Search for Neutrinoless Double-Beta Decay Using Fast Photo-Detectors and Quantum-Dot-Doped Scintillators

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with C.Aberle[1], H.Frisch[2], M.Wetstein[2] and L.Winslow[1]

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Snowmass on the Mississippi, Minneapolis, August 2, 2013

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Outline

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- What is neutrinoless double-beta decay?
  - why is it interesting?
  - what are the challenges?
- Ideas for next generation experiments
- Requirements for the detectors
  - timing characteristics
  - scintillators properties
- Summary

$\longrightarrow$ **work I am involved in**

$\longrightarrow$ **reporting for my UCLA colleagues**

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What is 0νββ?

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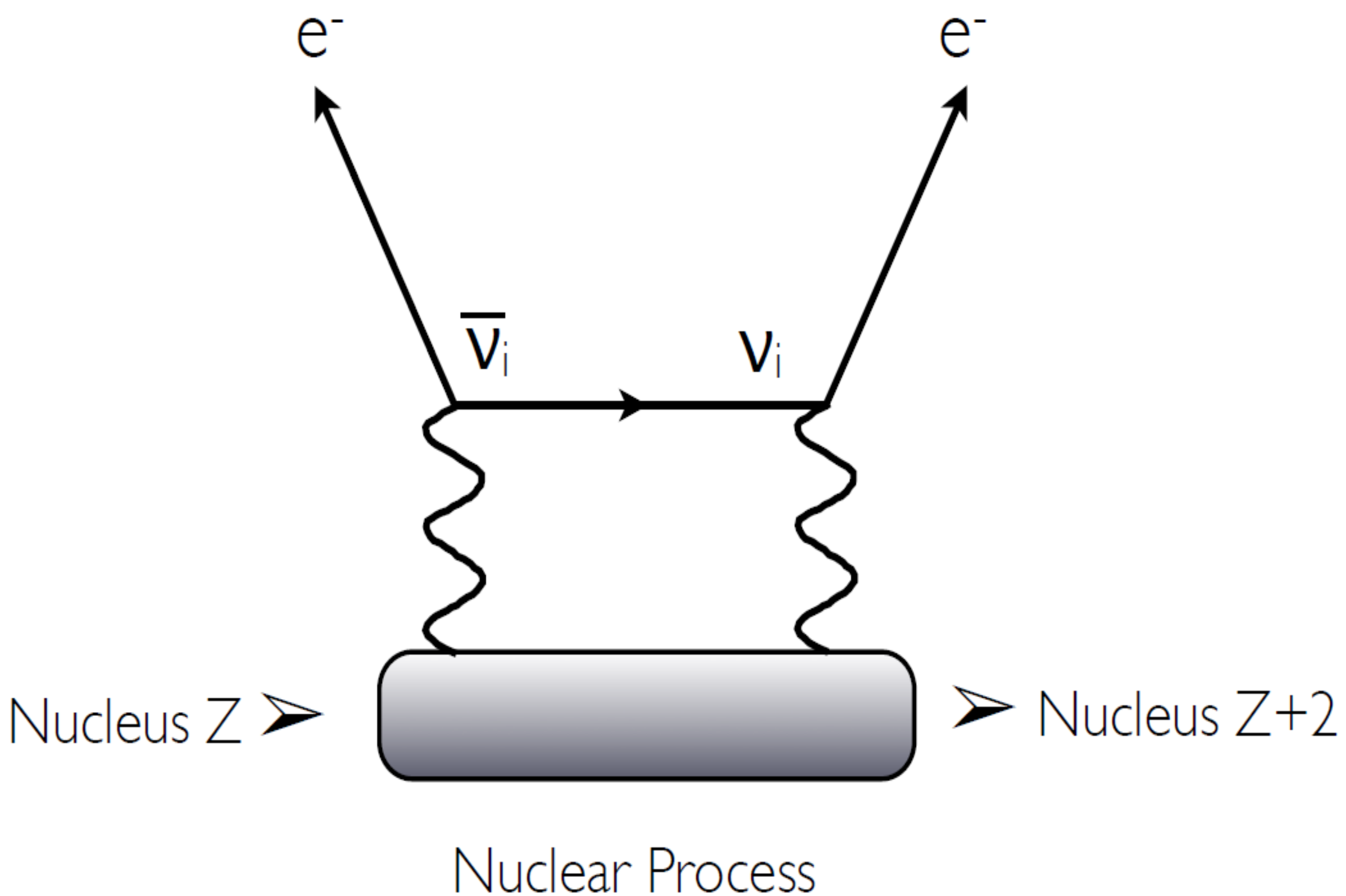
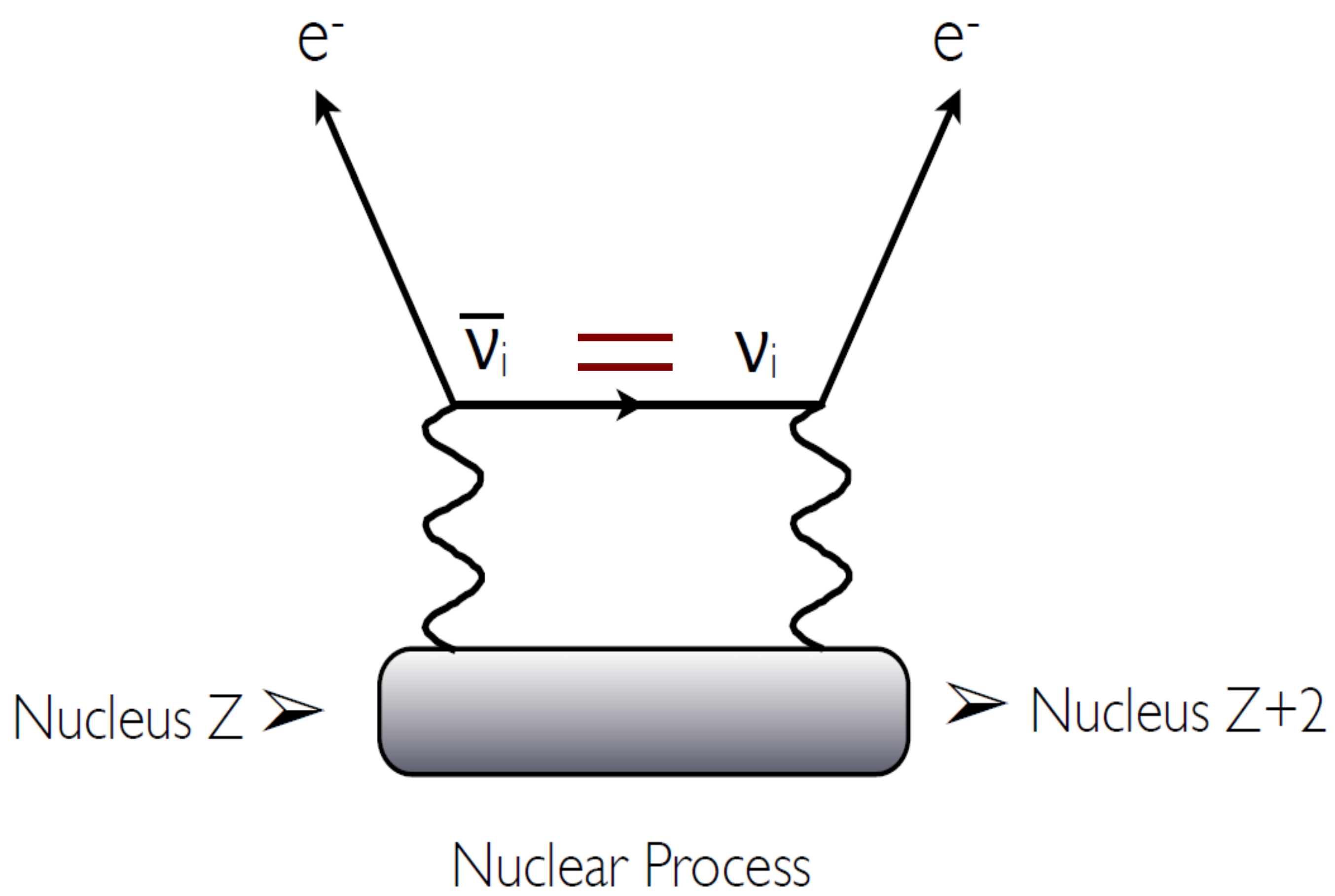


