Search for inelastic WIMP-nucleus scattering with XENON1T

Adam Brown
University of Zurich

University of Zurich UZH

Xe XENON Dark Matter Project

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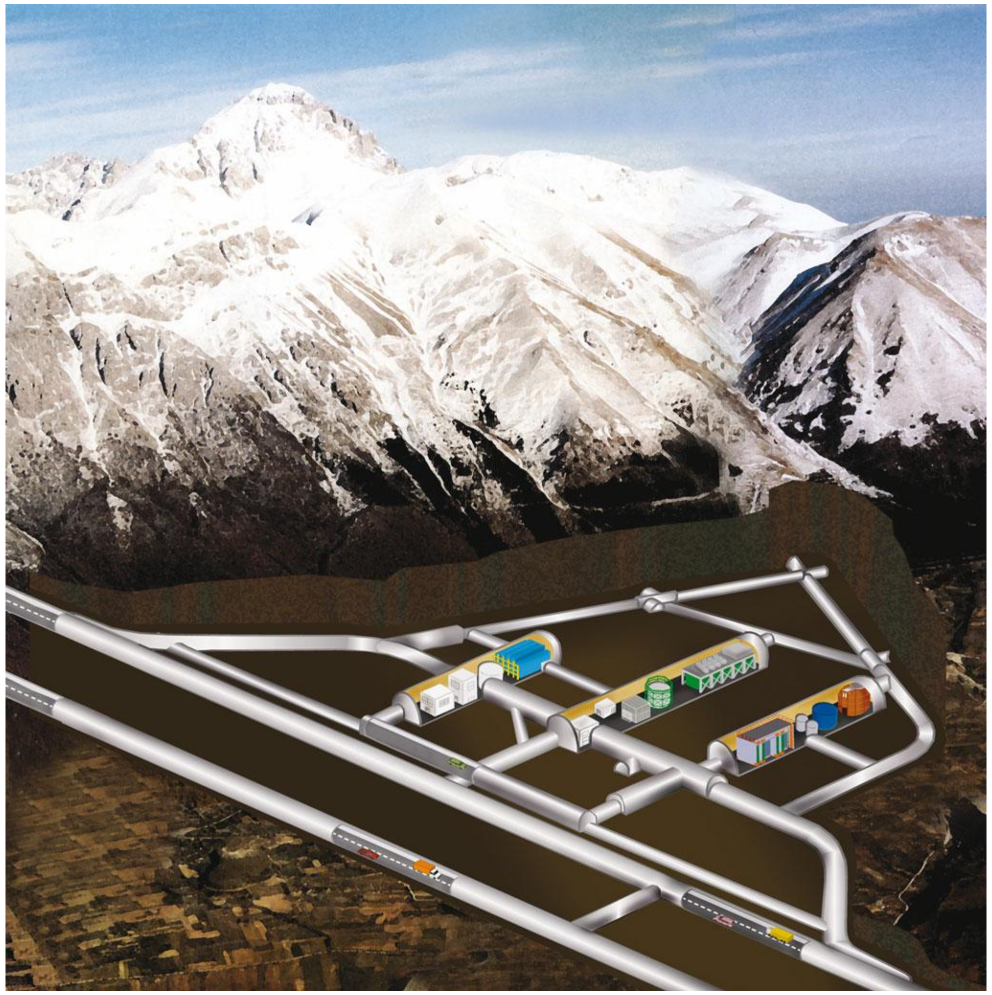
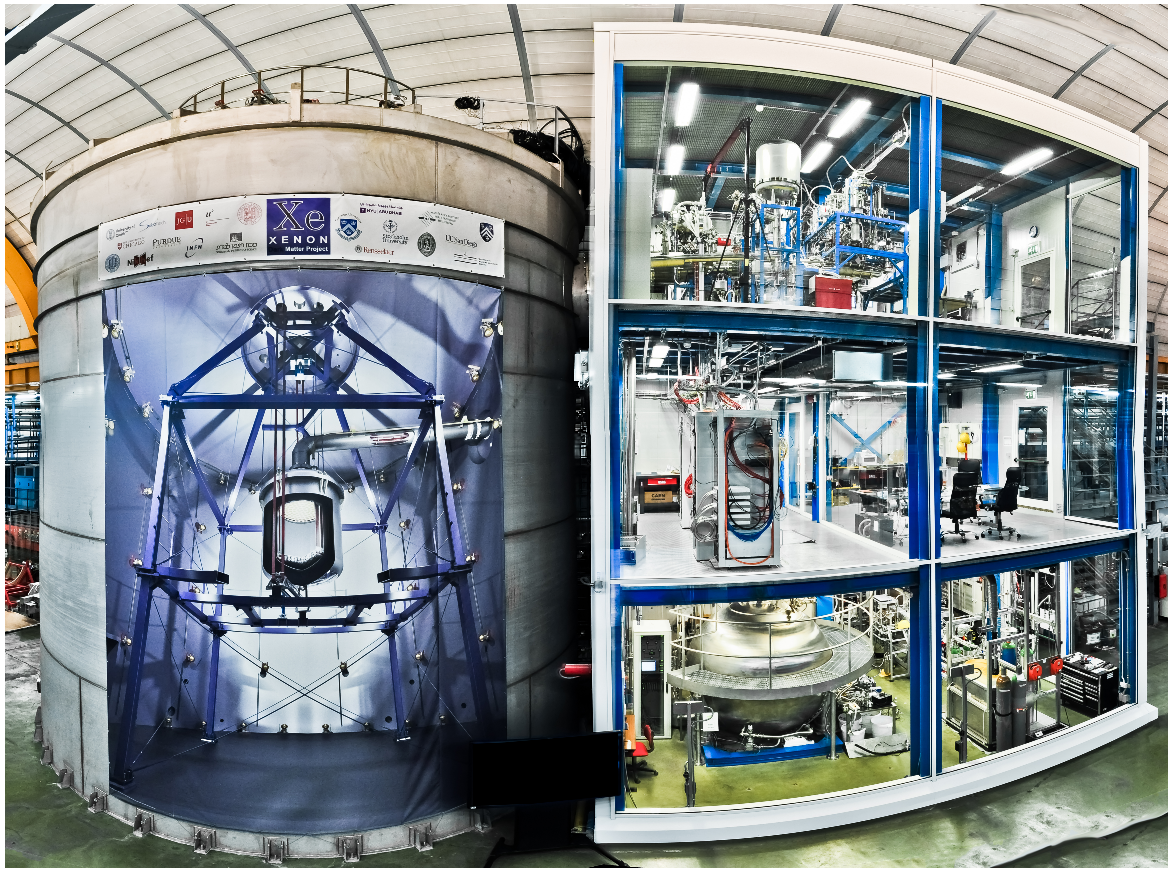
The XENON experiment and collaboration



- ~150 scientists at 27 institutions
- Detector at LNGS, Italy
- Buried under ~1400 m of mountain equivalent to 3600 m water
- See it on Google Street View: https://tinyurl.com/lngstour

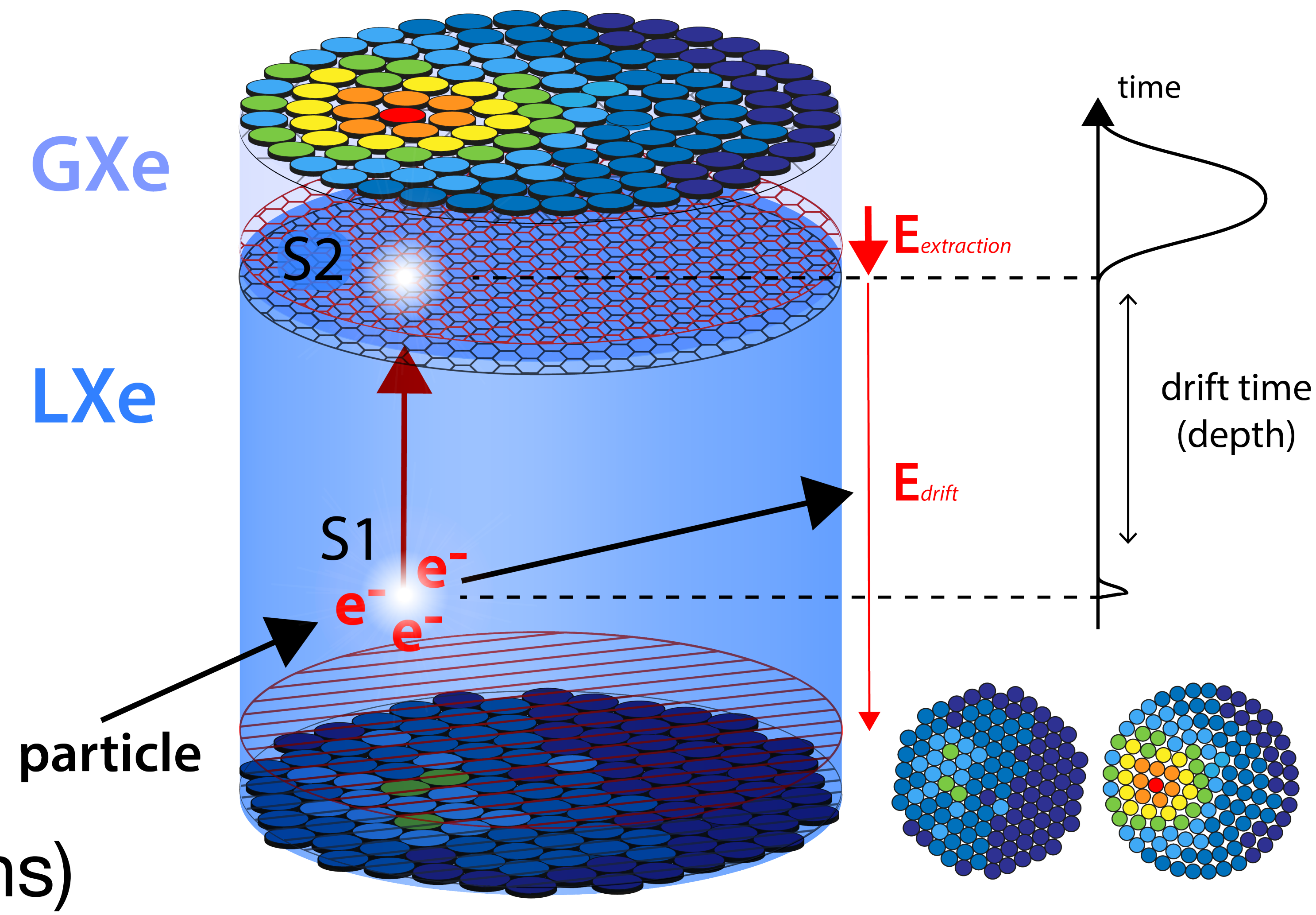


- ~ 1 x 1 m cylindrical liquid xenon time-projection chamber (TPC)
- Total 3.2 t of xenon
  2.0 t instrumented in TPC

