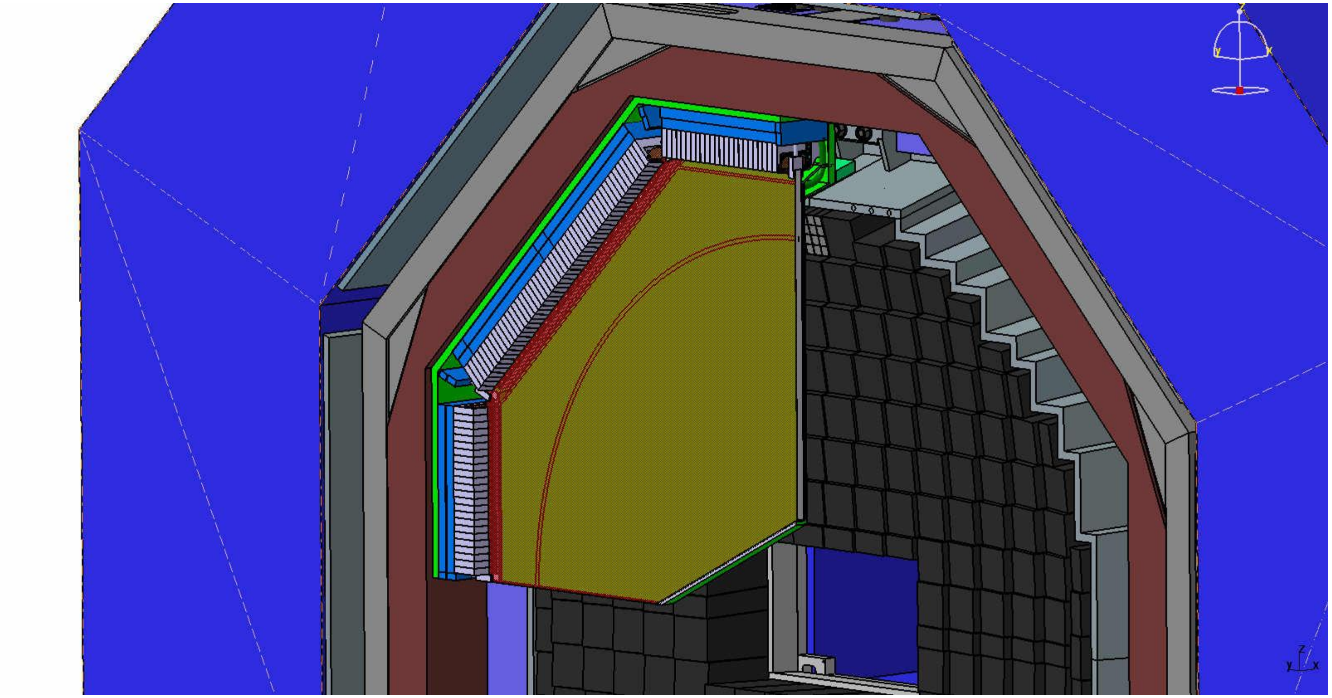
The PANDA 3D Disc DIRC



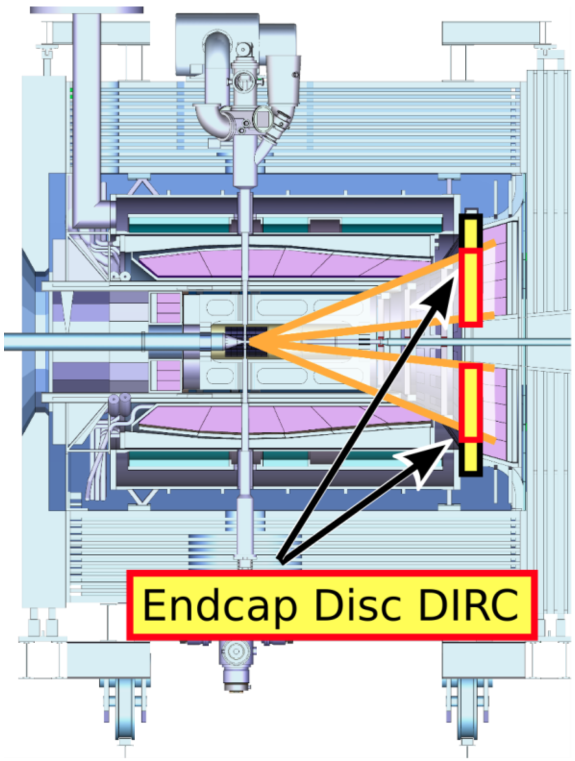
Prof. Dr. M. Düren
on behalf of the Panda Cherenkov Group

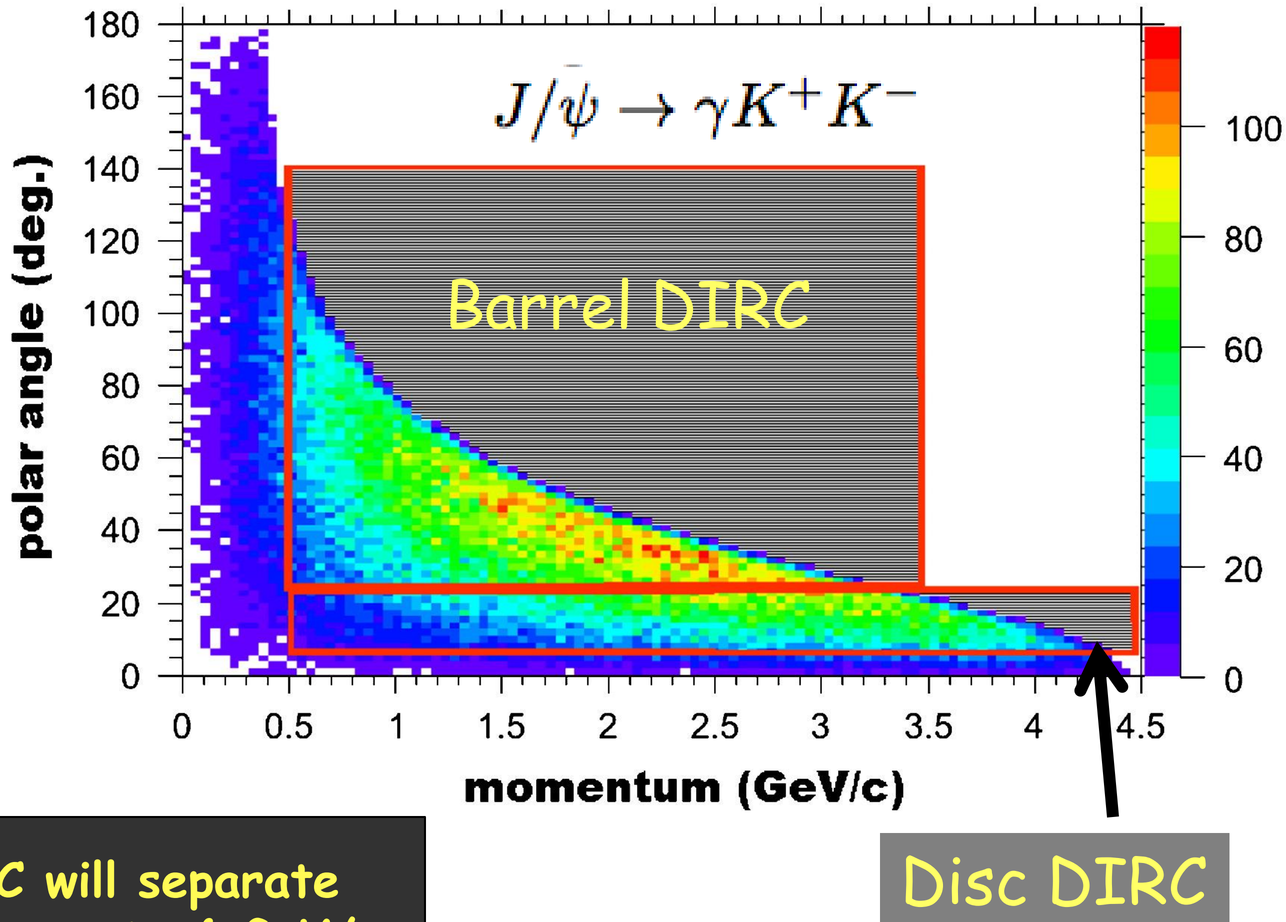
II. Phys. Inst., Justus-Liebig-Universität Giessen

DIRC2011: Workshop on Fast Cherenkov Detectors" (04.-06.04.2011)
Rauischholzhausen, April 5, 2011

Panda Particle Identification System

- The purpose of the PANDA Disc DIRC (PDD) is to provide particle identification in the end-cap region of PANDA.



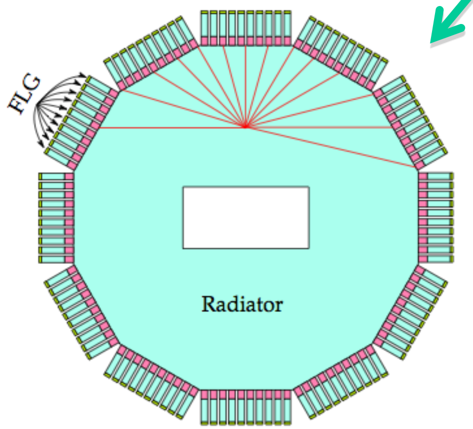


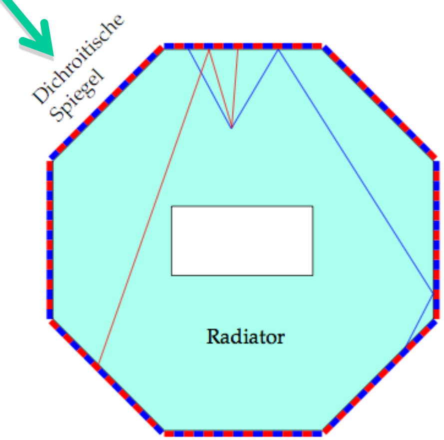
The 3D DIRC will separate kaons and pions up to 4 GeV/c

Evolution of DIRC concepts at Panda

BaBar DIRC

1999





Focussing Light Guide
(Edinburgh/Glasgow)

Time-of-Propagation
(Giessen)

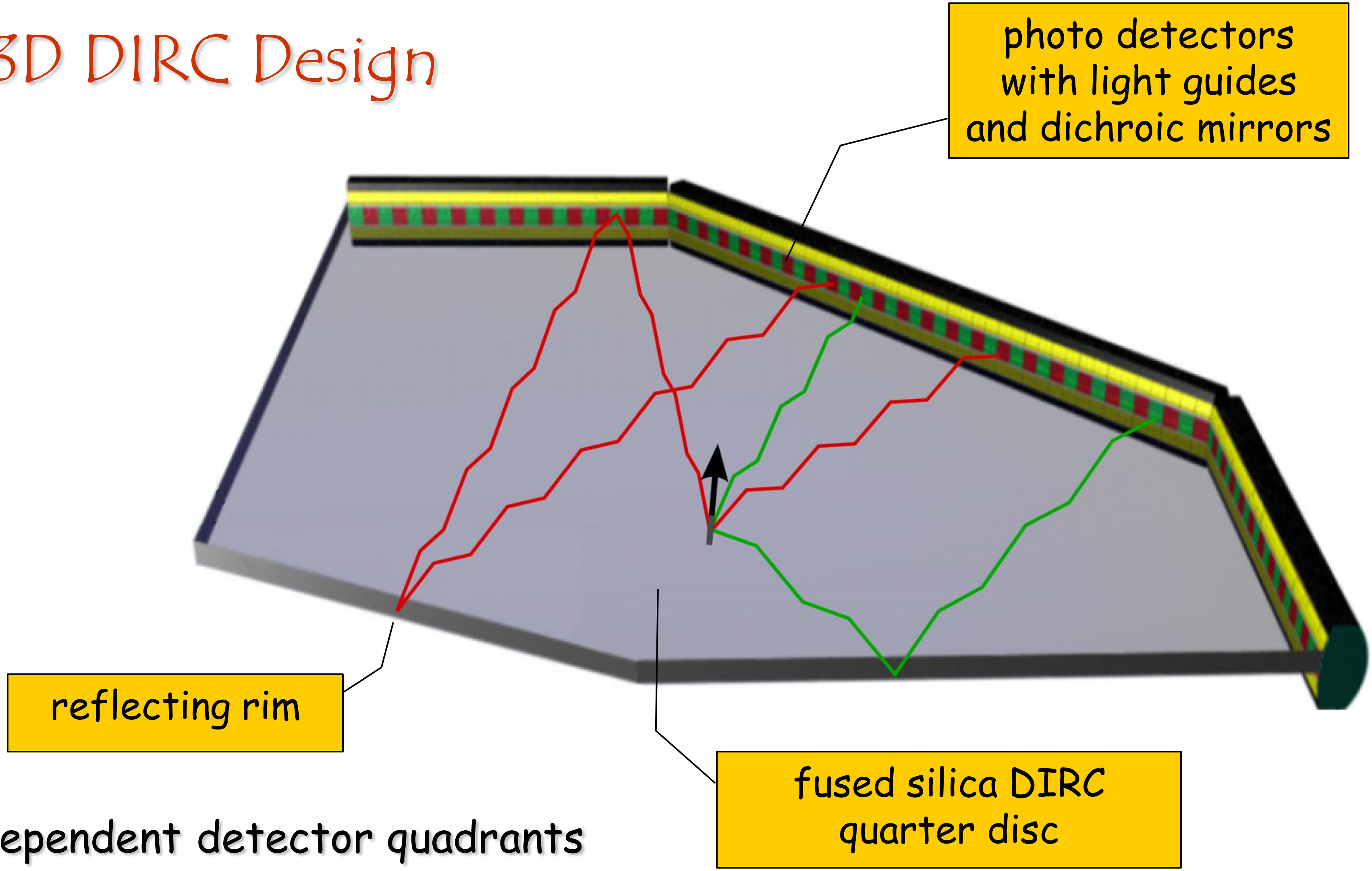
2006

PANDA 3D DIRC

2010

...2016

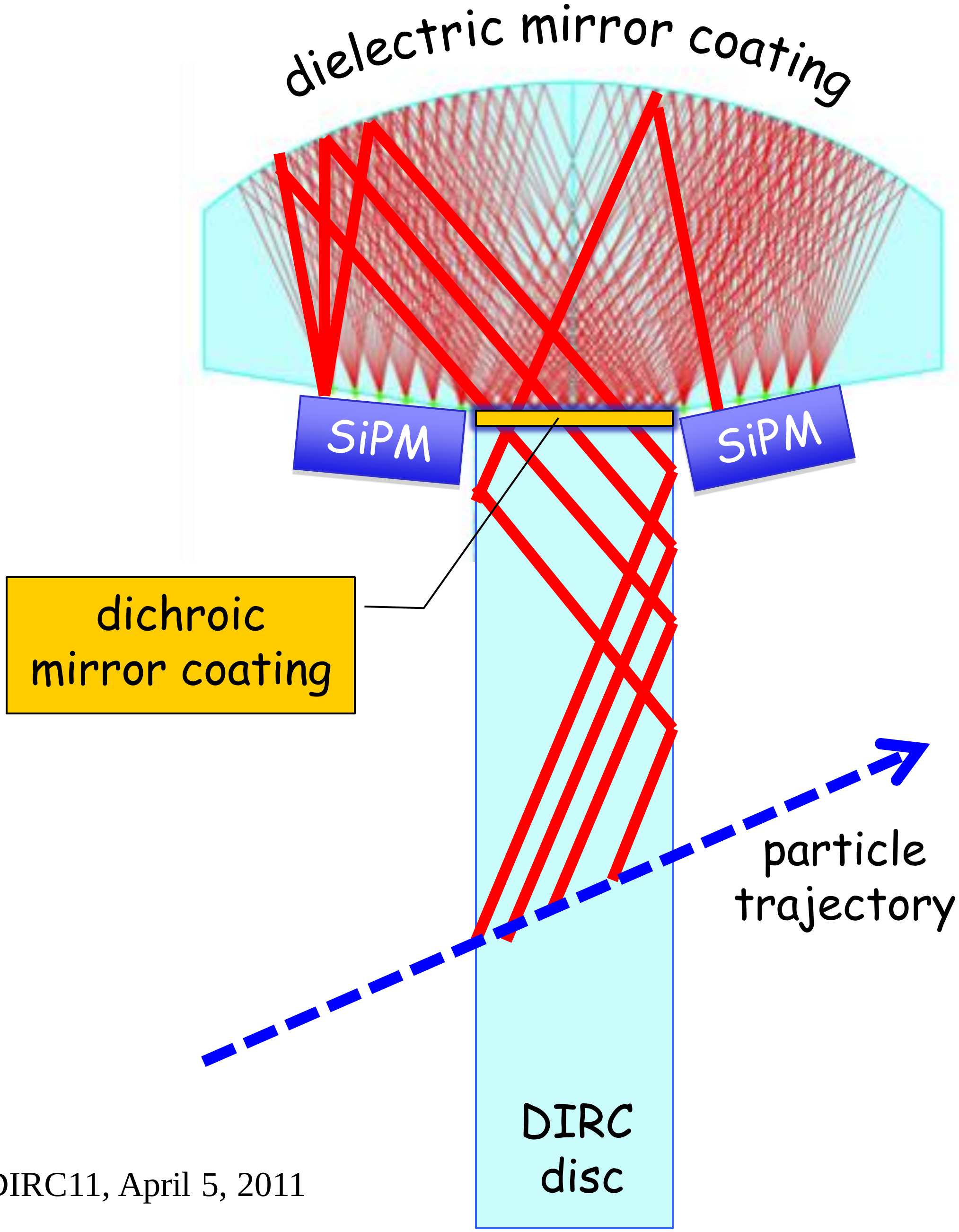
3D DIRC Design



- independent detector quadrants
- reflecting rim
- small light guides

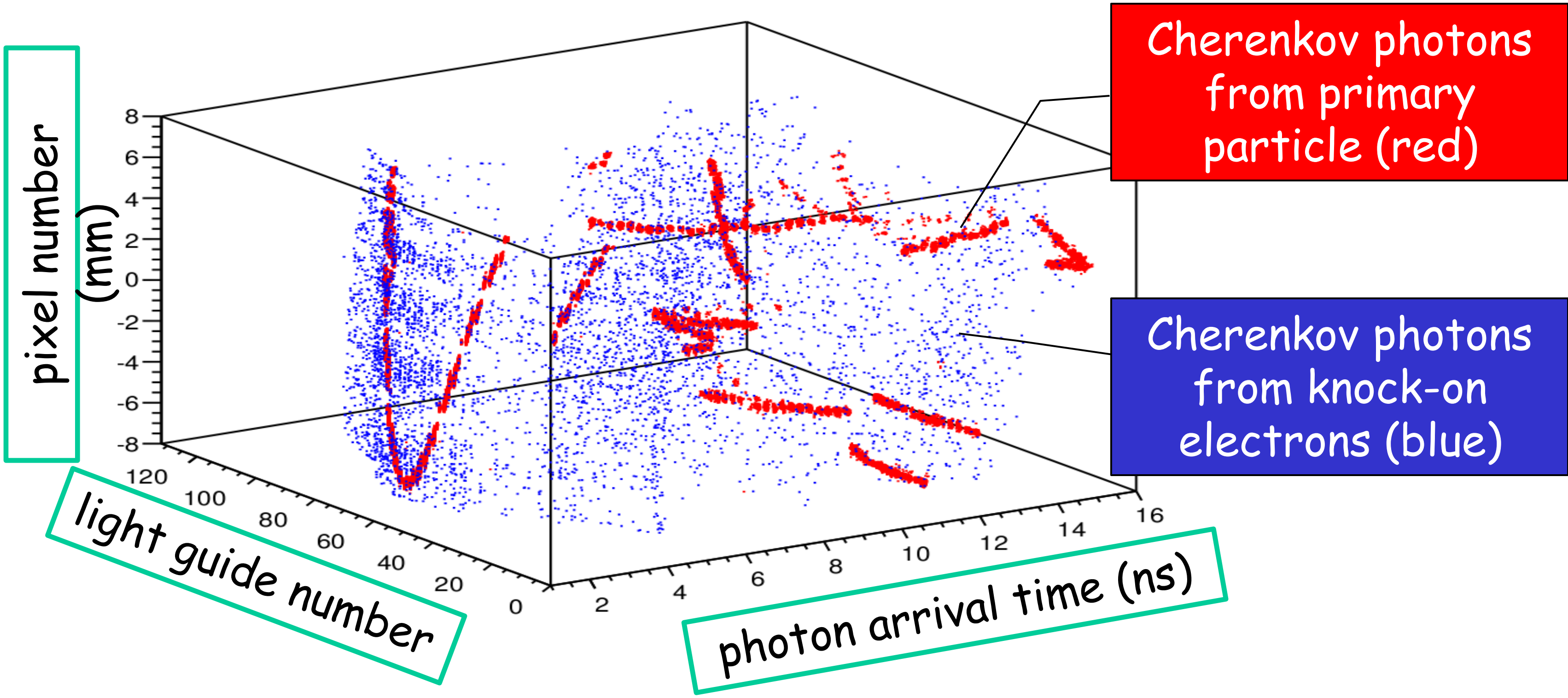
3D DIRC Design

- Fast and small pixel detectors:
  SiPMs or MCPs
- Angle measurement by small focussing light guides und multi-pixel detectors
- ToP measurement by small light guides and fast photo detectors
- Dispersion handling by dichroic band pass filters



