Detecting Antineutrinos Using the SNO+ Detector

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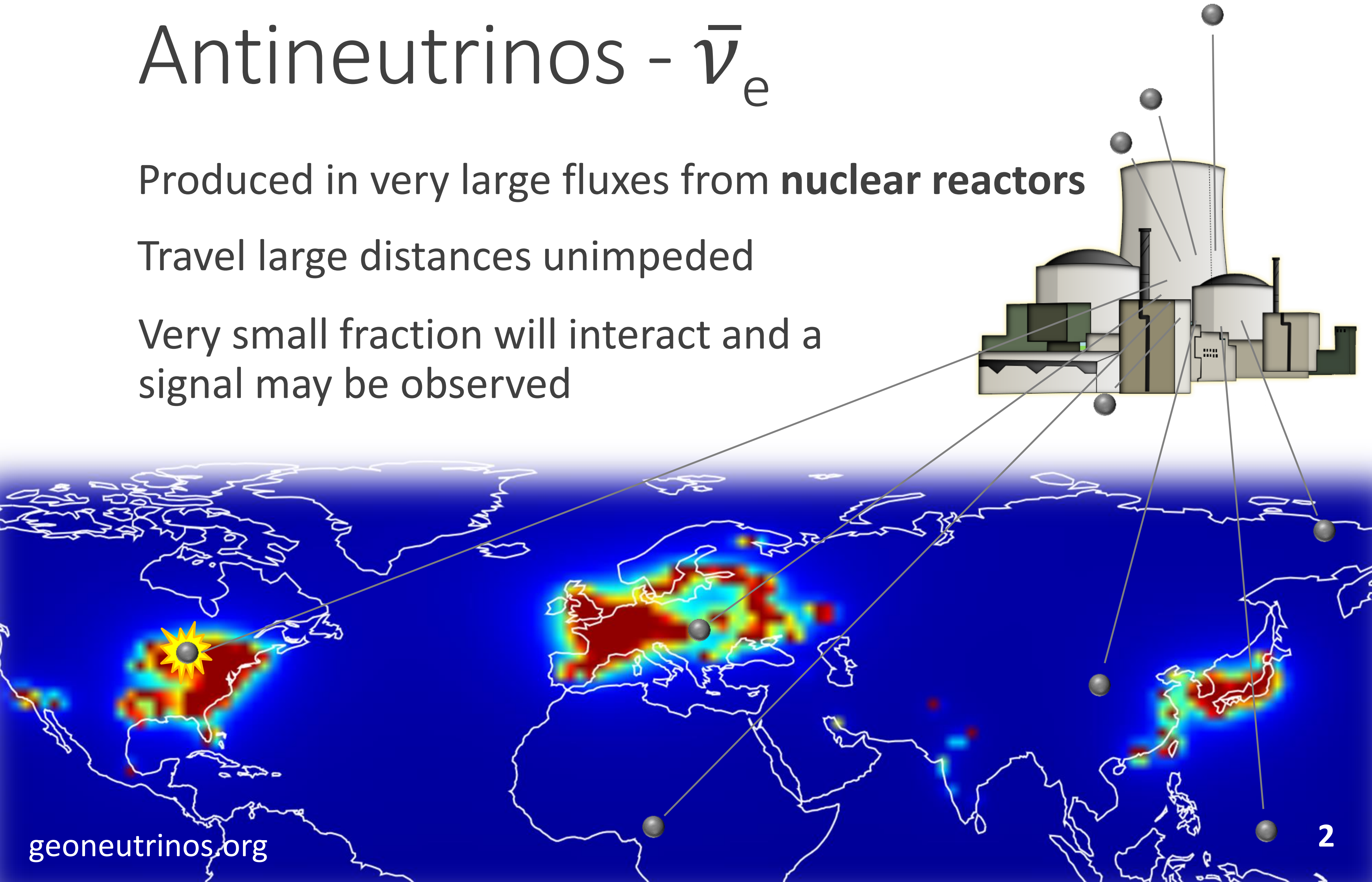
UNIVERSITY OF ALBERTA

Antineutrinos - $\bar{\nu}_e$

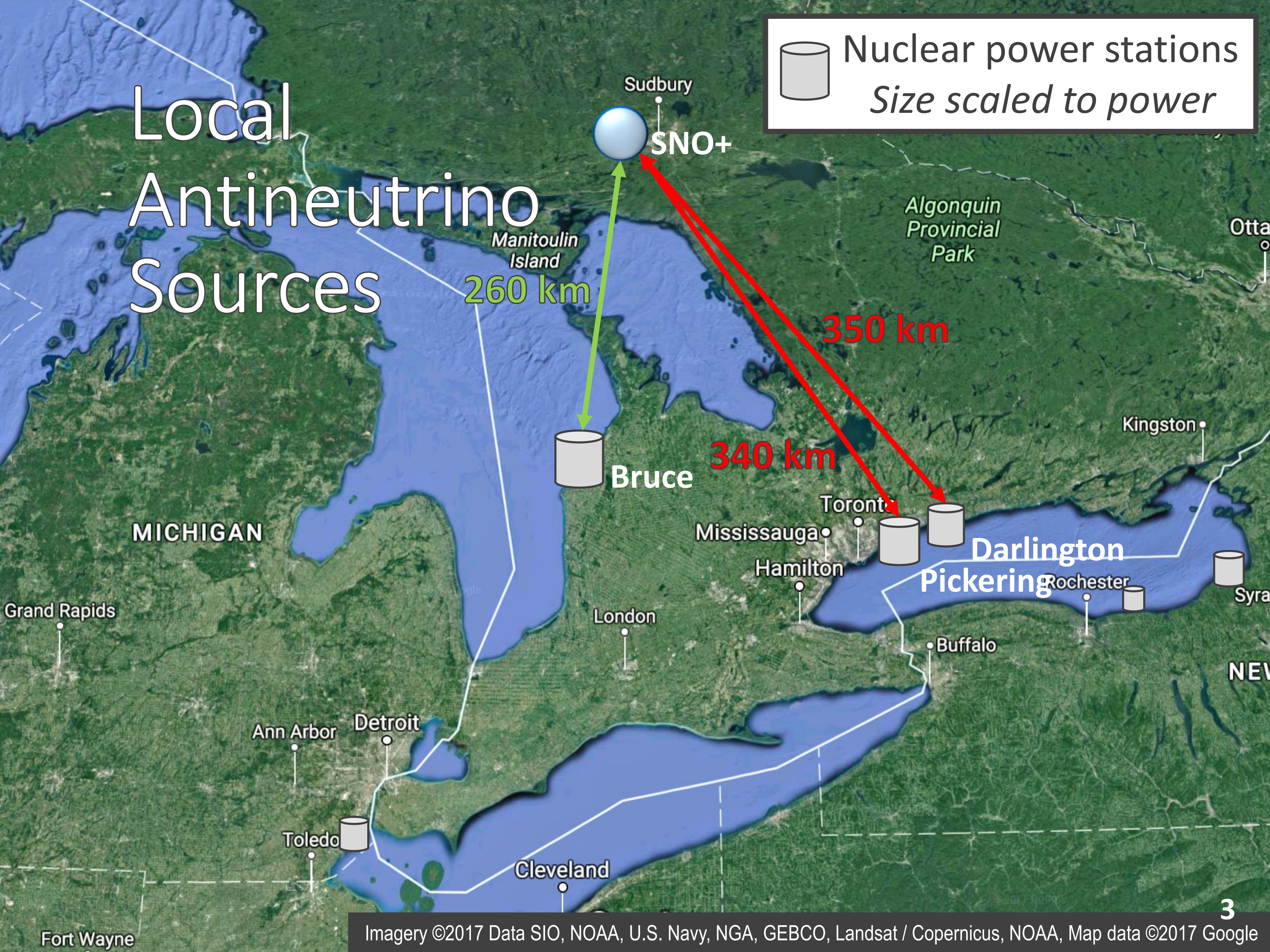
Produced in very large fluxes from **nuclear reactors**

Travel large distances unimpeded

Very small fraction will interact and a signal may be observed



Local Antineutrino Sources



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Antineutrino Oscillation

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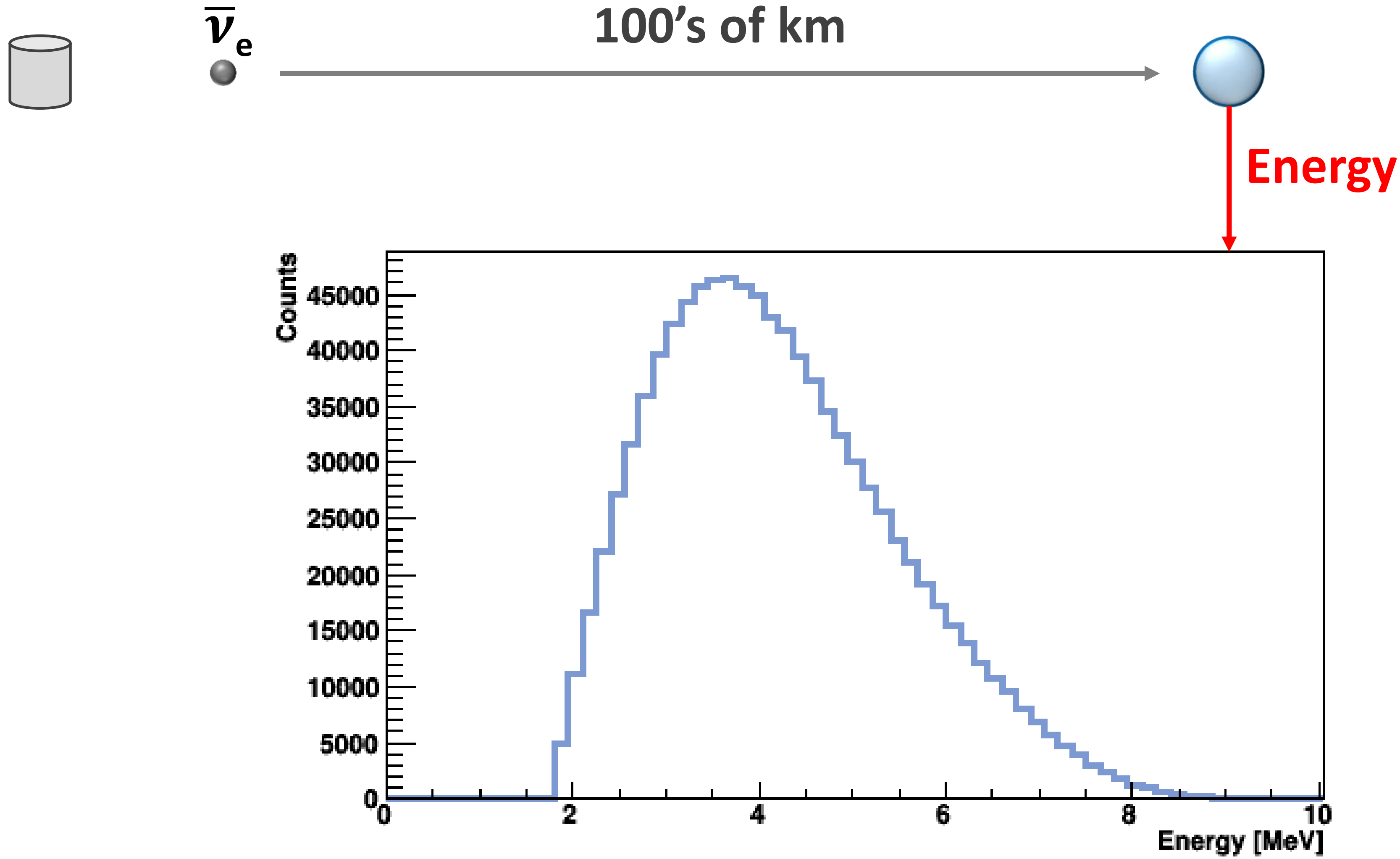
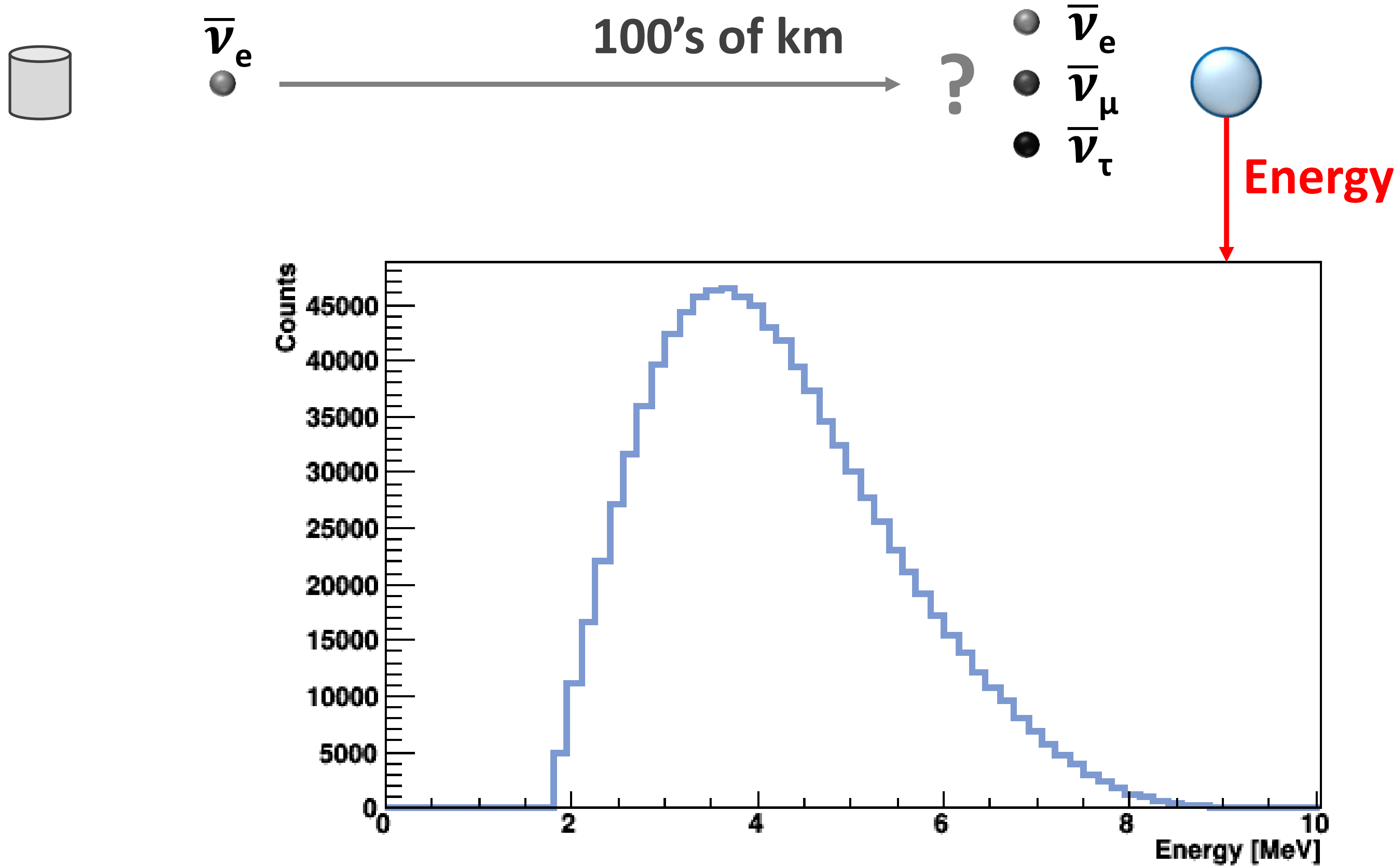


