New Water-based Liquid Scintillator For Large Physics Experiments

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BROOKHAVEN
NATIONAL LABORATORY

Brookhaven Forum 2013

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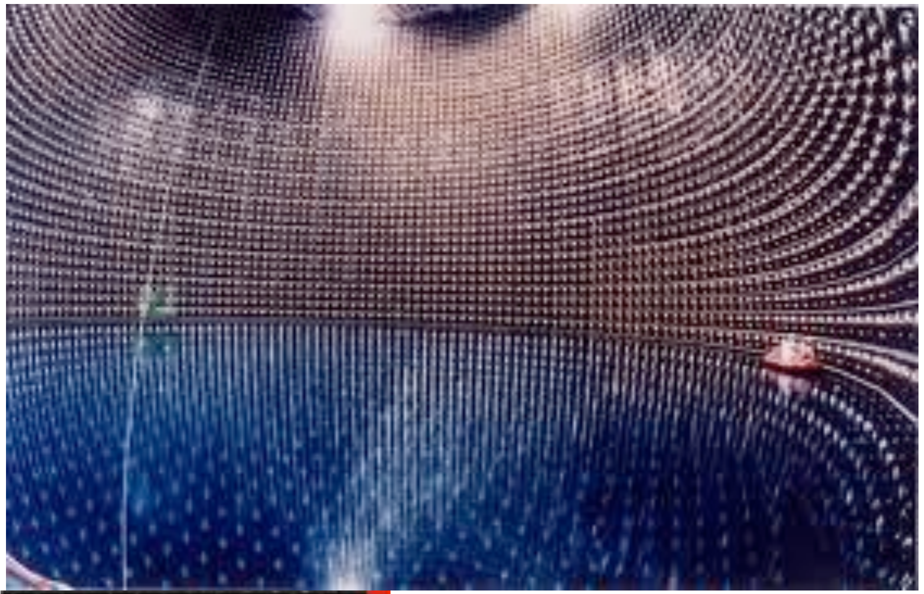
Can we combine the best part of a Cherenkov Detector with a Liquid Scintillator Detector?



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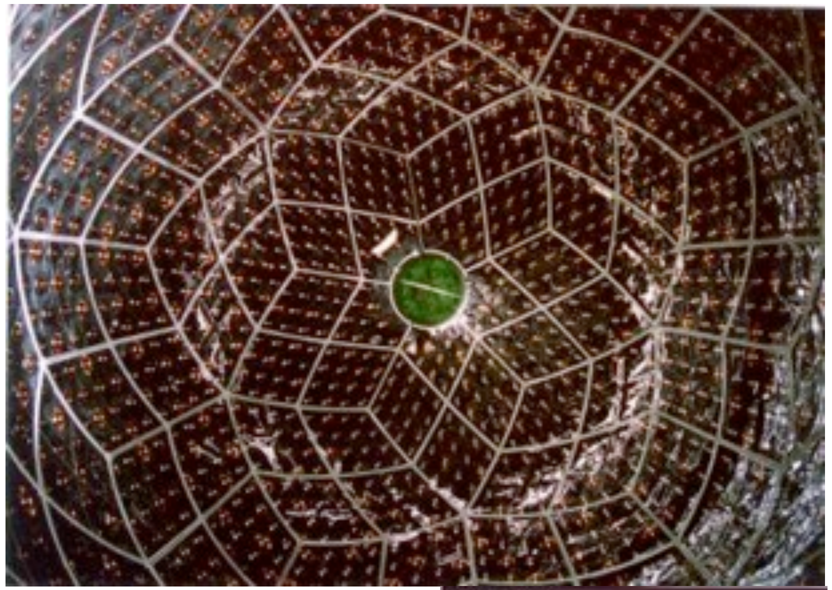
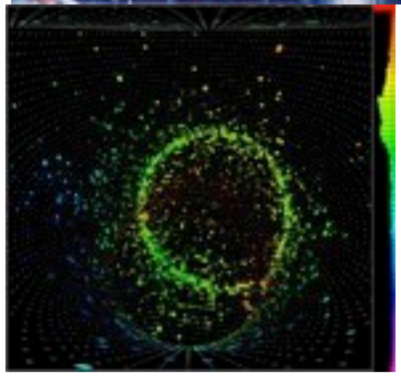


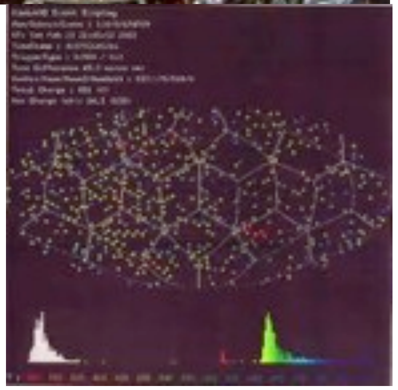


1GeV muon

=

?

2MeV positron & photon



Clear particle ID
Direction information
Highly transparent
Cost effective
Safe to handle

Lots of light
High efficiency
(even at low energy)

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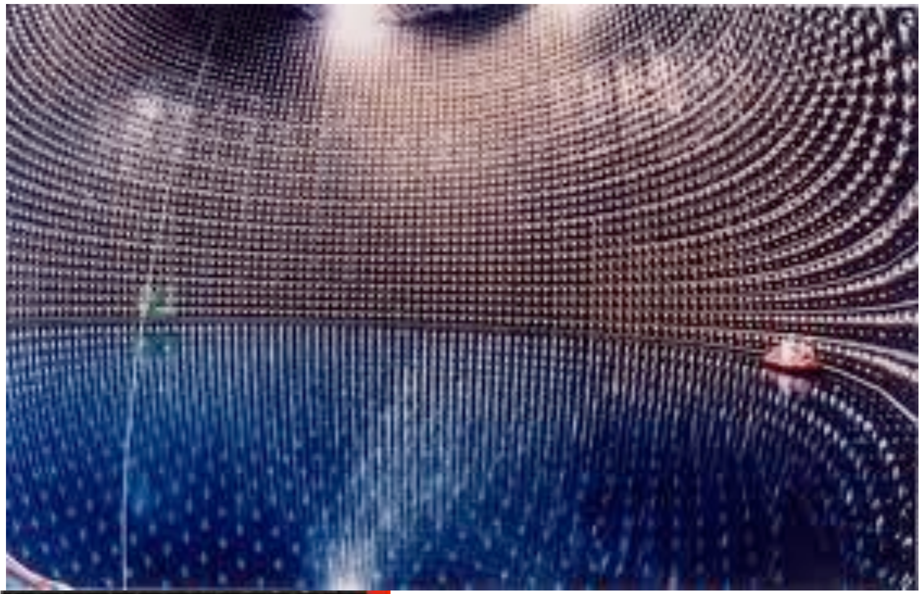

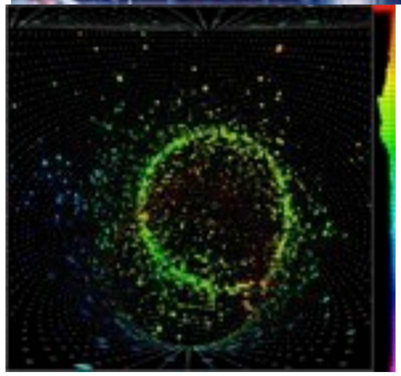

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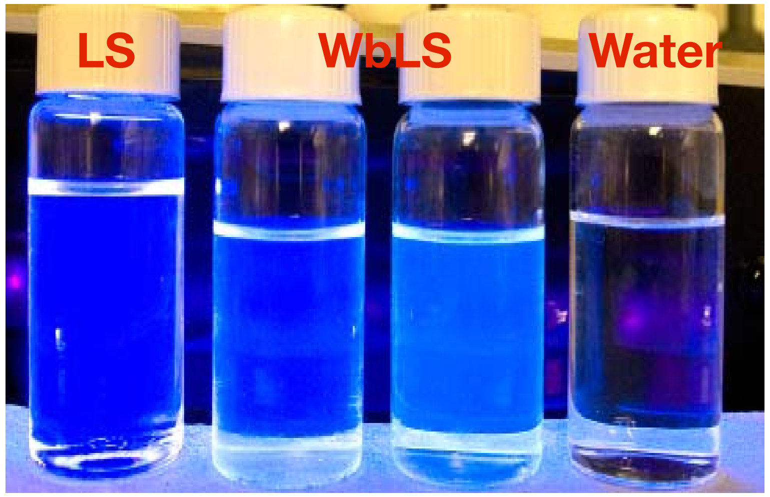
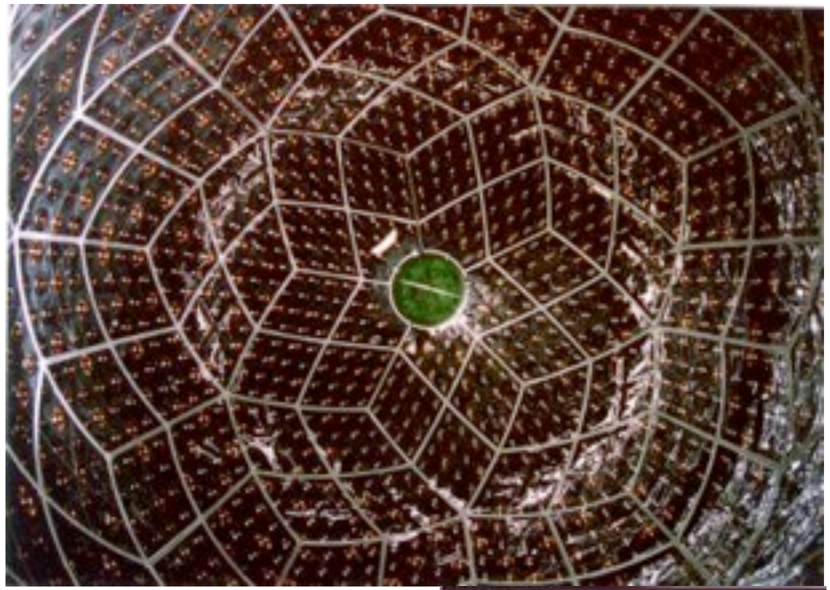
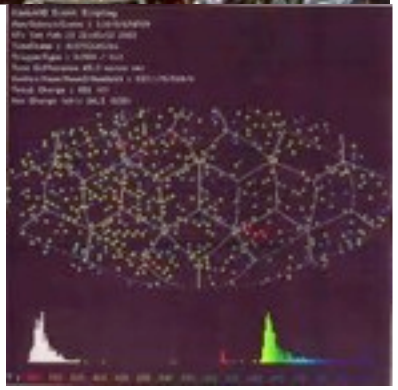
Water-based Liquid Scintillator