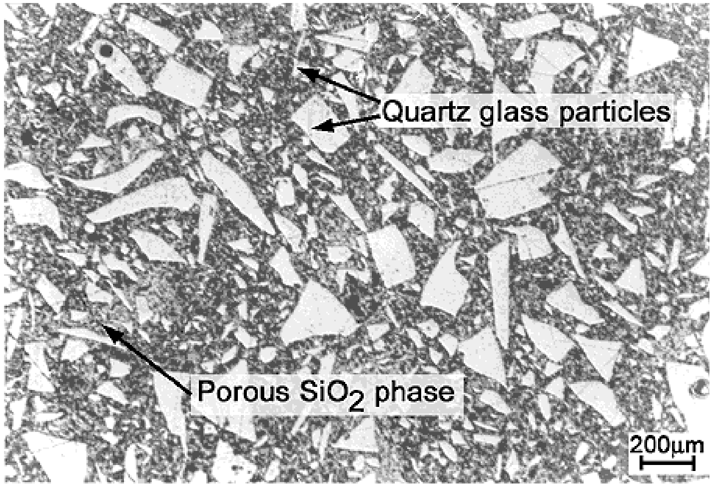
Why 3D?

- 3D pattern looks complicated but…
- signal/background separation much better in 3 dimensions than in a 2-dimensional projection

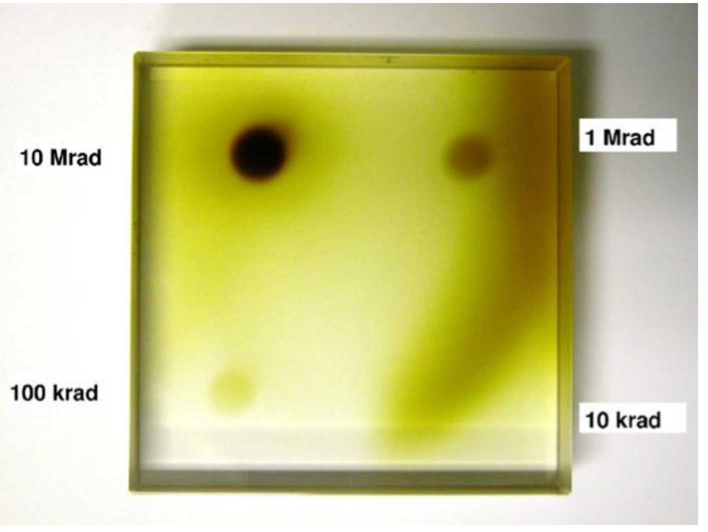


The radiator plate: material choice

① Acrylic glass plate (WASA)
② Float glass plate (Prototype)
③ Fused silica (PANDA)



- Fused silica will be used for PANDA unless somebody can prove that the radiation properties and optical properties of other material work



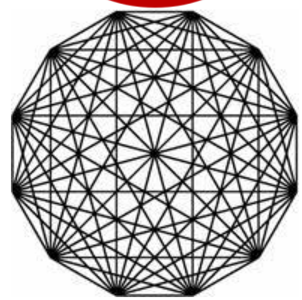
radiation damage of flint glass

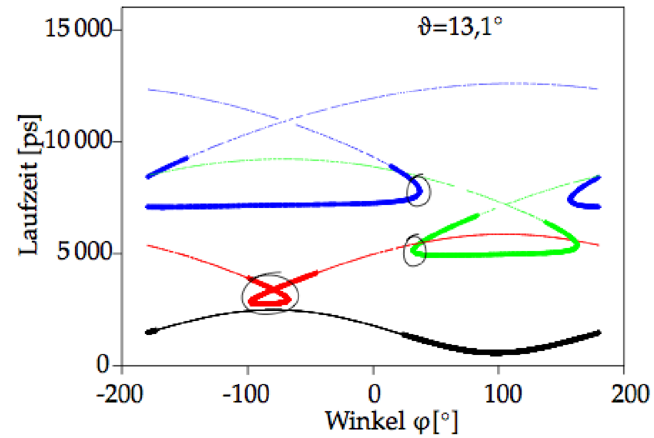
The radiator plate: shape

① round disc

② multi-polygonial disk

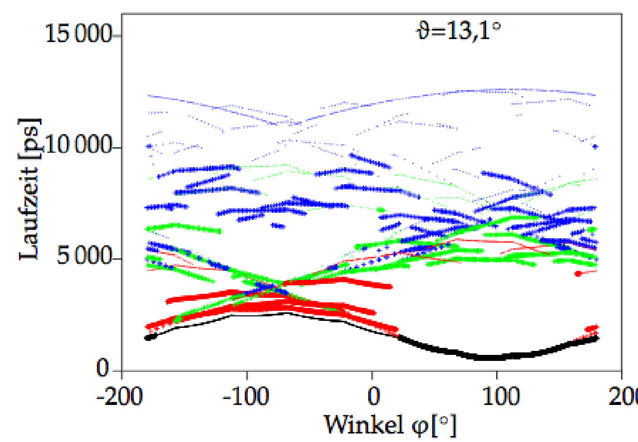
③ octagonal disk





pattern of round disk

- shape affects:
  - pattern of photons
  - costs of plate polishing
- Octagonal shaped disc is used as
  - it matches the PANDA magnet symmetry
  - it is sufficienty "round"
  - with a minimum of corners



pattern of octagonal disk

The radiator plate: construction

① Radiator plate produced as one piece:
- impossible for reasonable price

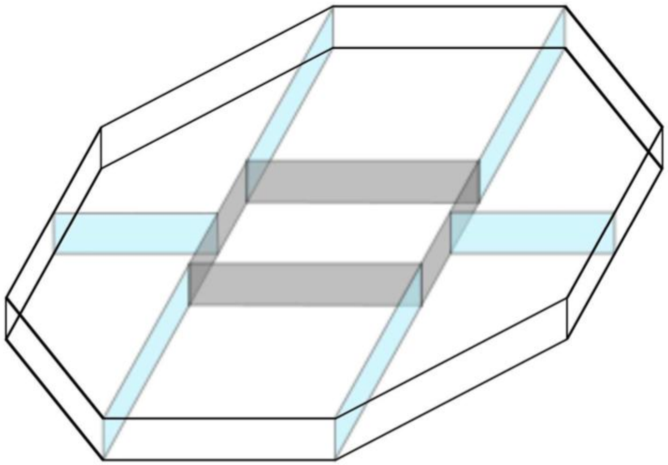
② Radiator plate glued from 4-6 pieces:
- unwanted reflections at glue joints
- mechanical stability and fitting of last piece problematic

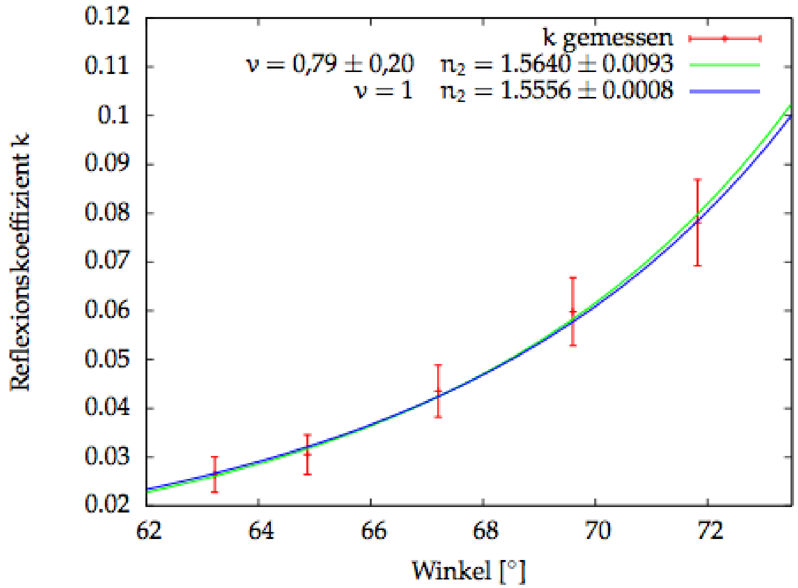
③ DIRC consists of 4 optically independent radiator plates

– 4 independent sub-detectors will be produced as reconstruction software is able to handle it

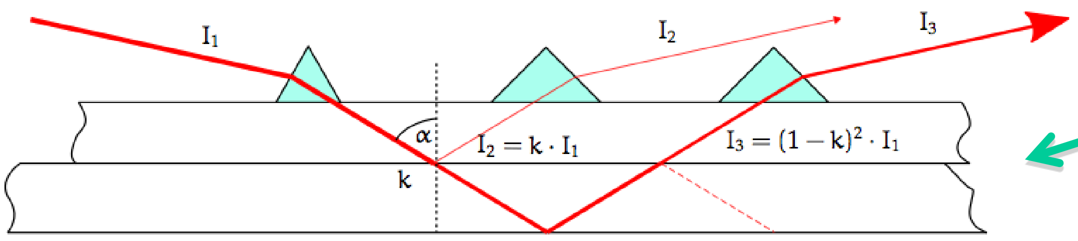
Problematic glue joints

- Two glued glass bars were measured: Fresnel formulae were verified



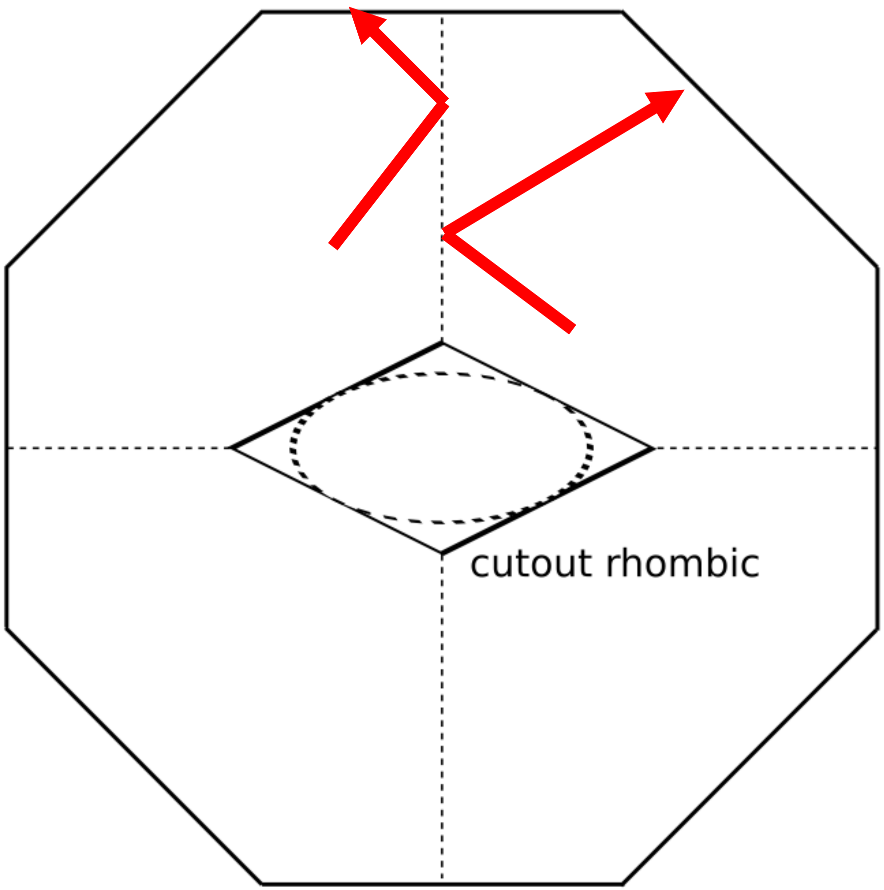


large losses for shallow angles in medium



The radiator plate: construction

- Produce 4 identical optically (and mechanically) decoupled quadrants:
  - significant cost saving
  - risk reduction (one spare)
  - large simplification in handling (~1 m size, ~50 kg)
  - additional complexity of reconstruction software



If companies do not want to glue one single 2 m disc, we also do not want it if we don't have to!

The radiator plate: beam hole shape

① Elliptic beam hole

② Rectangular beam hole

③ Diamond shaped beam hole

- "diamond shape" hole avoids inner corners in plate production:
  - easier to produce and lower costs
  - acceptance loss is moderate

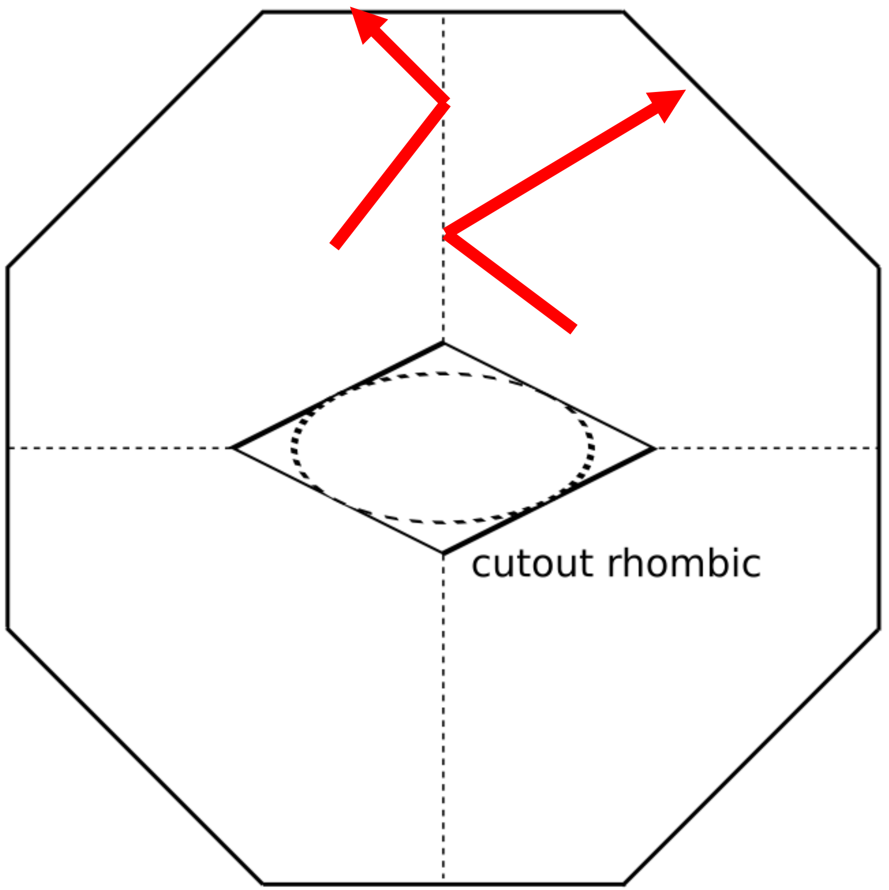
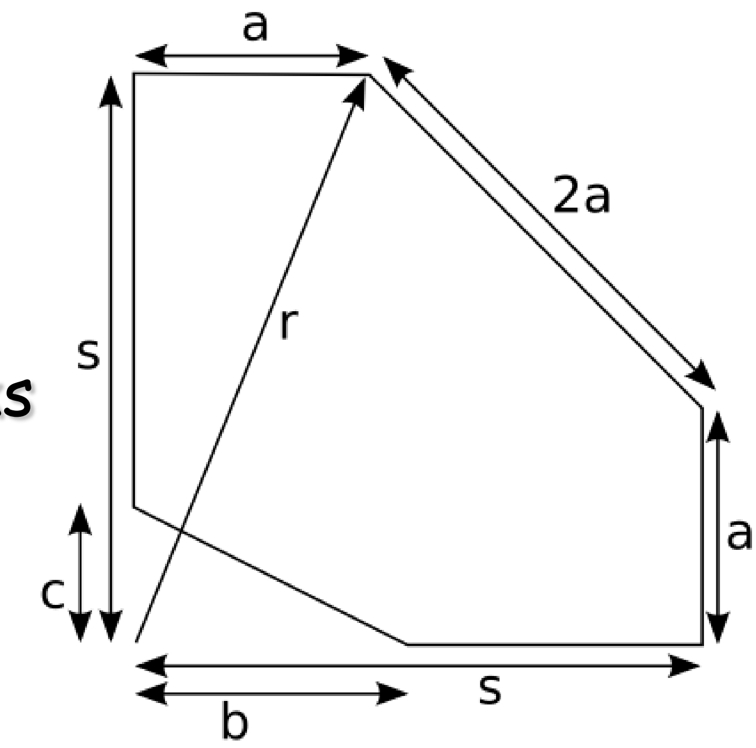


