NOBLE LIQUID DETECTOR TECHNOLOGY

韩 柯 HAN, Ke (SJTU)

Credit: LINDE

SECTION 1: INTRODUCTION

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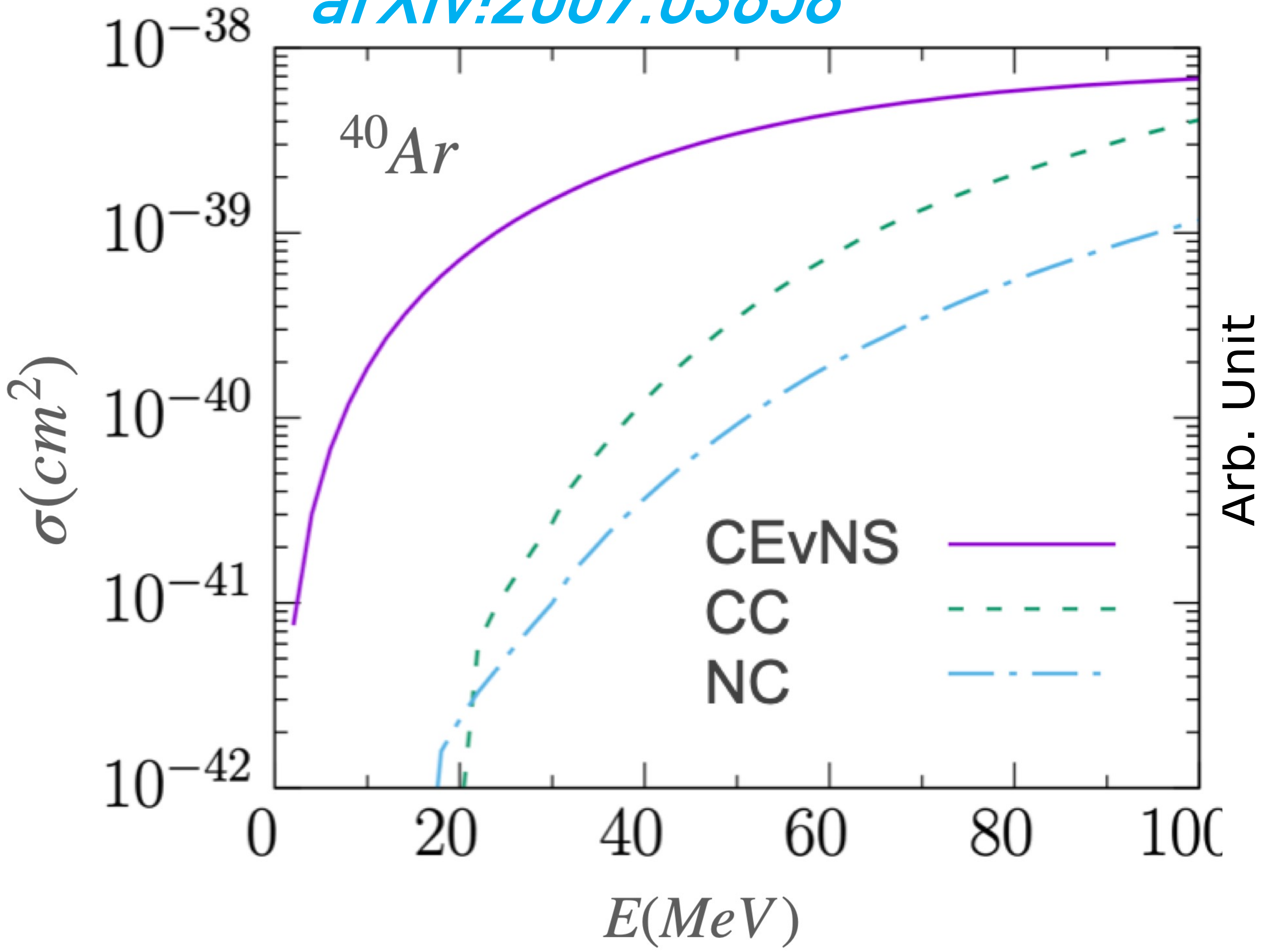
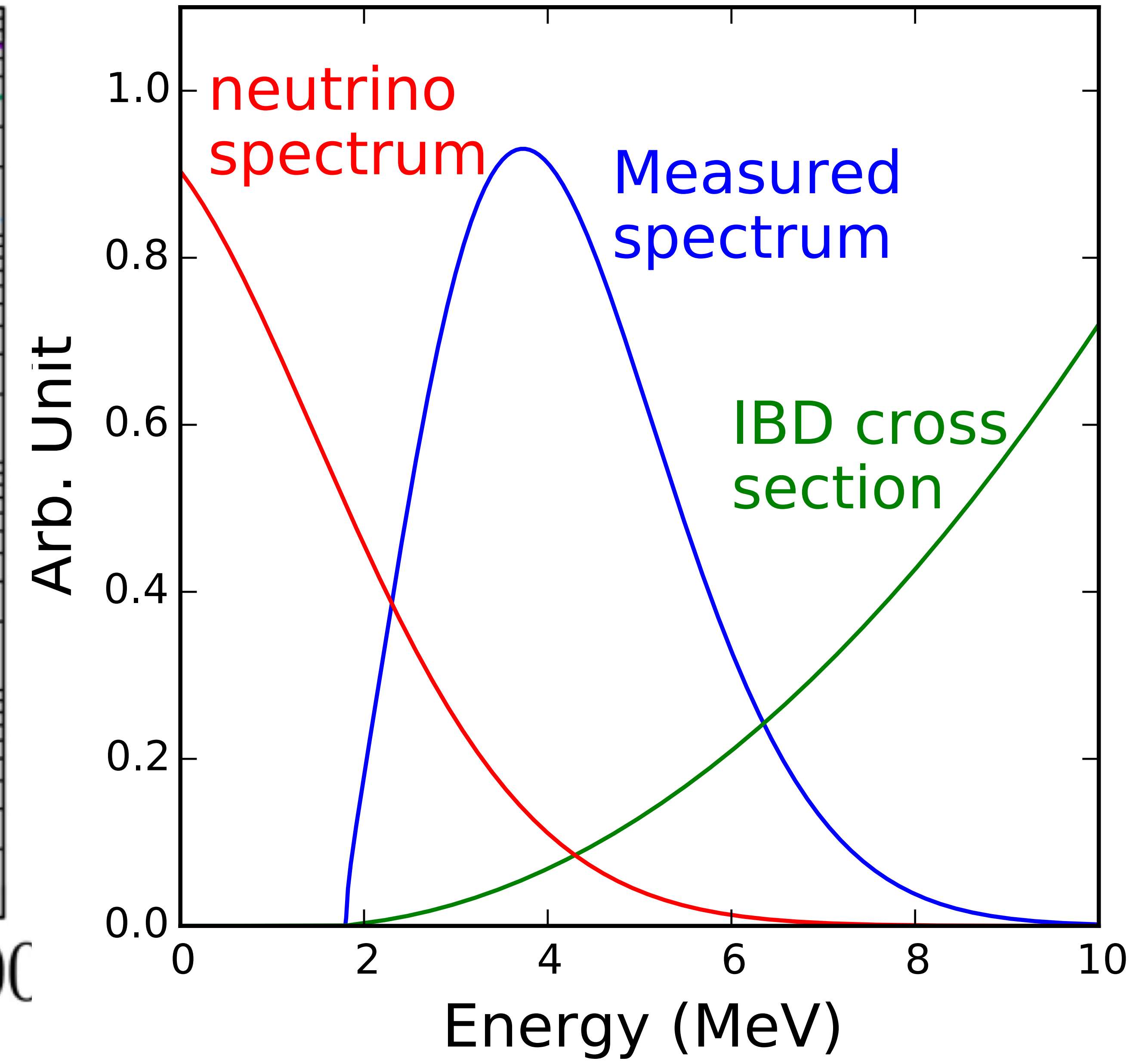
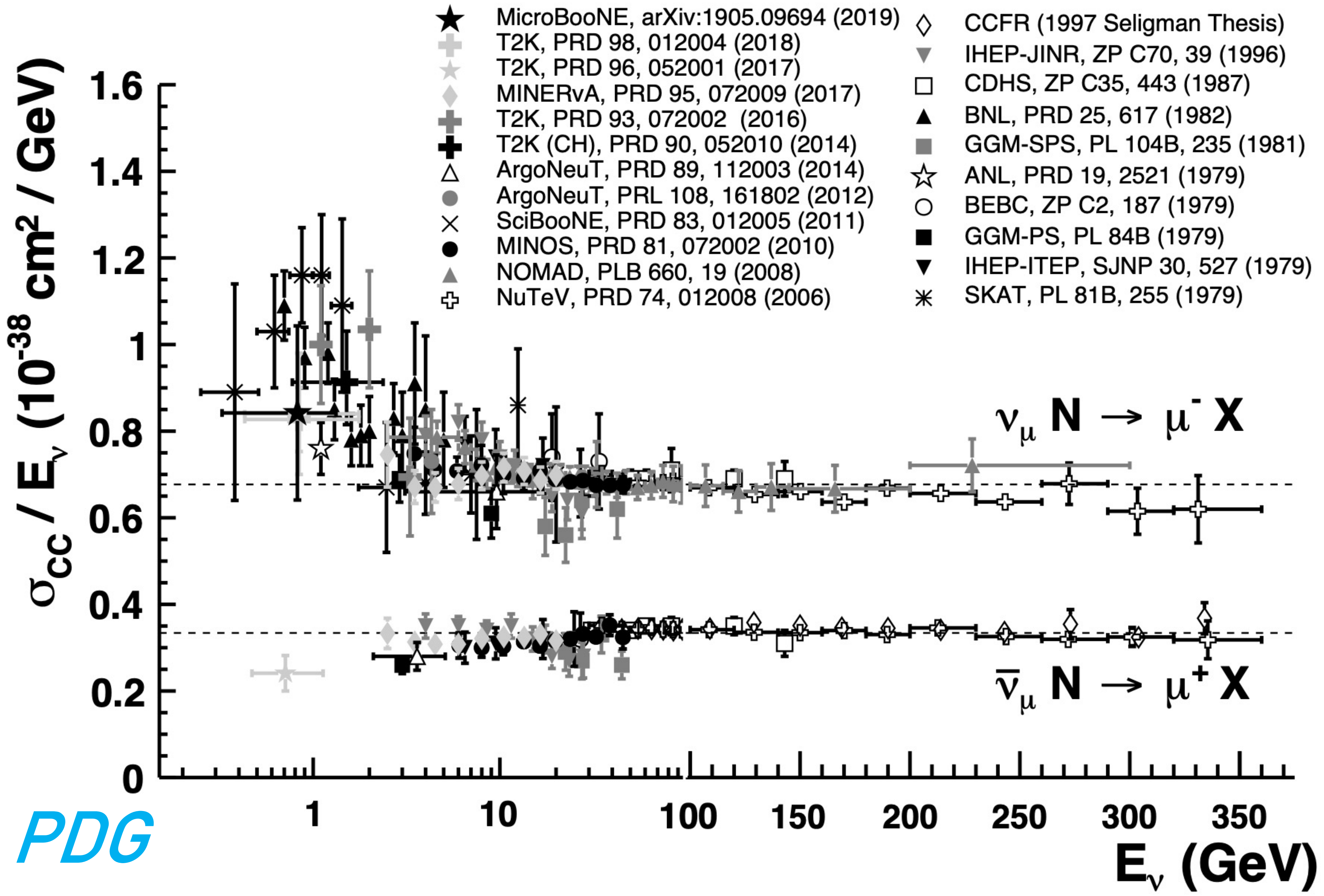
NEUTRINO DETECTION (INTERACTIONS WITH DETECTORS)

- Low energy (< 100 MeV)
  - Coherent scattering
  - Neutrino capture on radioactive nuclei
  - Inverse beta decay
- High Energy (>100 MeV)
  - Elastic and quasielastic scattering
  - Resonance production
  - Deep inelastic scattering

