Design of a pulsed, low energy, high precision electron calibration source for the PTOLEMY experiment

Research project status

Karolina Rozwadowska

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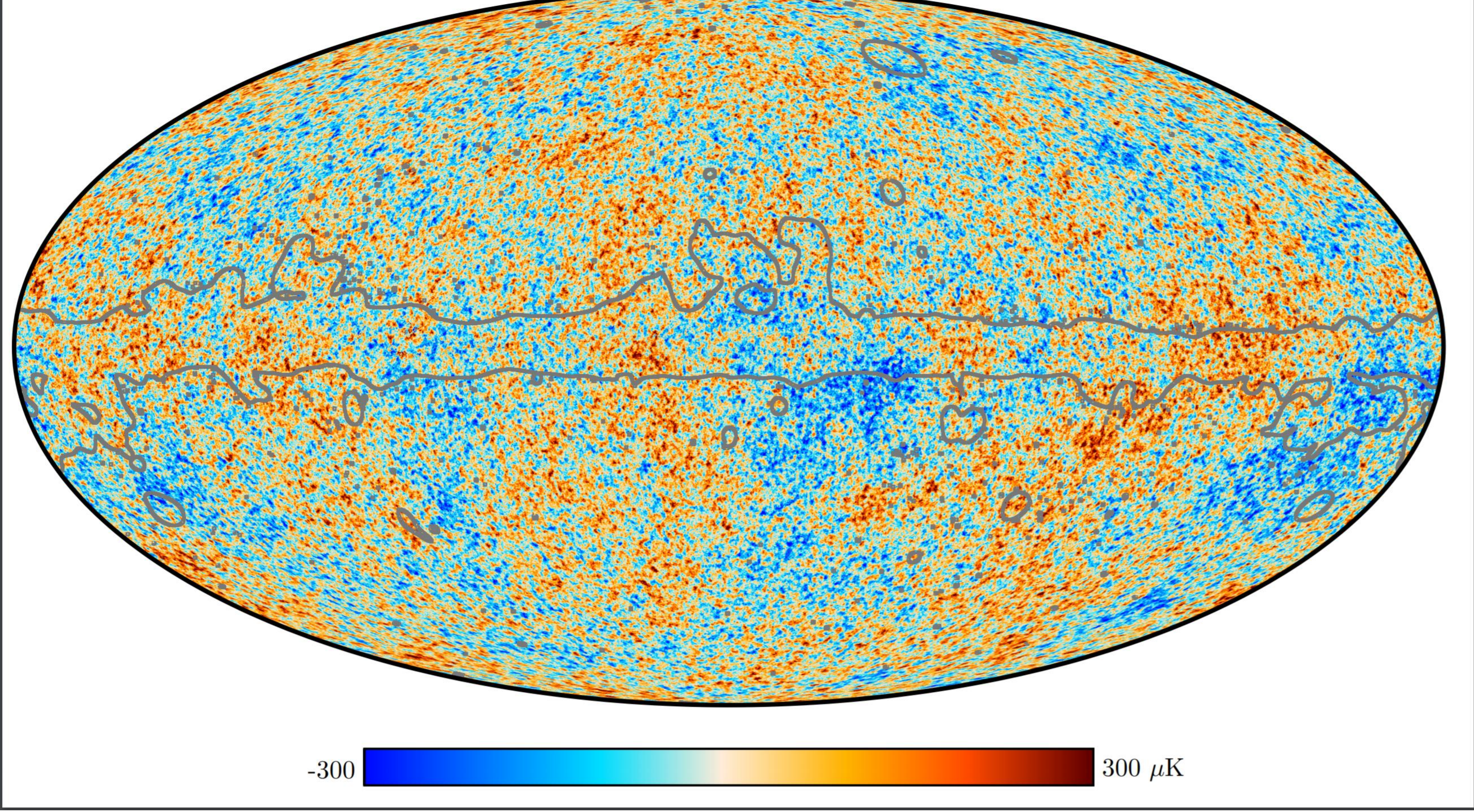
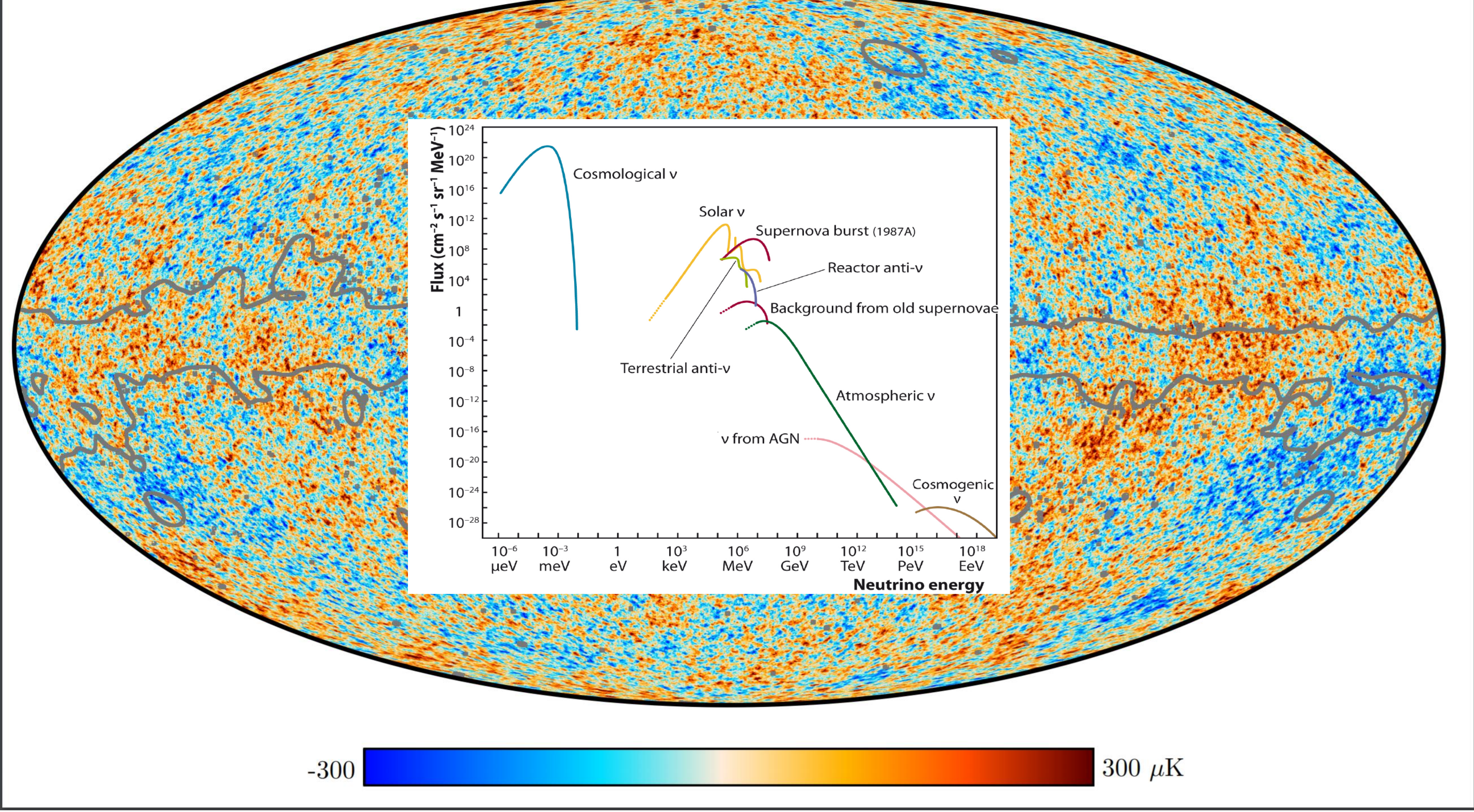
Goals and motivations