Compare to normal beta decay: Z → (Z+1), e-, $\bar{\nu}_e$

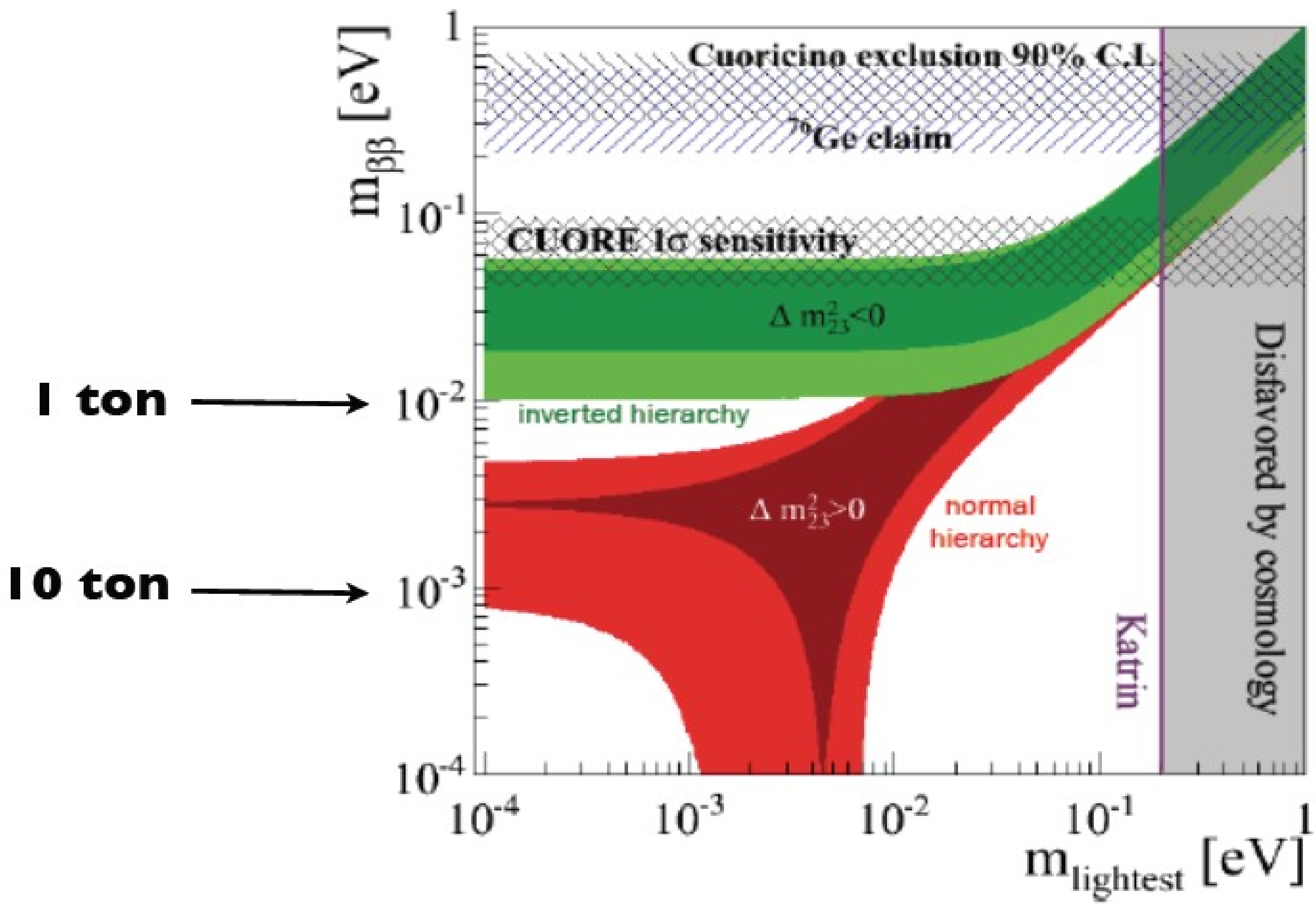
Why is it interesting?



If observed, neutrino is a Majorana particle, i.e. own antiparticle.

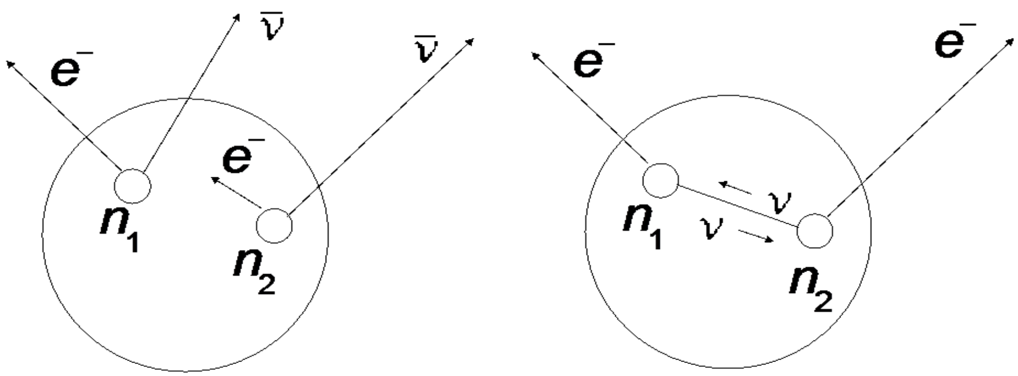
What are the challenges?