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& photon

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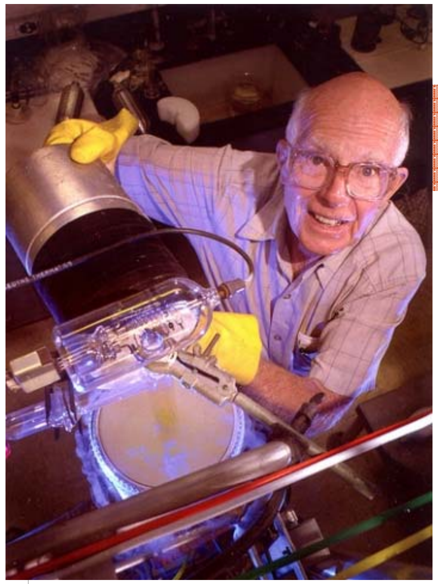
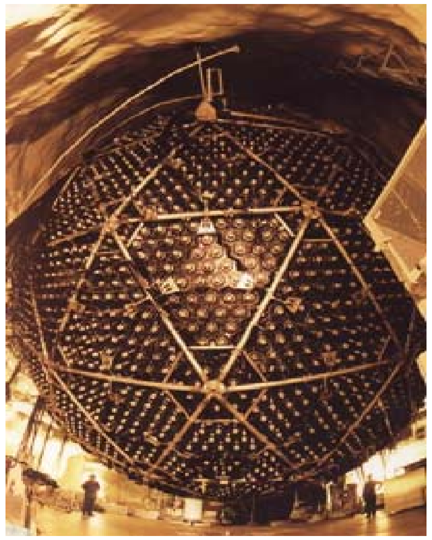
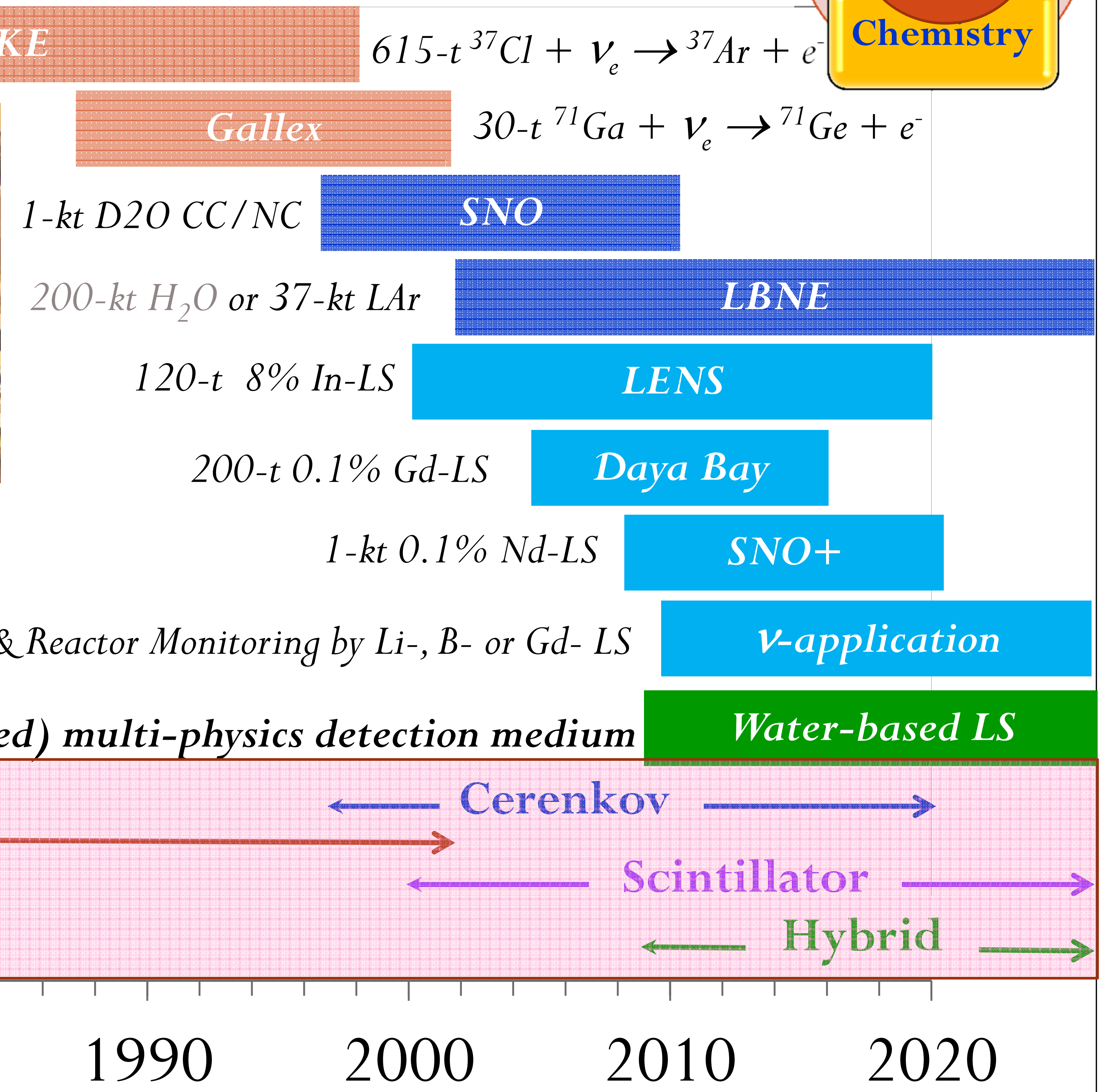
BNL Neutrino and Nuclear Chemistry

Neutrino 50 Chemistry







HOMESTAKE 615-t $^{37}Cl + \nu_e \rightarrow {}^{37}Ar + e^-$

Gallex 30-t $^{71}Ga + \nu_e \rightarrow {}^{71}Ge + e^-$

1-kt D2O CC/NC *SNO*

200-kt H_2O or 37-kt LAr *LBNE*

120-t 8% In-LS *LENS*

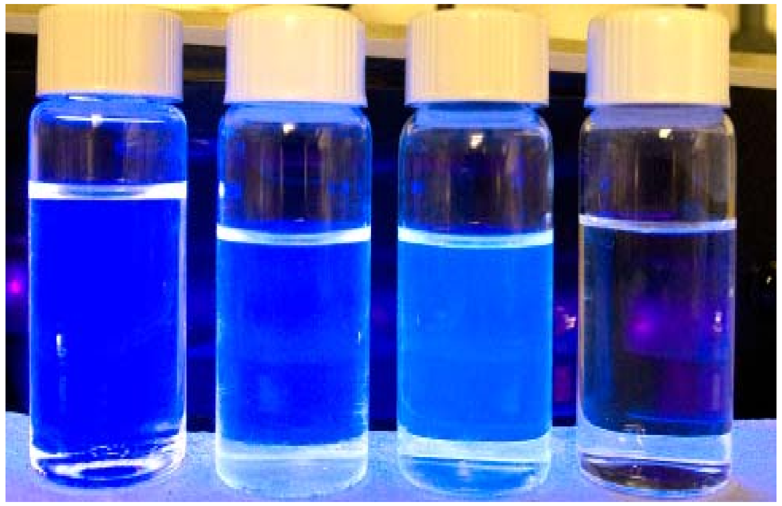
200-t 0.1% Gd-LS *Daya Bay*

1-kt 0.1% Nd-LS *SNO+*

Nonproliferation & Reactor Monitoring by Li-, B- or Gd- LS *ν-application*

(metallic-loaded) multi-physics detection medium ***Water-based LS***

What is water-based LS?



WbLS is not a mix of water and fluor or shifter.