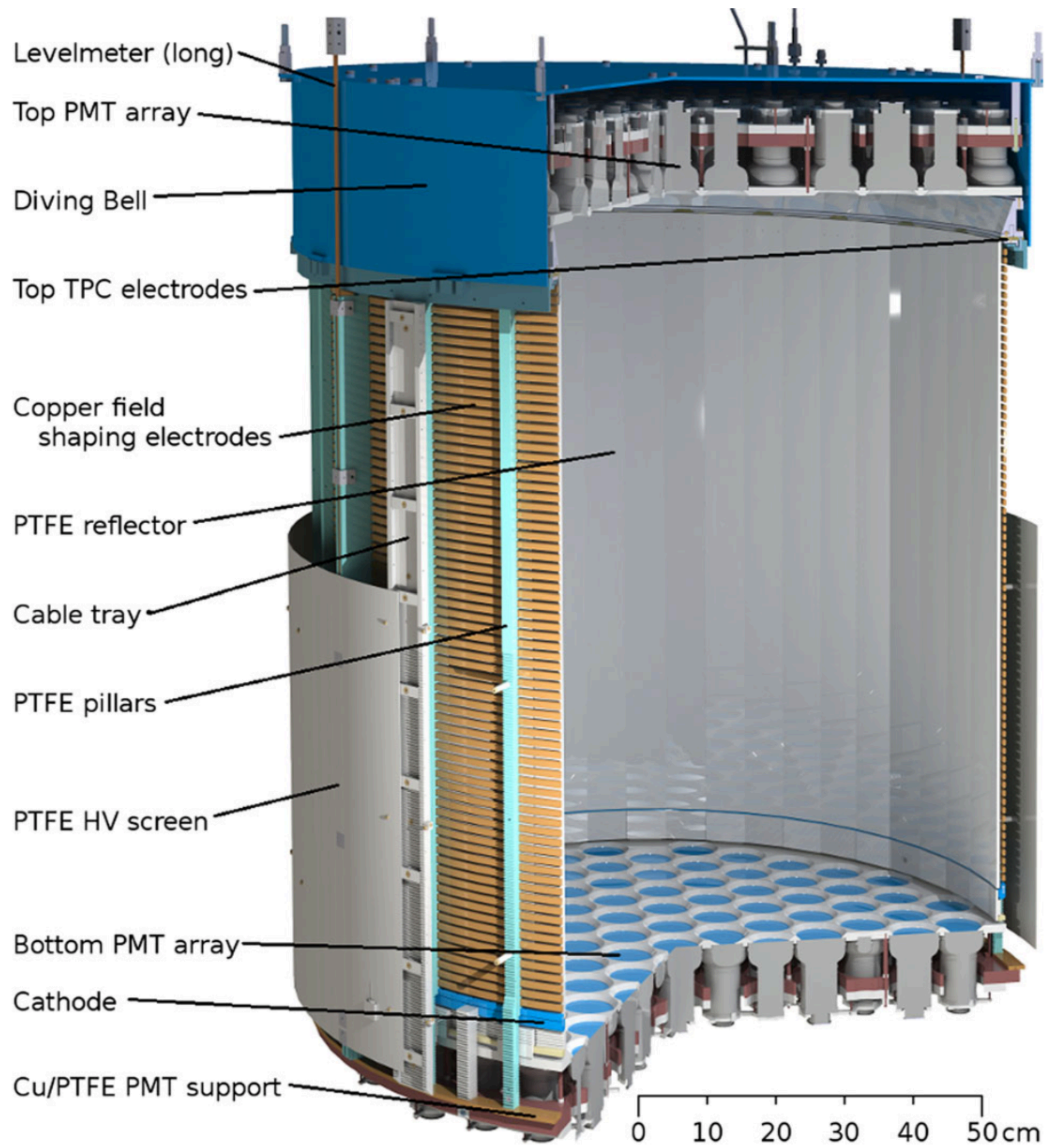
XENON1T instrumentation paper: Aprile *et al.*, Eur. Phys. J. C 77, 881 (2017)

Two-phase TPC operating principle

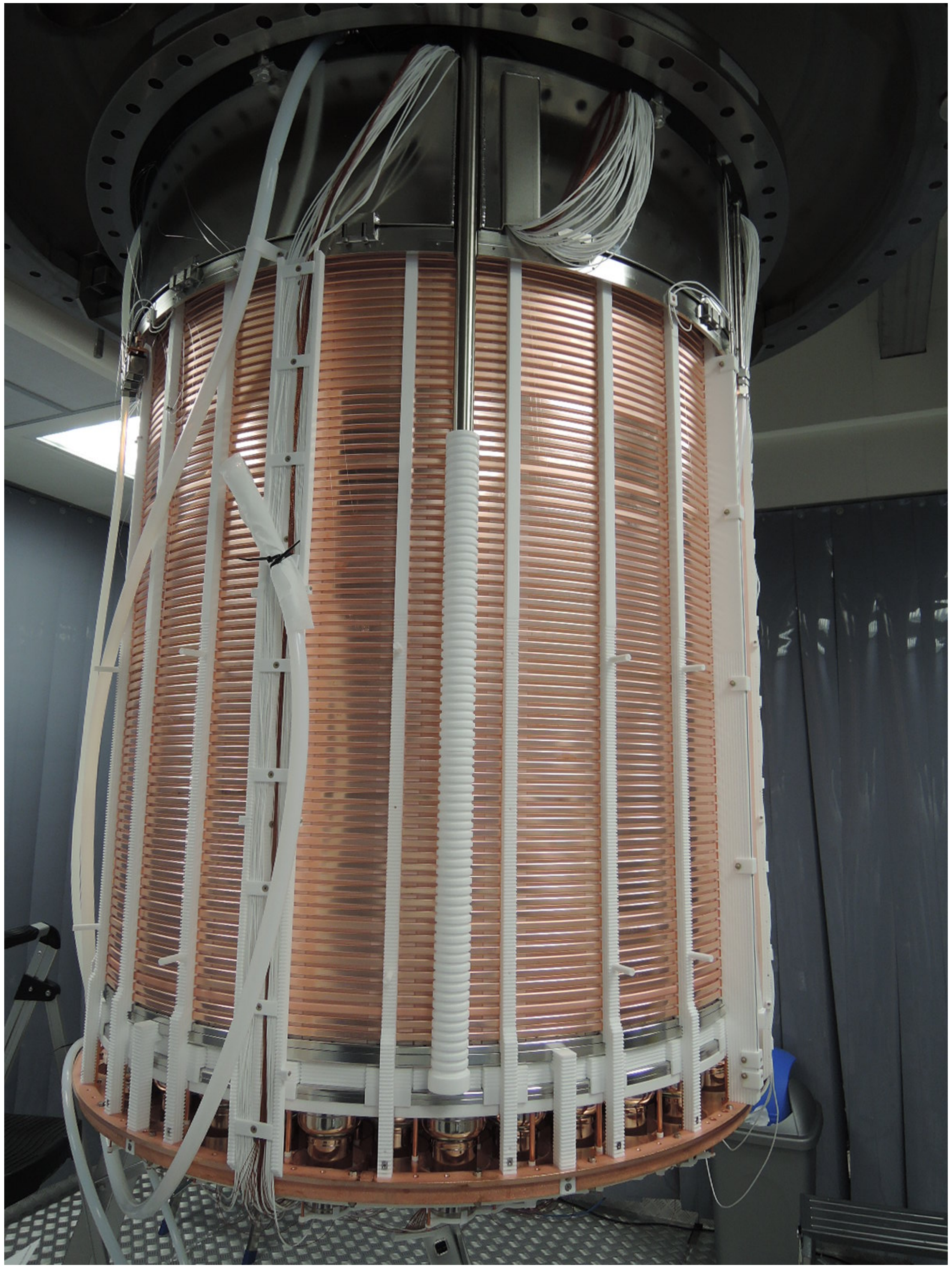
- Particle interaction causes primary scintillation light (S1) and ionisation of xenon atoms.
- Electrons drift upwards in field to gas/liquid boundary
- Xe—e⁻ collisions in gas $\Longrightarrow$ excited gas xenon (S2)
- Two PMT arrays observe signals
- 3D vertex reconstruction
- S2/S1 ratio different for interactions with electrons (most background) and with nuclei (WIMPs, neutrons)



The XENON1T TPC



- Double walled cryostat from low-activity stainless steel
- Around 1x1 m with 2.0 t instrumented xenon
- PTFE panels around active region are very reflective for Xe scintillation light
- Copper field shaping rings
- 248 low radioactivity 3” PMTs from Hamamatsu