Rare process (e.g. $T_{1/2}[^{136}Xe] > 10^{25}$ years): need to get bigger

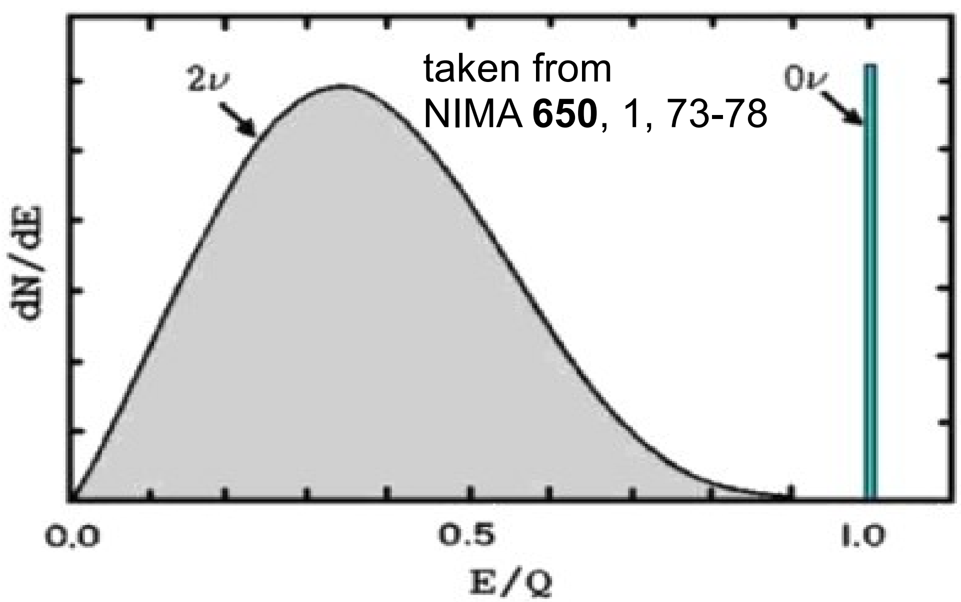


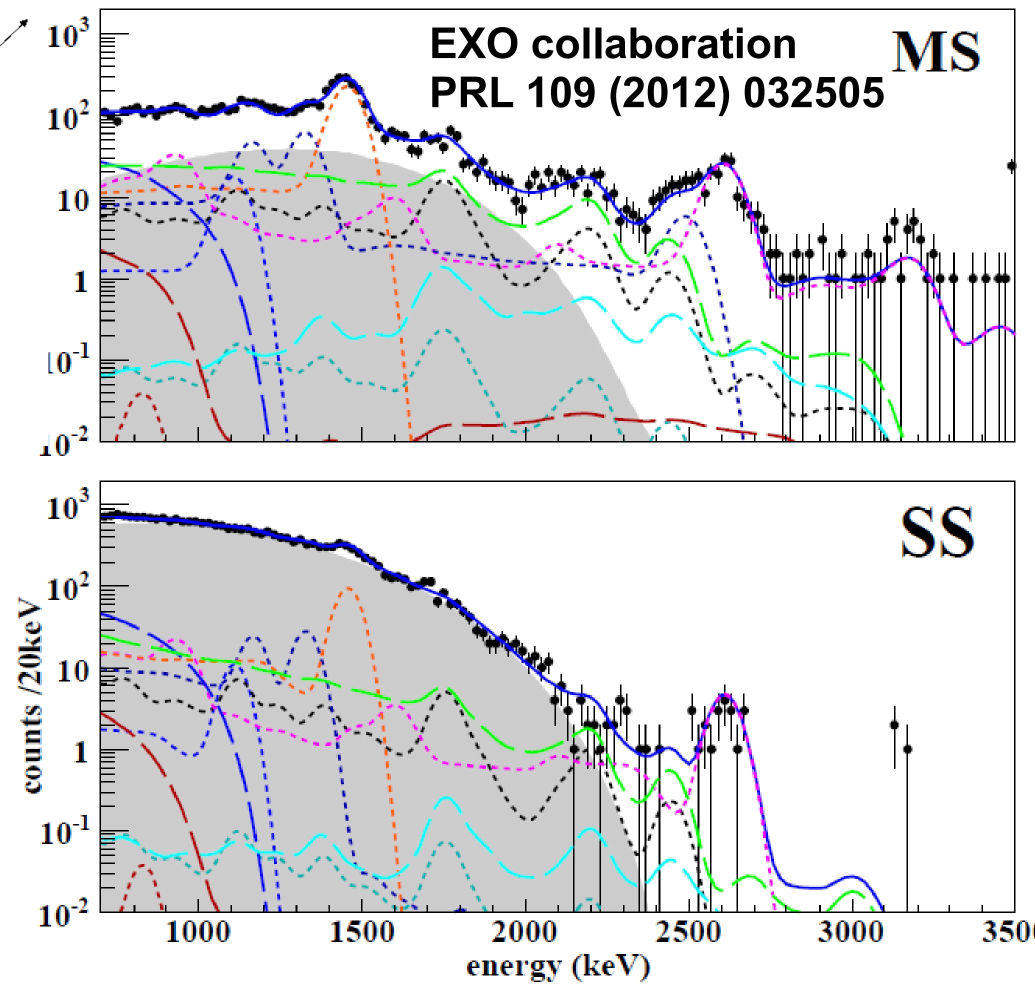
What are the challenges?

Tough backgrounds: need to get smarter



2vββ 0vββ





Ideas for 0νββ experiments

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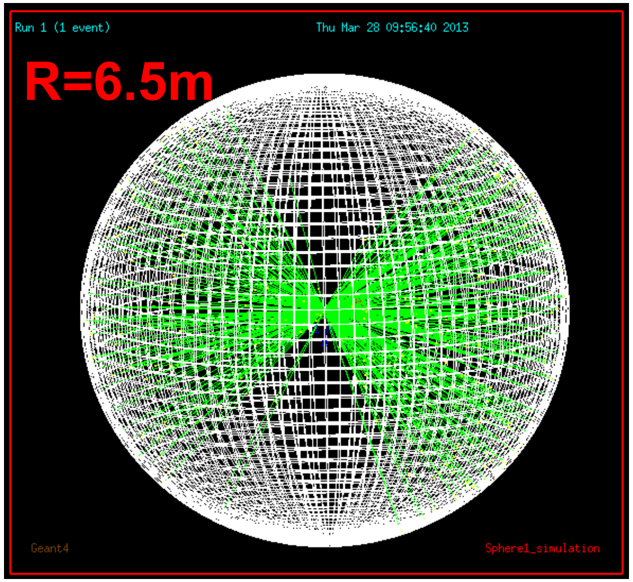
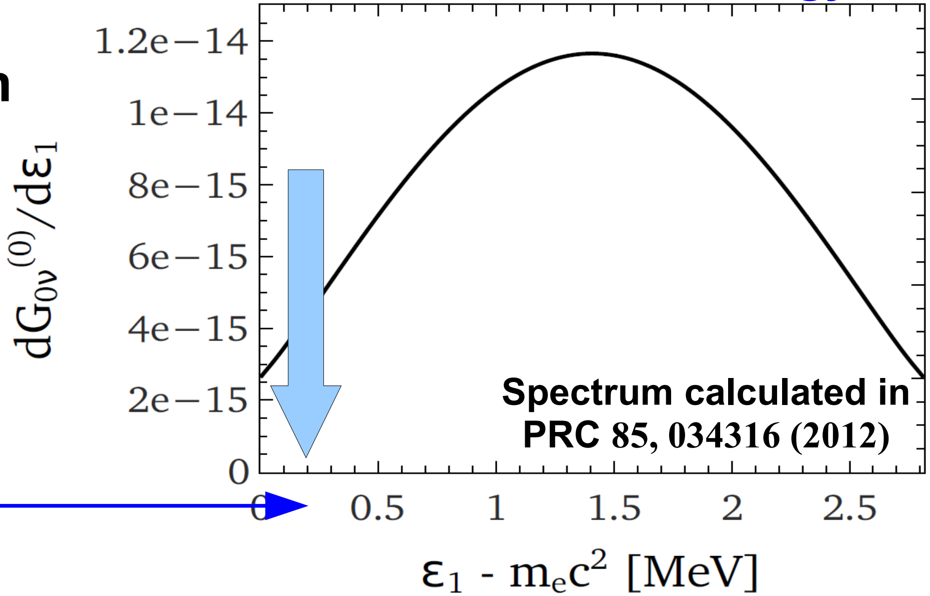
- Total energy in signal events is well defined.
- Use scintillation light for energy measurements
- Use event topology to suppress backgrounds
  - signal is two, mostly, “back-to-back” electrons
- Electrons are ~1MeV → above Cherenkov threshold
- Use Cherenkov light to extract directionality of the two electrons
  - all light can be used to constrain location of the vertex
  - Cherenkov light arrives early because of longer wavelength and delay of the scintillation process

Simulation of ^{116}Cd 0νββ event



Electron kinetic energy



Cherenkov threshold for n=1.47

Emission Spectra

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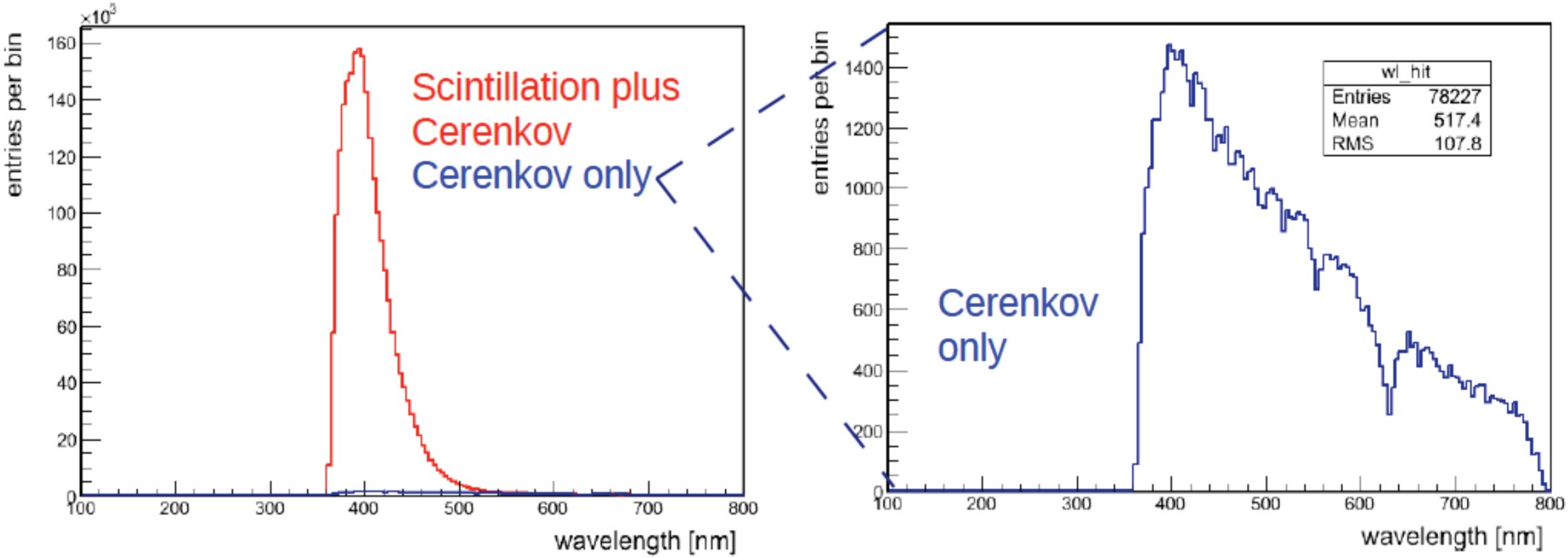
Simulation of 5 MeV electrons in KamLAND scintillator