A net light gain of 4.4±0.5

X. Dai et al., NIM-A 589 (2008) 290.

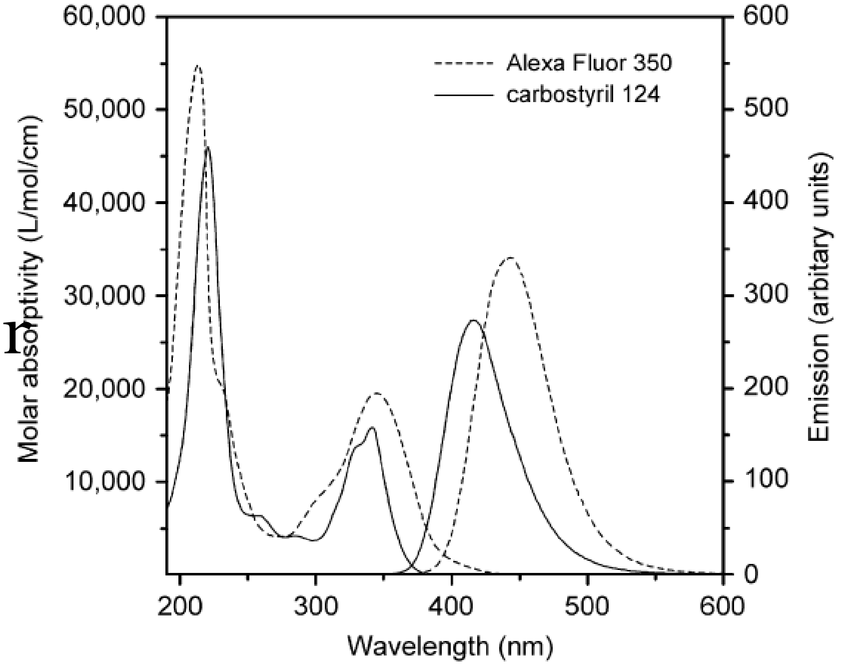
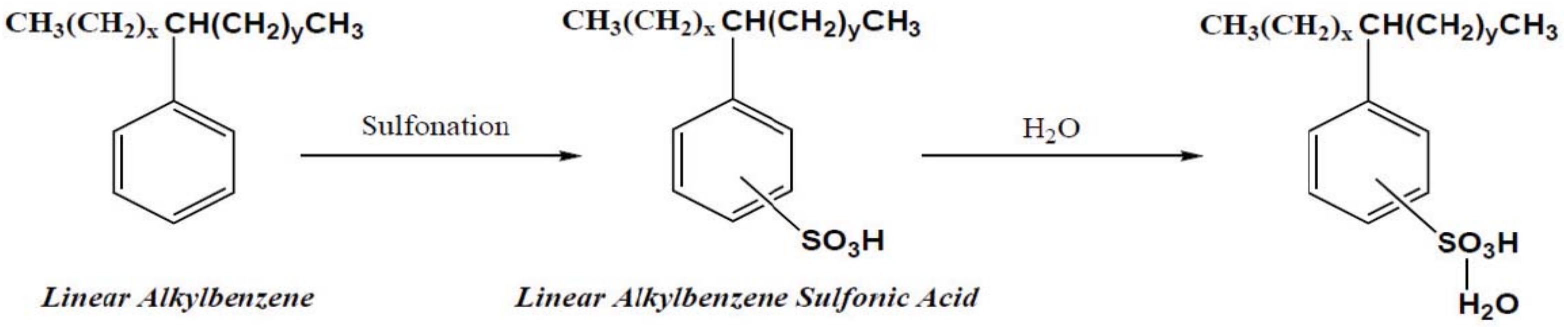
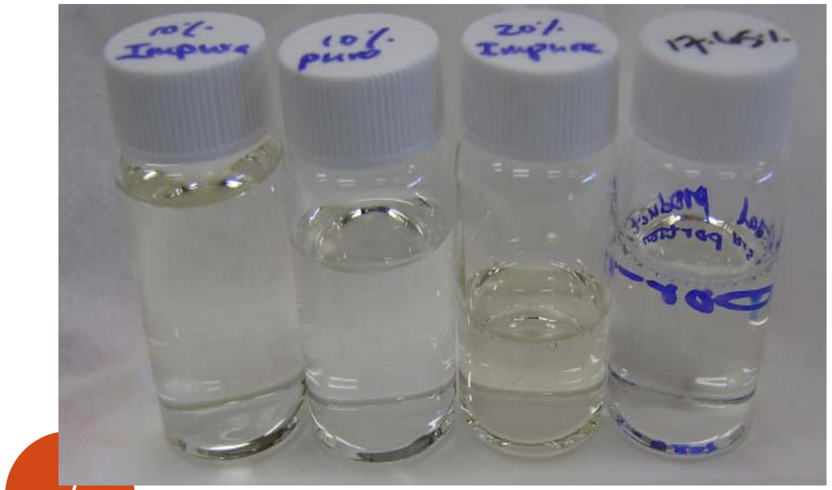


Fig. 2. The UV/VIS absorption (left) and fluorescence emission spectra (right) for carbostyril 124 and Alexa Fluor 350.

Previous WbLS trials are either gel-like or not stable over time.

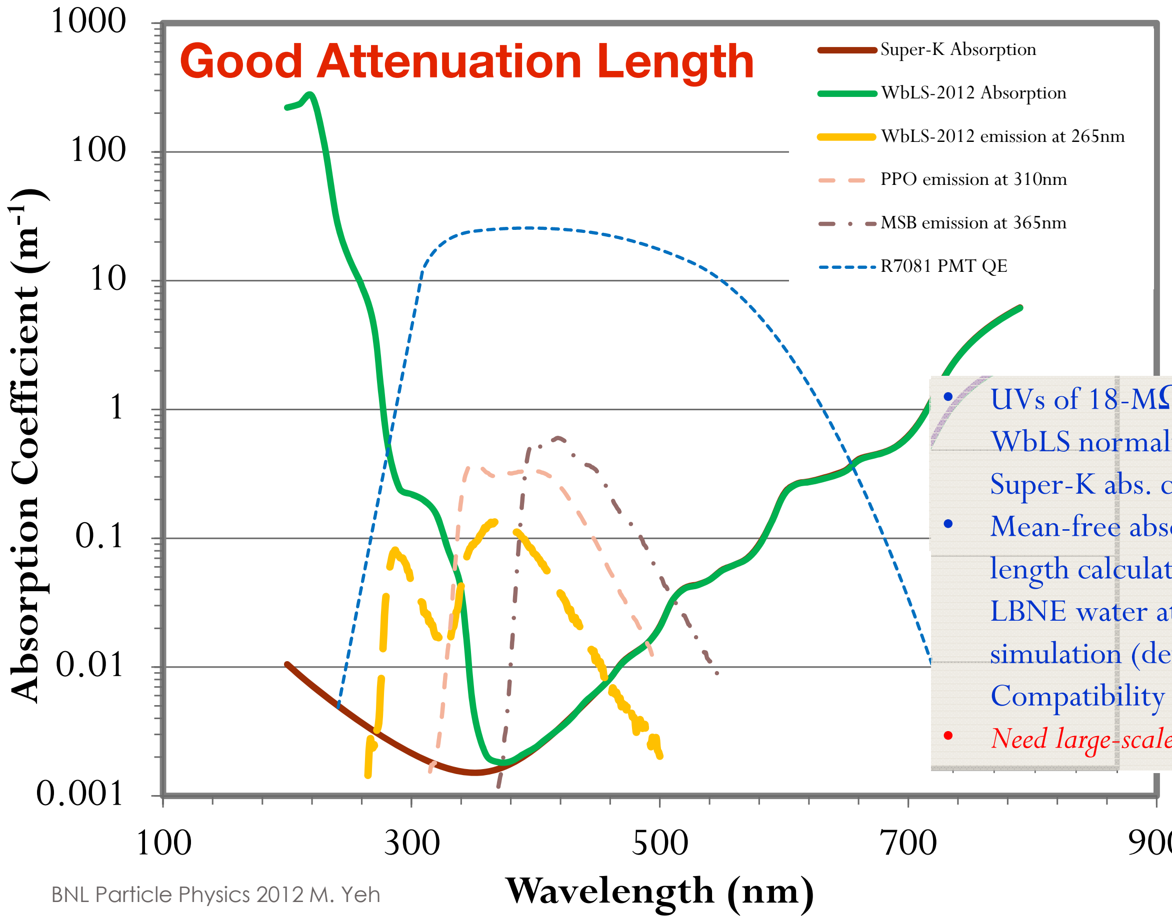




A scintillation water serves as energy spectrometer that probes physics below Cerenkov threshold.

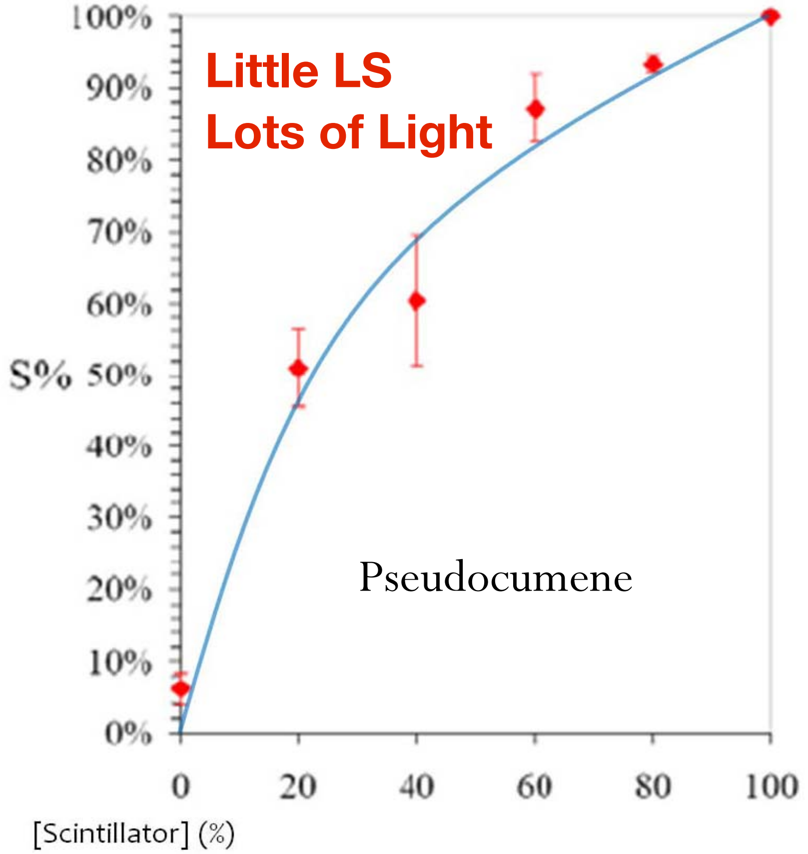
bridged by non-ionic syurfactant, i.e. LAB derivatives, sulfonate, sulfonic amine, etc.

