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Photoelectron Yield
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LENA

Investigation of Optical Scintillation Properties and the Detection of Supernovae Relic Neutrinos

M. Wurm

January 18, 2006

Outline

1. **LENA**
   - Detector
   - Physics Goals
   - Scintillator
2. **Optical Properties**
   - Light Yield
   - Attenuation
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   - Scattering
3. **SRN**
   - Phenomenology
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4. **Summary**

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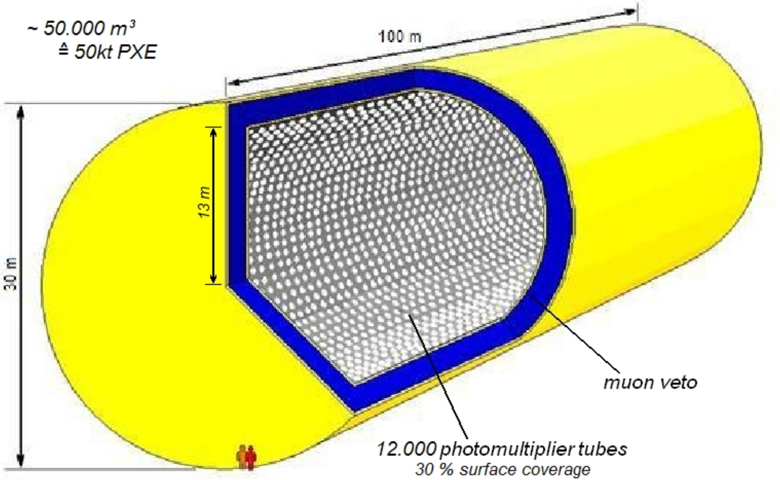
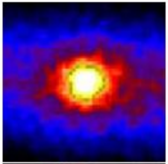
The LENA Detector



Physics Goals

about 50 kt of liquid scintillator, so:

- Solar Neutrinos — $5.4 \cdot 10^3$/d
- Neutrino Properties
- Supernovae Neutrinos — $2 \cdot 10^4$
- Supernovae Relic Neutrinos — 6/a
- Geoneutrinos — $(0.4\text{-}4) \cdot 10^3$/a
- Proton Decay — $\tau_p > 4 \cdot 10^{34}$a
- Indirect Dark Matter Search

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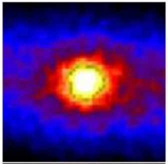
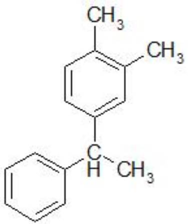
but! high transparency needed
attenuation length $\lambda_{att} \sim 10$m



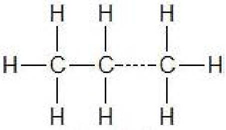

Proposed Scintillator



PhenylXylylEthane $C_{16}H_{18}$

specific gravity:	$0.986\ kg/\ell$
flash point:	$160\ ^\circ C$
HMIS rating:	$0-1$
CTF2:	$\lambda_{att} \sim 4$m

$\Rightarrow$ Al_2O_3-column purification

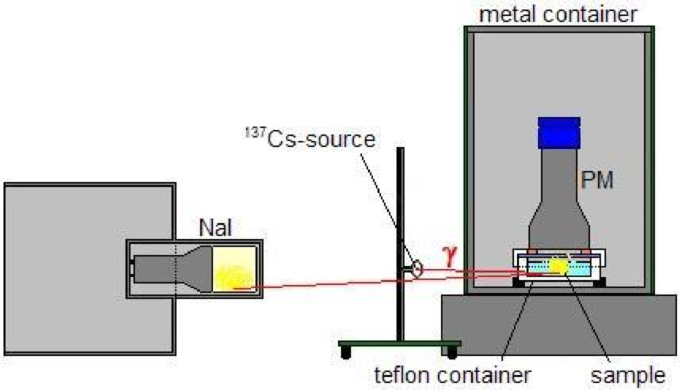


Dodecane $C_{12}H_{26}$

specific gravity:	$0.749\ kg/\ell$
flash point:	$74\ ^\circ C$
HMIS rating:	$0-2$
attenuation length:	$>$10m

