Preliminary results on water-based liquid scintillator in a proton beam

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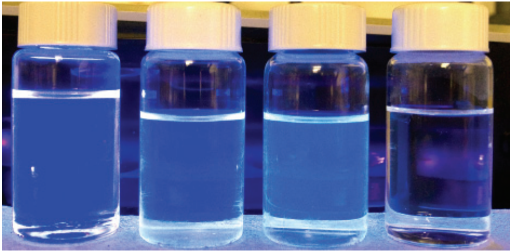


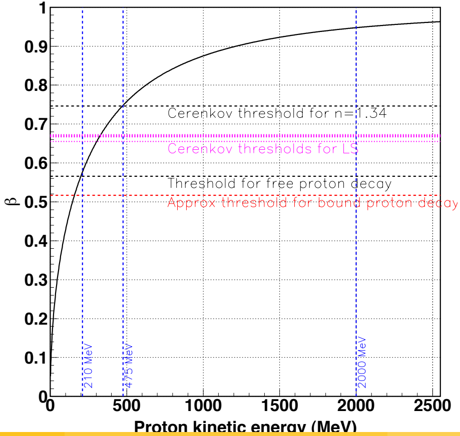
2nd Open Meeting for Hyper-Kamiokande Project

Outline

1. Water-based Liquid Scintillator (WbLS) applications (Details)
    1. $p \to K^+\nu$
    2. Low energy $\bar{\nu}_e$ detection
    3. Near-site WbLS-based detector
2. Investigation of $p \to K^+\nu$ capabilities using low-energy, low-intensity proton beam at BNL's NASA Space Radiation Laboratory (NSRL)
    1. Beam kinetic energies $T_p = (100, 2000)\ \mathrm{MeV}$
    2. RF $\approx$ 2 MHz $=$ 1/500 ns
    3. Intensity adjustable to allow $\approx$ 1 protons per RF bunch
    4. Beam spot size $1 \times 1\ \mathrm{cm}^2$ at 2000 MeV, $5.4 \times 5.4\ \mathrm{cm}^2$ at 210 MeV
    5. $\sim$4s cycle time with $\sim$0.4s spill
    6. Five hour run at $\sim$\$4300/hour

Proton beam energies

Why?	β	T_p (MeV)	Comment
$p \rightarrow K^+\nu$	0.57	210	bound protons $\beta_K \approx 0.52$
Č threshold	0.75	475	Assumes $n = 1.34$
Maximum T_p	0.95	2000	



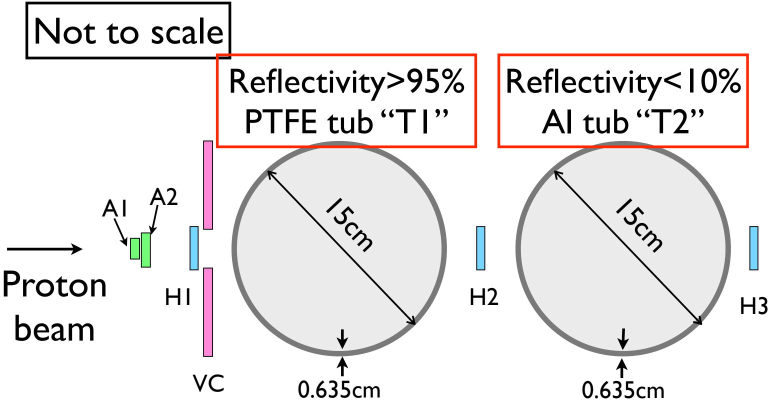
Liquid samples exposed to proton beam

1. Pure water.
2. WbLS-1: 1% LAS+0.4%PC+0.4g/L PPO+3mg/L MSB
3. WbLS-2: 4.14%LAS+0.99%PC+1.36g/L PPO+7.48mg/L MSB
4. LS: LAB + 2g/L PPO + 15mg/L MSB.

We exposed two identical samples of each composition in different containers to each of the three beam energies.

LAS is Linear Alkylbenzene Sulfonic acid, a non-ionic surfactant derivative of Linear Alkyl Benzene (LAB).