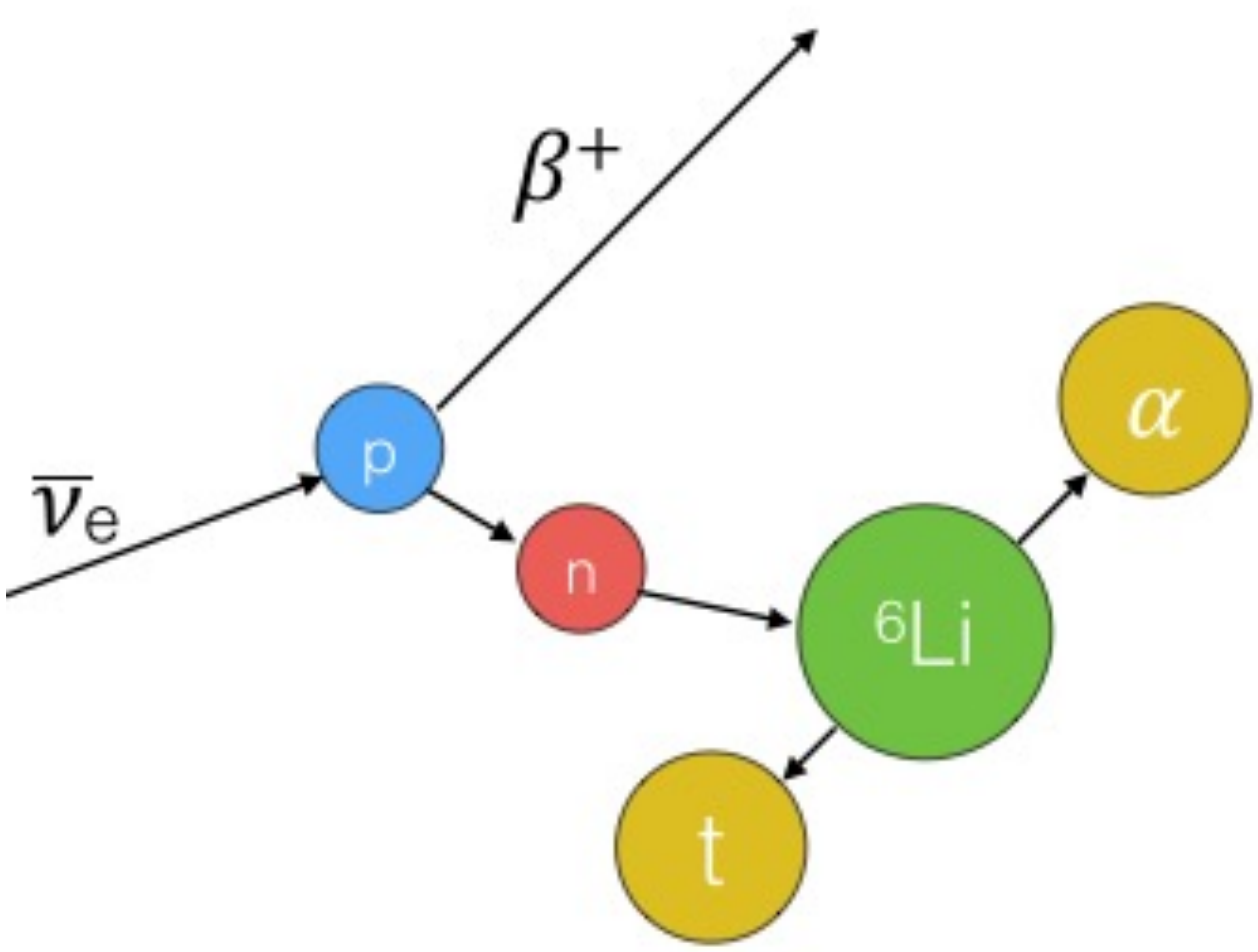
arXiv:2007.03658







PDG



NEUTRINO DETECTOR TECHNOLOGY

- Specifically designed neutrino detector for detecting neutrino
- Measure neutrino properties via the familiar gamma/electron/neutron/alpha, etc
- Detectors in neutrino physics are not always about neutinos
  - e.g. neutrinoless double beta decay
- Noble liquid detector technology, described more broadly.

STRUCTURE OF THIS SERIES

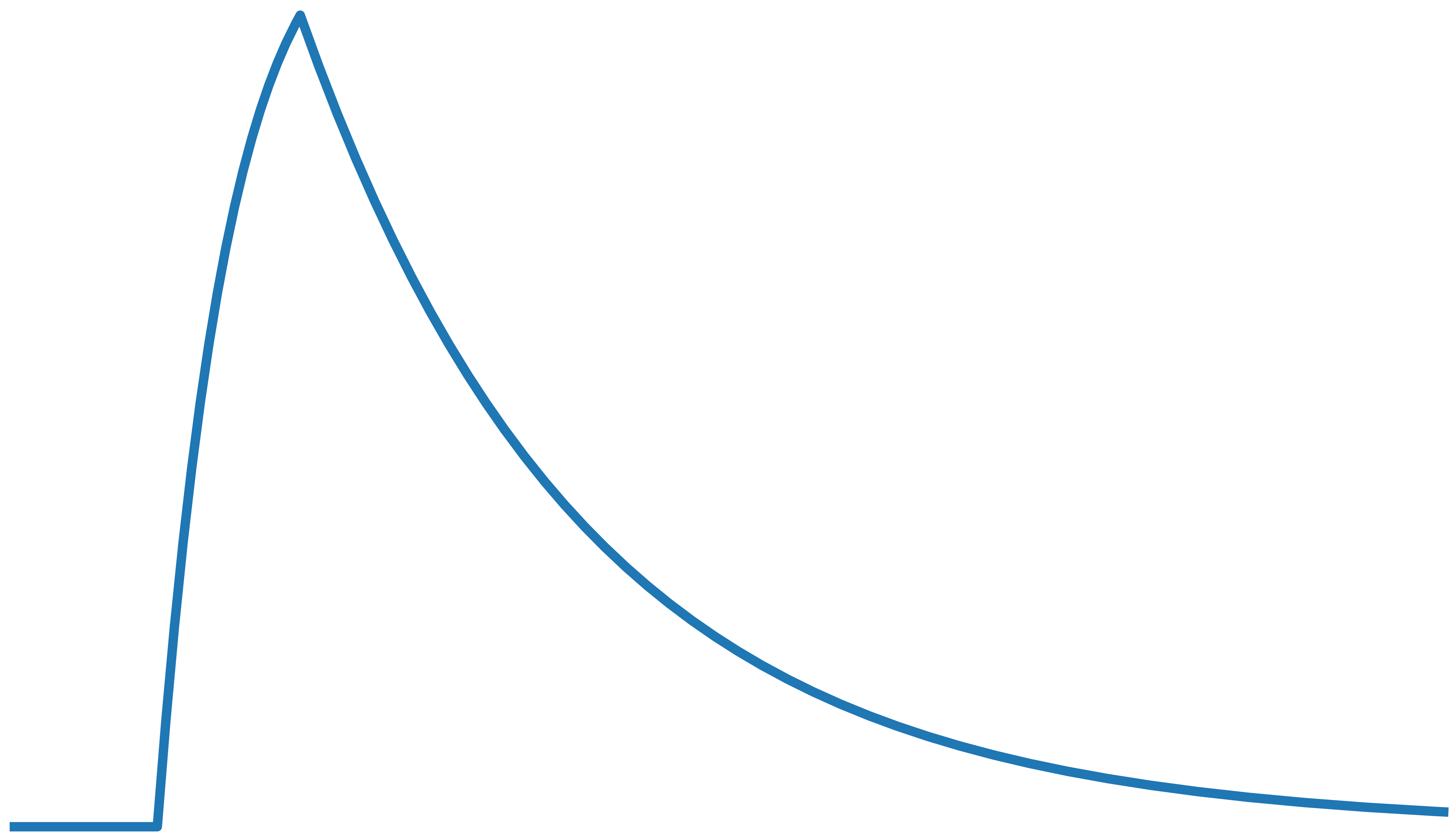
1. Introduction: physics properties of noble liquids (NL); energy loss in medium; ionization and scintillation of NL
2. Liquid xenon detectors
3. Liquid argon detectors
4. Other NL detectors; NL detectors recap (by applications)

Reference: PDG, Aprile, Bolotnikov, Bolozdynya, and Doke: Noble Gas Detectors

DETECTION OF WHAT?

✓ Flux ✓ Energy ✓ Tracks ✓ Timing structure

Event by event detection only



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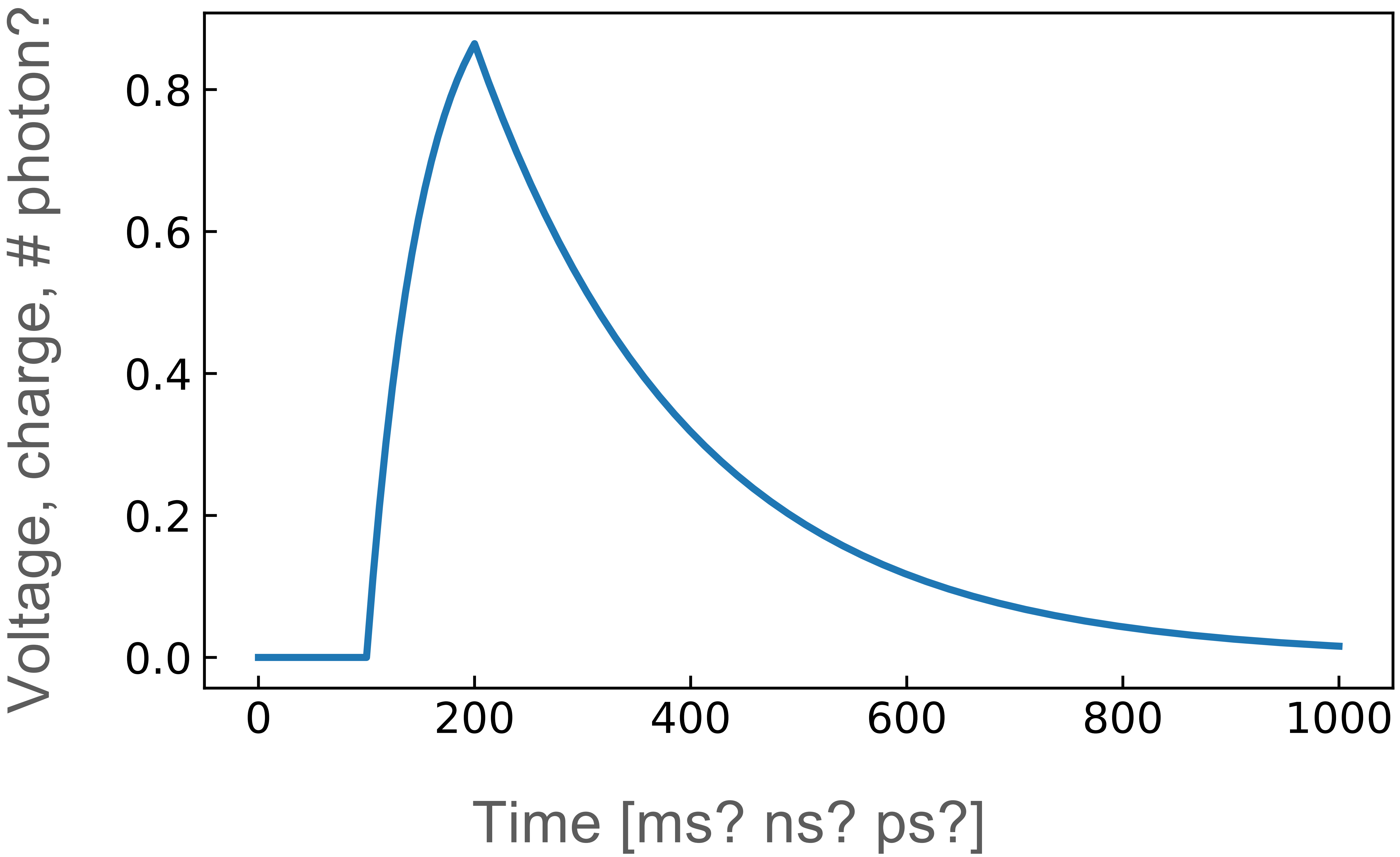

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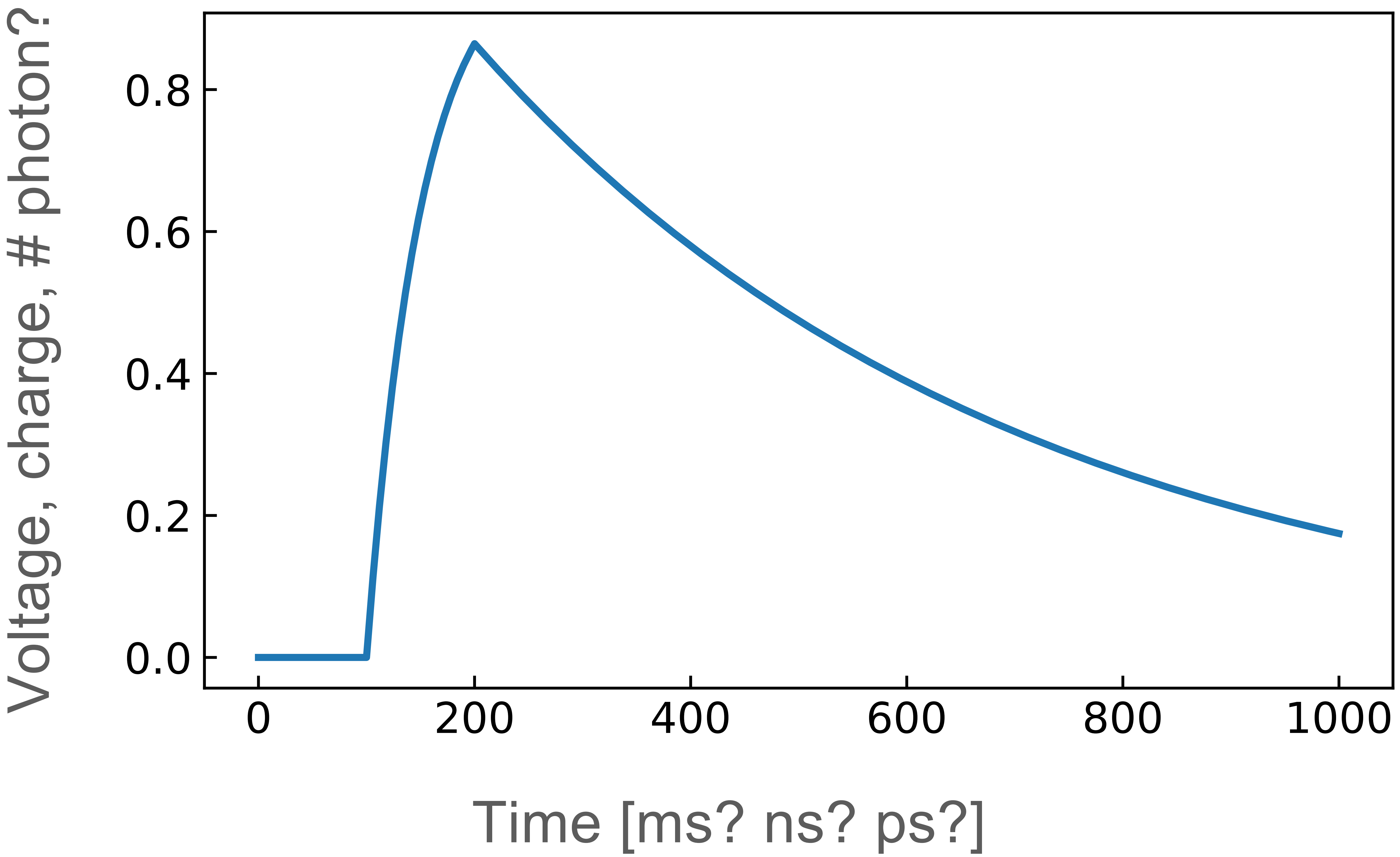


HOW A PULSE IS GENERATED?