Plate specifications

- Radiation hardness ~1000 Gy
- Thickness nominal 20 mm tolerance 0.20 mm
- Bulk absorption: effective absorption length >>10 m for 300-700 nm (or 400-700 nm) (including impurities like grains and bubbles)
- Refractive index *n: variation smaller than 10^{-4} (for stochastic variation) (exact values depending on size, potential periodicity, orientation)*
- *All sides polished*
- *Surface roughness <15 Å RMS (or better, to be valid for any mm2 spot on disc)*
- *Waviness <0.1 mrad (relative to nominal planar surface)*
- *Edge rounding / edge denting / side imperfections < 2 % of side surface*
- *Edge angle 90° nominal, tolerance 1 mrad*
- *Edge surface quality < 5 nm RMS*

Offer by company:

- specifications can be fulfilled
- 1+4 quadrants (one prototype; used as spare afterwards)
- production time about 48 weeks
- price: yes



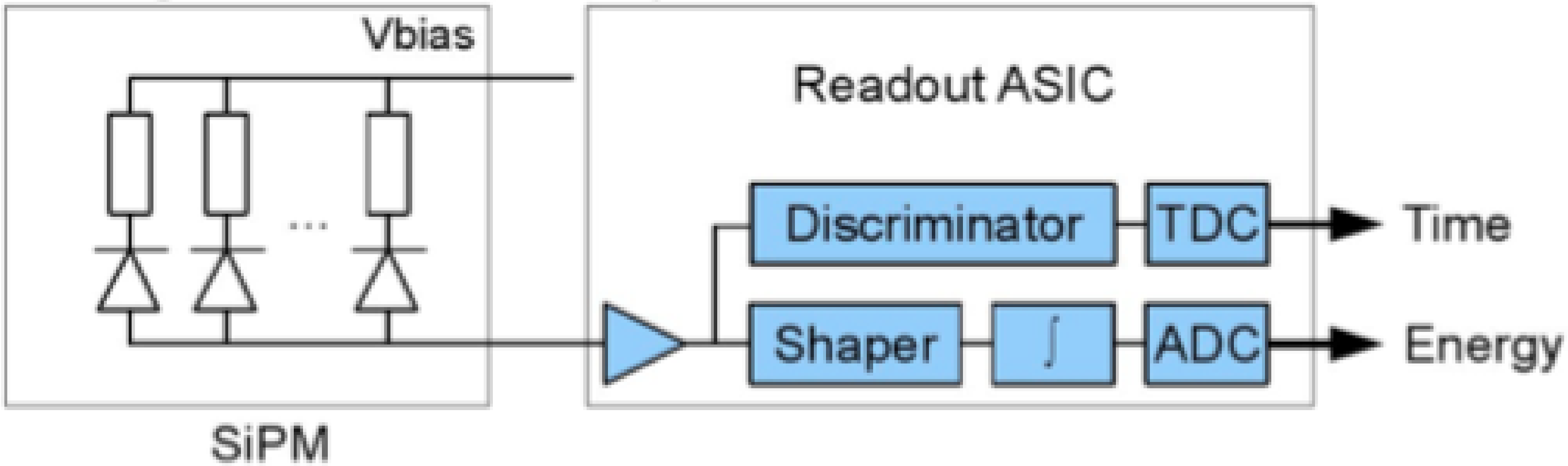
Radiator plate: ✔

Photon Detector Requirements

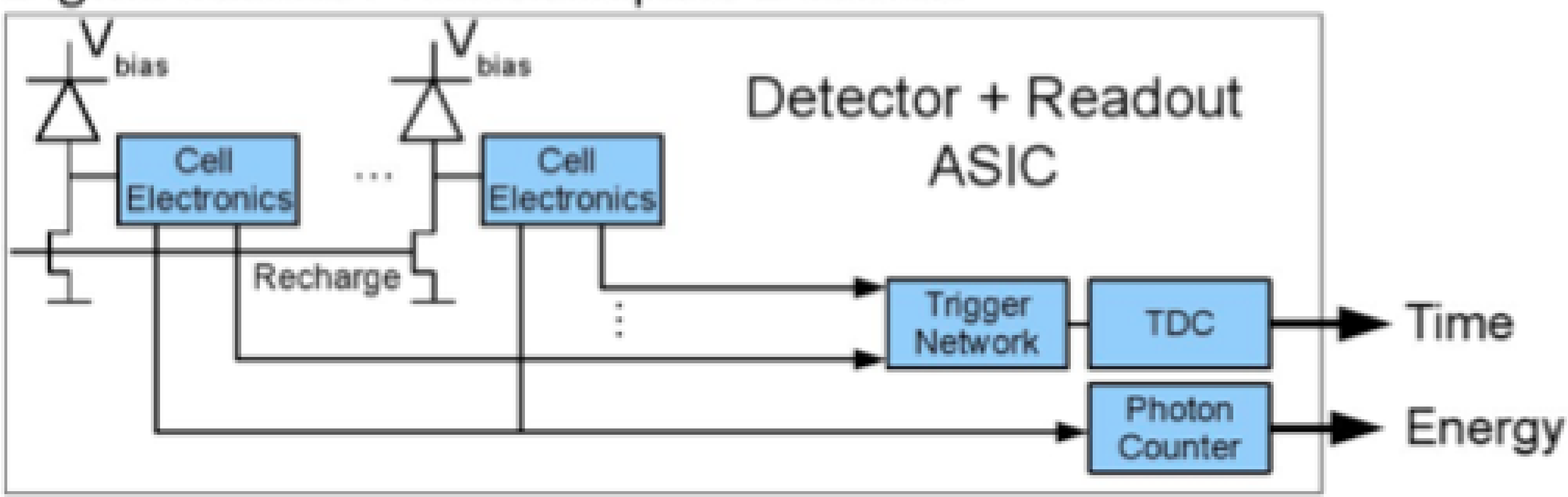
- single photon detection with high quantum efficiency
- insensitivity against a strong magnetic field in a non-parallel field direction
- long lifetime in a high photon flux
- good time resolution
- large repetition rates
- high spatial resolution
- acceptable price per pixel
- moderate radiation hardness
- reasonable dark count rate
- acceptable HV and readout cabling in a limited space.

Photon Detector: The Philips option

Analog Silicon Photomultiplier Detector



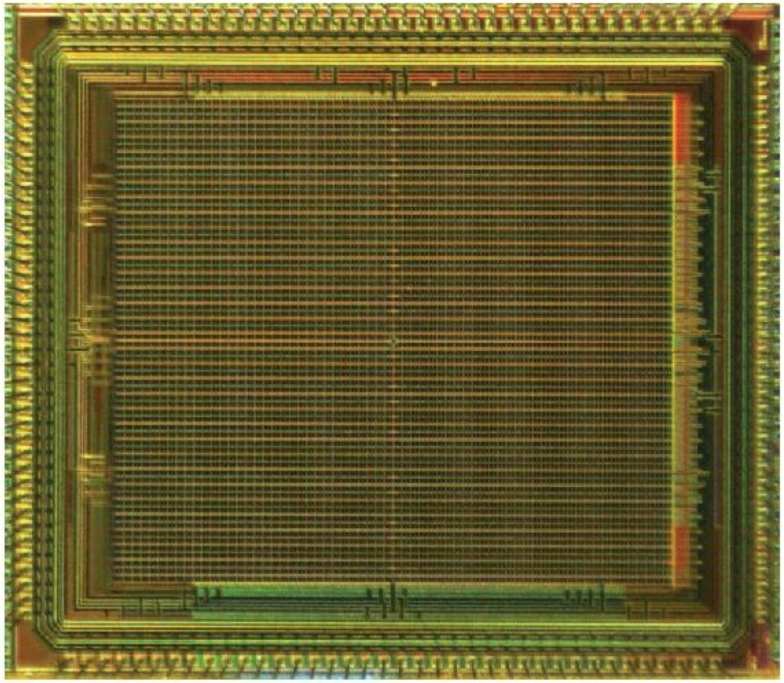
Digital Silicon Photomultiplier Detector



Photon Detector

Philips dSiPM:

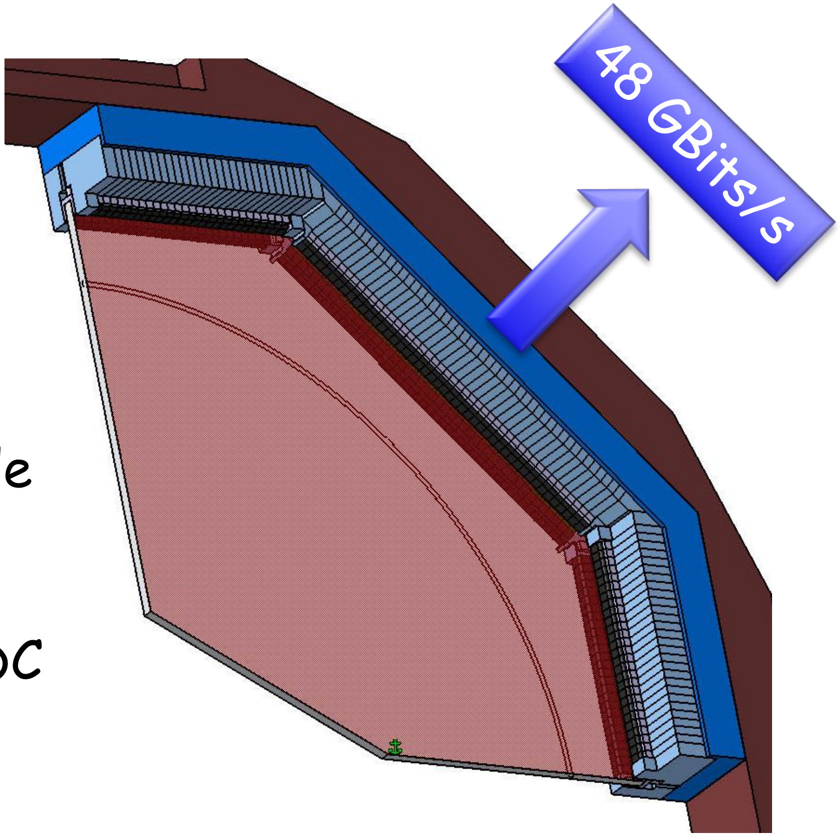
•large sensors
•high spatial resolution
•good time resolution
•high quantum efficiency
•reduction of dark count by cooling
•suppression of noisy pixels
•digitization on chip
•no analogue cables
•no external preamp, CFD or TDC
•compact, reliable and manpower saving!



• … but not (yet) available and ready for mass production

Data rate estimate

- assume 20 MHz event rate
- for now we assume that we get 4 charged track/event above Cherenkov threshold (1 on each Quadrant)
- MC yields ~ 50 detected photons per track, this makes 9.2 MHz per light guide or 1.2 MHz/sensor chip
- we allocate 6 Byte information per detected photon (2 for location, 3 of TDC and 1 for Slow control info)
- consider every quadrant as a single detector. One quadrant will have a data rate of 48 GBits/s



dSiPM dark count rate

- The expected dark count rate at -25° C is 100 kHz/sensor (off-time, i.e. random timing, 100 kHz (~1 hit/10 µs)
- The good data rate is 1.2 MHz/sensor chip (on-time with the track (~1 hit/0.8 µs)
- on "hit level": dark count rate is further reduced by cut on timing (~60 ps window)
- on "trigger level" dark count rate is suppressed by requiring a multiplicity of e.g. >10 hits per quadrant in a narrow time window (~4 ns)

Photon detector options

① Diamond PMTs

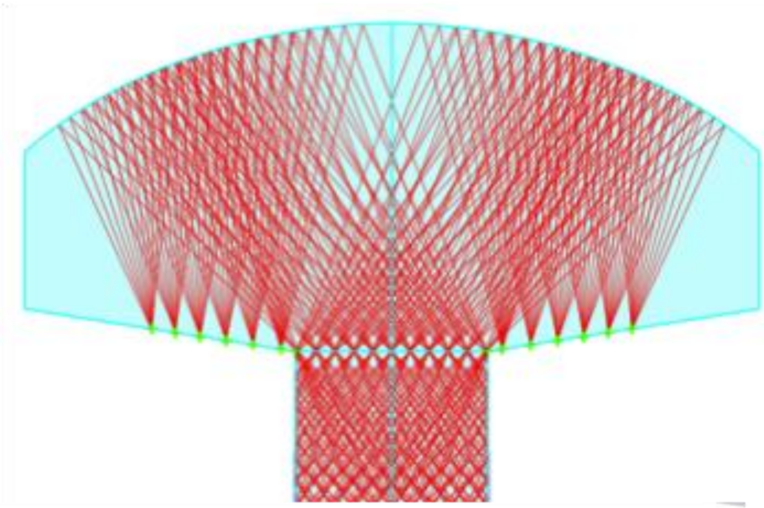
② MCP-PMTs

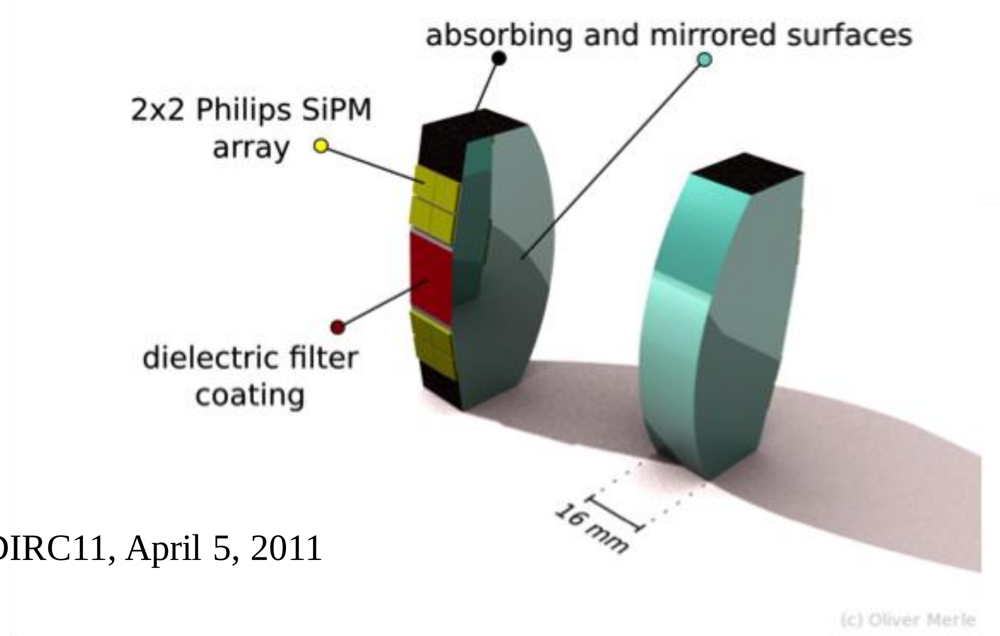
③ dSiPMs

- Proposal: Use dSiPMs if they turn out to match all requirements:
  - dark rate (cooling; check by MC/reconstruction)
  - DAQ rates (should be ok)
  - radiation hardness (what is required?)
- Study other sensors in parallel.

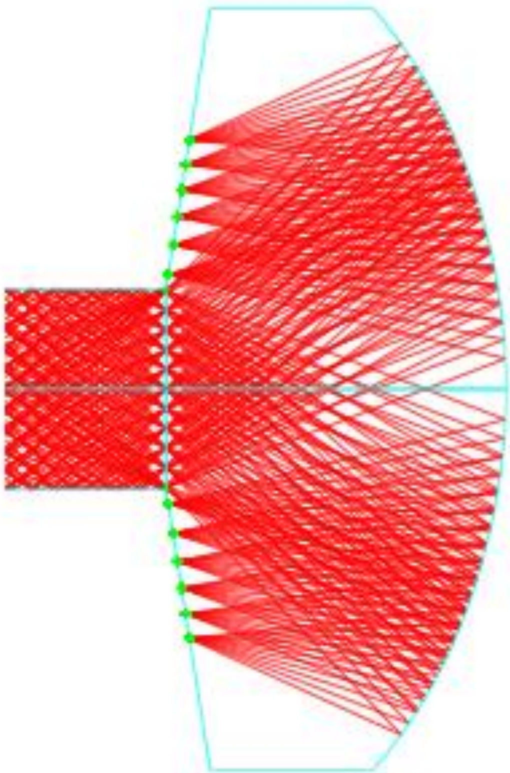
Focussing light guides

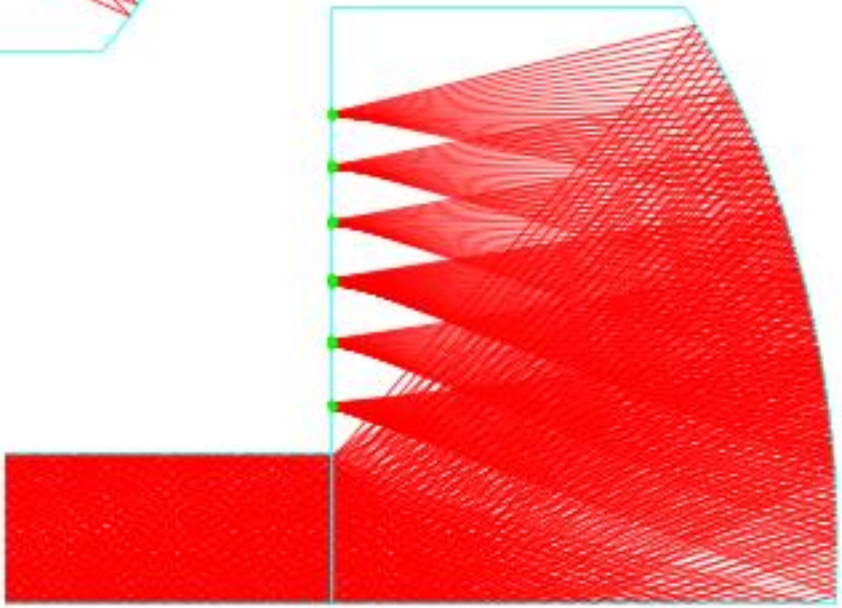
- Use symmetric, coated light guides that are matched to SiPMs
- azimuthal resolution: 16 mm (~432 pieces in total)





