Studies of charge-sensor and gas properties of an ion-TPC for *NνDEx* experiment

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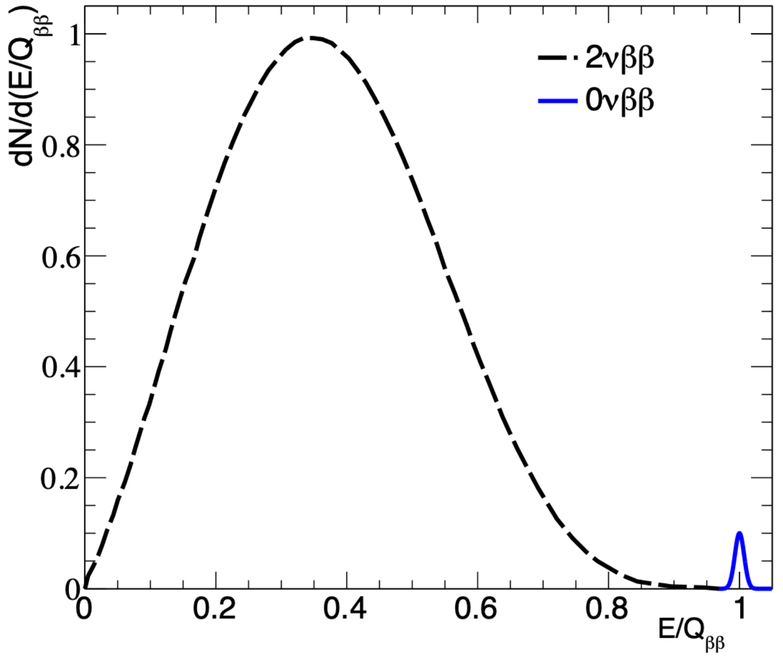
Outline

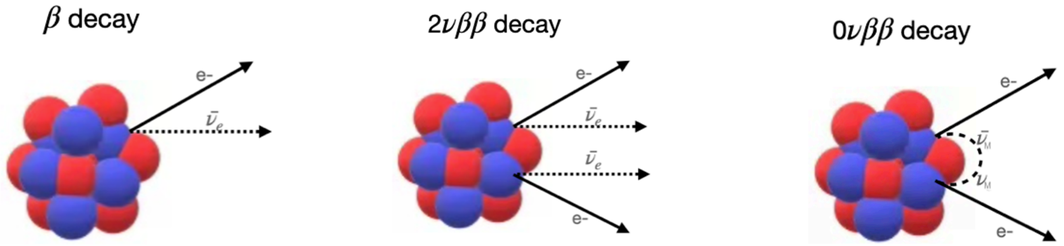
- Neutrinoless double beta decay
- $N\nu DEx$ experiment
  - China Jinping Underground Lab (CJPL)
  - Ion TPC with $^{82}SeF_6$
- Charge collecting chip Topmetal-S
- Mobility of SF_6 near atmosphere
- Summary

Neutrinoless double beta decay

- Double beta decay ($2\nu\beta\beta$):
  a second order weak transition **allowed** by **standard model**
  (A,Z) → (A,Z + 2) + 2e⁻ + 2ν

- Neutrinoless double beta decay ($0\nu\beta\beta$):
  Violates lepton number conservation
  (A,Z)→(A,Z + 2)+2e
  - Majorana or Dirac properties of neutrino
  - Absolute mass of neutrino
  - New physics beyond standard model





Neutrinoless double beta decay

Searching for neutrinoless double beta decay

- The rate of neutrinoless double beta (0νββ) decay occurrence (if it occurs) is extremely low, making experimental observations difficult.
- Half-life sensitivity:
- $$T_{1/2}^{0\nu 2\beta} \propto \begin{cases} aM\epsilon t \text{(zero-background)} \\ a\epsilon\sqrt{\frac{Mt}{B\Delta E}} \text{(Background)} \end{cases}$$
- a - constant
  M - mass of isotope
  t - time of exposure
  B - background index
  ϵ - efficiency of detector
  ΔE - energy resolution
- Isotopes for 0νββ should with high Q value and high natural abundance

Isotopes	Natural Abundance (%)	Q value（keV)
Ca-48	0.187	4272
Ge-76	7.8	2039
Se-82	**9.2**	**2996**
Zr-96	2.8	3348
Mo-100	9.6	3034
Pd-110	11.8	2018
Cd-116	7.5	2814
Sn-124	5.6	2288
Te-130	34.5	2528
Xe-136	8.9	2458
Nd-150	5.6	3371

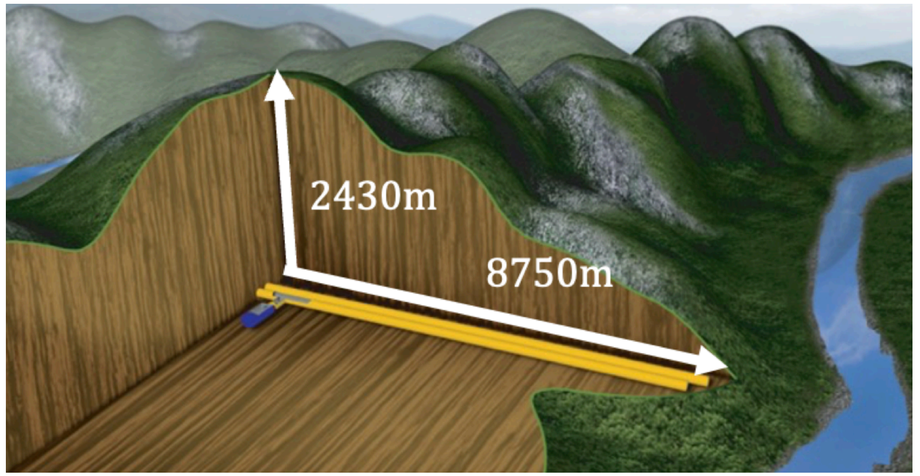
$N\nu DEx$ experiment
Overall

- NνDEx：**N**o **neutrino** **D**ouble-beta-decay **Ex**periment
- China JinPing Underground Lab
- $^{82}SeF_6$ (toxic): high Q value of ^{82}Se (2.996 MeV)
- Charge collecting chip TopmetalS : directly collect charge without avalanche
- TPC: Ion charge carriers, z coordinate reconstruction by time difference of SeF_5^- and SeF_6^-