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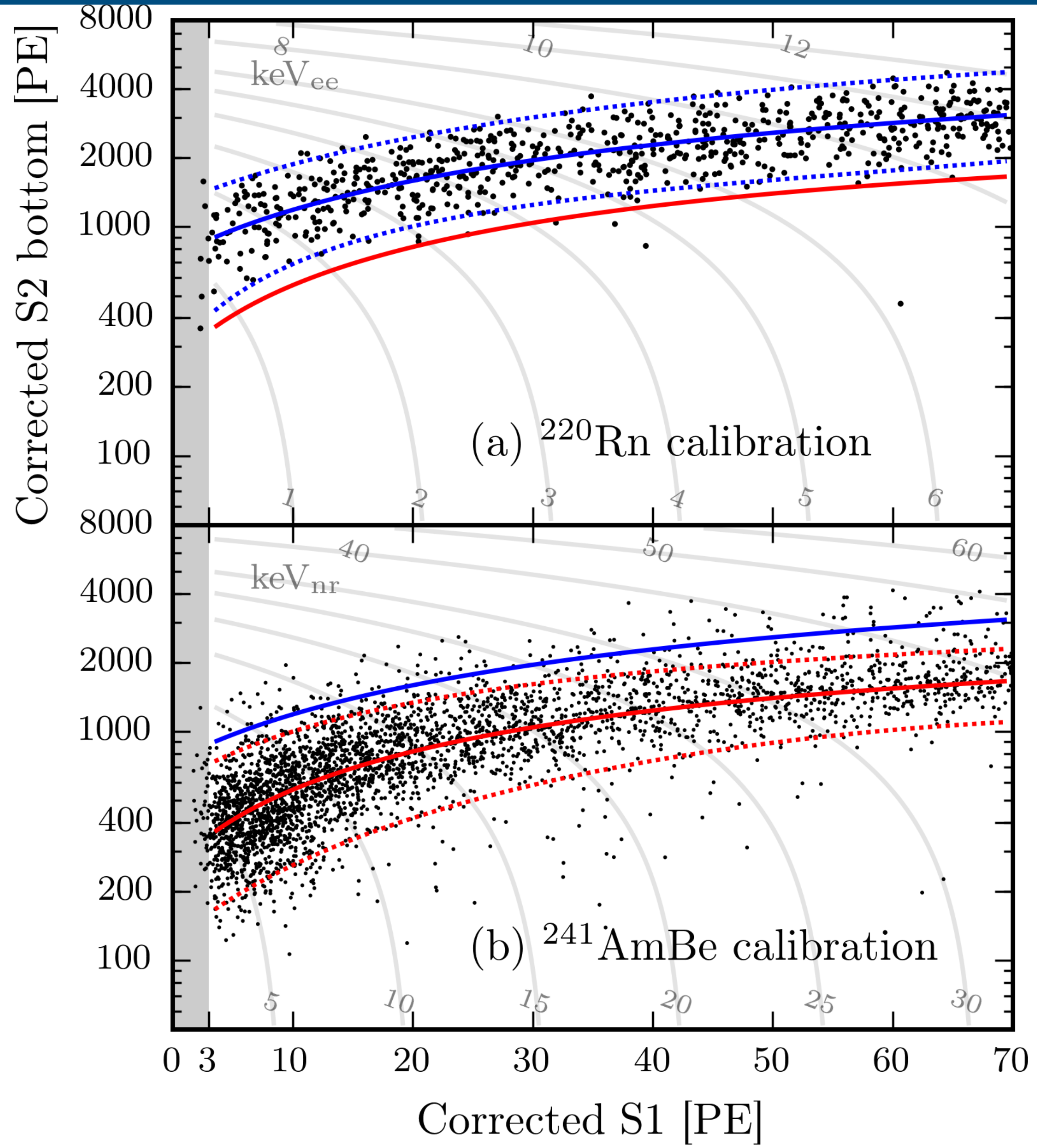
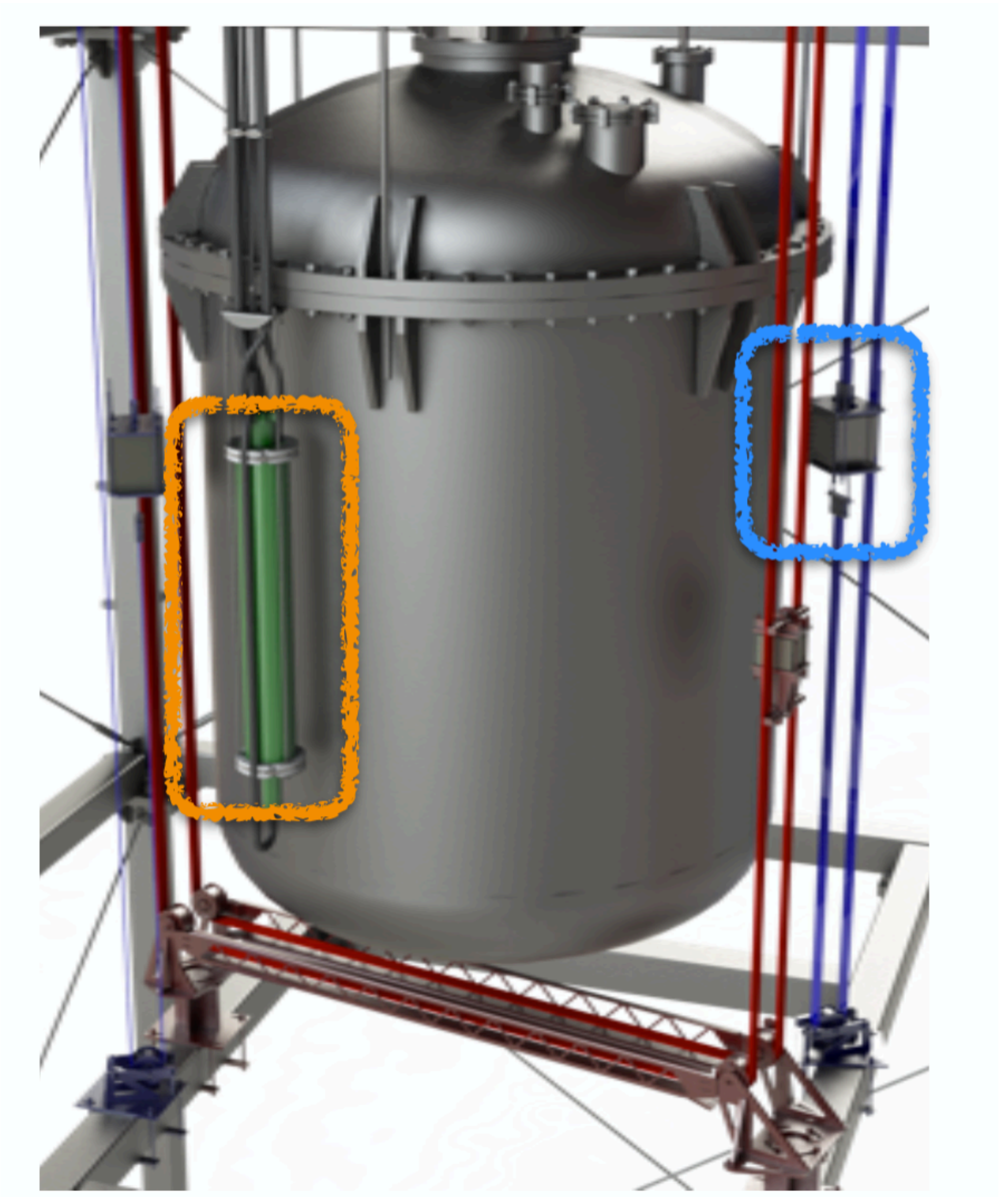


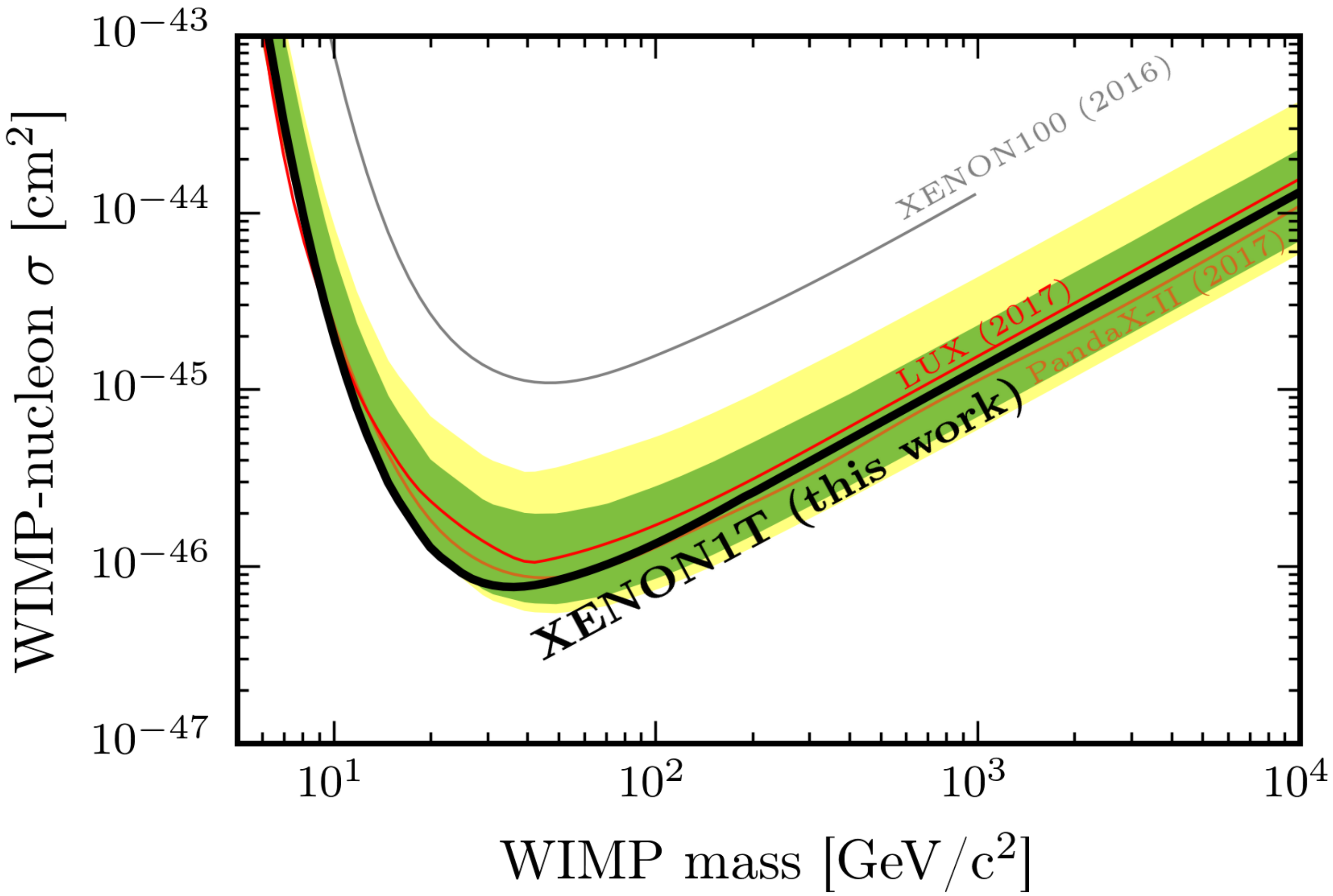
- Calibration of electron recoils (major background) with Rn220 source, injected into the TPC

