LENA
Scintillator Development

ANT 09
University of Hawaii, Manoa
August 14, 2009

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Outline

Laboratory Measurements

Light Emission

Large-Scale Propagation

Solvent/Solute Candidates

Detector Performance (MC)

Energy/Time Resolution

LENA

Low-**E**nergy **N**eutrino **A**strophysics

Liquid Scintillator
ca. 50kt PXE/LAB

Inner Nylon Vessel
radius: 13m

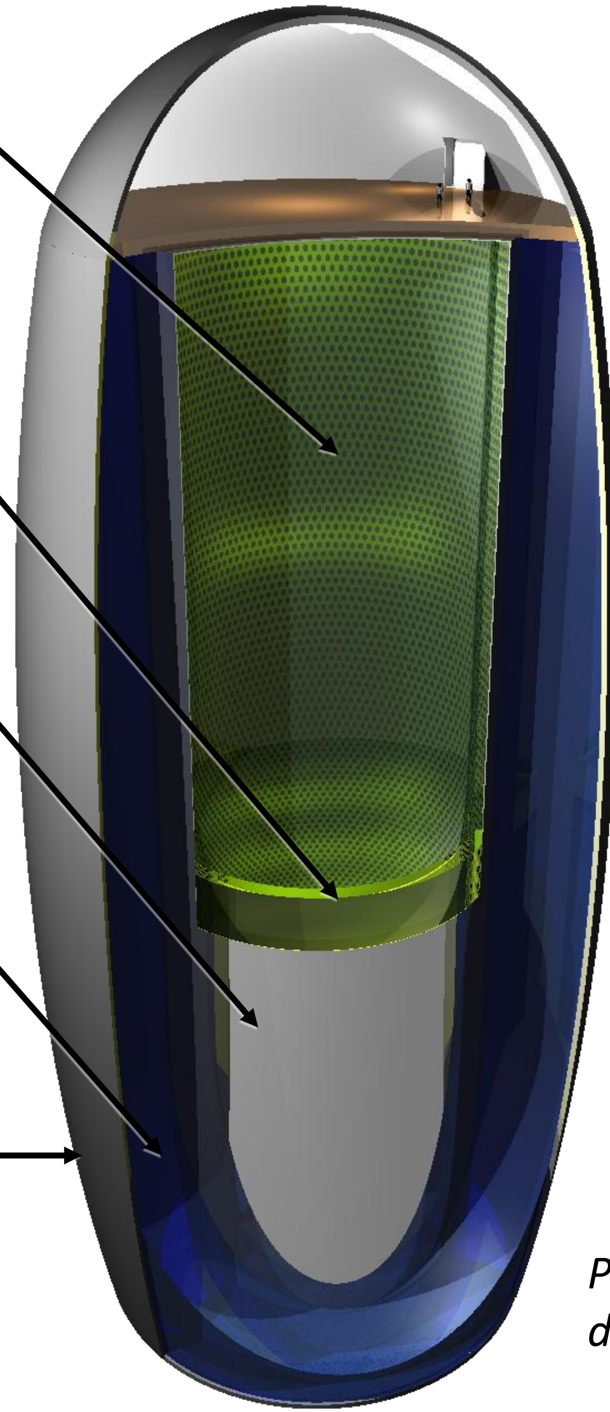
Buffer Region
inactive, $\Delta r = 2m$

Steel Tank, 13500 PMs
r = 15m, h = 100m,
optical coverage: .3

Water Cherenkov Veto
1500 PMTs, $\Delta r > 2m$
fast neutron shield

Egg-Shaped Cavern
about 10^8 m^3

Overburden: 4000 mwe



Pyhäsalmi design

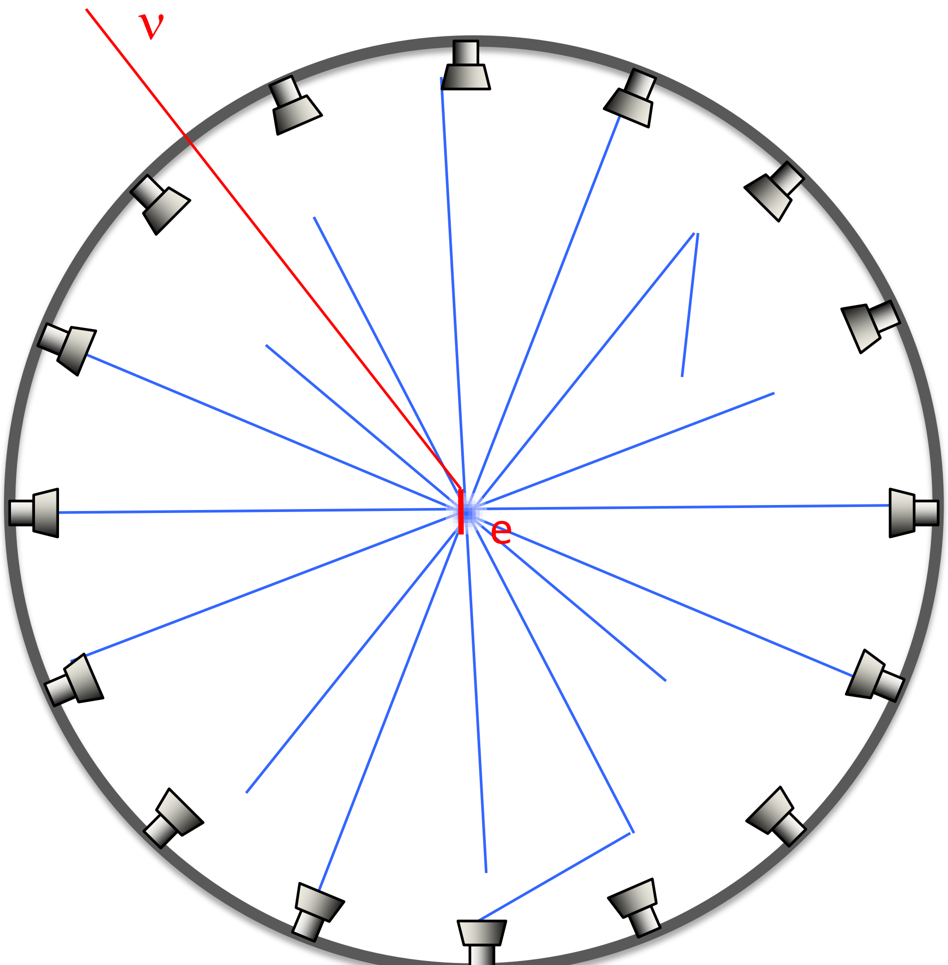
organic liquid:
in total 70kt

diameter
governed by
scintillator
transparency

Scintillator Parameters

Parameter	affects
Light yield	Energy resolution and threshold
Emission spectrum	Light transmission
Fluorescence times	Time resolution, particle discrimination
Attenuation length	Light loss by transmission => energy resolution
Scattering Length	Light yield corrections and signal shape
Quenching	Detector response, energy calibration