5 MeV is just a starting point to test the idea on using Cherenkov light from low energy electrons



All photons below 360nm get absorbed

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Cherenkov vs Scintillation

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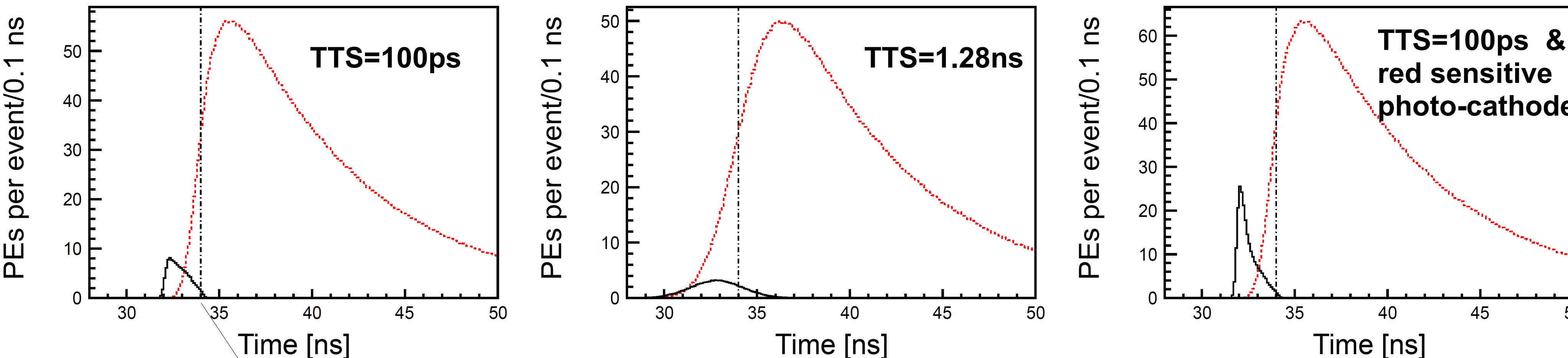
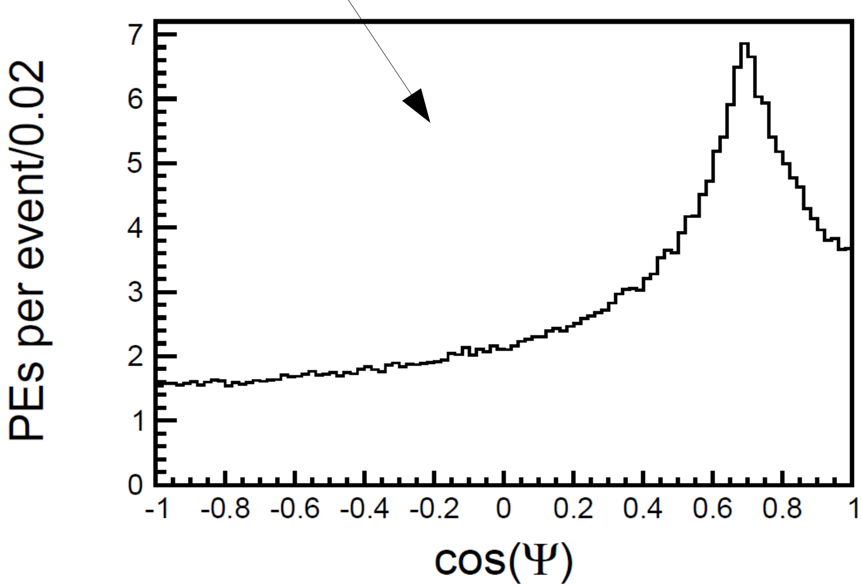
Simulation of 5 MeV electrons in KamLAND scintillator





Use early light to extract directionality

A shift between cherenkov and scintillation spectra is a plus

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Directionality of 5 MeV e^-

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Measuring Directionality in Double-Beta Decay and Neutrino Interactions with Kiloton-Scale Scintillation Detectors

C. Aberle,[1] A. Elagin,[2] H. J. Frisch,[2] M. Wetstein,[2] and L. Winslow[1]

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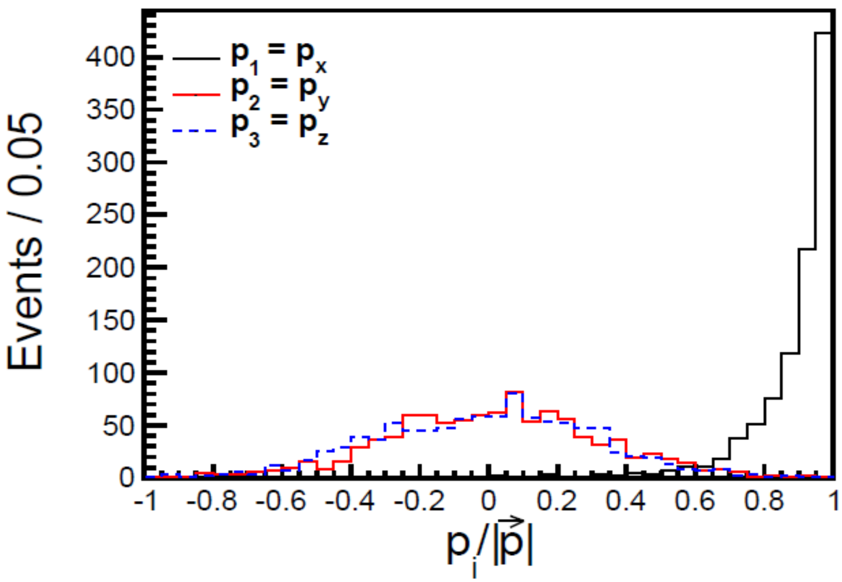
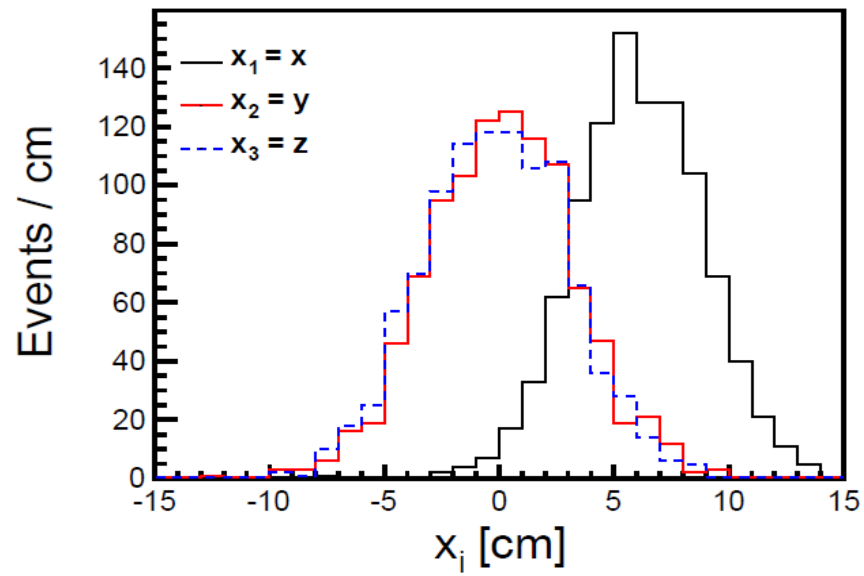
[2] *University of Chicago, Chicago, IL 60637, USA*

(Dated: July 23, 2013)

arxiv:1307.5813

Large liquid-scintillator-based detectors have proven to be exceptionally effective for low energy neutrino measurements due to their good energy resolution and scalability to large volumes. The addition of directional information using Cherenkov light and fast timing would enhance the scientific reach of these detectors, especially for searches for neutrino-less double-beta decay. In this paper, we develop a technique for extracting particle direction using the difference in arrival times for Cherenkov and scintillation light, and evaluate several detector advances in timing, photodetector spectral response, and scintillator emission spectra that could be used to make direction reconstruction a reality in a kiloton-scale detector.





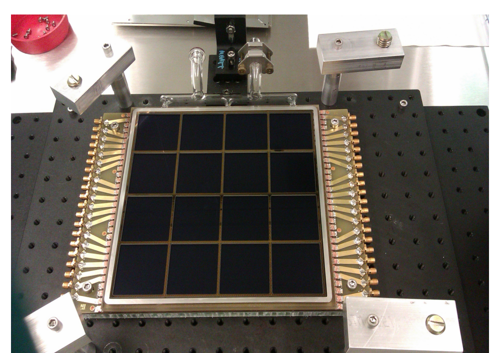
5 MeV electrons look very promising → working on reconstruction for 1 MeV

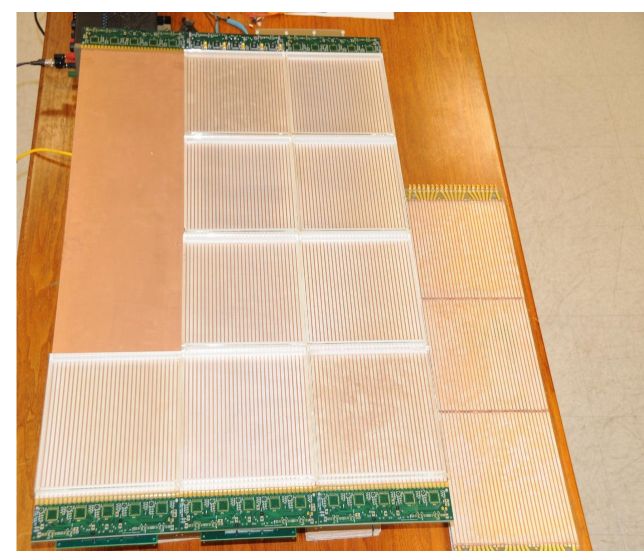
Can we do better with photo-detectors?

