THEIA:

An Advanced Scintillator Detector at LBNF

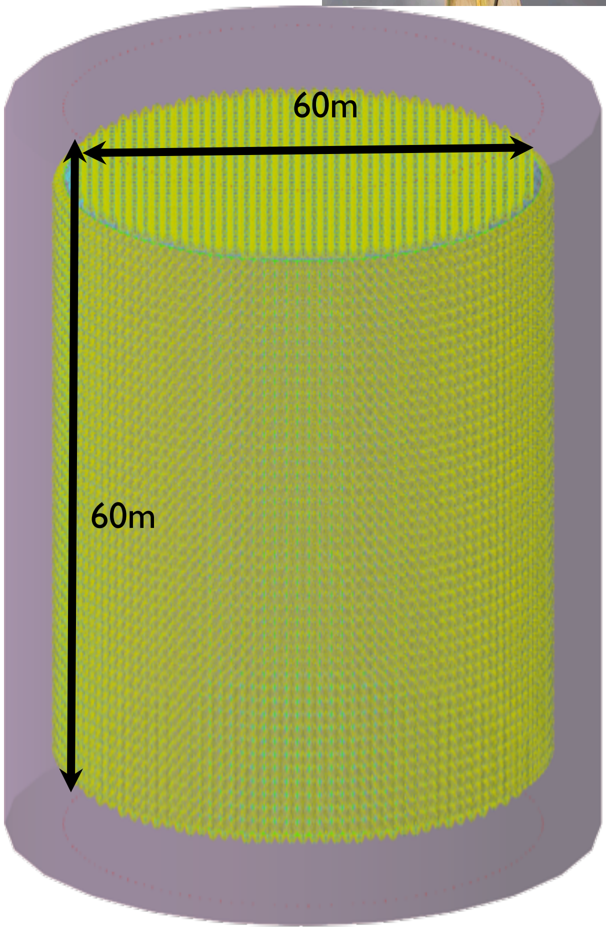
An Opportunity

Evolution of LBNE into DUNE@LBNF is major change:

US is building a world-class neutrino facility

World is coming to build DUNE

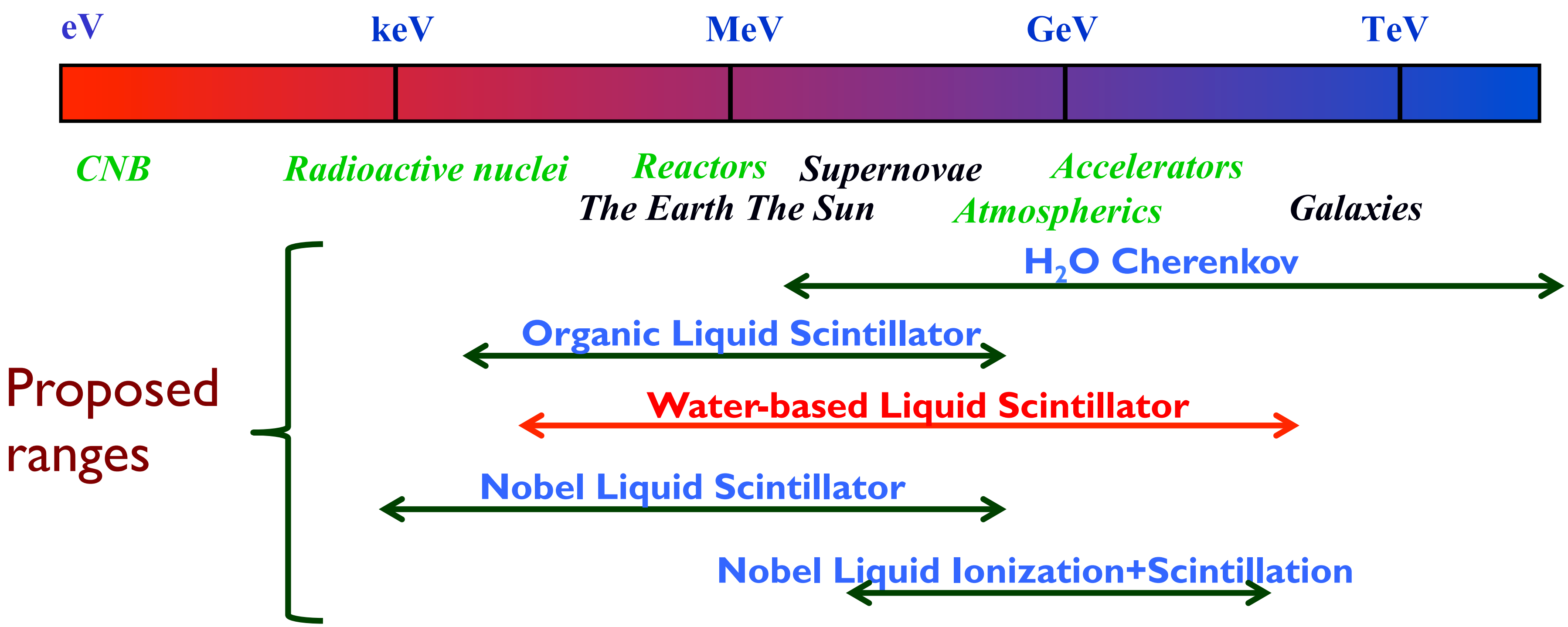
Basic idea is to leverage long-baseline physics program to also provide a much broader neutrino program.



Reference Design:

- 50-100 ktonnes WbLS
- Cylindrical geometry
- >80% coverage with photon sensors
- 4800 mwe underground
- Loading of various isotopes (Gd, Li, Te)
- Ability to deploy inner "bag"

An Opportunity



More bluntly: why not use a >50 kt WbLS detector in place of 20 kt (out of 40 kt) LAr?

An Opportunity

Critical long-term questions:

- How well can Theia do LBL physics?
- How well can Theia do broader (low-energy) physics?
- Is the cost reasonable?
- Can it be built on a reasonable time scale?

Critical near-term questions:

- What are the optical properties of WbLS?
  - Tells us how big detector can be
- How does the light yield scale vs scintillator fraction?
  - Tell us how many PMTs we need for low-E program
- How well can we separate cherlight from scintlight?
  - Tells us how well we can do LBL program
  - Tells us how well we can do particle ID at all energies

Path Forward Toward THEIA

THEIA "Interest Group" formed with concept paper:

Advanced Scintillator Detector Concept (ASDC):
A Concept Paper on the Physics Potential of Water-Based Liquid Scintillator

arXiv:1409.5864

J. R. Alonso,[1] N. Barros,[2] M. Bergevin,[3] A. Bernstein,[4] L. Bignell,[5] E. Blucher,[6] F. Calaprice,[7] J. M. Conrad,[1] F. B. Descamps,[8] M. V. Diwan,[5] D. A. Dwyer,[8] S. T. Dye,[9] A. Elagin,[6] P. Feng,[10] C. Grant,[3] S. Grullon,[2] S. Hans,[5] D. E. Jaffe,[5] S. H. Kettell,[5] J. R. Klein,[2] K. Lande,[2] J. G. Learned,[11] K. B. Luk,[8,12] J. Maricic,[11] P. Marleau,[10] A. Mastbaum,[2] W. F. McDonough,[13] L. Oberauer,[14] G. D. Orebi Gann*,[8,12,†] R. Rosero,[5] S. D. Rountree,[15] M. C. Sanchez,[16] M. H. Shaevitz,[17] T. M. Shokair,[18] M. B. Smy,[19] A. Stahl,[20] M. Strait,[6] R. Svoboda,[3] N. Tolich,[21] M. R. Vagins,[19] K. A. van Bibber,[18] B. Viren,[5] R. B. Vogelaar,[15] M. J. Wetstein,[6] L. Winslow,[1] B. Wonsak,[22] E. T. Worcester,[5] M. Wurm,[23] M. Yeh,[5] and C. Zhang[5]

50 authors, 23 institutions, lots of experience: Borexino, DUNE, KamLAND, SNO, Double CHOOZ, SNO+, Daya Bay, LENA, KamLAND-Zen, MiniBOONE, Super-Kamiokande, WATCHMAN, ANNIE, T2K....