Energy Resolution



Basic Ingredients

Light Yield (/MeV)	10^4
Photoactive Coverage	30%
PMT Photoefficiency	20%
+ Light Absorption/Scattering	
Photoelectrons/MeV	<600

Light intensity in distance *r*:

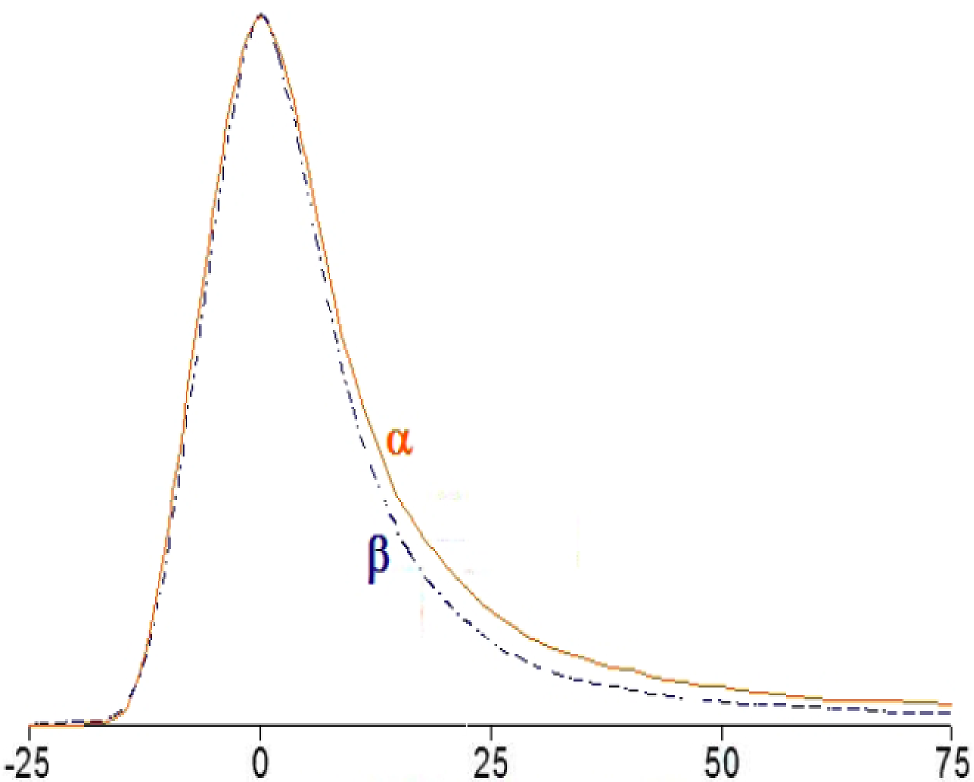
$$I(r) \approx \frac{I_0}{4\pi r^2} e^{-r/L}$$

I_0 initial intensity

L attenuation length:

$$\frac{1}{L} = \frac{1}{\ell_{\mathrm{scatter}}} + \frac{1}{\ell_{\mathrm{absorption}}} + \ldots$$

Time Resolution



For low energy signals (but also for proton decay), sum signal of all PMTs is used for timing.

Contributing Parameters

Fluorescence constants:

fast component	ca. 3ns
slow component(s)	>20ns
Time of flight diff.	O(100ns)

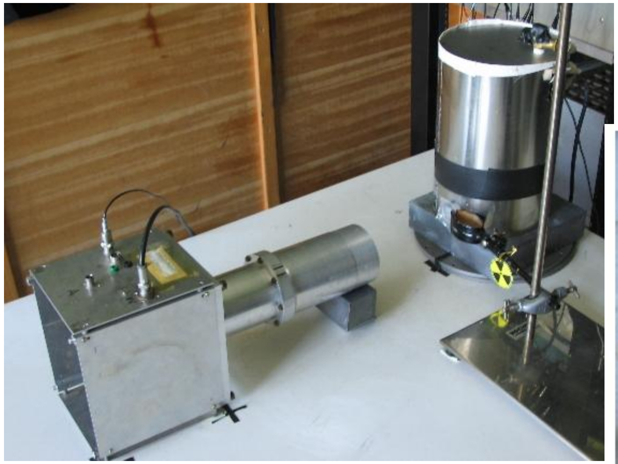
Light Scattering

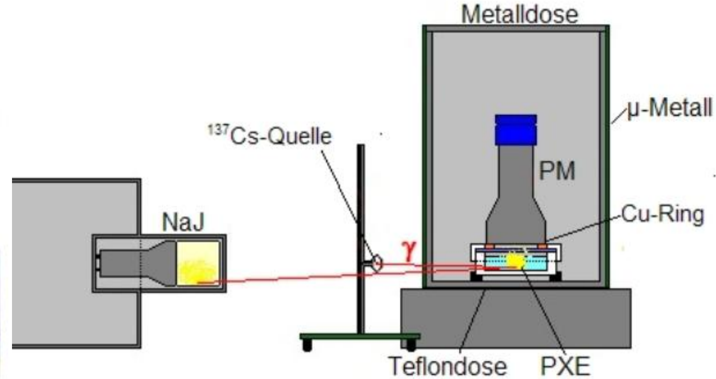
Leading edge determines timing

Trailing edge for particle ID

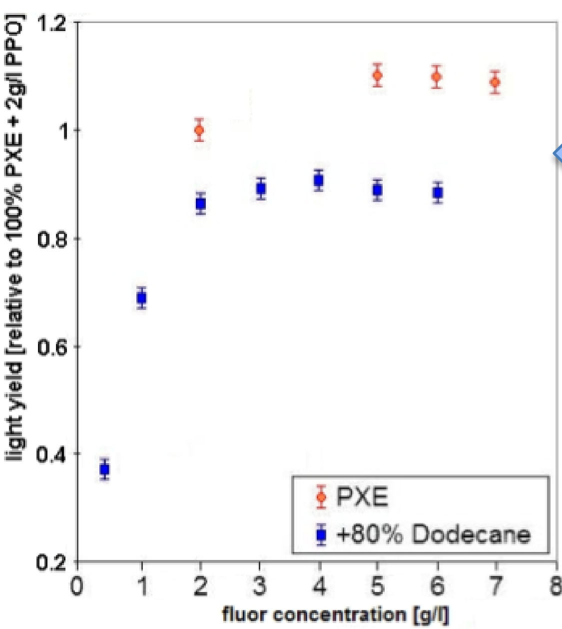
Including position reco improves the timing (subtracting TOF).

