GPU simulation of Cherenkov photons, notes on **optical** photon detection

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pfRICH S&C meeting
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Outline

Notes on (Cherenkov) photon detection:

– Anti reflective coating

– Thin film interference

– Incident angle dependence of photon detection efficiency

What we are doing @ NPPS:

Simulating Cerenkov photons on GPU -> Faster simulations

Anti reflective coating

For PMTs the nominal QE ~25%

If we add an additional antireflective coating

(eg. BeO) to a bialkali tube, QE gain of 40-45% [2]

Impedance matching theory [1]

Table 2. Optimized solutions for KCsSb.

Cathode thickness (nm)	Mean enhancement factor over 380–680 nm wavelength range	Optimum thickness of zirconia (nm)	Global maximum enhancement factor	Optimum thickness of zirconia (nm)	Wavelength of global maximum (nm)
10	2.1%	105	*9%*	*92*	*530*
15	7%	97	*18%*	*81*	*530*
20	**11%**	**84**	***27%***	***73***	***530***
25	16%	69	*34%*	*67*	*530*
30	20%	61	*39%*	*68*	*545*
35	24%	57	*43%*	*63*	*545*

Table 3. Optimized solutions for RbCsSb.

Cathode thickness (nm)	Mean enhancement factor over 380–680 nm wavelength range	Optimum thickness of zirconia (nm)	Global maximum enhancement factor	Optimum thickness of zirconia (nm)	Wavelength of global maximum (nm)
10	2.7%	100	*10%*	*102*	*575*
15	8%	90	*20%*	*92*	*575*
20	14%	79	*29%*	*84*	*575*
25	**19%**	***70***	***38%***	***77***	***575***
30	23%	*63*	*44%*	*72*	*575*
35	27%	*58*	*48%*	*67*	*575*

[1] Harmer et al., Enhancement of photomultiplier sensitivity with anti-reflective layers

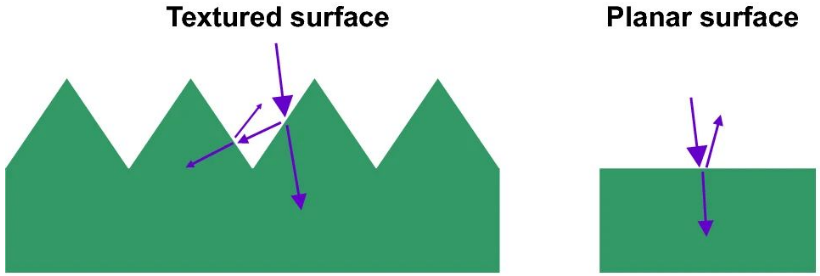
[2] Watase F et al, 2007 European Patent application EP 1939917A2

https://iopscience.iop.org/article/10.1088/0022-3727/45/5/055102

ARC and texture for SiPMs

How to improve QE more?

- Multiple ARC layers [3]
- Texture [3]



[3] Tao et al., Advanced antireflection for back-illuminated silicon photomultipliers to detect faint light, Scientific reports 2023

https://www.nature.com/articles/s41598-022-18280-y

ARC and texture for SiPMs

1. **Single-layer ARC (SiNx):**
    - **Thicknesses studied:** ~ 55 nm
2. **Double-layer ARC (MgF_2/ZnS):**
    - **Magnesium fluoride (MgF_2):** 77 nm
    - **Zinc sulfide (ZnS):** 48 nm
3. **Triple-layer ARC (MgF_2/HfO_2/TiO_2):**
    - **Magnesium fluoride (MgF_2):** 77 nm
    - **Hafnium oxide (HfO_2):** 55 nm
    - **Titanium oxide (TiO_2):** 42 nm

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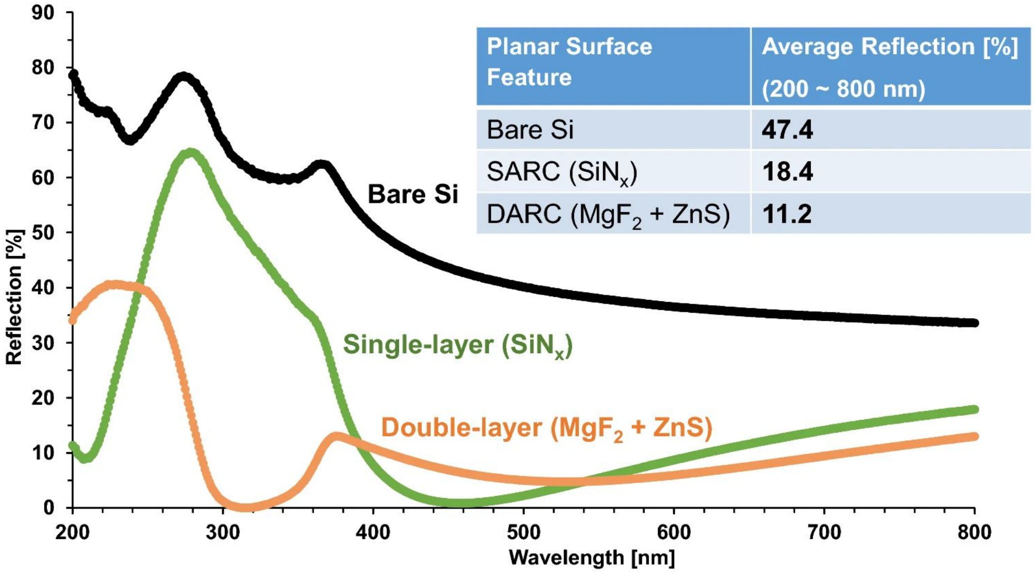