Neutrinoless double beta decay and $N\nu DEx$ experiment

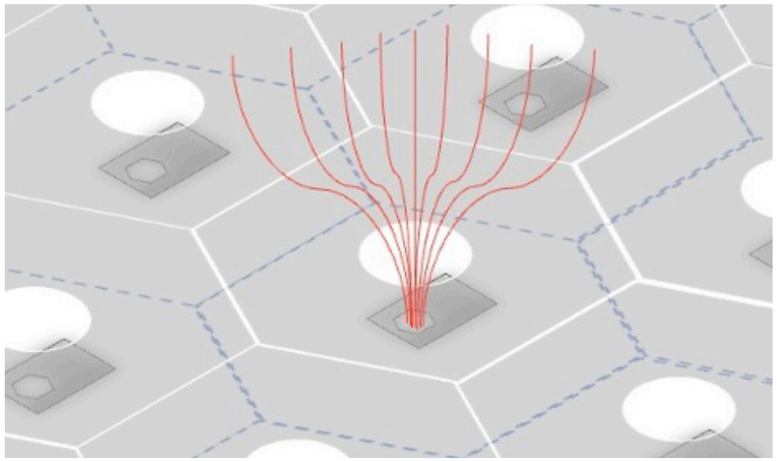
China Jinping Underground Lab (CJPL) and $0\nu\beta\beta$

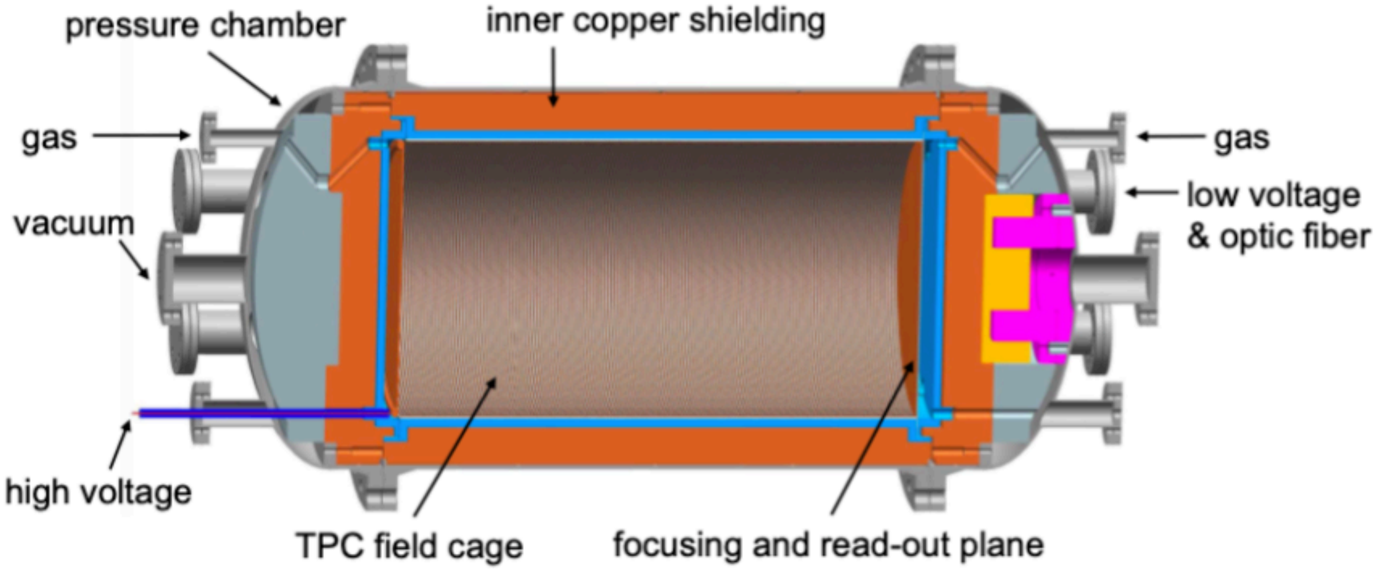
- Yalong river hydroelectric station, **Jinping Mountain,** Liangshan Yi Autonomous Prefecture, SiChuan, China
- Experiment requires low background could be deployed in underground lab: Dark matter, neutrino, cosmic……
- CJPL is the deepest underground lab in the world with the thickest rock overburden.
- $0\nu\beta\beta$: $N\nu DEx$, PandaX-III, CDEX, CUPID-China …



$N\nu DEx$ experiment
Ion TPC

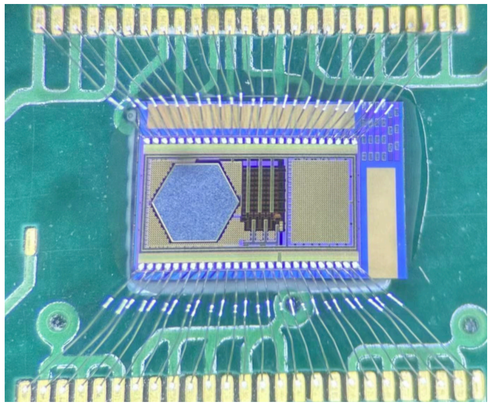
- 10 bar SeF_6
- SeF_5^- and SeF_6^-:
  - the electronegativity of SeF_6.
  - Time difference could reconstructs the absolute z-coordinate.