Antineutrino Oscillation



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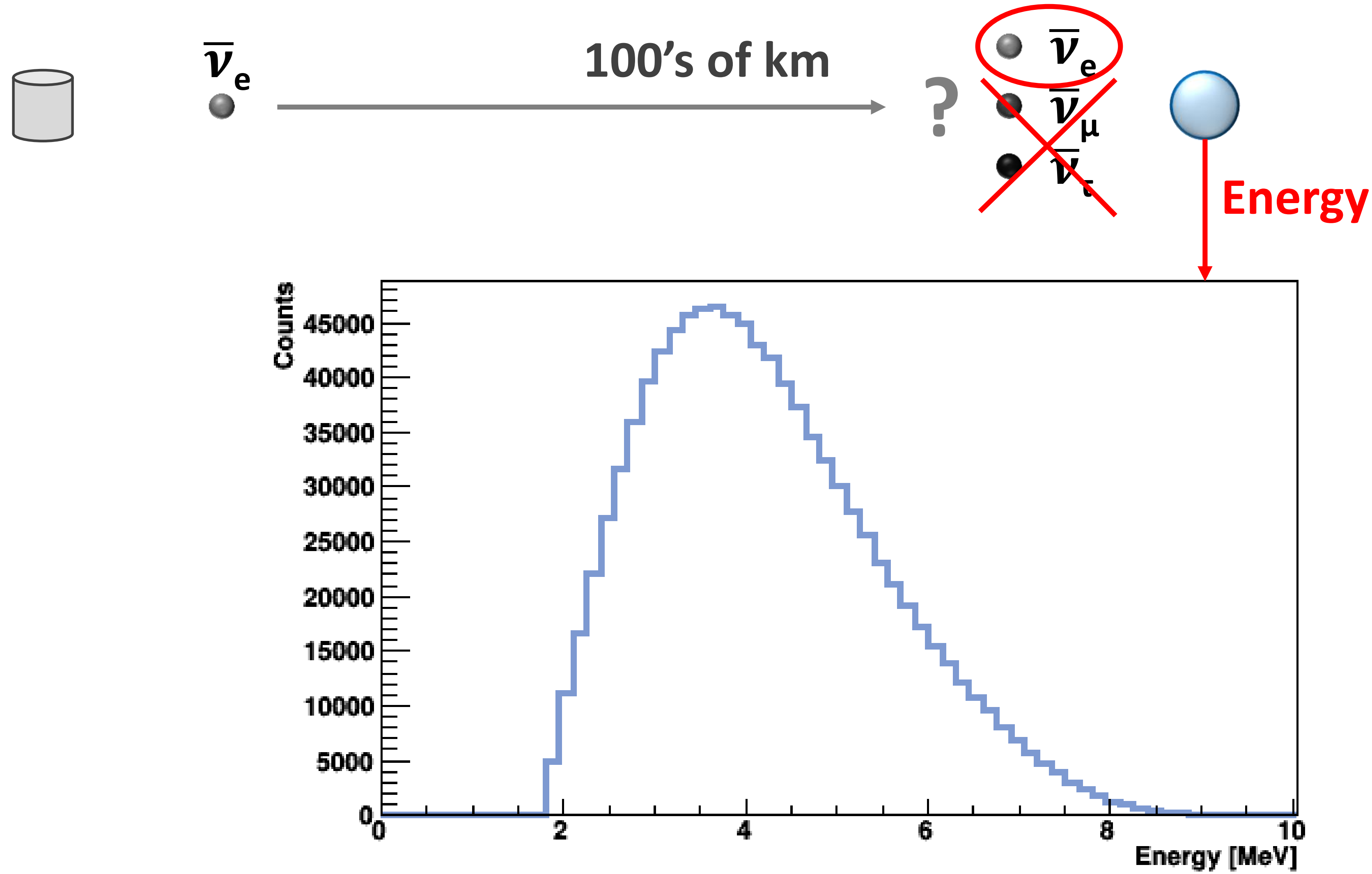

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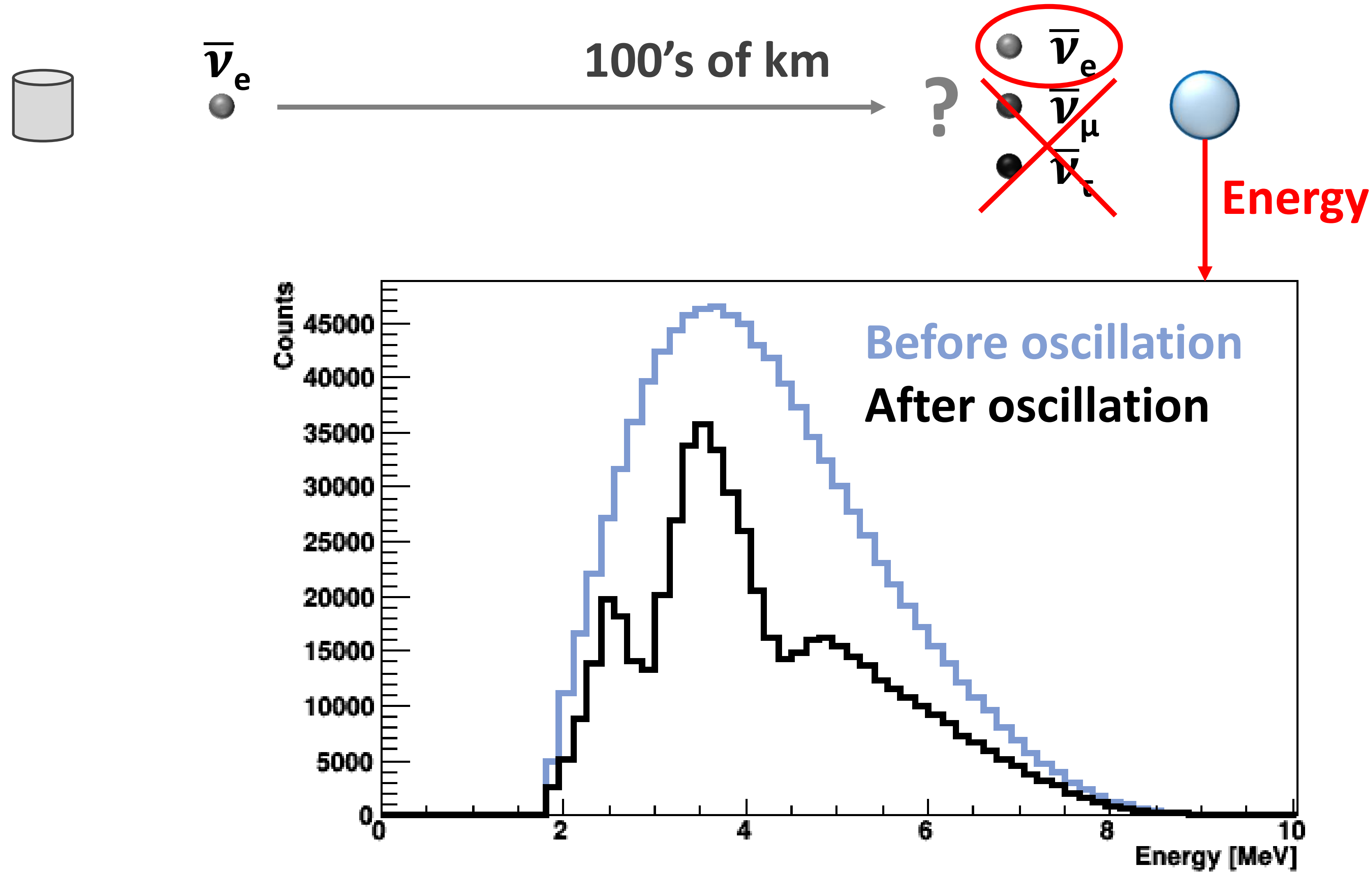
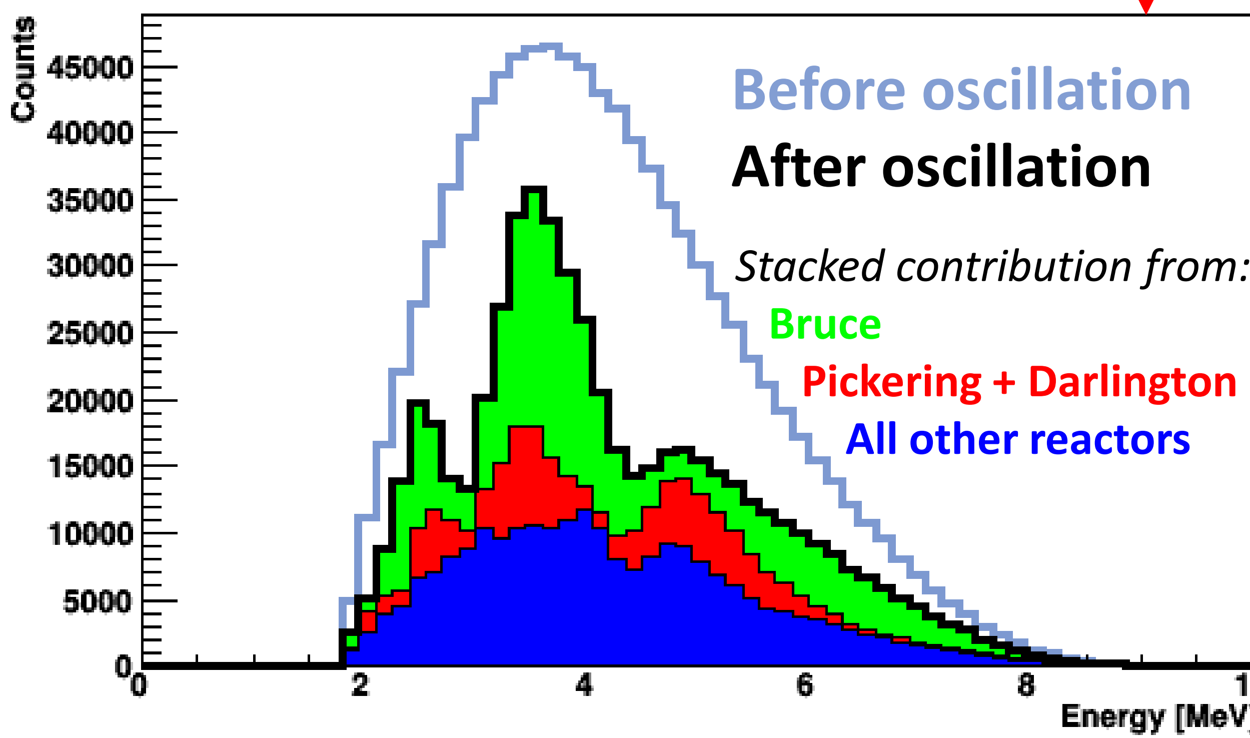


Antineutrino Interaction

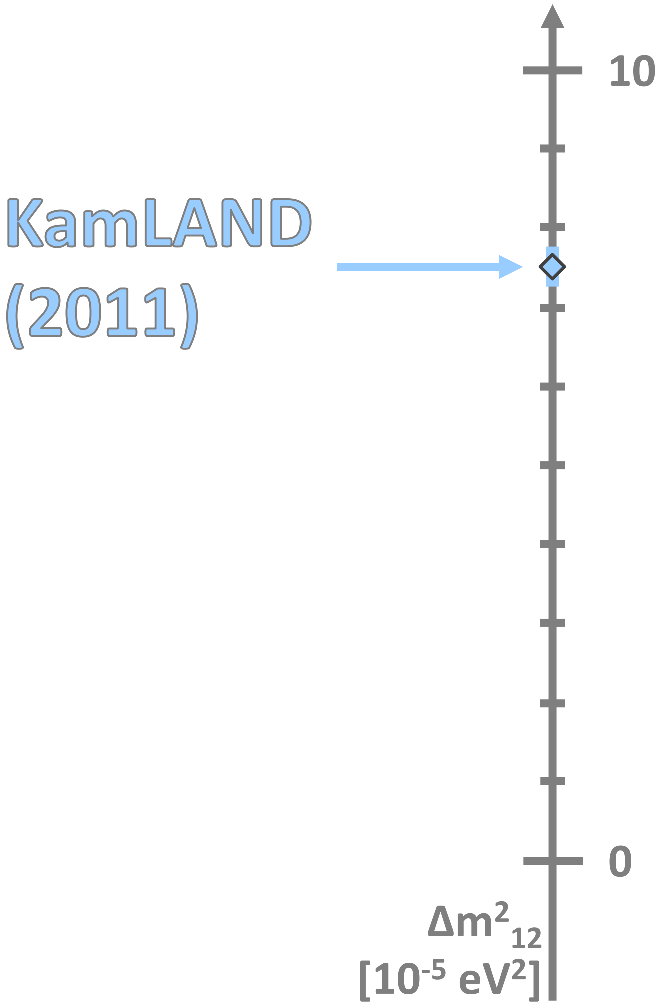
Expecting:

110 interactions per year

Sensitivity to **Δm^2_{12}** of **0.2×10^{-5} eV^2**



Added motivation



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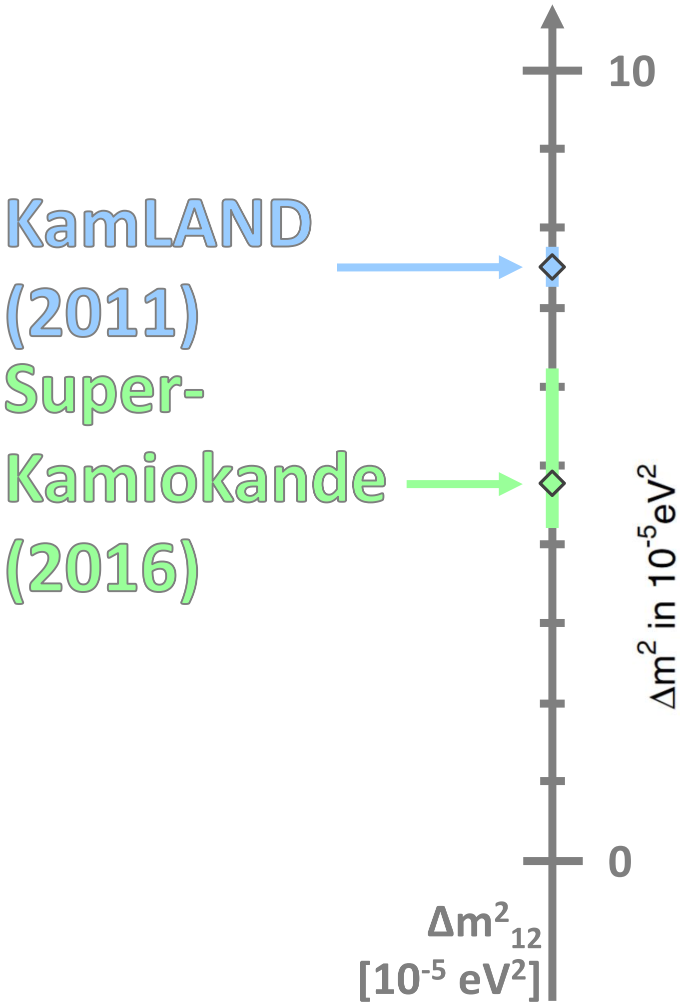
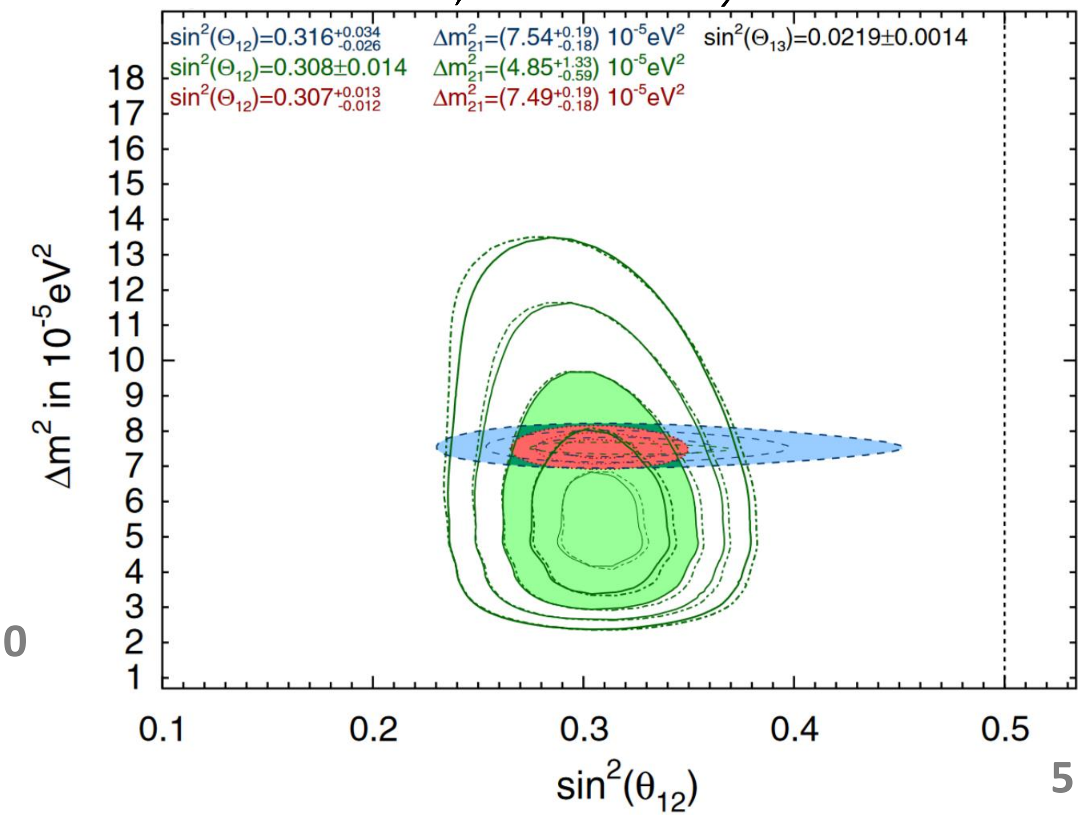


K. Abe, et al. 2016. *Phys. Rev. D* 94:052010



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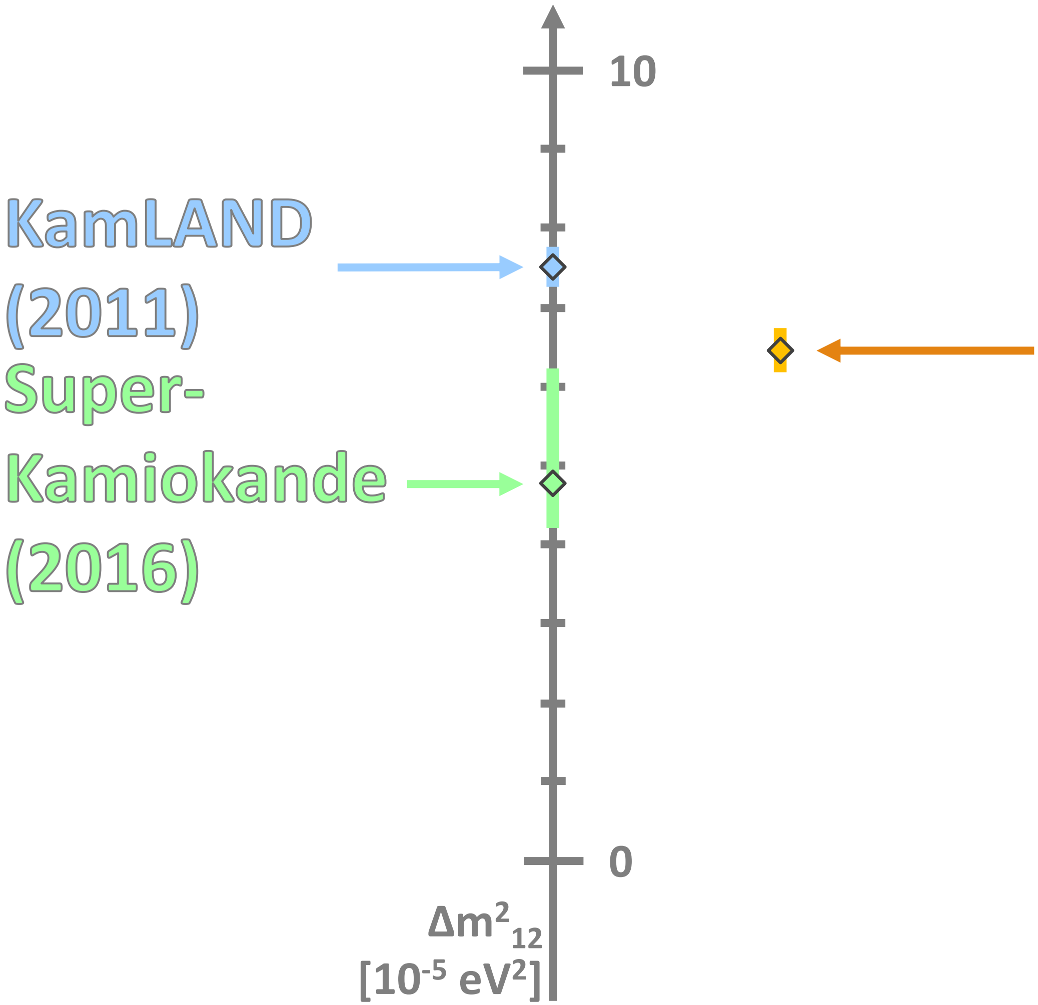
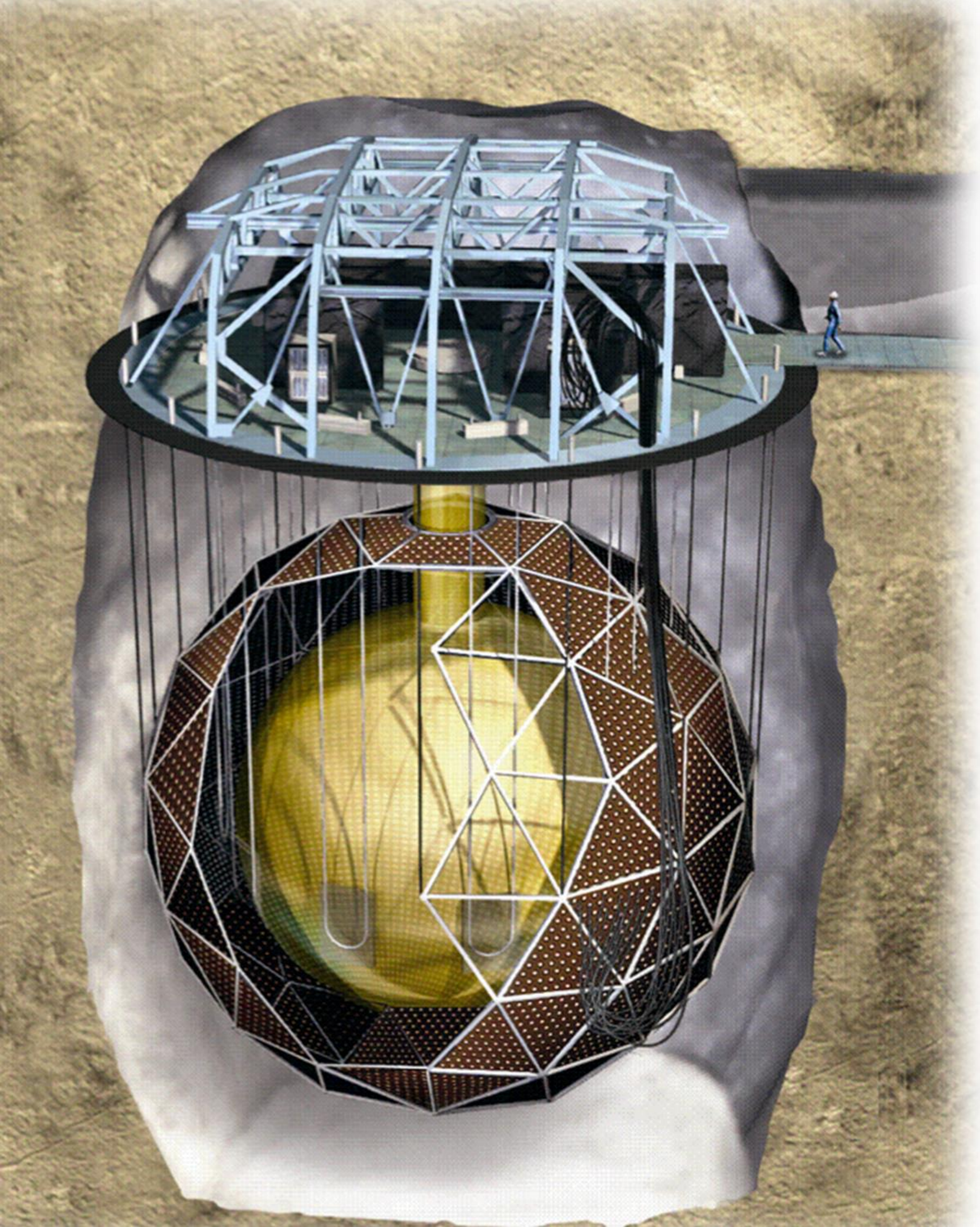


SNO+ will be able to add an independent measurement



SNO+ Detector

Consists of:

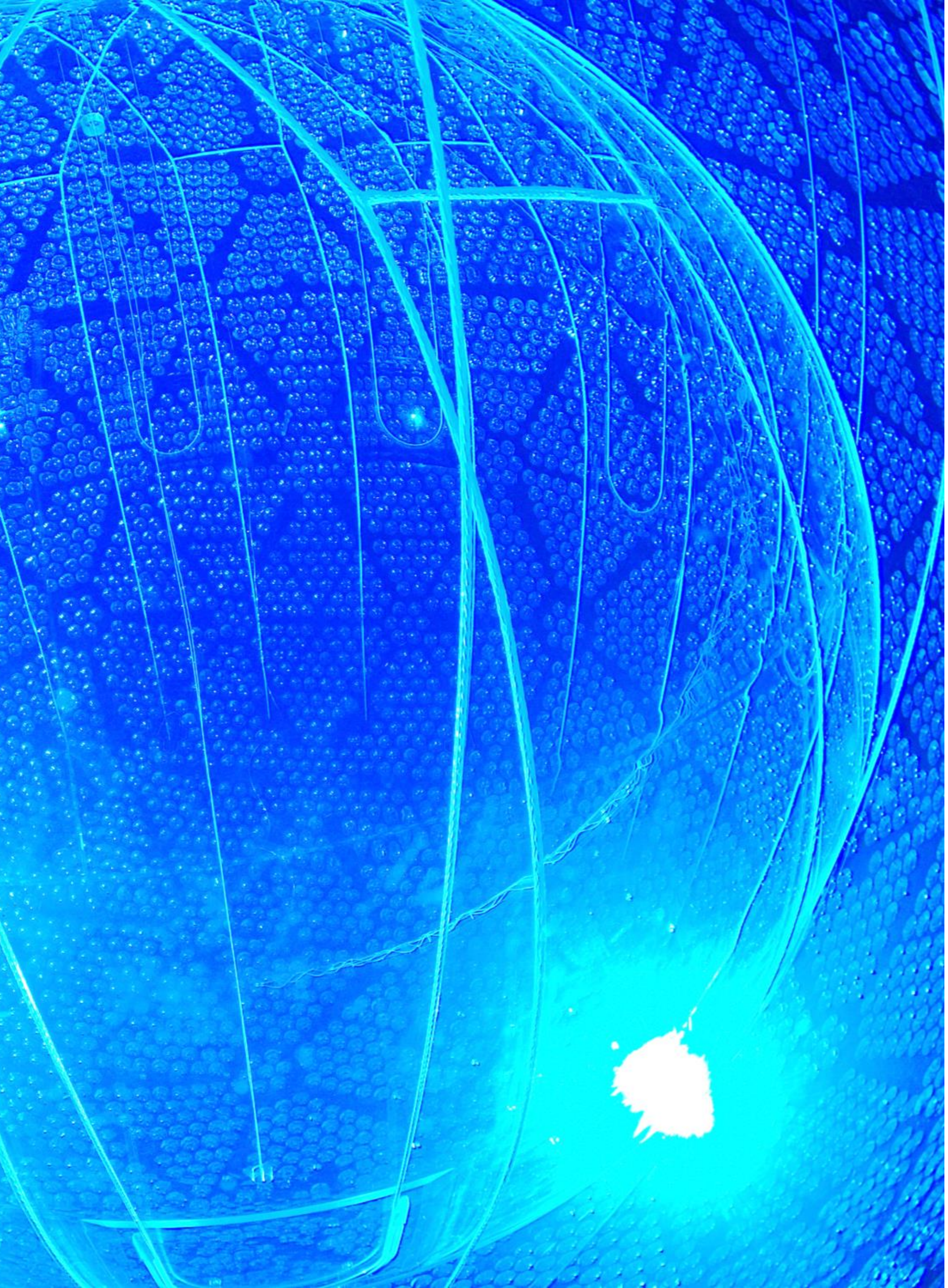
12 m diameter acrylic sphere

9300 photomultiplier tubes (PMTs)

7000 tonnes of surrounding water

Will be filled with **780 tonnes** of liquid scintillator

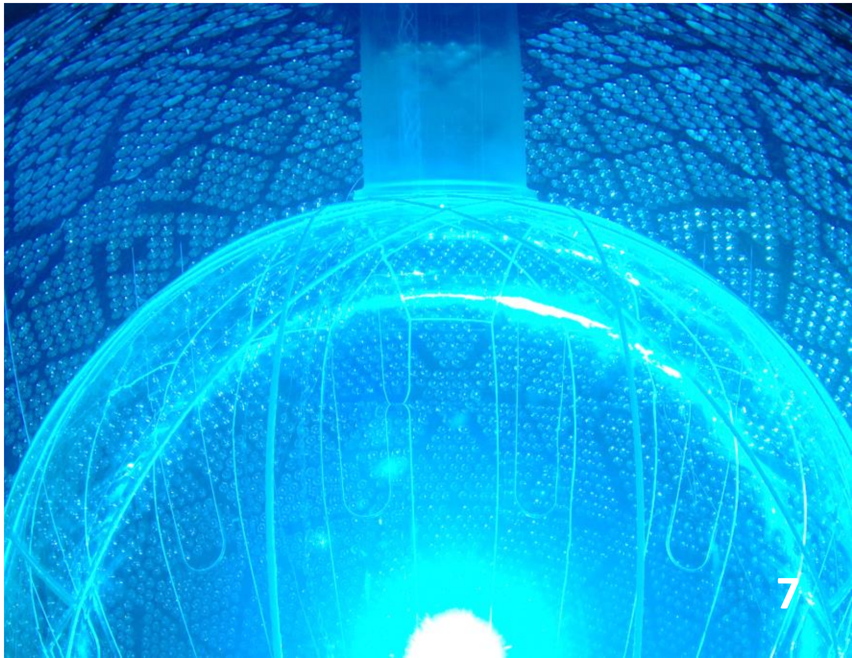
- Also **3.9 tonnes** of natural tellurium



Currently…

Filled with **water**

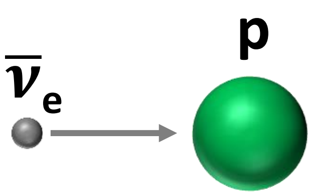
Now collecting **physics data**



Inverse Beta Decay

Antineutrinos may interact in the SNO+ detector via the inverse beta decay (IBD) reaction:

$$\bar{\nu}_e + p \rightarrow e^+ + n$$



t = 0

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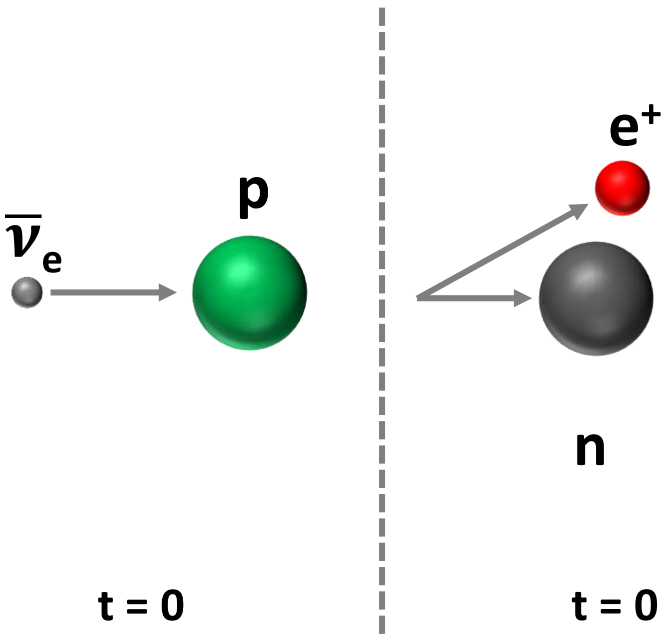

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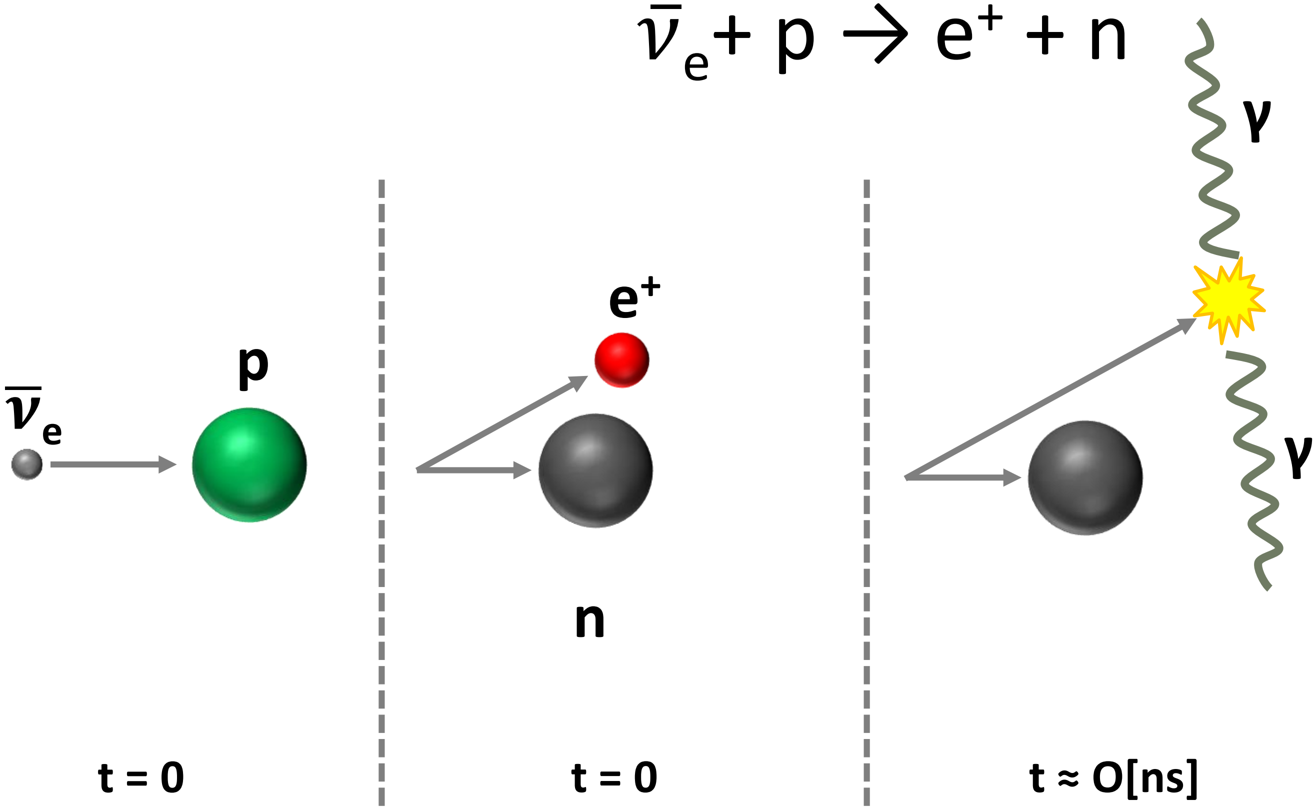