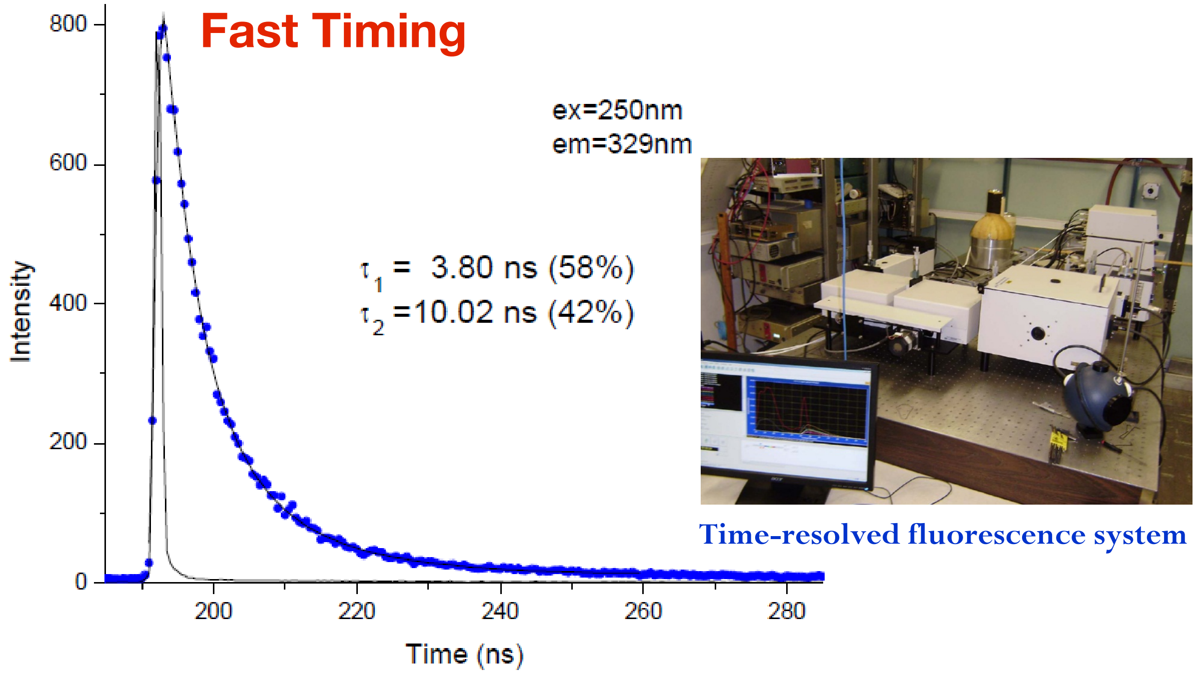
Properties of Water-based Liquid Scintillator



- UVs of 18-MΩ water and WbLS normalized to Super-K abs. curve.
- Mean-free absorption length calculated by LBNE water attenuation simulation (developed for Compatibility test).
- *Need large-scale verification*

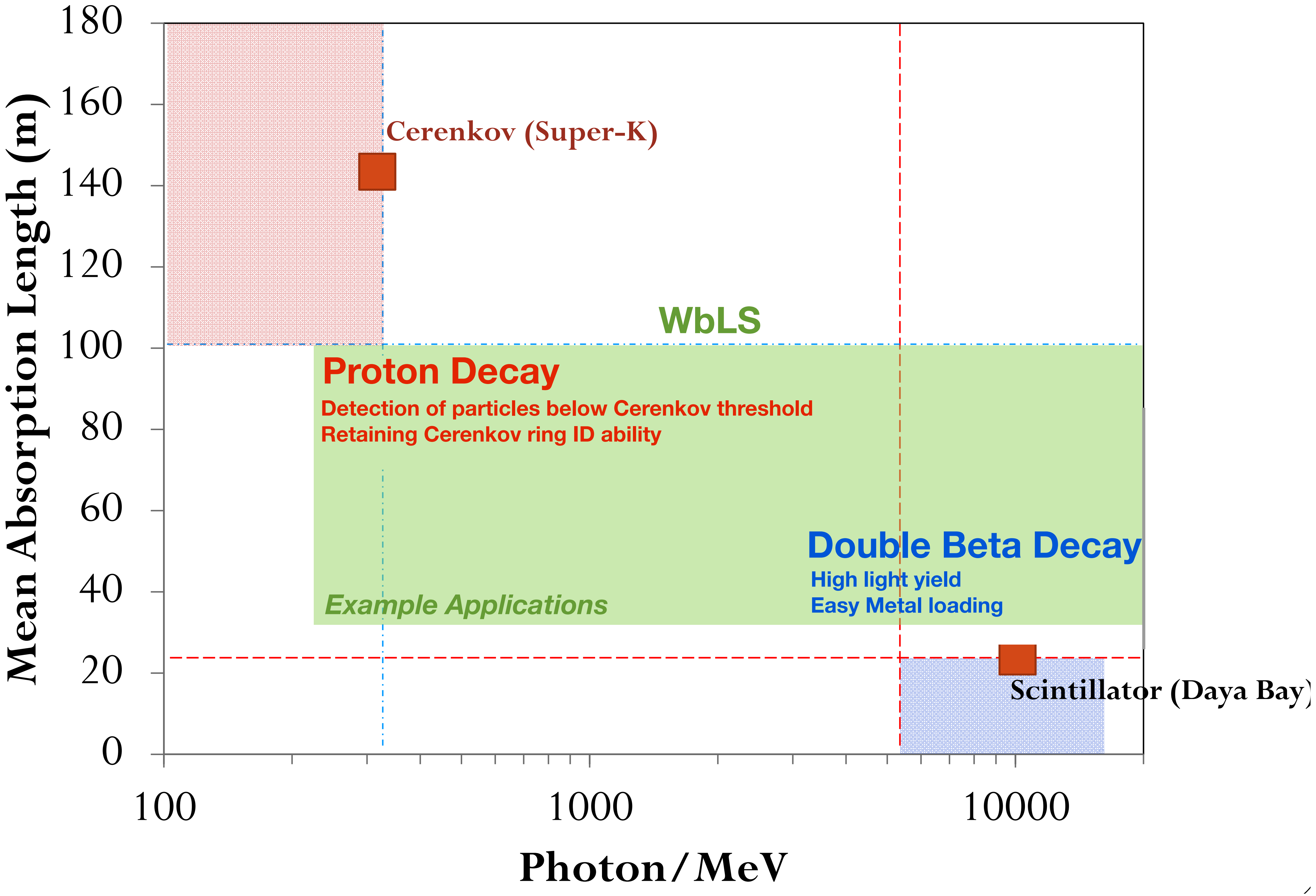
BNL Particle Physics 2012 M. Yeh





Time-resolved fluorescence system

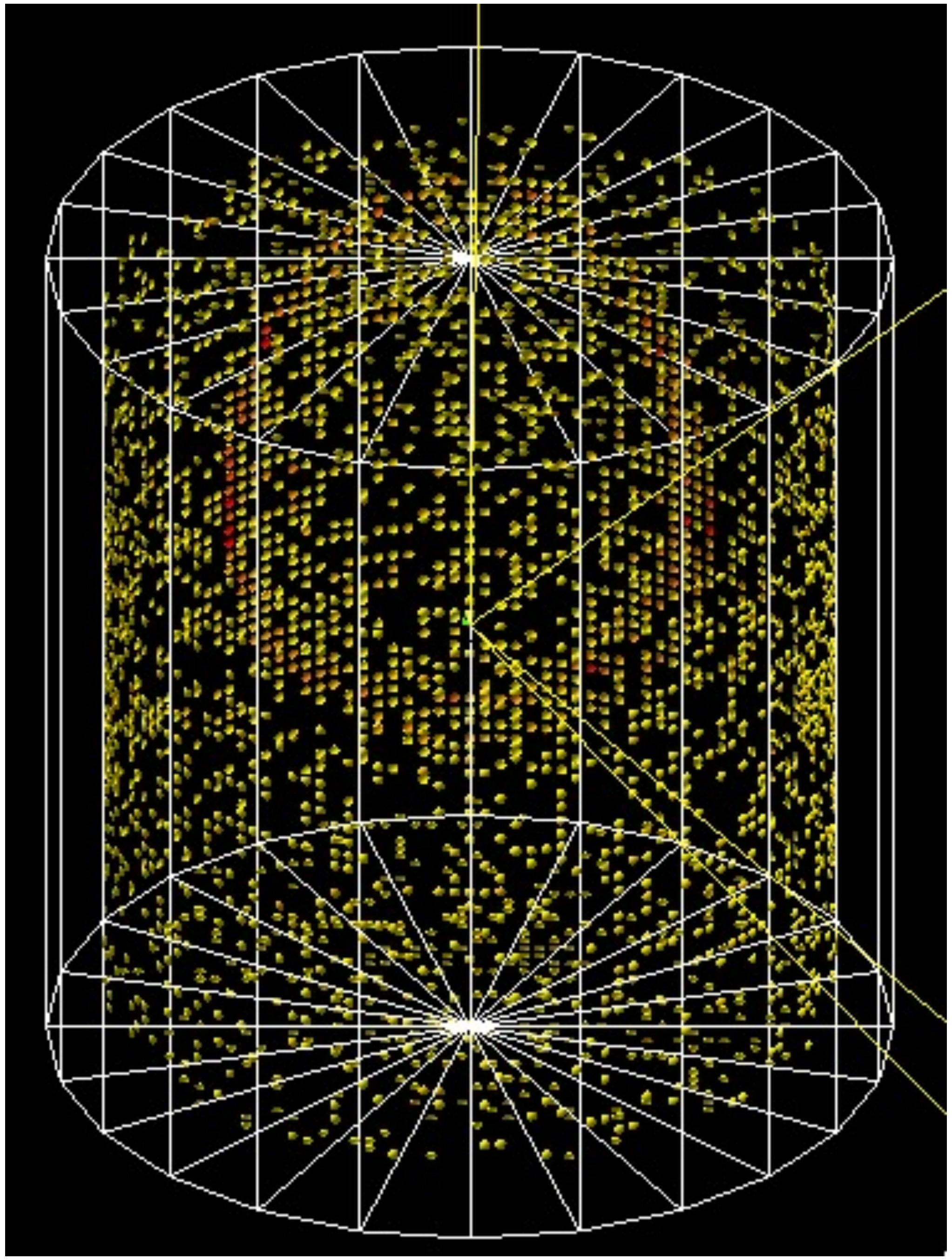
Applications of Water-based Liquid Scintillator