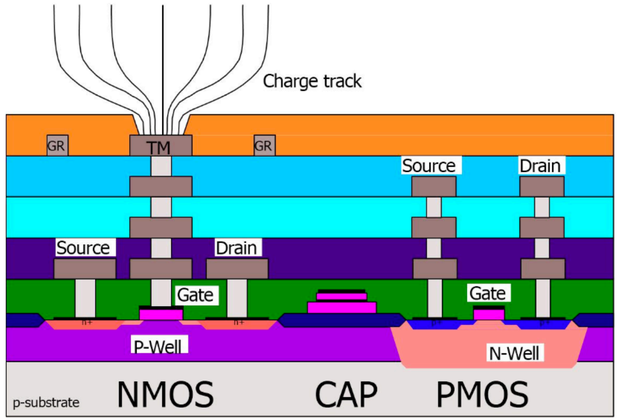




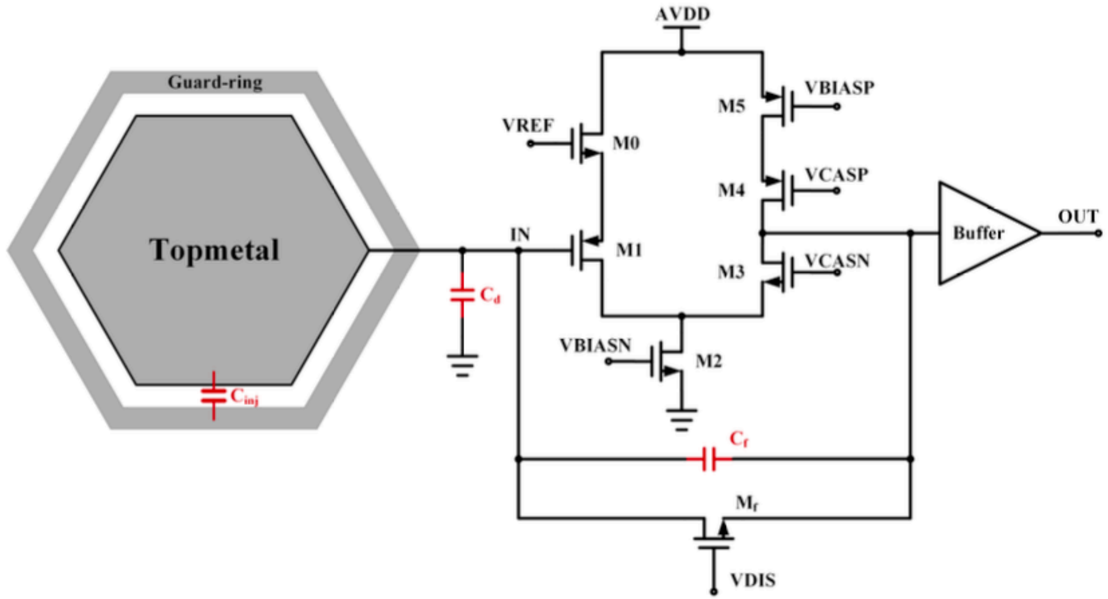
- Directly collecting ion charge carriers by about 10k Topmetal- S chips.
- Focusing layer: focus drift charges onto the 1 mm^2-sized charge collecting electrodes of the Topmetal- S chips.

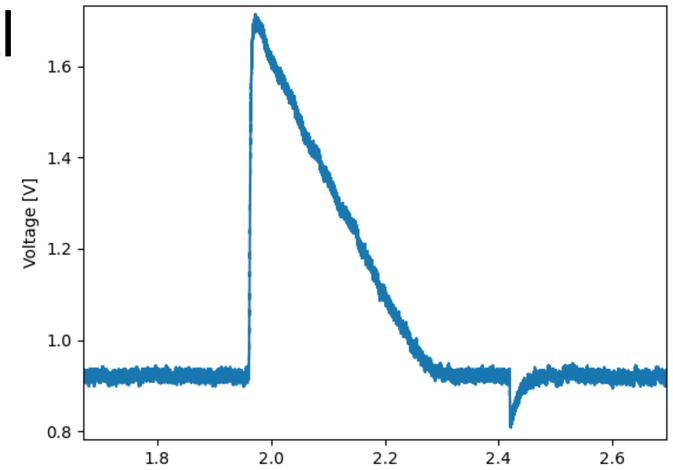
Topmetal-S chip





- Topmetal-S: hexagon exposed metal (1 mm diameter) with CSA.