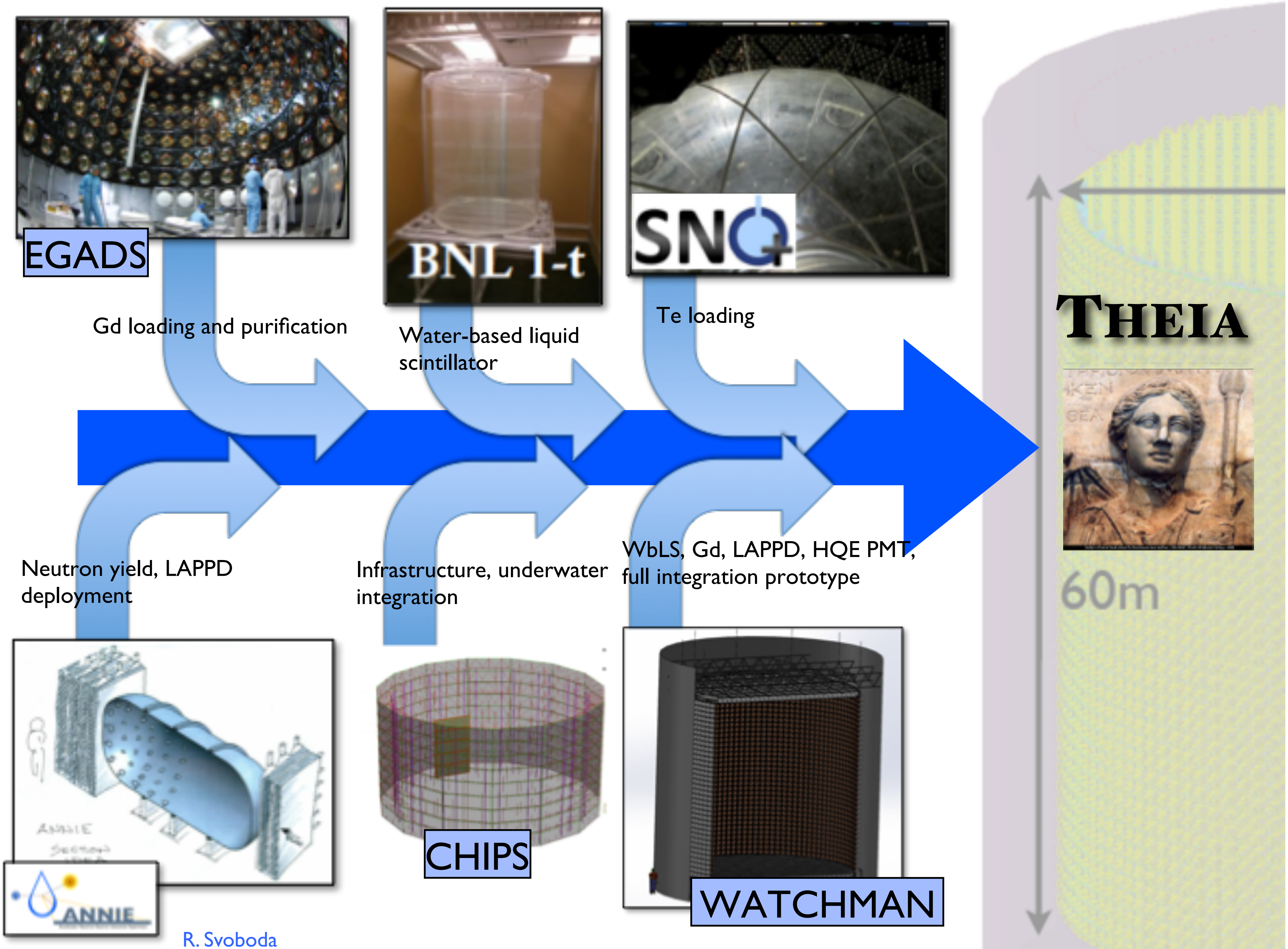
Brookhaven National Laboratory
University of California, Berkeley
University of California, Davis
University of California, Irvine
University of Chicago
Columbia University
University of Hawaii at Manoa
Hawaii Pacific University
Iowa State University
Lawrence Berkeley National Laboratory
Los Alamos National Laboratory
University of Maryland
MIT
University of Pennsylvania
Princeton University
Sandia National Laboratories
Virginia Polytechnic Inst. & State University
University of Washington
RWTH Aachen University
TUM, Physik-Department
University of Hamburg
Johannes Gutenberg-University Mainz

wbls@lists.lbl.gov
wblsrd@lists.lbl.gov

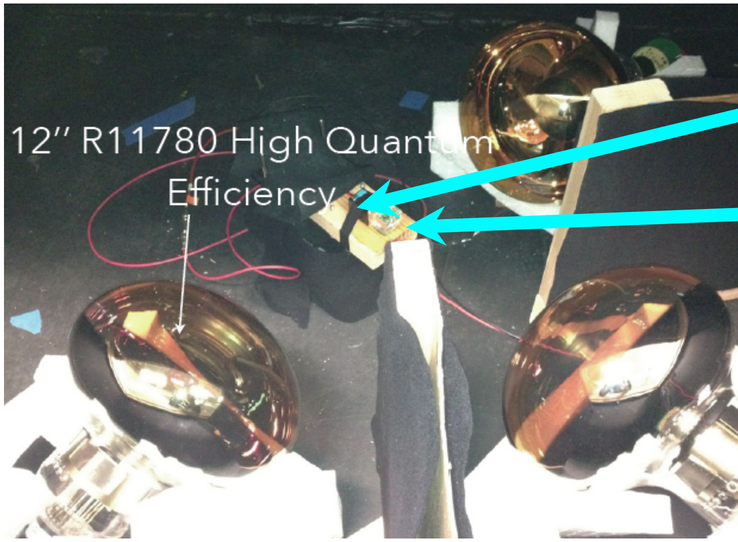
New participation welcome
Contact
G.D. Orebi Gann, R. Svoboda, E. Blucher, JRK

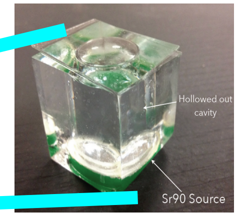
Planned Demonstrations

Site	Scale	Target	Measurements	Timescale
UChicago	bench top	H2O	fast photodetectors	Exists
CHIPS	10 kton		electronics, readout, mechanical infrastructure	2019
EGADS	200 ton	H2O+Gd	isotope loading, fast photodetectors	Exists
ANNIE	30 ton			2016
WATCHMAN	1 kton			2019
UCLA/MIT	1 ton	LS	fast photodetectors	2015
Penn	30 L	(Wb)LS	light yield, timing, loading	Exists
SNO+	780 ton			2016
LBNL	bench top	WbLS	light yield, timing, cocktail optimization, loading, attenuation, reconstruction	Early 2015
BNL	1 ton			Summer 2015
WATCHMAN-II	1 kton			2020


EGADS
BNL 1-t
SNO+
THEIA
60m
Gd loading and purification
Water-based liquid scintillator
Te loading
Neutron yield, LAPPD deployment
Infrastructure, underwater integration
WbLS, Gd, LAPPD, HQE PMT, full integration prototype
ANNIE
CHIPS
WATCHMAN
R. Svoboda