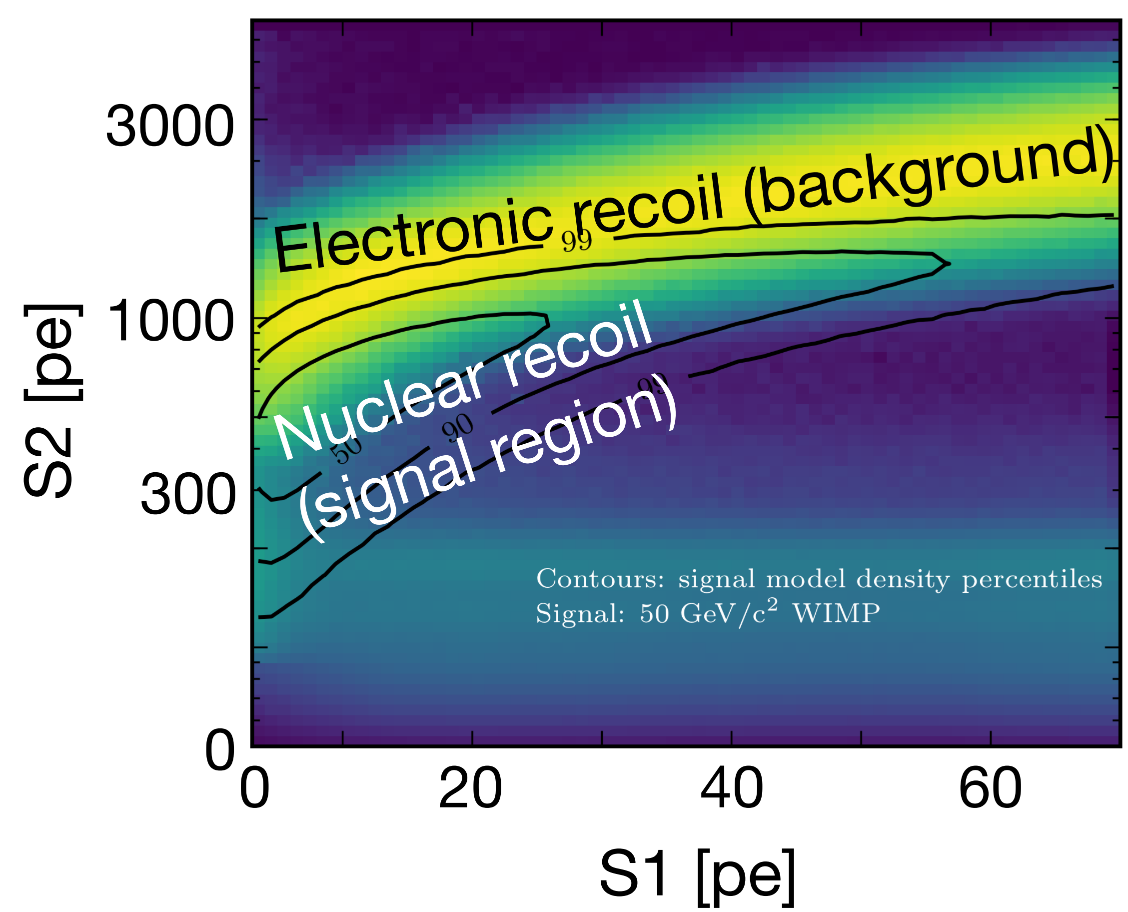


- Calibration of nuclear recoils (signal model, minor background) with AmBe and neutron generator, external to the TPC

XENON1T results — spin-independent elastic

- XENON1T designed to search for dark matter in form of WIMPs (weakly interacting massive particles)
- First results on elastic WIMP scattering published last year — best limit on cross-section in world
- Next results expected this month

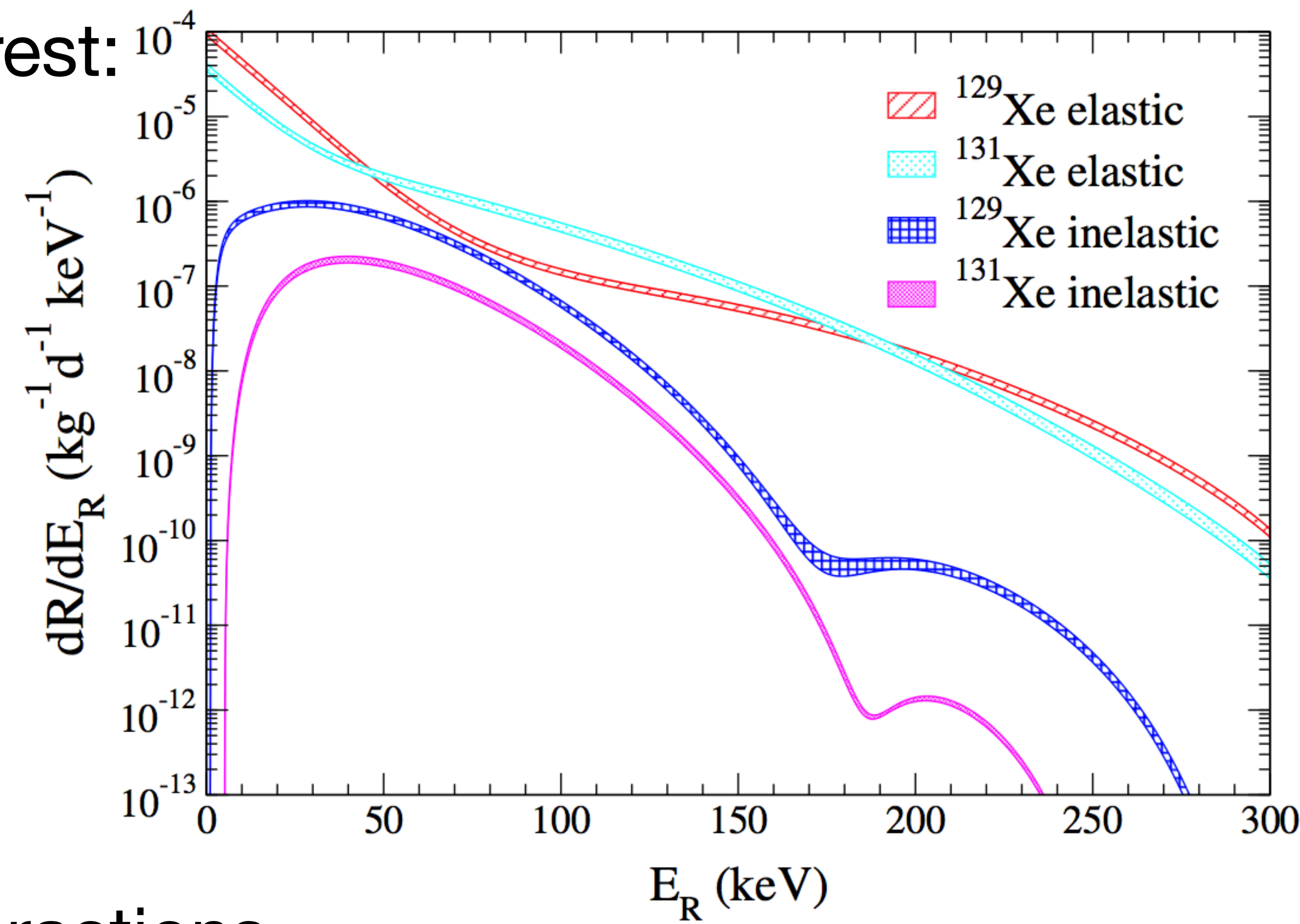




XENON1T first results: Aprile *et al.*, Phys. Rev. Lett. 119, 181301 (2017)

Inelastic scattering

- Can also search for *inelastic* scattering of WIMPs
- Nuclear transition to low excited states
- Two Xe isotopes of interest:
- ^{129}Xe: 39.6 keV state, 26.4% abundance
- ^{131}Xe: 80.2 keV state, 21.2% abundance
- For certain momentum transfers the inelastic scattering can become comparable to elastic for spin- dependent interactions



Baudis *et al.*, Phys. Rev. D 88, 115014 (2013)

