Outer Detector (WP2)
XLZD@Boulby

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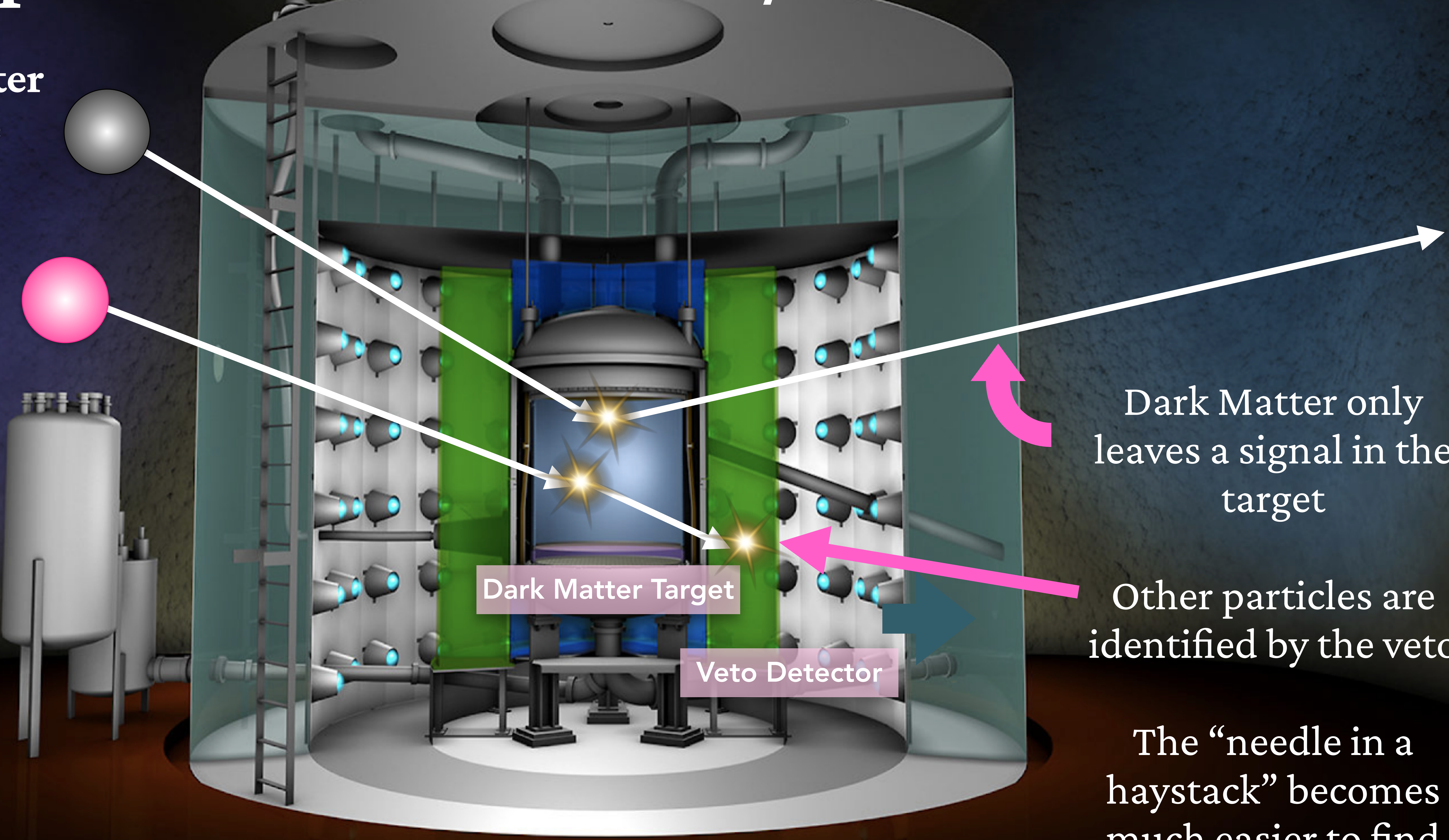
Principle of an Outer Detector/Veto

Dark Matter Particle

Background (neutron, γ-ray...)



Dark Matter only leaves a signal in the target

Other particles are identified by the veto

The "needle in a haystack" becomes much easier to find

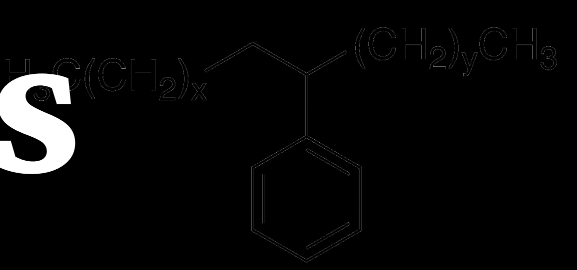
LZ's Outer Detector

LZ: A Three Detector System

~30 keV_{nr} nuclear recoil
Single scatter in TPC
Tagged by the OD

(DD Calibration)

LZ's OD: Acrylic Vessels

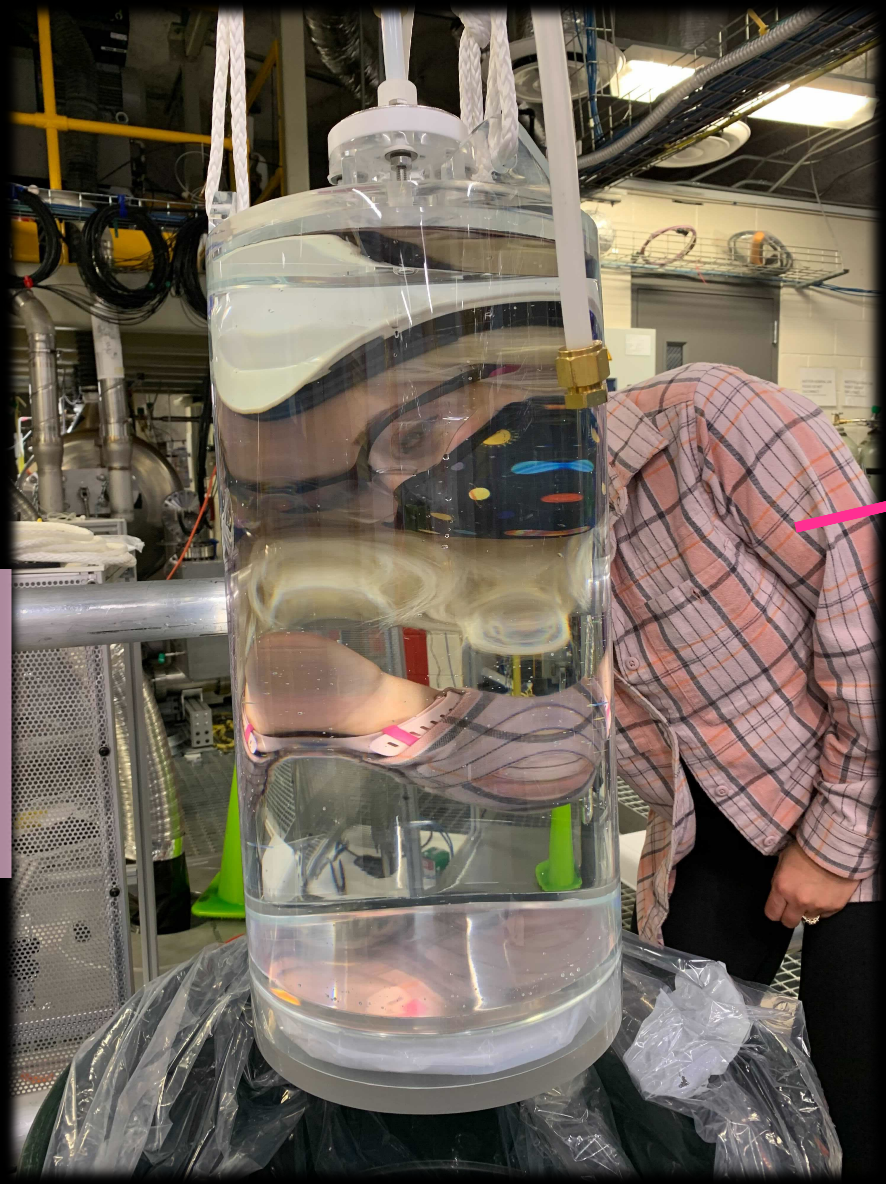


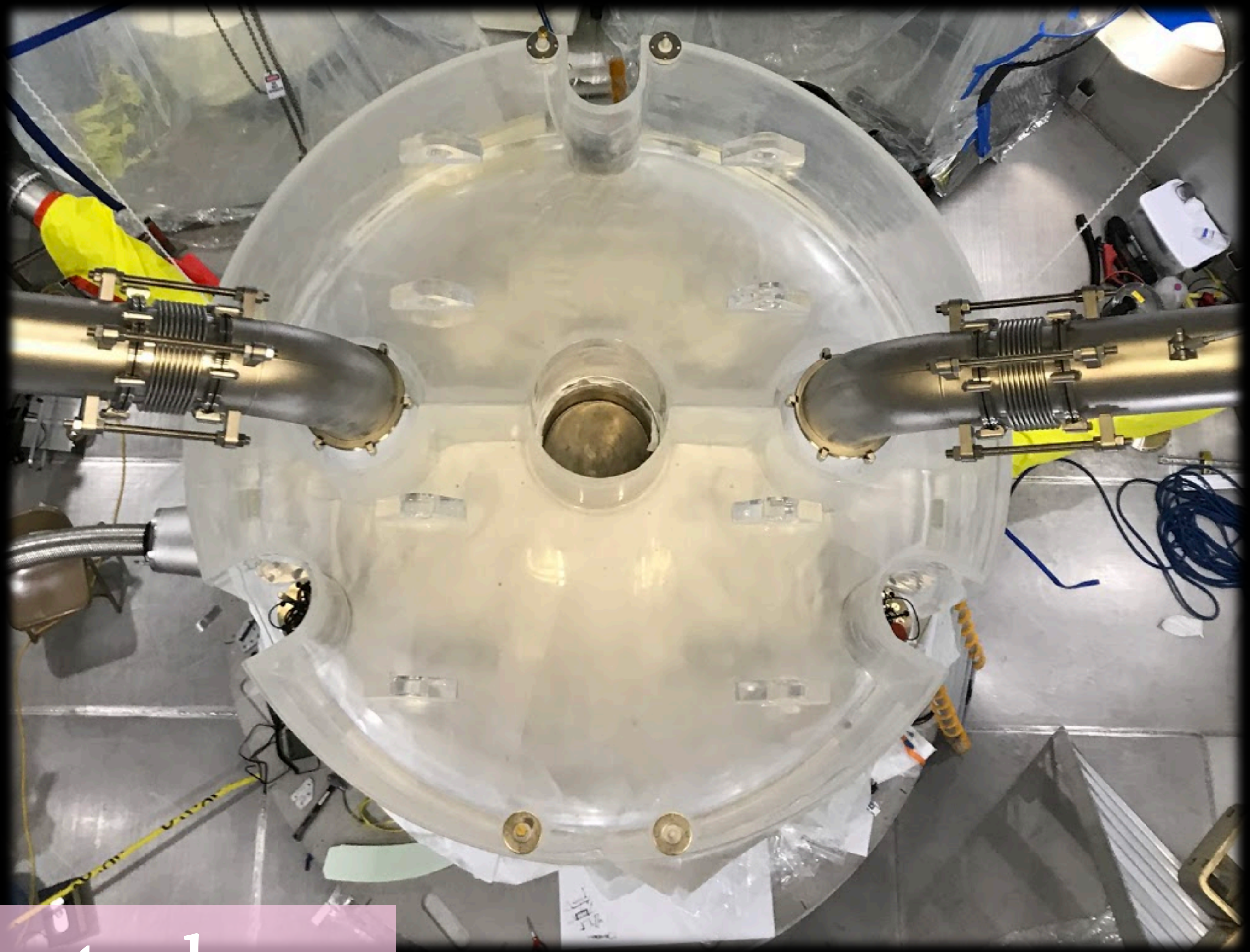
Reynolds POLYMER TECHNOLOGY, INC.

