Accidents in the Dark:

Exploring Accidental Coincidences in Dark Matter Direct Detection

Pranati Kharbanda

NNV Subatomic and Astro/Particle Physics | Soesterberg | 8th November, 2024

What will this talk explore?

Detecting dark matter using XENONnT detector

A particularly notorious background:
Accidental Coincidences

How do we deal with them?

Probing the unknown with XENONnT detector

Low background experiment to search for rare events

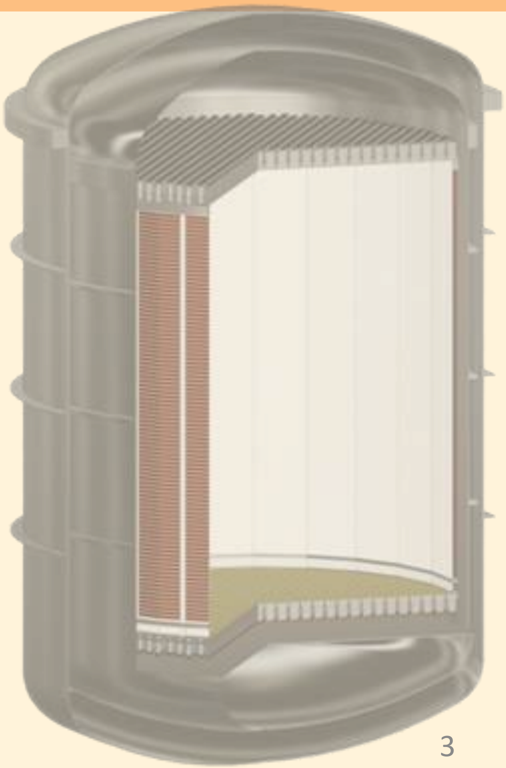
Physics focus:

- ✓ **Dark Matter direct detection**
- ✓ Neutrino physics
- ✓ Beyond SM

Operating underground at INFN – Laboratori Nazionali del Gran Sasso (LNGS), Italy

Increasing xenon = better sensitivity

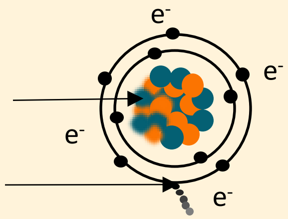
	1	2	3	4	5
	XENON10	XENON100	XENON1T	XENONnT	XLZD
(years)	2005 - 2007	2008 - 2016	2016 - 2019	2020 - Present	?
KG	15	62	2000	5900	60000
[t.day.keV]$^{-1}$	1000	5.3	0.2	0.04	?