Measurement of Light Yield

Experimental Setup



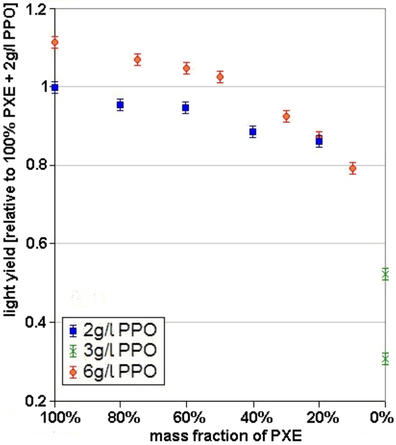
Compton backscattering provides monoenergetic **e**$^-$ ($480keV$)

$\Rightarrow$ relative measurement of different samples

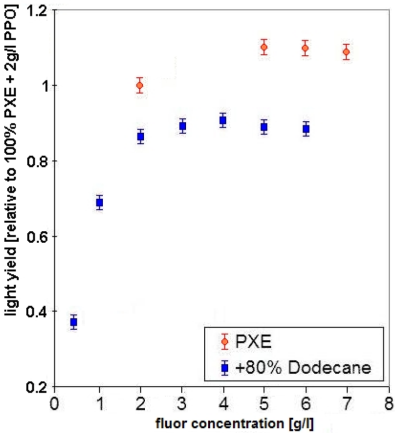
Measurement of Light Yield
Results

light yield depending on...

solvent composition



fluor concentration



Measurement of Attenuation Length
Experimental Setup

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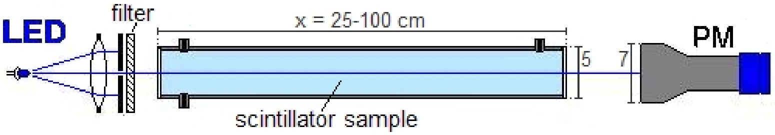

- LED emits short light pulses at ~430nm
  ⇔ emission band of scintillation light
- both absorption and scattering reduce intensity
  ⇒ total attenuation measured
- $I(x) = I_{in} \cdot e^{-x/\lambda_{att}}$

x tube length
λ_{att} attenuation length
I_{in} infalling intensity
$I(x)$ measured intensity

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Attenuation Length @ 430±10* nm [in m]				
Sample		**purified**	**Garching**	**MPI-K HD**
PXE	CTF2	$\times$	1.77±0.02	2.25±0.21
	Dixie	$\times$	2.26±0.03	-
	Nippon	$\surd$	-	9.3±0.4
Dodecane	90%+	$\times$	3.65±0.04	-
	99%+	$\times$	-	12.1±1.0

* *exact LED emission wavelength unknown*

Results:

- Al_2O_3-column purification effective
- adding high purity Dodecane would increase λ_{att}

Photoelectron Yield
Approximation

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approximated yield of pholoelectrons (per MeV):

$$Y_{pe} = Y_L \cdot \frac{2}{3} \cdot e^{-R/\lambda_{att}} \cdot c_{PM} \cdot \varepsilon_{PM}$$

Y_L light yield; $2/3$ geometry
R detector radius
c_{PM} PM coverage
ε_{PM} quantum efficiency

scintillator (Al_2O_3*-purified)*		Y_L/Y_{CTF2} ($\pm 2\%$)	$\lambda_{att,prop}$ [m]	Y_{pe} [MeV^{-1}]
PXE (6g/ℓ PPO)		1.01	9.3±0.4	100 ± 6
proportion of PXE to Dodecane (2g/ℓ PPO)	100:0	0.92	9.3±0.4	91 ± 6
	40:60	0.81	11.0±1.0	100 ± 11
	20:80	0.78	11.6±1.1	102 ± 11
	0:100	0.37	12.1±1.0	50 ± 5

- sufficient photoelectron yield in both cases!
- mixtures would provide a higher number of free protons for inverse beta decay: $\bar{\nu}_e + p \rightarrow n + e^+$

Photoelectron Yield

GEANT4 Simulations

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- attenuation combines light absorption and scattering, so