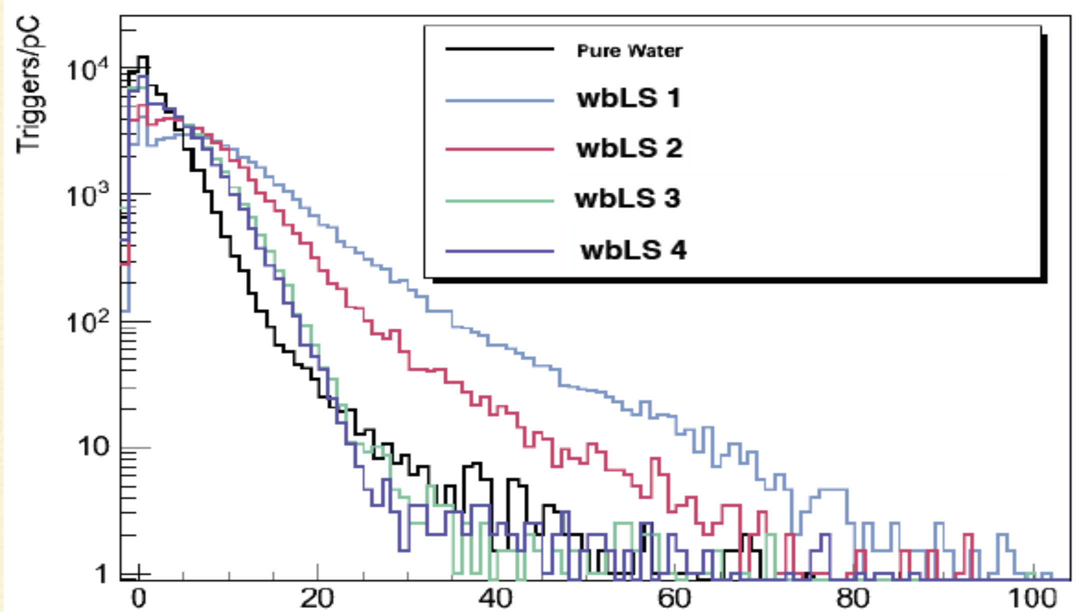
Water-based Liquid Scintillator





SAMPLE	MEASURED P.E. : WBLS/WATER	SCINTILLATION LIGHT YIELD
WbLS1	4.00 ± 0.06	~300 photons/MeV
WbLS2	2.71 ± 0.07	~200 photons/MeV
WbLS3	1.68 ± 0.09	~110 photons/MeV
WbLS4	1.52 ± 0.08	~100 photons/MeV
WbLS5	1.9 ± 0.09	~125 photons/MeV

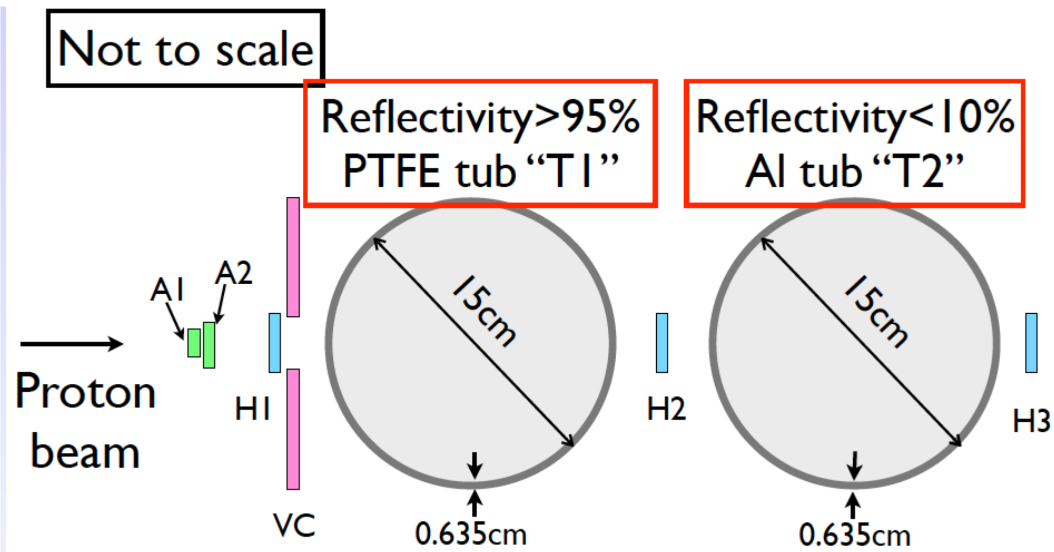
At low energies, intrinsic light yield scales with scintillator fraction.

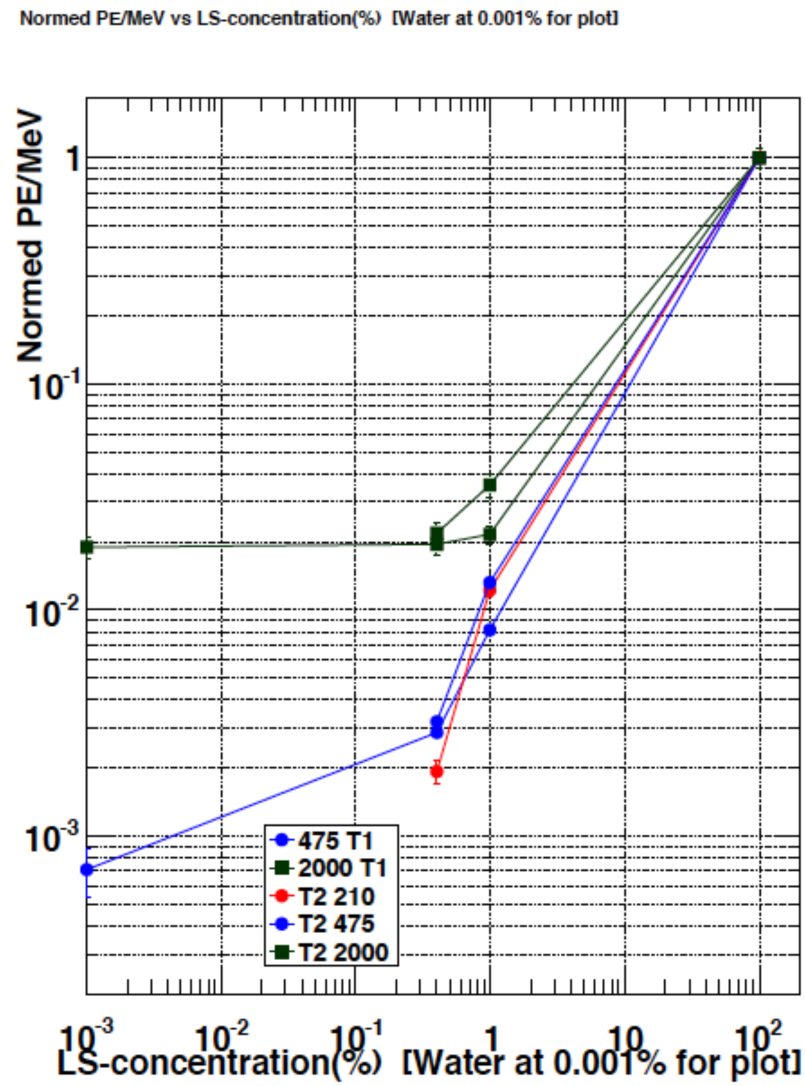


S. Grullon et al., U. Penn

Water-based Liquid Scintillator

And at high energies, until Cherenkov contribution becomes large.