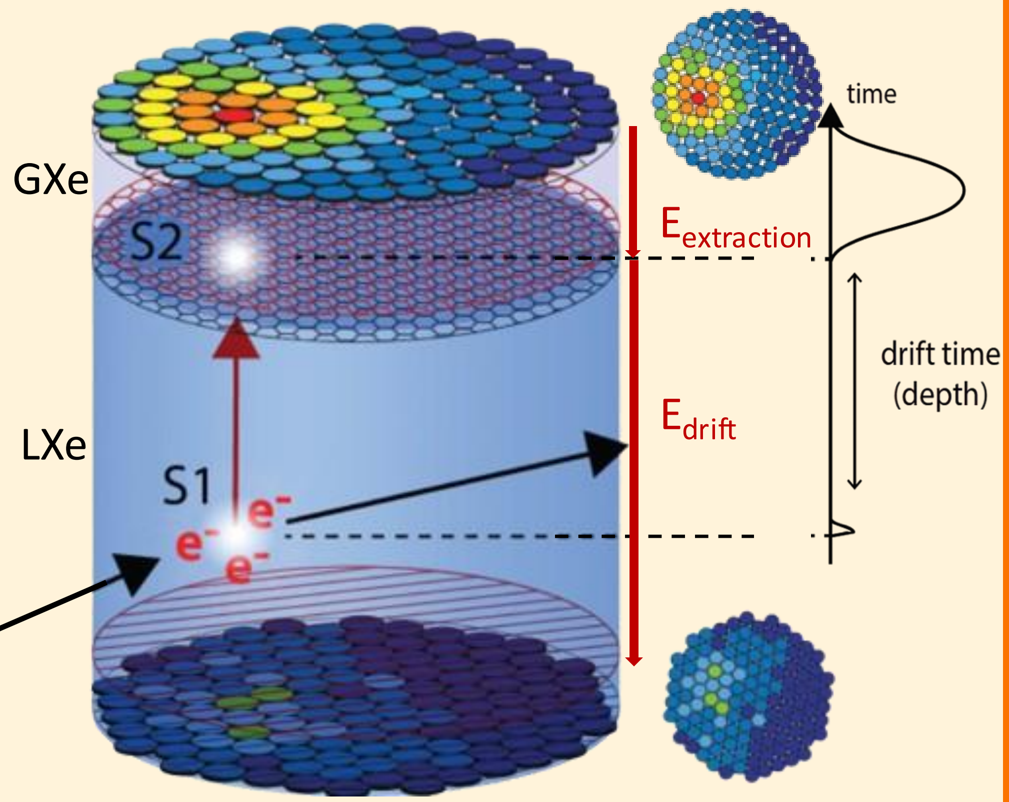


? **Increasing exposure ⟶ new backgrounds?**

How does the detector work?

- Particle interacts with a xenon atom
- Recoil (nuclear or electronic) occurs, leading to scintillation, **S1**, & ionization
- Produced electrons drift upwards
- Cause a second scintillation, **S2**

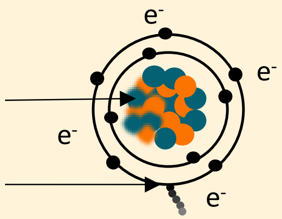




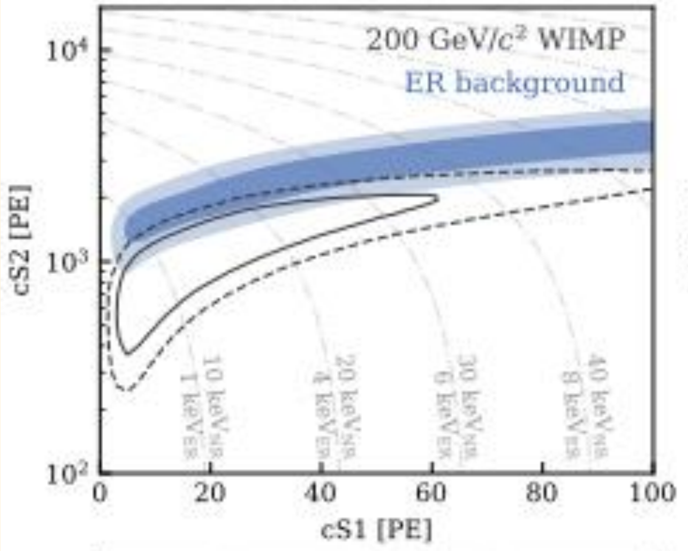
EVERY INTERACTION CREATES AN S1 AND S2!

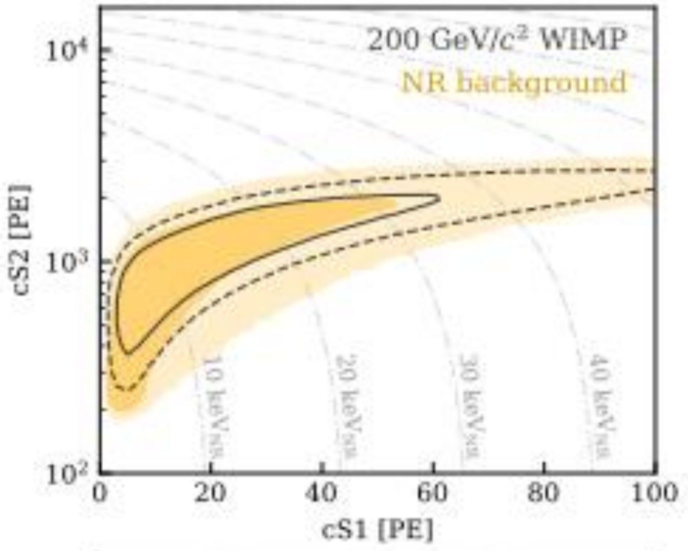
Challenge in detection of rare events: Backgrounds