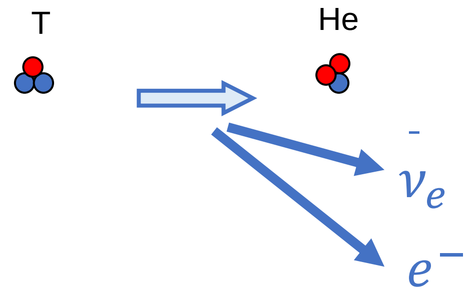

-300
300 μK



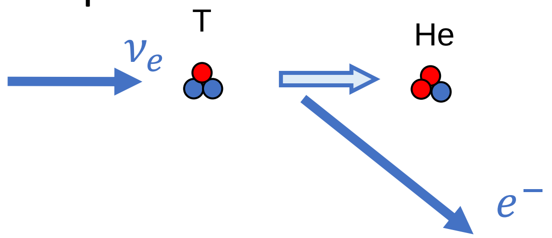
Flux (cm⁻² s⁻¹ sr⁻¹ MeV⁻¹)
10^{24}
10^{20}
10^{16}
10^{12}
10^{8}
10^{4}
1
10^{-4}
10^{-8}
10^{-12}
10^{-16}
10^{-20}
10^{-24}
10^{-28}
Cosmological ν
Solar ν
Supernova burst (1987A)
Reactor anti-ν
Background from old supernovae
Terrestrial anti-ν
Atmospheric ν
ν from AGN
Cosmogenic ν
10^{-6} μeV
10^{-3} meV
1 eV
10^{3} keV
10^{6} MeV
10^{9} GeV
10^{12} TeV
10^{15} PeV
10^{18} EeV
Neutrino energy
-300
300 μK