Light Yield





fluor concentration

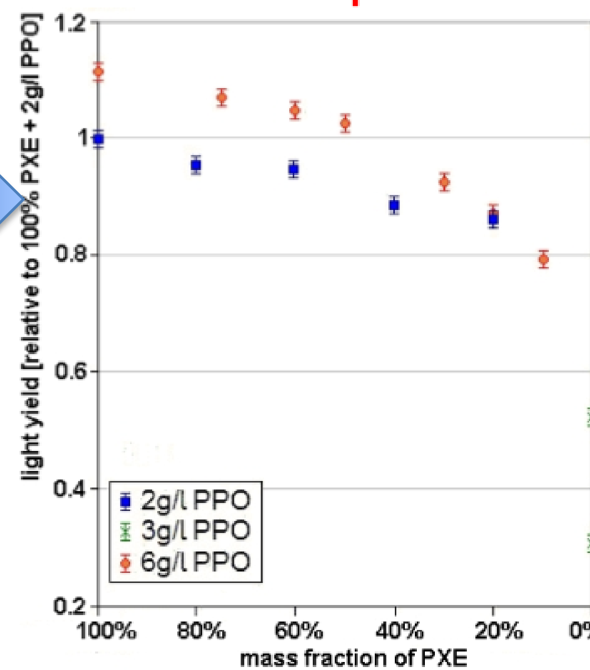


light yield dependent on solvent (+C12), fluor type and fluor concentration.

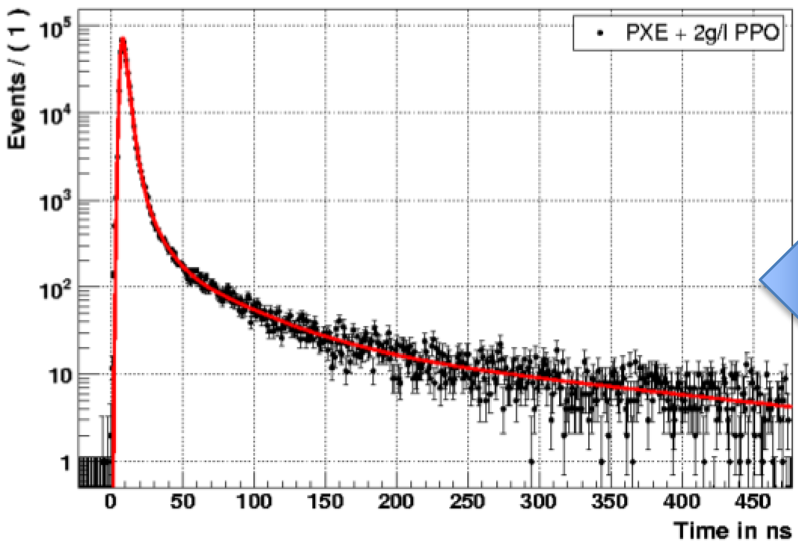
Common: $10^4\gamma$/MeV

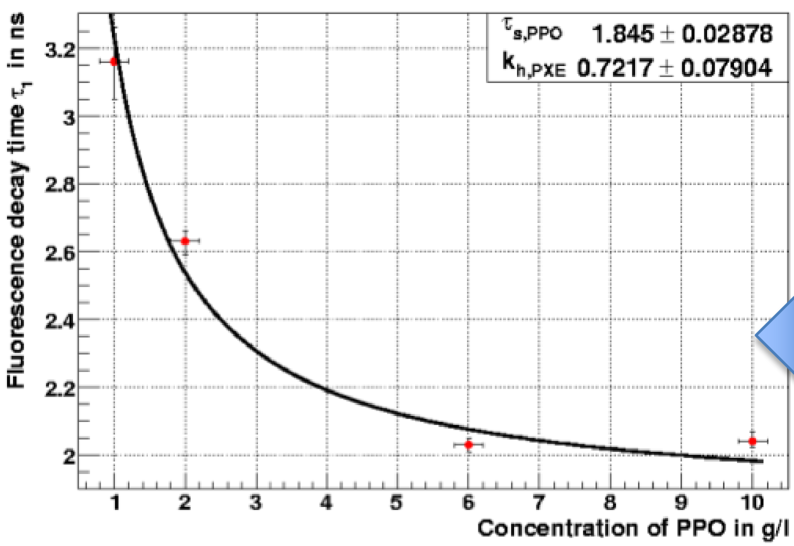
TUM: Michael Wurm, Patrick Pfahler, Jürgen Winter, Teresa Marrodán, Timo Lewke
MPIK: Christian Buck

solvent composition



Fluorescence Decay Times



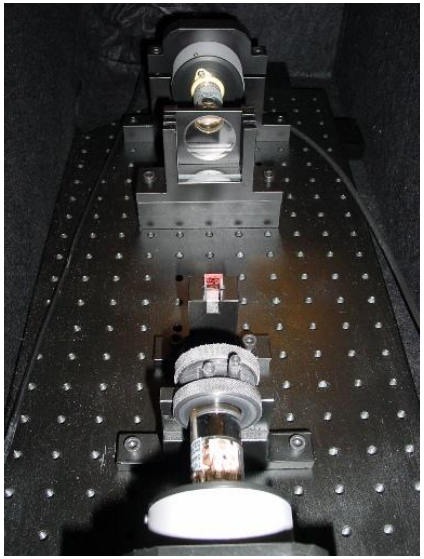


Fluorescence times and relative contri-butions for different combinations of solvent and fluor(s).

Typical values:

fast component:
A=90%, τ=3-7 ns

slow components:
A=O(%), τ>20ns



Dependence of fast signal component on fluor concentration.

