香港中文大學(深圳)
The Chinese University of Hong Kong, Shenzhen

Progress of solar pp neutrino search with XENONnT

Jingqiang Ye（叶靖强）
yejingqiang@cuhk.edu.cn
The Chinese University of Hong Kong, Shenzhen
On behalf of the XENON Collaboration

August 26th, 2025
Xichang, China
Topics in Astroparticle and Underground Physics (TAUP2025)

XENON collaboration

30 institutes
~200 scientists

XENON Collaboration Meeting, June 2025

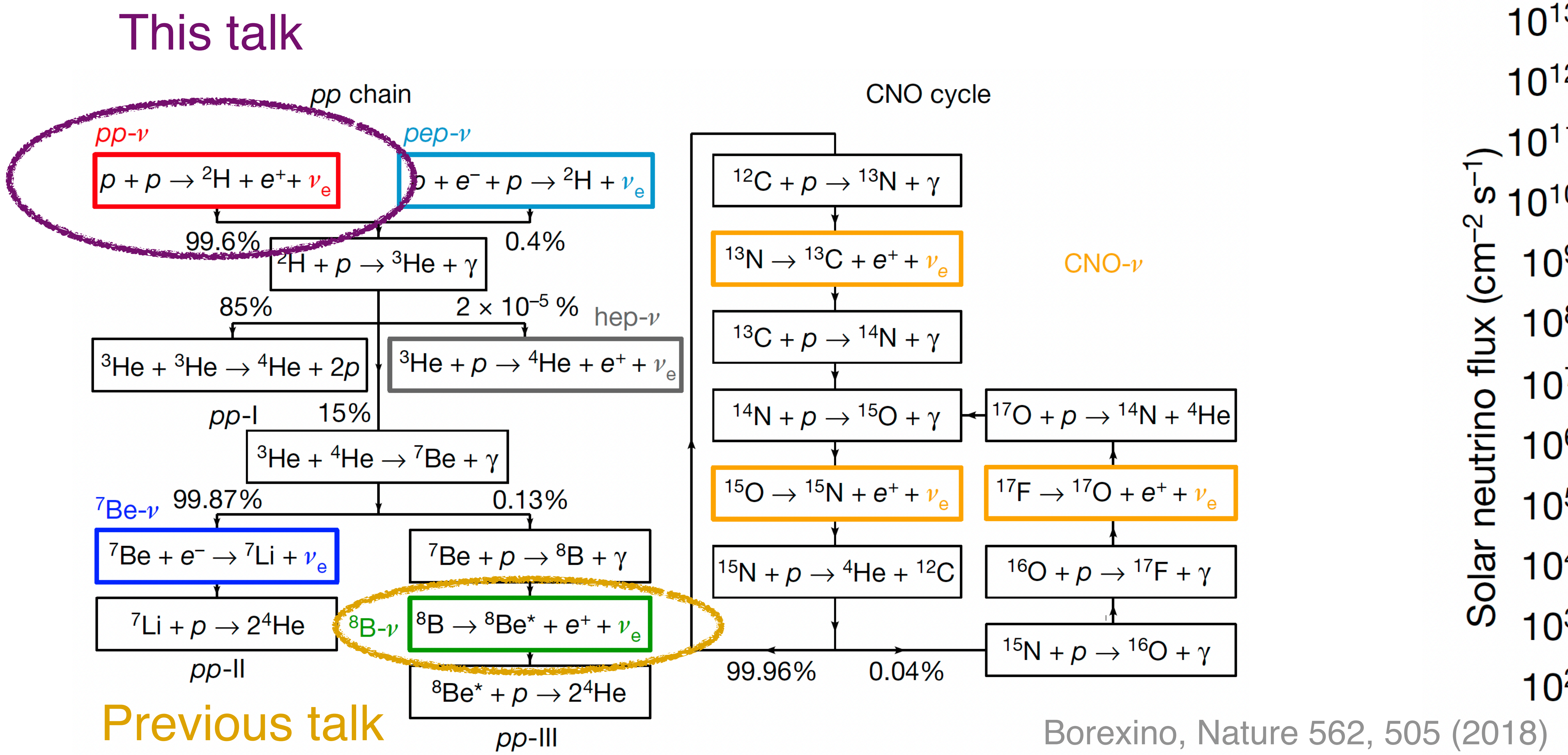
AMERICA
- UC San Diego — San Diego
- Houston
- The University of Chicago — Chicago
- Columbia University in the City of New York — New York City
- Bucknell University — Lewisburg

EUROPE
- Zurich
- KIT Karlsruhe Institute of Technology — Karlsruhe
- Universität Münster — Münster
- Uni Freiburg — Freiburg
- JGU — Mainz
- Max-Planck-Institut für Kernphysik Heidelberg — Heidelberg
- Universität Heidelberg Zukunft seit 1386 — Heidelberg
- Nikhef — Amsterdam
- Stockholm University — Stockholm
- Universidade de Coimbra 1290 — Coimbra
- Subatech — Nantes
- LPNHE Paris — Paris
- INFN Torino — Torino
- Bologna
- Università degli Studi dell'Aquila — L'Aquila
- INFN LNGS — Assergi
- Napoli

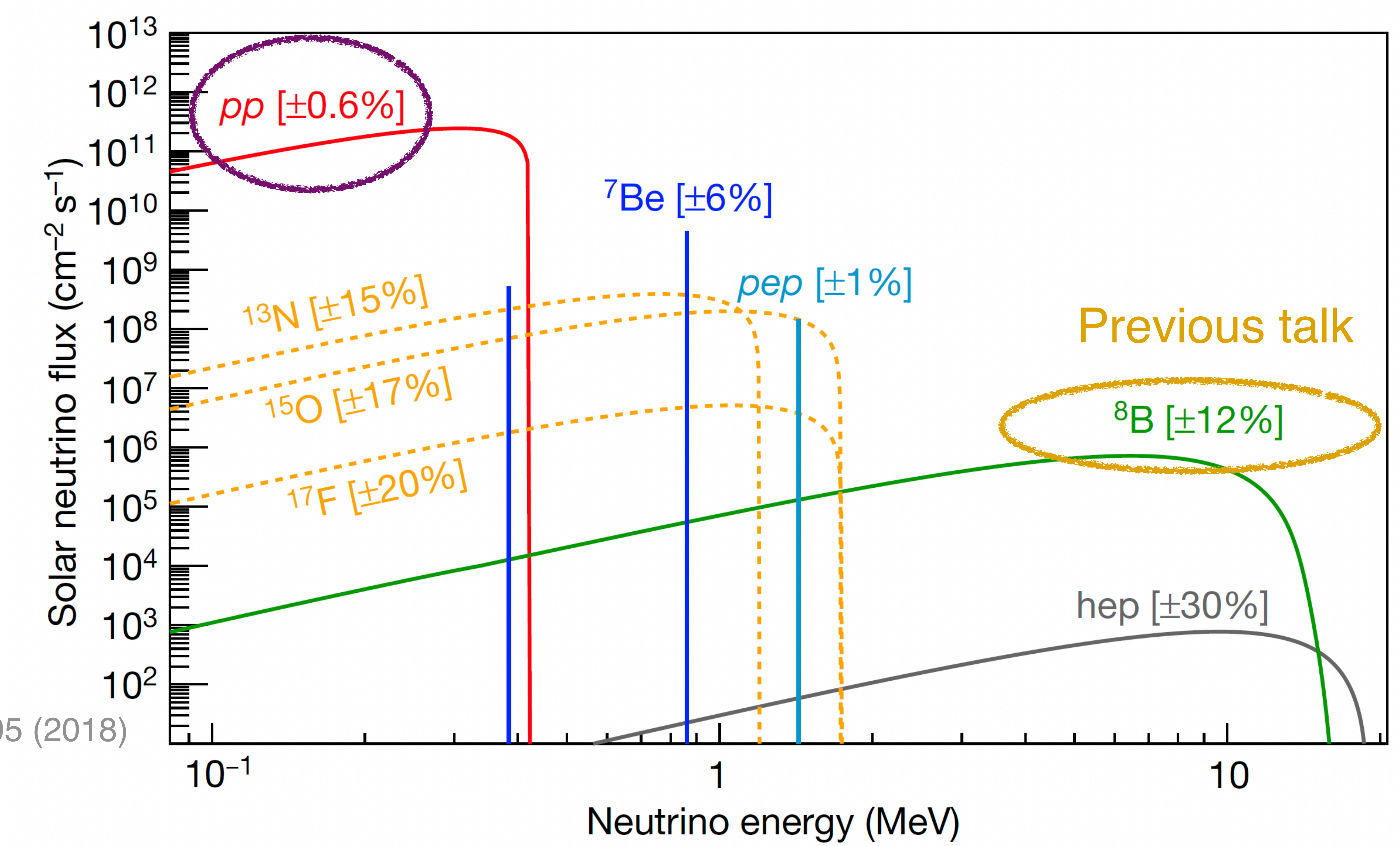
MIDDLE EAST
- מכון ויצמן למדע Weizmann Institute of Science — Rehovot
- جامعة نيويورك أبوظبي NYU ABU DHABI — Abu Dhabi

ASIA
- 清華大学 Tsinghua University — Beijing
- 西湖大学 Westlake University — Hangzhou
- Shenzhen
- 東京大学 The University of Tokyo — Tokyo
- Nagoya University — Nagoya
- Kobe University — Kobe

