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Columnar Recombination Study in High Pressure Xenon Gas for Direction-sensitive Dark Matter Search

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for the AXEL collaboration

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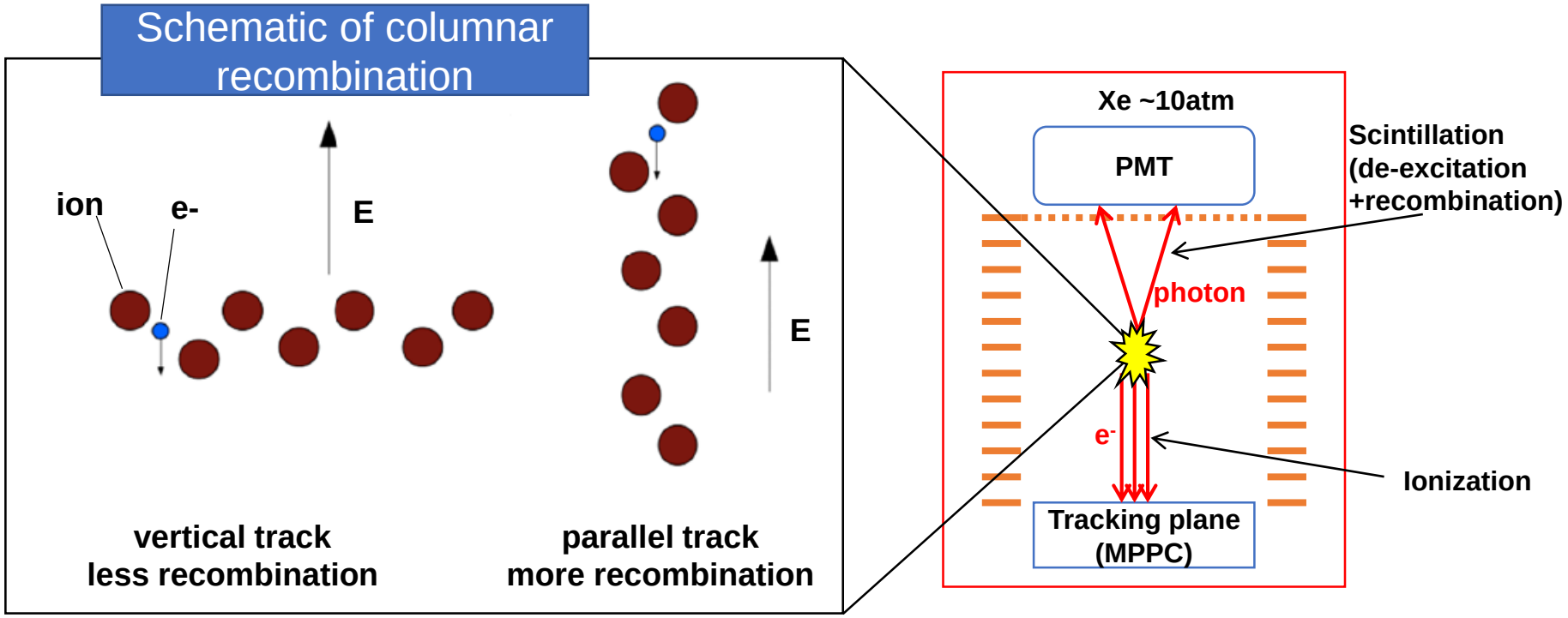
Direction-sensitive method

- 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
  - **Large 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

