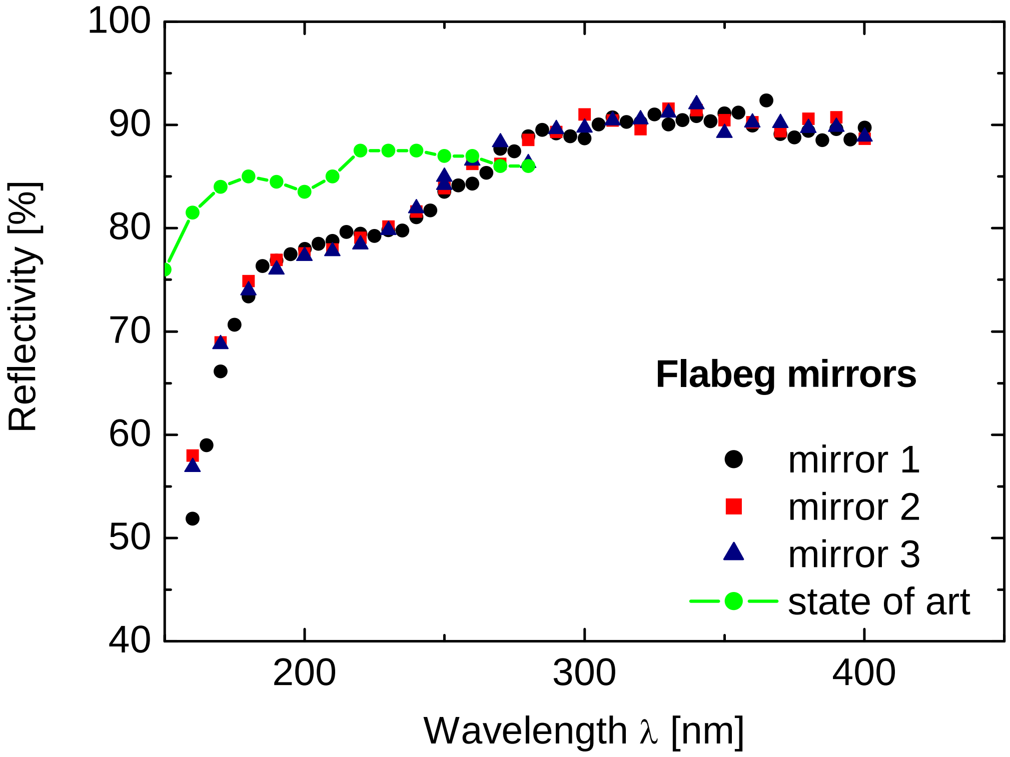
Results



- Very good reflectivity between 400 nm and 270 nm
- First drop around 250 nm
- Second drop at about 180 nm

Reflectivity measurements

Results – comparison with state of the art

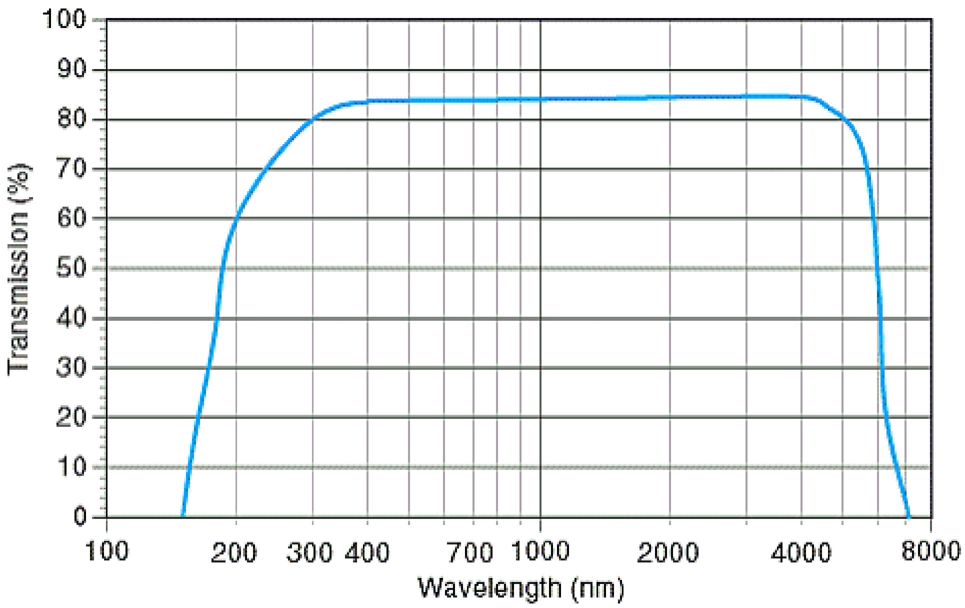


- Very good reflectivity between 400 nm and 270 nm
- First drop around 250 nm
- Second drop at about 180 nm
- state-of-the-art data courtesy of A. Braem

Reflectivity measurements

Influence of aluminum oxide

Transmission of Al_2O_3 bulk material

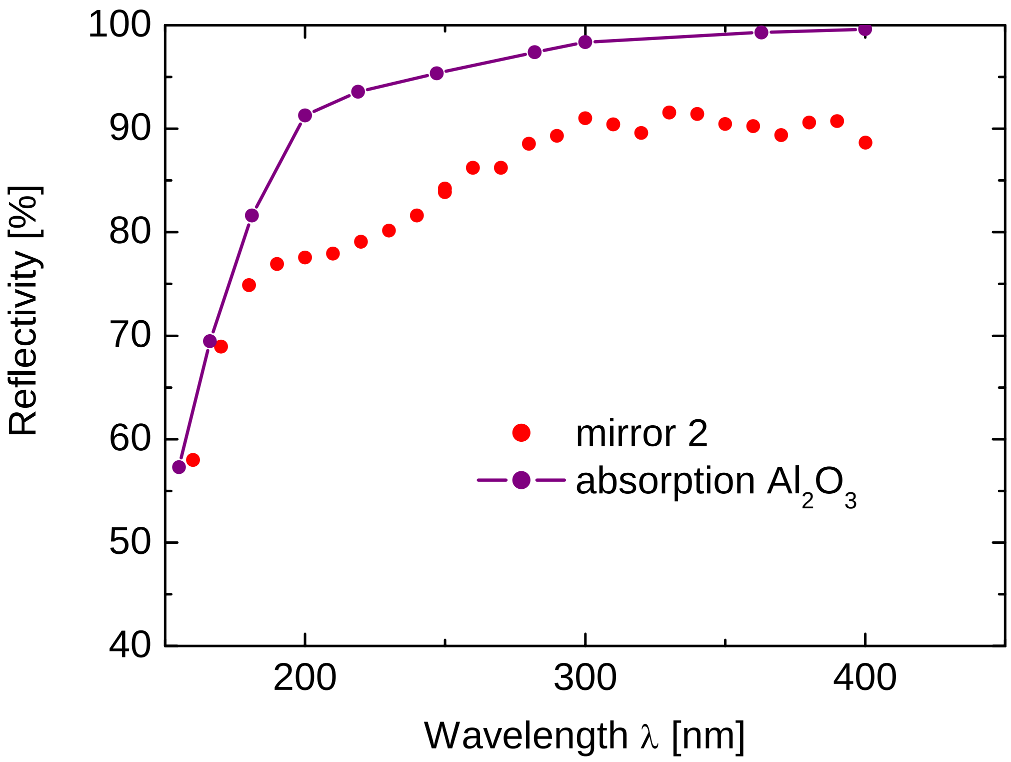


Reason 1:

- absorption of Al_2O_3 formed during the process (absorption edge of bulk material at 200 nm)

Reflectivity measurements

Influence of aluminum oxide



Reason 1:

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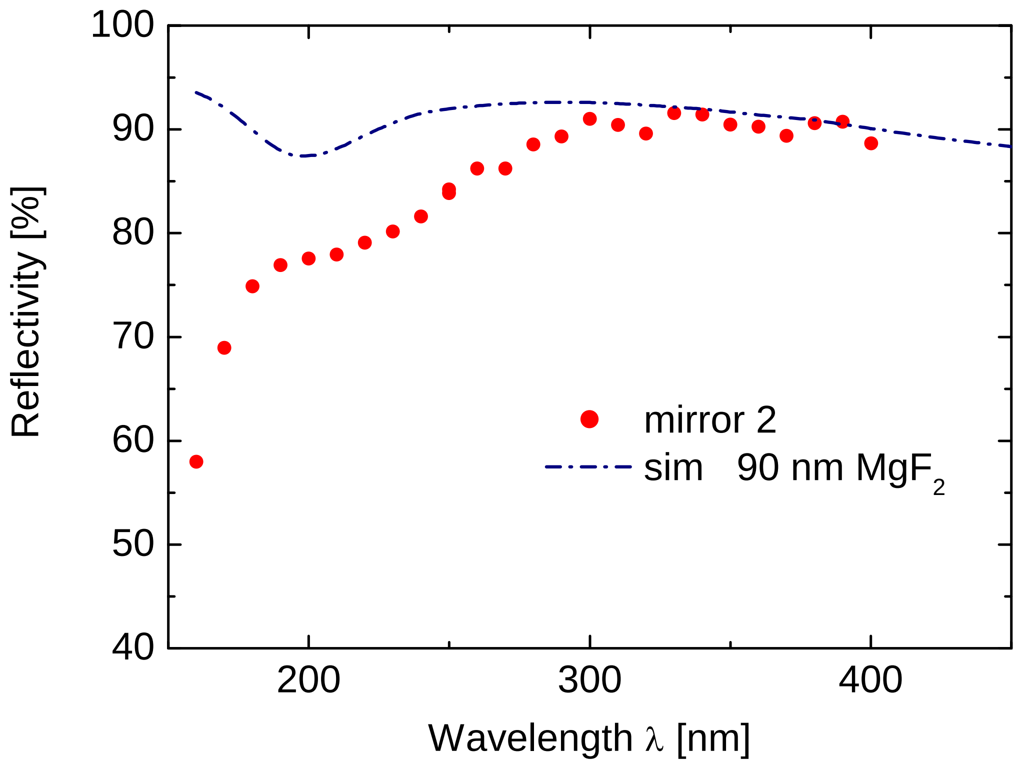
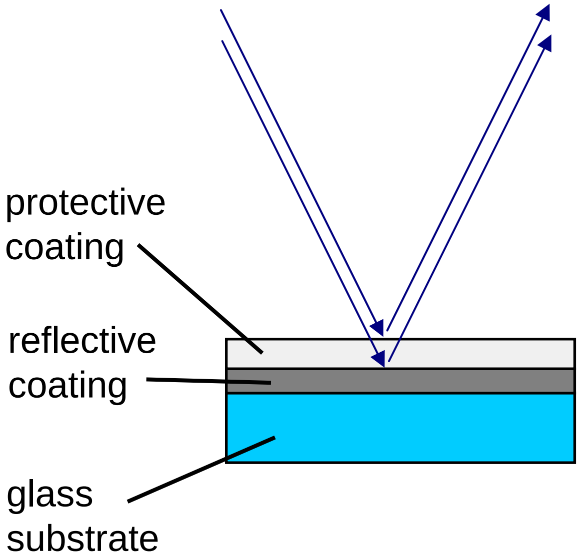
Reflectivity measurements

