Analysis of the Geometrical Interface of a Scintillator Tile and a SMD Photomultiplier

Lennart Adam
Johannes Gutenberg-Universität, Mainz

B. Bauß, V. Büscher, J. Caudron, P. Chau, R. Degele, K. Geib, S. Krause, Y. Liu, L. Masetti, U. Schäfer, R. Spreckels, S.Tapprogge, R. Wanke

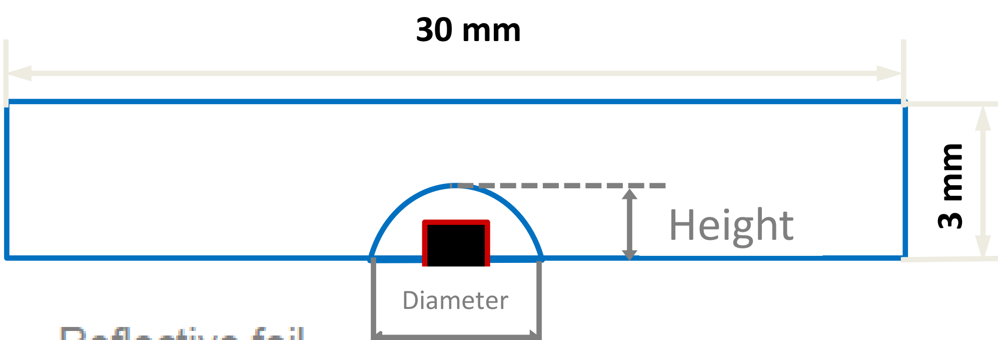
Overview

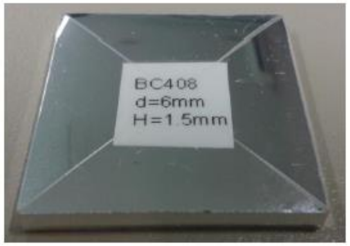
- Scintillator Tile Design for SMD SiPM
- Implementation & Validation of Raytracing Software
- Geometrical Analysis of Initial Design
- Optimization of Tile Design

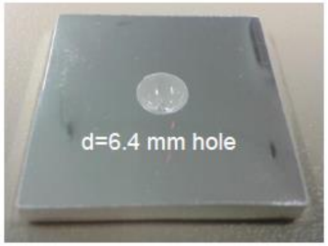
Introduction

- Scintillator Tile Design for SMD SiPM
  - Tile placed on HBU **over** SiPM

  →„Dimple“ (cavity) drilled into scintillator-tile
  - GEANT4: Light yield & uniformity of scintillator-tile highly dependent on shape/size (H,D) of dimple



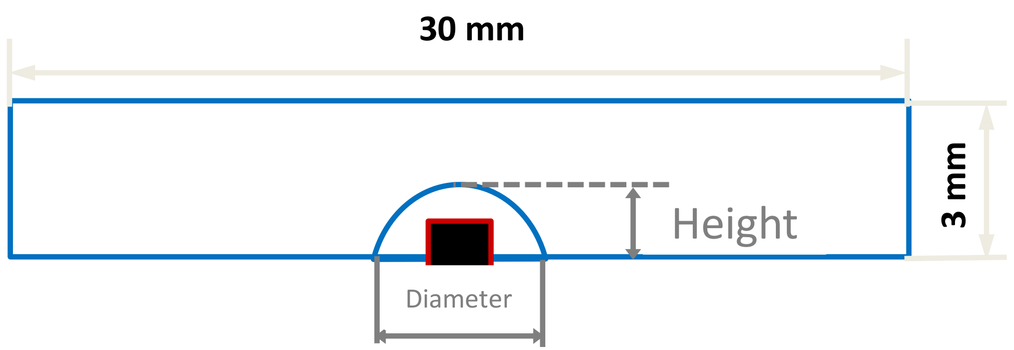




Graphics: Yong Liu (Mainz)

Introduction

- Initial Tile Design
- GEANT4 Simulation *:
  - Spherical shape chosen due to symmetry and resulting uniformity



Most promising design:
(Spherical shape)
H=1.5mm
d=6mm

Optical effects determine uniformity & light yield

→ Use Raytracing Software

- improve understanding of interdependency Dimple geometry & light yield / uniformity
- easier to handle geometry and shorter runtime

*Performed by Y. Liu (Mainz)

Raytracing

- *FRED Optimum – Version 13.60*
- Company: Photon Engineering (http://photonengr.com/)
- Optical Engineering Software

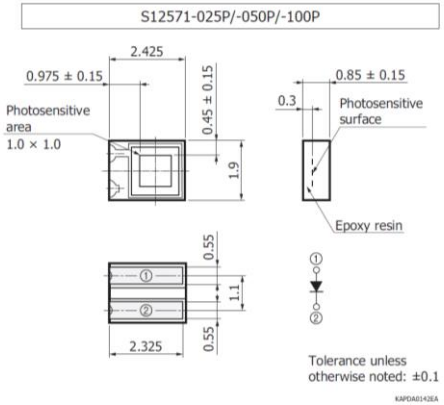
Employed features:

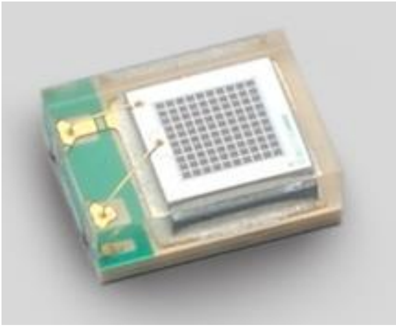
- primitive solids with Boolean operation capability
- refraction indices (scintillator, epoxy, air)
- light attenuation (scintillator), absorption (package)
- coatings (specular reflective)
- detailed light source models (power, direction)
- scripting Tool (BASIC)

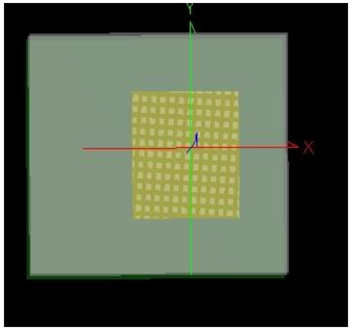
…

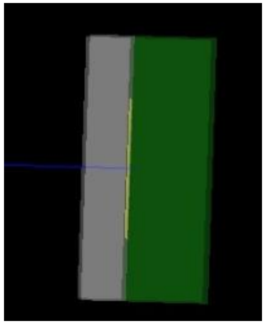
Implementation

- Implementation of SiPM

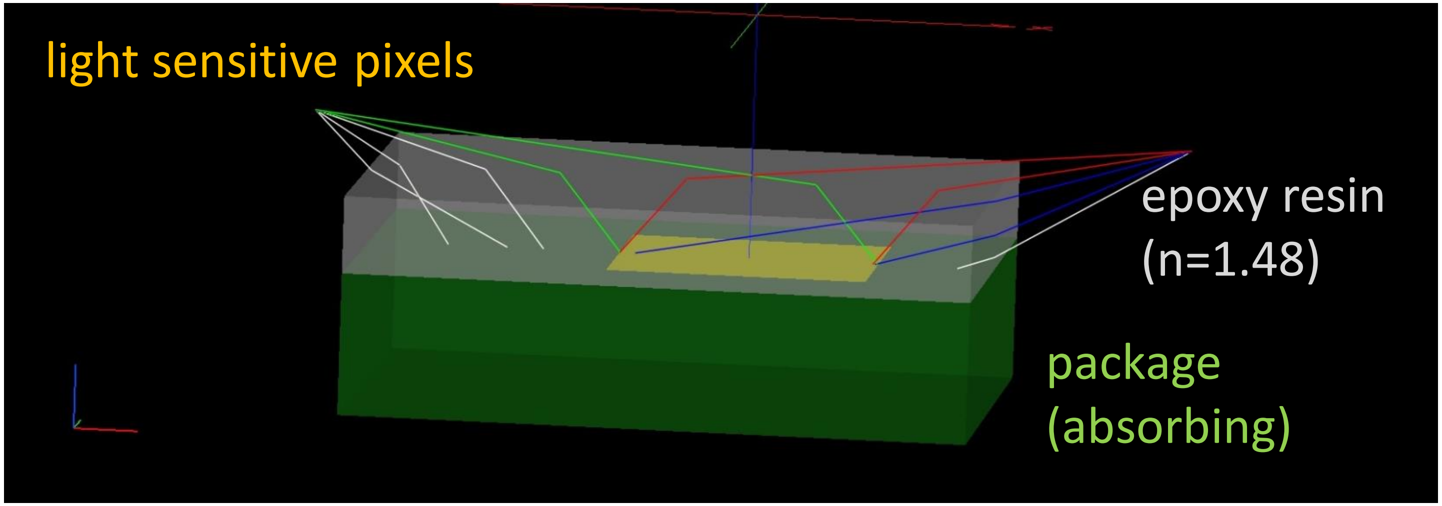






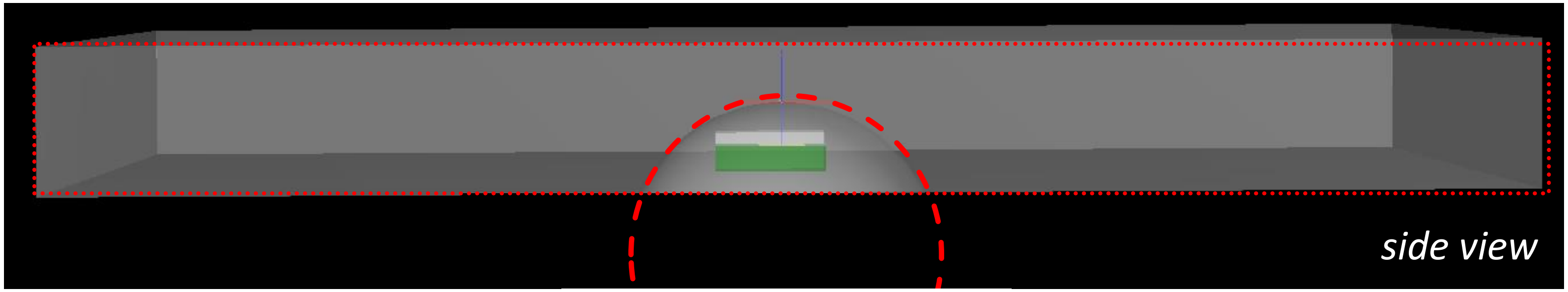


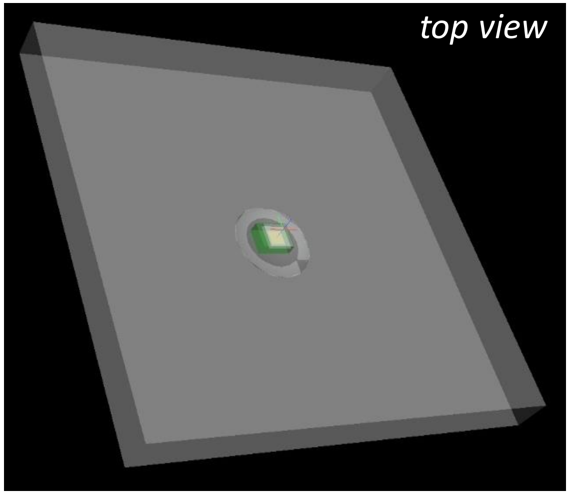
Datasheet: MPPC, Hamamatsu Photonics, K.K., Solid State Division (Oktober 2013)



