Calibrating XENONnT and its novel water Cherenkov neutron-veto using tagged neutrons

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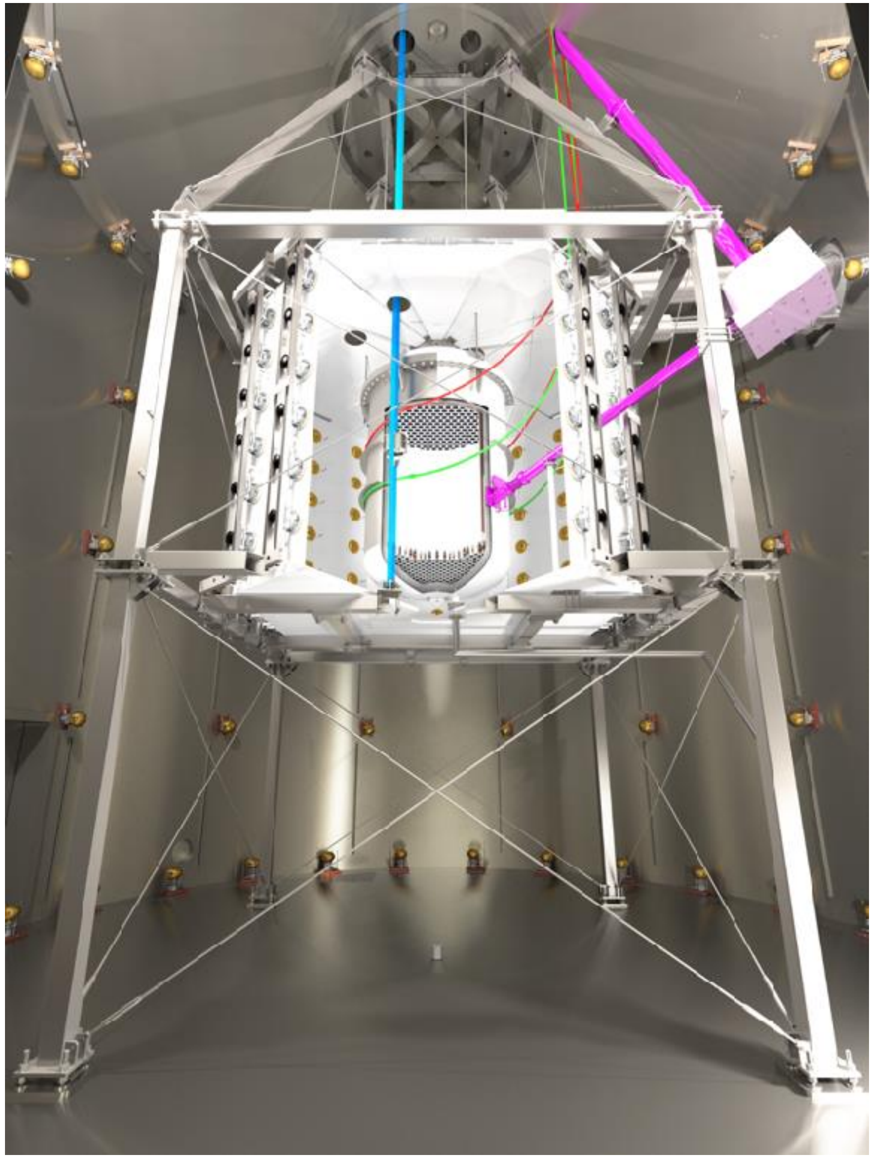
XENONnT‘s neutron-veto

- Water Cherenkov neutron-veto surrounding TPC within water Cherenkov muon-veto
  - 120 8” PMTs
  - Surfaces covered with ePTFE
  - Hydrogen neutron-capture
    - Only a few photons are emitted (about 260 for 2.2 MeV)
    - Average neutron-capture time ~200 µs

- Requirements of the nVETO:
  - High light collection efficiency:
  - Large PMTs with high quantum efficiency
  - High reflectivity ~99 %
  - High water transparency

- Gd-loading at a later stage
  - Reduces capture time to ~20 µs
  - Increases deposited energy to ~8 MeV



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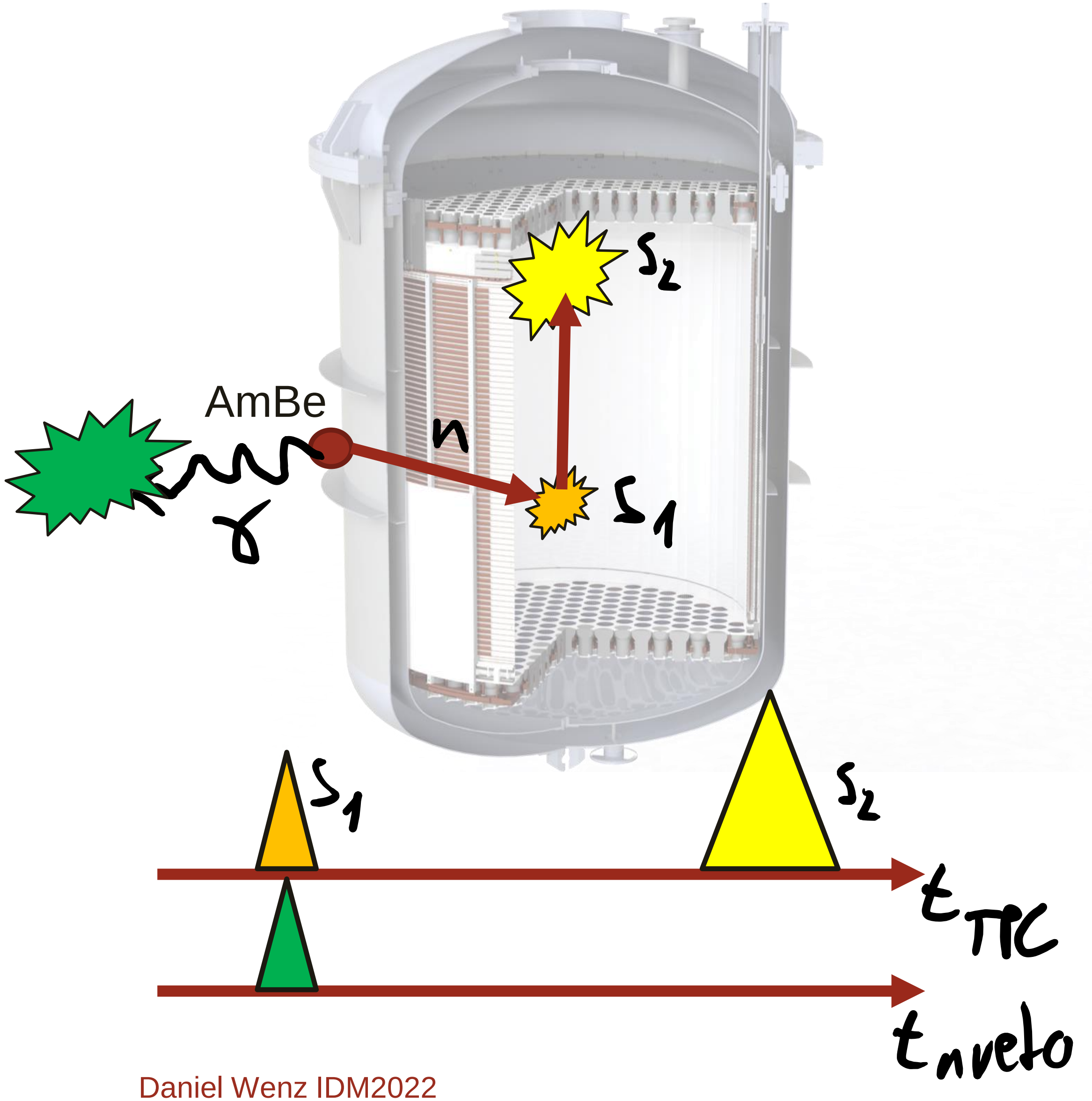
XENONnT NR calibration:

- Use tagged neutrons from AmBe
  - AmBe emits in about 50 % (tbd) of all cases a coincident 4.4 MeV gamma
  - Select 4.4 MeV gammas in the neutron-veto and build a coincidence between S1 and neutron-veto



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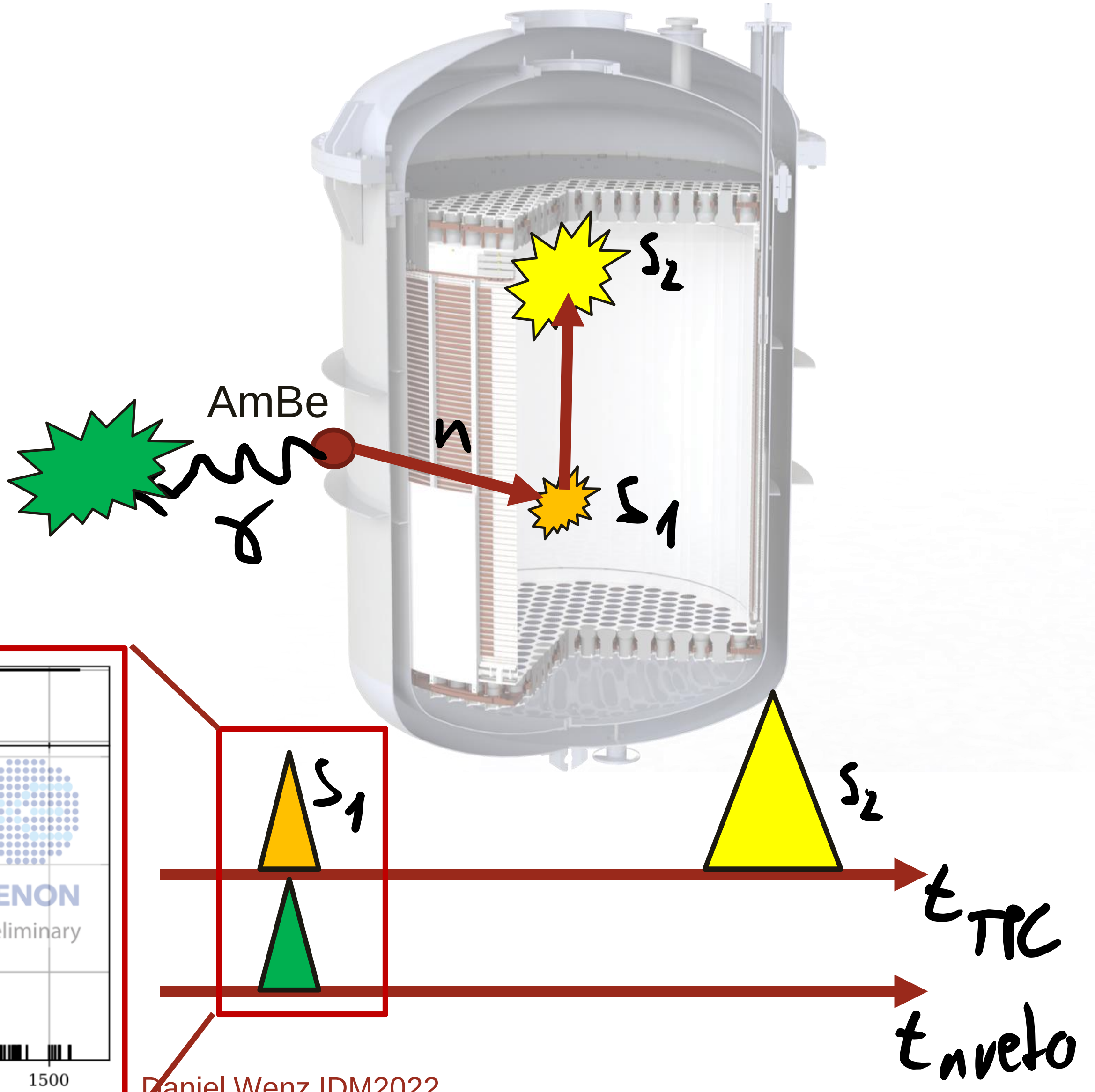
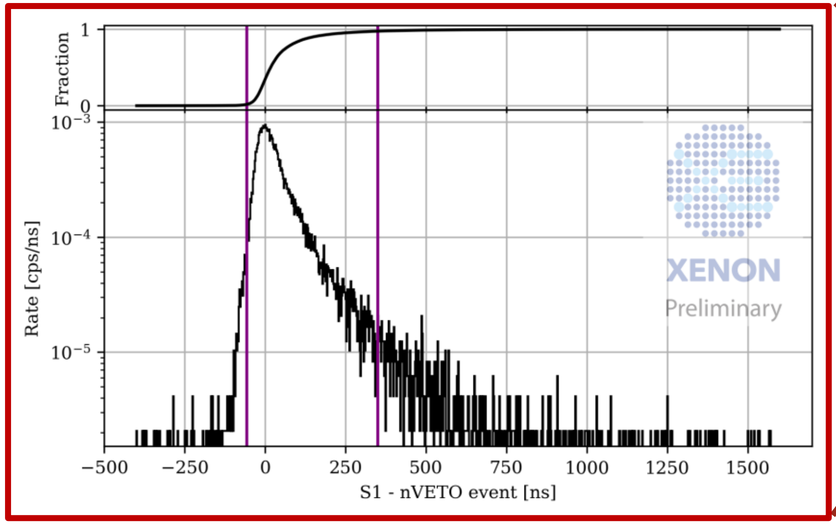
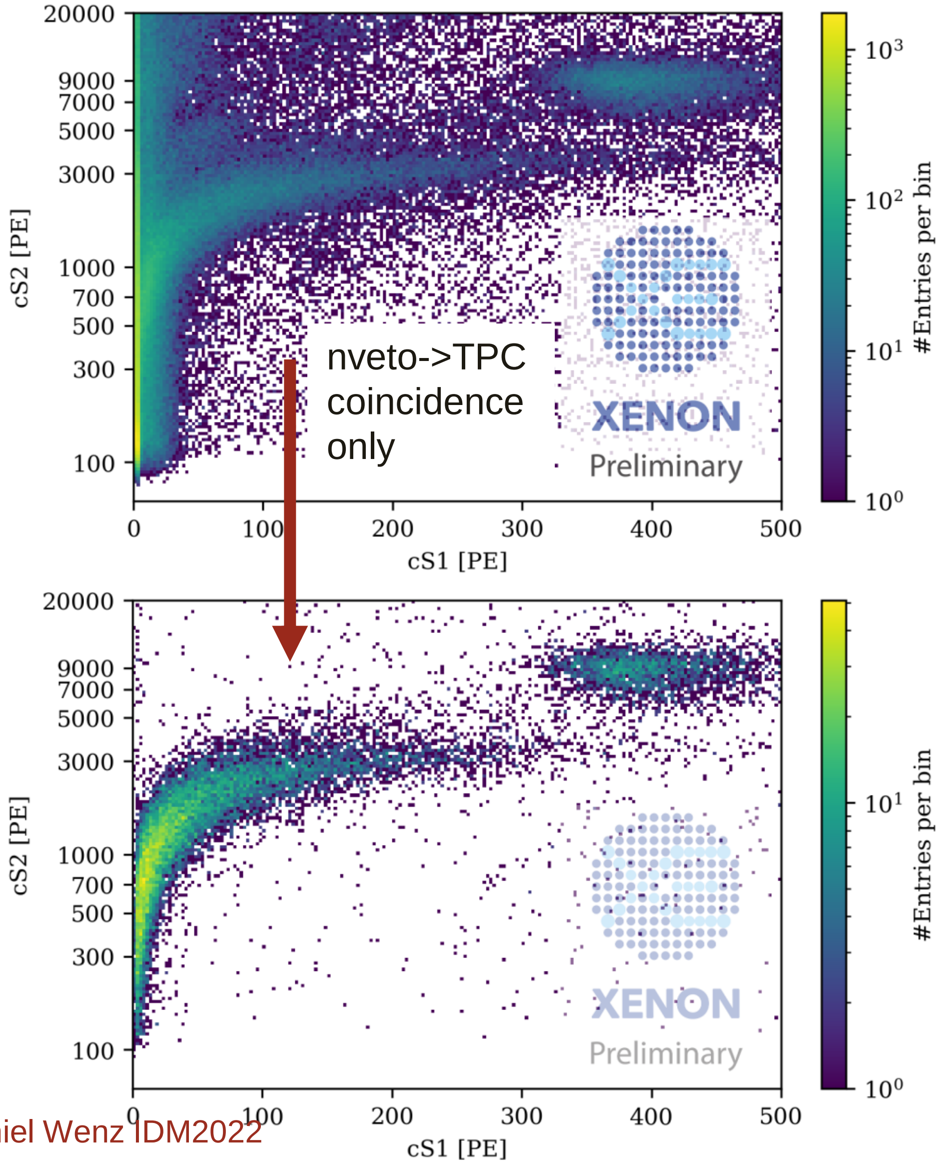
  - AmBe emits in about 50 % (tbd) of all cases a coincident 4.4 MeV gamma
  - Select 4.4 MeV gammas in the neutron-veto and build a coincidence between S1 and neutron-veto
- Tight coincidence window of 408 ns
  - Strong reduction of ER and accidental events background.





