KATRIN, TRIMS and future analysis in protoDUNE

Ana Paula Vizcaya Hernández

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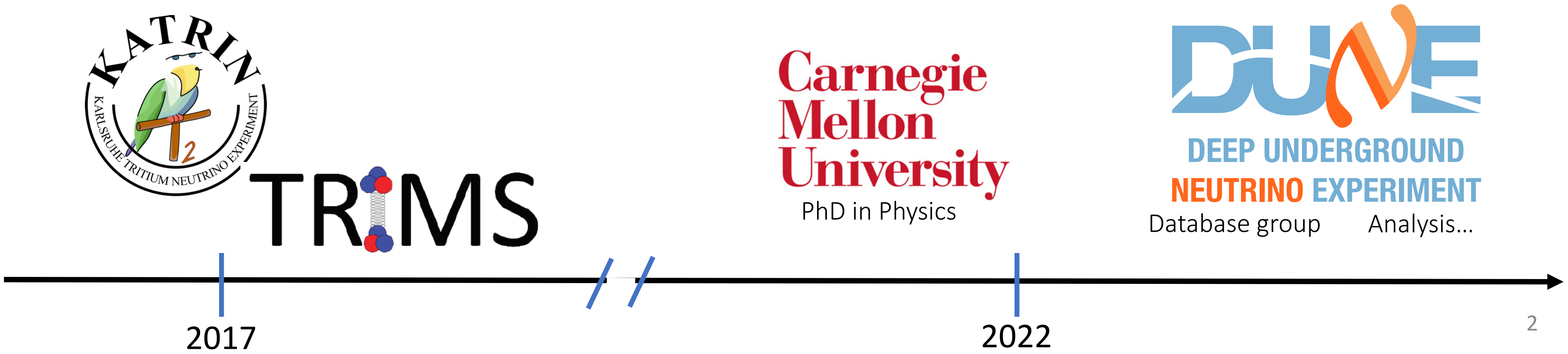
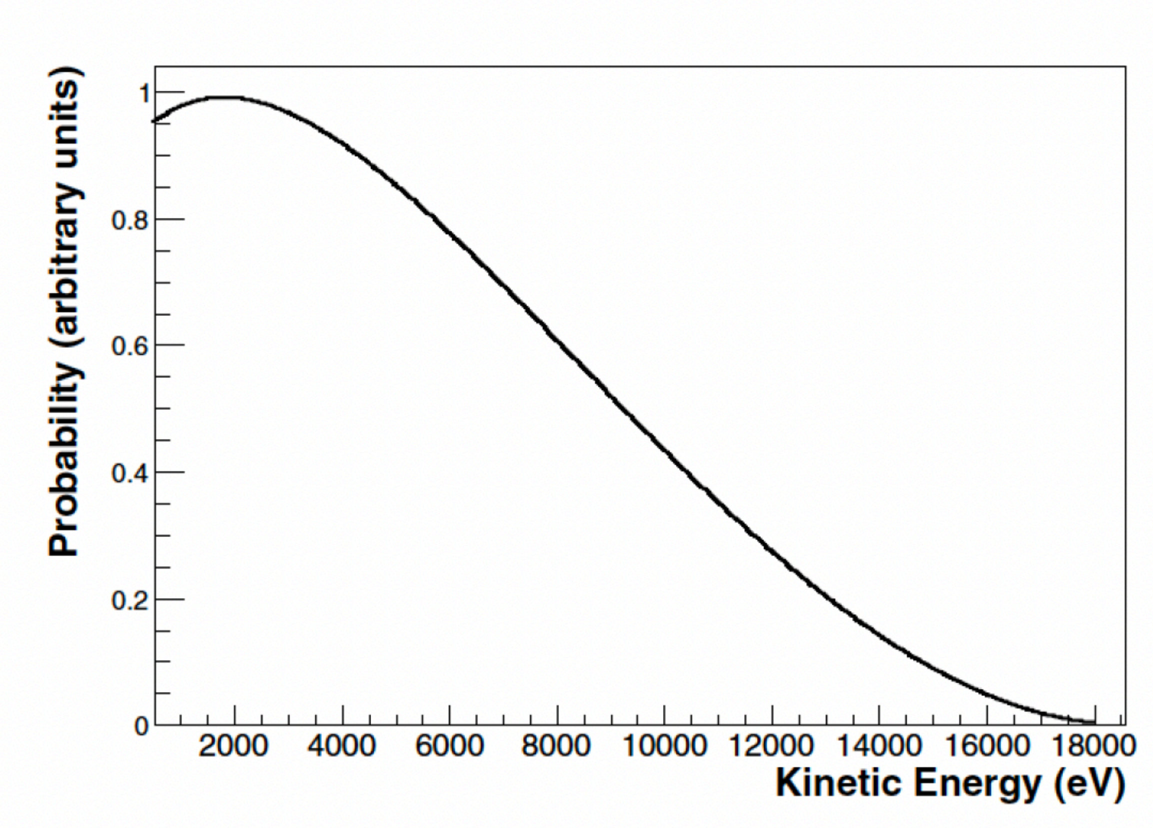
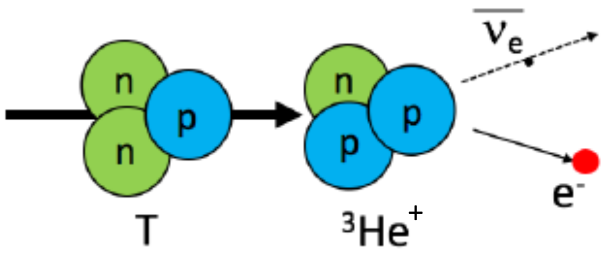
Outline

- Introduction to the KATRIN and TRIMS experiments
- Selected analysis projects
  - Ion background characterization in the KATRIN experiment
  - Ion studies in the TRIMS experiments – paper coming out soon
- Future analysis plan with ProtoDUNE data



Effective neutrino mass measurement from tritium β decay





Effective neutrino-mass squared is a free parameter in the fit to the energy spectrum.

