XENONnT & DARWIN / XLZD
Supernova Neutrino Detection Sensitivities

SNvD@LNGS
L'Aquila *29/05/2023*

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XENON Collaboration

180 scientists, 27 institutions, 11 countries

Columbia

KIT

Nikhef

Muenster

Stockholm

Mainz

MPIK, Heidelberg

Freiburg

Zurich

Chicago

Tsinghua

UCSD

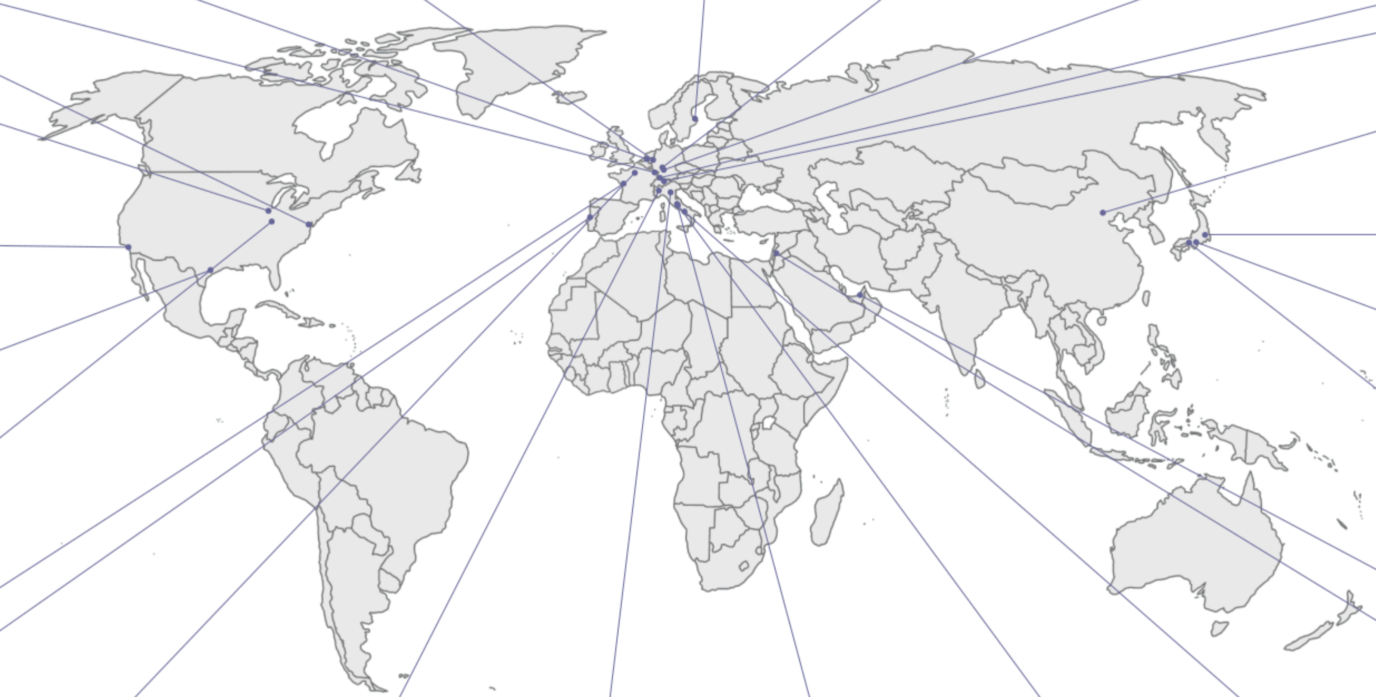
Tokyo

Rice

Nagoya

Purdue

Kobe



Subatech

Coimbra

LPNHE

Torino

Bologna

L'Aquila

LNGS

Napoli

Weizmann

NYUAD

XENON10

~ 10^{-43} cm^2

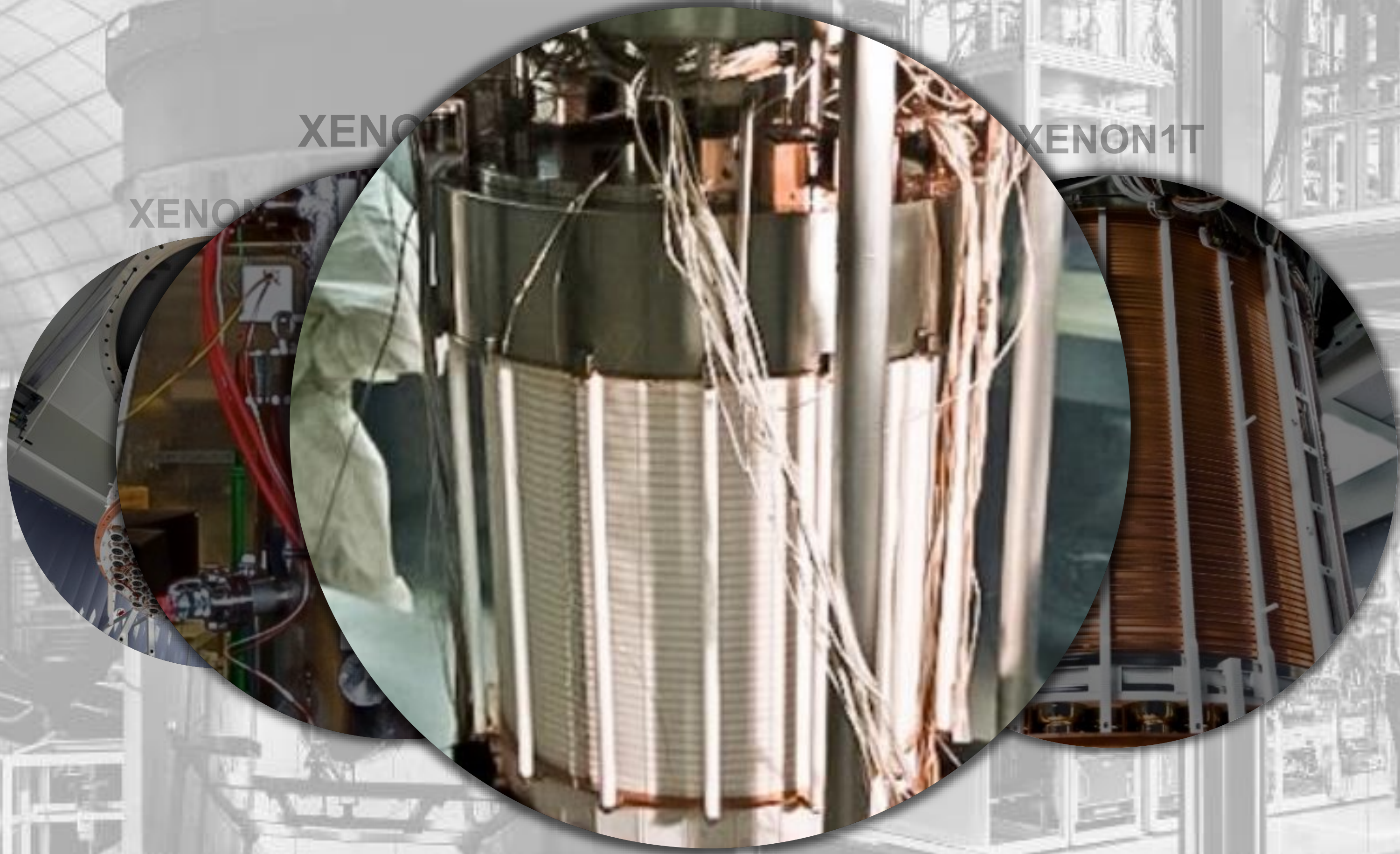
14 kg
Xe

~ 2M background
ER/(keV t yr)

2005-2007

Phys. Rev. Lett. **100**, 021303

XENON100



~ 10^{-45} cm^2

62 kg Xe

~ 1800 background ER/(keV t yr)

2008-2016

Phys. Rev. Lett. 105, 131302
Astropart. Phys. 35, 573-590 (2012)

XENON1T

2t Xe

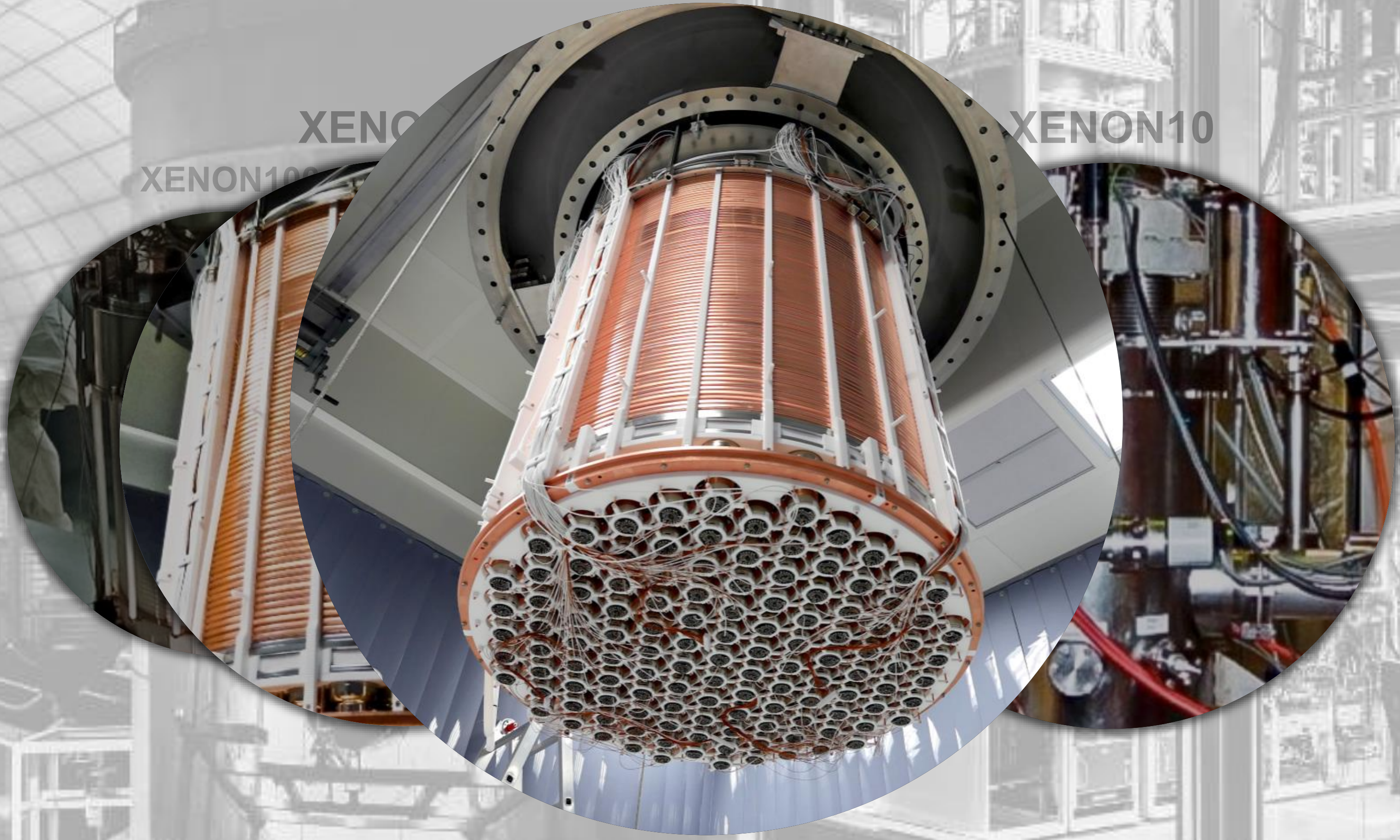
~ 4x10^{-47} cm^2

~ 82 background ER/(keV t yr)

2012-2018

Phys. Rev. Lett. 121, 111302
Phys. Rev. D 102, 072004

XENONnT



5.9 t Xe
(8.5t total)

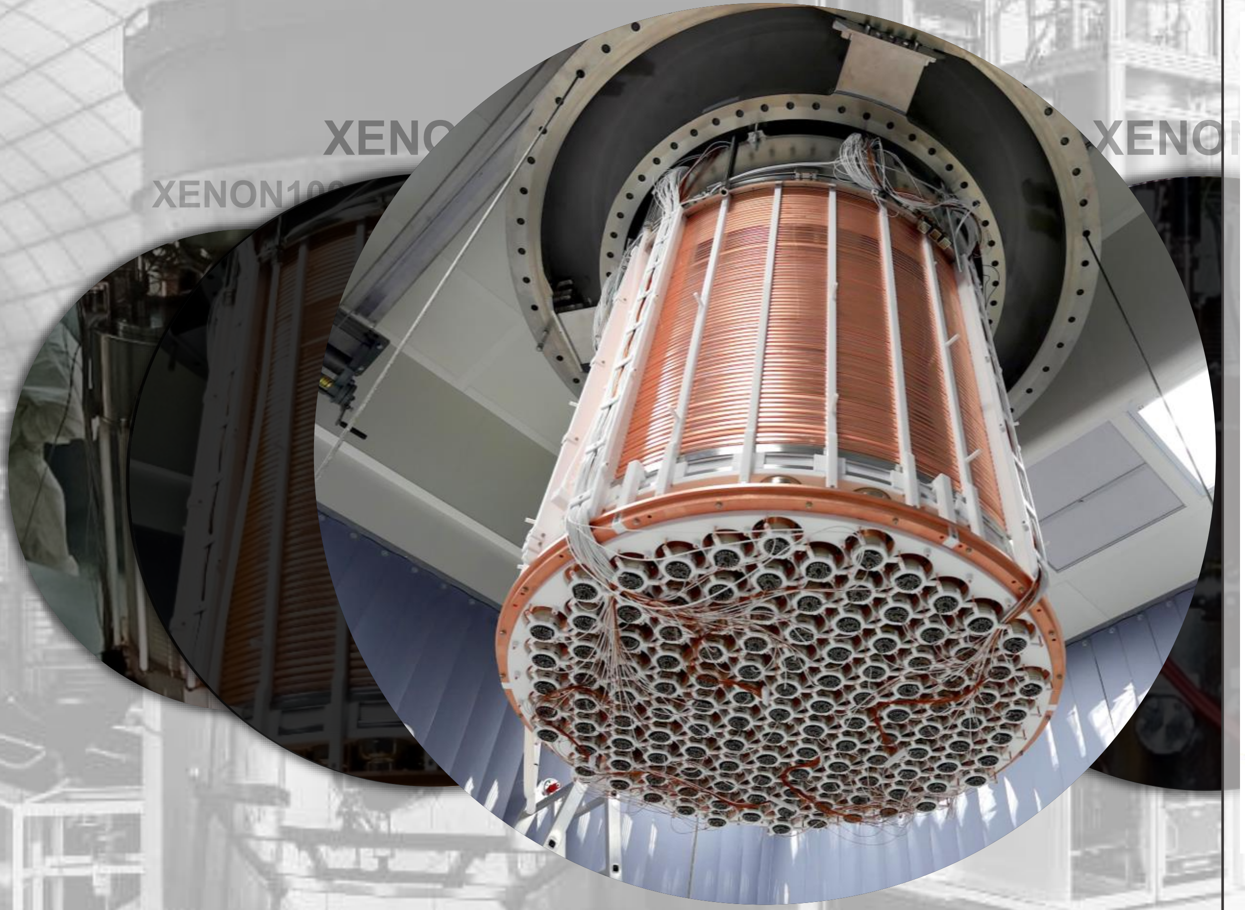
~ 1.4×10^{-48} cm^2
(projected for 20 t yr)

~ 16.1 background
ER/(keV t yr)

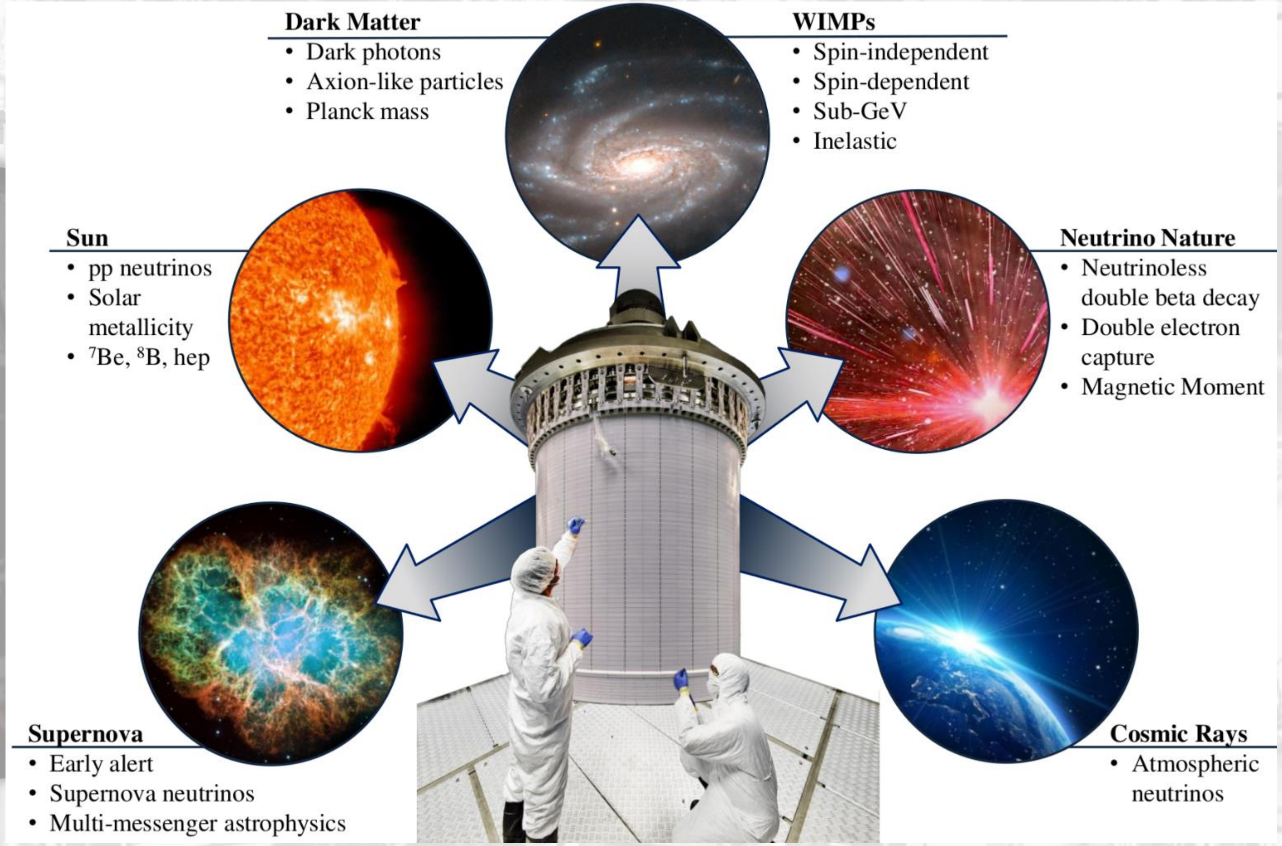
2019 -

arXiv:2303.14729 [hep-ex]