Implementation

- Implementation of scintillator tile
- Geometry:
  - Subtract ***sphere*** (*r=3.5mm*) from ***block*** (*30mm x 30mm x 3mm*)



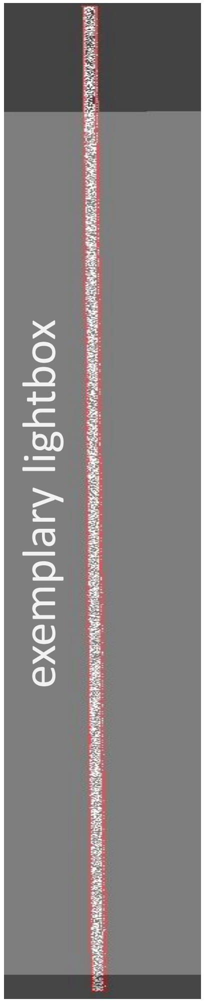


Material properties of BC-408:

- refraction index **n=1.58**
- light attenuation length (→GEANT4 & uniformity scans at MPI Munich): **l≈100cm**
- surface 95% specular reflective (→foil)

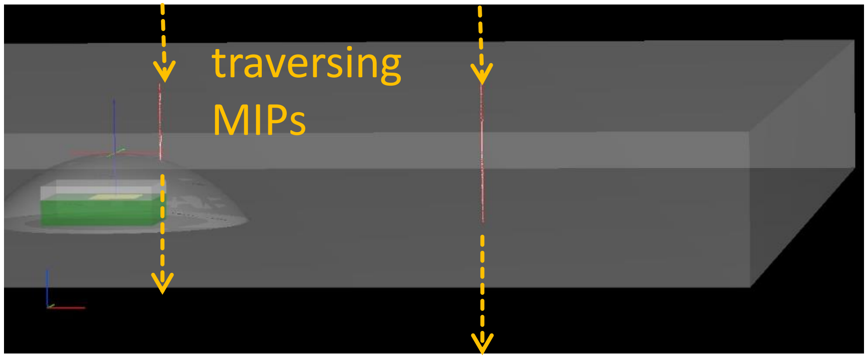
Implementation

- Scintillation Algorithm



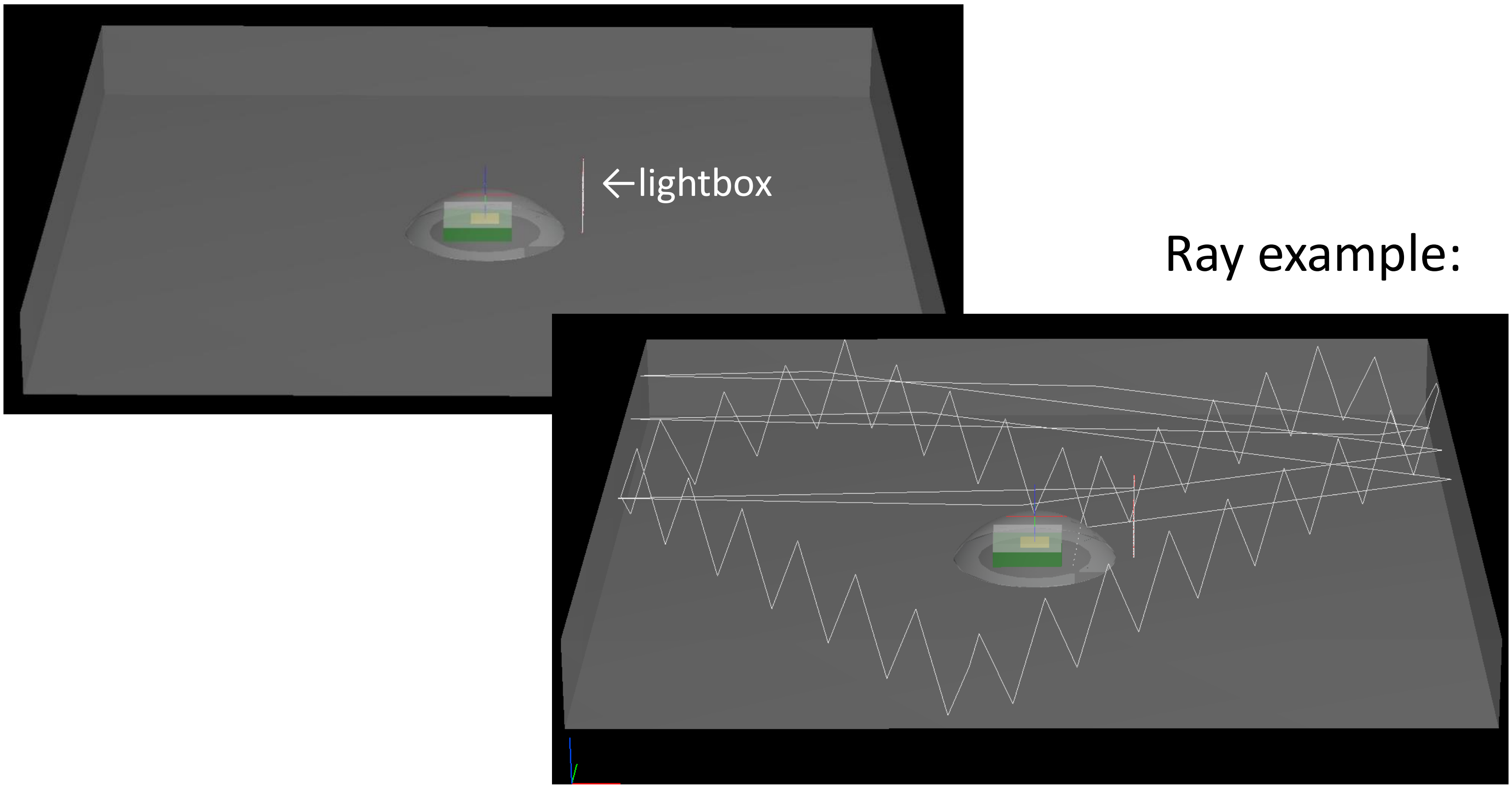
1MIP simulated as:

- narrow box volume (=MIP path) randomly filled with 10000 point sources
- each one shooting one ray uniform in solid angle
- total power of lightbox proportional to path length in scintillator
- **Assumption:** power (prop. intensity) proportional to number of photons



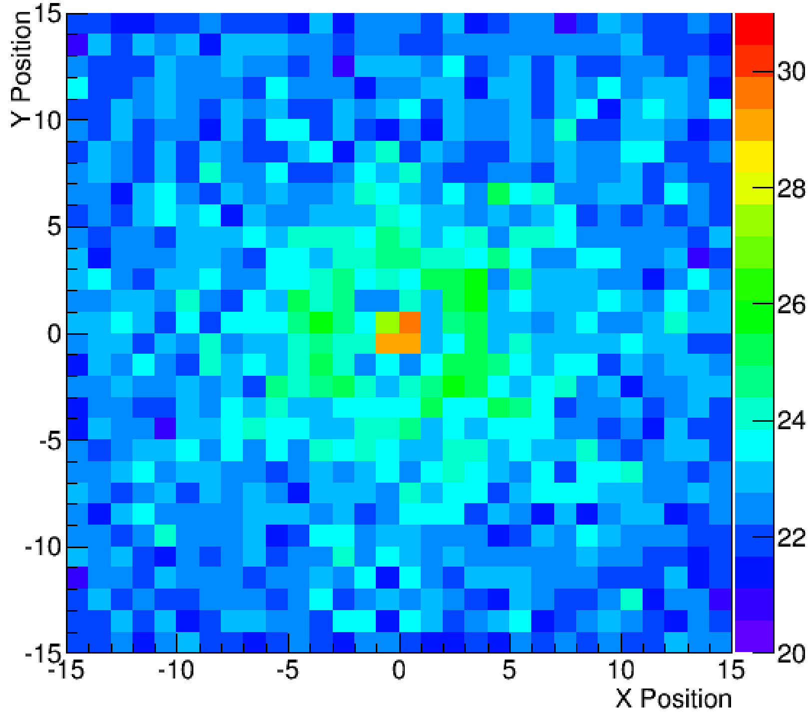
Implementation

- Raytracing

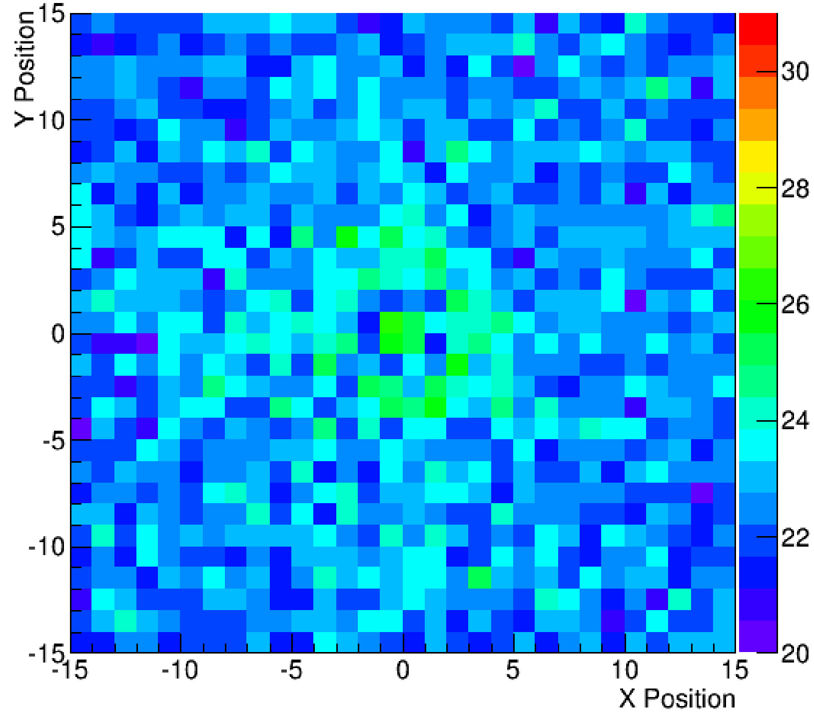


Validation with Geant4

Number of detected photons GEANT4



Number of detected photons FRED (scaled power units)



GEANT4:

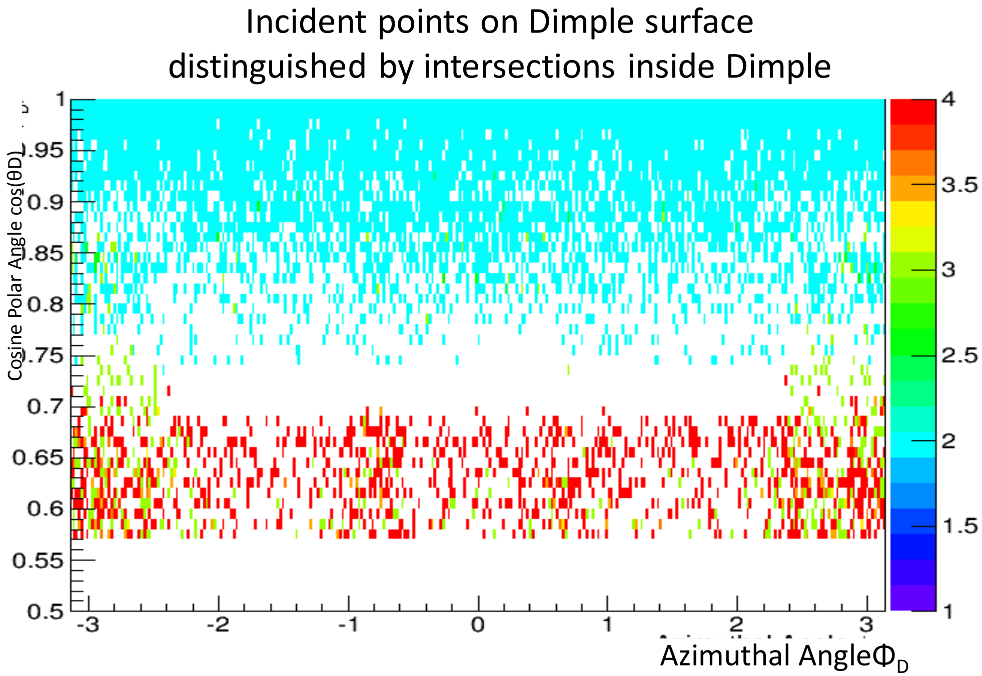
- Myons traversing tile through 1mm² pixel
- Plot mean number of detected photons

FRED:

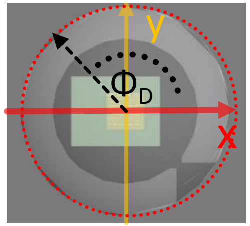
- detected power scaled to obtain equal total light yield

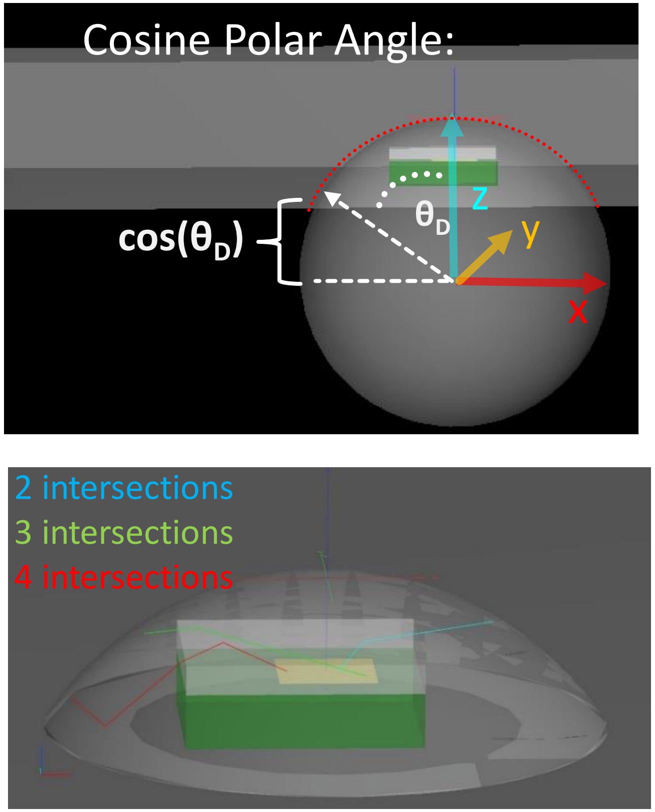
Geometrical Analysis of Initial Design

- Origin of uniformity pattern:
  - Incident points on Dimple surface for detected photons



Azimuthal Angle:

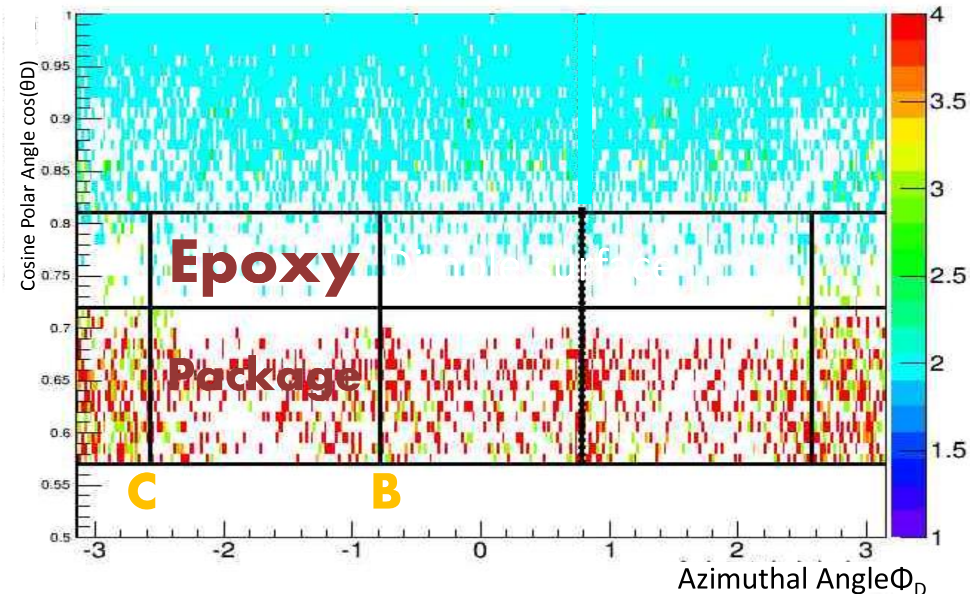


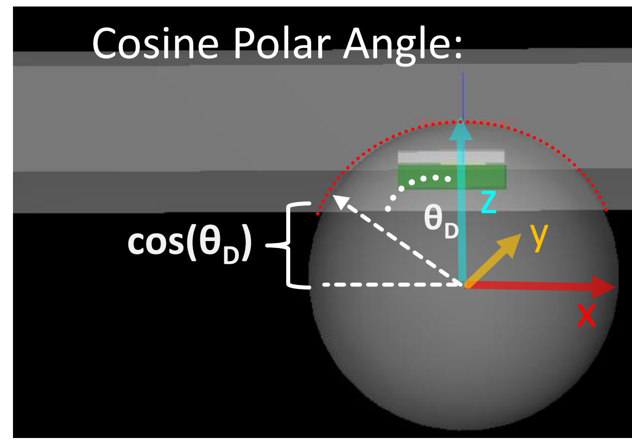


Geometrical Analysis of Initial Design

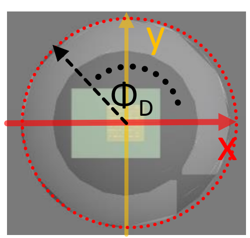
- Origin of uniformity pattern:
  - Incident points on Dimple surface for detected photons

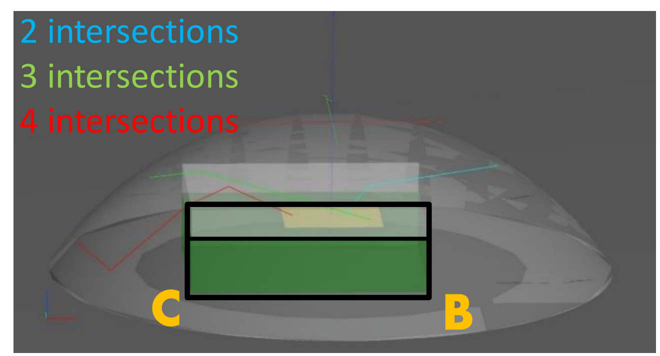
Incident points on Dimple surface
distinguished by intersections inside Dimple





Azimuthal Angle:





Geometrical Analysis of Initial Design

- Origin of uniformity pattern:
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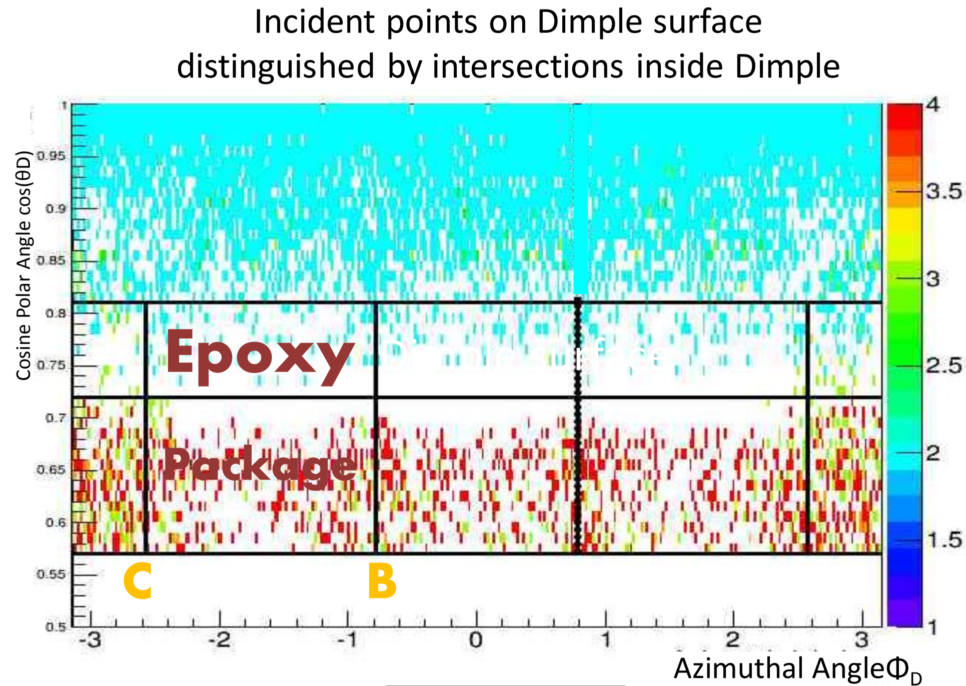
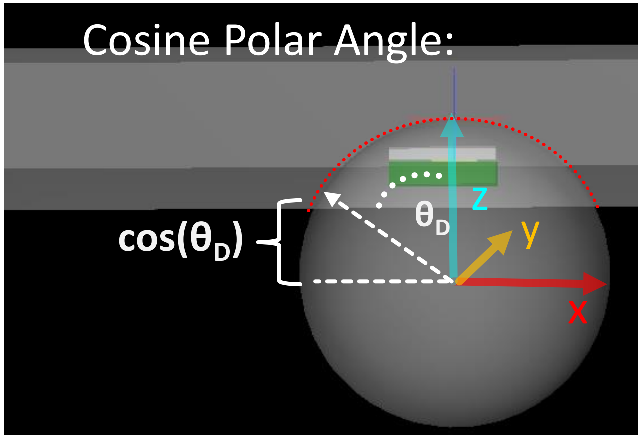
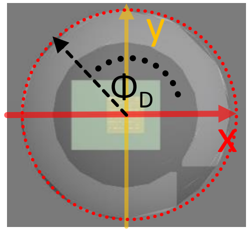
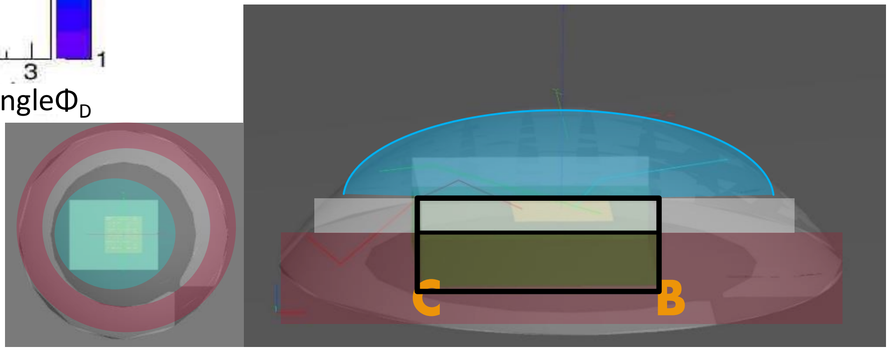