Influence of MgF_2 layer





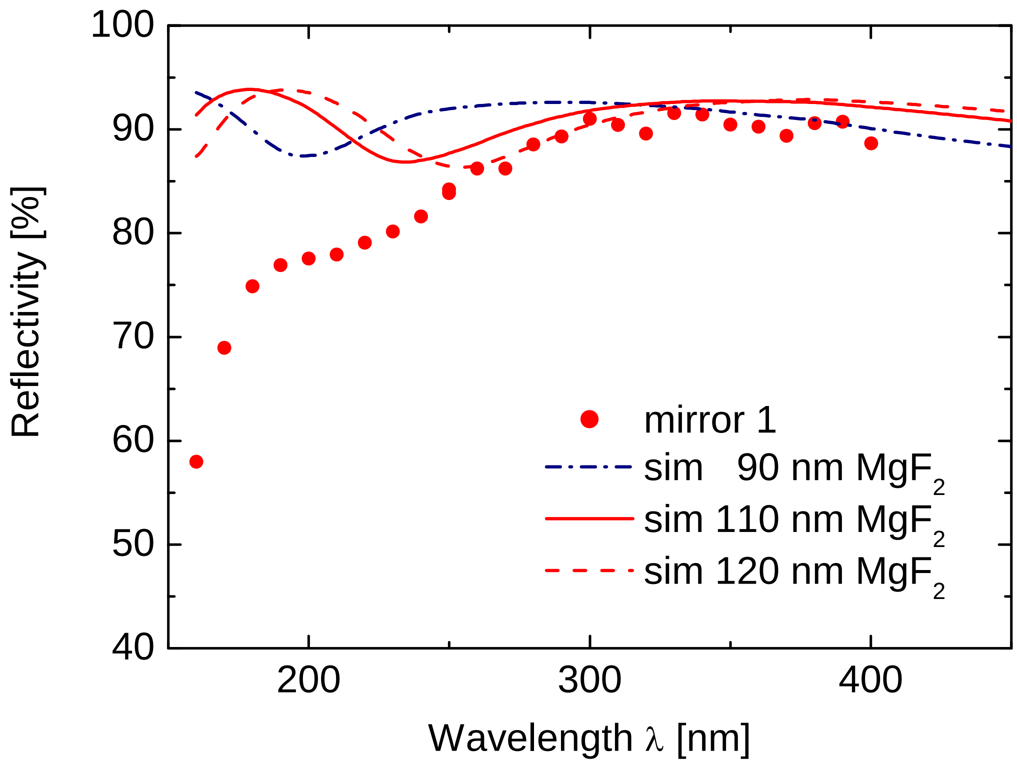
Simulations: A. Braem

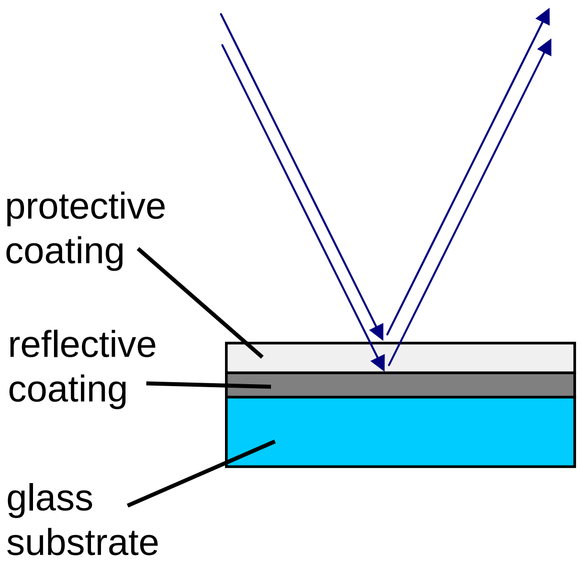
Reason 2:

- interference of light reflected at Al-layer with light reflected at MgF_2-surface

Reflectivity measurements

Influence of MgF_2 layer





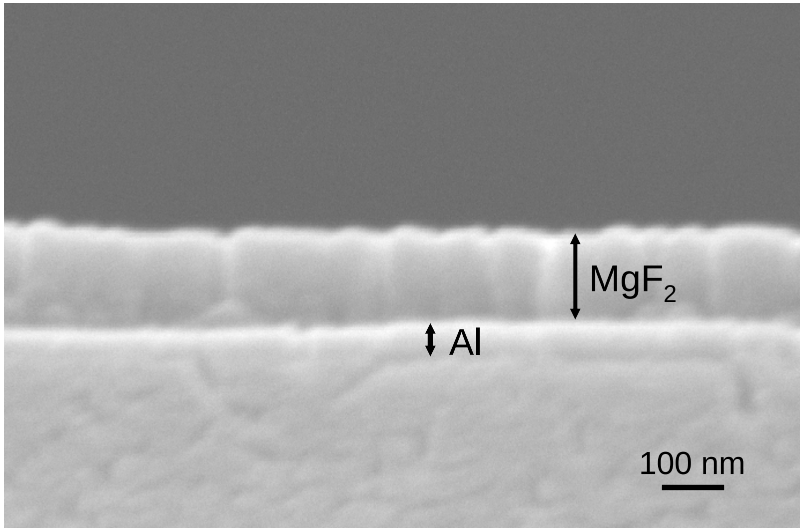
Simulations: A. Braem

Reason 2:

- interference of light reflected at Al-layer with light reflected at MgF_2-surface

Coating Quality

Scanning electron microscopy

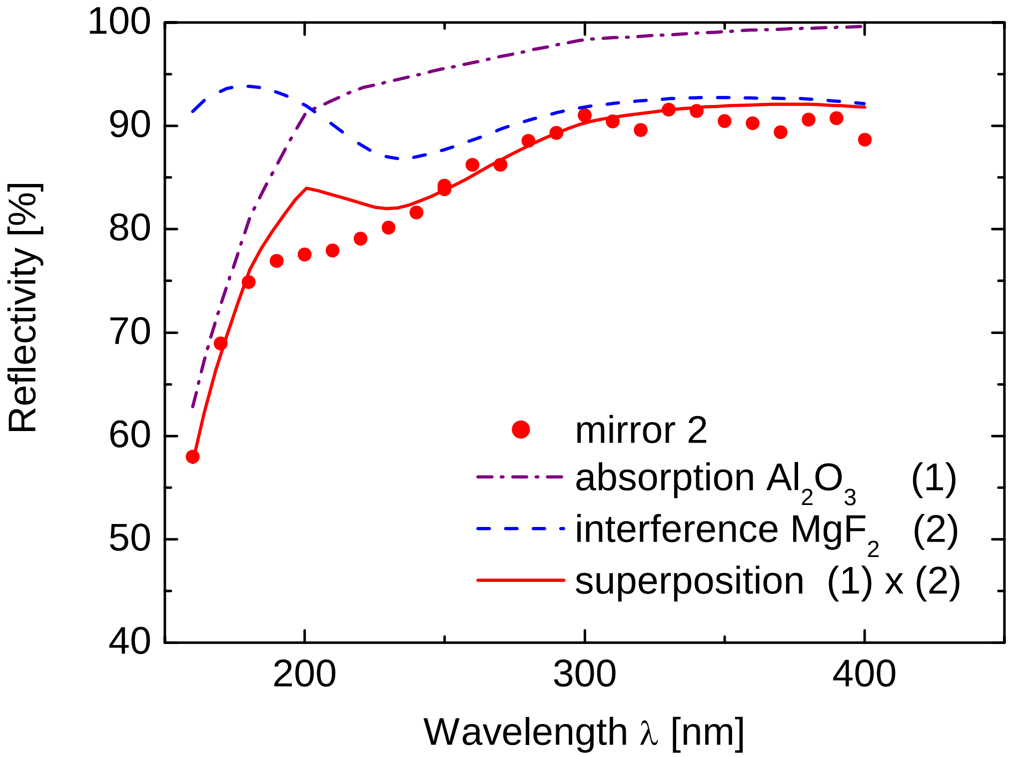


Layer thickness:

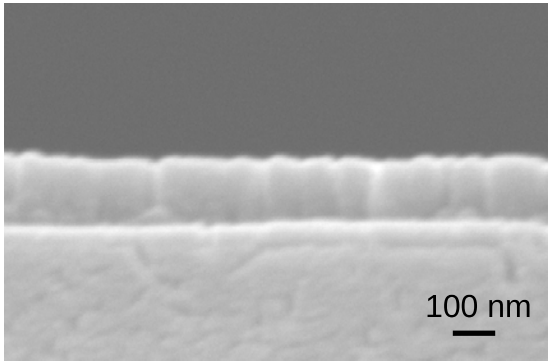
- Al-layer: d ≅ 55 nm
- MgF_2-layer: d ≅ 120 nm

Reflectivity measurements

Influence of aluminum oxide and MgF_2 layer

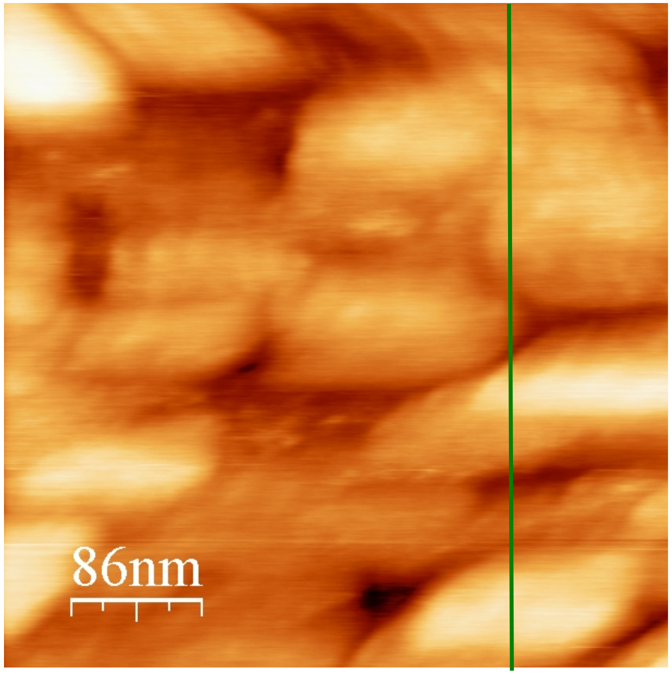


- good overall representation
- still some discrepancies
- influence of surface roughness?