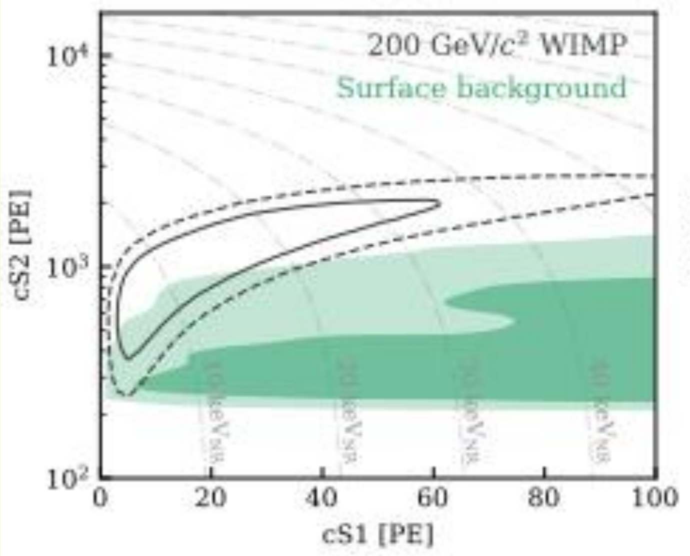
- Electronic recoil (ER)
  - ✓ ^{222}Radon and its decay products
  - ✓ Detector materials



- Nuclear recoils (NR)
  - ✓ Radiogenic neutrons
  - ✓ Elastic scattering of neutrinos with nucleus
- Surface background
  - ✓ ^{210}Pb plate-out on detector walls

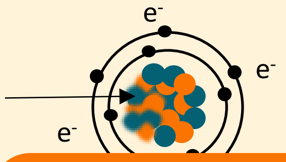






Challenge in detection of rare events: Backgrounds

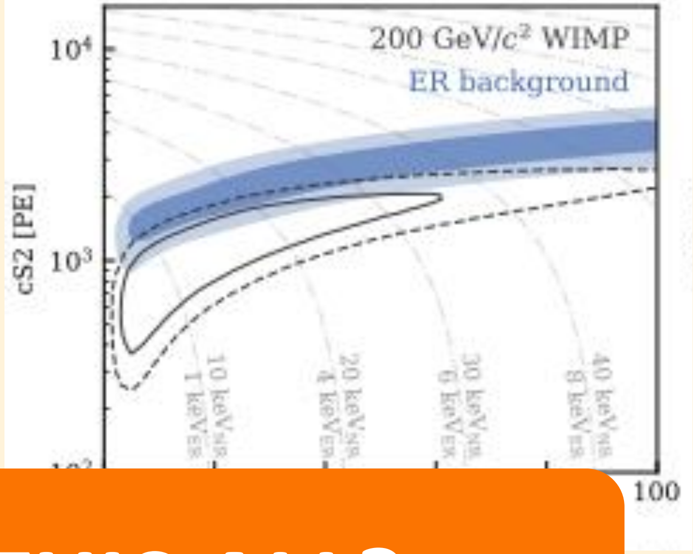
- Electronic recoil (ER)
  - ✓ ^{222}Radon and its decay products
  - ✓ Detector materials