Solar pp neutrinos

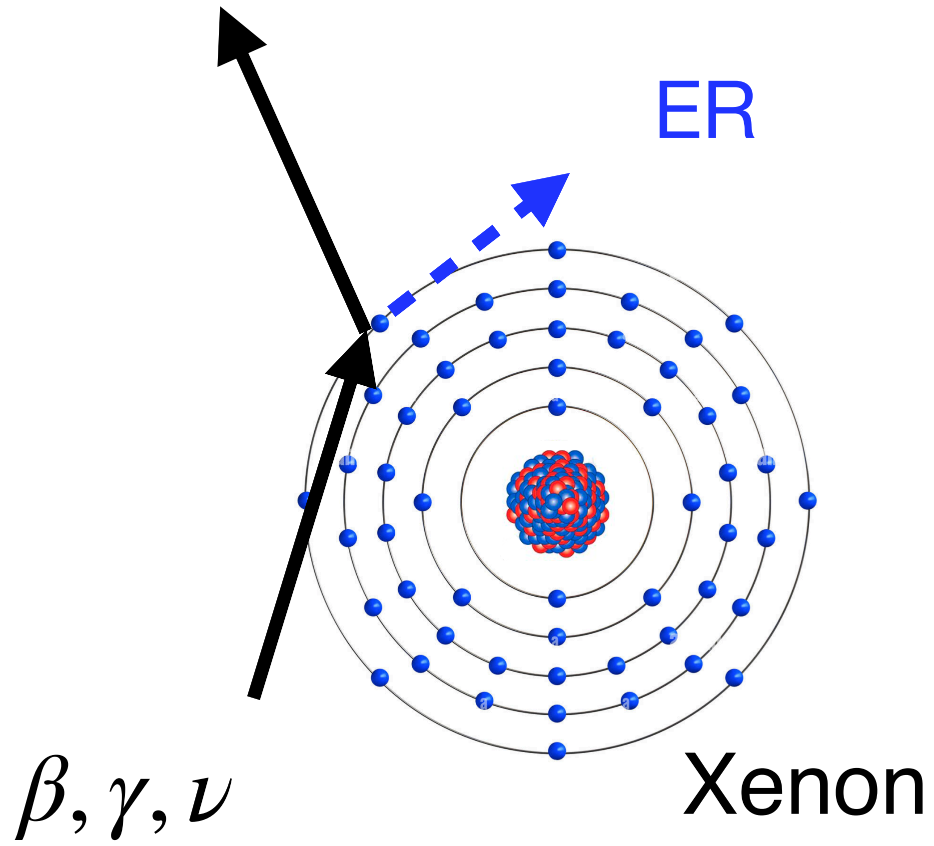


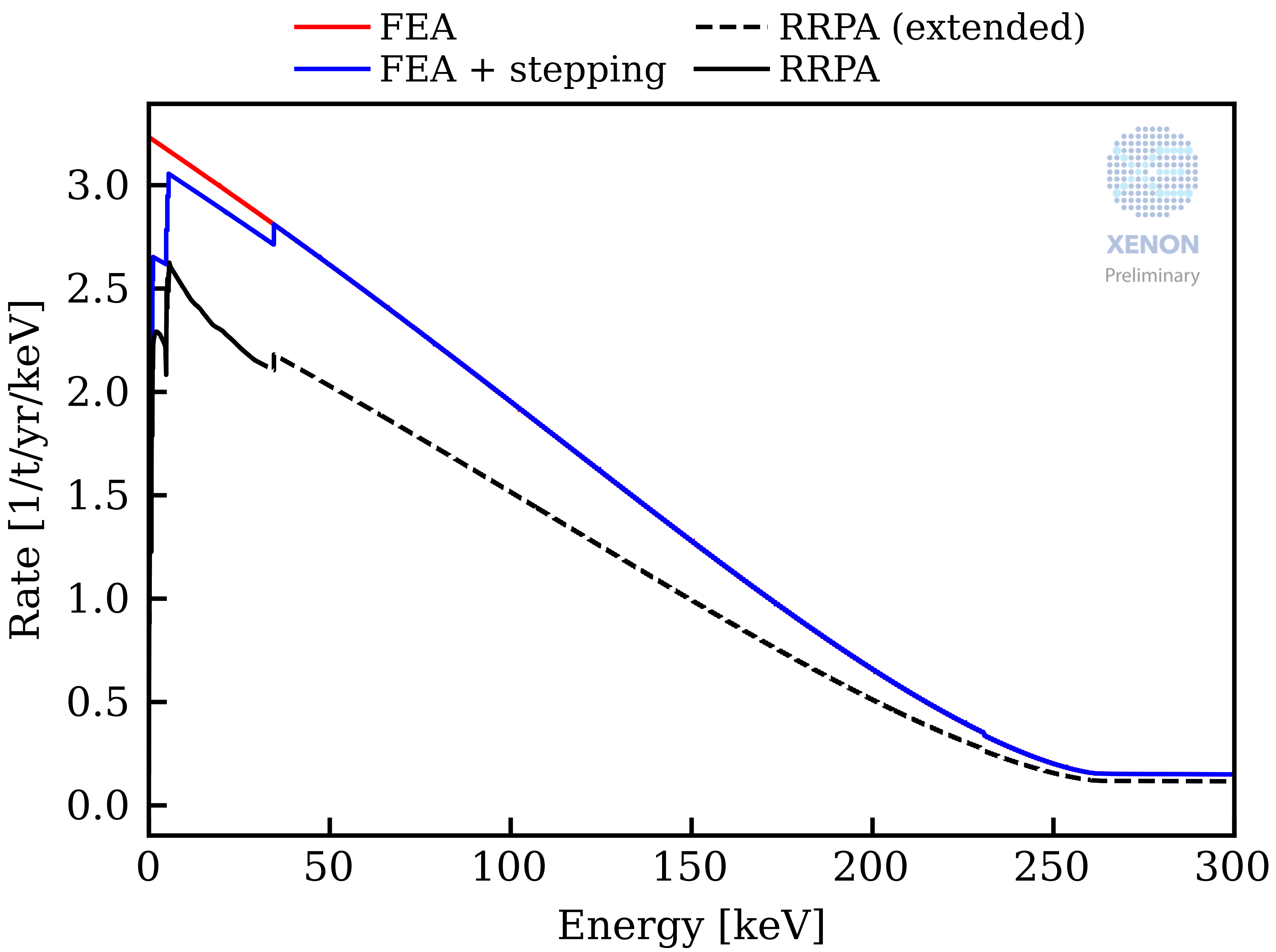
This talk



- Produced in the proton-proton fusion process in the Sun
- Dominant in solar neutrino flux (~91%) but with low energies

Signal spectrum in xenon





- Electronic recoil (ER) signal, recoil energy below ~250 keV
- Free electron approximation (FEA): assume electrons are free
- FEA + stepping: binding energies
- Relativistic random phase approximation (RRPA): many-body effect between electrons
- RRPA extended: extrapolation above 30 keV

J. Chen et al., PLB 774, 656-661 (2017)

Chih-Pang Wu's talk on Thursday

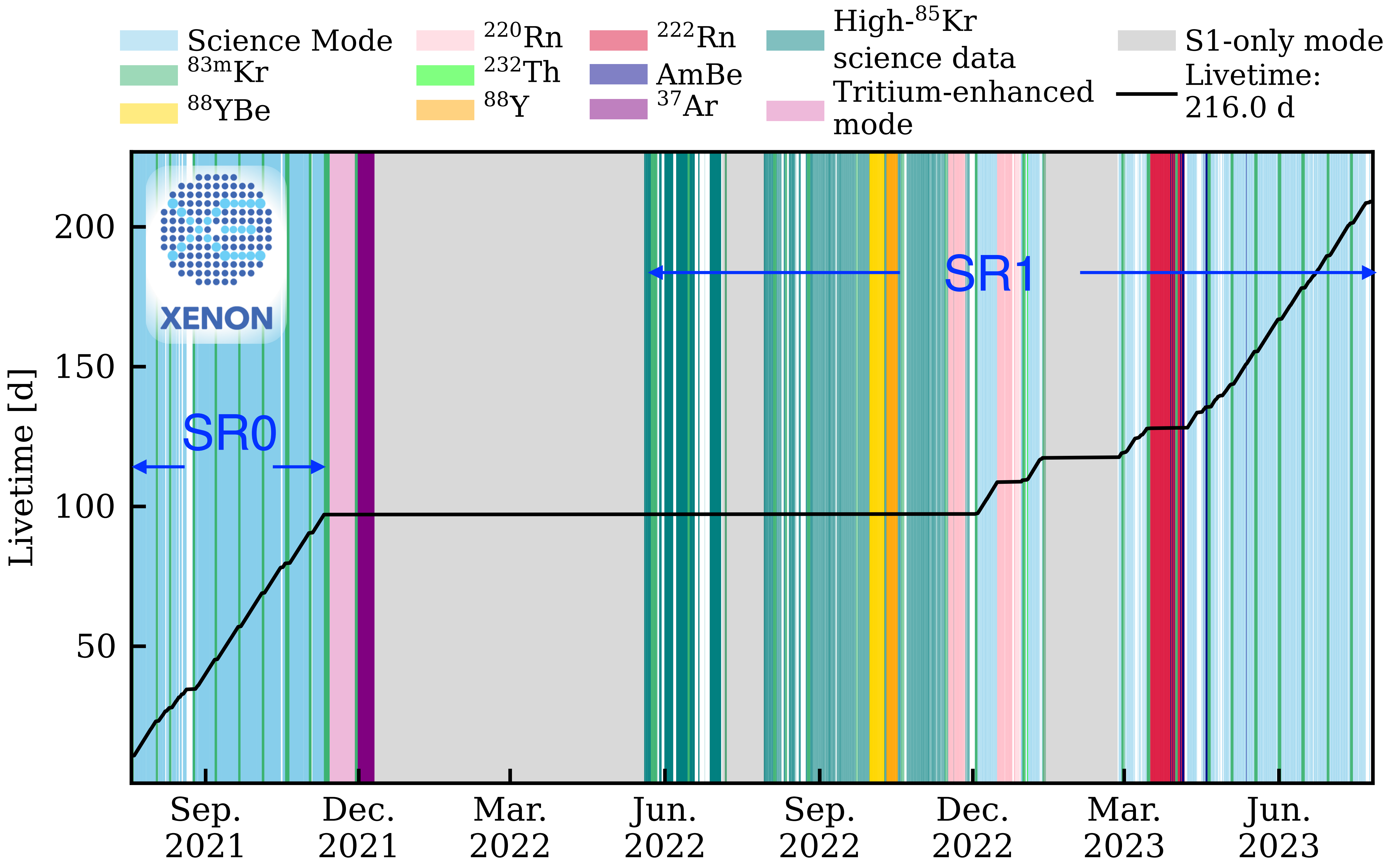
Why xenon?

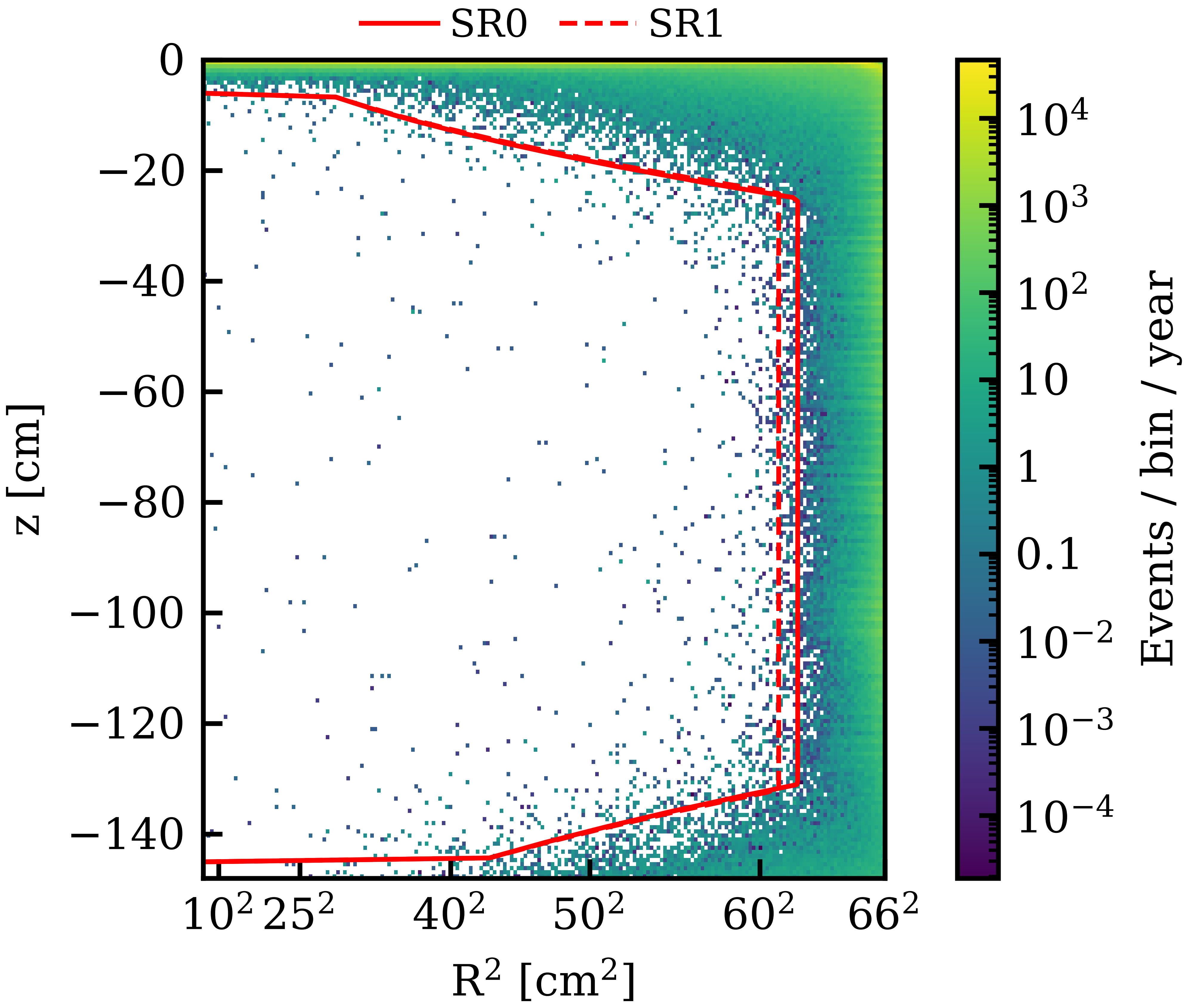
Selected Properties of Xe

Property	Value
Atomic Number (Z)	54
Atomic Weight (A)	131.30
Number of Electrons per Energy Level	2,8,18,18,8
Density (STP)	5.894 g/L
Boiling Point	−108.1 °C
Melting Point	−111.8 °C
Volume Ratio	519
Concentration in Air	0.0000087 % by volume