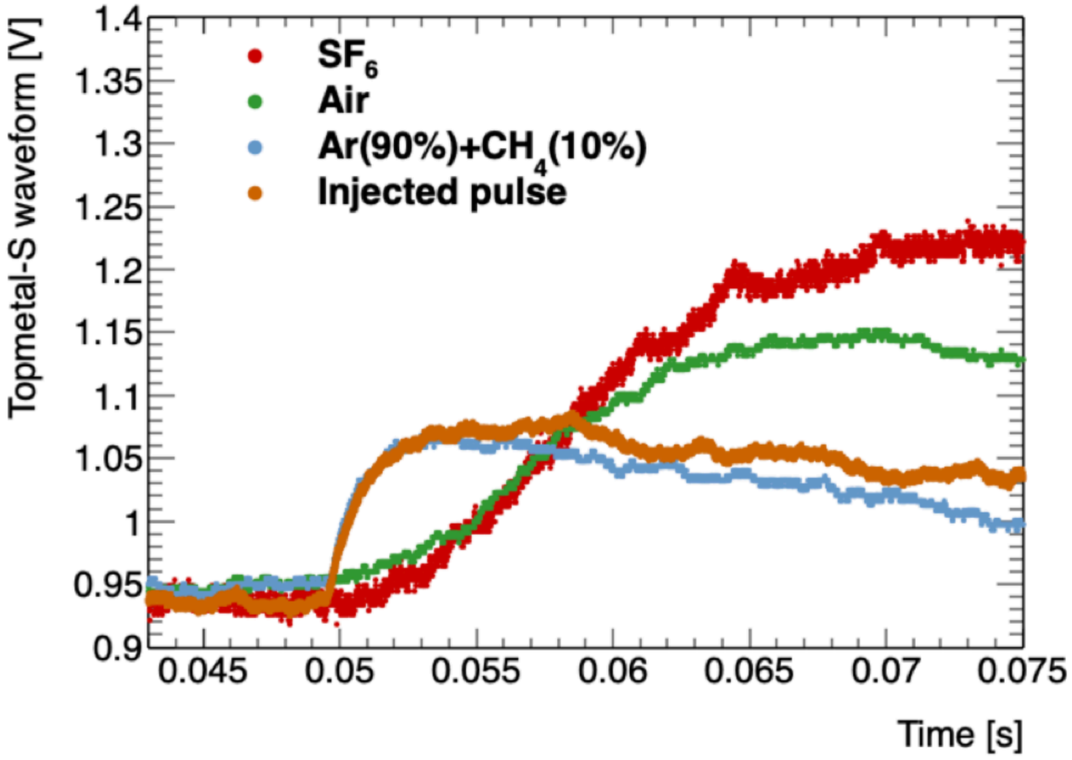


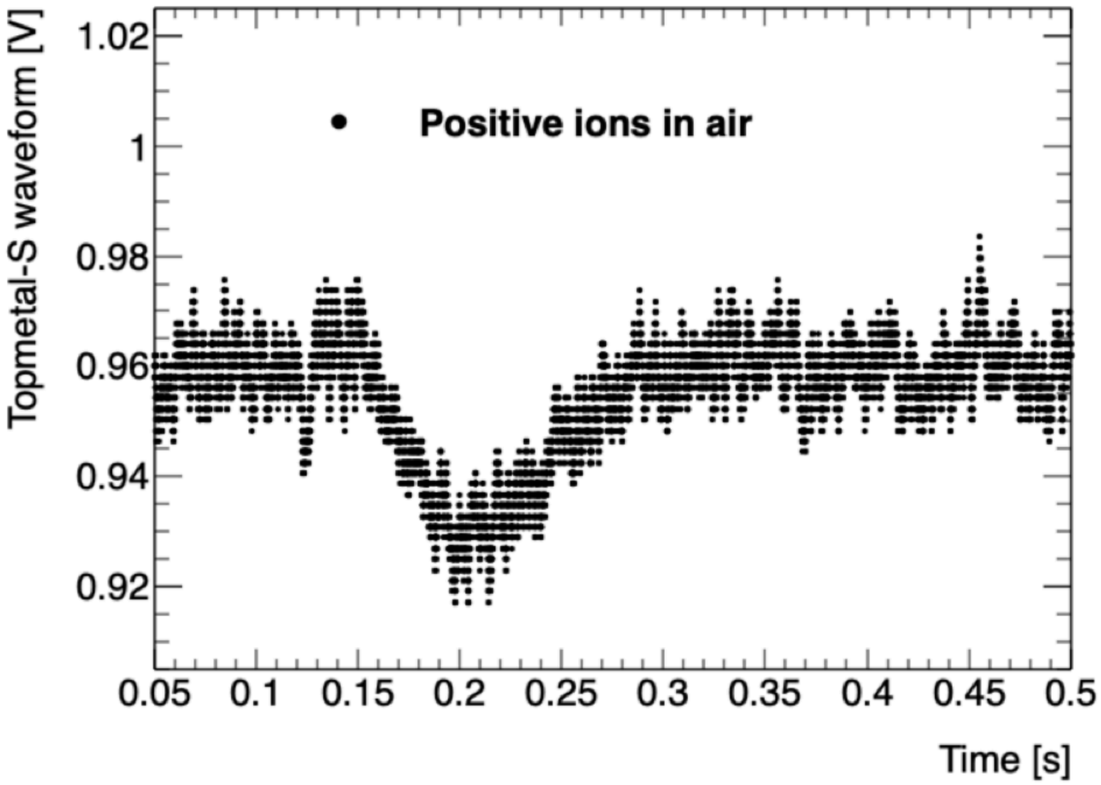
- The current noise is ~100 e-, with the aim to reduce it to ~40 e-.