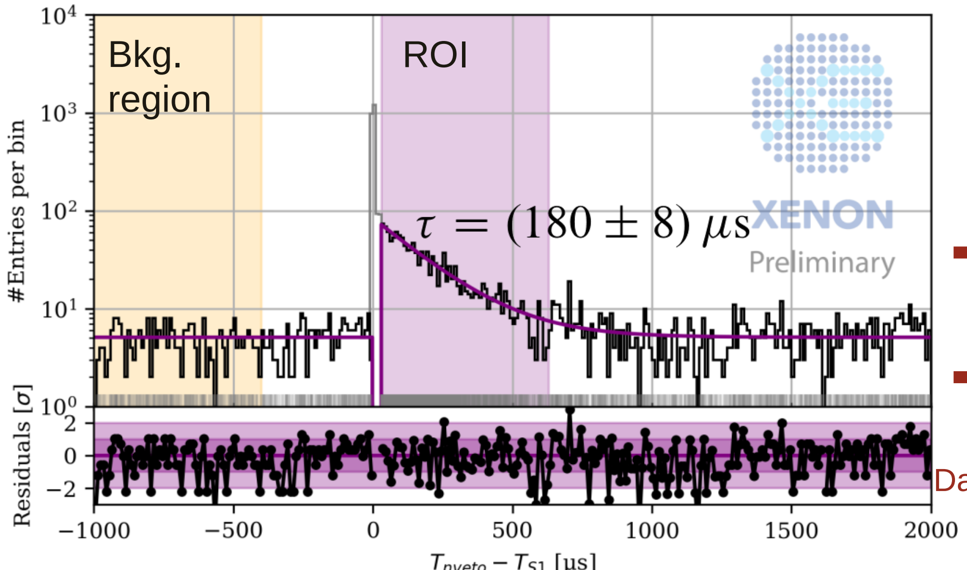
XENONnT NR calibration:

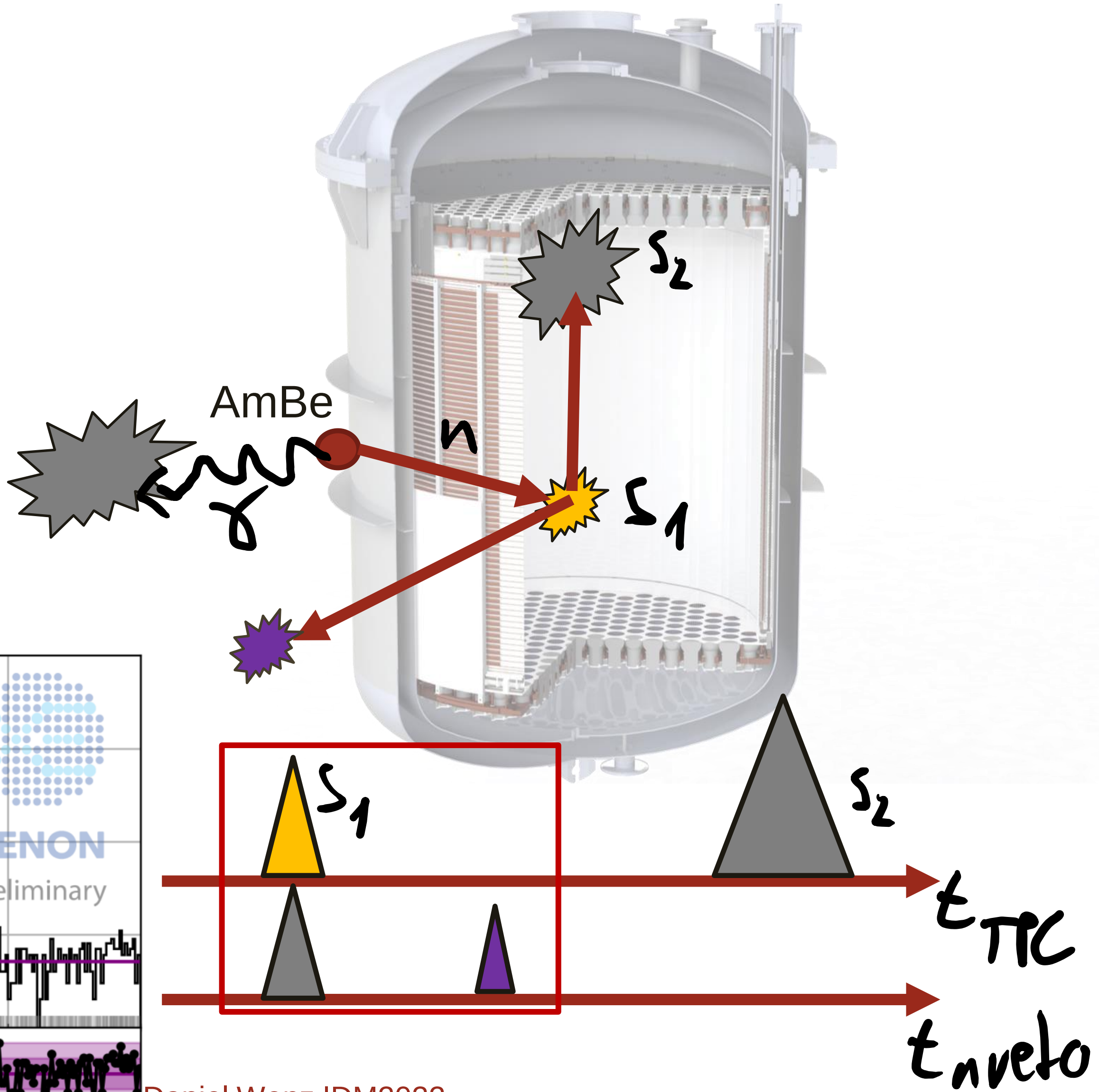
- Strong reduction of accidental coincidences and ER background
- Additional data quality cuts:
  - Cuts against multi-scatter
  - Cuts against wrong S1/S2 pairing
- NR single scatter events to calibrate neutron-veto tagging efficiency



Neutron-veto tagging efficiency:

- Use NR single scatter events as a starting point to calibrate tagging efficiency
- Look for coincidence between TPC and neutron-veto in a large coincidence window
- Define ROI of capture signals and side band background region





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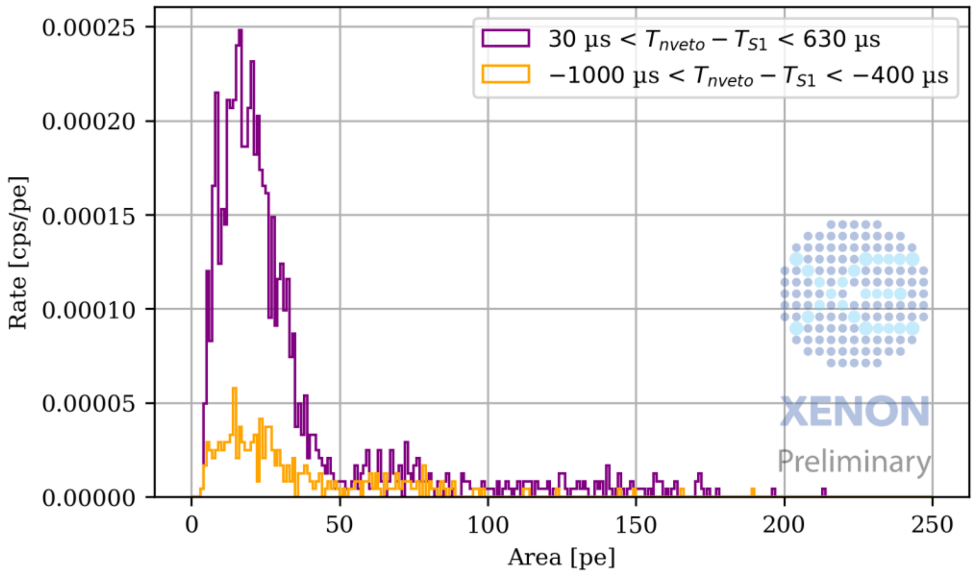
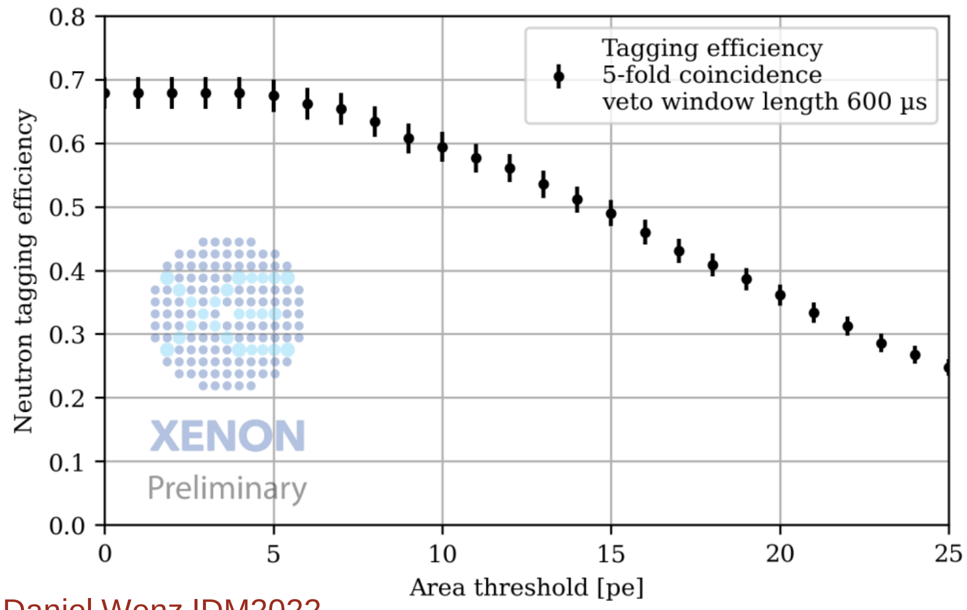
Neutron-veto tagging efficiency:

- Subtraction of bkg region from ROI
- Estimate tagging efficiency for given thresholds:

$\Rightarrow$ $(67.5 \pm 2.9)\ \%$ @ 5-fold coincidence, 5 pe threshold and 600 µs window





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Neutron-veto tagging efficiency:

- Subtraction of bkg region from ROI
- Estimate tagging efficiency for given thresholds:

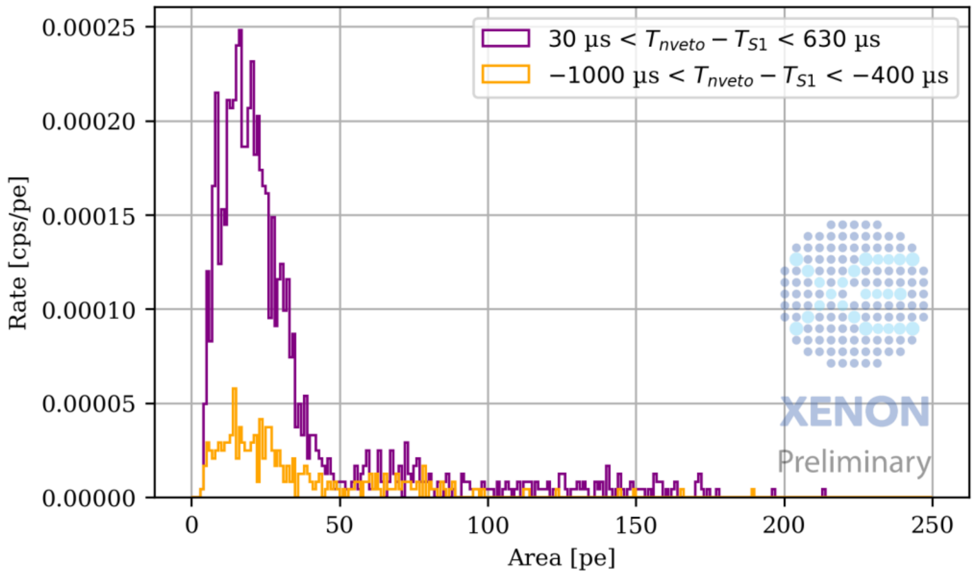
➔ $(67.5 \pm 2.9)\ \%$ @ 5-fold coincidence, 5 pe threshold and 600 µs window

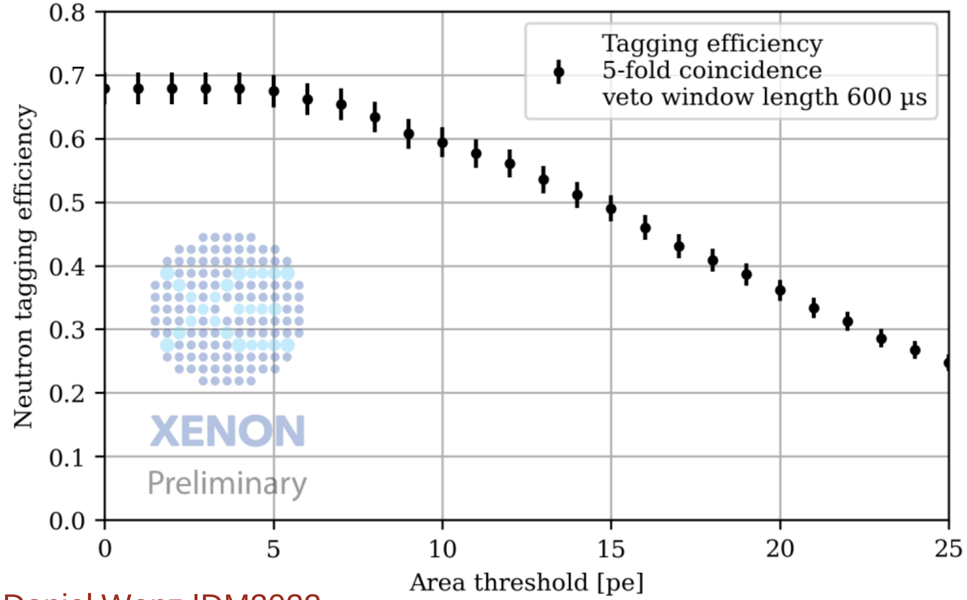
- Can also estimate neutron detection efficiency:

$$\frac{\text{“Number of neutrons detected | selection“}}{\text{“Number of 4.4 MeV gamma detected in the TPC”}}$$

➔ $(80.2 \pm 1.3)\ \%$ @ 5-fold coincidence, 5 pe threshold and 600 µs window

➔ To our knowledge highest detection efficiency ever measured in a water Cherenkov detector.