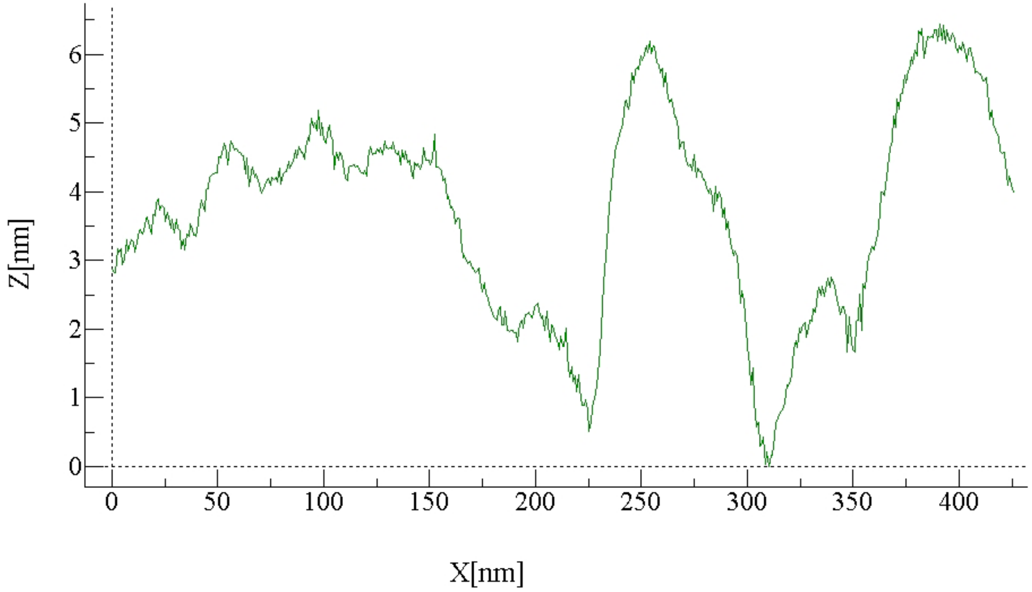


Coating Quality

Atomic Force Microscopy

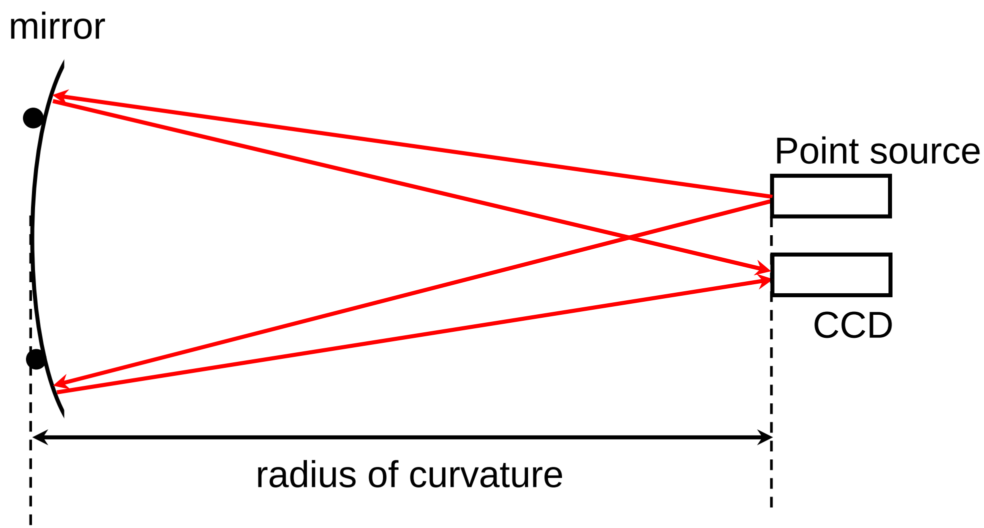


Line scan:



Radius of Curvature – D_0

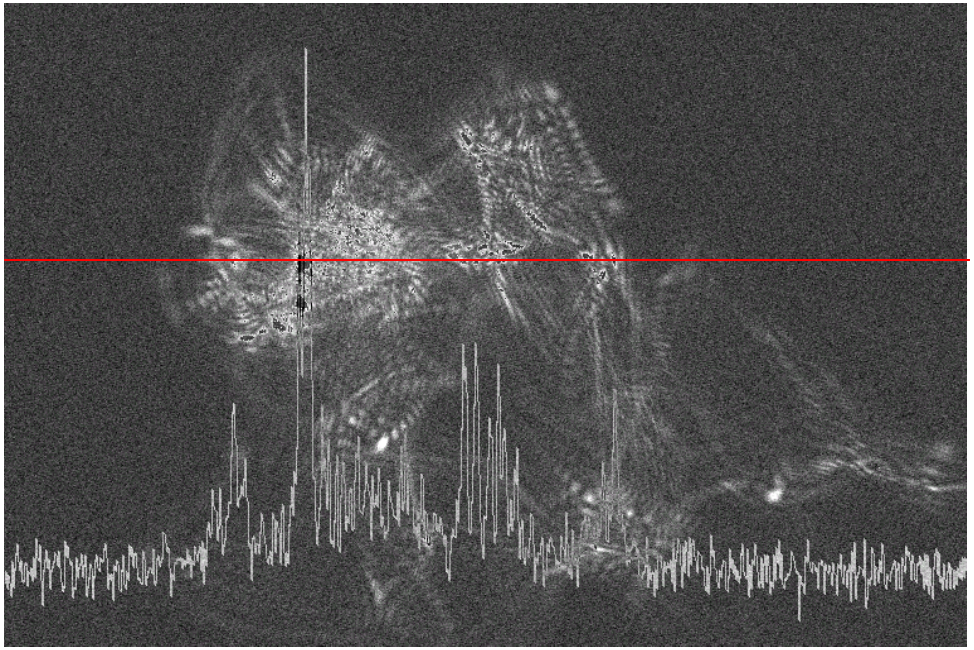
Radius of curvature – measurement set up



at CERN – Carmelo D'Ambrosio

Radius of Curvature – D_0

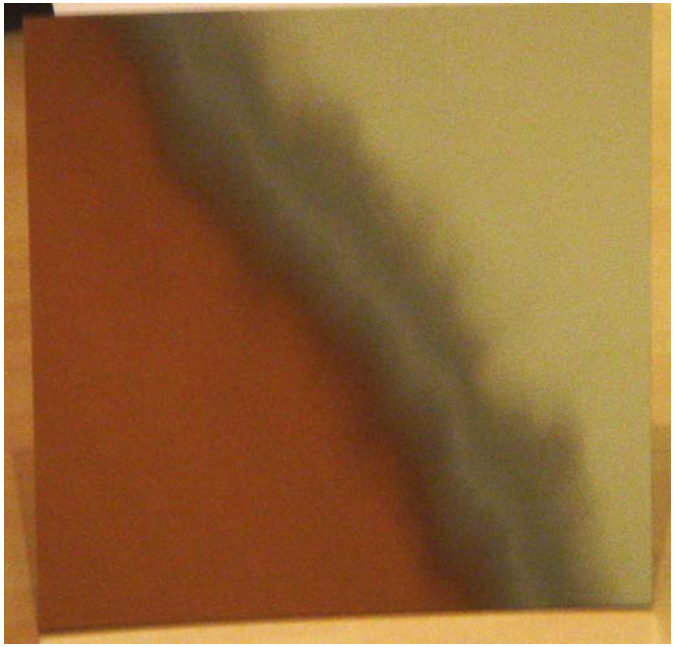
Results



- very broad feature, **most of the intensity in the background**

Radius of Curvature – D_0

Results

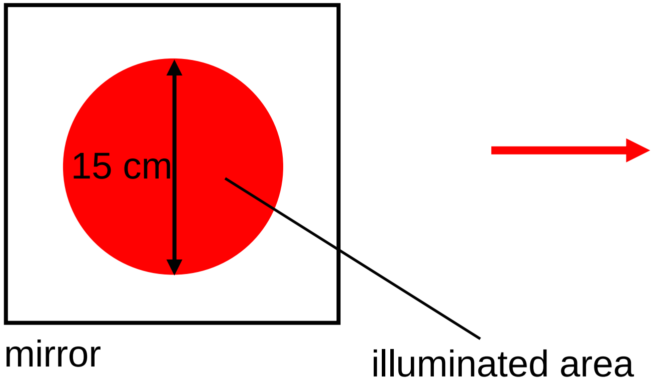


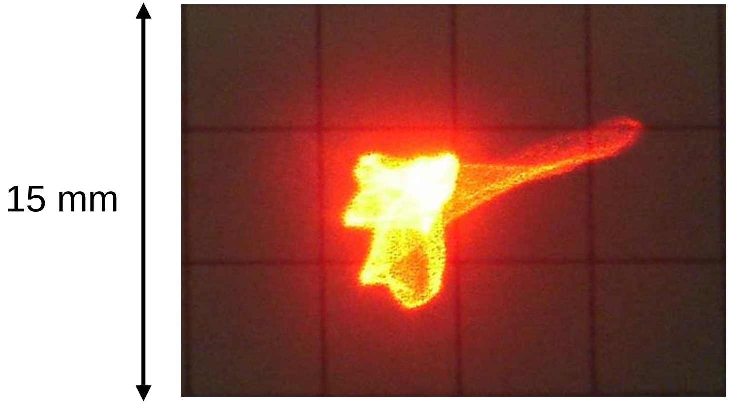
- very broad feature, most of the intensity in the background
- pronounced irregularities on the cm-scale
- possible explanations:
  - rather low-cost fabrication process
  - rather thick glass substrate

Flabeg mirrors II

Different substrates

- some more substrates were delivered
- thickness between 3 mm and 6 mm
- preliminary measurements of D_0 did show minor improvements
- Example:



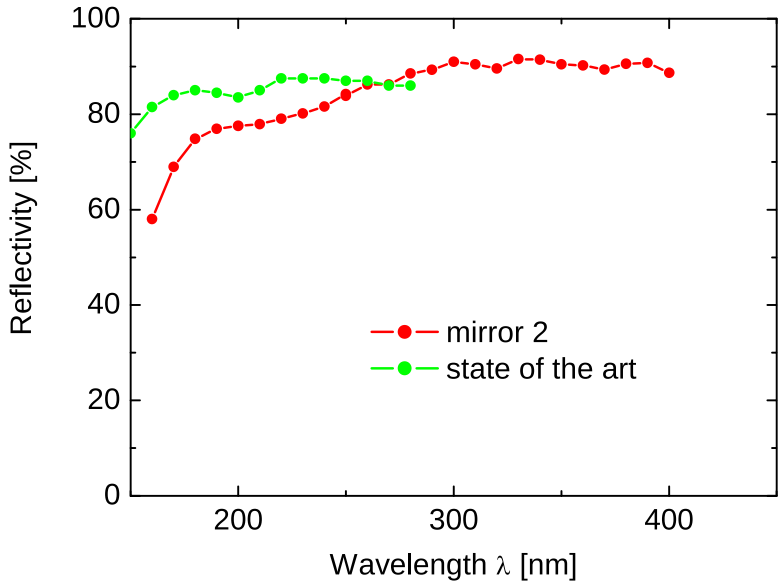


Conclusions

Reflectivity – coating

- good reflectivity for a „first-shot“ trial
- improvements expected from
  - higher evaporation rate
  - better base pressure

    (both feasible at Flabeg)



Radius of curvature – glass substrate

- low homogeneity of the surface on the cm-scale
- minor improvements from thinner glass and changed fabrication process

Options

Companies possibly to cooperate with

- Flabeg, Germany (mirrors) √
- Compas, Czech Republic (mirrors)
- Siso, France (coating)

Compas

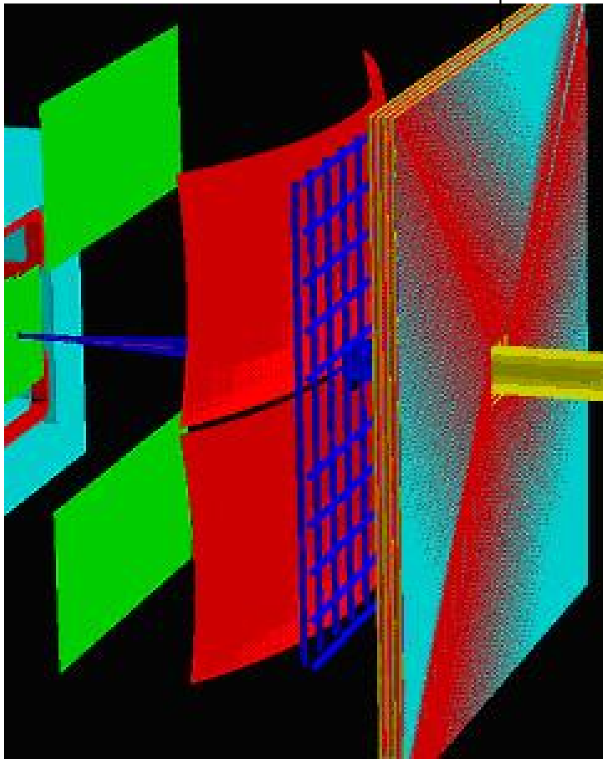
- delivered substrates for LHCb, can do coating themselves