Energy loss in a detector medium:

- Charged particle
  - Electrons
  - Alpha particles
  - ions
- Neutral particles:
  - Photons: gamma-ray, x-ray
  - Neutrons
  - Neutrinos

- Scintillation
- Ionization
- Heat

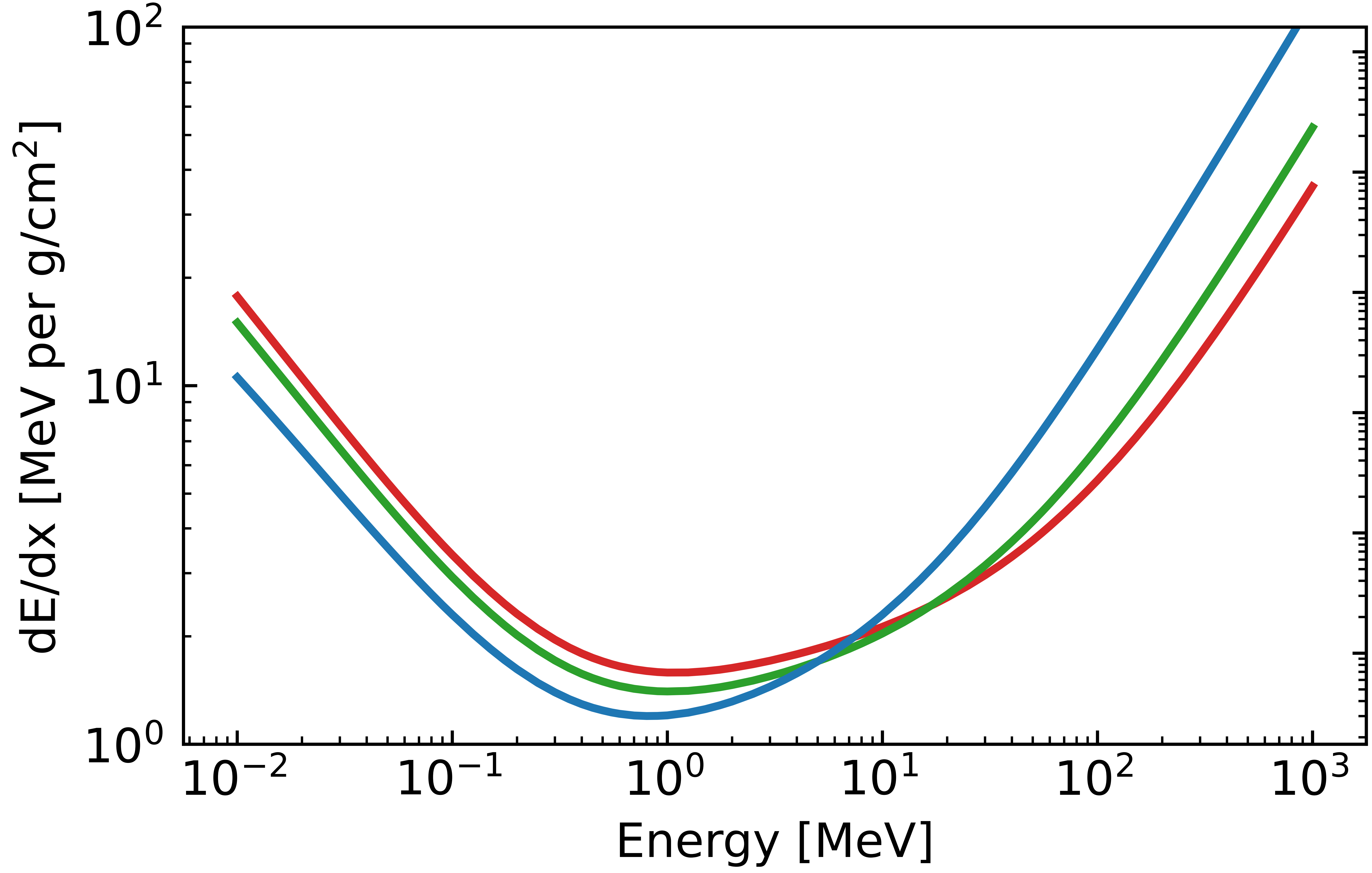
→ electronic signal

NOBLE LIQUIDS

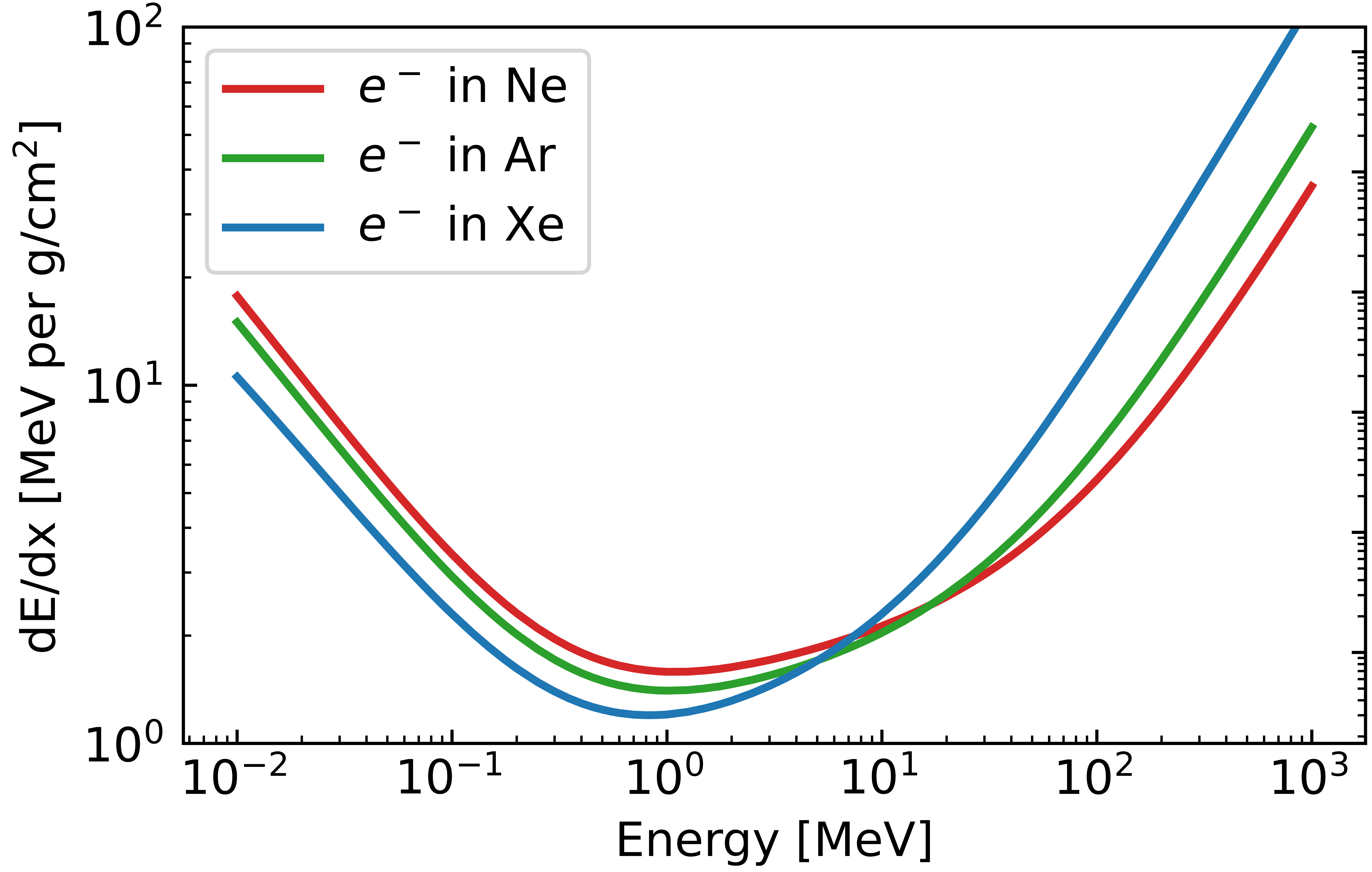
	$_{2}$He	$_{10}$Ne	$_{18}$Ar	$_{36}$Kr	$_{54}$Xe
Isotopes	3, 4	20, 21, 22	36, 38, 40	78, 80, 82, 83, 84, 86	124, 126, 128, 129,130, 131, 132, 134, 136
Mol. Mass (g/mol)	4.0026	20.183	39.948	83.80	131.3
Abundance	✓✓	✓✓	✓✓✓	✓	✓
Boiling point @ 1ATM (K)	4.2 (^{4}He)	27.102	87.26	119.74	169
Liquid density (kg/m^3)	130 (4.2)	1204	1399	2413	3100
Gas density (kg/m^3)	0.1785	0.8881	1.7606	3.696	5.8971

