# Review of Photodetector Technology:

Status and Future Goals

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Massachusetts Institute of Technology

**As was announced this morning, we are beginning a Basic Research Needs Study.**

**The detection of photons is ubiquitous in high energy physics from the Colliders to the CMB and everything in between.**

# Photomultiplier Tubes

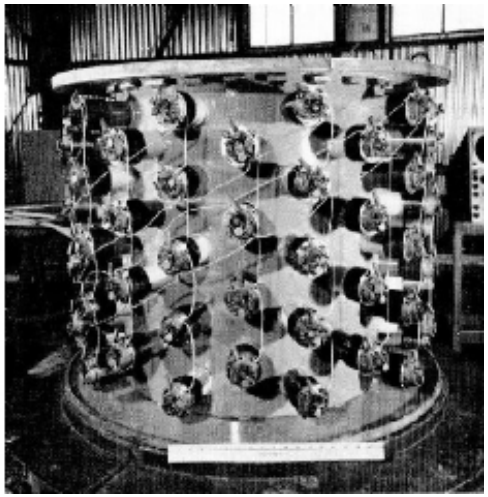
They have been the workhorse of particle detectors for more than fifty years!

www.hamamatsu.com

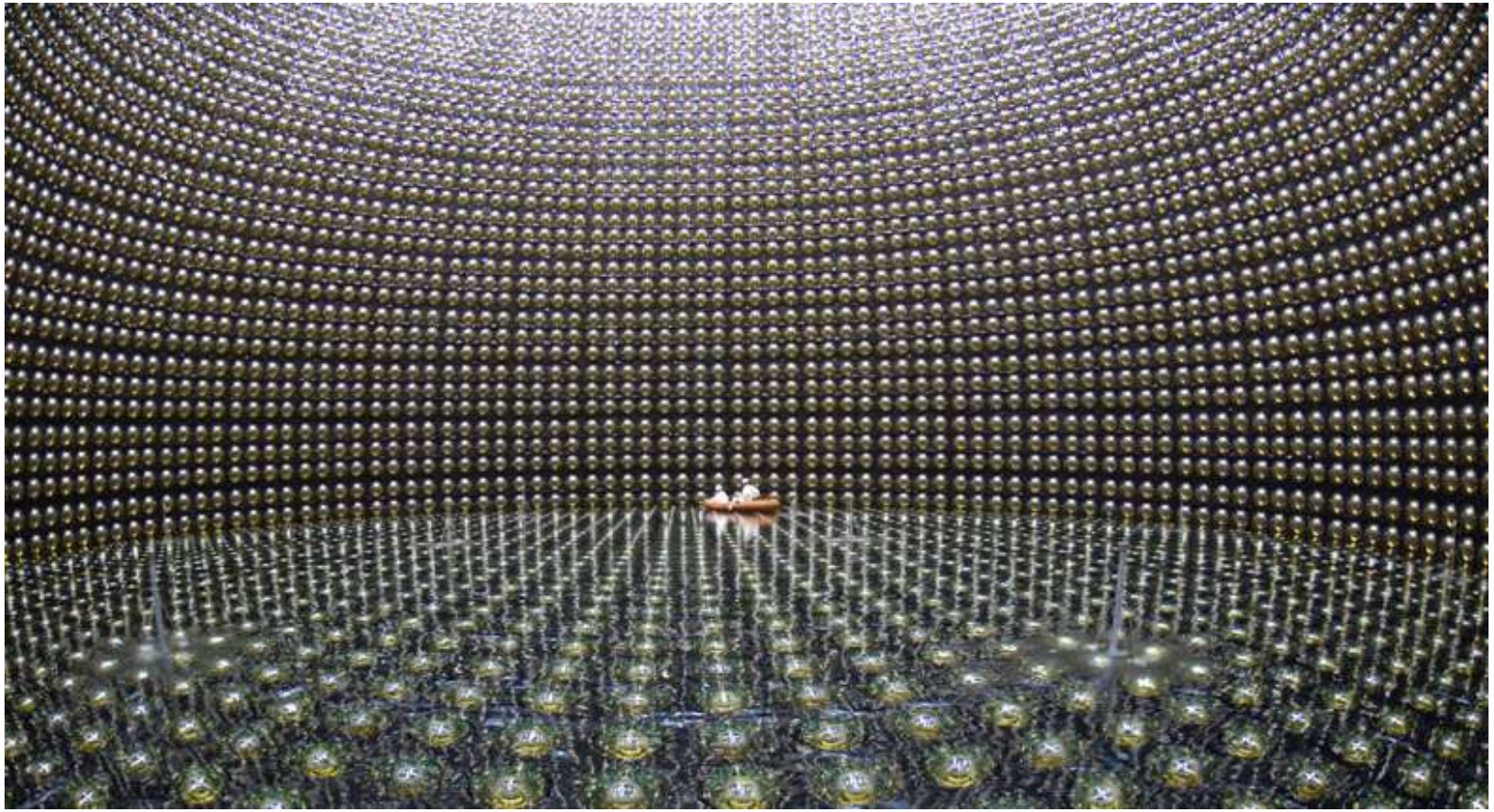
- Single photon sensitivity.
- Low dark rate.
- Robust.
- Versatile.

# **Poltergeist:**

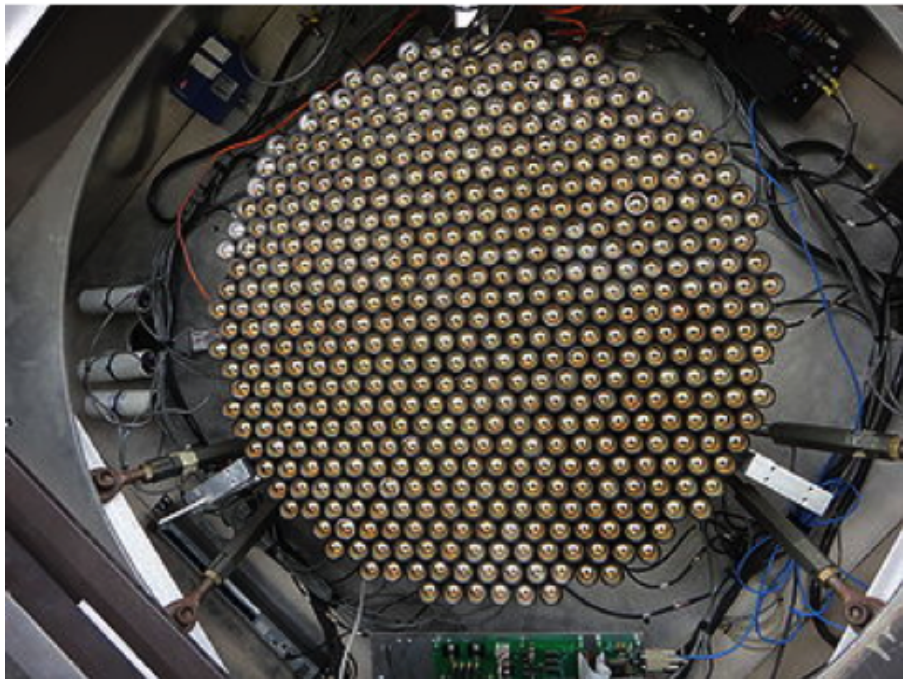
## Reines' & Cowan's Discovery of the neutrino