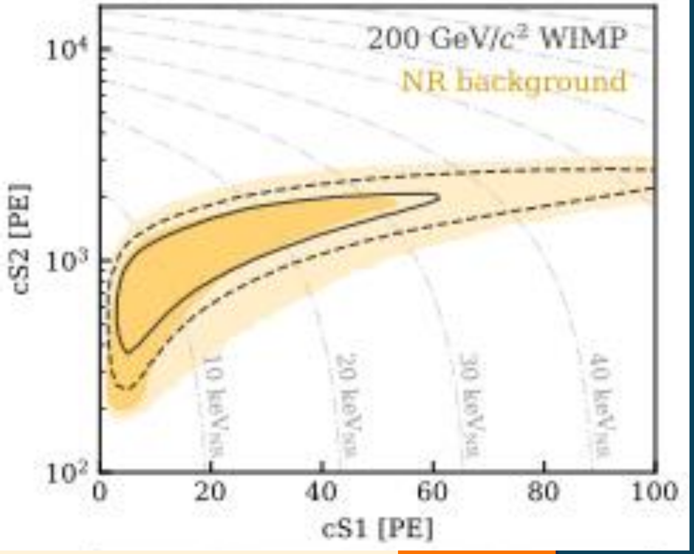


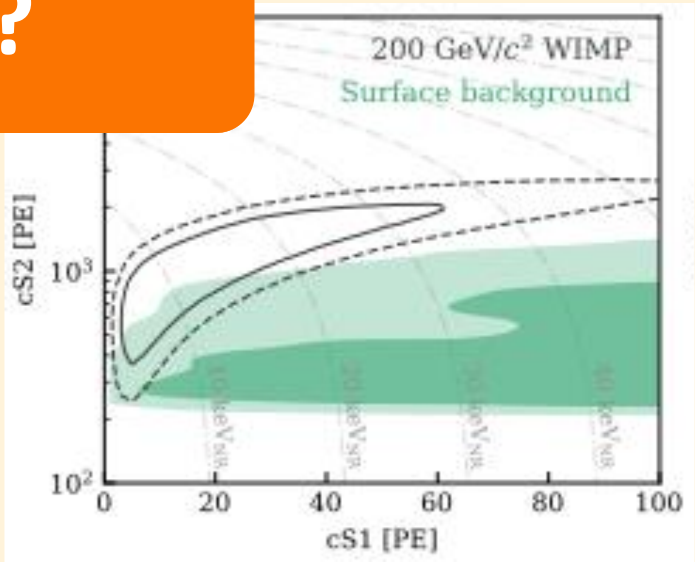
- Nuclear recoils (NR)
  - ✓ Radiogenic neutron
  - ✓ Elastic scattering of