Material Budget

RICH detector – material budget

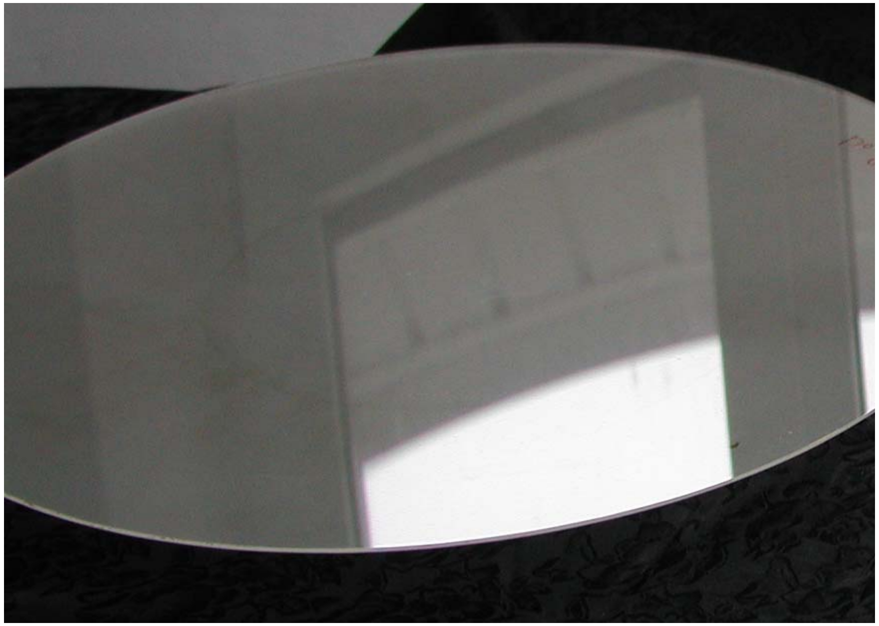
- 2.9 m radiator (nitrogen) = 0.95 % X_0
- entrance/ exit window from kapton foil ≤ 0.5 % X_0
- radiation length of glass 12-14 cm
- radiation length of Al 8.9 cm
- material budget of 6 mm glass = 4.6 % (e.g. RICH2 @ LHCb)
- typically: material budget of support ≤ 50 % of mirror but non-uniformly distributed

⇒ material budget of RICH detector mainly concentrated in mirror + support



Compas Mirrors

Specs according to simulations at that time



photography

dimensions:

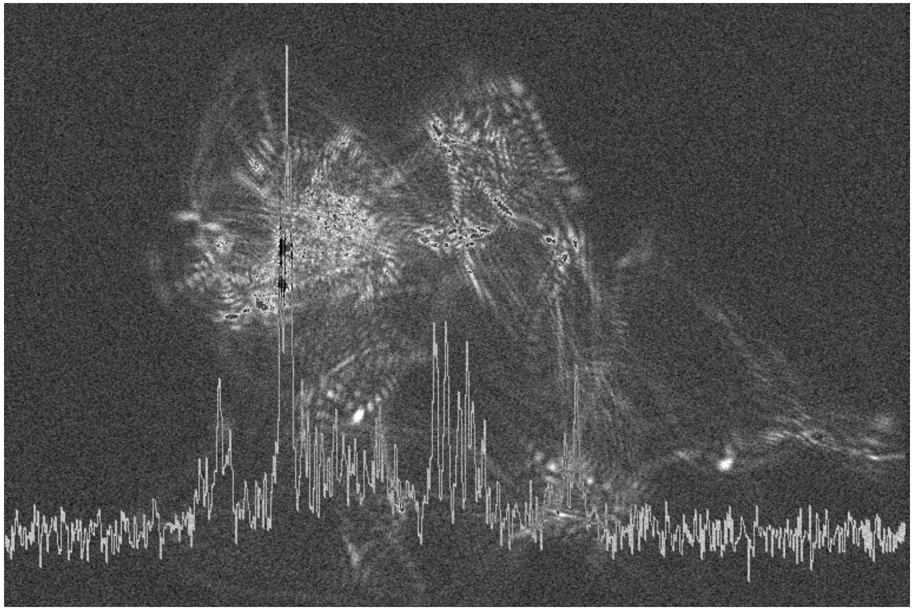
Size: R = 300 mm
glass: d = 3 mm
Radius: r_0 = 3000 mm

coating:

Al: d = ?
MgF_2: d = ?

Radius of Curvature – D_0

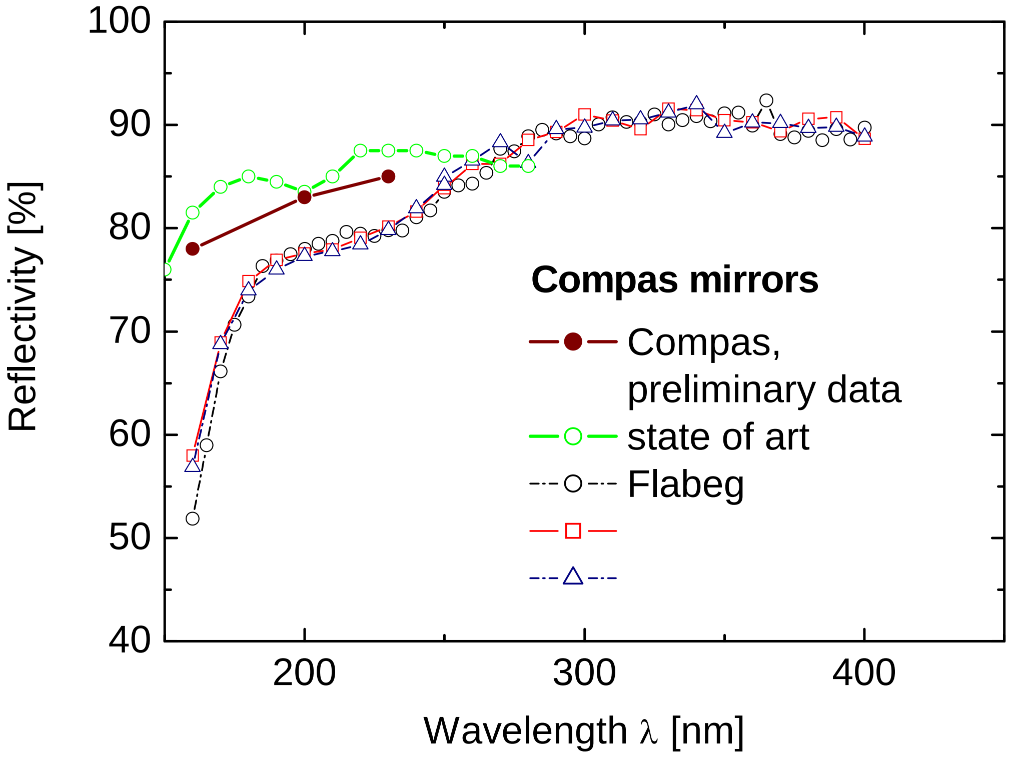
Results



- $D_0 \cong 2$ mm (90 % intensity)

Reflectivity measurements

Results – comparison with Flabeg and state of the art



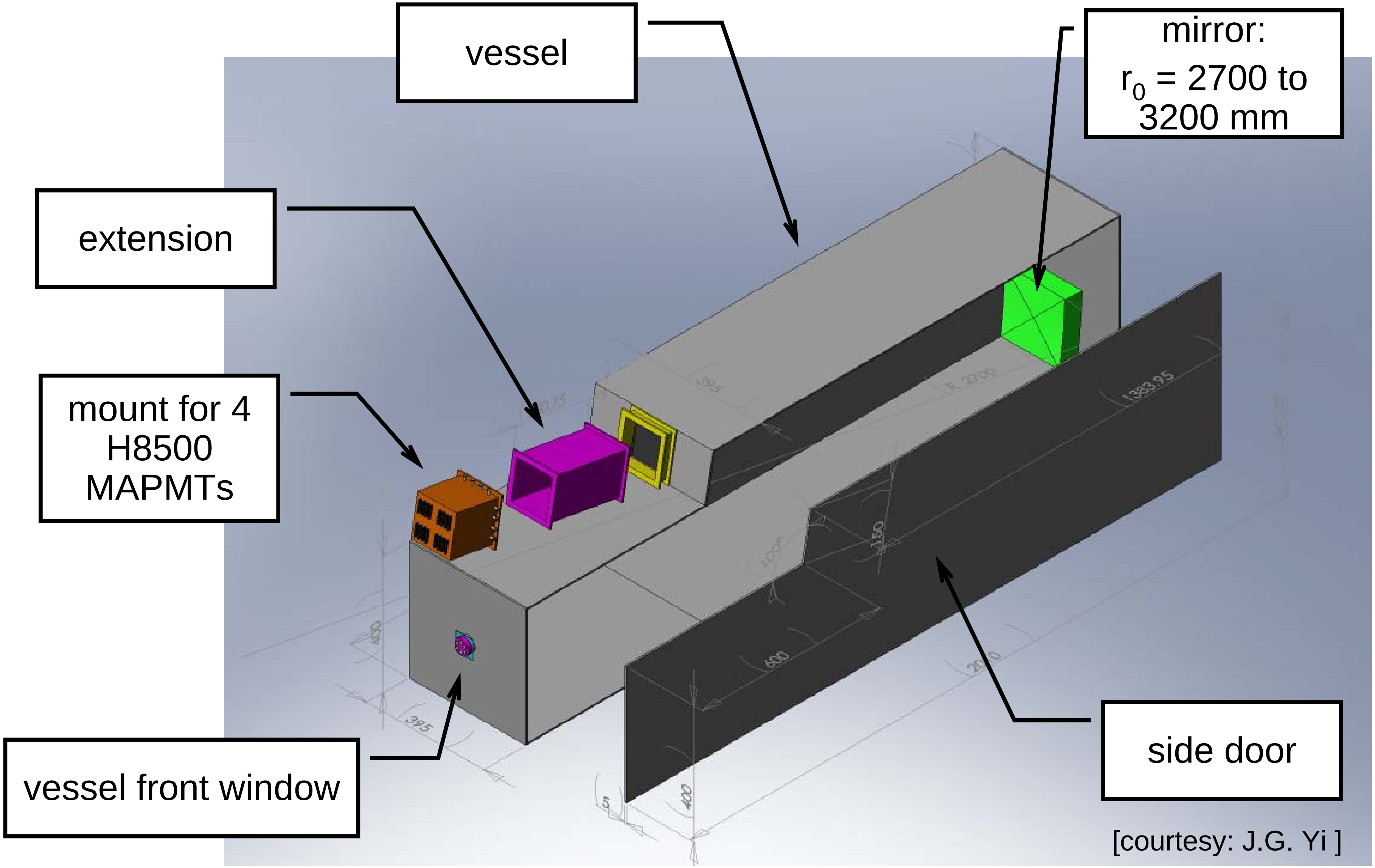
- good reflectivity in the UV-region
- more data points needed
- to be confirmed by CERN measurements

Summary Compas mirrors

Results and outlook

- thickness of 3 mm and good D_0 possible
- good reflectivity (to be confirmed!)
- test in Pusan's mini-RICH?
- work on design of mirror support

Outlook: RICH prototype PNU



[courtesy: J.G. Yi]