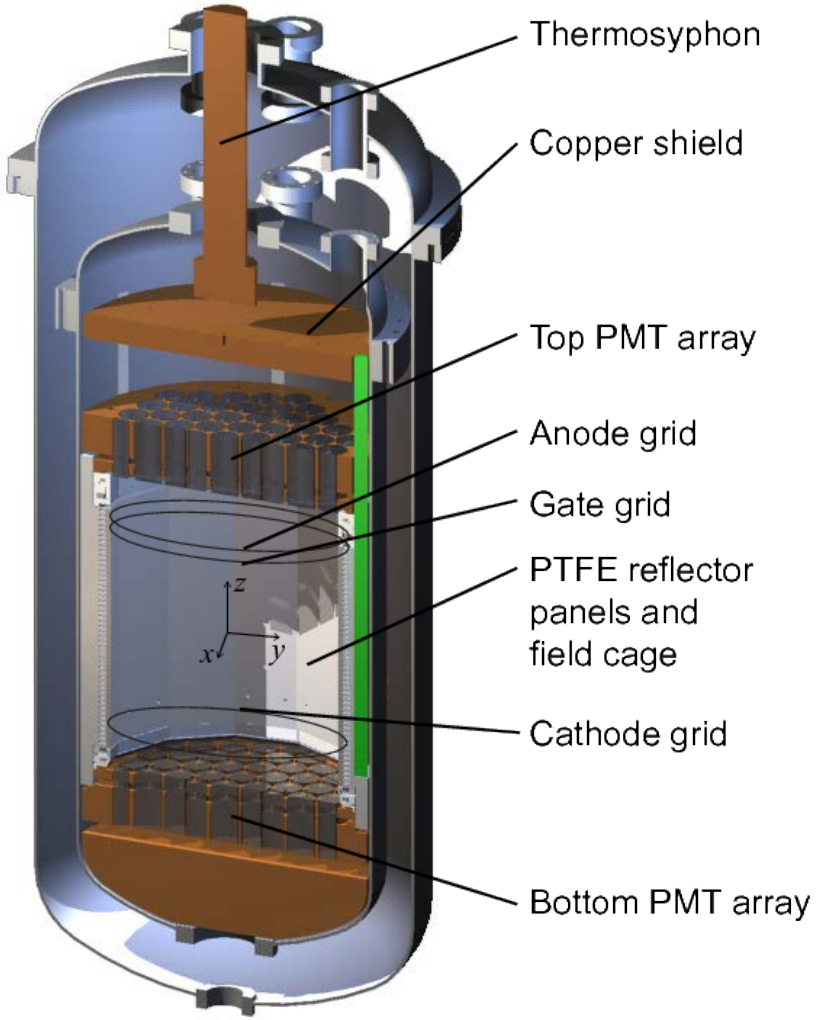
# Super Kamiokande

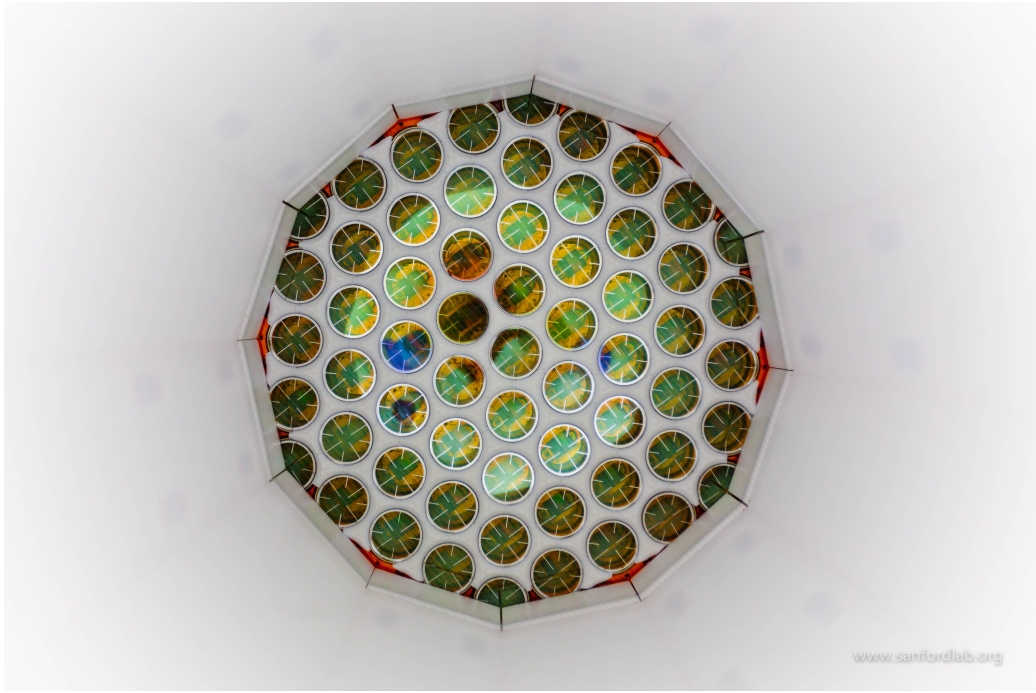


# VERITAS Gamma Ray Telescope

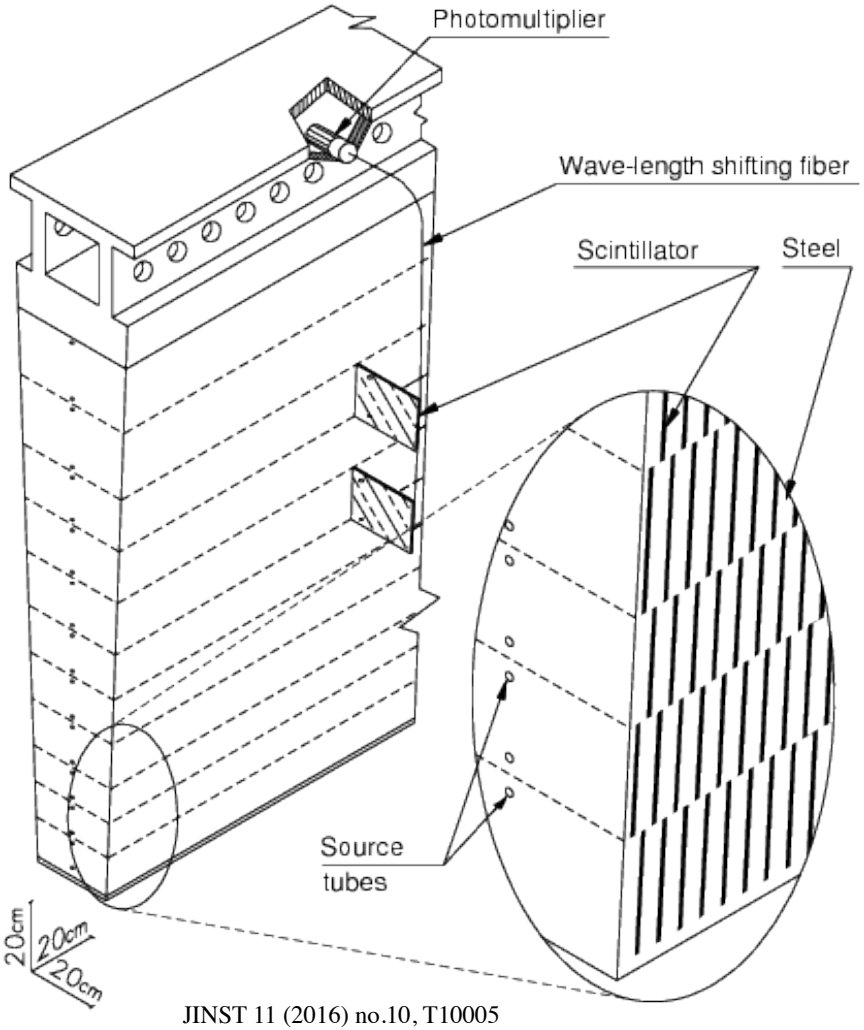


# LUX Dark Matter Search



# ATLAS Tile Calorimeter

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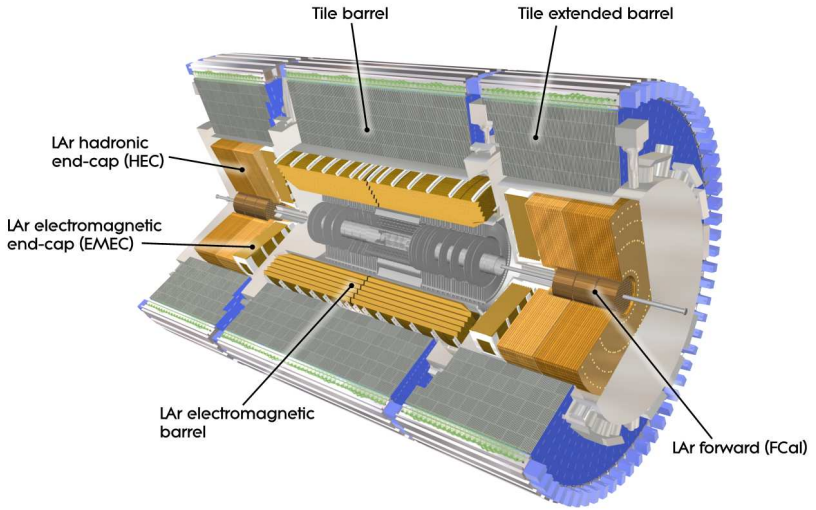
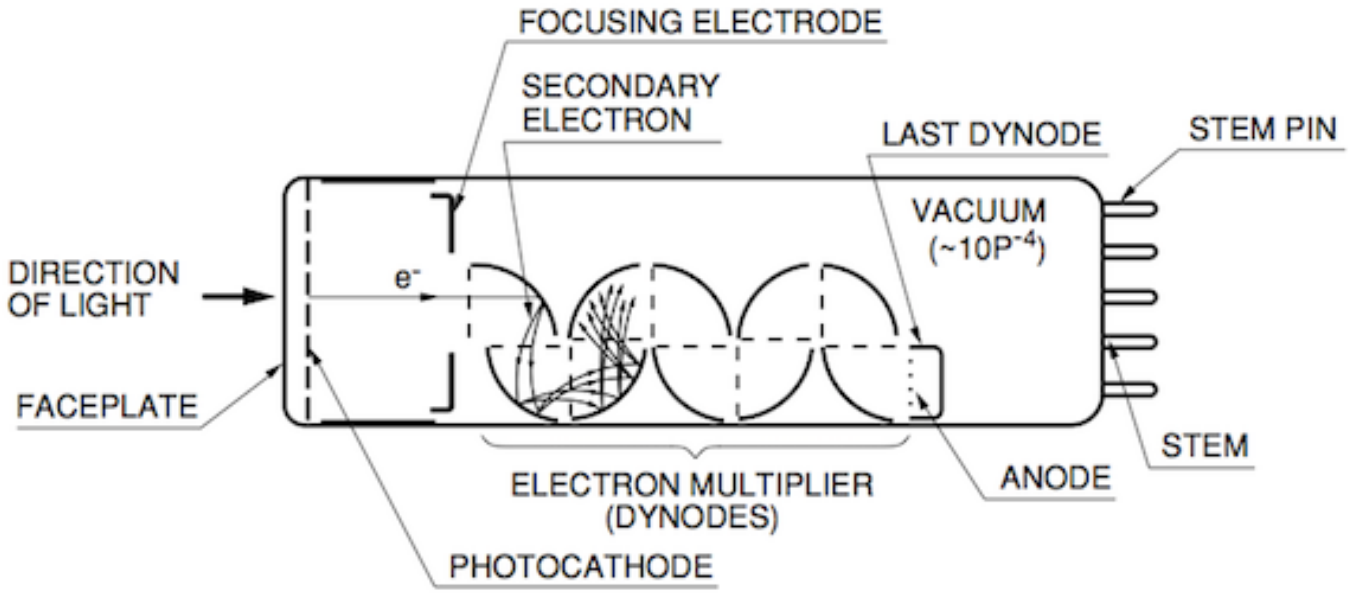



