Trapping light for particle detection: the X-ARAPUCA technology

Laboratório de Instrumentação e Física Experimental de Partículas - LIP
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DEEP UNDERGROUND NEUTRINO EXPERIMENT

Unifal MG

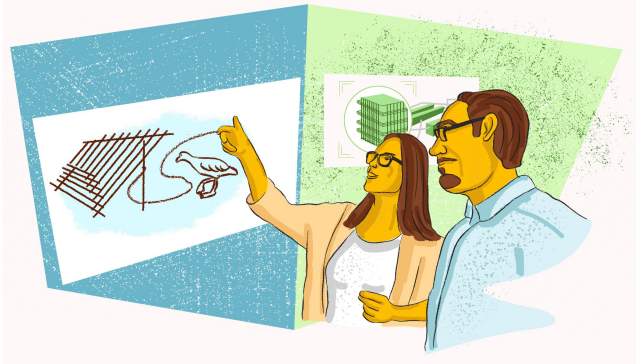
INSTITUTO DE CIÊNCIA E TECNOLOGIA

What is an arapuca?

- The word comes from the Guaraní language and means "bird buster", referring to a classical trap build by the Brazilian natives to catch small animals.
- Despite its rudimentary look, it is a clever and efficient device.
- The basic principle is: "bird goes in and can't get out" (as all traps should do)

What is the ARAPUCA?

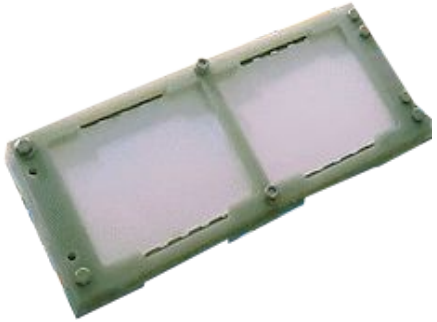
- The ARAPUCA is a photon detection device which works by enhancing a commercially available silicon photomultiplier (SiPM).
- In this case, "enhancing" means increasing the collection area and re-tuning its wavelength sensibility.
- The basic principle is: "photon goes in and can't get out" (and that's the analogy).



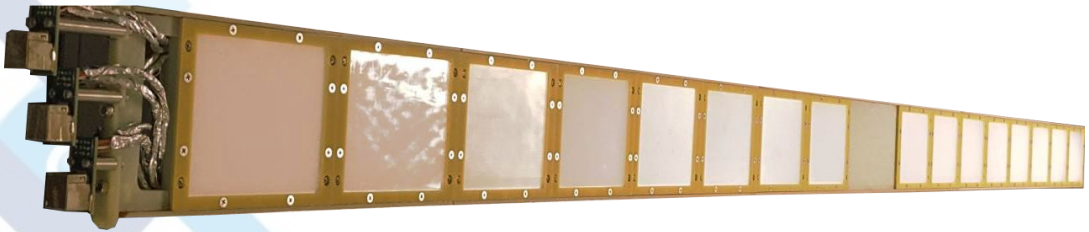
Ana Amélia Machado and Ettore Segreto

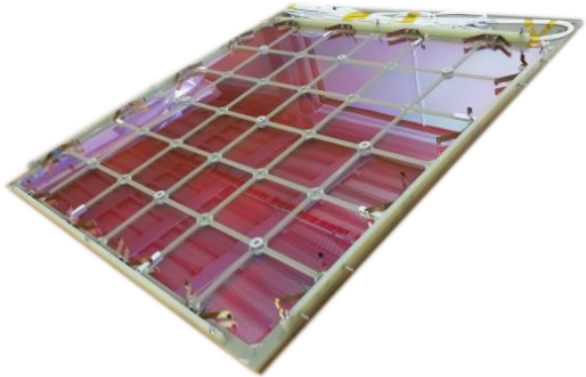
"Let there be Light Traps" by Lauren Biron
Symmetry Magazine, 2019
www.symmetrymagazine.org/article/arapuca-let-there-be-light-traps

The ARAPUCA Family of devices

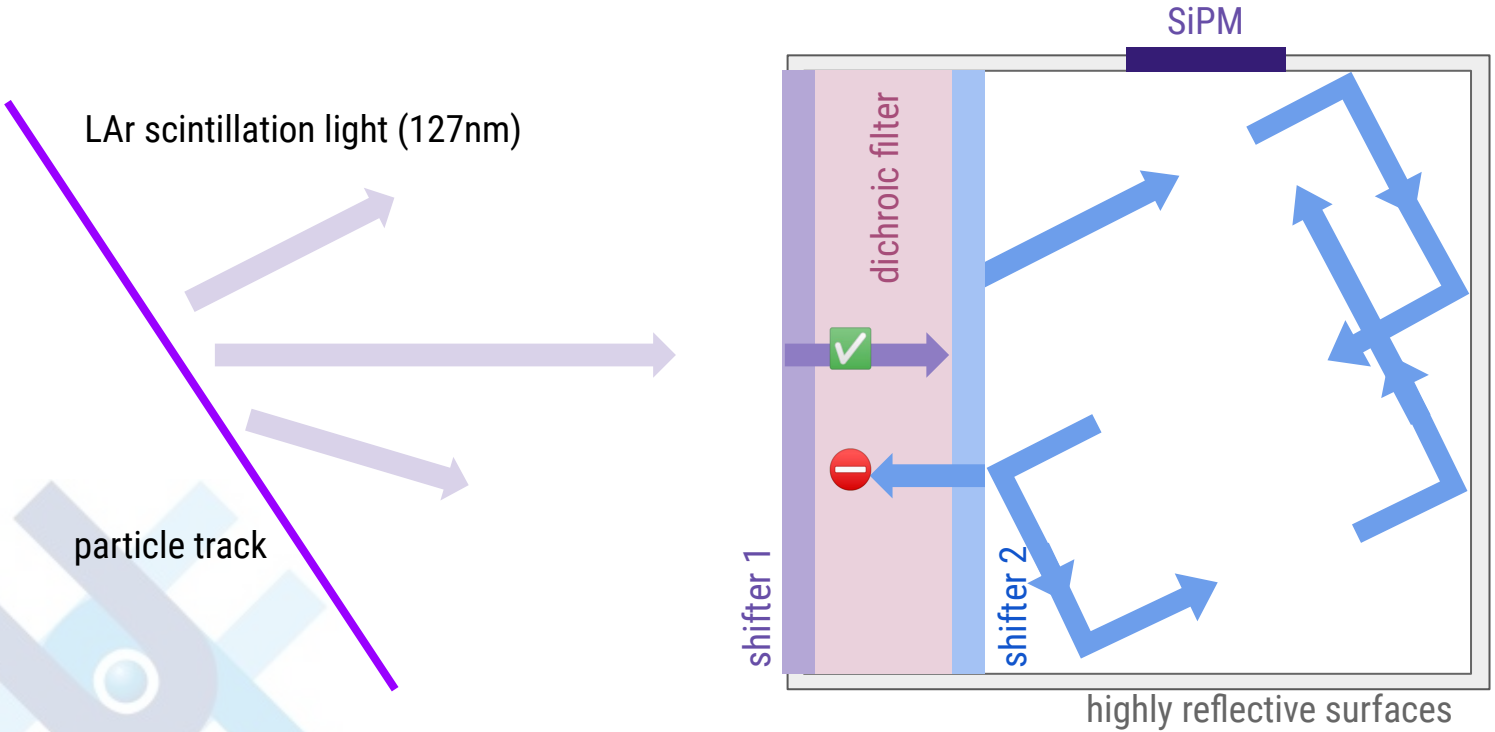


- It comes in different forms, but always with the same characteristic "mosaic" look, due a limitation in the filters manufacturing.
- Cover area goes from tens of cm² up to m².
- These are actually X-ARAPUCAs, which are the second generation (I will explain the difference in a moment).

