Water-based liquid scintillator development
&
Characterization experiments

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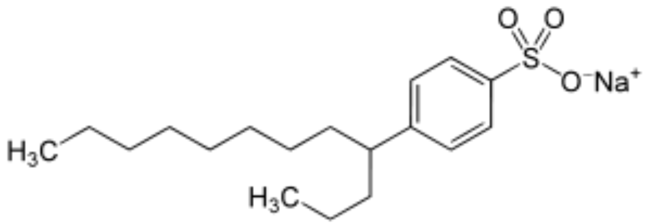
Synthesis of WbLS – Surfactants & Organic Solvents

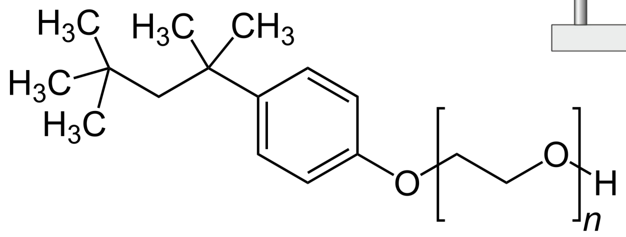
WbLS samples: Various mixtures are tested with respect to their solubility via surfactants in water.

Some examples:

- LAB + 2.5 g/l PPO + x mg/l bisMSB
- LAB + 5.0 g/l PPO + x mg/l bisMSB
- LAB + 10 g/l PPO + x mg/l bisMSB
- **LAB + 90 g/l PPO**
- Other organic solvents: Dioxane, DIN, …



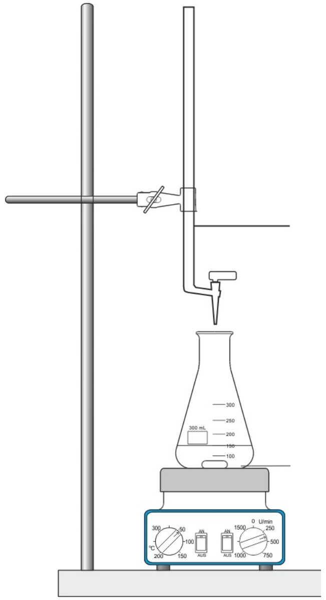
Sodium dodecylbenzenesulfonate



Triton X100

Focus of the previous work:

- testing different surfactants (LAS, Triton X100, …)
- chemical and physical purification of the surfactant
- tuning the organic scintillator (solvents, WLSs, emission spectrum)
- minimizing the amount of required surfactant



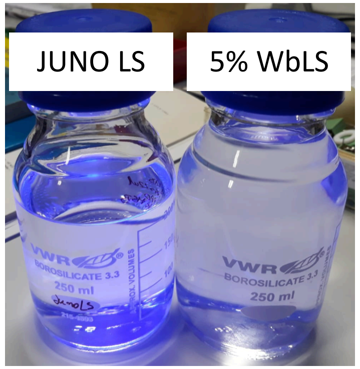
Make an aqueous surfactant solution (perform fine-filtration)

Produce LS Master Solution (dissolve PPO in LAB)

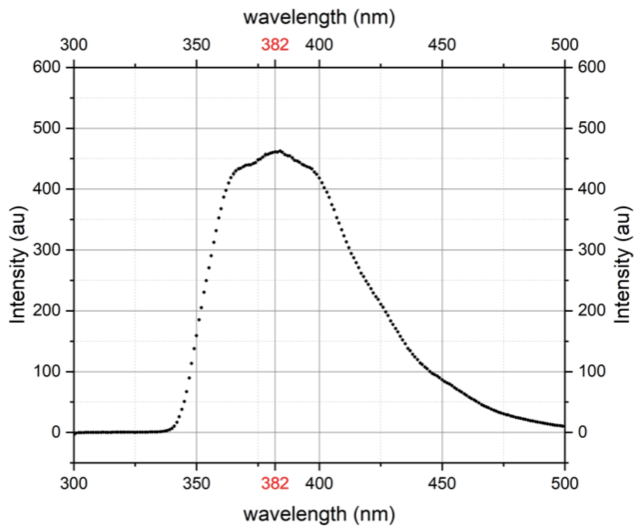
Add Master Solution slowly to the aqueous surfactant solution while stirring!

Perform fine-filtration and ultra-filtration!

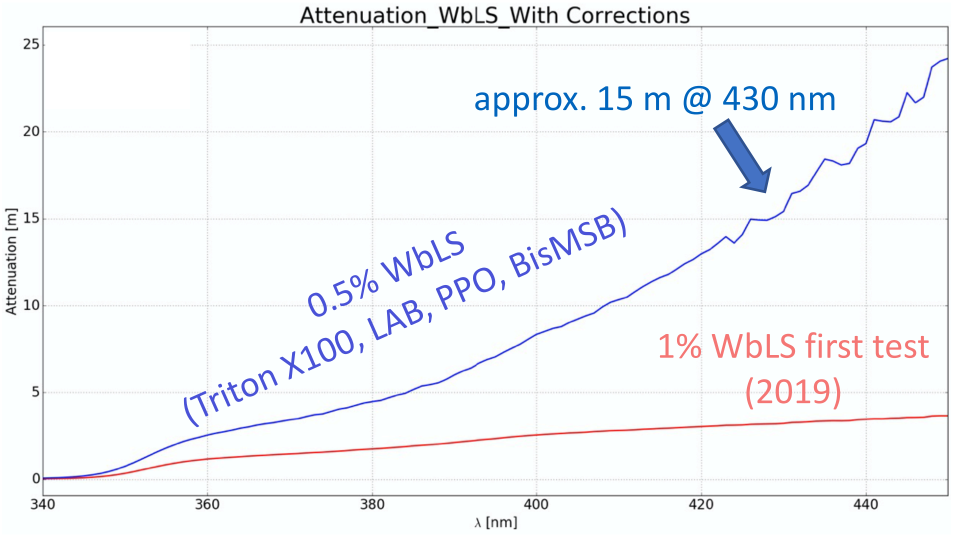
Degas the sample thoroughly (using an ultrasonic bath)