Building the Impossible

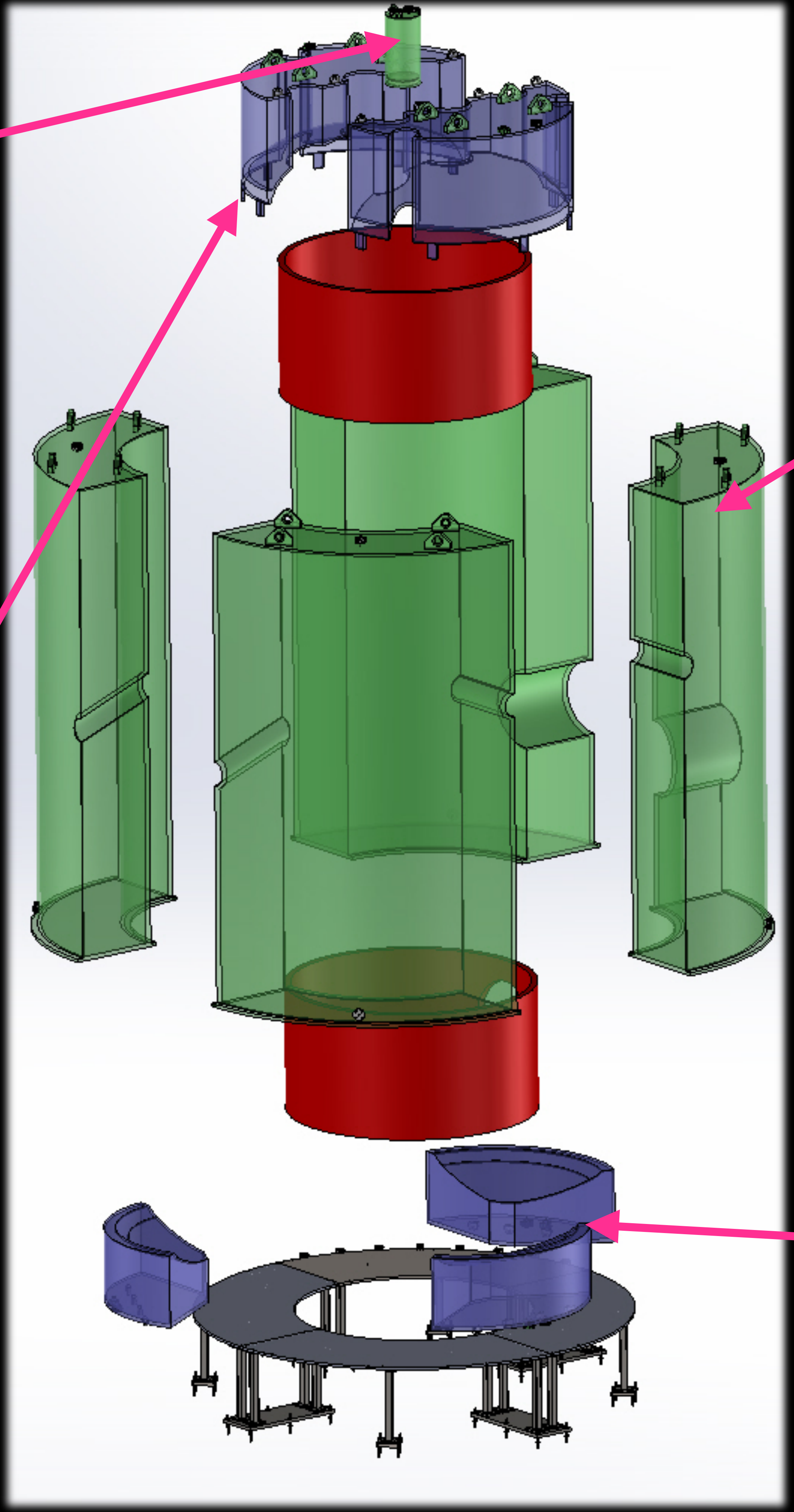
10 segmented acrylic tanks built by Reynolds Polymer, Grand Junction, CO

Removable "plug" to be switched for YBe calibration source



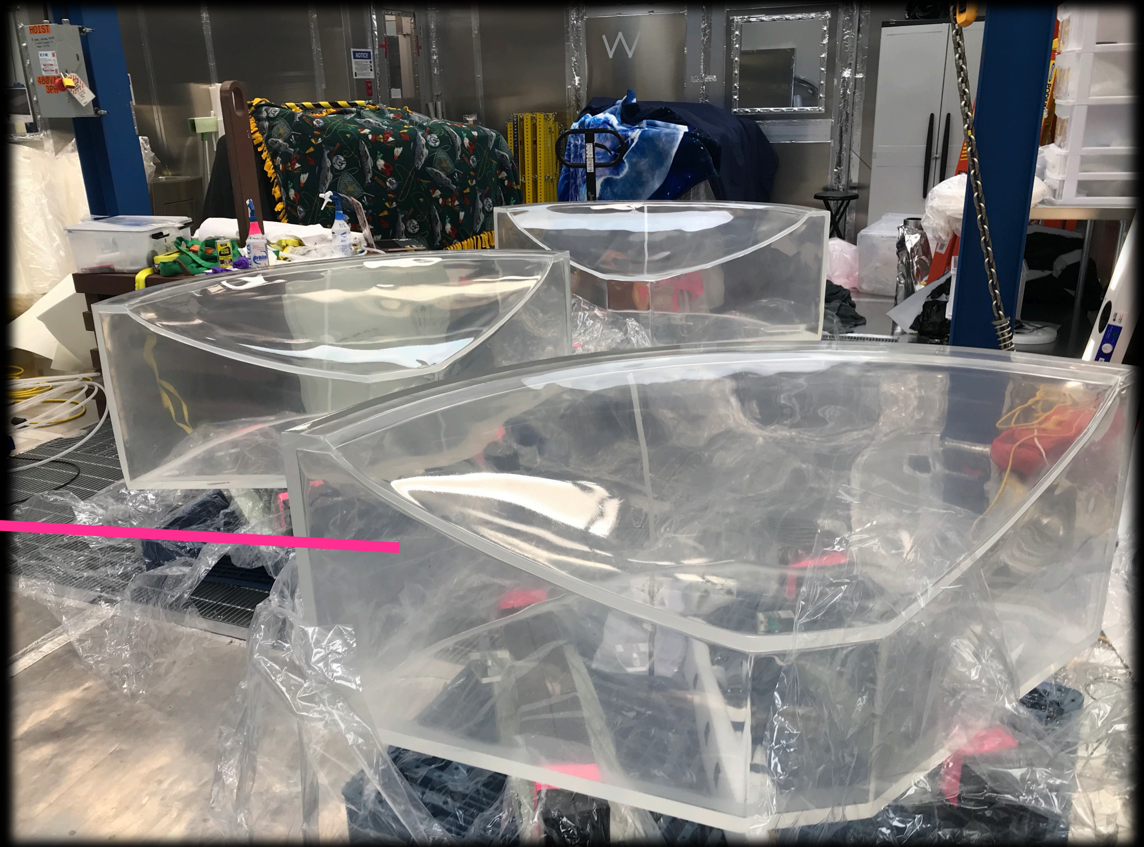


2x top tanks



Size of side tanks limited by dimension of shaft

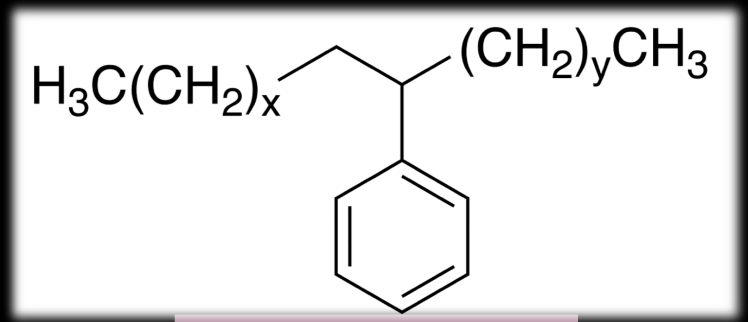
4x side tanks



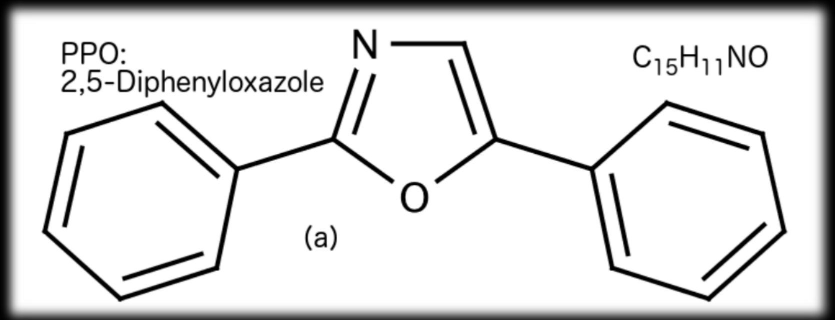
3x bottom tanks

LZ's OD: Scintillator

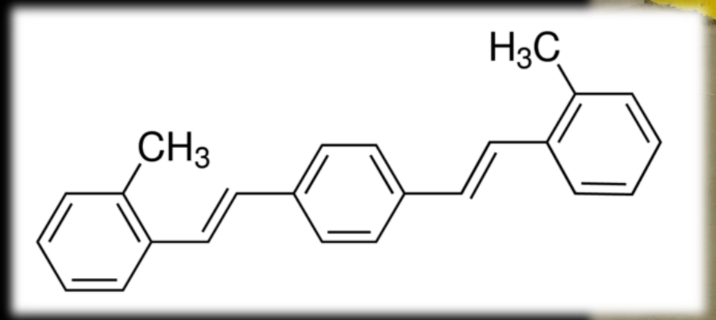
Solvent - Linear Alkylbenzene (LAB)