XENONnT



The future: DARWIN / XLZD

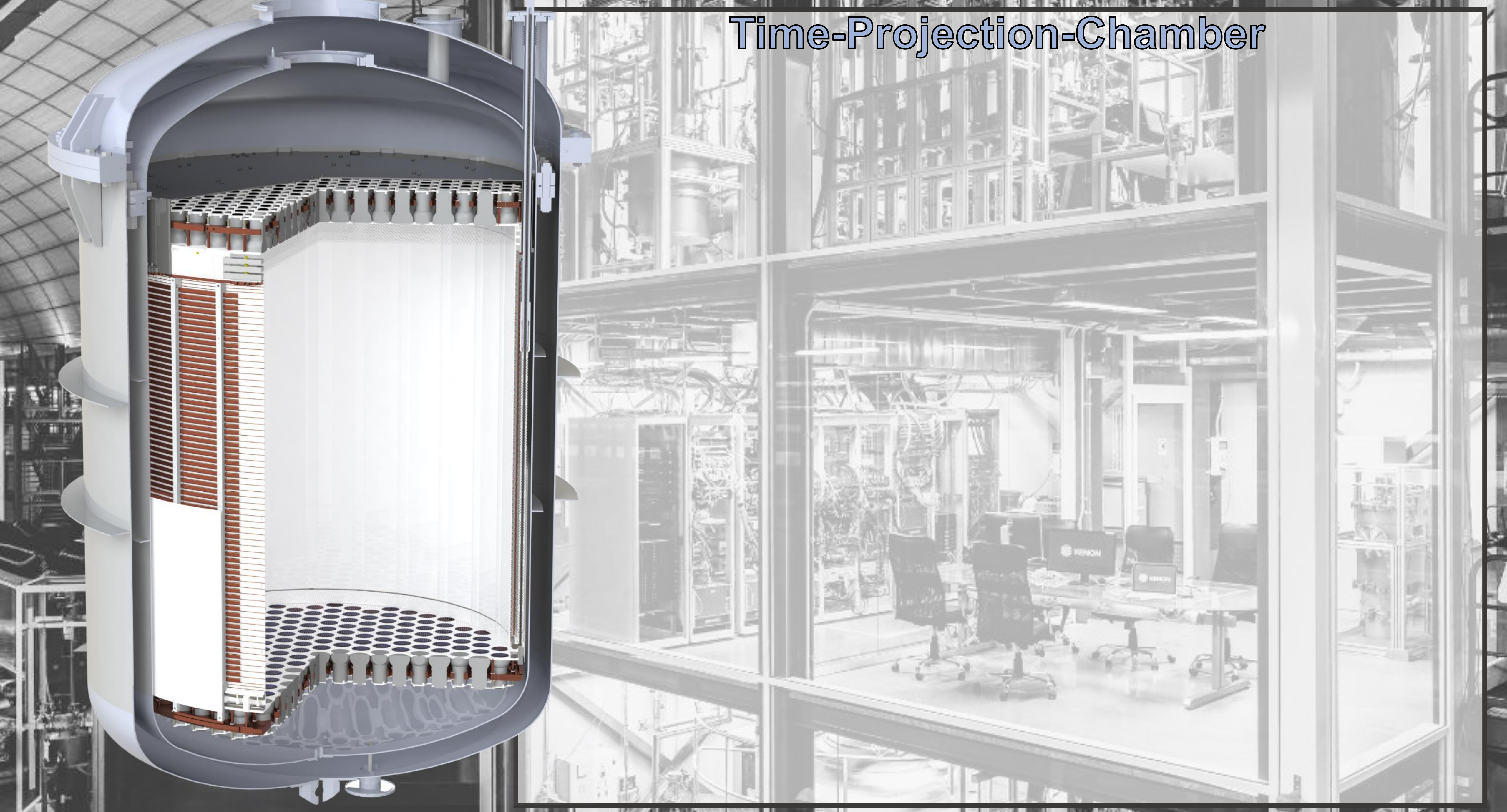


Ultimate WIMP detector
40 t Xe target, 2.6 m diameter 1:1
Multi-purpose rare-event search

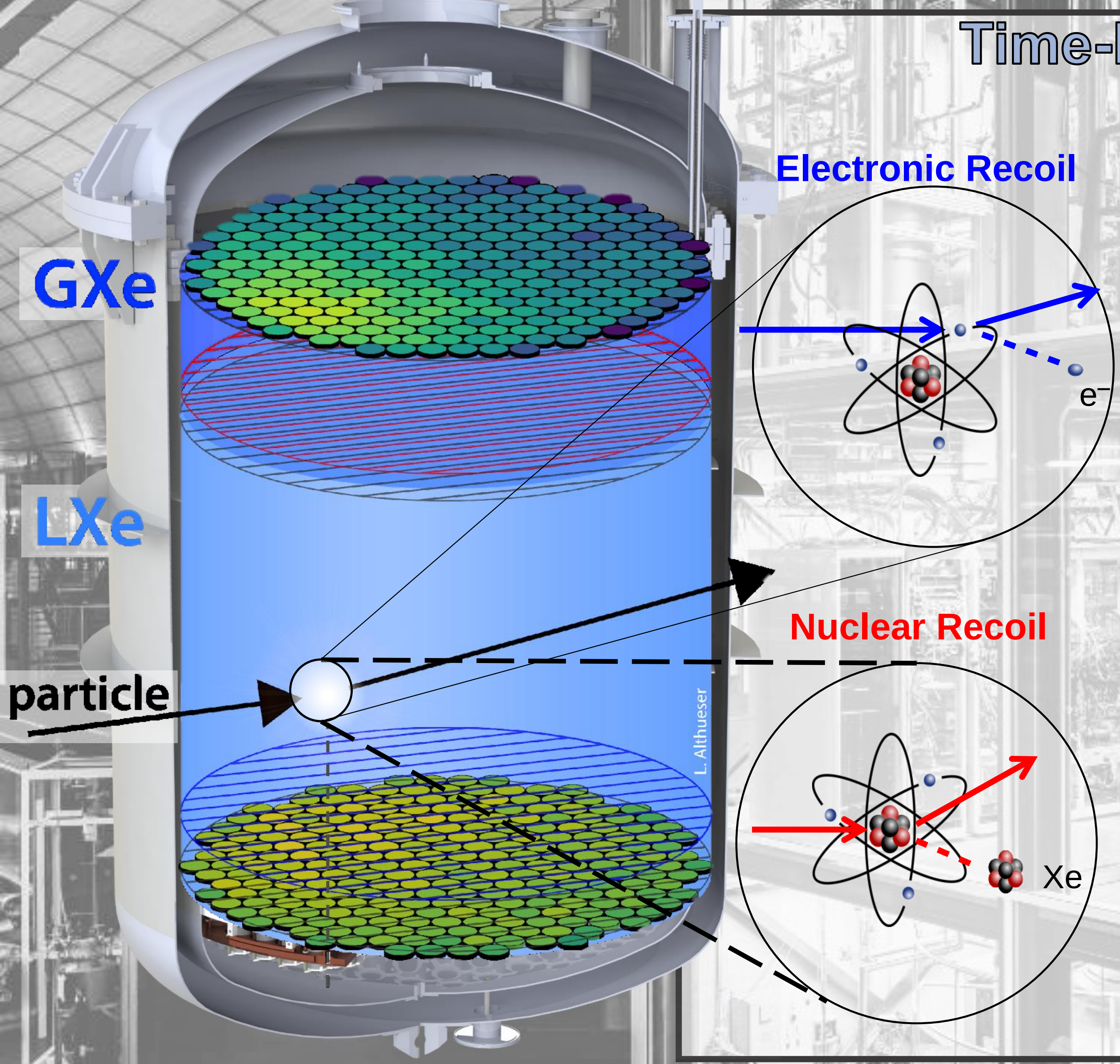
JCAP 11, 017 (2016), J Aalbers et al 2023 J. Phys. G: Nucl. Part. Phys. 50 013001


XENON
Matter Project
UC San Diego
Rensselaer
XENON
XENON

Time-Projection-Chamber

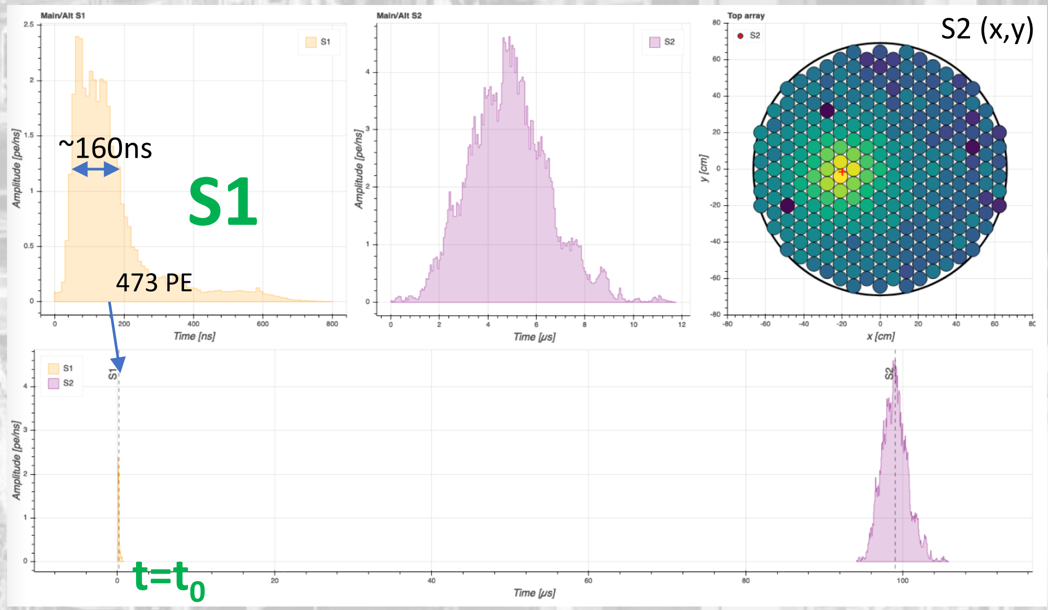


Time-Projection-Chamber



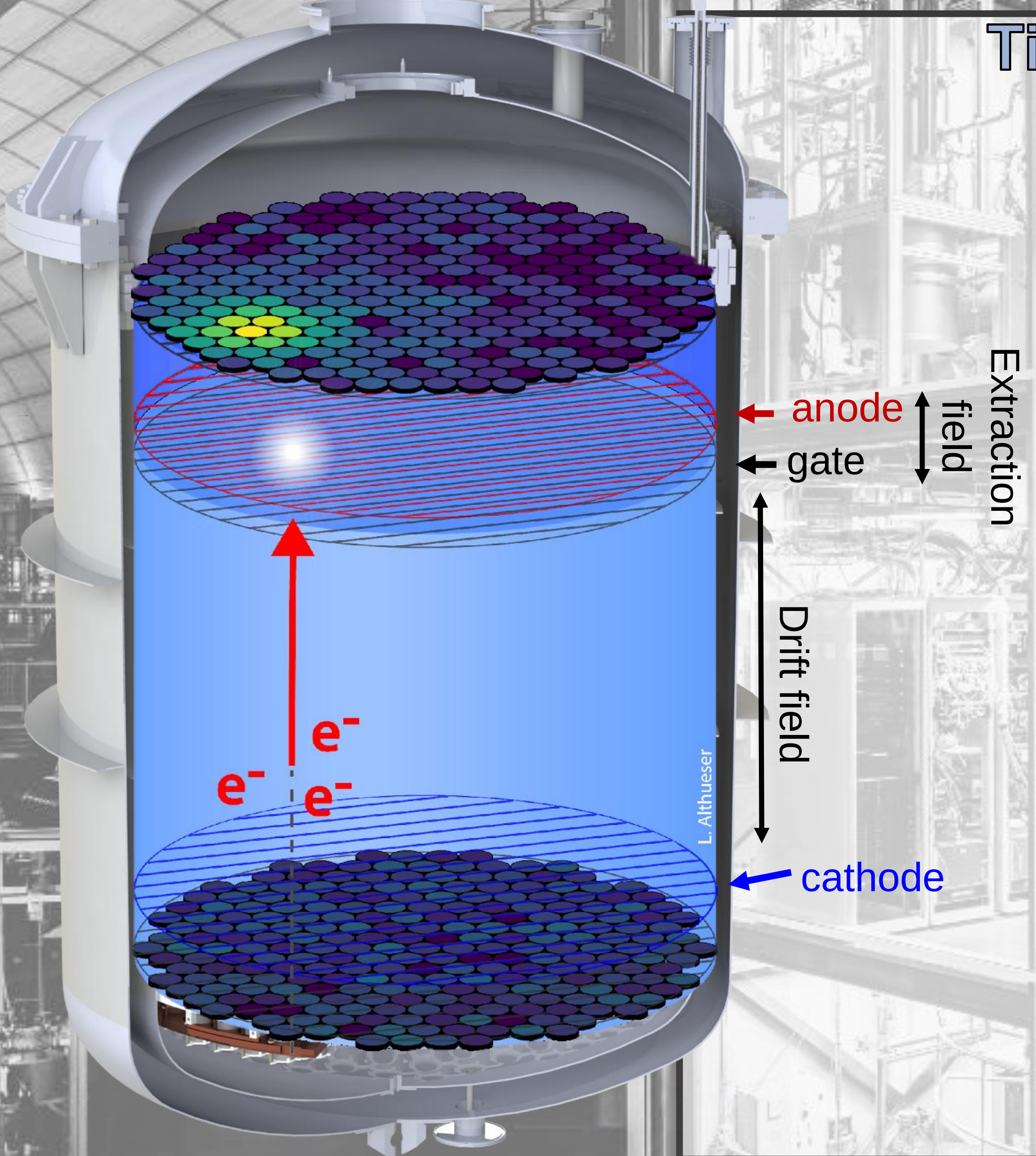
ER: Beta, gamma, neutrinos

NR: WIMPs, neutrons, neutrinos (CEvNS)



Prompt scintillation signal in LXe: S1

Time-Projection-Chamber



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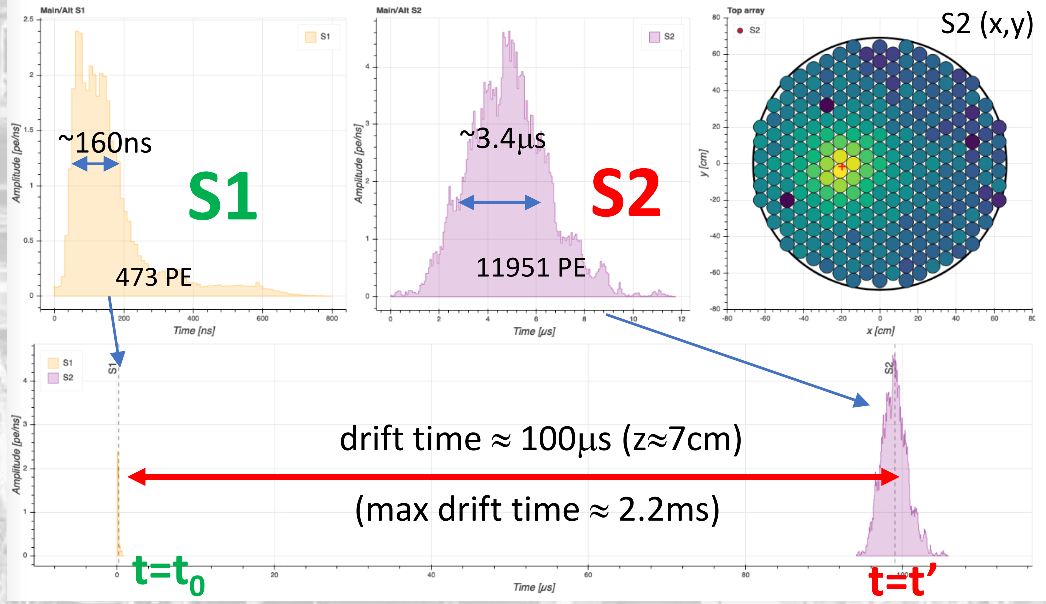