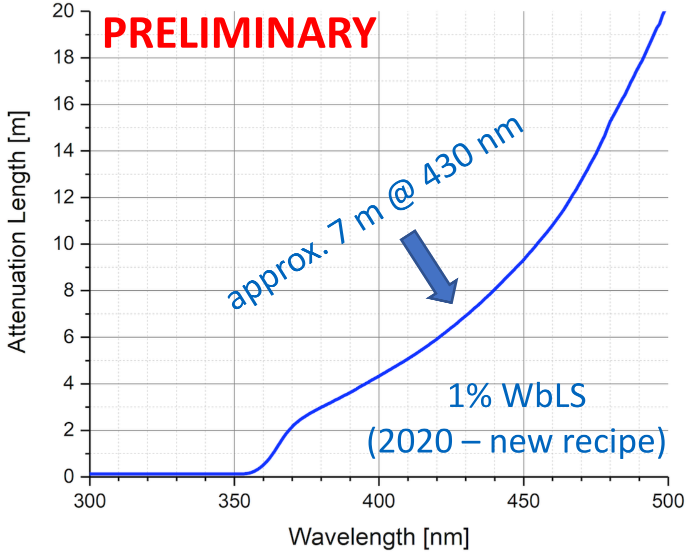
Synthesis of WbLS – Light Emission and Transparency



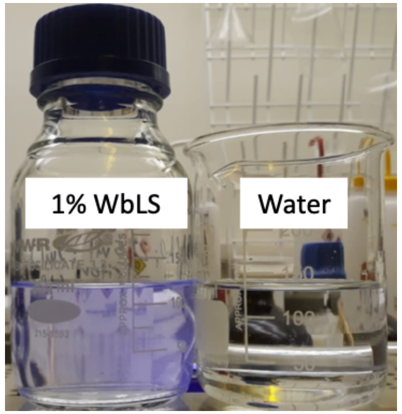
Emission Spectrum of 0.5% WbLS
(Triton X-100, LAB + 3g/L PPO + 40mg/l BisMSB)

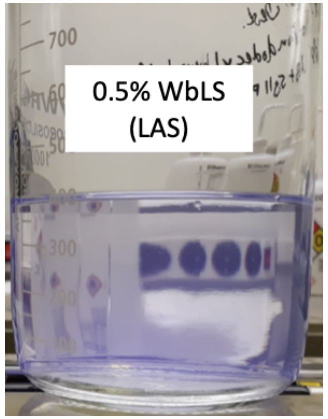


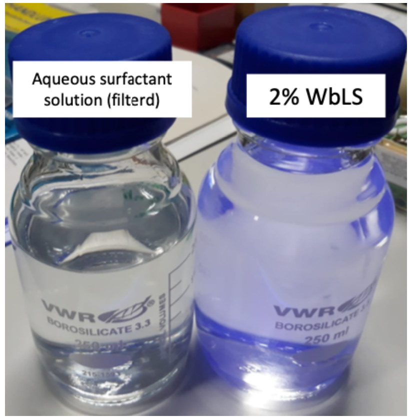
Attenuation Length Measurement
(with commercial UV/Vis Spectrometer)