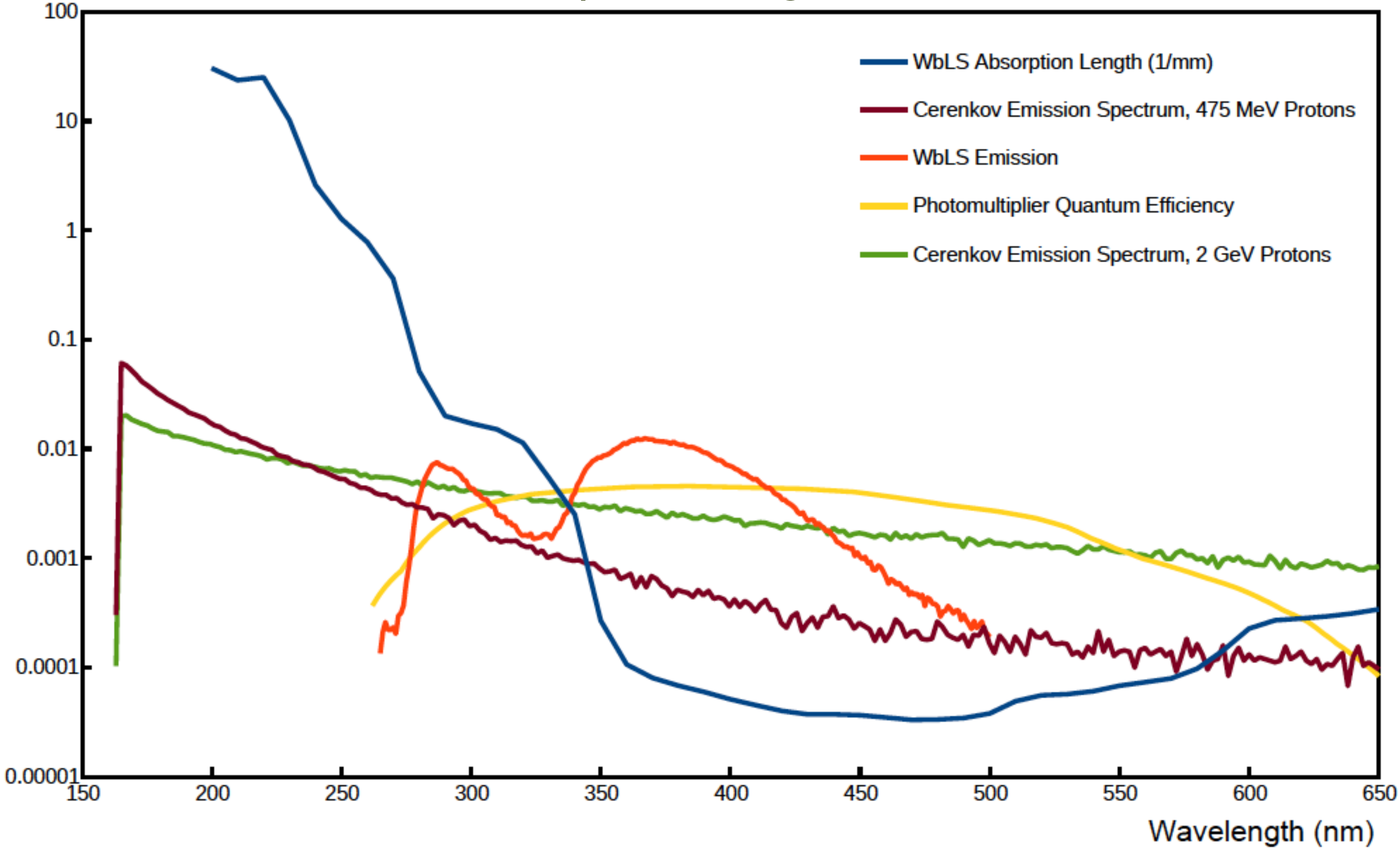


See M. Yeh's talk

D. Jaffe, BNL

Water-based Liquid Scintillator

Optics look good

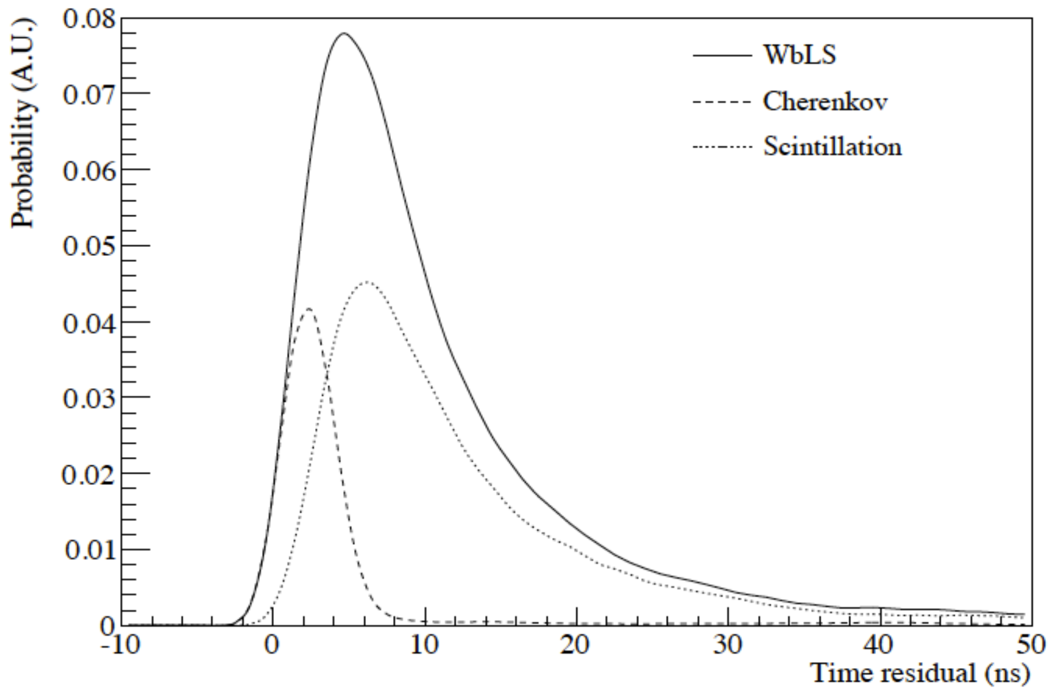


See M. Yeh's talk

D. Jaffe, BNL

Cherenkov/Scintillation Separation

- Long extinction length means detector can be large
- About ½ of Cherenkov light absorbed or scattered
- But separation of two components still possible



A. Mastbaum, Penn

Cherenkov ID scales like

$$R_{s/c} \sim \frac{\gamma_C}{\gamma_S} \frac{t_{jitt}}{\tau_{scint}} \rho(\cos\alpha_C) R(\lambda)$$

t_{jitt} = transit time spread of PD
τ_{scint} = scintillation time constant
γ_C=number of Cherenkov photons
γ_S=number of scintillation photons
$\rho(\cos\alpha_c)$ = angular weighting function
$R(\lambda)$=spectral response function

So for a 4% scintillation fraction, standard PMTs, no use of angular information, and equal spectral response for C and S, $R_{s/c}$~ 0.25