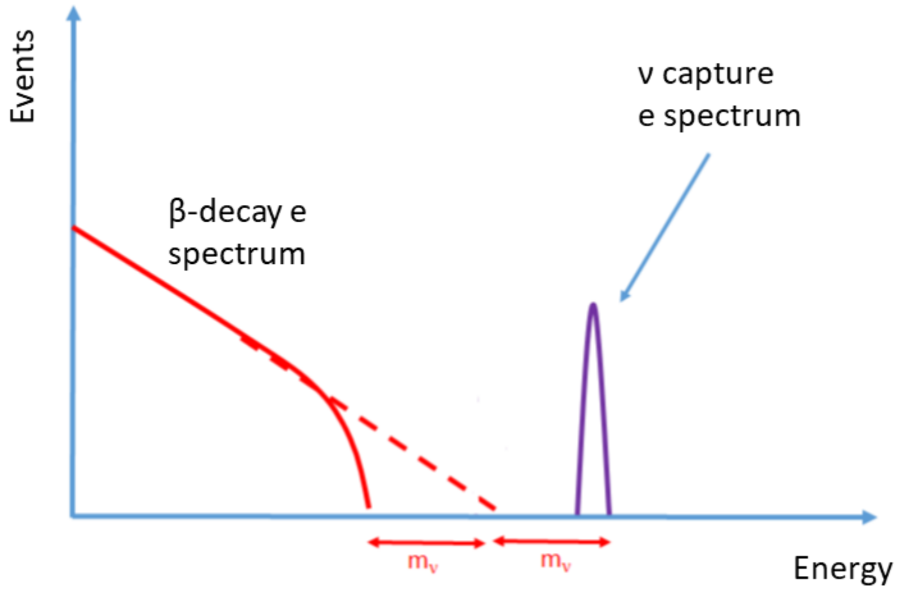
Relic neutrino capture

β-decay of T atom



ν capture on T atom



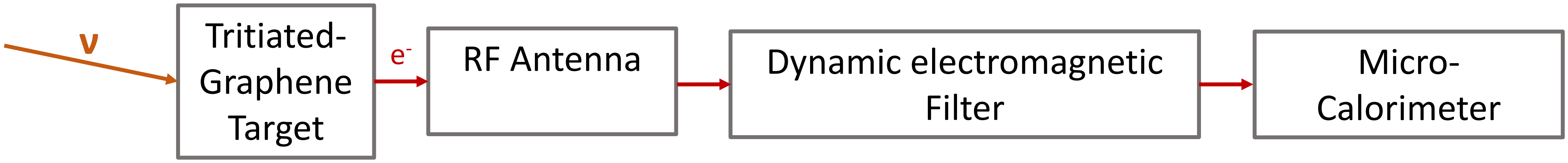


Neutrino mass constraints

$m_\nu < 1.1$ eV KATRIN 2019

$\sum m_\nu < 0.12$eV Planck 2018

PTOLEMY block diagram



Electron originates from tritium weakly bound on graphene

Momentum measurement

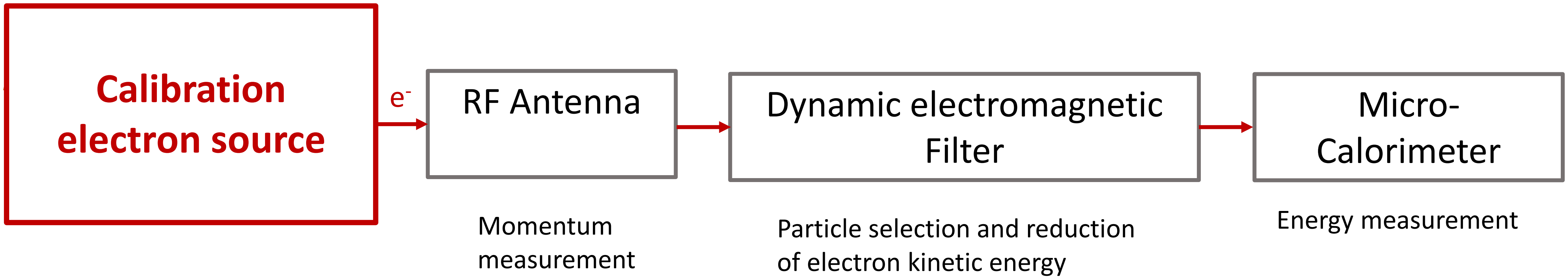
Particle selection and reduction of electron kinetic energy

Energy measurement

$$E_{electron} = q \cdot (V_{anode} - V_{source}) + E_{calorimeter}$$

Total energy resolution target ΔE = 0.05 eV

PTOLEMY block diagram



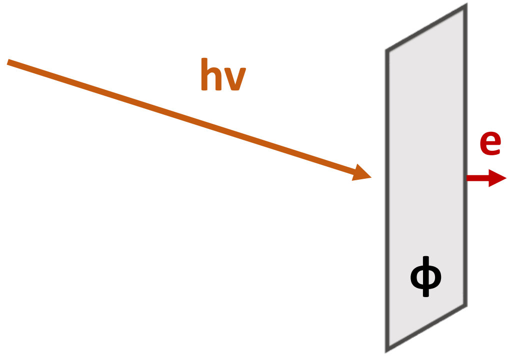
Electron source R&D

- Electron extraction
- Electron transport
- Electron detection

Low energy electron extraction

Photoelectric effect

Photons matching the extraction potential generate low energy electrons



$K_e = h\nu - \phi$

J. Behrens et al., A pulsed, mono-energetic and angular-selective UV photo-electron source for the commissioning of the KATRIN experiment, Eur.Phys.J.C 77 (2017) 6, 410

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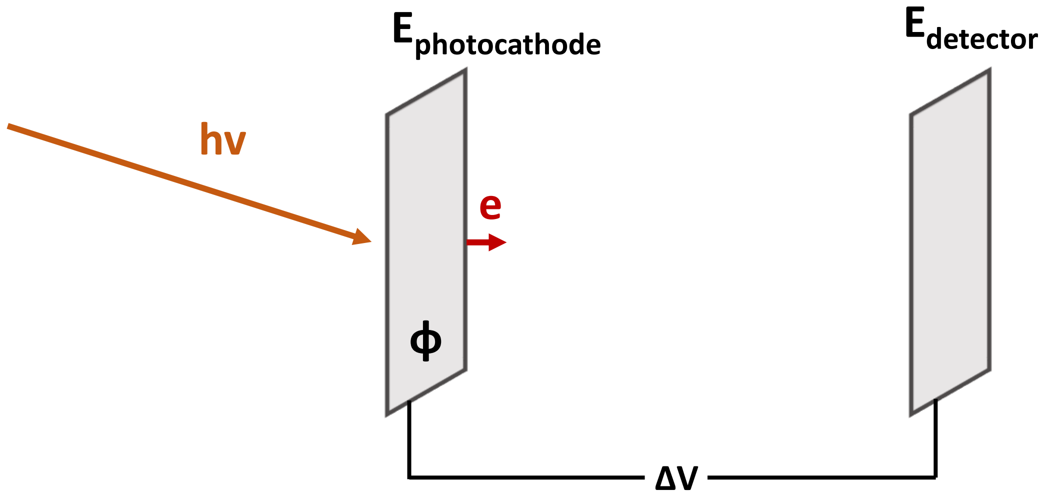
Electron kinetic energy controlled by electrostatics