Improved transparency for 1% WbLS



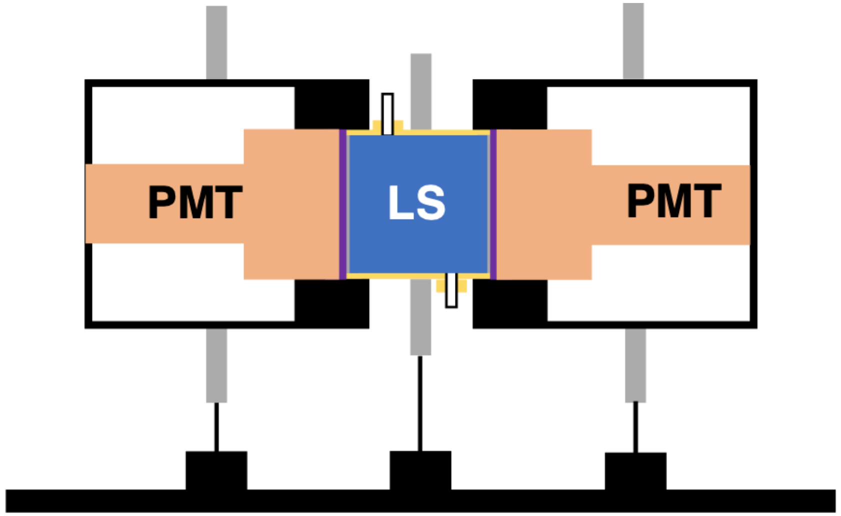


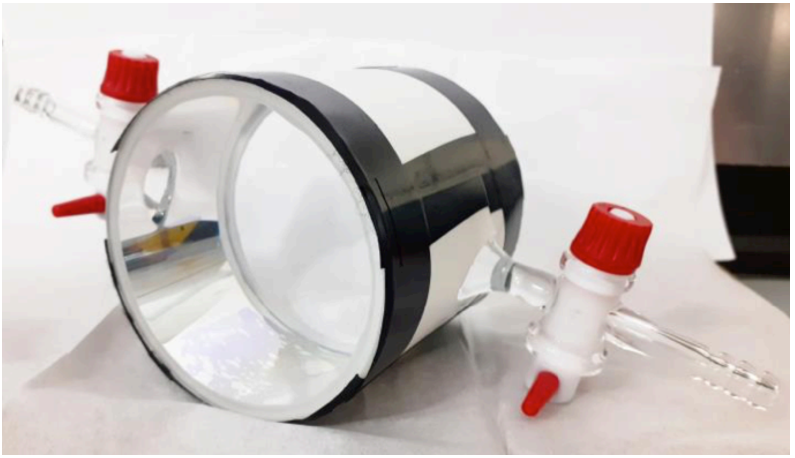


Results:

- Attenuation length: approx. **7 m @ 430 nm** in a 1 % WbLS mixture
- **LY:** ~**200 Ph./MeV** (0.5% WbLS) & ~**500 Ph./MeV** (2 % WbLS)
- Optimum surfactant concentrations have been determined.
- Influence of temperature during sample production on light yield and transparency under study!
- Filtration techniques under investigation!
- Production of WbLS with reliable properties for laboratory studies possible! → **We are getting ready for the ~10 l test detector @ JGU!**

TUM Relative Light Yield Measurement Setup

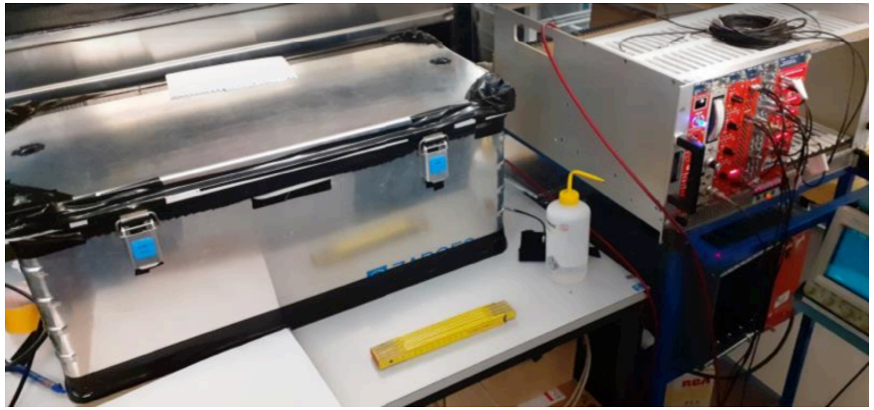




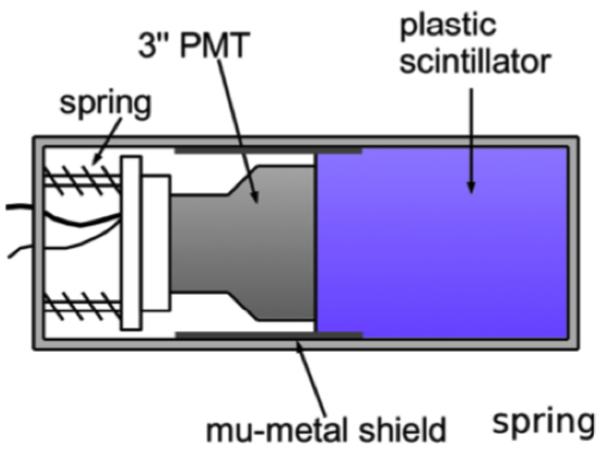
- Maximize solid angle coverage! → get as much light as possible!
- Two 3-inch PMTs (ETEL 9821B) optically coupled by dedicated Saint Gobain gel pads to the LS volume!
- 3 inch LS cylindric glass vessel with 0.7 mm thin windows
- Usage of a mirror foil (> 95% reflectivity @ 400 nm)

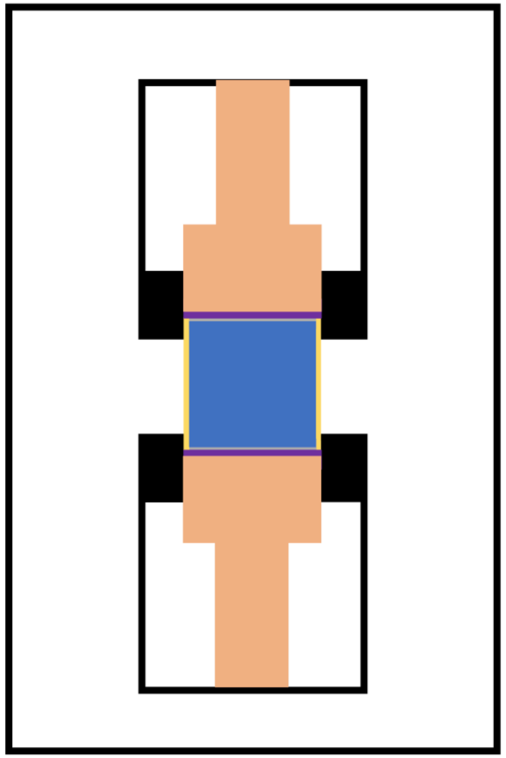
Bachelor Thesis: David Dörflinger

- Characterizing detector with JUNO LS sample and commercial LS EJ-301 (known light yield: 12000 ph/MeV)
- Study LY as function of organic component concentration in WbLS!