- Surface background
  - ✓ ^{210}Pb plate-out on detector walls

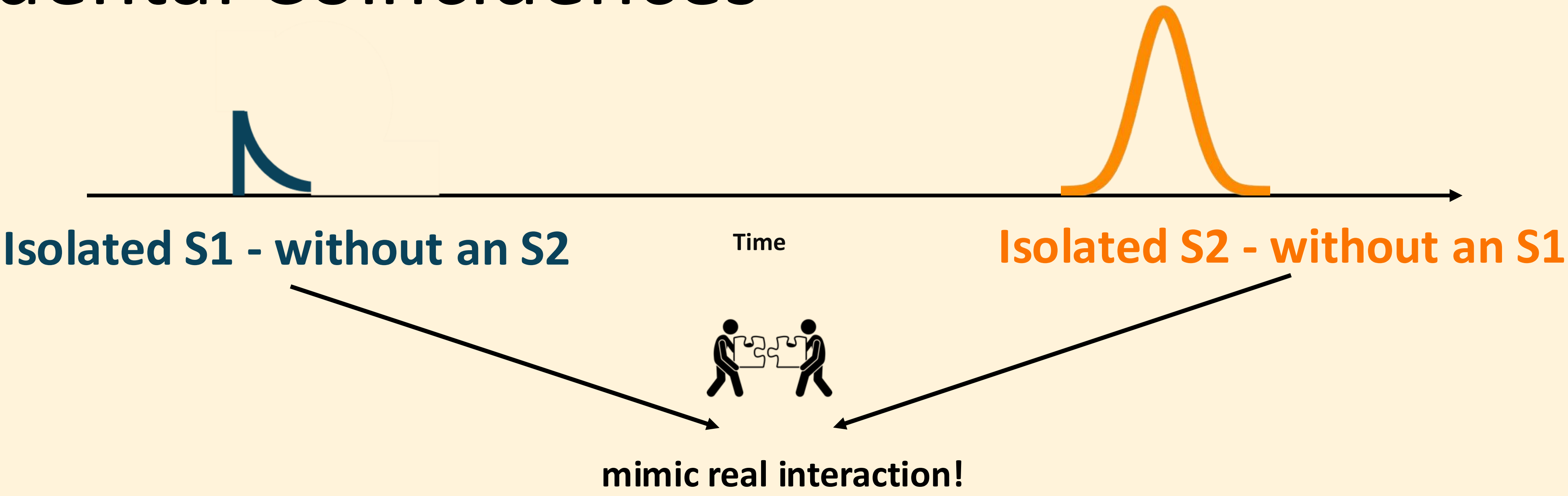
IS THIS ALL?







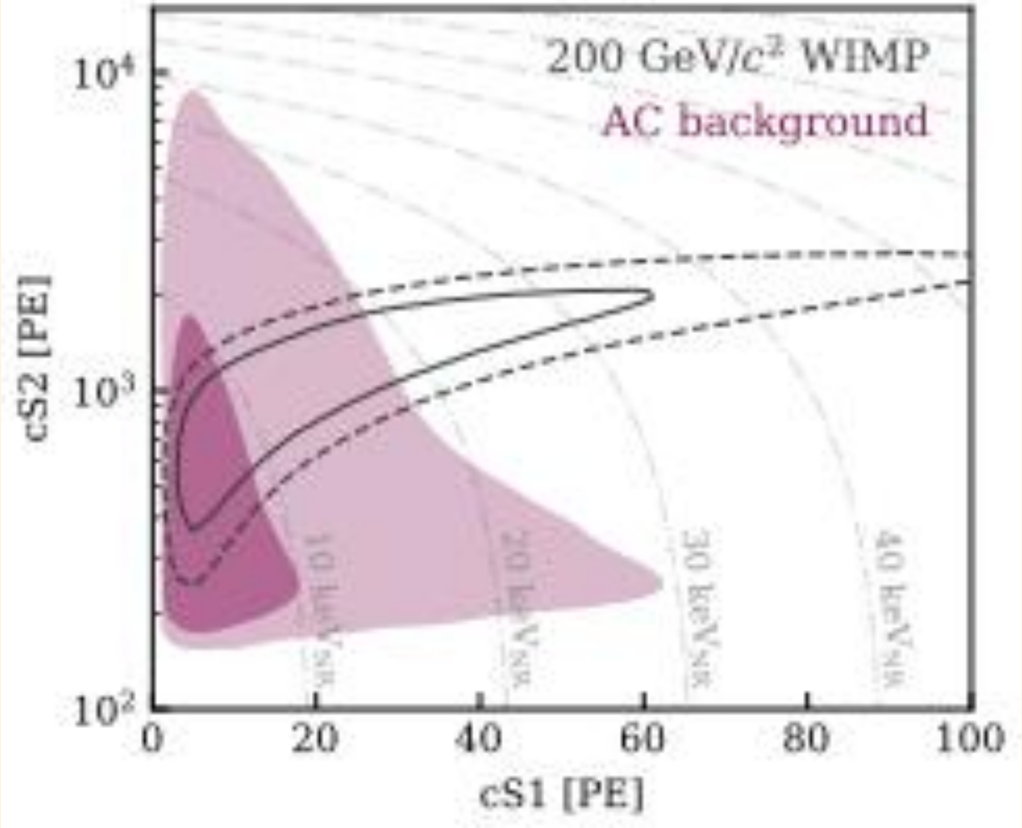
Instrumental background: Accidental Coincidences