KATRIN

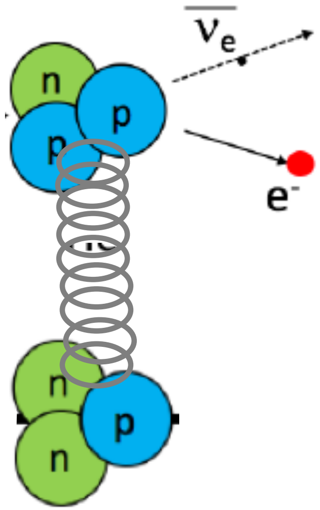
KARLSRUHE TRITIUM NEUTRINO EXPERIMENT

Current result on $m_\nu < 0.8$ eV at 90% CL

$$\frac{dN}{dE_e} = \frac{G_F^2 m_e^5 \cos^2\theta_C}{2\pi^3\hbar^7}|M_{\mathrm{nuc}}|^2 F(Z,E_e)p_eE_e$$

$$\times \sum_{i,k}|U_{ei}|^2 P_k(E_{\mathrm{max}} - E_e - V_k) \times \sqrt{(E_{\mathrm{max}} - E_e - V_k)^2 - m_{\nu i}^2} \times \Theta(E_{\mathrm{max}} - E_e - V_k - m_{\nu i})$$

Molecular final-state distribution



Excitations in T_2 gas:
- Electronic: 20 eV
- Vibrational: ~0.1 eV
- Rotational: ~0.01 eV

Probability to bound molecular final state

Molecule	Theory	Snell *et al.*	Wexler *et al.*
HT	0.55 – 0.57	0.932(10)	0.895(11)
T_2	0.39 – 0.57	-	0.945(6)

Bodine, Parno, Robertson, Phys. Rev. C 91, 035505

Beta energy spectrum is modified by the probability P_k and excitation energies V_k

TRIMS

Paper coming out soon!!

$$\frac{dN}{dE_e} = \frac{G_F^2 m_e^5 \cos^2\theta_C}{2\pi^3\hbar^7}|M_{\text{nuc}}|^2 F(Z,E_e)p_e E_e$$

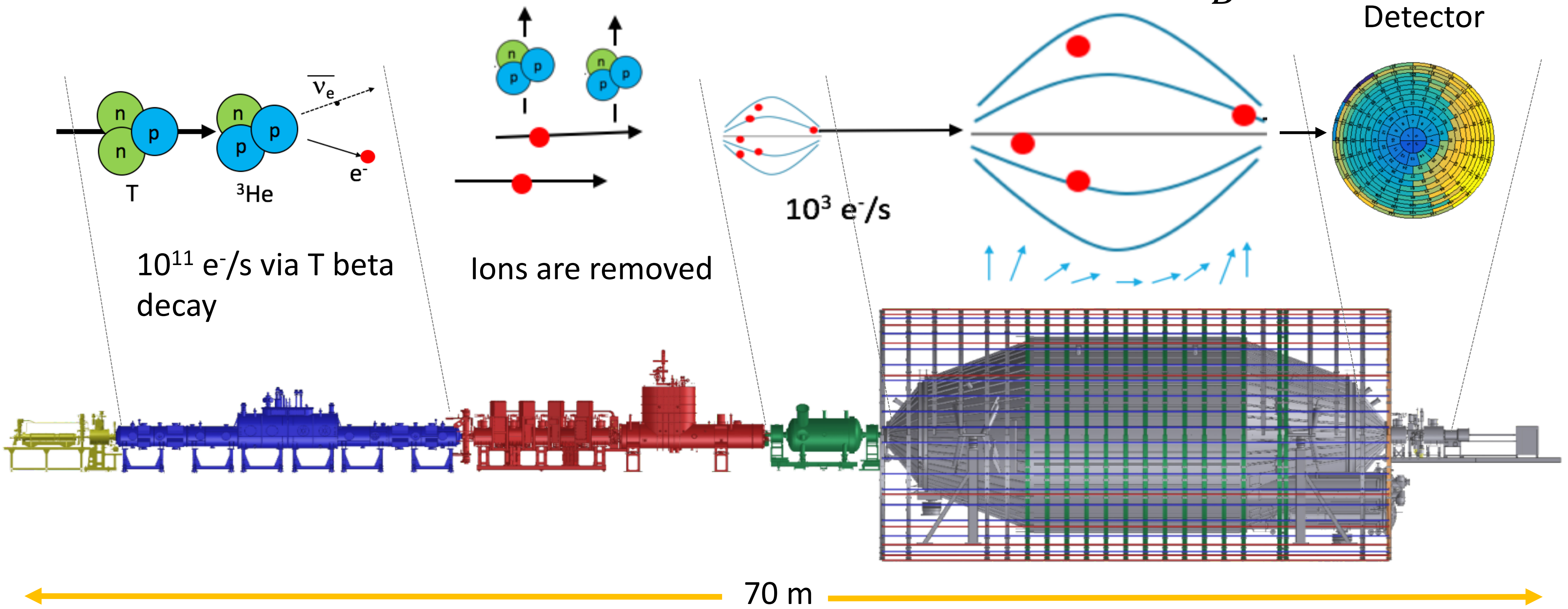
$$\times \sum_{i,k}|U_{ei}|^2 P_k(E_{\text{max}} - E_e - V_k) \times \sqrt{(E_{\text{max}} - E_e - V_k)^2 - m_{\nu i}^2} \times \Theta(E_{\text{max}} - E_e - V_k - m_{\nu i})$$


KATRIN
KARLSRUHE TRITIUM NEUTRINO EXPERIMENT
T
2

KATRIN (Karlsruhe TRItium Neutrino experiment)

Electron momentum relative to magnetic field is conserved

$$\mu = \frac{E_\perp}{B} = const$$



10^{11} e^-/s via T beta decay

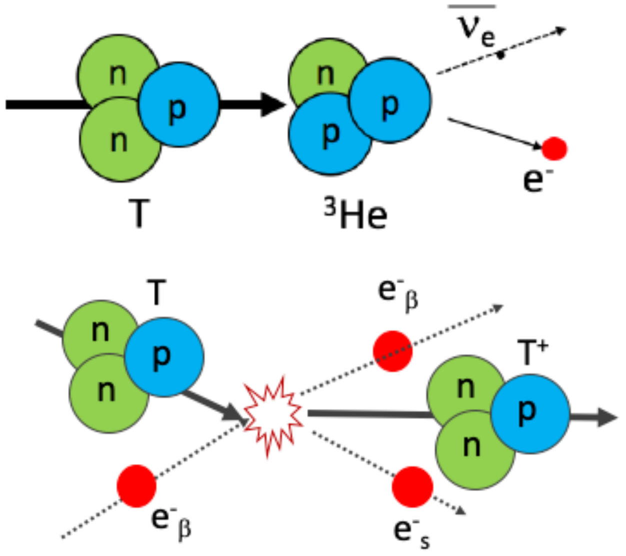
Ions are removed

Ions created in KATRIN experiment

Ion creation rate in the Source:

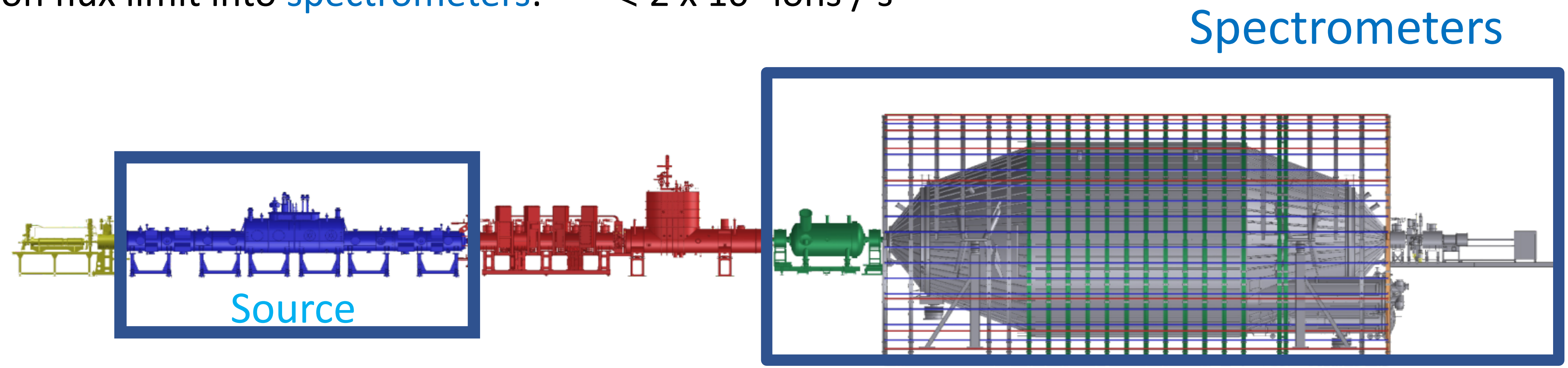
Tritium beta decay ➔ 10^{11} ions/s

Scattering ➔ 10^{12} ions/s

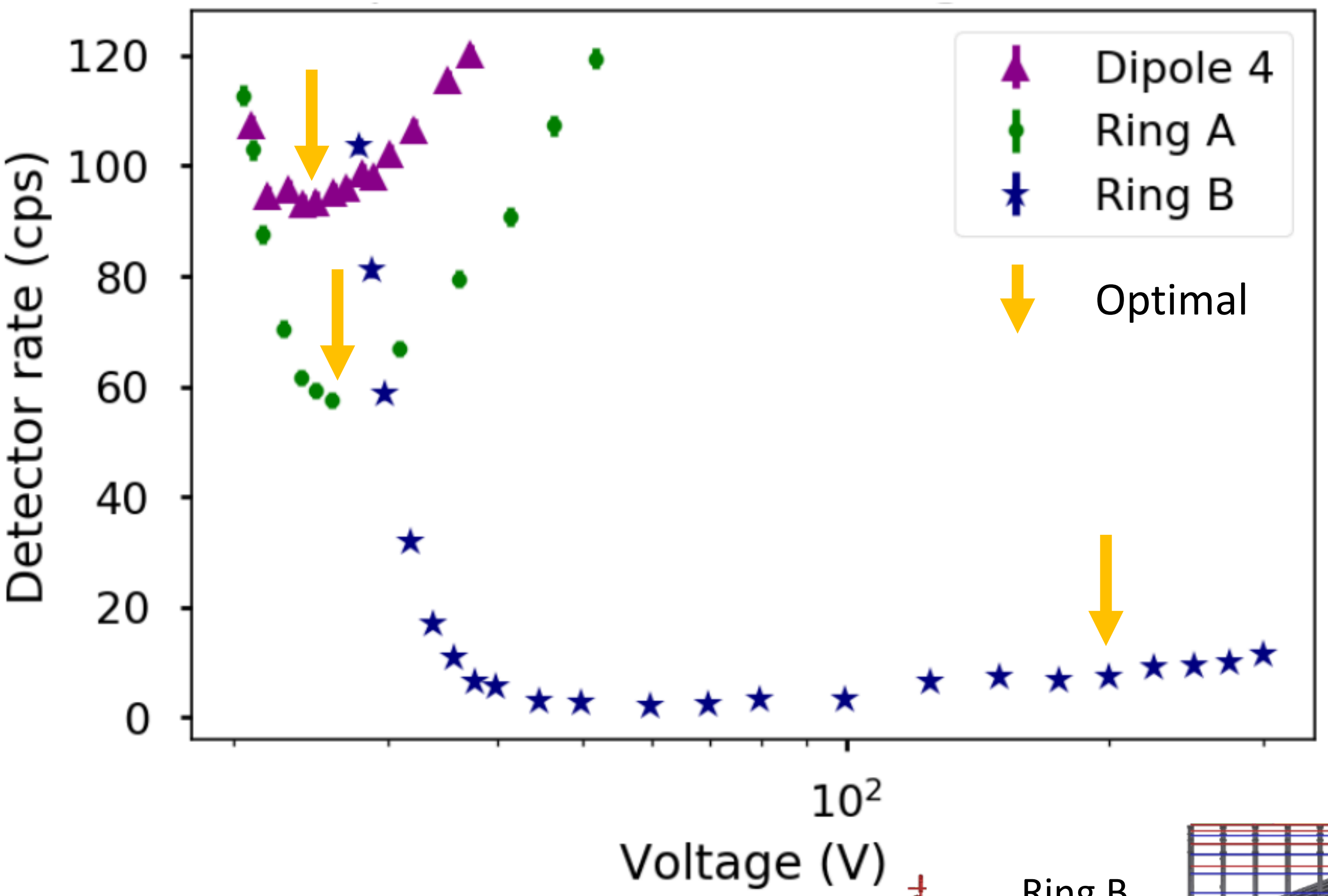


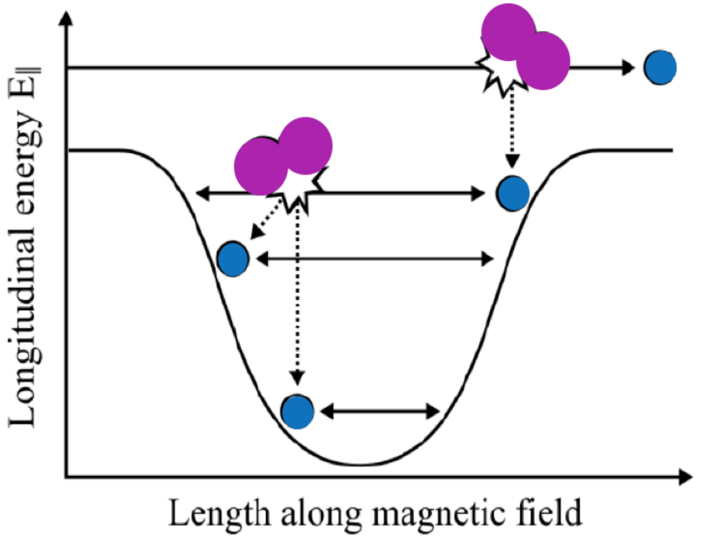
➔ **Background** for neutrino mass measurement