N_2 boiling point: 79K; NaI density 3890 kg/m^3

ENERGY LOSS IN MEDIUM: ELECTRON IN NOBLE LIQUIDS



ENERGY LOSS IN MEDIUM: ELECTRON IN NOBLE LIQUIDS



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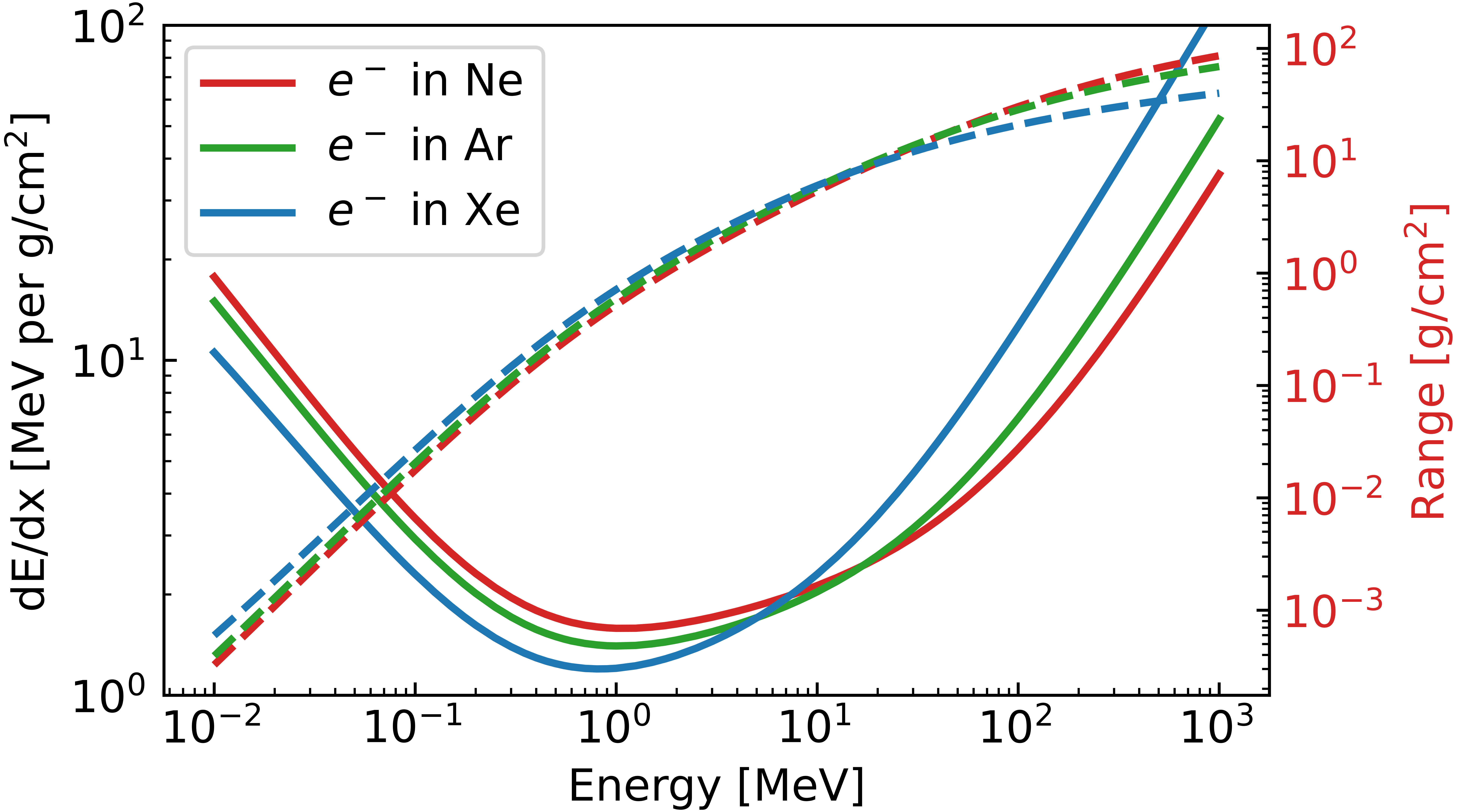
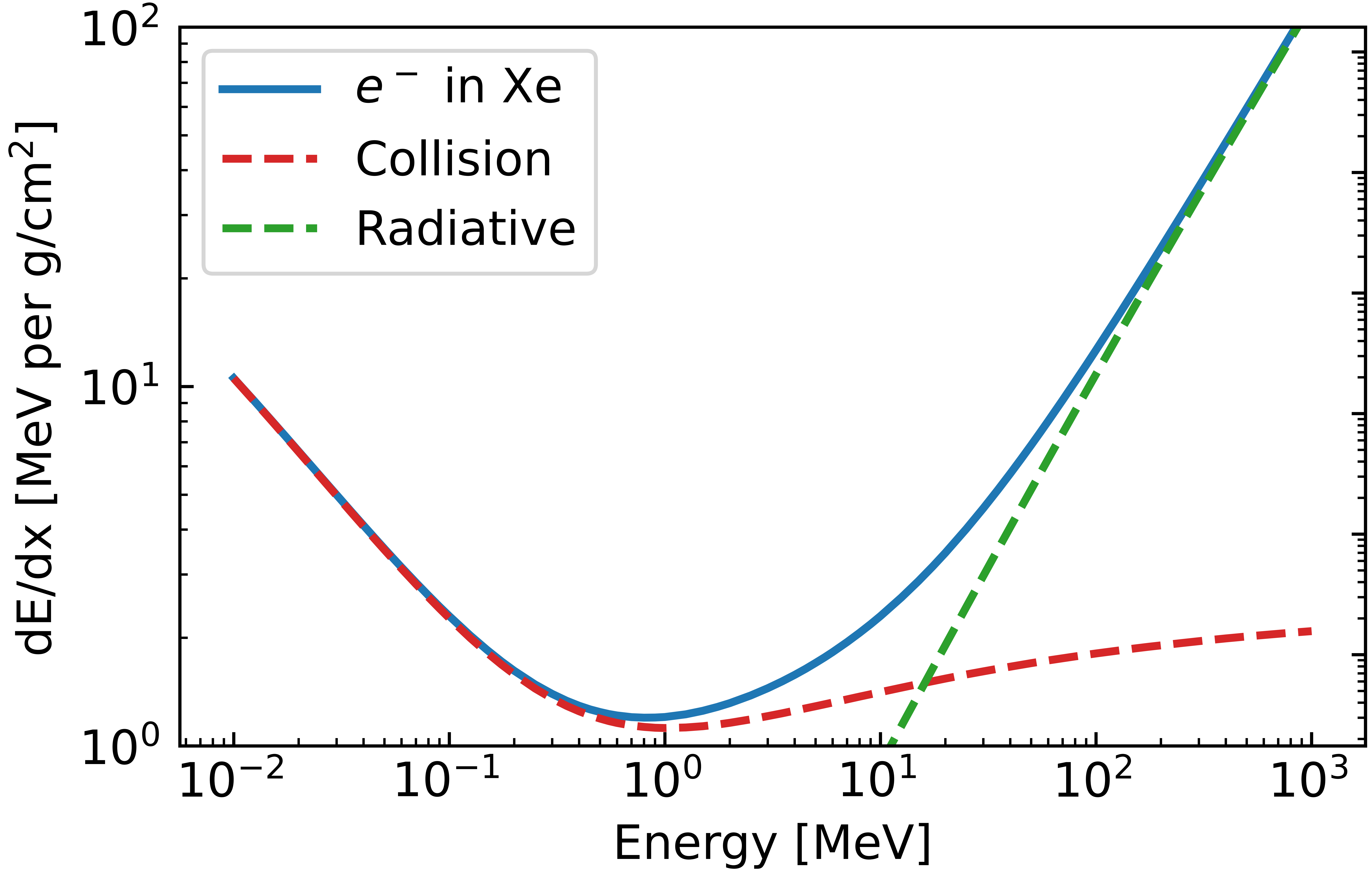
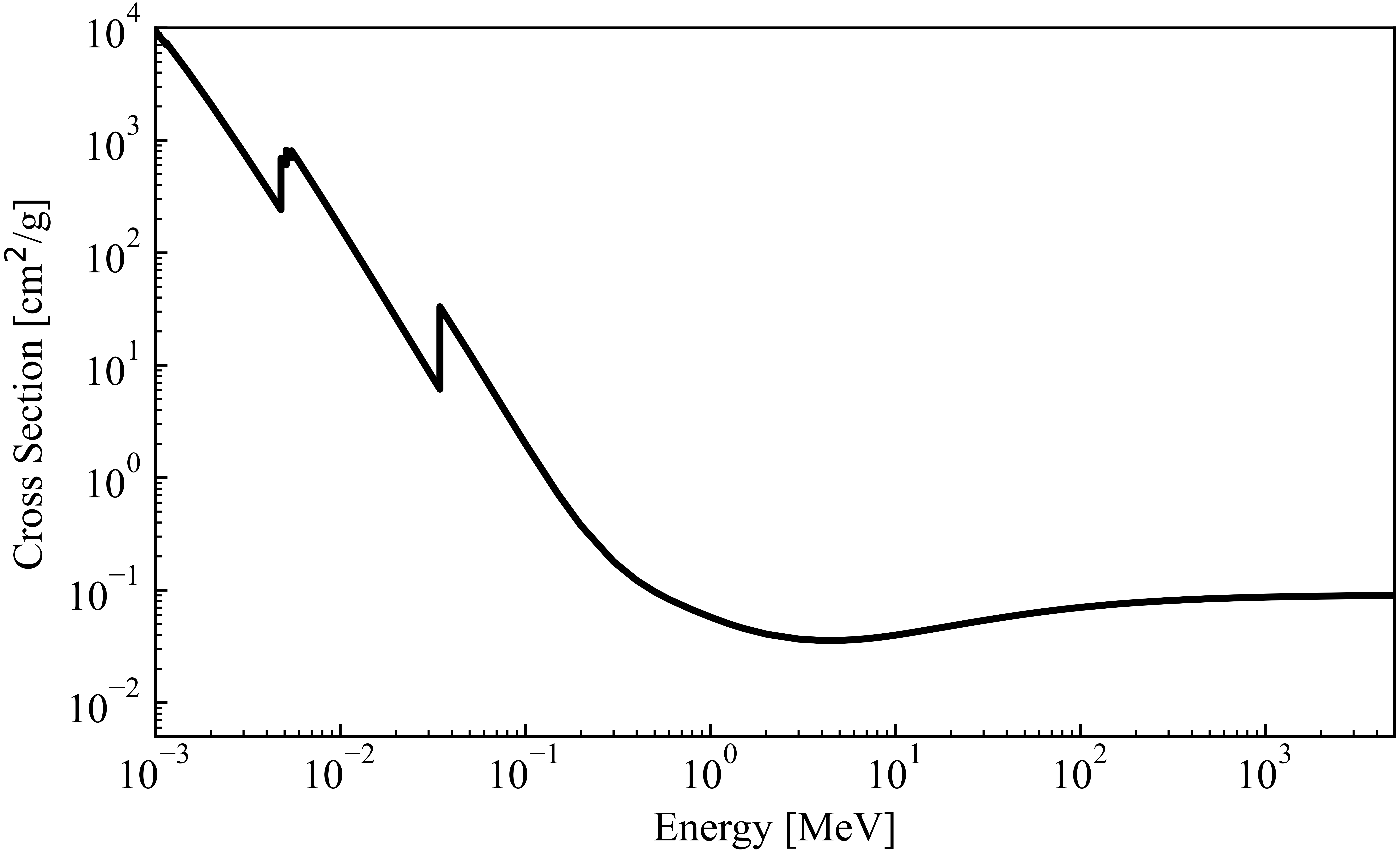


ENERGY LOSS IN MEDIUM: ELECTRON IN NOBLE LIQUIDS



ENERGY LOSS IN MEDIUM: GAMMA CROSS SECTION IN XENON



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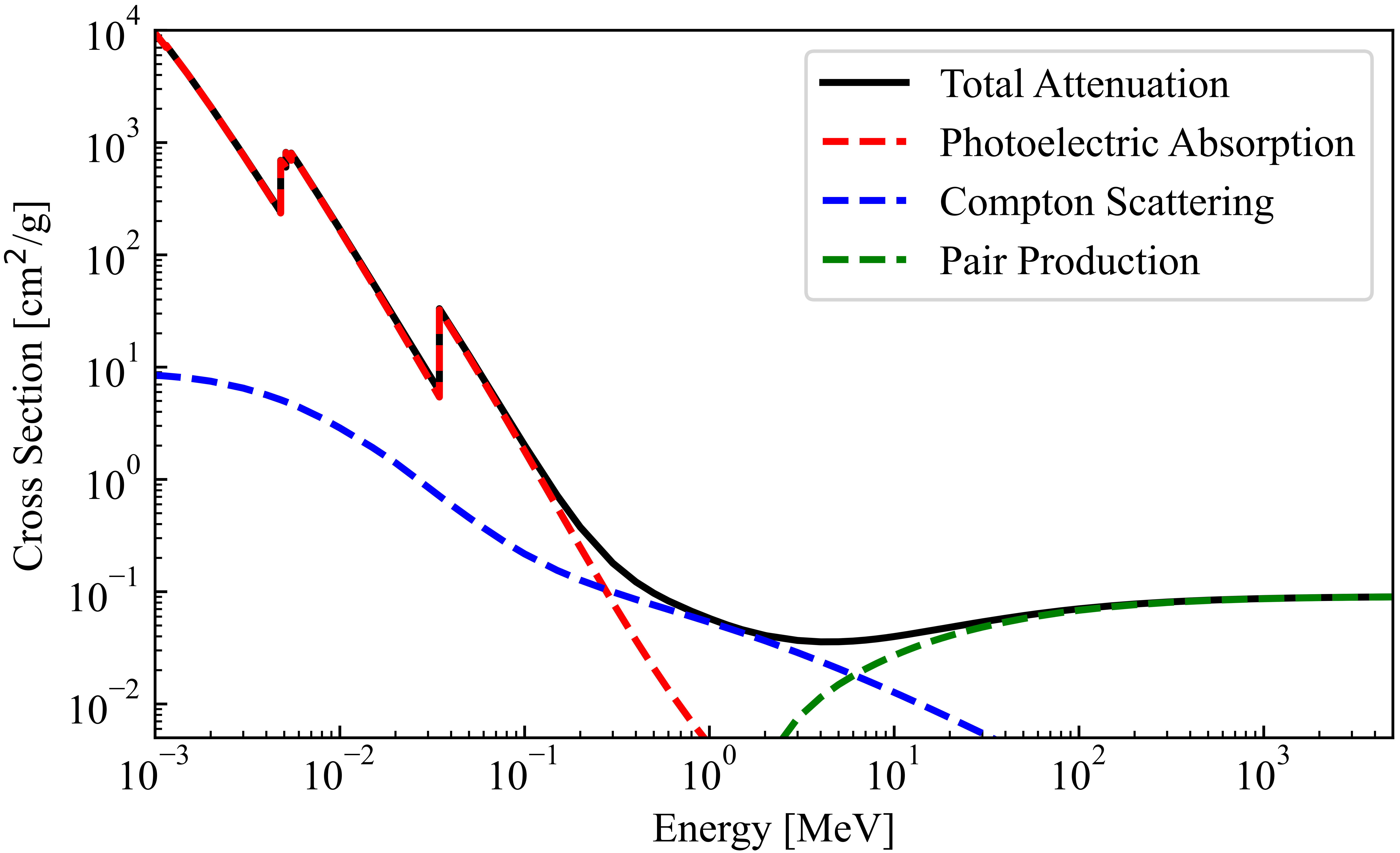
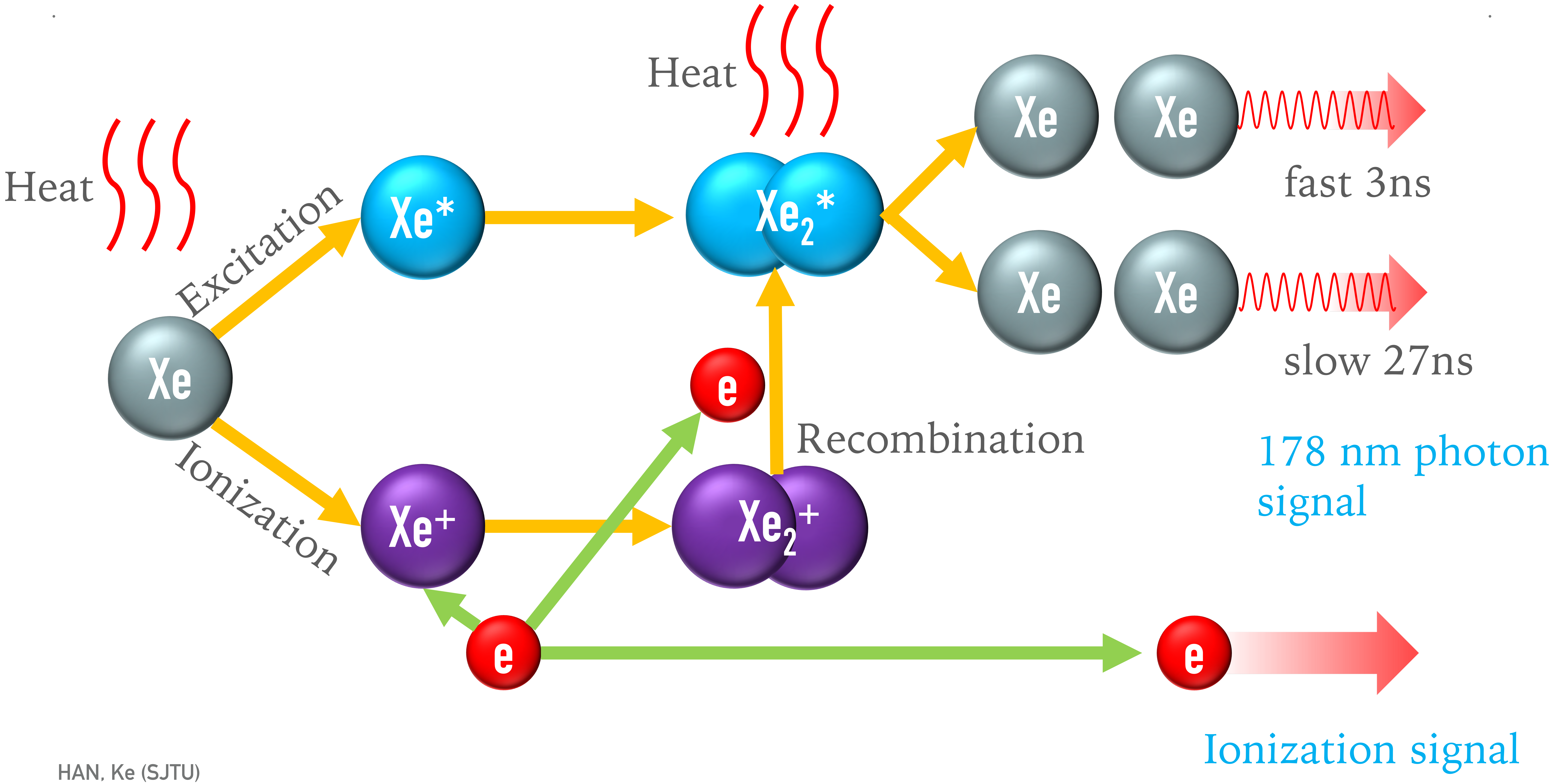
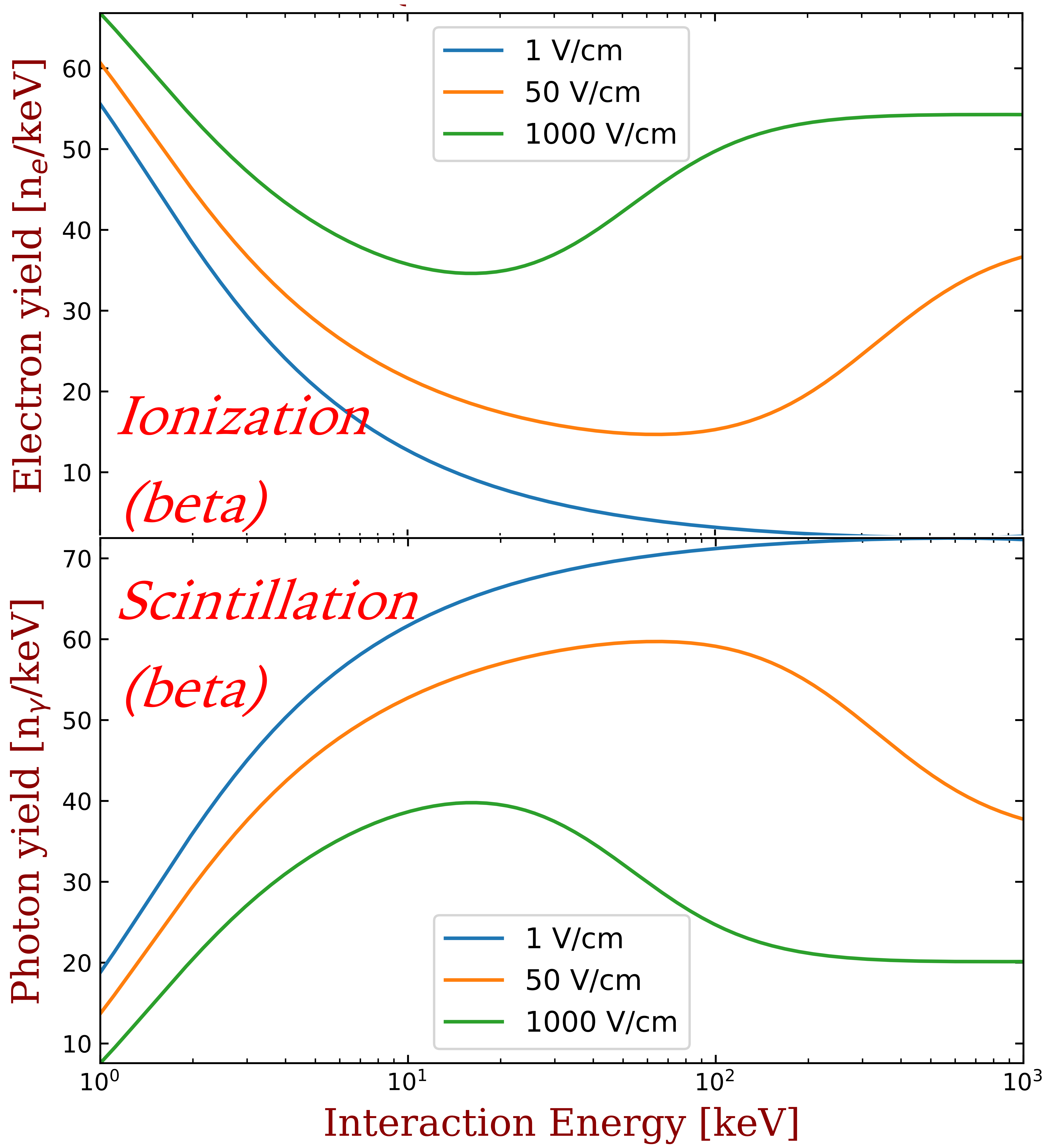


