Angular dependence of columnar recombination in high pressure xenon gas using time profile of scintillation emission

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Direct dark matter search

• Annual modulation
  • event rate: summer > winter
  • difference is few %
  • environmental systematics
  • conventional method

• Directionality
  • anisotropy of recoil nuclei
  • difference is several time (large)
  • track length is short --> difficult
  • possibility of searching beyond neutrino coherent scattering BG
Direction-sensitive method

• A strong signal of arrival anisotropy can be obtained

• Direction-sensitive dark matter search experiments
  • Low pressure gas detector: DRIFT, NEWAGE, DM-TPC, MIMAC, D3
  • Nuclear emulsion: NEWS-DM
  • (ZnWO4, DNA, CNT, etc)

• Requirement
  • Target mass (currently about 10-150g)
  • SI sensitivity (currently most targets are \(^{19}\)F. Even heavy \(^{32}\)S)

• --> High pressure xenon gas detector!
Columnar recombination

- High pressure xenon gas TPC can be a dark matter detector with directionality + mass + SI sensitivity

Previous research by NEXT

- Xe + TMA (penning effect)
- Ionization have angular dependence
- Scintillation was suppressed

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5MeV alpha-ray

Figure 8. Primary scintillation light yield with Xe+TMA gas mixture, measured at approximately 4 bar total pressure and various TMA concentration.
Time profile of scintillation

- slow is mainly recombination
- slow may have angular dependence
Principle demonstration detector

- PMT detect both scintillation and EL (ionization)
- 5MeV alpha-ray
Signal waveform

- EL-timing $\propto \cos\theta$
- Initial angle $\theta$ can be known

$EL\text{-timing} = \frac{t_{\text{rise}} + t_{\text{fall}}}{2}$

8atm Xe
$E_{\text{drift}}=6.6\text{V/cm/atm}$
$E_{\text{EL}}=900\text{V/cm/atm}$
Averaged waveform

- Low E (6.6V/cm/atm): columnar recombination
- Middle E (13V/cm/atm): partially inverted
- High E (102V/cm/atm): no difference
Angular dependence of yield

- fast (de-excitation): const.
- slow (recombination): neg. relation
- EL (ionization): pos. relation

$\cos \theta = 1 \leftrightarrow \cos \theta = 0$
$\theta = 0^\circ \leftrightarrow \theta = 90^\circ$

$E_{\text{drift}} = 6.6 \text{V/cm/atm}$

Diagram:
- Fast: de-excitation
- Slow: recombination
- EL: ionization

Legend:
- vertical $\leftrightarrow$ horizontal
High electric field

- fast (de-excitation): const.
- slow (recombination): decreased
- EL (ionization): increased

--> No angular dependence

\[ E_{\text{drift}} = 102 \text{ V/cm/atm} \]

\[ \cos \theta = 1 \quad \longleftrightarrow \quad \cos \theta = 0 \]

\[ \theta = 0^\circ \quad \longleftrightarrow \quad \theta = 90^\circ \]
Middle E (13 V/cm/atm)

- Angular dependence
  - fast: constant
  - slow2: columnar-like
  - slow1: inverted columnar-like
  - EL: constant

- For middle E, angular dependence of the slow-component depend on the time range

  fast: de-excitation
  0-0.04us

  slow1: recombination
  0.1-0.8us

  slow2: recombination
  0.8-3.0us

  EL: ionization
  3-40us
One interpretation of middle E

- Middle E may ...
  - diffusion is smaller than low E
  - field is not too strong to separate electrons from ion completely

- There are two options!
  - columnar recombination in low E
  - band recombination in middle E
Conclusion

• Angular dependence of columnar recombination was observed in both photon and charge signal
  • gas: 8atm Xe 100%
  • particle: 5MeV alpha-ray

• Low electric field is needed
  • 6.6V/cm/atm this time

• Next plan: Low energy study (252Cf)
Loss of electrons due to the drift plane

• Problem
  • For horizontal tracks, the amount of ionization electrons decrease due to the drift plane
  • The angular dependence is similar to that of columnar recombination

• Correction
  • Create correction function so that $\cos \theta$ dependence of EL yield becomes flat with data of high electric field
  • Correct photon yield as function of $\cos \theta$ (EL, slow)

\[ E = 100 \text{V/cm/atm} \]