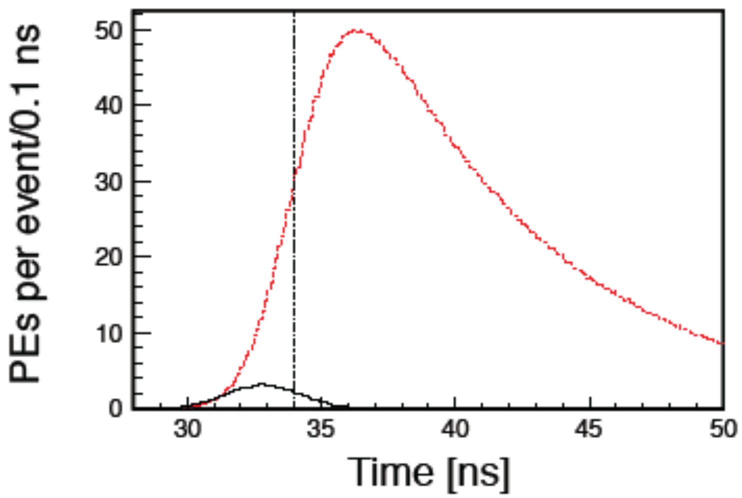
Cherenkov/Scintillation Separation

Separation via Timing

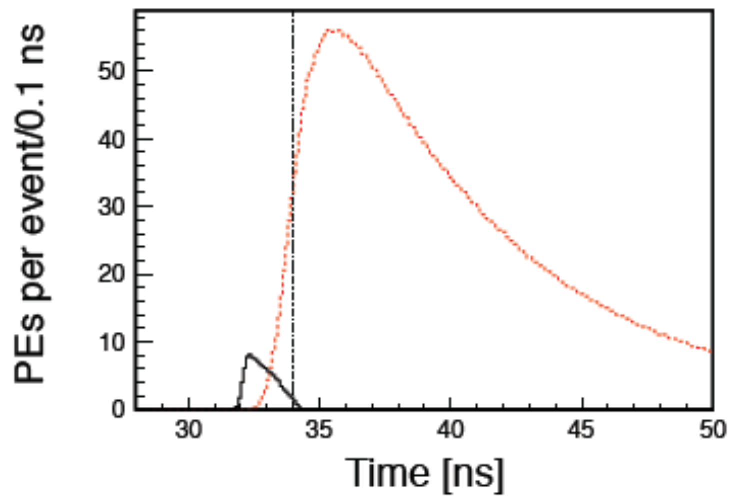
Simulation of 5MeV electrons in KamLAND-like detector

Cherenkov (prompt, scarce)

Scintillation (delayed, abundant)



1.3 ns timing of standard PMT



0.1 ns time resolution e.g. LAPPD

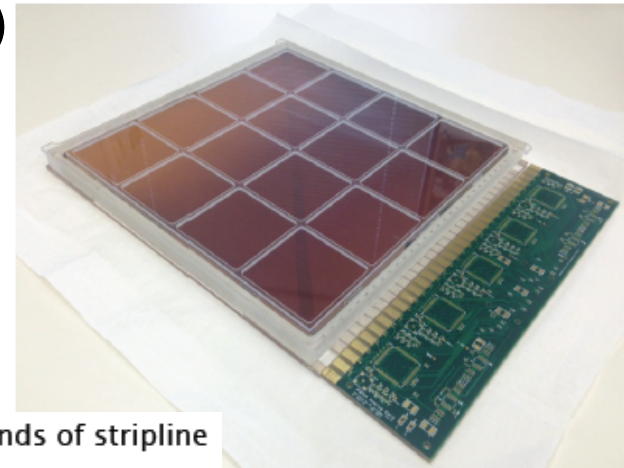
C. Aberle et al, JINST 9 P06012 (2014)

Cherenkov/Scintillation Separation

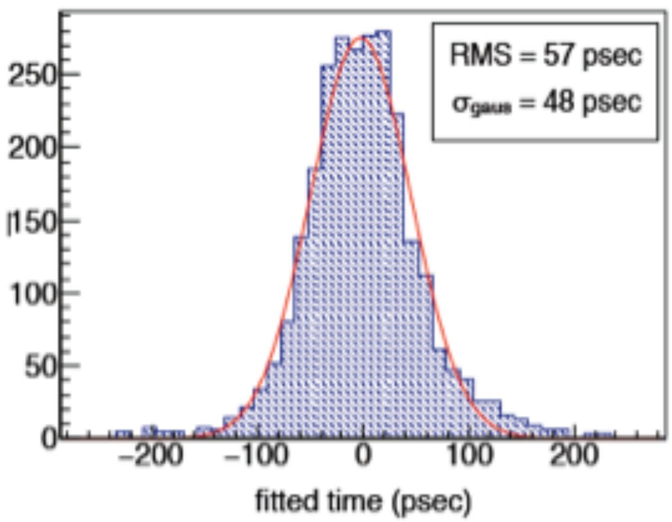
Separation via Timing

Large Area Picosecond Photodetectors (LAPPDs)

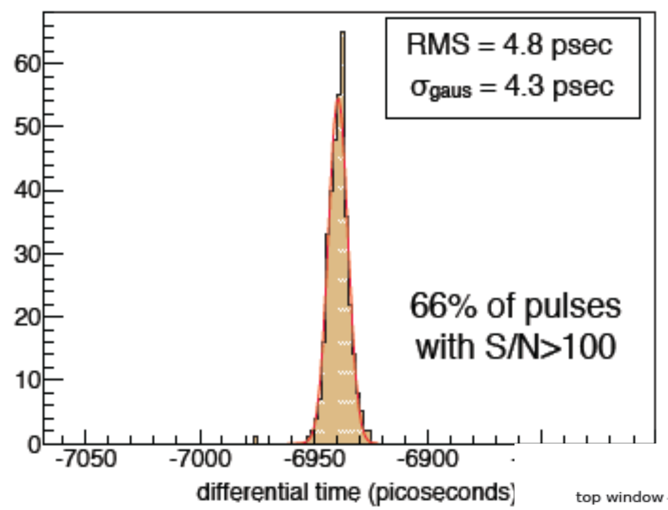
- Large, flat-panel MCP-based photosensors
- 50-100 ps time resolution (<1cm spatial)
- working readout system

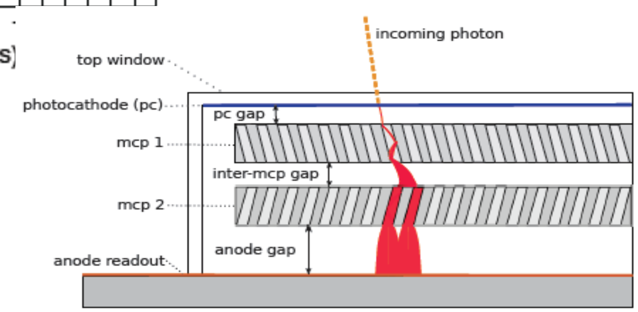


single photoelectron absolute time resolution



differential time resolution between 2 ends of stripline





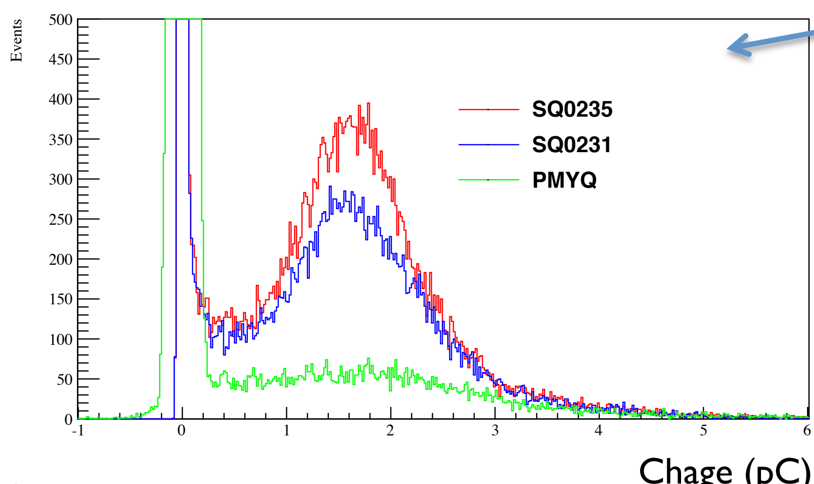
M. Wetstein

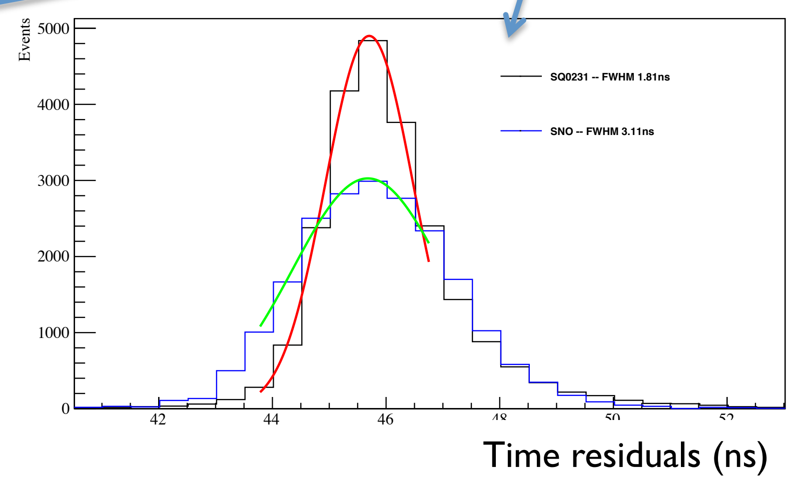
Cherenkov/Scintillation Separation

Separation via Timing

Exiting PMTs may be good enough

12” HQE (Hamamatsu) | 11” HQE (ETL) | 10” HQE (Hamamatsu) | 8” standard (ETL) | 8” HQE (Hamamatsu) | SNO PMT