Simulation of a Large WbLS Detector

- Based on WCSim software (Geant4-based simulation used in LBNE Water detector concept design)
- SK-like geometry, 22.5 kton Fiducial Volume
- SK 20” PMT, 40% coverage
- WbLS material + scintillation + wavelength shifting

x%-WbLS (d=0.9945 g/cm^3) +PPO					
Element composition (%)	**H**	**O**	**C**	**S**	**N**
	65.9	**30.9**	**3.1**	**0.09**	**0.006**
Refractive Index	**1.3492 @580nm**				
Timing	**1.23 ns (26%) + 9.26 ns (74%)**				
Absorption length	**50m @430 nm**				
Birks Constant	**0.124 mm/MeV**				
photon yield	**90 / MeV (tunable)**				



Example: a 500 MeV Muon

The $p \to K^+\bar{\nu}$ Channel in Cerenkov Detectors

$$p \to K^+\bar{\nu}$$

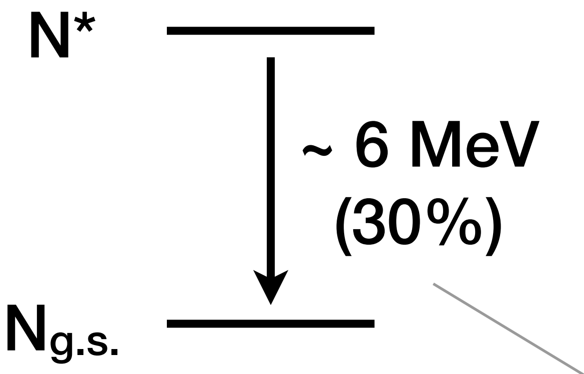
12.4 ns

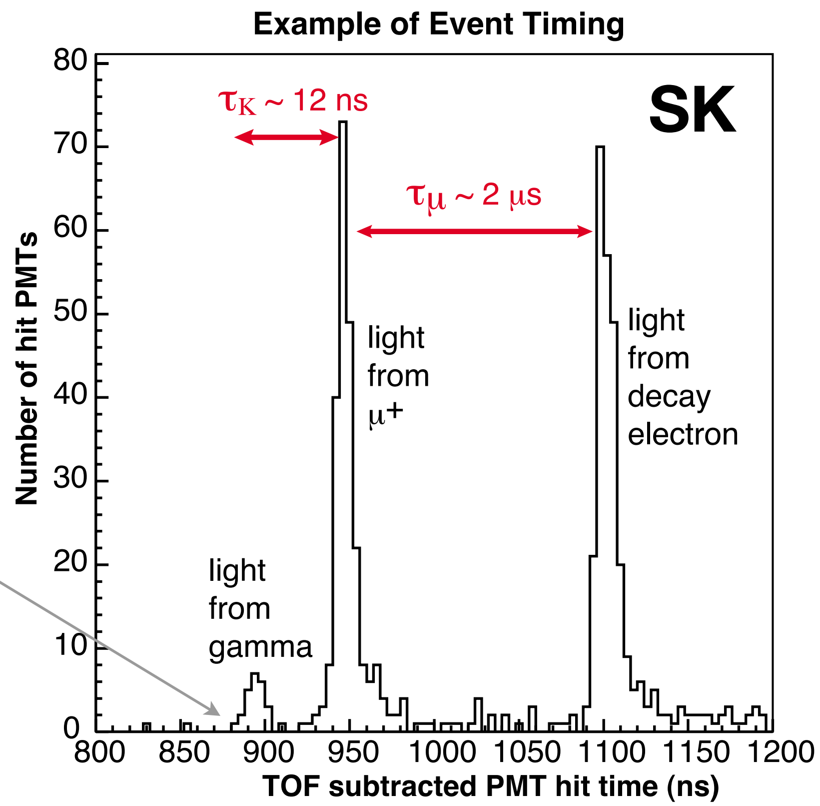
63% $K^+ \to \mu^+\nu_\mu$

21% $K^+ \to \pi^+\pi^0$

Favored SUSY decay mode

Kinetic Energy of K^+ is 105 MeV,
invisible in water Cerenkov detectors





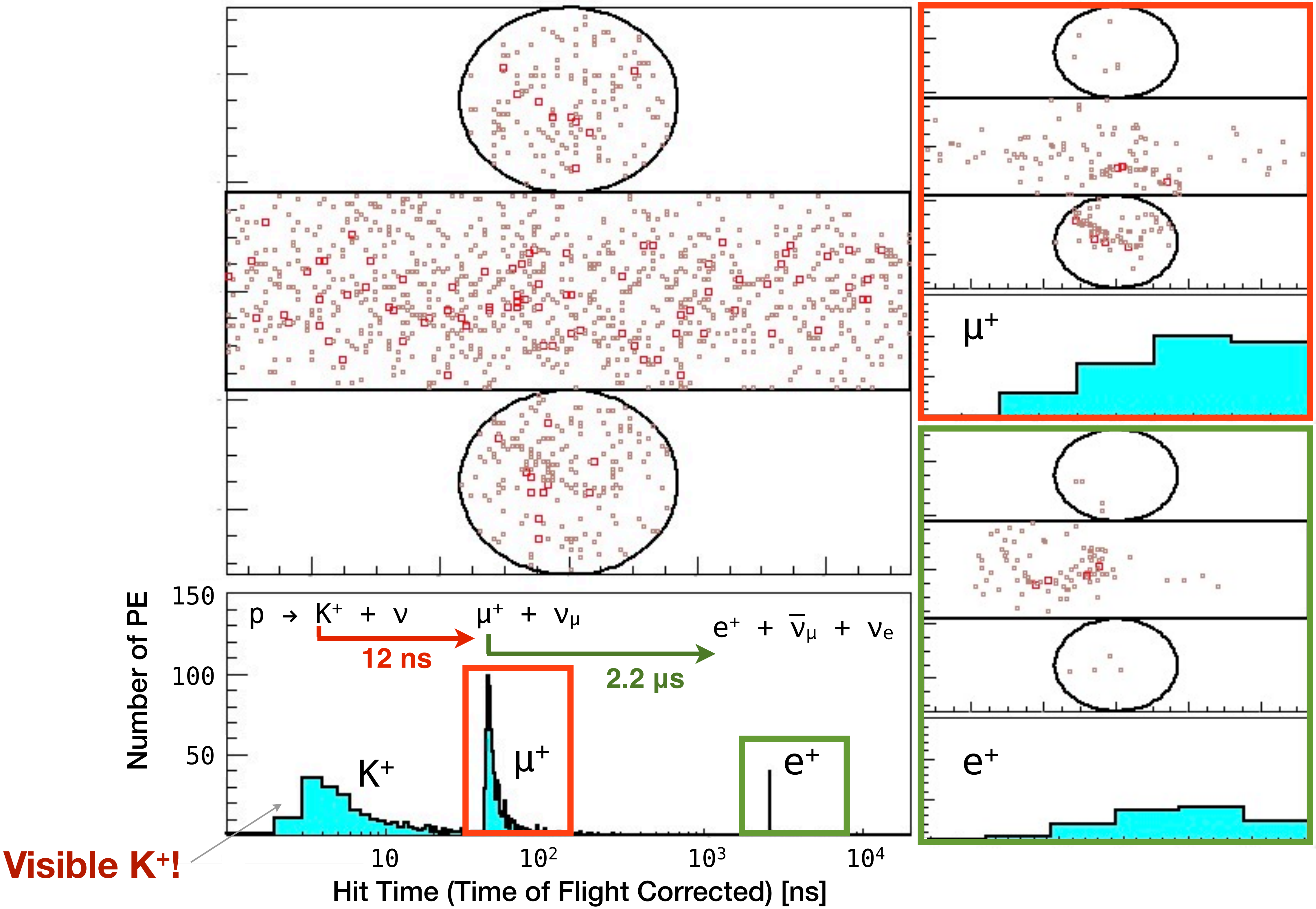
SK Limit $\tau(p \to K^+\bar{\nu}) > 2.8\times10^{33}$ yrs at 90% C.L.