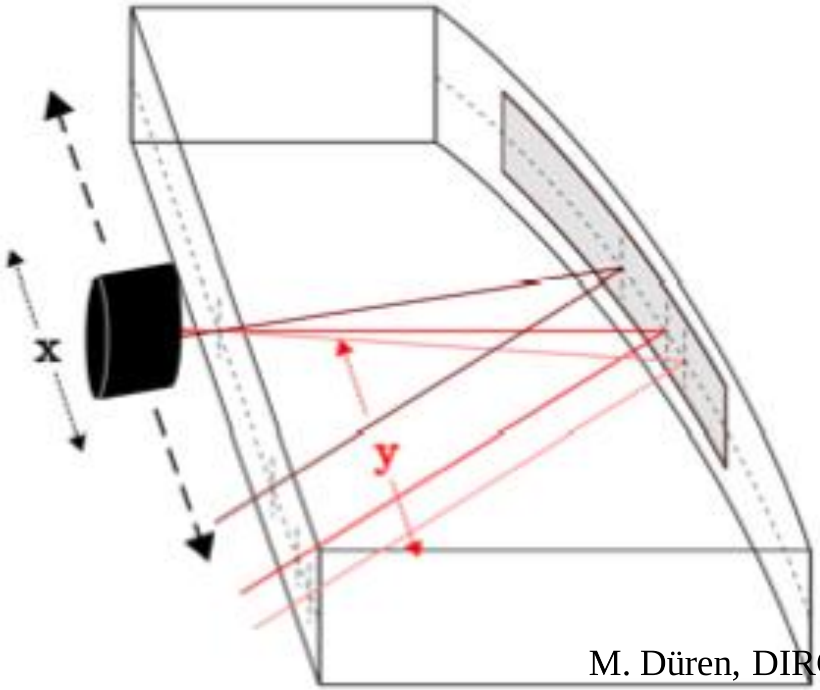
Light guide designs

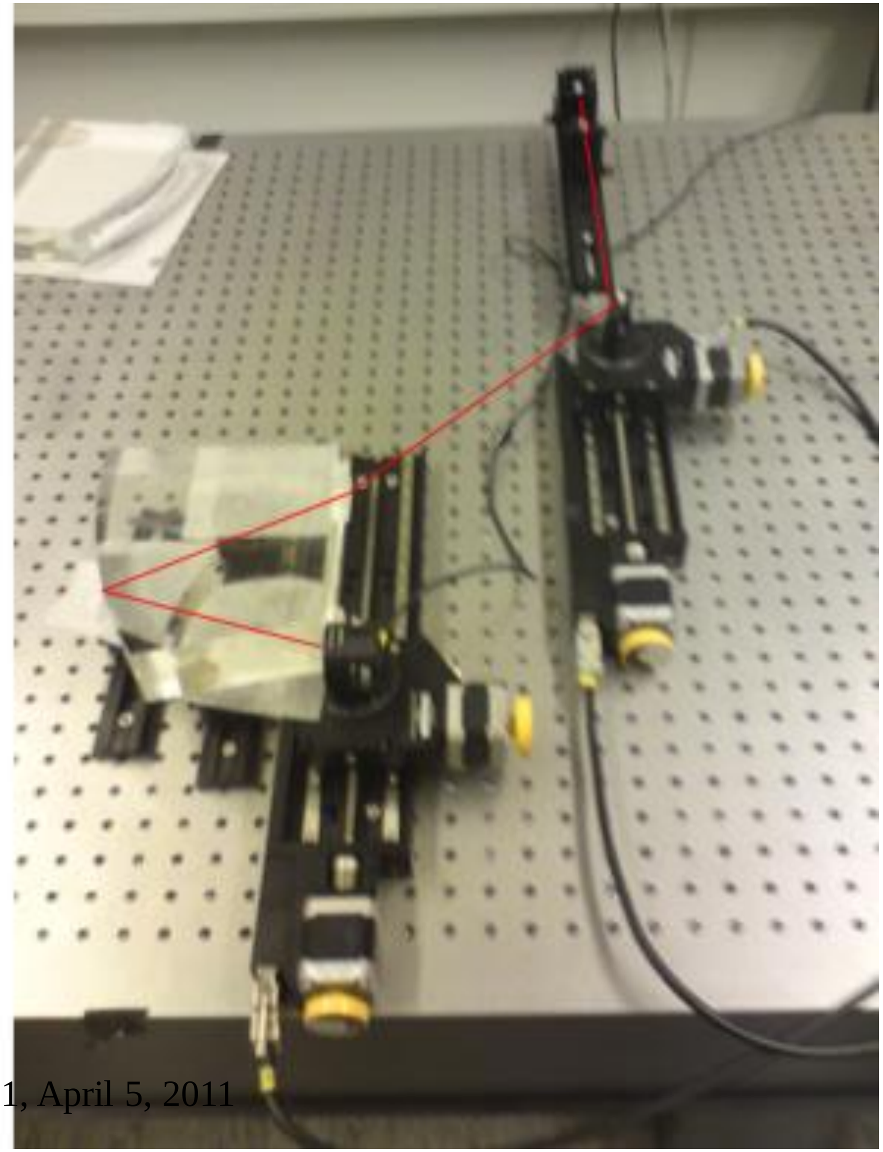




light guide: survey

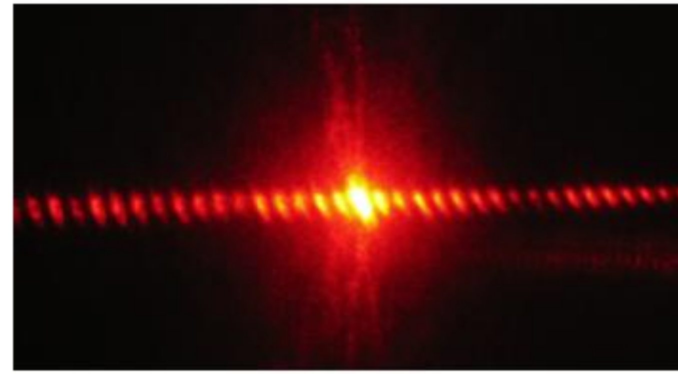
- Laser scan of focusing properties

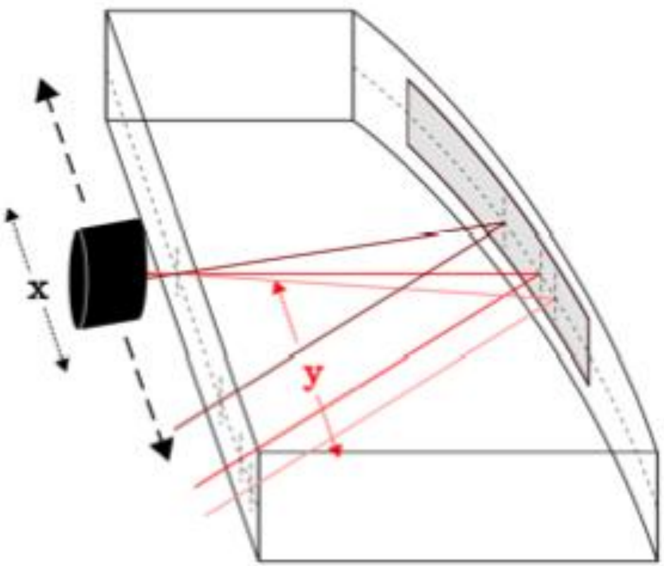


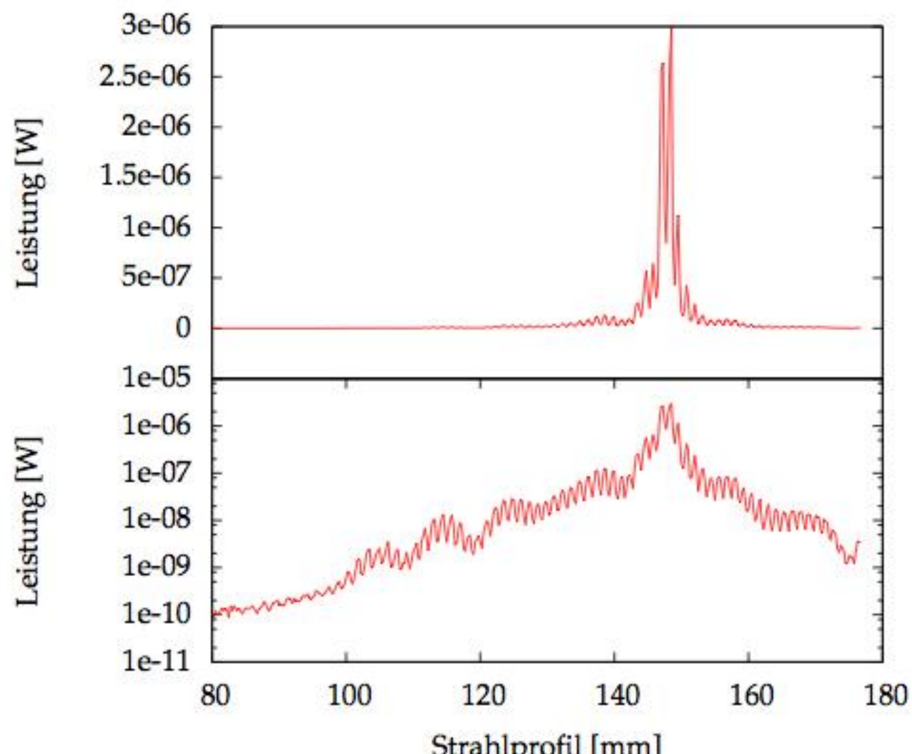


light guide: survey

- Observation of interference patterns from diamond-cut surface







Options: Focussing light guides

① No light guides (ToP)
② Large light guides (FL)
③ Small light guides (3D)

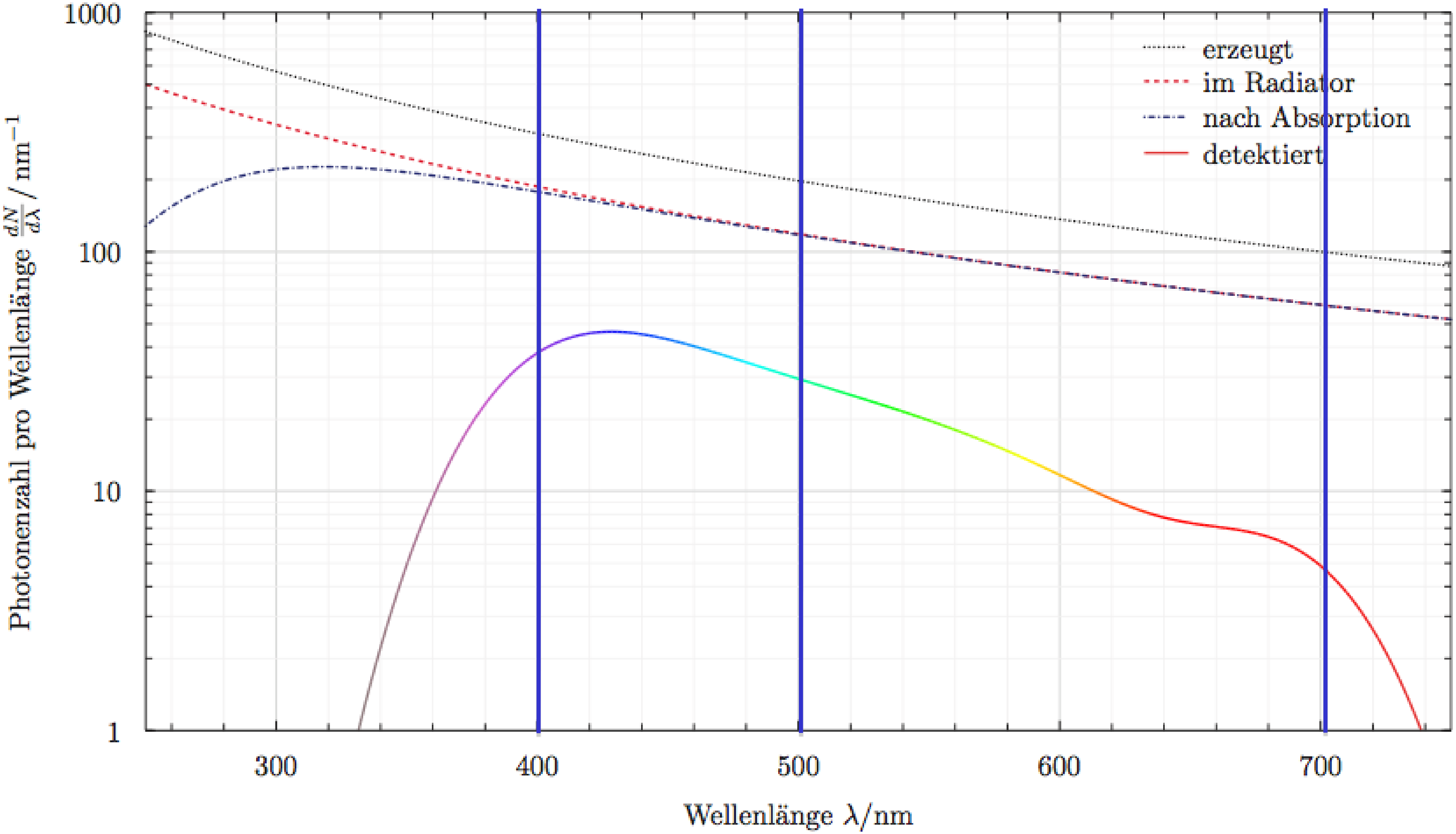
- Proposal: Use small light guides if dSiPMs work
- Alternatives: larger light guides for MCP-PMTs or no light guides for ToP design.

Option: Dispersion correction

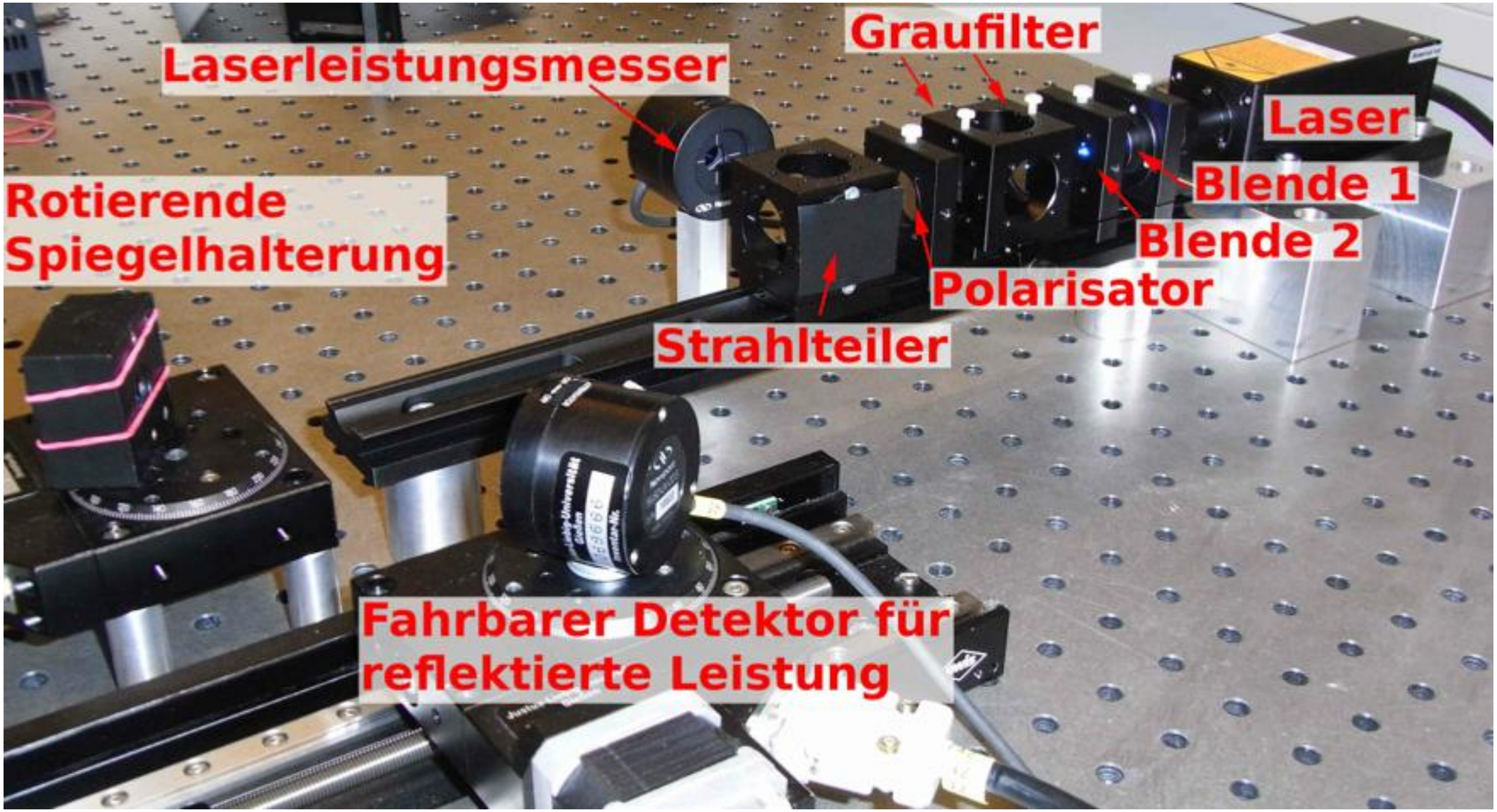
① No dispersion correction
② LiF/CaF block (angular correction only)
③ Dichroic mirrors (optical band pass)

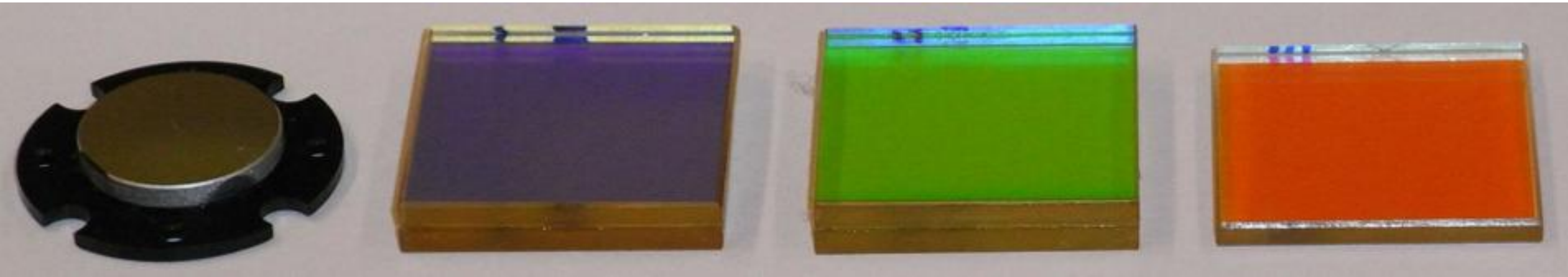
- Proposal: Use dichroic mirrors as they reduce angular smearing and time smearing