Conclusion and Outlook:

- Tagged neutrons excellent tool to calibrate NR and neutron-veto
- The XENONnT neutron-veto performs very well even as a pure-water Cherenkov detector.
- Next steps:
  - Study NR band without any S1 threshold
  - Use tagged neutrons to compute cS2-only instead of S2 only in calibrations
  - Use as NR tagged signals to study Migdal effect
  - Load neutron-veto with 0.2 % ($Gd_2(SO_4)_3$ x $8(H_2O)$)
    - 10 PMTs at 0.5 PE threshold, within 150 µs

→ Tagging efficiency: 87 %

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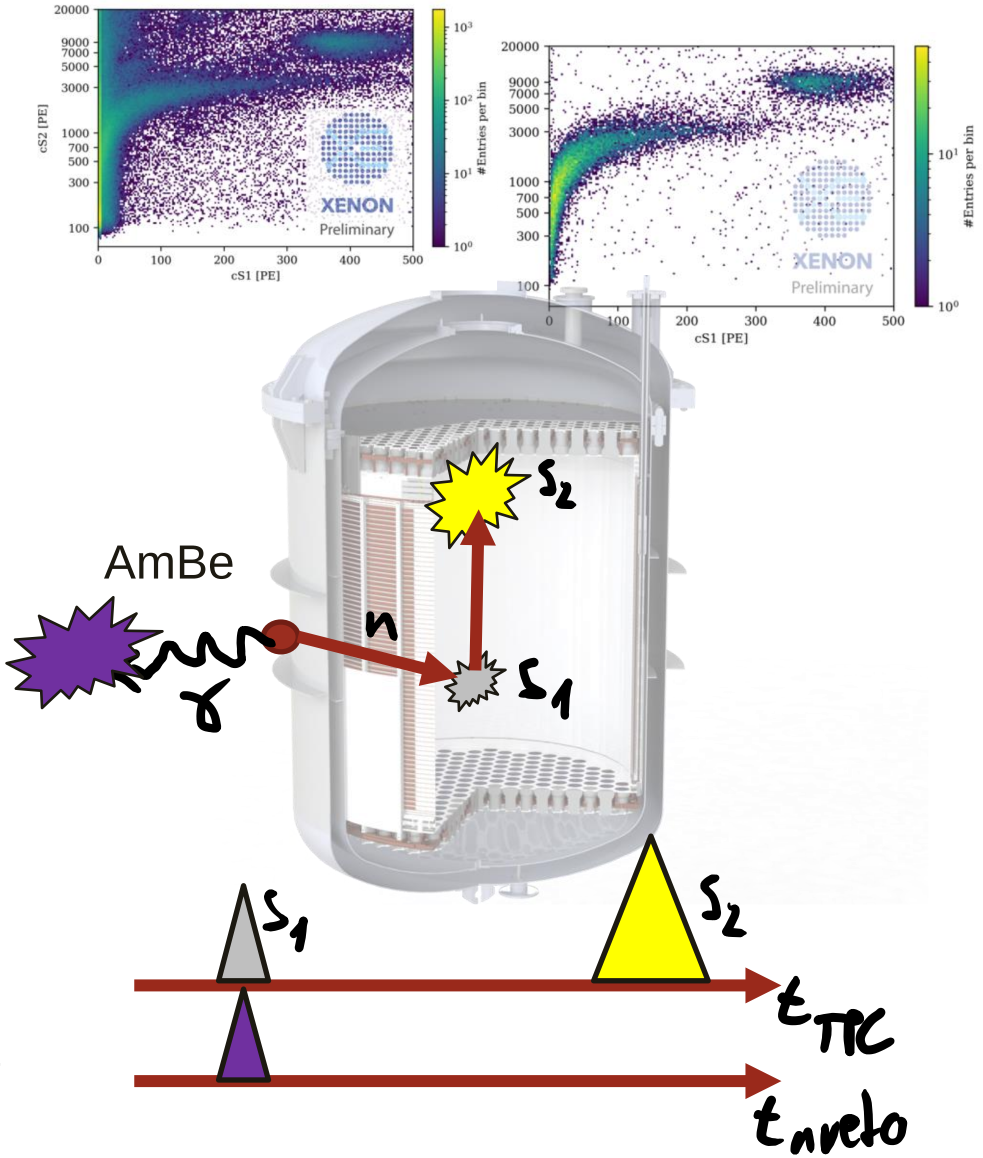


Back-up slides:

Neutron-veto detection efficiency:

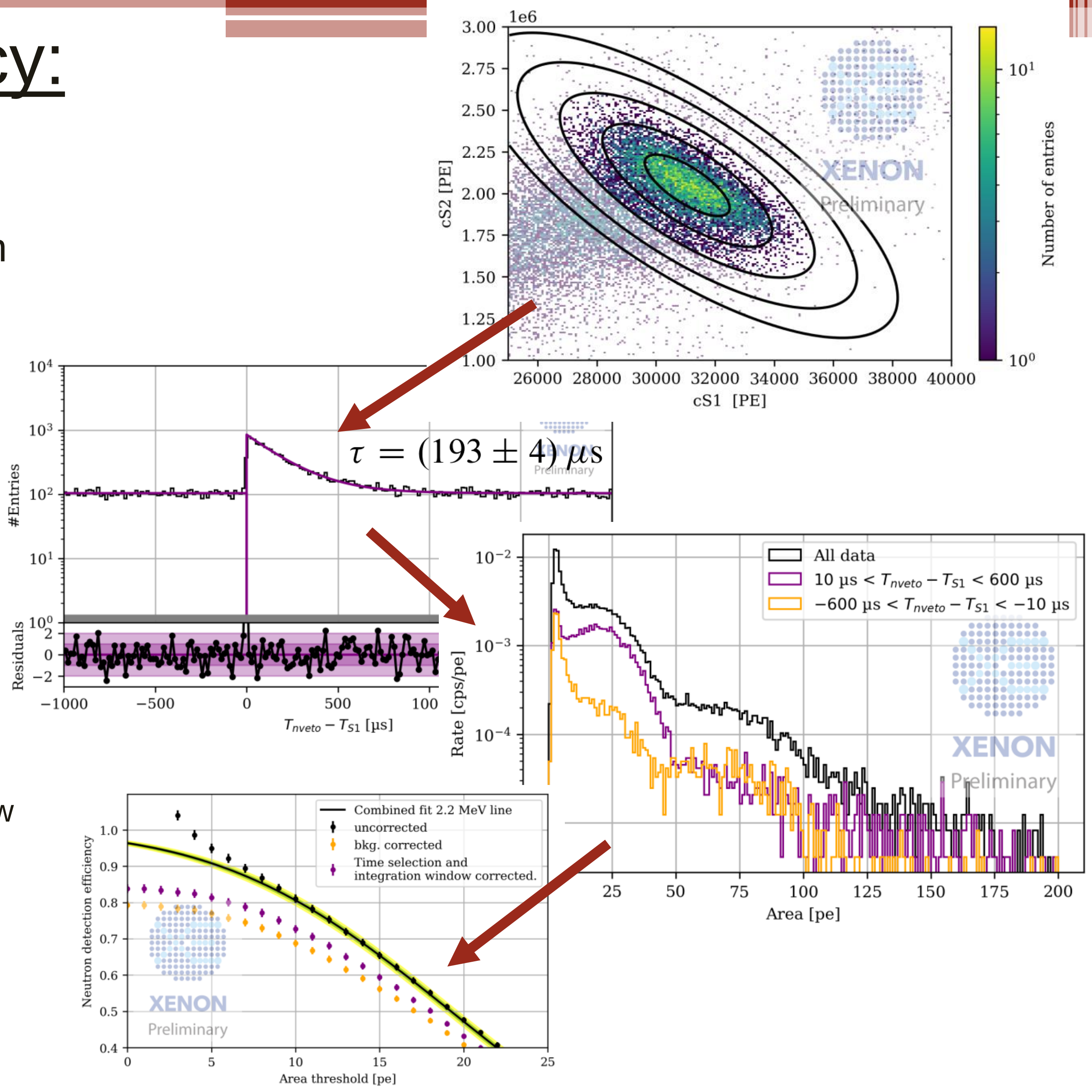
- Detection efficiency:
  - Chance to detect a neutron in the nveto given the number of 4.4 MeV gammas detected in the TPC

