Solid Light Concentrators - Production and First Experiences

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in cooperation with ETH Zurich

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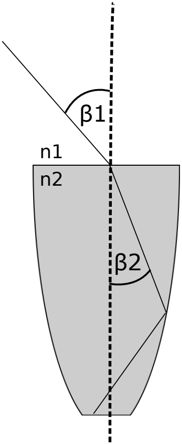
Outline

- The Motivation for Solid Cones
- Design Criteria of the Prototypes
- Ray-Tracing Simulations
- Production Iterations
- Goniometer Test Setup
- Preliminary Results
- Next Steps

The Motivation for Solid Cones

solid cones provide ...

- **total internal reflection** with **nearly 100% reflectivity**
- a **larger area concentration** compared to hollow funnels **at the same cutoff angle**
- **minimum Fresnel losses** in case of a **camera front window**
- a possible production mechanism: **injection moulding**



solid cones require ...

- **minimum surface roughness**
- **transmission of at least 70% at 350 nm**
- an **excellent coupling** to the photo sensor

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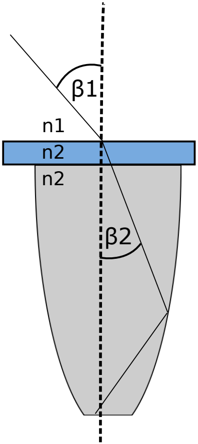

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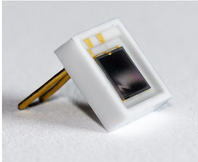
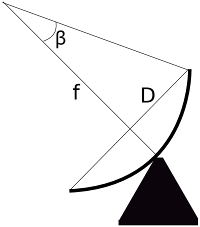
Design Criteria of the Prototypes

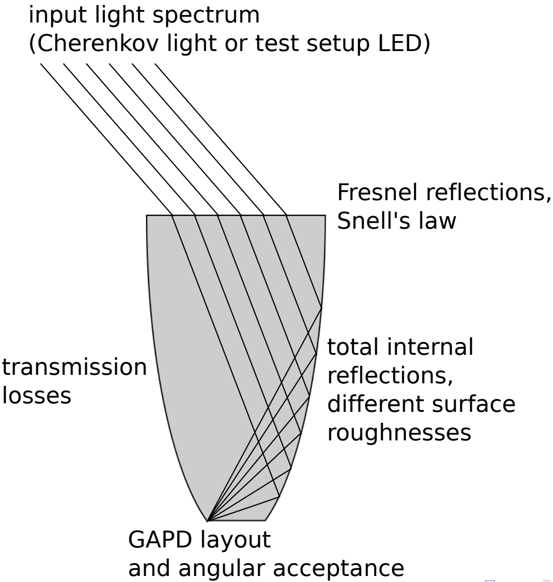
The present prototypes were designed ...

- to match a **G-APD** with **3x3 mm^2** sensitive area and a top layer with **n≈1.5** (Hamamatsu MPPC S10362-33-100C)
  - **square-shaped output** area
- to allow for optimum fill factor and equal distances between pixel centers
  - **hexagonal entrance**
- for a telescope with f/D=1.4, thus an **angular acceptance** of $\beta = arctan(\frac{D}{2f}) \approx$ **20^o**





Ray-Tracing Simulations



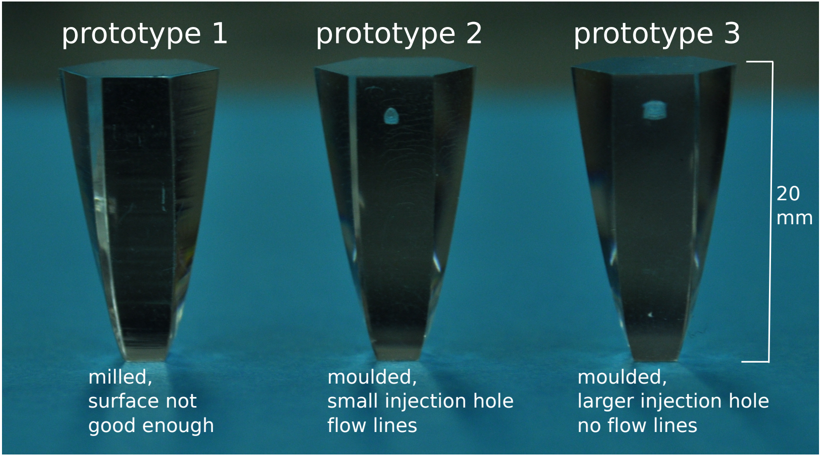
Ray-Tracing Simulations

The ray-tracing simulations resulted in a version with **non-tilted parabolic sidewalls** which ...