- exposure — Decent
- detector threshold — Low
- background — Extremely low

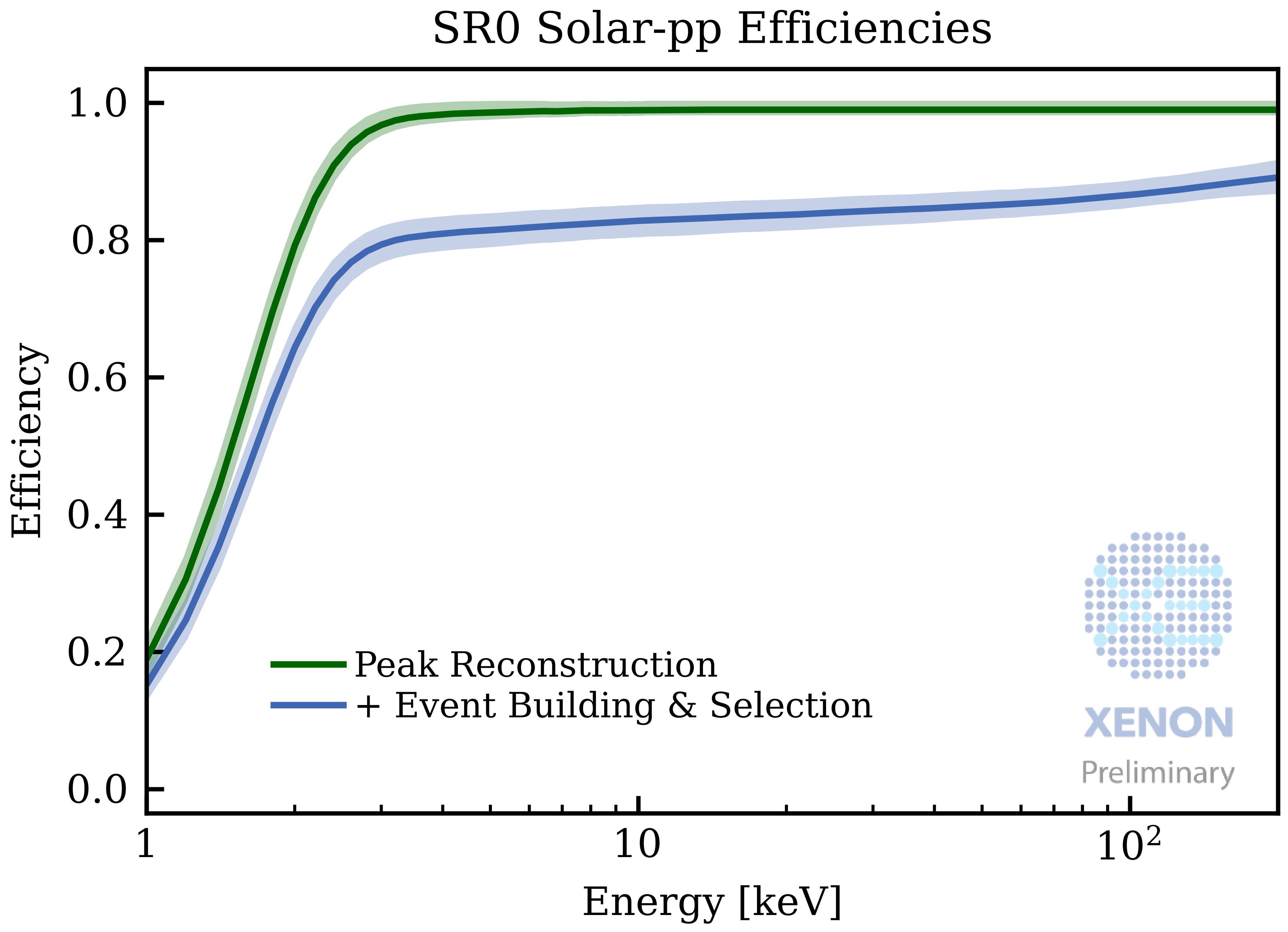
Exposure

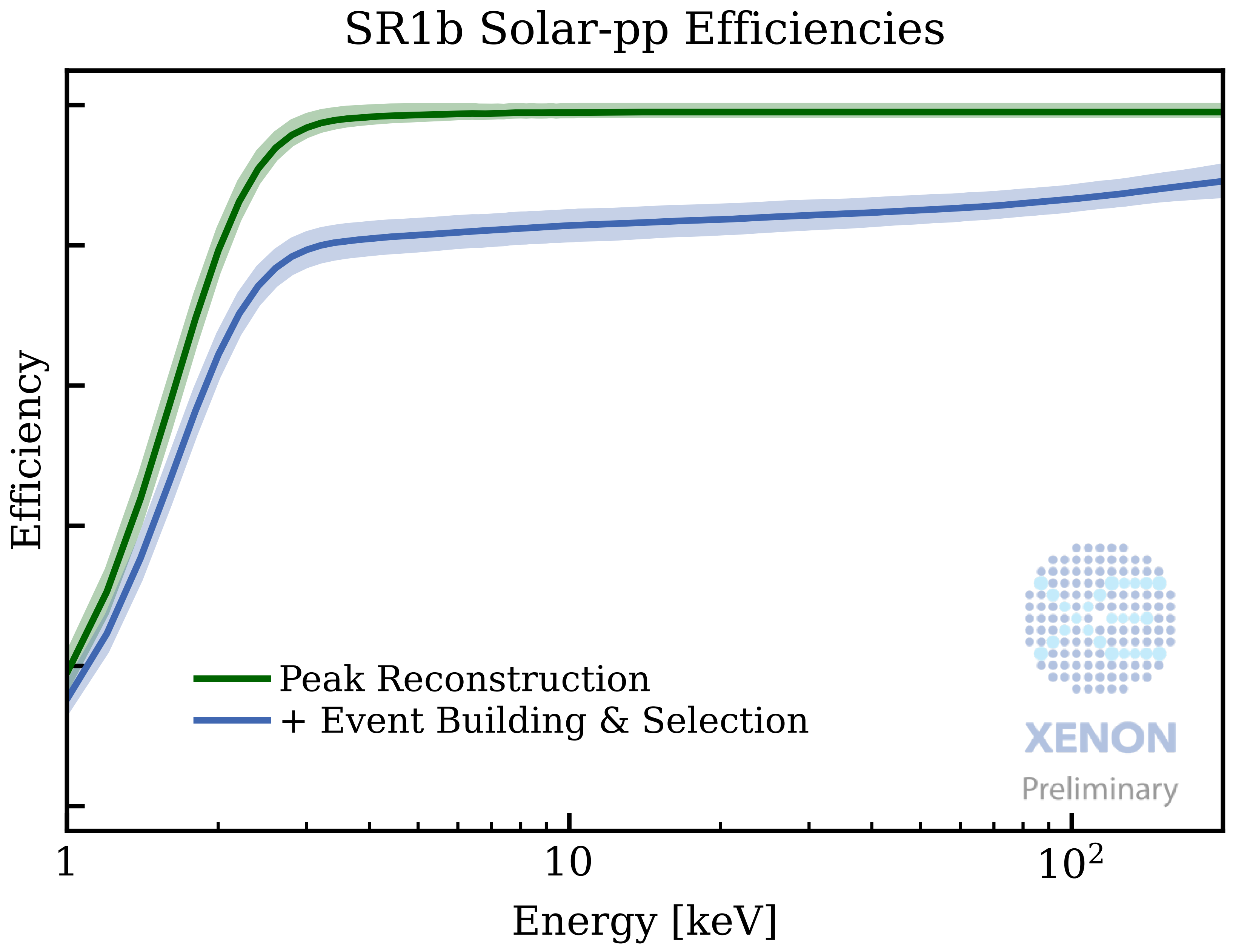


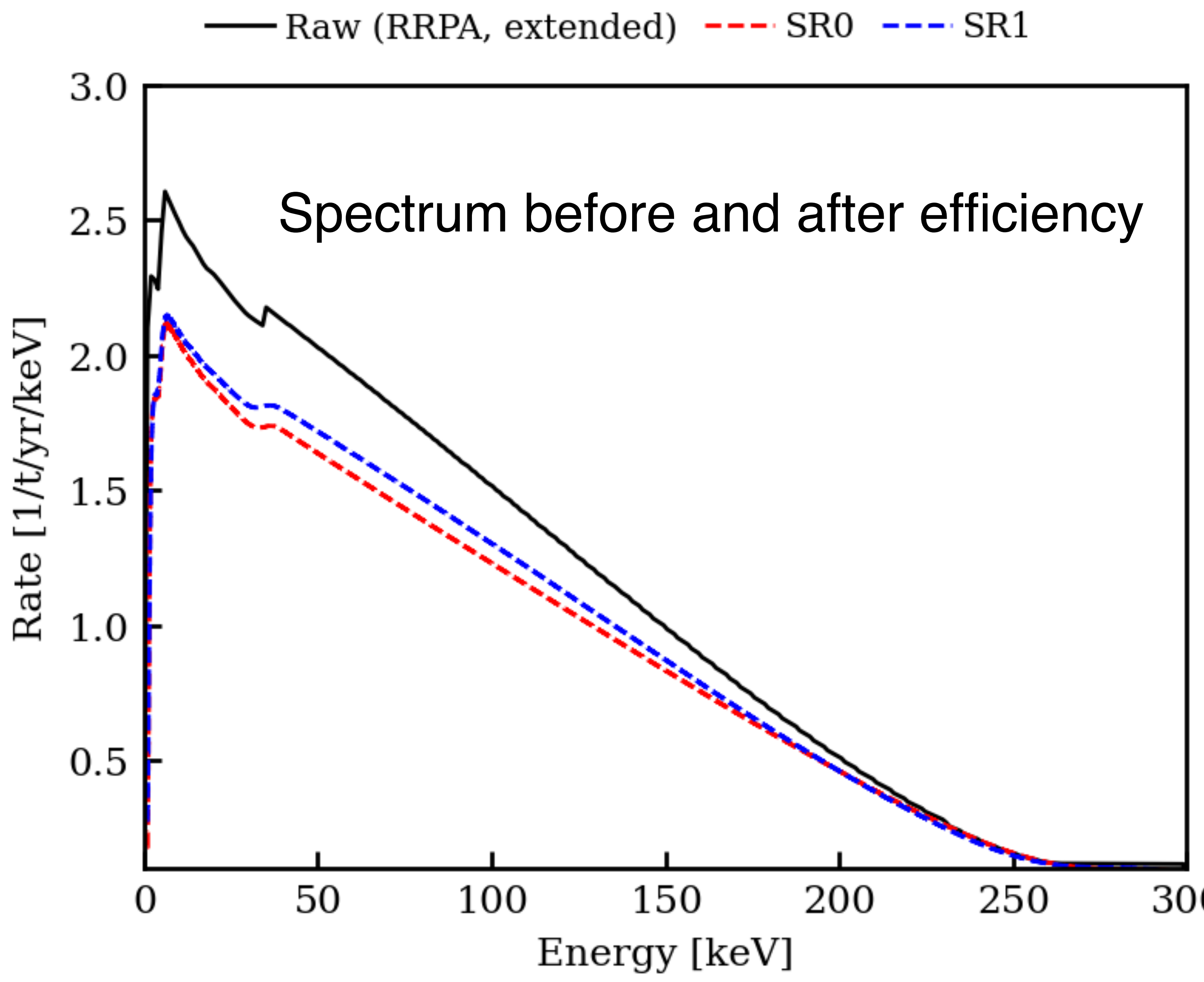


- Two science runs (216 live days)
  - Science Run 0 (SR0): Jul. 6th, 2021 - Nov. 10th, 2021
  - Science Run 1 (SR1): May. 19th, 2022 - Aug. 8th, 2023
- SR0 and SR1 fiducial volume (FV) ~4 tonnes
- Total exposure ~2.5 tonne·year