SIGNAL GENERATION IN XENON



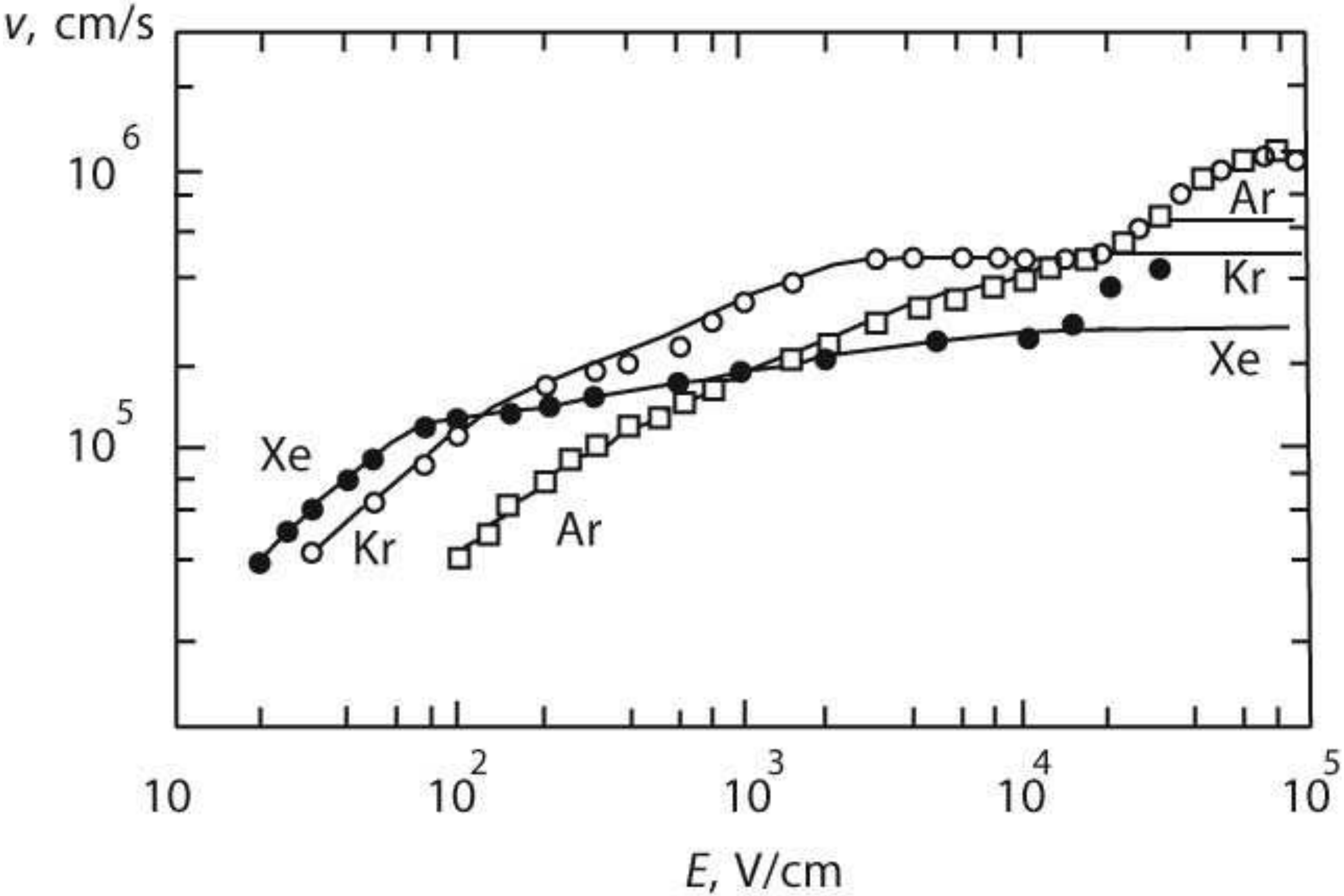


IONIZATION VS. SCINTILLATION

- Clean anti-coorelation
- Change vs. energy
- Change vs. E field
- Average energy scale for ionization or scintillation?
- Suppression of ionization/scintillation?

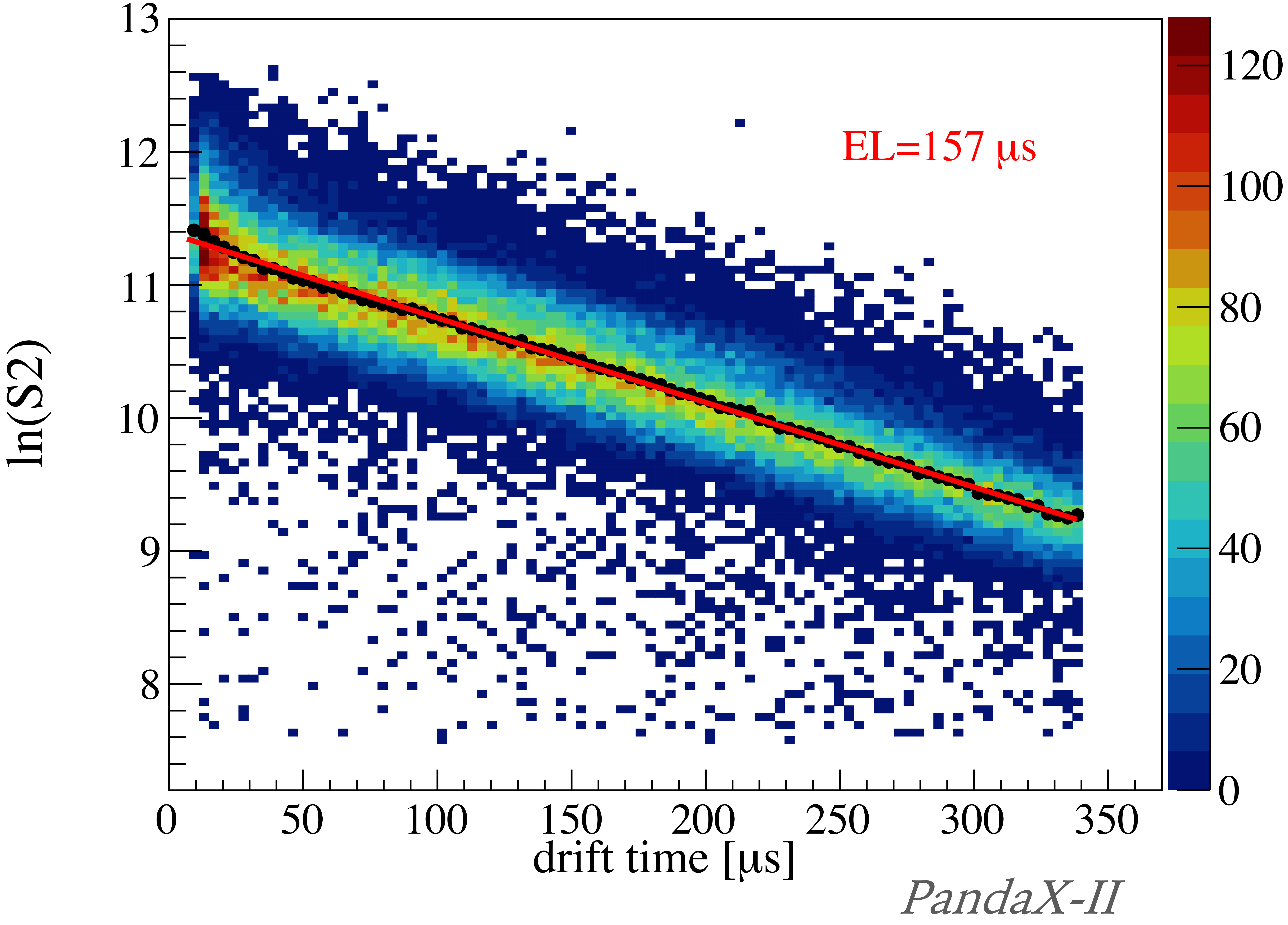
(NEST simulation)

IONIZATION SIGNAL: DRIFT



ELECTRON "LIFETIME"