- has the same efficiency as the optimized tilted version
- was easier to be produced by a mould

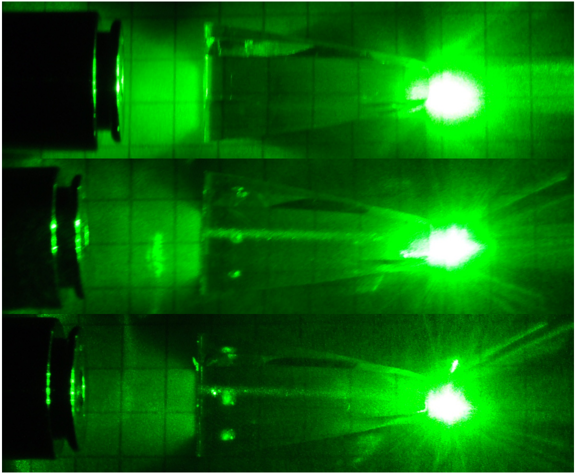
This version is produced out of **Plexiglas** by injection moulding

Production Iterations



Production Iterations

Microbubbles

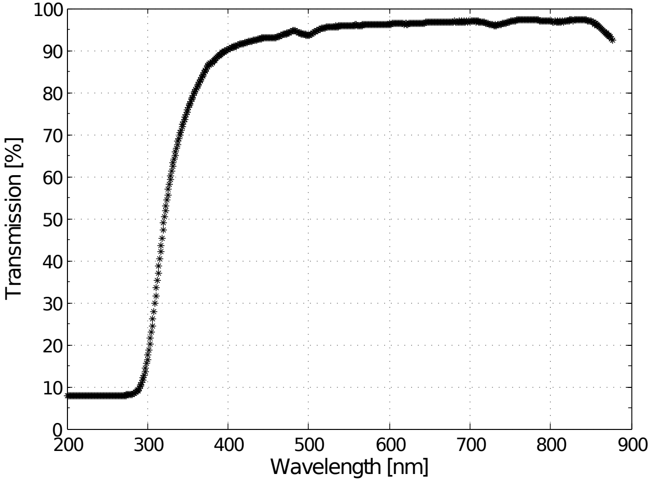


Prototype 1: none

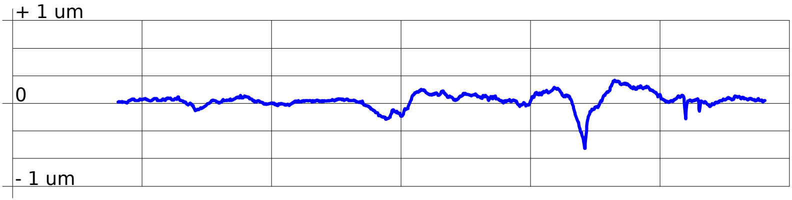
Prototype 2: microbubbles

Prototype 3: less

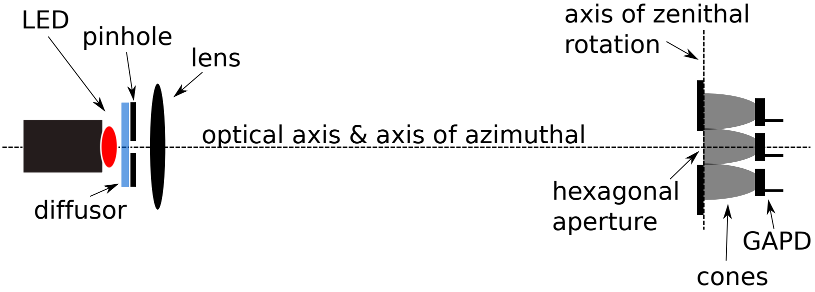
Even though, the material fulfills the requirement of 70% at 350 nm