TUM Relative Light Yield Measurement Setup



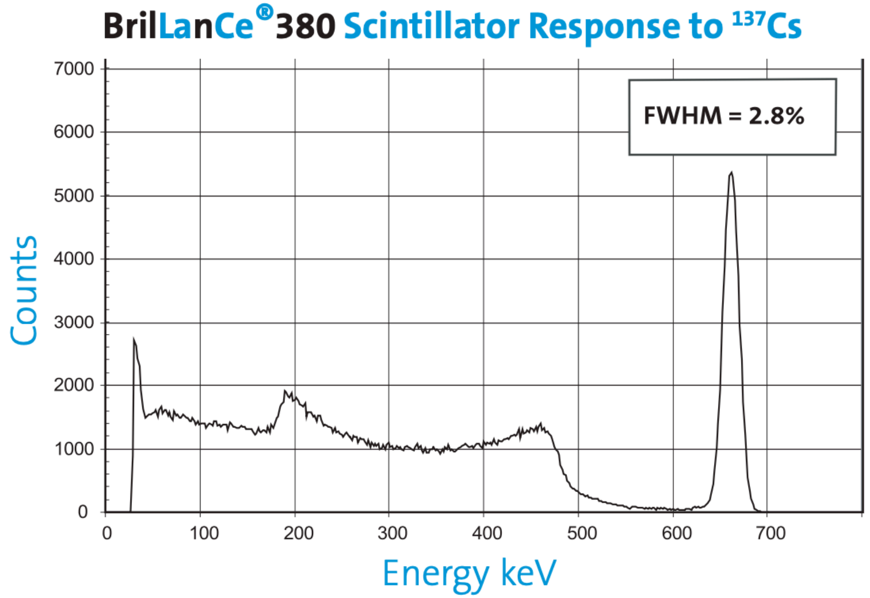


Alternative third detector:

Fast Lanthanum Bromide ($LaBr_3$(Ce) or $LaBr_3$(Ce+Sr) scintillator detector in coincidence!

Energy resolution of < 3% at 662 keV!

Make the measurement more flexible!