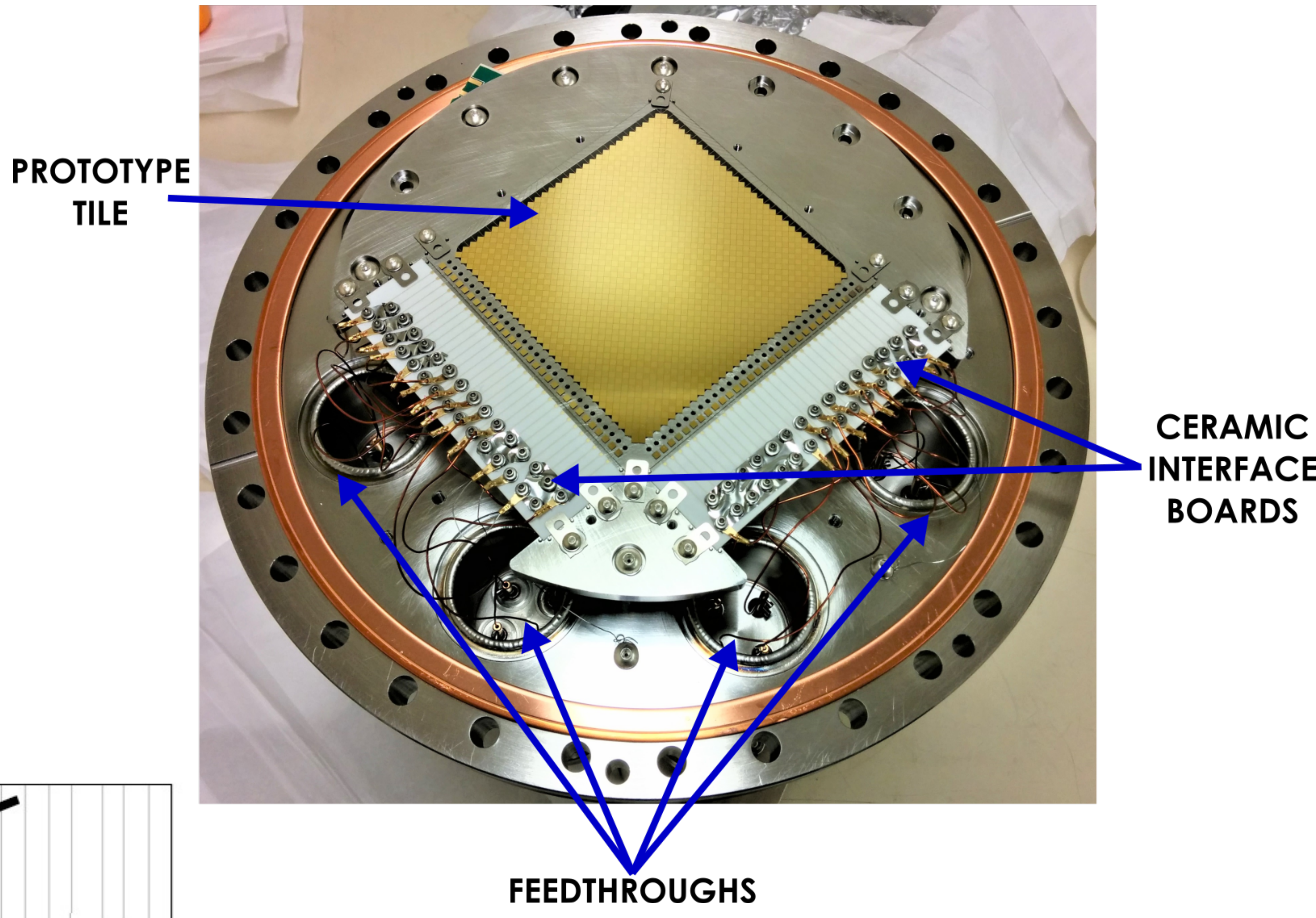
- Drifting electrons may recombine with xenon
- Electronegative negative impurity (e.g. water) greatly increases the probability of recomination, thus electron loss

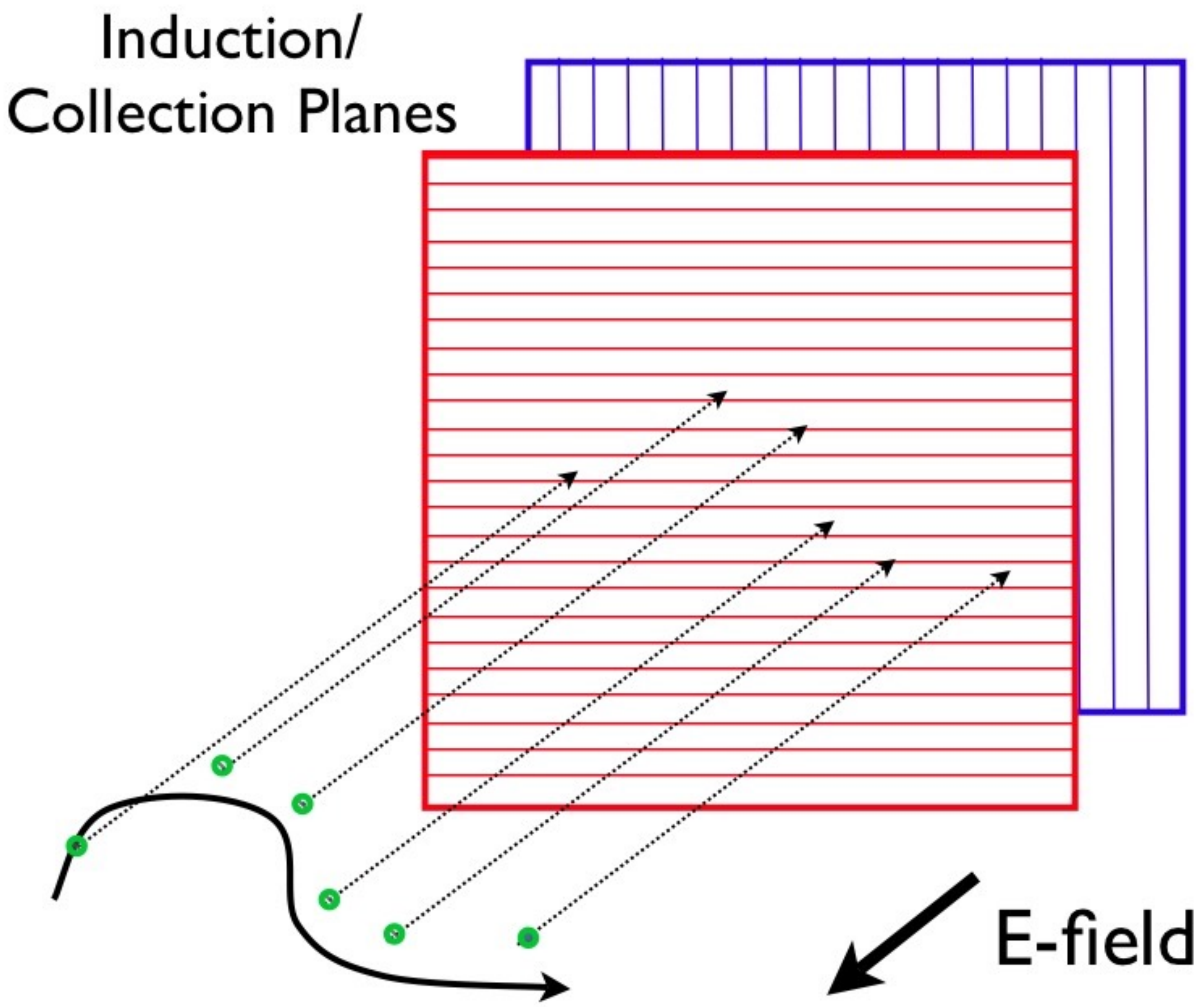


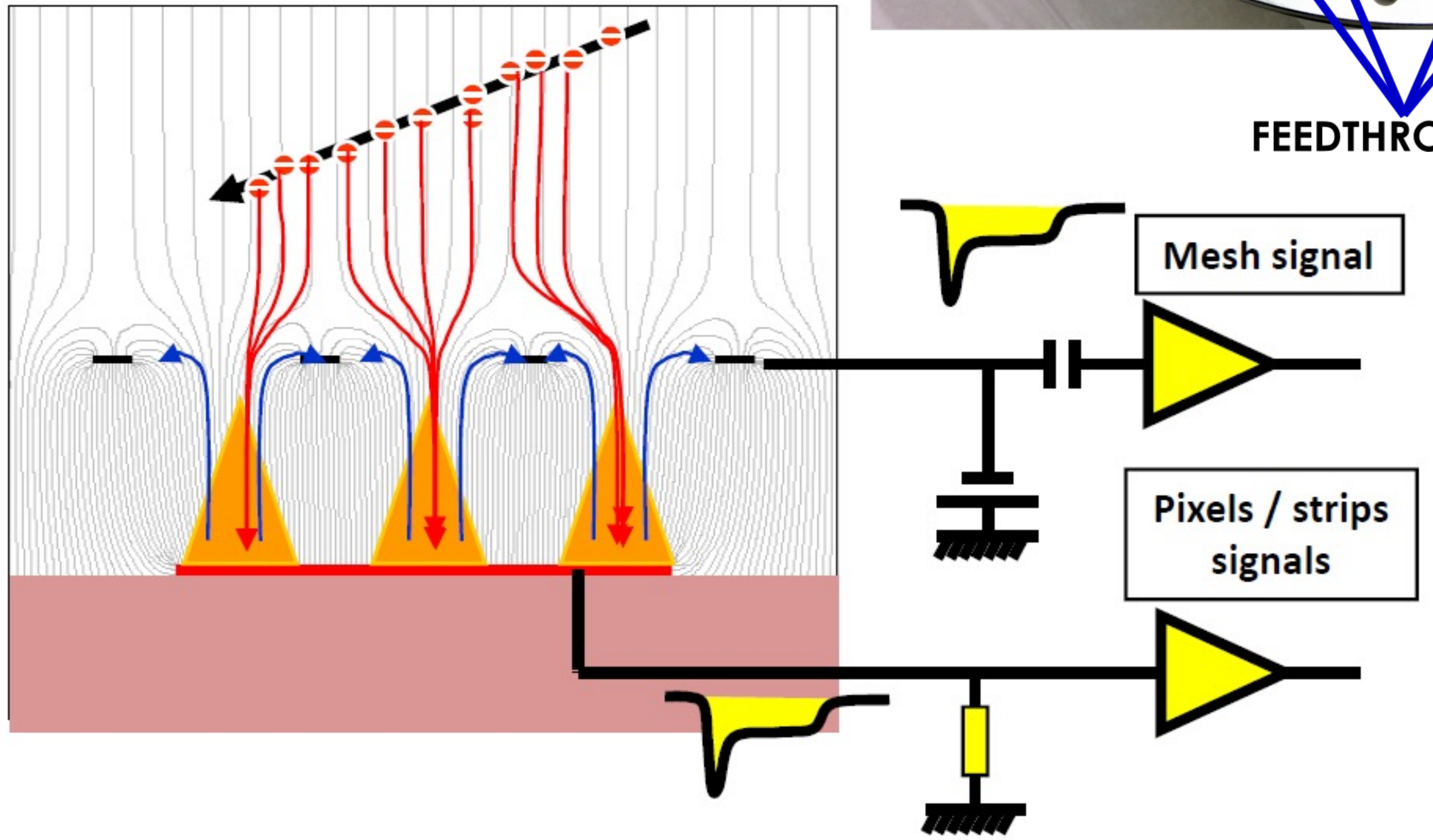
IONIZATION SIGNAL: COLLECTION

Electron Readout:

- ➤ Wires: induction and collection
- ➤ Micro-structure: amplification before collection
- ➤ Charge readout tiles: pixelization