The material's surface is close to perfect.
A **R_a-value of 0.064** μm (= mean value of all the peaks and valleys) corresponds to the **second highest quality class**



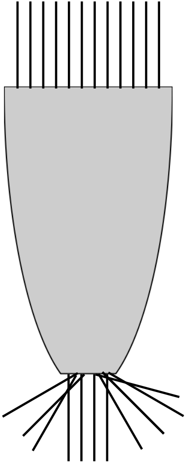
Goniometer Test Setup



- very stable light source
- parallel incident light
- linear photo sensor (GAPD in photodiode-mode)

The **light throughput efficiency** compares the incident parallel light flux at the hexagonal cone entrance with the light flux that is present at the square-shaped cone output

However:
optimum coupling between the cone and the GAPD has not yet been found



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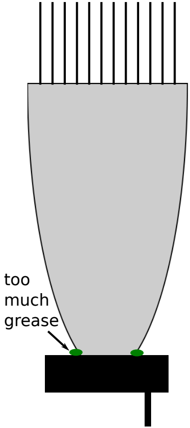
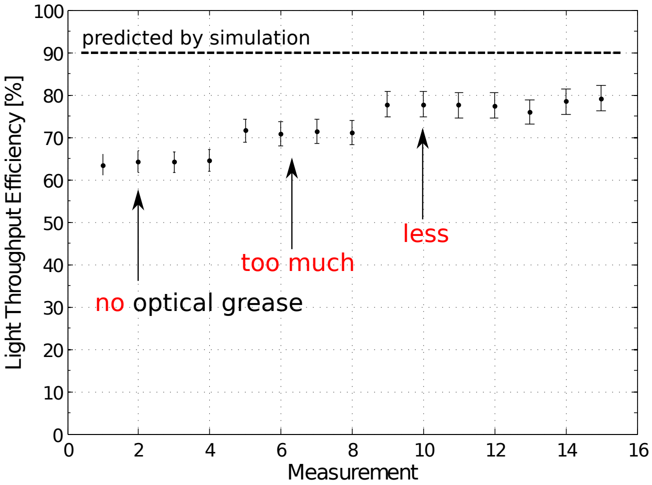
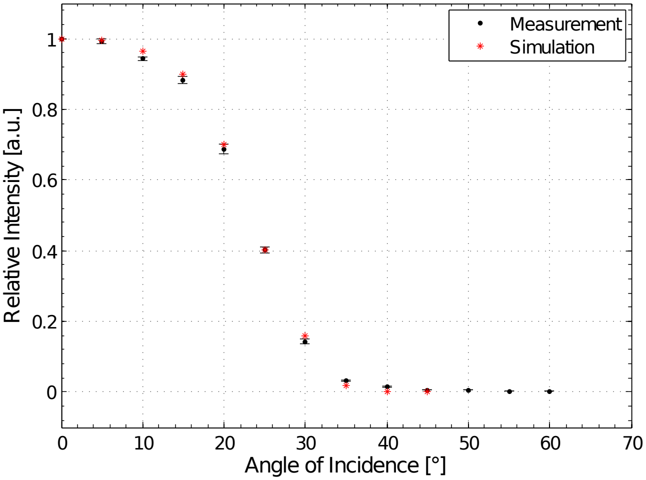


Preliminary Results
Light Throughput Efficiency



Preliminary Results

Angular Acceptance at Azimuth = 0°



Next Steps

- optical coupling has to be studied and a well-defined procedure has to be found
- prototype 3 is still not the final version, since inpurities are present, **prototype version 4** which will not have these inpurities is expected during the next weeks
- the final version will be used for the FACT camera project (see talk by T.Bretz)

Concerning CTA

- injection moulding: easy production, also for larger scales
- single cone production:
  mould costs about 15000 Euro, 1-2 Euro per cone
- idea: 8x8 arrays
  mould: $\sim$ 100000 Euro, $<$ 90 Euro per array
  BUT: not yet shown, that 8x8 arrays can be produced homogeneous enough

BackUp

Ray-Tracing Simulations

Winston case:

- parabola is fixed by three points
- area concentration ratio determines cutoff angle
- but height is then already given since parabola's ($y = ax^2$) focal point $f = \frac{1}{4a}$ is positioned at outer edge of output area

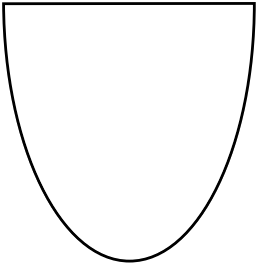
non-tilted parabolic case:

- area concentration ratio determines cutoff angle
- height determines cutoff sharpness
- for each ratio setting, the height was varied and optimized to sharpness and minimum number of reflections in order to minimize possible reflection losses

Ray-Tracing Simulations

Extensive ray-tracing simulations compared numerous of different designs with tilted and non-tilted parabolic sidewalls.

- non-tilted version



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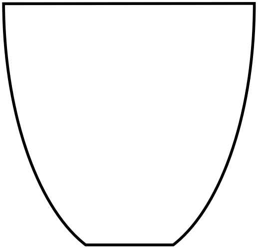

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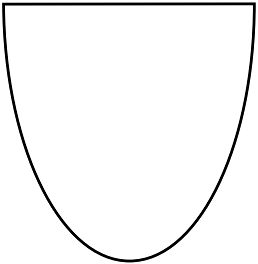

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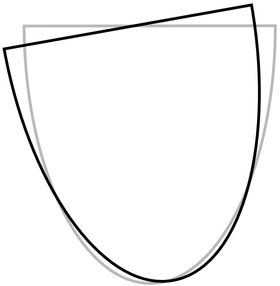

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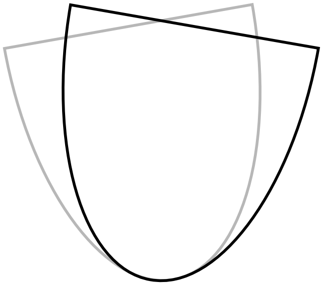

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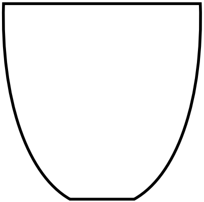
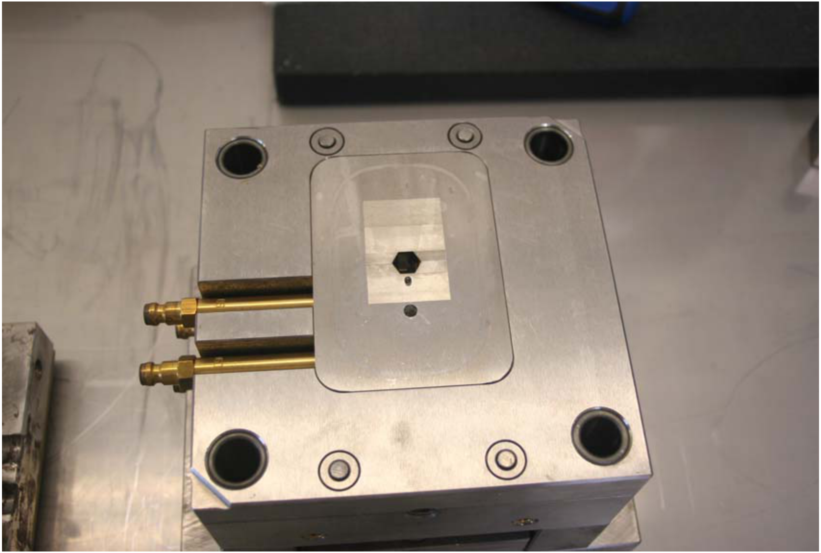