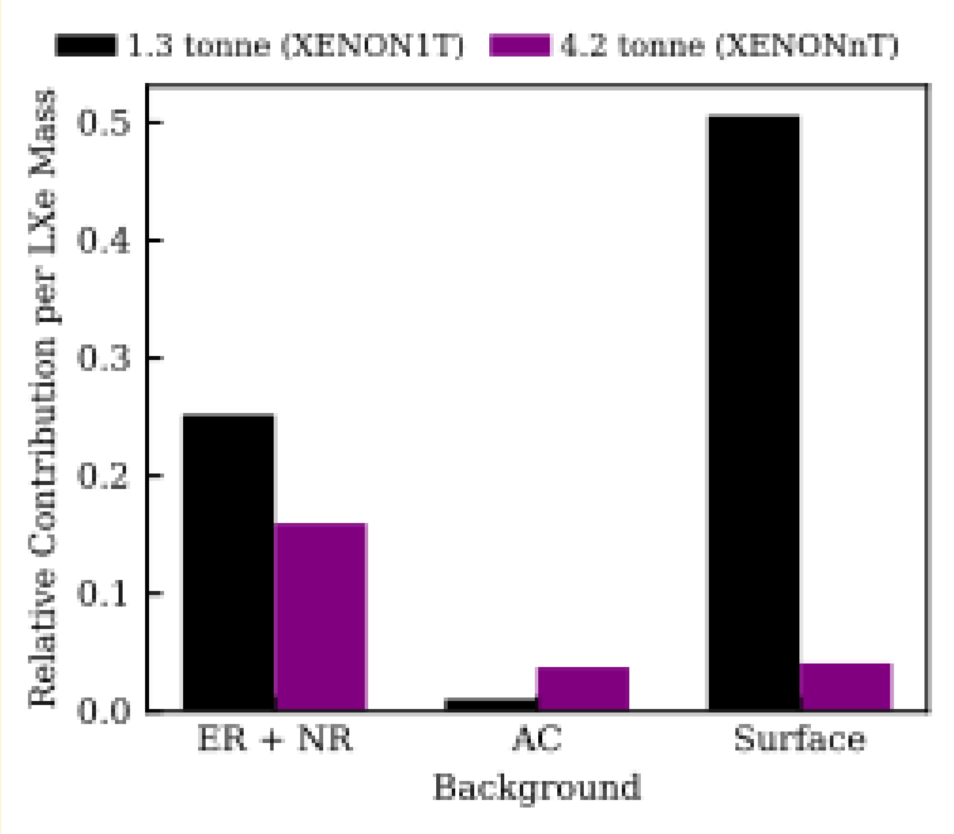
- No physics model as of yet
- Not implemented in Monte Carlo simulations
- Cannot predict rate in bigger detectors

Why are they important to study?

Significant background



Scaling with mass



How do we estimate them?

Data driven approach

- Selection of isolated S1 and S2 from data
- Artificially pair these S1 and S2 to make an event
- Create PDF of S1 and S2

NEW

First principles model

- Identify sources of isolated S1 and S2
- Create mathematical model of PDF of S1 and S2

Comparing the two approaches

Data driven

- 👎 No predictive power for next-gen detectors
- 👎 Not fundamental
- 👍 Simple and fast
- 👍 Benefits from large volumes of existing data

First principles

- 👍 Has predictive power for next-gen detectors
  - **Influence design choices (XLZD)**
  - Predict sensitivity
- 👍 Fundamental
- 👎 Complex and convoluted effects
- 👎 Need data driven model to be validated