Planar Surface Feature	Average Reflection [%] (200 ~ 800 nm)
Bare Si	**47.4**
SARC (SiN_x)	**18.4**
DARC (MgF_2 + ZnS)	**11.2**

ARC and texture for SiPMs

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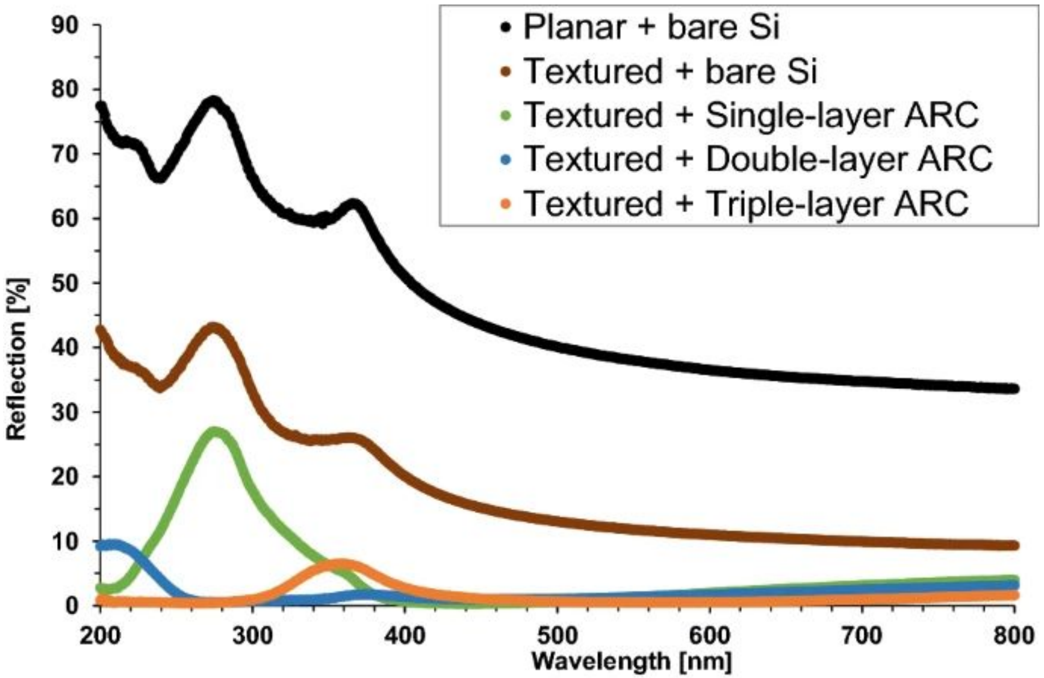
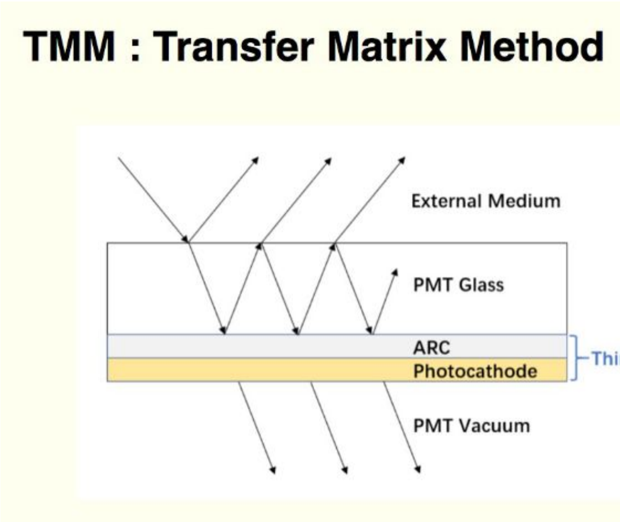