Efficiency and threshold





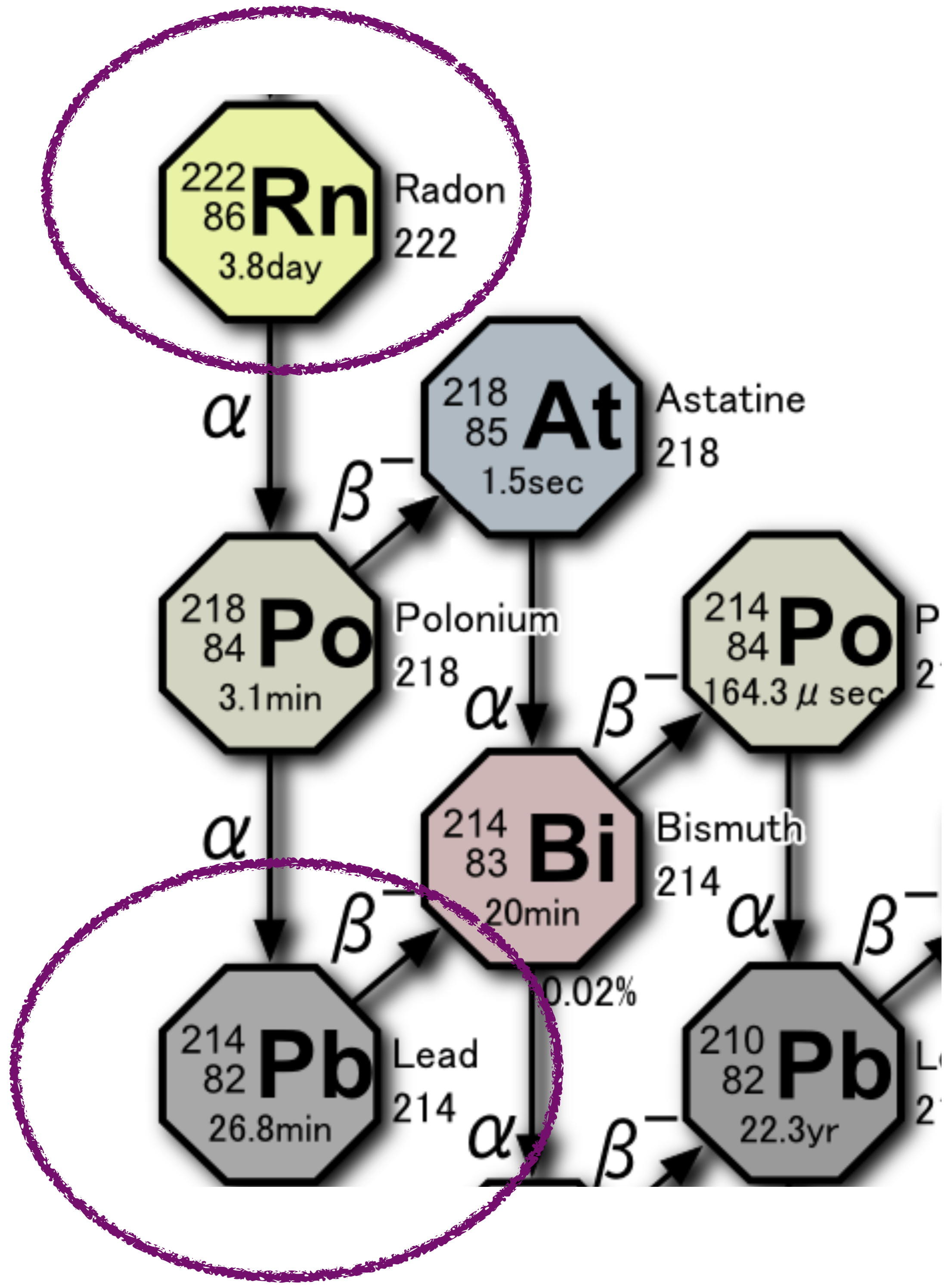


- Peak reconstruction efficiency: ability to reconstruct S1 or S2 signals
- Total efficiency > 80% after 3 keV
- 1 keV threshold for this search
    - 190 keV threshold for Borexino search (2018)

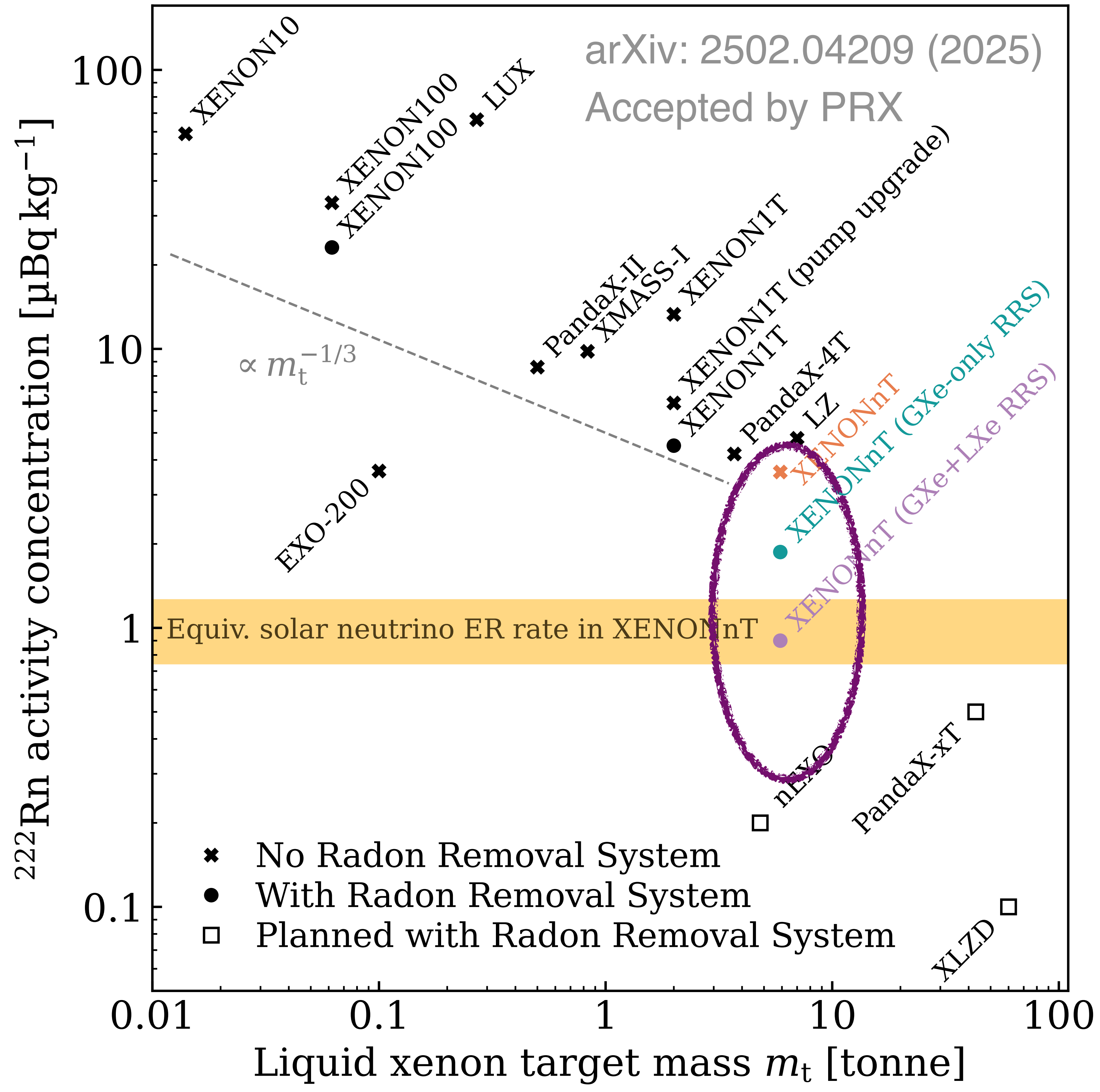
detector threshold

Pb214 background - reduction

Rn-222 decay chain



Radon Distillation Column

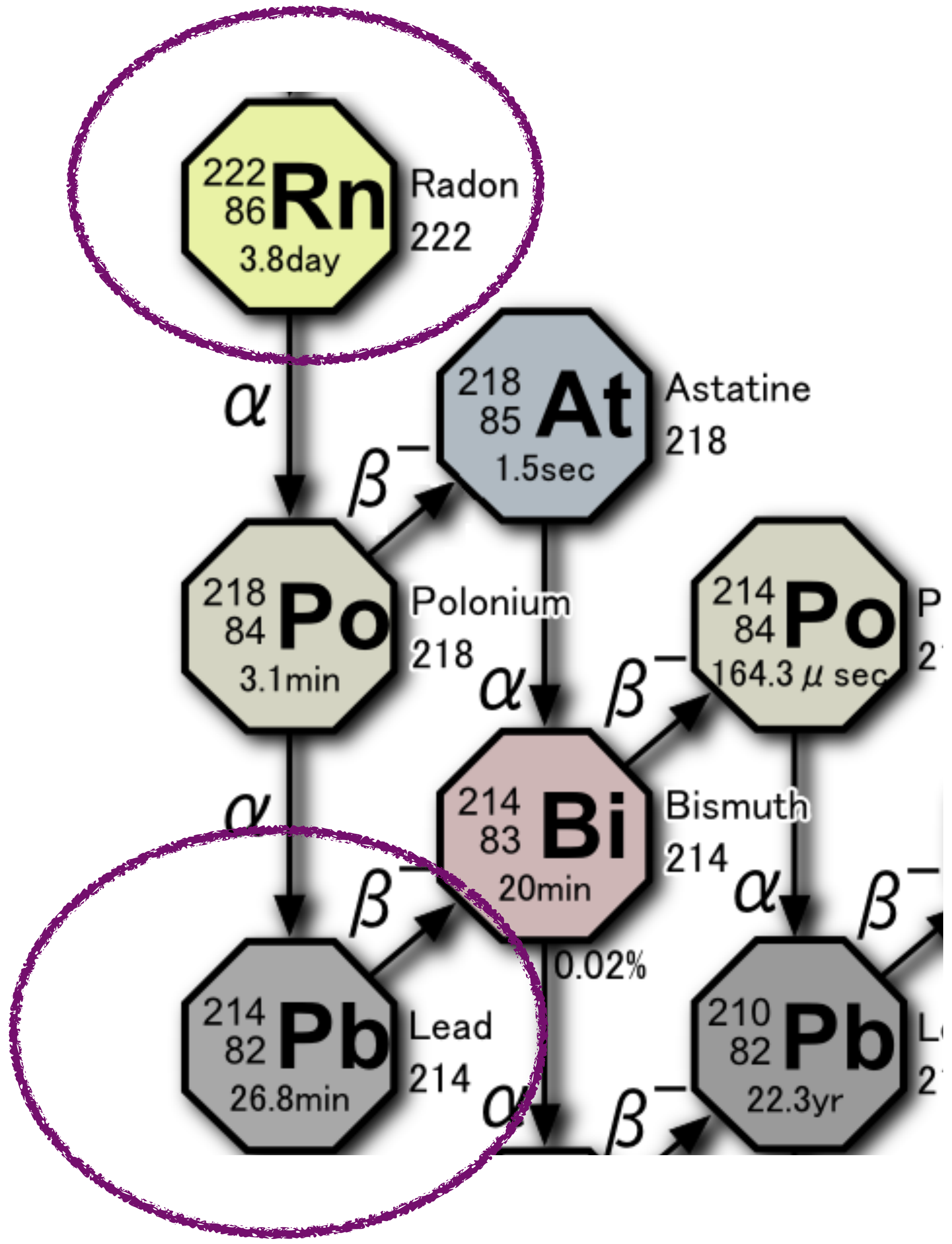


- Pb-214 from the Rn-222 decay chain has a significant contribution to ER backgrounds.
- Radon distillation column: reduce Radon exploiting difference in vapor pressure of Xe and Rn
  - SR0: 1.9 uBq/kg
  - SR1: 0.9 uBq/kg. Comparable level to solar neutrino background.