Inelastic scattering

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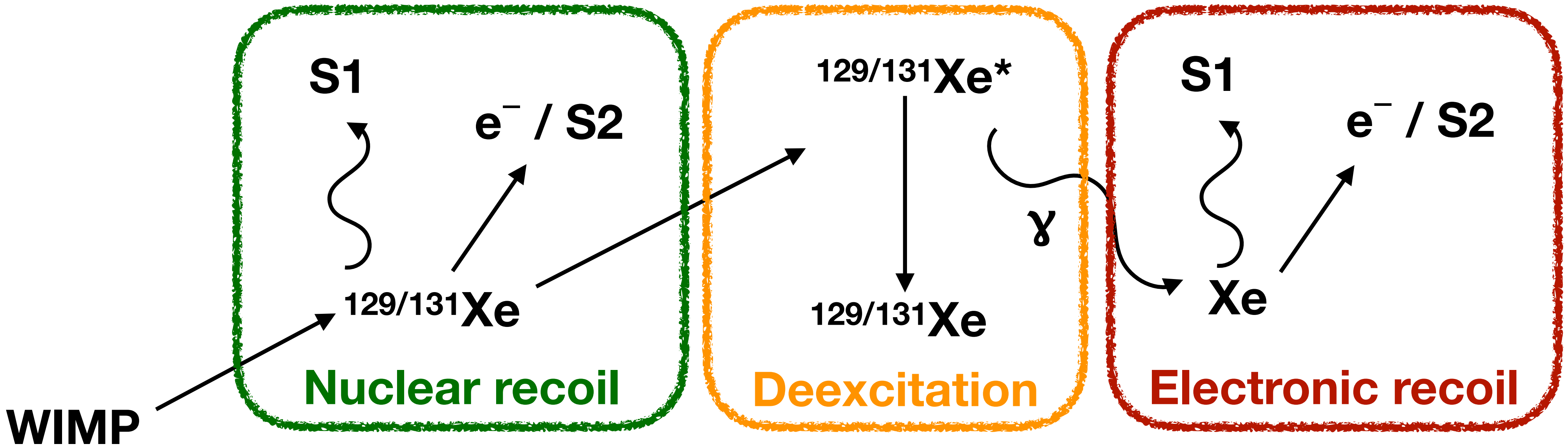
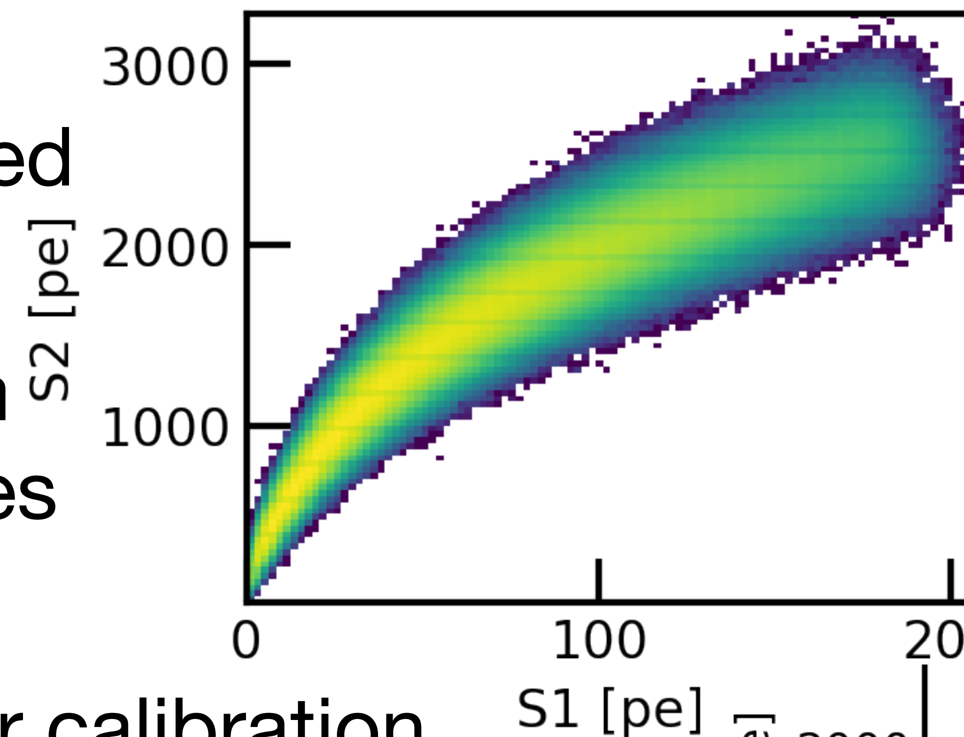
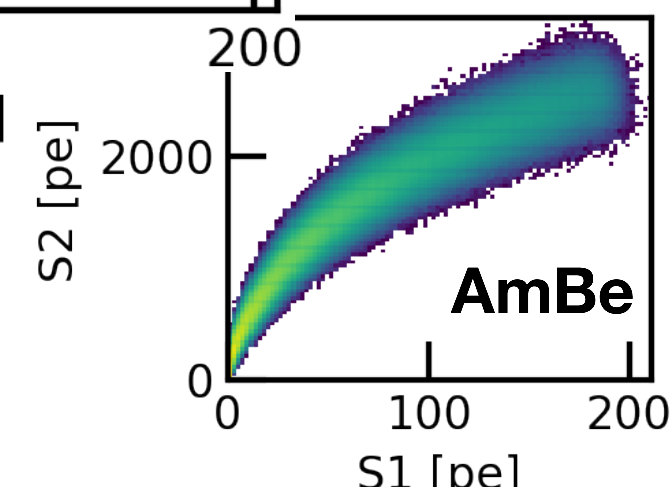
- Nuclear transition to low excited states
- Two Xe isotopes of interest:
- ^{129}Xe: 39.6 keV state, 26.4% abundance
- ^{131}Xe: 80.2 keV state, 21.2% abundance
- Observe nuclear recoil (NR) from WIMP scattering coincident with electronic recoil (ER) from deexcitation γ

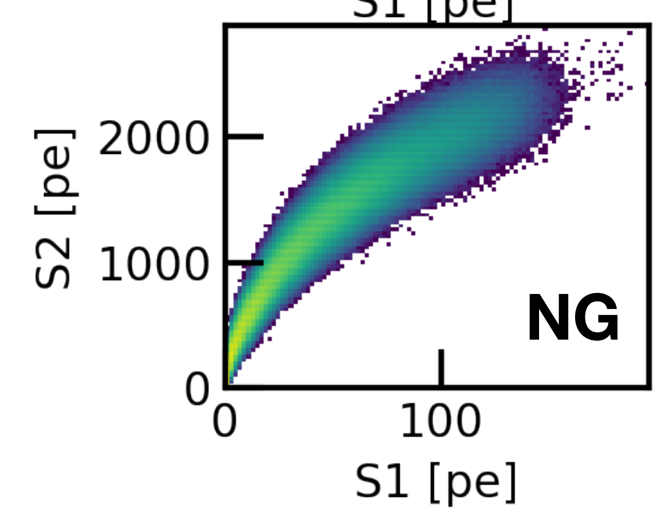
Focus on this as rate higher

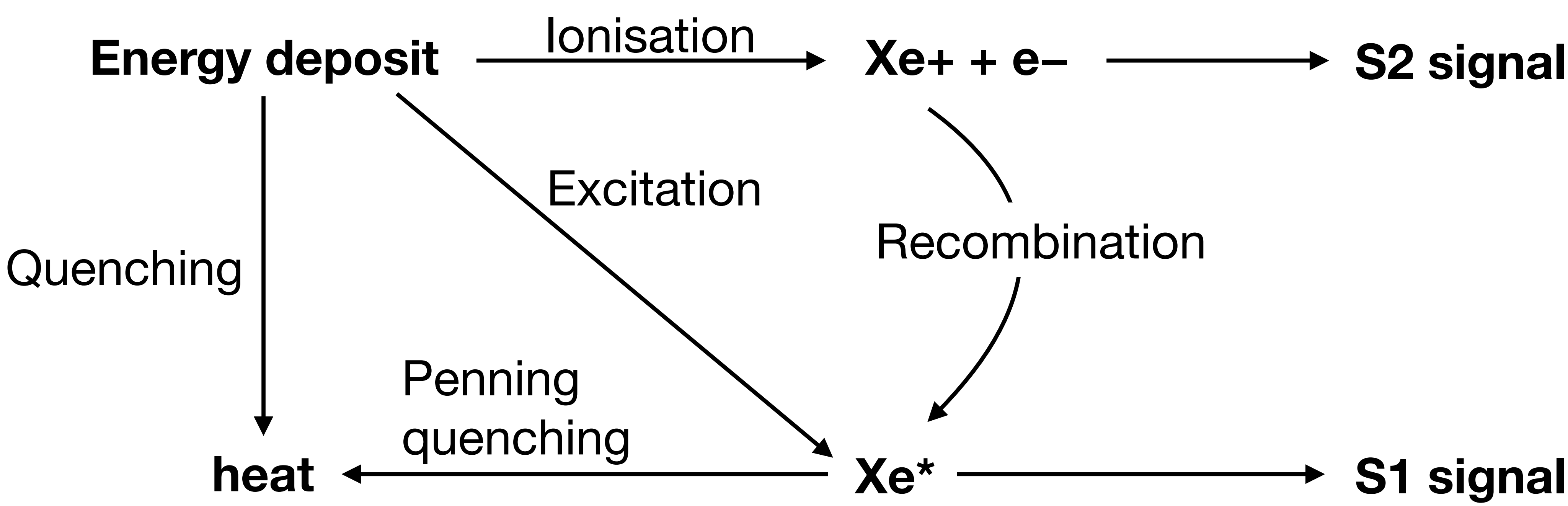


- Excited nuclear state lifetime < 1 ns so electronic recoil and nuclear recoil seen together
- NR model physically motivated
- Monte-Carlo generated by drawing from recoil spectrum and applying xenon processes
- Models produced for WIMP and AmBe, neutron generator calibration