Teresa Marrodán,
>> Quirin Meindl

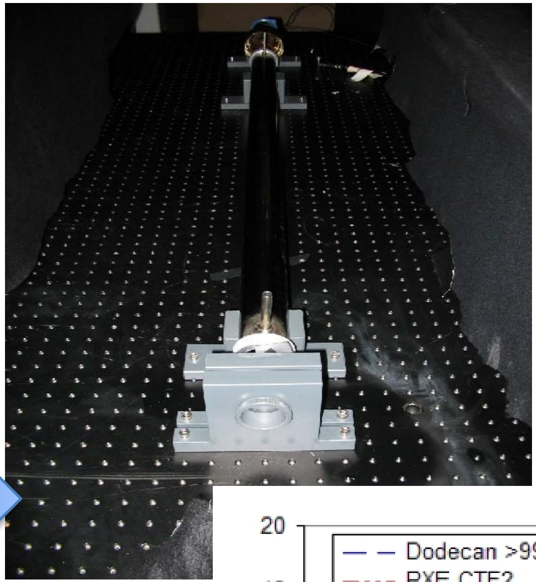
Scintillator Transparency

Measured quantity:

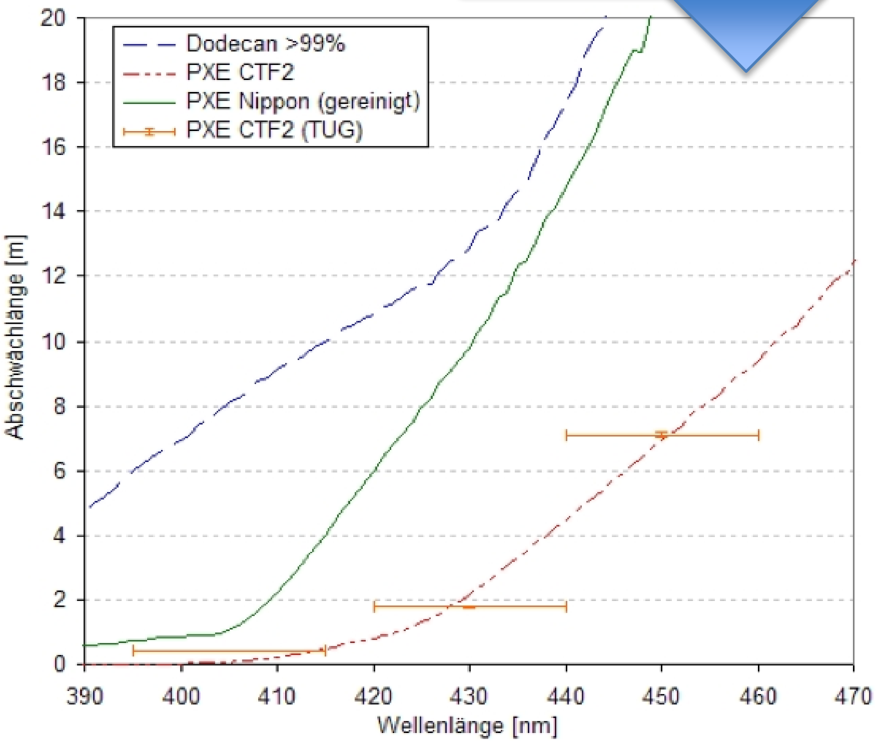
attenuation length L

$$\frac{1}{L} = \frac{1}{\ell_{\text{scatter}}} + \frac{1}{\ell_{\text{absorption}}} + \ldots$$

Measurements were done using a 1m scintillator tube at 10nm accuracy at TUM and for a 10cm cell at 1nm accuracy at MPI-K.



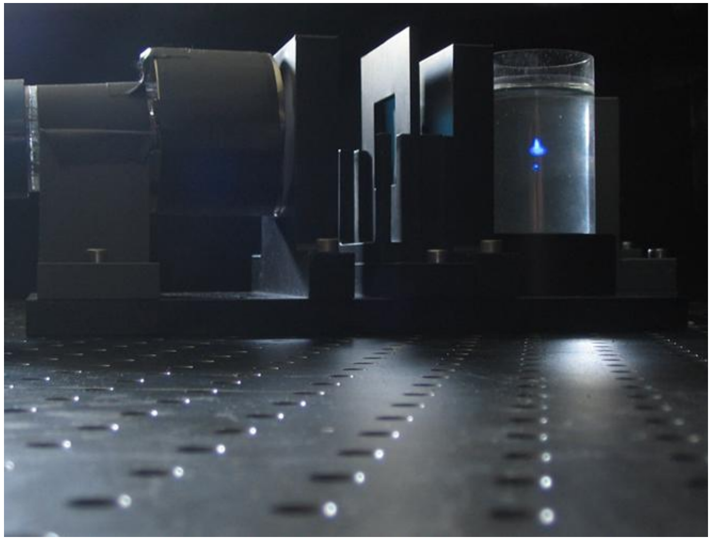
Transparency considerably increases with wavelength.
Needed:
10m @ 430nm