Prompt scintillation signal in LXe: S1

Proportional scintillation signal in GXe: S2

S1 Peak + S2 Peak → signal event

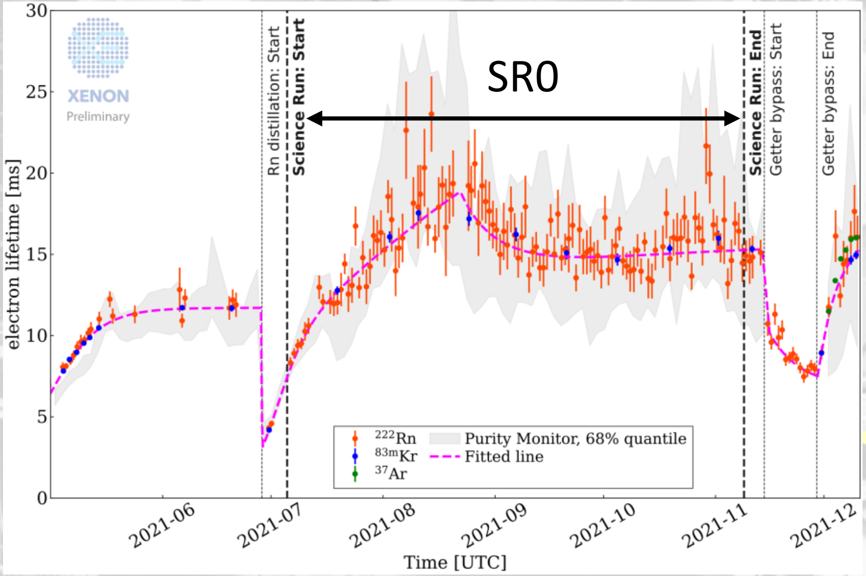
Nuclear recoil vs electronic recoil discrimination Based on S2/S1 ratio

LXe & GXe Purification

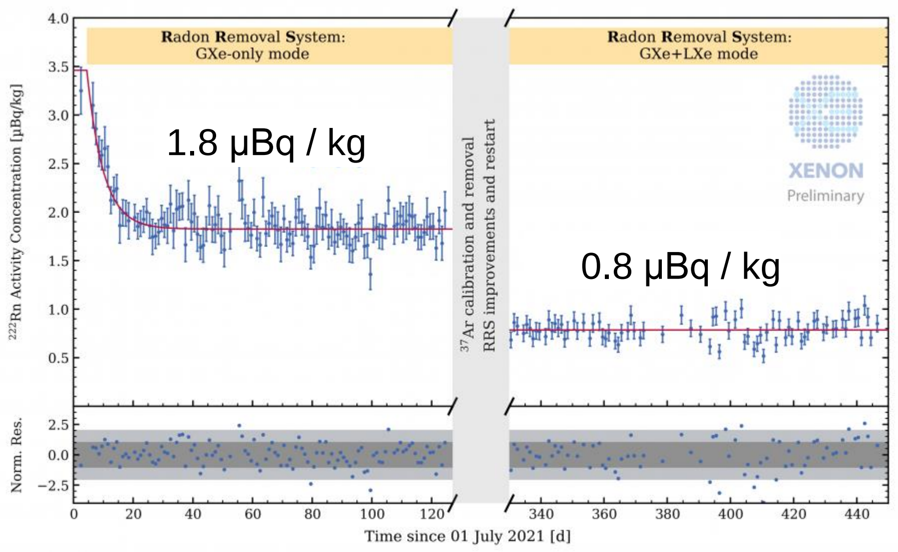
High purity, low intrinsic background

Full length electron drift time: **2.2 ms**
Electron lifetime: **15 ms**
Electron survival at full drift length: **86 %**

Background from intrinsic radioactive isotopes:
^{214}Pb (^{222}Rn daughter)
^{85}Kr
1.8 µBq/kg using **GXe-only** mode
0.8 µBq/kg using **GXe + LXe** mode

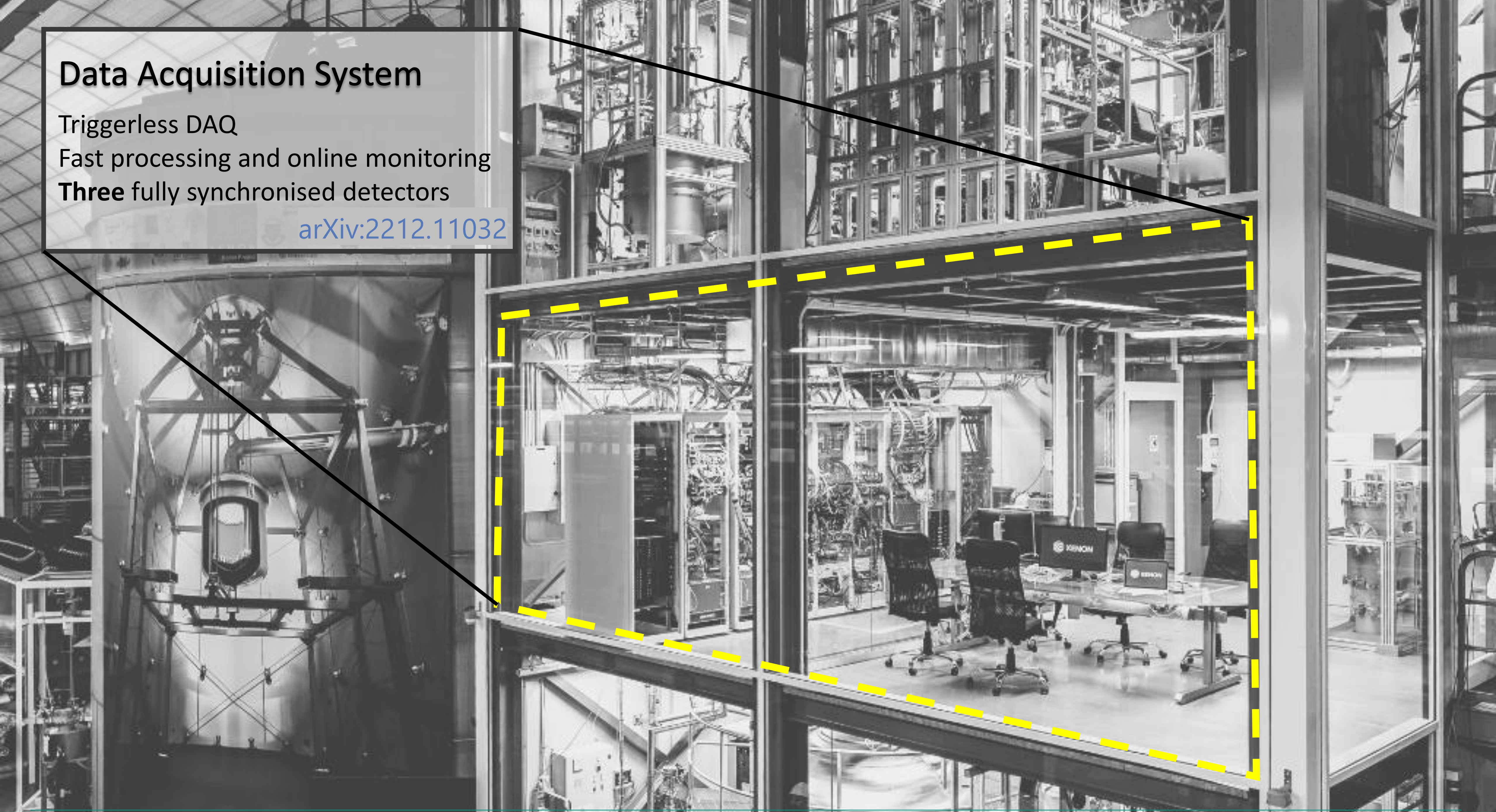


Distillation Radon & Krypton



Eur. Phys. J. C 82, 860 (2022)

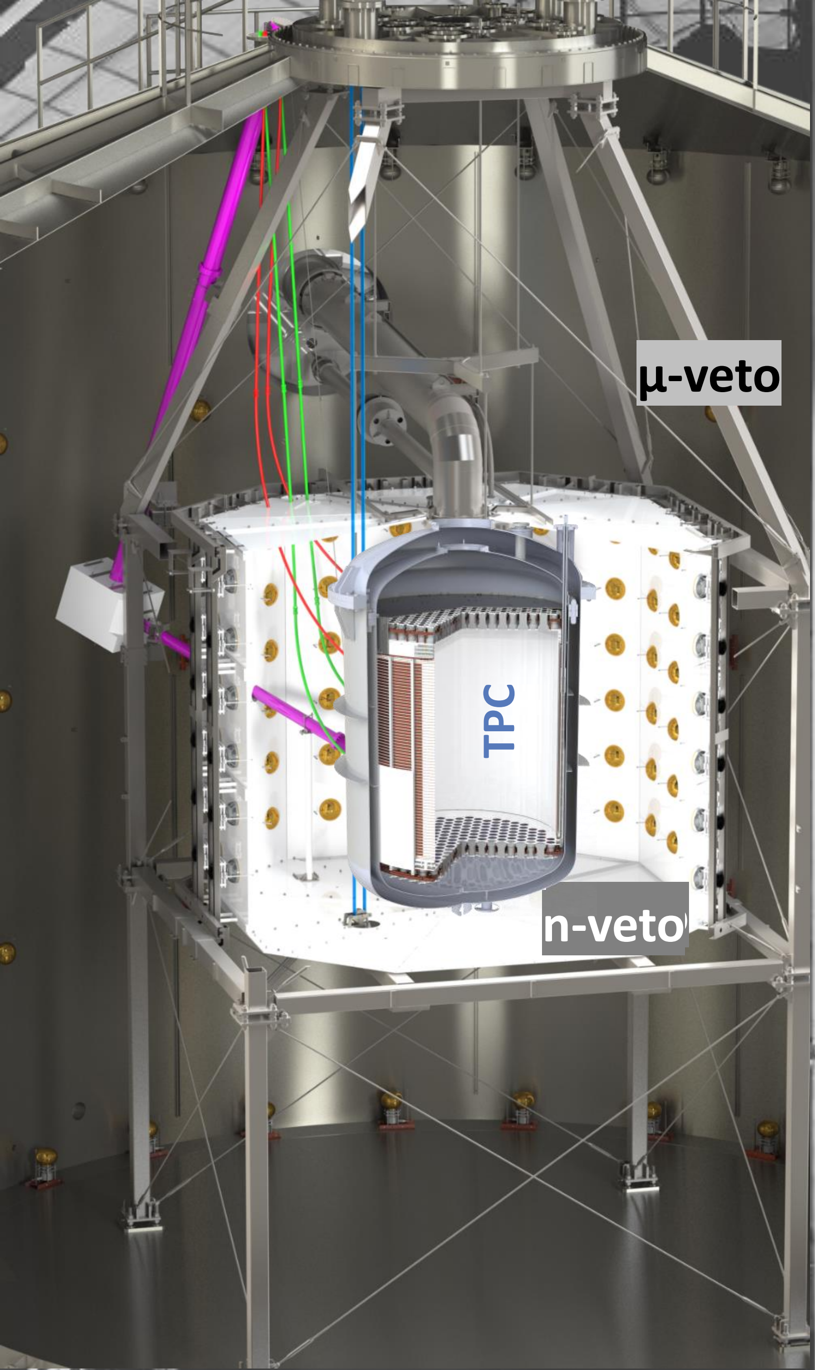
Eur. Phys. J. C 82, 1104 (2022)



Data Acquisition System

Triggerless DAQ
Fast processing and online monitoring
Three fully synchronised detectors

arXiv:2212.11032



Veto Systems: Cherenkov Detectors

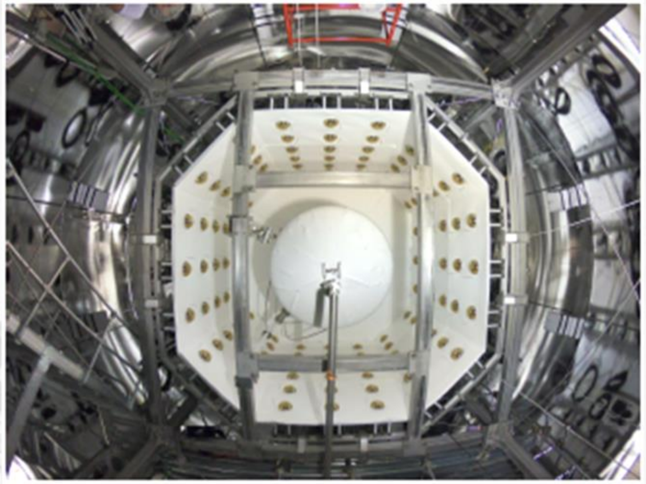
700 t water tank

84 (120) PMTs in nVETO (μVETO)

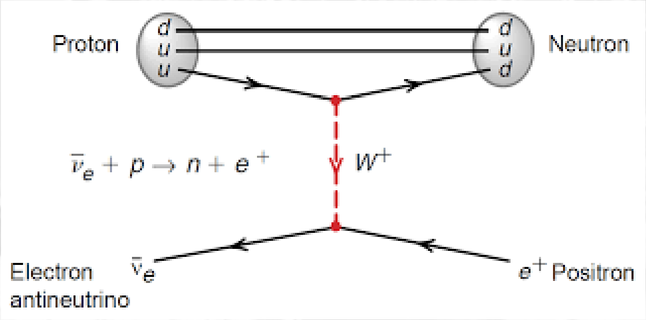
n-veto

Highly reflective ePTFE and ultra-pure water to maximize light-collection efficiency

Tag neutrons through the neutron-capture on hydrogen which releases a 2.22 MeV γ-ray



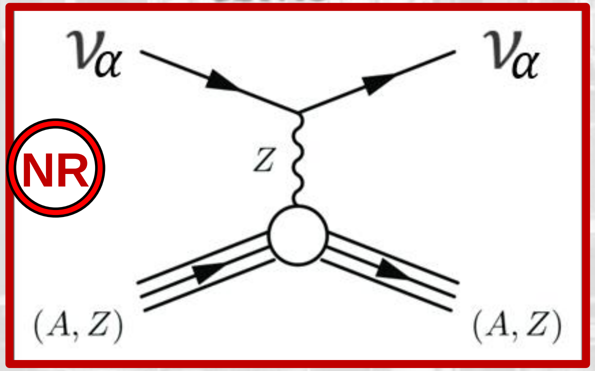
Supernova Neutrino Detection through inverse-beta decay channel



Initial studies indicate that From a supernova @10 kpc ~70-200 events are expected

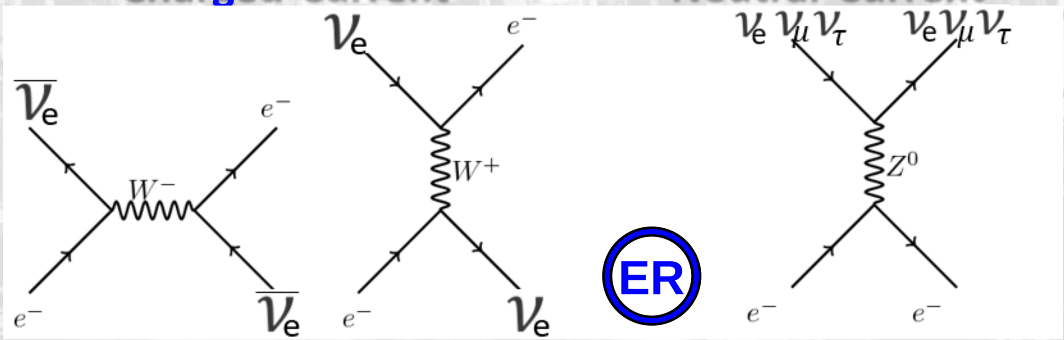
Neutrino channels in dual phase TPCs

CEvNS



Charged-Current

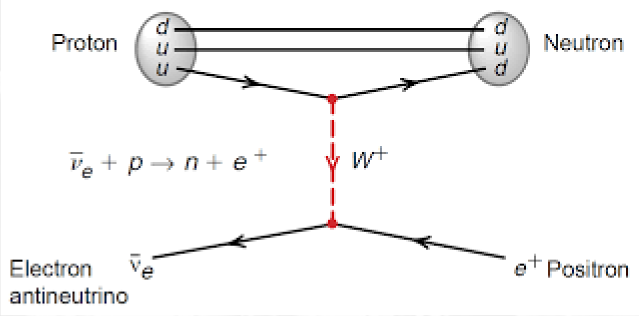
Neutral-Current



Sub-dominant for SN neutrinos

At low energies, scattering cross-section is ***coherently*** enhanced by the square of the nucleus's neutron number

Inverse Beta Decay



Inside the veto volume
Cherenkov Detectors
Initial studies indicate that @10 kpc ~70-200 events are expected. Work in progress.