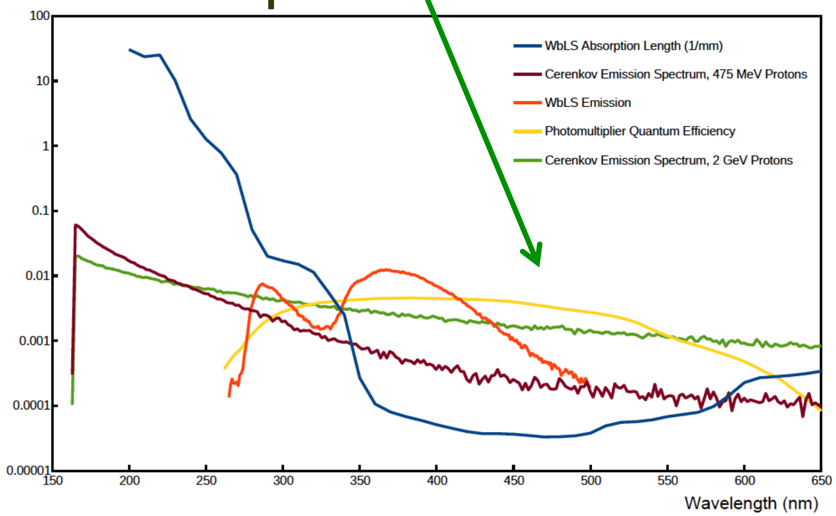
See Tanner Kaptonoglu’s talk

Charge and time response dramatically better

Cherenkov/Scintillation Separation

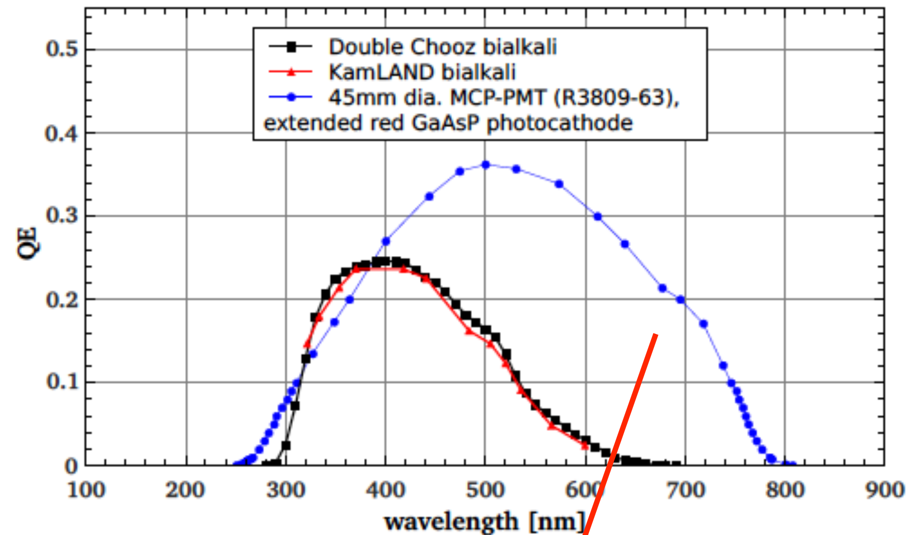
Separation via Wavelength (+timing)

Cherenkov light extends beyond scintillation emission and absorption

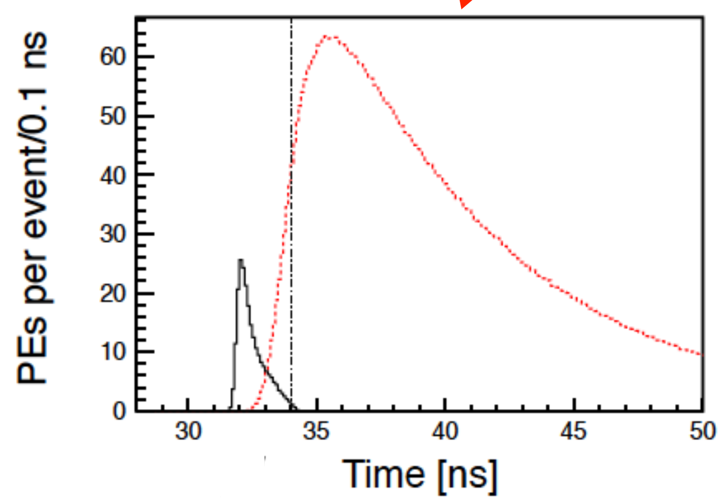


And red travels faster than blue…

Red-sensitive PMTs exist



L. Winslow



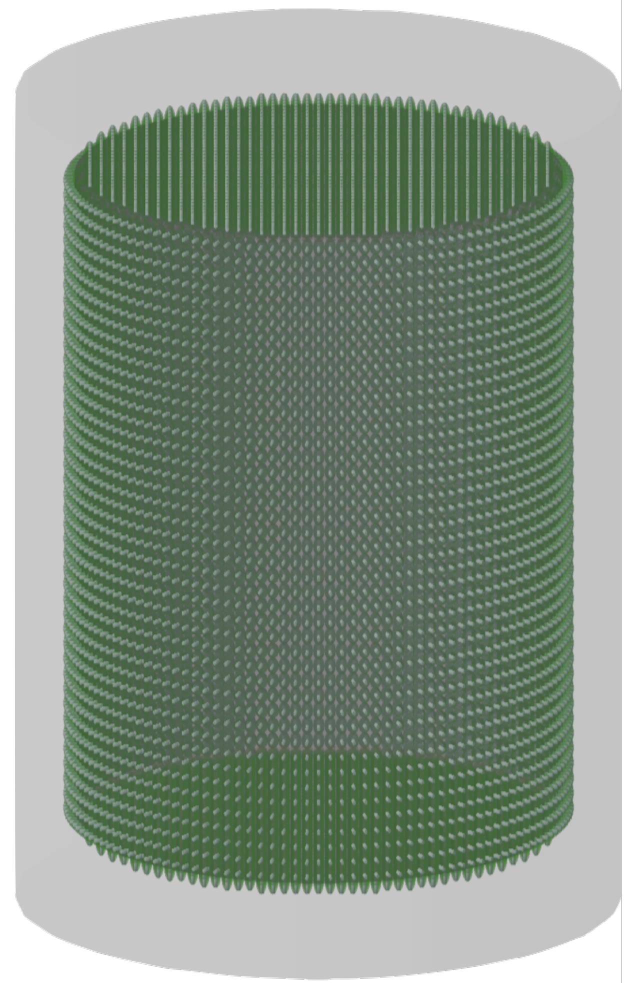
Path Forward Toward THEIA

Simulation and Analysis Development

- Started with "RAT" simulation/analysis package
- Plus Additional Code from L-Z development