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$\Delta K_e = e\,\Delta V$

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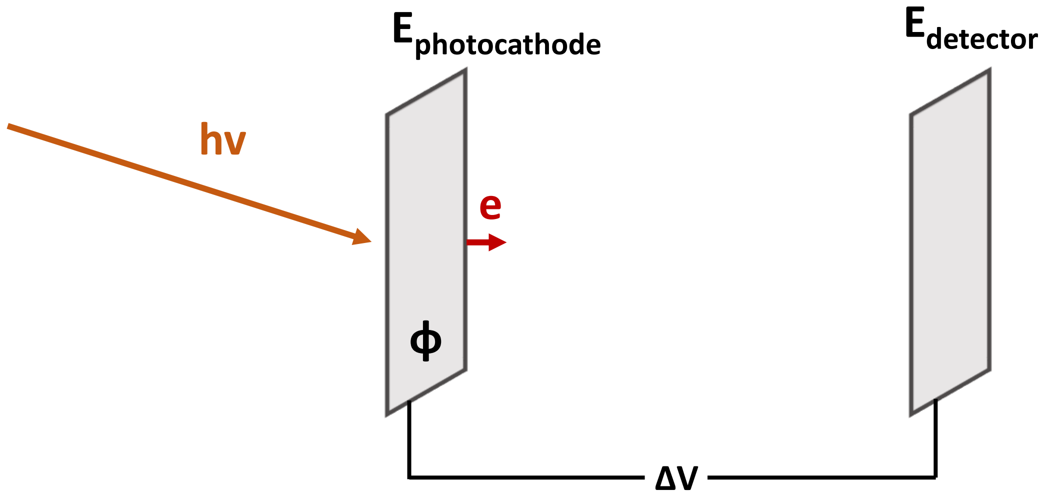

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Work function of selected elements

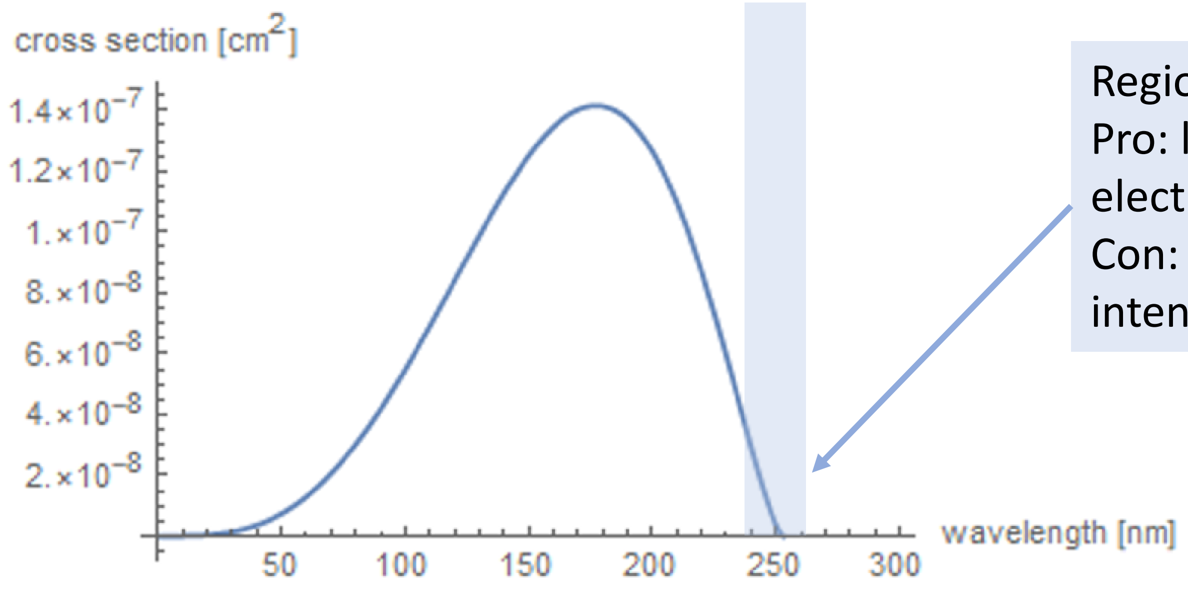
Element	Work function [eV]
Pt	5.64
Au	5.10
Ag	4.26 – 4.73
C	4.30 - 7.70

J. Behrens et al., A pulsed, mono-energetic and angular-selective UV photo-electron source for the commissioning of the KATRIN experiment, Eur.Phys.J.C 77 (2017) 6, 410

Low energy electron extraction

Photoelectric effect

The case of Au, ϕ_{Au} = 5.1 eV



Region very close to ϕ
Pro: low energy of extracted electrons
Con: cross section very small, intense light source needed