Photon spectrum:
band pass for two or three wavelengths



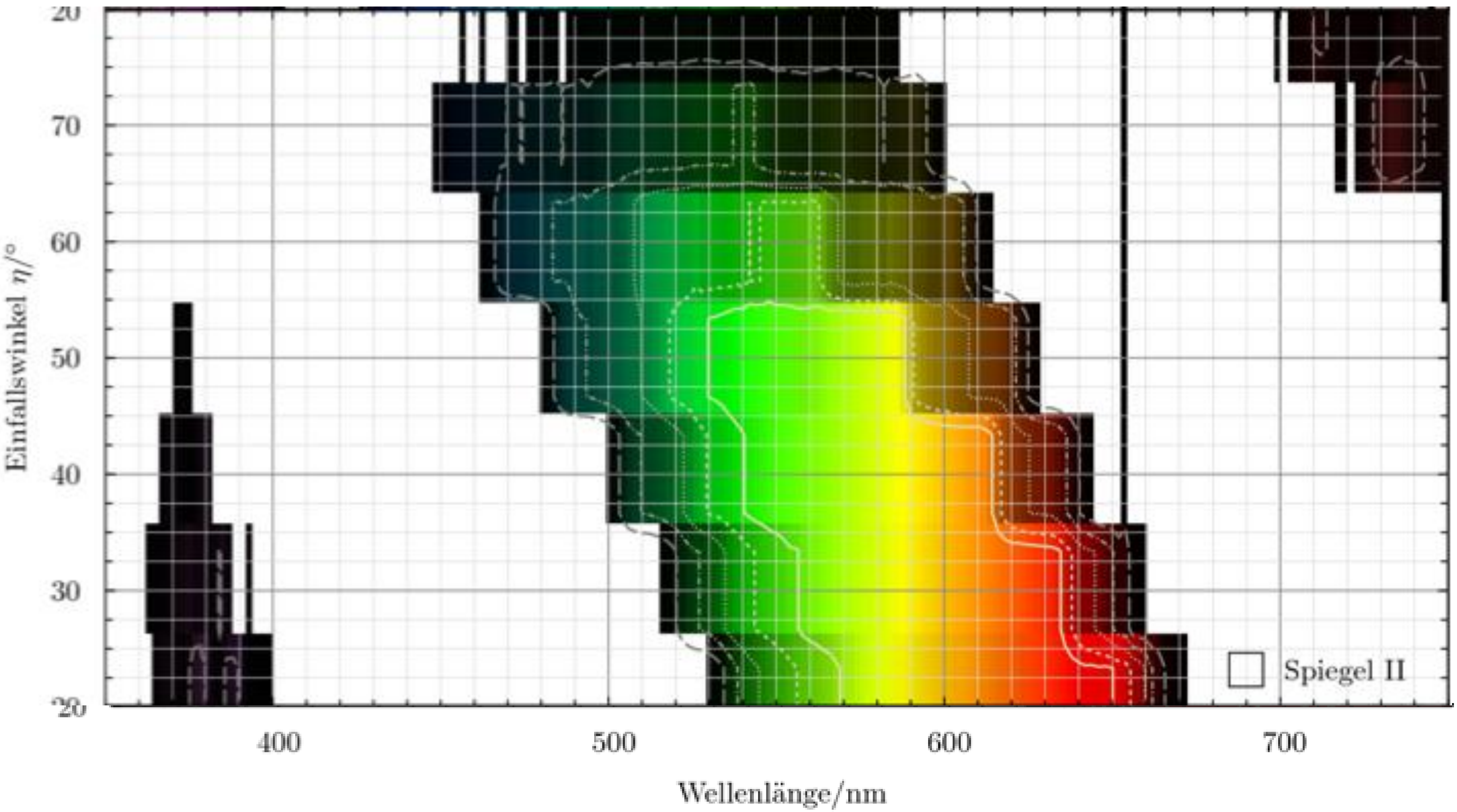
Dichroic filters: evaluation of properties





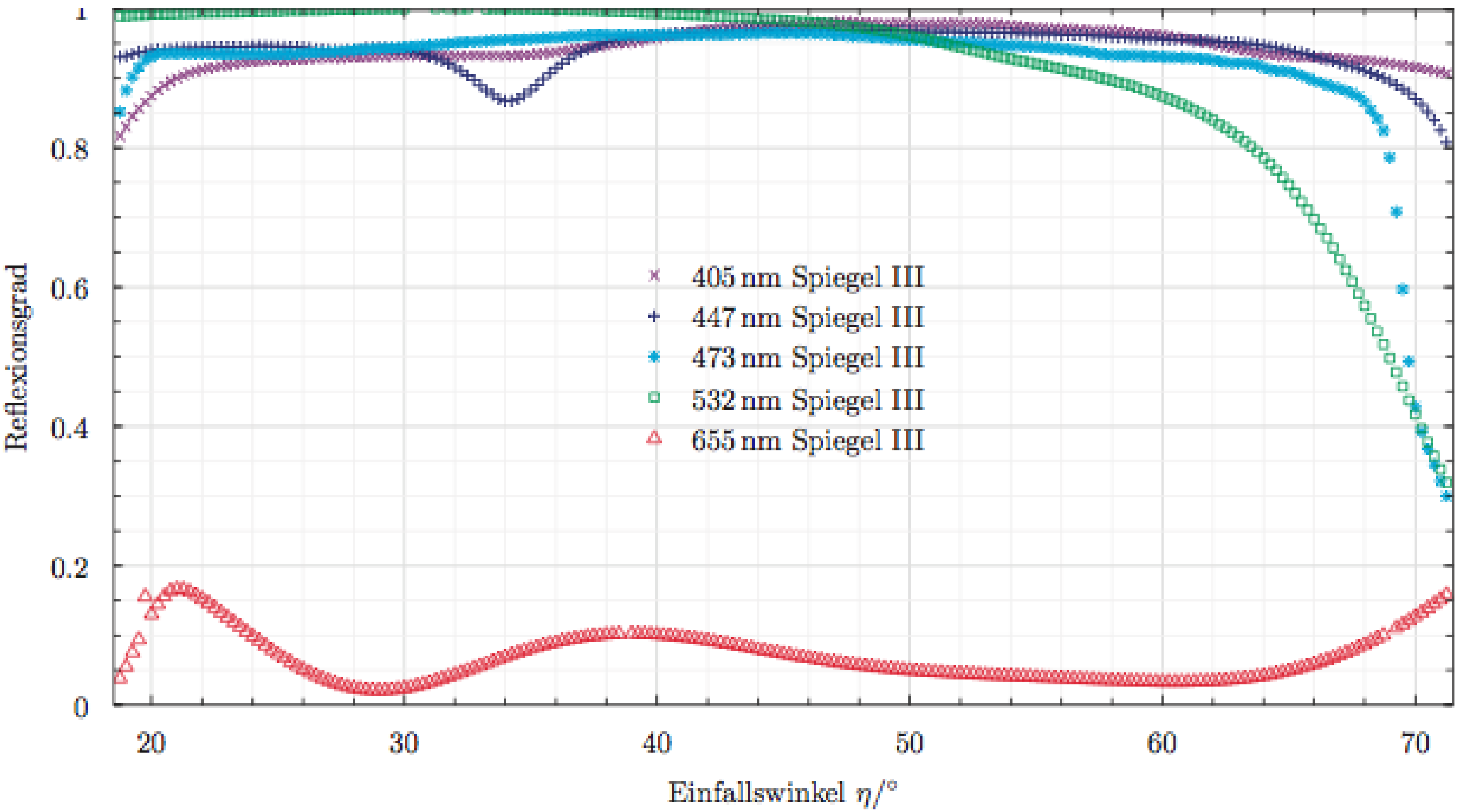
Dichroic filters: evaluation of properties

- angular dependence of wavelength dependent transmission



Dichroic filters: evaluation of properties

- angular dependence of wavelength dependent reflection



Dichroic mirrors:

- No effect by irradiation (1 kGy γ's) on dichroic coatings

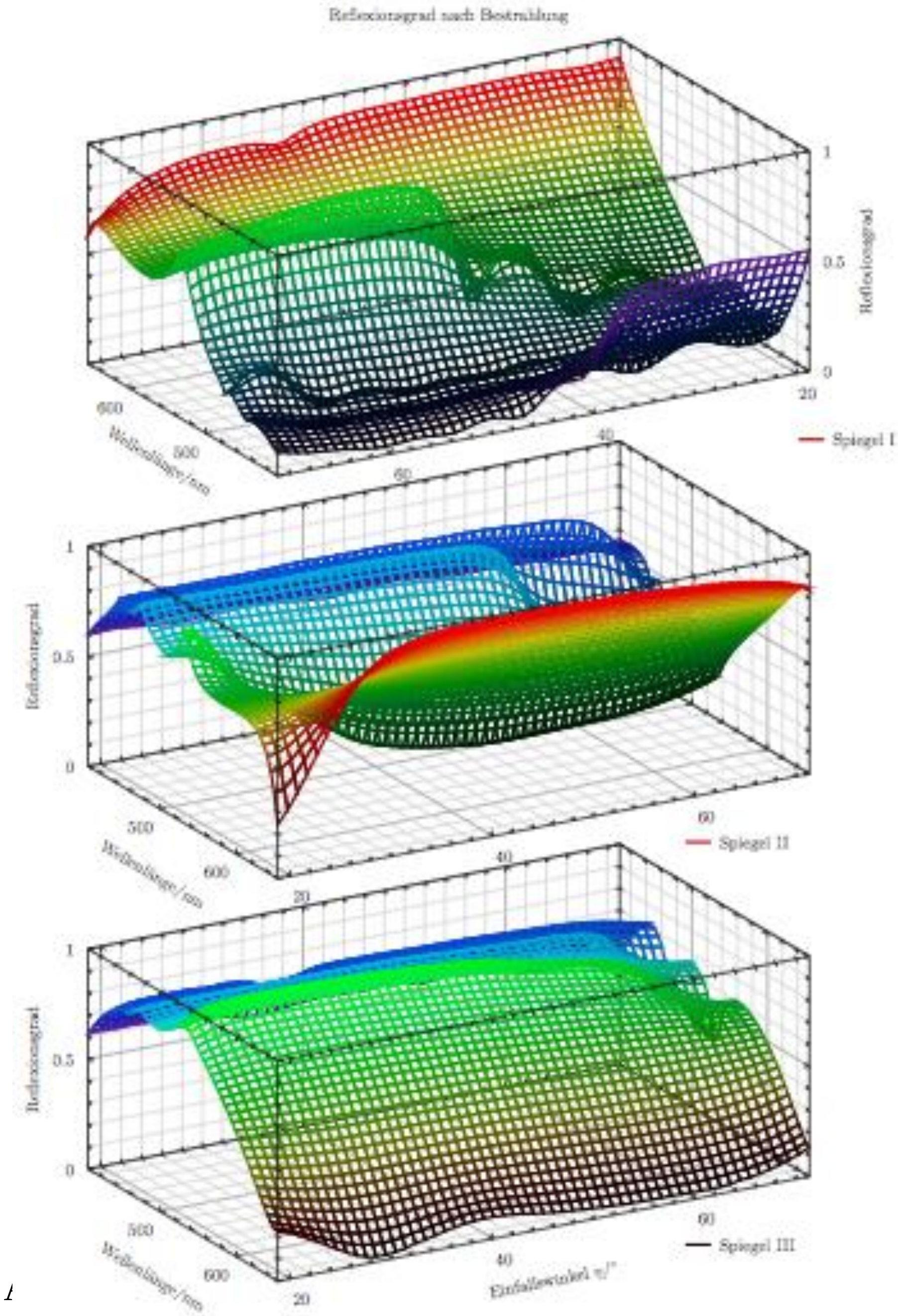
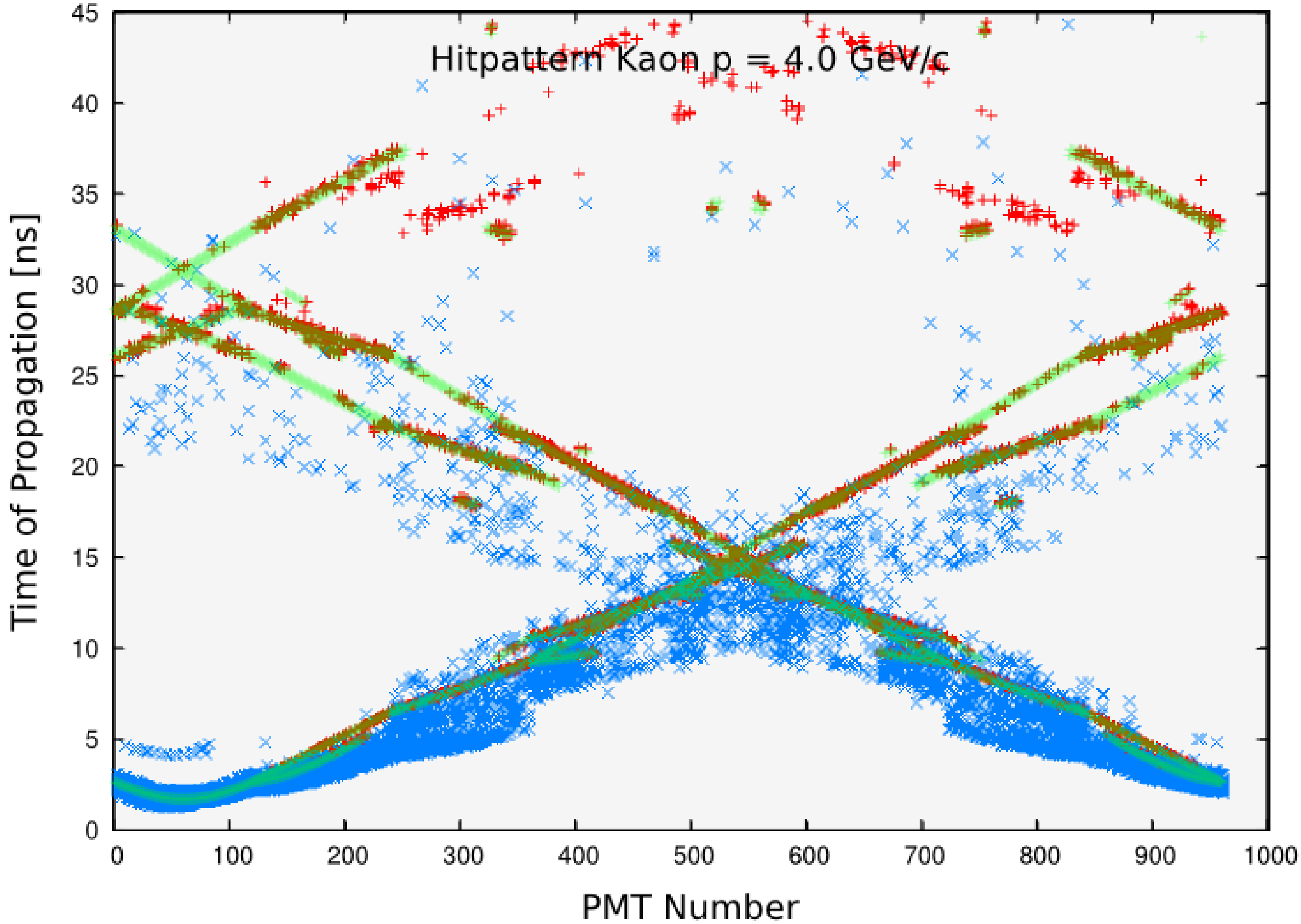
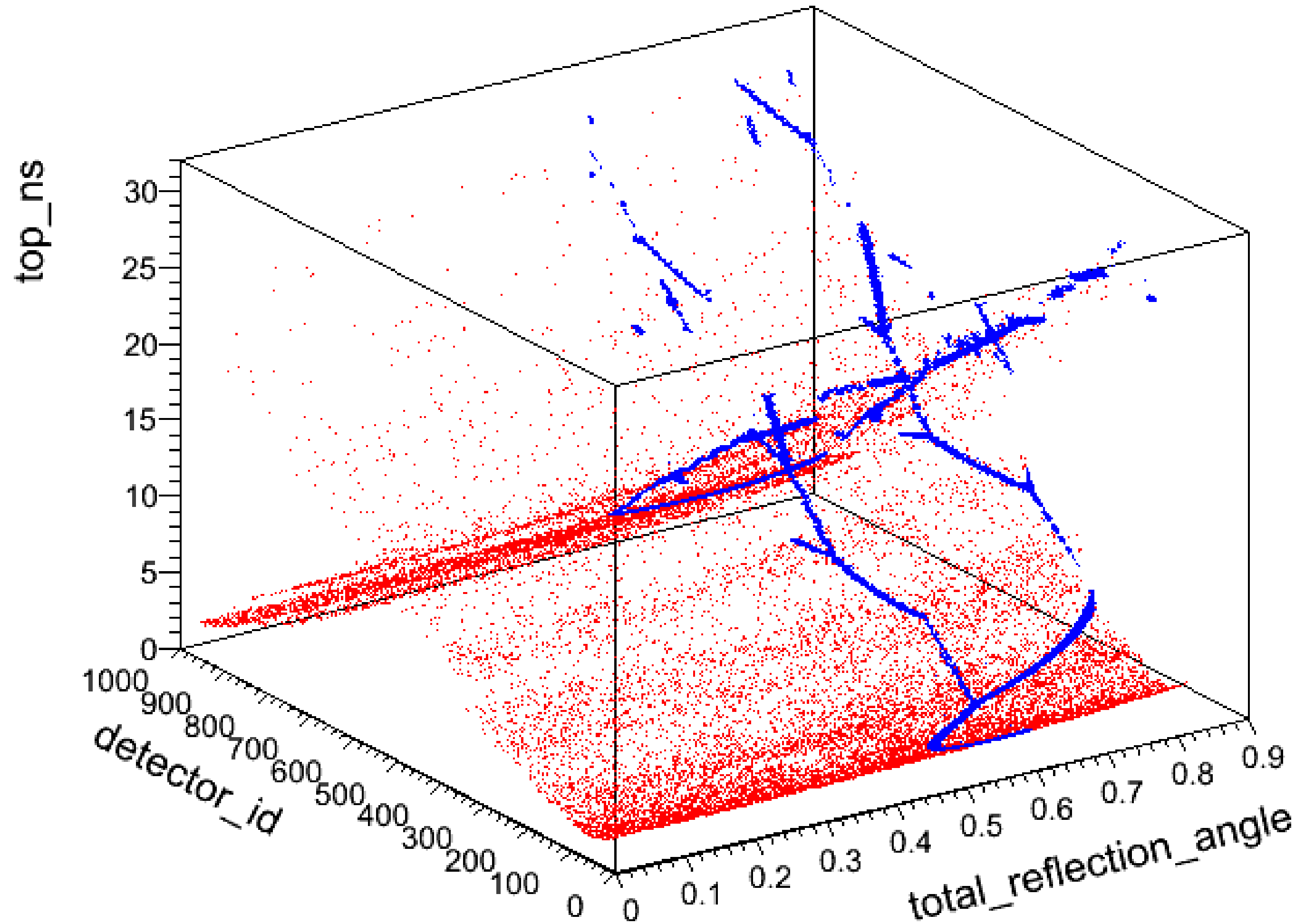