Azimuthal Angle:

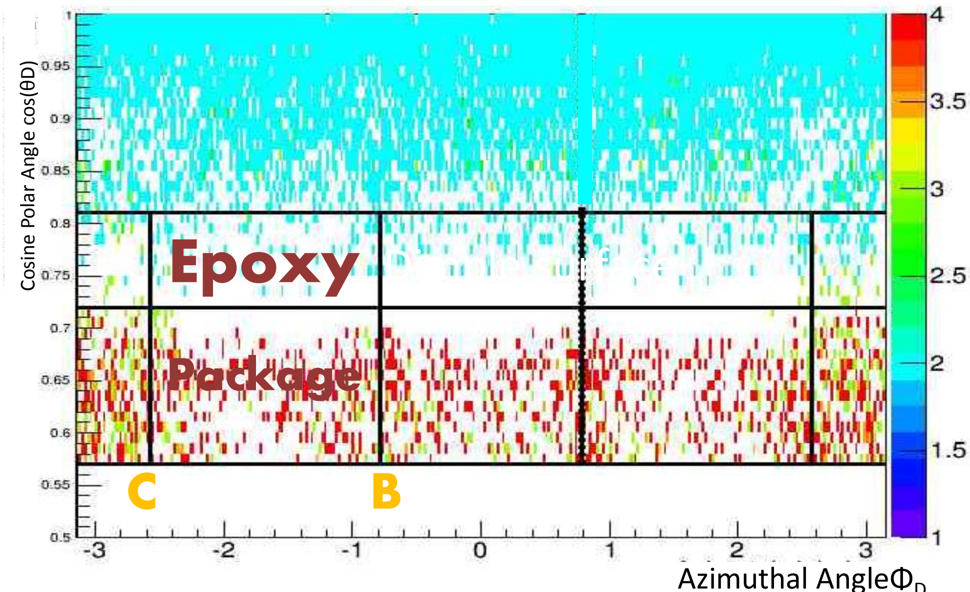




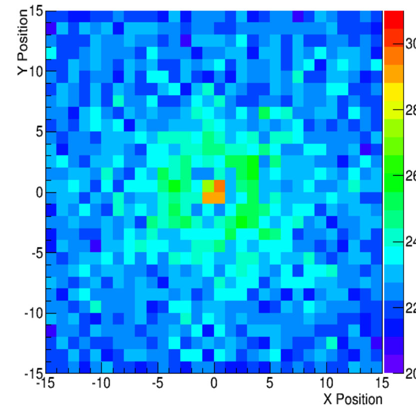
Geometrical Analysis of Initial Design

- Origin of uniformity pattern:
  - Incident points on Dimple surface for detected photons

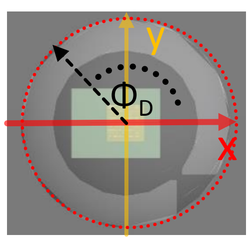
Incident points on Dimple surface
distinguished by intersections inside Dimple

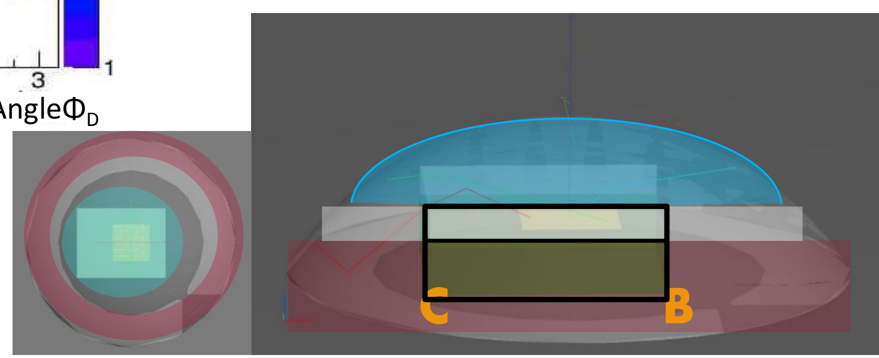


Number of detected photons GEANT4



Azimuthal Angle:





Geometrical Analysis of Initial Design

- Origin of uniformity pattern:
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Incident points on Dimple surface
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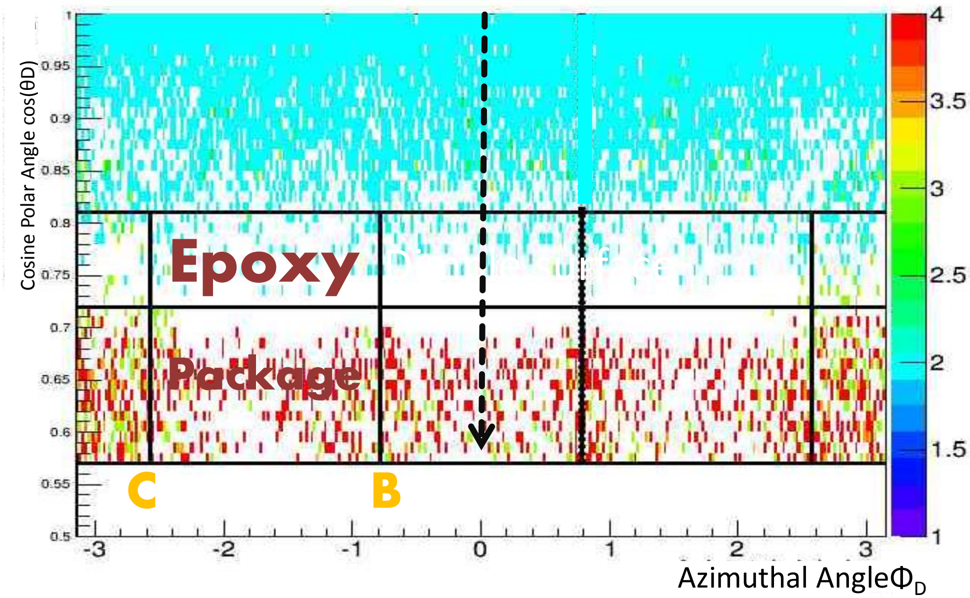
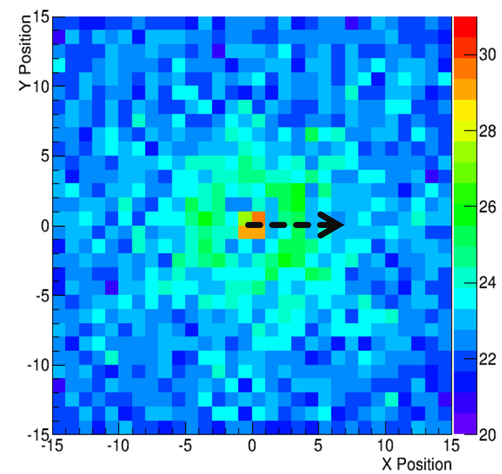
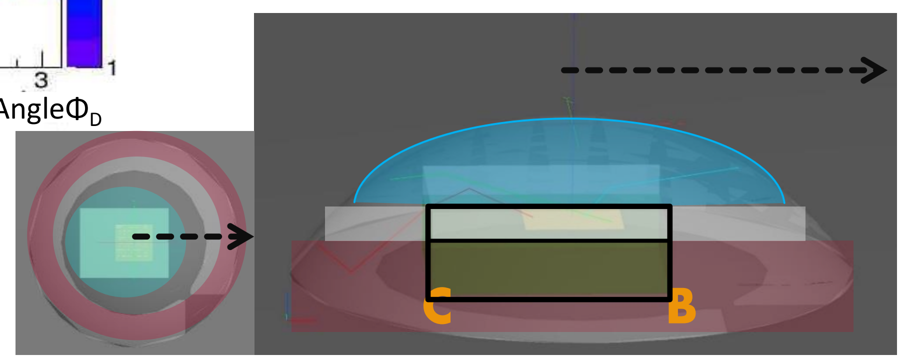