- Same analysis strategy as for the neutron-tagging efficiency:

- Estimated detection efficiency to be:

$$(80.2 \pm 1.3)\ \%$$ @ 5-fold coincidence, 5 pe threshold and 600 µs window

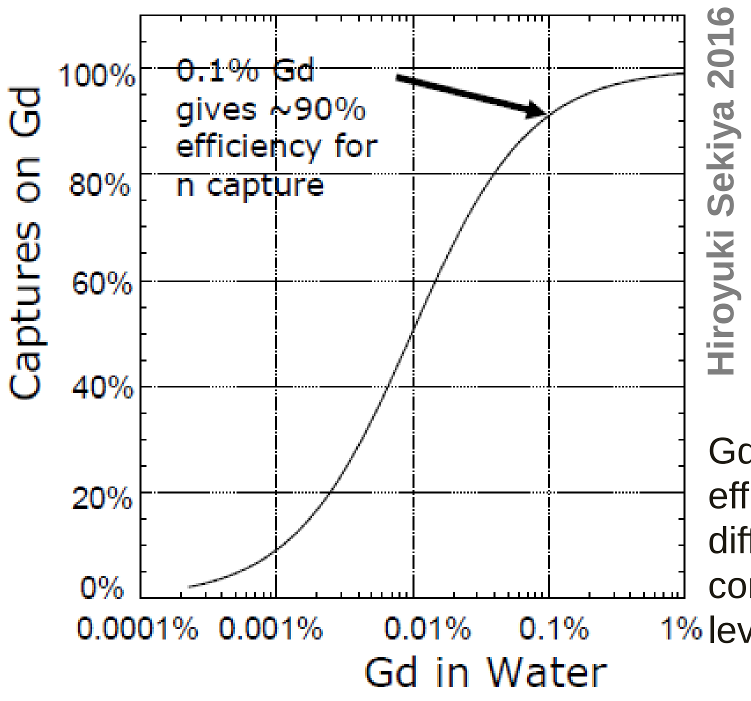
➡ To our knowledge highest detection efficiency ever measured in a water Cherenkov detector.



Why ($Gd_2(SO_4)_3$ x 8(H_2O)) ?:

- 0.2 % Gd-concentration (by weights)
  - 3.4 tons of Gadolinium-sulfate-octahydrate ($Gd_2(SO_4)_3$ x 8(H_2O)) in 740 t water
  - Neutron capture efficiency of > 90 %

	H-capture:	Gd-capture:
Capture-Crosssection σ	0.333 b	~49 kb
De-excitation energy	2.2 MeV	~8 MeV



Gd-capture efficiency for different concentration levels

- Simulation of tagging efficiency and background :
  - 10 PMTs at 0.5 PE threshold, within 150 μs