Low energy electron extraction
Photoelectric effect

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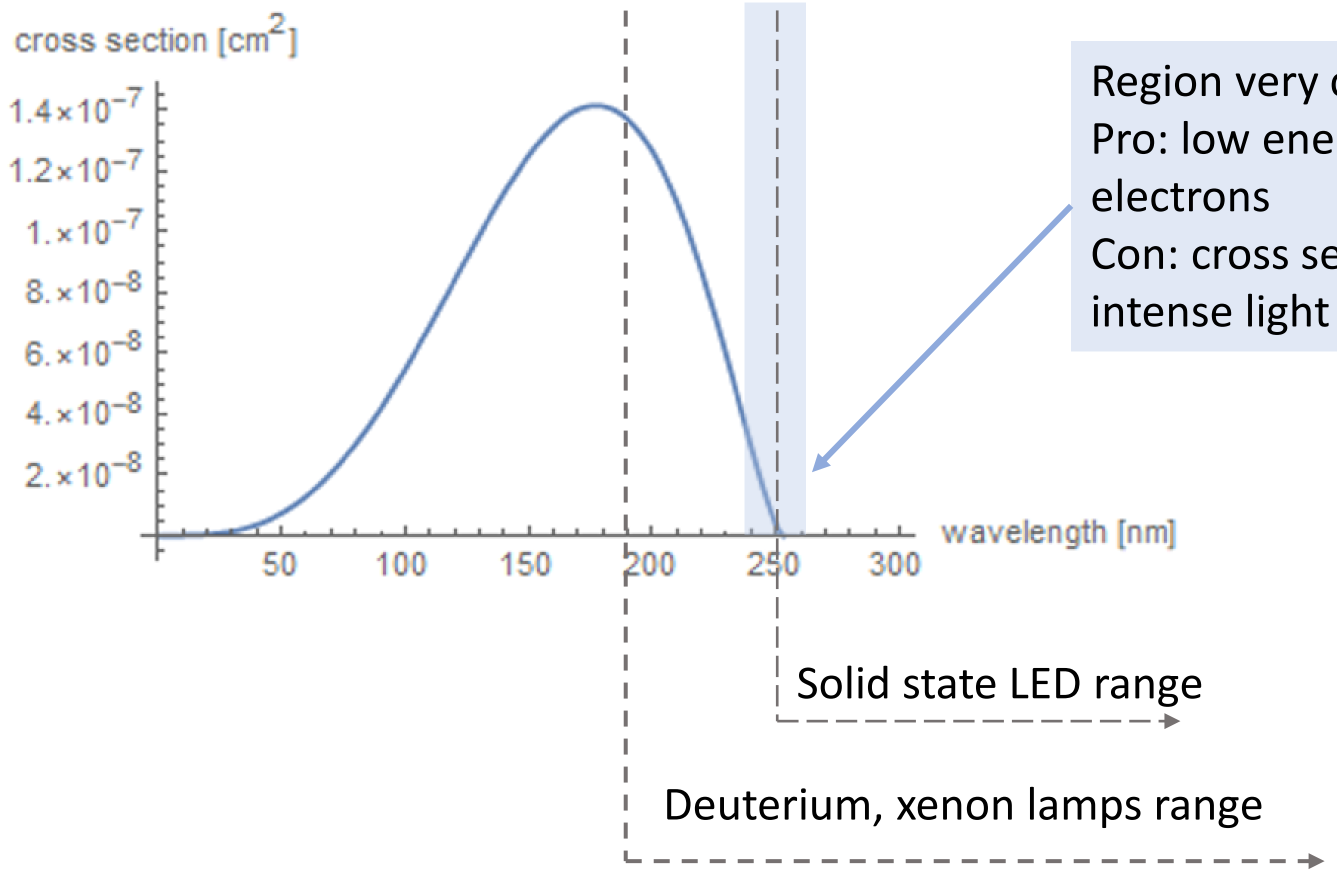
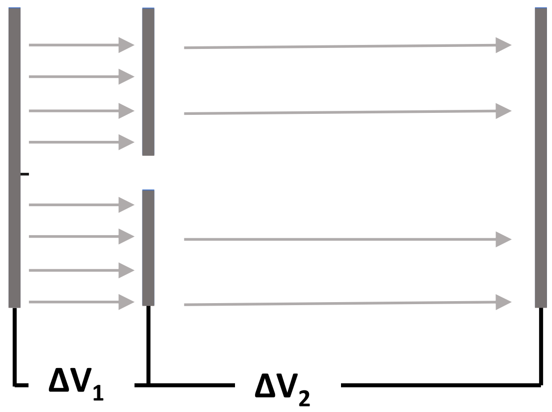
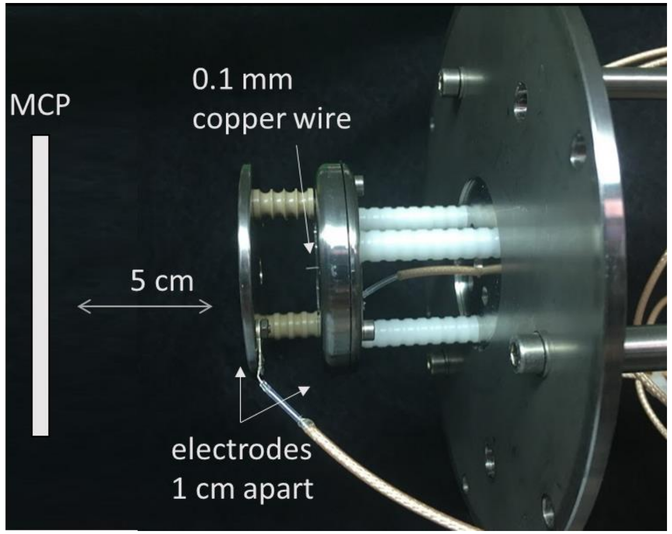