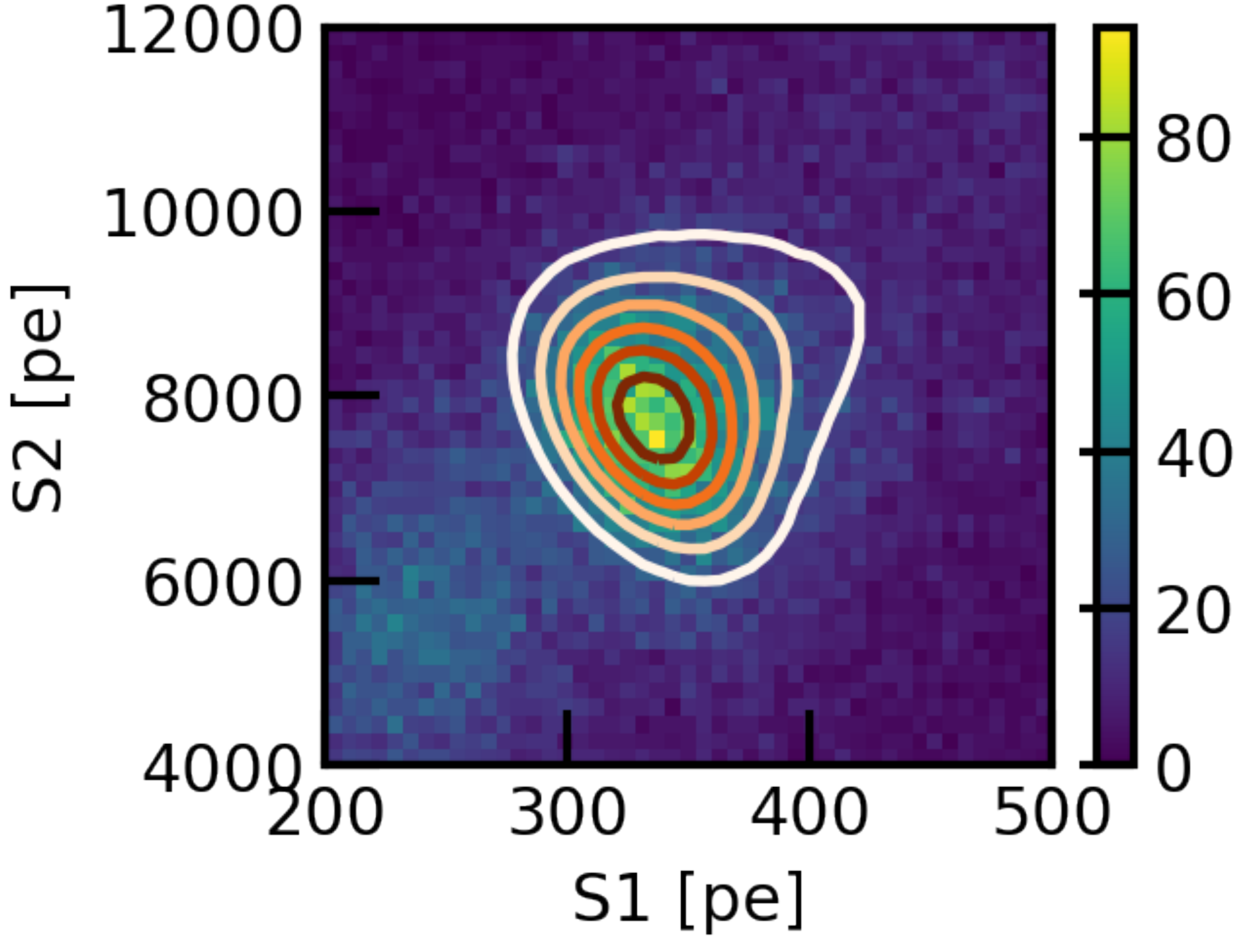




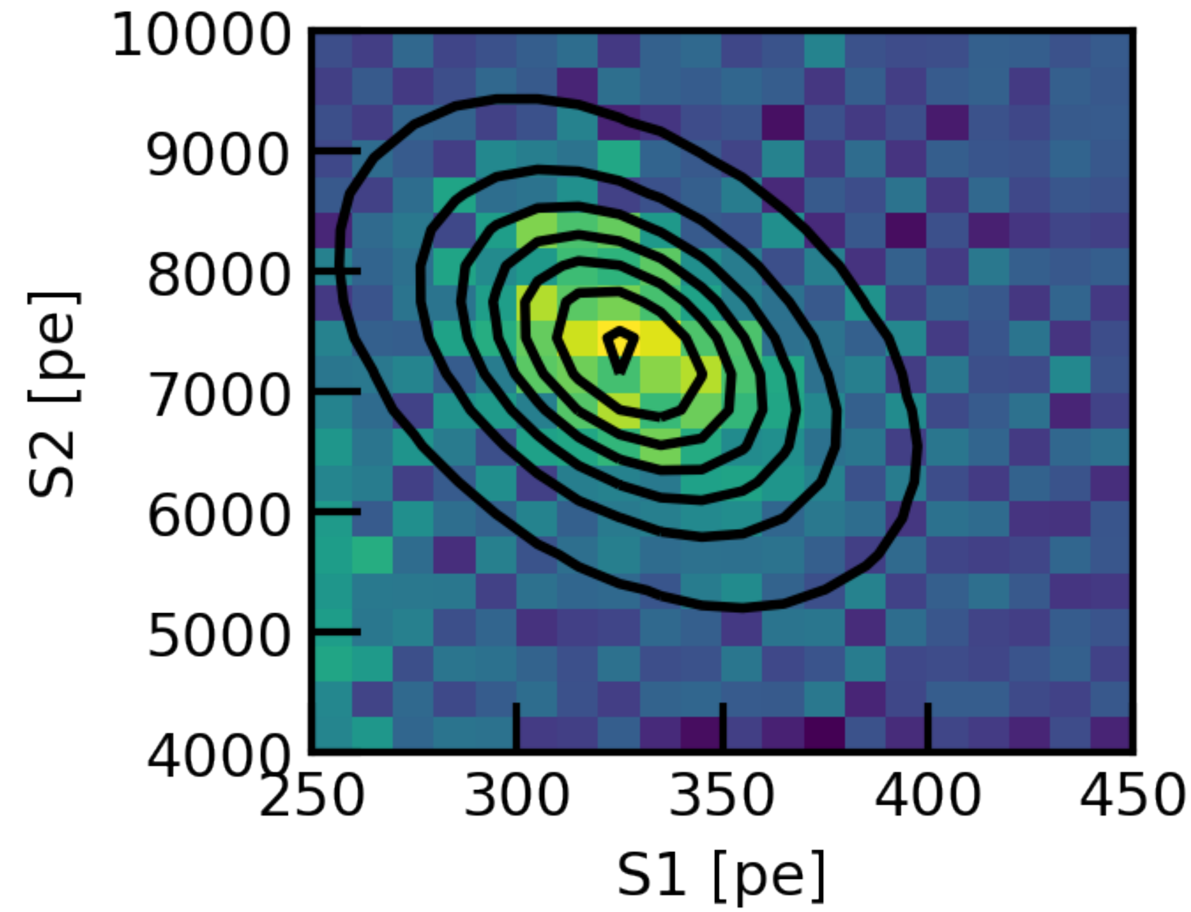
Inelastic WIMP scattering signal

- Electronic recoil component is mono-energetic
- Can be modelled as a 2-dimensional Gaussian

AmBe calibration data and inelastic scattering prediction (no fit)



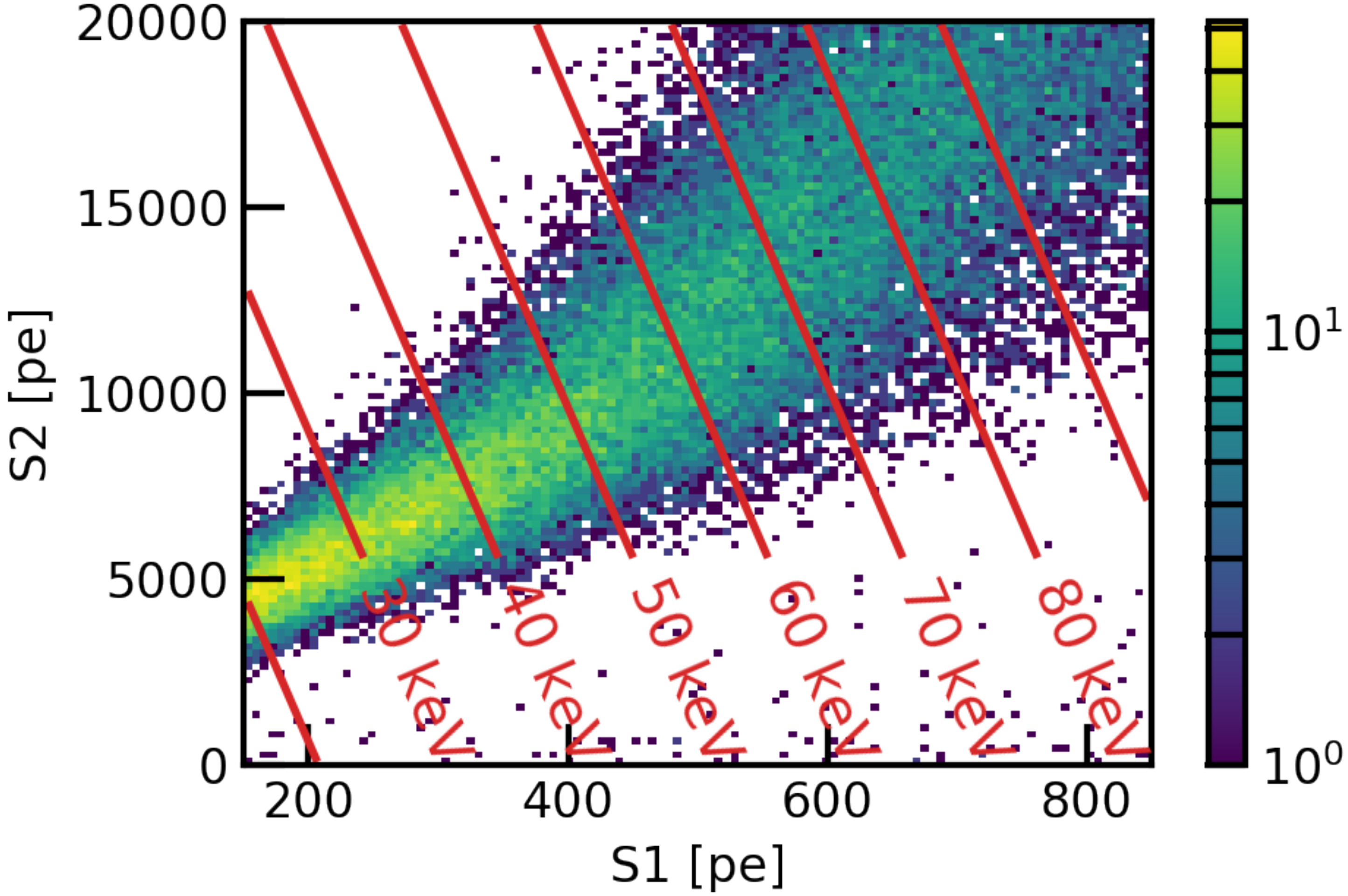
Neutron generator calibration data after deconvolution of nuclear recoil