# What sort of photodetector advances does particle physics need?

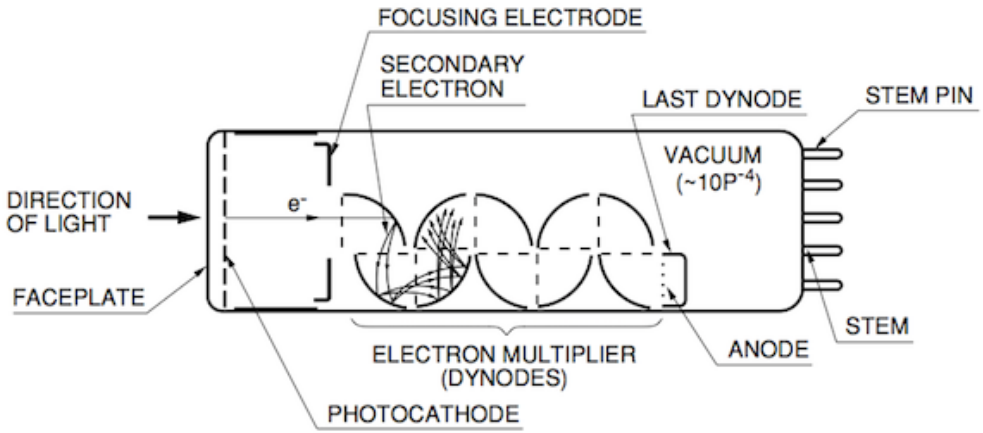
# How does a PMT work?




**https://www.hamamatsu.com/resources/pdf/etd/PMT_handbook_v3aE.pdf**

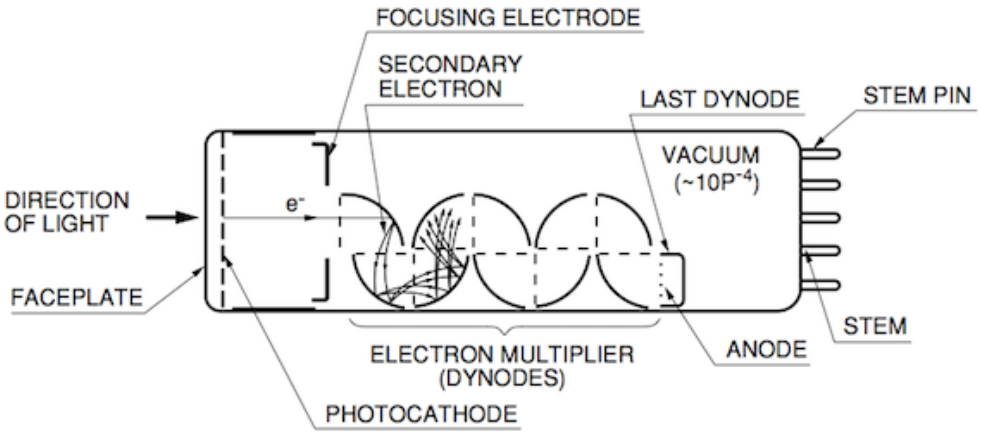
# What do we want?

- Cheaper
- Bigger
  - OR smaller
  - OR better spatial resolution.
- More sensitive photocathode
- Photocathodes sensitive at different wavelengths.
- Better timing ( <100ps)



# What do we want?

- Insensitive to magnetic fields
- Robust at high pressures
- Operate at cryogenic temperatures
- Low radioactivity



# Alternatives to PMTs

Microchannel Plates (MCP-PMTs) provide many advantages in timing and resistance to magnetic fields and can be made large.

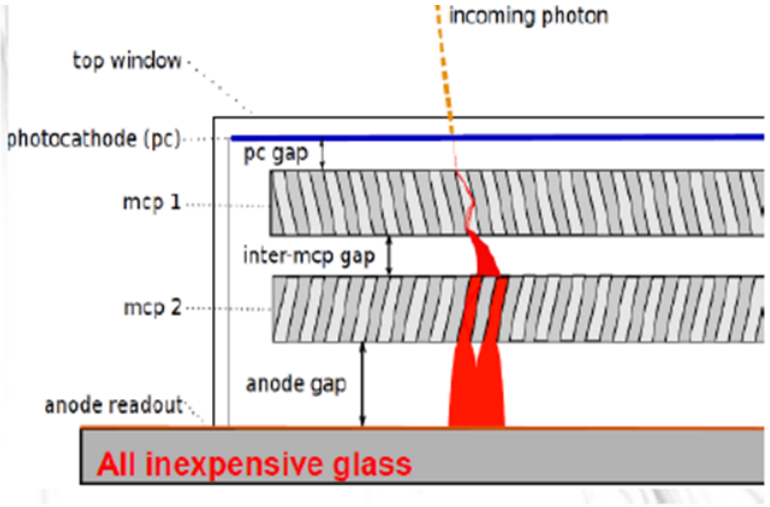
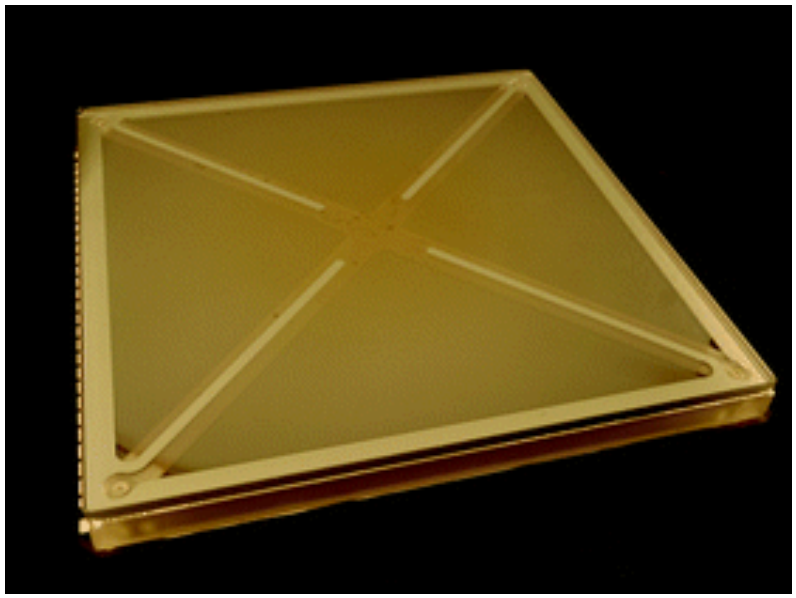


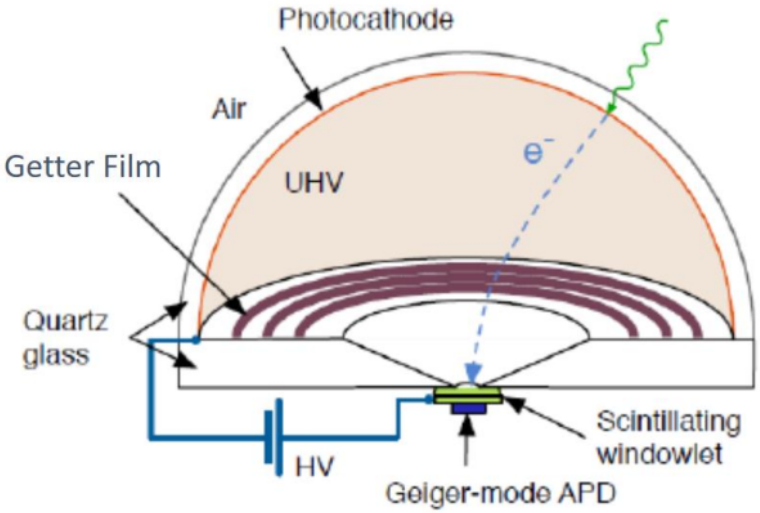

Illustration provided by Univ. of Chicago



- LAPPD is being commercialized by Incom Inc.
- 8″ Tiles are beginning to be produced regularly.
- Contact Incom Inc. to buy one of the first.

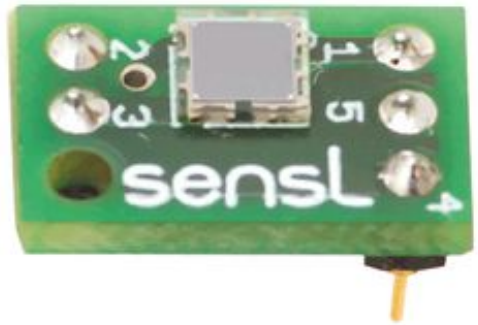
# Alternatives to PMTs

ABALONE Photodetector is working to reduce cost and improve robustness by eliminating glass/metal connections.