Tagging efficiency: 87%

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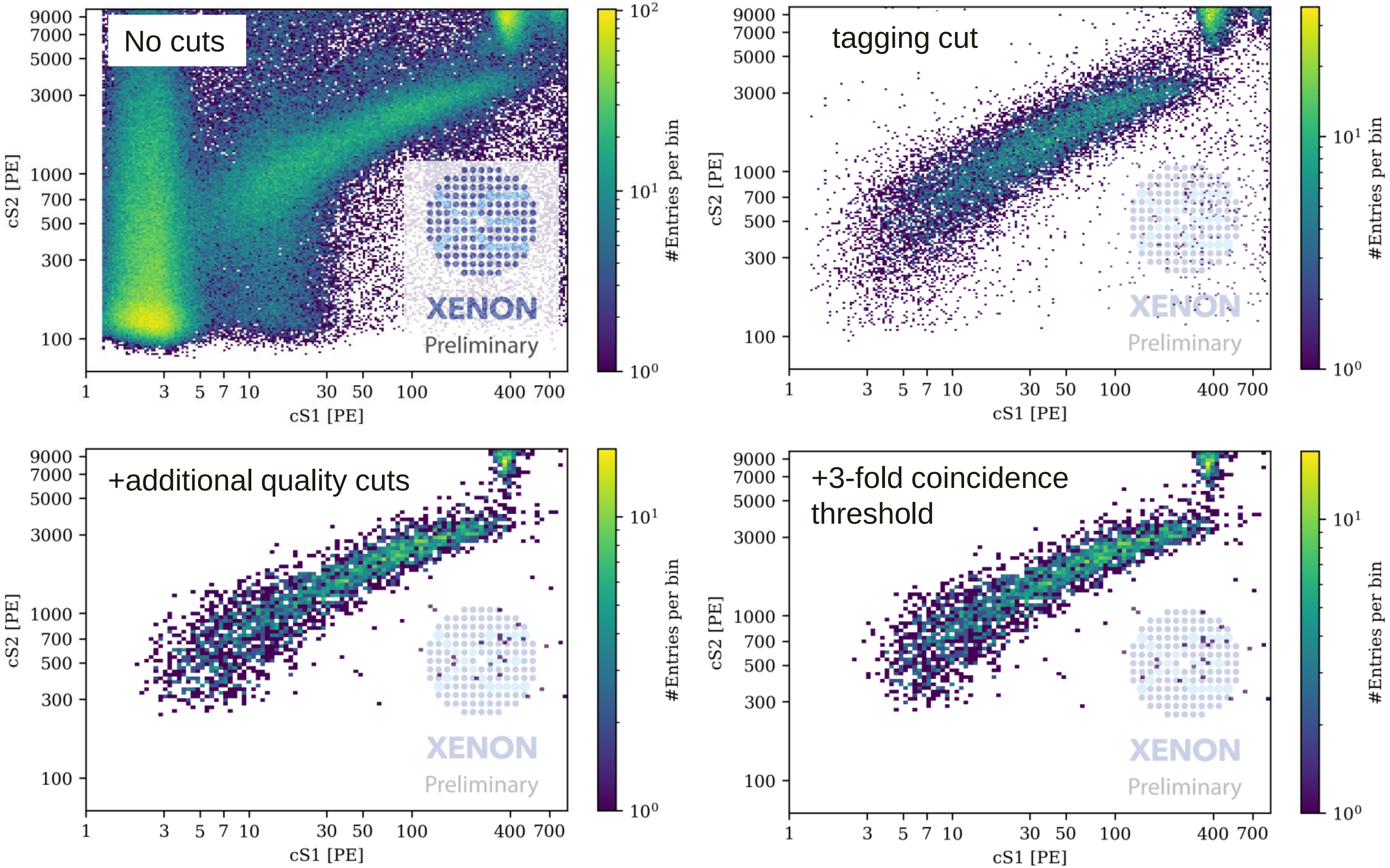
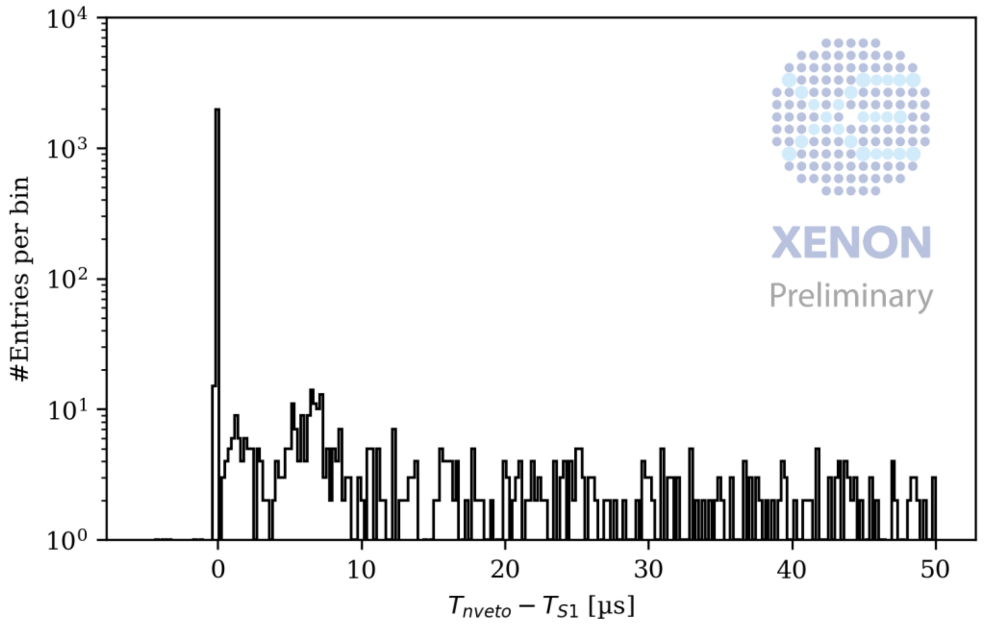
NR band applying all cuts:



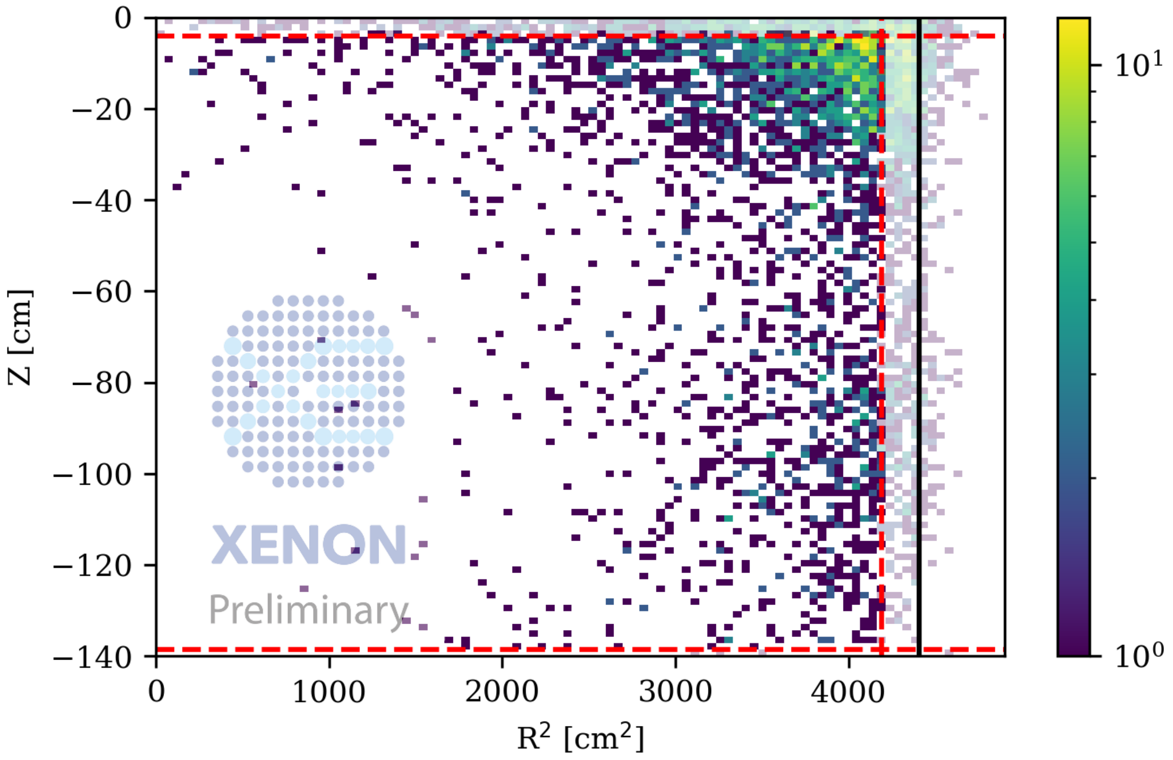
Neutron-veto gamma-peak:

- A region between -1 µs and 30 µs was excluded from the time distribution fit of the neutron-veto tagging
  - Contamination from the 4.4 MeV gamma in the neutron-veto
  - Higher chance to find accidental events due to PMT afterpulses



Spatial distribution AmBe calibration:

- AmBe data taking at different positions around the cryostat
- Localization of the calibration data due to some technical issues and issues with the DAQ during calibration.
  - Improvement is expected during SR1



Spatial distribution of the AmBe NR calibration events. Shaded events are outside of the fiducial volume used during calibration.