Phys.Rev.D 94 (2016) 10, 103009
Ann. Rev. Nucl. Part. Sci. 27, 167 (1977)

CEvNS: Coherent Elastic Neutrino-Nucleus Scattering

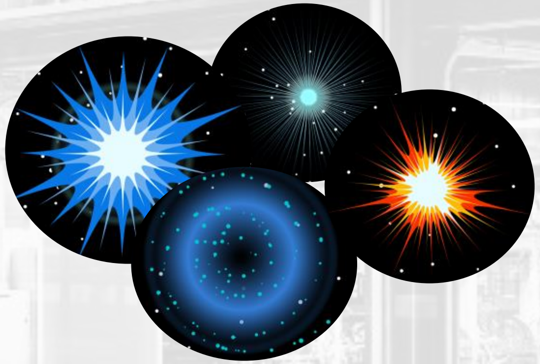
GitHub

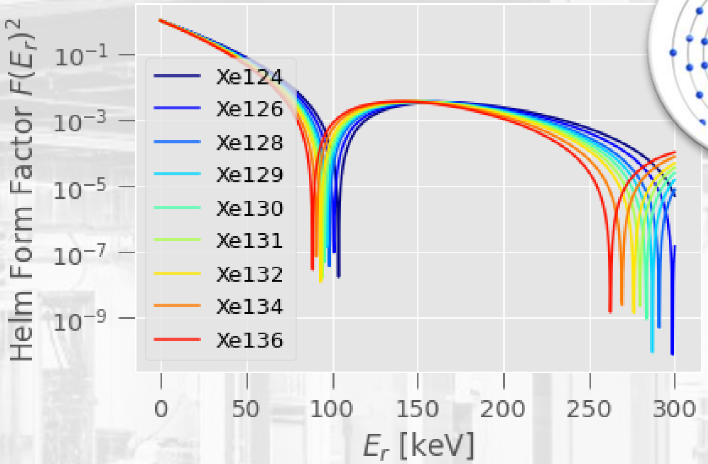
SNAX

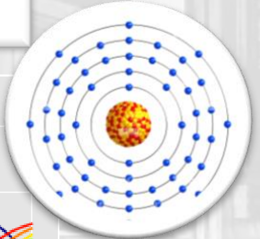
Differential CEvNS rates

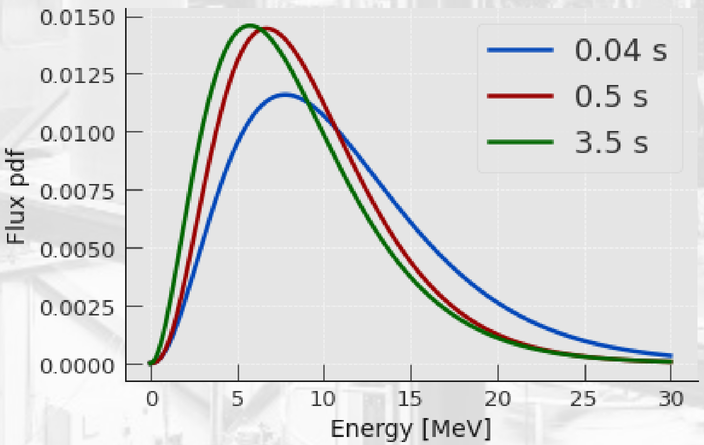
$$\frac{d^2R}{dE_R\,dt_{pb}} = \sum_{\nu_\beta} N_{Xe} \int_{E^\nu_{min}} dE_\nu \, f_\nu(E_\nu, t, d) \, \frac{d\sigma}{dE_R}(E_\nu, E_r)$$

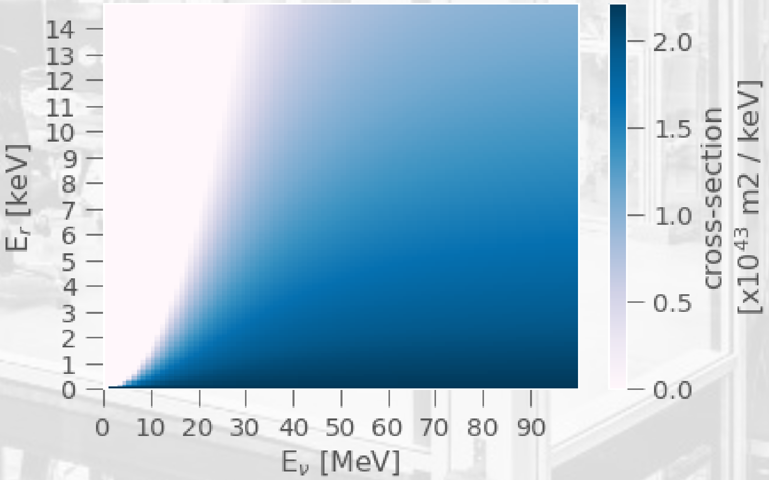
SNEWPY, Astrophys.J. 925 (2022) 2











CEvNS: Coherent Elastic Neutrino-Nucleus Scattering

GitHub
SNAX

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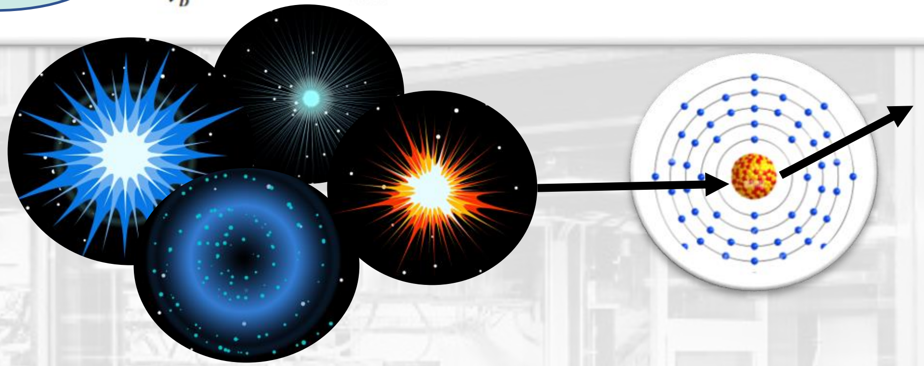
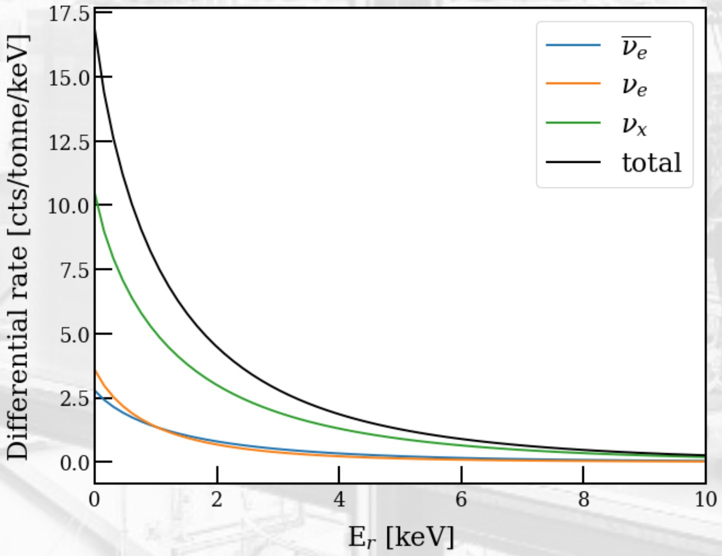
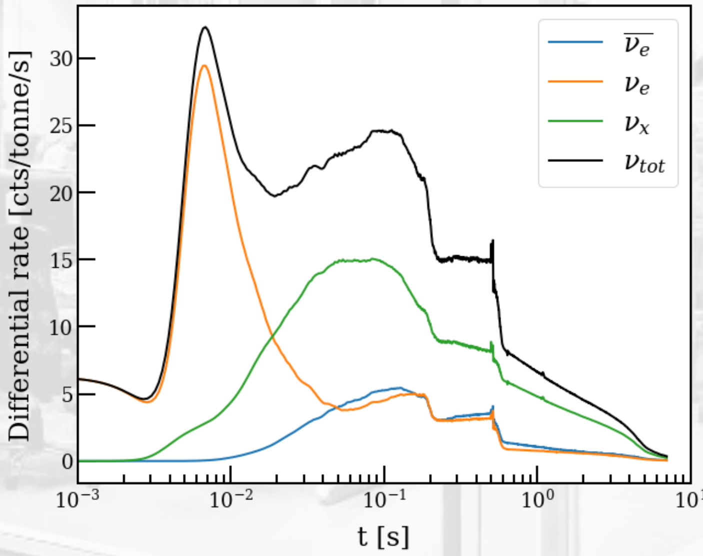
$$\frac{d^2 R}{dE_R\, dt_{pb}} = \sum_{\nu_\beta} N_{Xe} \int_{E^{\nu}_{min}} dE_\nu\, f_\nu(E_\nu, t, d)\, \frac{d\sigma}{dE_R}(E_\nu, E_r)$$



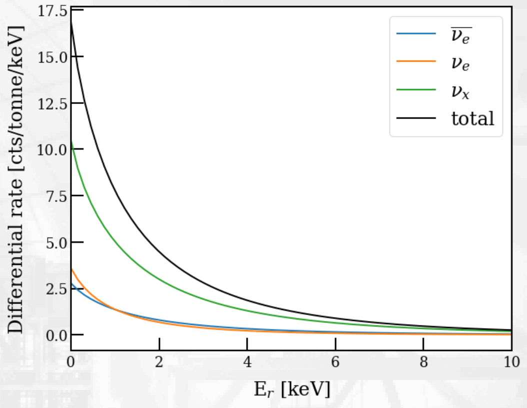


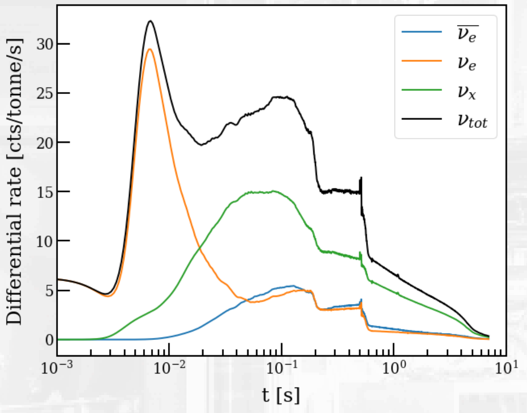


@10 kpc ~100 interactions

Differential CEνNS rates

$$\frac{d^2R}{dE_R dt_{pb}} = \sum_{\nu_\beta} N_{Xe} \int_{E^{\nu}_{min}} dE_\nu \, f_\nu(E_\nu, t, d) \, \frac{d\sigma}{dE_R}(E_\nu, E_r)$$

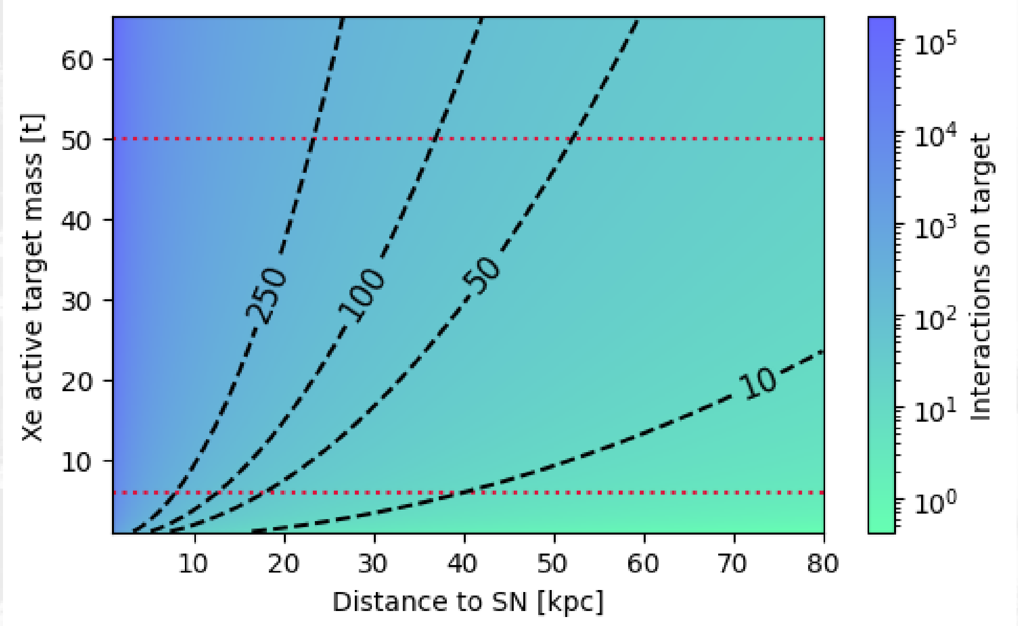


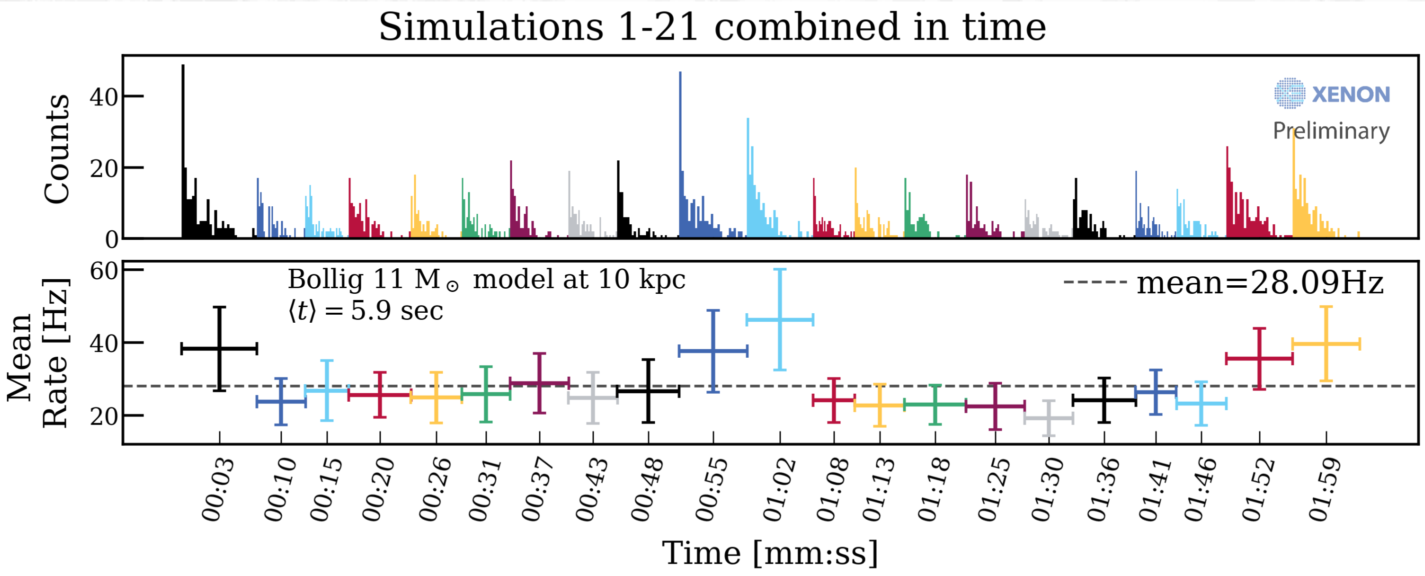


Expected number of Interactions vs "Detectable Signal"

$$\frac{d^2R}{dE_R dt_{pb}}$$

Differential interaction rate gives the total rates of expected interactions with *any* possible recoil energy.





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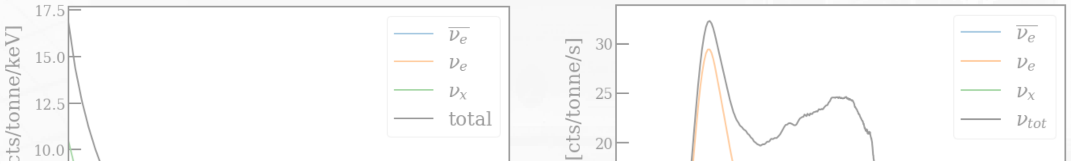
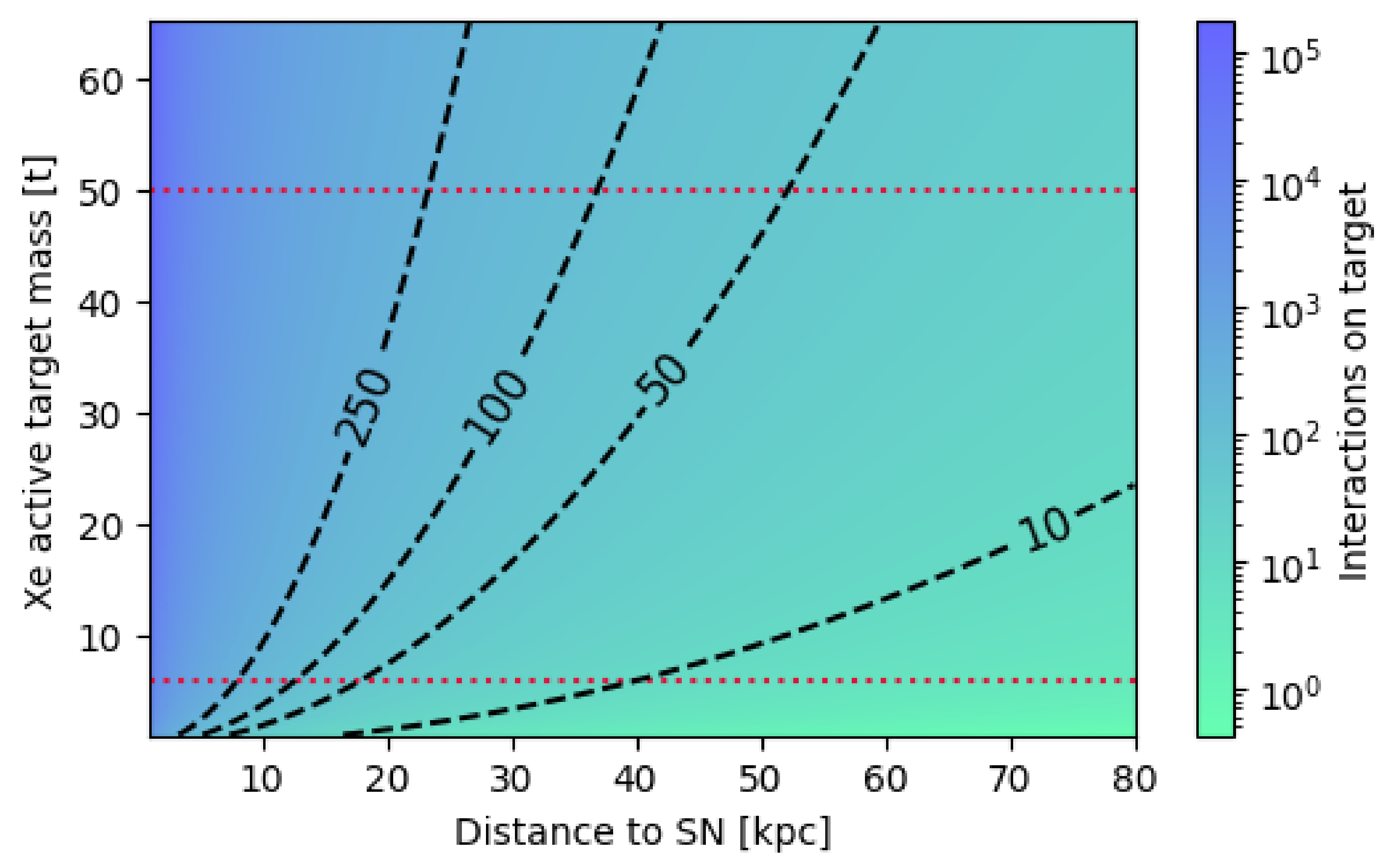