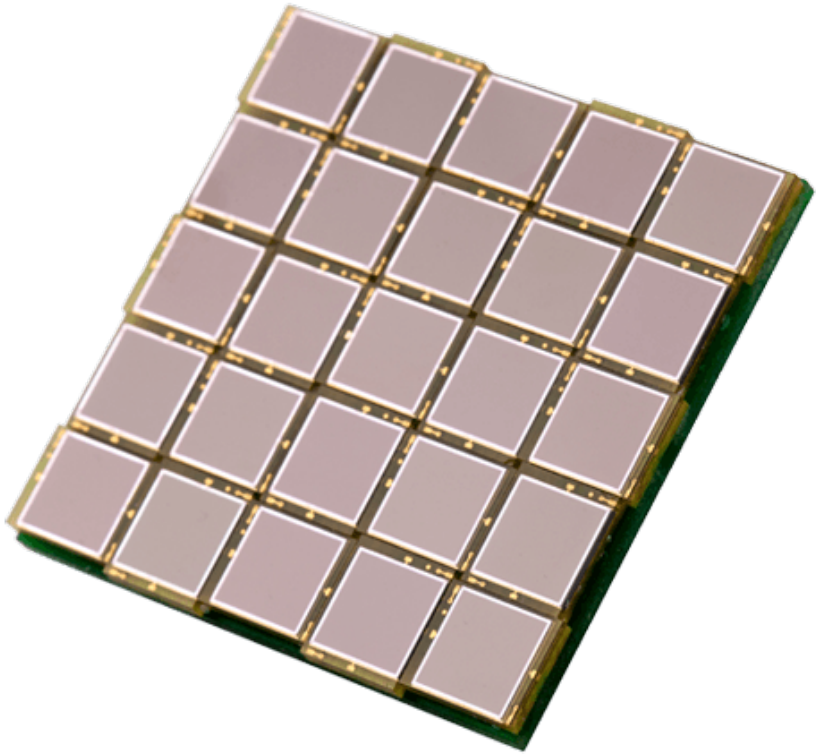



# Alternatives to PMTs

SiPMs are rapidly becoming competitive and being adapted by a variety of experiments from colliders to dark matter searches.




- Compact
- Insensitive to magnetic fields
- Robust at high pressures
- Operate at cryogenic temperatures
- Low radioactivity



*They are small so the challenge in most applications is the packaging and readout into arrays.*

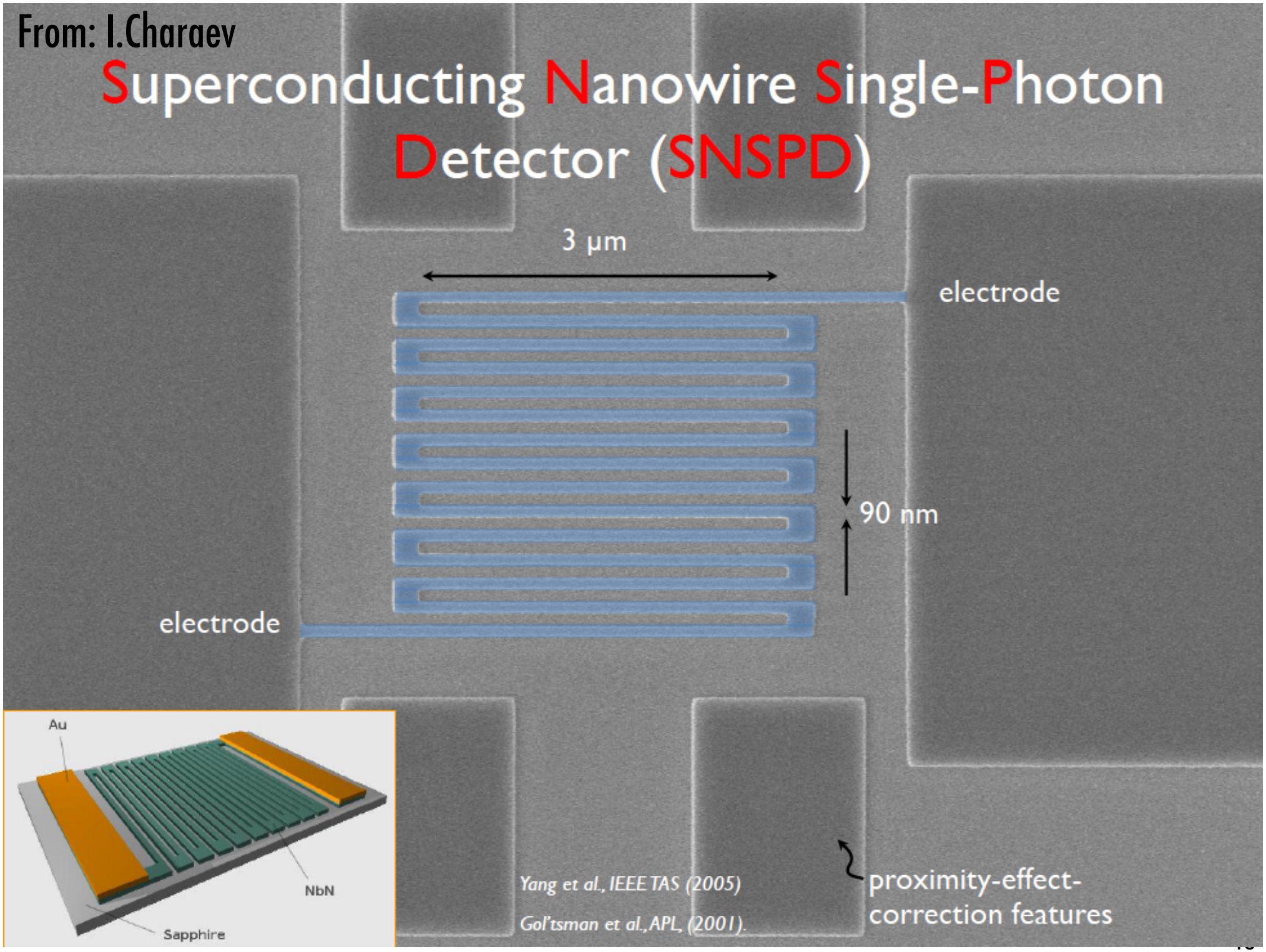
# Novel Detectors

- Nanowires
- Quantum-dot-based solid state detectors
- Transition edge sensors

*These are all cryogenic sensors with overlap with quantum information technologies.*