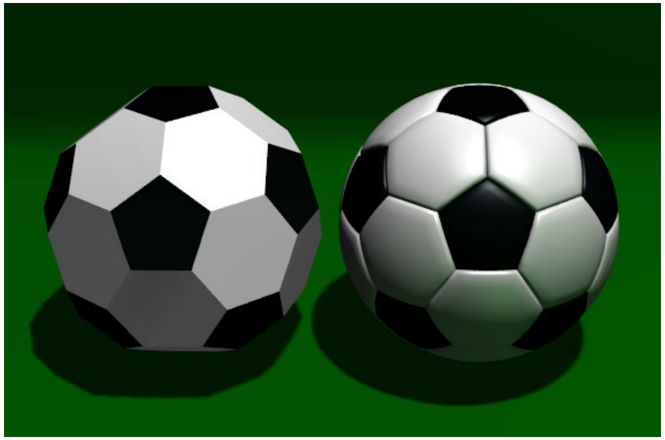
Design

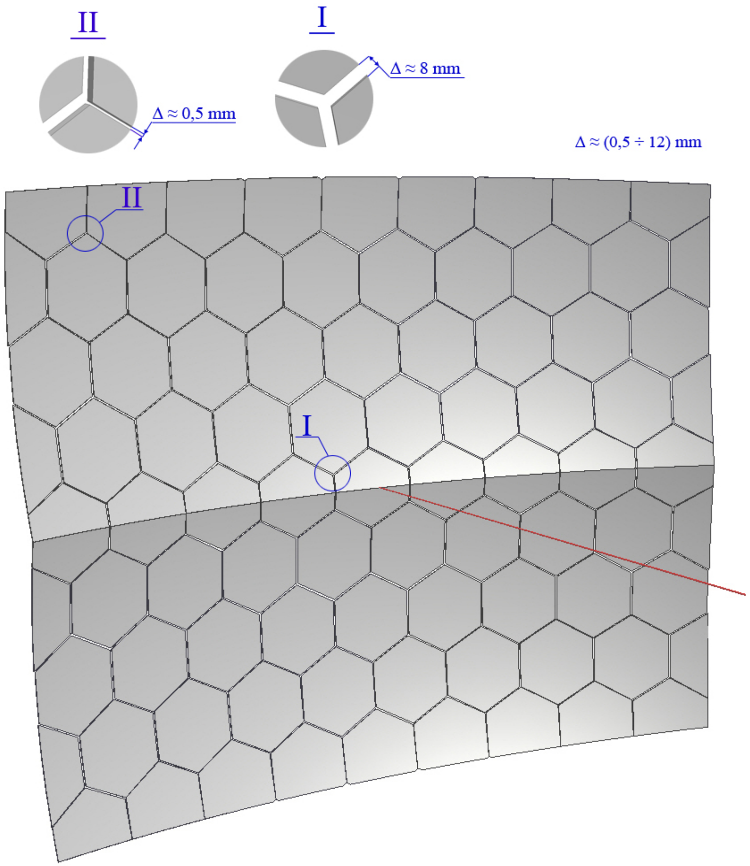
Shape of tiles

Hexagonal versus quadratic:

- impossible to divide a spherical surface into hexagons exactly
- approximation by irregular gaps between them (0.5-12mm)

→ different size of hexagons or large gaps (due to small r_0)



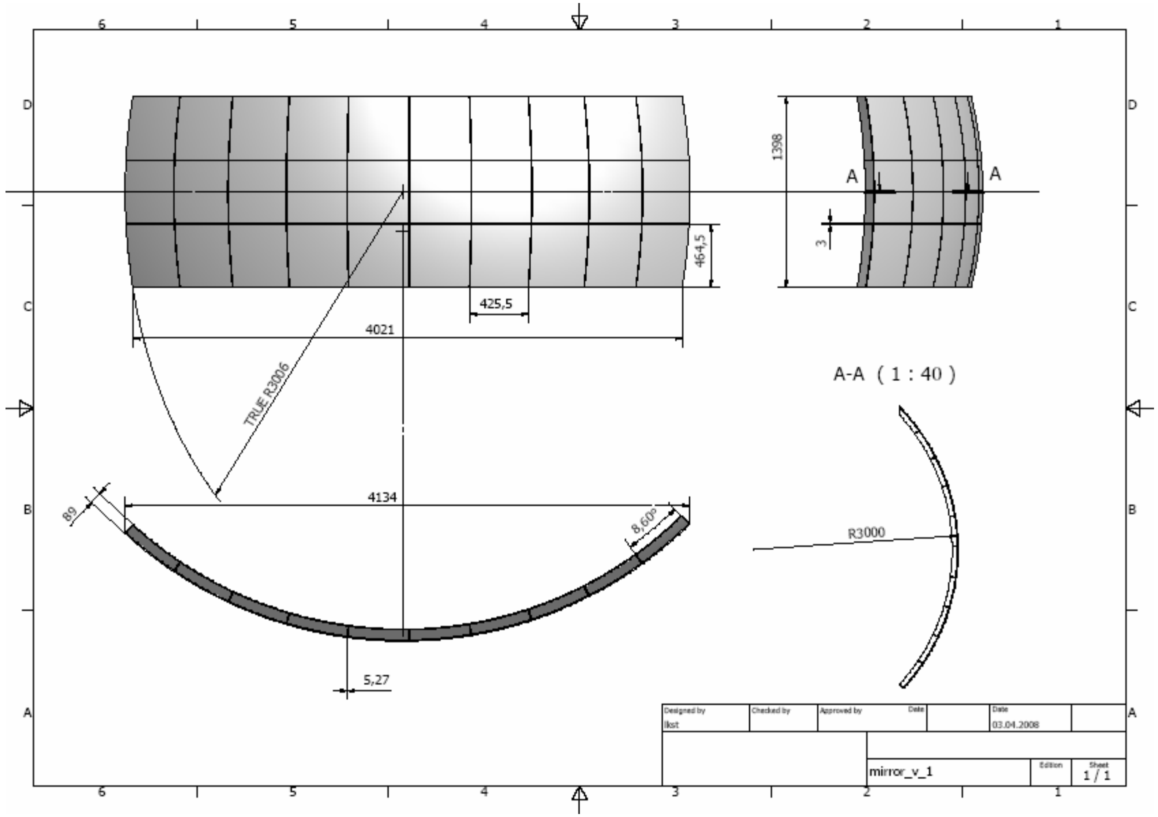


[E. Vznuzdaev, PNPI St. Petersburg]

Design

Shape of tiles

• possible solution for CBM: approx. 30 tiles of 40 x 40 cm^2 for each mirror half



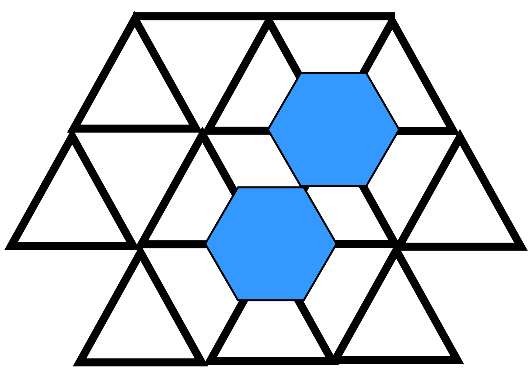
[E. Vznuzdaev, PNPI St. Petersburg]

Design

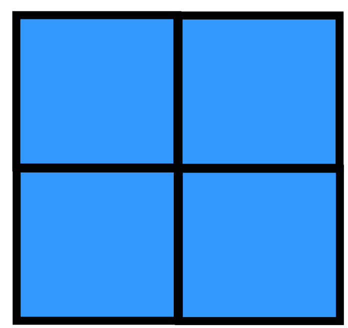
Mirror support structure

- mirror support structure depends on shape of mirror tiles

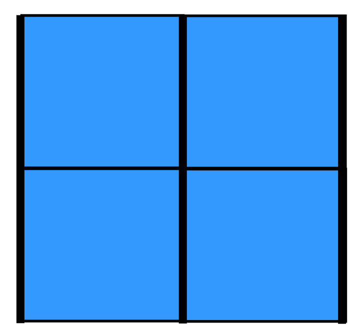
- hexagon tiles:
one mount in center of mirror
adjustment around 2 axis



- rectangular tiles:
typically 3 adjustable mounts
(shift along z-axis possible)



or

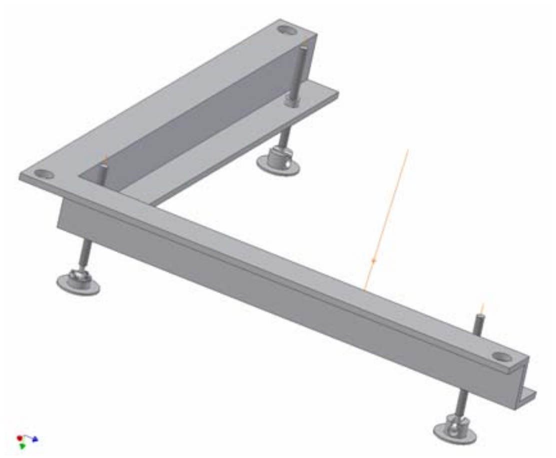


or ...

Design

Mirror support structure

- mirror support structure depends on shape of mirror tiles



- rectangular tiles:
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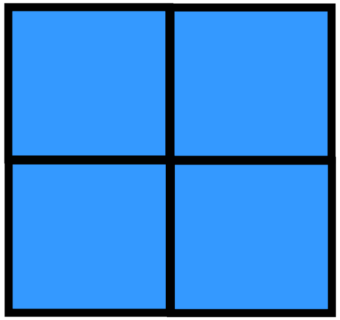
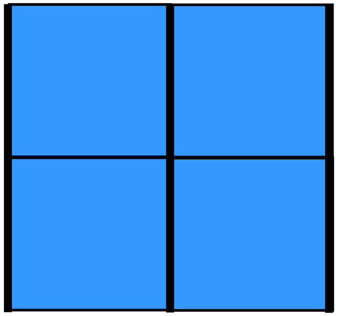


or



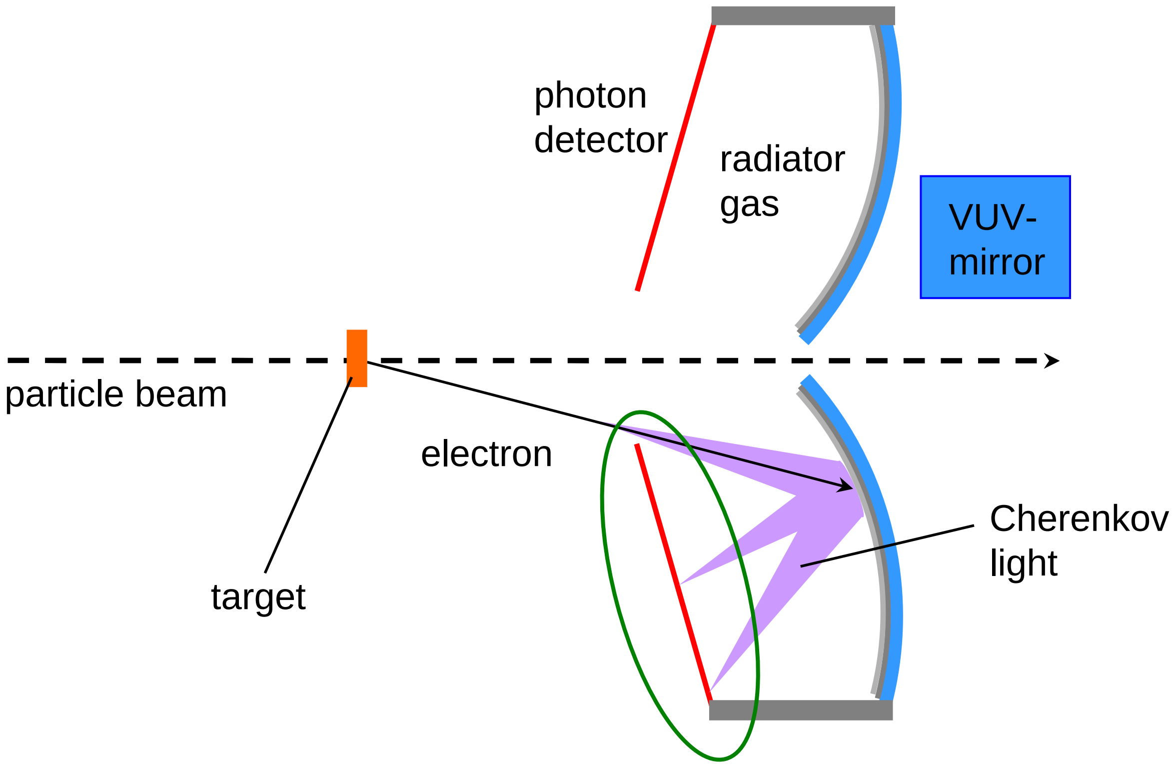
or ...