Ion flux limit into spectrometers: $< 2 \times 10^4$ ions / s



Optimization of blocking devices

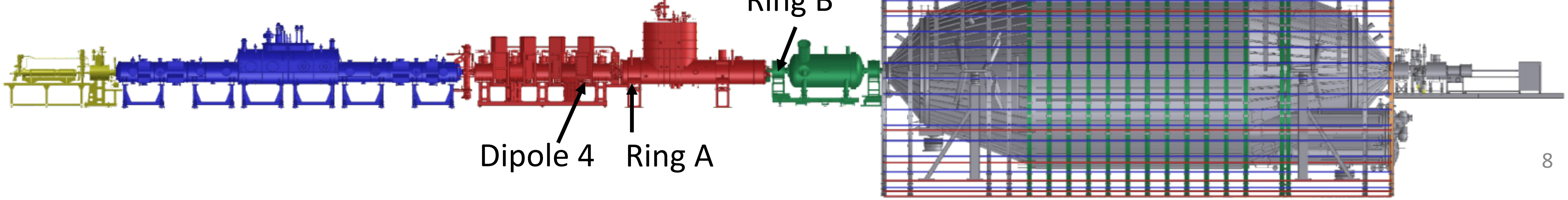




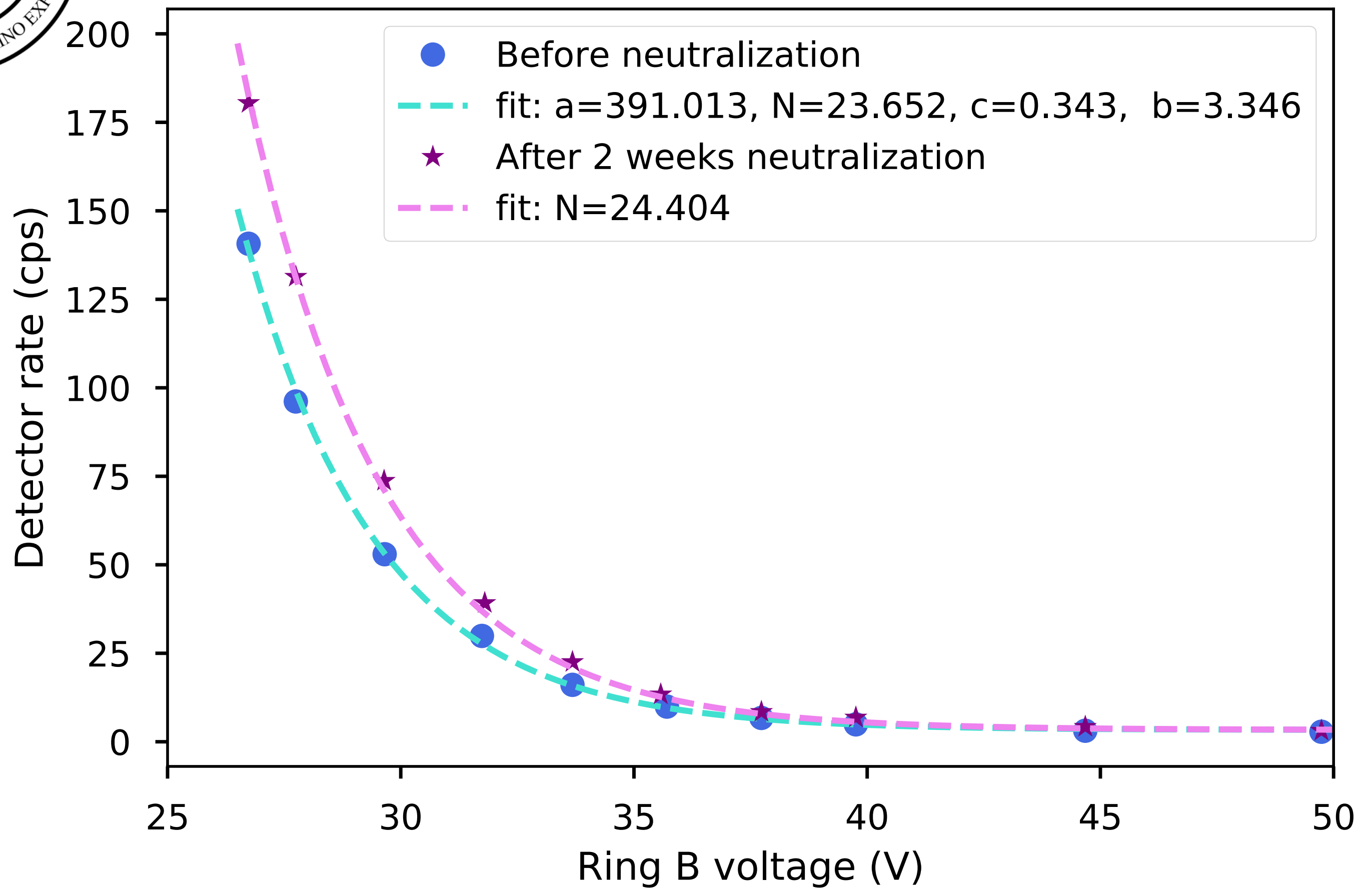
The optimal settings are:

- Dipole 4 ➔ 25 V
- Ring A ➔ 26 V
- Ring B ➔ 200 V because of low Penning ion rate

Ions are successfully blocked!



Ring electrode neutralization



Background was fixed to average rate at PS1 = 50 V.

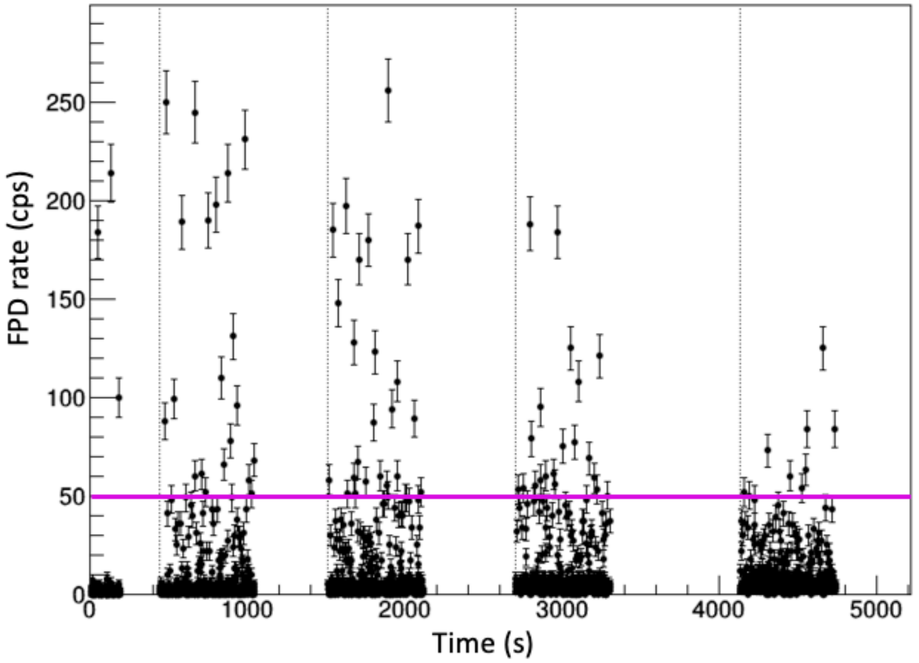
Recommendation:

Empty traps every two weeks.