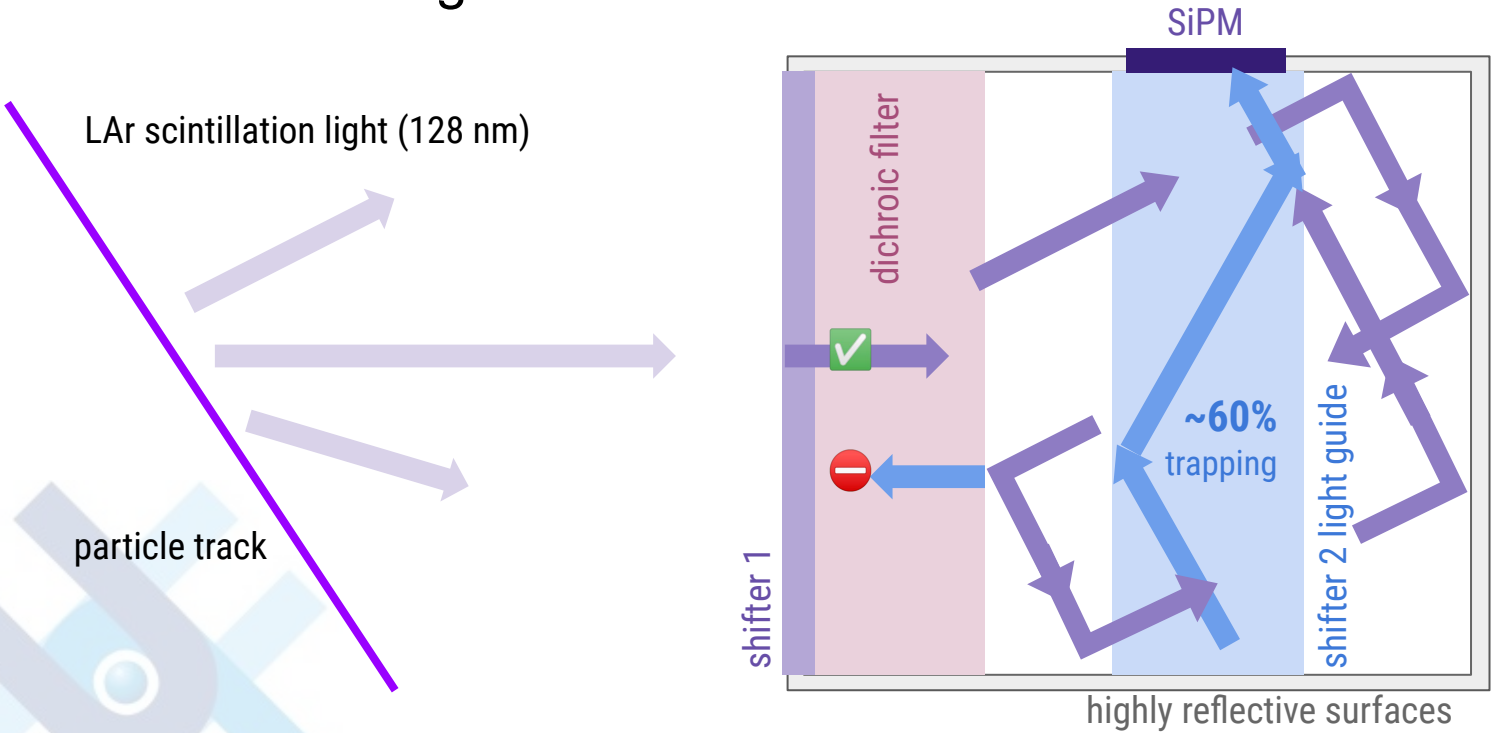




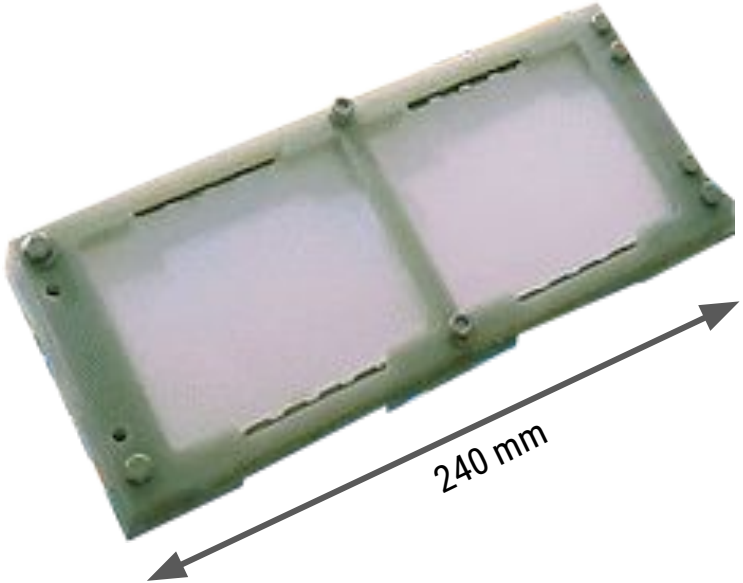
How does it work?



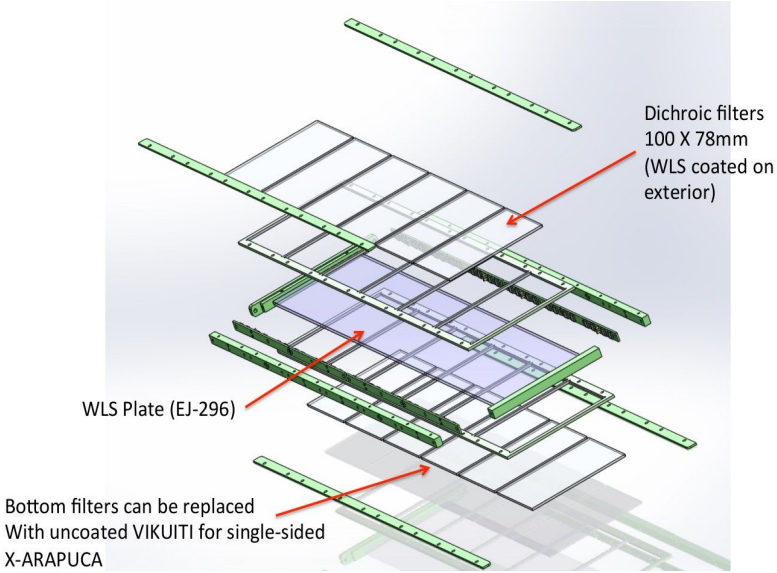
X-ARAPUCA design

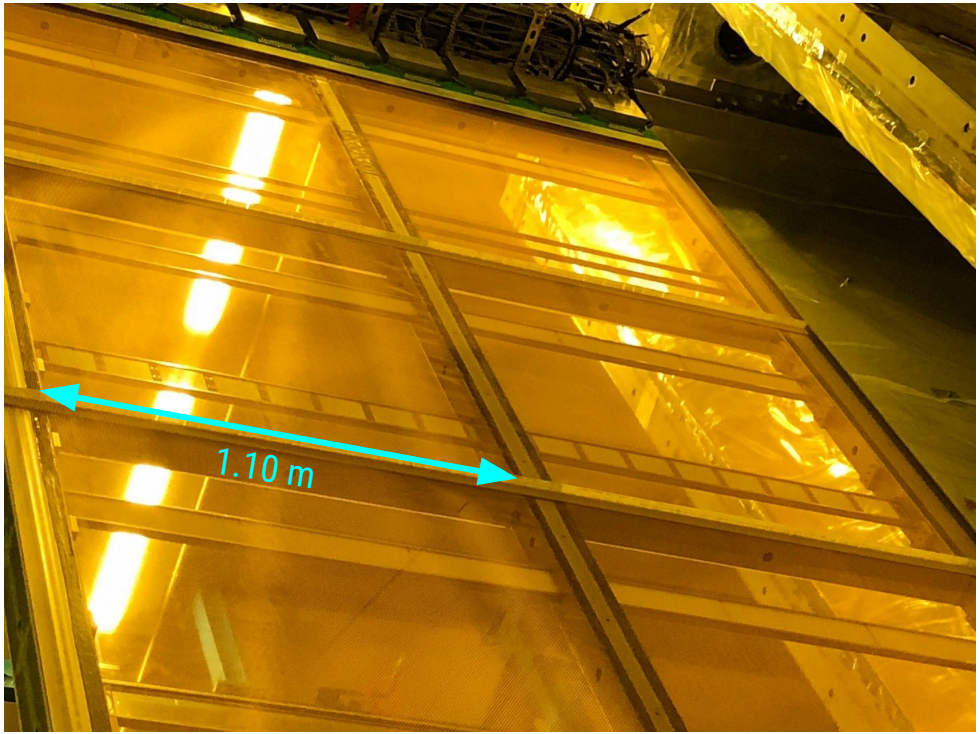


Dualcell Model (SBND)