requirements:

- no additional stress on the mirrors
- stabilization against gravity (→ distortions)

Introduction

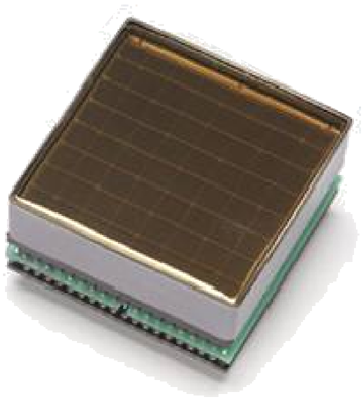
RICH detector – principle

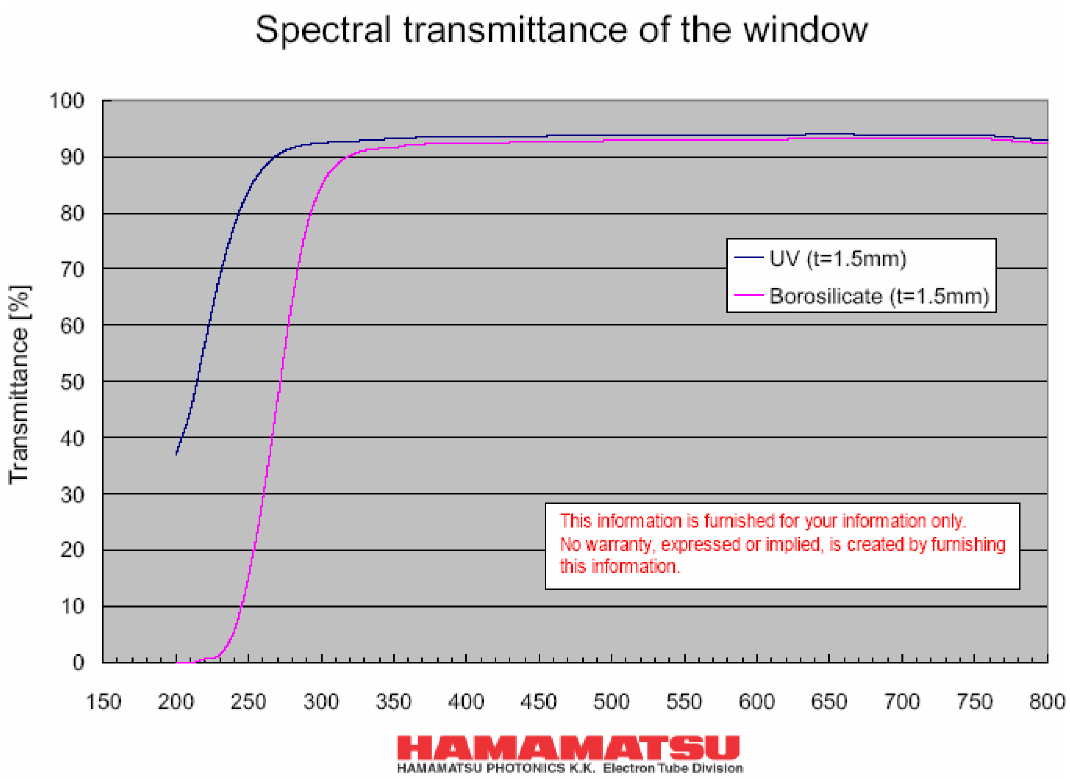


Photodetector

- quantum efficiency limited by transmission/absorption of window
- examples: borosilicate – UV extended – quartz

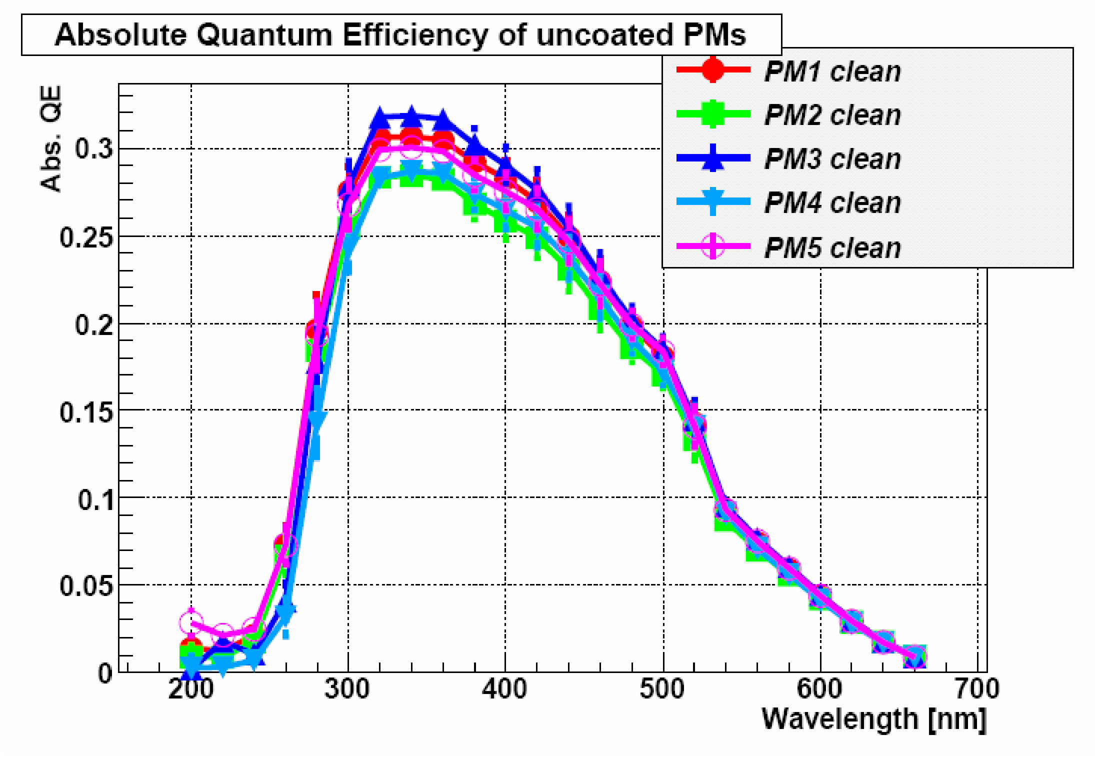
- Hamamatsu H8300-03:





Photodetector

Performance and limitations



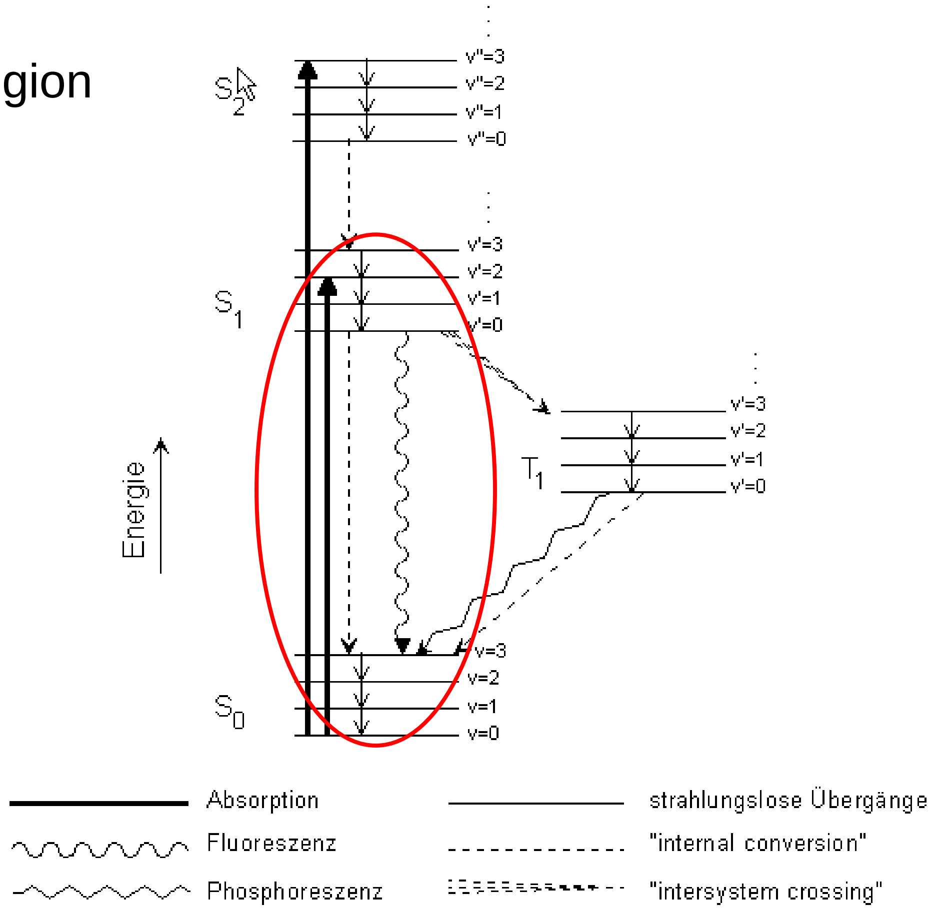
[Data: P.Koczon]

- PM: Photonis XP3102
- good quantum efficiency around 300 nm to 400 nm
- low efficiency below 300 nm

WLS - films

Wavelength shifting films – principle and application

- Organic molecules absorbing in the short (UV) wavelength region
- Strong fluorescence in visible region