Topmetal-S chip

Signals for ion charge carriers

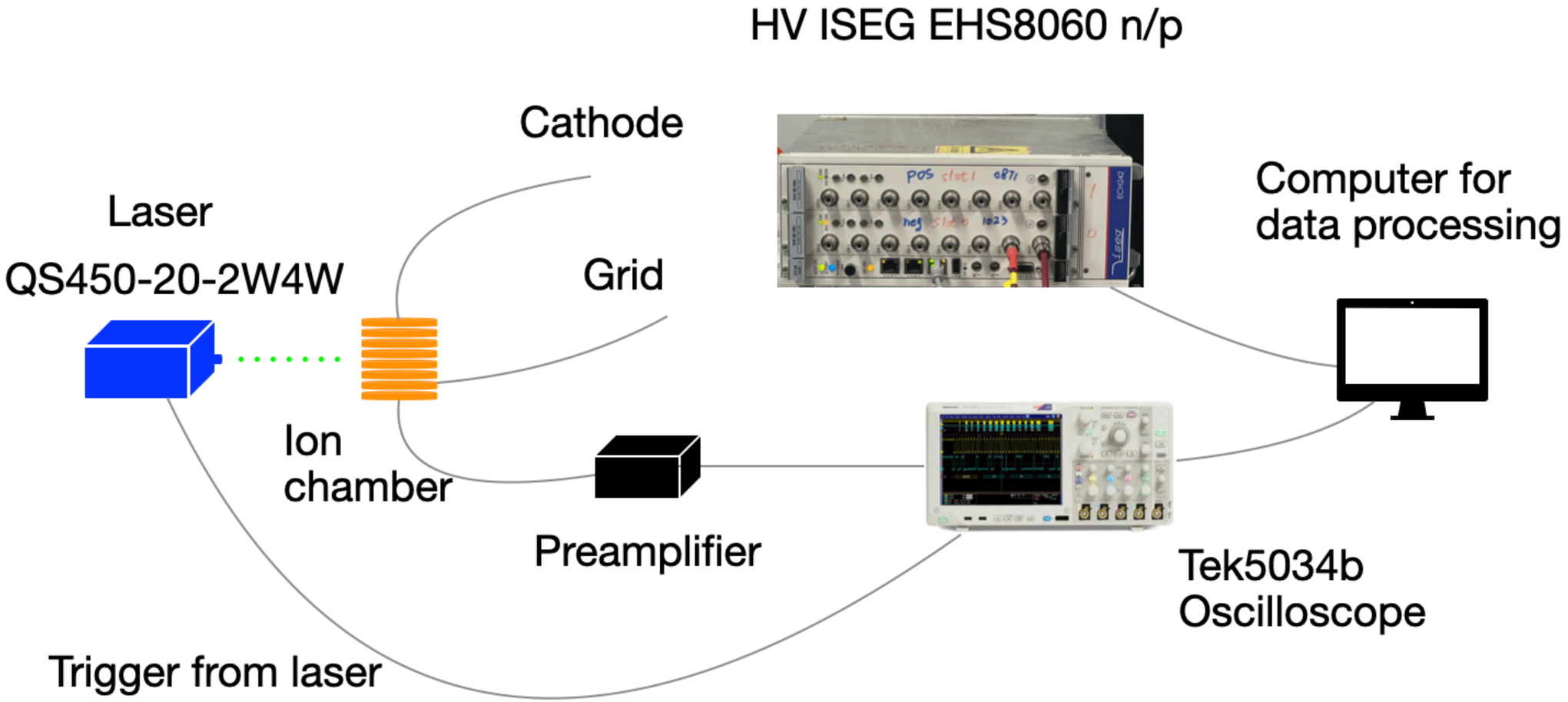
- With the focusing plane structure, the signals of ion charge carriers were observed for both positive and negative charges, with signals generated by α particles from ^{241}Am.