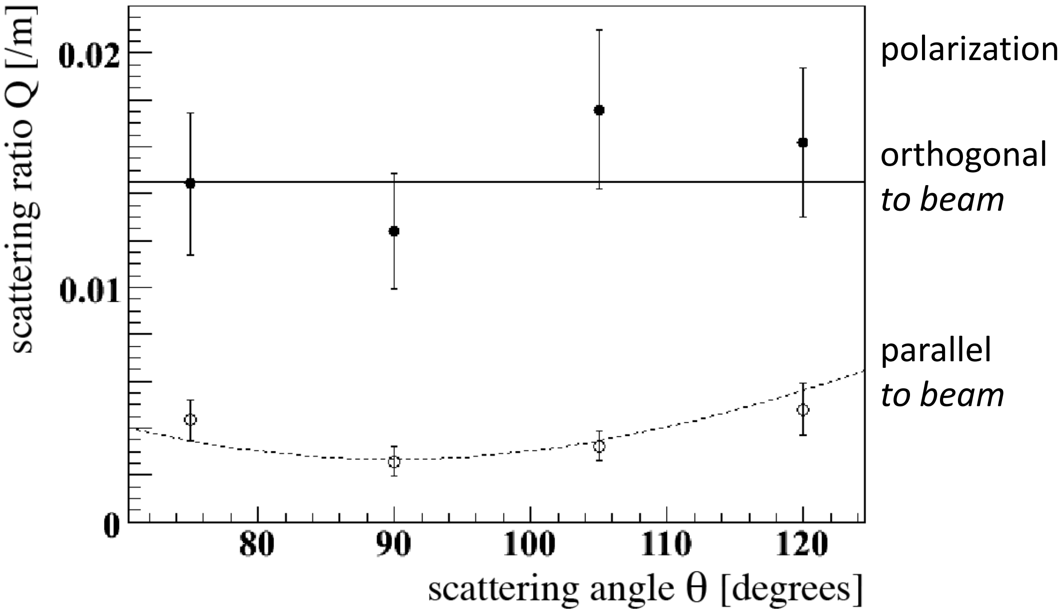


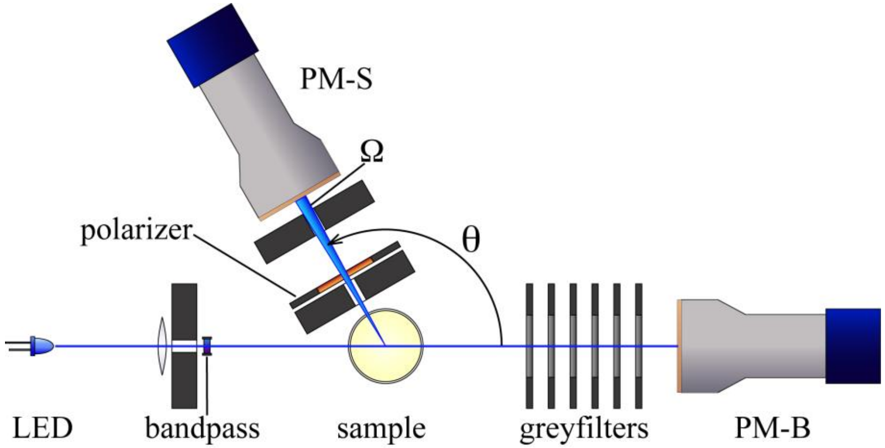
Coming soon at TUM:

spectrally resolved transmission measurement over distances >1m

Light Scattering



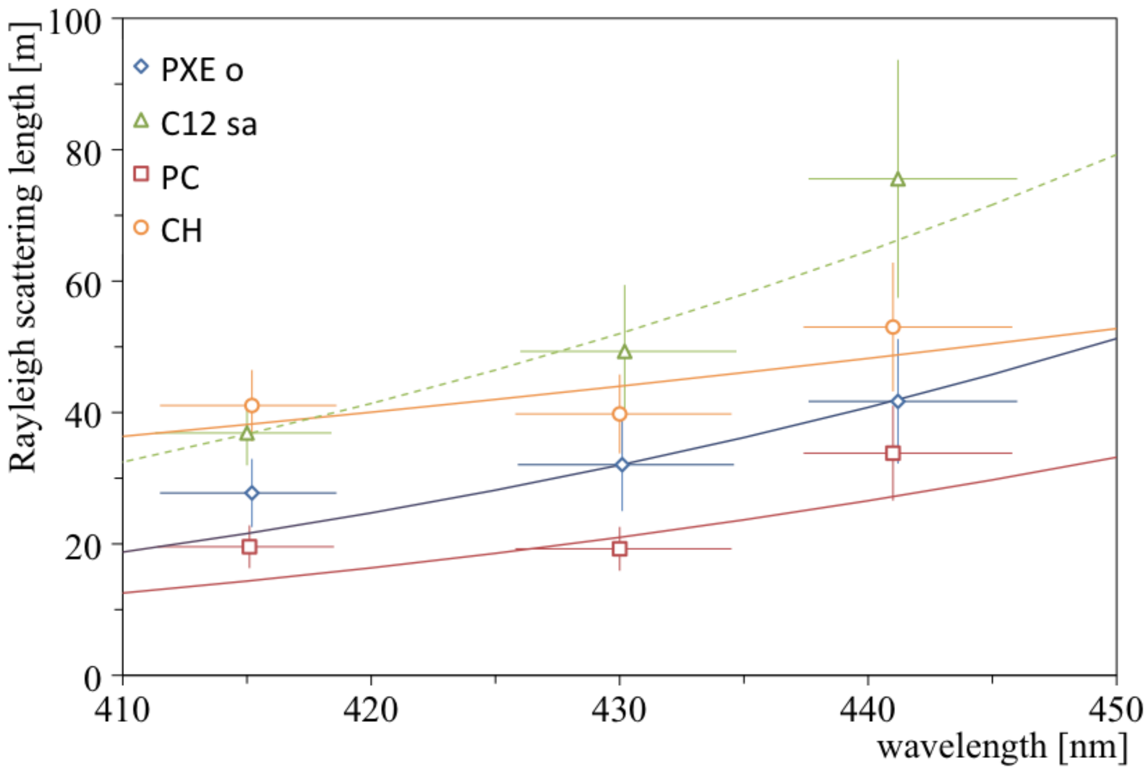




Measurement of the scattered intensity as a function of both scattering angle and polarization allows to distinguish individual scattering modes: Rayleigh, Mie, also absorption/reemission ...

Scattering Length Results

- no hints for Mie-scat.
- anisotropic scattering in good agreement with Rayleigh expectation
- correct wavelength-dependence found
- literature values for PC, cyclohexane correctly reproduced



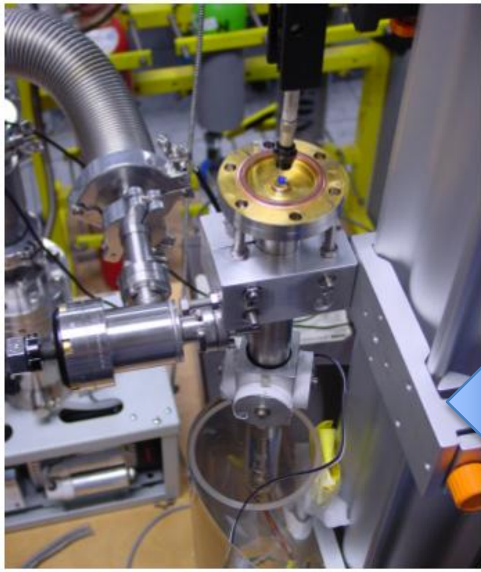
Results for λ=430nm

Sample	ℓ_{is} [m]	ℓ_{an} [m]	ℓ_S [m]	χ^2/ndf	ℓ_{ray}
PXE U	22.8±1.0	33.6±4.0	13.6±0.7±1.0	1.39	32
C12 SA	258±54	40.9±3.9	35.3±3.0±2.2	0.92	37
C12 AC	132±16	48.5±5.6	35.4±3.1±2.3	0.77	37
LAB P500	75.3±5.3	40.2±4.4	26.2±1.9±1.6	1.23	45
LAB P550	60.5±3.7	40.5±5.2	24.3±1.9±1.5	1.29	45
LAB 550Q	66.3±5.7	40.0±4.6	25.0±1.9±1.6	0.80	45
CH	n.a	45.0±4.5	44.9±4.5±2.9	0.74	44