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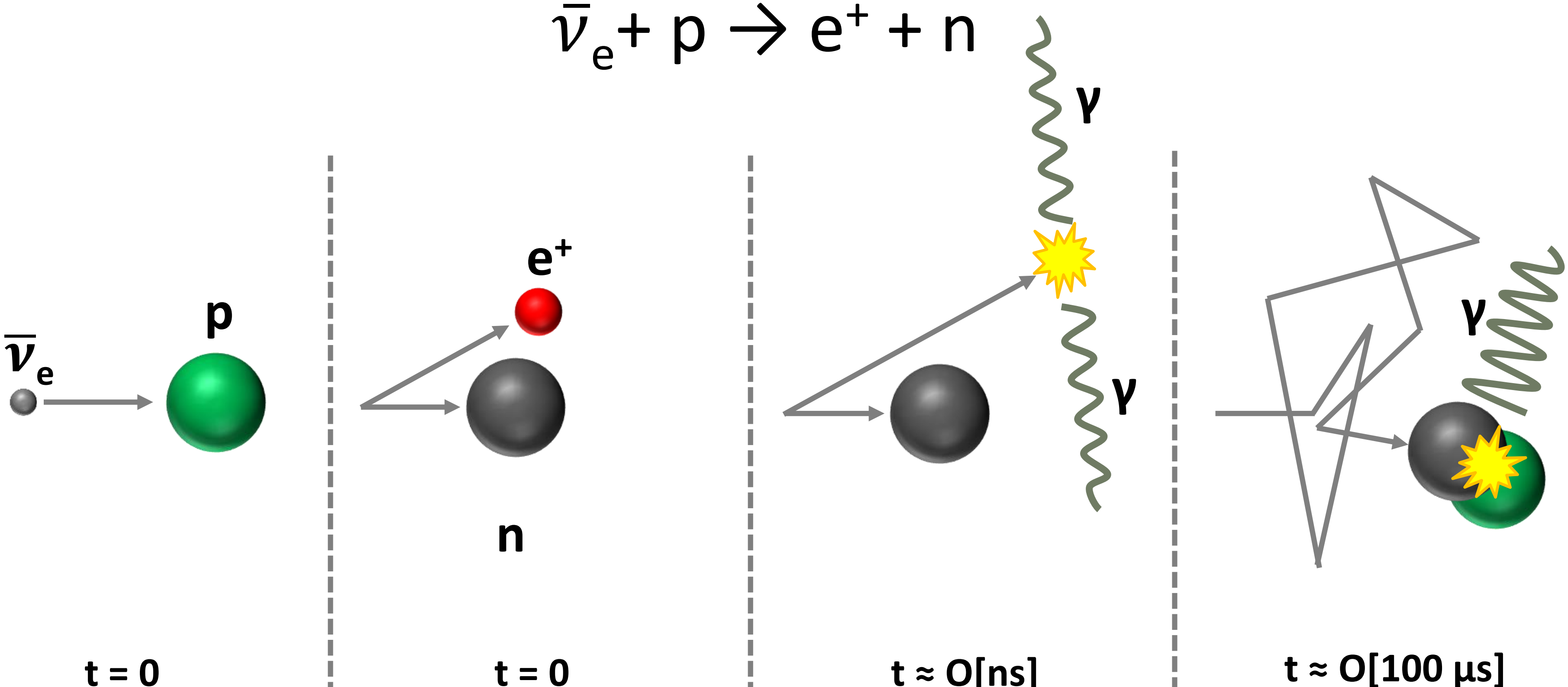
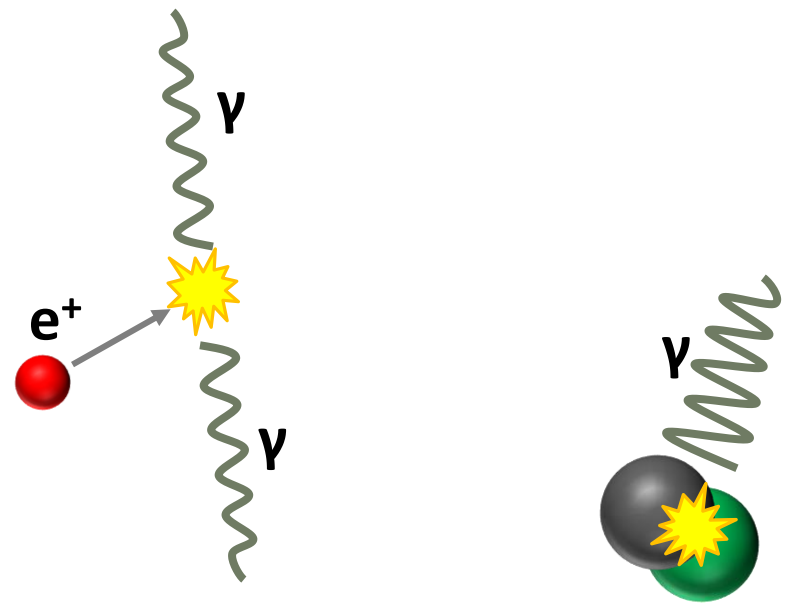
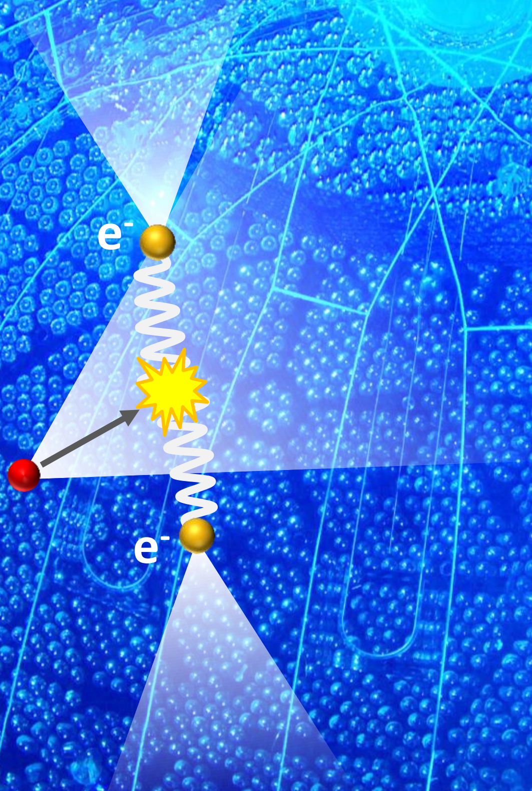


Inverse Beta Decay

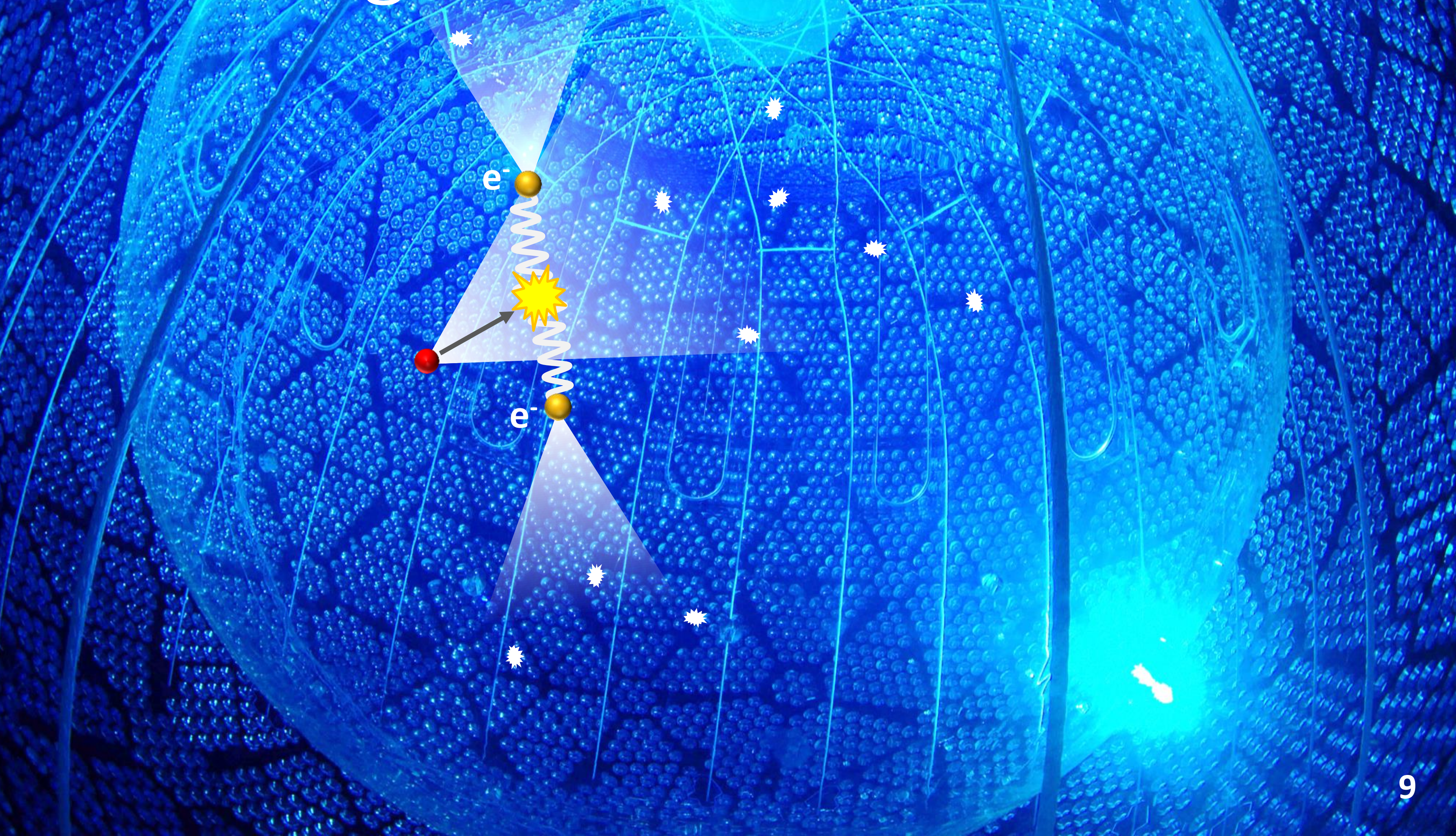


IBD Signal in SNO+



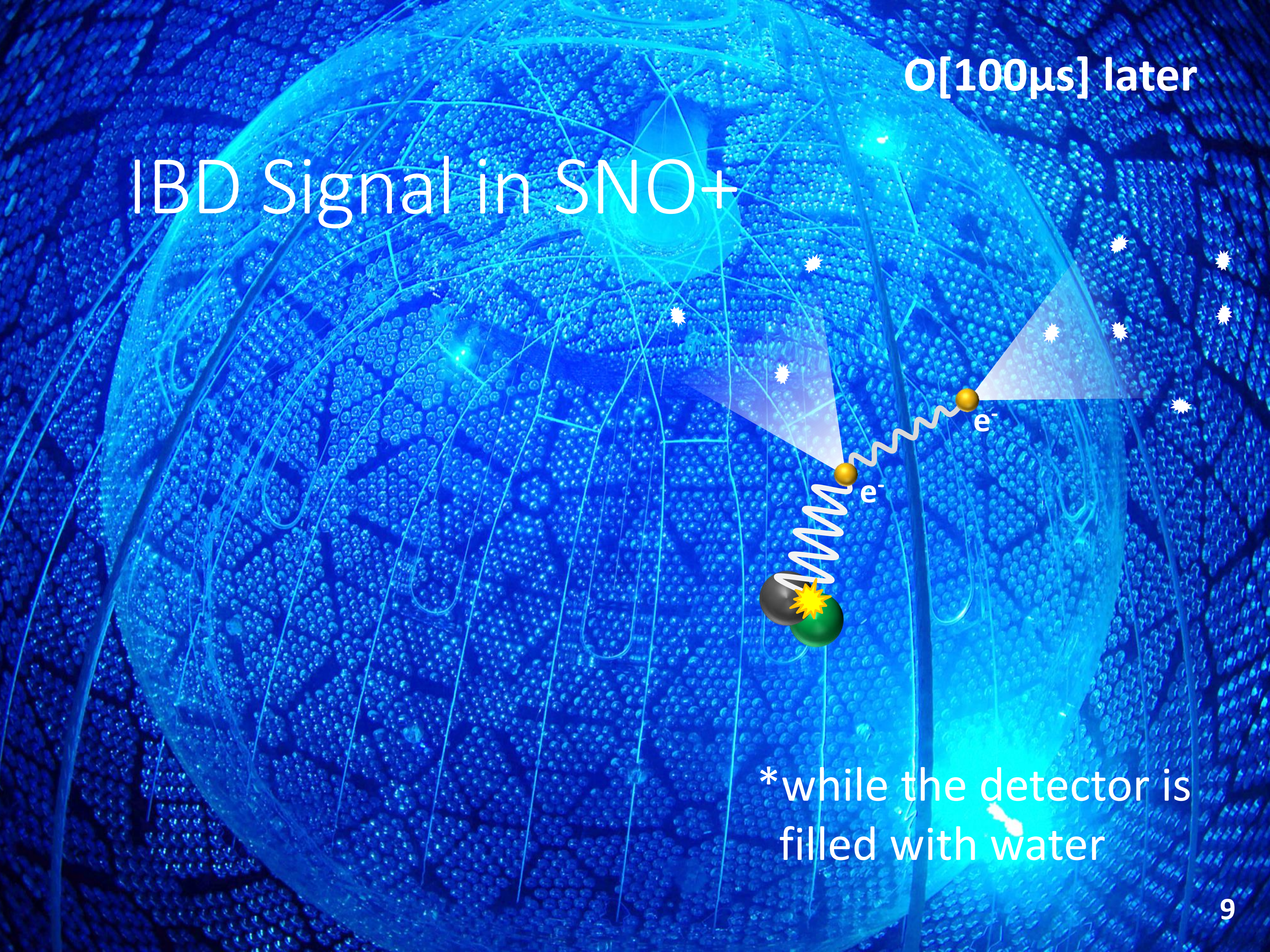
*while the detector is filled with water