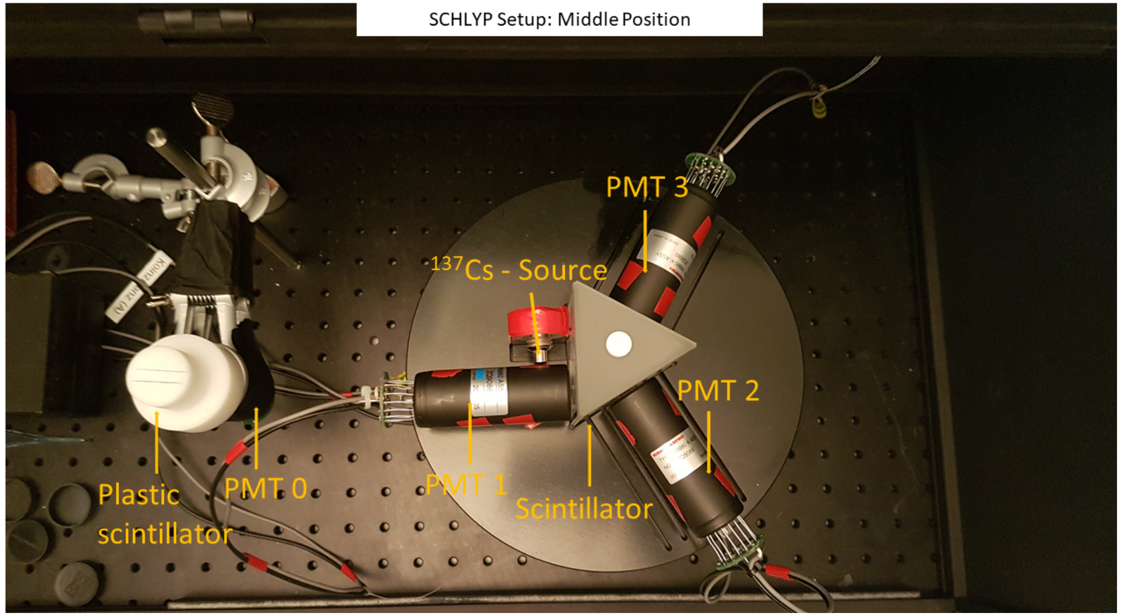


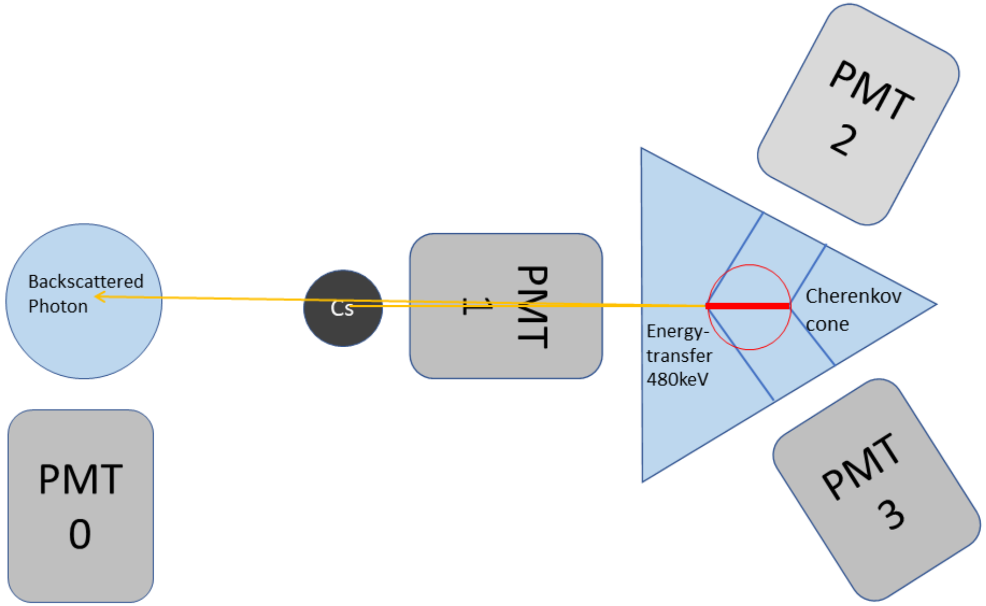
Using a third PMT coupled to a plastic scintillator (Saint Gobain BC-404).

Trigger on coincidence of the two close PMTs and look for events in the PS detector offline or trigger directly on triple coincidences.

Calibrate the detector on the backscatter peak!

JGU: The SCHLYP Setup (Scintilllation CHerenkov Light Yield Prism)





Function Principle:

Photons from the ^{137}Cs source scatter in the scintillator!

PMT 0 detects the backscattered photon!

A Cherenkov cone is created in the scintillator, its light can be detected using PMT 2 and 3 (in addition to the created scintillation light)

PMT 1 detects the scintillation light only!

Idea:

Substraction of the detected light of PMT 1 from the light of PMT 2 and PMT 3

The remaining light should be the Cherenkov light

JGU: The SCHLYP Setup (Scintilllation CHerenkov Light Yield Prism)

Several measurements taken with LAB and different concentrations of WLSs (mainly PPO).

Measurements taken on different positions, to understand geometrical properties of the setup!

Results:

Due to geometrical differences in the setup, the substraction didn‘t yield good results!

A closer look at the early detected photons: more light detected in the Cherenkov PMTs 2 and 3.

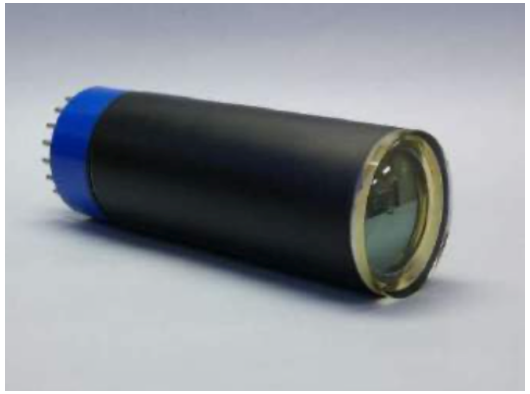
→ faster Cherenkov photons

Declining excess light yield in PMT 2 and 3 compared to PMT 1 for higher concentrations of PPO!

→ Less Cherenkov light is detected with more PPO

Indirect detection of the Cherenkov light possible!

Ideas for improvements:



Get more light out of the prism!

Replace 1‘‘ PMTs against fast 2‘‘ PMTs.

Purchased: HZC XP2020

Usage of a much stronger ^{137}Cs source as the measurements are requiring too much runtime now!

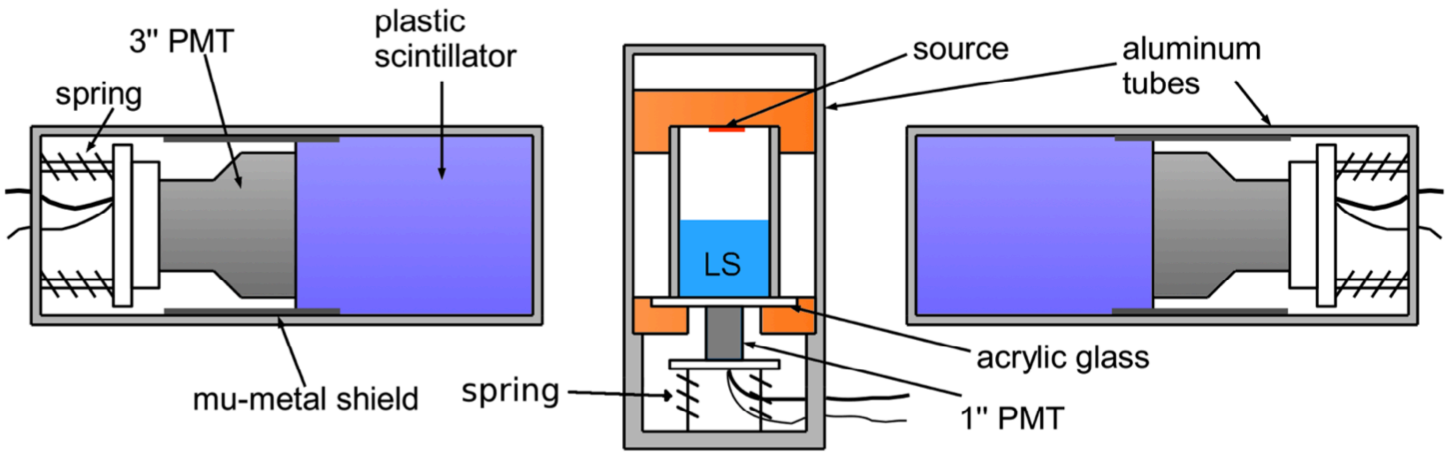
Replacing the small 1‘‘ PS detector against a $LaBr_3$(Ce) detector!