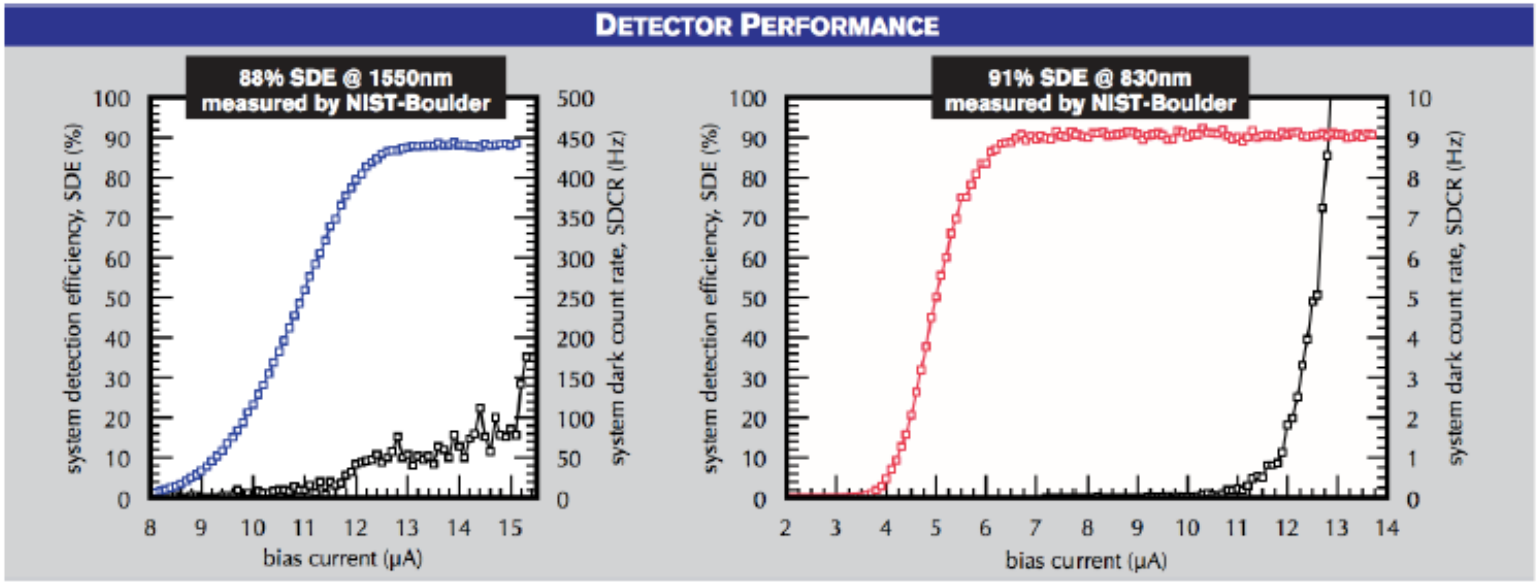
From: I.Charaev

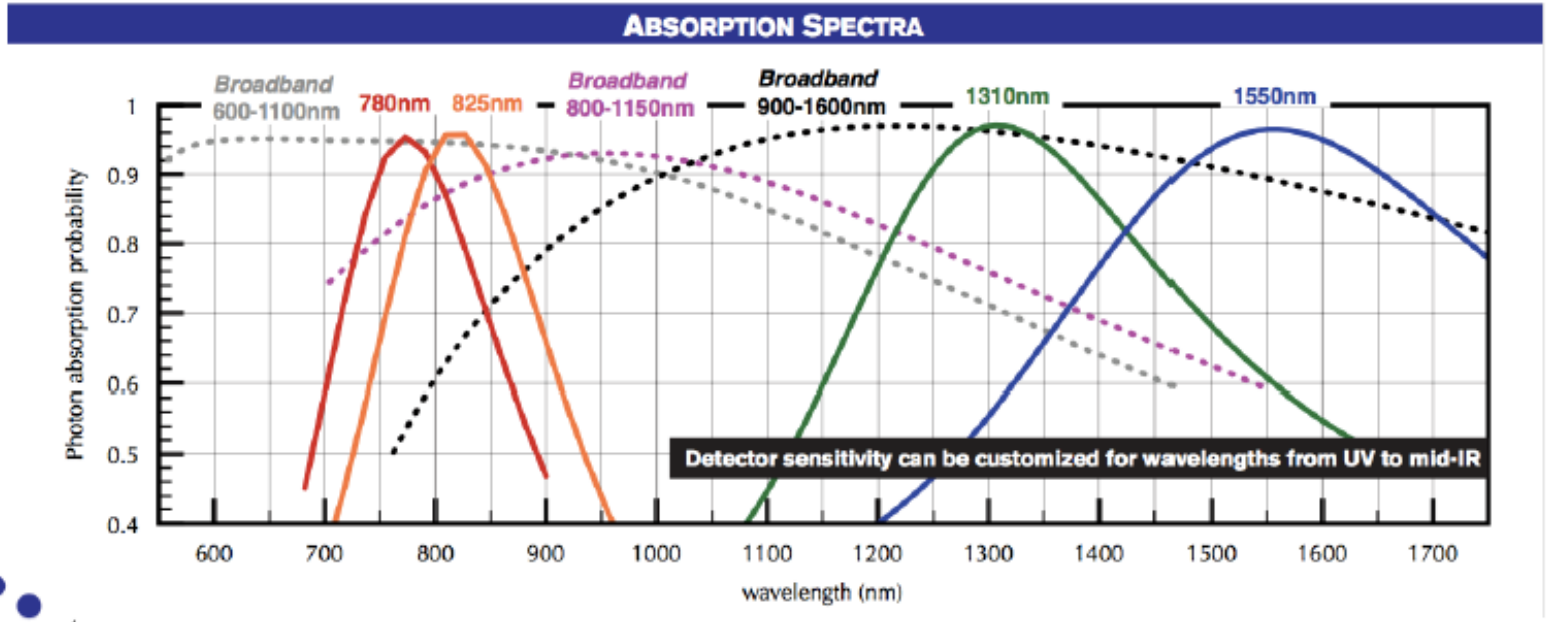
# Superconducting Nanowire Single-Photon Detector (SNSPD)



From: I.Charaev

# Detector Performance



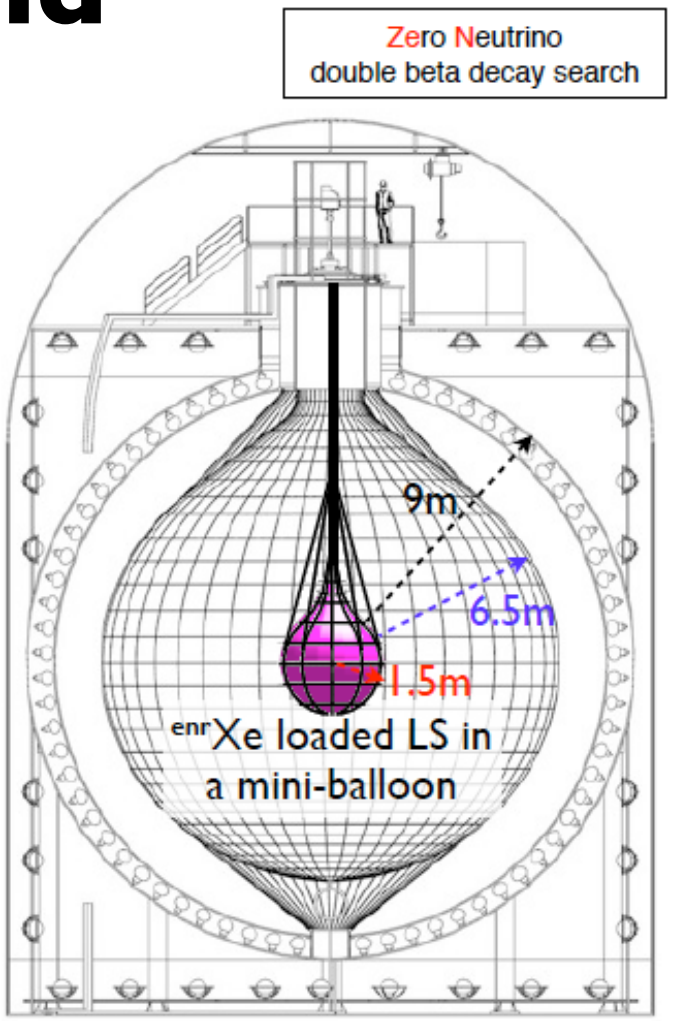




Photon Spot

www.photonspot.com

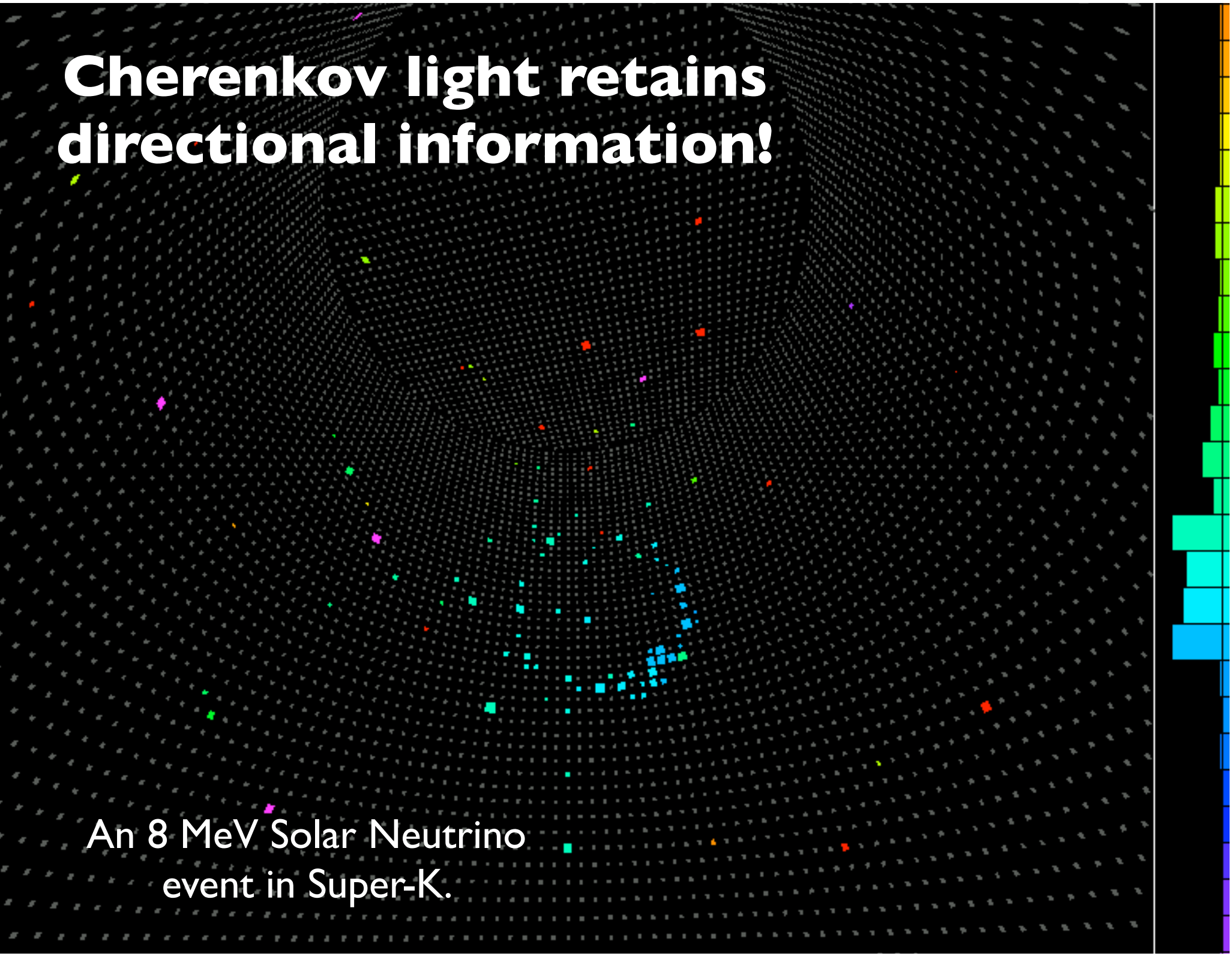
# Reverse the question: What could you do with an extreme photodector?