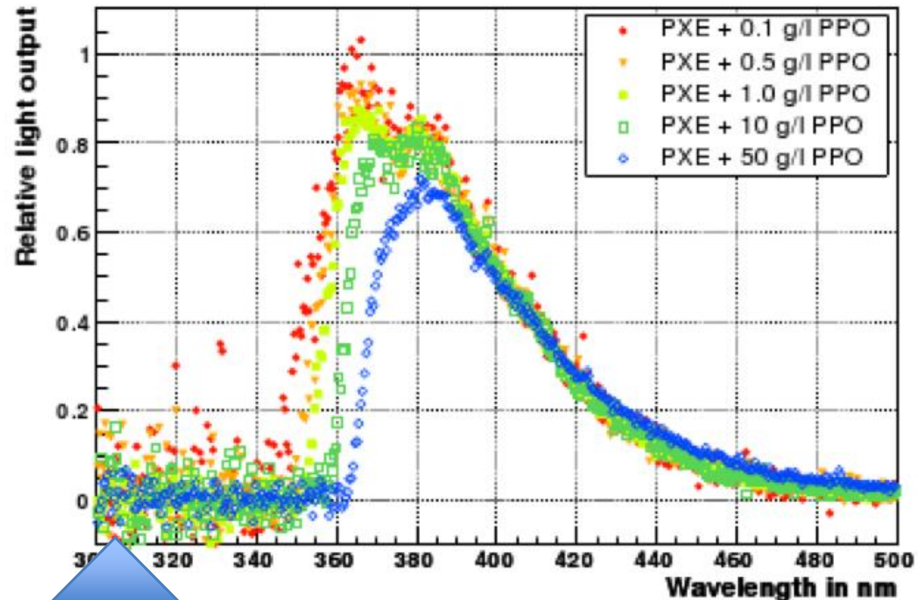
L_S = 22±3 m

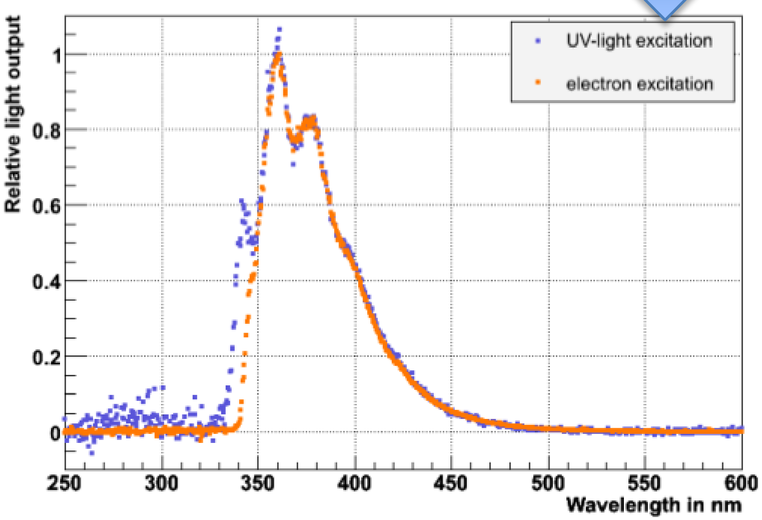
after purification in Al_2O_3-column

Light Emission Spectra

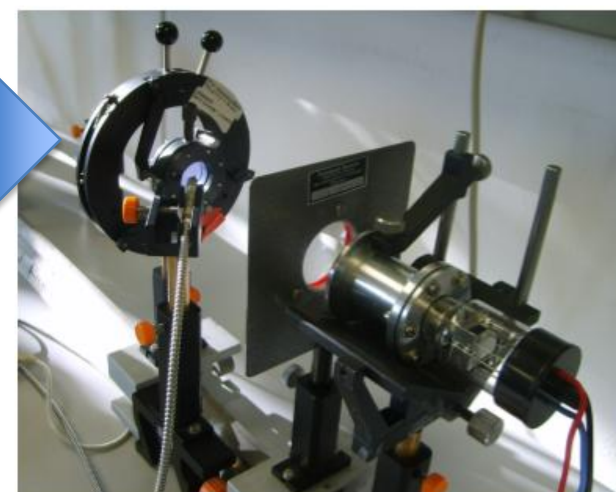


Search for spectral differences in the light emission after UV/electron excitation.