Number of detected photons GEANT4

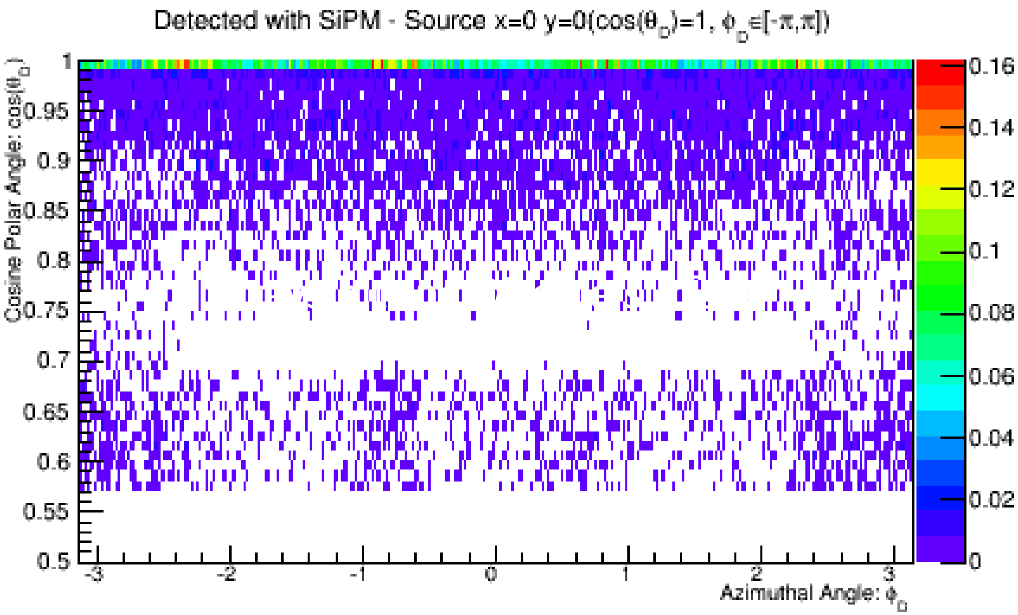




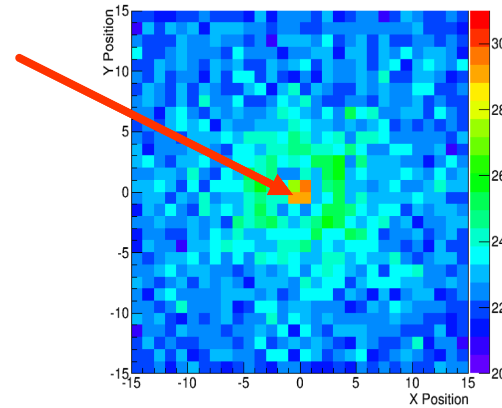
Shifting light source over areas of
different efficiency = variation of response

Geometrical Analysis of Initial Design

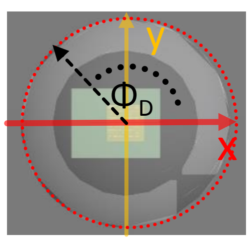
- Origin of uniformity pattern:
  - Incident points on Dimple for light created in center of tile

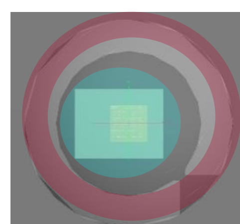


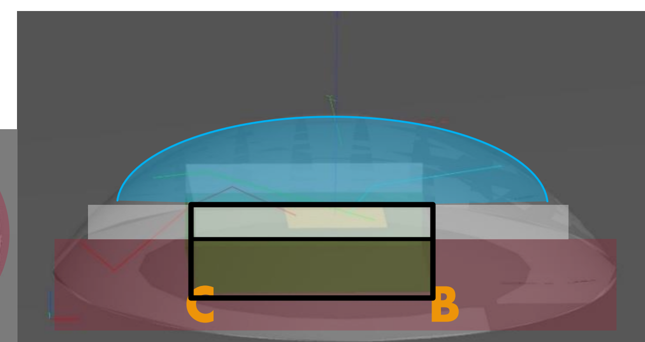
Number of detected photons GEANT4



Azimuthal Angle:

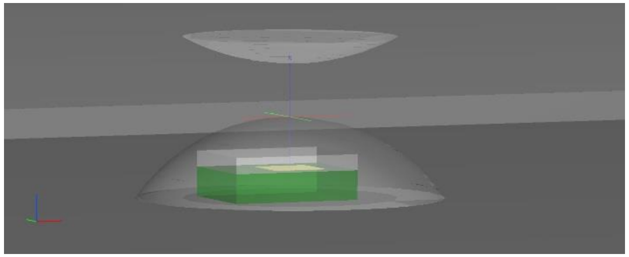


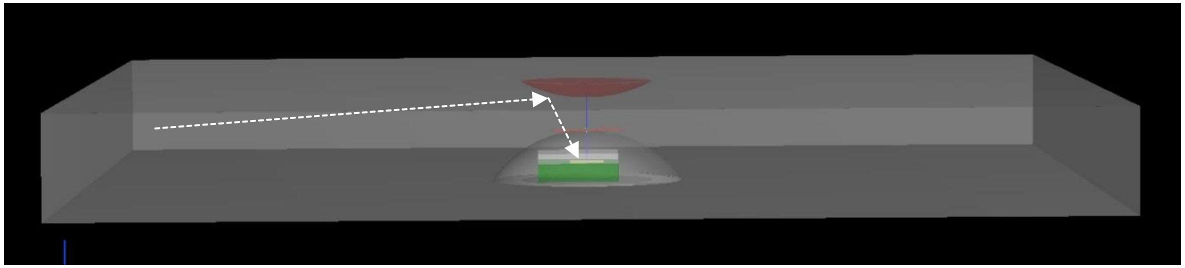




Optimization

- Focus light rays:
  - **Double Dimple** = add 2nd Dimple (Sphere) on top





Effects:

- Rays guided to SiPM by total reflection

FRED: Size optimized in dependence of lower Dimple

- Additional light yield (in comparison to initial design): **+18%**

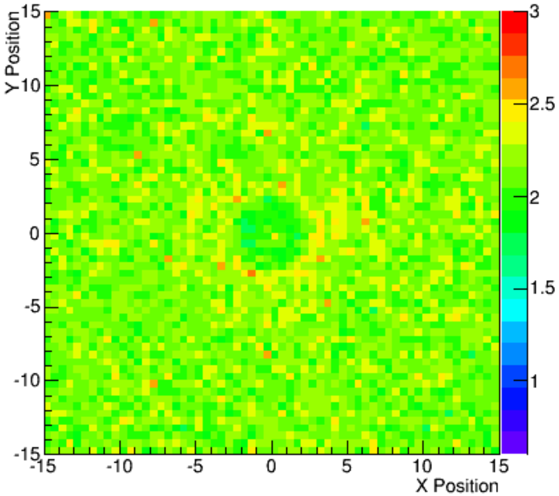
First prototypes built and in test stage

Optimization

- Focus light rays:
  - **Double Dimple** = add 2nd Dimple (Sphere) on top

Uniformity: FRED simulation

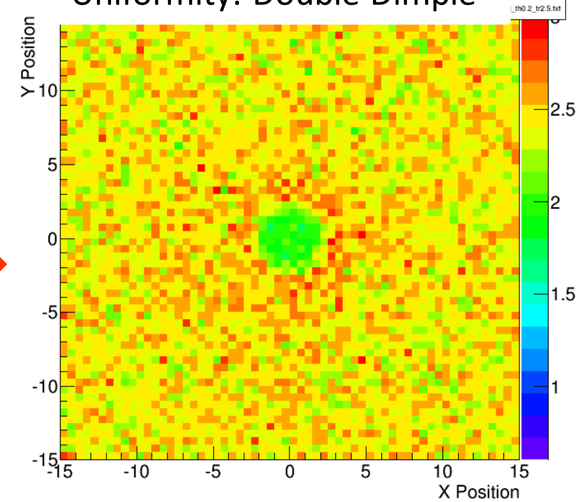
Uniformity: Initial Design



Mean detected power: 2.14

Add 2nd Dimple:
+18% light yield

Uniformity: Double Dimple



Mean detected power:

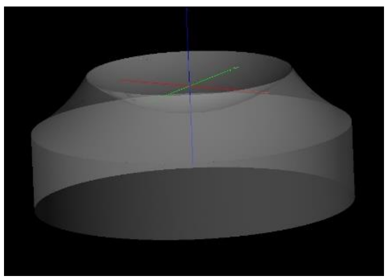
- Outer part: 2.40
- Center: 1.90

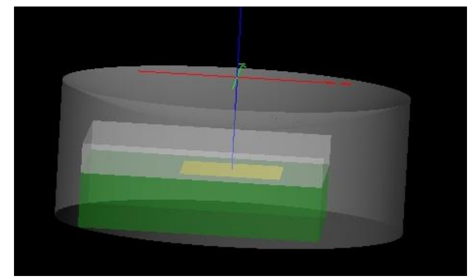
Optimization

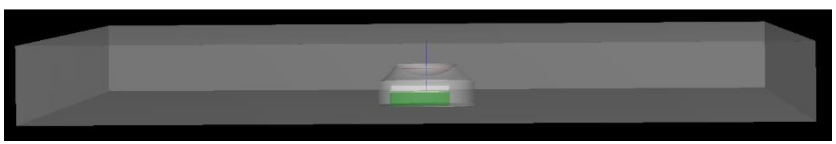
- Minimize Total Reflection : **Collecting Designs**

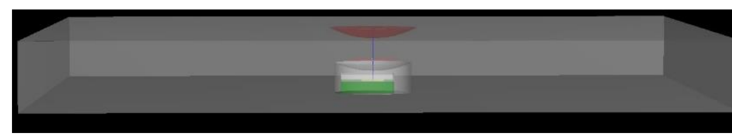
Volcano Dimple

Cylinder with convex top
+ 2nd Dimple









Additional light yield In comparison to initial Design	**+40%**	**+32%**

Effects:

- Convex shape acts as collecting lens
- higher light yield but worse uniformity

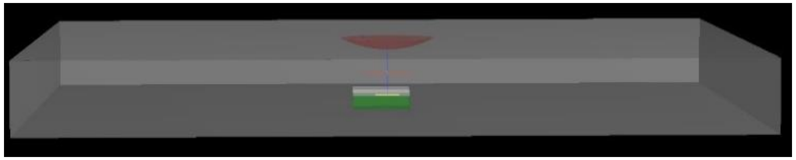
Optimization

- Minimize Total Reflection: **Direct Coupling**
- Ideal case: Fill Dimple with scintillator material

FRED Simulation:

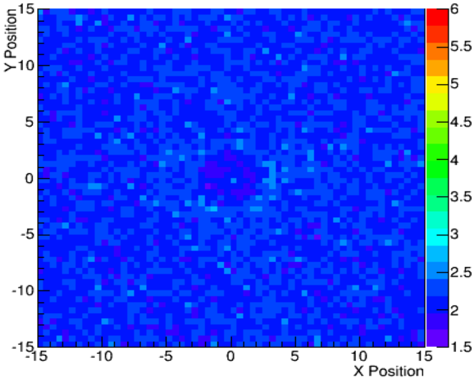
+102% light yield

(in comparison to initial design)

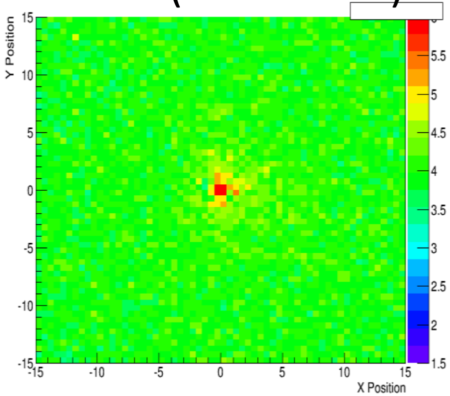


- SiPM inside scintillator tile
- no hole in foil
- 2nd Dimple

Single Dimple (mean 2.14)