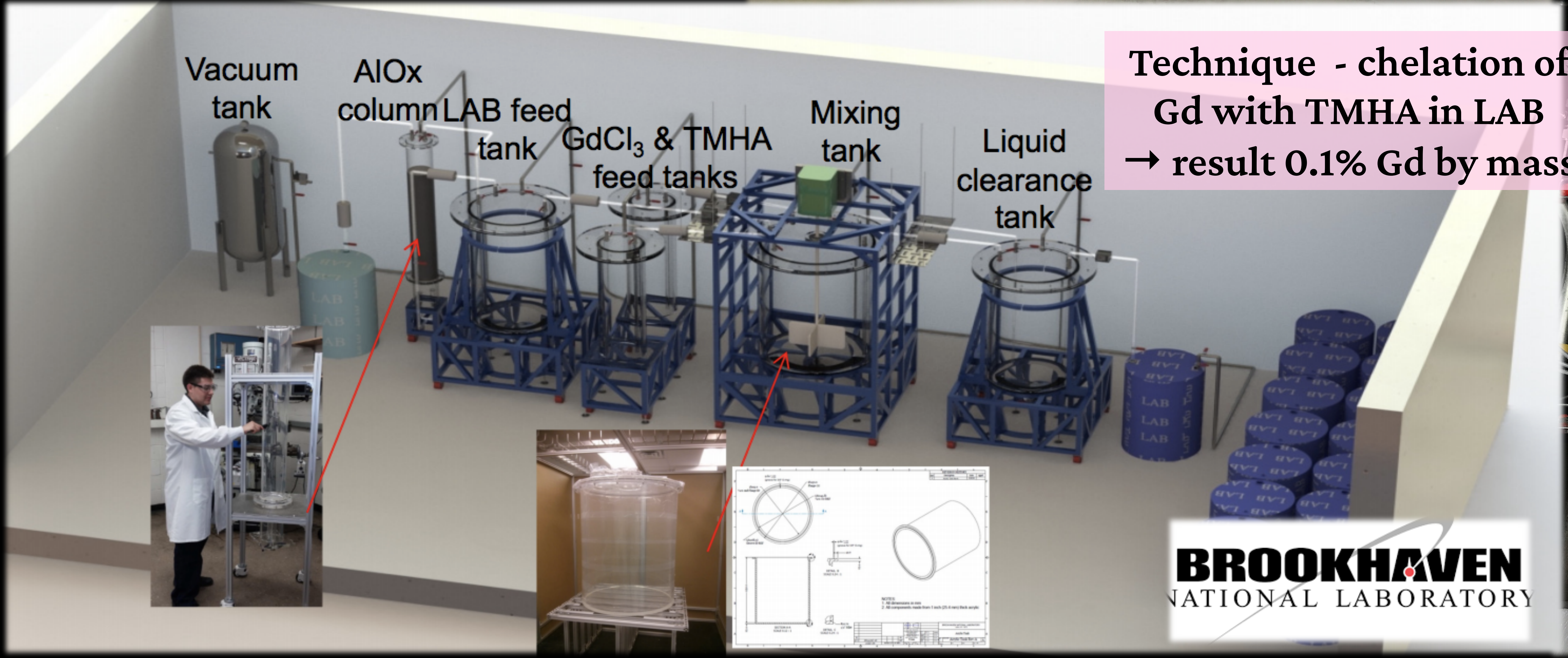
Fluor: PPO



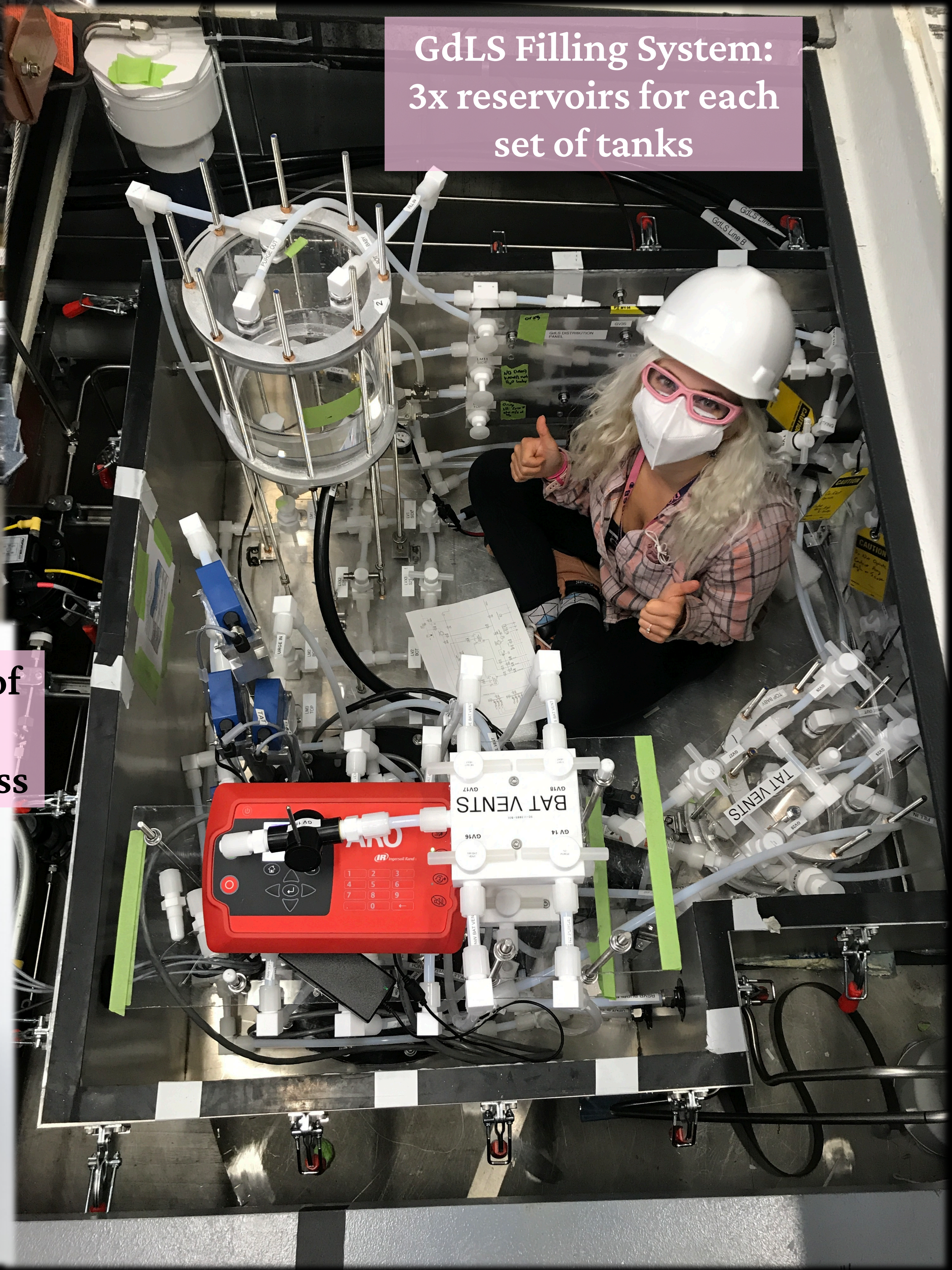
Wavelength shifter: bis-MSB



GdLS in storage in South Dakota



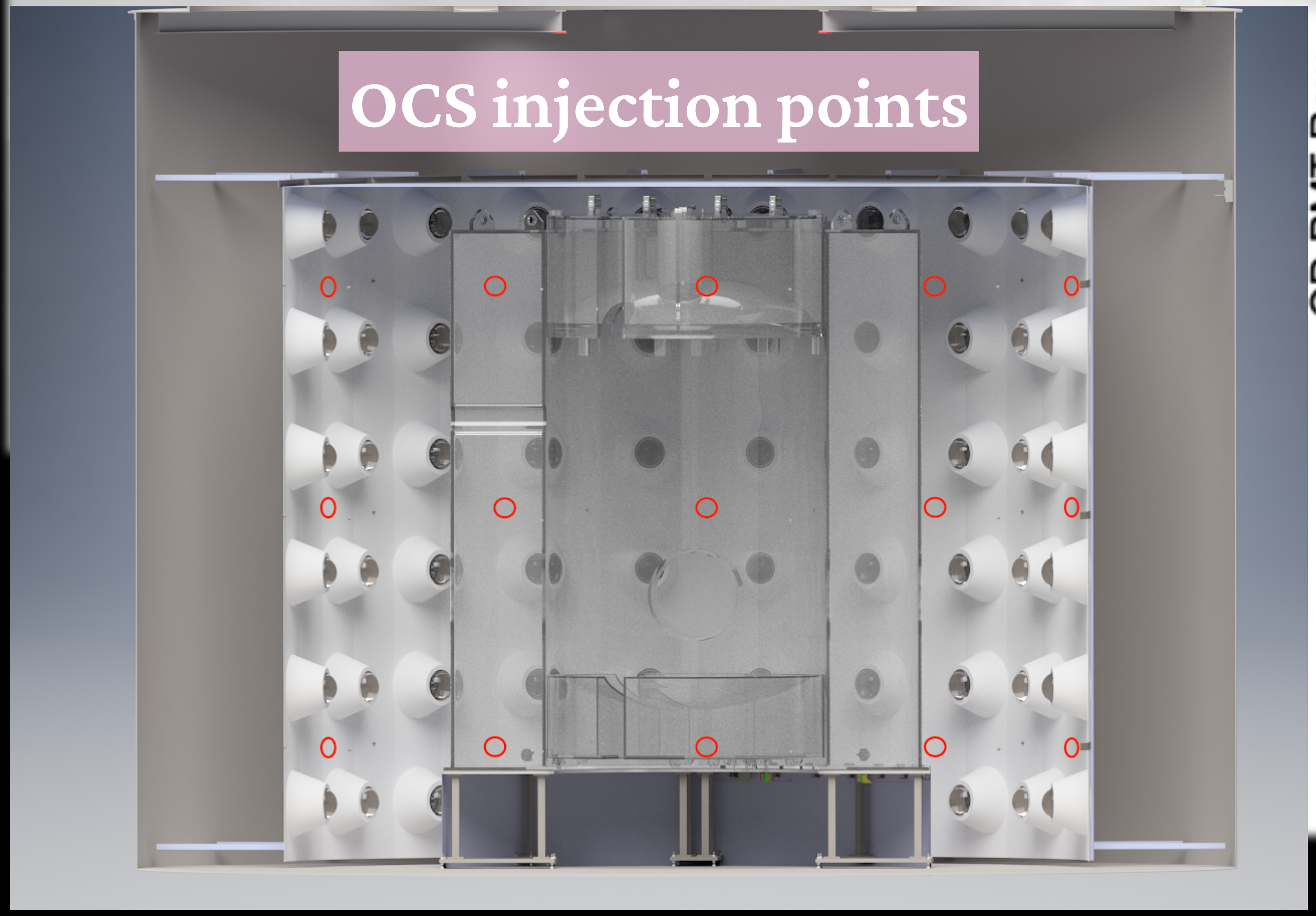
Technique - chelation of Gd with TMHA in LAB → result 0.1% Gd by mass

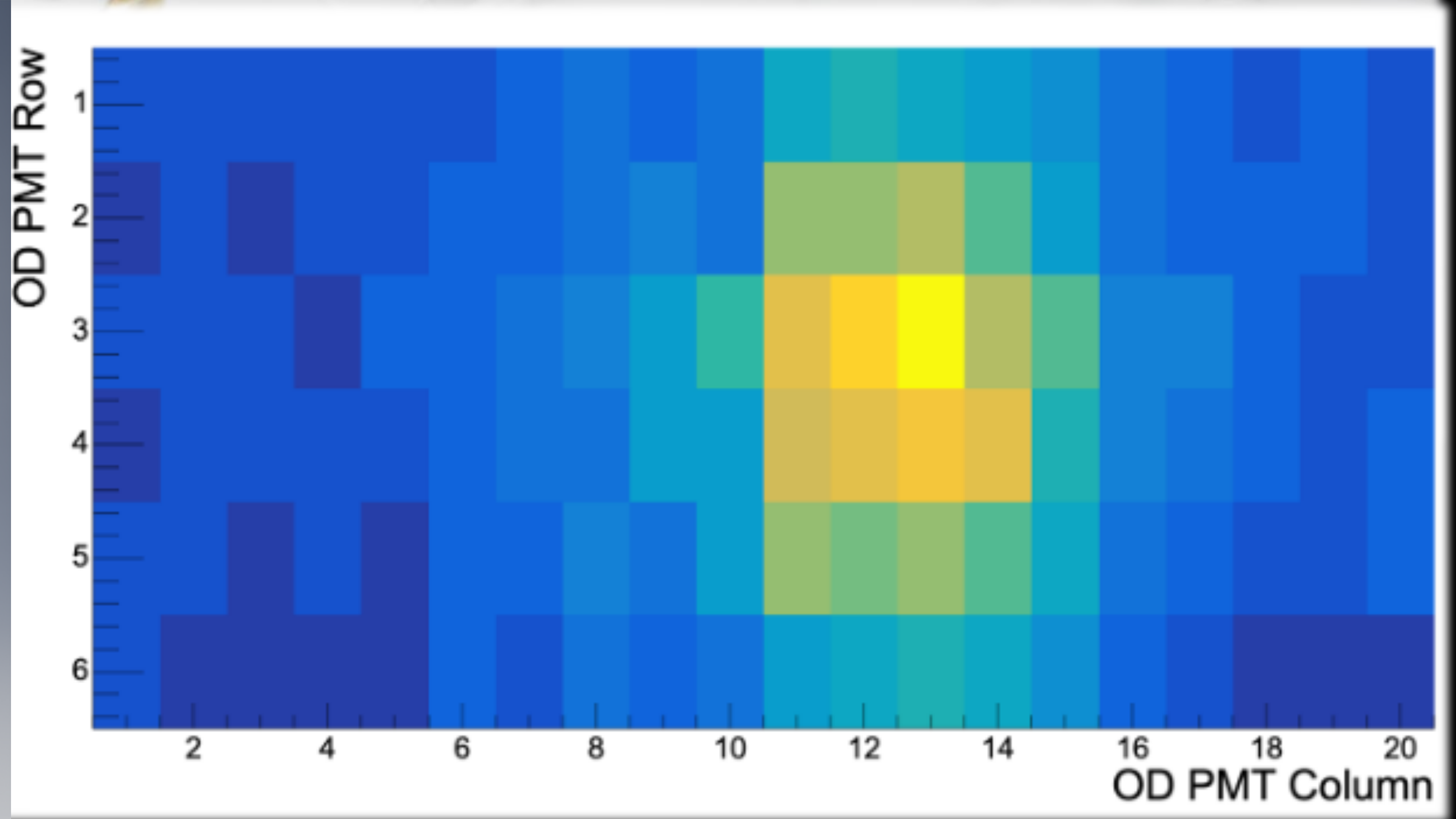


GdLS Filling System: 3x reservoirs for each set of tanks

LZ’s OD: PMTs

- **120 8” Hamamatsu R5912 PMTs** arranged in 20 ladders of 6
- **Tyvek** used as reflector, every surface in water tank wrapped
- **Optical Calibration System** in place to inject photons for PMT calibration and monitoring of optical properties of GdLS and acrylic
- Simulated light collection efficiency is ~7%, but in data, 2x this is observed