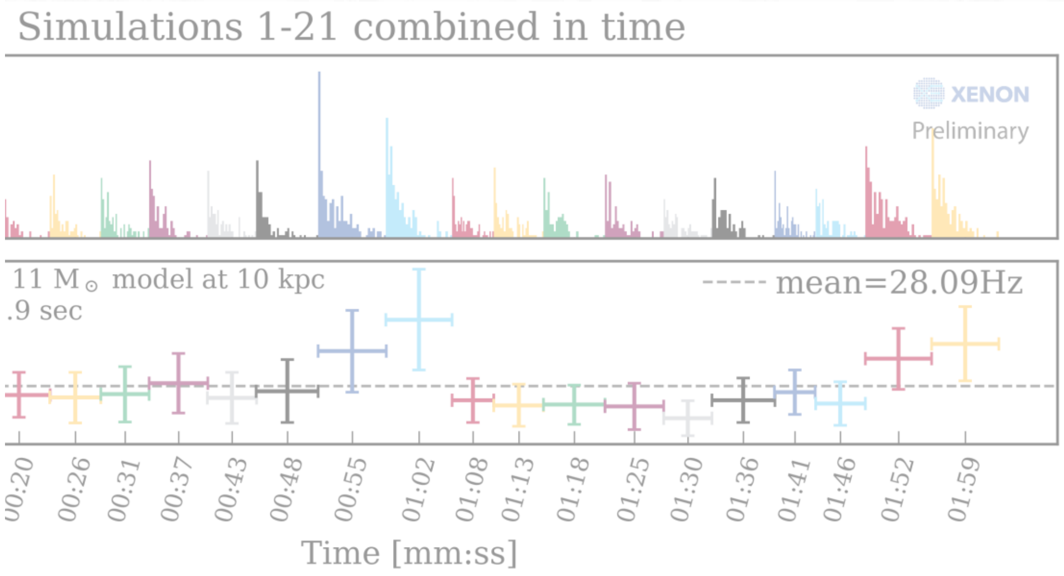
Expected number of Interactions vs "Detectable Signal"

$$\frac{d^2R}{dE_R dt_{pb}}$$

Differential interaction rate gives the total rates of expected interactions with *any* possible recoil energy.

Perfect detection efficiency gives these counts.



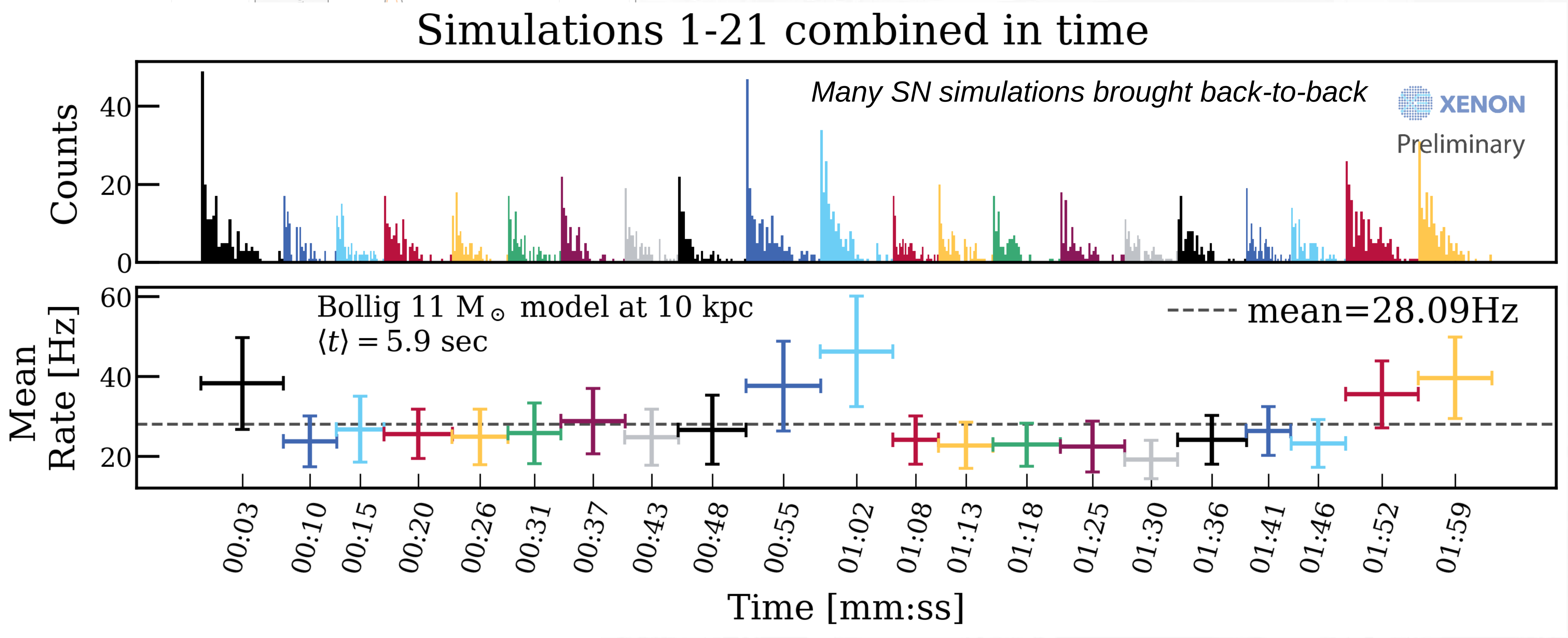


Differential CEνNS rates

$$\frac{d^2R}{dE_R dt_{pb}} = \sum_{\nu_\beta} N_{Xe} \int_{E^\nu_{min}} dE_\nu\, f_\nu(E_\nu, t, d)\, \frac{d\sigma}{dE_R}(E_\nu, E_r)$$

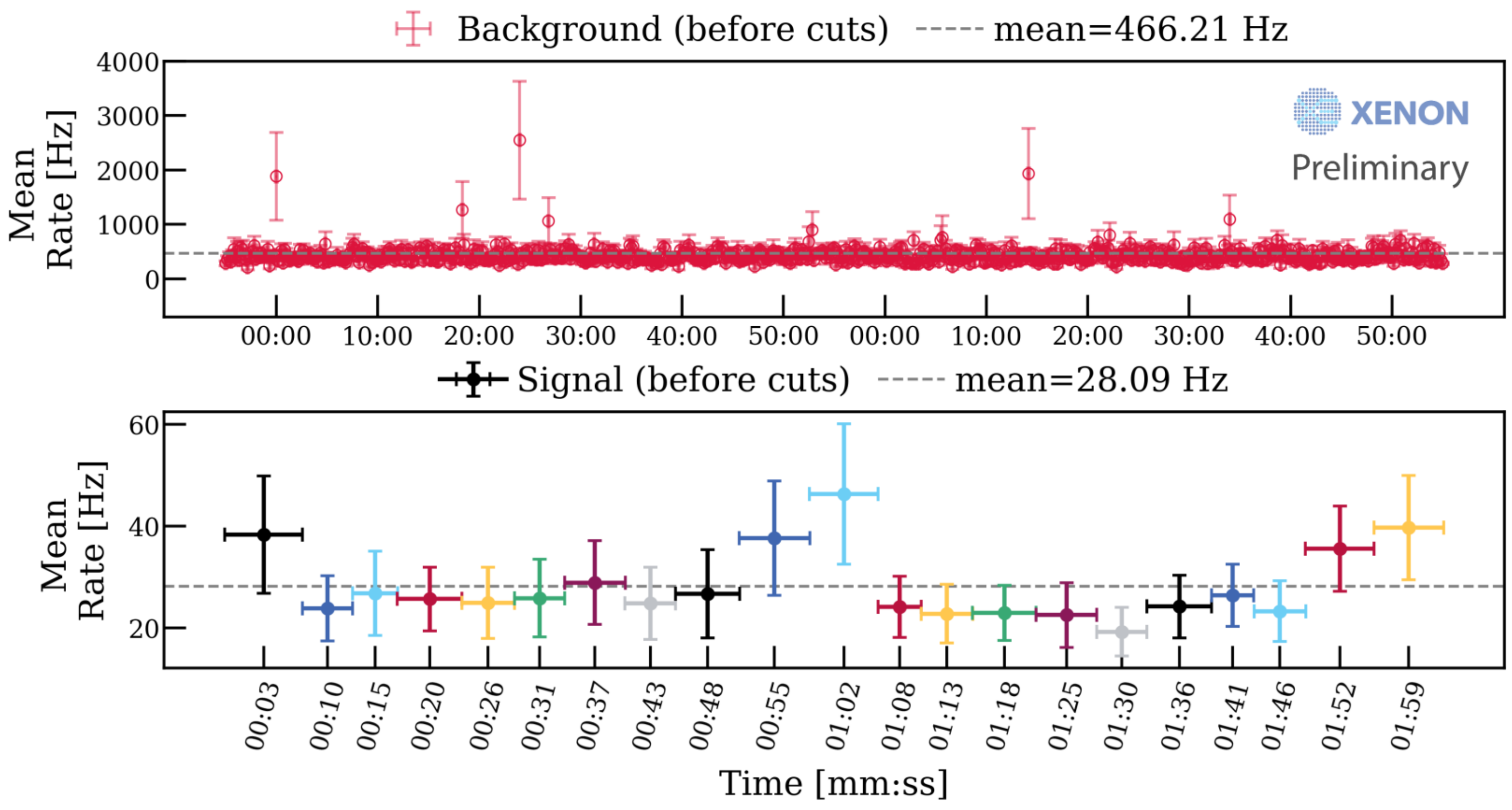
Expected number of Interactions vs "Detectable Signal"

Detector-like signal simulations using
Waveform Simulator: WFSim !
The **detection efficiencies** are taken care of



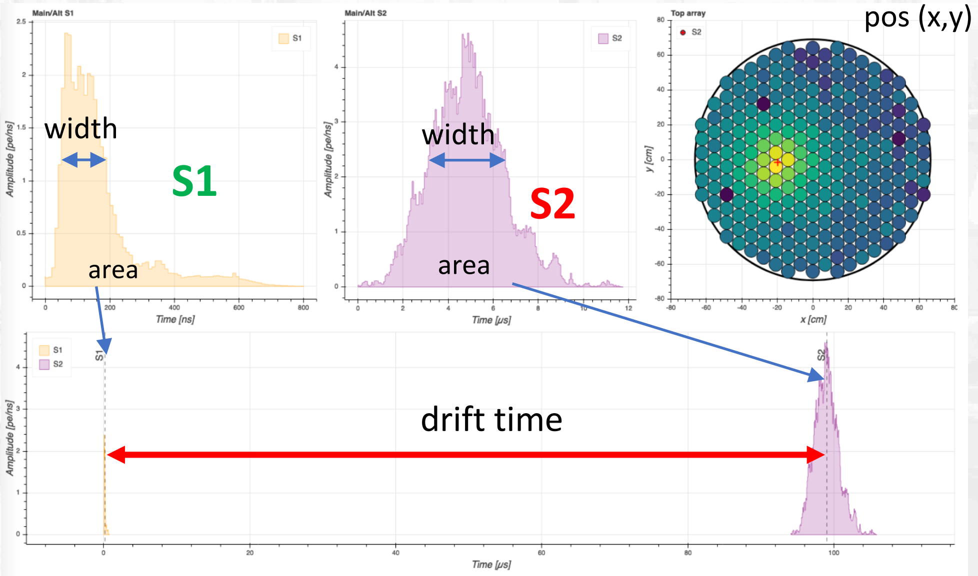
Supernova signal in the detector

Peak rates for **Background** and **Supernovae** signal
before applying any selection.

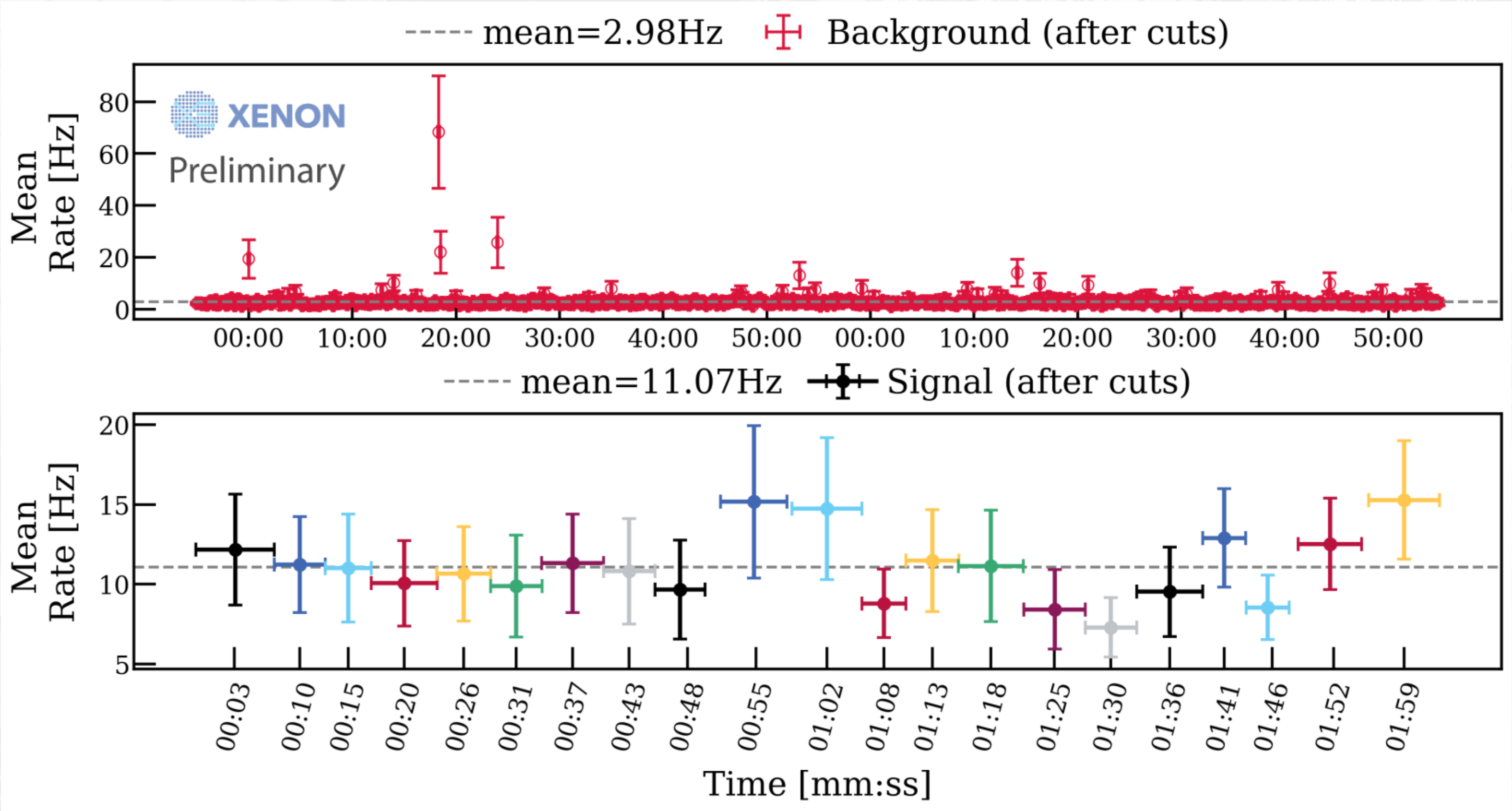


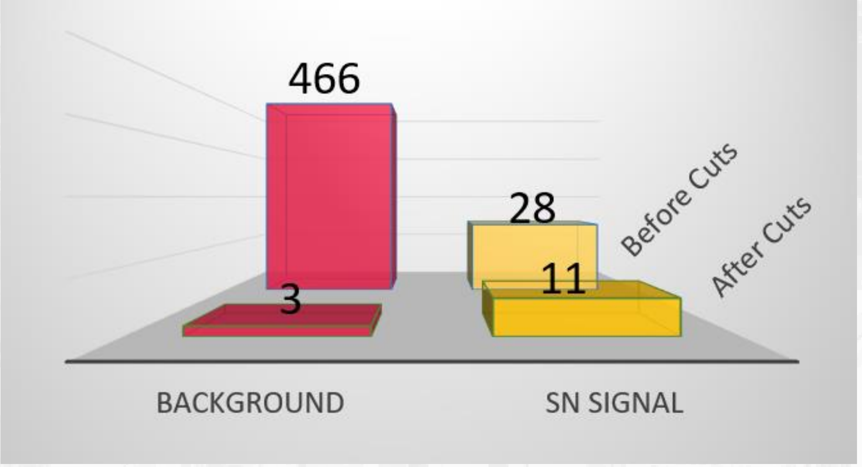
Background rates in a 10-sec bins for 2 hours and
Signal rates as total counts/duration for each realization

Optimize cuts on peak features like Peak area, width, rise time, x-y position, area fraction top and previous large peaks etc.



Supernova signal in the detector





Peak rates for **Background** and **Supernovae** signal <u>after</u> applying all cuts.