Region very close to ϕ
Pro: low energy of extracted electrons
Con: cross section very small, intense light source needed

Low energy electron extraction
Field emission from a metal tip

Electrons measured over 5 cm and 15 cm drift lengths





Advantages: much more efficient than photoelectric effect,

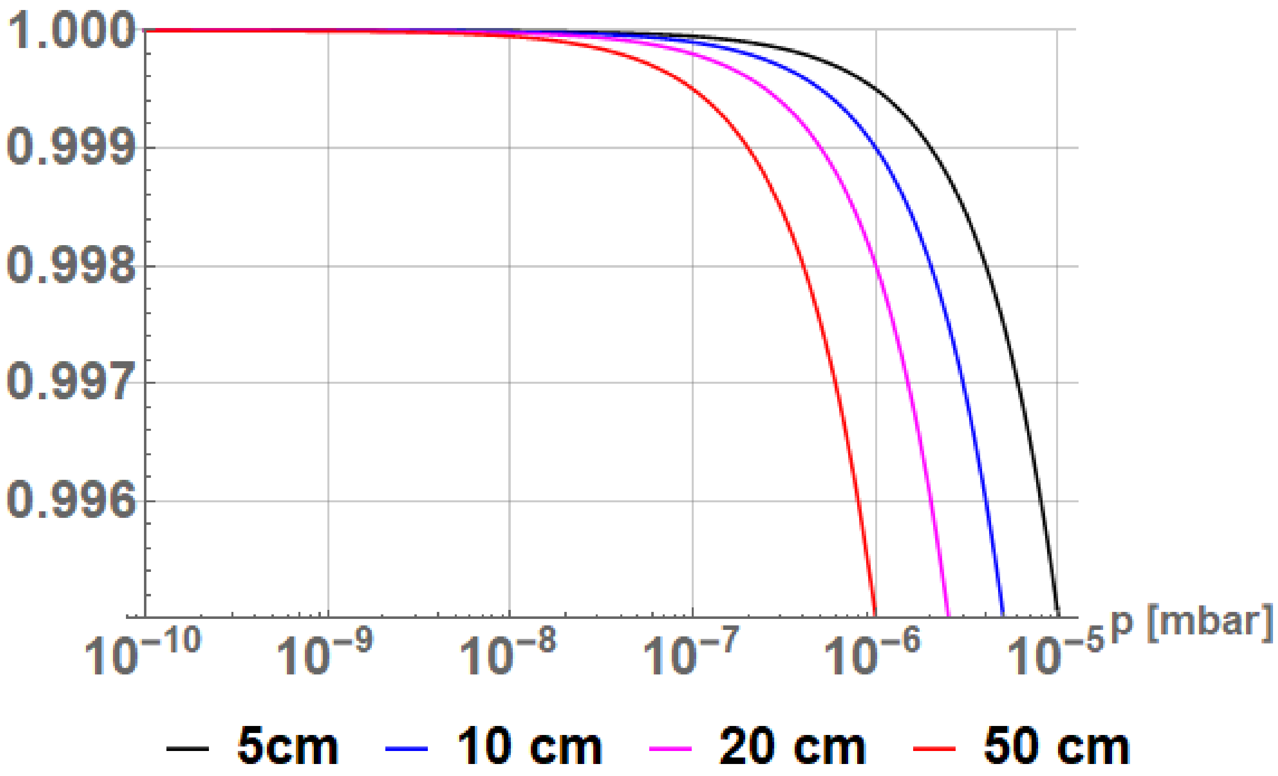
→ will be used to study and optimize transport and detection techniques

Drawback: constant (not pulsed) electron source.

→ Possibilities to introduce timing information are currently studied

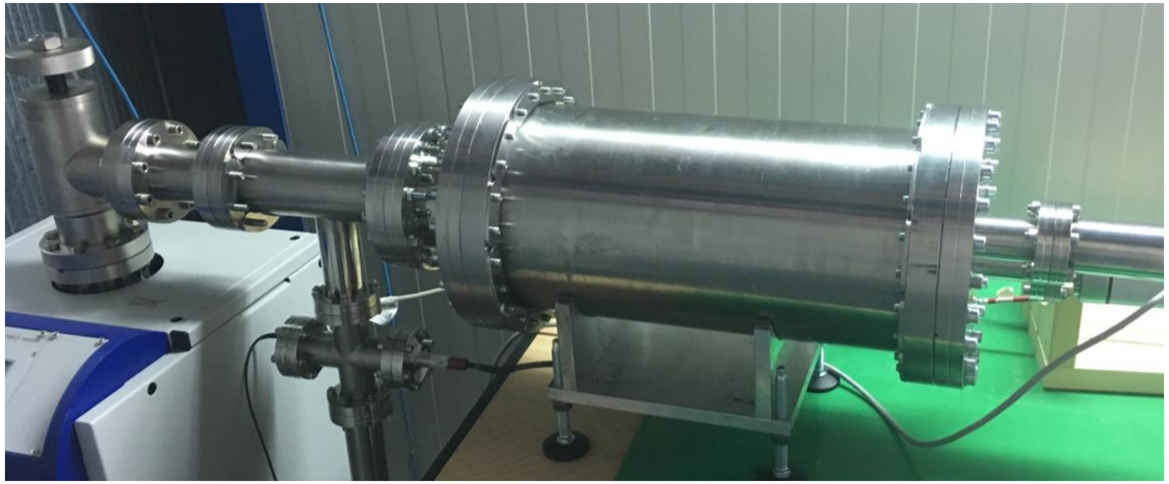
Electron transport
Vacuum requirements

Electron survival rate in air at 25° C



We operate at pressure below 10^{-6} mbar
→ survival rate > 99.5% for paths up to 50 cm