D. Nygren J Phys. Conf. Ser. 460 (2013) 012006

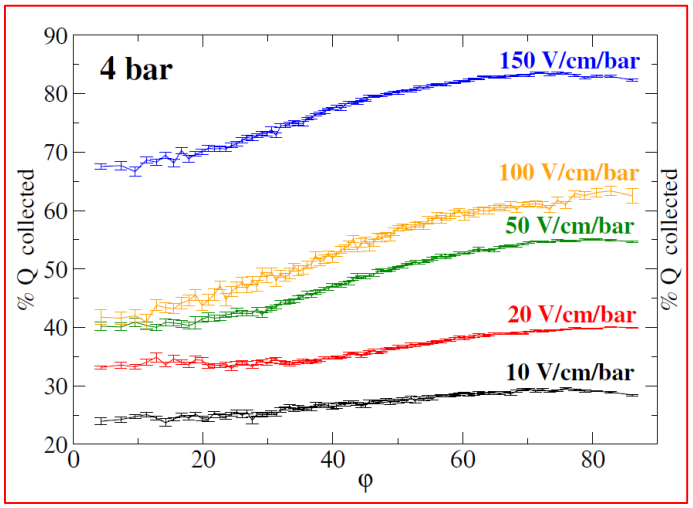


Previous research by NEXT

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

PoS (TIPP2014) 057

J. Phys. Conf. Ser. 650 (2015) 012012



5MeV alpha-ray

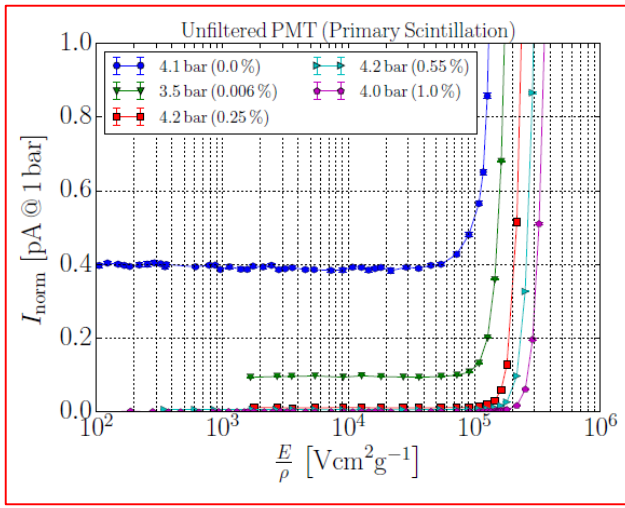
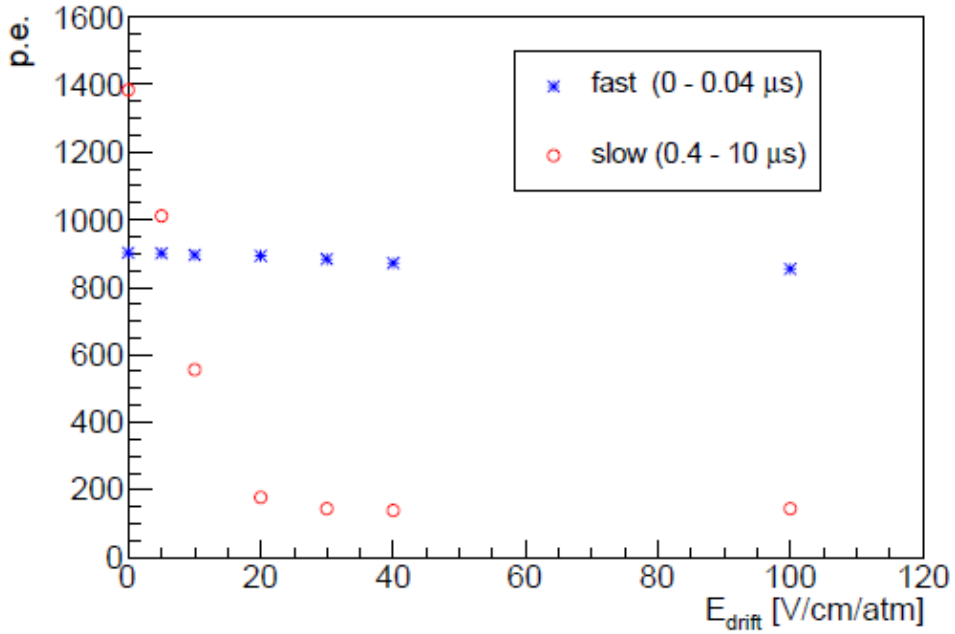
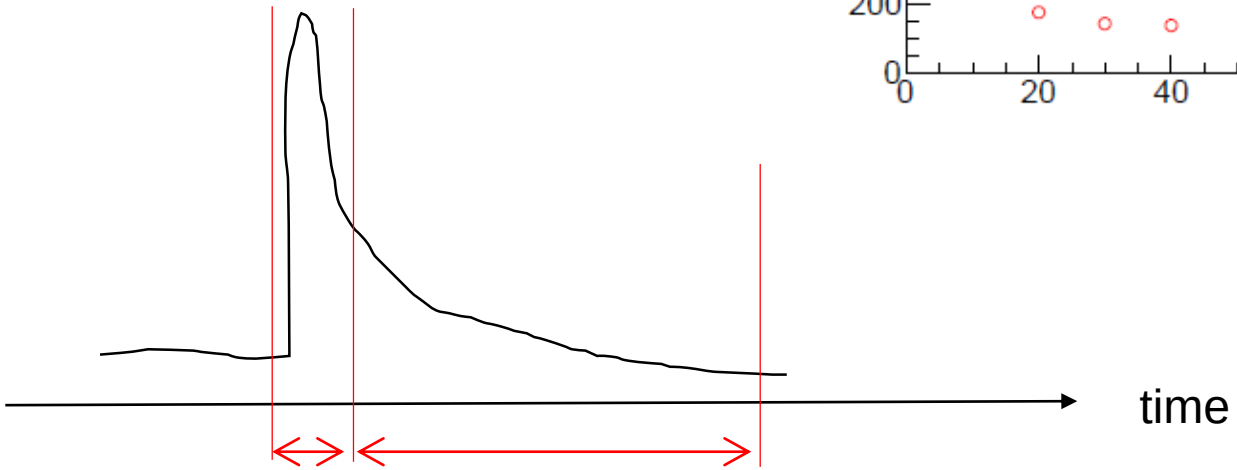


Figure 8. Primary scintillation light yield with Xe+TMA gas mixture, measured at approximately 4 bar total pressure and various TMA concentration.

Time profile of scintillation

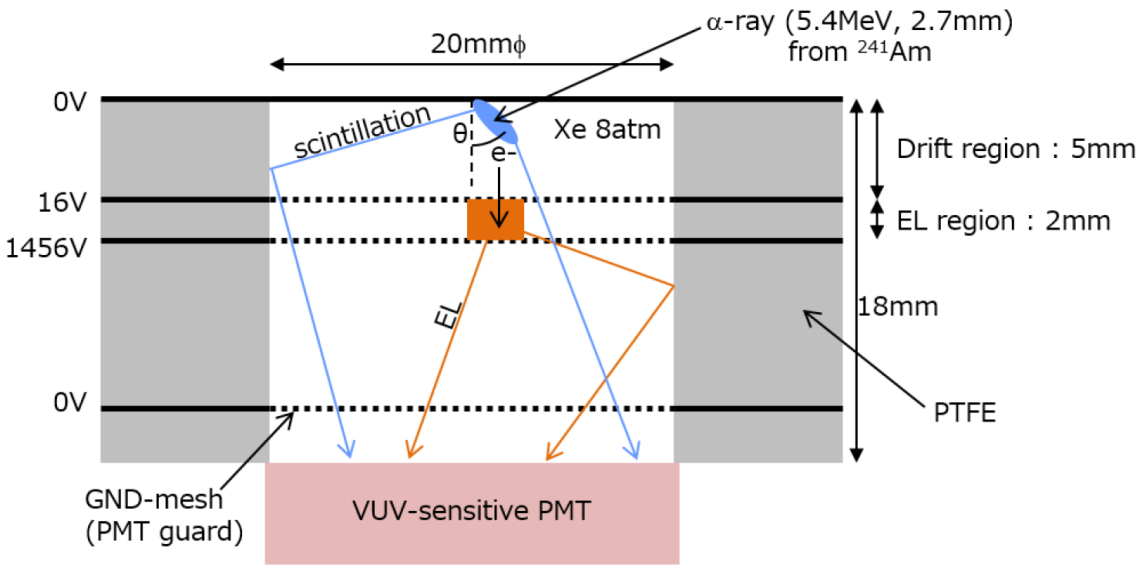
- slow is mainly recombination
- slow may have angular dependence