After applying cuts, better supernova signal selection is possible
The background should remain stable and the signal peak rates change as a function of
distance and **supernova model**

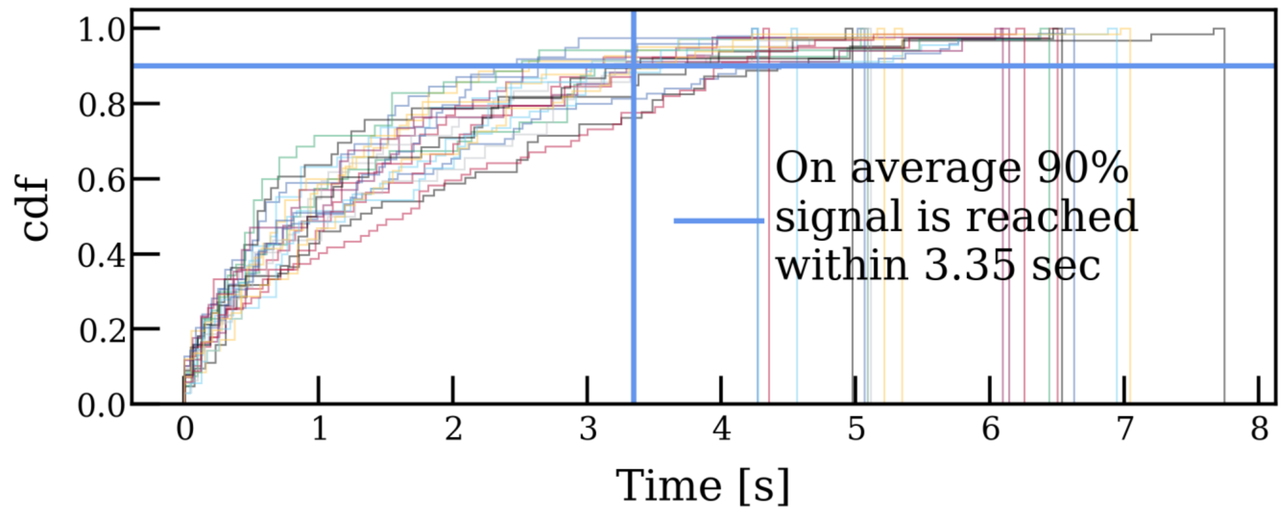
Benchmark model: Bollig 2016 11 Solar mass at 10 kpc
Mirizzi et al. Rivista del Nuovo Cimento Vol 39 N. 1-2 (2016)

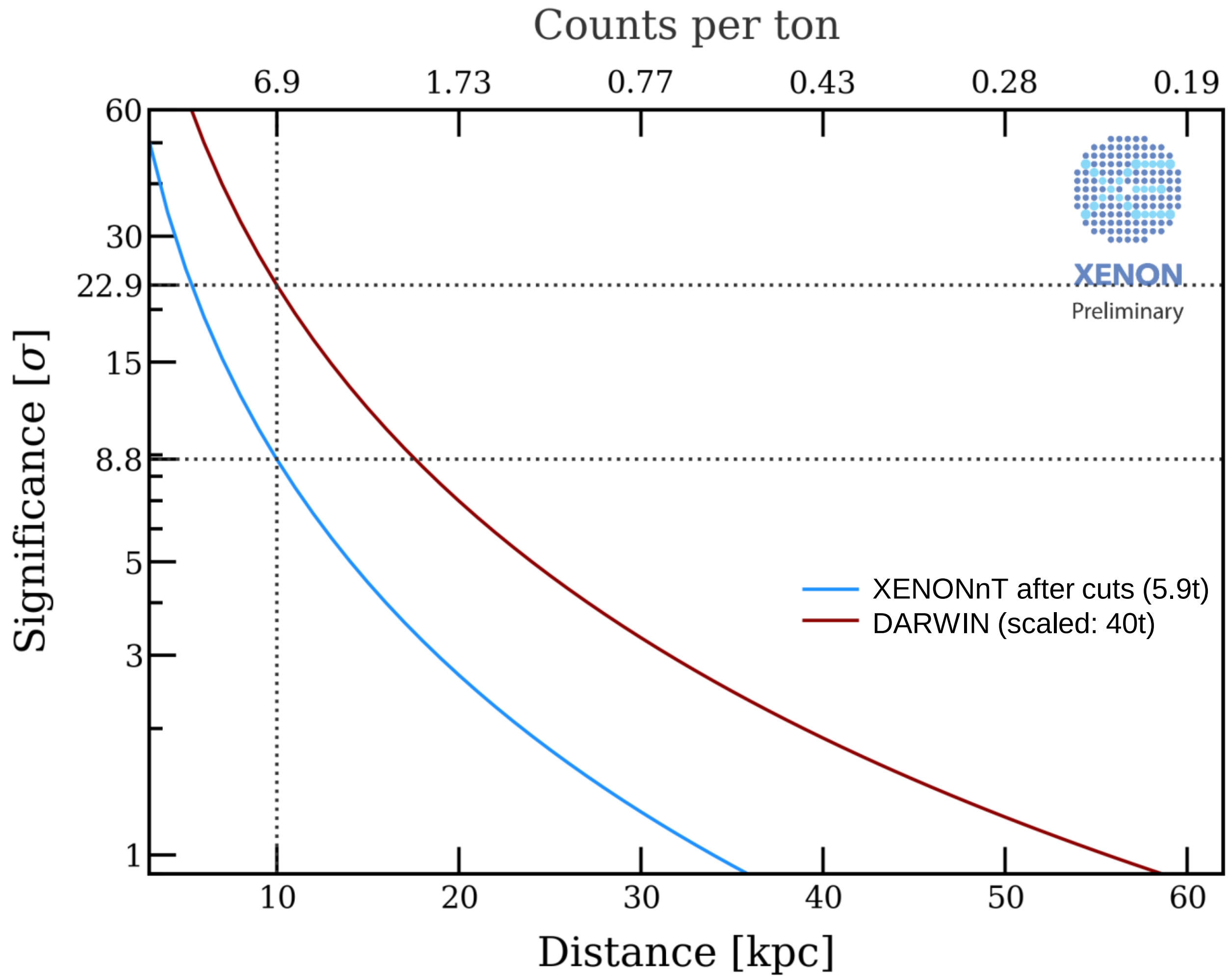
Sensitivity Projections

Background: 2.98 Hz
Average signal counts at 10 kpc: **~45 counts**
Average signal duration: ~ 5.9 sec = **~17.6 counts**

Significance
(from [Cowan et al. 2010](#) Eur.Phys.J.C 71 (2011))

$$\mathrm{med}[Z_0|1] = \sqrt{q_{0,A}} = \sqrt{2\left((s+b)\ln(1+s/b) - s\right)}$$





Covering only a part of time $t_{90\%\ \mathrm{signal}}$
Average signal : **~40 counts**
Accumulated background : **~11 counts**
Counts are then scaled by the distance and volume

Not fully optimized yet.

SuperNova Early Warning System Integration

1) Listening protocol

Subscribe and be alerted when there is a Supernova
Ensure data taking, process for inspection

2) Heartbeats

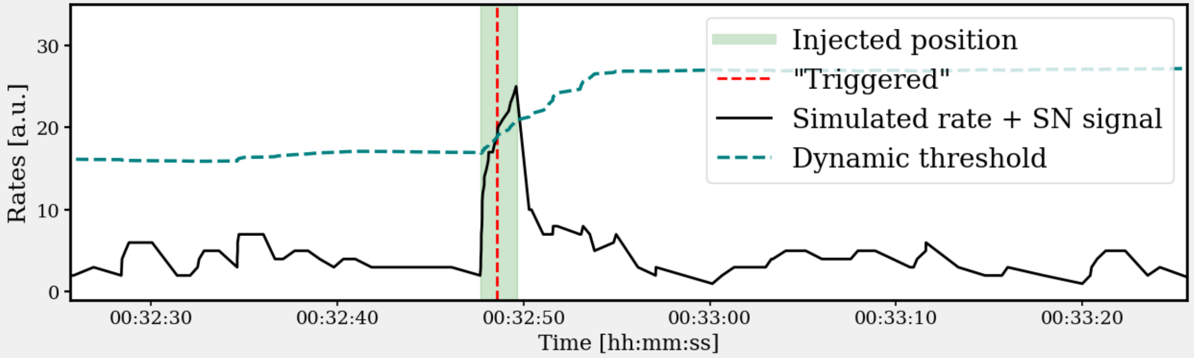
Check current run mode and send heartbeats

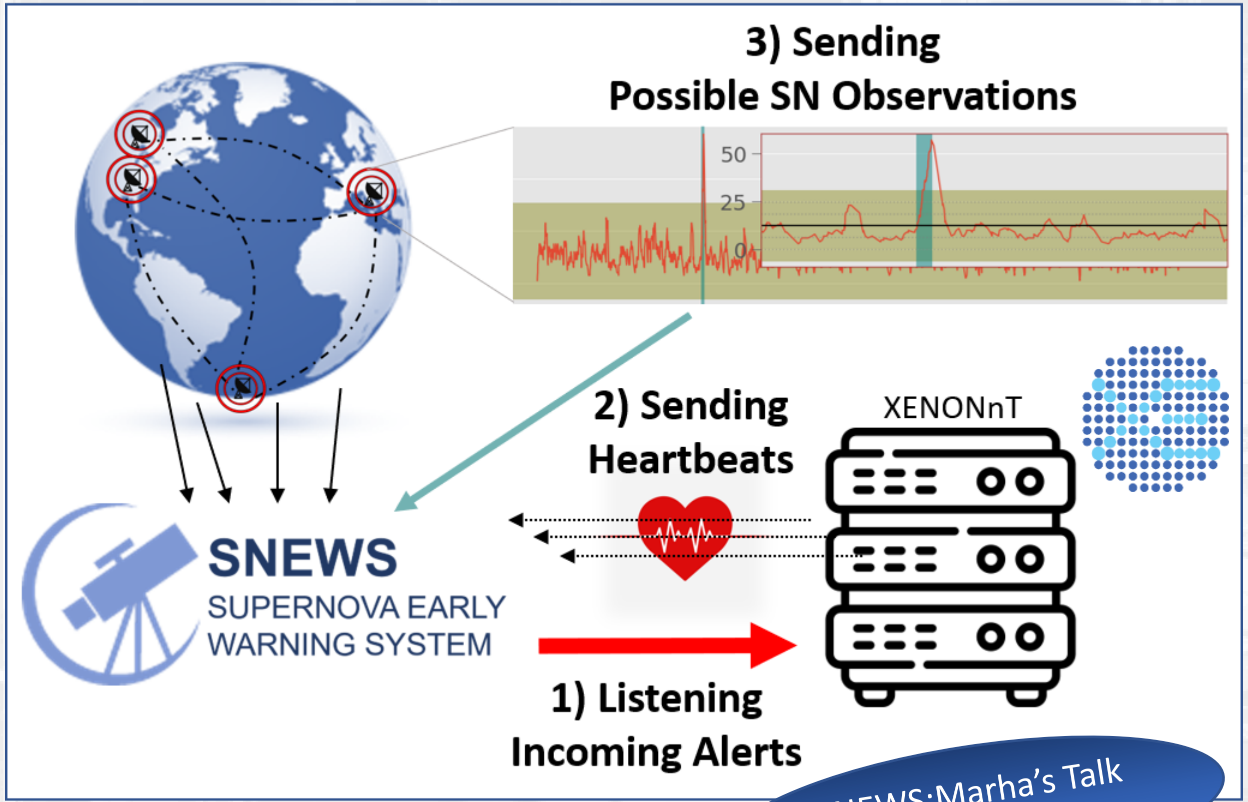
3) Online monitoring

Triggerless DAQ (arXiv:2212.11032) continuous data taking

Apply cuts, create a dynamic threshold

Monitor the rates in a rolling window to catch "anomalous" increases in rate.





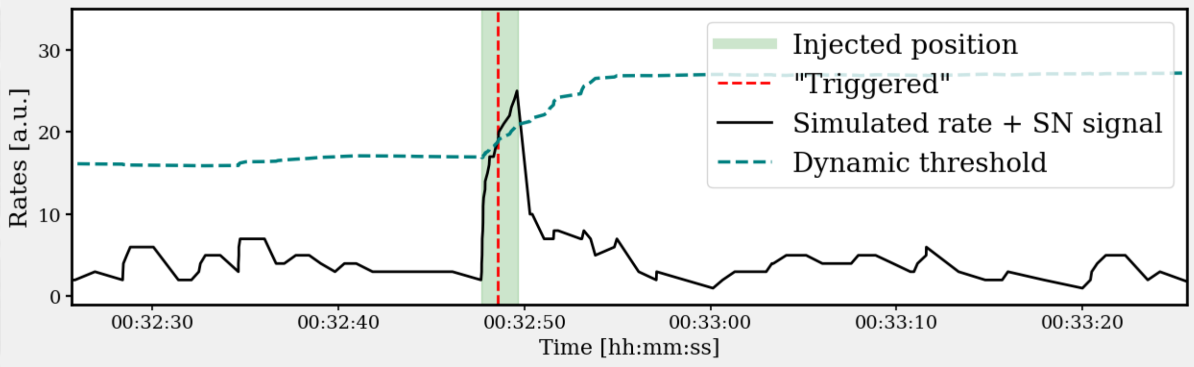
WIP: Inject many labelled signal and train an LSTM model to detect supernovae signal, use continuous learning to update

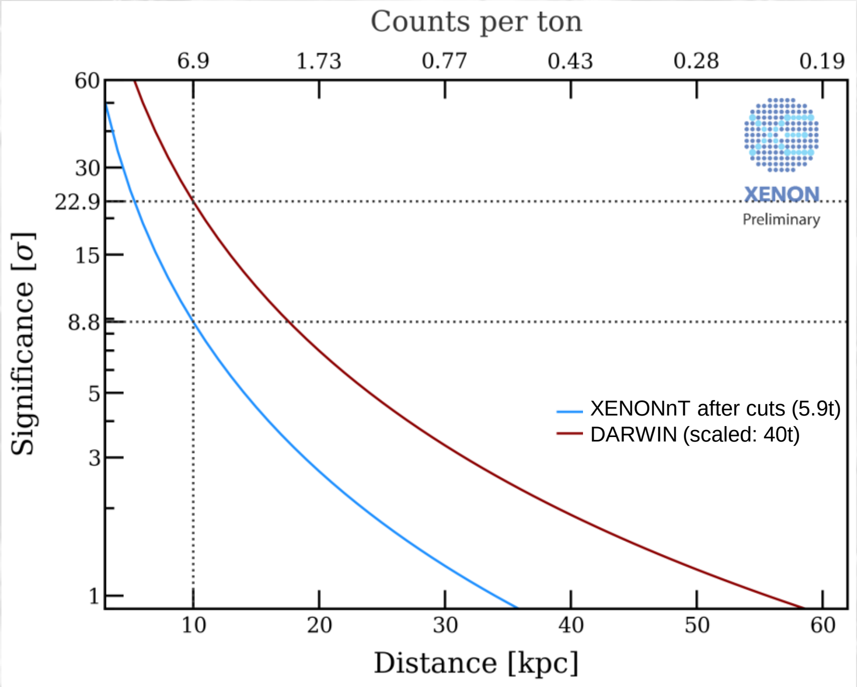
SNEWS:Marha's Talk on Wednesday!

Summary & Outlook

- Dual phase dark matter detectors can detect supernova neutrinos.
- Large atomic number of xenon = dominant signal in CEvNS.
- XENONnT is ready to participate in Supernova Early Warning System.
- Dedicated cuts are able to reduce the background down to ~2 Hz.
- More than 8σ significance within 10 kpc.
- DARWIN/XLZD is the ultimate dark matter detector at least 7x larger target mass!