# One of my favorite detectors, the kiloton-scale liquid scintillator detector KamLAND.

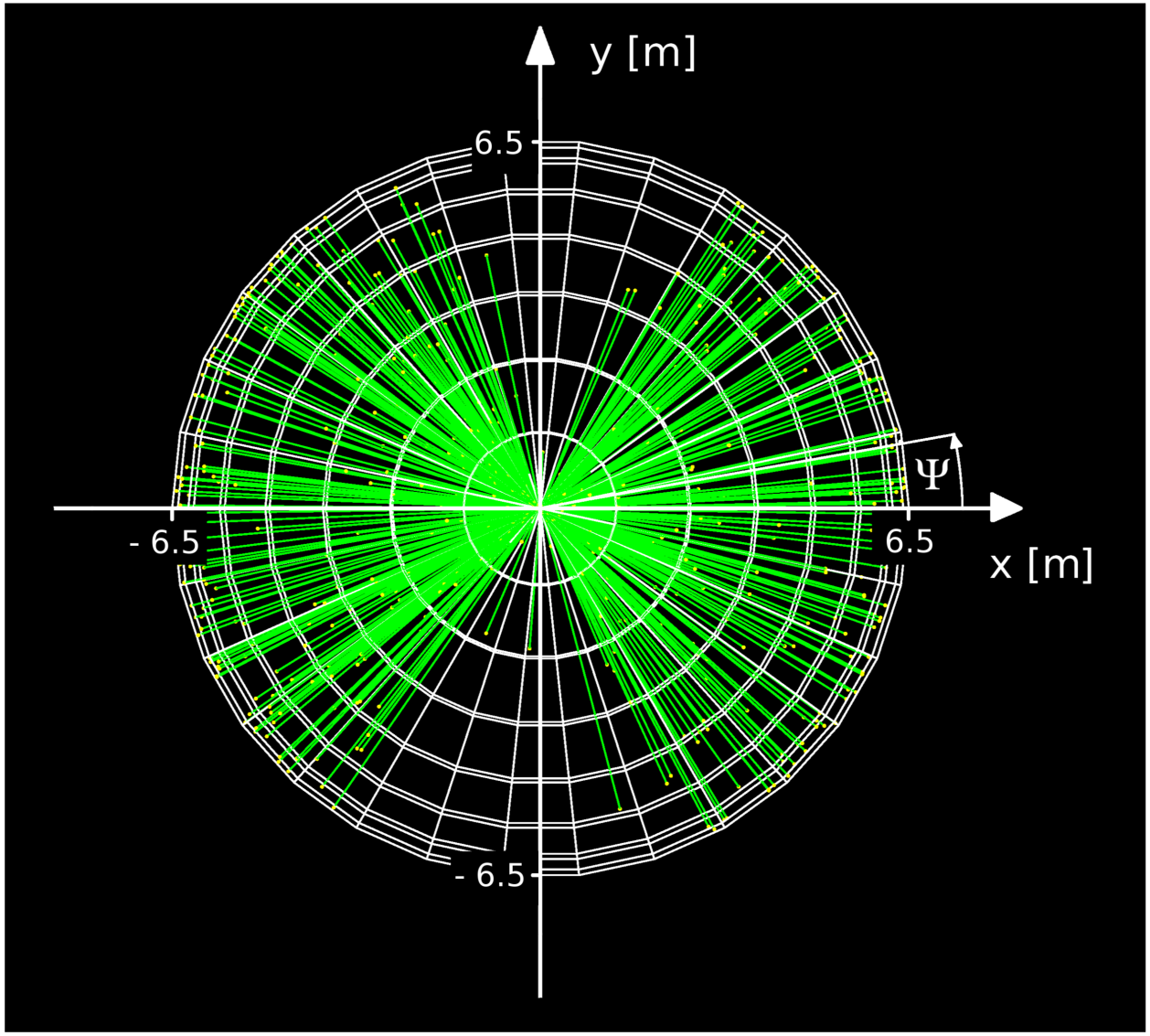



~320kg 90% enriched $^{136}$Xe installed so far
615 kg in hand

**Problem:**
**Scintillation light**
**is isotropic.**


Cherenkov light retains directional information!
An 8 MeV Solar Neutrino event in Super-K.

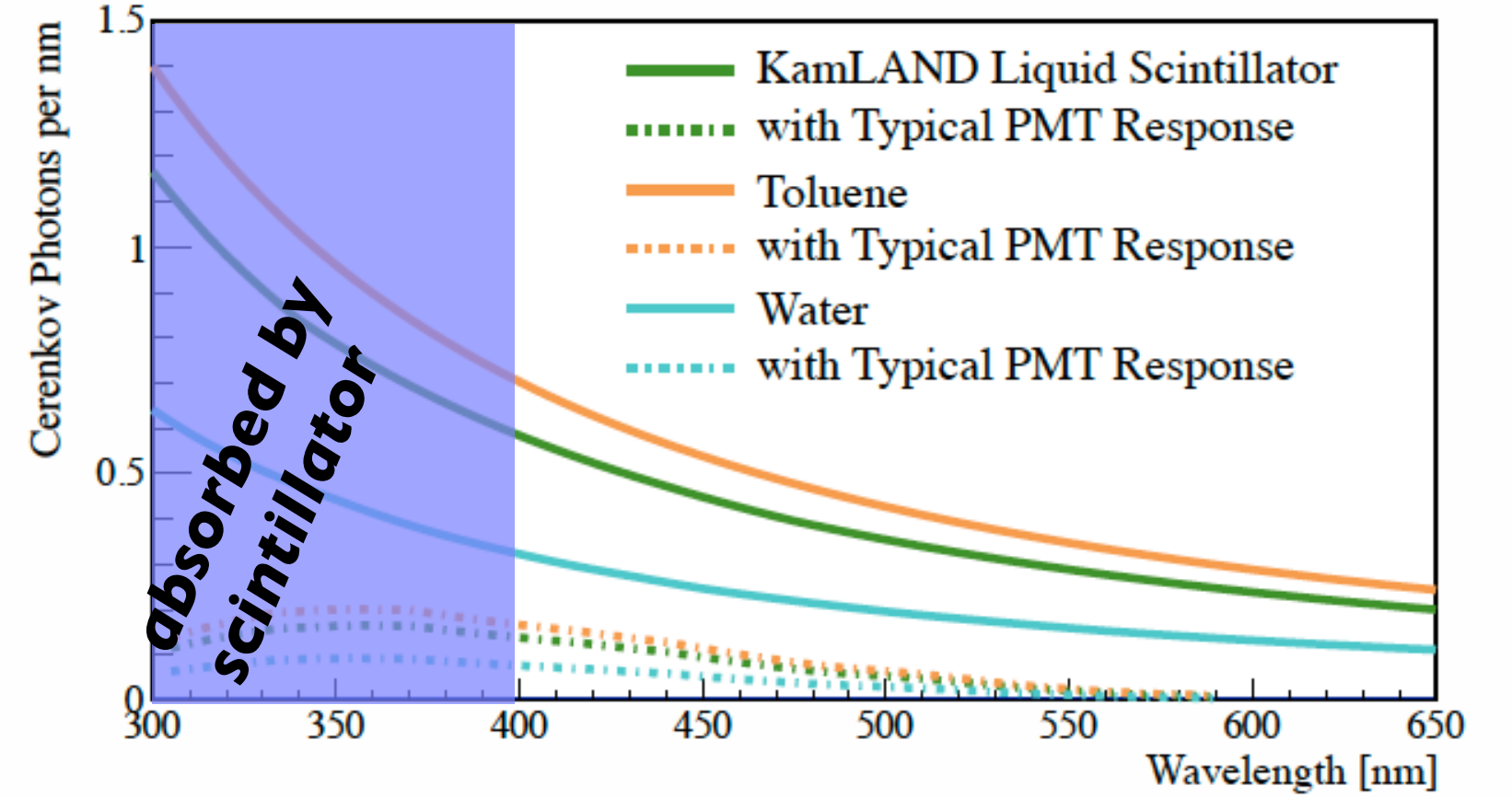
# Neutrinoless Double Beta Decay




**(Cherenkov Only)**

# How does it work?

Number of Cherenkov Photons for a 1MeV e-




Retains directional information!

Important in Big Detector.