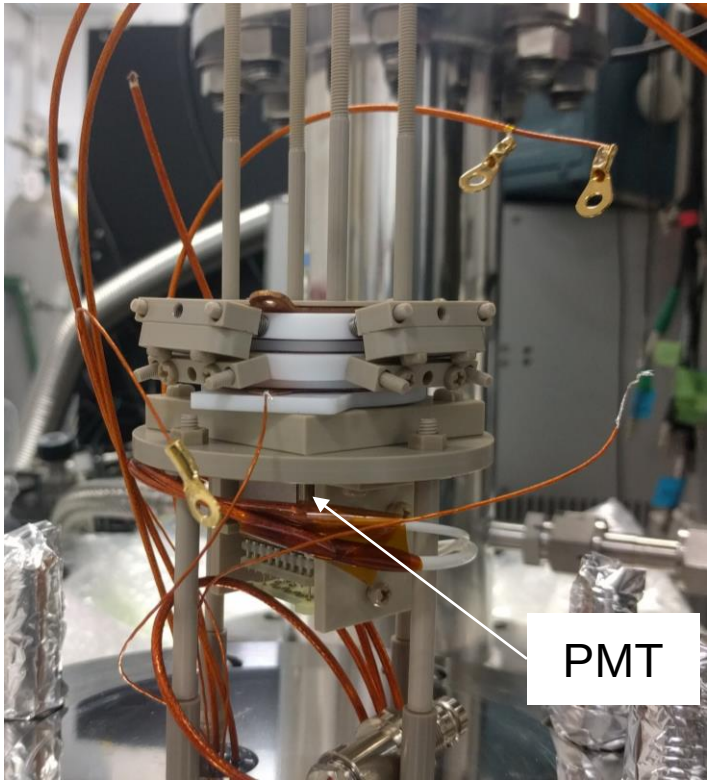




Principle demonstration detector

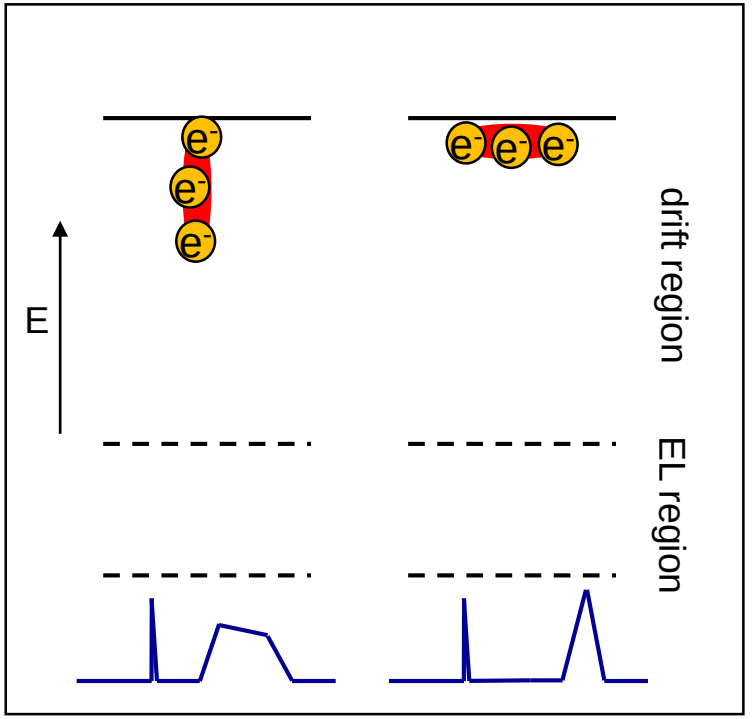
- PMT detect both scintillation and EL(ionization)
- source: 5MeV alpha-ray





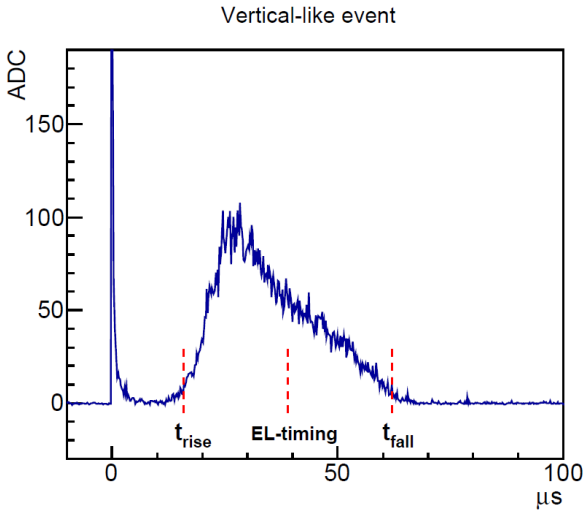
Signal waveform

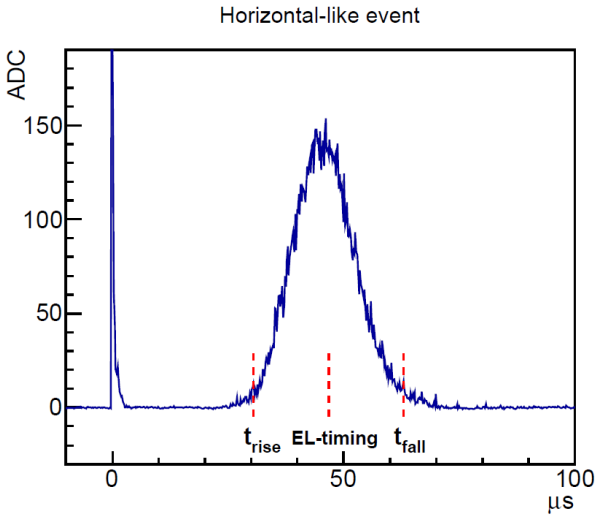
- EL-timing ∝ cosθ
- Initial angle θ can be known