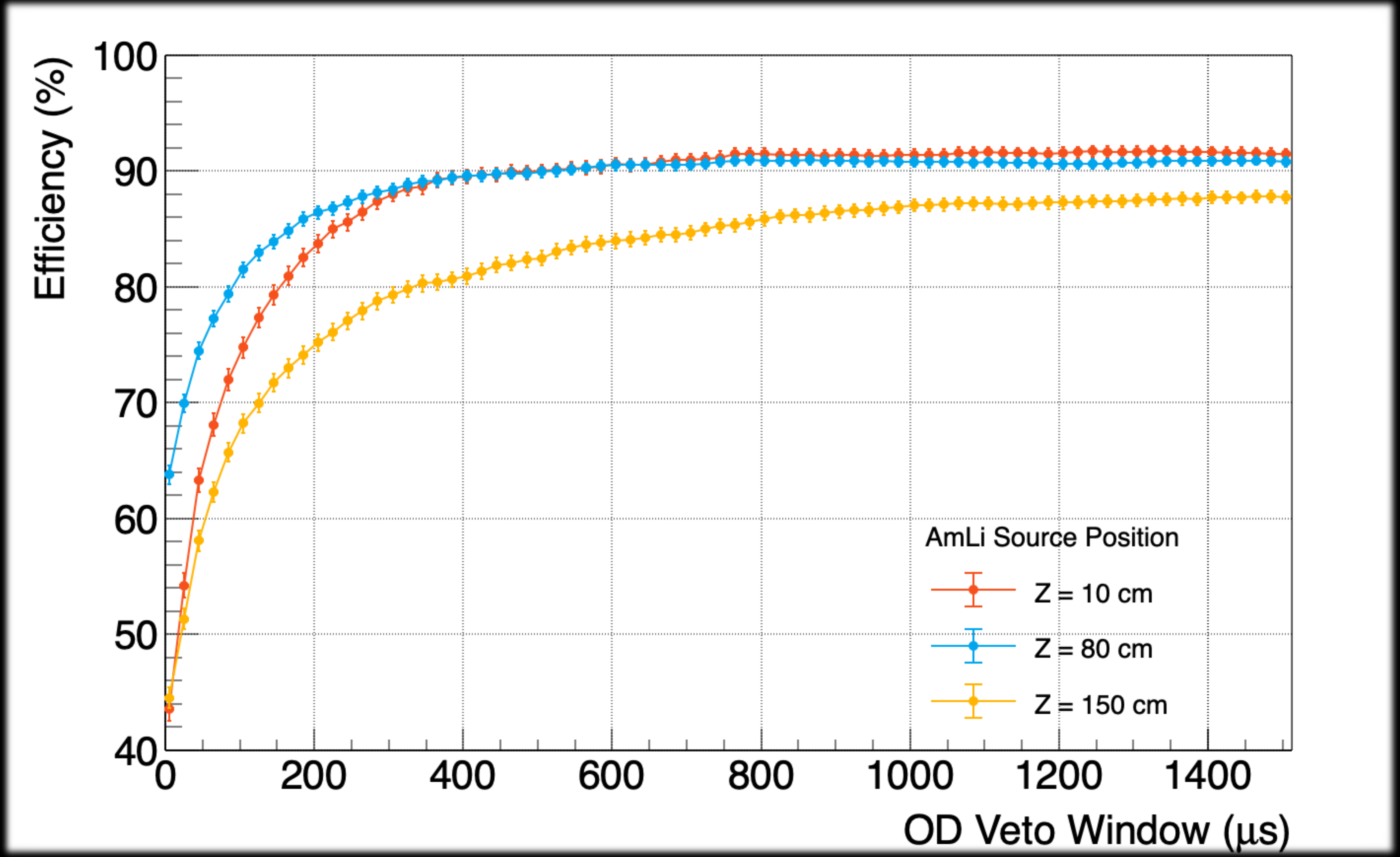
PMT response to an injection

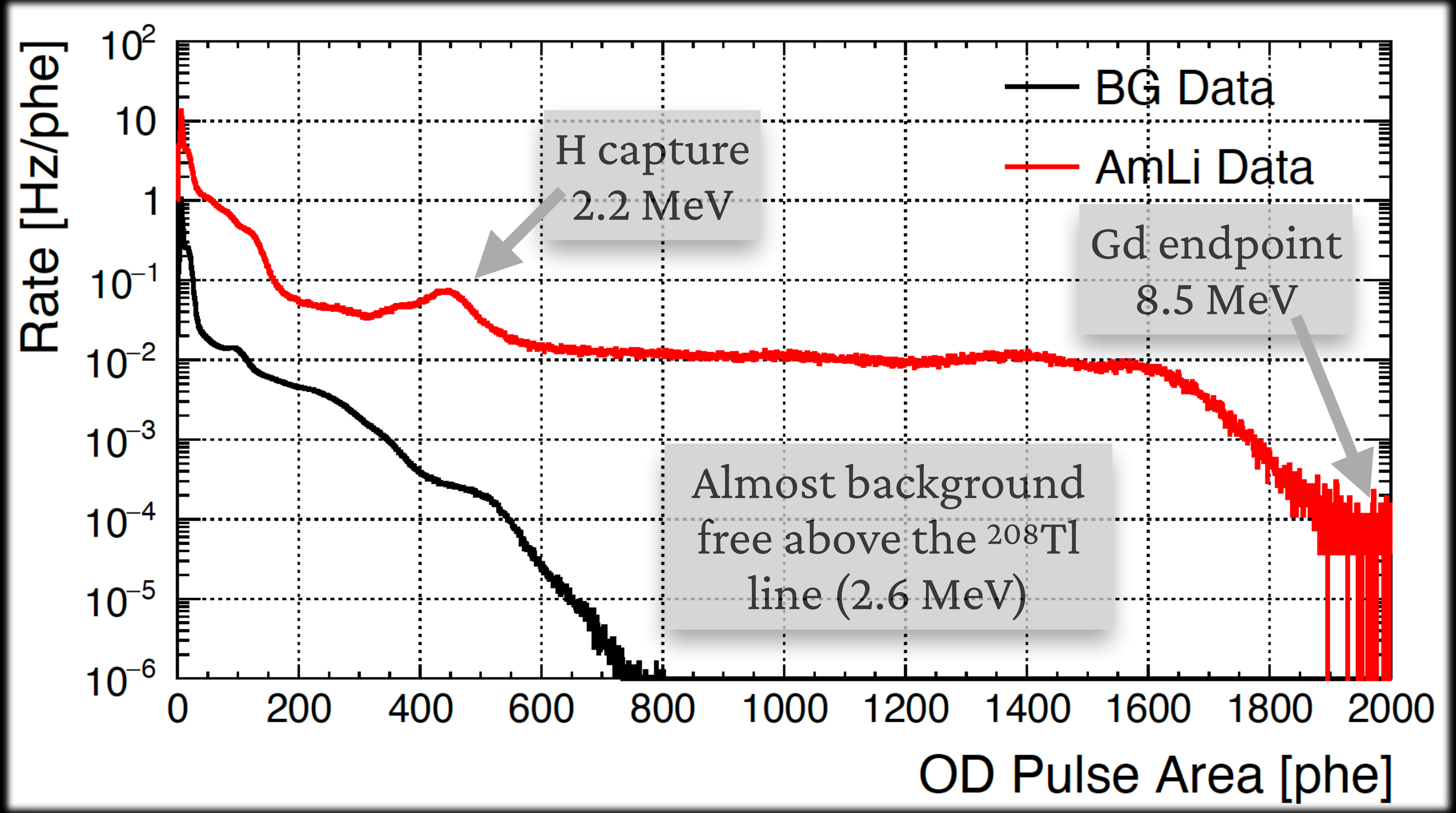
LZ's OD: Performance

Parameter	Specification	Achieved
Neutron Veto Efficiency	95%	(89 ± 3)%*
Outer Detector Threshold	200 keV (50% efficiency)	200 keV (89% efficiency)
Photoelectrons per MeV	80	200
Background rate above 200 keV	< 100 Hz	43 Hz

*Measured efficiency is average of data taken with an AmLi neutron source at 3 Z-positions (top right). This is expected to be lower than for background neutrons

OD doesn't just tag neutrons, it probes the radiation environment of LZ, confirms background simulations.. **ESSENTIAL in the case of a DM signal!**

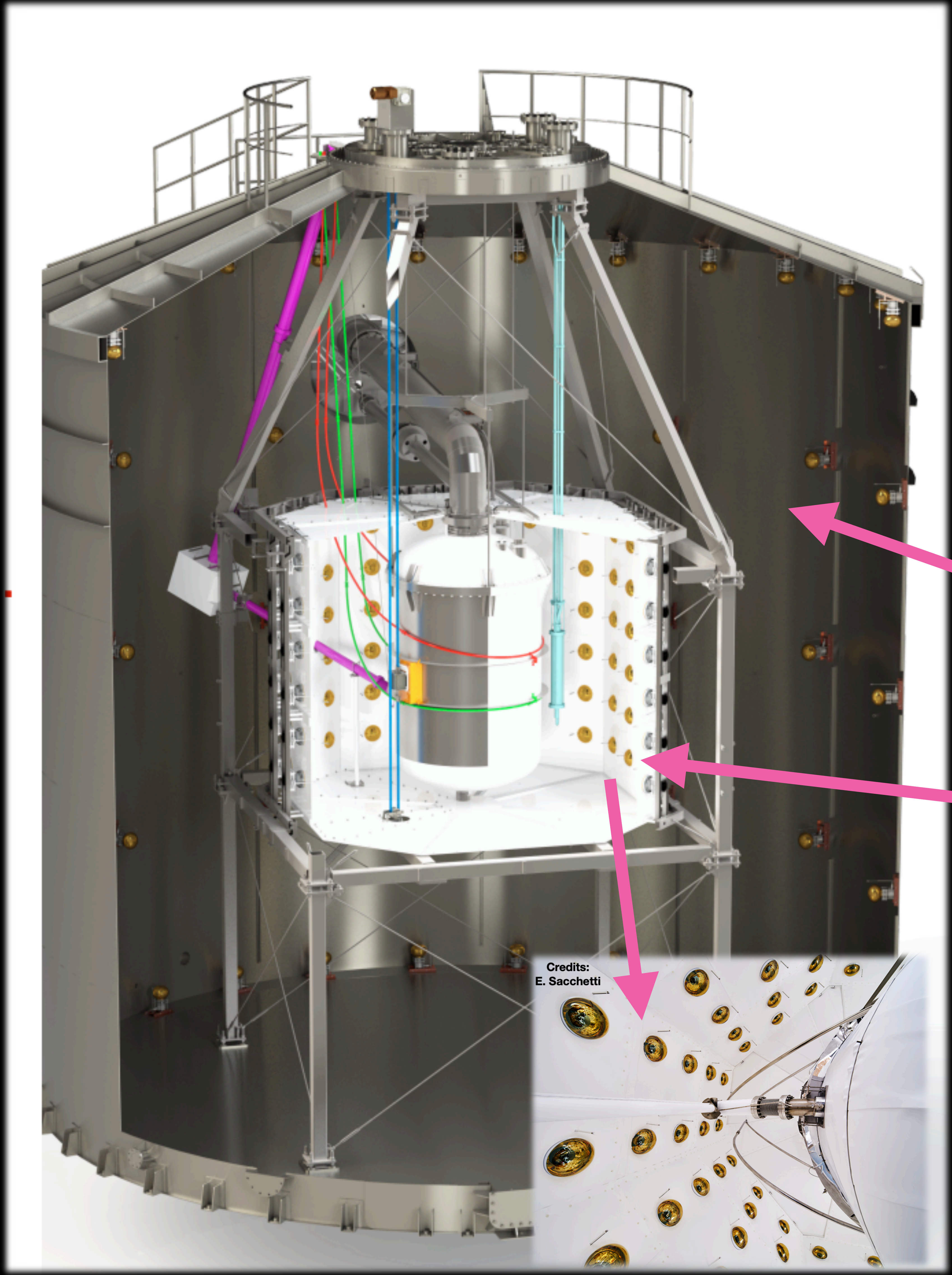




XENONnT's nVeto

Water Cherenkov veto, calibrated using an external ^{241}AmBe source (4.44 MeV γ-ray used to tag NR S1 signals)
Veto window: 250 µs
Threshold: 5-fold PMT coincidence + event area >5 PE

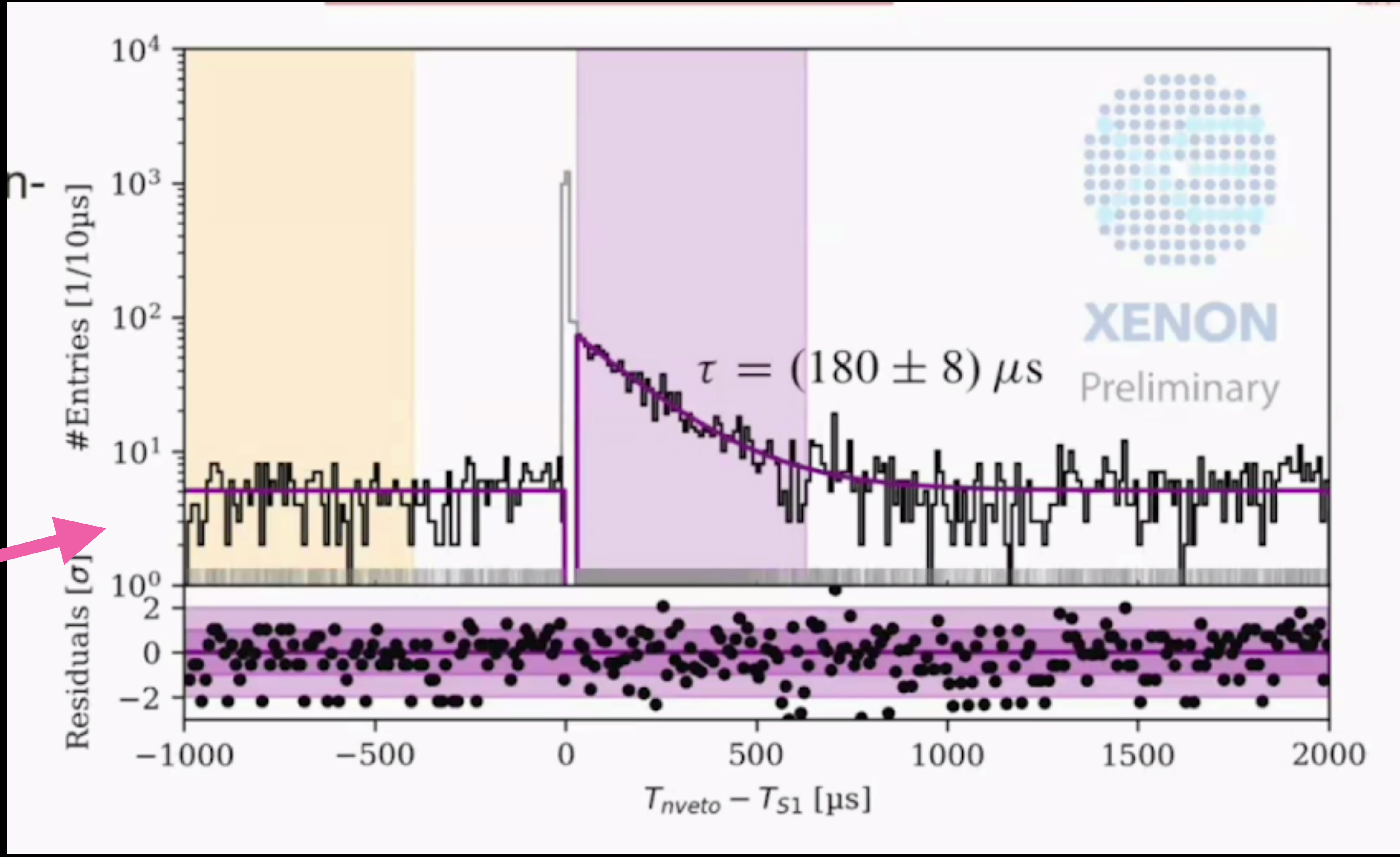
Tagging efficiency **(53 ± 3) %**, livetime reduction of 1.6 %