M. Shiozawa, NNN09

In WbLS, the Kaon prompt signal is suddenly visible

The $p \to K^+\overline{\nu}$ Channel in WbLS Detectors

A simulated event with 90 scintillation photons/MeV

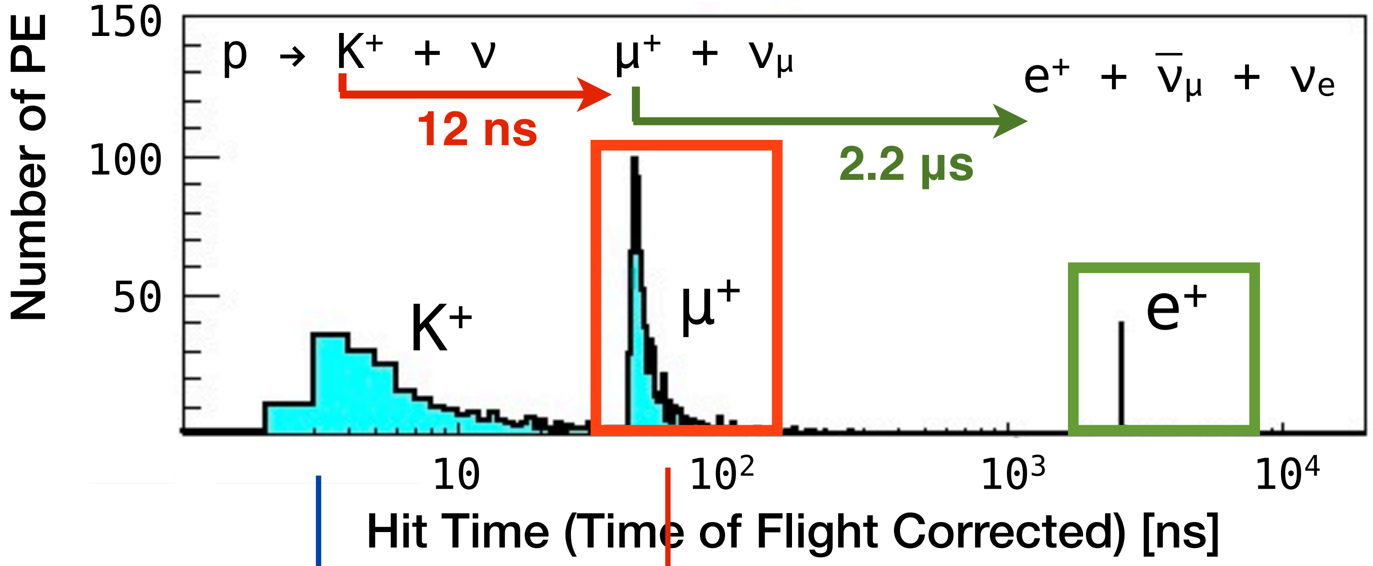


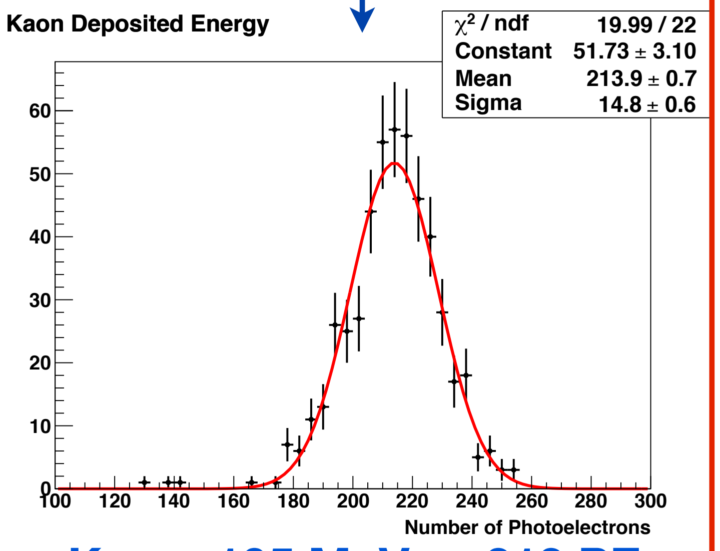
Visible K+!

Main background: atmospheric ν_μ

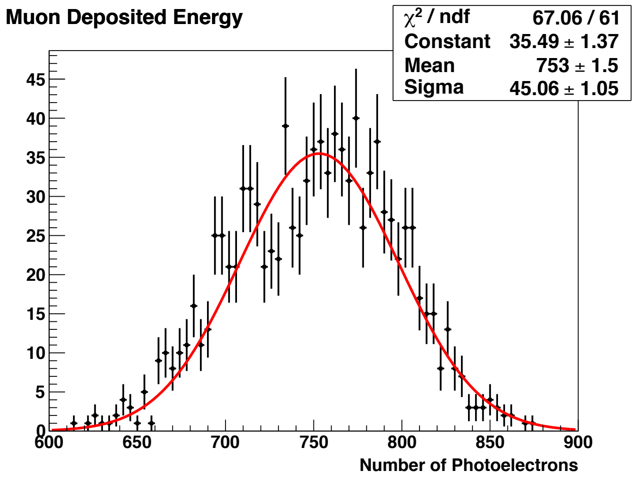
Reduce by:

- **Rising-time cut**: distinguishes one-pulse (background) from two-pulse (signal) by rising-time (from 15% to 85% of maximum pulse height) of the pulse shape
- **Reconstructed Kaon energy cut**: by subtracting the reconstructed muon energy