Overview of first principles model

Step 1: Identify sources

Isolated S1

- ✓ Noise from sensors
- ✓ Events with electrons not being detected
- ✓ Signal misclassification
- Light emission from detector materials

Isolated S2

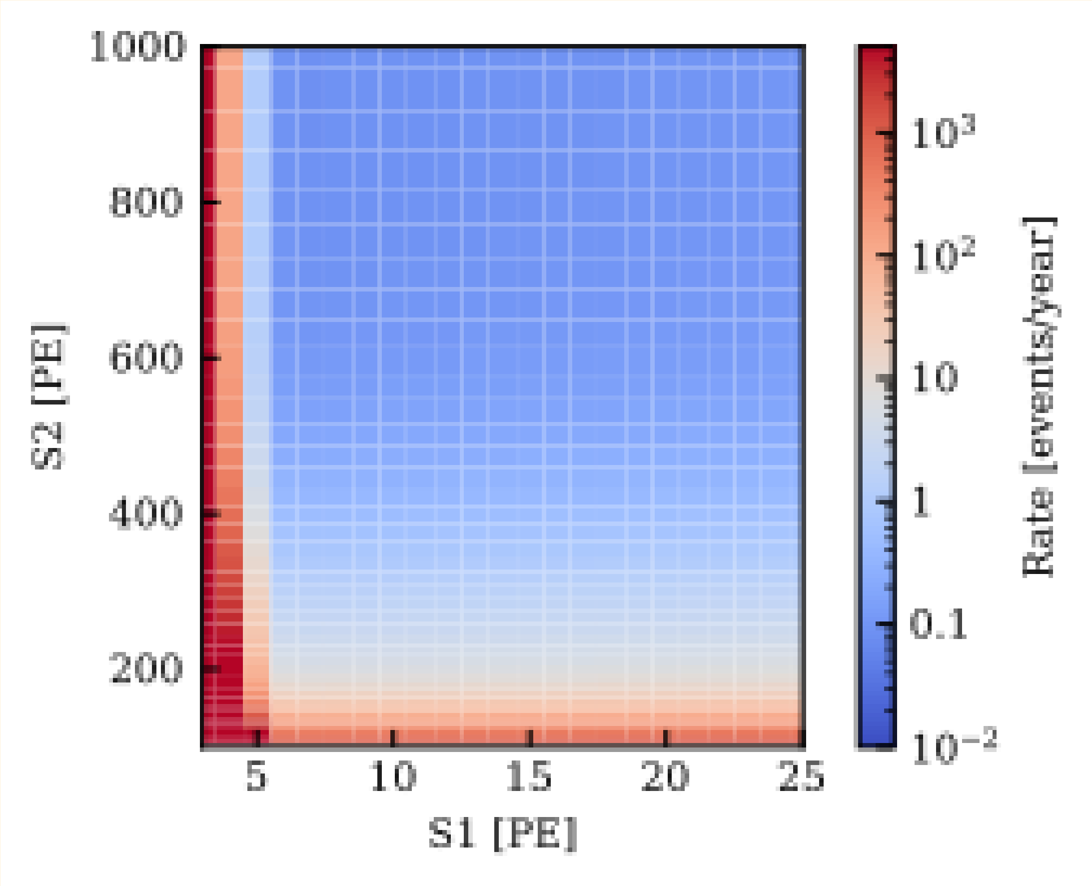
- ✓ Events with photons not reaching sensors
- Electron emission from detector materials/impurities
- Inefficiency of electron extraction
- Events in gas

Overview of first principles model

Step 2: Create math model of PDF of S1 and S2

- Function of detector parameters
- ✓ Detector geometry
- ✓ Electric field
- ✓ Efficiencies