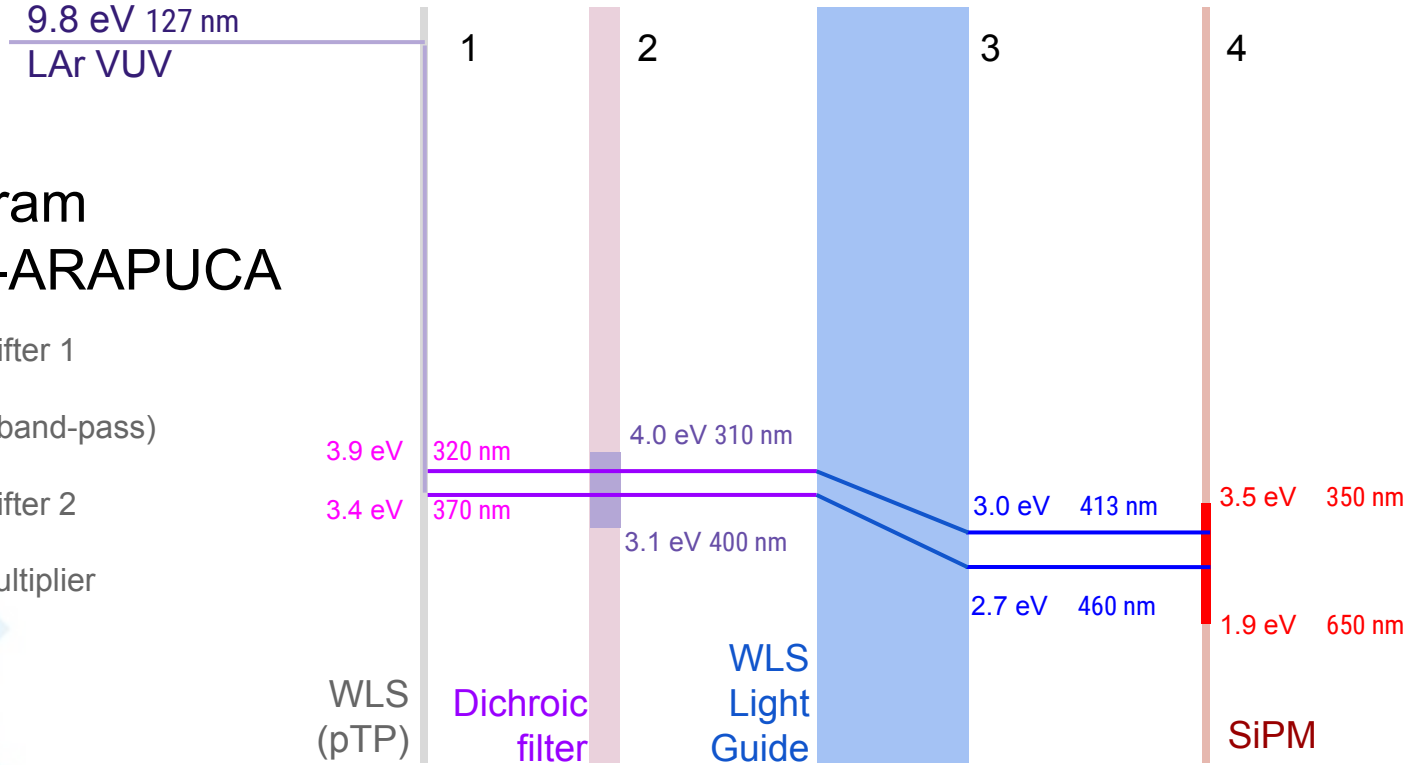
Supercell Model (DUNE)



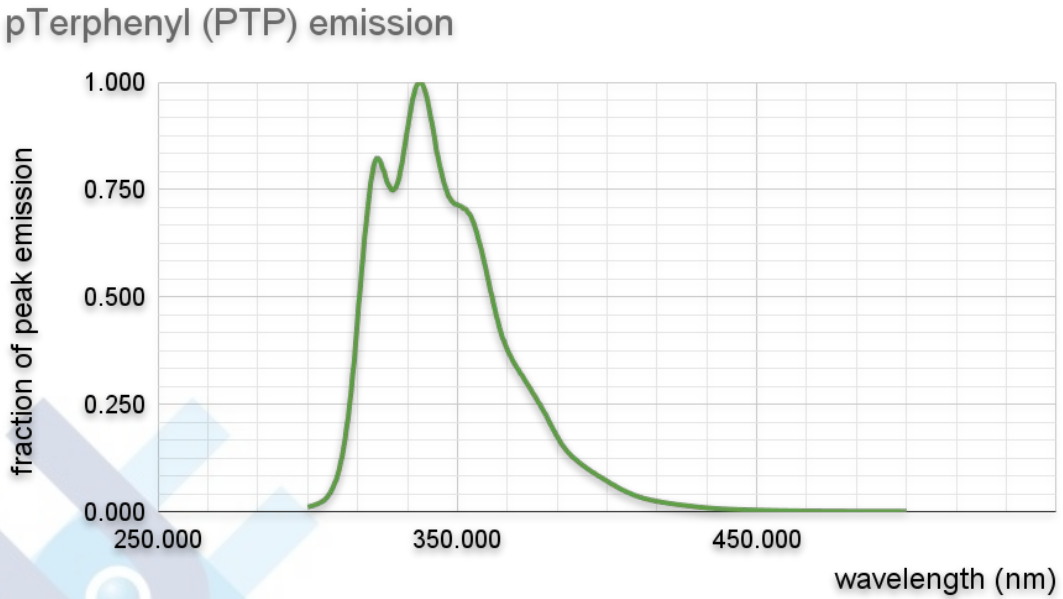


Energy Diagram
X-ARAPUCA

1. Wavelength Shifter 1
2. Dichroic Filter (band-pass)
3. Wavelength Shifter 2
4. Silicon Photomultiplier

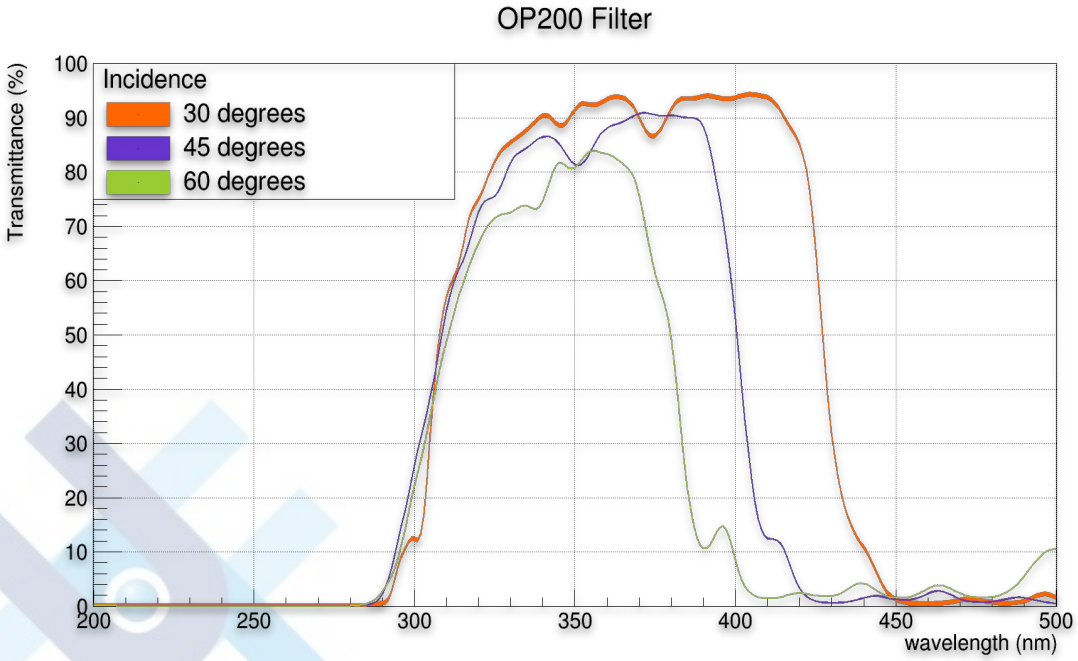


pTerphenil (pTP) - wavelength shifter 1



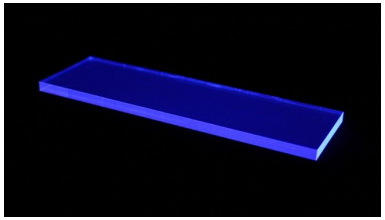
- Converts 128 nm light from LAr to its spectrum ~320 to 370 nm.
- Layer is designed to be ~100% absorbent.
- Emission is isotropic, so only 50% of incoming light has a chance of going into the trap.