- [ ] Study other models from snewpy
- [ ] Improved online monitoring using machine learning
- [ ] Tune the threshold using false-alarm-rates in the data
- [ ] Include the analysis on the veto systems
- [ ] Combined analysis (TPC: CEvNS ~100) and (veto volume: IBD ~150)
- [ ] Study model discrimination power





snewpy: Astrophys.J. 925 (2022) 2, 107

Thanks!
Questions?

https://xenonexperiment.org

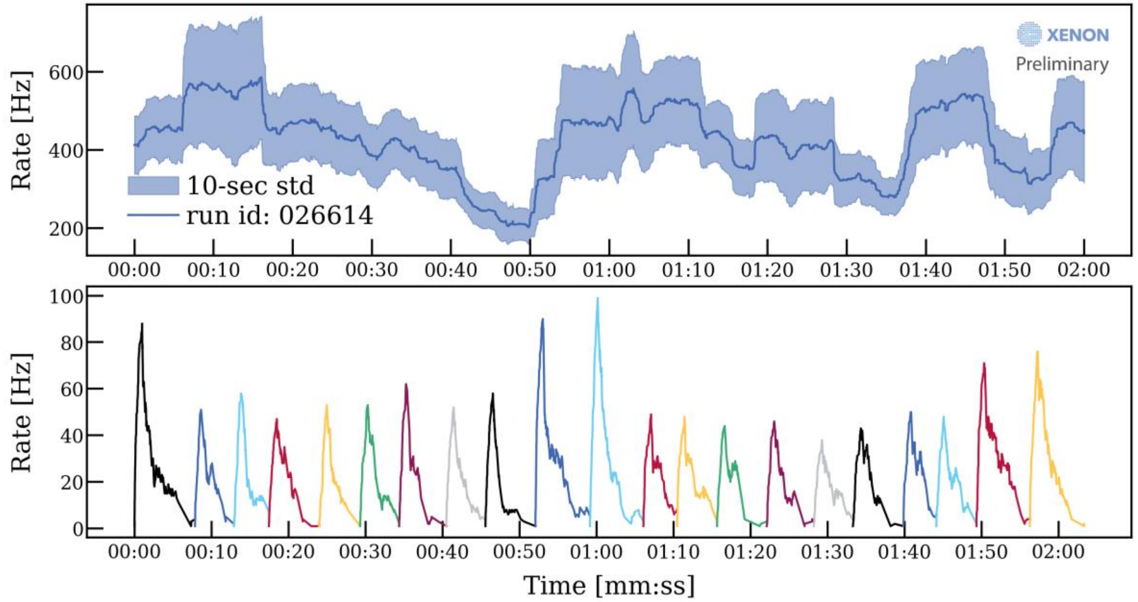
@XENONExperiment

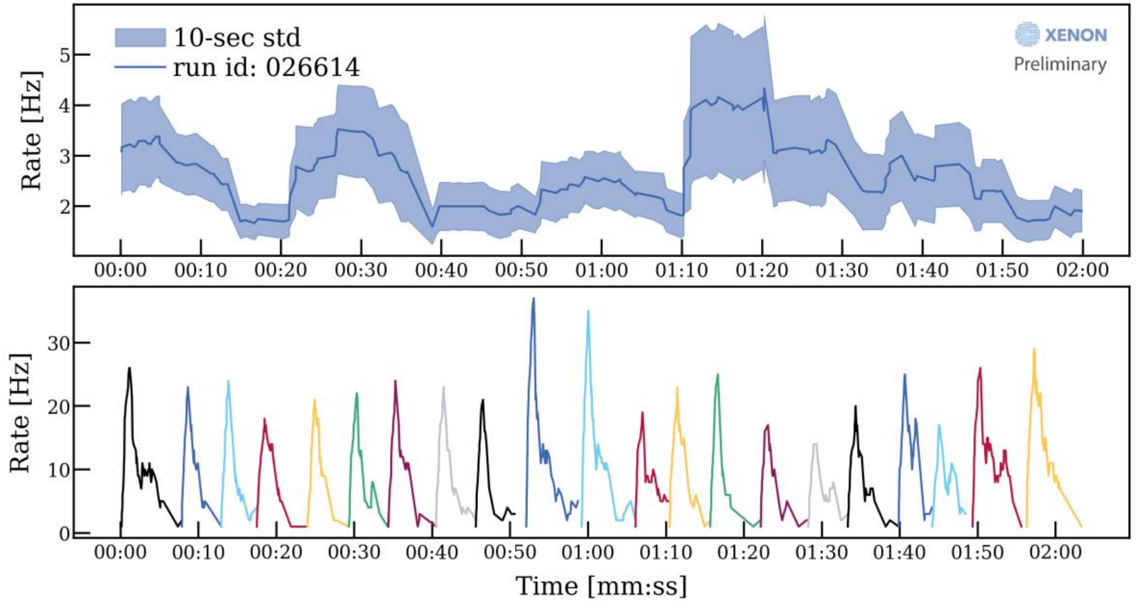
@xenonexperiment

@xenon_experiment

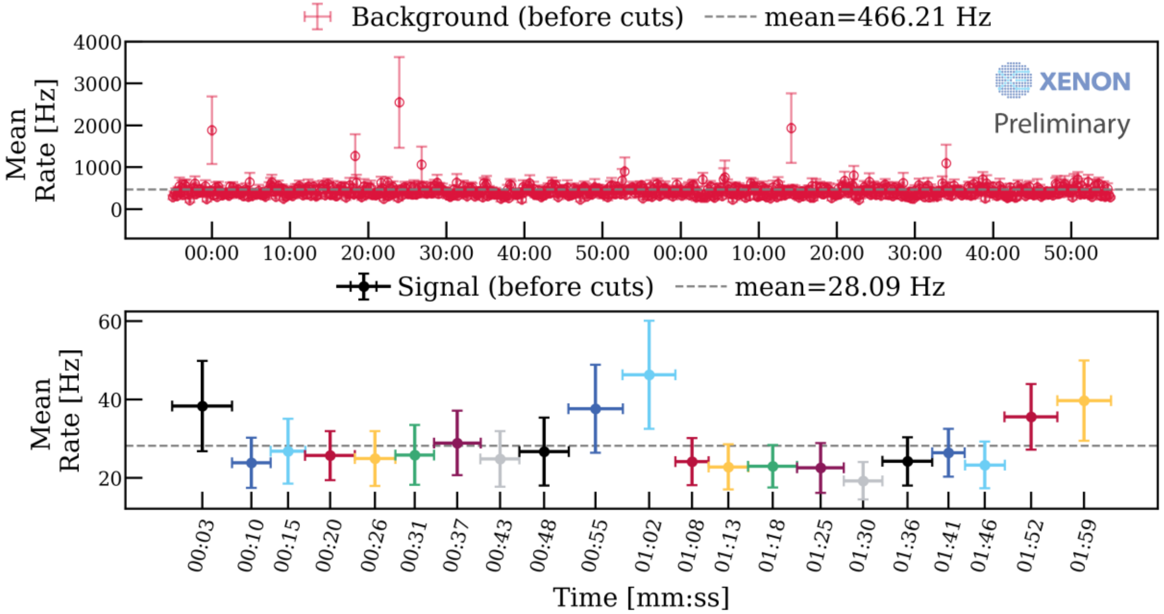
Back-up

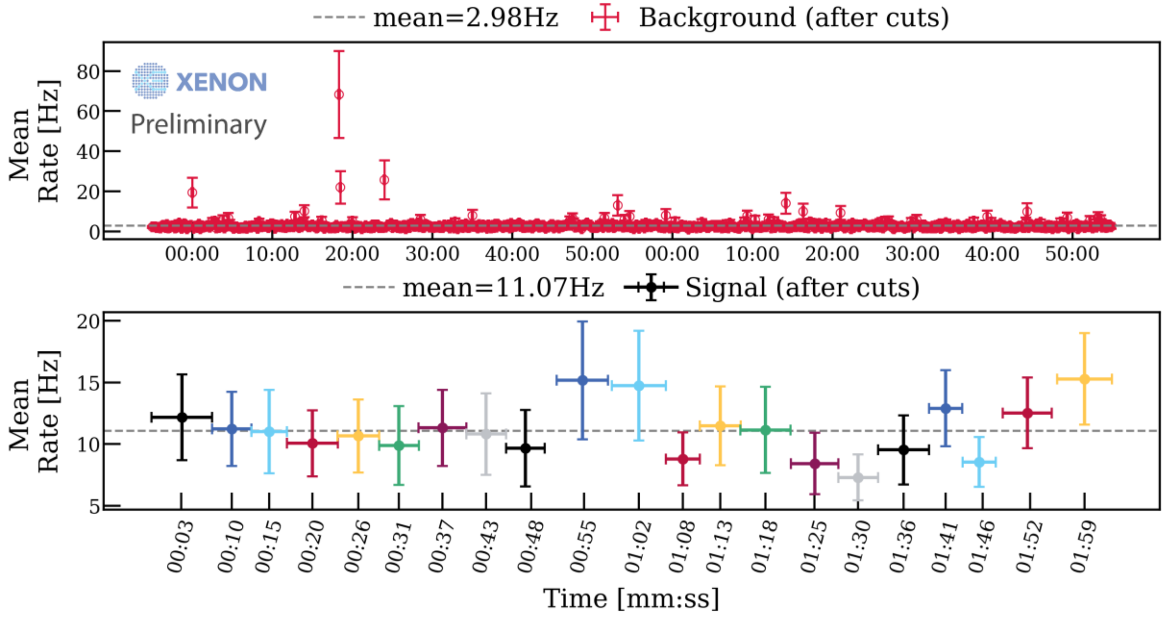
Rates in a 10-sec rolling window (background) for 2 min and
Rates as counts/sec per realization (signal)



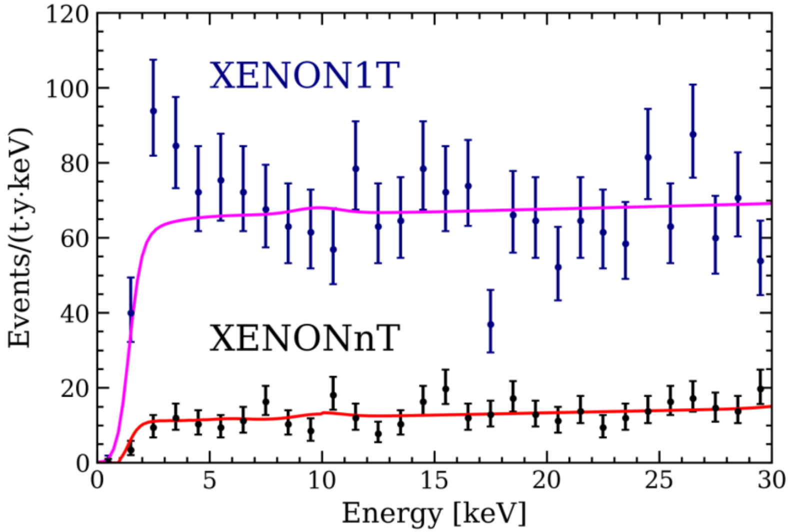


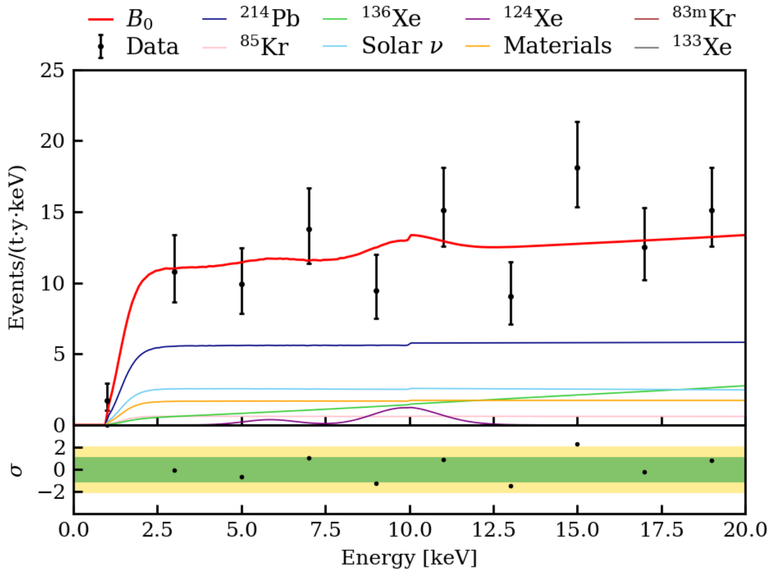
Background rates in a 10-sec bins for 2 hours and
Signal rates as total counts/duration for each realization





Record-low ER background rate: (15.8 ± 1.3) events / (t · yr · keV)





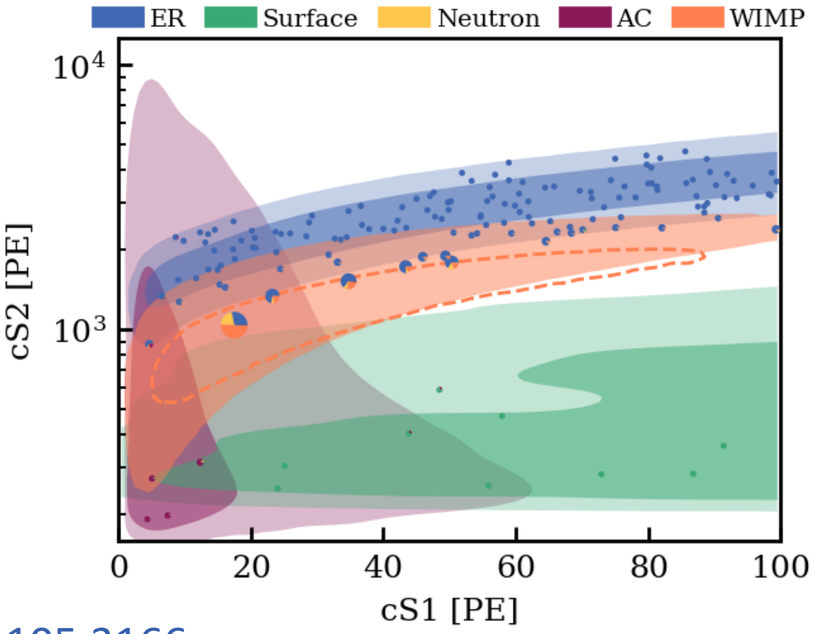
$$\sigma^{SI} < 2.64 \cdot 10^{-47}\ \mathrm{cm}^2$$

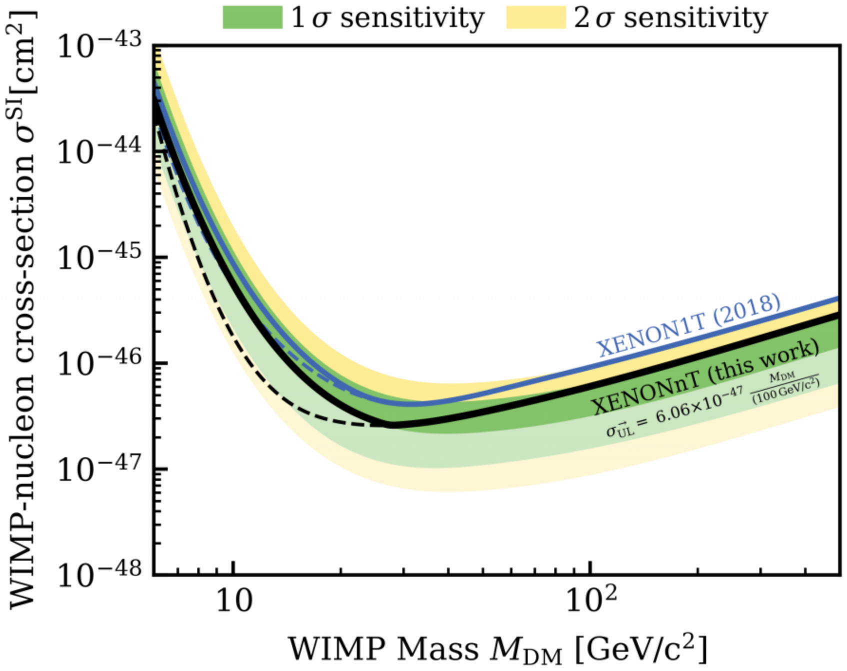
(M_{DM} = 28 GeV/c²)

$$\sigma^{SI} < 6.06 \cdot 10^{-47} \frac{M_{DM}}{100\ \mathrm{GeV/c^2}}\ \mathrm{cm}^2$$

(for M_{DM}>100 GeV/c²)

	Nominal	Best Fit	
	ROI		Signal-like
ER	134	135^{+12}_{-11}	0.81 ± 0.07
Neutrons	$1.1^{+0.6}_{-0.5}$	1.1 ± 0.2	0.42 ± 0.10
CEvNS	0.23 ± 0.06	0.23 ± 0.06	0.022 ± 0.011
AC	4.3 ± 0.2	4.32 ± 0.15	0.363 ± 0.013
Surface	14 ± 3	12^{+0}_{-4}	$0.34^{+0.01}_{-0.11}$
Total	154	152 ± 12	$1.95^{+0.12}_{-0.16}$
WIMP	-	2.4	1.2
Observed:	-	152	3





152 events in ROI, 16 in blinded region

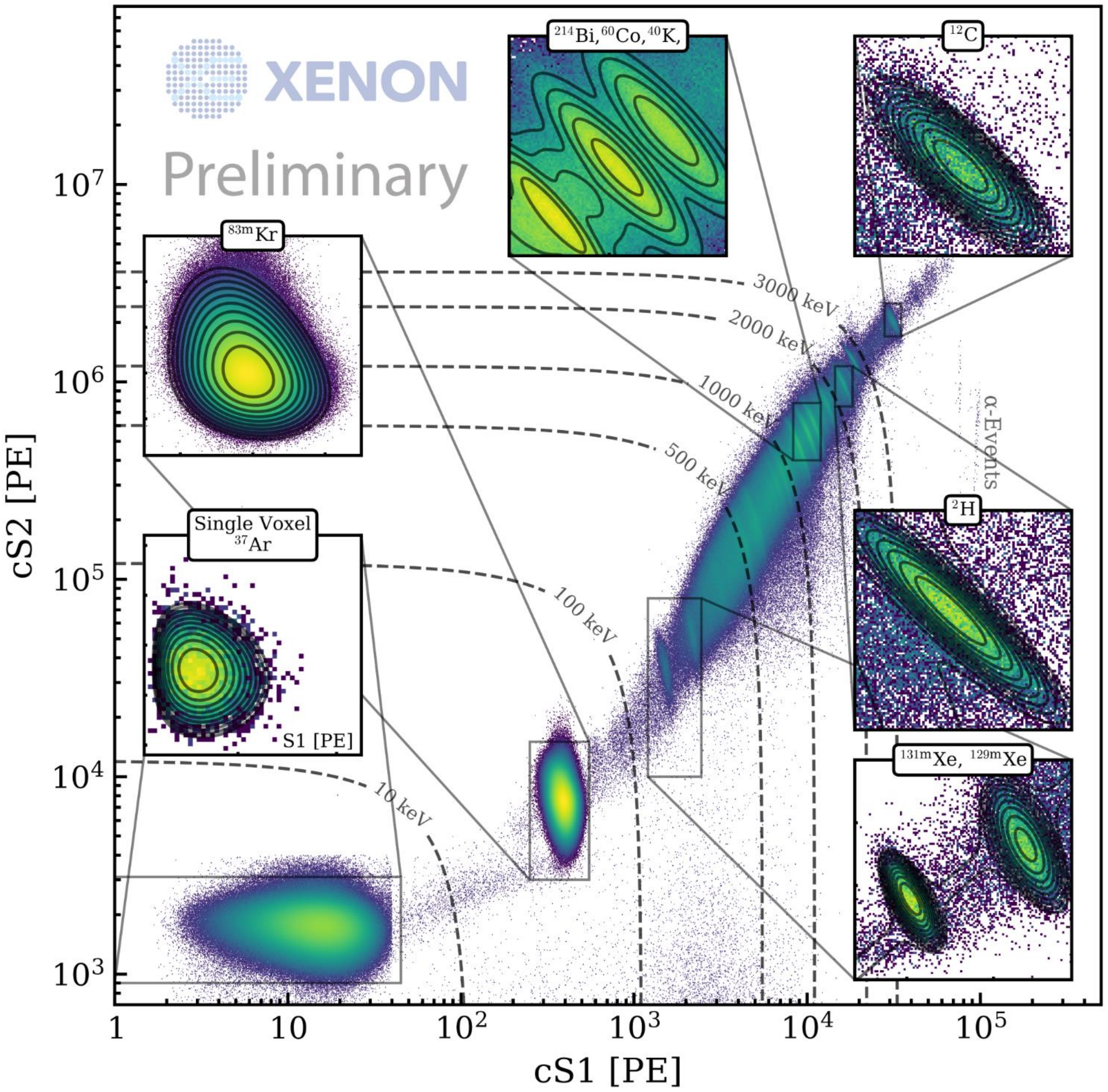
Best fit indicates **no significant excess**