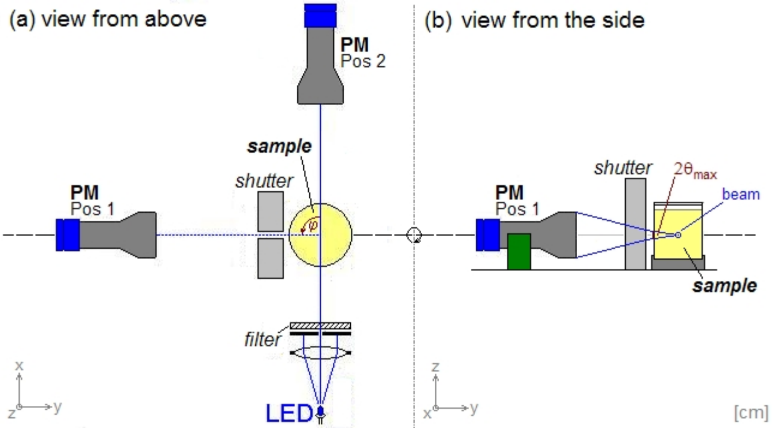
$$I(x) = I_{in} \cdot e^{-x/\lambda_{abs}} \cdot e^{-x/\lambda_{scat}} = I_{in} \cdot e^{-x/\lambda_{att}}$$

- scattered light is only partially lost to PMs
  $\Rightarrow \lambda_{abs}, \lambda_{scat}$ important for pe simulations

λ_{att} (m)	λ_{abs} (m)	λ_{scat} (m)	Y_{pe} (/MeV)
5	10	10	58
7	14	14	116
9	18	18	161
10	12	60	110
10	15	30	145
10	20	20	180
10	30	15	230
10	60	12	303

Measurement of Scattering Length

Experimental Setup



Measurement of Scattering Length
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Sample	λ_{scat} [m]
PXE	$9.6^{+2.9}_{-1.7}$
PXE (Al_2O_3-purified)	23^{+16}_{-7}
Dodecane 90%+	13^{+5}_{-3}

Further aims:

- improved accuracy of the measurement (higher statistics)
- investigation of further samples (Dodecane 99%+, mixtures ...)
- determination of the proportions of Rayleigh- to Mie-scattering in the samples

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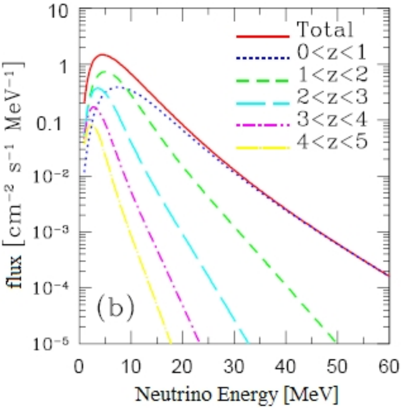
Supernovae Relic Neutrinos

Phenomenology

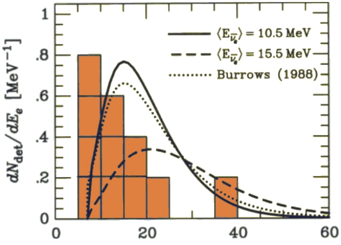
What are Supernovae Relic Neutrinos?

- Supernovae release 99% of their gravitational binding energy in νs, all flavours are generated
- all SN contribute to an isotropic background of νs, the SRN
- energies of νs emitted by SN at z>0 are red-shifted
- $\bar{\nu}_e$ can be detected by inverse beta decay
  $$\bar{\nu}_e + p \rightarrow n + e^+$$
- SK limit: 1.2 $\bar{\nu}_e$/cm^{2}s for E_ν >19.3 MeV



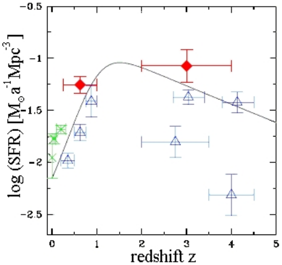
Phenomenology
Model Calculations

spectral form and flux of the SRN depend on:



SN ν-spectra

- influence spectral form
- insufficient exp. data
- three SN models:
  Lawrence Livermore - LL
  Keil Raffelt & Janka - KRJ
  Thompson Burrows & Pinto - TBP



