The OSIRIS Pre-Detector

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Forschergruppe JUNO

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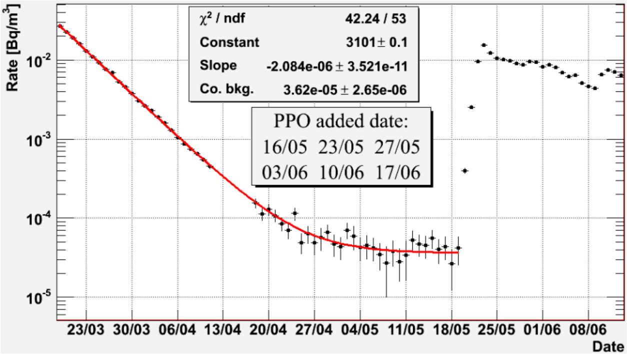
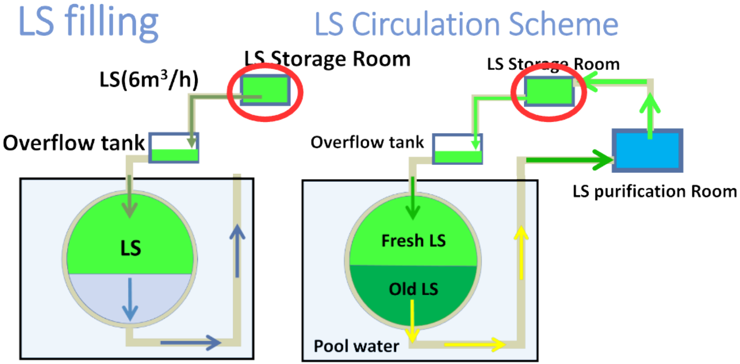
Dangers of LS Contamination

From Daya Bay Liquid Scintillator Replacement Experiment:
Danger of $^{222}\mathrm{Rn}$-contamination of LS



Possible issues in JUNO:

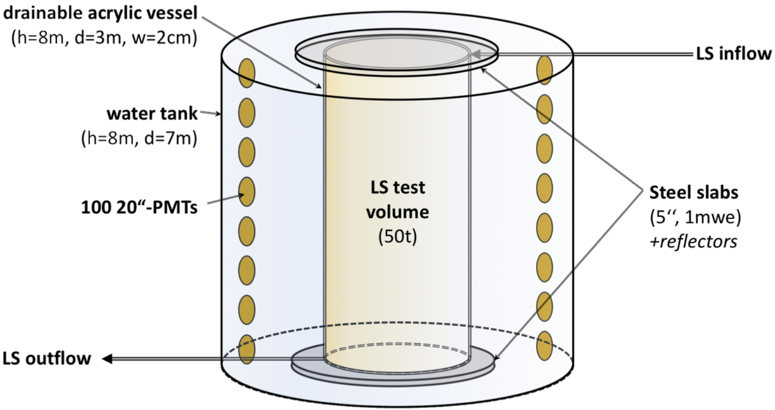
- Air leak in filling line?
- Failure of purification plants?
- Unforeseen problems?



- Joint use of on-site LS storage tank as radioactivity pre-detector
- Measure radioactive background during storage/filling/cycling

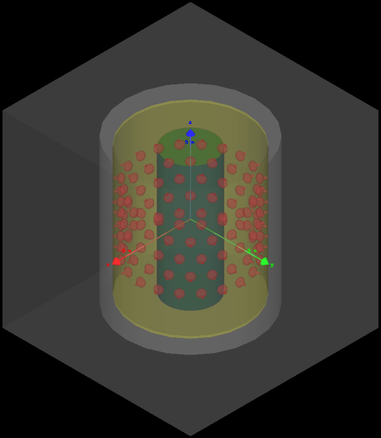
OSIRIS

Online Scintillator Internal Radioactivity Investigation System

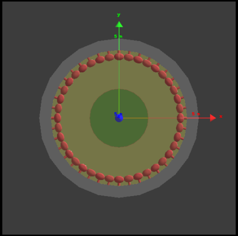


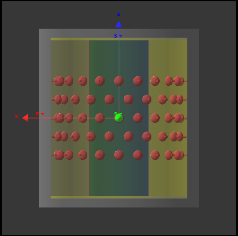
Geant4-Simulation

- 8 m height
- 100 20" wall PMTs, honeycomb arrangement
- 2 cm acrylic tank, $\varnothing = 3\,\mathrm{m}$
- Water buffer, $\varnothing = 7\,\mathrm{m}$
- 6 mm steel walls, 60 cm rock cavern
- 5" steel slabs on top and bottom