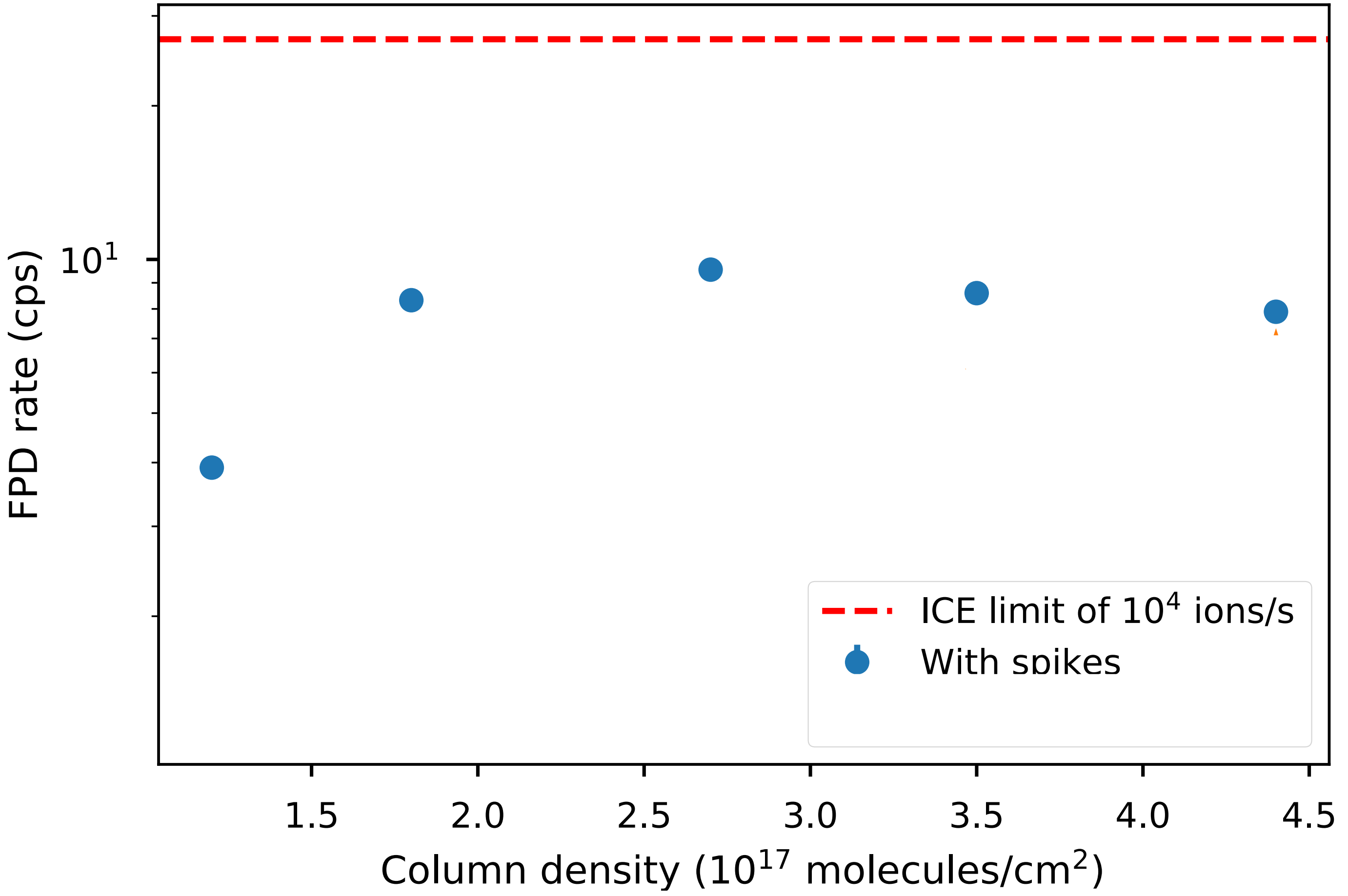
Ring electrode	Nominal (V)	Minimum (V)	Neutralization (V)	Measurement time (days)
Ring A	40	25	0.09 ± 0.24	~ 8
Ring B	200	60	0.96 ± 0.28	~ 14

ICE monitoring during ICE ramp up

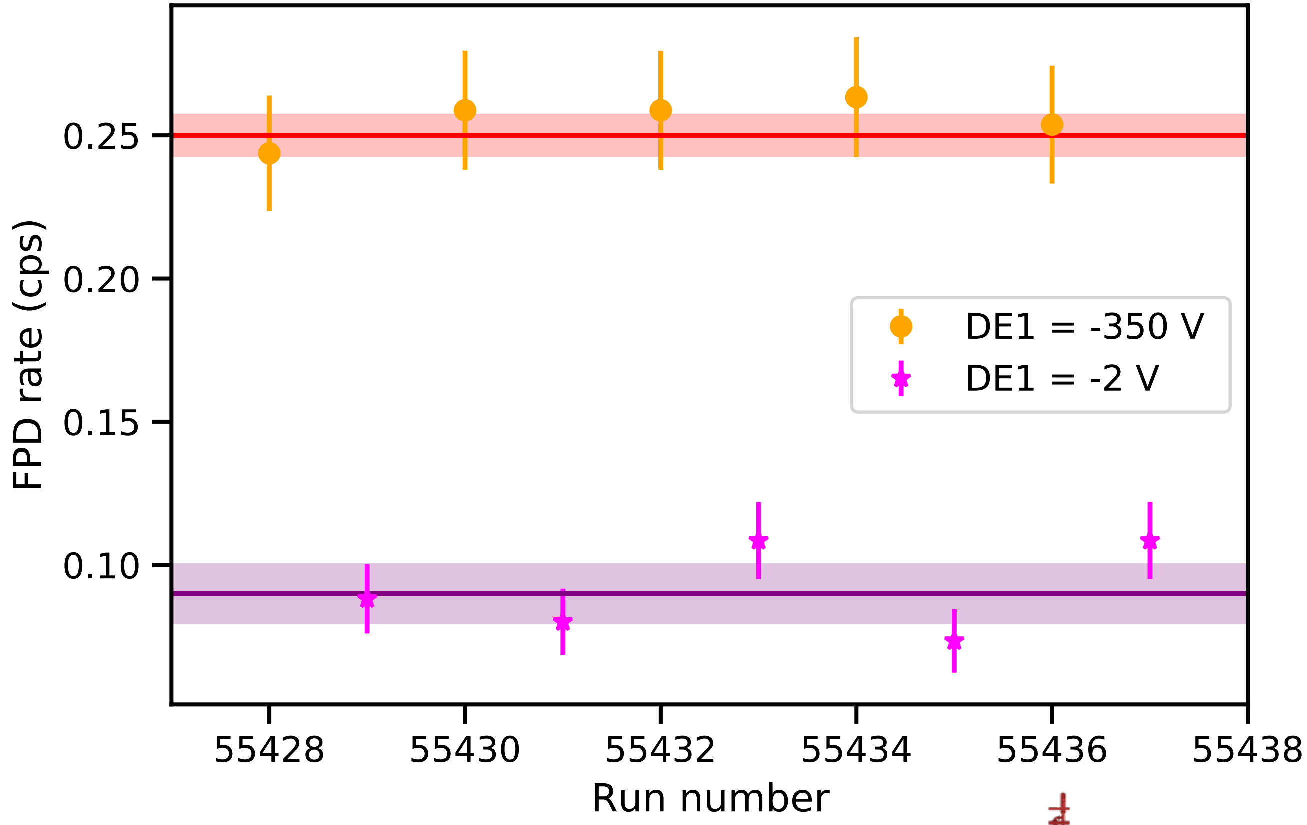
- Monitor that the ion flux into the spectrometer section is below the limit