Abbildung F.2: Reflexionsgrad der Spiegel I–III nach Bestrahlung mit 1 kGy γ-Strahlung

Full 3D GEANT simulation of geometry, photon generation and photon propagation

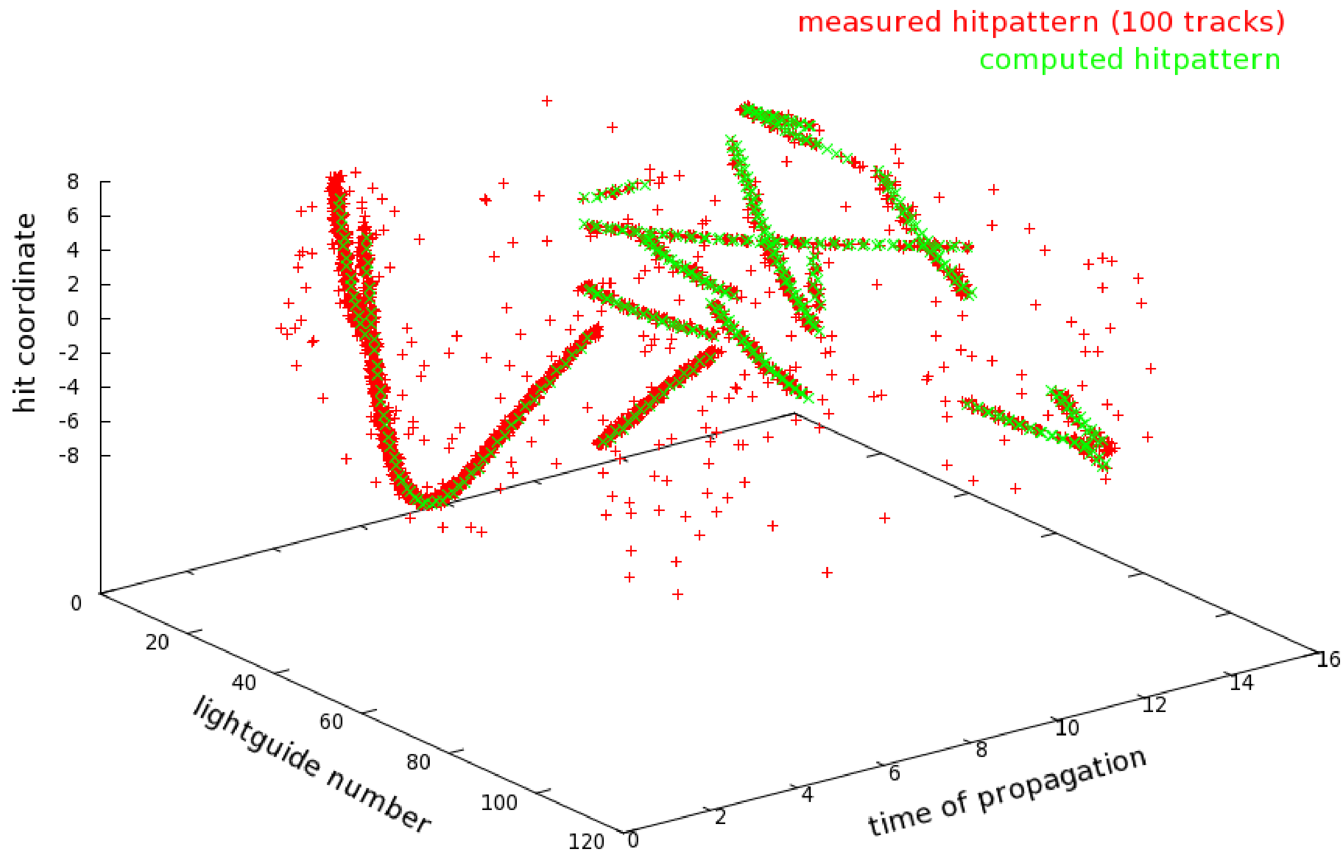


Red: simulated kaon patterns (1000 tracks). Blue: background caused by knock-on electrons which again emit Cherenkov photons. Green overlay: predicted hypothesis of the reconstruction algorithm.



Blue: photons emitted by primary particle.
Red: background photons emitted by knock-on electrons.

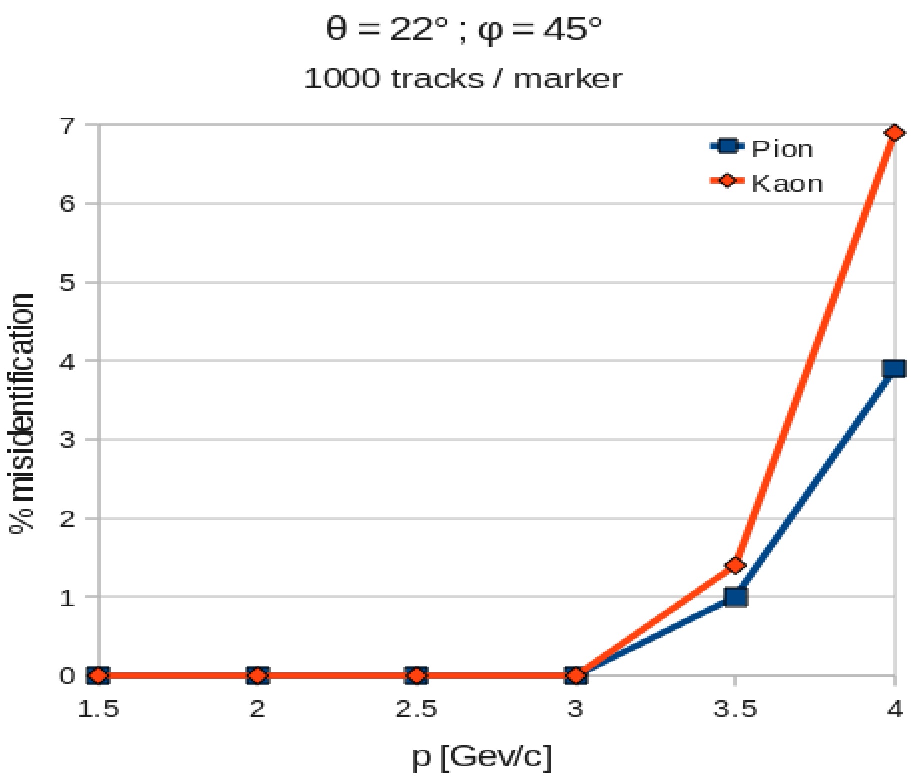
Full reconstruction method implemented in software, based on likelihood algorithms

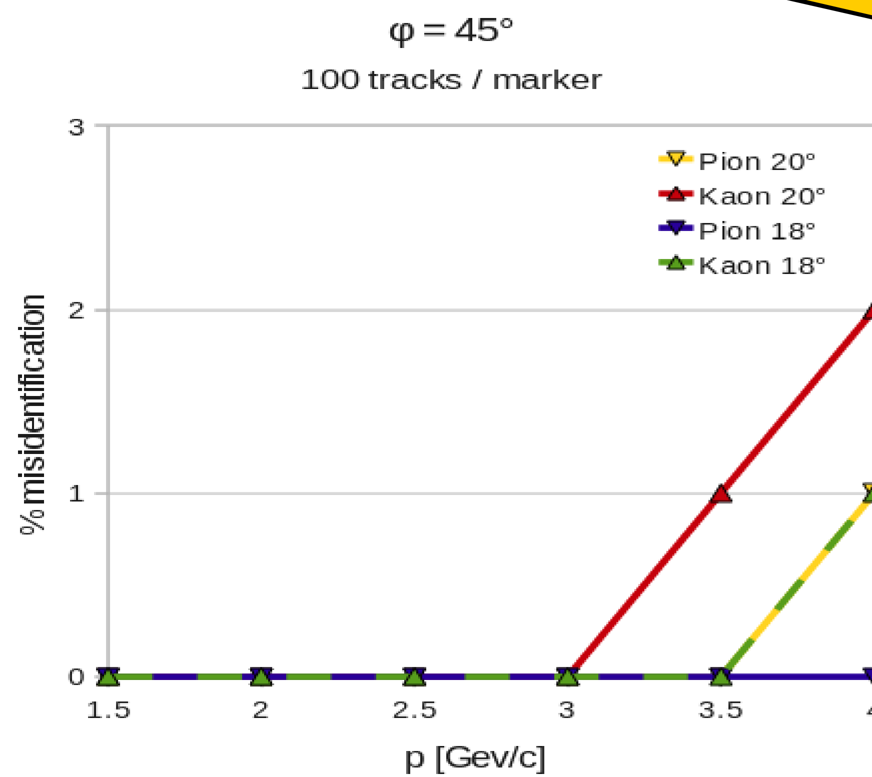


Red: photons emitted by primary particle (100 equal tracks).
Green: Pattern prediction generated by the reconstruction method.

DIRC performance as extracted from full simulation/reconstruction chain (preliminary)

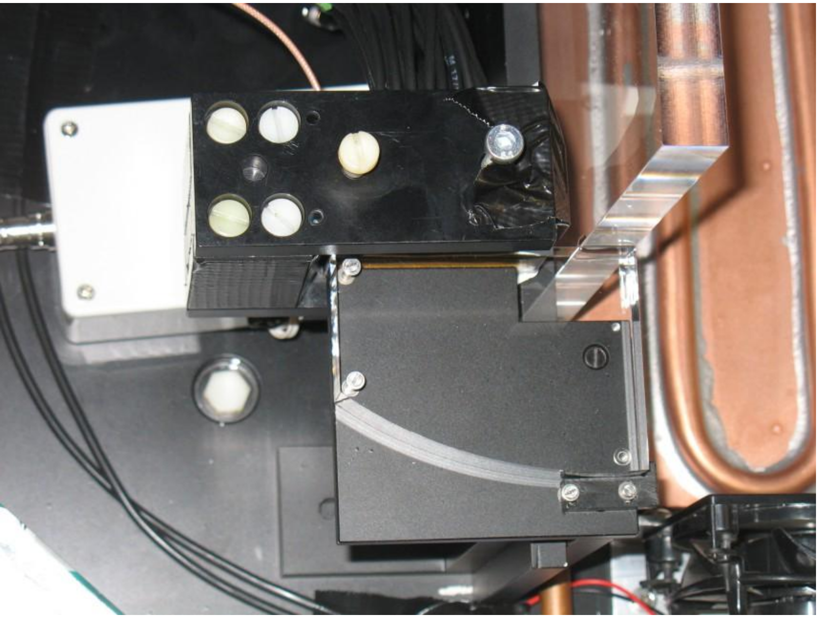
see talk by Oliver Merle!

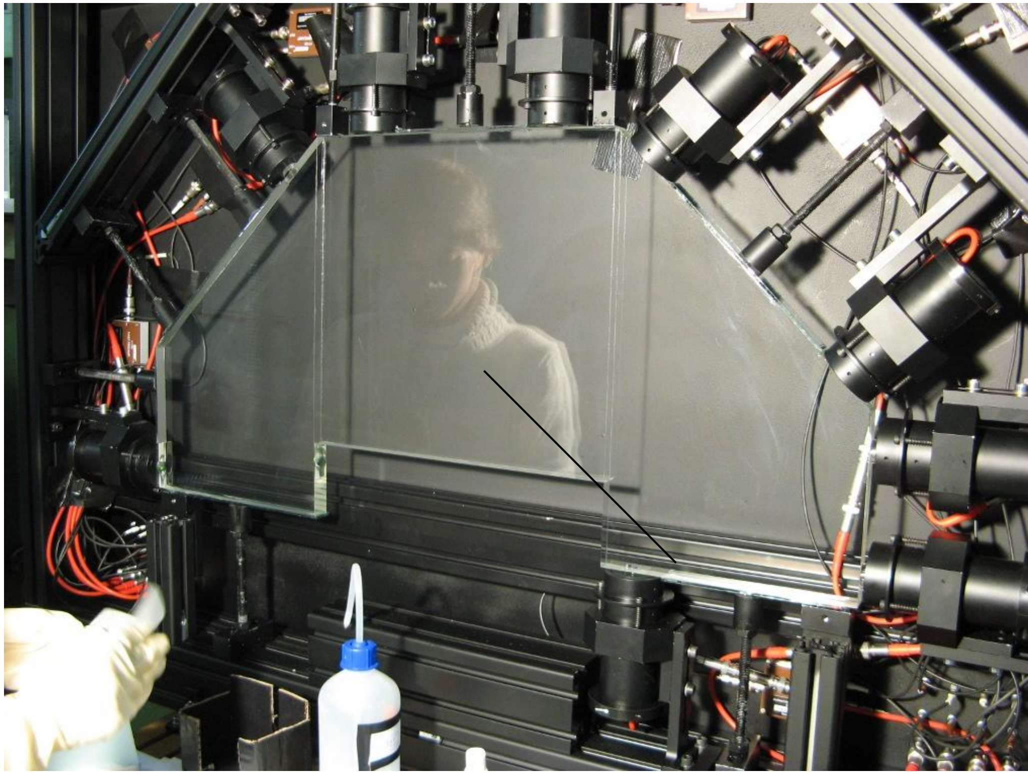


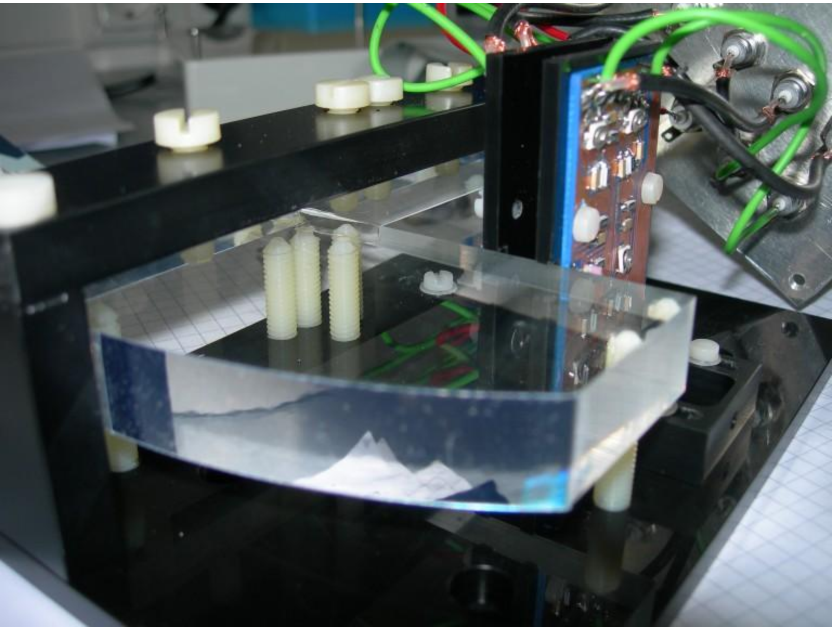


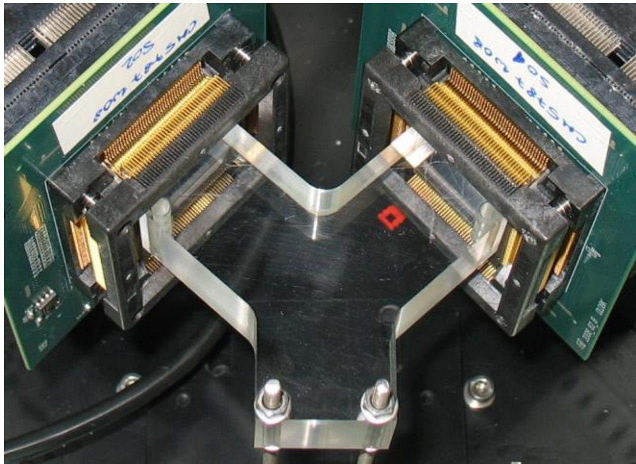
Left: misidentification in % at different momenta and θ=22° , where geometrical effects reduce the resolution and the separation is expected to be at its worst.
Right: low statistics results (only 100 tracks) for lower angles. At θ=18° the misidentifi- cation is already < 2%. The resolution increases at the inner parts of the disc.