Star Formation Rate (SFR)

- corresponds to SN rate
- UV-, H_α- and FIR-observations are impeded by dust extinction

SRN Spectrum

Event Rates & Energy Window

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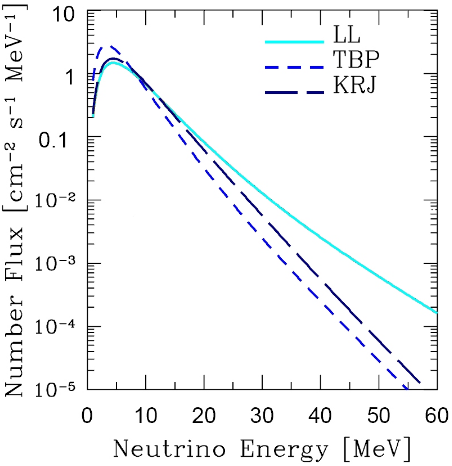

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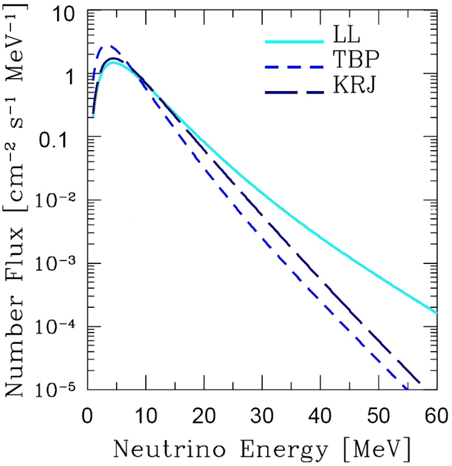
Events in LENA: 53-74 in 10a $\left(^{+400\%}_{-30\%}\right)$



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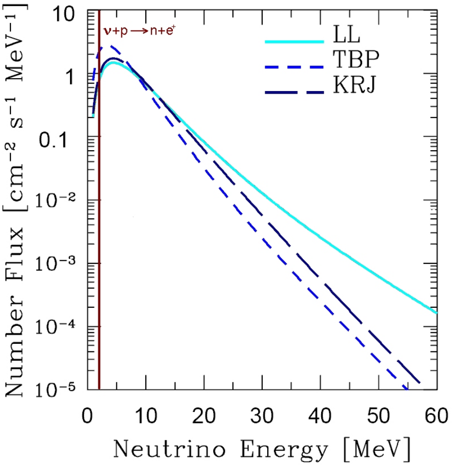

thresholds:

- inverse β-decay
  $E_\nu > 1.8 MeV$

SRN Spectrum

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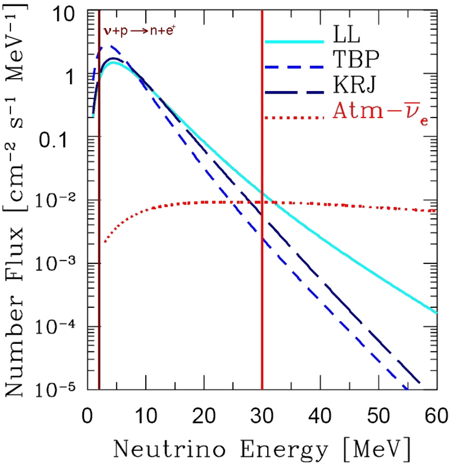

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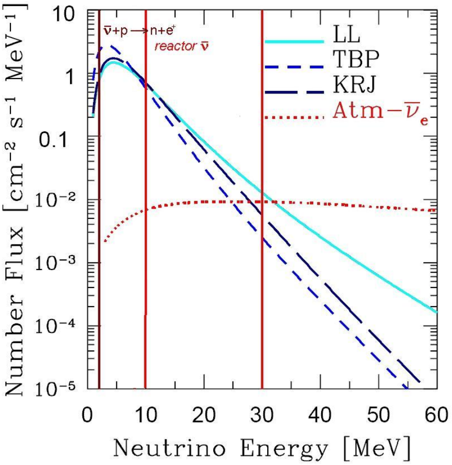