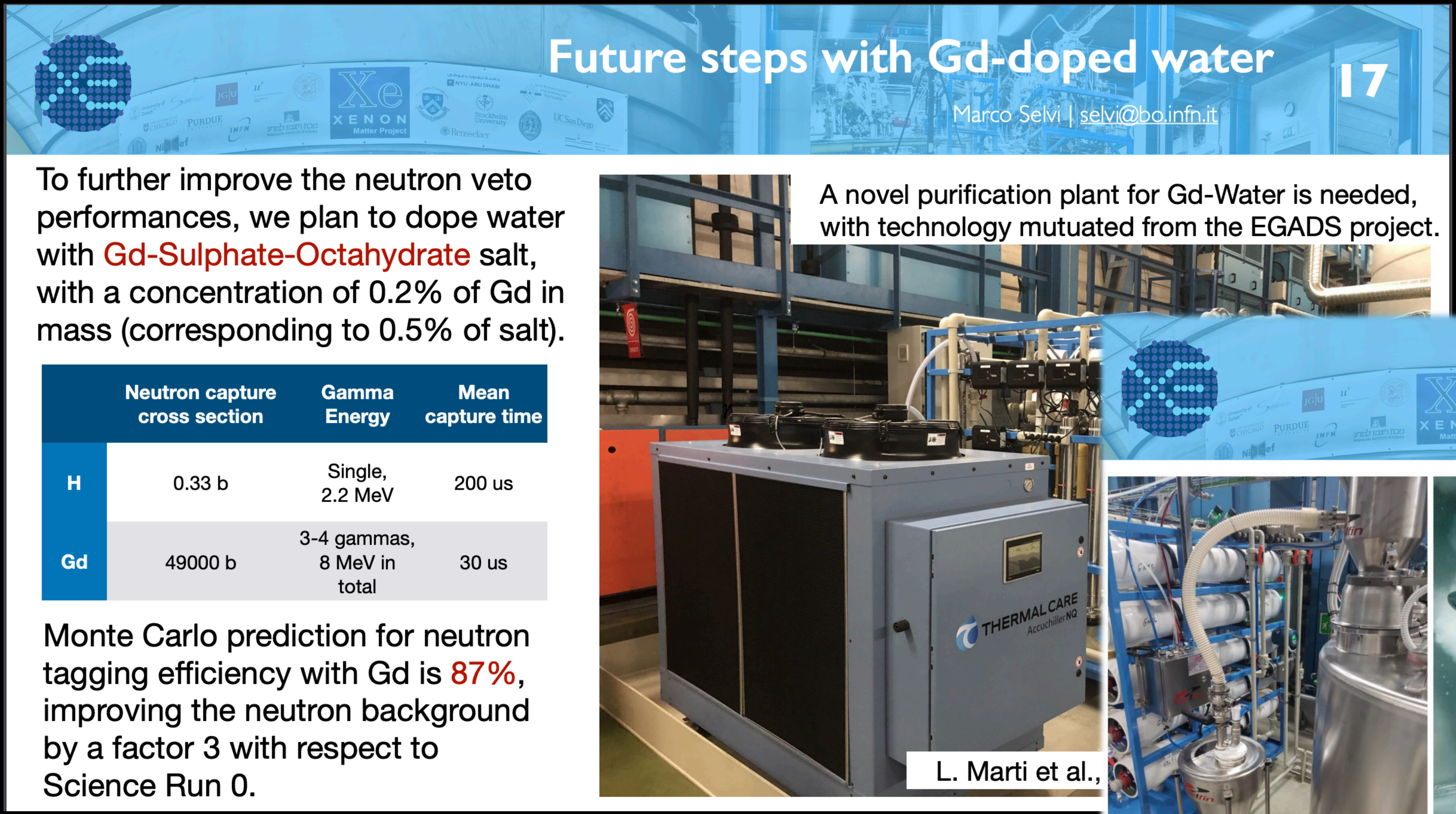
Muon veto

Neutron veto

Timing distribution of neutron captures in AmBe data



XENONnT's nVeto



Future steps with Gd-doped water

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To further improve the neutron veto performances, we plan to dope water with Gd-Sulphate-Octahydrate salt, with a concentration of 0.2% of Gd in mass (corresponding to 0.5% of salt).

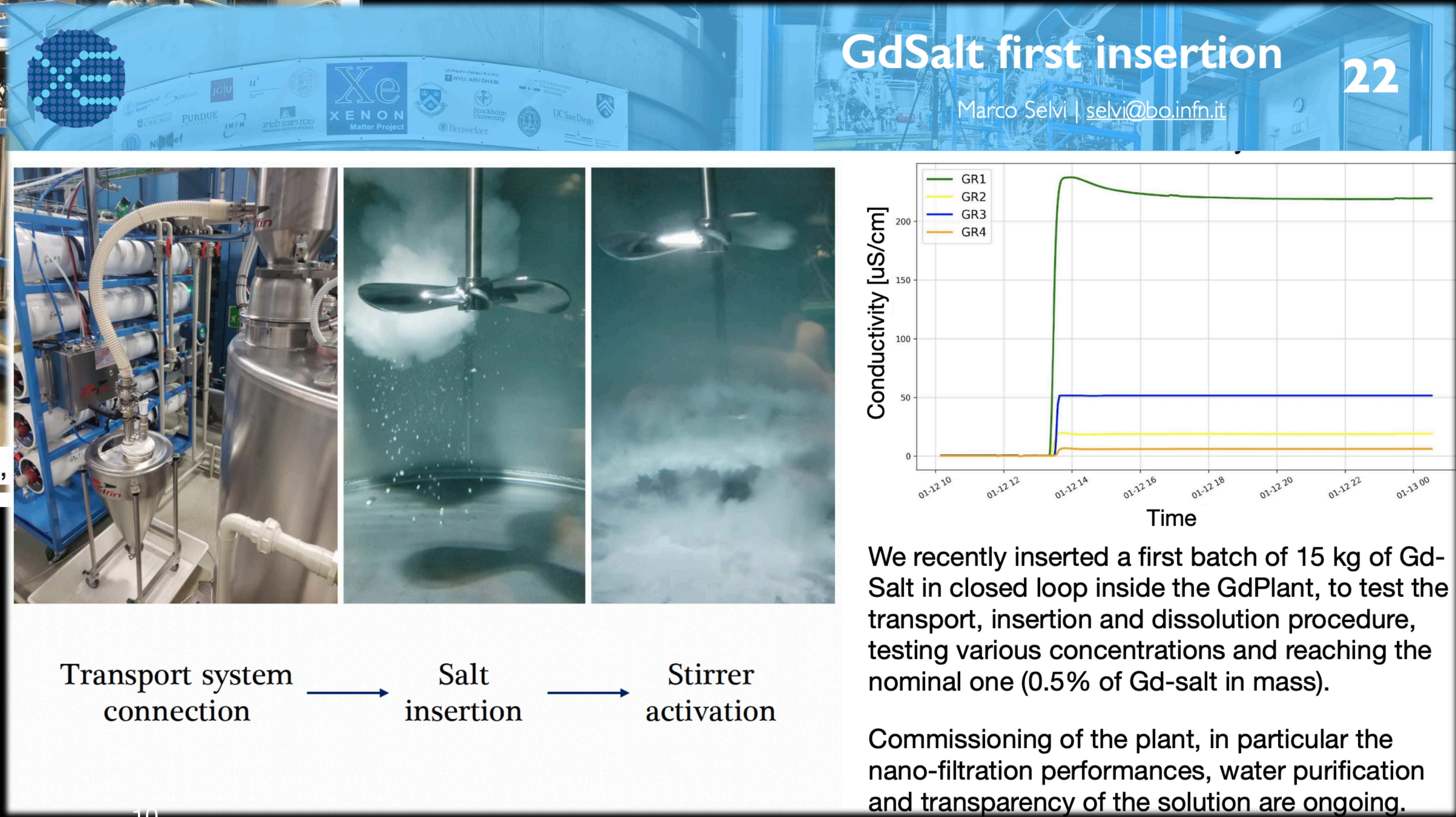
	Neutron capture cross section	Gamma Energy	Mean capture time
H	0.33 b	Single, 2.2 MeV	200 us
Gd	49000 b	3-4 gammas, 8 MeV in total	30 us

Monte Carlo prediction for neutron tagging efficiency with Gd is 87%, improving the neutron background by a factor 3 with respect to Science Run 0.

A novel purification plant for Gd-Water is needed, with technology mutuated from the EGADS project.

L. Marti et al.,

Plans to add Gd to water:
Expected efficiency 87%



GdSalt first insertion

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Transport system connection → Salt insertion → Stirrer activation

We recently inserted a first batch of 15 kg of Gd-Salt in closed loop inside the GdPlant, to test the transport, insertion and dissolution procedure, testing various concentrations and reaching the nominal one (0.5% of Gd-salt in mass).

Commissioning of the plant, in particular the nano-filtration performances, water purification and transparency of the solution are ongoing.

WP2: XLZD OD

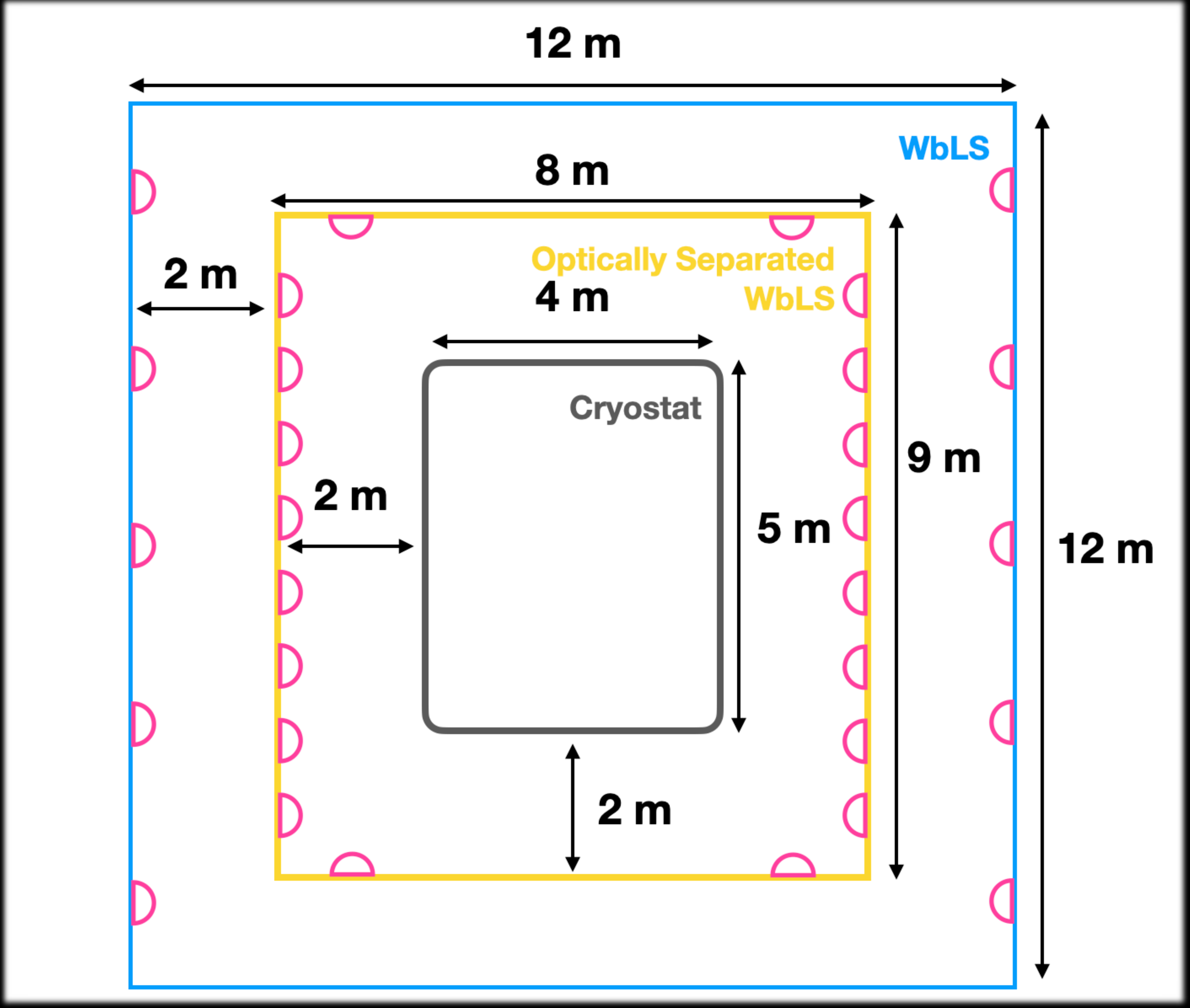
Design must be optimised for:

- **High efficiency for neutron tagging**
- **Low threshold** for background characterisation
- **Sufficient shielding** from external background

Need significant effort in simulation of whole detector (optimising parameters such as cryostat thickness, skin thickness, OD size together).