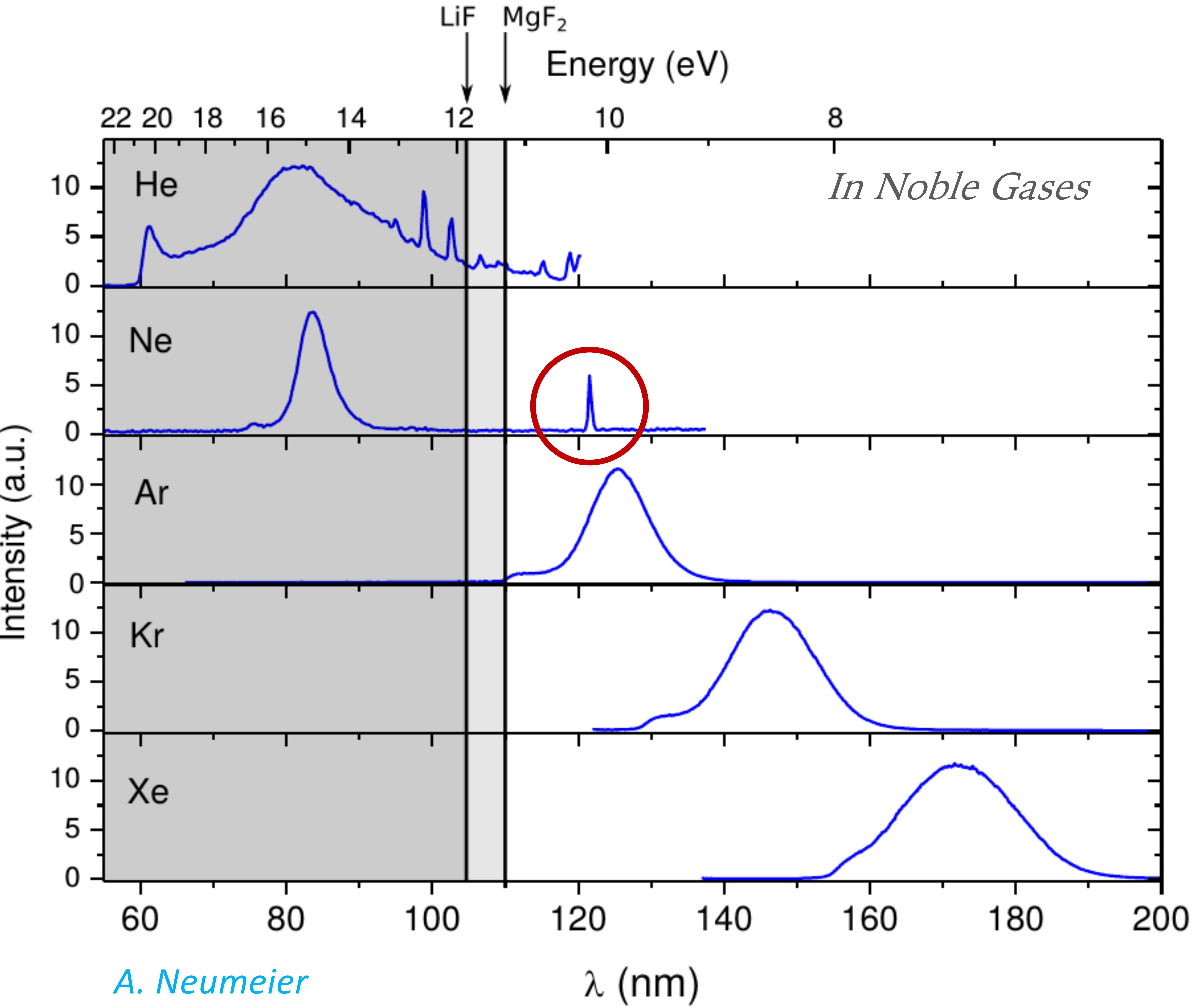






SCINTILLATION SIGNAL

➤ Light emssion in VUV region



A. Neumeier

SCINTILLATION SIGNAL

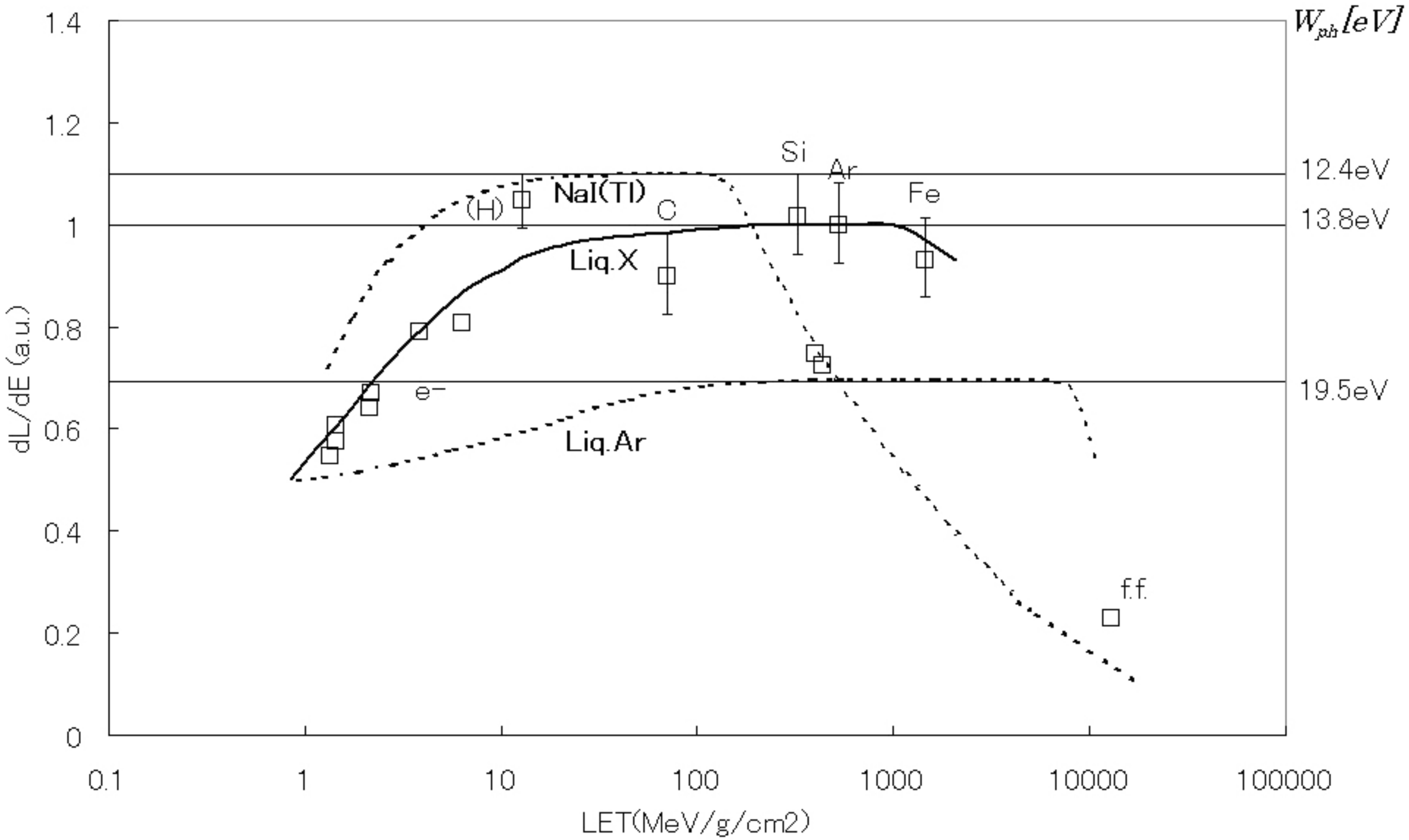
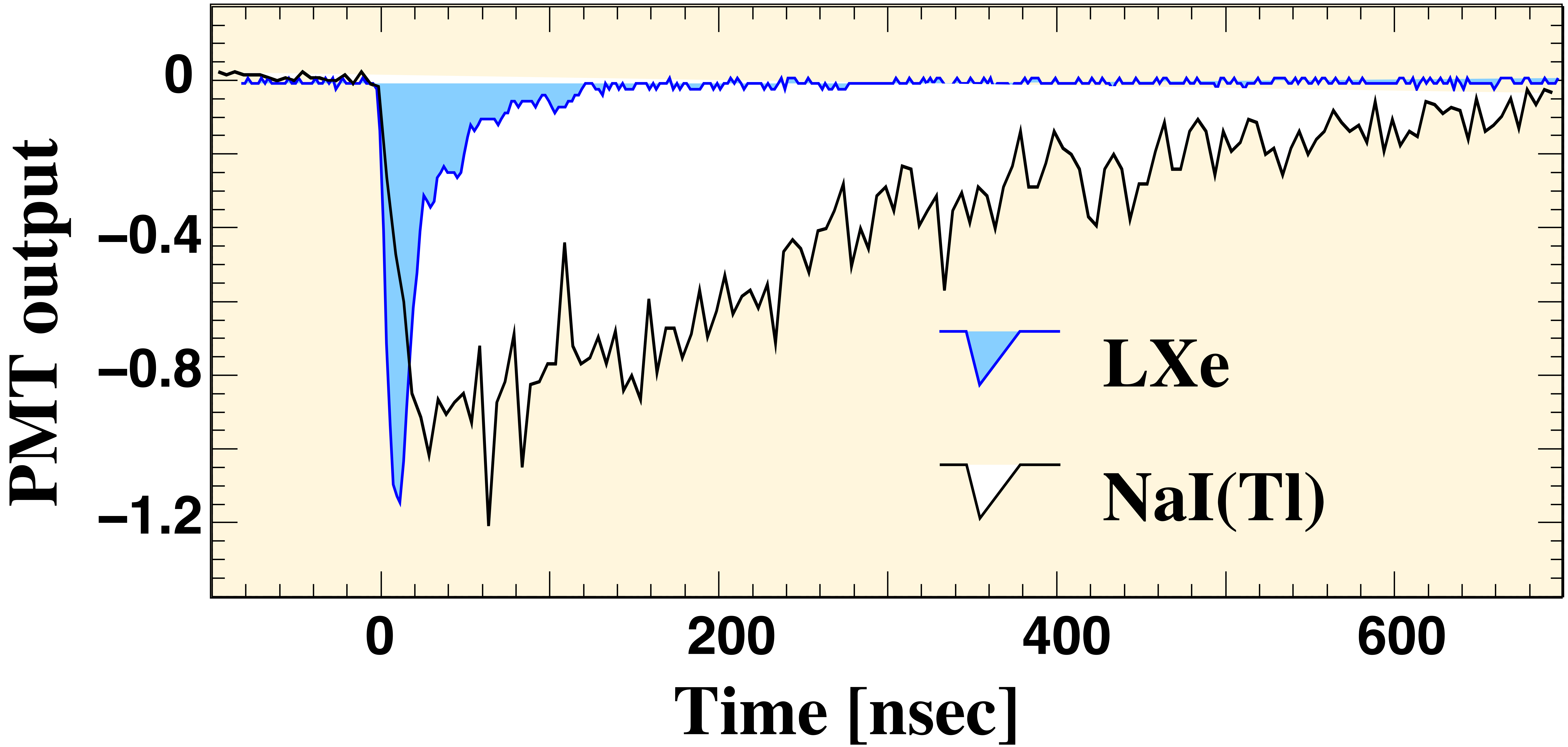


Fig. 3.41 Three LET dependences of scintillation yield curves, the upper curve is that of NaI(Tl) crystal, the lower curve is liquid argon and the middle curve is liquid xenon. The abscissa on the right side shows the value of W_{ph}.

- Light emssion in VUV region
- High light yield
  - Xe: 80% of NaI
  - Ar: 60% of NaI