Thin film interference

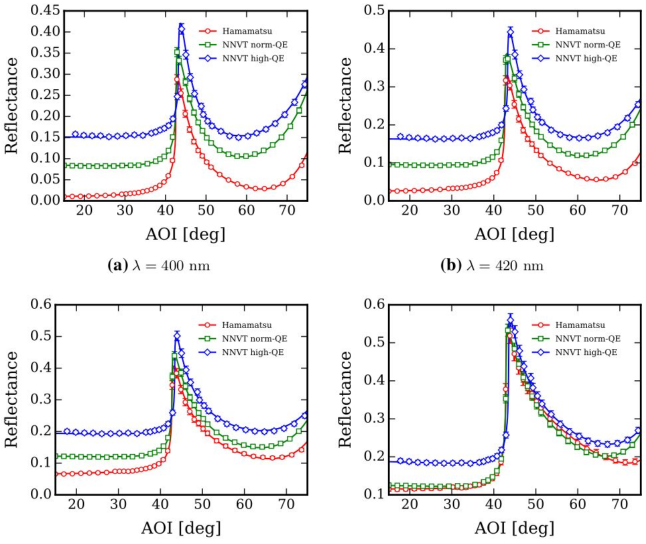
- If thin film thickness is ~ wavelength
- Multiple reflections -> interference
- Some wavelengths are amplified, some diminished
- Even without ARC we get interference
- Transfer matrix method:
  - analytically solve transmission and reflectivity



Angle of incidence

- Incoming angle of photon matters!
- Measurements with HRPPD?

[4] https://link.springer.com/article/10.1140/epjc/s10052-022-10288-y



(a) $\lambda = 400$ nm **(b)** $\lambda = 420$ nm **(c)** $\lambda = 450$ nm **(d)** $\lambda = 500$ nm

Thin film interference -> How to model?

- Wang et al, A new optical model for photomultiplier tubes, The European Physical Journal C, 2022 [4]
- Geant4 can handle a single thin layer by default
- JUNO folks implemented TMM for N layers in C++ for Geant4, CPU and GPU [5]

[4] https://link.springer.com/article/10.1140/epjc/s10052-022-10288-y

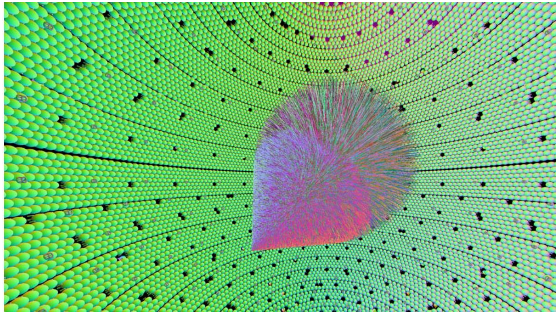
[5] https://raw.githubusercontent.com/simoncblyth/customgeant4/refs/heads/main/C4MultiLayrStack.h

How to make Geant4 simulations faster?

- Let’s use GPUs!
- Many projects building generic MC sim. on GPUs for years
    - Very hard
- Low hanging fruit:
    - GPU for optical photon simulation only
- Main tasks:
    - Convert detector geometry into GPU compatible one
    - Implement all the optical physics on GPU
        - Rayleigh scattering, Fresnel reflection, polarization…
    - Transfer optical photon data to GPU
    - Perform ray-tracing
    - Return results from GPU and integrate with other SW

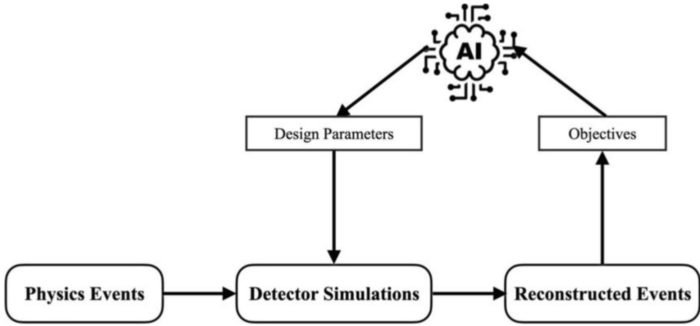
Plan

- Investigating two frameworks to simulate optical photons:
  - Opticks (JUNO, LHCb)
  - Mitsuba (LHCb)
- Opticks is a proven framework for JUNO experiment
- pfRICH geometry could not be plotted in G4
  - Bug in G4, did a workaround, it works now
- Tried loading in pfRICH geometry into Opticks, does not work yet -> Need to implement some basic volumes
- Next months we expect to run both Geant4 and Opticks simulation, benchmarking for speed-up



Why make Geant4 faster?

- Simulating Cerenkov photons on GPU will yield 10-100x faster detector simulations
- We can simulate a lot of detector geometries -> better detector optimization
- Provide more data to ML -> better detector optimization with ML
- AI-assisted detector design for the EIC (AID2E)



DOI:10.1007/s41781-024-00113-4

Geant4

```
## 2022-10-26 Daren Sawkey (materials-V11-00-17)
- G4MaterialPropertiesIndex, G4MaterialPropertiesTable, G4SurfaceProperty
 Parameters to specify opticalphoton transport through thin film coating.
 Contribution of Laurie Cappellugola et al, Aix Marseille U.
```

coated.mac:/opnovice2/surfaceConstProperty COATEDTHICKNESS 100e-6 # 100 nm

void AddCoatedDielectricRefraction()

https://www.sciencedirect.com/science/article/pii/S0168900209022037#fig4

```
fBoundaryProcs[CoatedDielectricRefraction]
```