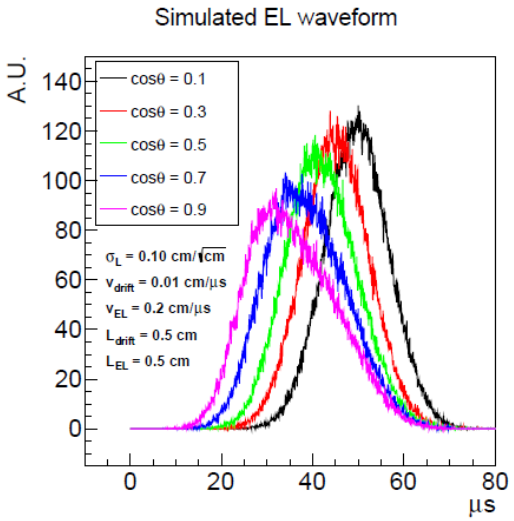


$$EL\text{-}timing = \frac{t_{rise} + t_{fall}}{2}$$

8atm Xe
E_{drift}=6.6V/cm/atm
E_{EL}=900V/cm/atm

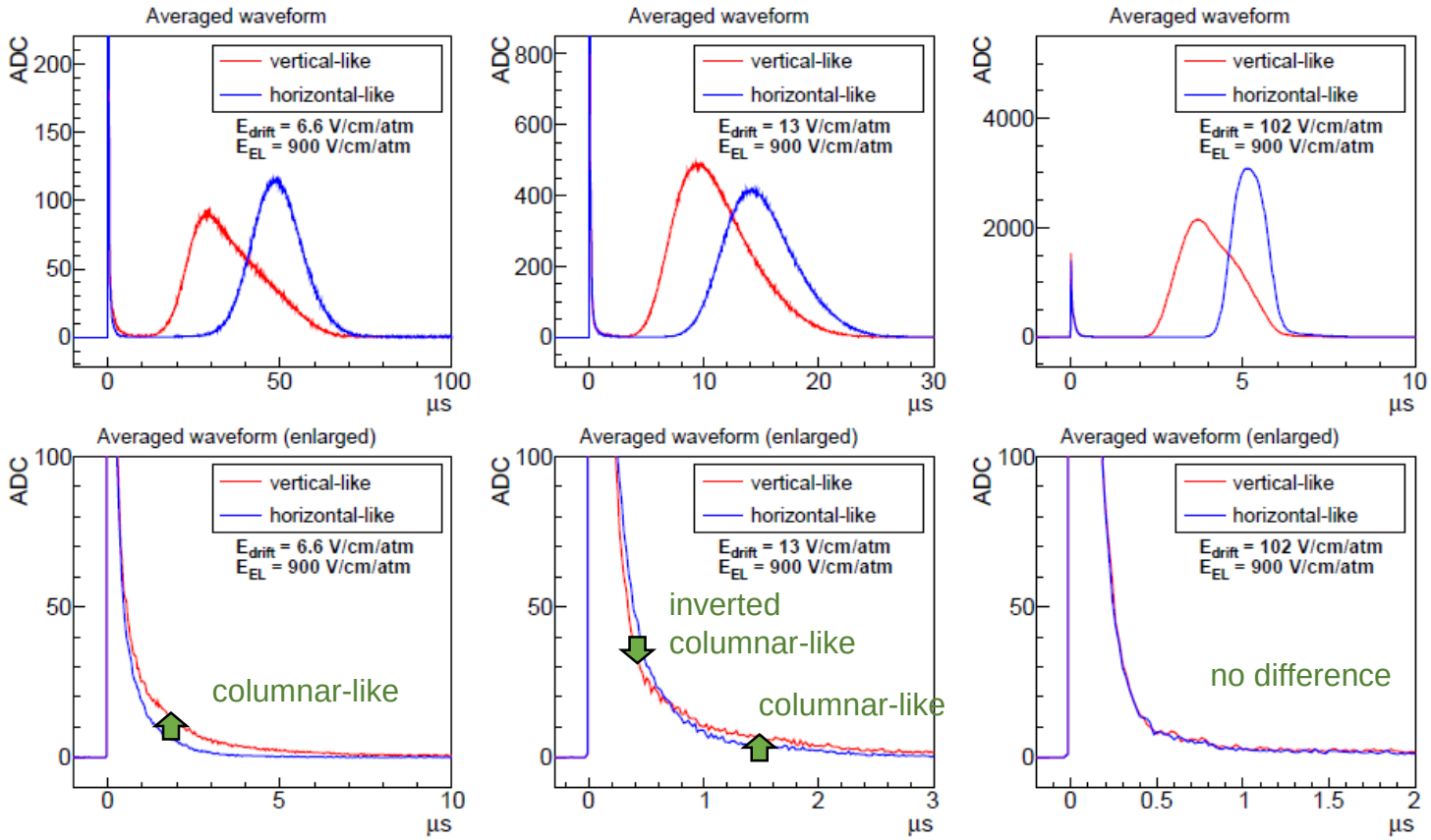






Averaged waveform

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

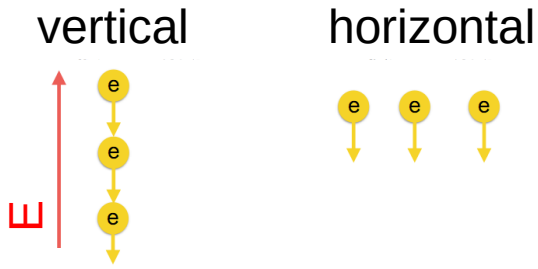


E_{drift}=6.6V/cm/atm

Angular dependence of yield

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

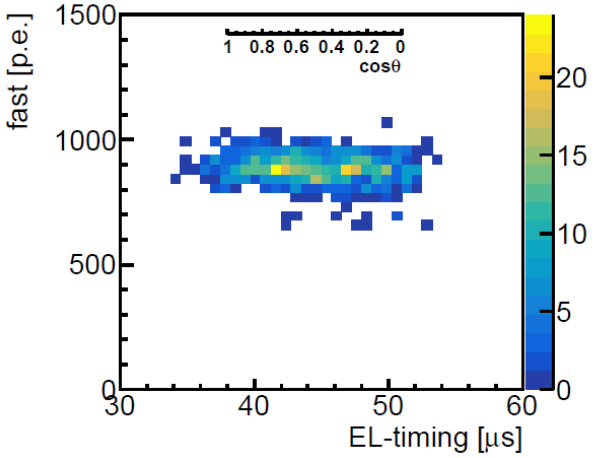
  --> Columnar recombination !