Rate increases with column density



Tritium density in dipole 1

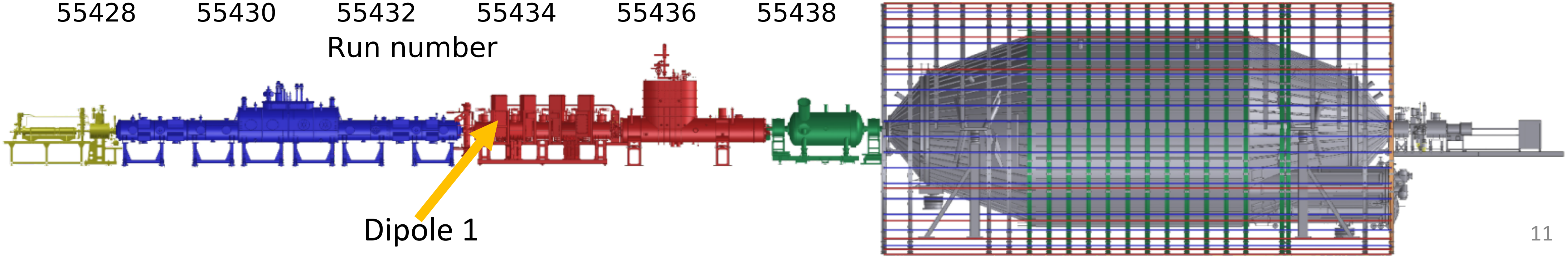


Method

- Spectrometer potential > T end point
- Measure at dipole voltages:
  0 V (min.) and -350 V (max.)

Results

- Dipole 1 column density is 10^{-6} times column density in source
- Neutrino mass shift of -0.003 eV^2 for the three dipoles

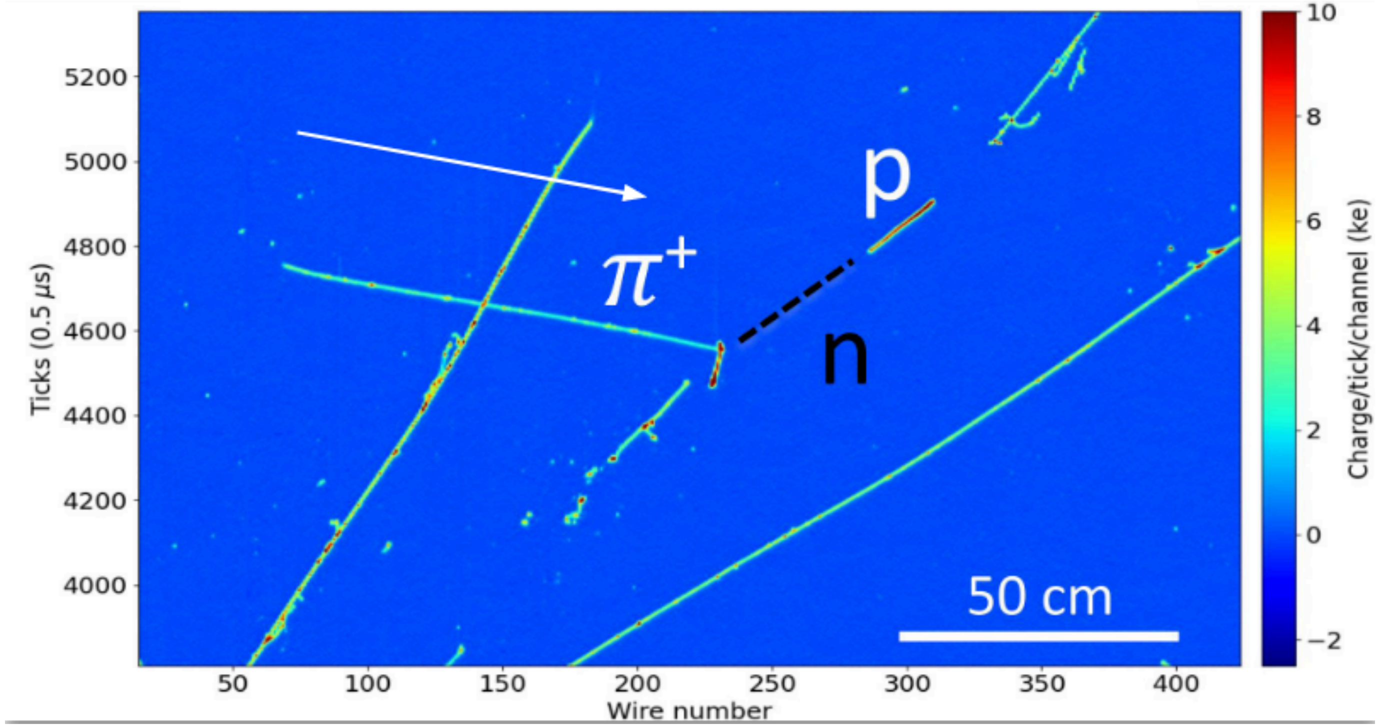


DUNE

DEEP UNDERGROUND
NEUTRINO EXPERIMENT

Analysis plan: Charged pion – Ar interactions

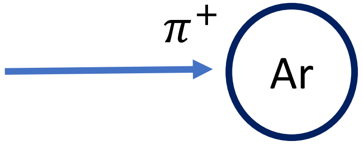
- Measuring interaction cross sections can help reduce systematic uncertainties across DUNE’s physics program.
  ➔ Already studied by Jake and Francesca
- Describing more of the dynamics of the Ar nucleus can help with the FSI models
  ➔ Which, amongst other things, have large effects on neutrino energy reconstruction



Charged pion – Ar interactions

Number/type of final state nucleons of absorption of pions

- Study possible final states of the interaction
- Identify any final state proton
- Identify final state neutrons, possibly by protons that have been knocked out a distance from the nucleus