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- reactor $\bar{\nu}_e$s
  $E_\nu > 10 MeV$ **?**

SRN Spectrum

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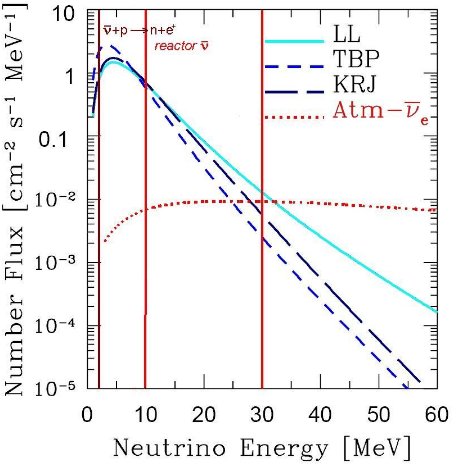

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  $E_\nu > 10 MeV$ **?**

$\Rightarrow$ 22-42 events in 10a!

SRN Spectrum

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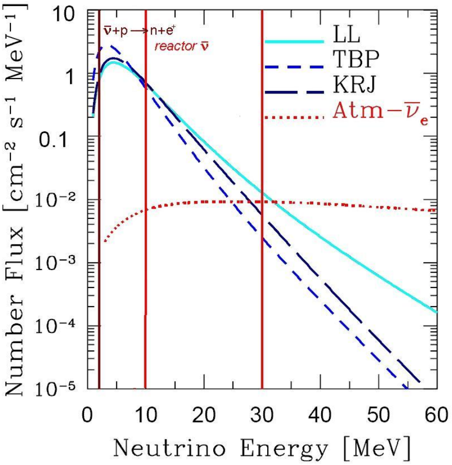

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  $E_\nu < 30 MeV$
- reactor $\bar{\nu}_e$s
  $E_\nu > 10 MeV$ **?**

$\Rightarrow$ 22-42 events in 10a!

H_2O-Čerenkov detectors

- spallation products
- invisible muons

$\Rightarrow$ no energy window!

Background
Lower E_ν Threshold

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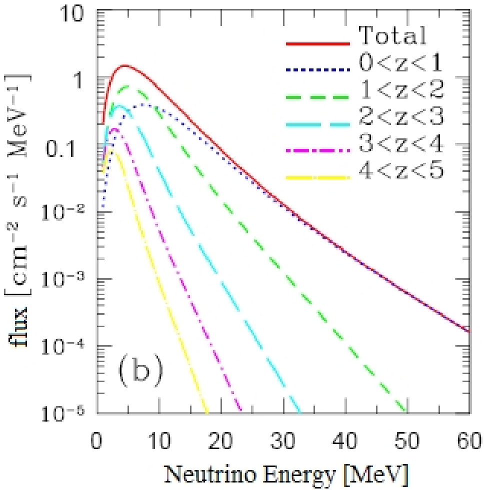


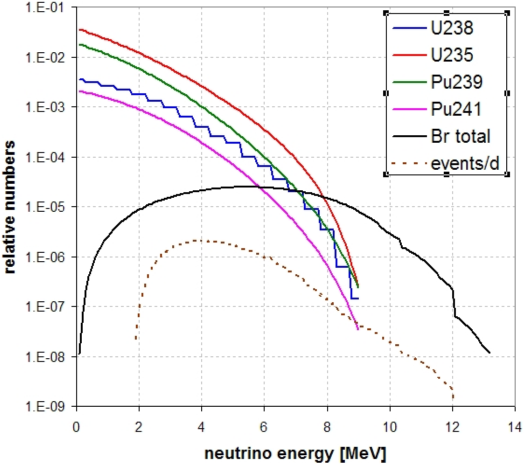
low energy threshold very important to see SRN contribution of z>1 regions!