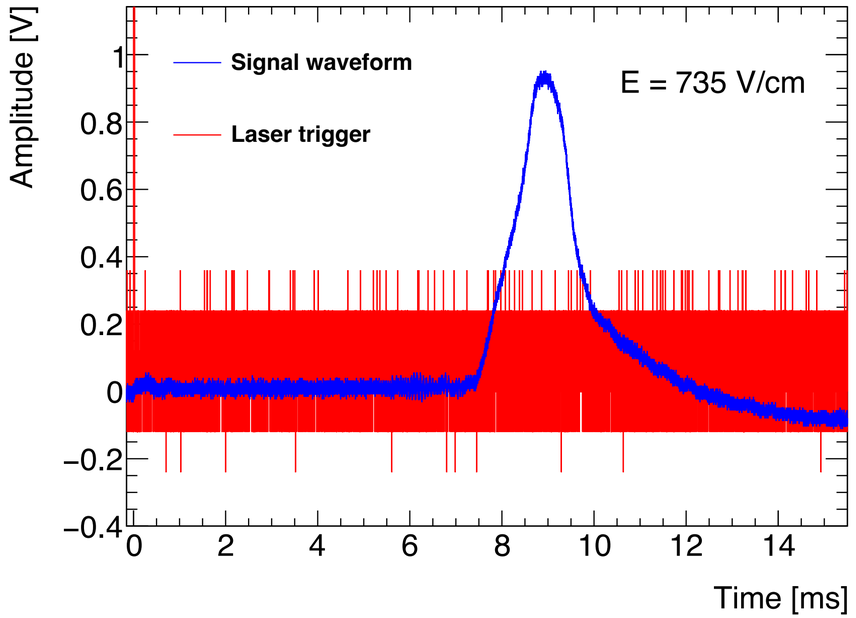
Properties of SF_6

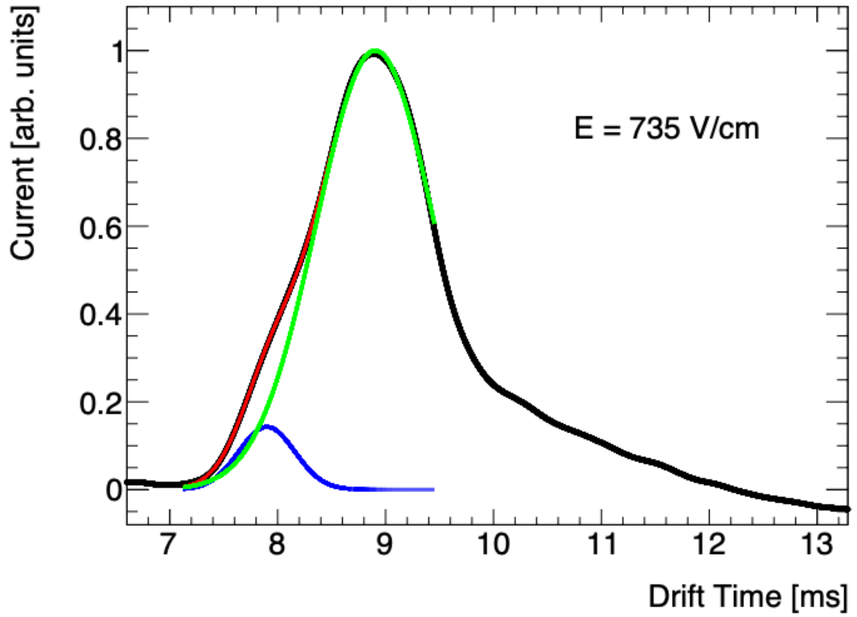
Device setup



Properties of SF_6
Waveform

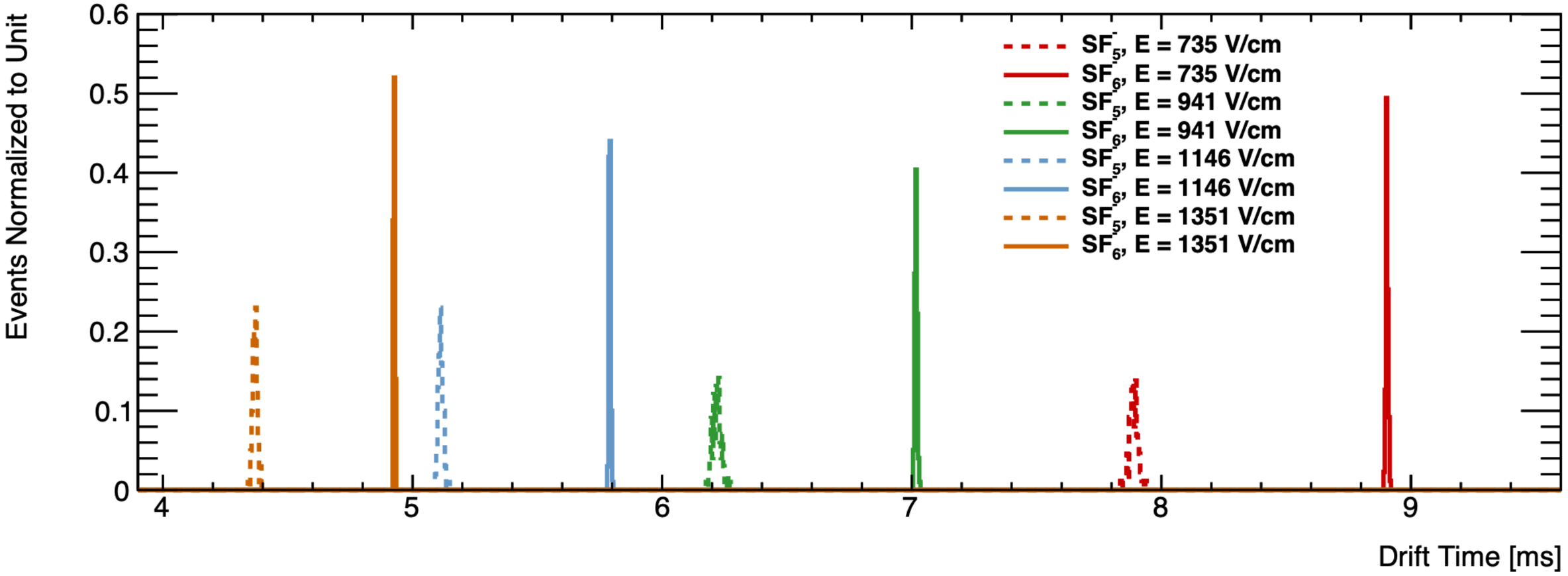
- Convert voltage to current:
$$I(t) \propto \frac{dV}{dt} - (-\frac{V}{\tau})$$
- Double gauss fit of current
- Time difference:
Start point: from laser
End point: from fit result of current
- Drift length: 3.7 ± 0.15 cm