PMT Distribution





PMT design based on JUNO simulation: ellipsoid + cylinder (mushroom)
Material properties (composition, density, refractive indices, etc.) based on LENA simulation with updates from JUNO

Energy Resolution

$$\left.\begin{array}{c}\left.\begin{array}{l}A_{PMT} = 20.27\,\mathrm{m}^2 \\ A_{Tank} = 152.38\,\mathrm{m}^2\end{array}\right\} r = 13.3\% \\ \\ \text{PMT QE} \times \text{CE} = 35\%\end{array}\right\} \text{Photons detected: } \sim 4.66\%$$

$$\text{Absolute light yield: } Y \approx 10{,}000\,\gamma/\mathrm{MeV}$$
$$\text{Photoelectron yield: } Y_{p.e.} \approx 466\,\text{p.e.}/\mathrm{MeV}$$

$$\text{Conservative estimate: } Y_{p.e.} \simeq 300\,\text{p.e.}/\mathrm{MeV} \text{ (considering absorption, etc.)}$$

$$\text{Energy resolution: } \frac{\Delta E}{E} = \frac{\Delta N}{N} \overset{\text{Poisson}}{=} \frac{1}{\sqrt{N}} = \frac{1}{\sqrt{Y_{p.e.} \cdot E}}$$

$$\Rightarrow \Delta E = \sqrt{\frac{E}{Y_{p.e.}}}$$

Signal

Bi-Po-coincidence within Uranium chain, daughters of $^{222}\mathrm{Rn}$:

$$^{214}\mathrm{Bi} \rightarrow ^{214}\mathrm{Po} \rightarrow ^{210}\mathrm{Pb}$$

$$\beta\ (99.979\%) \qquad \alpha$$

$$\text{Q-Value: } 3.26\,\mathrm{MeV} \qquad E_\alpha = 7.69\,\mathrm{MeV}$$

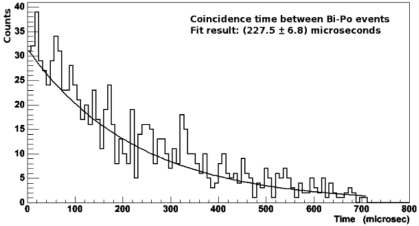


Fig. 11 - Measured time difference between pairs of ^{214}Bi and ^{214}Po events; $\tau(^{214}\mathrm{Po}) = 236.6\ \mu s$.

CTF (arXiv:0705.0239[physics.ins-det])

$$\tau(^{214}\mathrm{Po}) = 236.6\,\mu\mathrm{s}$$

Select coincidence window: 710 μs (three lifetimes τ)

External Backgrounds

Bq / kg	$^{40}\mathrm{K}$	$^{232}\mathrm{Th}$	$^{238}\mathrm{U}$
PMT	8.96	3.71	3.76
Rock	220	123	142
Steel	$13.4 \cdot 10^{-3}$	$8 \cdot 10^{-3}$	$1.2 \cdot 10^{-3}$
Acrylic	$270 \cdot 10^{-6}$	$4 \cdot 10^{-6}$	$12 \cdot 10^{-6}$