**Longer wavelengths travel faster in scintillator**

**and**

**Scintillation processes have inherent time constants.**

Always Important

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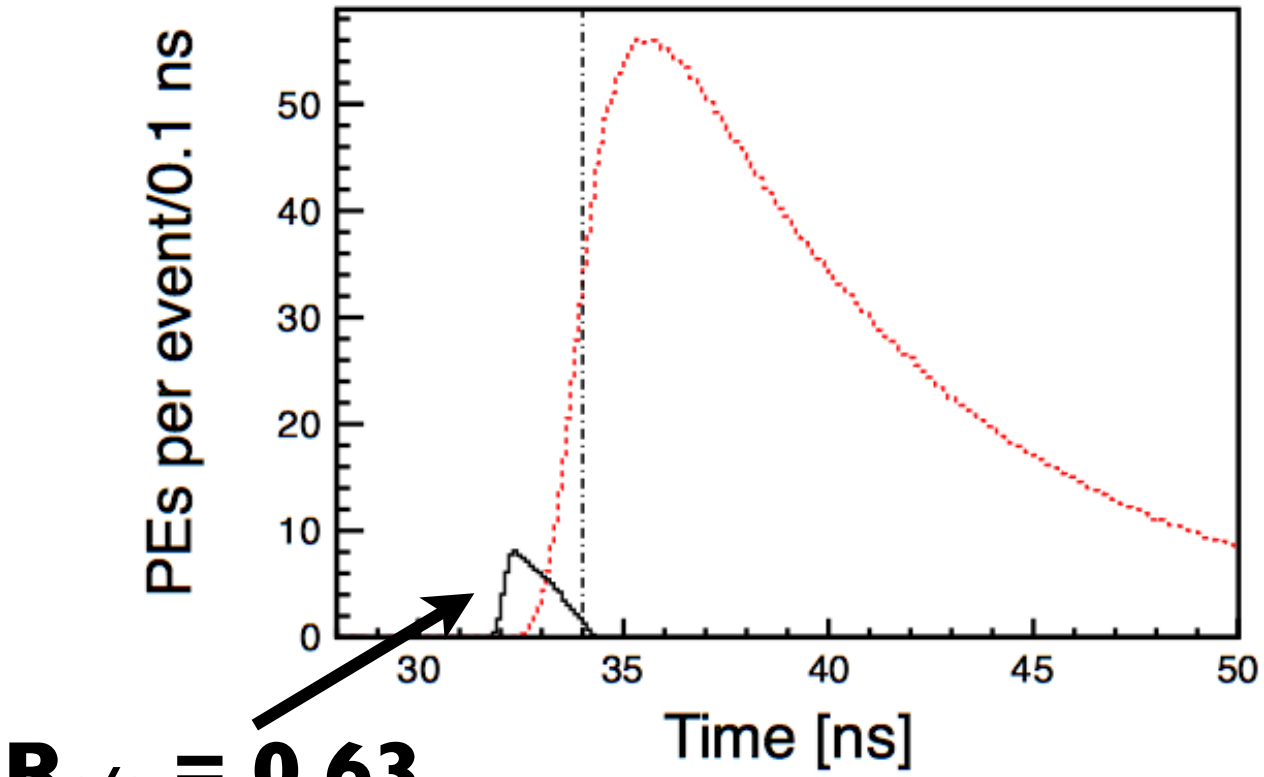
# So if you have good enough timing....




$R_{c/s} = 0.63$

.... you should be able to separate the scarce Cherenkov from the abundant scintillation light.

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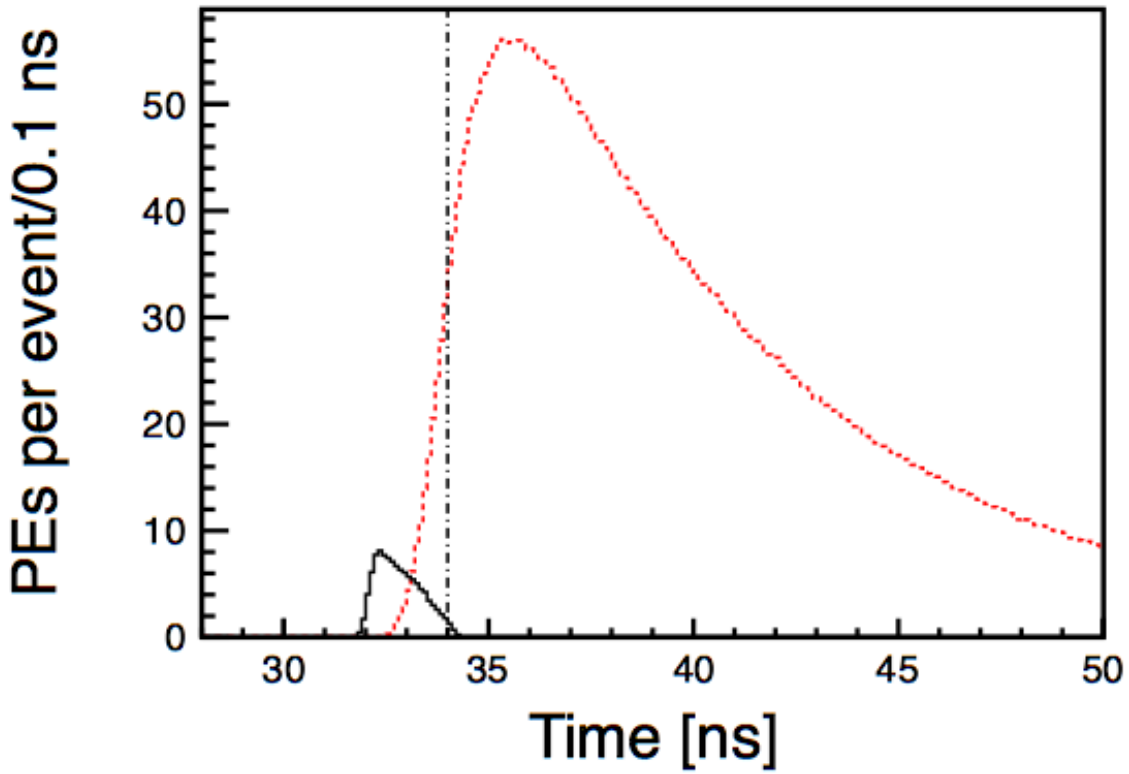
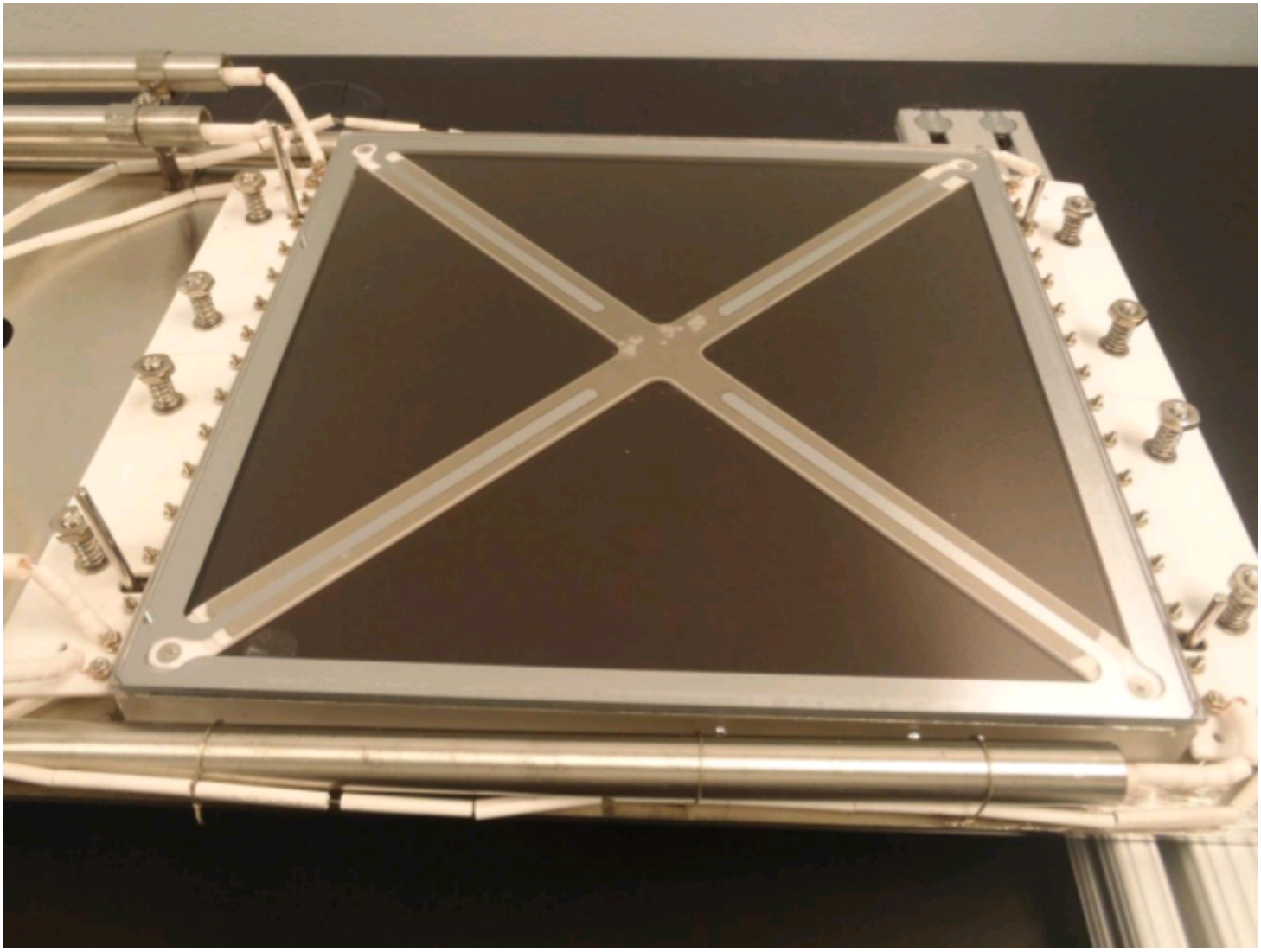
**This corresponds to 0.1 ns.**