cosθ=1 ⟷ cosθ=0

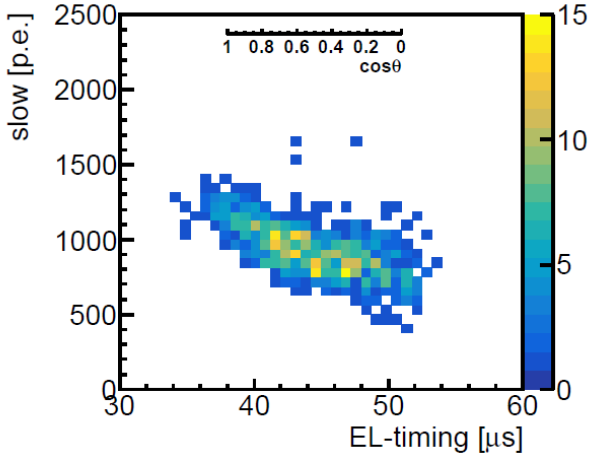
θ=0° ⟷ θ=90°

fast : de-excitation



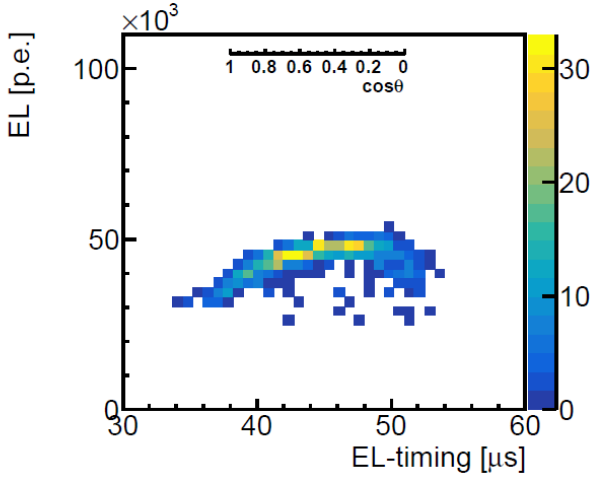
vertical ⟷ horizontal

slow : recombination



vertical ⟷ horizontal

EL : ionization



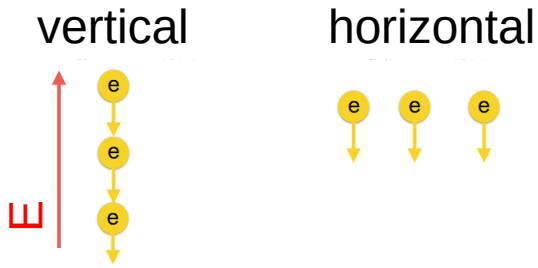
vertical ⟷ horizontal

E_{drift}=102V/cm/atm

High electric field

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

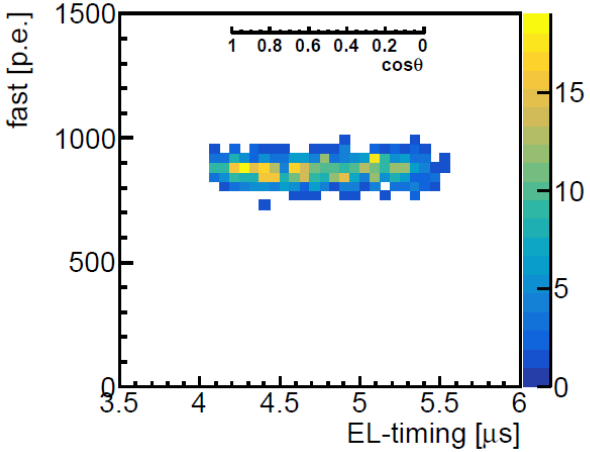
  --> No angular dependence



cosθ=1 ⟷ cosθ=0

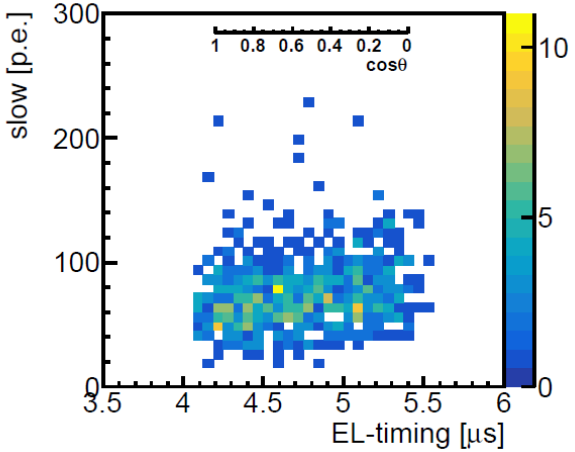
θ=0° ⟷ θ=90°

fast : de-excitation



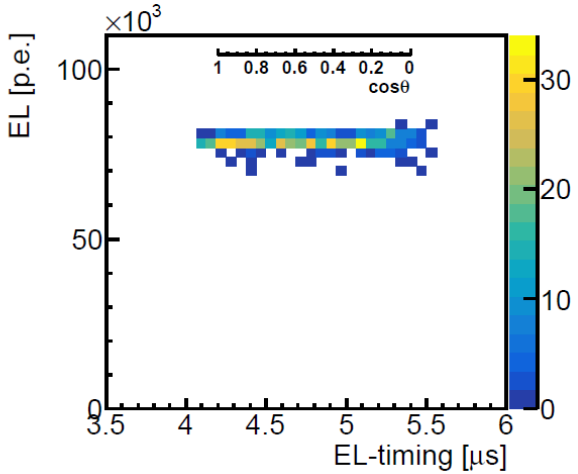
vertical ⟷ horizontal

slow : recombination



vertical ⟷ horizontal

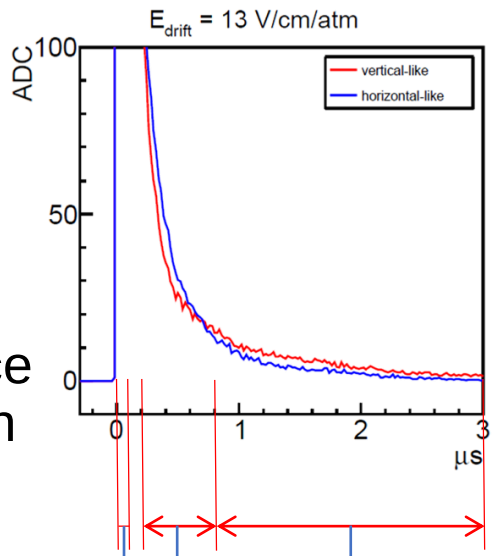
EL : ionization

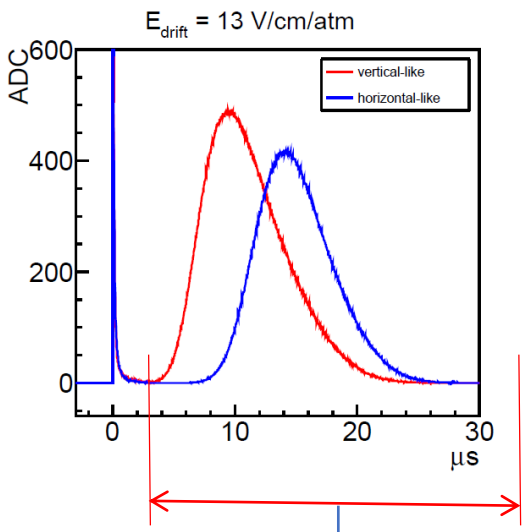


vertical ⟷ horizontal

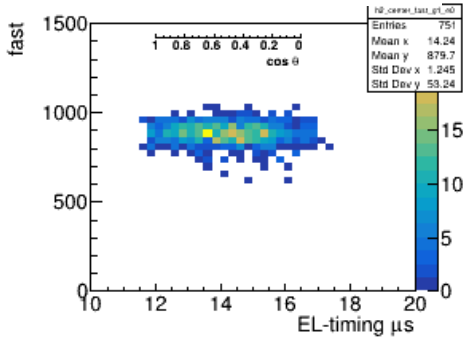
Middle E (13V/cm/atm)