IBD Signal in SNO+



IBD Signal in SNO+

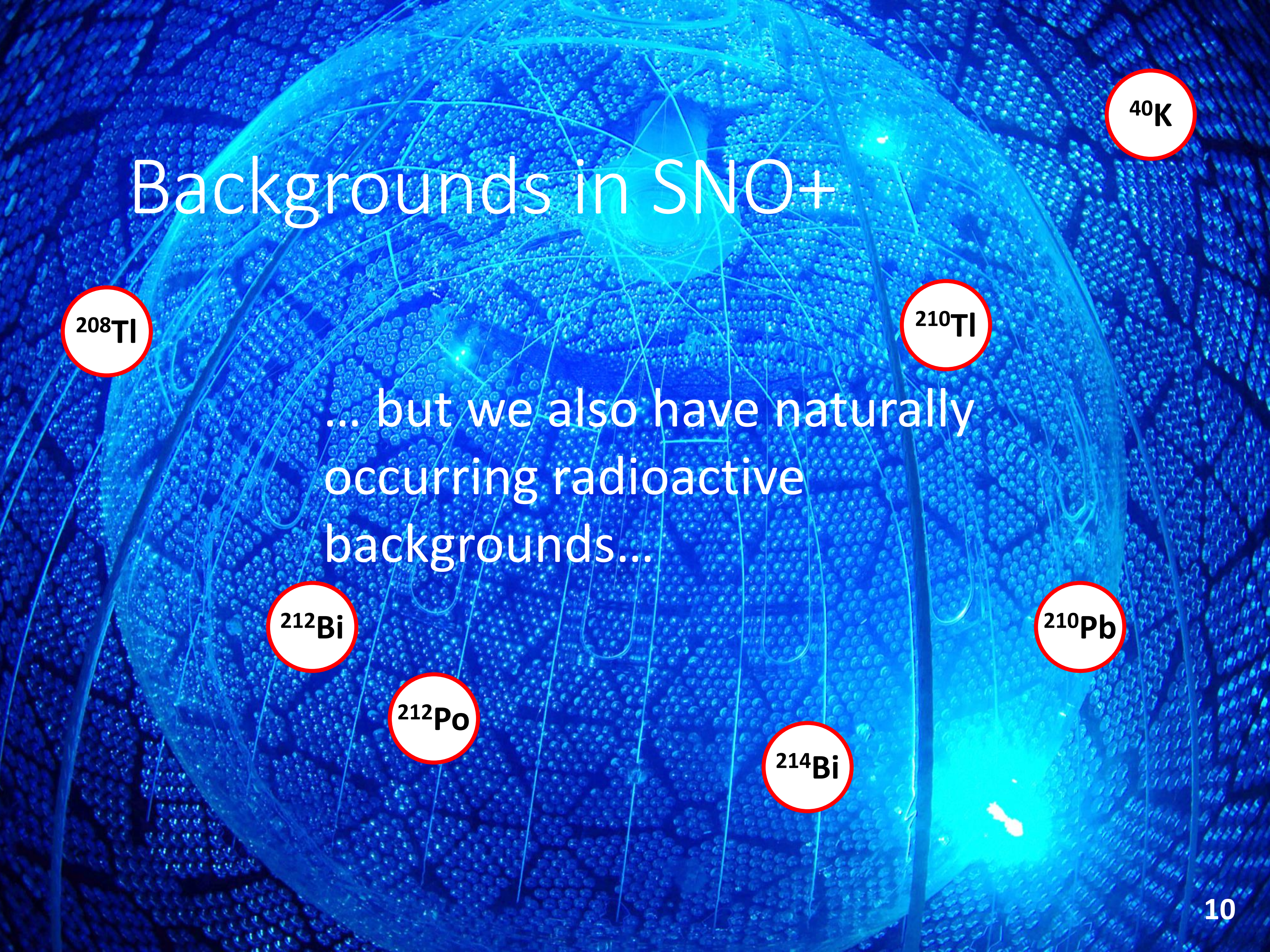
O[100μs] later



*while the detector is filled with water

Backgrounds in SNO+

… but we also have naturally occurring radioactive backgrounds…



Backgrounds in SNO+

… but we also have naturally occurring radioactive backgrounds…

^{212}Po ^{214}Bi ^{208}Tl ^{212}Bi ^{212}Po ^{212}Bi ^{40}K ^{212}Po ^{212}Bi

^{208}Tl ^{212}Bi ^{212}Po ^{40}K ^{208}Tl ^{40}K ^{210}Tl ^{214}Bi ^{212}Po

^{40}K ^{212}Po ^{212}Bi ^{212}Bi ^{214}Bi ^{212}Po ^{214}Bi ^{210}Pb ^{212}Po

^{214}Bi ^{212}Bi ^{212}Po ^{212}Po ^{208}Tl ^{214}Bi ^{40}K

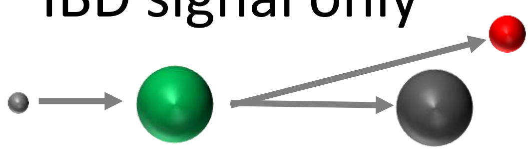
Could two background events that occur within a short time of each other and mimic this signal?

How can we distinguish the signal from antineutrinos?

Simulation – Antineutrino Search

<u>Two Monte Carlo simulations:</u>

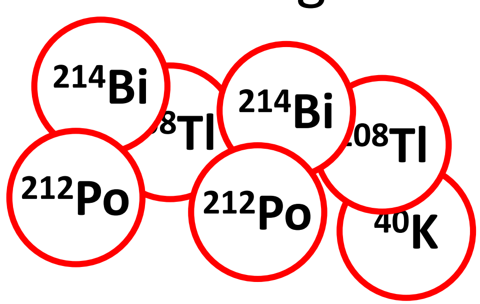
IBD signal only



… with statistics corresponding to…

5000 years of data taking

All expected backgrounds



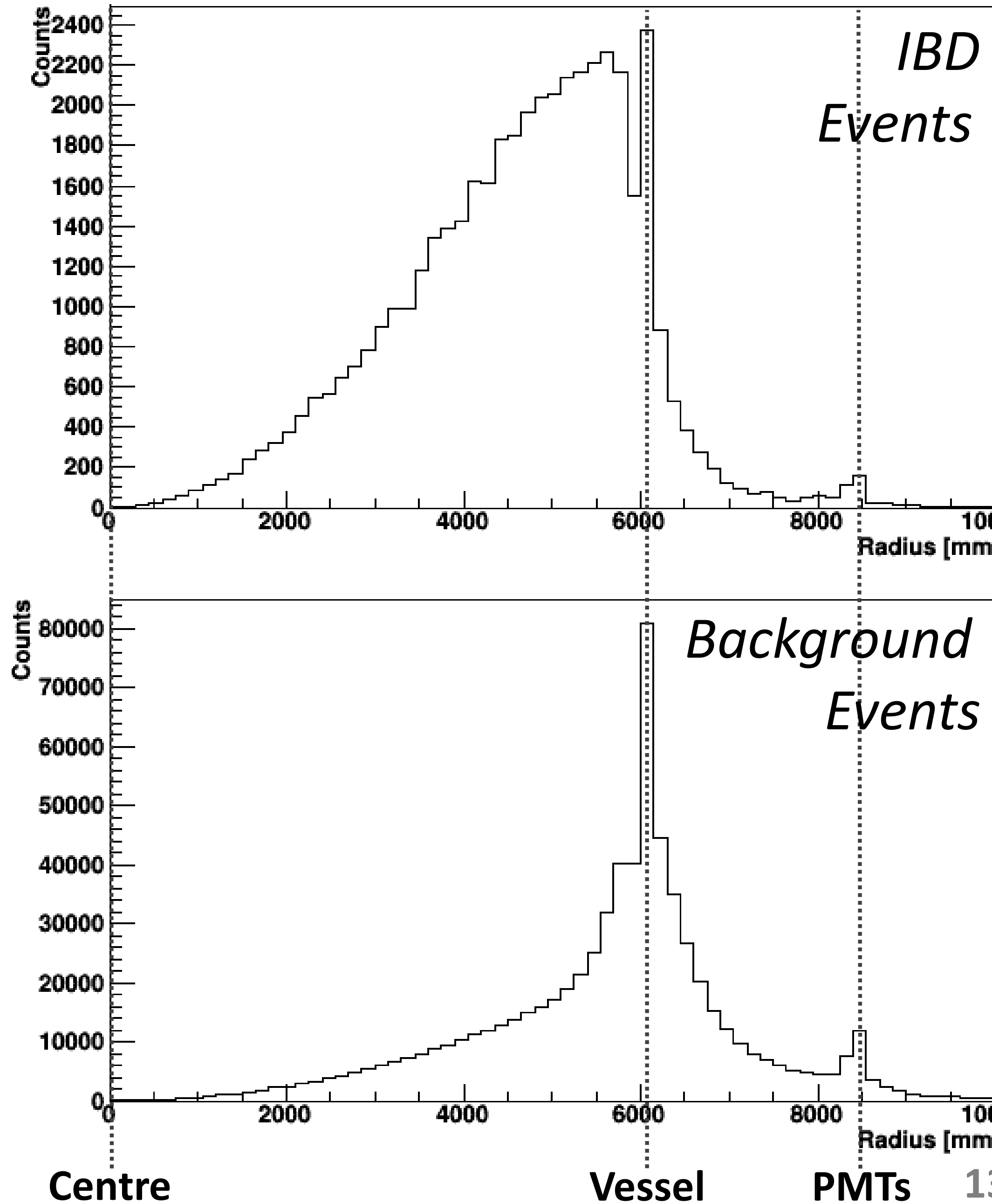
60 minutes of data taking

Selection Criteria

First **remove** events that occur near or past the surface of the spherical vessel (more radioactivity here)

- Impose a fiducial volume cut (FV)

Reconstructed position



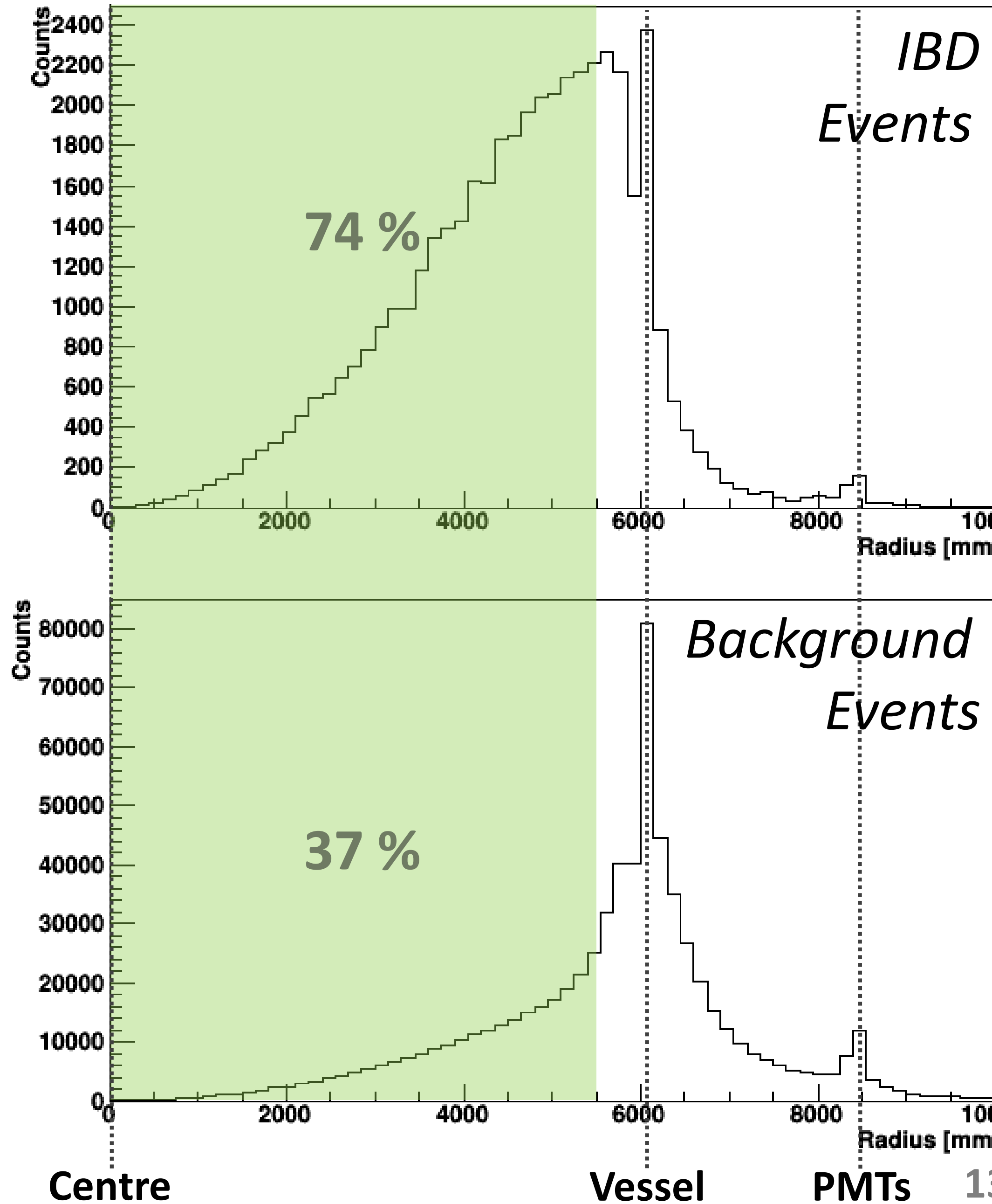
Selection Criteria

First **remove** events that occur near or past the surface of the spherical vessel (more radioactivity here)

- Impose a fiducial volume cut (FV)

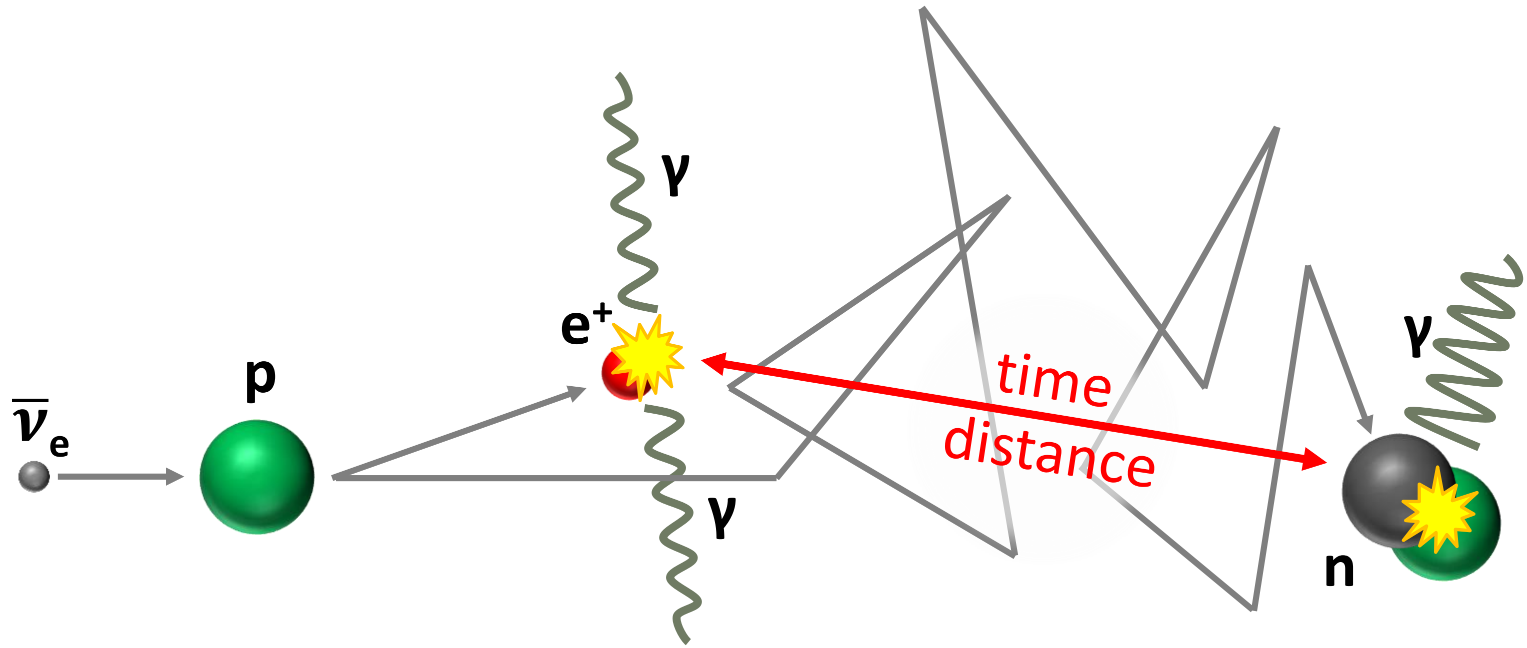
Radius r < 5.5 m

Reconstructed position



Selection Criteria – Cont'd

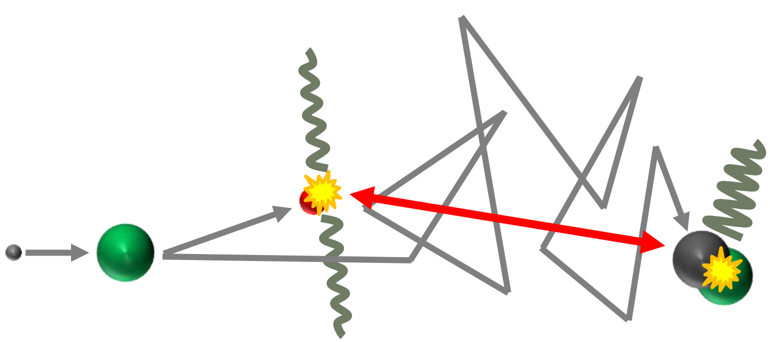
See that these signal events have correlations between them