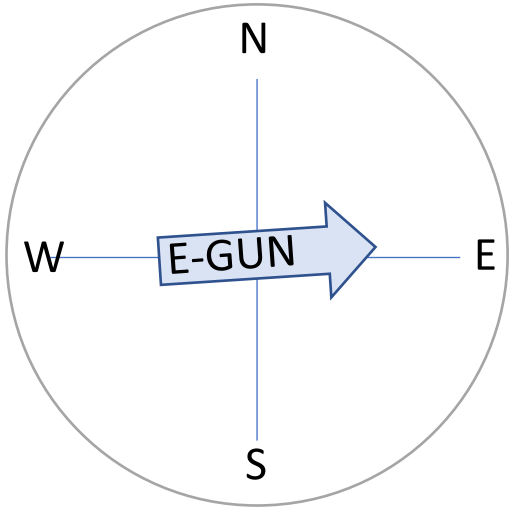
Vacuum chamber hosting electron gun setup at LNGS, connected to a vacuum pump

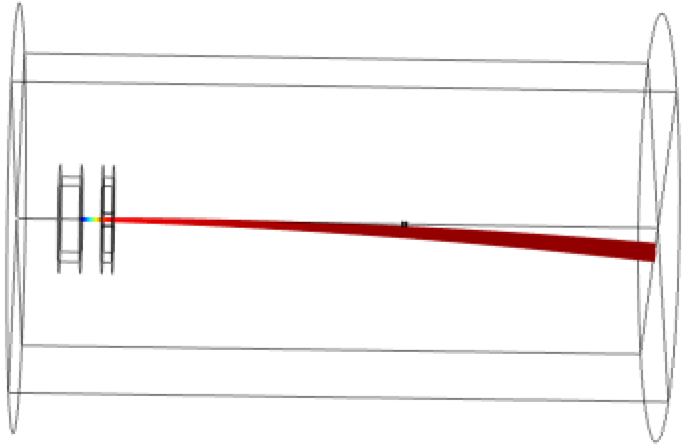


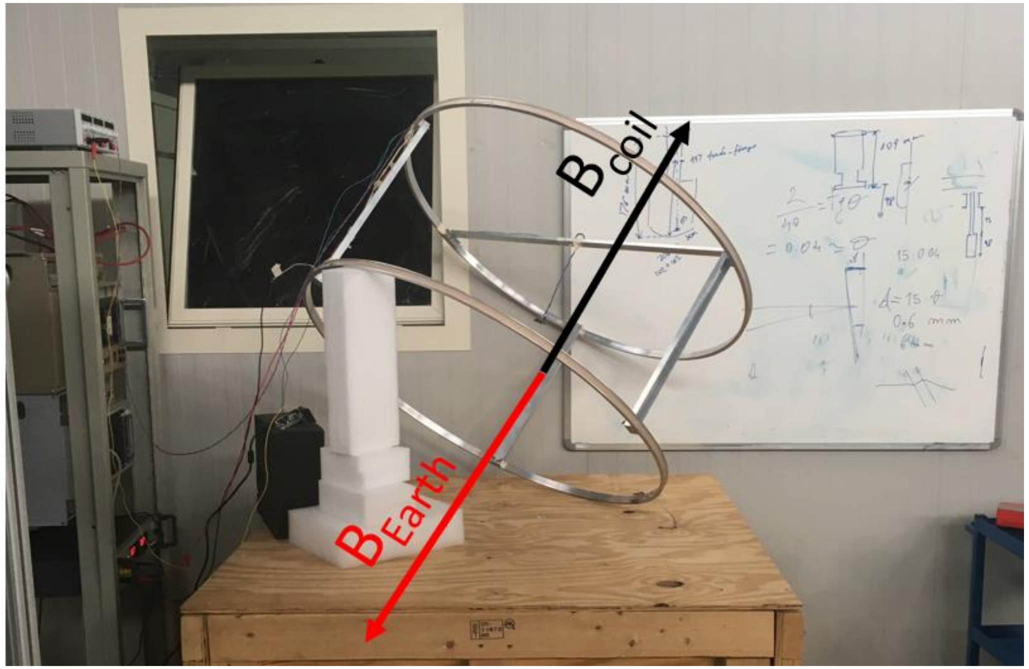
Electron transport

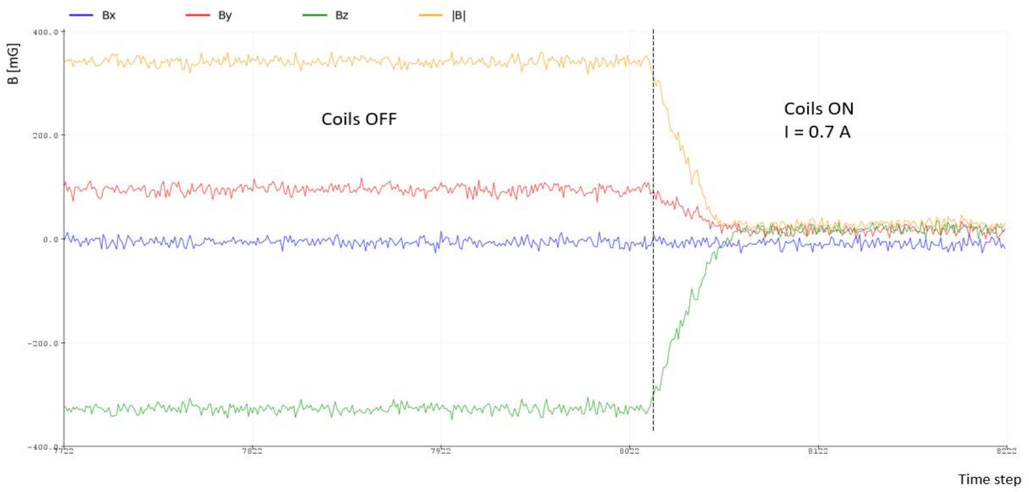