Closer distances to the prism become possible!

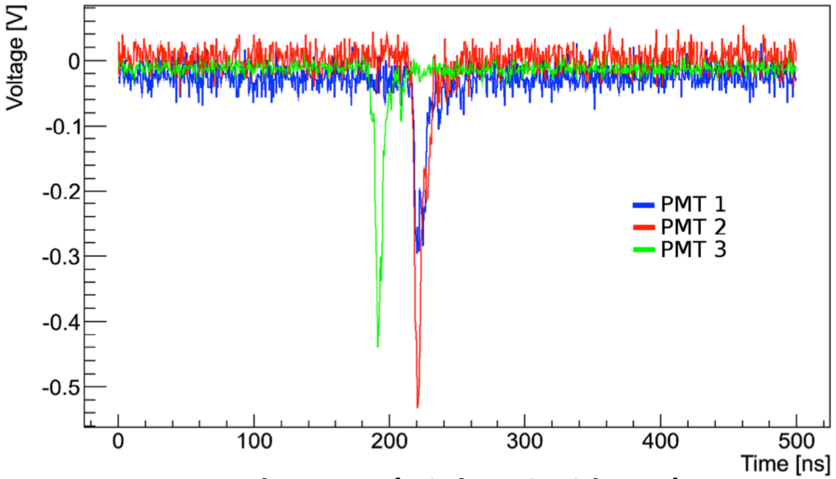
Measurement no longer dependant on the small solid angle that is highly decreasing the rate!

Liquid scintillator characterization experiments

Novel measurement system for the lifetime and formation probability of ortho-positronium in liquid scintillator and WbLS



Scheme of the PoLiDe experiment



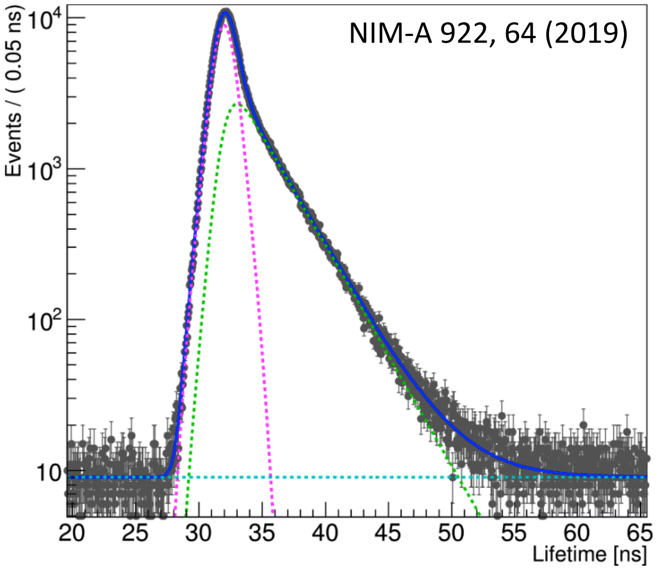
Example event (triple coincidence)

Kapton encapsulated ^{22}Na positron emitting source irradiates the LS sample.

The light produced by the e^+ as well as interactions of the two 511 keV gammas (annihilation) are detected in coincidence.

Time Measurement:

- Start Signal: e^+ in the LS
- Stop Signal: coincidence of γ's



Time difference between central and outer detectors

Results for a LAB based mixture:

τ_{oPs} = **(2.98 ± 0.05) ns**
I_{oPs} = **(44 ± 3) %**

Published in: NIM-A 922, 64 (2019)

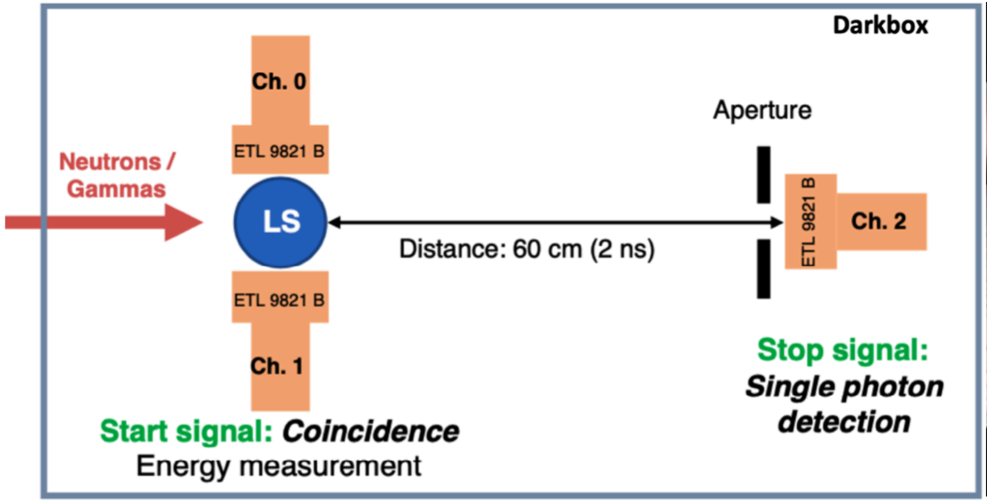
First measurements for **water based liquid scintillators** (WbLS) were perforemd! Lifetimes close to the one of water were found.