Ideal (mean 4.35)

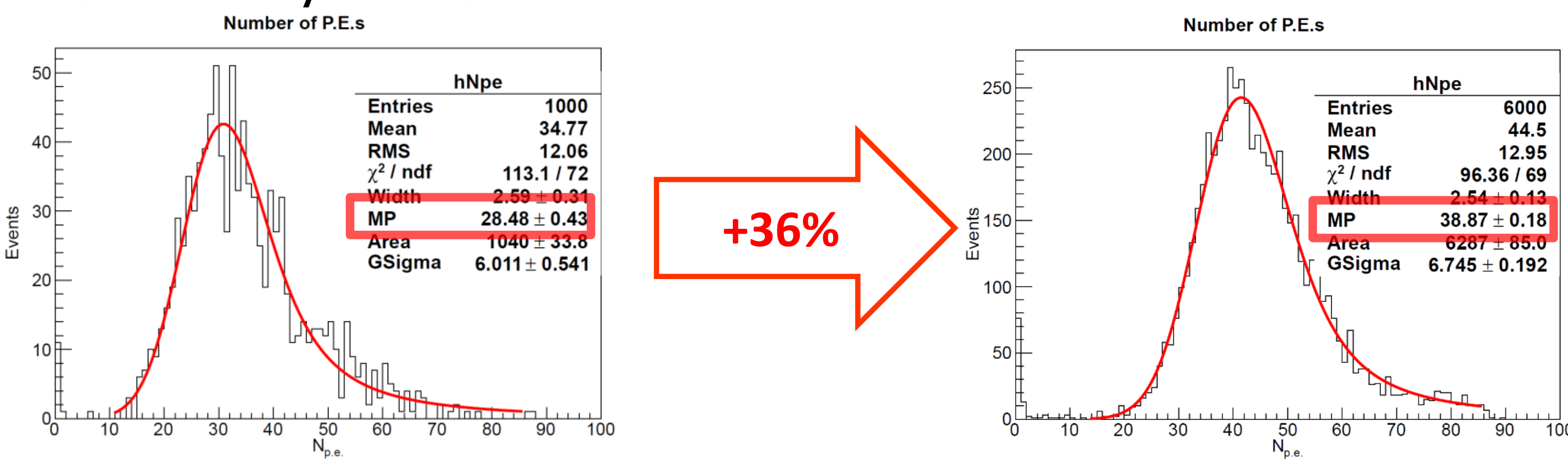


Optimization

- Minimize Total Reflection: **Direct Coupling**
- Realistic Implementation: Optical Coupling

➢ **Measurement:**

Optical Grease* applied to Double Dimple Prototype and tested in Cosmic Ray Test Stand:



Double Dimple tile (**with** hole in foil r=2mm) before grease injection

Same tile (**with** hole in foil) grease injected

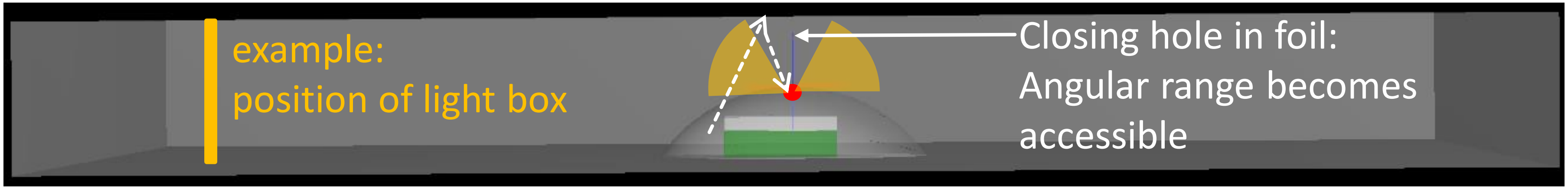
*Saint-Gobin Crystals: Silicone Grease BC-630 (refraction index n=1.465 (BC-408: 1.58, Epoxy: 1.55))

Optimization

- Minimize light loss: Maximize reflective area
- Minimize hole in reflective foil

Design features	Additional light yield
Double Dimple + optical grease - hole in foil (r=2mm) (measurement)	**+36%** in comparison to initial design
Similar Design without hole (FRED simulation)	**+80%** in comparison to initial design (measurement to be done)

Reflective area close to SiPM important for ray detection:



Conclusion & Outlook

Conclusion:

- Focus rays → 2^{nd} Dimple
- Minimize total reflection → optical coupling
- Minimize light loss → foil as close as possible to SiPM

To Do:

- Measurement without hole in foil
- Test long term application of optical grease
- Optimize refraction index of optical coupling
- Revisit Dimple shape

Thank you for your attention.

Calorimeter for ILC

PRISMA Cluster of Excellence

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

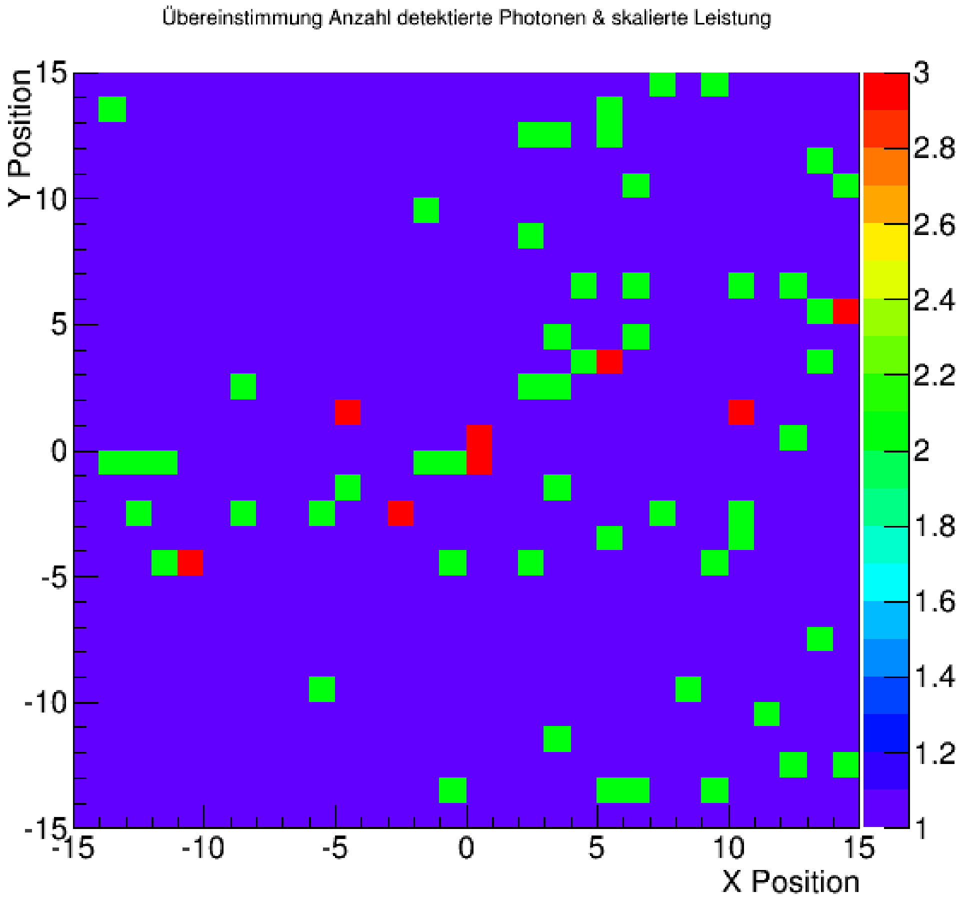
BACKUP

FRED Optimum – Version 13.60

- Purchase Options
  - 1) Single PC License 11.160 Euro
  - 2)Network License 12.510 Euro
    - (12 months support & updates included)
    - Followings periods 1.1210/1.340Euro
  - 3) 3 months lease: 3.050 Euror
    - 4 x 3 months lease period + following immediate purchase of one support/update period → ownership of license
  - *Gratis temporary license for thesis*