- 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



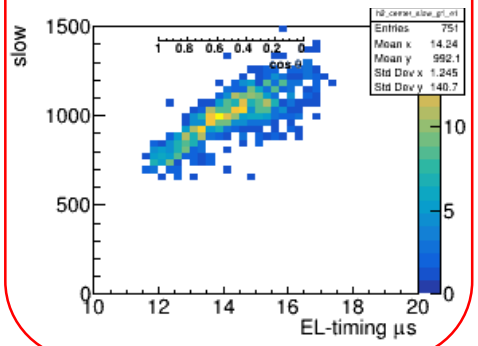


fast : de-excitation
0-0.04us



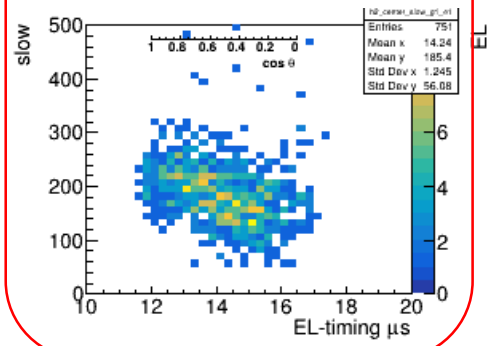
vertical ⇔ horizontal

slow1 : recombination
0.1-0.8us



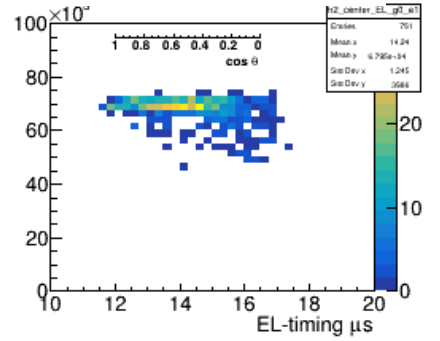
vertical ⇔ horizontal

slow2 : reconbination
0.8-3.0us



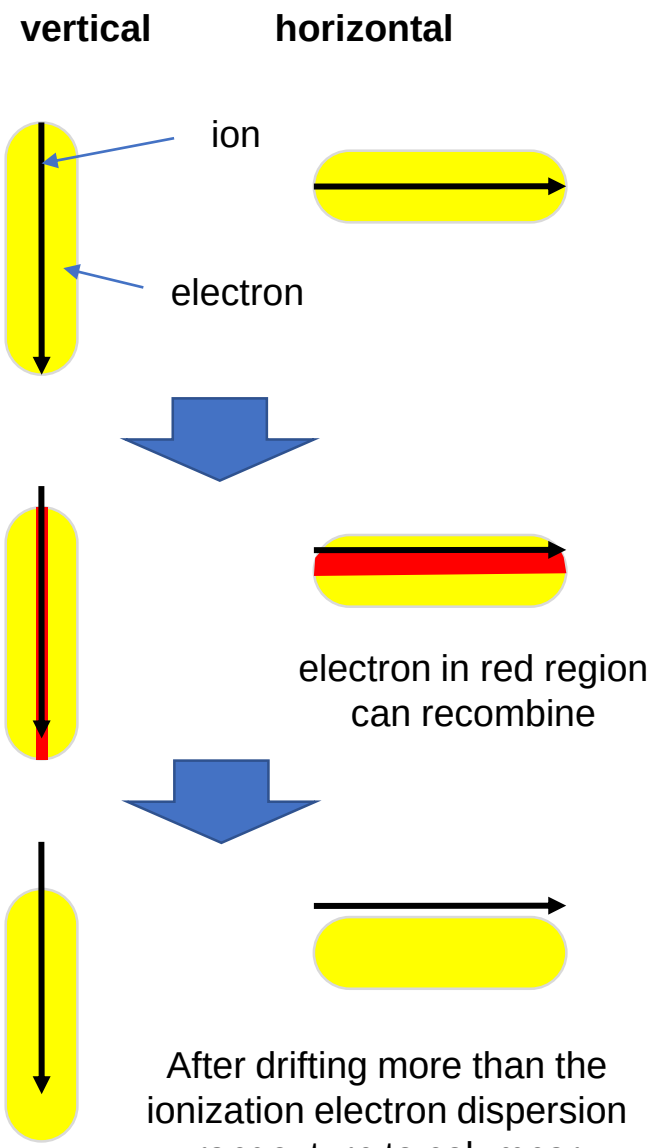
vertical ⇔ horizontal

EL : ionization
3-40us



vertical ⇔ horizontal

One interpretation of middle E



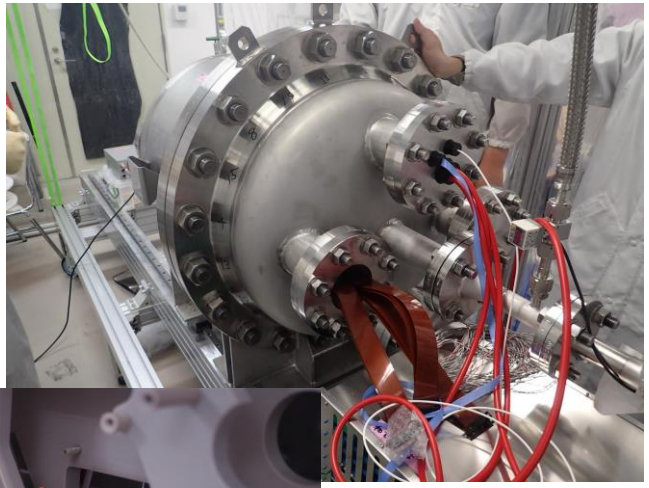
- Middle E may ...
  - diffusion is smaller than low E
  - field is not too strong to separate electrons from ion completely

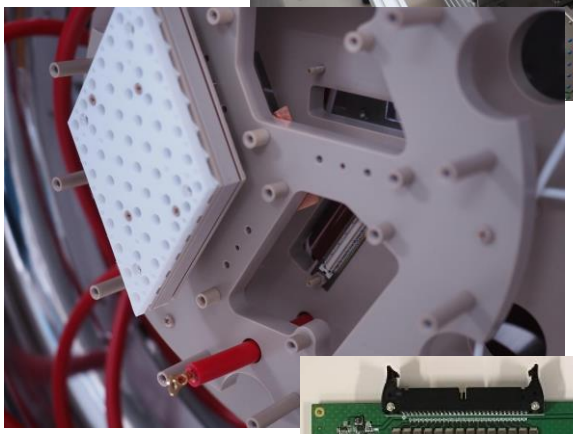
- There are two options !
  - columnar recombination in low E
  - band recombination in middle E