- Initial estimates assuming WbLS → 1300T detector (c.f. LZ 17T)
- Looking to avoid difficulties faced with LZ OD with acrylic, filling, external backgrounds
- Large size makes shipping a liquid scintillator very expensive/hard - consideration for material choice

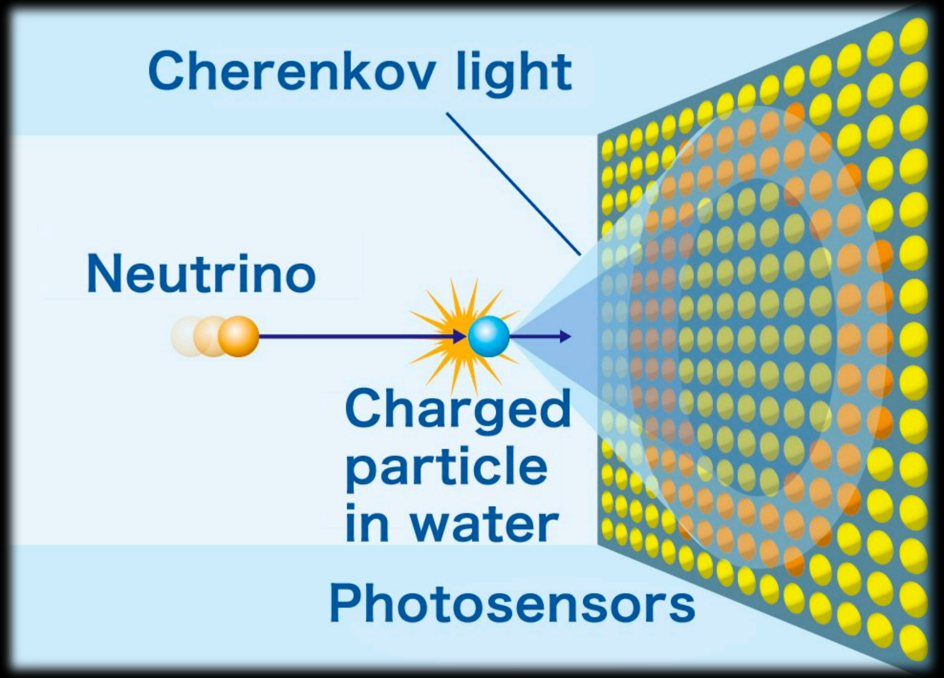
Example rough design:
→ Outer region acts as muon veto, inner as neutron veto
→ 2m of water shielding reduces intensity of 8 MeV γ to 0.8% (11x smaller than LZ where n captures on water tank were problematic)
→ 2m of water shielding reduces intensity of 3. MeV γ to 0.04% (50x less than LZ where cavern gammas dominated the OD background)

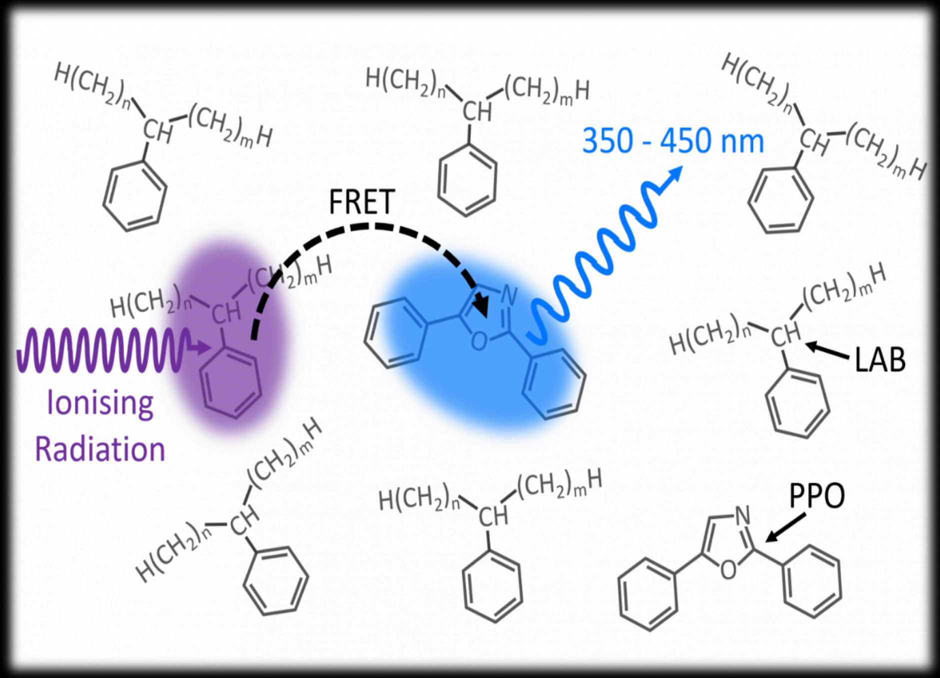


Water-Based Liquid Scintillator

WATER CHERENKOV

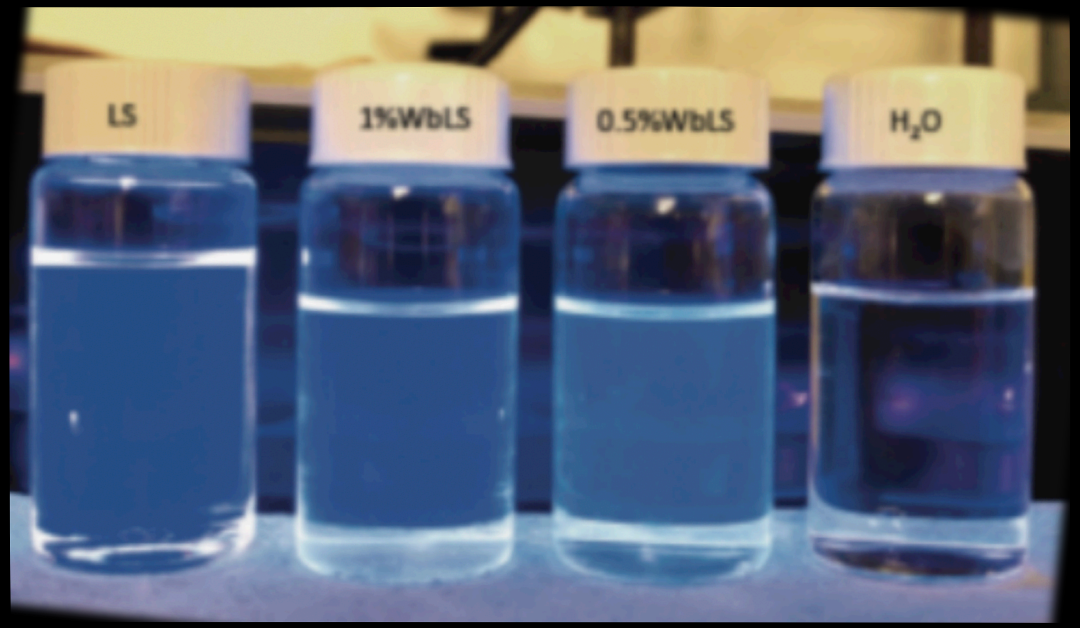
Low cost, safe
Low light attenuation
Direction reconstruction



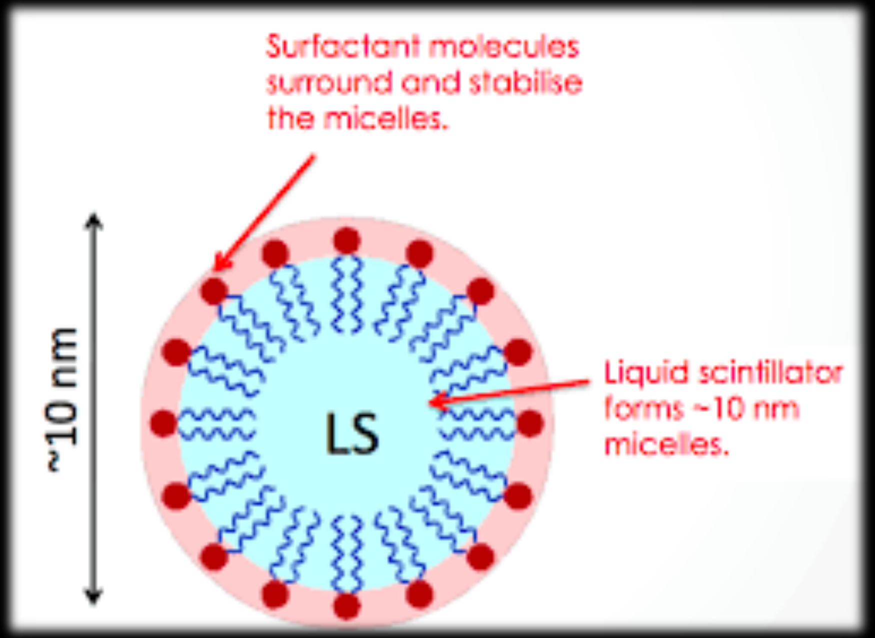


LIQUID SCINTILLATOR

High light yield
Low threshold detection



BROOKHAVEN NATIONAL LABORATORY



WATER-BASED LIQUID SCINTILLATOR

Scintillator is added to water through a surfactant (forms micelles)
Safe, environmentally friendly
Light yield can be adjusted by varying concentration
Can be scaled up - scintillator component can be added to an existing water system

Conclusions

Whilst radioassay and shielding can reduce neutron backgrounds, they can not be fully removed (and surprises can happen), thus an Outer Detector is **necessary** for XLZD to reach its full potential.

Any NR DM signal will be under an enormous amount of scrutiny! Here, an OD is **essential** for proving a **full understanding of backgrounds** to both ourselves and the community.

The UK has significant expertise from the LZ OD (leading this WP) and a strong history of veto detector development from the ZEPLIN programme.

WP2 will deliver:

Design of the gadolinium-loaded liquid scintillator veto detector system that surrounds the central Xenon Detector, including scintillator handling and purification; photosensors and front-end electronics; optical and particle calibration.

Thank you!

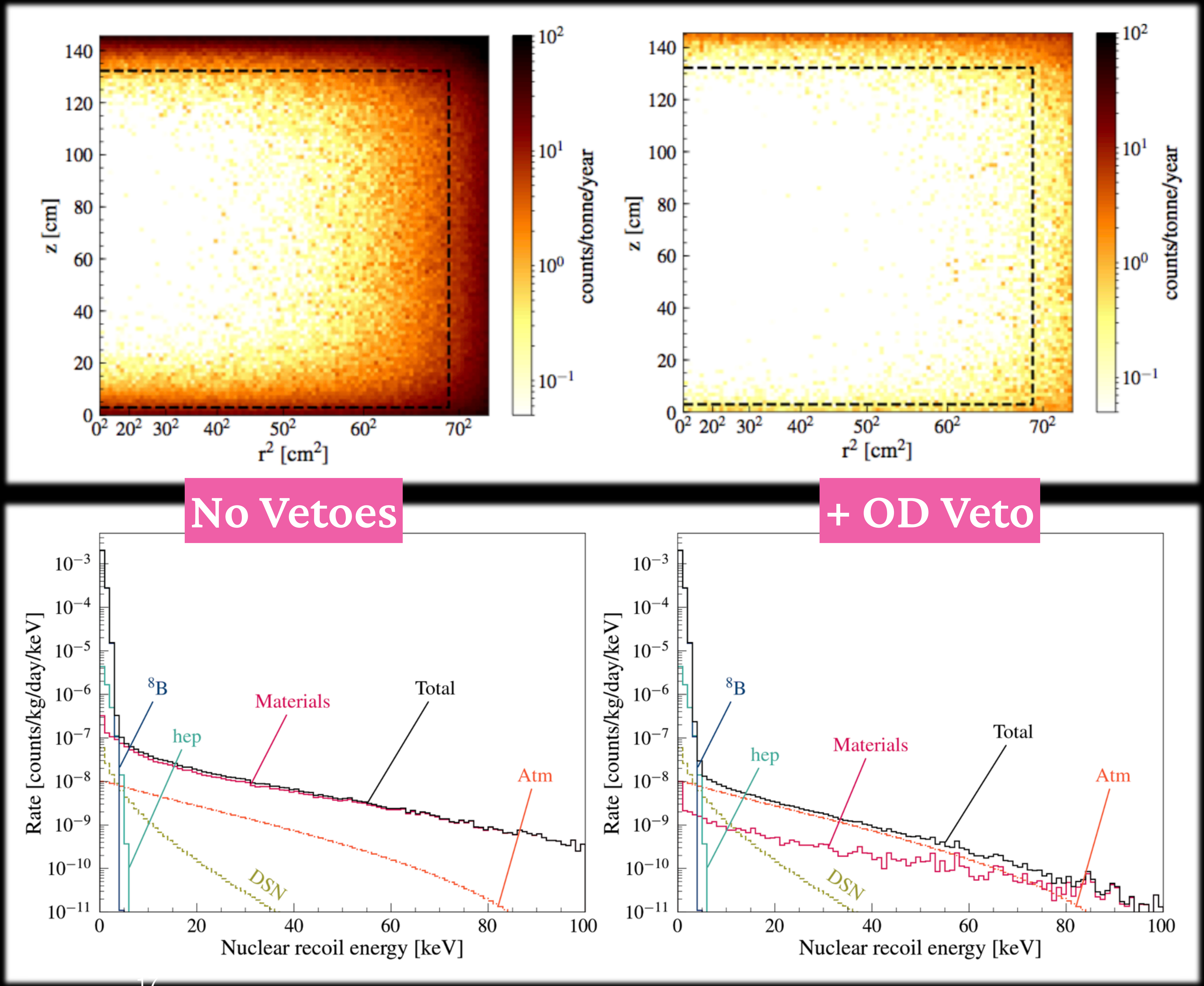
Back Up / Extra Slides


A neutron is emitted from an (α,n) reaction in the PMTS
It scatters from a Xe nucleus, causing a nuclear recoil inside the LXe detector
It enters the Outer Detector, slows down and captures on Gadolinium or Hydrogen
γ-rays are emitted from the post-capture nucleus
γ's interact in the liquid scintillator, producing photons, which are detected by PMTs