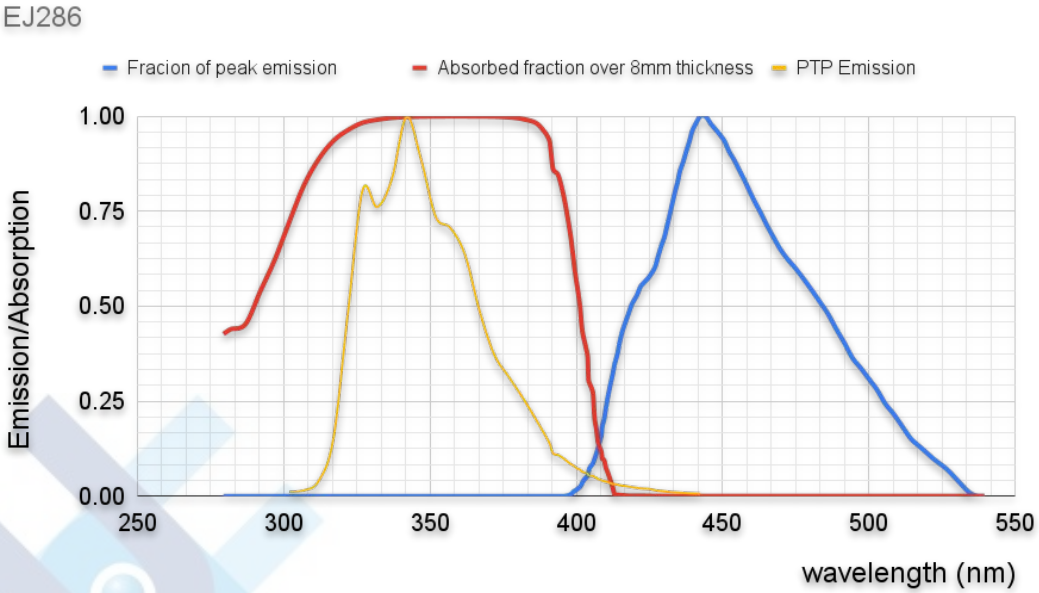
Dichroic filter - optical band-pass



- Interference layers deposited over a glass substrate.
- Designed to allow the pTP spectrum to pass with 45^{o} incidence.
- Average transmission over 80% for the pTP spectrum.

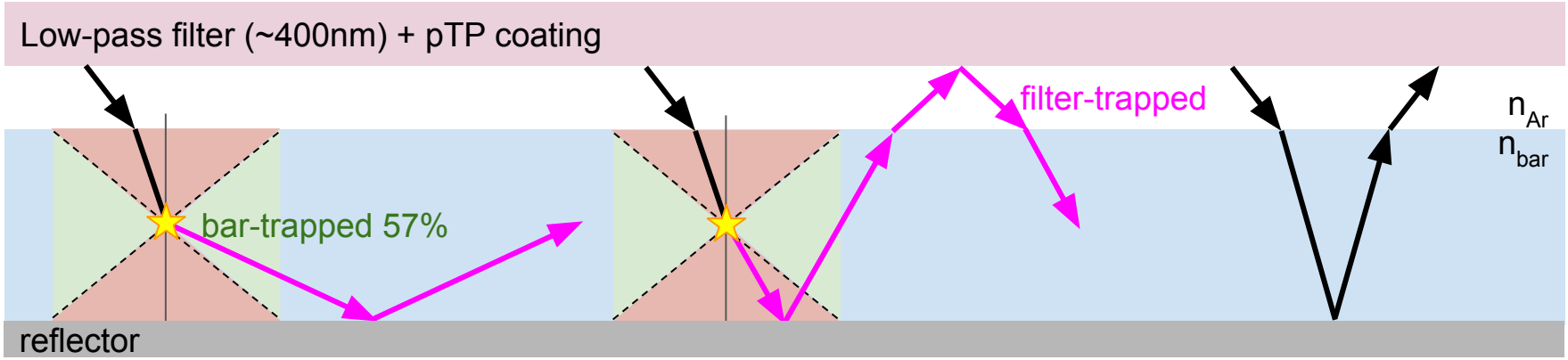
EJ286 - wavelength shifter 2





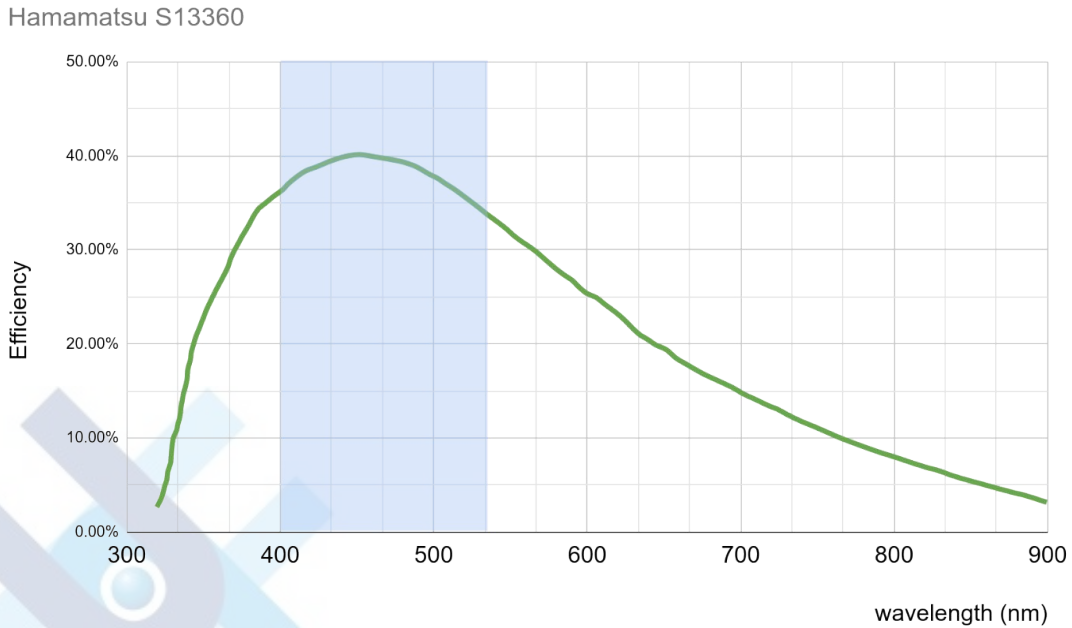
- Light-guide doped with commercial shifter (ELJEN)
- Concentration of dopant enough to make it 100% absorbent over the pTP spectrum.
- Emission is isotropic. Part of the converted light is trapped inside the guide, leading to the SiPM (see next slide).

Conversion + guiding effect



- Due to the combination of refraction indices, ~57% of the converted light is guided.
- The remaining 43% is trapped between the filter and the Vikuiti reflector at the bottom.

Hamamatsu S13360 (SiPM) - Silicon Photomultiplier

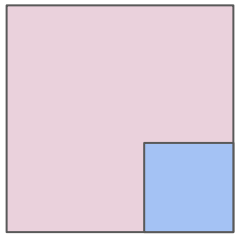


- Most sensible to the EJ286 emission spectrum.
- Can be operated at overvoltages, driving the average efficiency to ~50%.
- Compatible with cryogenic environments.