- Scalable to bigger detectors



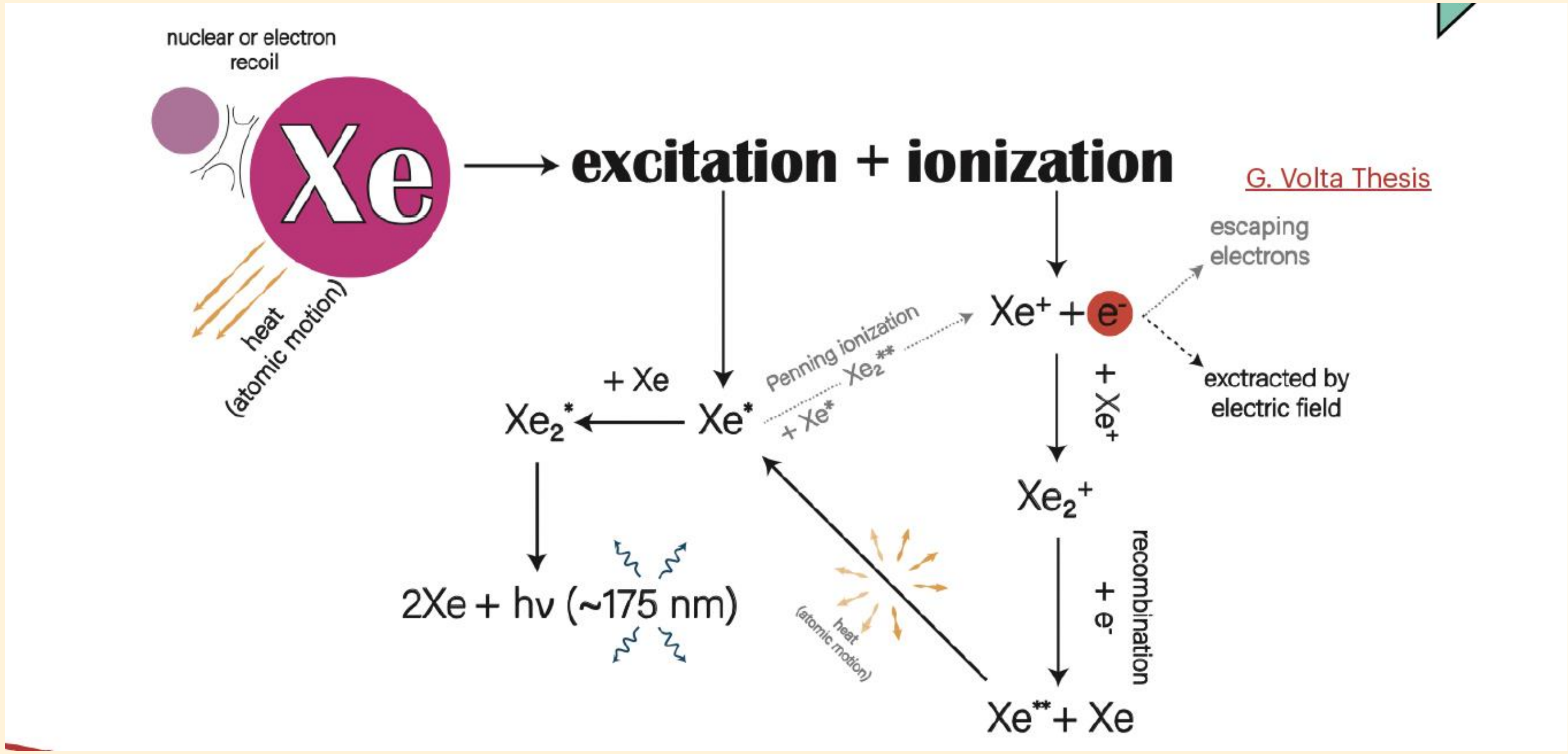
Outlook

- Refine model and include remaining sources
- See the effect on sensitivity for XLZD detector
- Define optimal configurations for XLZD detector to mitigate ACs

Thank you! Questions?

Backup

Quanta generation



Isolated S1 and S2 spectra