**This sort of timing is available in very tiny MCP-based PMT's/SiPMs…for now.**

# The LAPPD:



INCOM
Bright Ideas in Fiberoptics

THE UNIVERSITY OF CHICAGO

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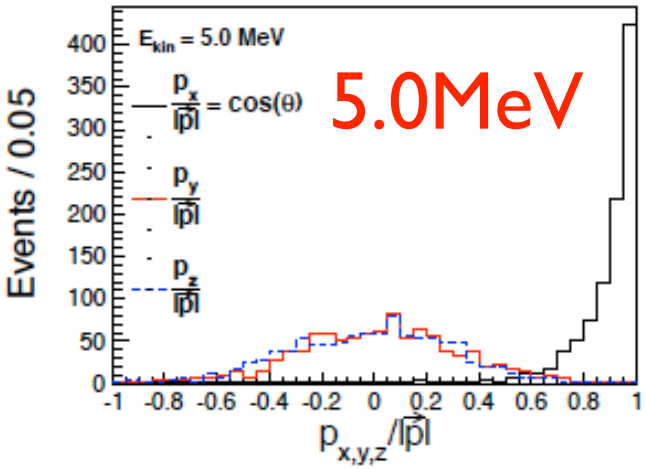
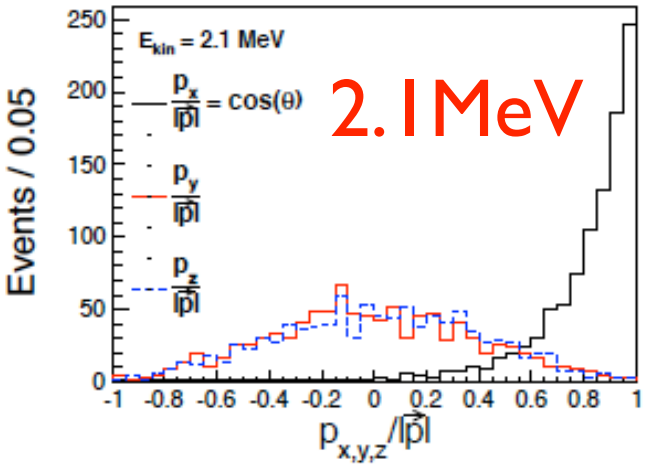
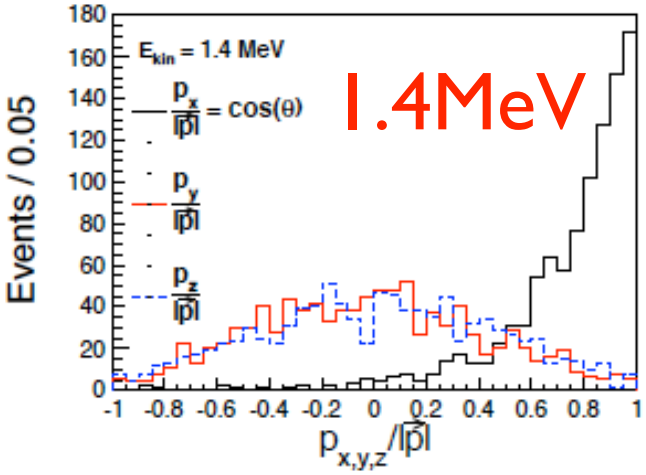
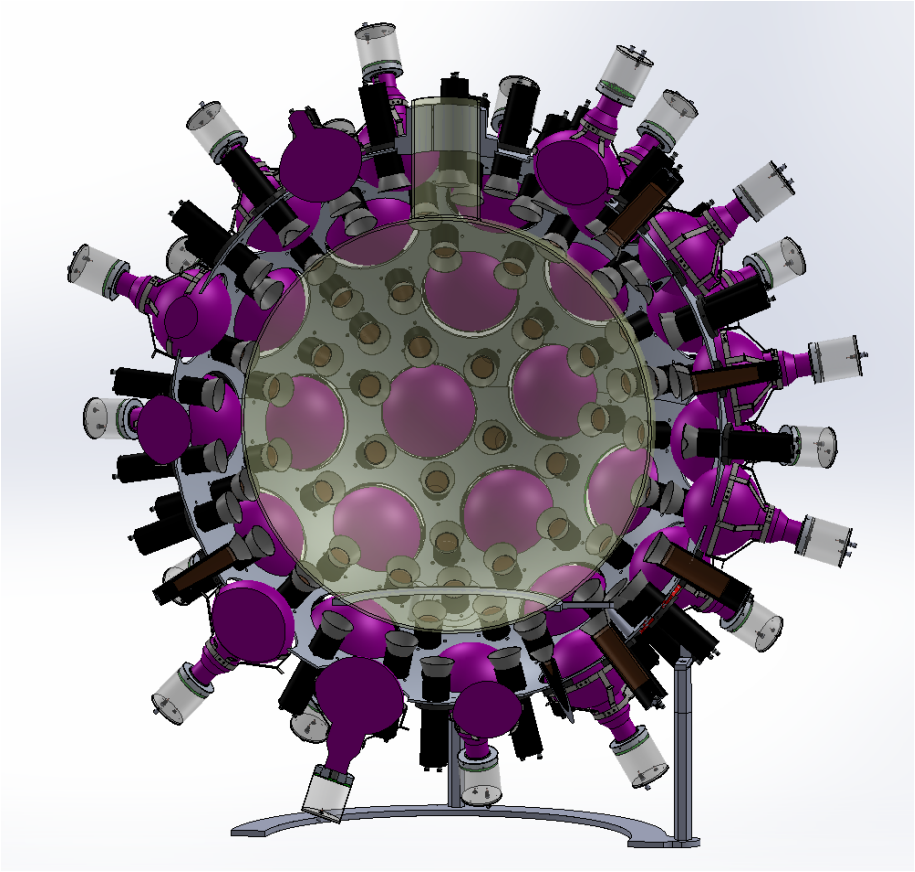


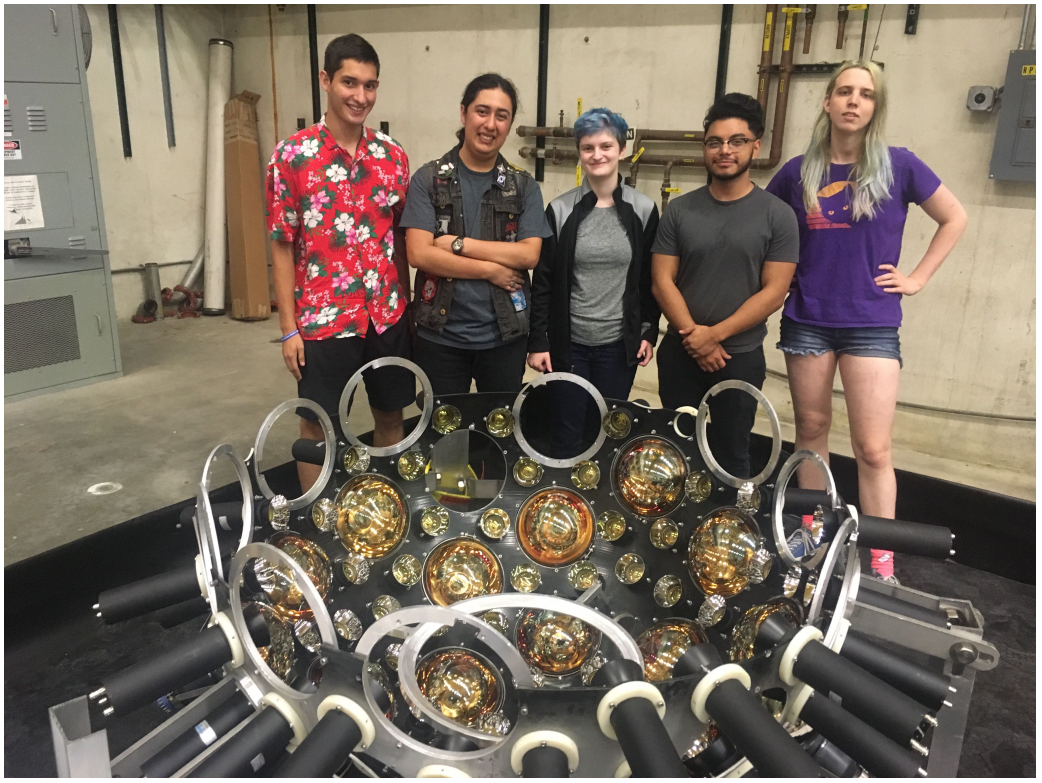

**With a basic algorithm, we can reconstruct the direction of single electrons!**

# NuDot:
# A Prototype Directional Liquid Scintillator Detector



- NuDot mechanical design completed by MIT-Bates Engineering Center.
- All components are ordered and many have arrived.
- Construction underway!

# NuDot:
# A Prototype Directional Liquid Scintillator Detector



**So what are you working on, what do you need, and what could you do?**

# Send me feedback:

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**lwinslow@mit.edu**