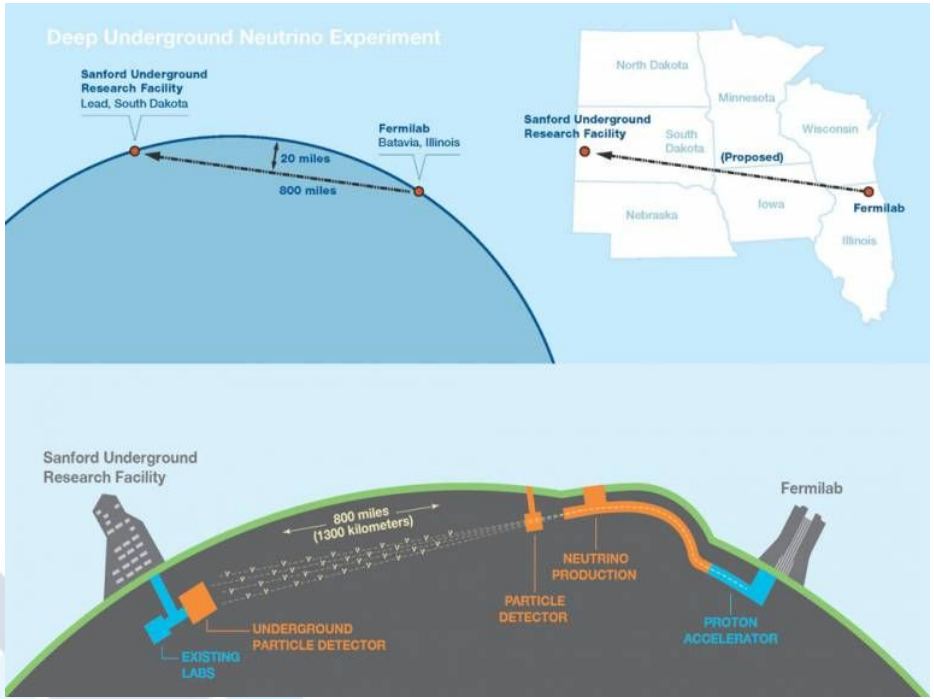
X-ARAPUCA Numbers

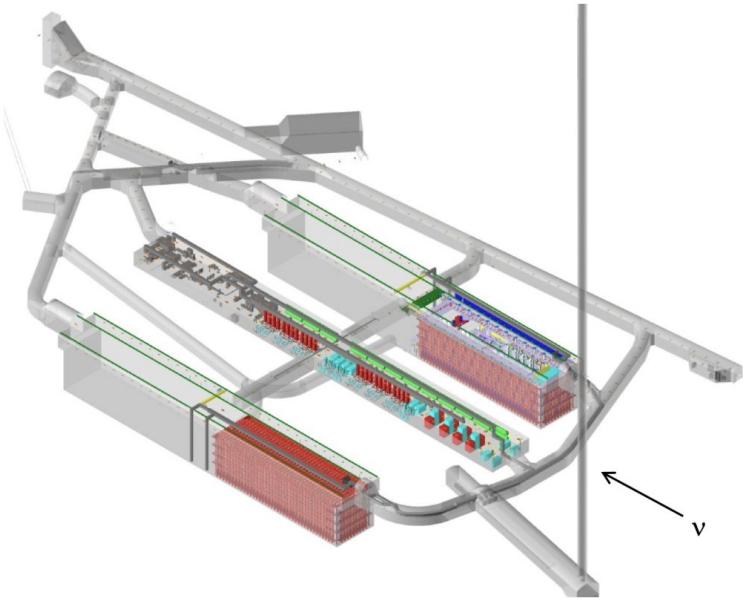
- Maximum theoretical efficiency: 50% x 80% x 57% x 50% **< 12%**
- Real efficiency measured to be between **2 and 3%**
- SiPM area = 48 x 6mm² = 288 mm² | Collection area = 6 x 7800 mm² = 46800 mm² →increase of **162 times**
- Even if we multiply by the efficiencies (we shouldn't but…) 288 x 50% = 144 mm², while 46800 x 2% = 936 mm²