Many test experiments were done in 2008-2010



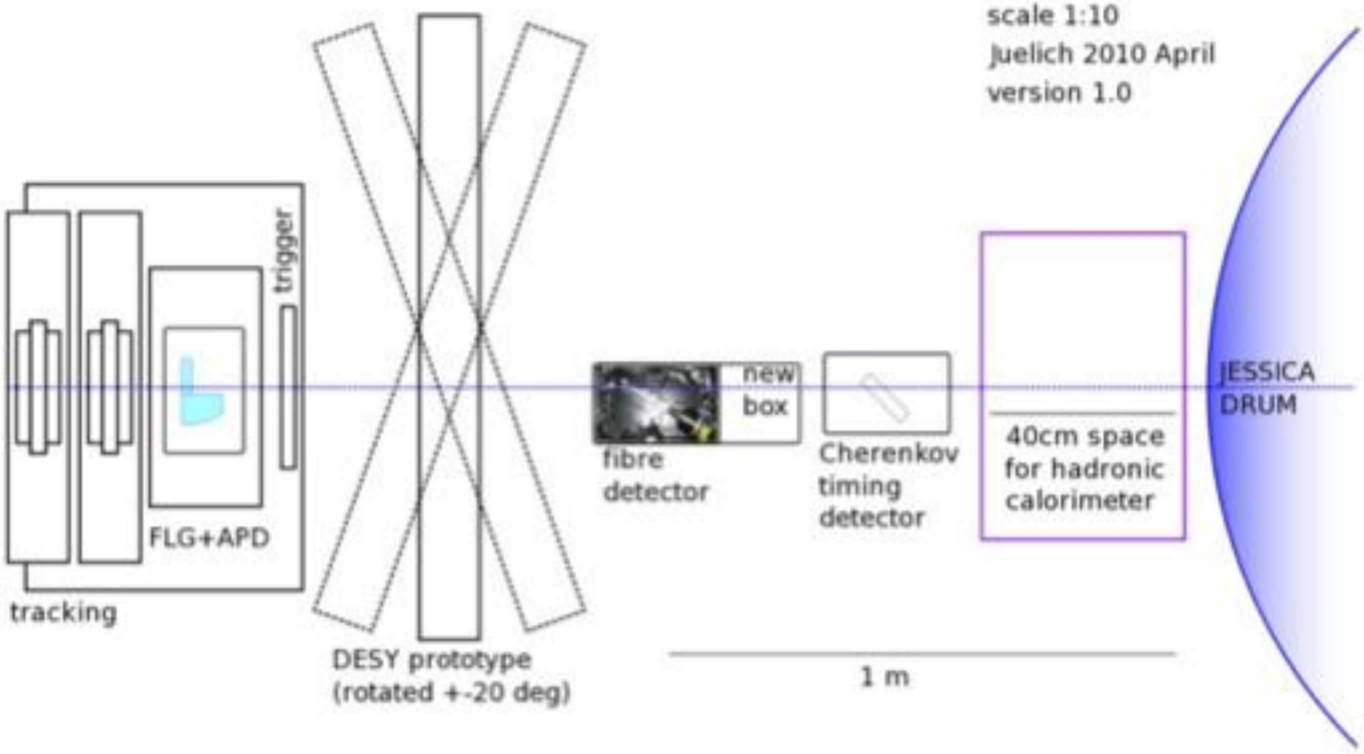




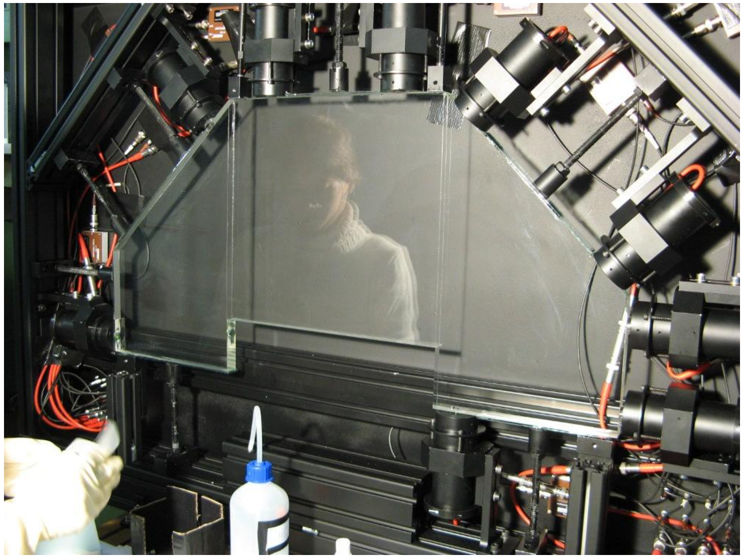


Focusing light guide and rotatable disc prototypes

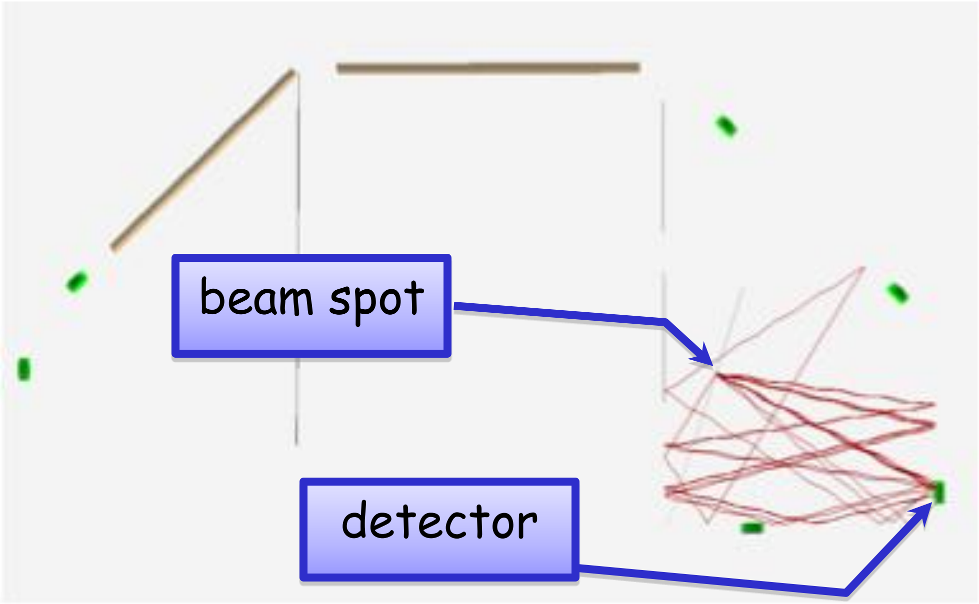
see talk by Peter Koch!

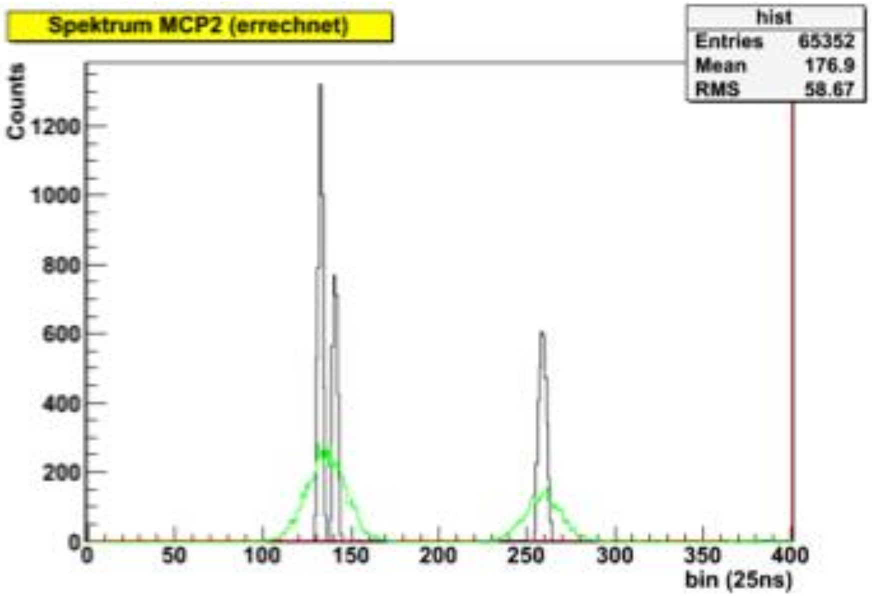


Studies on light paths



- Simulated possible photon paths



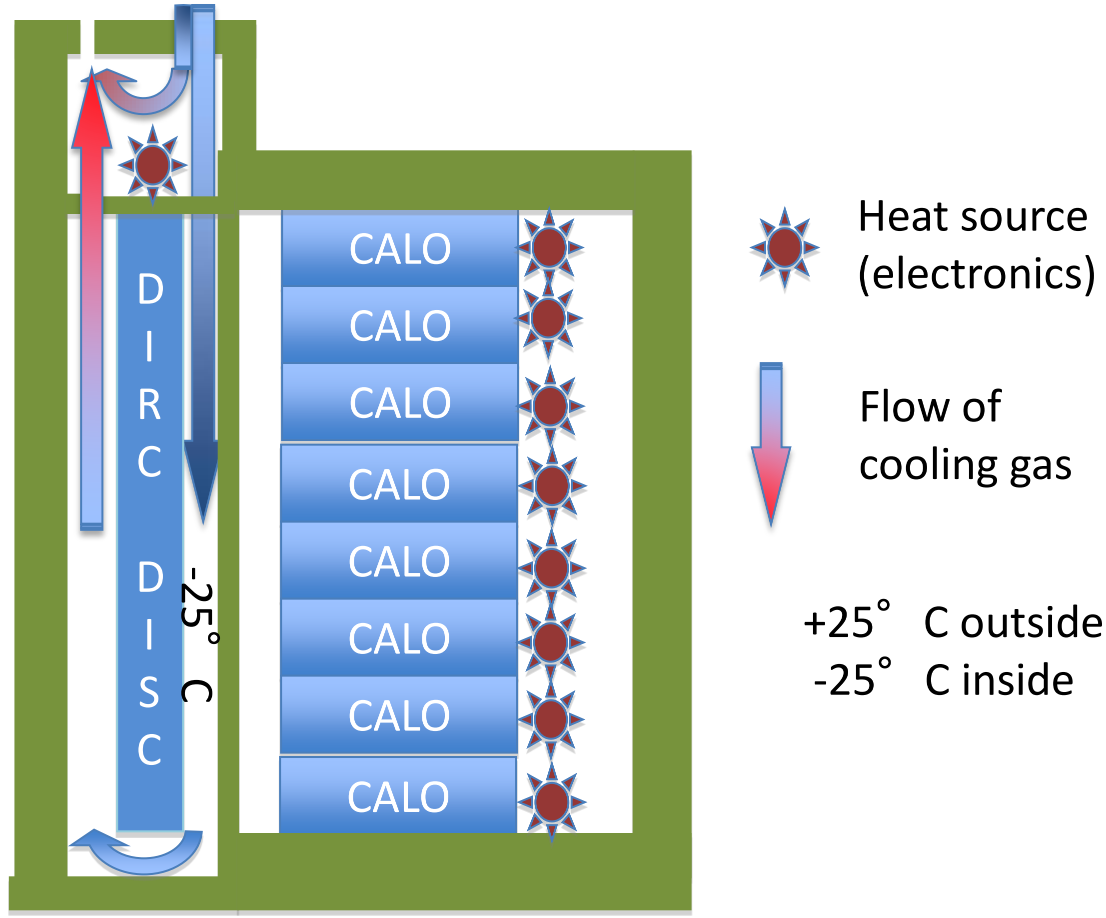


Cooling Concept A: cold disc

- Disc is cooled to same temperature as calorimeter by cold gas flow

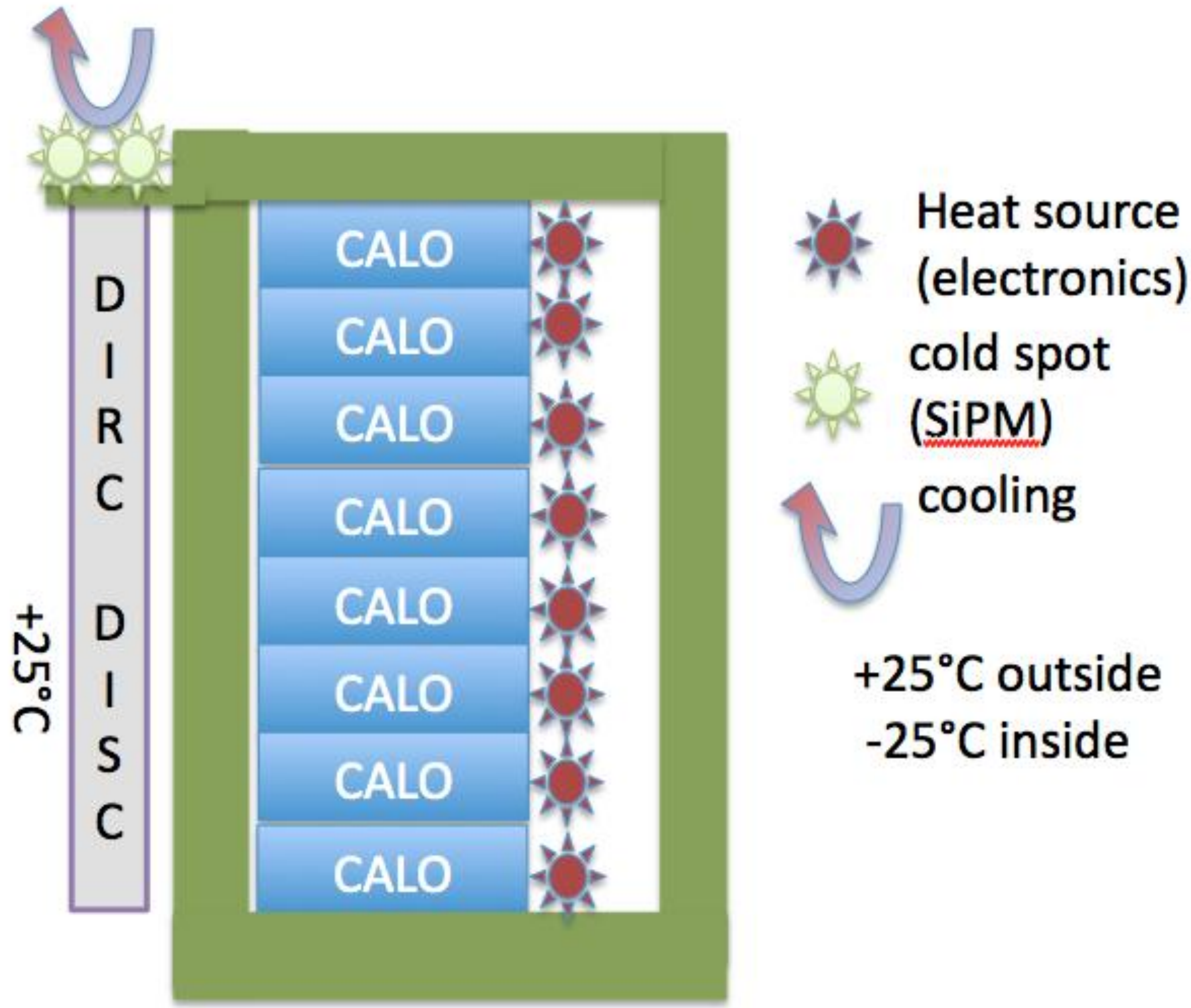
- Thermal insulation against calorimeter can be thin

- Additional separate isolation towards DIRC electronics

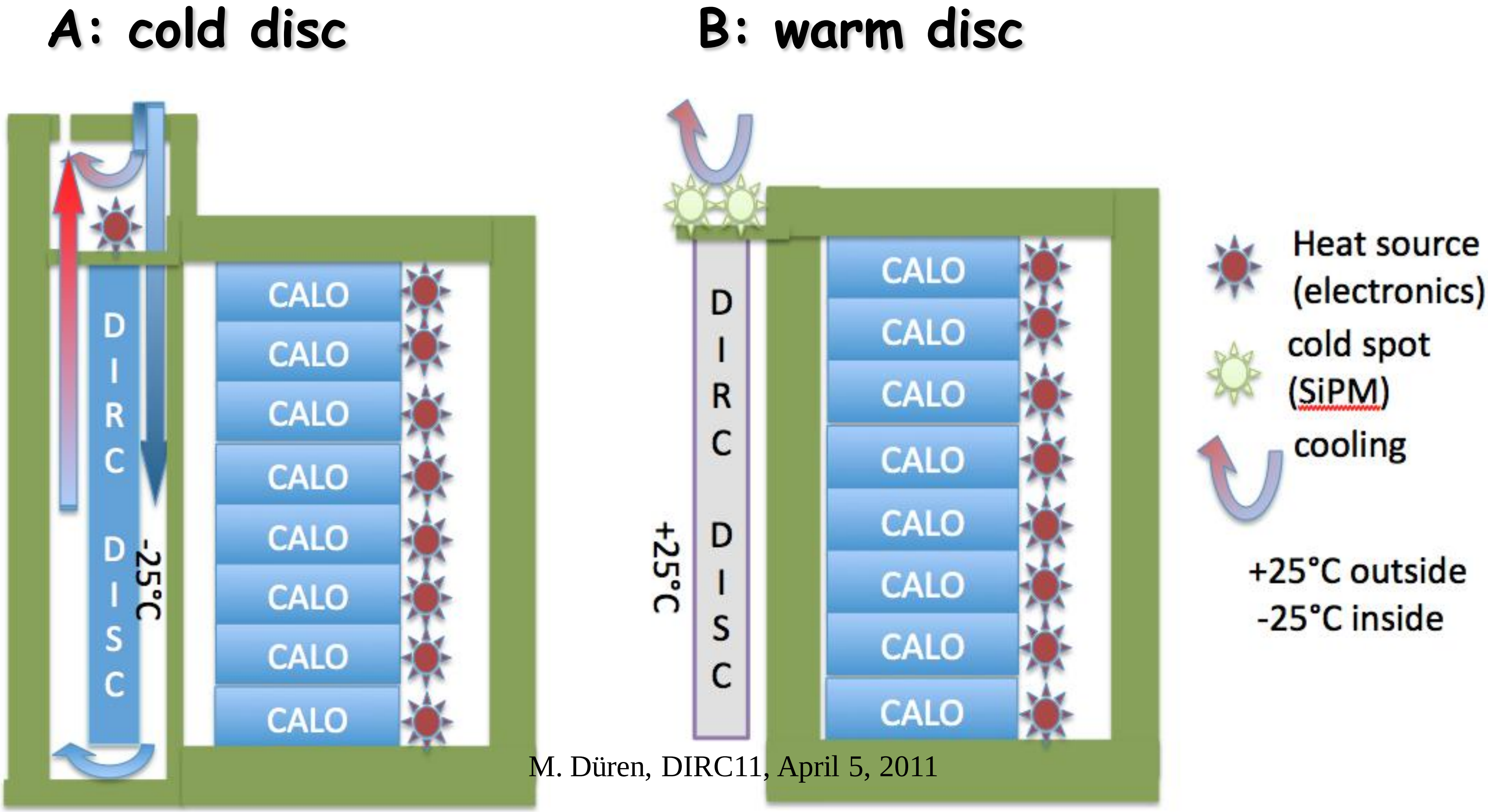


Cooling Concept A: warm disc

- Disc is at room temperature
- photo detector is cooled locally
- Thermal insulatio against calorimete has to be thick