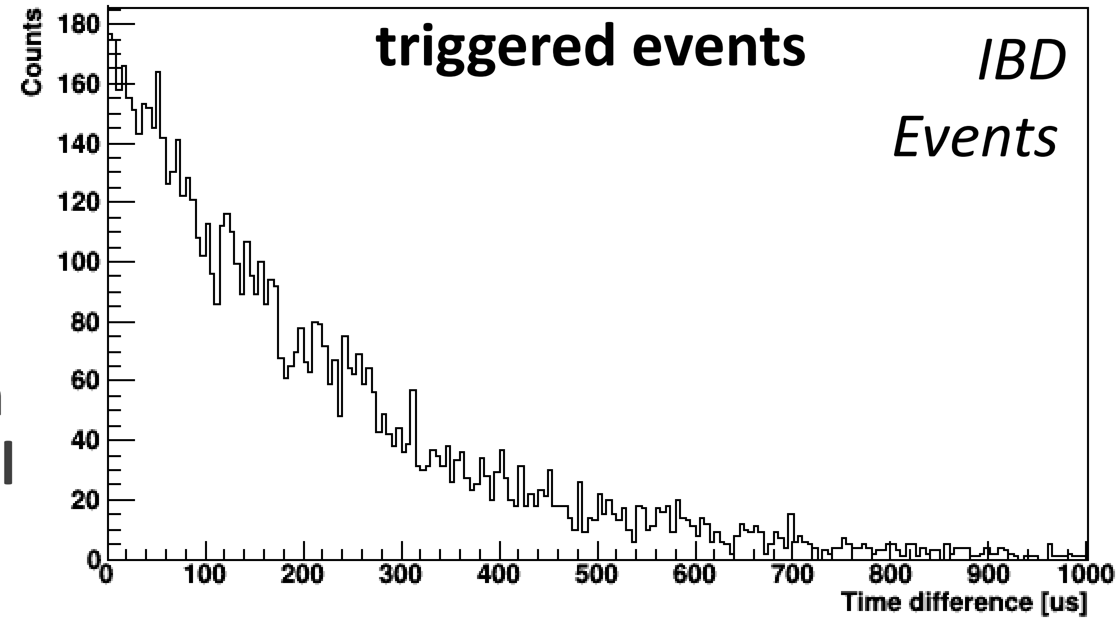
Selection Criteria

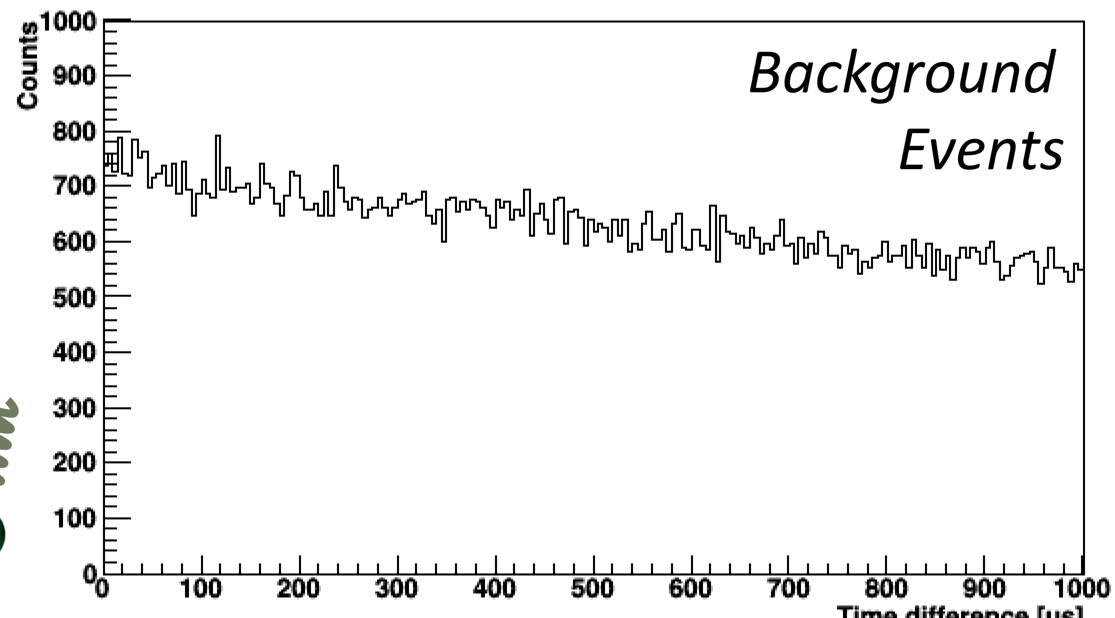
Next, **keep** only event pairs that occur within a specific **time interval** of each other

- Coincident events



Time difference between subsequent triggered events



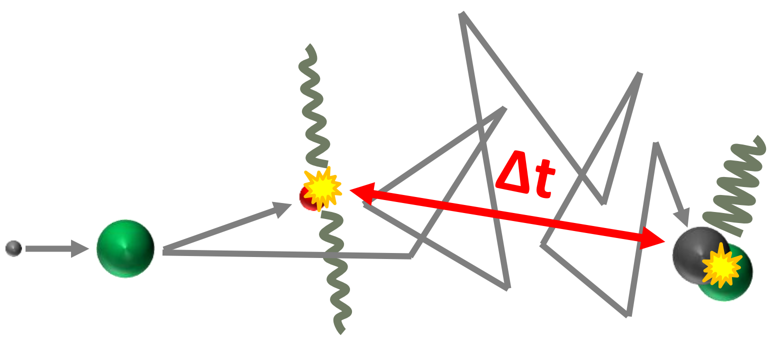


Selection Criteria

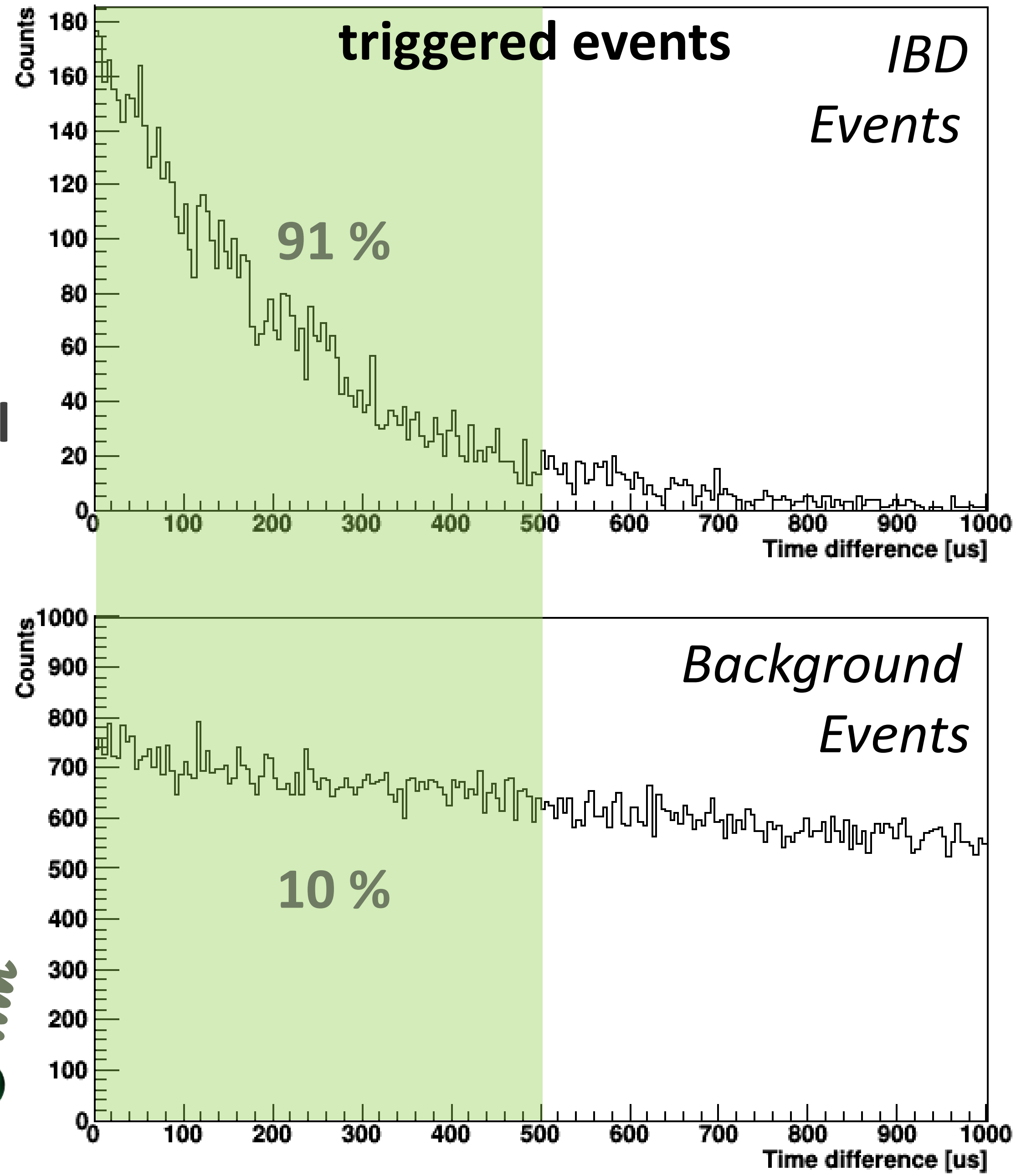
Next, **keep** only event pairs that occur within a specific **time interval** of each other

- Coincident events

Time difference
Δt < 500 μs



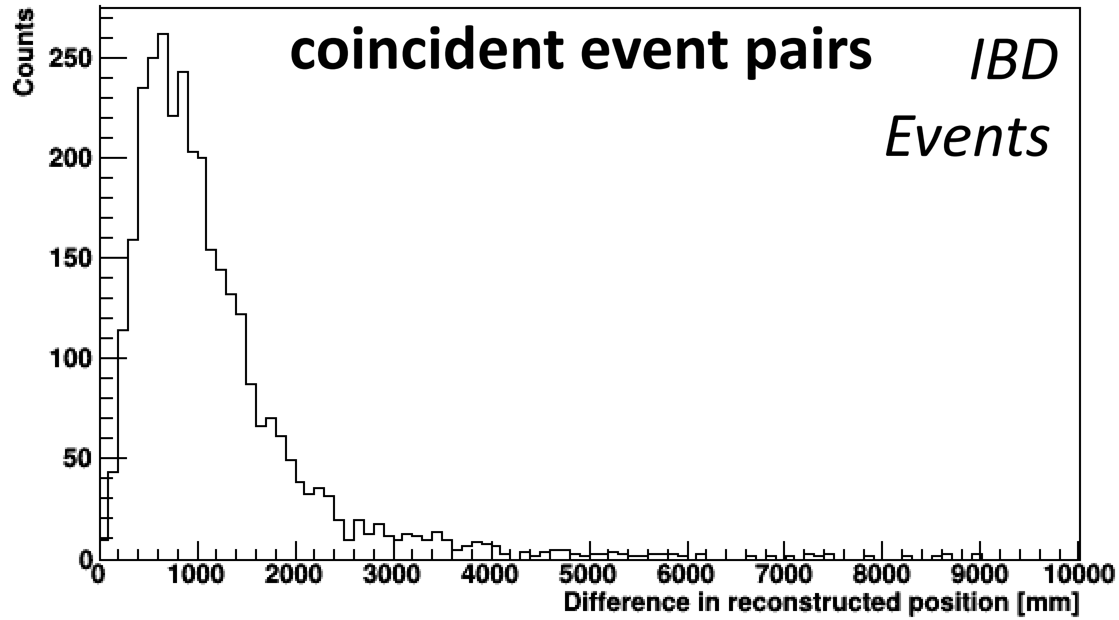
Time difference between subsequent triggered events