a gain of 6.5 times of effective area

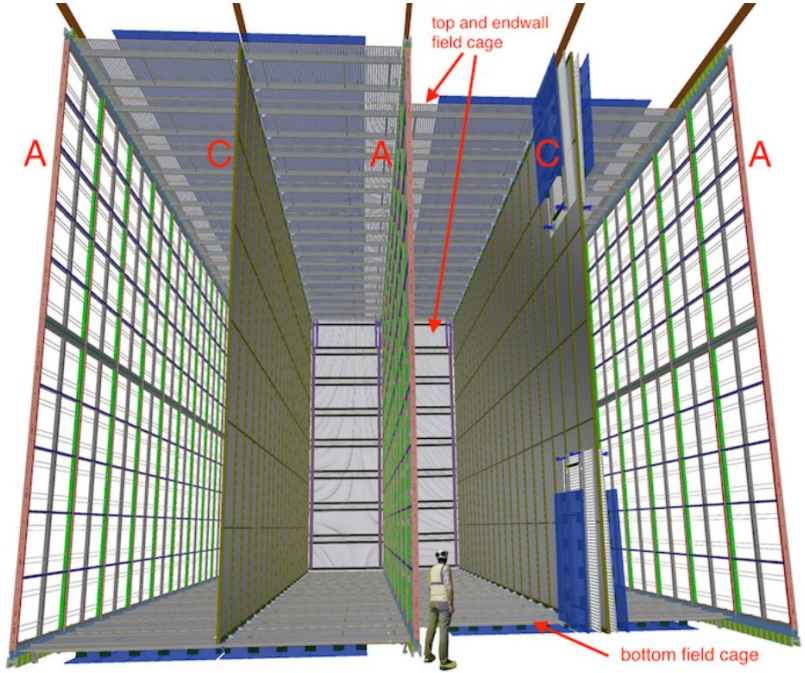


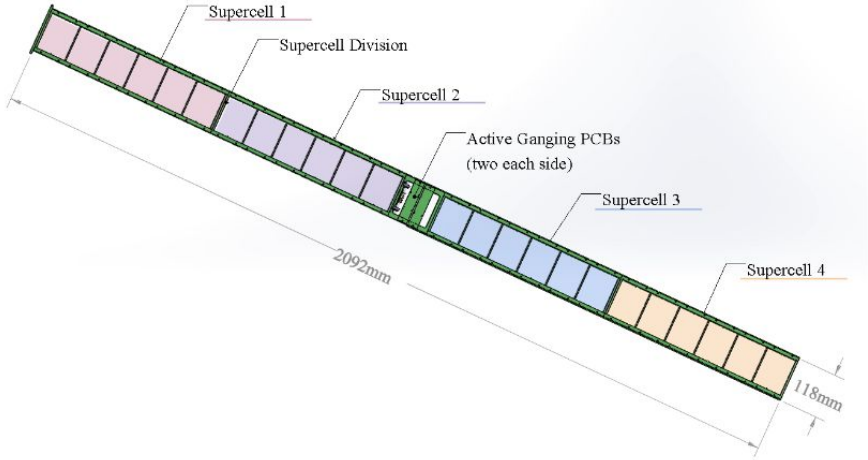
DUNE's Detectors

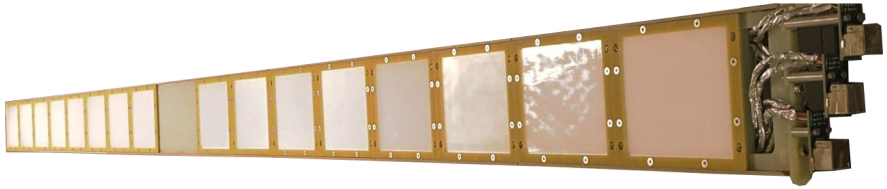




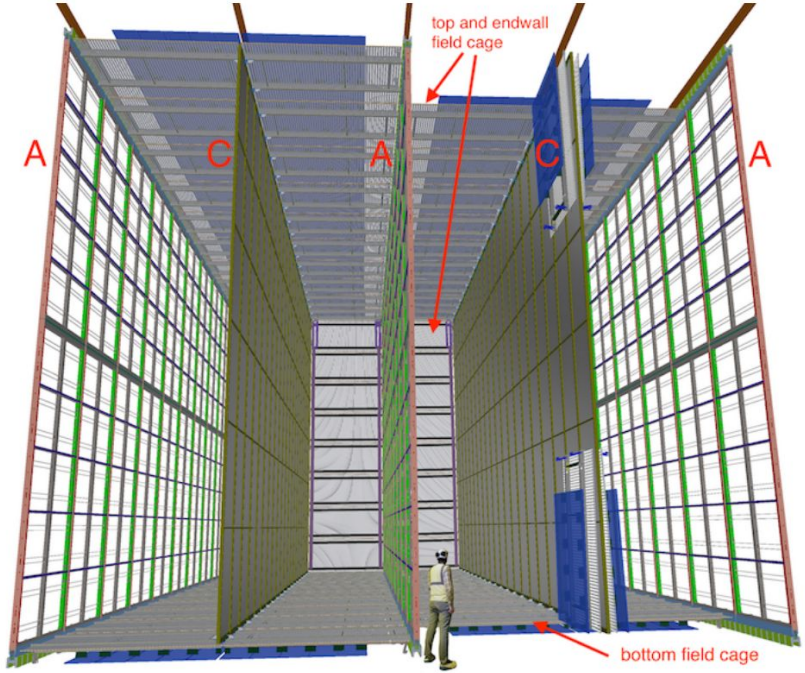
DUNE's Photon Detection System



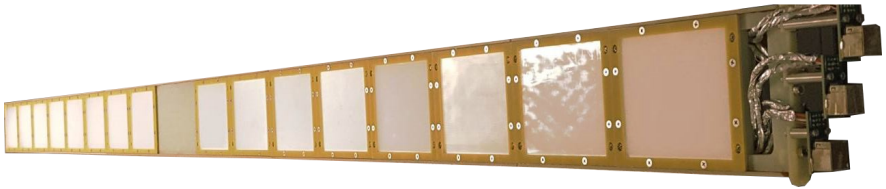




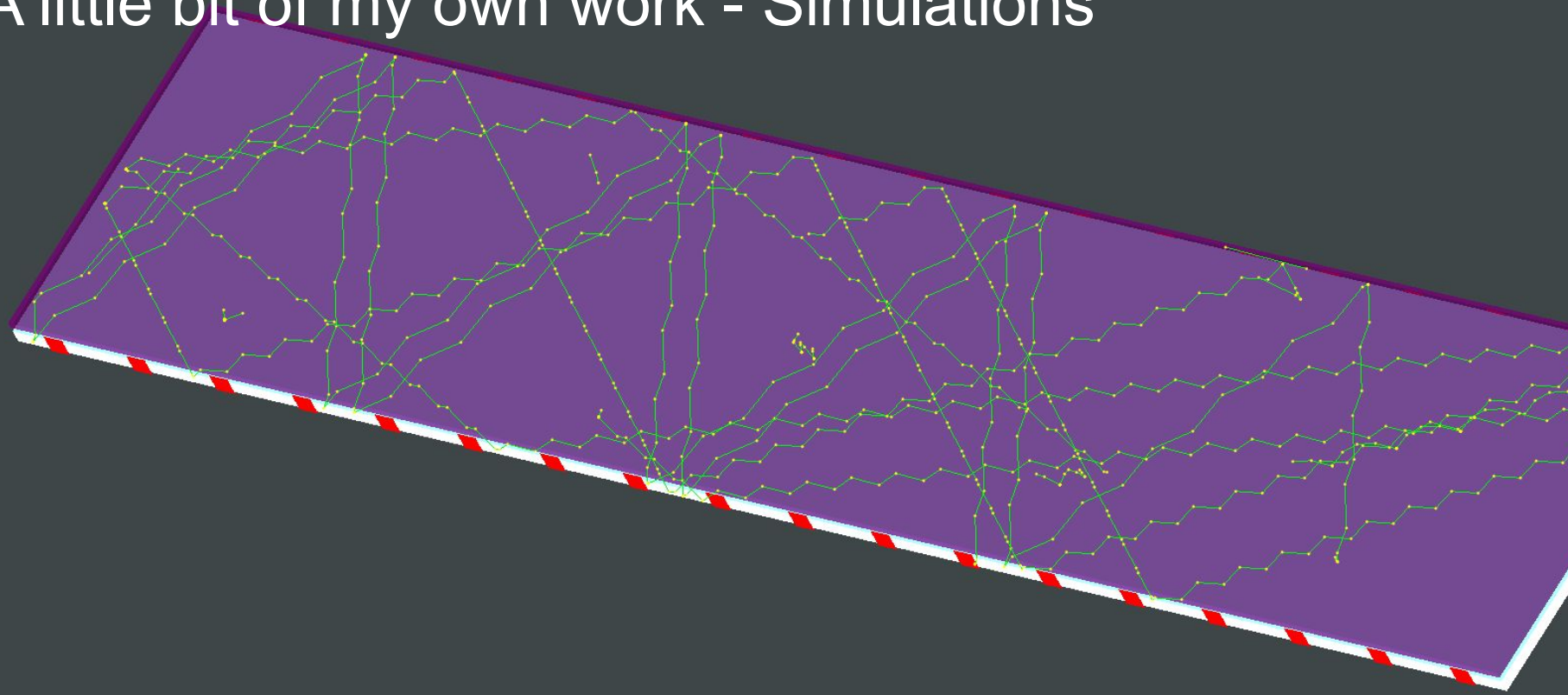
DUNE's Photon Detection System



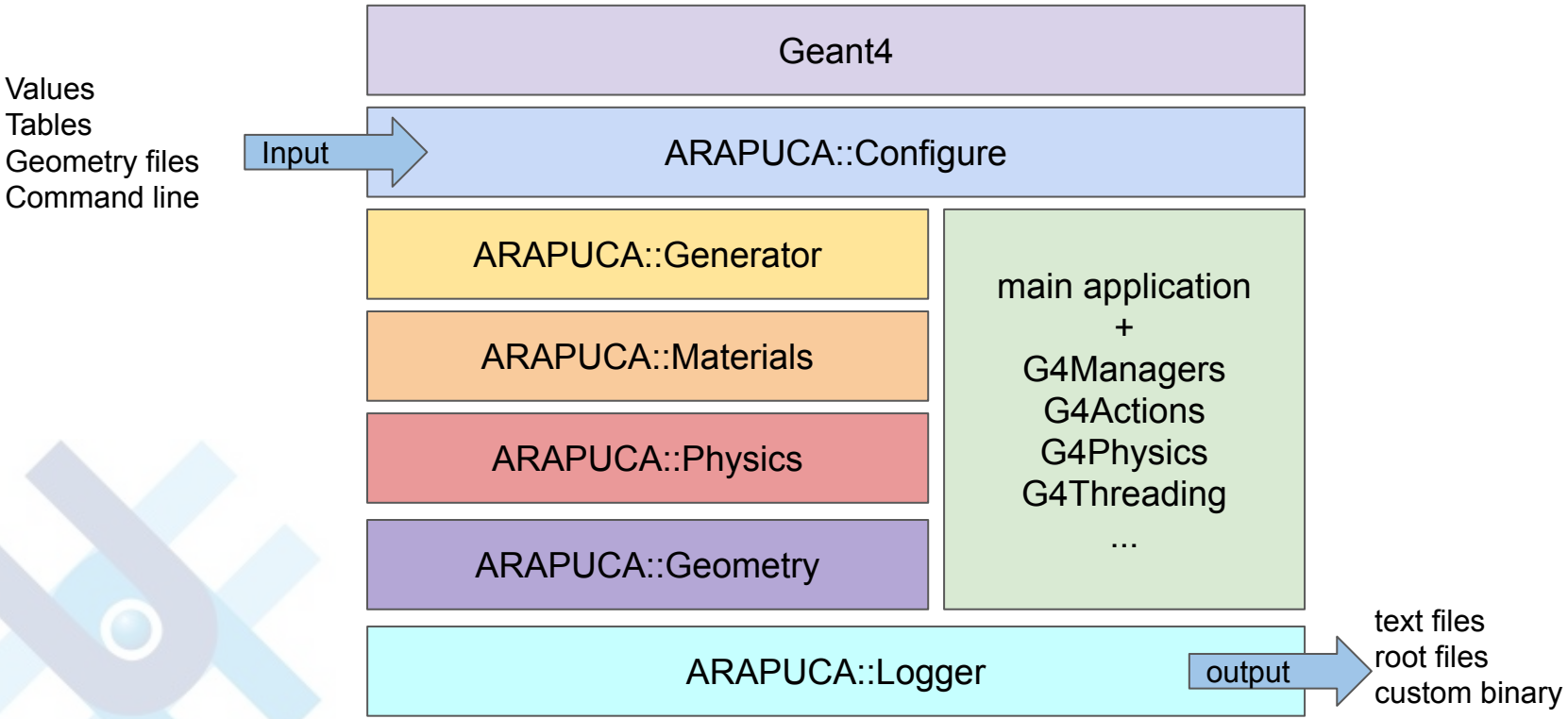
- 1500 Modules
- 6000 Supercells
- 36000 filters
- 288000 SiPMs