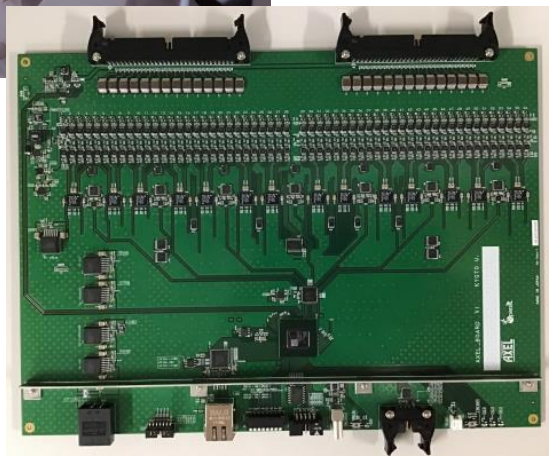
Recent AXEL: large prototype

0nbb search experiment

- Chamber
  - up to 10 bar
  - feedthrough using FPC cable
- Tracking plane
  - split type
  - 56 MPPCs / unit
- Electronics
  - take 56 waveforms
  - bias adjustment for each MPPCs







- --> common R&Ds for DM search !

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Conclusion

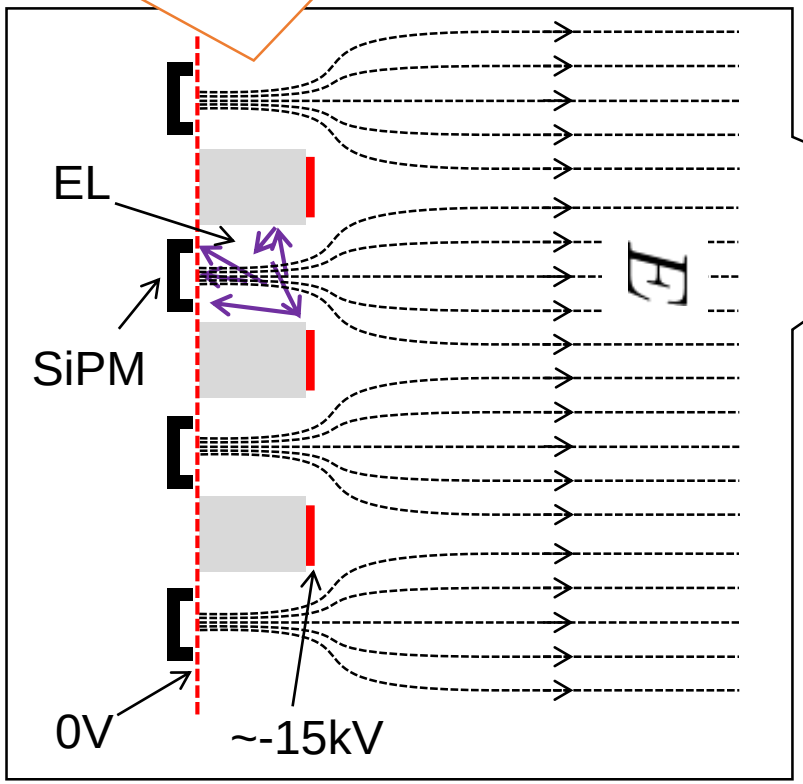
- Angular dependence of columnar recombination was observed in both photon and charge signal
  - gas: 8atm Xe 100%
  - particle: 5MeV alpha-ray
  - about 20% difference in signals
- Low electric field is needed
  - 6.6V/cm/atm this time
- Now: developing large size detector (as AXEL)
- Next: low energy study

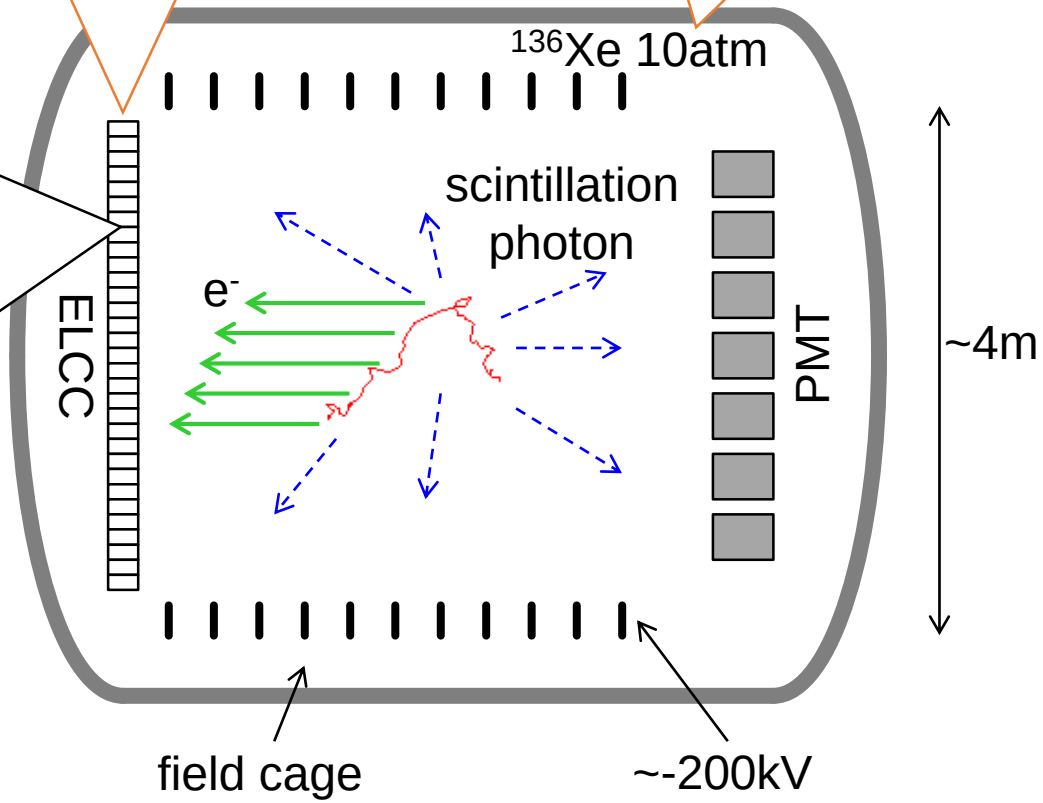
High pressure xenon gas TPC

Energy resolution: gaseous xenon + electroluminescence (EL) readout
target: 0.5%FWHM