Injection Mould



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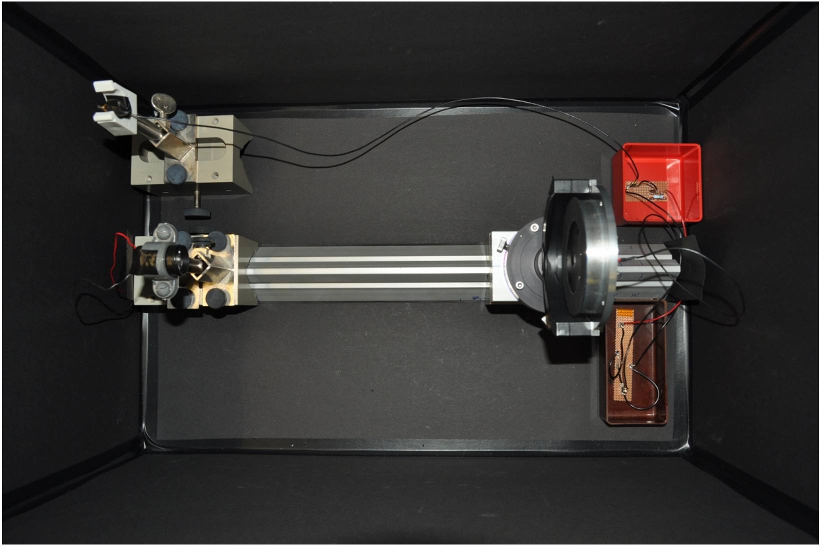
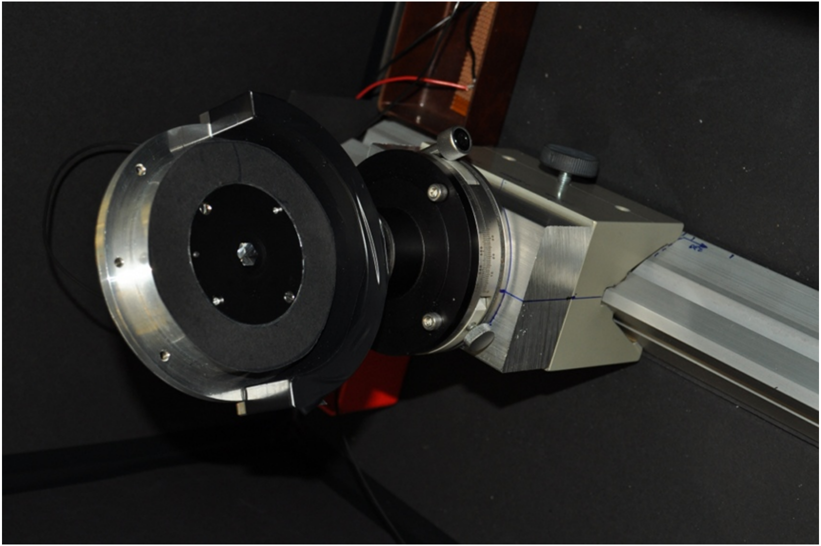
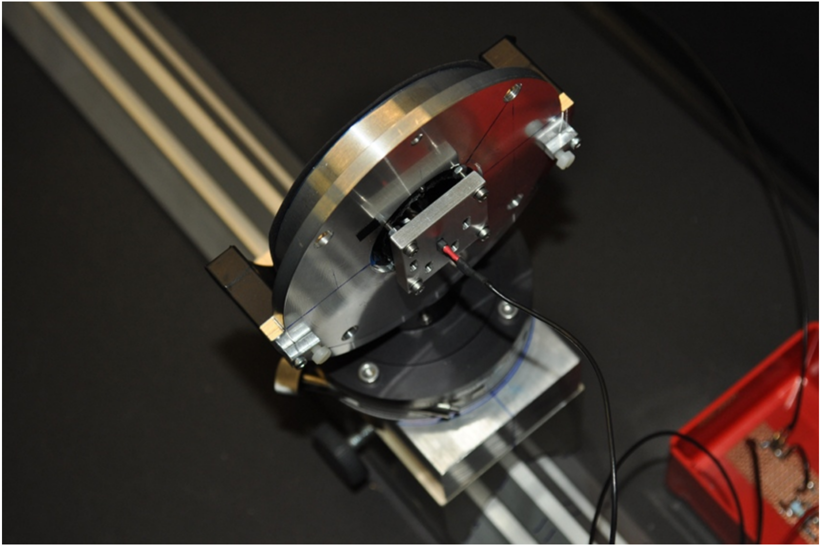