=  RAT-PAC

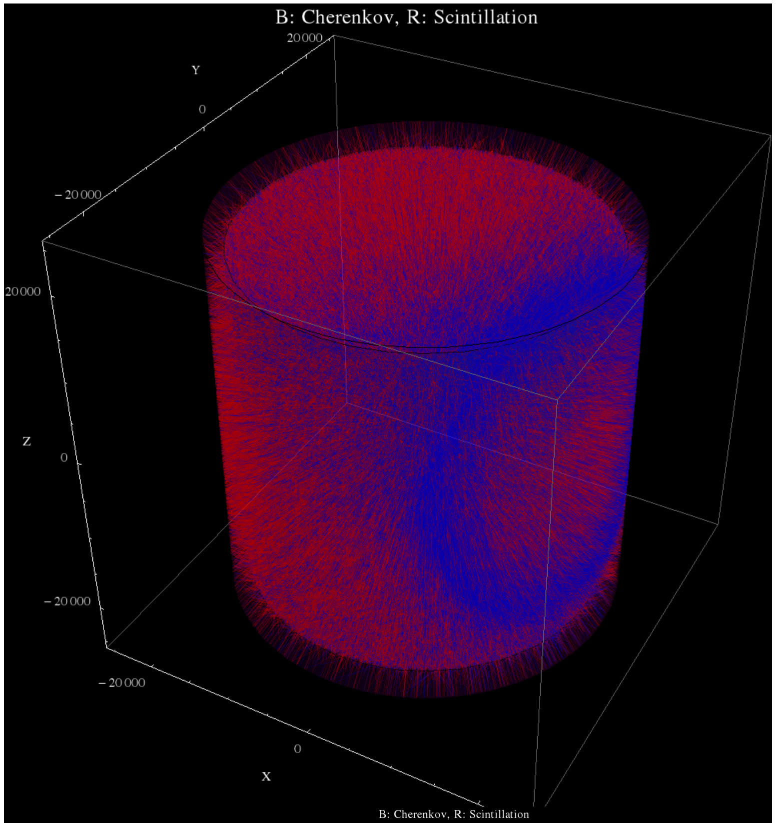
- Fully Open Source
- Includes complete THEIA geometry
  - 12" HQE PMTs
  - Simple WbLS properties
- Ported reconstruction algorithms from SNO and Super-K
- Adopted also by WATCHMAN
- Easily adaptable to test-stands
- Lots of development happening!