Crosscheck

- Agreement within Error-Intervalls

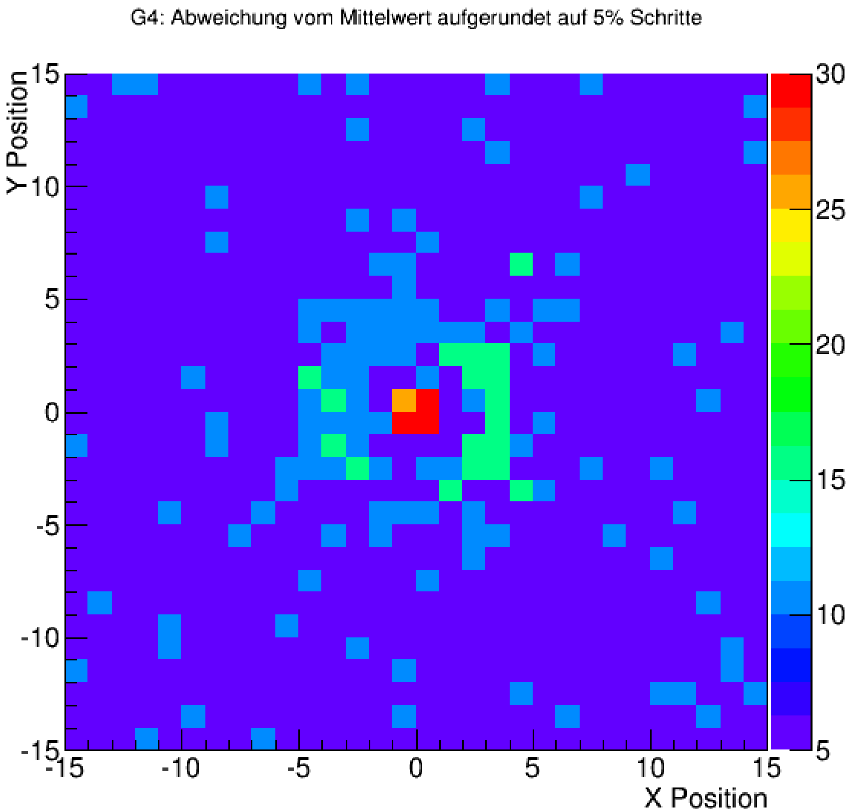


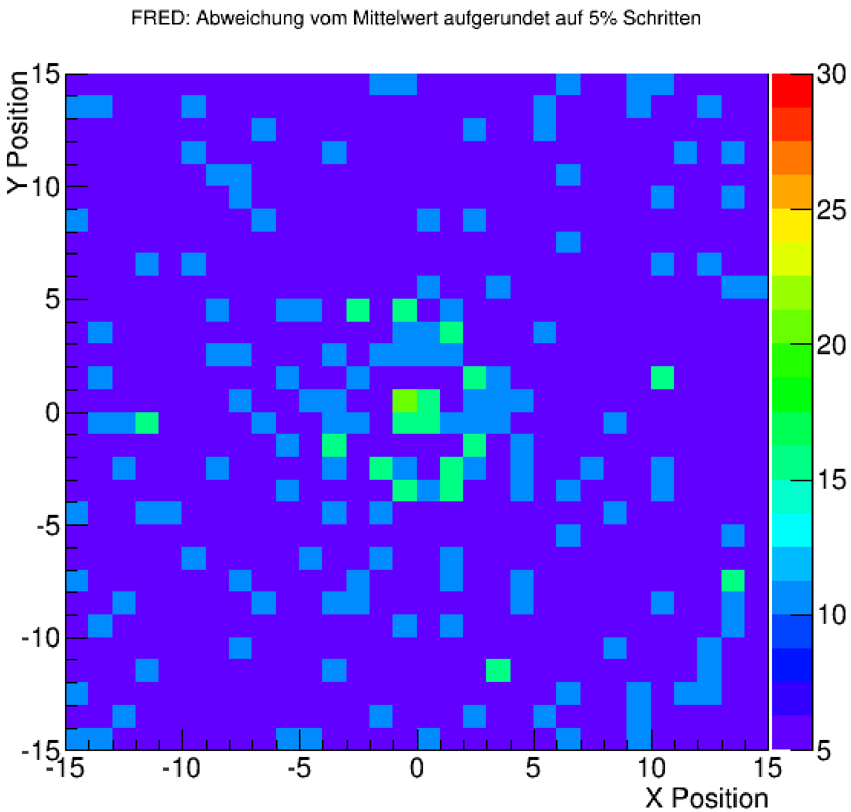
- ca. **90%** of area **agree within errors**
- FRED: poisson error dependent on number of rays (here ≈2%)
- GEANT4 error of same dimension

Crosscheck

- Uniformity

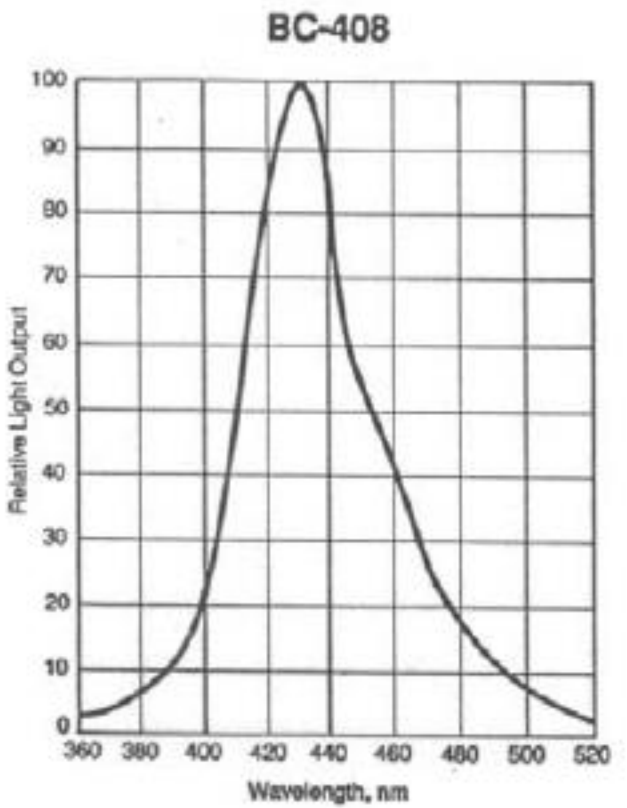
relative deviation from mean in 5% steps



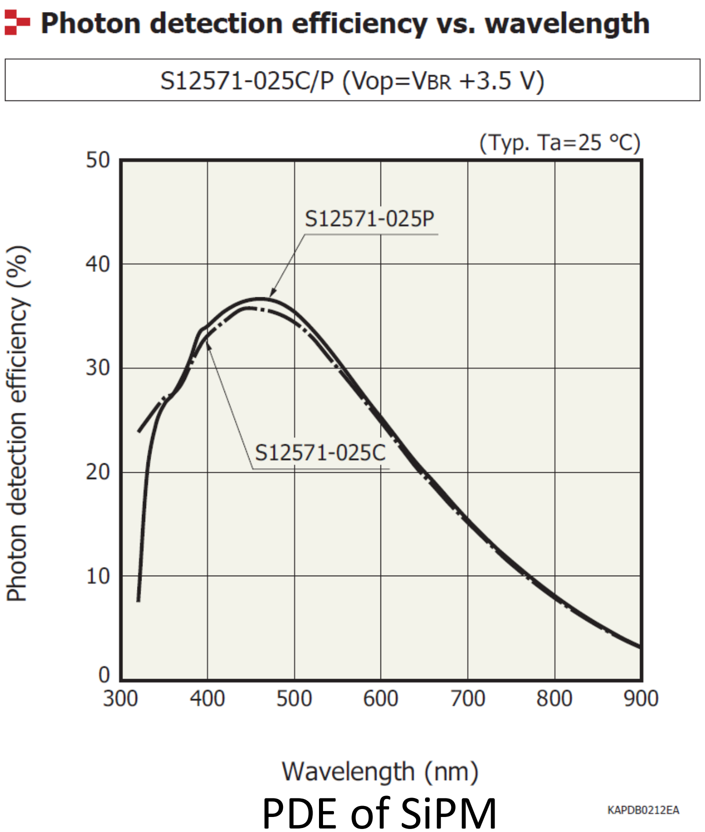


Wavelength Dependency

- Only two parts known to be wvl. dep.



Scintillation spectrum BC-408



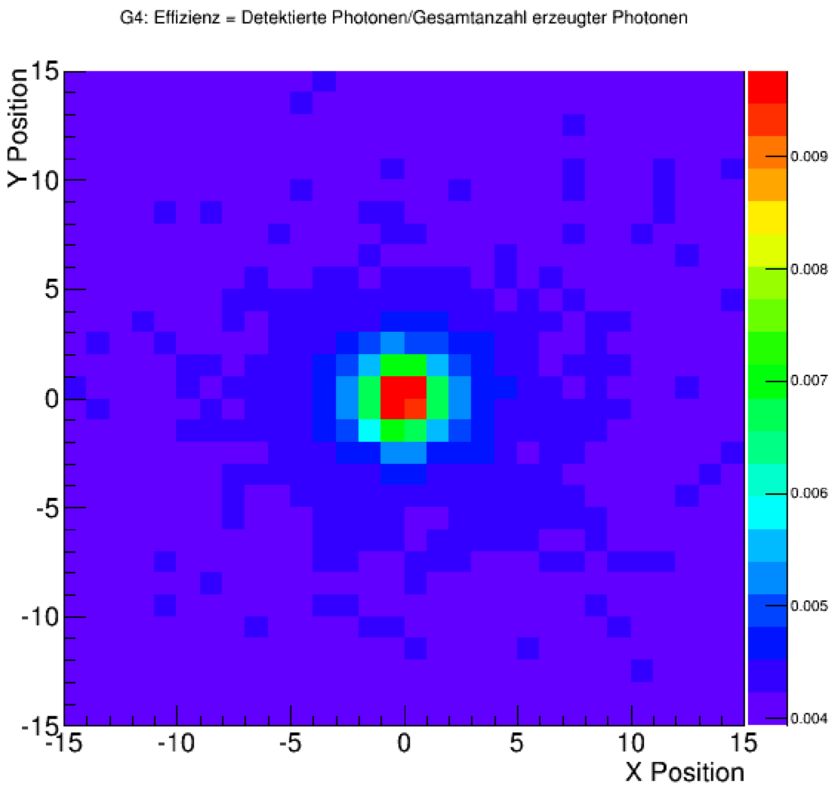
PDE of SiPM

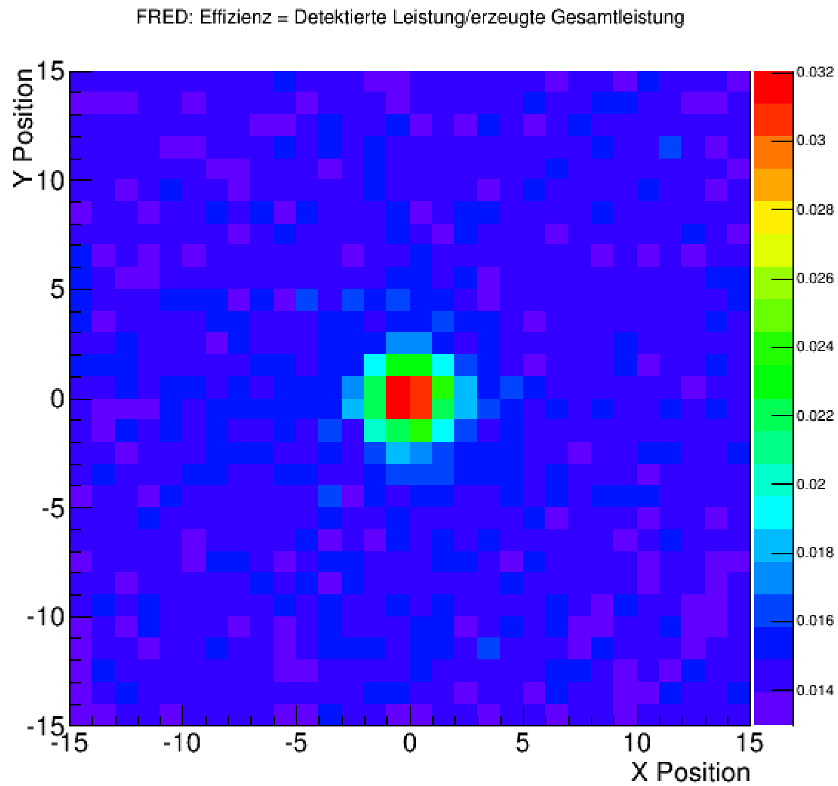
Convolution: roughly 0.3

Crosscheck

- Compare Efficiency

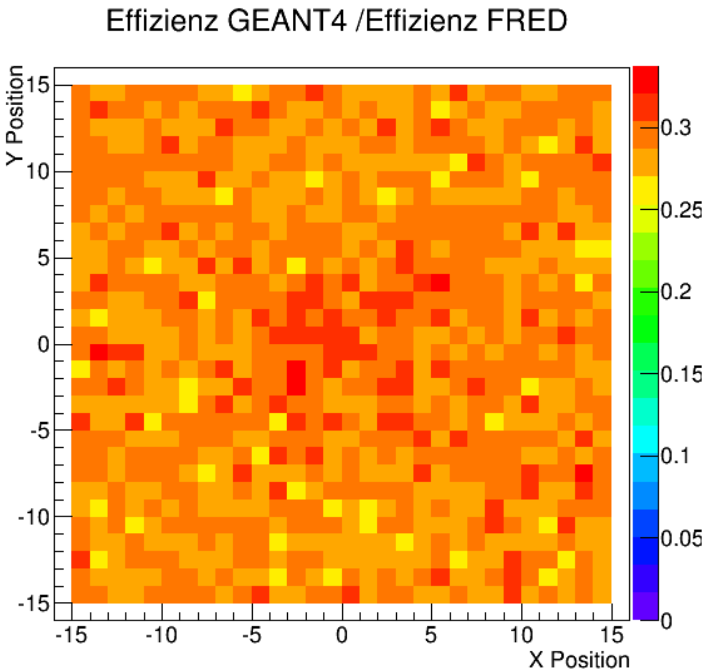
= photons (power) produced by particle divided by number of detected photons (power)