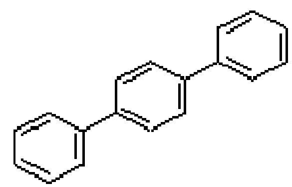


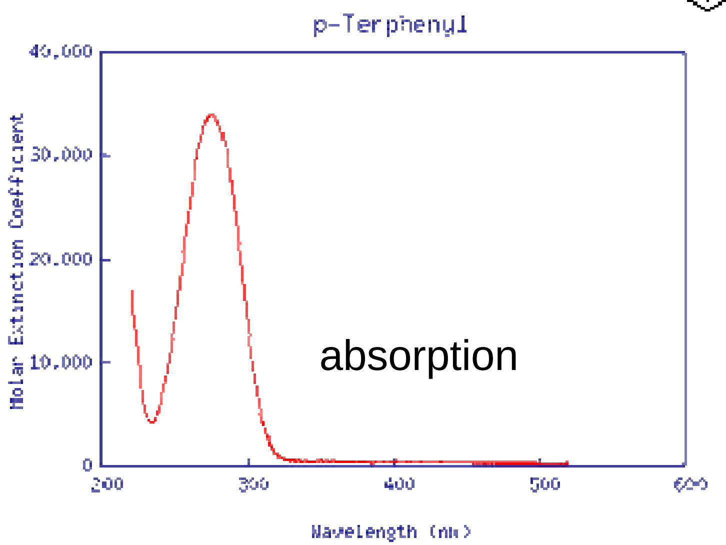
WLS - films

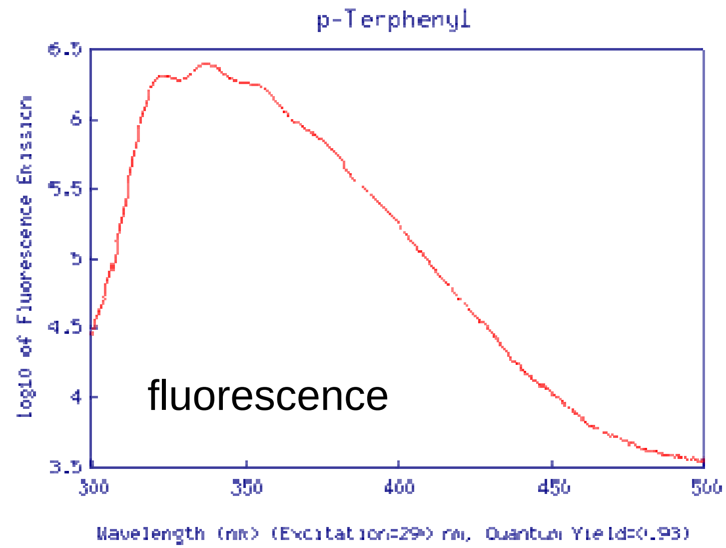
Wavelength shifting films – principle and application

- Organic molecules absorbing in the short (UV) wavelength region
- Strong fluorescence in visible region

Example: p-Terphenyl







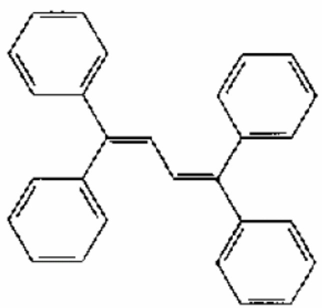
http://omlc.ogi.edu/spectra/PhotochemCAD/html/p-terphenyl.html

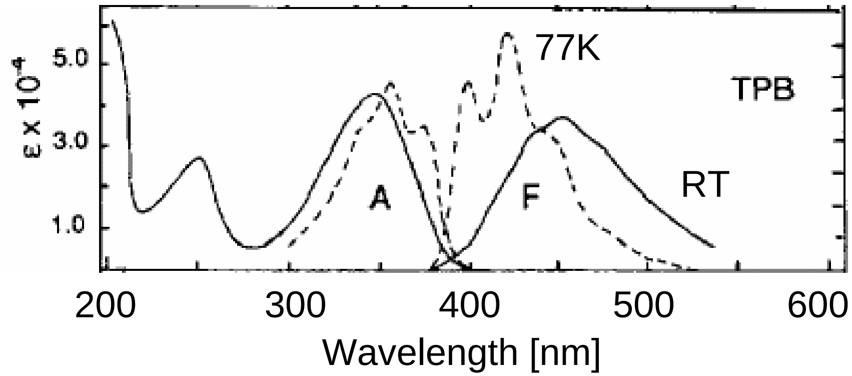
WLS - films

Wavelength shifting films – principle and application

- Organic molecules absorbing in the short (UV) wavelength region
- Strong fluorescence in visible region

Example: TPB = Tetraphenyl Butadiene



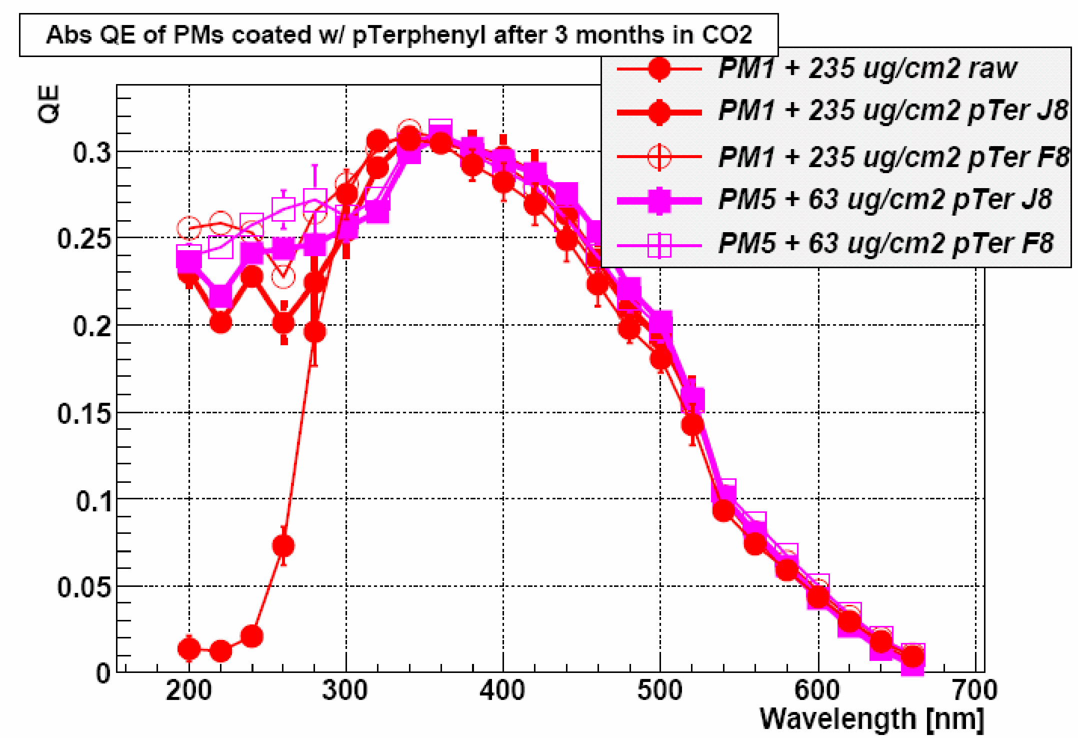


WLS - films

Wavelength shifting films – principle and application

- Depending on material used, improved photomultiplier performance in the short wavelength region

P-Terphenyl:



- good long-term stability when stored in CO_2 (under dark)

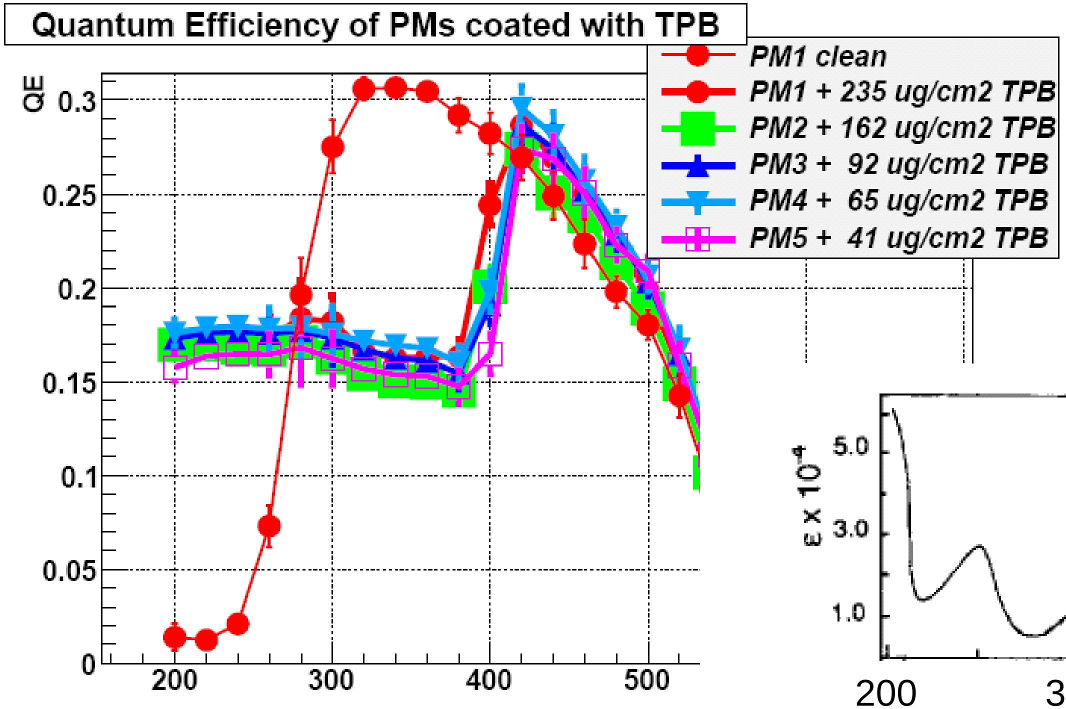
[Data: P.Koczon]

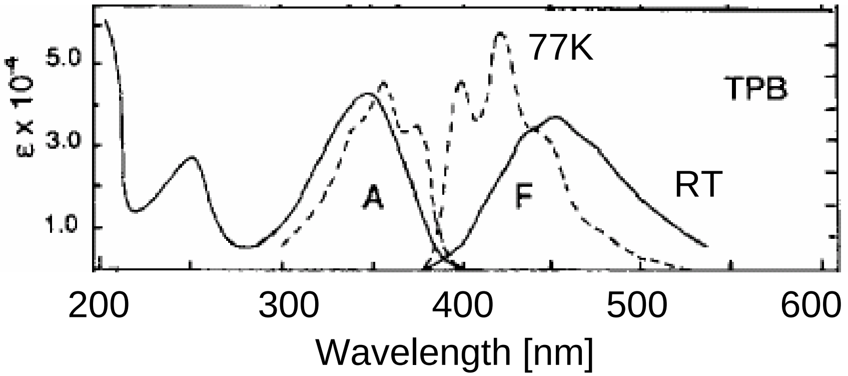
WLS - films

Wavelength shifting films – principle and application

- Depending on material used, improved photomultiplier performance in the short wavelength region

TPB:





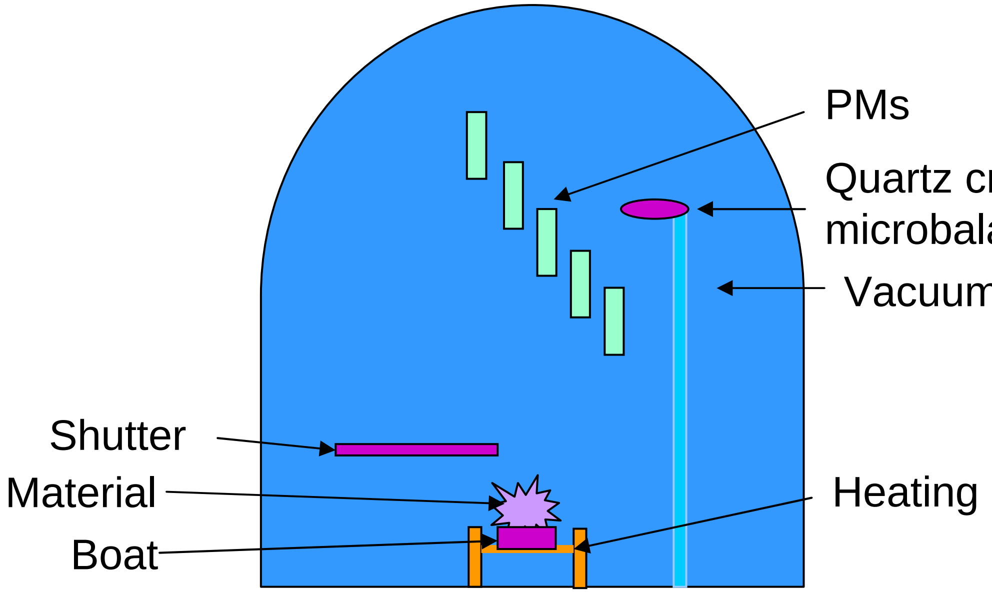
[Data: P.Koczon]