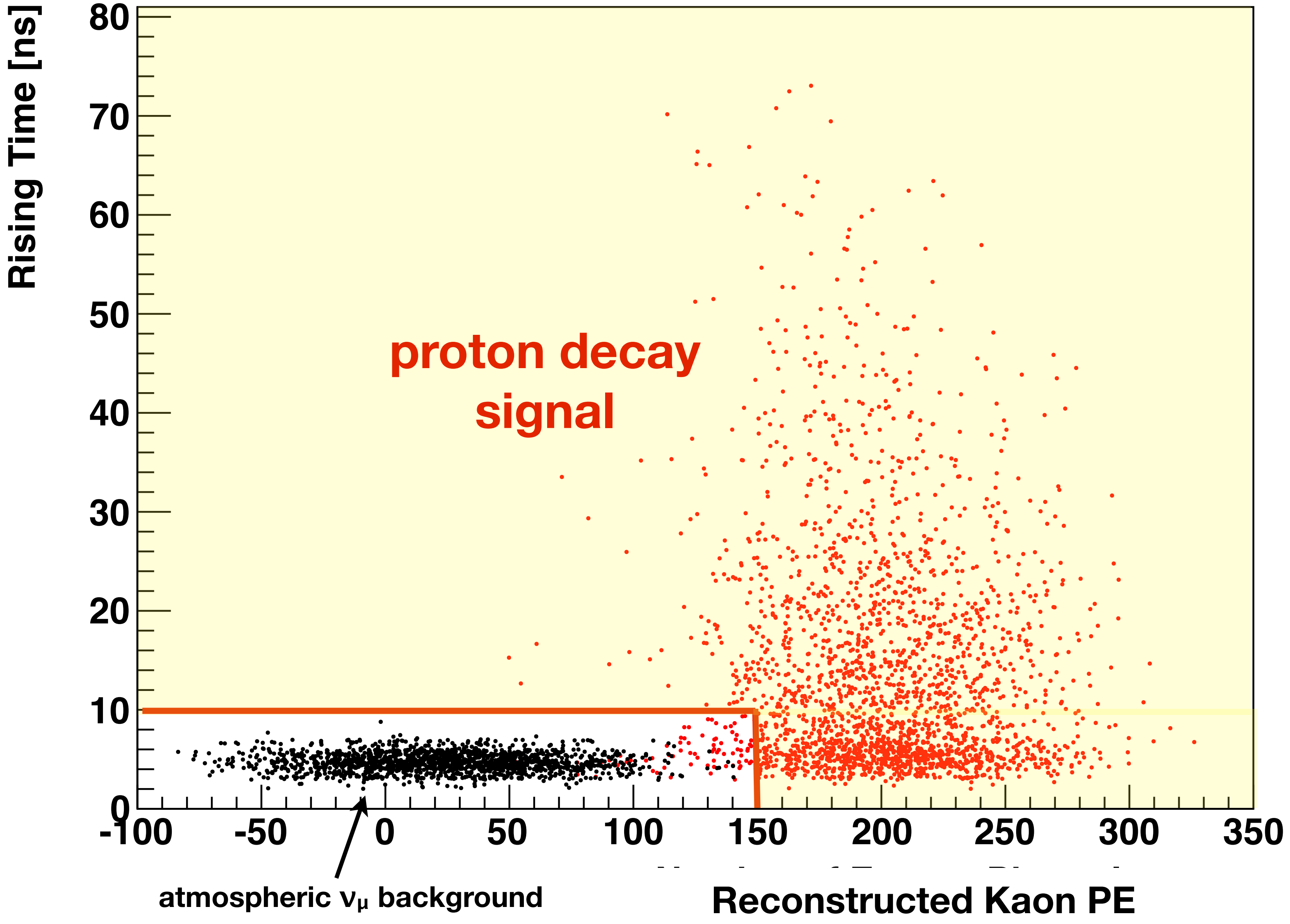




Kaon: 105 MeV -> 213 PE



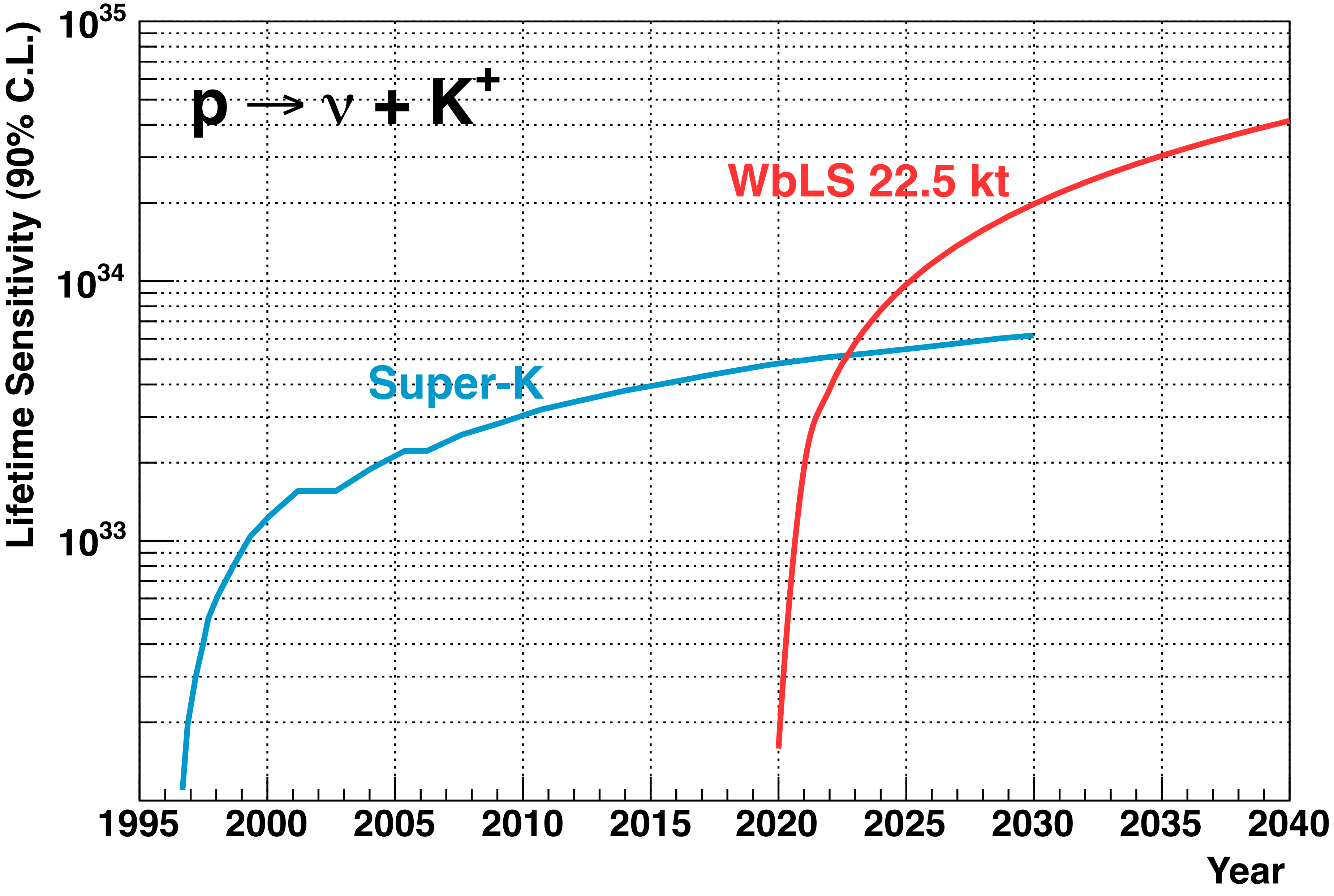
Muon: 152 MeV -> 753 PE



Summary of Efficiency, Signal, Background

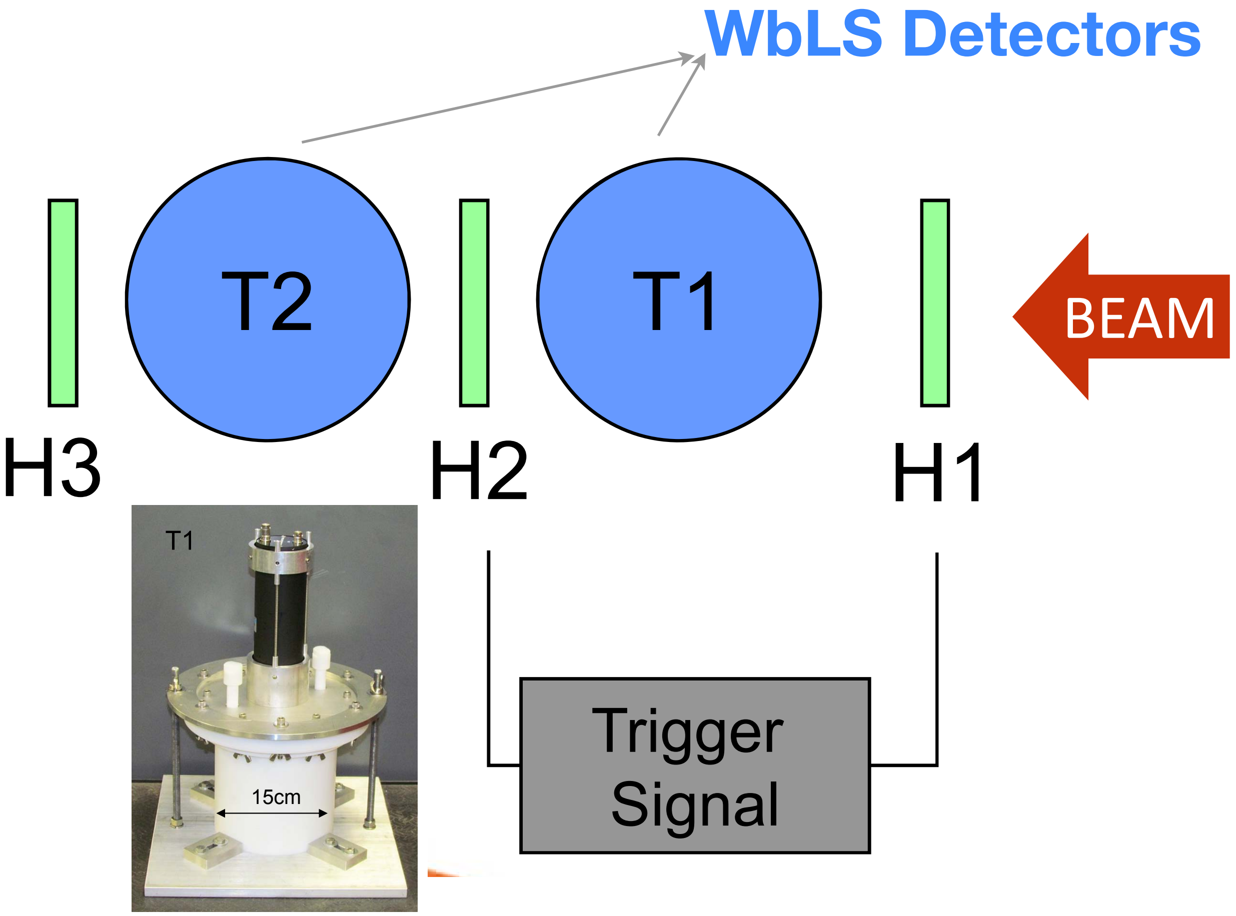
Selection	Efficiency	
800 < PE in first 100 ns < 1100	96.8%	
One Michel positron	99.2%	
Muon decay later than 100 ns	95.6%	
Rising time >= 10 ns or Reconstructed Kaon PE > 150	Free Protons	Bound Protons
	96.4%	75.2%
Total Efficiency	88.5%	69.0%
#Protons (22.5 kton)	1.53E+33	5.98E+33
Predicted Signal Events (in 10 y, $t_{1/2}$=2.8E33 y)	**15.2**	
Predicted Background (in 10 y)	**0.1**	

Projected Sensitivity



$$\tau(p \to K^+\bar{\nu}) > 2 \times 10^{34}\text{y at 90\% C.L. in 10 years}$$

Can We Achieve 90 photons/MeV?



3 low Intensity Proton Beams

210 MeV	dE/dx ~ K+ from PDK
475 MeV	Cerenkov threshold
2 GeV	MIP

4 Material Samples

Water	pure water
WbLS 1	0.4% LS
WbLS 2	0.99% LS
LS	pure LS

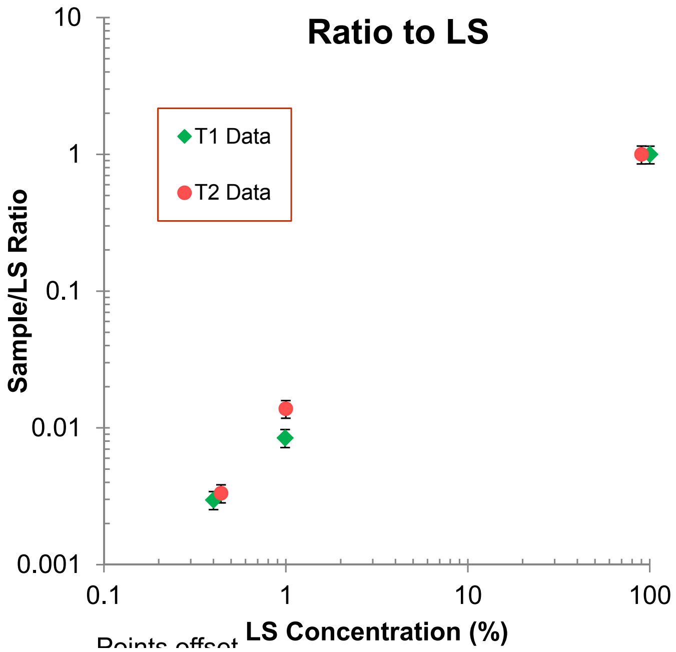
2 Detectors

Tub 1	PTFE (highly reflective white Teflon)
Tub 2	Aluminum coated with black Teflon