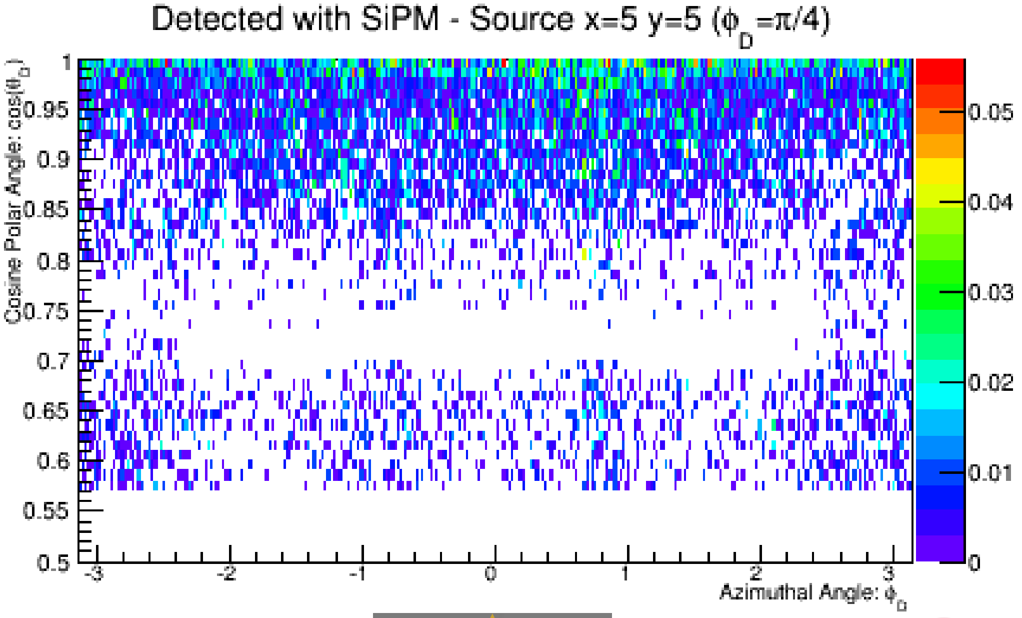
Crosscheck

- Compare Efficiency
  - Divide Eff. GEANT4 by Eff. FRED:
    - ➢ roughly constant: ≈0.3

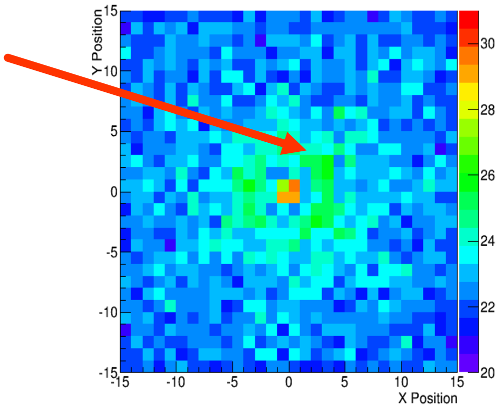


Geometrical Analysis of Initial Design

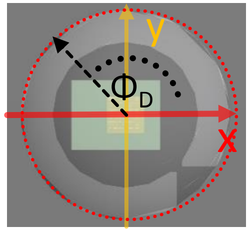
- Origin of uniformity pattern:
  - Incident points on Dimple for light created apart from Dimple

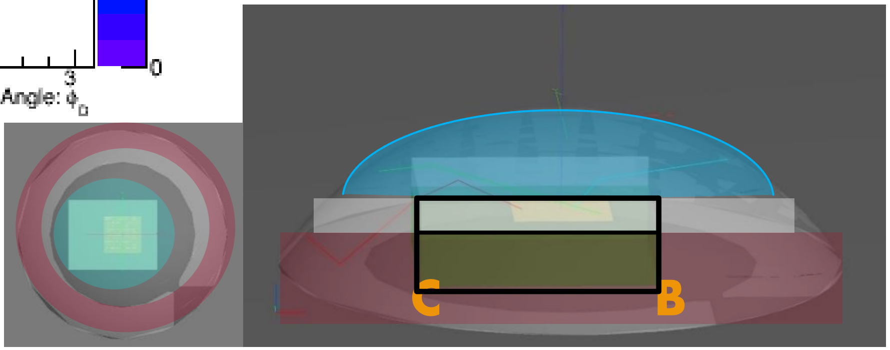


Number of detected photons GEANT4



Azimuthal Angle:

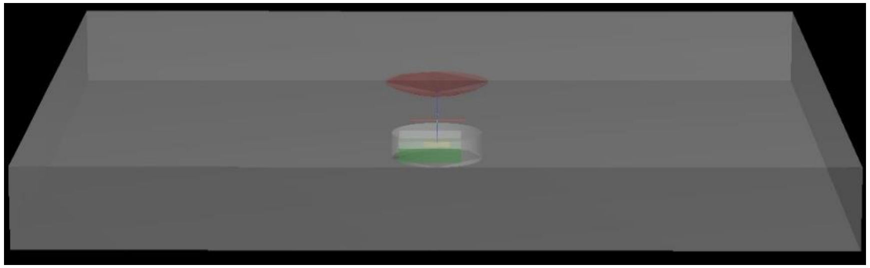




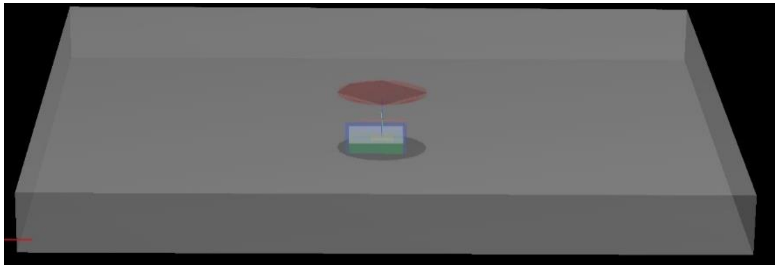
Optimization

- Approximate ideal Design with FRED
  - Smallest possible Dimple (within error margins SiPM)

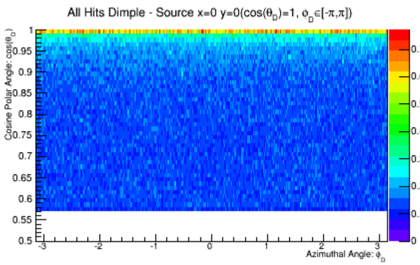
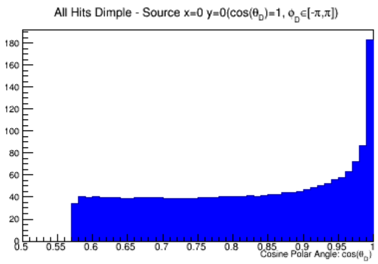
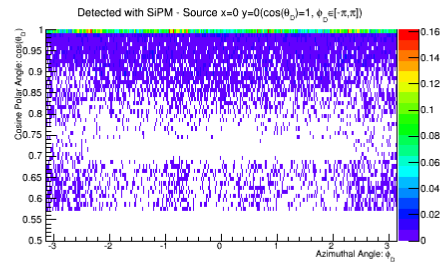
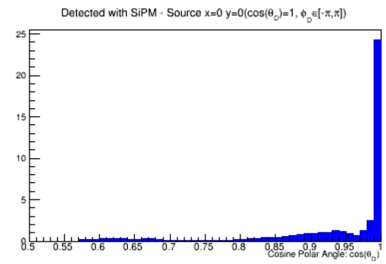
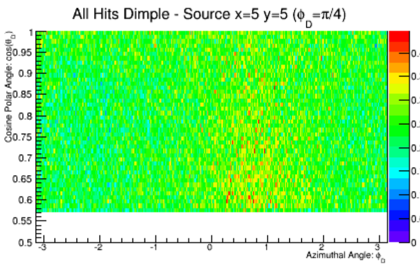
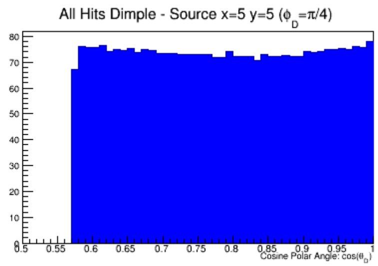
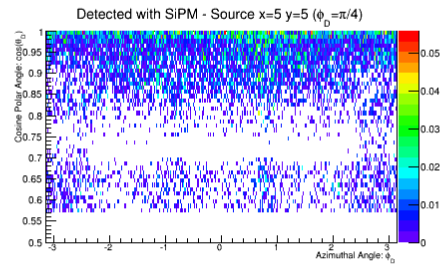
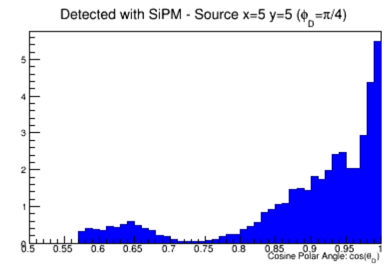
Cylinder Dimple



Block Dimple



Design features	Additional light yield	
2^{nd} Dimple + hole equal Dimple + opt. grease	+76%	+88% (hole r= 2mm: +48%)


All Hits Dimple - Source x=0 y=0(cos(θD)=1, ϕD∈[-π,π])
Cosine Polar Angle: cos(θD)
Azimuthal Angle: ϕD

All Hits Dimple - Source x=0 y=0(cos(θD)=1, ϕD∈[-π,π])
Cosine Polar Angle: cos(θD)

Detected with SiPM - Source x=0 y=0(cos(θD)=1, ϕD∈[-π,π])
Cosine Polar Angle: cos(θD)
Azimuthal Angle: ϕD

Detected with SiPM - Source x=0 y=0(cos(θD)=1, ϕD∈[-π,π])
Cosine Polar Angle: cos(θD)

All Hits Dimple - Source x=5 y=5 (ϕD=π/4)
Cosine Polar Angle: cos(θD)
Azimuthal Angle: ϕD

All Hits Dimple - Source x=5 y=5 (ϕD=π/4)
Cosine Polar Angle: cos(θD)

Detected with SiPM - Source x=5 y=5 (ϕD=π/4)
Cosine Polar Angle: cos(θD)
Azimuthal Angle: ϕD

Detected with SiPM - Source x=5 y=5 (ϕD=π/4)
Cosine Polar Angle: cos(θD)