From DocDB 2140, 1377

Internal Backgrounds

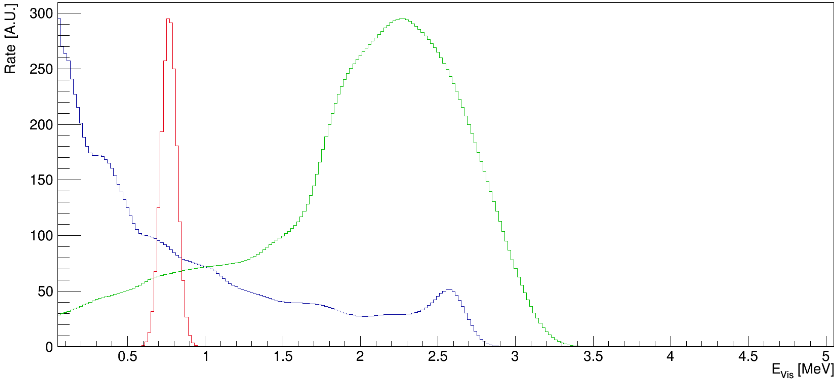
$^{40}\mathrm{K}$	$1 \cdot 10^{-17}$g/g
$^{238}\mathrm{U}$	$1 \cdot 10^{-16}$g/g
$^{232}\mathrm{Th}$	$1 \cdot 10^{-16}$g/g
$^{11}\mathrm{C}$	1000 cts/d/kt
$^{10}\mathrm{C}$	20 cts/d/kt

From solar neutrino requirements

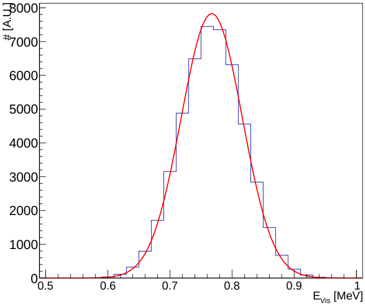
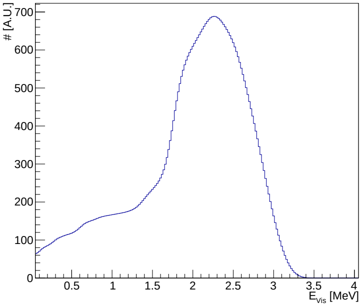
Compare Signal to Background

How small can the signal get so that we can still identify it against the background?

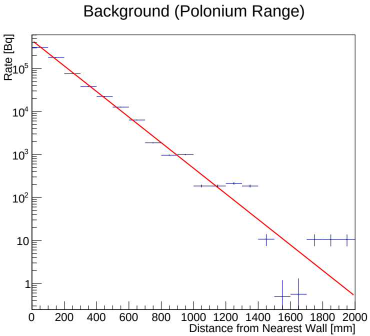
Qualitative shape comparison:



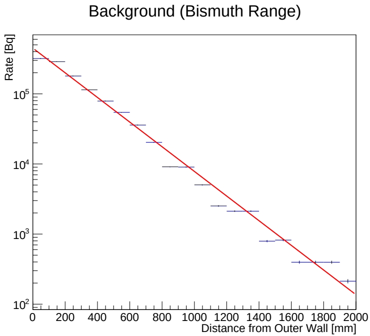
Accepted Energy Ranges

Polonium	Bismuth
	
Fit Gaussian Select 1σ around mean Range: $(0.77 \pm 0.05)\,\mathrm{MeV}$	Identify BG minimum Use statistics beyond $^{208}\mathrm{Tl}$-peak Select range: $2\,\mathrm{MeV} \leftrightarrow 3.5\,\mathrm{MeV}$

Shielding

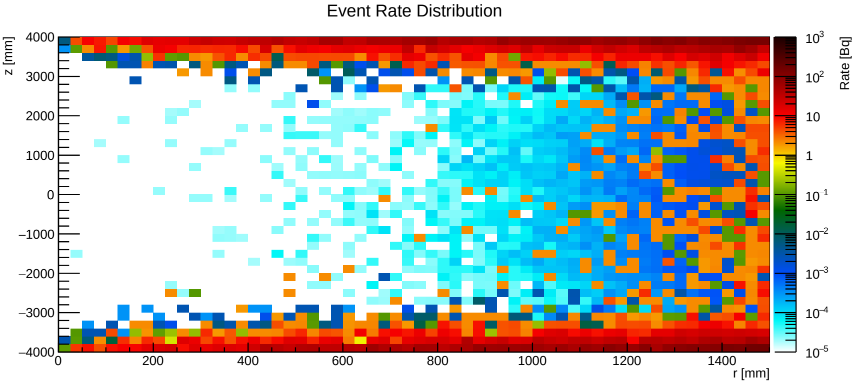


$$1\text{m}: \ 1.93 \cdot 10^{-3}$$
$$2\text{m}: \ 3.69 \cdot 10^{-6}$$



$$1\text{m}: \ 1.88 \cdot 10^{-2}$$
$$2\text{m}: \ 3.17 \cdot 10^{-4}$$

Rate Distribution



Expected Number of Events

Number of accidental coincidences:

$$N_{BG} = \underbrace{\overbrace{t_{Tank}}^{\approx 1-4\,\mathrm{d}} \times R_{BG}(\mathrm{Bi\text{-}Range})}_{\substack{\text{Number of false events}\\ \text{in the Bi energy range}}} \times \underbrace{\overbrace{\Delta t_{Coinc}}^{710\,\mu\mathrm{s}} \times R_{BG}(\mathrm{Po\text{-}Range})}_{\substack{\text{Fraction with a second event in}\\ \text{the Po energy and time range}}}$$

Number of signal events:

$$N_{BiPO} = \underbrace{t_{Tank} \times R_{Bi}}_{\substack{\text{Number of real}\\ \text{Bismuth events}}} \times \underbrace{(1 - \exp(-\Delta t_{Coinc} / \overbrace{\tau}^{236.6\,\mu\mathrm{s}}))}_{\substack{\text{Coincidence window}\\ \text{time cut}}} \times \underbrace{\overbrace{\epsilon_{Bi}}^{59.0\%} \times \overbrace{\epsilon_{Po}}^{68.3\%}}_{\substack{\text{Cut}\\ \text{efficiency}}}$$

False Coincidence Estimation

In order to distinguish signal from background: $N_{BiPo} \sim 2 \cdot \sqrt{N_{BG}}$

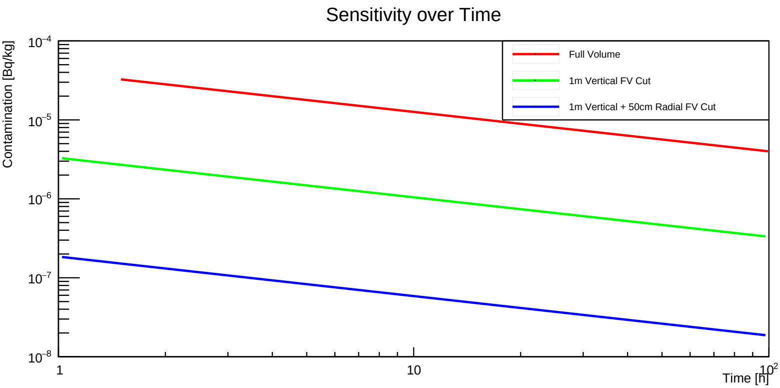
$$\Rightarrow R_{Bi} \gtrsim \frac{2 \cdot \sqrt{R_{BG}(\mathrm{Bi}) \cdot \Delta t_{Coinc} \cdot R_{BG}(\mathrm{Po})}}{\left(1 - \exp(-\frac{\Delta t_{Coinc}}{\tau})\right) \cdot \epsilon_{Bi} \cdot \epsilon_{Po}} \cdot \frac{1}{\sqrt{t_{Tank}}}$$

Background rates for various fiducial volumes:

Volume	Mass	Bi-Range	Po-Range	Accidentals
Full	48.6 t	1324 Bq	529 Bq	497 Bq
$\lvert z \rvert \leq 3\,\mathrm{m}$	36.5 t	104 Bq	26 Bq	1.9 Bq
$\lvert z \rvert \leq 3\,\mathrm{m}, r \leq 1\mathrm{m}$	27.4 t	24 Bq	0.2 Bq	3.4 mBq