Phys. Rev. Lett. 129, 161805 & arXiv:1105.3166

- 1.1 tonne-year exposure
- Data compatible with no-WIMP hypothesis
- 90% C.L. limits

Internal source: ^{37}Ar, ^{83m}Kr, ^{129m}Xe, ^{131m}Xe, ^{220}Rn

External sources like: ^{241}Am(α, n) ^{9}Be and Th



LXe purification

e-lifetime >> max drift time

20x higher purity than XENON1T

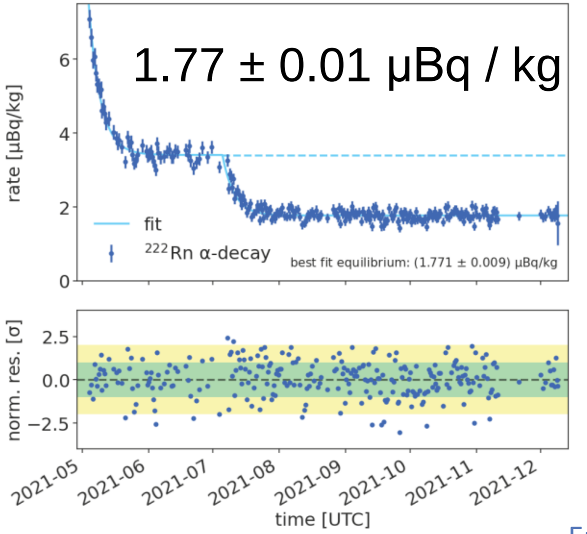
Cryogenic Distillation

Radon removal

^{214}Pb

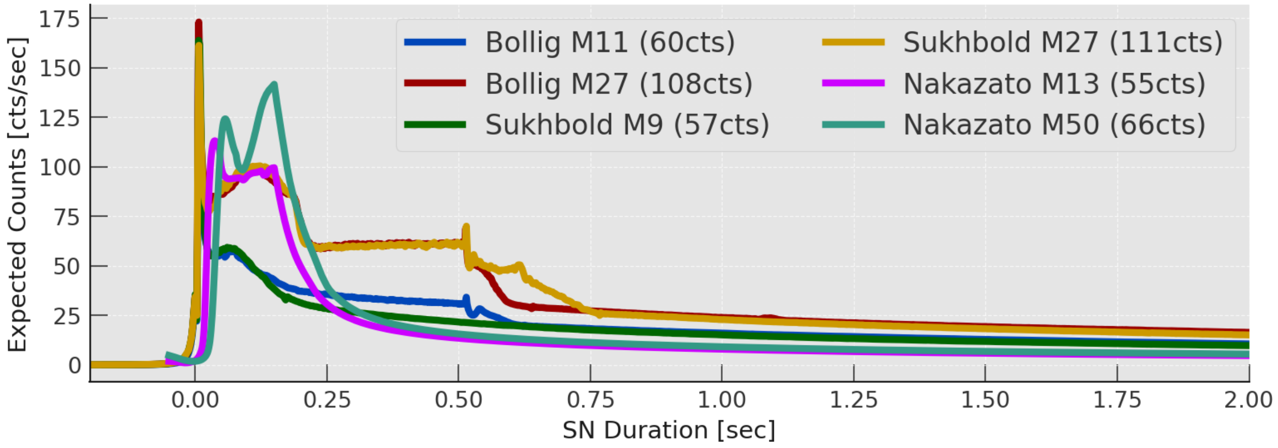
(^{222}Rn daughter)

^{85}Kr

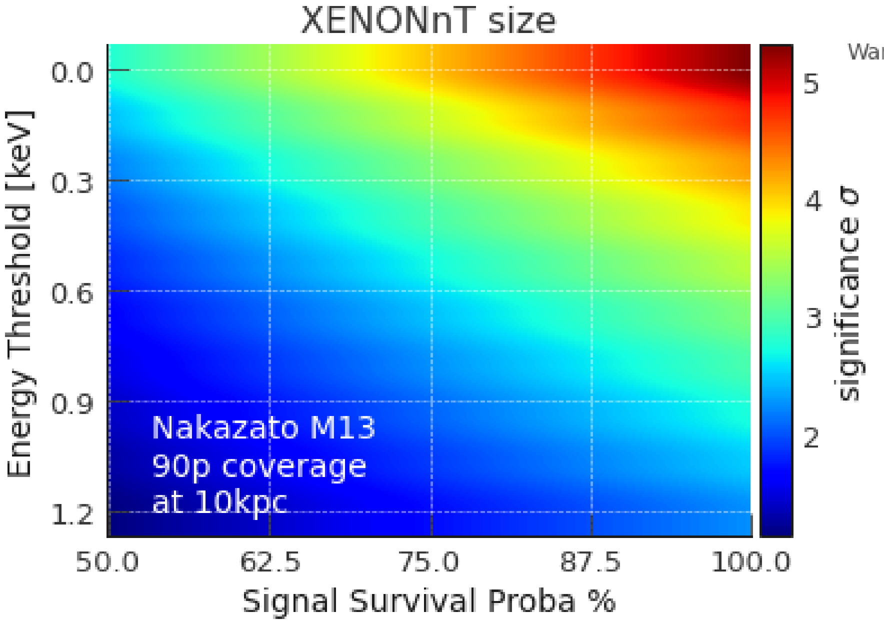


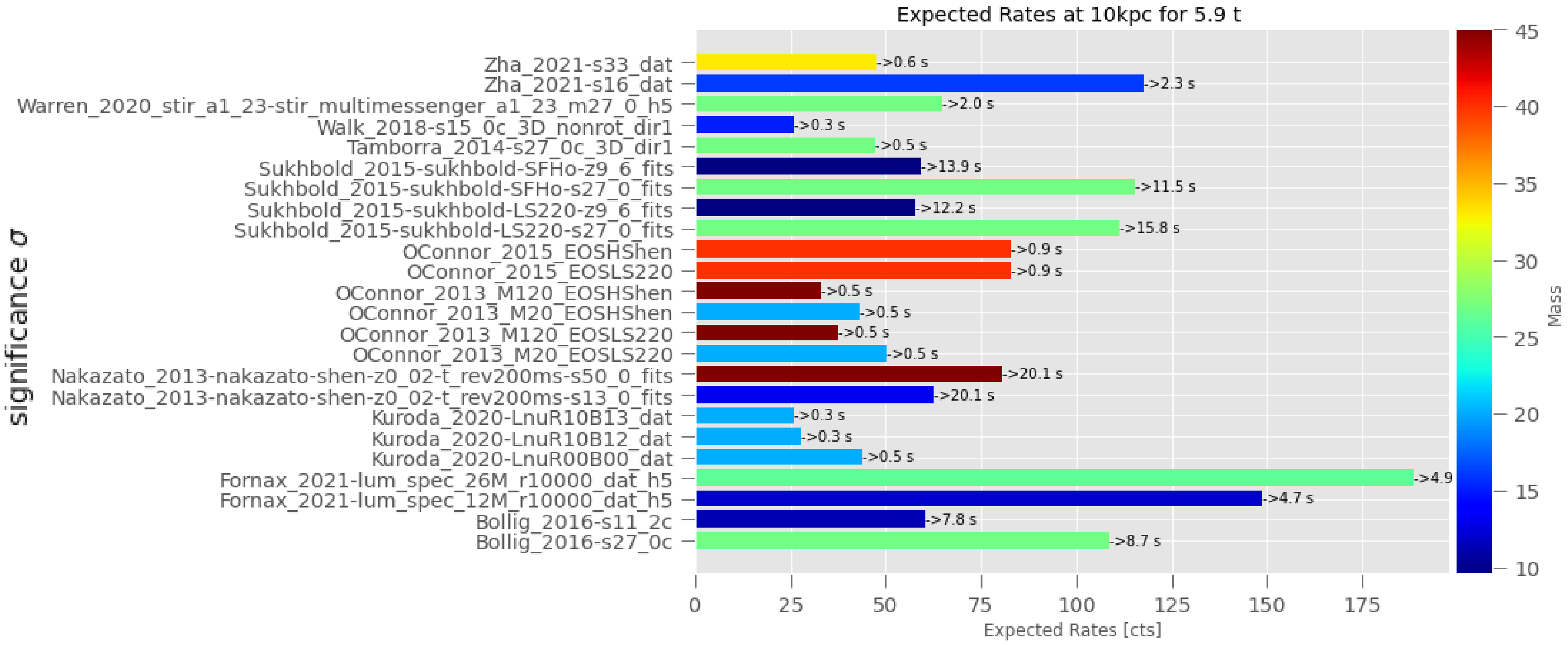
Eur. Phys. J. C 82, 1104 (2022)

100+ models in snewpy, various
Masses, EoS, durations, metallicities etc
Lightcurve reconstruction might allow us to reject some models



Lowering energy threshold (increasing detection efficiency)
And/or increasing selection performance





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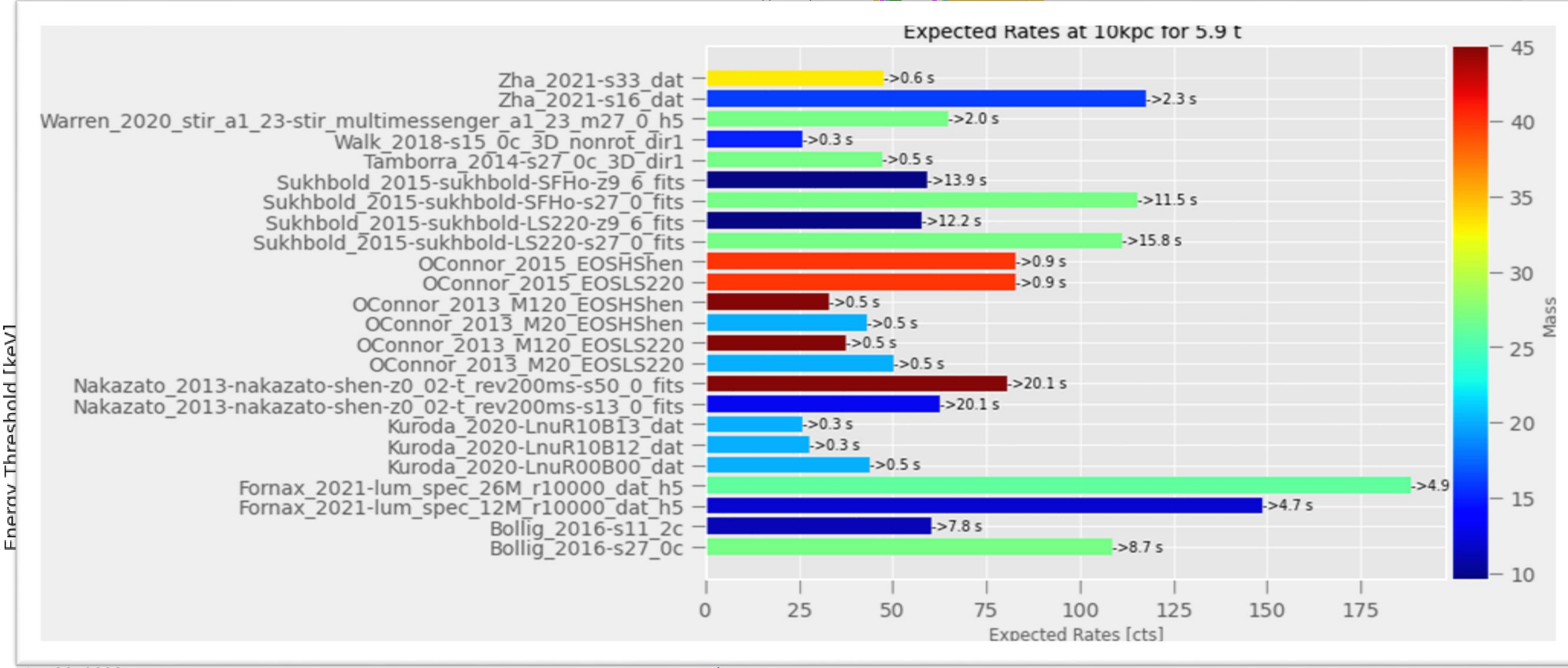

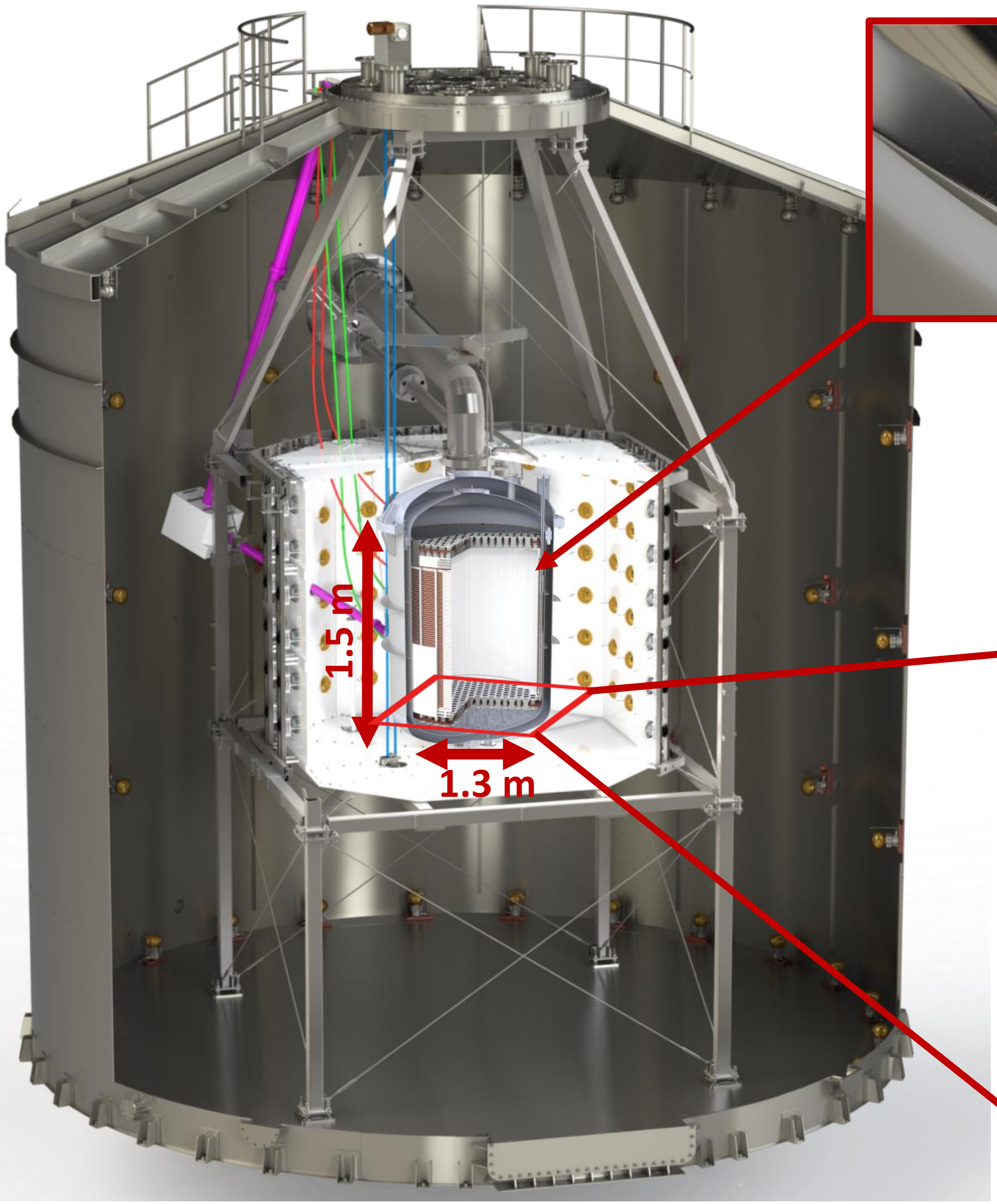

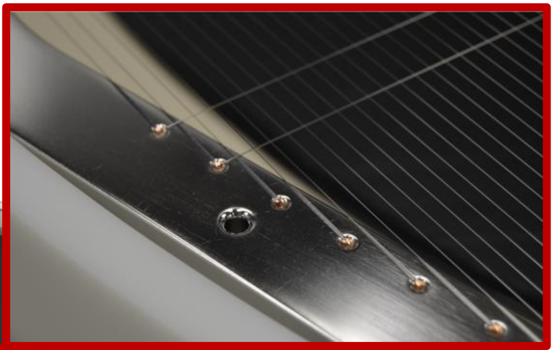

- Cylindrical PTFE walls for high reflectivity
- New design compared to 1T, reduced relative amount of mass
- All materials carefully screened and selected
- 494 3” PMTs (R11410-21)