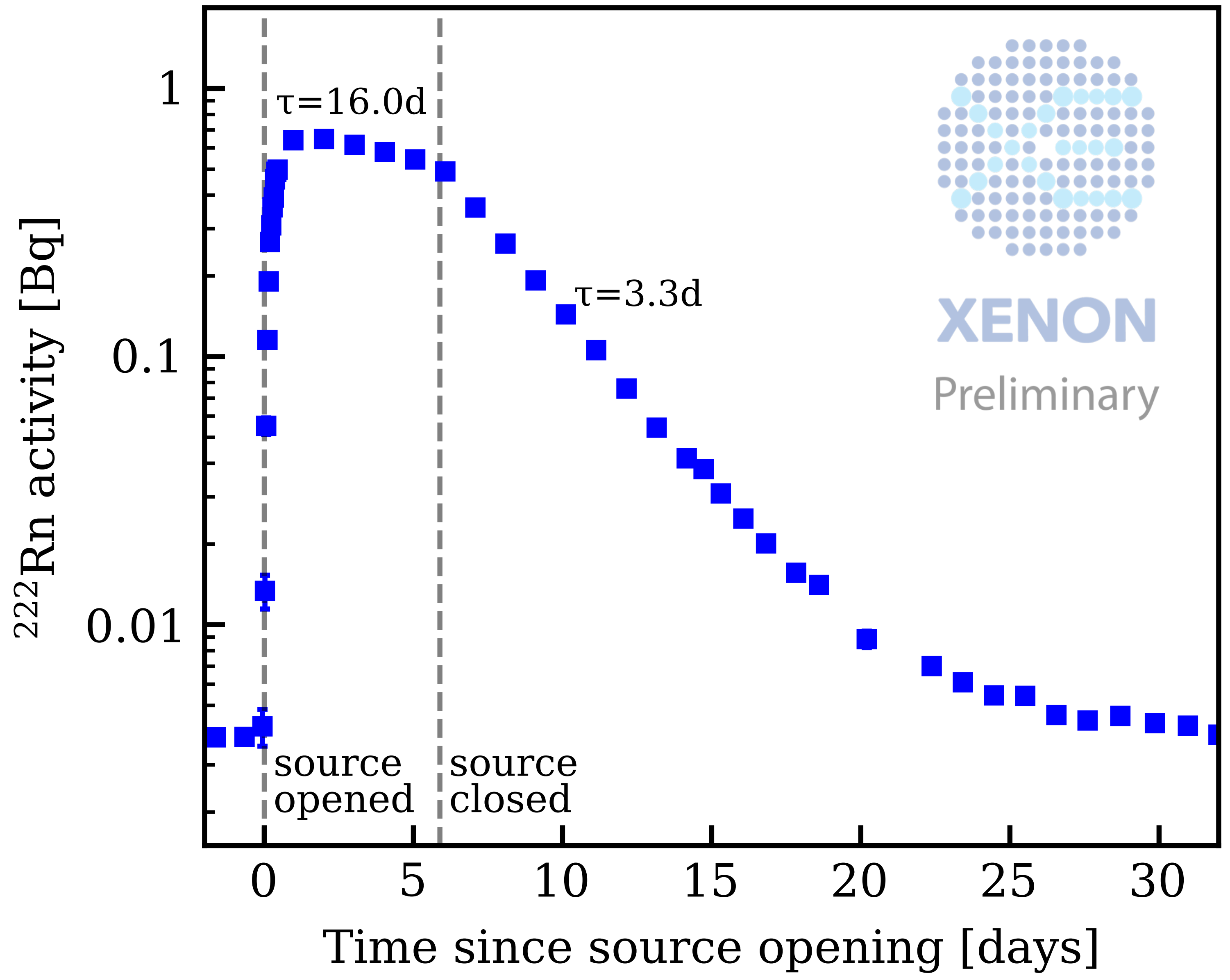
background

Pb214 background - constraints

Rn-222 decay chain

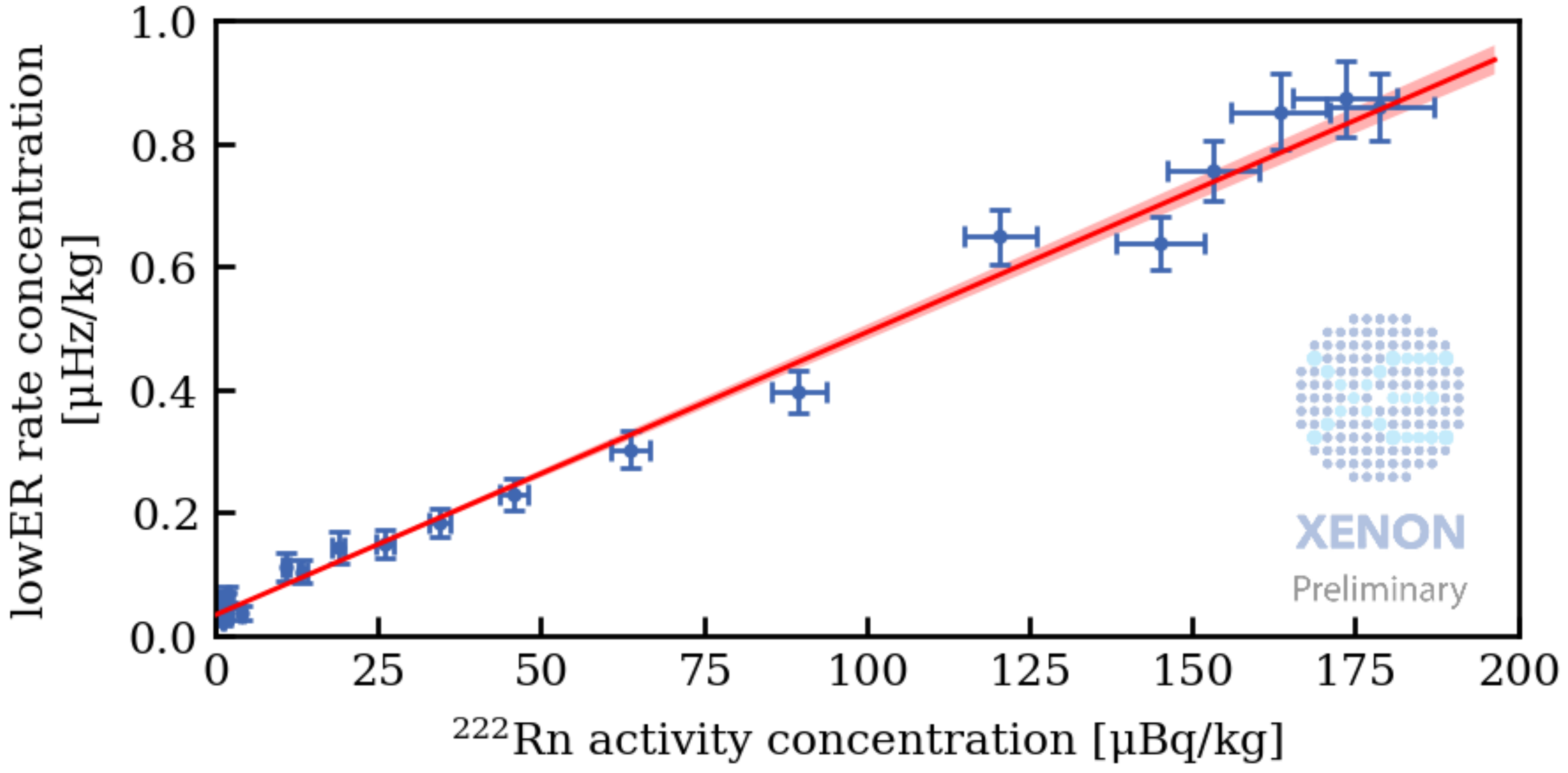


Rn-222 calibration



Event rate = $R_{\text{Pb214}} + b$

$= r \cdot R_{\text{Rn222}} + b$

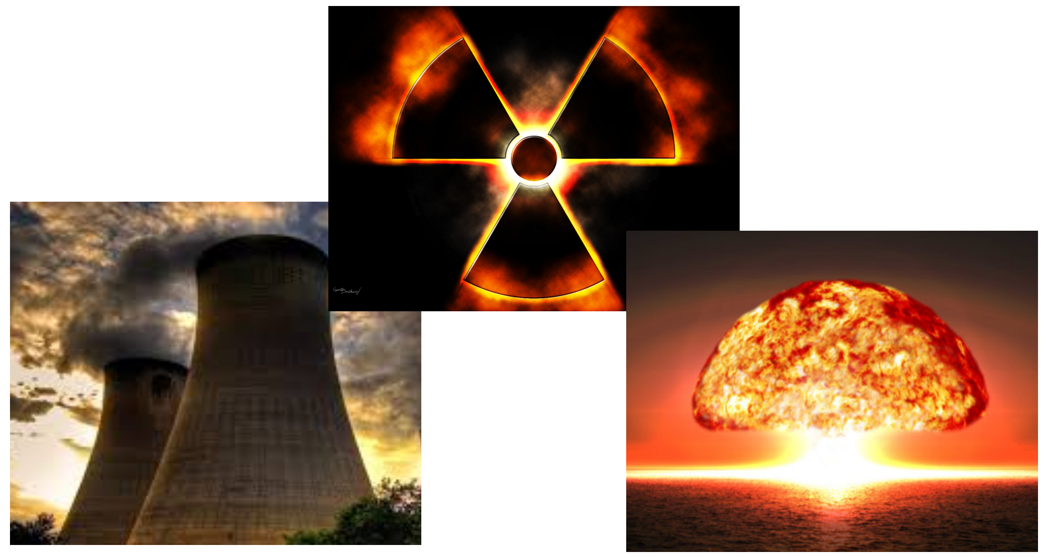


- Rn-222 alpha rate can be precisely measured, but Pb-214 rate is not
- Rn-222 calibration: constrain the Pb-214/Rn-222 ratio to constrain Pb-214
- Measured ratio during Rn-222 calibration: 0.67 +/- 0.03