Large Area Picosecond Photo Detectors (LAPPD)

LAPPD Collaboration web-page:
http://psec.uchicago.edu

- *Large area*
- *Fast timing*
- *Inexpensive*





Glass Package (20x20cm^2)

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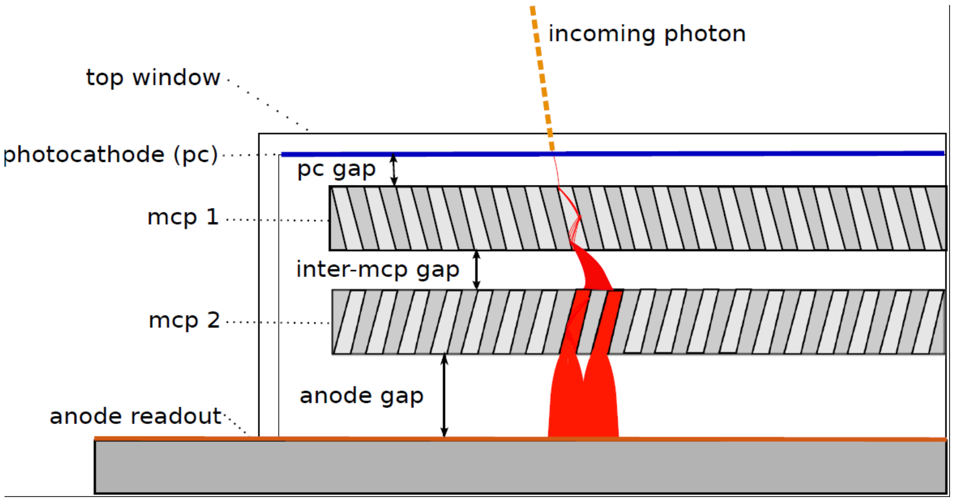
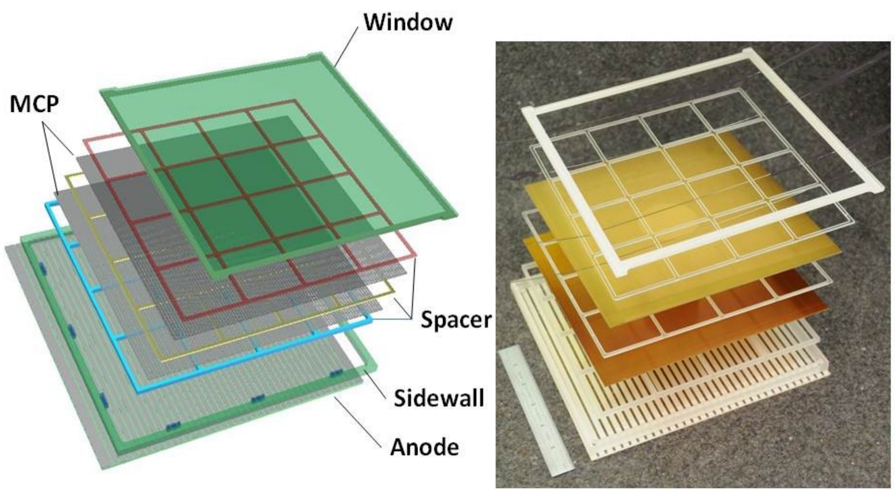
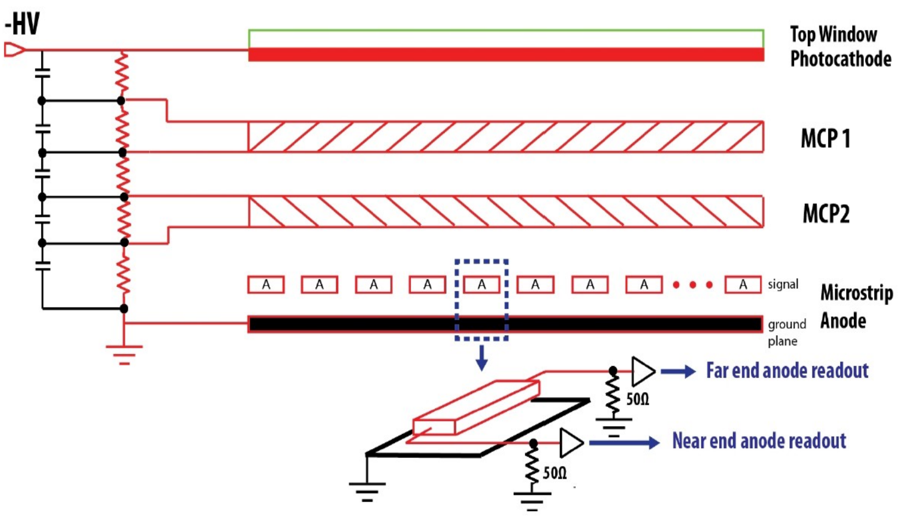




Design Drawing - September 2010

Actual Glass Parts - April 2012

The Frugal Tile



- Cheap, widely available float glass
- Anode is made by silk-screening
- Flat panel
- No pins, single HV cable
- Modular design
- High bandwidth 50 Ω object
  - designed for fast timing

Ceramic body packaging is a parallel (and collaborative) effort at Berkeley SSL

Detector Prototype: "Demountable"