LZ’s Outer Detector

OD reduces materials background so that neutrinos are the dominant NR background.

Access to a much larger fiducial volume is available.



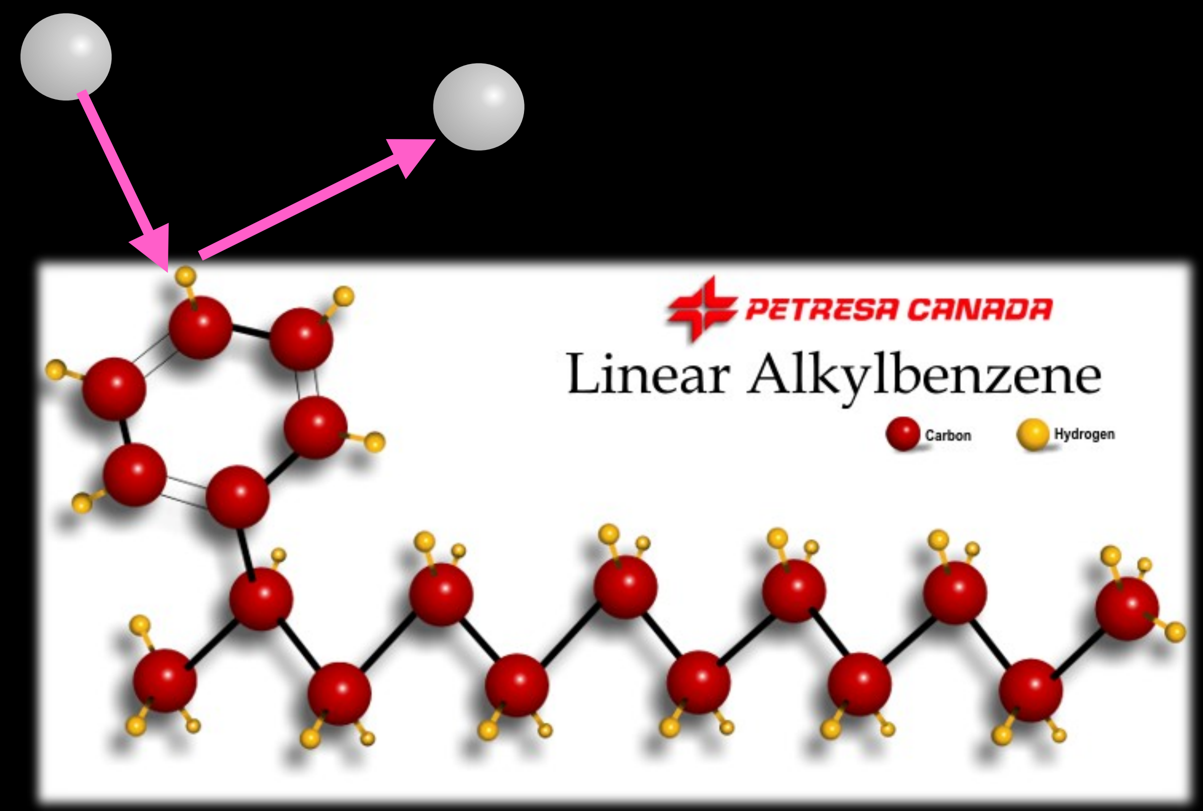
Neutron Detection in the LZ OD

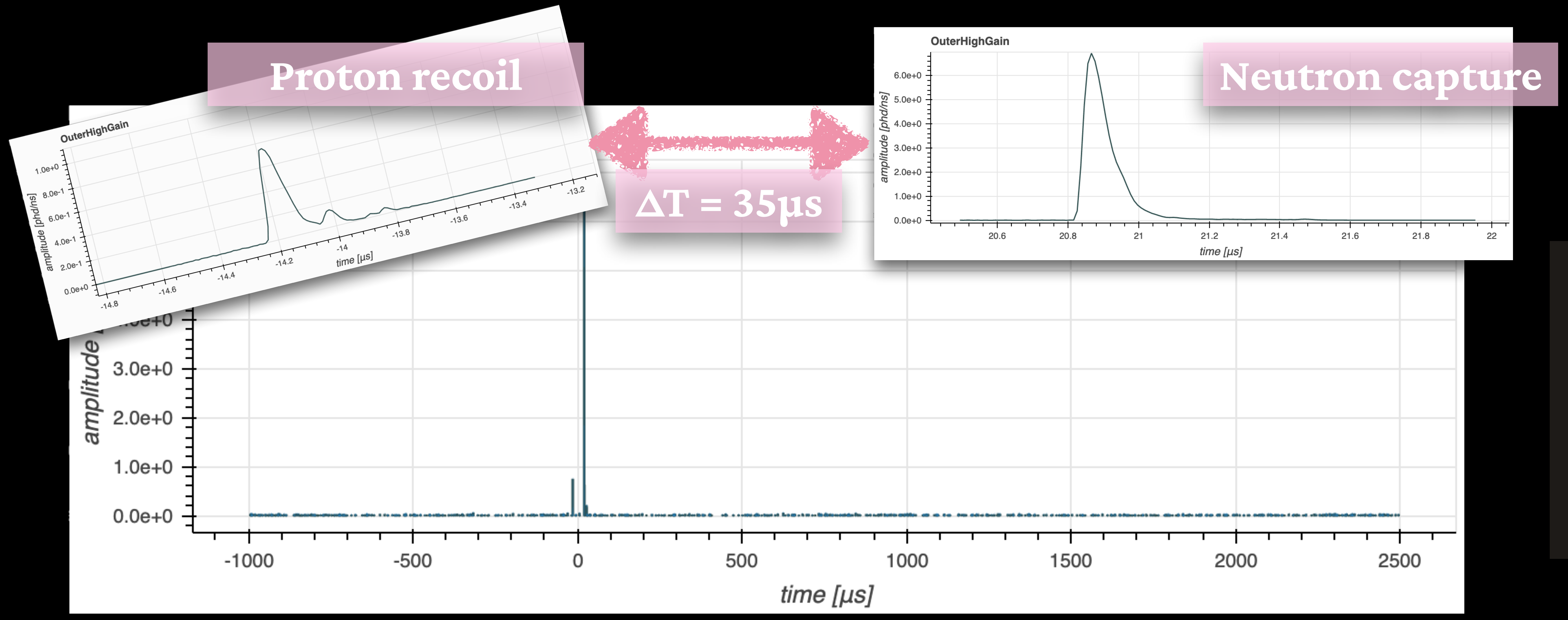
Proton Recoil:

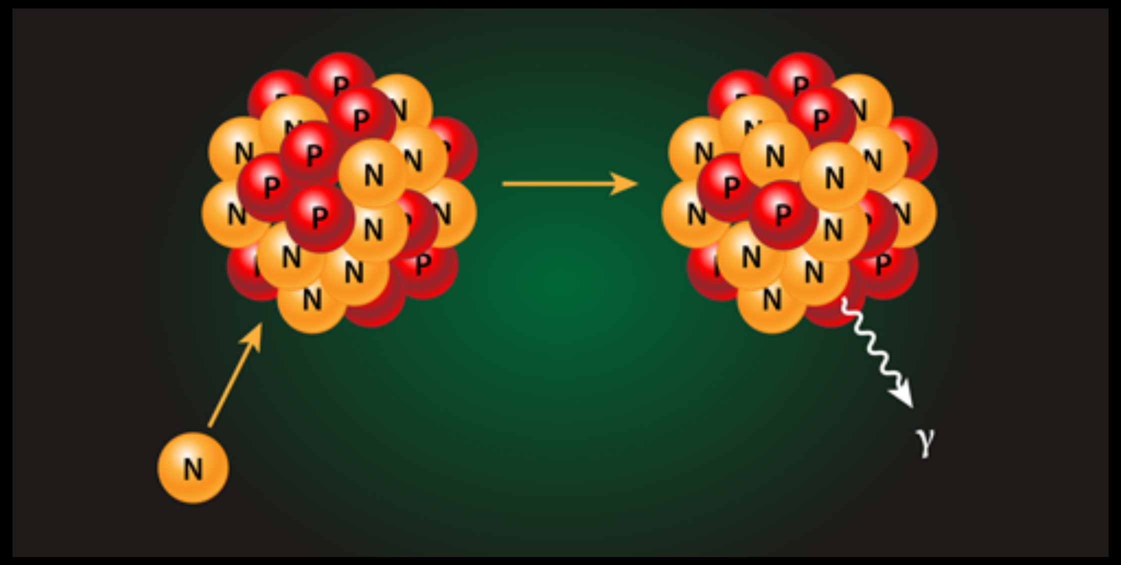
- Neutron scatters from a proton - LAB is H rich
  - Will lose ~½ its energy ($m_p \cong m_n$) to the proton
  - Proton recoil creations **scintillation light**
- Proton recoil scintillation is quenched compared to electrons/**γ**'s
  - Signal will be small but much more **prompt** than the neutron capture signal

Neutron Capture:

- Neutron **thermalises** through scattering on protons and will capture on Gd (or H)
- ^{155}Gd & ^{157}Gd - **extremely high thermal neutron capture cross sections** (highest of all stable elements)
  - reduces the time for neutrons to capture
  - Large energy release - 7.9 & 8.5 MeV
  - High multiplicity of **γ**'s - 4-5, high detection efficiency