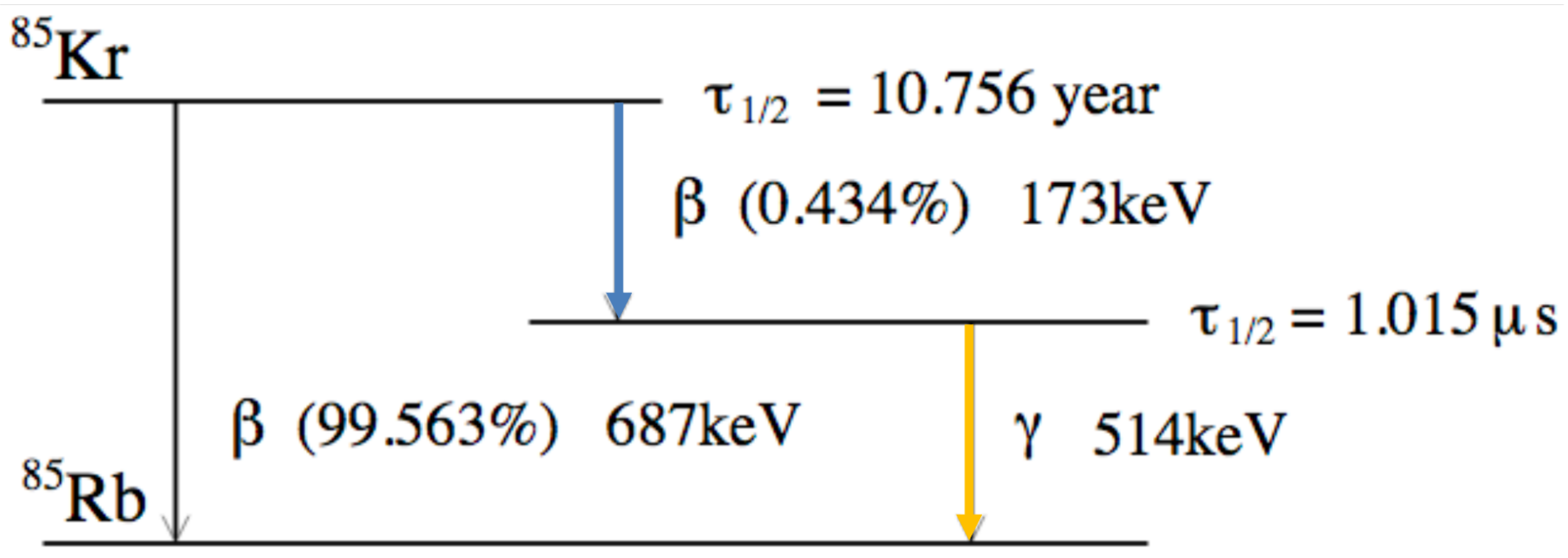
background

Kr85 background

Kr-85 source



Delay coincidence



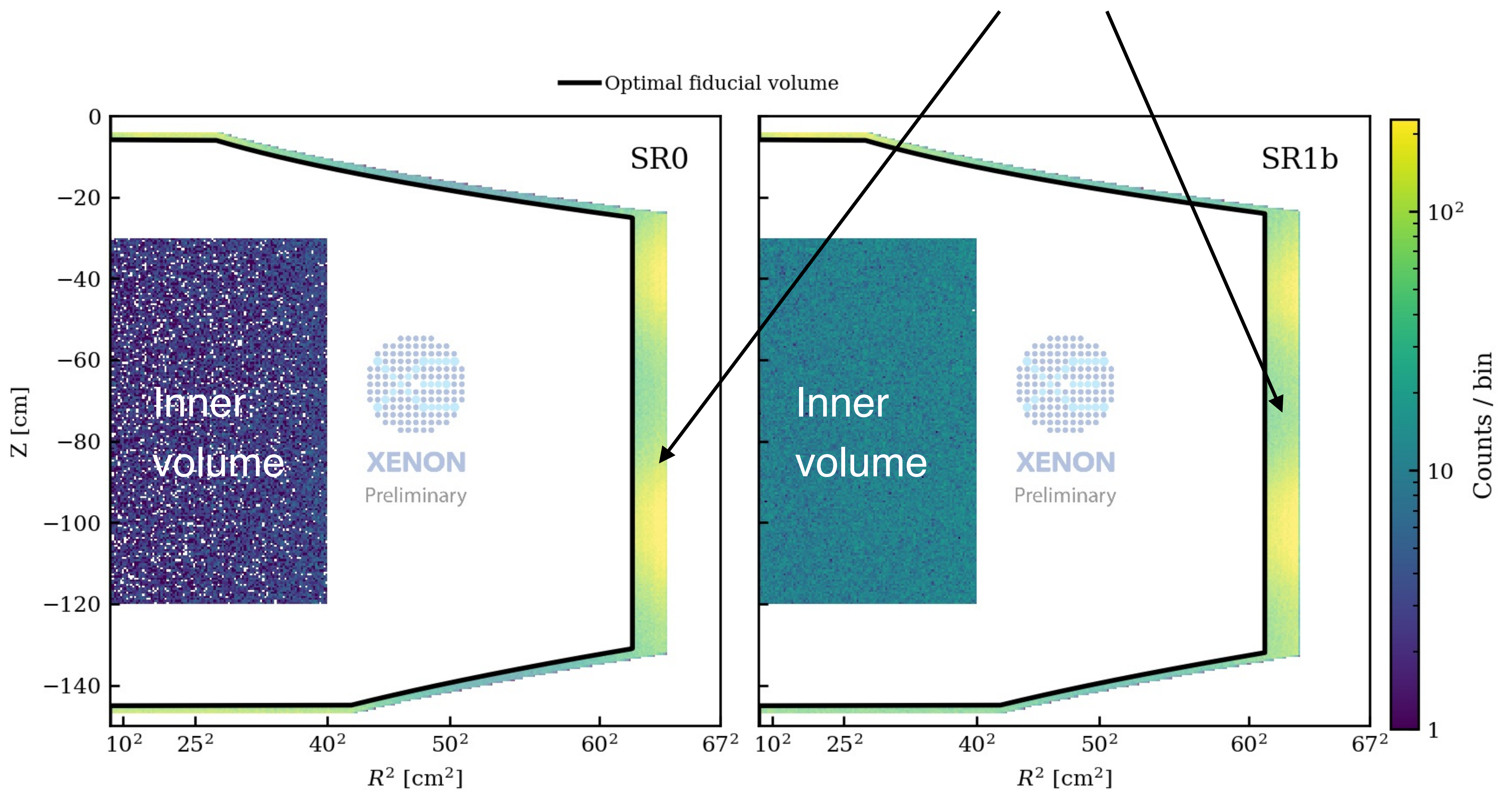
Krypton Distillation Column

- Anthropogenic radioactive isotope
- Kr reduction: Krypton distillation column
- Kr-85 constraint
  - Natural Kr measurement using rare gas mass spectrometer (RGMS) + Kr-85/nat Kr ratio
  - Delay coincidence (beta + gamma). See Y. Kaminaga's poster for more details.

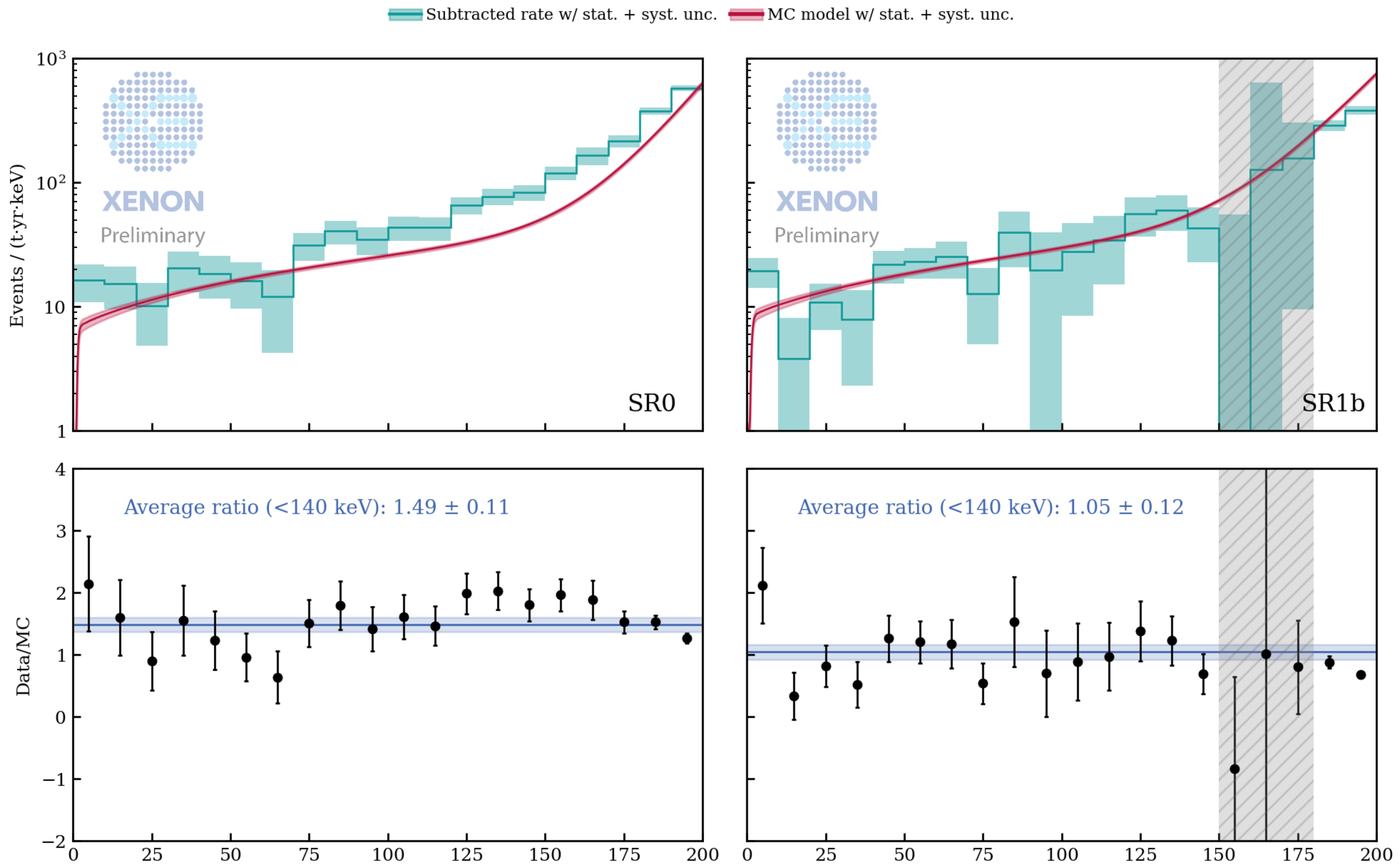
background

Material background

Edge volume



Data-MC comparison in edge volume

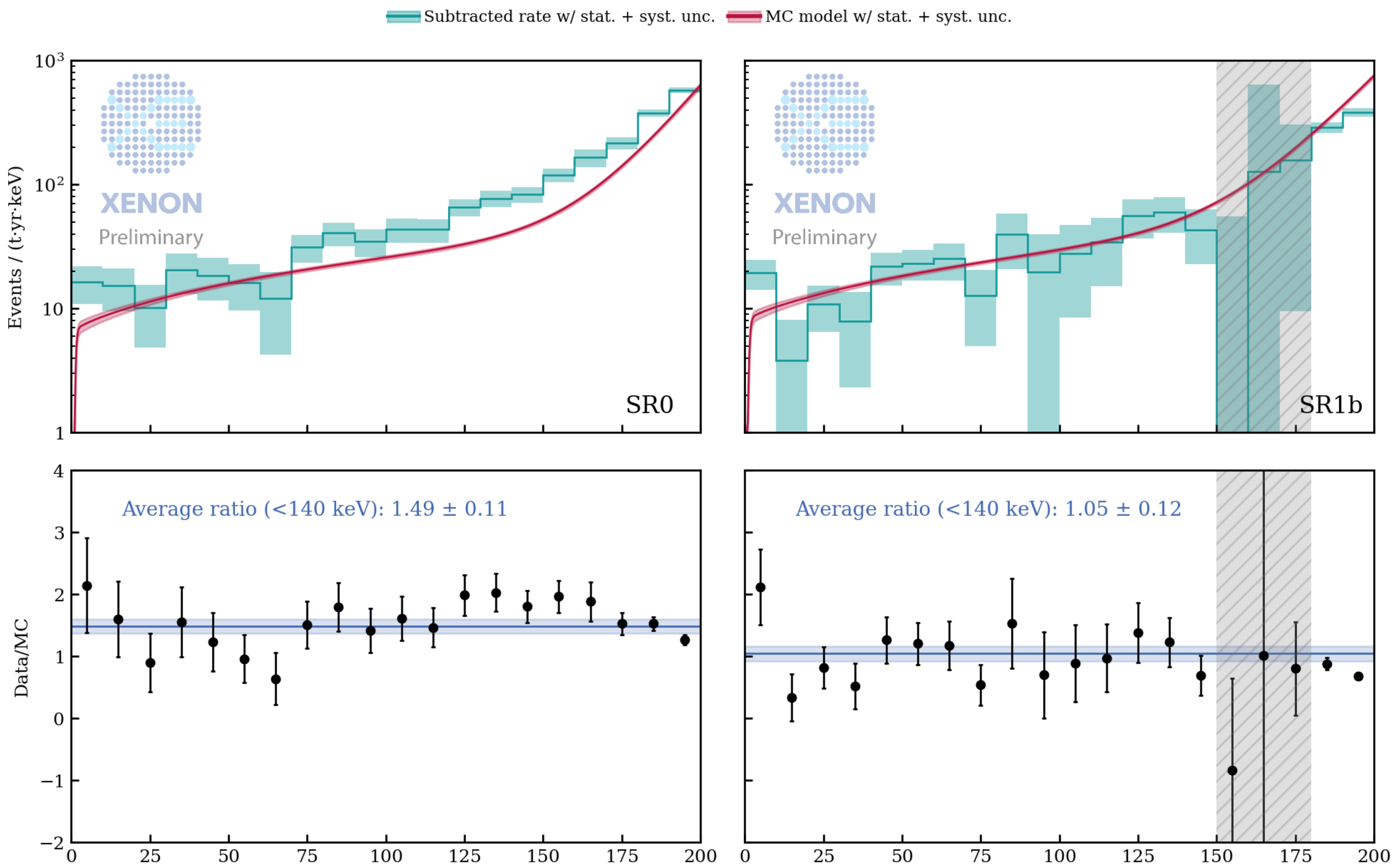


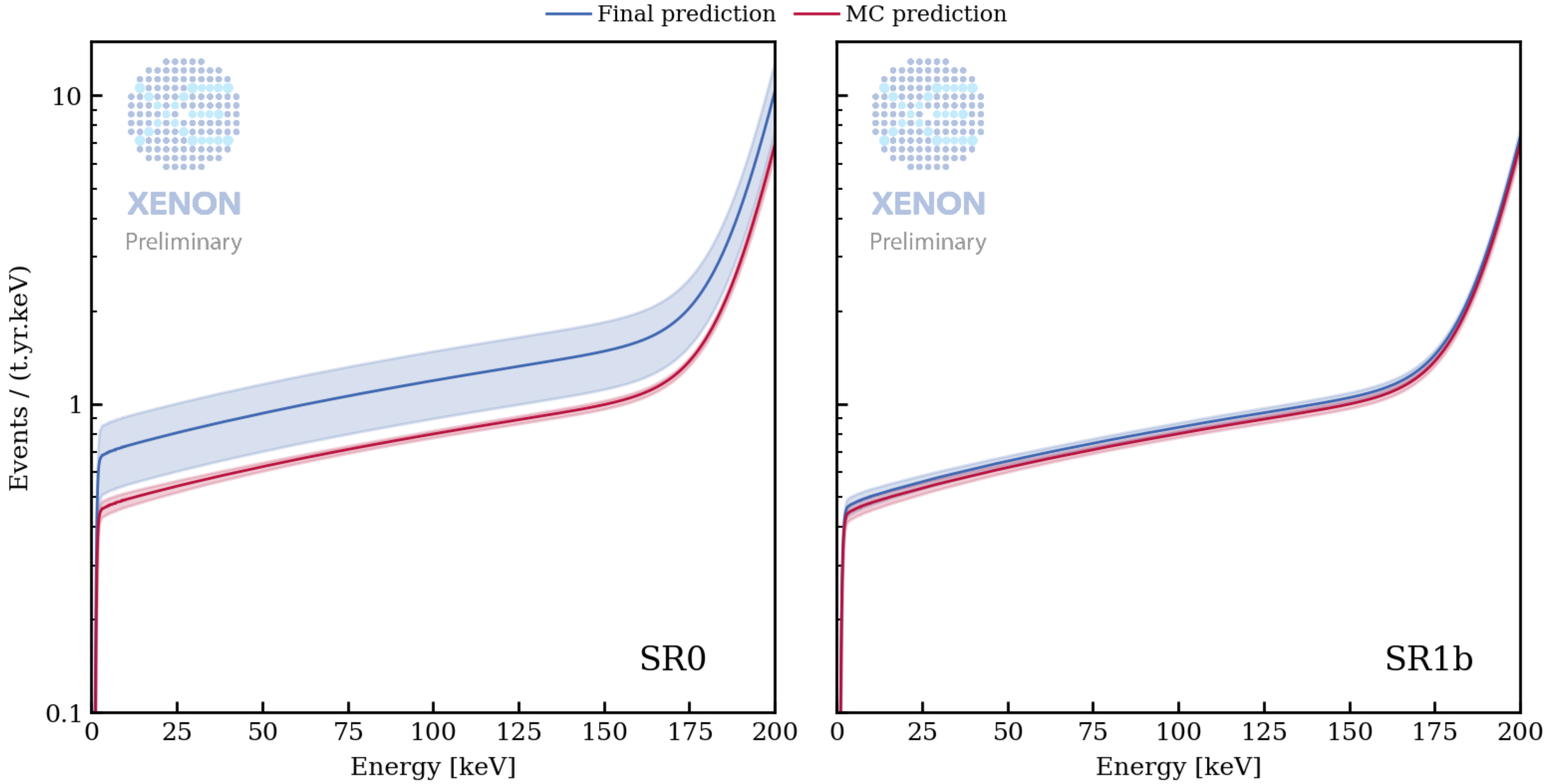
- Material backgrounds: Compton scattering of gammas from detector materials
- Reduction: careful material selection and screening [XENON, EPJC 82, 599 (2022)]
- Constraint: Data-MC comparison in the edge volume (2 cm outside FV)
  - MC: simulation using screening inputs
  - Data: edge volume - inner volume