Goniometer



GAPD Holder



GAPD Angular Acceptance

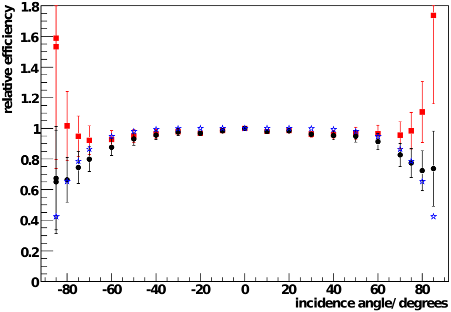
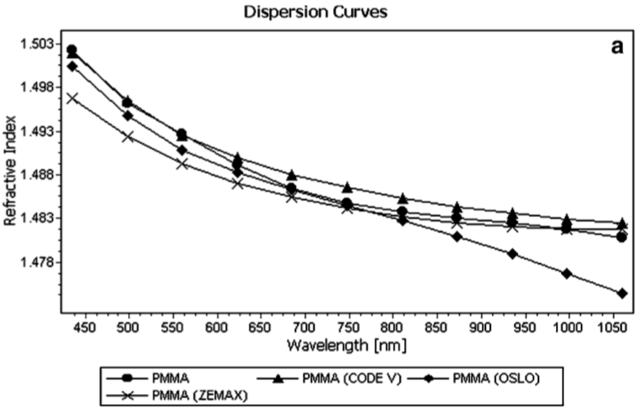


Figure 1: G-APD angular acceptance measured at 450 nm without protective resin. The angular acceptance is normalized to 1.0 for vertical incidence. Black circles: measurement, blue stars: Fresnel equation, red squares: intrinsic (see text for explanation). Error bars include the statistical and systematic errors discussed in the text.

[I. Braun et al., *Winston Cones for a secondary optics telescope with a G-APD Camera*.]

Plexiglas Dispersion



[S. Kasarova et al., *Analysis of the dispersion of optical plastic materials.*]

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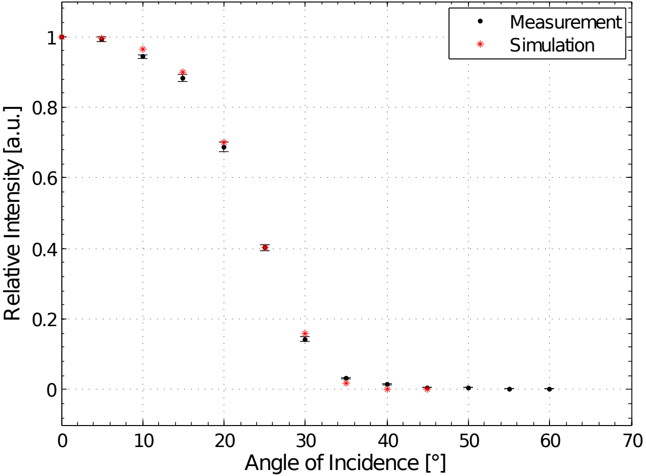

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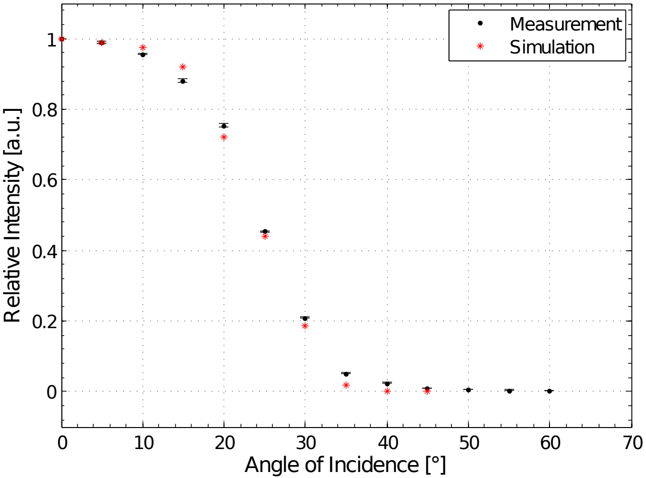
Angular Acceptance at Azimuth = 45°



Preliminary Results

Angular Acceptance at Azimuth = 90^o