XENONnT and Kr-83m Calibration

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Dark Matter Context

- **What is dark matter?**
  - 85% of the matter in the universe

- **How do we know it exists?**
  - Galaxy rotation curves
  - Cosmic Microwave Background
  - Galaxy collisions

- **What are the leading theories about dark matter?**
  - Weakly Interacting Massive Particles
  - Non-luminous
  - Stable
  - Neutral
  - Massive
  - Non-relativistic

Top image courtesy of NASA, bottom image courtesy of ESA
XENON Dark Matter Project

- Experiment is located at Gran Sasso National Laboratory
- 27 institutions around the world are searching for WIMPs

Left image courtesy of LNGS, right image courtesy of XENON collaboration
Time Projection Chambers

- Particle detectors full of xenon, recording all particle interactions
- Interactions consist of a light and a charge signal
- What do we learn about each event?
  - Location
  - Energy
  - Light and charge

Animation courtesy of Lutz Althüser, Michael Murra, and Henning Schulze Eißing
XENONnT

- Newest generation of XENON TPC detectors
- First science run in 2021

Images courtesy of XENON collaboration
Summer Research Goals

- Study the XENONnT Kr-83m calibration process
- Characterize the detector’s response to light and charge signals from a control group
Kr-83m Background

- What is Kr-83m?
- Why do we use Kr-83m to calibrate the detector?
  - Uniform volume distribution
  - Internal radiation source
  - Short half-life and quick decay
  - Low energy signals

Image courtesy of O. Lebeda
How Kr-83m is added to the TPC

- Generate Kr-83m with Rb-83
- Mix Kr-83m with liquid and gaseous xenon in the detector

About 90% of the GXe + Kr-83m mixture gets liquefied
What does a Kr-83m Event Look Like?

- Double events and Kr-83m decays
  - Pileup events, double S1s, and merged S2 peaks
- Center time differences
Kr-83m Corrections

- Why does Kr-83m data need to be corrected?
- Corrections procedure
  - 1. Select relevant data
  - 2. Fit the data with an exponential decay function
  - 3. Statistical methods for validating the fit
Creating a Kr-83m Cut

- Selecting data
- Which center time differences provide useful information about Kr-83m events but not backgrounds?
Statistical Methods for Validating the Kr-83m Cut

- Chi-squared goodness of fit test
- Residuals and Gaussian fitting
Results of the Kr-83m Cut

Mean center time differences in Kr-83m runs

χ² / n_{out} = 16.3 / 147
a = 194.902 ± 42.104
r = 158.072 ± 12.387
c = 0.244 ± 0.212

\[ f(x) = ae^{-\frac{x}{\tau}} + c \]

Number of events per residual value

χ² / n_{out} = 0.762 / 147
a = 0.697
b = 0.037
c = 0.327

\[ f(x) = ae^{-\frac{b}{x}} \]
Results of the Kr-83m Cut

- Statistical findings
- Half-life fitting
Visualizing Kr-83m Events in S1/S2 Space
Fiducial Volume Cutting

- Z-cut
- R-cut

S1a vs S2 area
with center time difference between 500 and 800 ns,
and fiducial location between -130 and -20 cm in z and under 4000 cm in r^2
Visualizing Kr-83m Events: Double Decays

- Double energy peaks
- Incorporating fiducial volume cut
Visualizing Kr-83m Events: 3D Detector Location

- Xenon reaches gaseous phase after about 80 minutes, quickly becomes homogeneous in liquid.
Conclusions

- Center time is a very effective parameter for accurately selecting Kr-83m events
- Visualizations in S1/S2 space are useful for characterizing detector response
- Kr-83m enters GXe first, then quickly mixes with LXe
Future Research Directions

● Refining the cut
● Testing Kr-83m drift time corrections
● Survey of recent data
● Utilizing information about Kr-83m distribution

Image courtesy of XENON collaboration
Acknowledgements

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References

- XENONnT wiki.