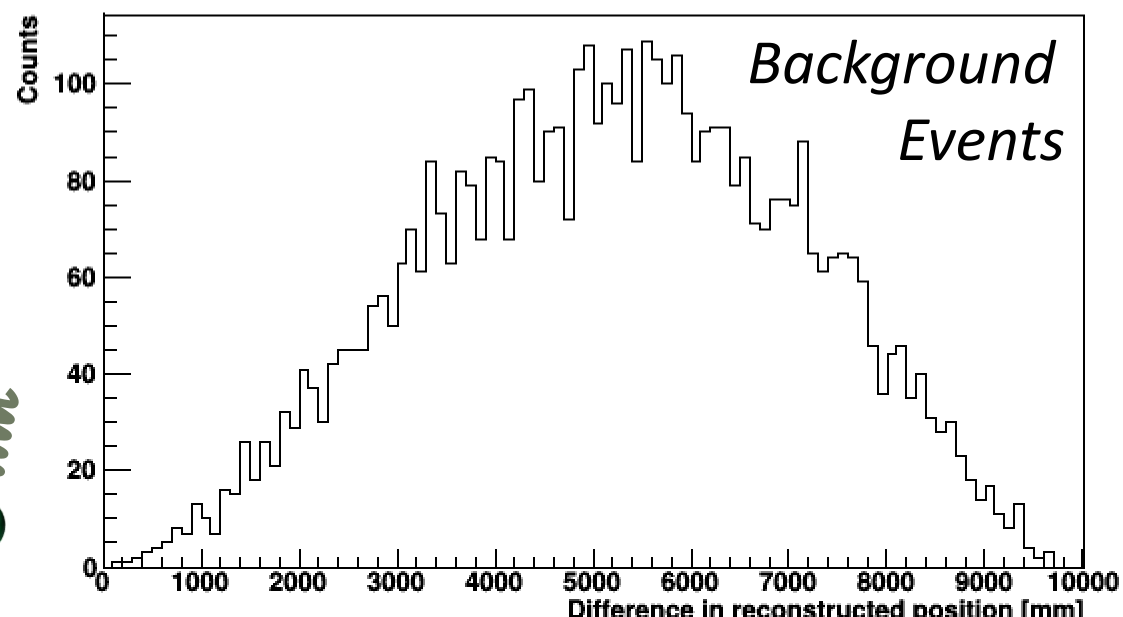


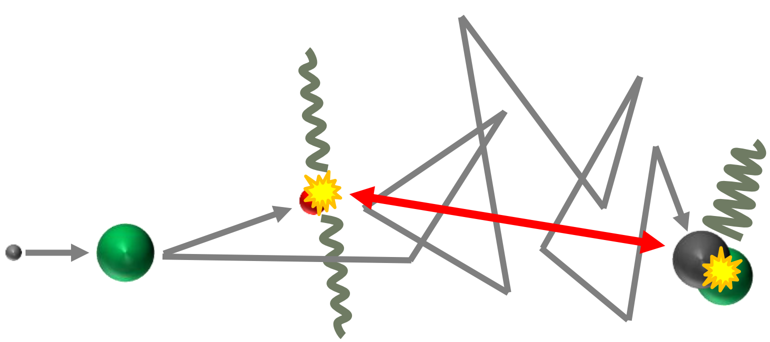
Selection Criteria

Third, **keep** only coincident events that occur within a short **distance** from each other

Reconstructed distance between coincident event pairs



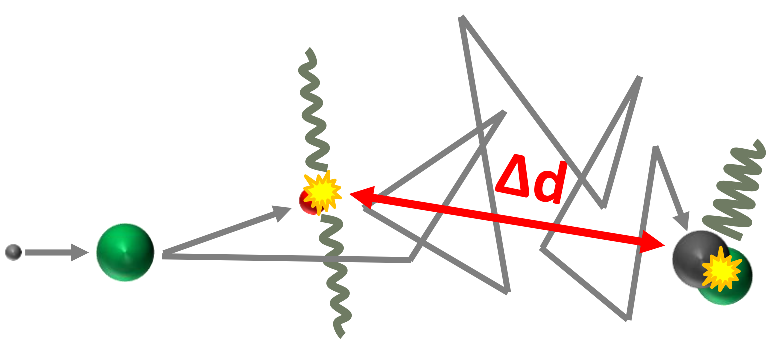




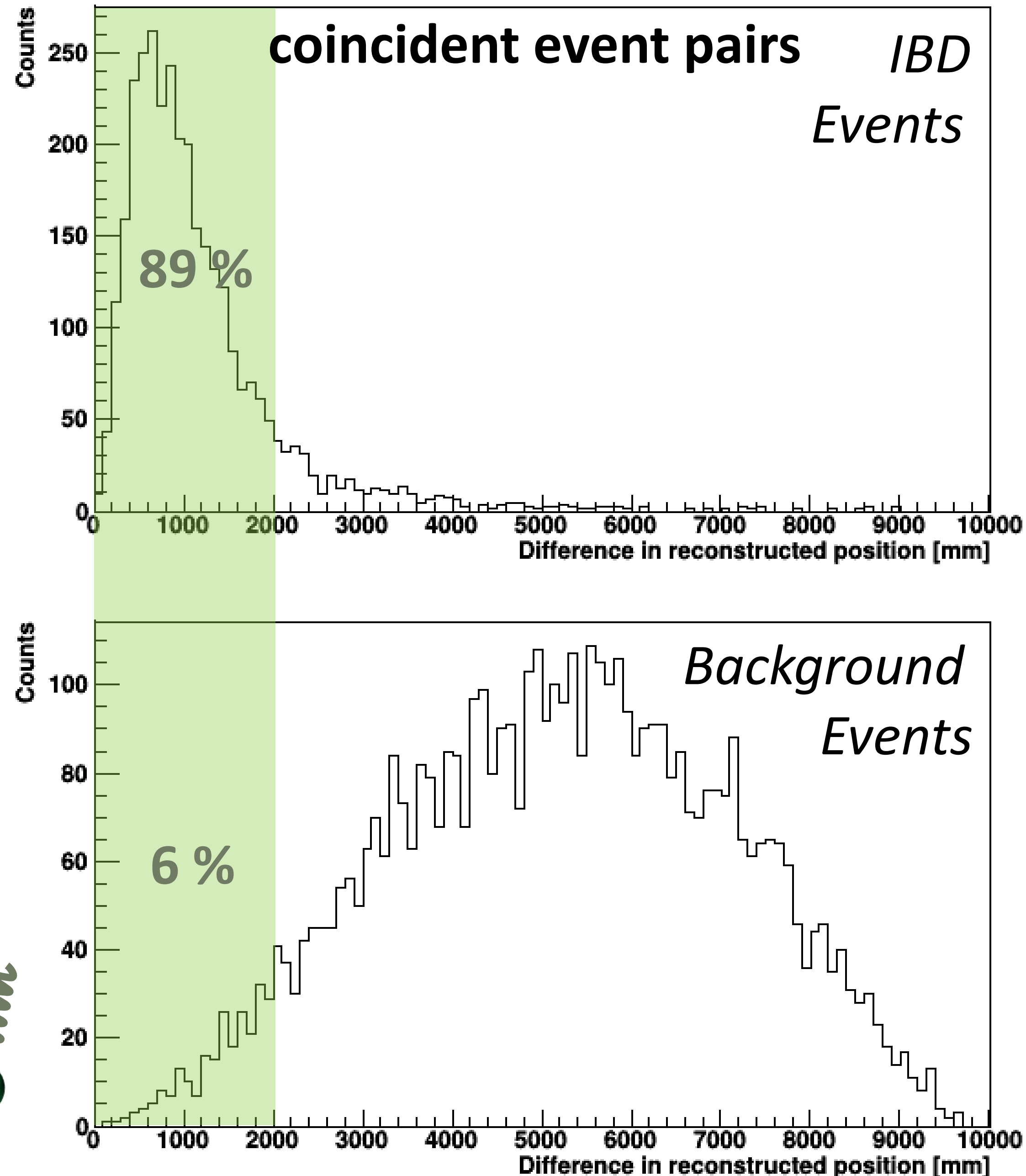
Selection Criteria

Third, **keep** only coincident events that occur within a short **distance** from each other

Position difference
d < 2 m



Reconstructed distance between coincident event pairs



Implications

Imposing this criteria:

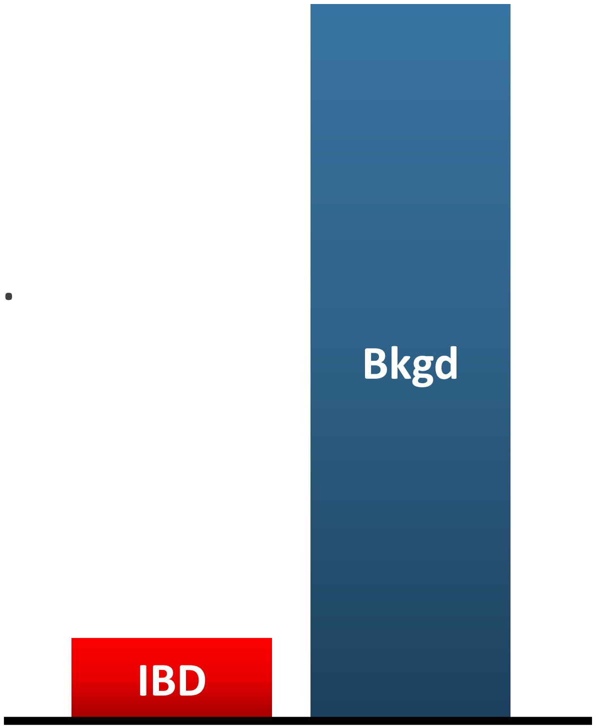
- Reduces signals from IBD events
- But **greatly reduces** signals from radioactive backgrounds

Realistically, only expect to have approx. **1 IBD decay event** left in our data set after these cuts are applied

- Assuming current data collection in water for **6 months**

More than likely, there will be many more background coincidences, drowning the signal

Illustration:
Expected # of events after cuts



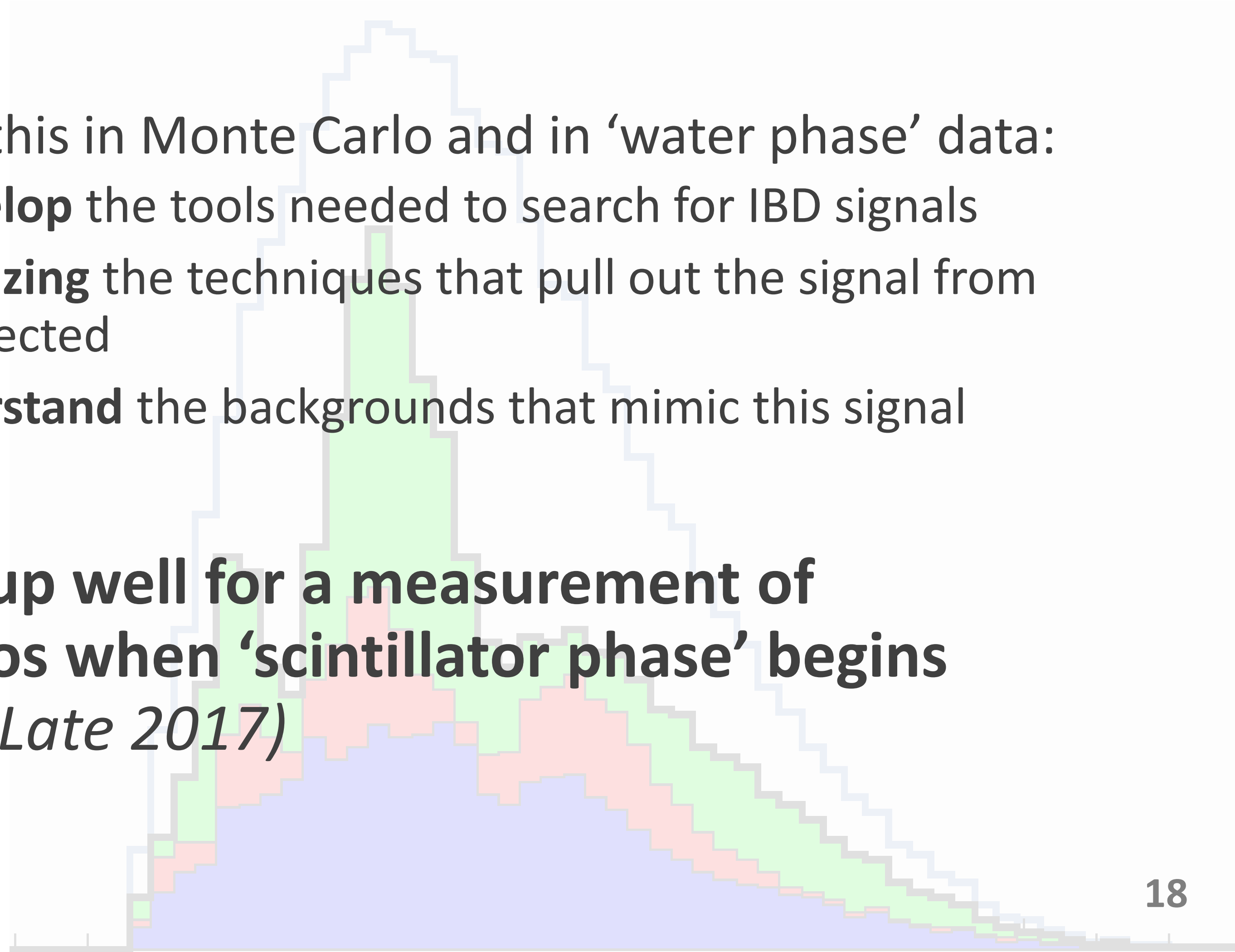
Conclusions

But…

By looking at this in Monte Carlo and in ‘water phase’ data:

- We can **develop** the tools needed to search for IBD signals
- Begin **optimizing** the techniques that pull out the signal from the data collected
- Better **understand** the backgrounds that mimic this signal

We are set up well for a measurement of antineutrinos when ‘scintillator phase’ begins
(scheduled: Late 2017)



Back-up Slides

Neutrino Oscillation

$$P_{\nu_\alpha \rightarrow \nu_\beta} = \sin^2(2\Theta)\,\sin^2(1.27\,\Delta m^2\,[eV^2]\,\frac{L\,[km]}{E\,[GeV]})$$