Properties of SF_6

Drift Time



Properties of SF_6

Reduced mobility

- $\mu_0 = \frac{v_\mathrm{d}}{E}\frac{N}{N_0}$

  v_d drift velocity

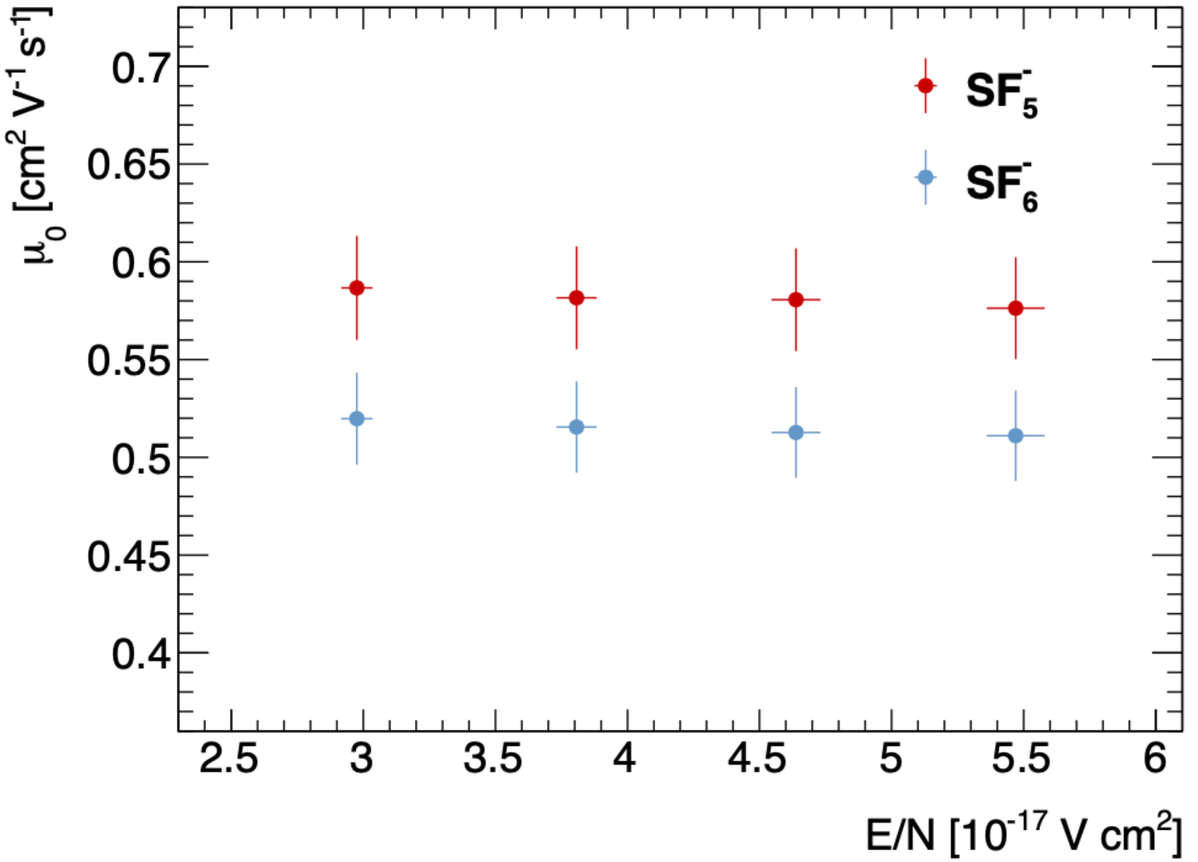
  E electric field

  N density of gas

  N_0 2.687×10^{19}

- $\mu_{SF5^-} = 0.58 \pm 0.026 cm^2/Vs$

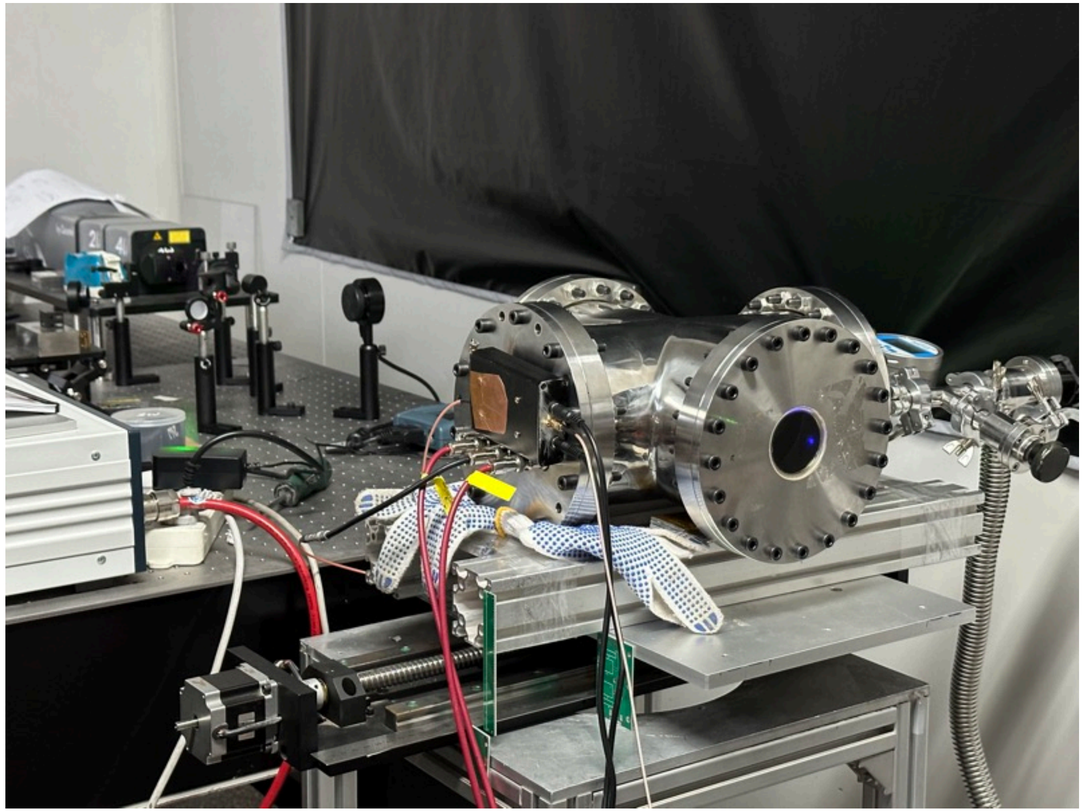
  $\mu_{SF6^-} = 0.52 \pm 0.024 cm^2/Vs$