Beam setup (identical liquids in each tub)



H1,H2,H3 plastic scint. hodoscope 2cmX2cmX0.5cm

Trigger: H1•H2

T1,T2 Hamamatsu R7723 2"PMTs
CAEN V1729A FADC 12bit,1GSPS

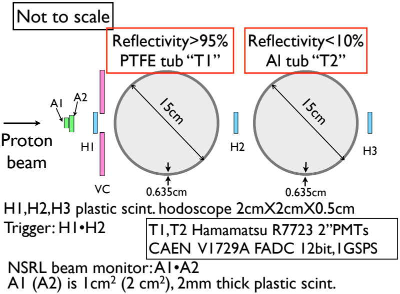
NSRL beam monitor: A1•A2

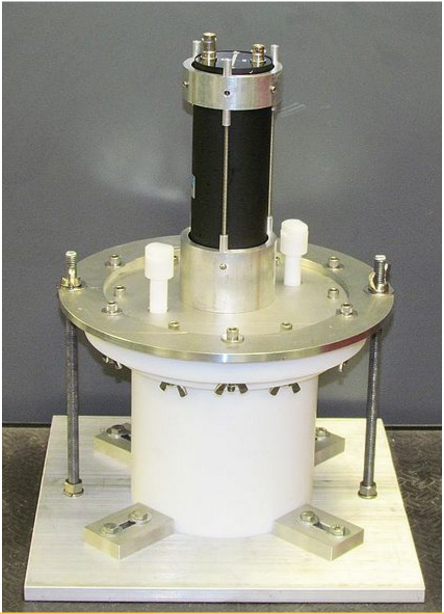
A1 (A2) is 1cm^2 (2 cm^2), 2mm thick plastic scint.

Data features and "T1"=PTFE Tub

Data features:

1. Spurious triggers due to H1,H2 electronics ⇒ apply H1,H2 requirement offline
2. PMT was saturated for 210 MeV, LS sample in T1. Does not affect T2.
3. VC fell into beam





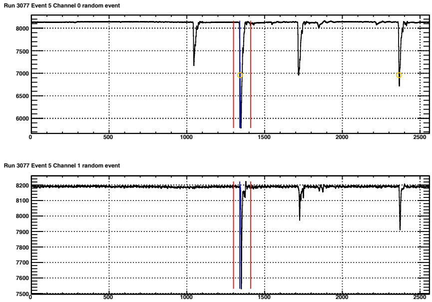
Incident and deposited energies

Beam energy	Incident β T1	Incident β T2	Incident energy T1	Incident energy T2	Energy deposited T1	Energy deposited T2	Sample
210	0.57	0.45	202	*113*	70	*113*	Water, WbLS
210	0.57	0.47	202	*124*	59	*124*	LS
475	0.75	0.72	470	421	39	42	Water, WbLS
475	0.75	0.73	470	427	34	36	LS
2000	0.95	0.95	1996	1962	28	28	Water, WbLS
2000	0.95	0.95	1996	1966	24	24	LS

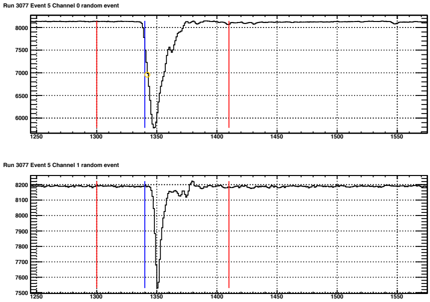
- Calculated incident velocities, incident and deposited energies in MeV for "T1" (PTFE tub) and "T2" (Aluminum tub) using NIST's proton stopping power and range tables (PSTAR).
- Material properties of WbLS and LS approximated by water and toluene, respectively.
- Estimated uncertainty is a few MeV.
- Detailed Geant4 simulation in progress

Waveform analysis method (Data: 210 MeV, WbLS2)