⇒ reactor $\bar{\nu}_e$ flux and spectra for E_ν>8MeV have to be carefully considered

⇒ suitable detector location (far from nuclear power plants) and high energy resolution needed

Background

Reactor $\bar{\nu}_e$ spectra - first approach



^{90}Br (Q=10.3MeV)
β-decay: 77%
yield: 0.6% ^{235}U
0.2% ^{239}Pu

^{92}Br (Q=12.2MeV)
β-decay: 70%
yield: 0.03% ^{235}U
0.002% ^{239}Pu

^{94}Br (Q=13.3MeV)
β-decay: 70%
yield: 0.0002% ^{235}U
0.003% ^{239}Pu

(NNDC Brookhaven)

$E < 8 MeV$ parameterised spectra of U&Pu
$E > 8 MeV$ neutron-rich bromine isotopes

Background
Difficulties

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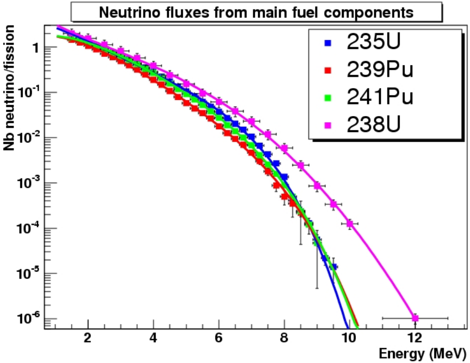
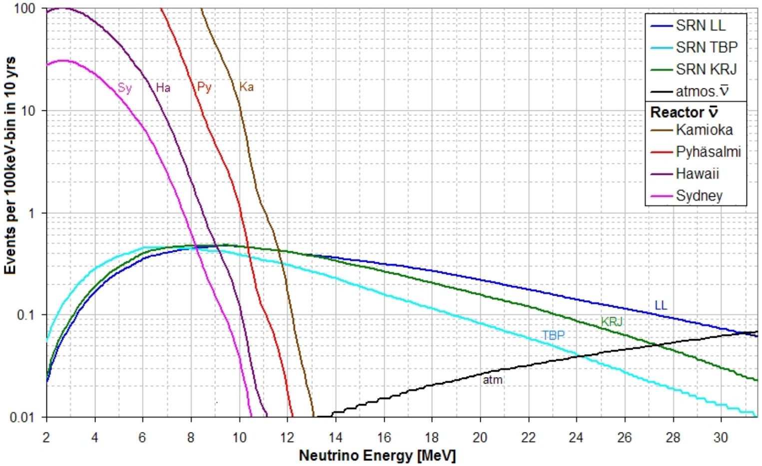
- β-decays: not always to ground state $\Rightarrow$ lower $\bar{\nu}_e$ energies
- additional elements with high endpoints: ^{96}Rb, ^{97}Rb, ^{98}Rb (Q=12.4 MeV)
- only the $\bar{\nu}_e$-spectrum corresponding to ^{235}U has actually been measured to E=12MeV
- ^{238}U may play an important role



SRN Spectrum
LENA placed at different locations

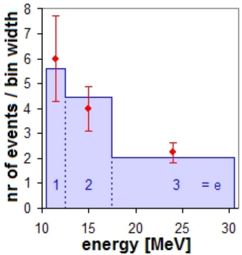


Energy Window (Pyhäsalmi): 10.5 MeV $< E_\nu <$ 30 MeV,
corresponding to 22-42 SRN events in 10 years
Reactor background: $\sim$1700 events per year

SRN Spectroscopy

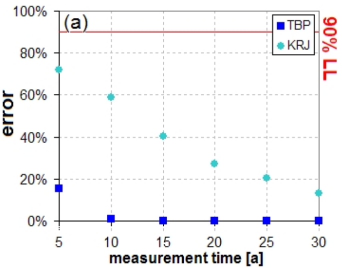
χ^2-tests

- MC spectra were generated for all models
- discrimination method: χ^2-tests comparing MC to all model spectra



Results:

- spectroscopy with LENA is possible
- LL and TBP model could be separated after 10 years with more than 90% C.L.



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- sufficient attenuation lengths ($\lambda \sim R$) are possible
- possible scintillators are pure PXE or mixtures with high percentages of Dodecane (+30% free p)
- measurement of scattering length important

- energy window for SRN detection in LENA, about 22-42 events in 10 years
- spectroscopy seems to be possible
- reactor background crucial for detecting z$>$1 SRN contribution