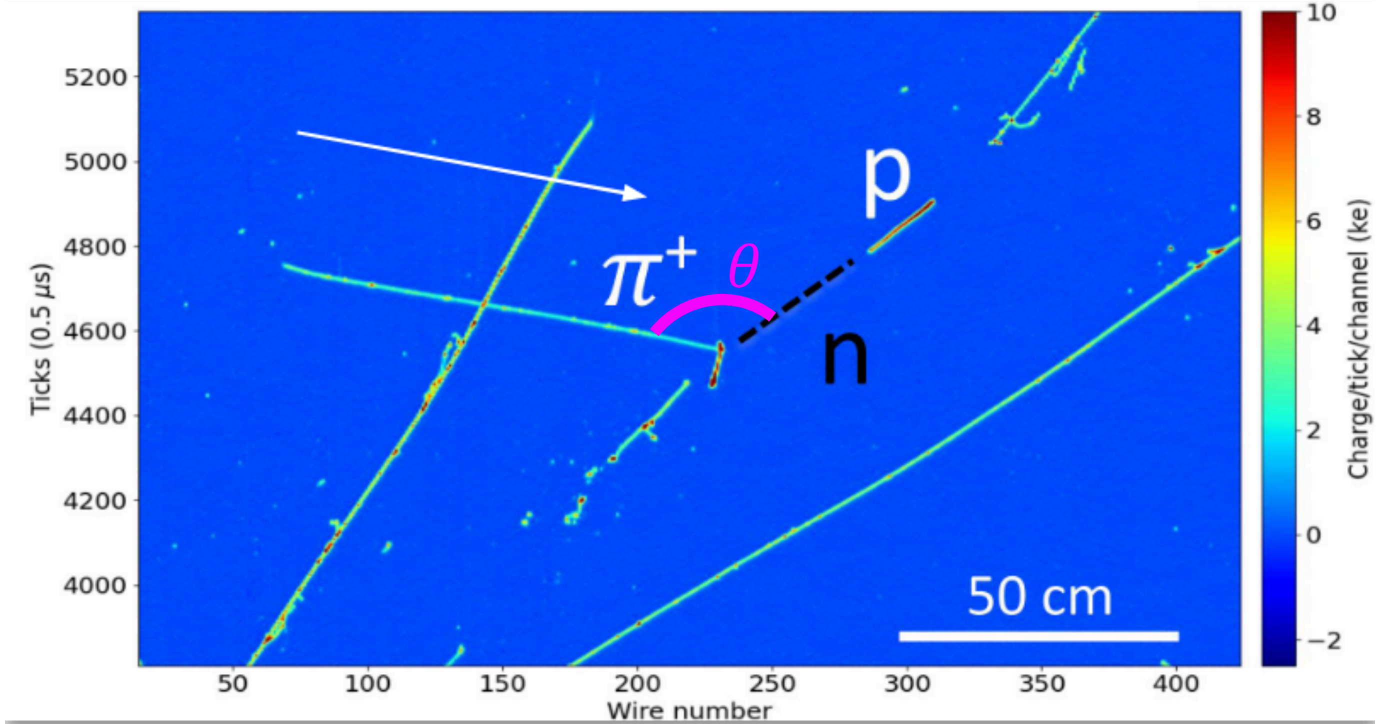
Charged pion – Ar interactions

Proton kinematics of Pion absorption events

- Get the angle of the outgoing proton relative to the incident pion

Status

- Just started to looking at data and MC events of this kind of interactions
- Possibility to improve on the selection of Pion absorption events



Conclusions

- I have worked on analysis projects of the KATRIN and TRIMS experiments
- Main focus on ion studies:
  - Ion background characterization in the KATRIN experiment
  - Ion studies in the TRIMS experiments – paper coming out soon
- I have chosen a ProtoDUNE analysis project, charged pion – argon interactions of absorption events
  - Expect to start analysis soon

Thank you!

TRIMS

KATRIN

KARLSRUHE TRITIUM NEUTRINO EXPERIMENT

DUNE

DEEP UNDERGROUND NEUTRINO EXPERIMENT

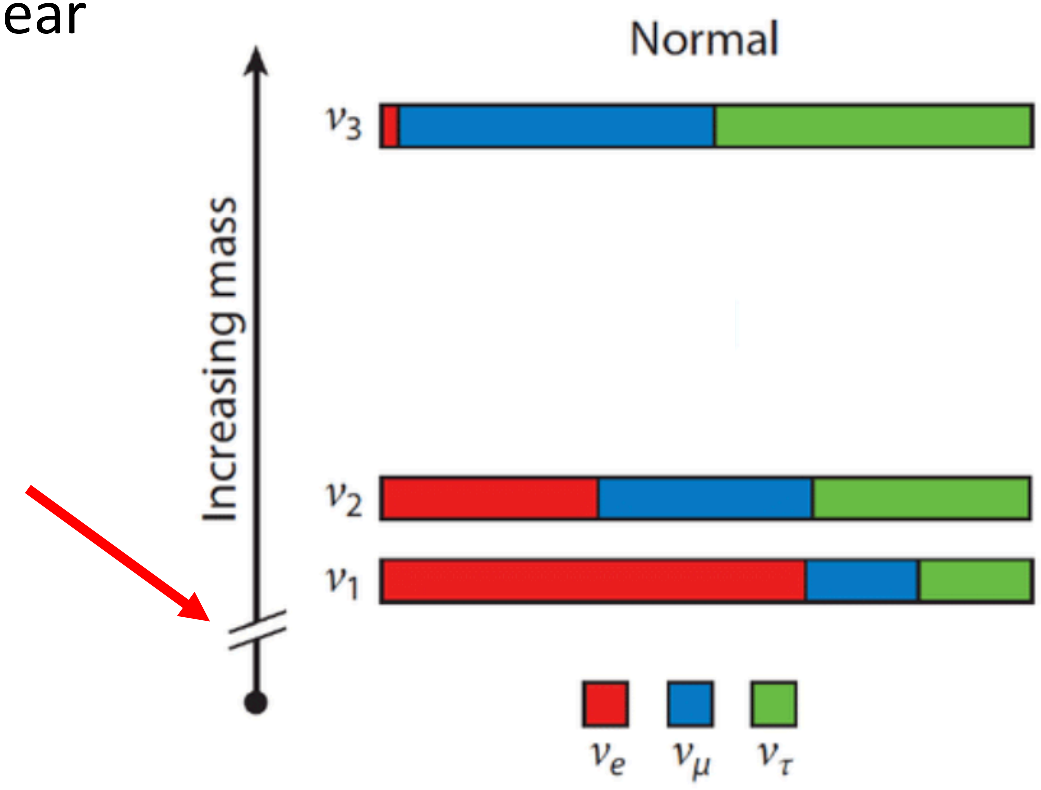
Backup slides

Neutrino mass

Each of the 3 neutrino masses is a linear combination of the 3 neutrino flavors

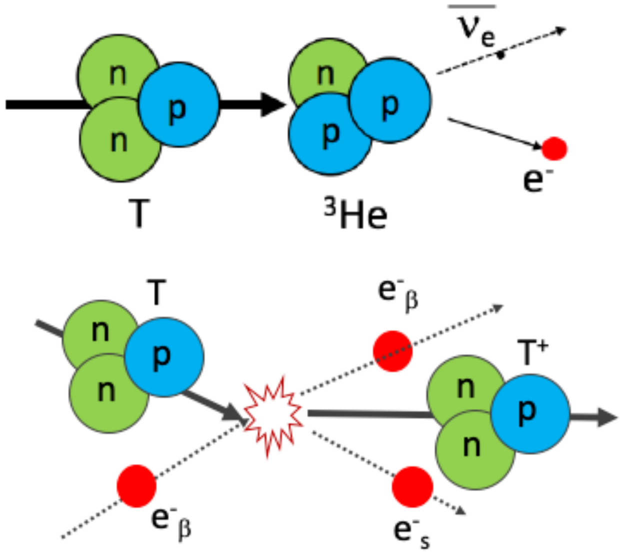
Where are we?