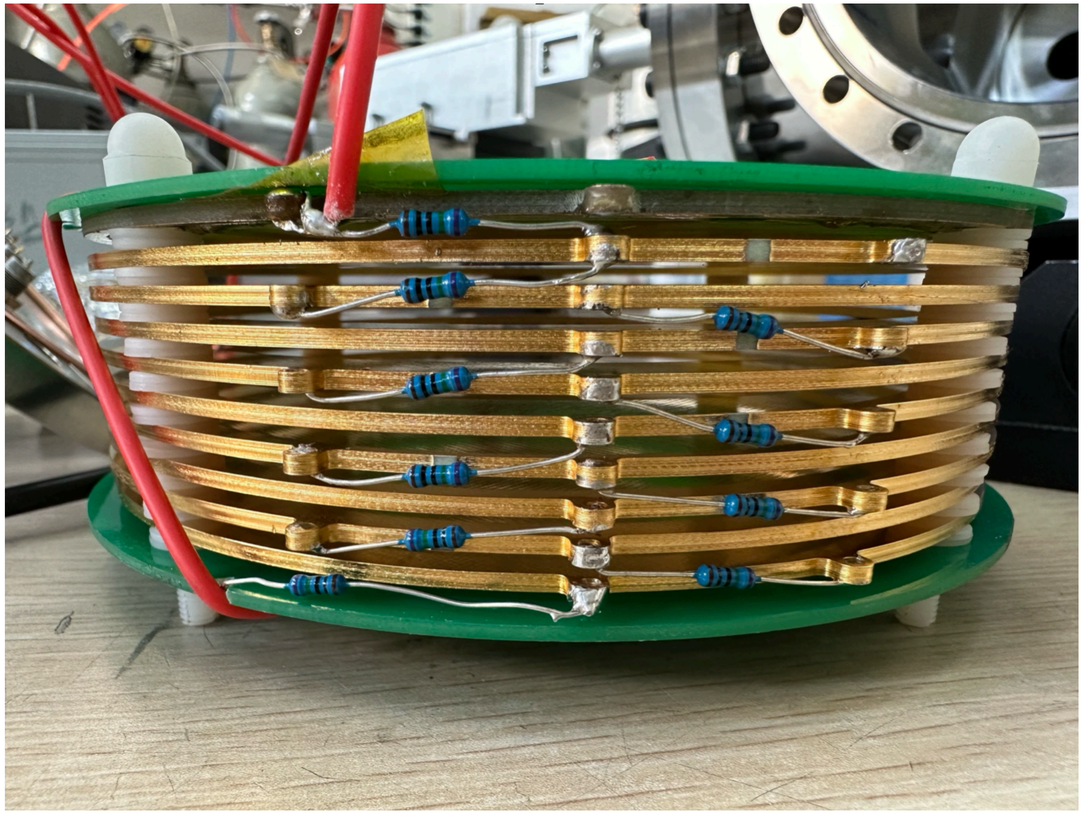


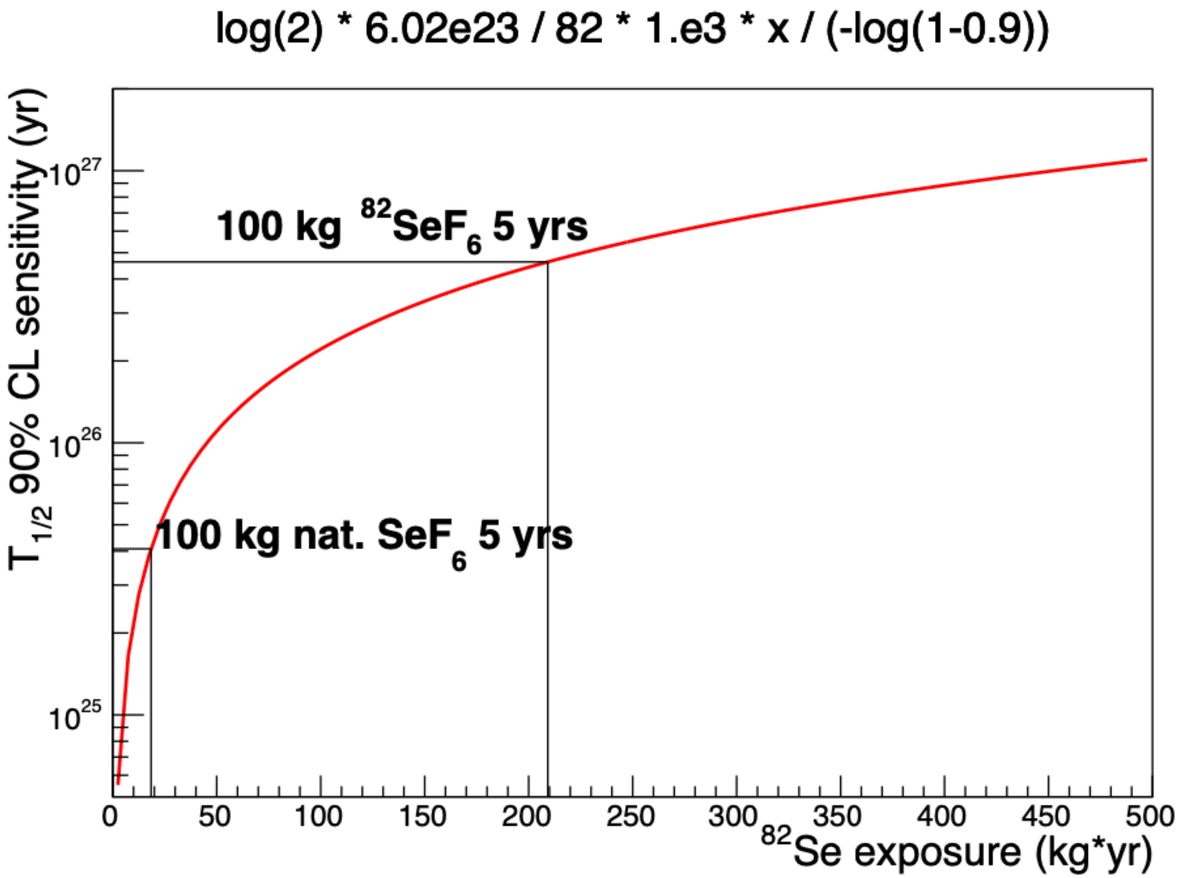
Summary

- $N\nu DEx$ experiment is aimed to search for neutrinoless double beta decay of ^{82}Se using a high-pressure SeF_6 gas TPC in China Jinping Underground Laboratory.
- Ion charges collecting without avalanche would yield excellent energy resolution, but requires low noise of Topmetal-S chip. The current noise is ~100 e-, with the aim to reduce it to ~40 e-. The detection of ion charges was confirmed with the chip.
- The measurement of reduced mobility SF_6 is 0.58 and 0.52 $cm^2(Vs)^{-1}$near atmosphere. Same method will be used to study SeF_6.

Properties of SF_6
Device setup






log(2) * 6.02e23 / 82 * 1.e3 * x / (-log(1-0.9))
$T_{1/2}$ 90% CL sensitivity (yr)
10^{27}
10^{26}
10^{25}
100 kg $^{82}SeF_6$ 5 yrs
100 kg nat. SeF_6 5 yrs
0
50
100
150
200
250
300
350
400
450
500
^{82}Se exposure (kg*yr)