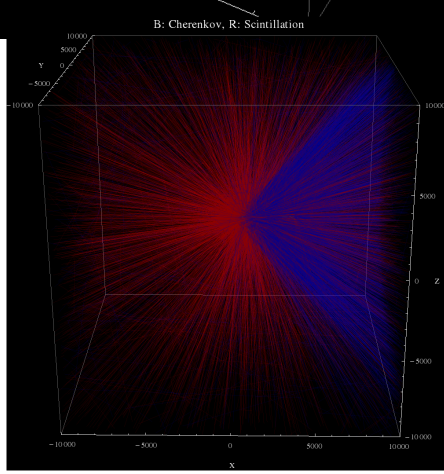


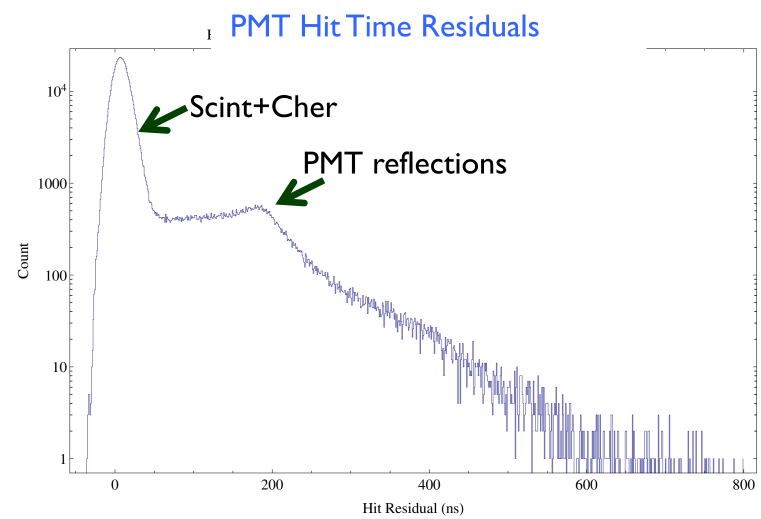
See Javier Caravaca's talk

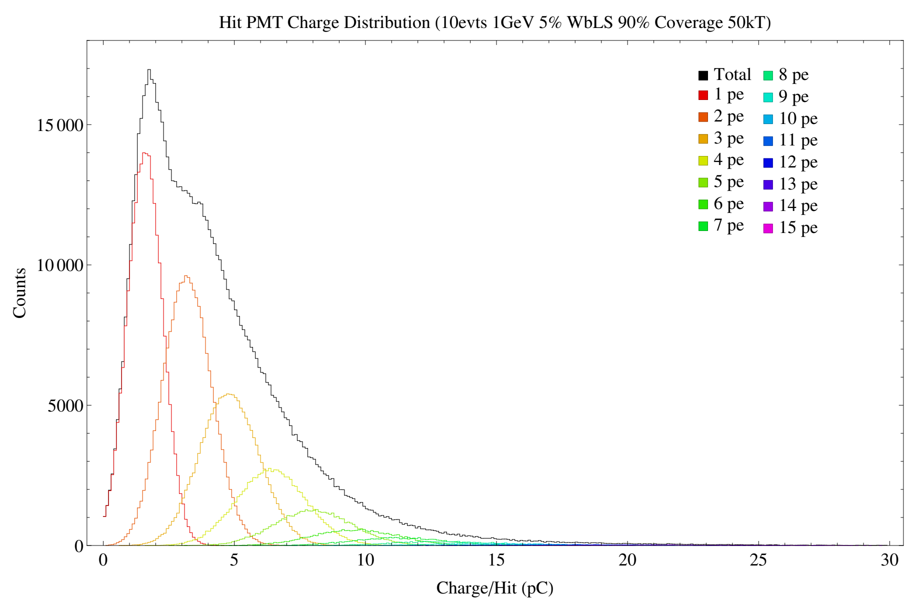
Path Forward Toward THEIA

Simulation and Analysis Development



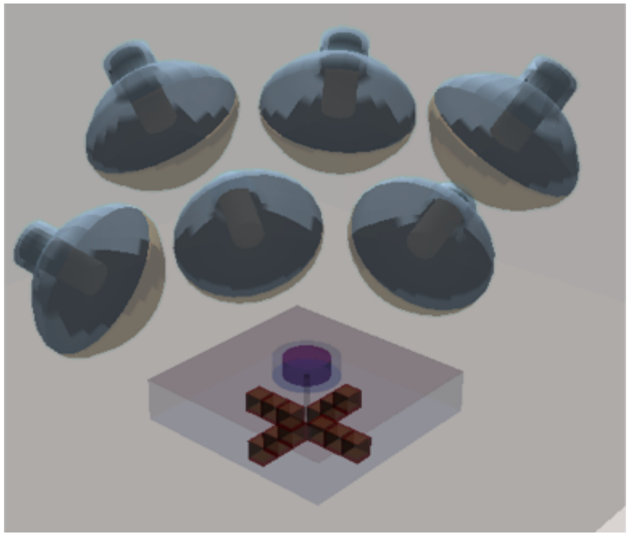


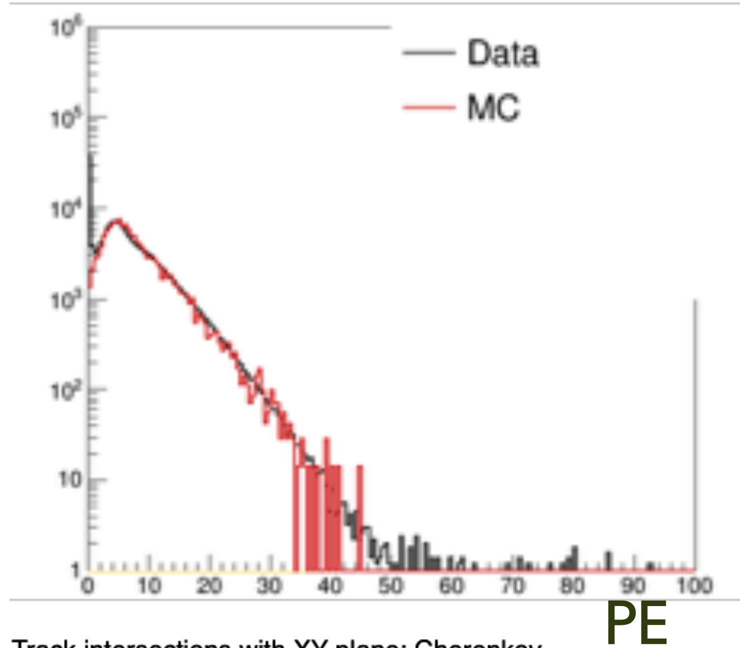


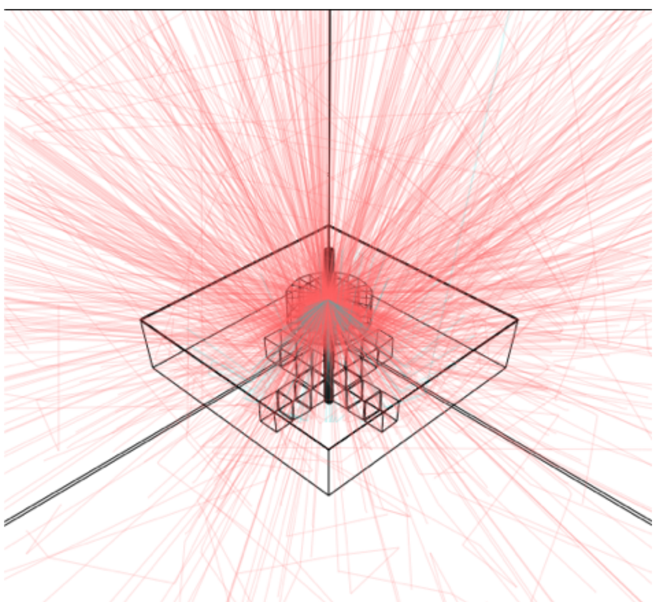


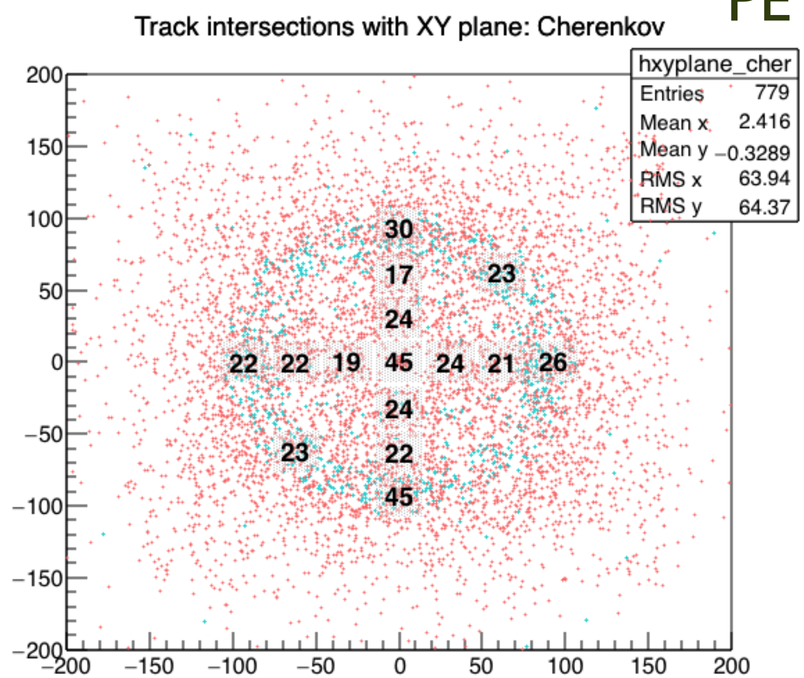
B. Land (Berkeley)

Cherenkov/Scintillation Separation



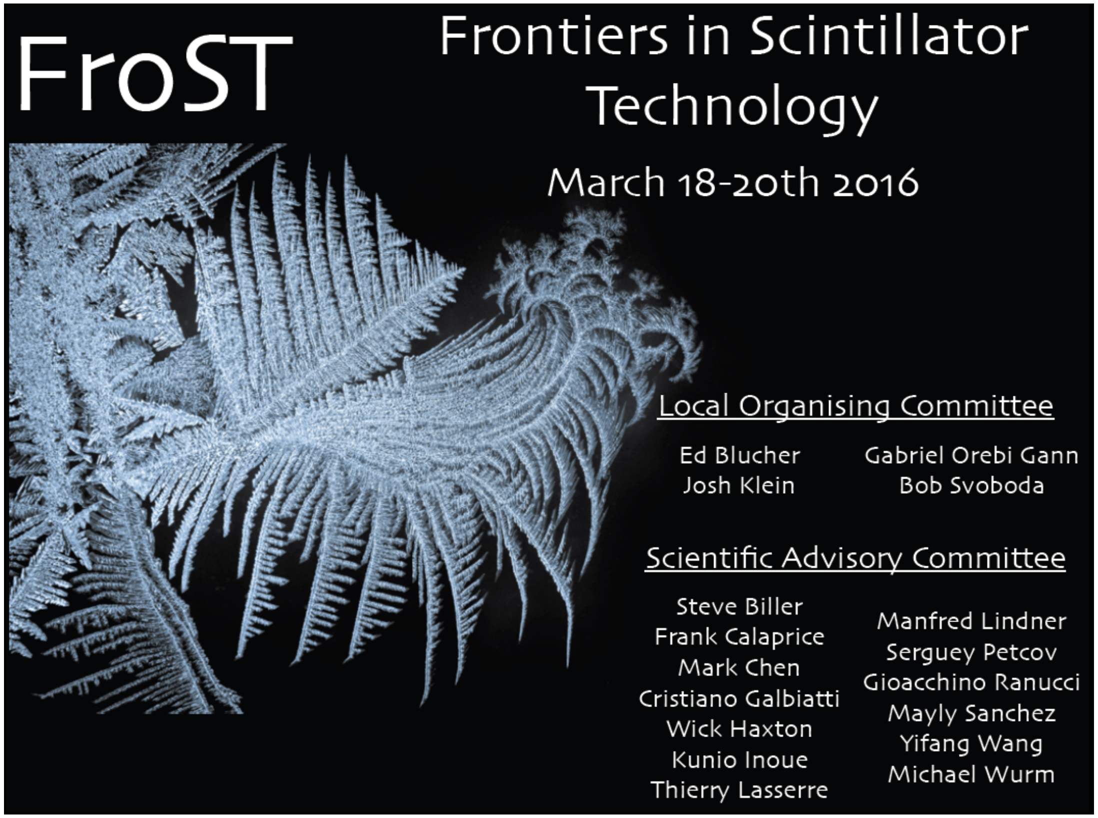






Berkeley

Path Forward Toward THEIA



Focus:

- Physics programs
- Requirements for future detectors
- Enabling technologies,
  - New scintillator cocktails (e.g., WbLS)
  - Loading techniques
  - Photosensors,
  - Inner containment vessels

Will begin serious community discussion on path toward a large-scale, multi-purpose detector like Theia