Background rejection: tracking by segmented EL readout

Large mass: high pressure ~ ton scale

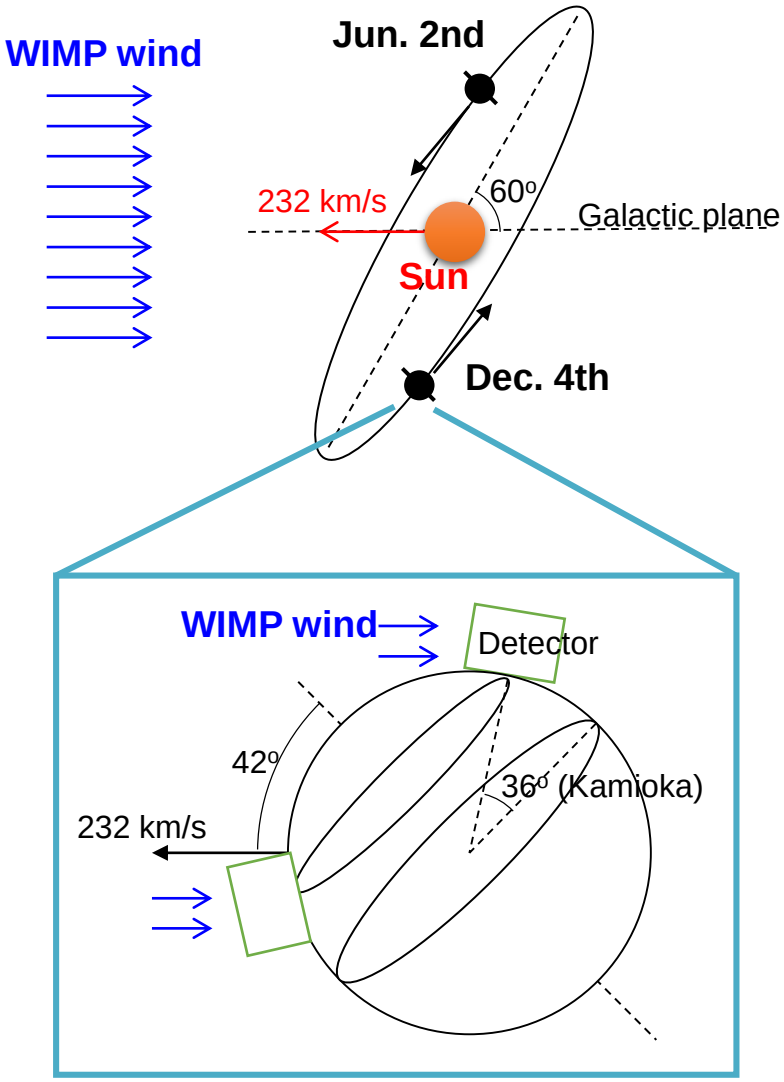




- AXEL group develop the TPC for 0nbb search

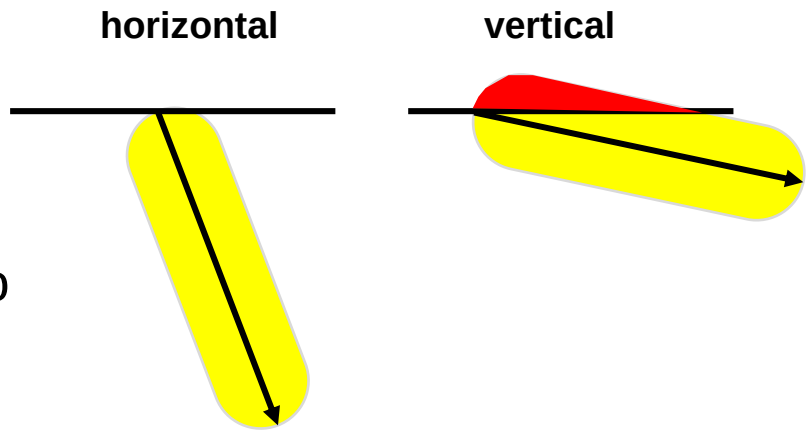
Direct dark matter search

- 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

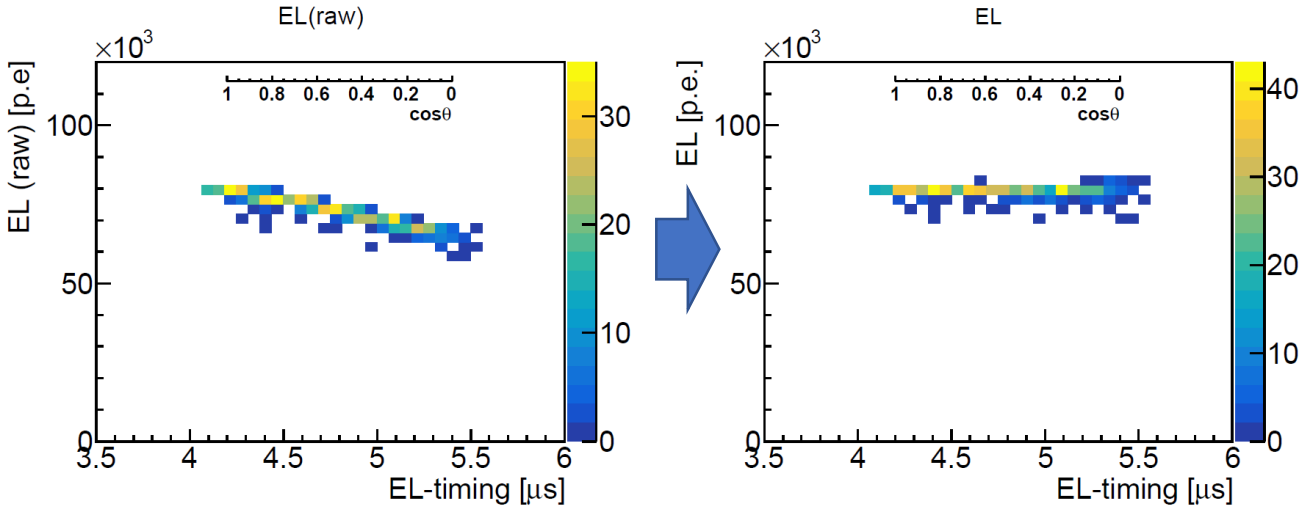


Loss of electrons due to the drift plane

- 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 cosθ dependence of EL yield becomes flat with data of high electric field
  - Correct photon yield as function of cosθ (EL, slow)



E=100V/cm/atm