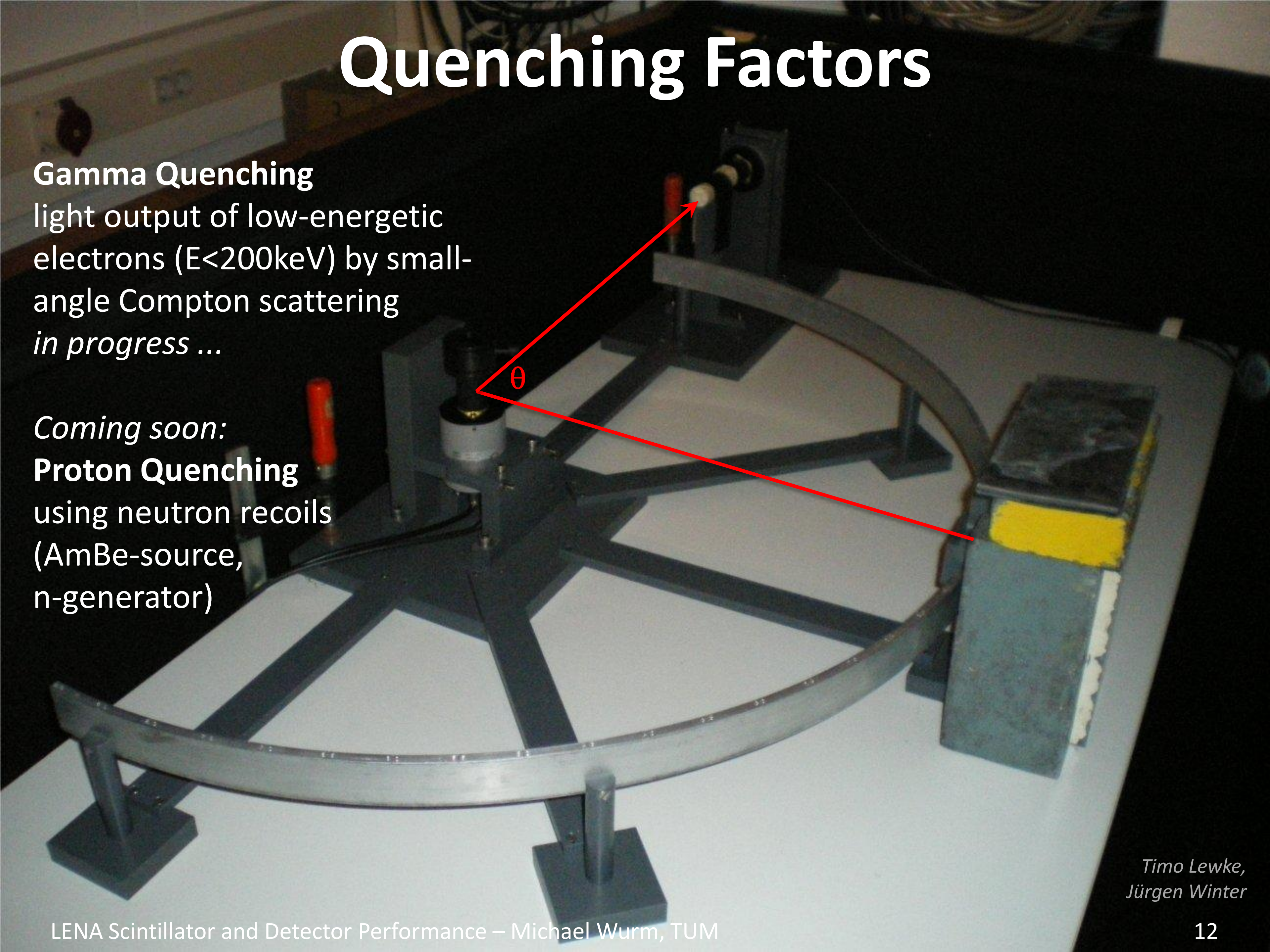


Influence of fluor type and concentration on the light emission spectrum.
PPO/bisMSB
400-430 nm



Teresa Marrodán

Quenching Factors



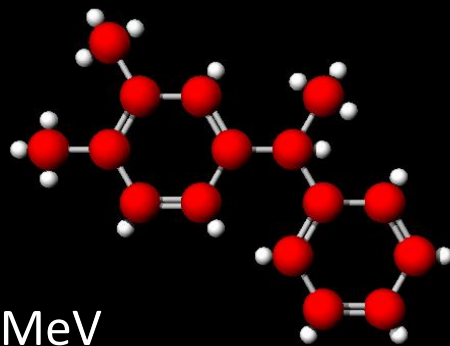
Gamma Quenching
light output of low-energetic electrons (E<200keV) by small-angle Compton scattering
in progress ...

Coming soon:
Proton Quenching
using neutron recoils (AmBe-source, n-generator)

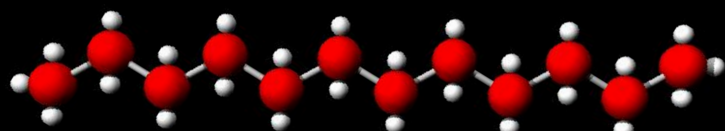
Timo Lewke, Jürgen Winter

Solvent Candidates

PXE, $C_{16}H_{18}$



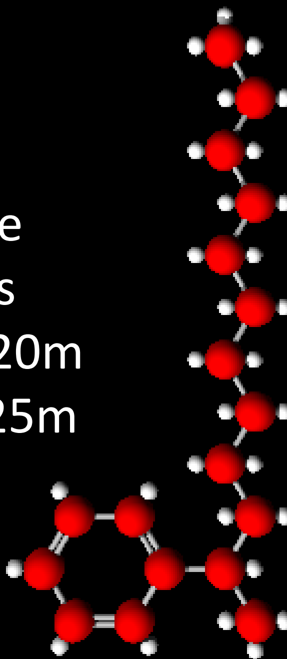
density: 0.99 kg/l
light yield:
ca. 10.000 ph/MeV
*fluorescence decay:*3ns
attenuation length: ≤12m
scattering length: 23m



+80% Dodecane, $C_{12}H_{26}$

density: 0.80 kg/l
light yield: ca. 85%
fluorescence decay slower
attenuation length: >12m
scattering length: 33m

LAB, $C_{16\text{-}19}H_{26\text{-}32}$



density: 0.86 kg/l
light yield: comparable
*fluorescence decay:*6ns
attenuation length: <20m
scattering length: 25m

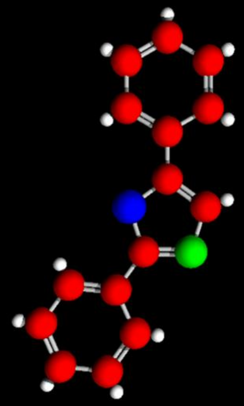
- For PXE, purification in a Al_2O_3 column is absolutely necessary.