A little bit of my own work - Simulations

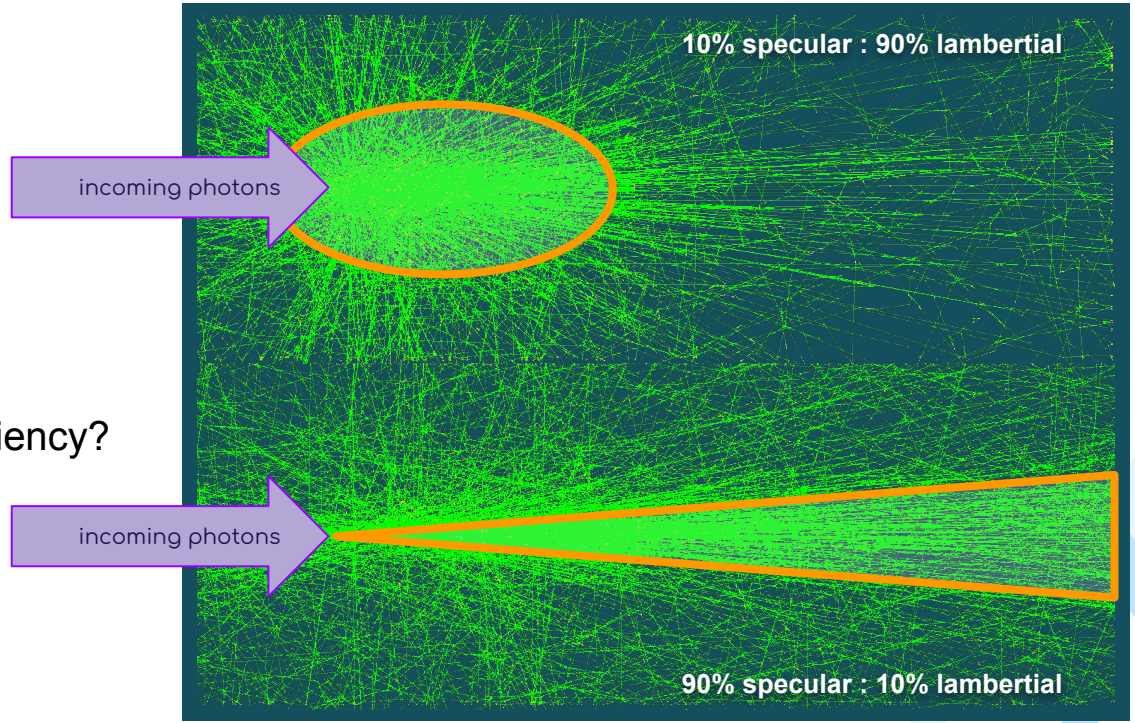


Software Architecture

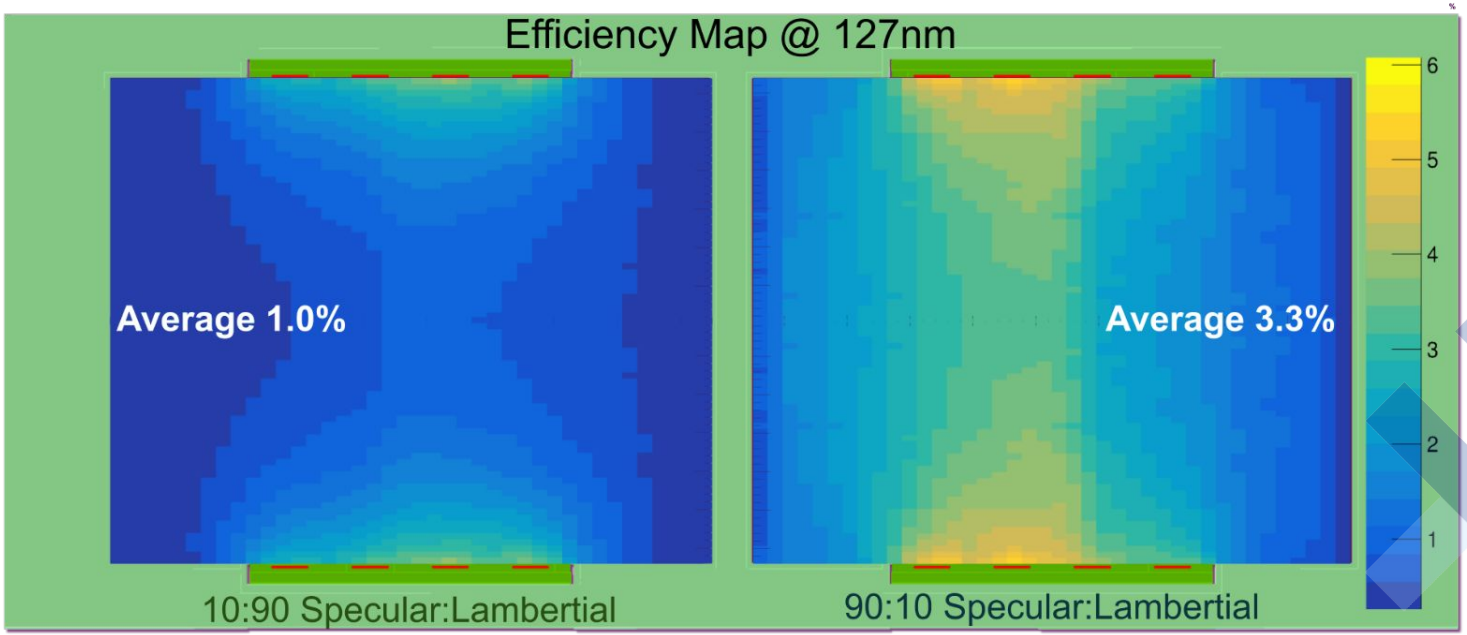


Simulation Studies - Light dispersion

- Lambertian vs. Specular
- How much does it affect the efficiency?



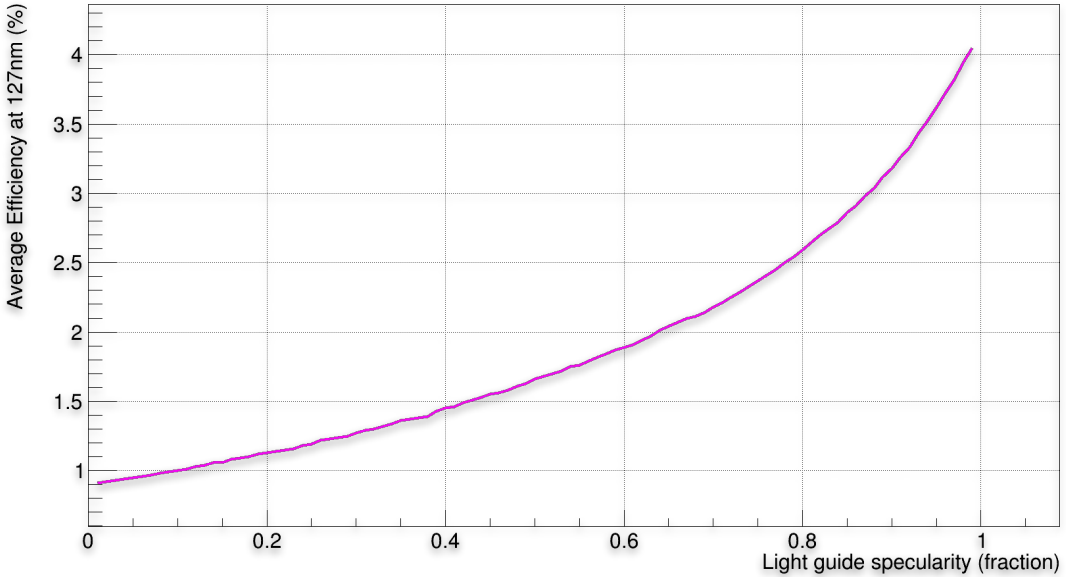
Simulation Studies - Light dispersion



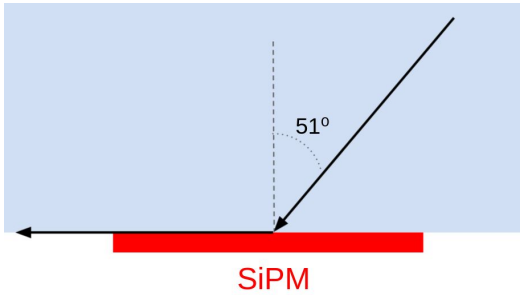
Simulation Studies - Light dispersion

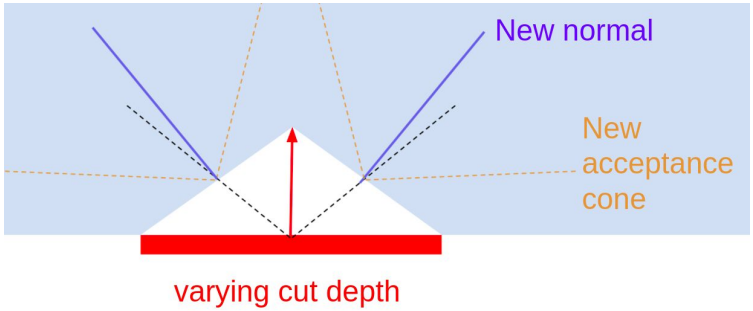
- Specularity inside the light guide seems to be around 0.8 and 0.9, given the current efficiency measurements.