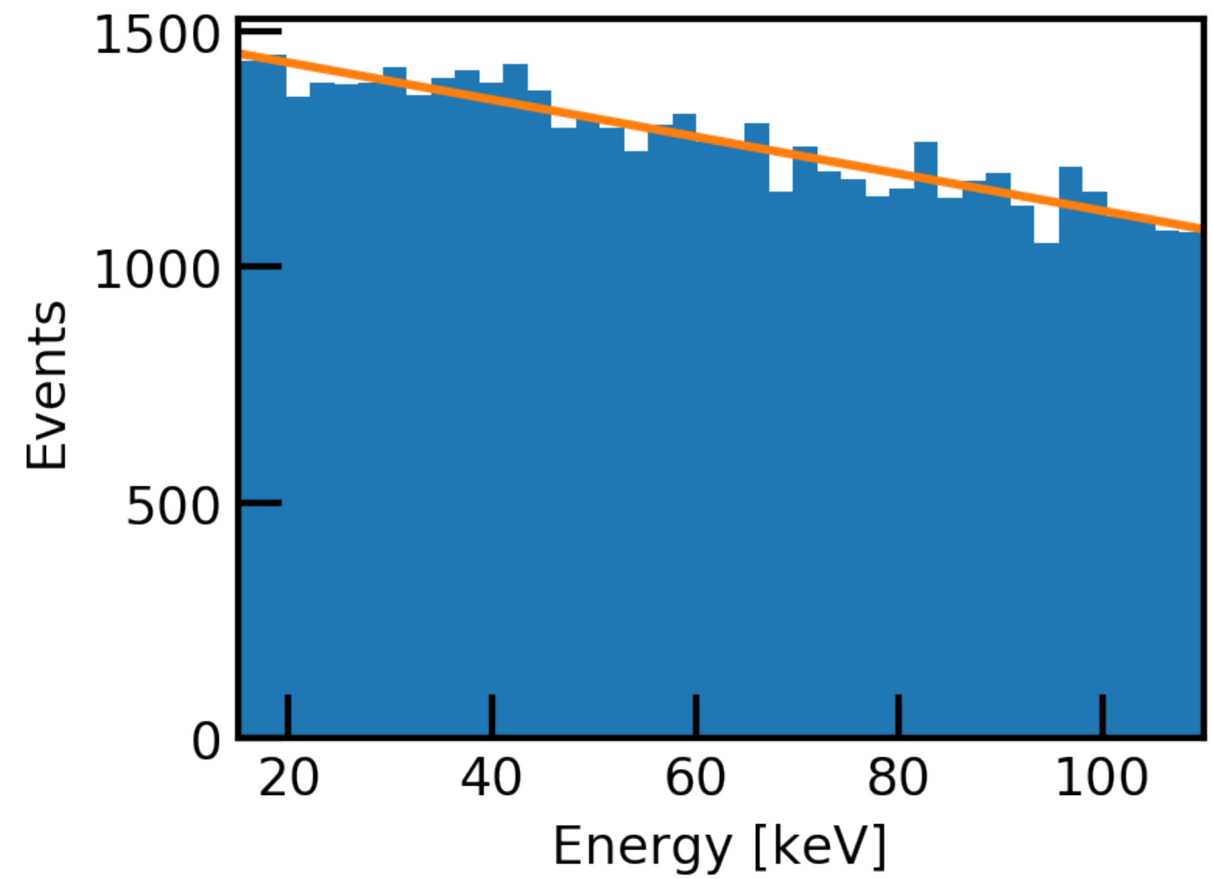


- Parameters obtained by fit to calibration data (NG data)
- Signal model validated against same line in AmBe data

Background: ER background

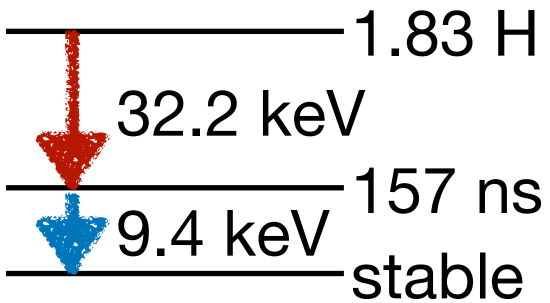
- Background model comes from calibration with ^{220}Rn, an injected source whose decay chain includes many suitable energies
- Spectrum is flattened and then a linear spectrum is used as background model, with slope as nuisance parameter