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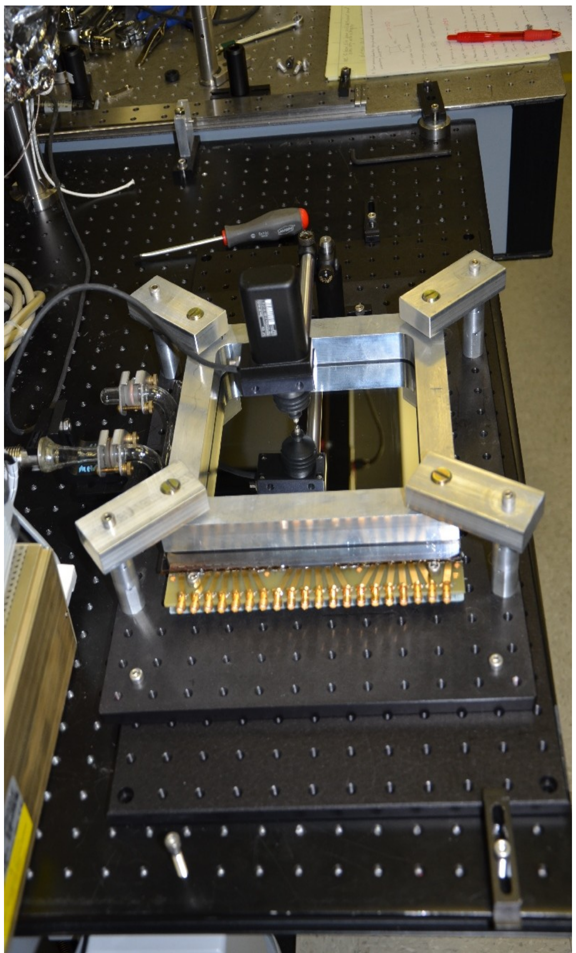
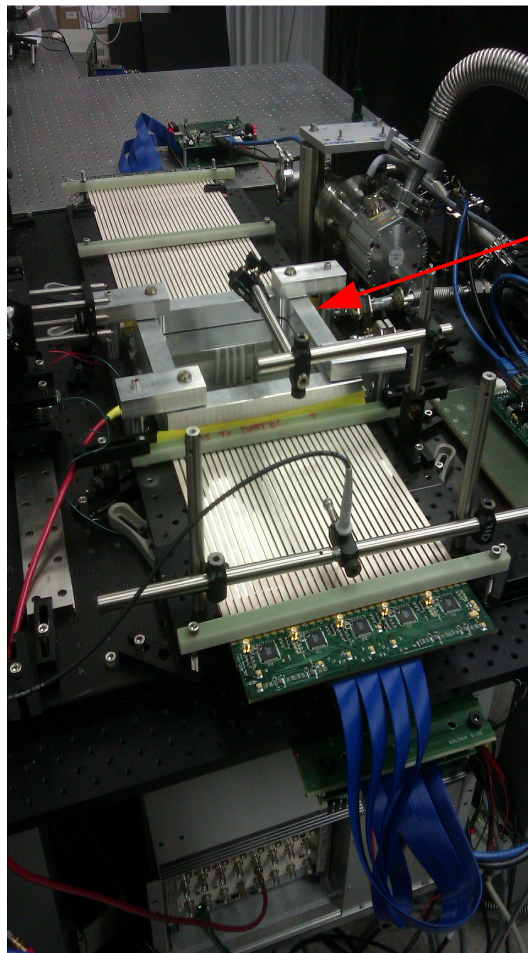
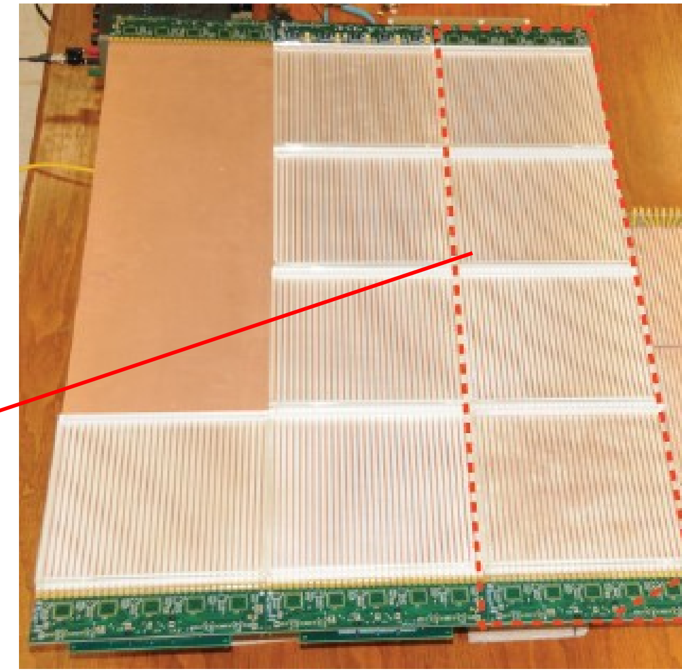
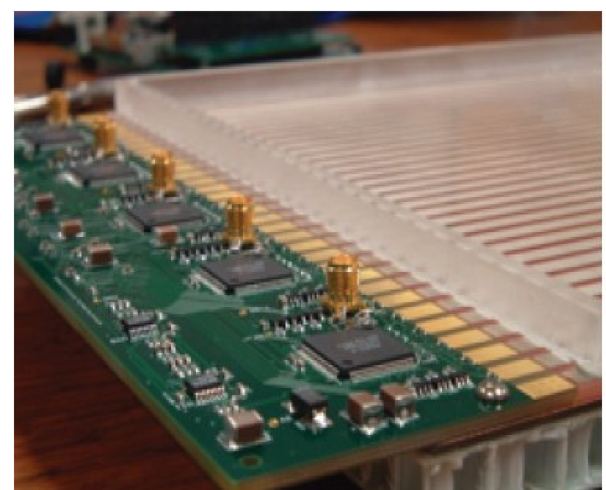
Demountable 1.0
(May 2012)

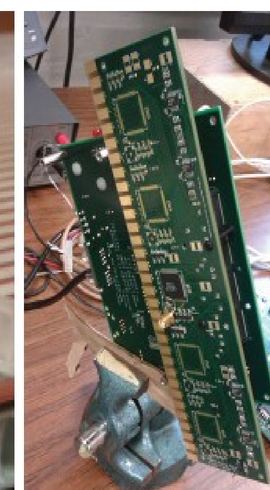


Demountable 3.0
(Sep-Dec 2012)