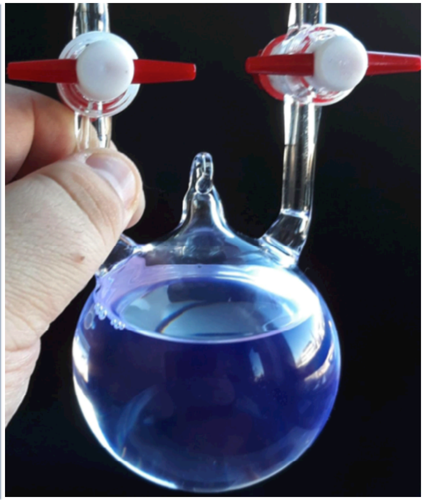
Currently an **upgrade with faster detectors** is ongoing to better discriminate backscatter events on the outer detectors.

Demonstrated time resolution: **σ = (303.6 ± 1.2) ps**

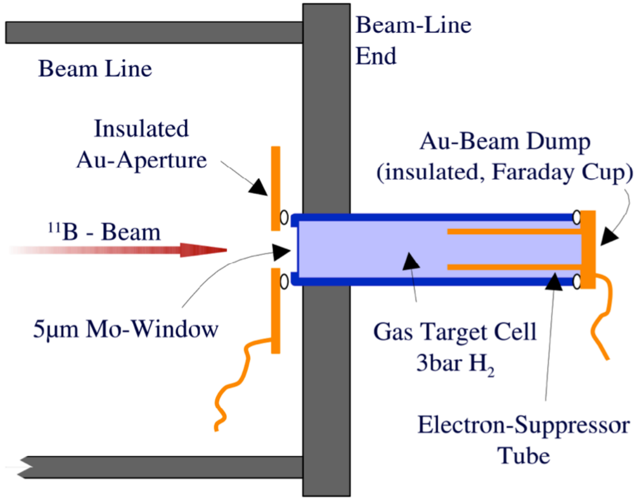
Liquid scintillator characterization experiments

Fluorescence time profile measurements and evaluating the PSD performance using a pulsed neutron beam





Experimental setup for the determination of the fluorescence time profile



Hydrogen target cell for the production of fast monoenergetic neutrons

How to sample the PDF of the scintillation light emission:

Start signal: coincident pulsing of two PMTs (Ch. 0 and Ch. 1) close to the LS vessel
Stop signal: single photon hit in the distant PMT (Ch. 2) placed behind an aperture

Single photon technique: opening's diameter of the aperture is adjusted such, that the probability for a signal in the distant PMT following a coincidence of Ch. 0 and Ch.1 is below 3 %.

Production of a pulsed monoenergetic neutron beam:

The tandem accelerator in Garching was used to prepare a bunched (5 ns) beam of $^{11}B^{5+}$ with an energy of 61.2 MeV.

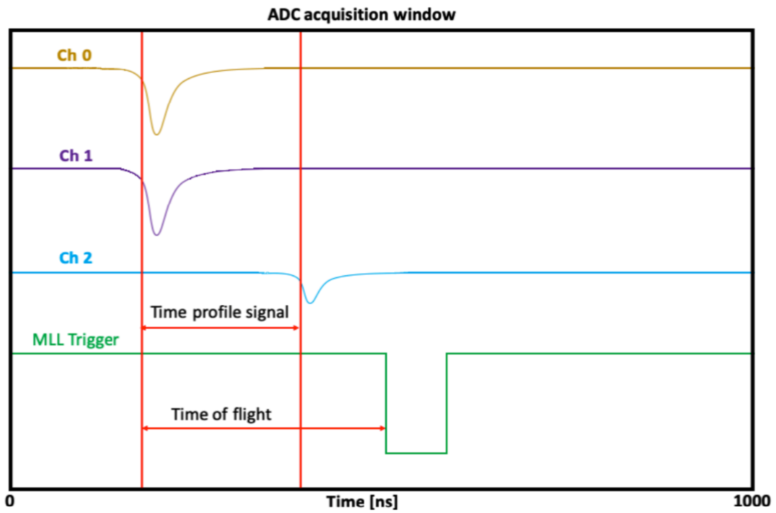
Resonant production of neutrons on hydrogen (fixed kinematics).