T1(top), T2(bottom): full 2500ns

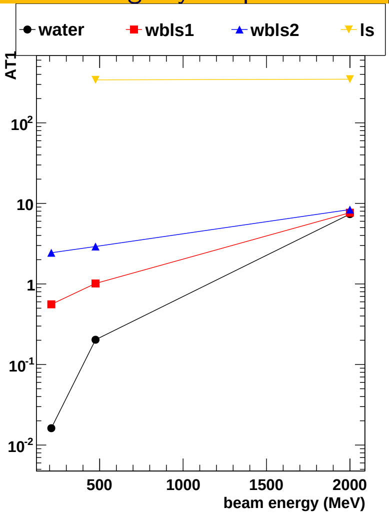


Zoomed in around trigger time

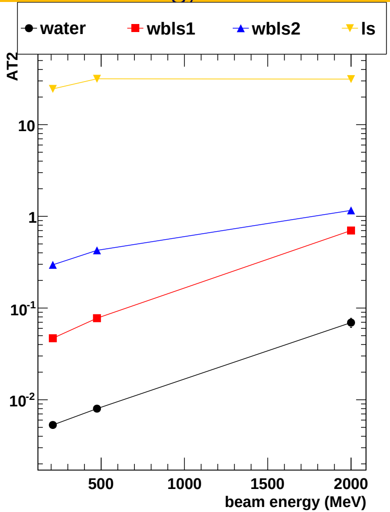


1. Waveform prior to pulse is averaged to estimate pedestal.
2. Pedestal-subtracted waveform is integrated over limits shown as estimate of light yield (LY). LY is in arbitrary units (∼ADC counts).
3. Estimated ∼5% uncertainty in LY due to baseline restoration
4. Cuts applied to select events with single in-time beam particle
5. Mean LY is determined from gaussian fit to LY distribution.

Results: Light yield per MeV deposited vs beam energy



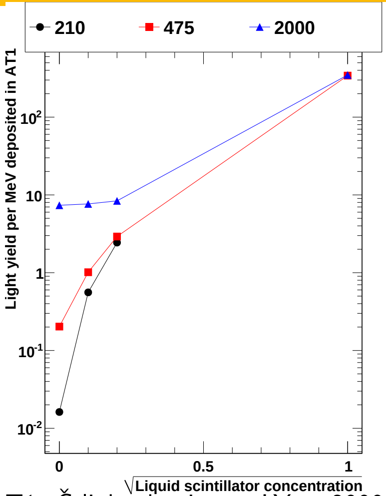
T1: LY at 2000 MeV dominated by Č light, except for pure LS.



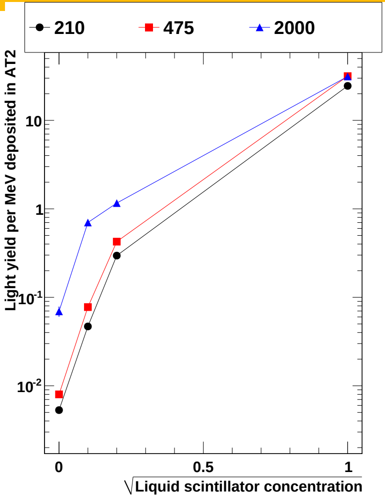
T2: Č light no longer dominant with low reflectivity tub.

Non-zero LY in water below Č threshold possibly due to knock-on electrons.

Results: Light yield per MeV deposited vs $\sqrt{\text{LS concentration}}$



T1: Č light dominates LY at 2000 MeV.



T2, low reflectivity tub

1. Non-linear increase in scint. light with LS concentration for low T_p.
2. Decrease in LY/MeV with reduction in beam energy as expected from scintillator quenching.

Summary

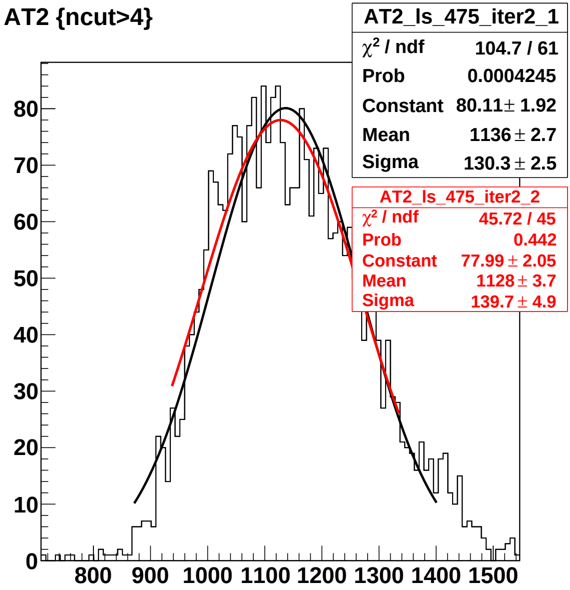
1. Observations
    1. Significant non-linear, light yield for 1% and 4% WbLS samples for protons below Čerenkov threshold
    2. Scintillator quenching present even for low LS concentrations.
    3. Reflectivity of container complicates isolation of Čerenkov and scintillation components
2. To-do
    1. Obtain estimate of light yield in terms of optical photons
    2. Develop Geant4-based model of WbLS for proton beam configuration
    3. Obtain data for larger range of WbLS concentrations for cosmics and gamma sources
    4. Possible second run at NSRL (spring 2013)