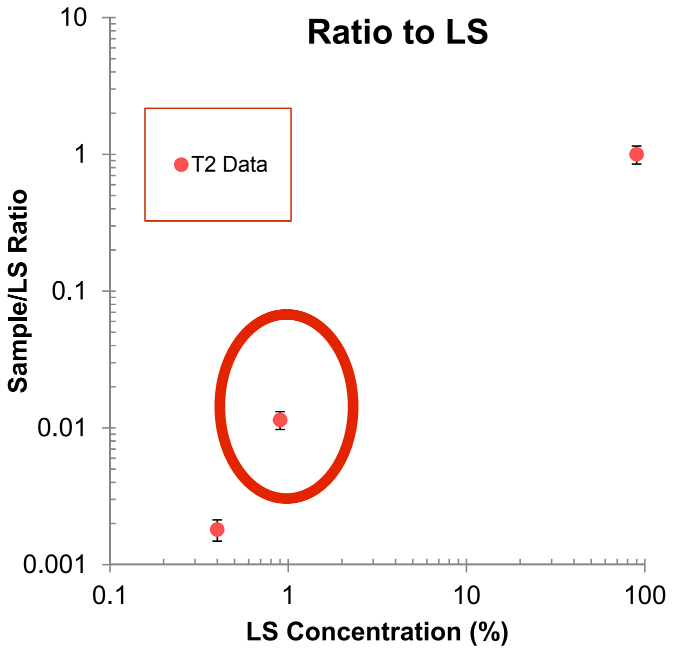
Light Yield Result from NSRL Run 2012

Light Yield Ratio of WbLS / pure LS

At 475 MeV



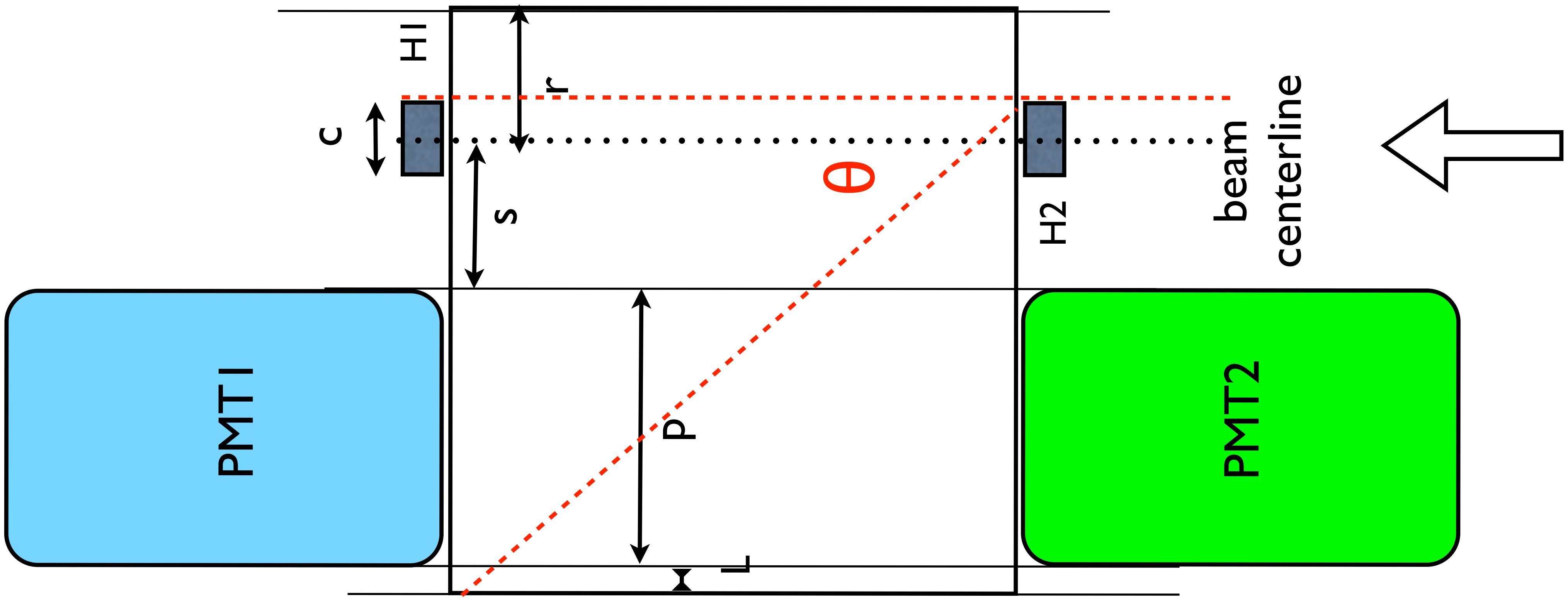
At 210MeV

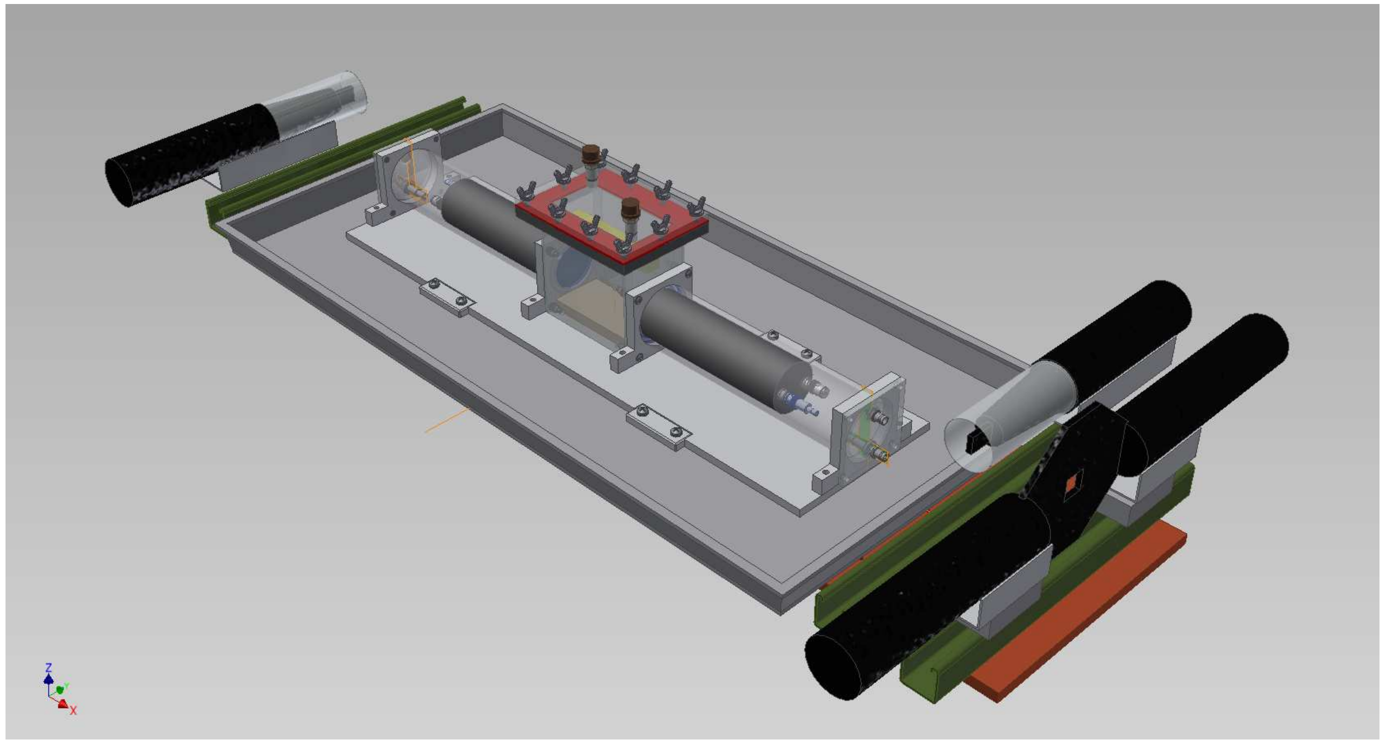


Beam energy (MeV)	Sample	T1 energy deposit (MeV)	T2 energy deposit (MeV)
210	Water, WbLS	70	*113*
	LS	59	*124*
475	Water, WbLS	39	42
	LS	34	36

- The light yield of WbLS with 0.99% LS is measured to be 1% of pure LS.
- Typical photon yield for pure LS is ~9K optical photons / MeV.
- We can fabricate WbLS with 90 scintillation photons / MeV that satisfies the requirements for $p \rightarrow K^+\overline{\nu}$ search !

Improvement on NSRL Run 2013





May 6, 2013

Better separation of Cerenkov and scintillation light

Summary

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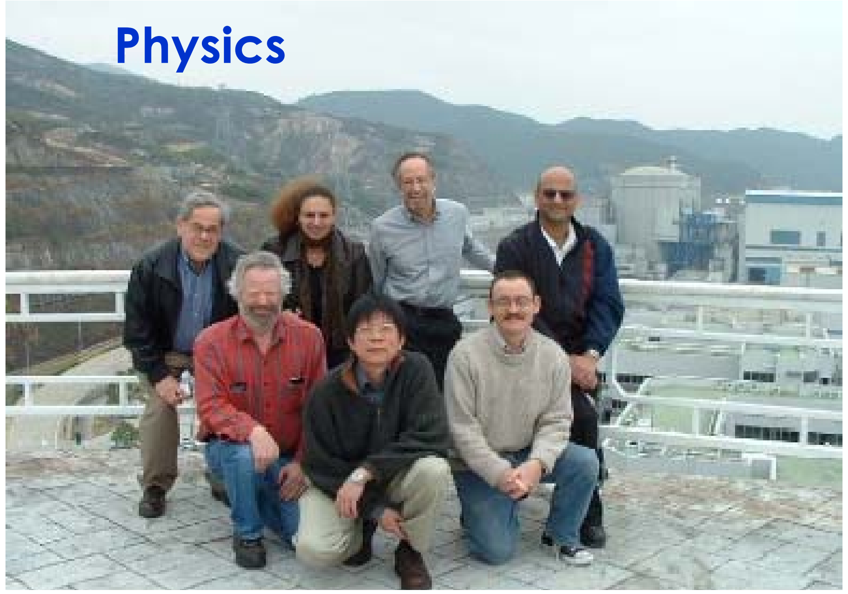
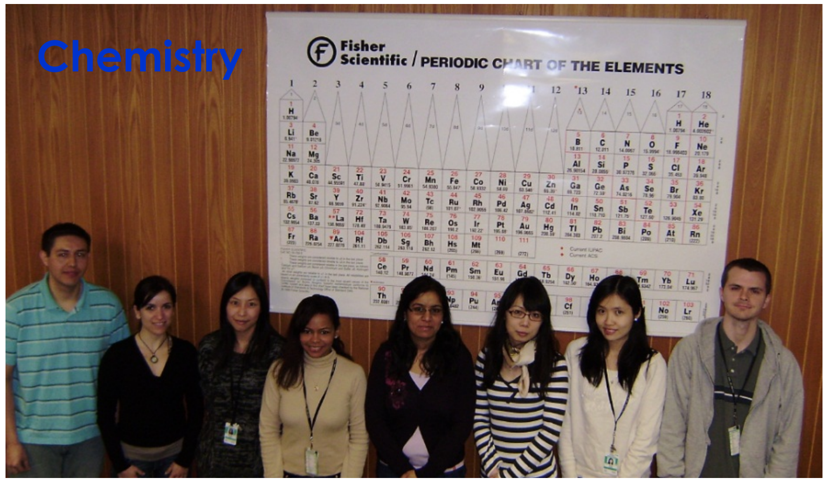
- Water-base Liquid Scintillator is a novel particle detection medium that is
  - mass-producible
  - cost-effective
  - safe to handle
  - with high optical performance.
- WbLS detector can adjust light production for different physics applications
  - nucleon decay (detection below Cerenkov threshold)
  - double beta decay (metallic loading)
  - reactor monitoring, veto system, etc.
- A Geant4 based full detector simulation for WbLS application shows great potential in searching for proton decay $p \to K^+\overline{\nu}$.





D. Beznosko. M.V. Diwan, S. Hans, L. Hu, D.E. Jaffe, S.H. Kettell, L. Littenberg, R. Rosero, H. Themann, B. Viren, E. Worcester, M. Yeh, C. Zhang