*In terms ofsolvent transparency, a30m diameter*detector*is feasible.*

Wavelength Shifters

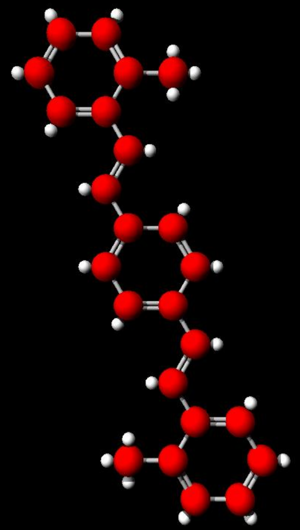
PPO, $C_{15}H_{11}NO$

primary fluor
absorption band:
280-325nm
emission band:
350-400nm



bisMSB, $C_{24}H_{22}$

secondary fluor
absorption band:
320-370nm
emission band:
380-450nm



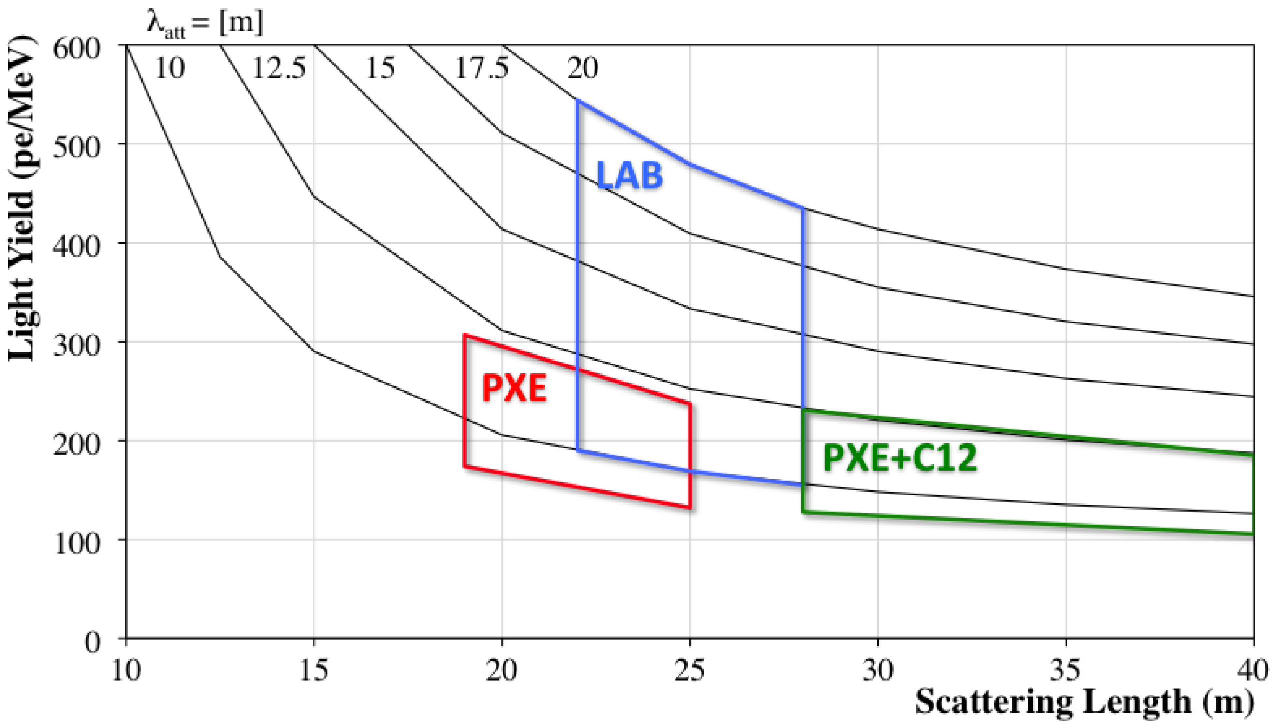
PMP, $C_{18}H_{20}N_2$

large Stoke-shift fluor
absorption maximum:
294nm
emission maximum:
415nm

used in the KARMEN experiment, currently not commercially produced

Concentration: the more fluor the better for light yield, particle ID, timing resolution.
But: self-absorption, radiopurity and price have to be considered.

MC Simulation of Light Yield

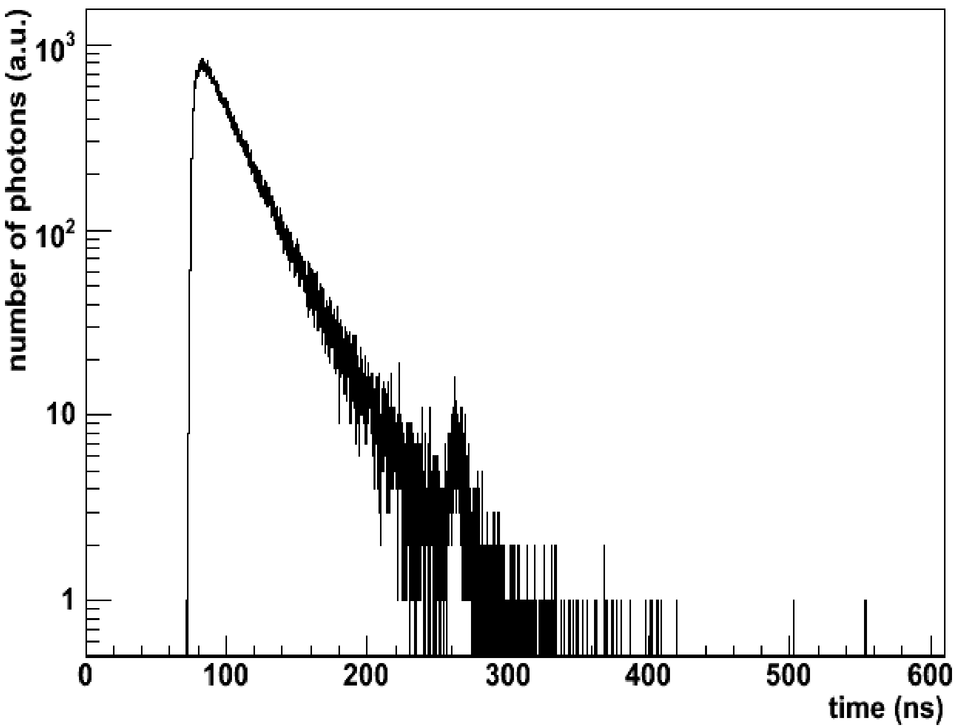


Input Parameters:

- event in the center
- 10^4 photons/MeV
- LENA radius: 15m
- optical coverage: 0.3
- photoefficiency: 0.2
- attenuation length
- scattering length

- overall range: 200-450 photoelectrons/MeV (optimum: 600pe/MeV) corresponding energy resolution at 1MeV: 7.1% to 4.6%
- yield can be increased using state-of-the-art photocathodes (ε ->40%)

MC of Timing



Rise time determines resolution.

General trends:

- fast fluorescence component has largest impact on both rise time t_s and decay flank τ_s
- no effect of refractive index
- lower scattering length smears out signal: t_s larger
- increase in attenuation length decreases t_s

Solvent Parameters					Energy Resolution		Time Res.	
Sample	L [m]	ℓ_S [m]	τ_f [ns]	n	Y_{pe} [/MeV]	r [%]	t_s [ns]	τ_s [ns]
PXE	10.5±1.5	22±3	2.63(3)	1.57	207^{+100}_{-75}	$7.0^{+1.7}_{-1.3}$	4.7±0.4	27±2
&C12	12±2	34±6	–	–	159^{+72}_{-54}	$7.9^{+1.8}_{-1.3}$	–	–
LAB	15±5	25±3	5.21(6)	1.49	334^{+207}_{-179}	$4.5^{+2.5}_{-1.1}$	6.9±0.5	30±5

Scintillator Parameters

Parameter	affects	LAB	PXE	+C12
Light yield	Energy resolution and threshold			-
Fluorescence times	Time resolution, particle discrimination	-	+	?
Attenuation length	Light loss by transmission => energy resolution	+	-	
Scattering Length	Light yield corrections and signal shape			+
Quenching	Detector response, energy calibration	?	-	
Chemical Purity	Liquid Handling	+	-	