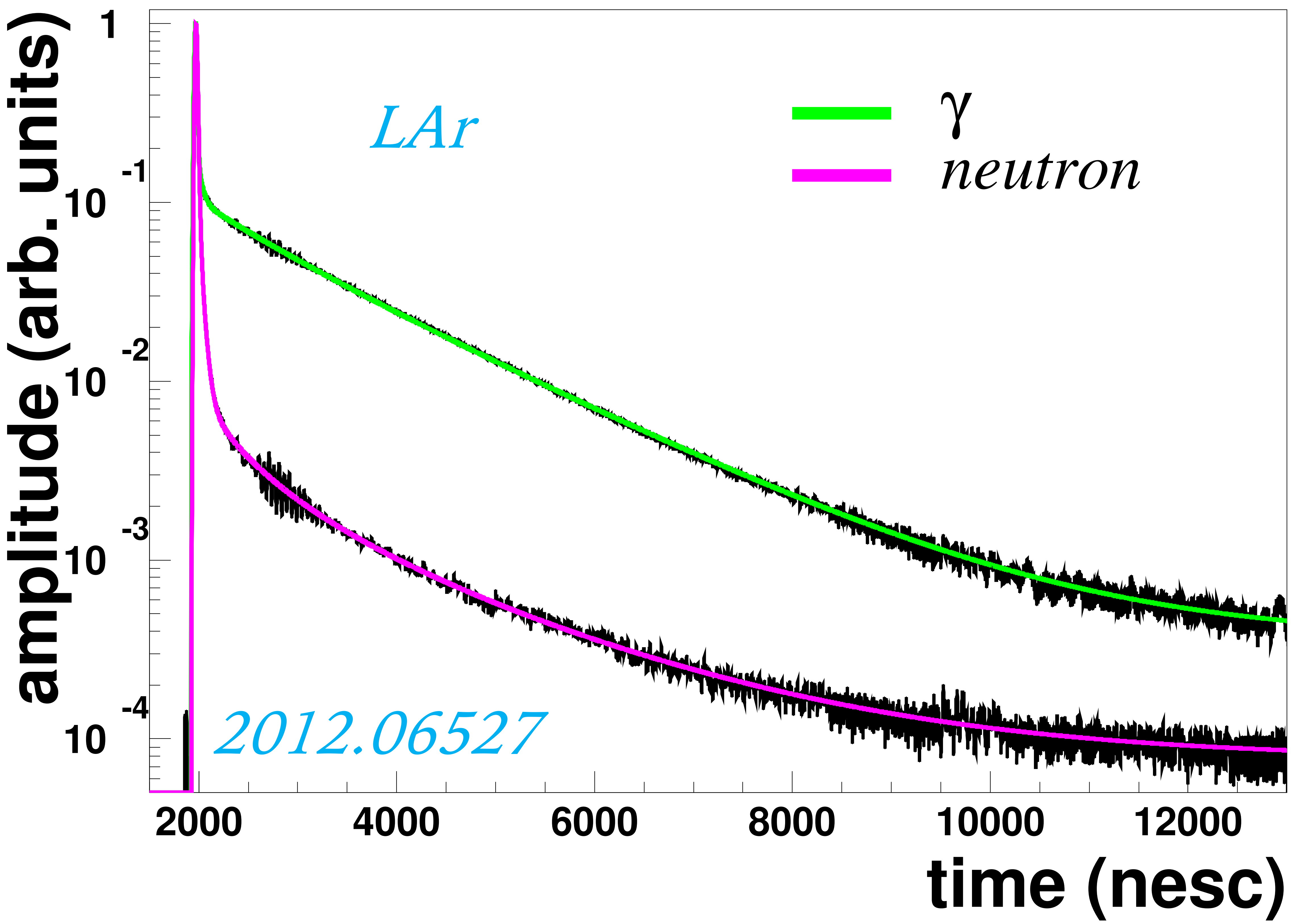
Aprile et al_2006_Noble Gas Detectors

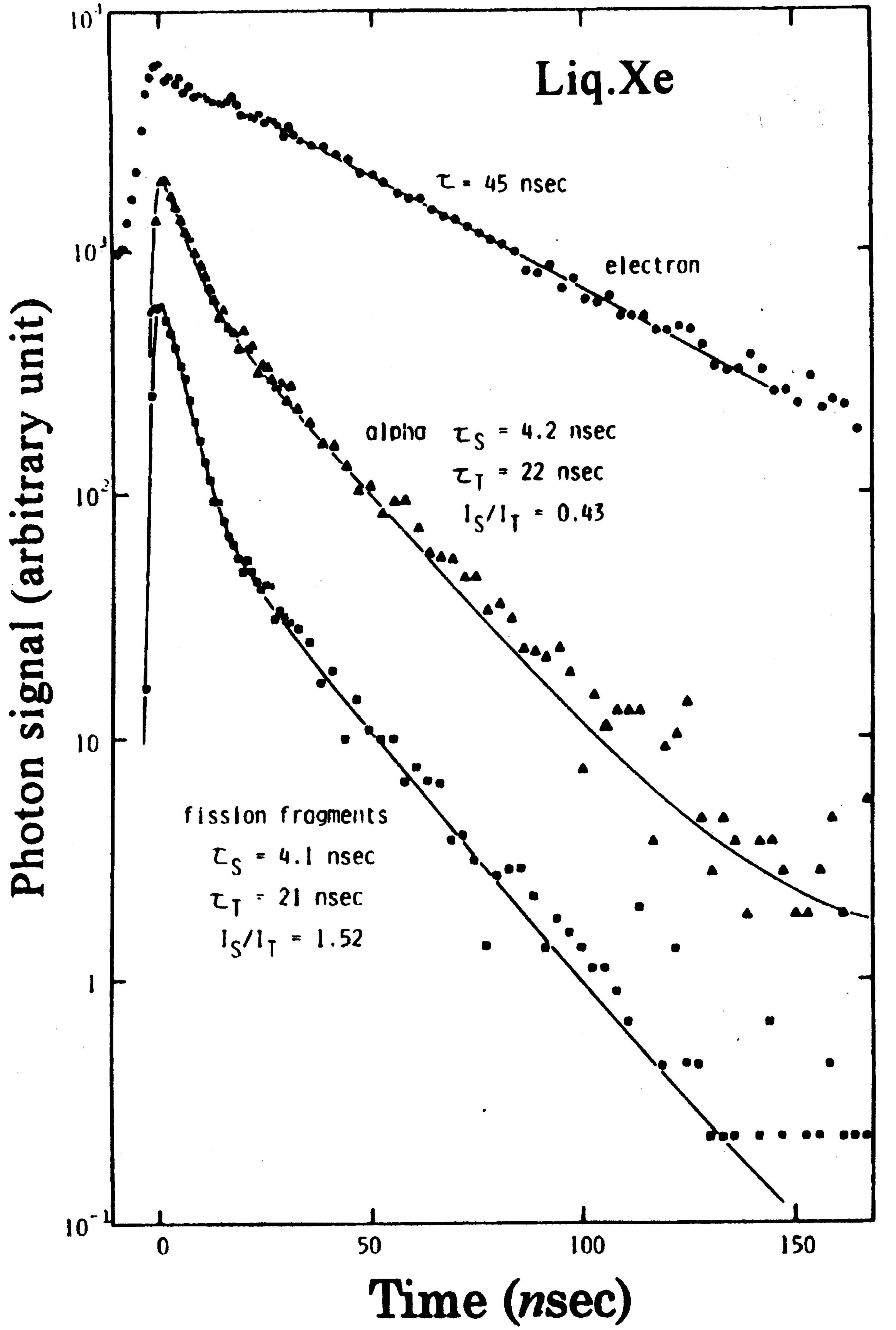
FAST PULSE TIMING



PULSE TIMING COMPARISON

➤ Very different timing for different noble liquids

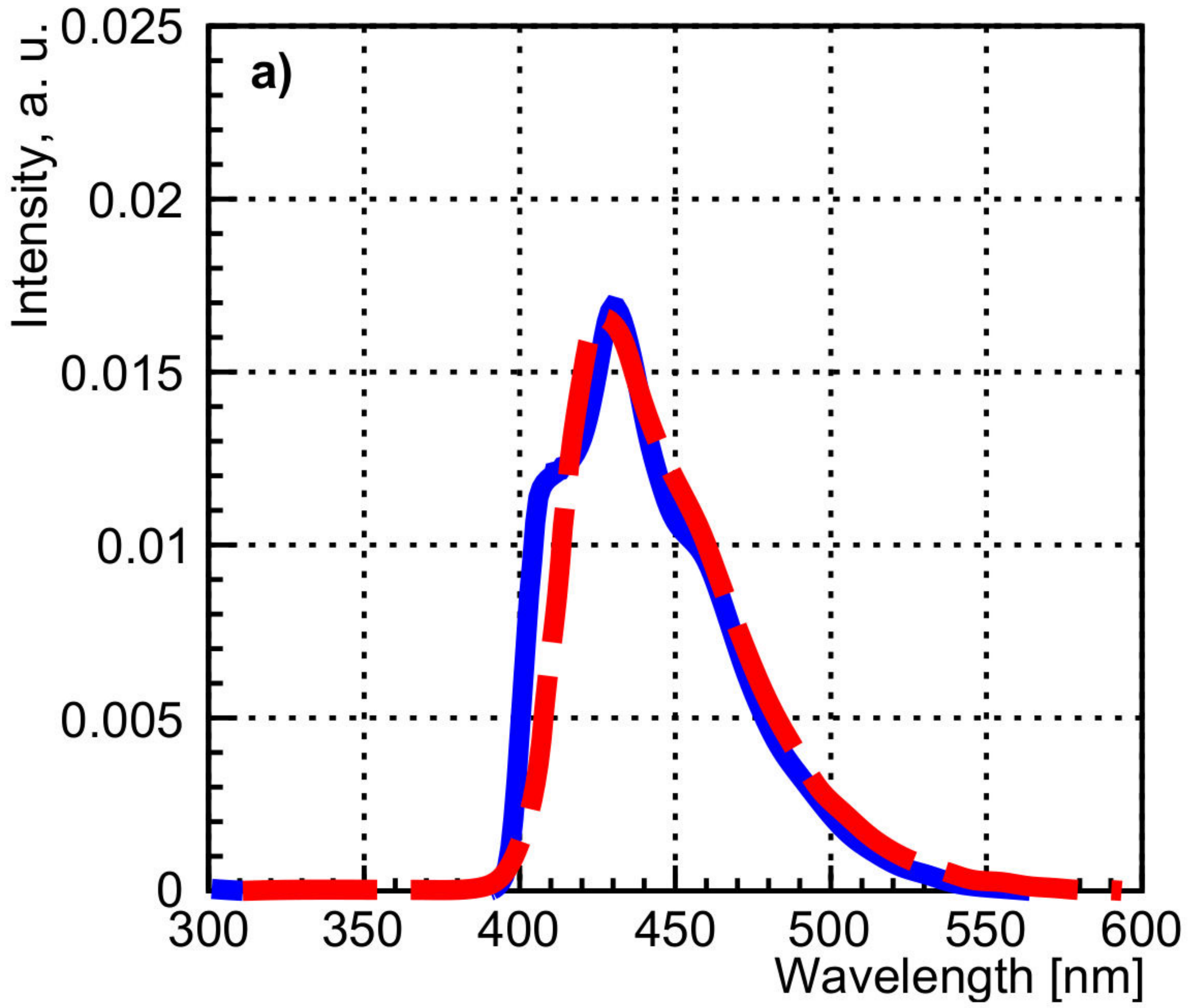




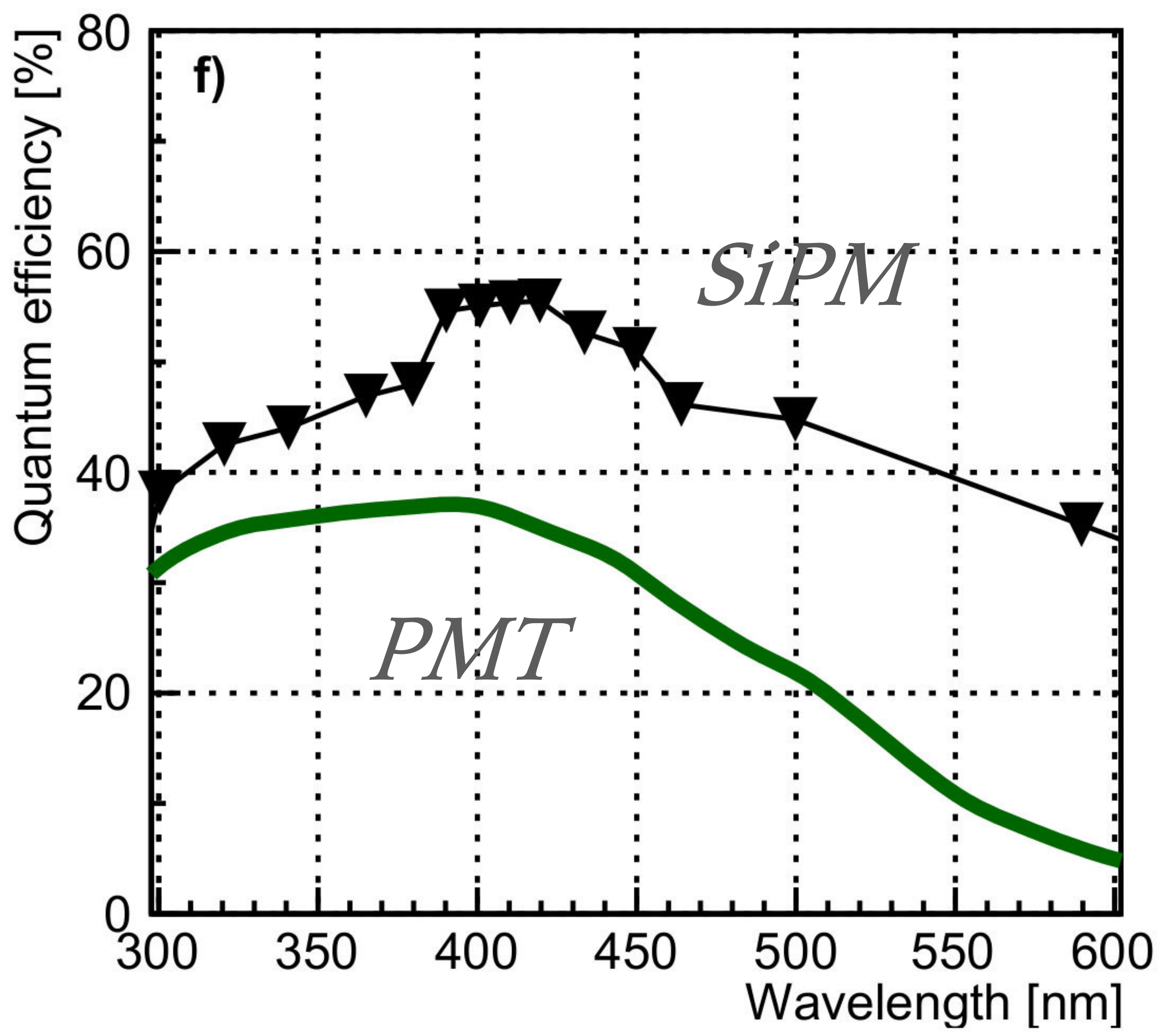
READOUT LIGHT

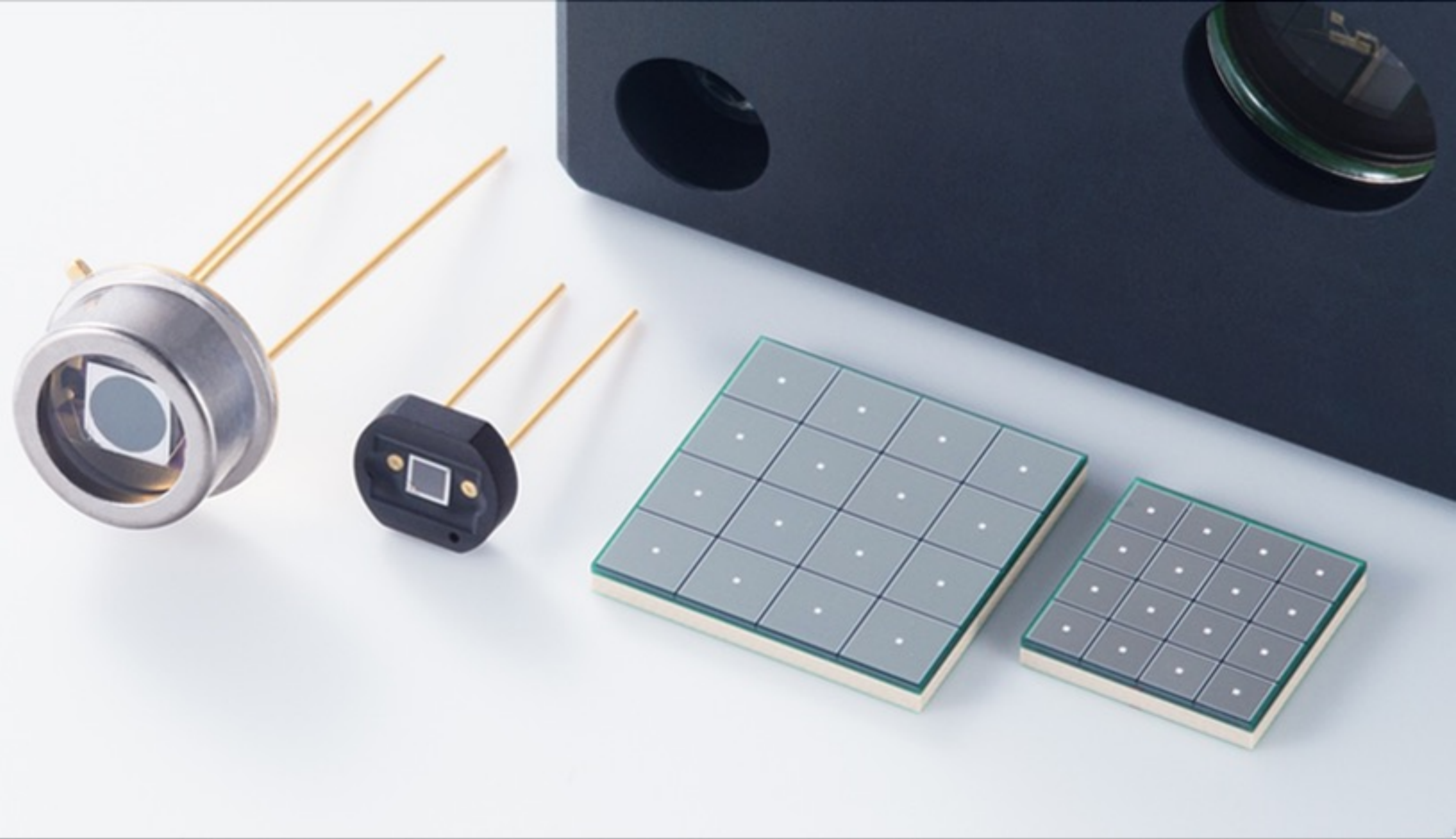
- VUV light from xenon can still be readout directly with PMT/SiPM
- Light from argon needs to be shifted to visible range.

TPB emission spectrum



Sensor reponse





Instruments 2021, 5(1), 4

SUMMARY

- NLs are detector medium with great scintillation and ionization properties
- Relative easy auxillary requirements (cost, cryogenics)