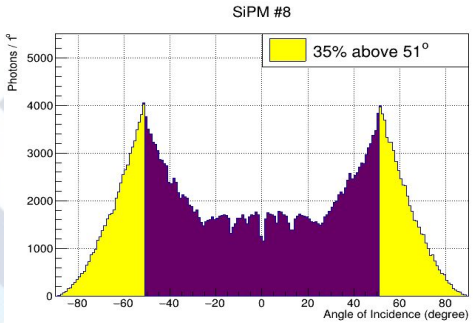
- A 10% variation of specularity in this range is not visible to the naked eye, but may explain some models being up to ±0.5% in efficiency.

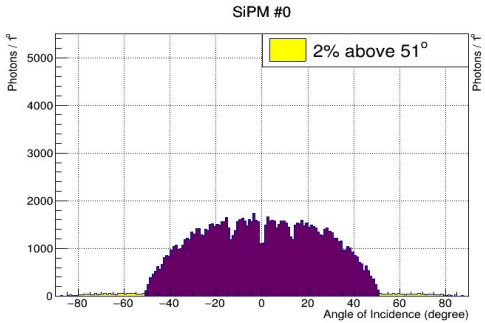


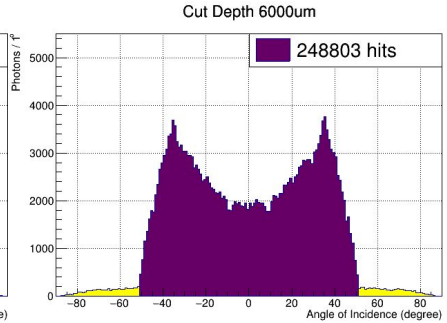
Simulation Studies - Untrapping







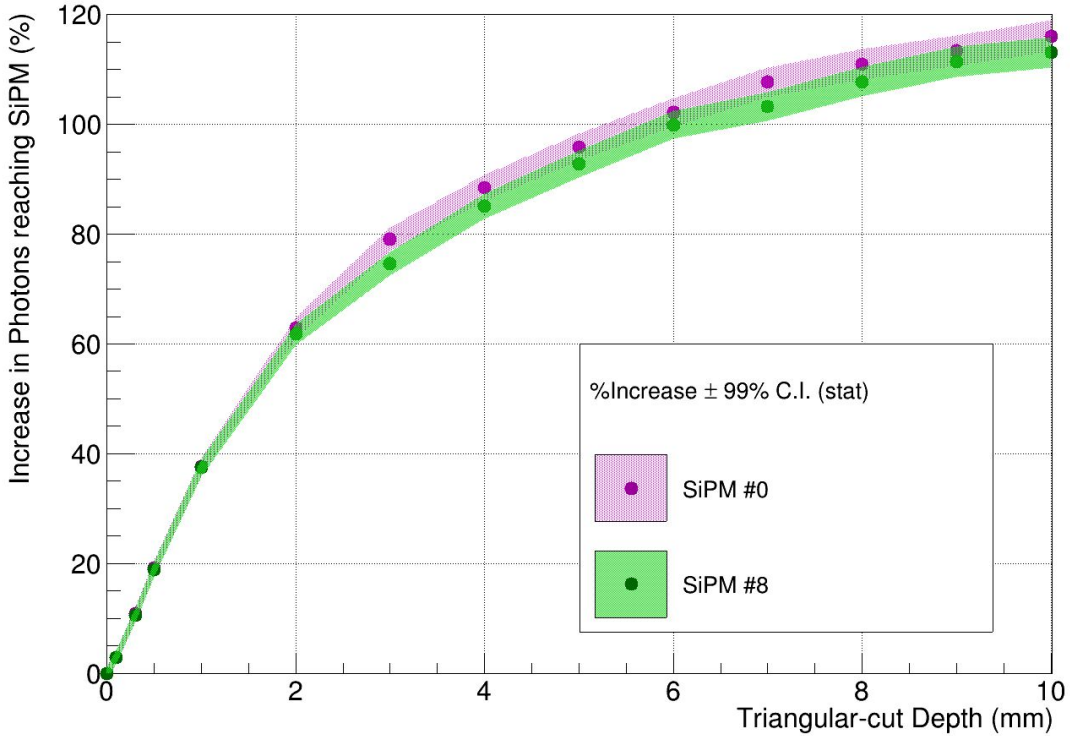




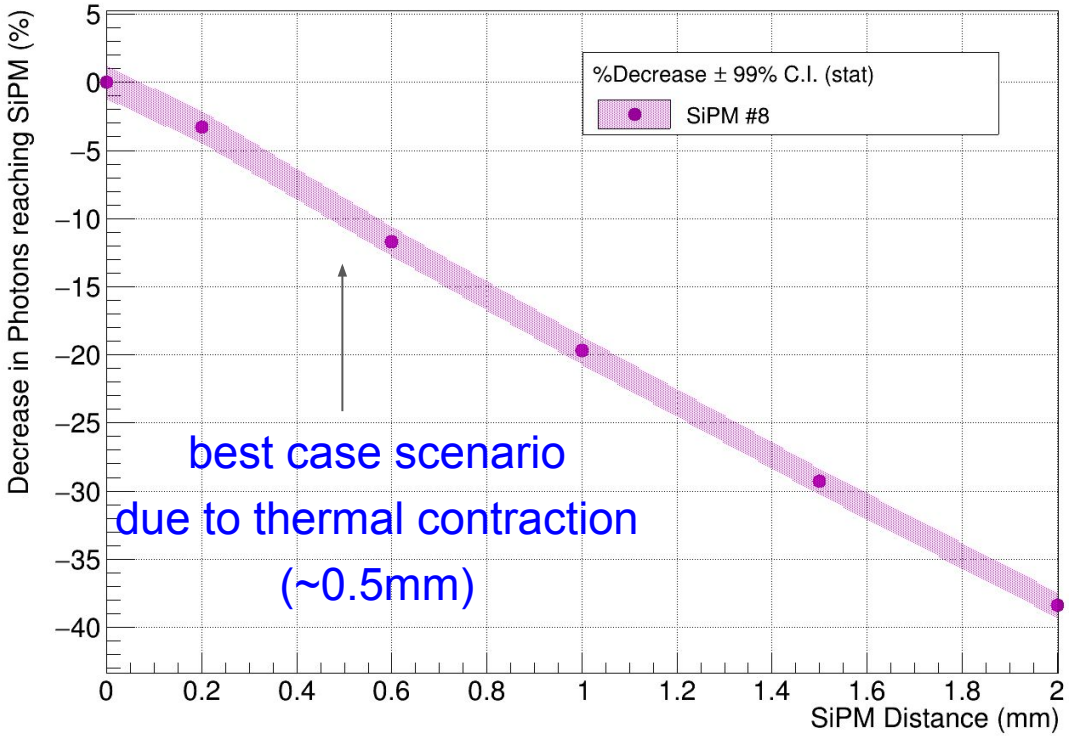
6mm deep cut

2x untrapped photons

Simulation Studies - Light dispersion



Simulation Studies - Thermal expansion



X-ARAPUCA Related publications

The X-ARAPUCA: an improvement of the ARAPUCA device

A.A. Machado[a,1] E. Segreto,[b] D. Warner,[c] A. Fauth,[b] B. Gelli,[b] R. Máximo,[b] A. Pissolatti[b] L. Paulucci[d] and F. Marinho[d]

10.1088/1748-0221/13/04/C04026

Enhancement of the X-Arapuca photon detection device for the DUNE experiment

C. Brizzolari,[a,b] S. Brovelli,[c,d] F. Bruni,[c,d] P. Carniti,[b,a] C. M. Cattadori,[b,a,1] A. Falcone,[a,b] C. Gotti,[b,a] A. Machado,[e] F. Meinardi,[c,d] G. Pessina,[b,a] E. Segreto,[e] H. V. Souza,[e,b] M. Spanu,[a,b] F. Terranova,[a,b] M. Torti[a,b]

10.1088/1748-0221/16/09/P09027

Simulating the X-ARAPUCA, DUNE's next generation light sensors

G. A. Valdiviesso* for the DUNE collaboration

10.22323/1.402.0249

Design, construction and operation of the ProtoDUNE-SP Liquid Argon TPC

The DUNE Collaboration

10.1088/1748-0221/17/01/P01005

Thank you.