Sensitivity over Time

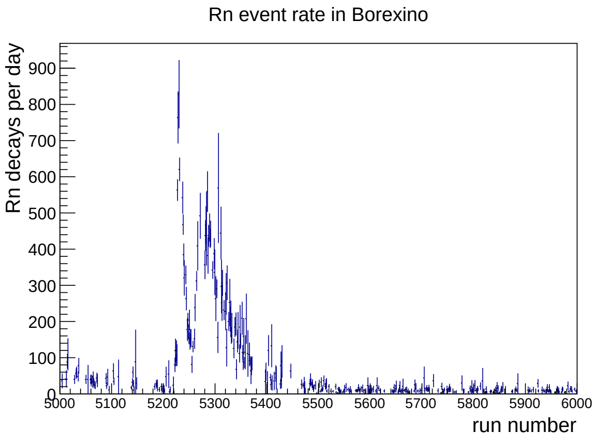
After scaling with fiducial volume mass:



One day measuring time:
Sensitive up to $3.8 \cdot 10^{-8}\,\mathrm{Bq/kg} \mathrel{\widehat{=}} 160\,\mathrm{cts/d} \mathrel{\widehat{=}} 6.8 \cdot 10^{-27}\,\mathrm{g/g}$ of $^{222}\mathrm{Rn}$

Reference for Contamination

May 2007: Rn contamination in Borexino due to air leak during filling



Maximal event rate: $\sim 800\,\mathrm{cts/d}$

Cost Estimate

Component	Costs (EUR)	Comment
Steel tank	35,000	assuming a conventional tank welded underground
Acrylic vessel	27,000	
Steel slabs	7,500	material costs for 4 m diameter
MCP-PMTs - mounting, potting, - cabling, electronics	350,000 +x +x	assuming 3,500 EUR per piece
Liquid Handling system - overflow tank	+x	

Total: $\sim$ 500,000 EUR

Re-purpose of Daya Bay PMTs:

- Huge cost savings
- DYB PMTs better operated in oil $\Rightarrow$ Change of buffer liquid?

Further Considerations

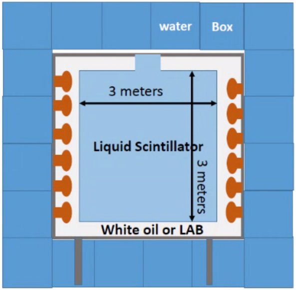
Trigger rate?

- DYB FADC: 100 Hz
- TDC/ADC: 2 kHz
- Singles background (above 500 keV) in OSIRIS: 5.8 kHz

Tank size issue

- Room size: L=42 m, W=12 m, H=10 m
- Welding underground not allowed
- Tank too heavy for crane
- 1 m additional height for calibration system?

Alternative Design



Smaller central volume

✓ Easier to transport ϟ Less fiducial volume

Array of small veto tanks

✓ Simplifies assembly ϟ Need crane on site

PMTs closer to CD

✓ Less PMTs needed ϟ Higher background

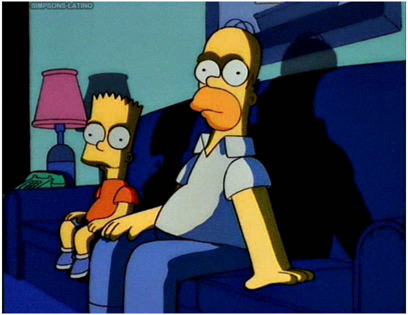
Summary

- Danger of Rn-contamination in Liquid Scintillator line (Air leak, purification failure, etc.)
- Joint use of LS tank as radioactivity monitor during filling/cycling
- Mounting of $\mathcal{O}(100)$ photomultipliers on tank inner walls
- Measuring $\mathrm{Bi\text{-}Po}$-214-coincidence vs external gamma background
- `Geant4`-simulation shows sensitivtiy up to
  $3.8 \cdot 10^{-8}\,\mathrm{Bq/kg} \mathrel{\widehat{=}} 160\,\text{cts/d} \mathrel{\widehat{=}} 6.8 \cdot 10^{-27}\,\mathrm{g/g}$ of $^{222}\mathrm{Rn}$
- Costs estimated to $\mathcal{O}$(500 kEUR)

Outlook

- Task Force summoned in the last collaboration meeting
- Find realizable construction solution, iron out discrepancies
- Move simulation to GIT/SVN project
- Rewrite geometry to investigate new design feasibility

Looking for people to contribute in the simulation



Join Us!


THANK YOU FOR YOUR ATTENTION
ANY QUESTIONS?
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