Additional slides

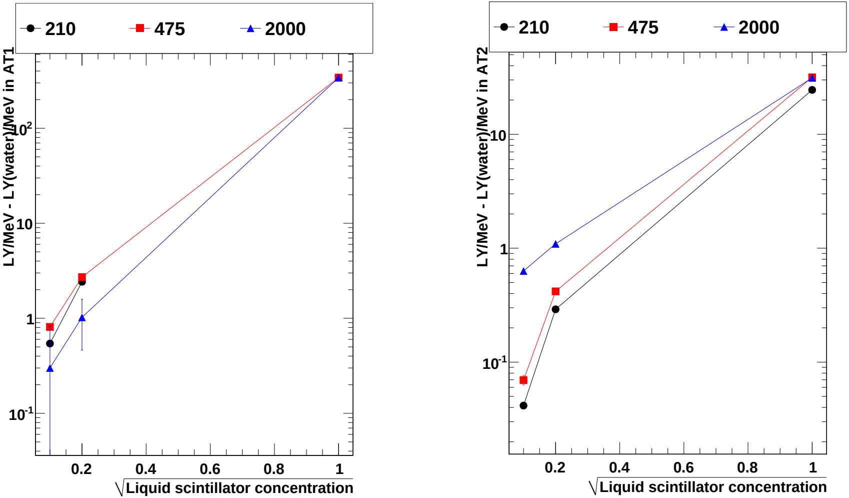
More info

- PTFE tub is Dupont NXT 85 Modified PTFE manufactured by Applied Plastics Technology
- Aluminum tub was fabricated in BNL shop. Coated with Teflon PFA black primer and 3 PFA topcoats by Donwell Company, Inc.
- Circulation system test: A circulation system is under design and will be in order soon...
- Further improvement of optical properties: The vendor will conduct a special production for us with a consequent improvement in optical properties.

Example of fit to obtain mean LY



Results: Scintillator LY per MeV deposited vs $\sqrt{\text{LS concentration}}$



Isolate scintillation light yield by subtracting off light yield in water.
Ignores absorption and re-emission of Čerenkov light.
Ignores different index of refraction in water and LS.

Statistics

Event counts for all data samples after sequential application of cuts

Water 210	Water 475	Water 2000	WbLS1 210	WbLS1 475	WbLS1 2000	WbLS2 210	WbLS2 475	WbLS2 2000	LS 210	LS 475	LS 2000	Cut
12888	15201	9150	17906	16988	20646	20122	19764	25345	21704	20067	20407	No cuts
6816	10476	4297	9364	11568	10828	10998	14130	12902	11336	12235	14713	Good pedestals
3410	6738	2577	3789	7134	6808	4815	8928	7322	4469	5948	6821	H1,H2 coincidence
2465	5400	1726	2748	5820	4964	3615	7564	5259	3538	4950	5600	no early H1,H2 activity
2148	4281	912	2290	4513	2810	3049	6060	2847	3103	3581	2175	Good H1,H2 pulseAreas
1726	4061	848	1368	4102	2444	2103	5585	2272	2251	3304	1959	Veto 2d pulse in V
0	1379	266	0	1504	1333	0	2120	1020	0	1495	1150	Good H3 hit (time,pulseArea)

Fractional event counts

Water 210	Water 475	Water 2000	WbLS1 210	WbLS1 475	WbLS1 2000	WbLS2 210	WbLS2 475	WbLS2 2000	LS 210	LS 475	LS 2000	Cut
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	No cuts
0.5289	0.6892	0.4696	0.5230	0.6810	0.5245	0.5466	0.7149	0.5091	0.5223	0.6097	0.7210	Good pedestals
0.2646	0.4433	0.2816	0.2116	0.4199	0.3297	0.2393	0.4517	0.2889	0.2059	0.2964	0.3342	H1,H2 coincidence
0.1913	0.3552	0.1886	0.1535	0.3426	0.2404	0.1797	0.3827	0.2075	0.1630	0.2467	0.2744	no early H1,H2 activity
0.1667	0.2816	0.0997	0.1279	0.2657	0.1361	0.1515	0.3066	0.1123	0.1430	0.1785	0.1066	Good H1,H2 pulseAreas
0.1339	0.2672	0.0927	0.0764	0.2415	0.1184	0.1045	0.2826	0.0896	0.1037	0.1646	0.0960	Veto 2d pulse in V
0.0000	0.0907	0.0291	0.0000	0.0885	0.0646	0.0000	0.1073	0.0402	0.0000	0.0745	0.0564	Good H3 hit (time,pulseArea)