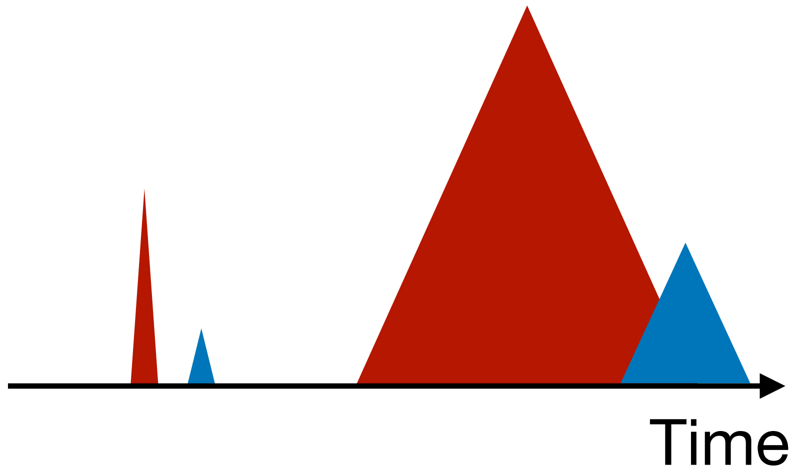




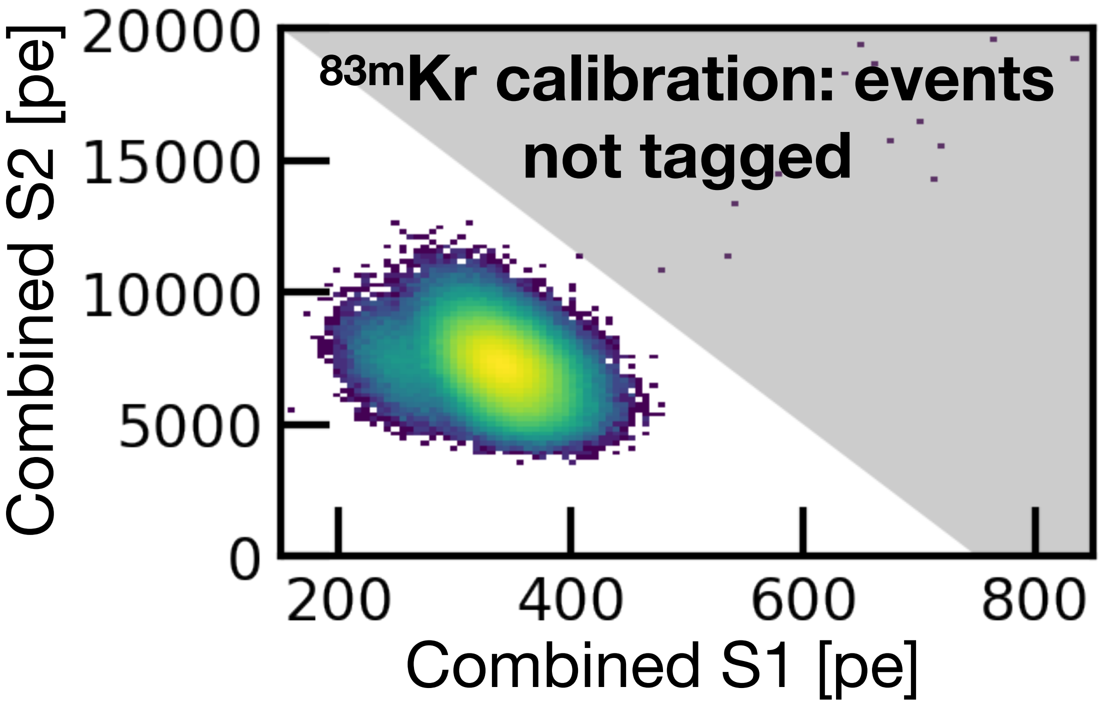
Background: Kr83m

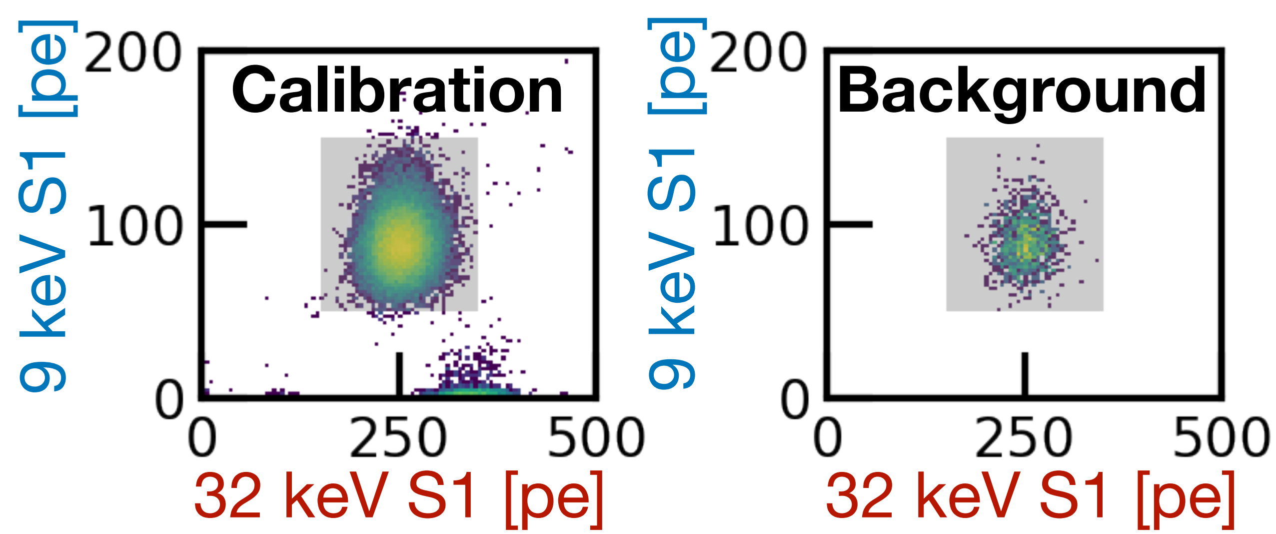
- Major background component for this analysis is trace amounts of Kr83m (~ 55 events per day)
- Used as calibration source which can be injected
- Has two-stage decay $\Longrightarrow$ some (not all) events are tagged



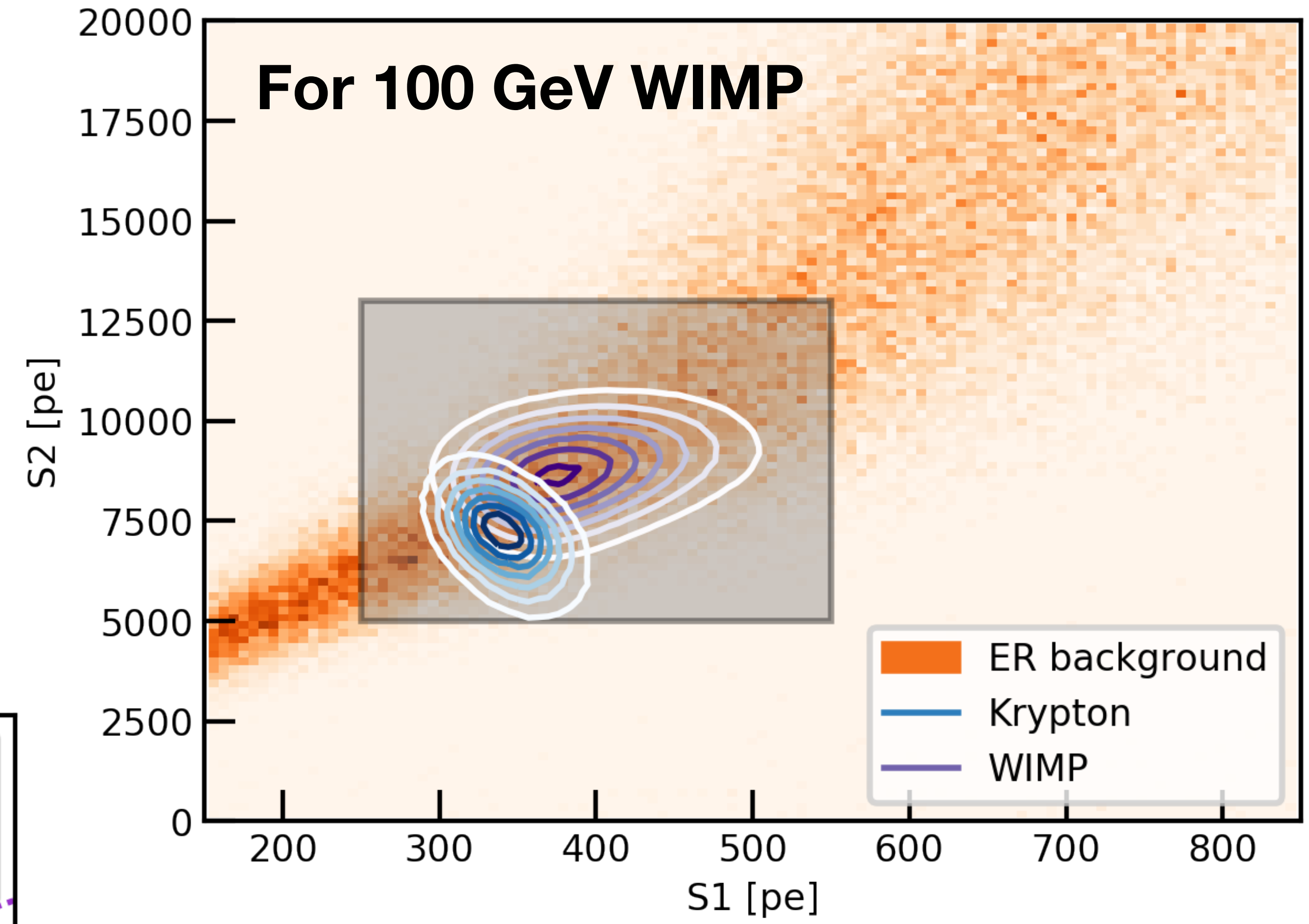


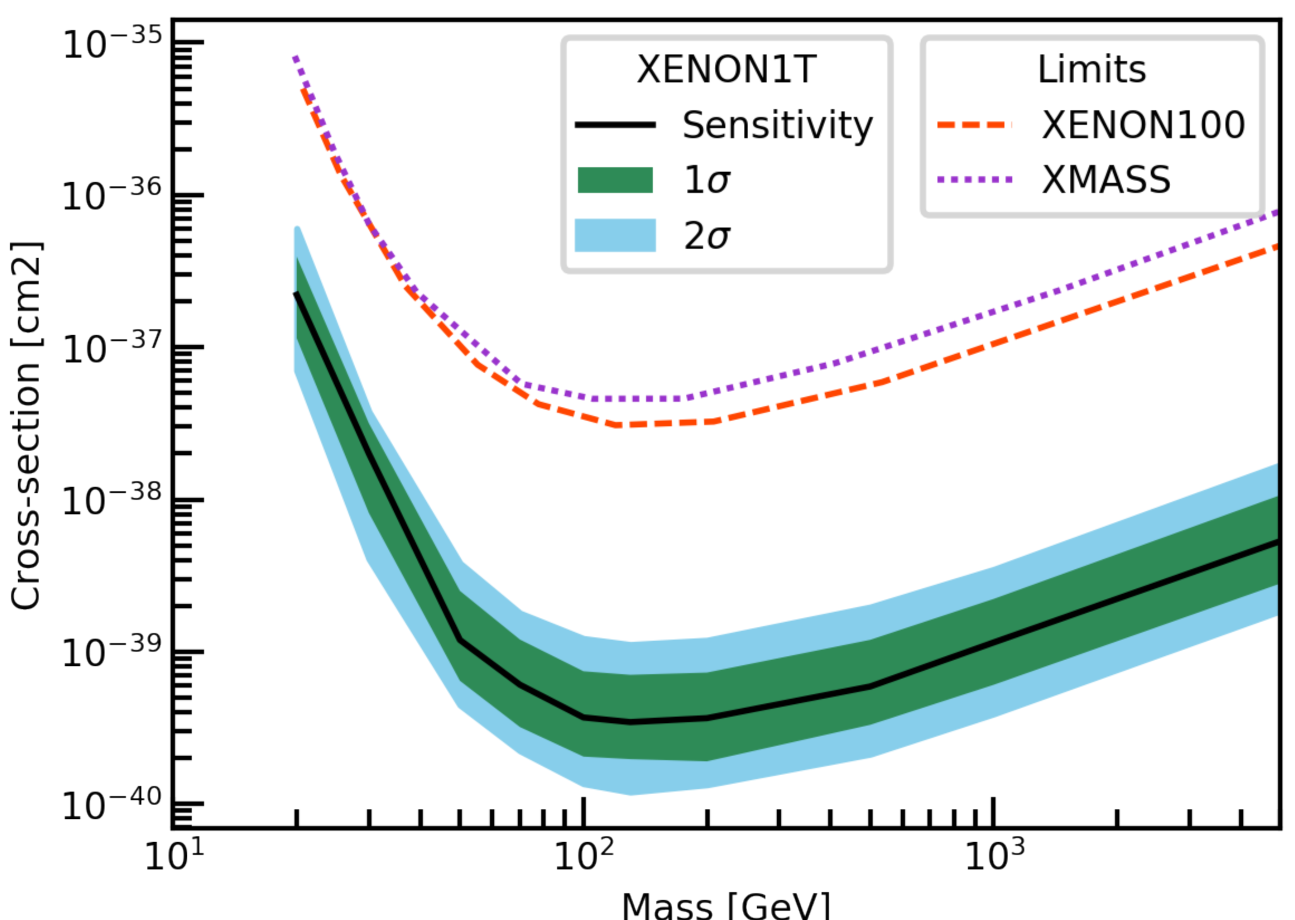
- Build model from calibration data
- Rate comes from comparing rate of tagged events in calibration and background





- Extended log-likelihood analysis with 3 components
- Validation ongoing
- Data currently blind





- The sensitivity is computed by toy Monte-Carlo experiments
- Around factor 100 stronger than XENON100

XENON100 results: Aprile *et al.*, Phys. Rev. D 96, 022008 (2017)
XMASS results: Uchida *et al.*, Prog. Theor. Exp. Phys. 2014, 063C01, (2014)

Thank you

Any questions?