background

Material background

Data-MC comparison in edge volume





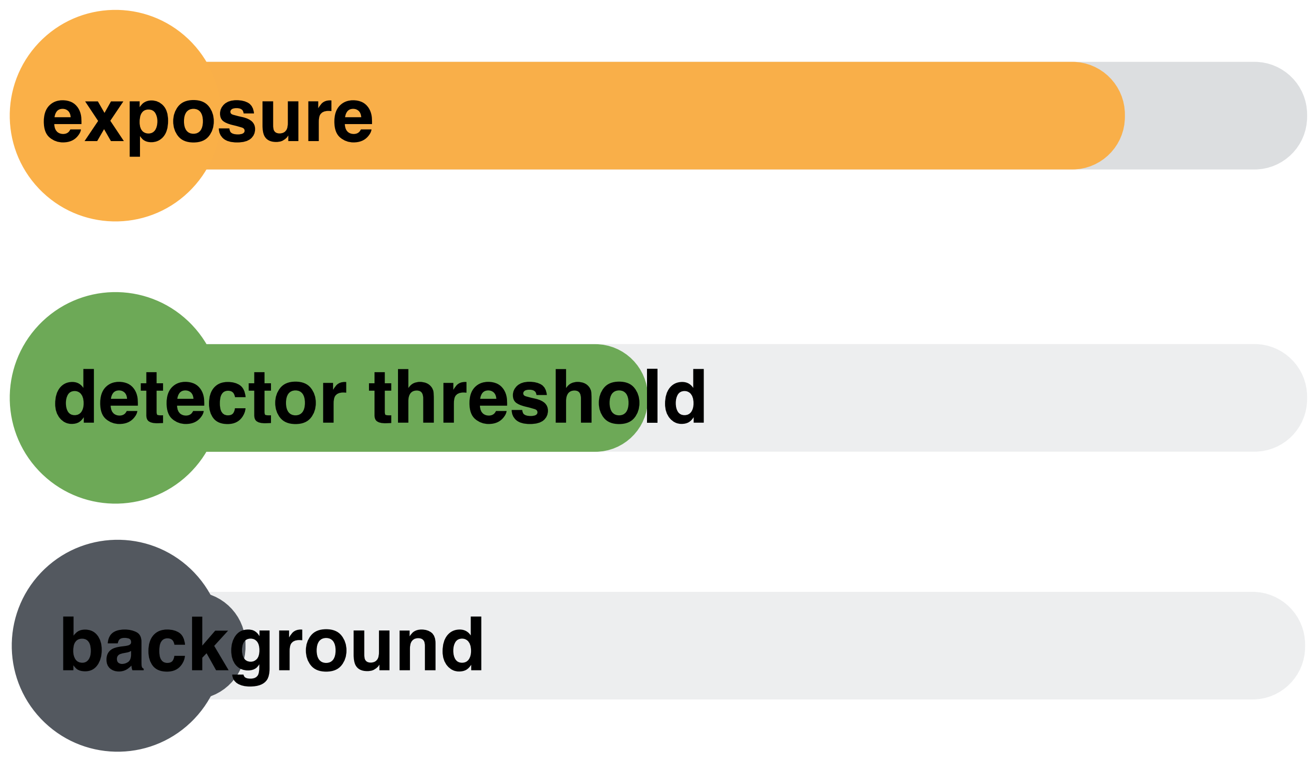
- Data higher than MC by a factor of 1.49 (1.05) in SR0 (SR1)
- Final prediction
  - Rate: scale MC result with the factor above
  - Uncertainty: statistical (simulation) and systematics (data-MC difference)

background

Summary

- Xenon detectors are suitable for searching solar pp neutrinos, as it has decent exposure, low threshold, extremely low backgrounds
- Dominant contributor of backgrounds for this search in XENONnT, Pb-214 from Rn-222 decay chain, has been reduced to a level where its contribution is similar to solar pp neutrinos below 10 keV.
- A dedicated Rn-222 calibration was performed to further constrain the Pb-214 background.
- Kr-85 background model ongoing, and improved modeling of material backgrounds.

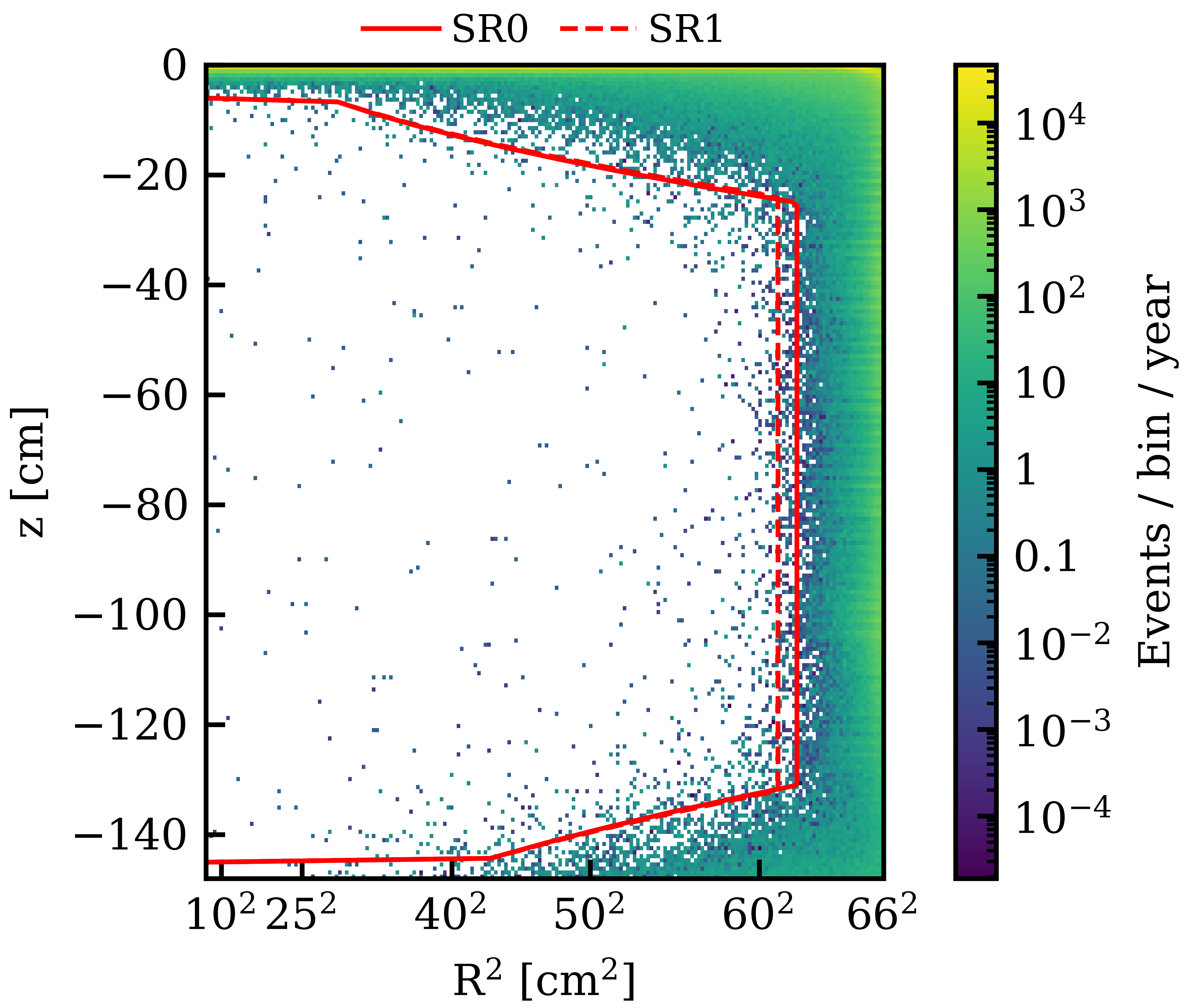
Stay tuned!