Nuclear reaction: $^{11}B + p \rightarrow {}^{11}C + n$

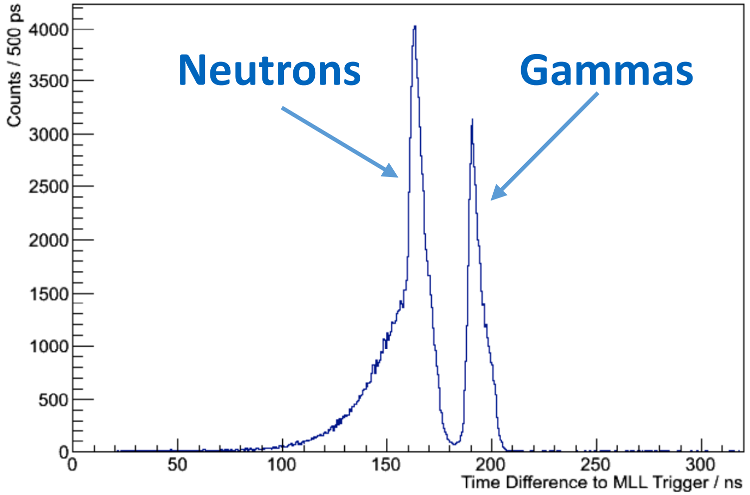
Particle identification: ToF measurement
(beam trigger: enables efficient n/γ-discrimination)

Liquid scintillator characterization experiments

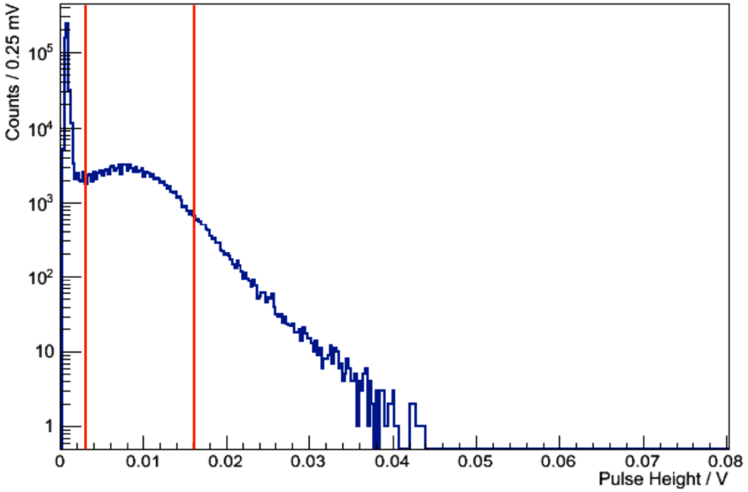
Fluorescence time profile measurements and evaluating the PSD performance using a pulsed neutron beam



Examples of the recorded signals during the beamtimes



ToF measurement with neutron and γ peak



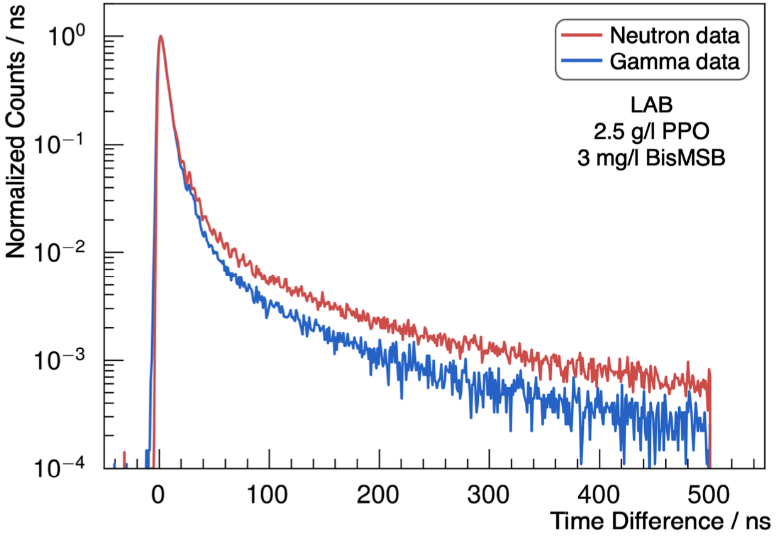
Single photon spectrum in the distant PMT

Time resolution of the setup: σ = (1.61 ± 0.01) ns
ToF resolution: Res_{ToF} = (5.33 ± 0.05) ns (FWHM)

Purity of the neutron sample: (99.58 ± 0.01) %
Purity of the gamma sample: (99.50 ± 0.02) %

Outlook:
Beamtimes at the XTU tandem accelerator (and at the BELINA neutron beamline) at the LNL in Legnaro (Italy).

→ study other LS mixtures (**WbLS, Slow-LS**)!
→ modified detector:
quenching factors of neutron induced recoils on protons and ^{12}C.



Fluorescence time profiles of the JUNO LS

i	Neutron $\tau_{i,N} \pm \Delta\tau_{i,N}$ [ns]	Neutron $n_{i,N} \pm \Delta n_{i,N}$	Gamma $\tau_{i,G} \pm \Delta\tau_{i,G}$ [ns]	Gamma $n_{i,G} \pm \Delta n_{i,G}$
1	4.51±0.05	0.607±0.007	4.71±0.05	0.718±0.008
2	15.72±0.42	0.242±0.005	15.65±0.57	0.199±0.007
3	75.4±5.7	0.095±0.004	79.5±8.8	0.063±0.004
4	358±51	0.057±0.009	447±204	0.021±0.010

Conclusion: good PSD performance for LAB based LS

Publication: to be submitted to NIM-A (July 2020)

Thank you for your attention!