- Neutrino oscillation experiments give the mass splitting
- What do we know about the offset of the smallest neutrino mass from zero?



*Creative commons figure

Ions created in KATRIN experiment



Ion creation rate in the Source:

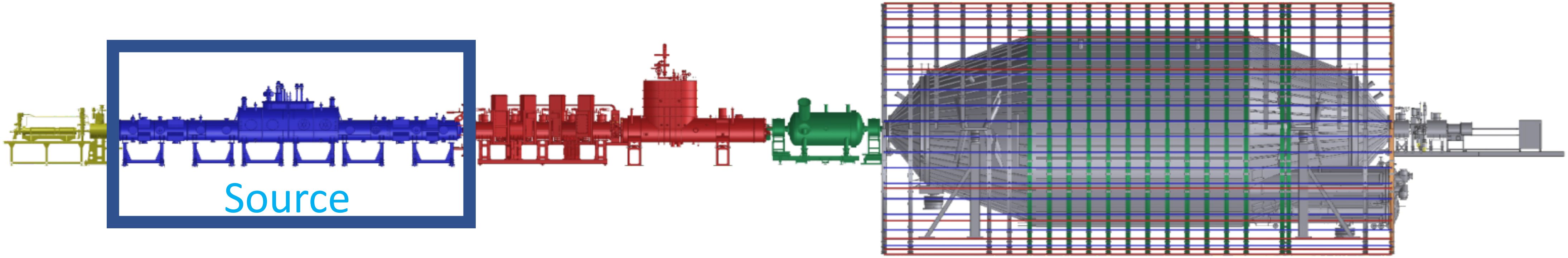
Tritium beta decay → 10^{11} ions/s

Scattering → 10^{12} ions/s

Energy: most ions have thermal energies ~ meV

molecular dissociation can have up to ~ 15 eV

Recombination: with thermal electrons and between + - ions

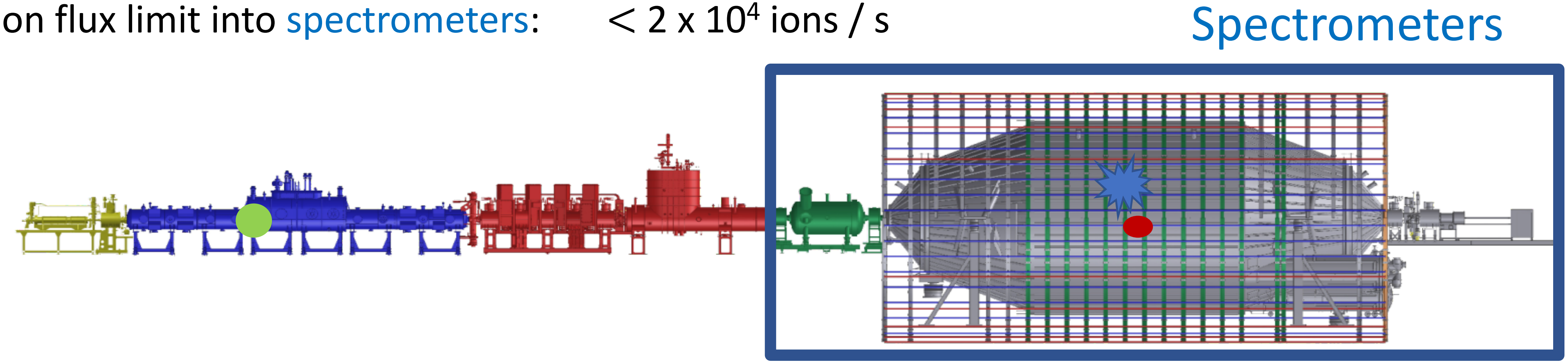


Influence of ions on KATRIN measurement

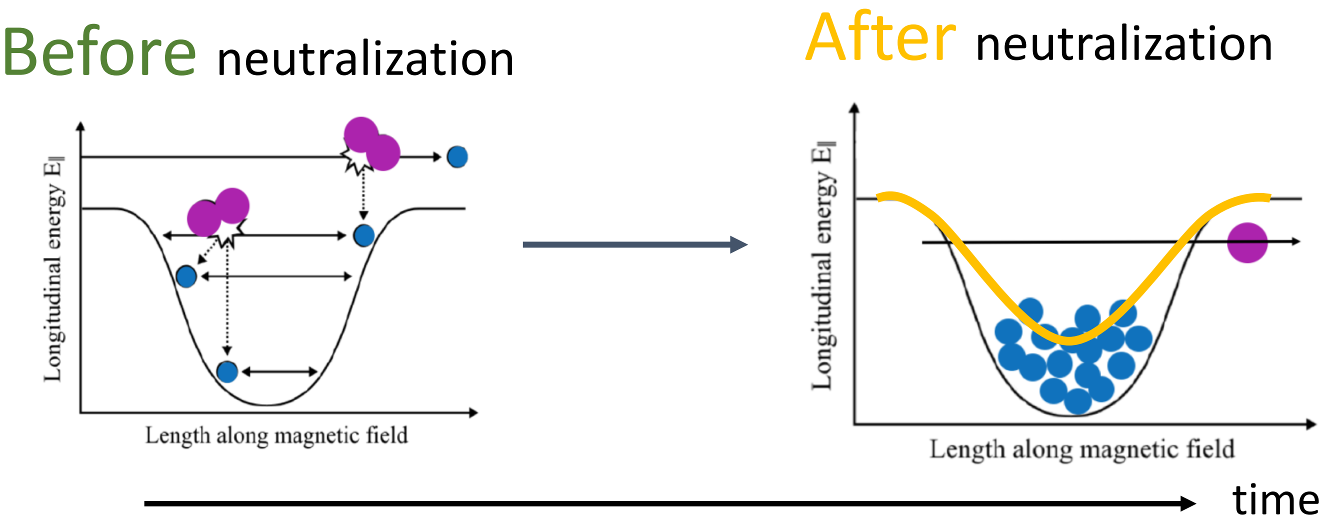
Ions are magnetically guided to spectrometers

- ➔ **Contamination** of the spectrometers section
- ➔ **Background** for neutrino mass measurement by
  1. ionization of residual gas after acceleration by high voltage (-18 kV)
  2. Sputtering of particles from vessel wall

Ion flux limit into spectrometers: $< 2 \times 10^4$ ions / s



Ring electrode neutralization


Before neutralization

After neutralization

The effective blocking potentials will decrease with time as more electrons are captured in the potential.

DANGER!

Ions are no longer blocked

Contamination of PS and MS

More background

Neutralization expectation