- O(tonne·year)
- 1 keV
- Extremely low

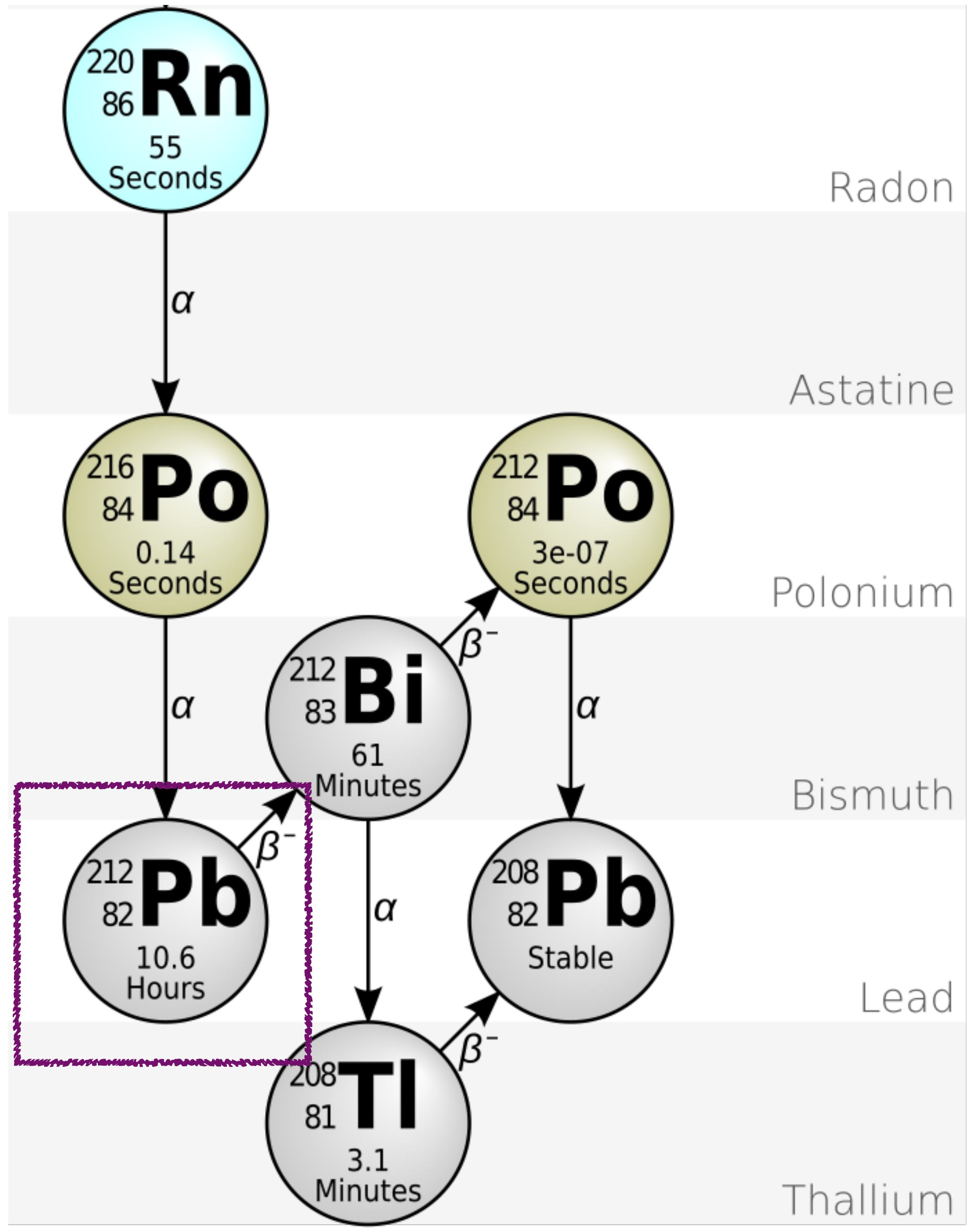
Back up

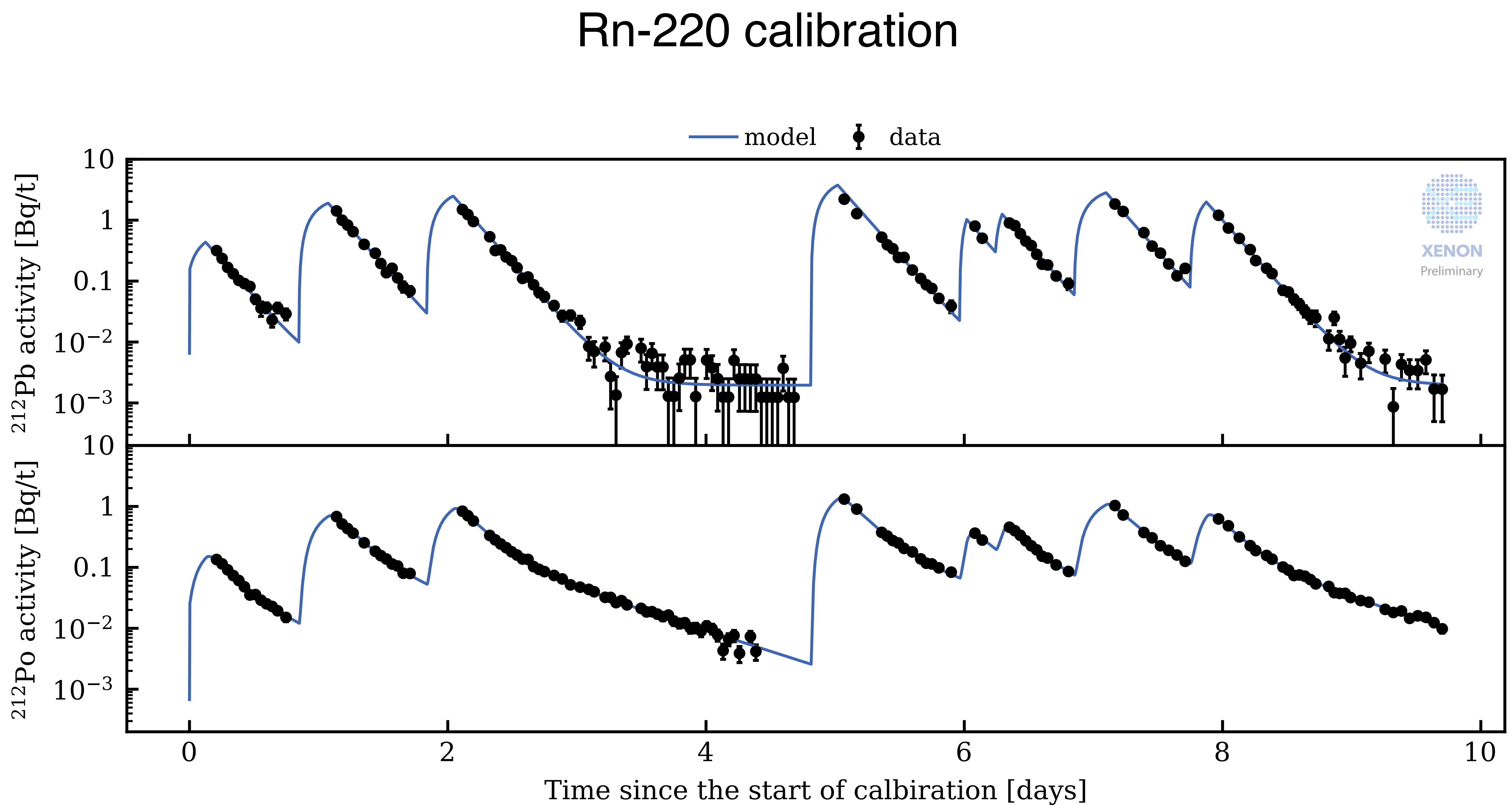
Fiducial volume



- The fiducial volumen (FV) for this search is largely driven by material backgrounds.
- SR0 and SR1 FV share similar shapes, with the mass as follows:
  - SR0: (4.13 +- 0.12) tonne
  - SR1: (4.24 +- 0.23) tonne
- SR0 and SR1 have different ways to account for the charge-insensitive volume, which makes SR0 FV look 'larger'.
  - SR0: indirectly in FV mass calculation (about 4% decrease)
  - SR1: directly in position correction

Pb212 background

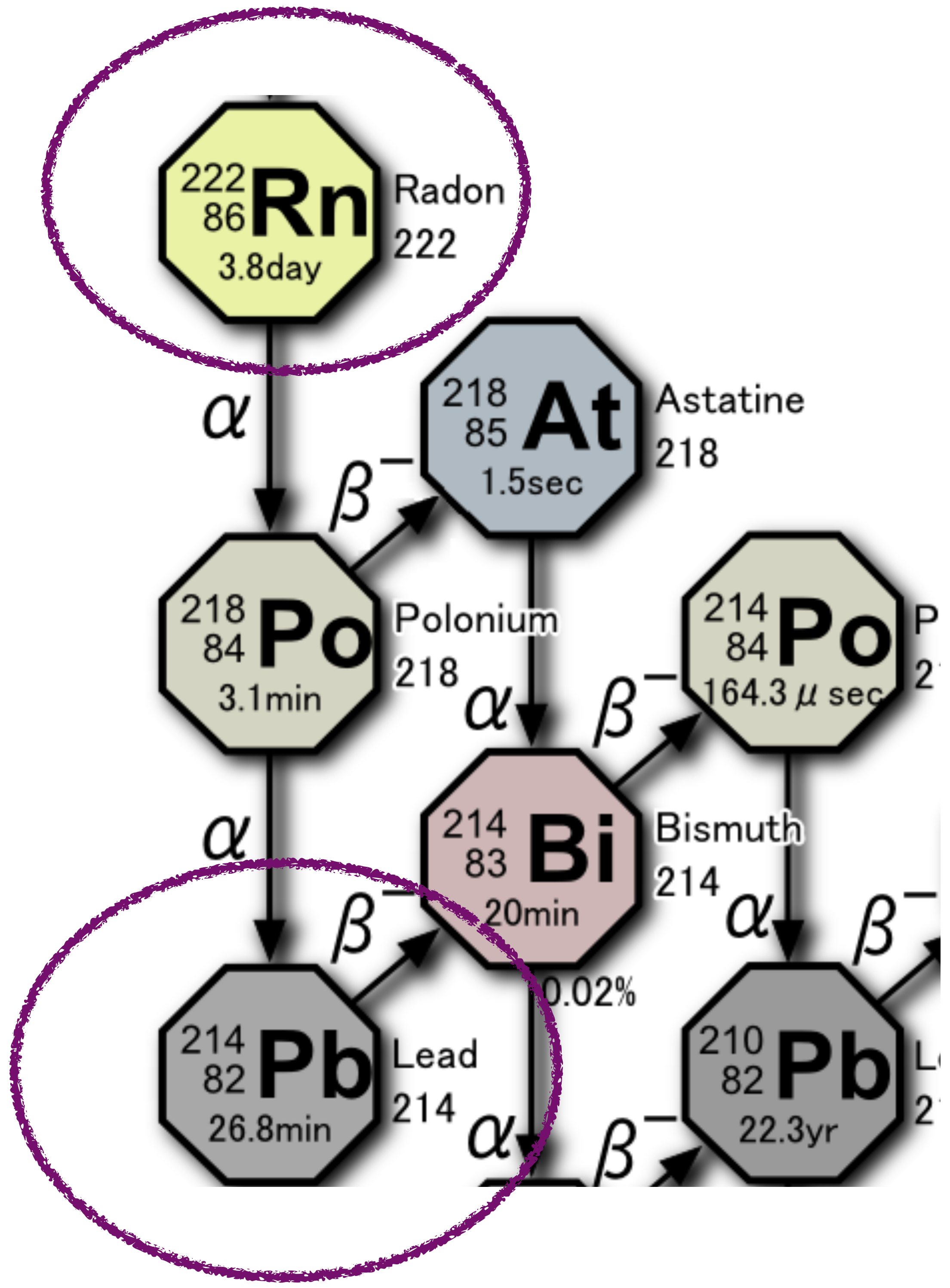


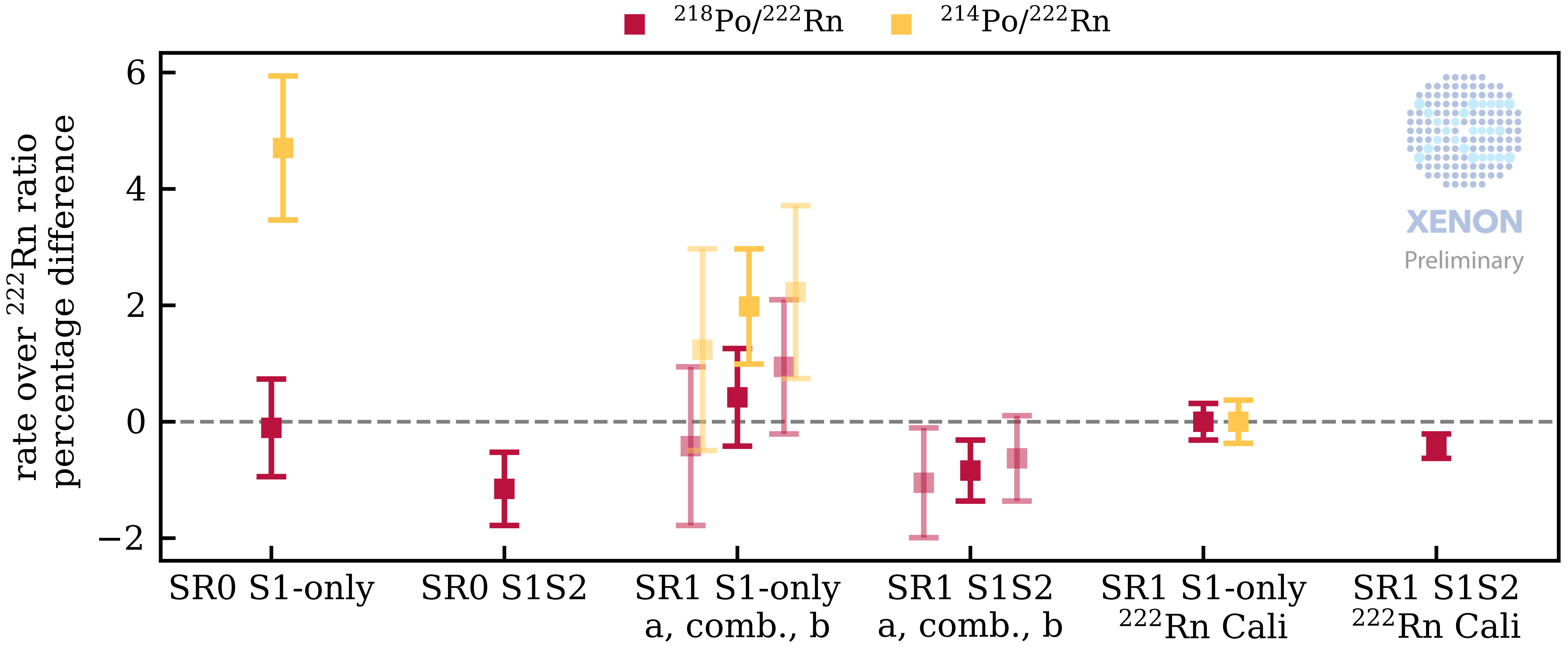


- Beta decay of Pb-212 from the Rn-220 decay chain could also contribute to ER background
- Pb-212 has relatively long half-life (10 hours) and may plate out on detector materials such as PTFE
- A plate out model is established using Rn-220 calibration data, which allows for constraining the Pb-212 background rate using the Rn-220 alpha rate that is easy to measure.

Plateout for Rn222 chain

Rn-222 decay chain





- Po-214/Rn-222 ratio is (almost) consistent between SR0, SR1, and Rn-222 calibration in SR1
- Po-218/Rn-222 ratio is not consistent, which may indicate different plateout effects in different periods.

Efficiency for SR0 and SR1