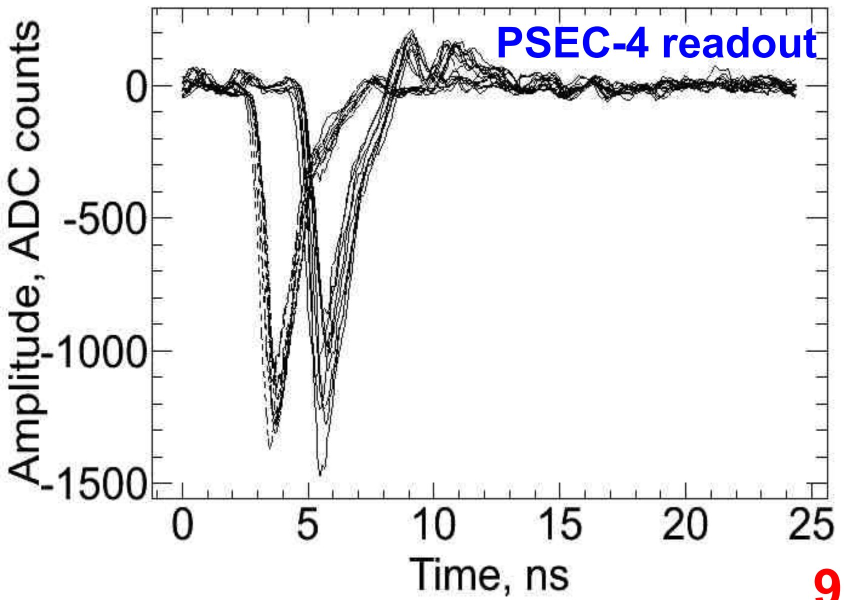


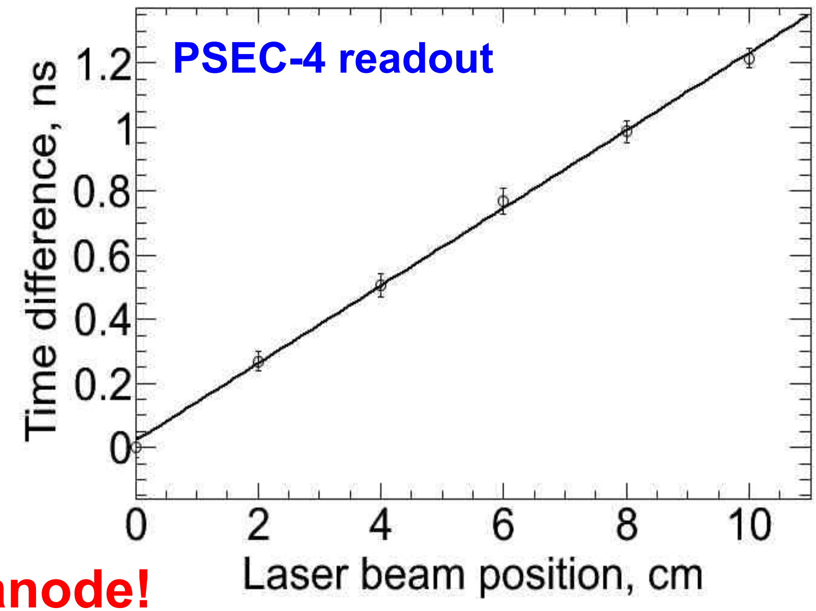




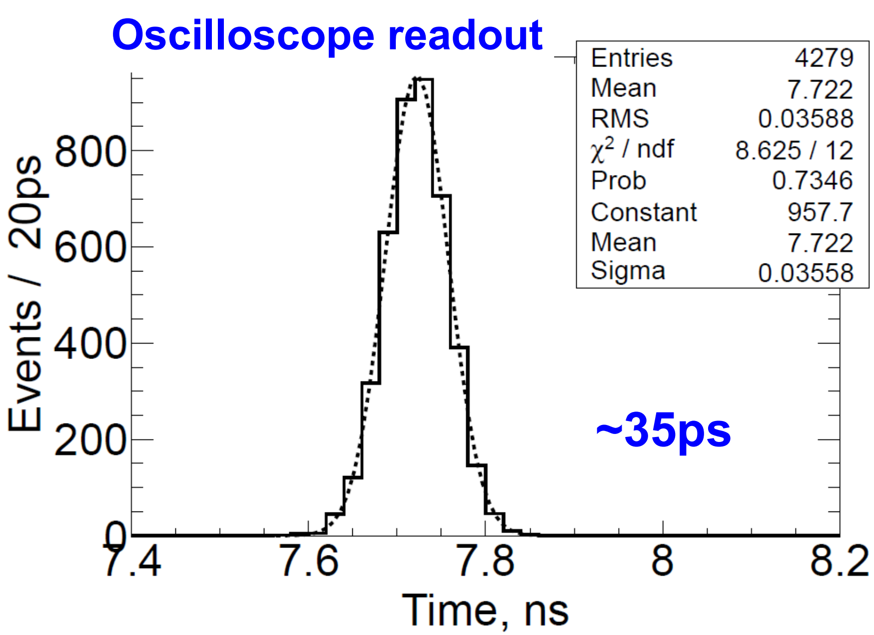


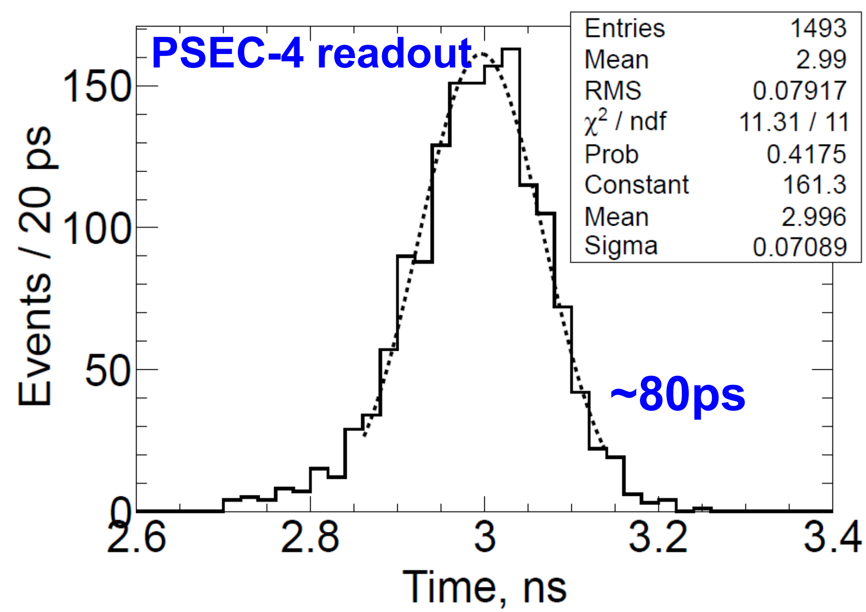
"Demountable" Performance





90-cm long anode!





Can we do better with liquid scintillators? UCLA

I'm showing these slides for Christoph and Lindley

Optical Properties of Quantum-Dot-Doped Liquid Scintillators

arxiv:1307.4742

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ABSTRACT: Semiconductor nanoparticles (quantum dots) were studied in the context of liquid scintillator development for upcoming neutrino experiments. The unique optical and chemical properties of quantum dots are particularly promising for the use in neutrinoless double beta decay experiments. Liquid scintillators for large scale neutrino detectors have to meet specific requirements which are reviewed, highlighting the peculiarities of quantum-dot-doping. In this paper, we report results on laboratory-scale measurements of the attenuation length and the fluorescence properties of three commercial quantum dot samples. The results include absorbance and emission stability measurements, improvement in transparency due to filtering of the quantum dot samples, precipitation tests to isolate the quantum dots from solution and energy transfer studies with quantum dots and the fluorophore PPO.

Can we do better with liquid scintillators?

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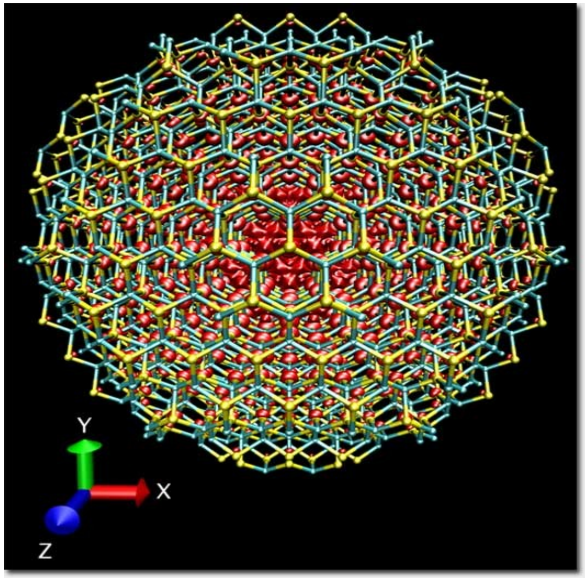
Quantum Dots Doping

Need:

- Narrow the scintillation spectrum
- Shift scintillation spectrum to shorter wavelength
- Dope with metals which can undergo 0vbb



Solution: Quantum Dots

- Quantum dots are seminconducting nanocrystals
- A shell of organic molecules is used to suspend them in an organic solvent (toluene) or water
- Common materials are CdS, CdSe, CdTe...

Candidate Isotopes for 0νββ

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Isotope	Endpoint	Abundance
^{48}Ca	4.271 MeV	0.0035%
^{150}Nd	3.367 MeV	5.6%
^{96}Zr	3.350 MeV	2.8%
^{100}Mo	3.034 MeV	9.6%
^{82}Se	2.995 MeV	9.2%
^{116}Cd	2.802 MeV	7.5%
^{130}Te	2.533 MeV	34.5%
^{136}Xe	2.479 MeV	8.9%
^{76}Ge	2.039 MeV	7.8%
^{128}Te	0.868 MeV	31.7%

Quantum Dots Properties

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- Because of their small size, their electrical and optical properties are more similar to atoms than bulk semiconductors
- The optical properties of quantum dots with diameter < 10nm are completely determined by their size
- Their size is easily regulated during synthesis

Example of CdS Quantum Dot Spectra

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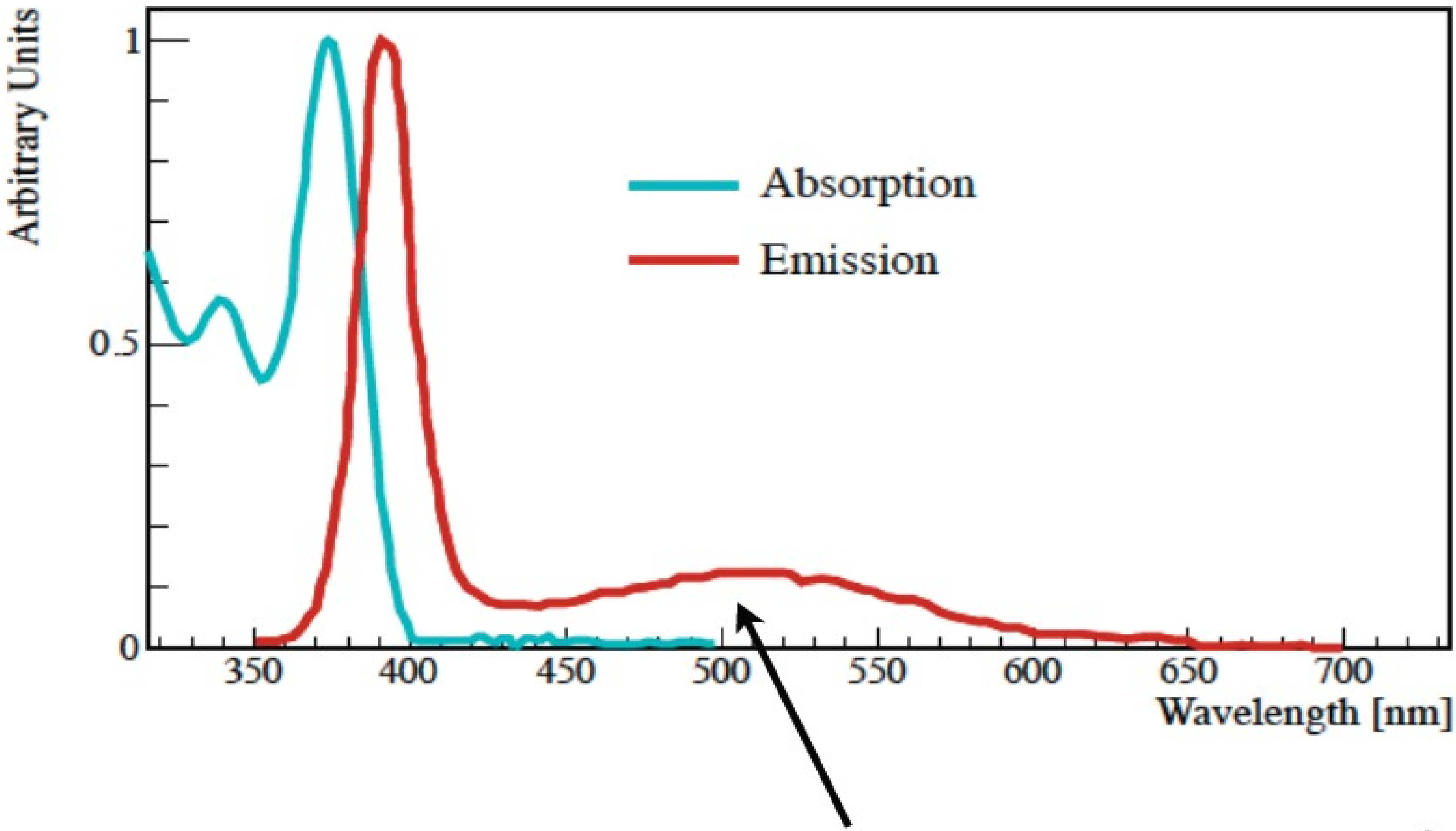