WLS - films

Application techniques

- Evaporation (used so far):

  - good optical properties (no solvents, no binders)
  - Inferior mechanical stability



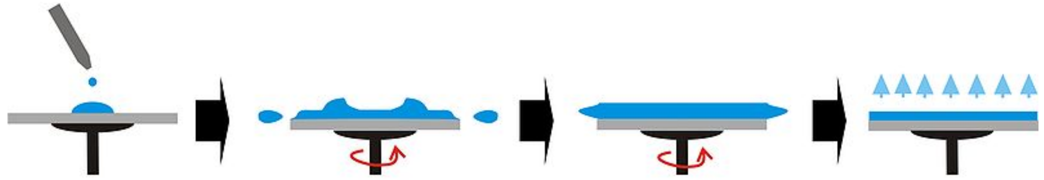
[Setup Andre Braem, CERN]

WLS - films

Application techniques

- Spin coating / dip coating
    - needs solvents → possible influence on optical properties
    - good mechanical stability

Spin coating:



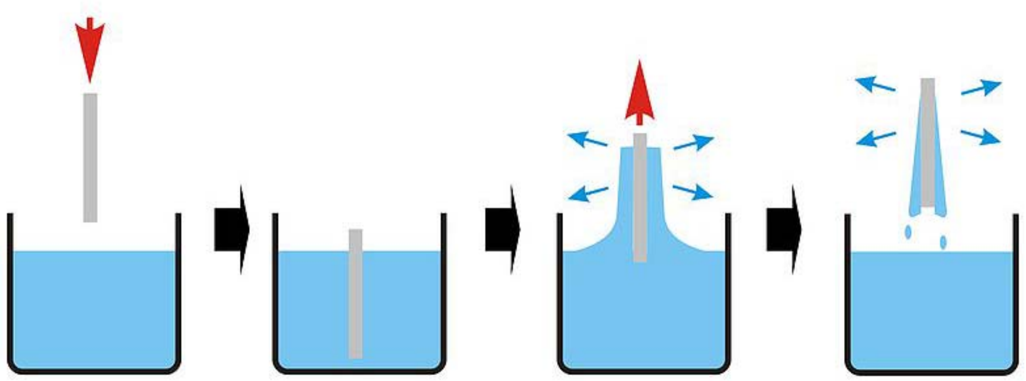
WLS - films

Application techniques

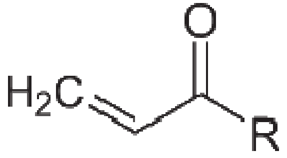
- Spin coating / dip coating

  - needs solvents → possible influence on optical properties
  - good mechanical stability

Dip coating:

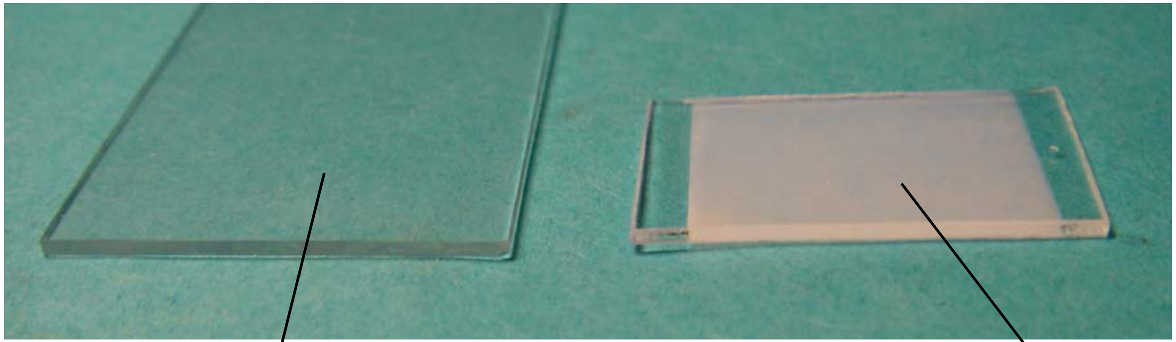


- speed of removal determines thickness of films
- concentrations in use: 1g / L
- binder in use: paraloid (acrylate), 2 g /L



WLS - films

Comparison evaporated films – dip-coated films



Dip-coated film, 6 cm/min

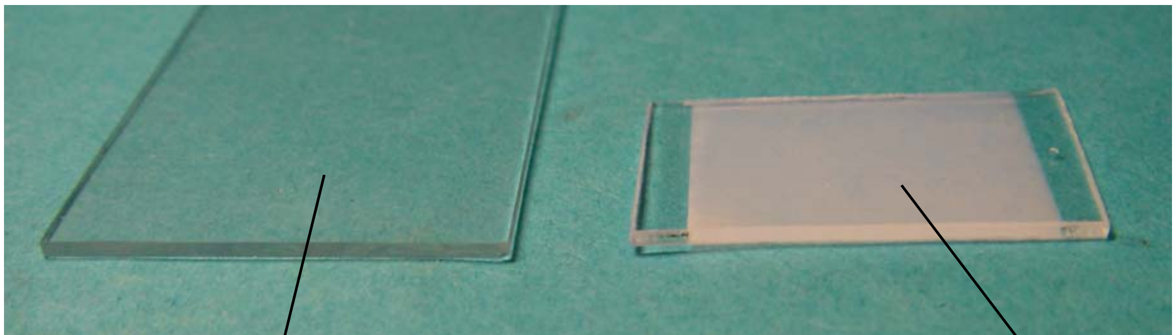
Evaporated film, 100 µg/cm^2

Dip-coated film:

- scratch proof
- transparent

WLS - films

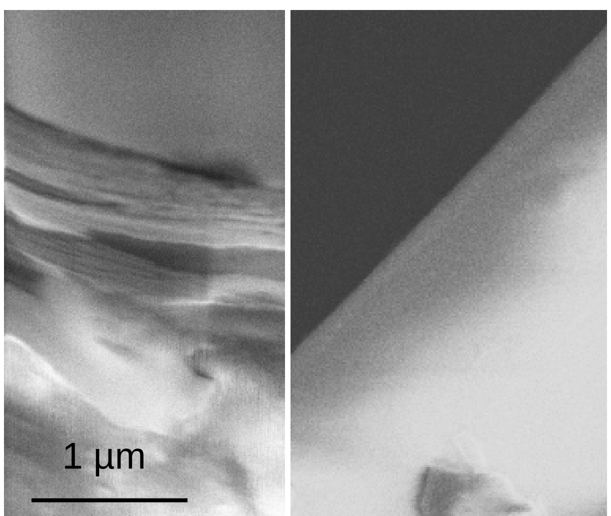
Comparison evaporated films – dip-coated films



- Evaporation leads to microcrystals in the µm-regime

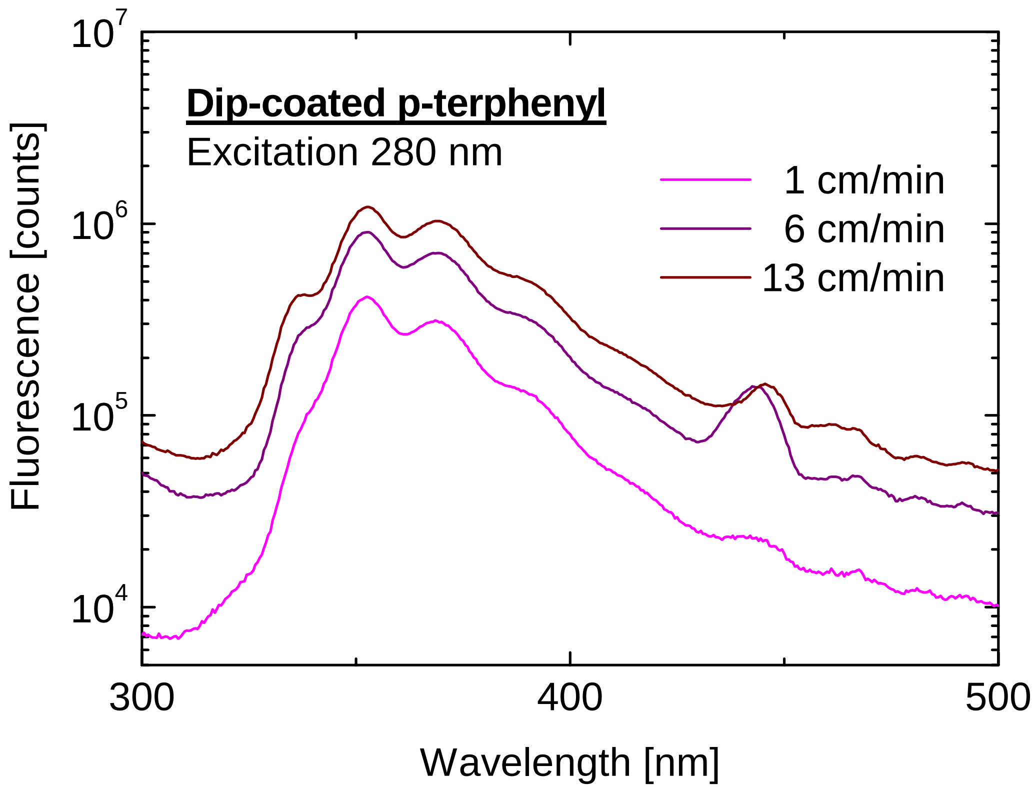
⇒ scattering of visible light

SEM images:

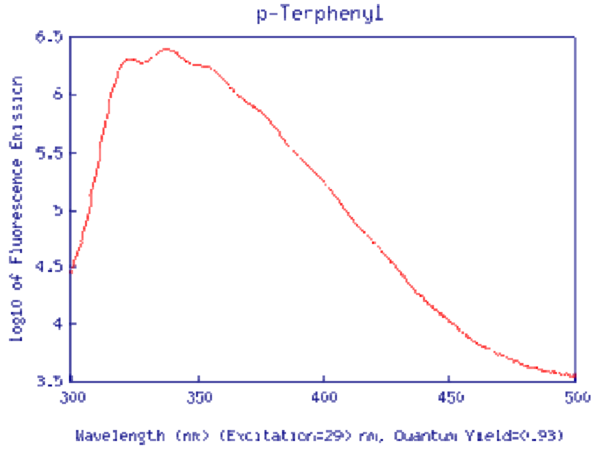


WLS-films

Fluorescence of dip-coated films



- Fluorescence spectrum comparable to reference
- thickness dependence (not all photons get absorbed)



WLS-films

To-do:

- Comparison evaporated/dip-coated films both with respect to fluorescence and efficiency of photomultipliers
- Test of photomultipliers
- Test of WLS-films on multi-anode structure (maybe in mini-RICH?)
- … and much more …

The End

Thank you for your attention!