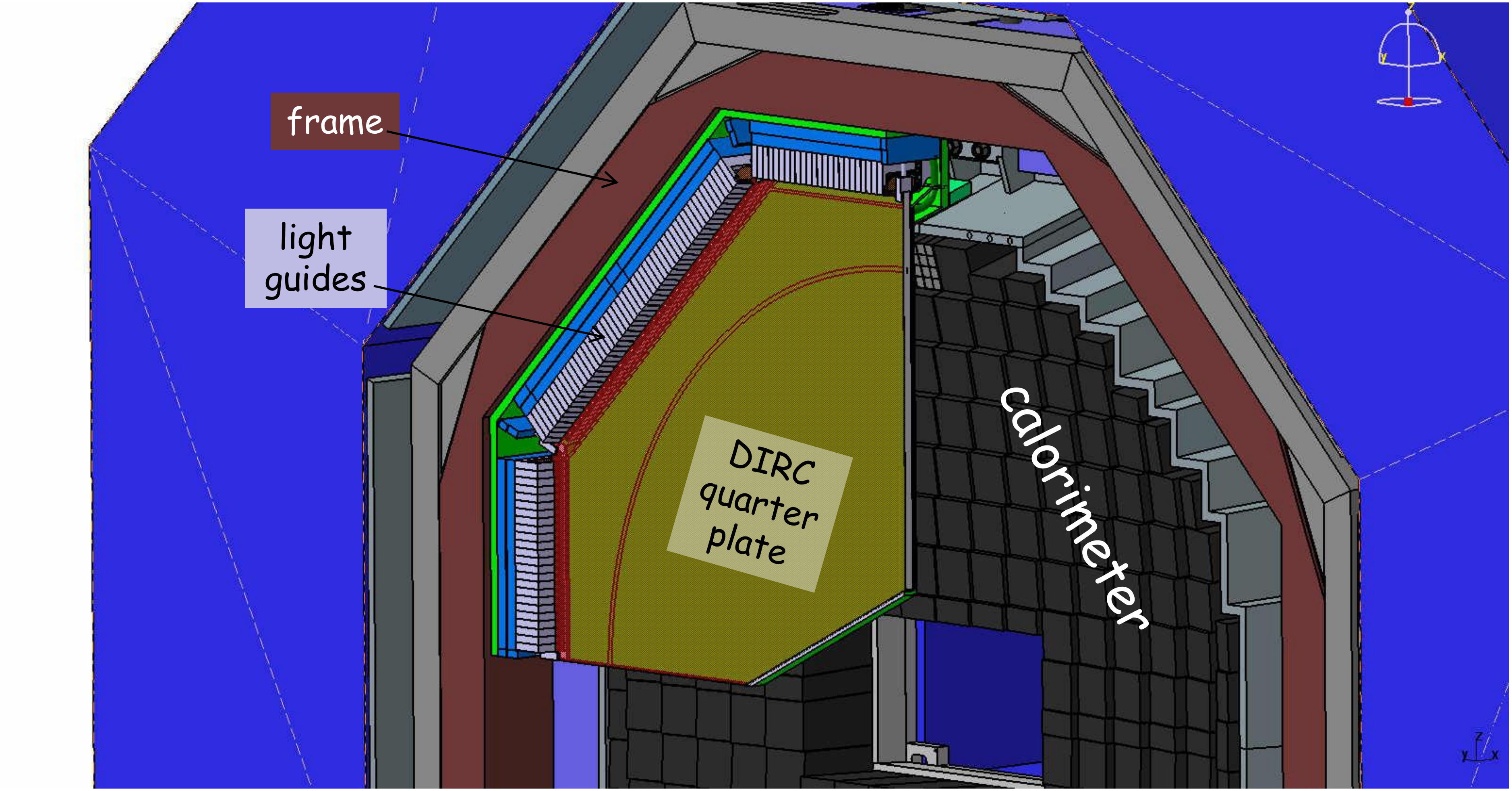
Preferred cooling concept: "B: warm disc"



Mechanical integration

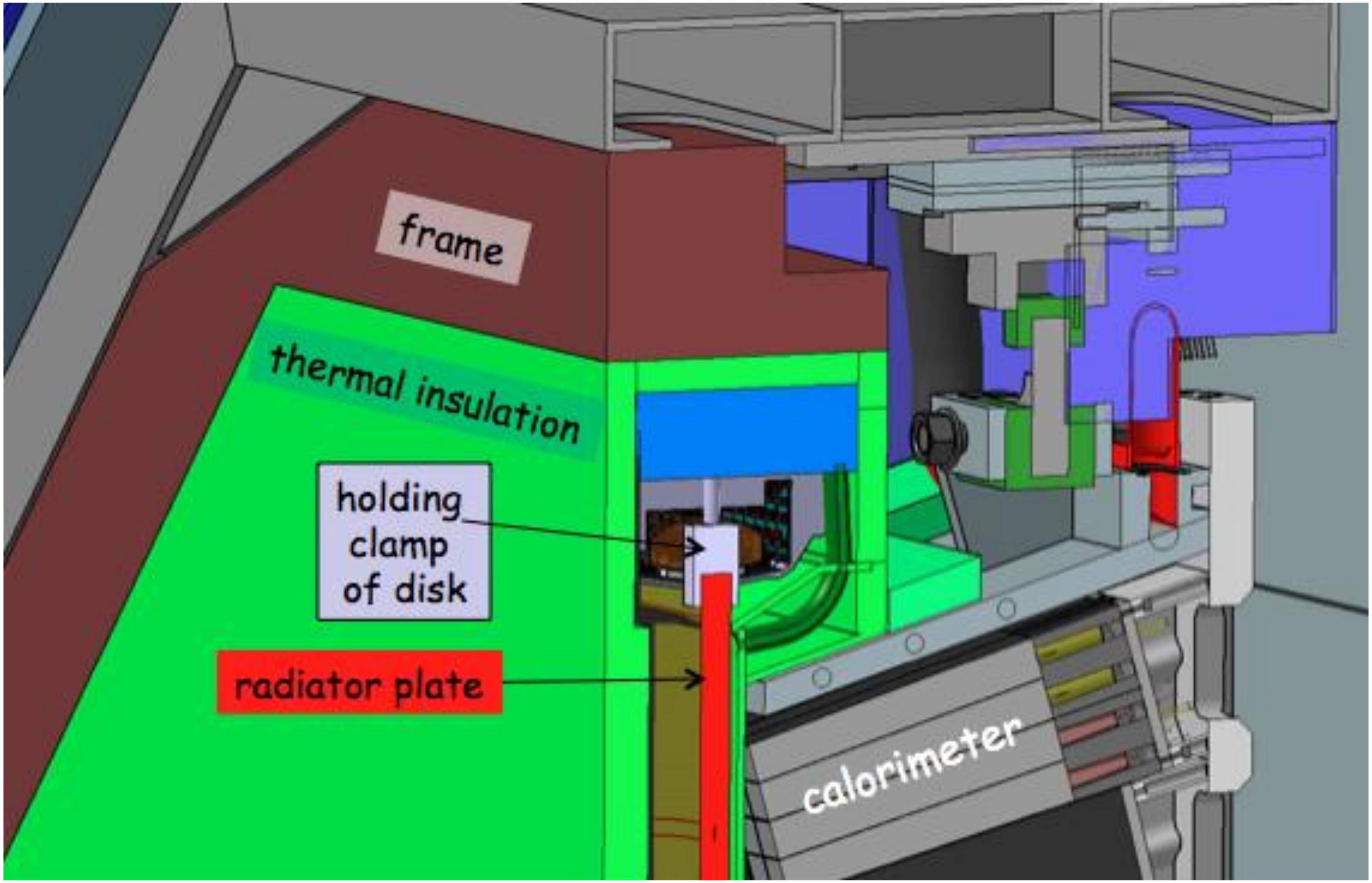
① Make the design independent on choice of photo detector: such that a MCP or PMT solution will fit in later.

Mechanical integration

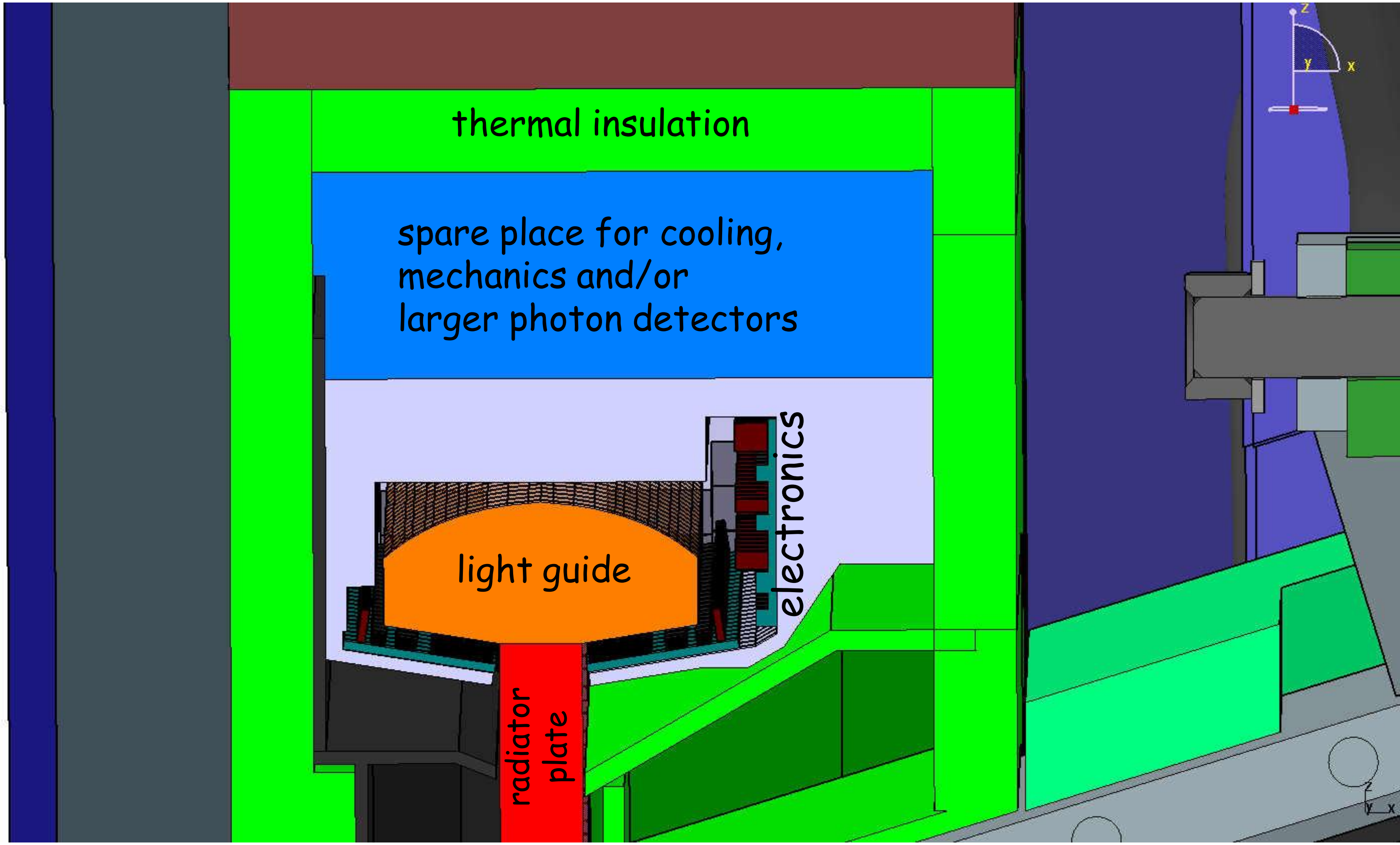


Mechanical integration

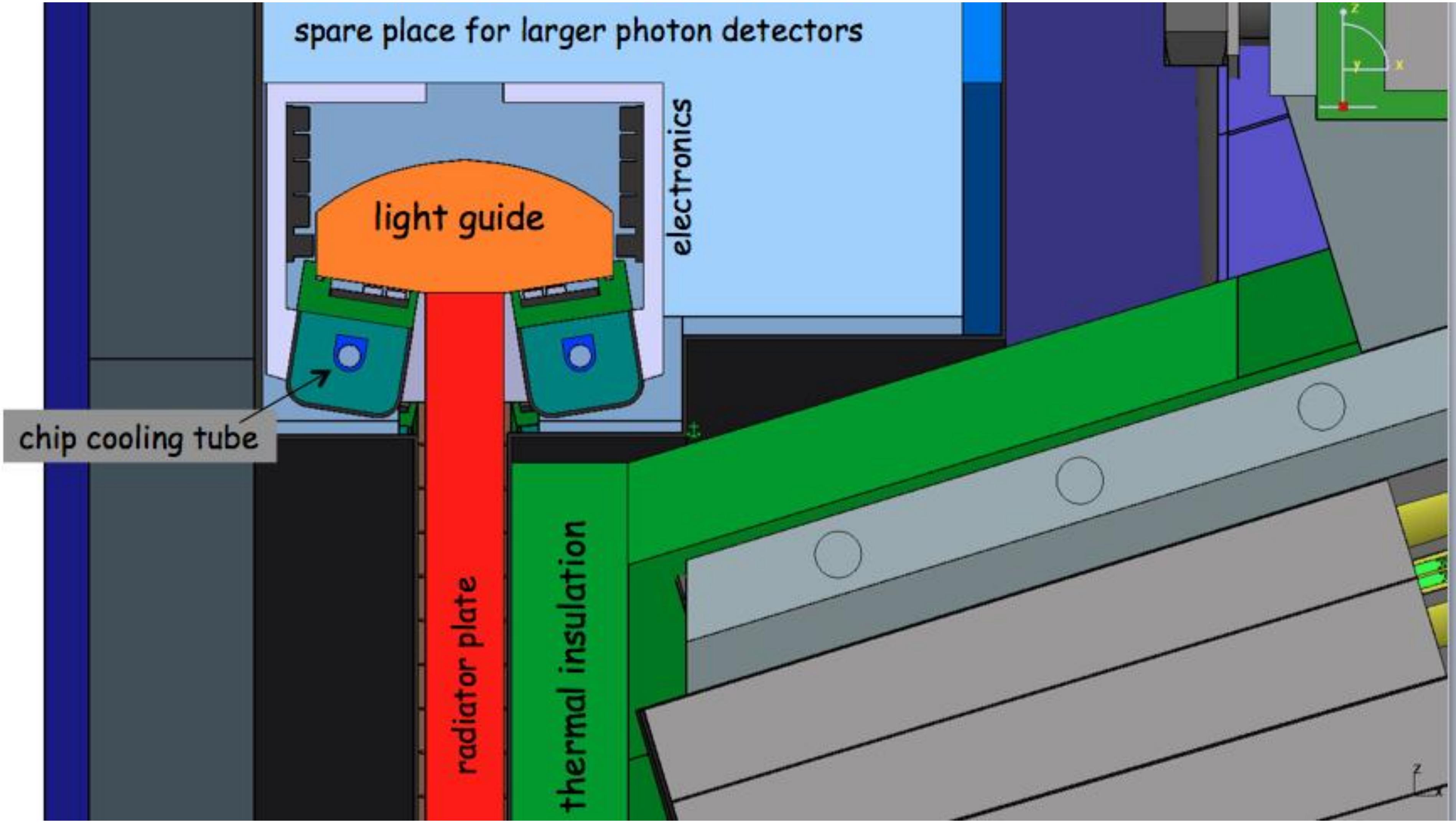
Mechanical integration (cold plate)



Mechanical integration (cold plate)

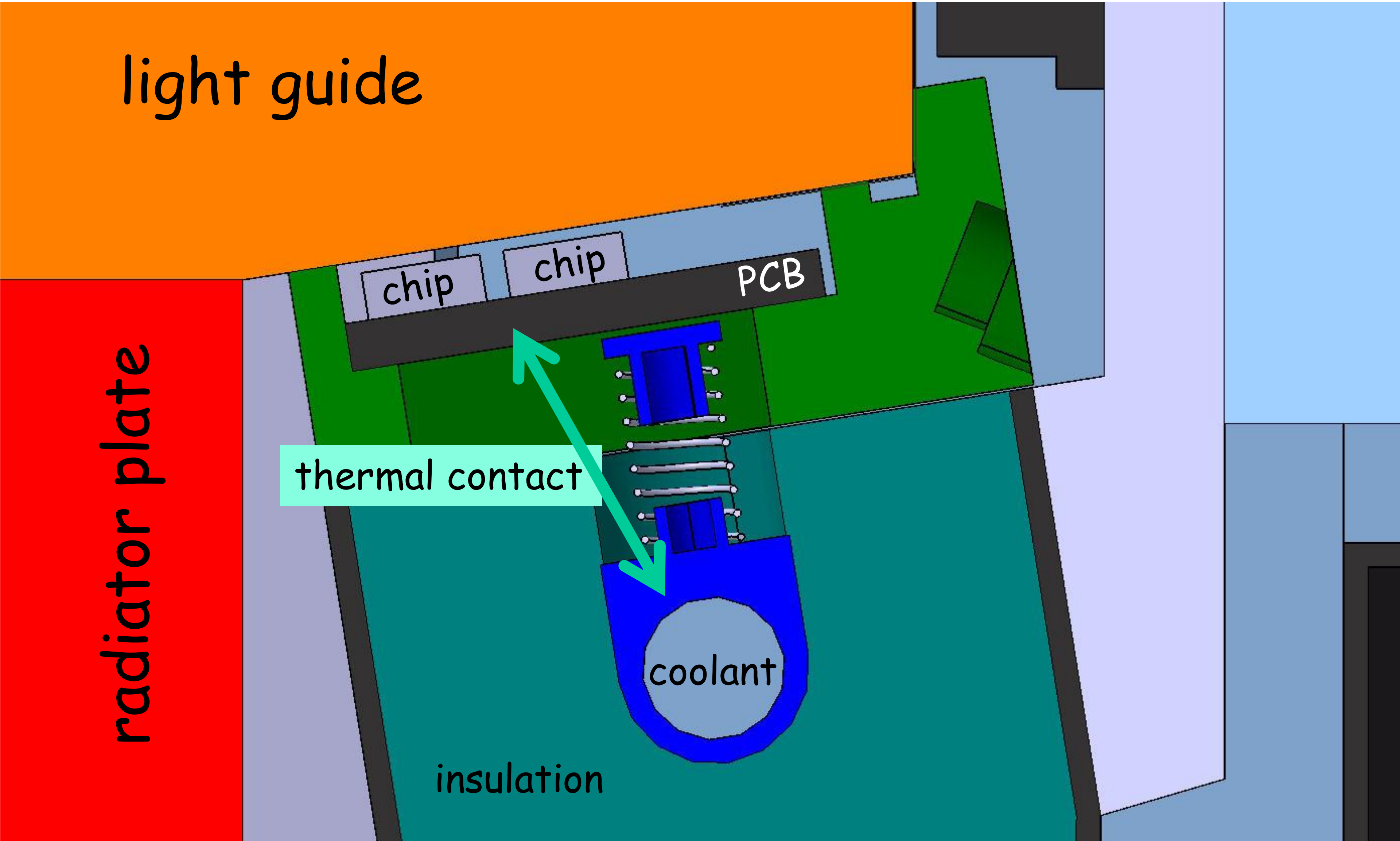


Mechanical integration (warm plate)



M. Düren, DIRC11, April 5, 2011

Photo sensor chip cooling



Conclusions

- a lot of new ideas have been developed
- simulation and reconstruction is in good shape
- prototype tests are ongoing
- photo detector still unclear
- hope to have a working solution at DIRC2013

Thanks to...

- the group from Giessen: Seth Colemans, Klaus Föhl, Avetik Hayrapetyan, Peter Koch, Benno Kröck, Oliver Merle, Kristof Kreutzfeldt, Ann-Kathrin Rink, Michael Sporleder, Nils Stöckmann, Thomas Wasem, Marko Zühlsdorf
- my colleagues from PANDA esp. from the Cherenkov groups in Erlangen, Glasgow, GSI, Vienna,...
- all of you

- JLU, BMBF, EU, HIC for FAIR for funding