Surface states which can be eliminated with a second shell

Trilite450 QDots vs KamLAND Scintillator

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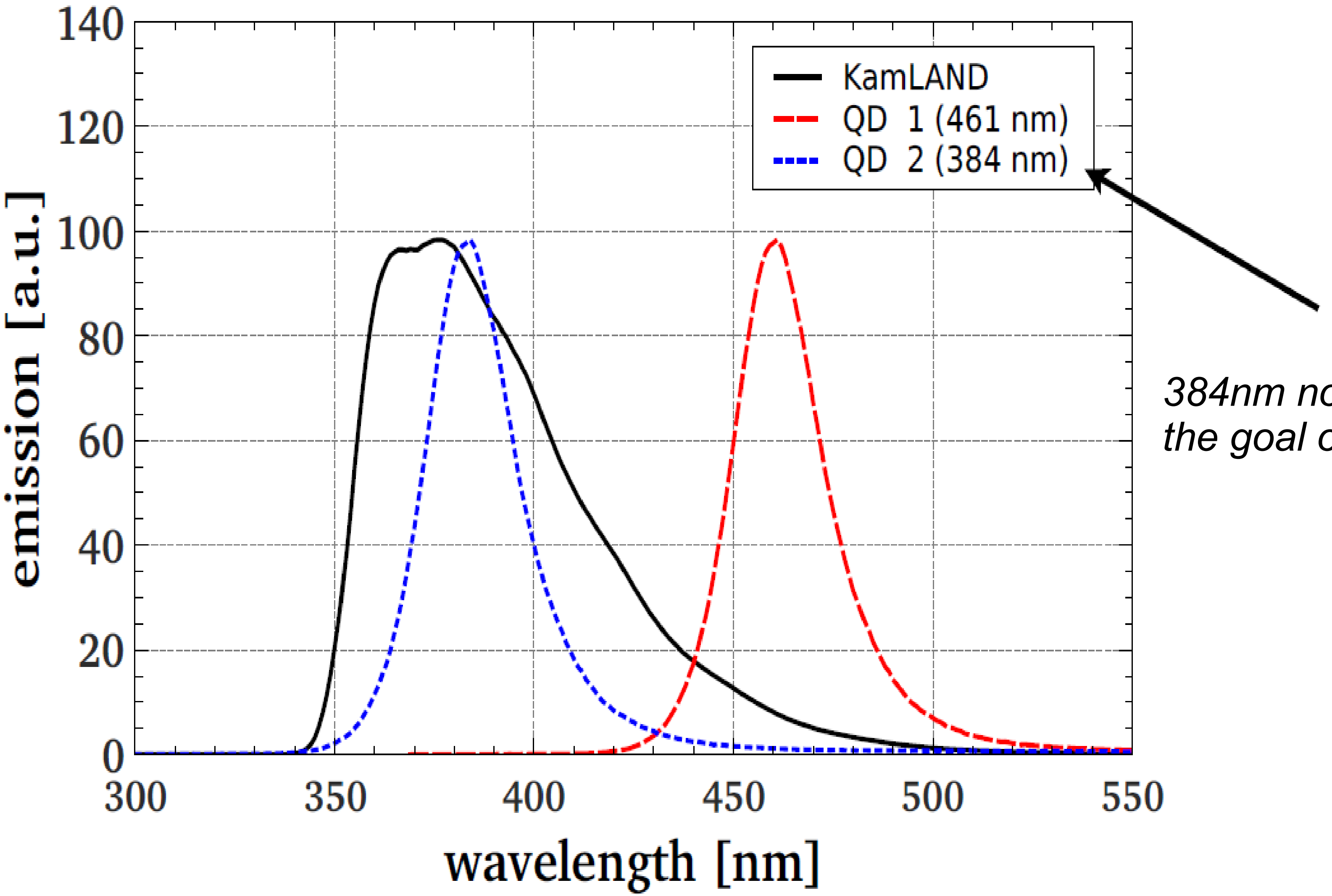

384nm not yet available, but is the goal of future work

No surface states. Narrow emission spectrum.

Attenuation Length

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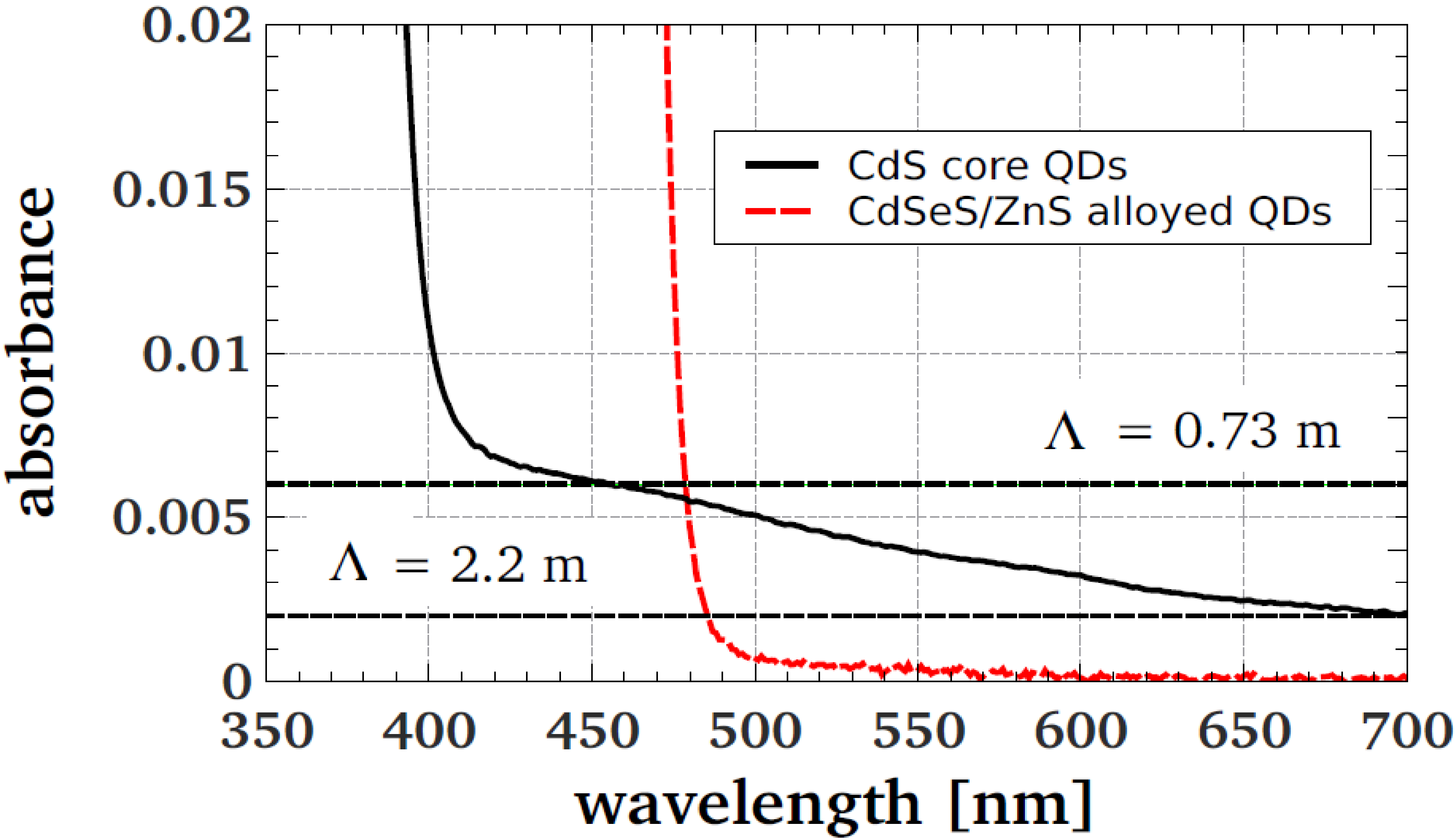

The new Trilite dots have attenuation length longer than 2m

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Summary

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- We propose to use Cherenkov light to reconstruct $0\nu\beta\beta$ event topology
- The following emerging technologies can make a big difference

  - Fast Photo-Detectors with TTS<100ps for separation early Cherenkov light from scintillation light

  - Quantum Dot Doped Scintillators to control and tune scintillator properties (light yield, emission spectrum and transparency)