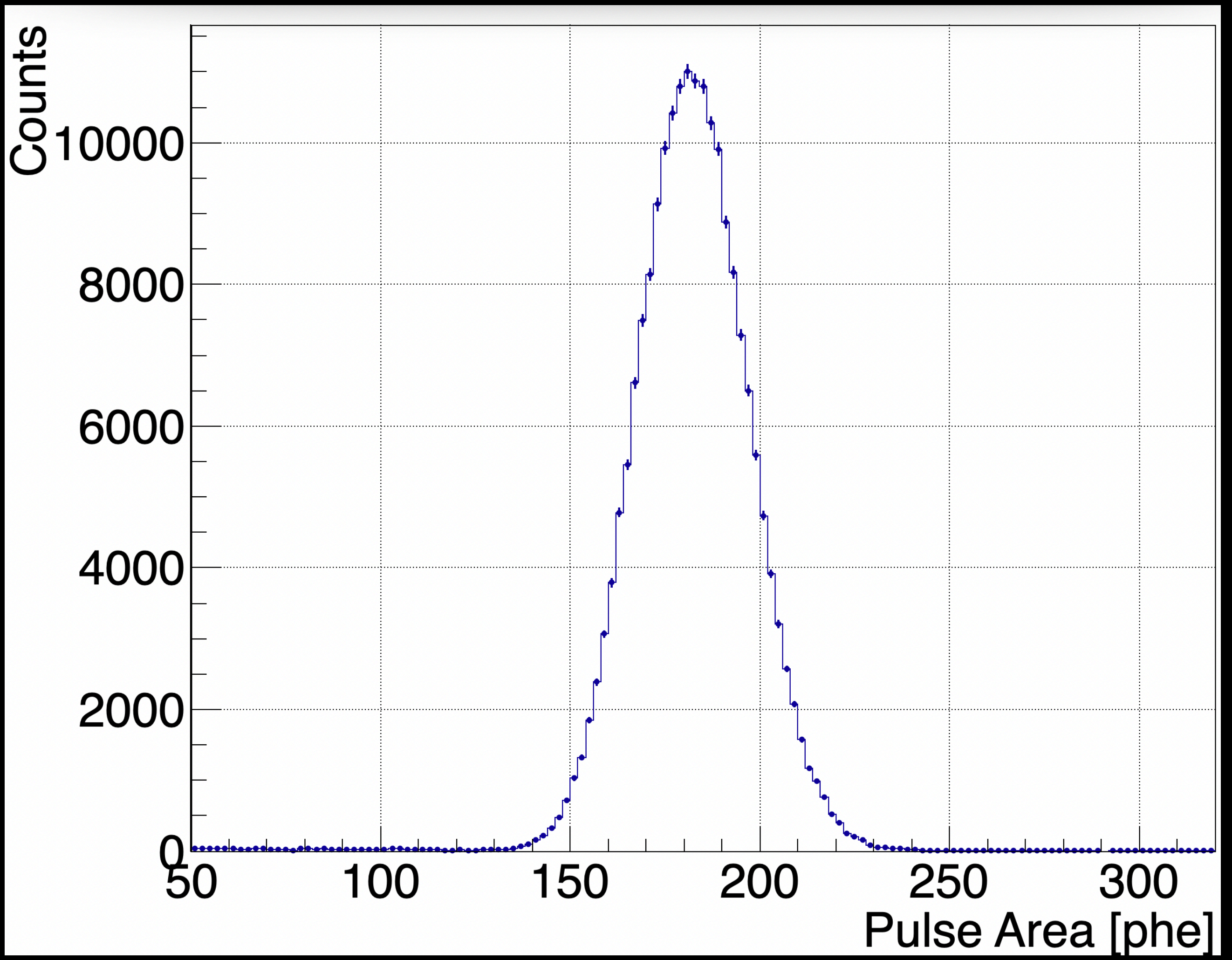




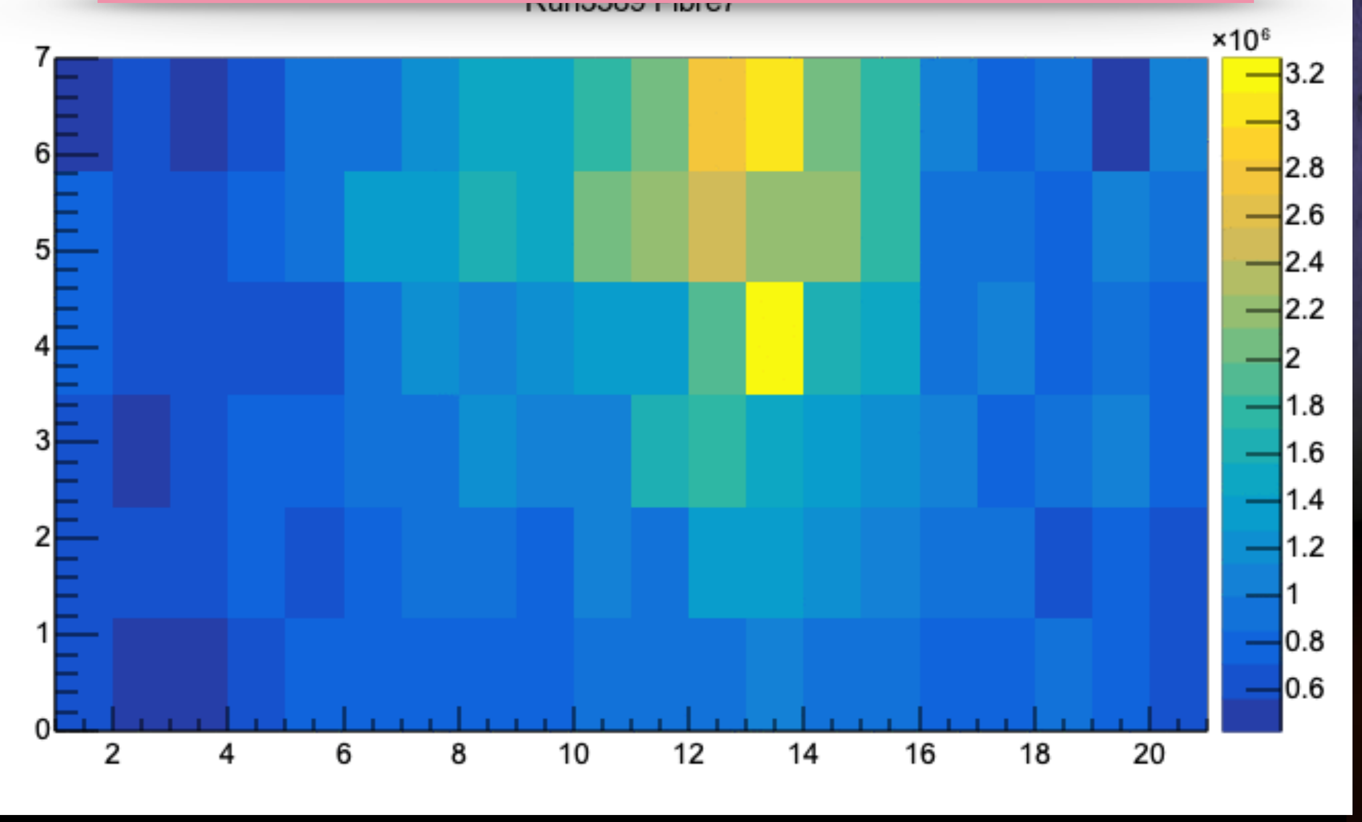


OD Calibration

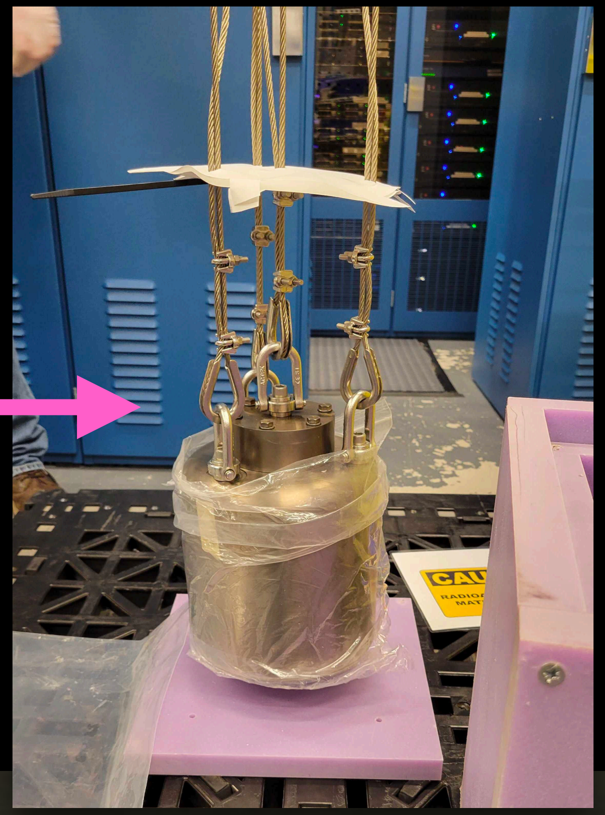
Optical Calibration System: high intensity light injection



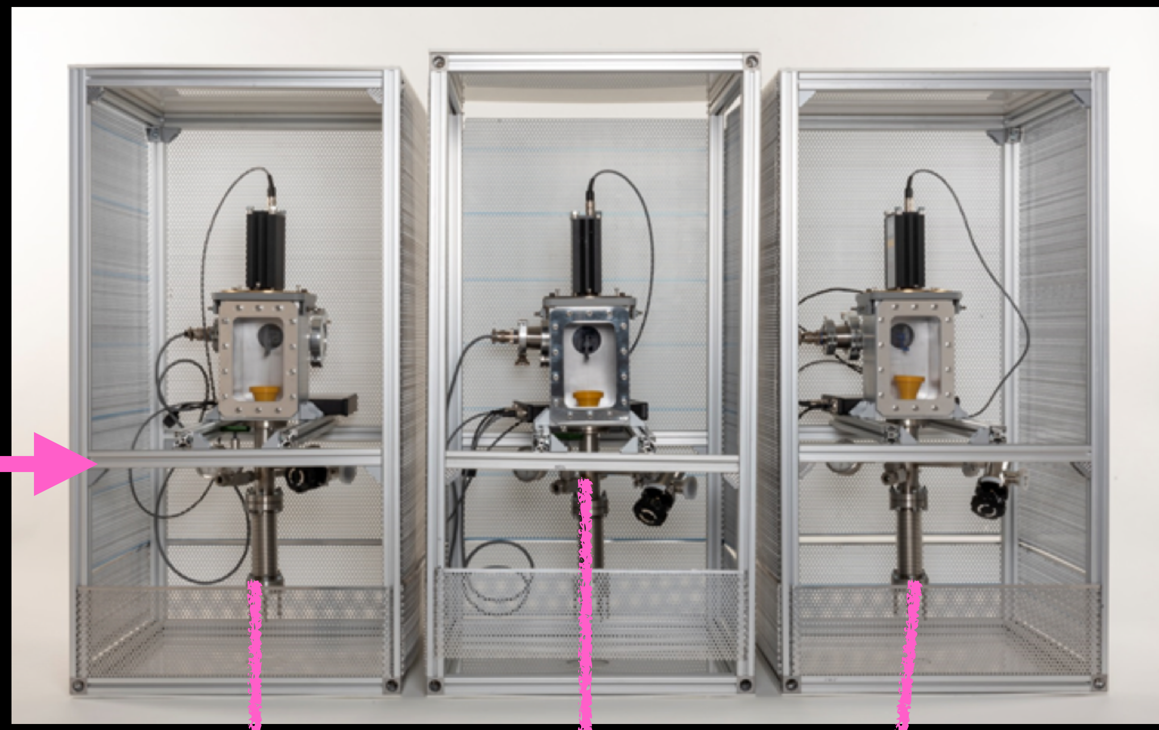
Changing injection point

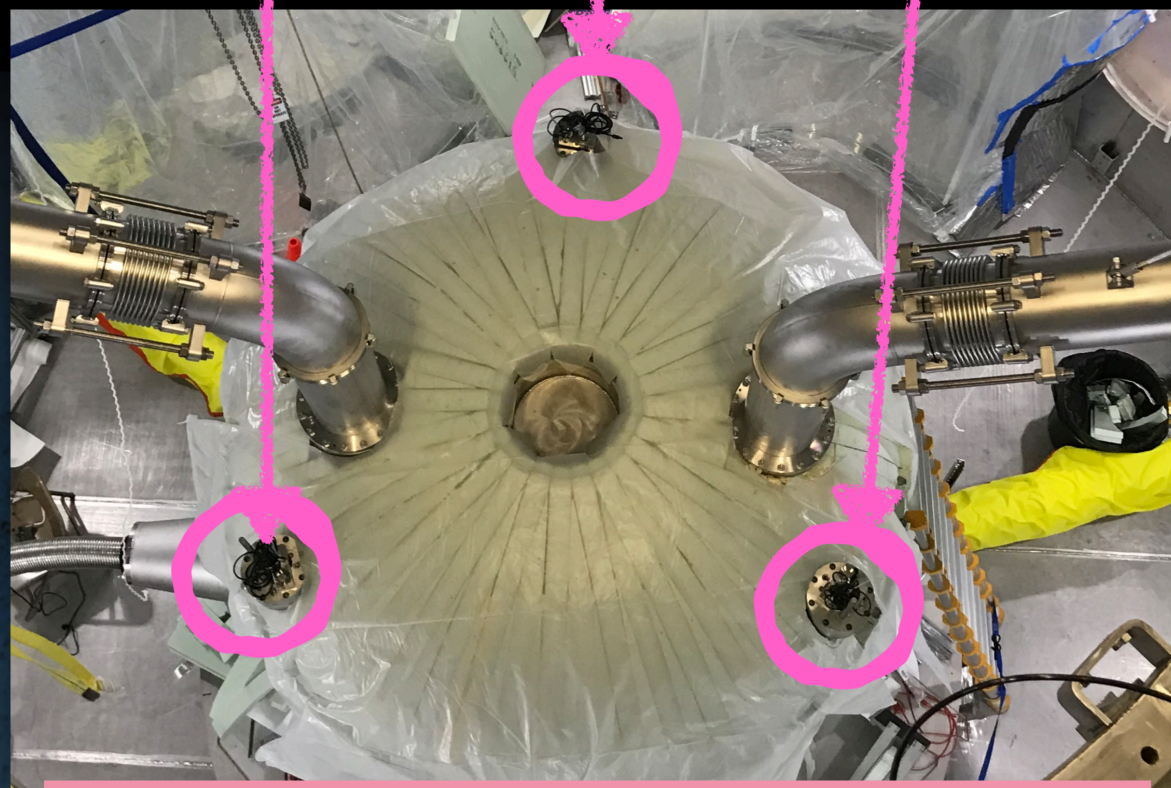


Source in tungsten shield lowered to top of OCV
Produces low energy neutrons



γ sources loaded in on upper deck and lowered to specified Z via computer-controlled motors





3 source tubes enter here and sit in vacuum space between Outer and Inner Vessels