Earth's magnetic field

At our location
B_N = 24 µT
B_W = -1 µT
B_{up} = -40 µT
|B| = 47 µT





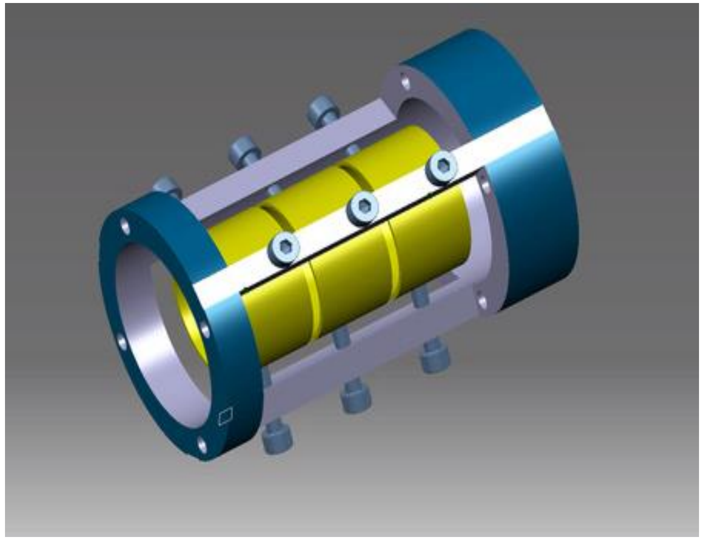


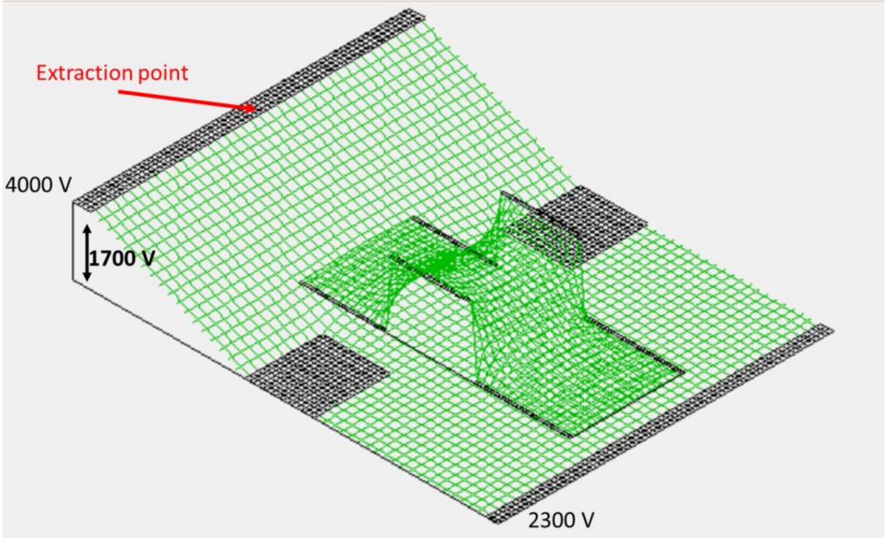


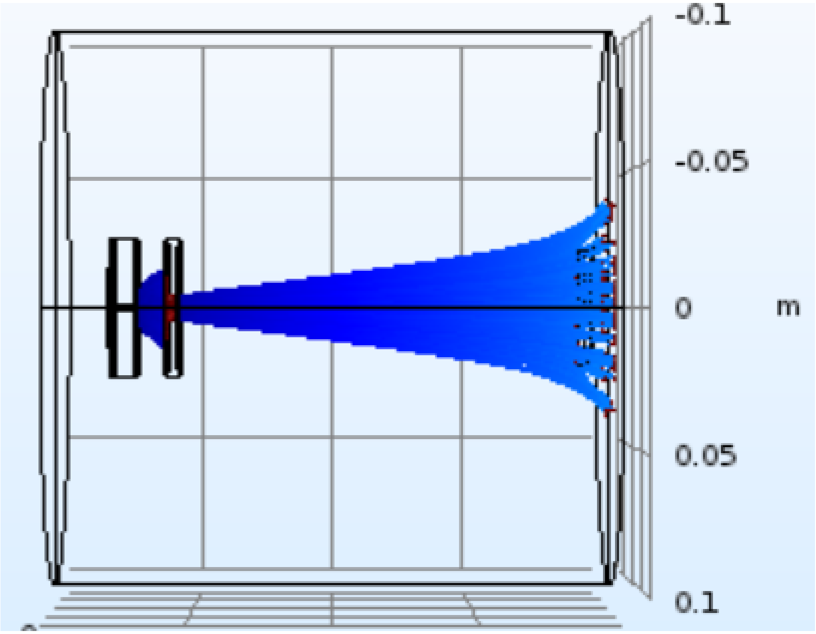
Electron transport

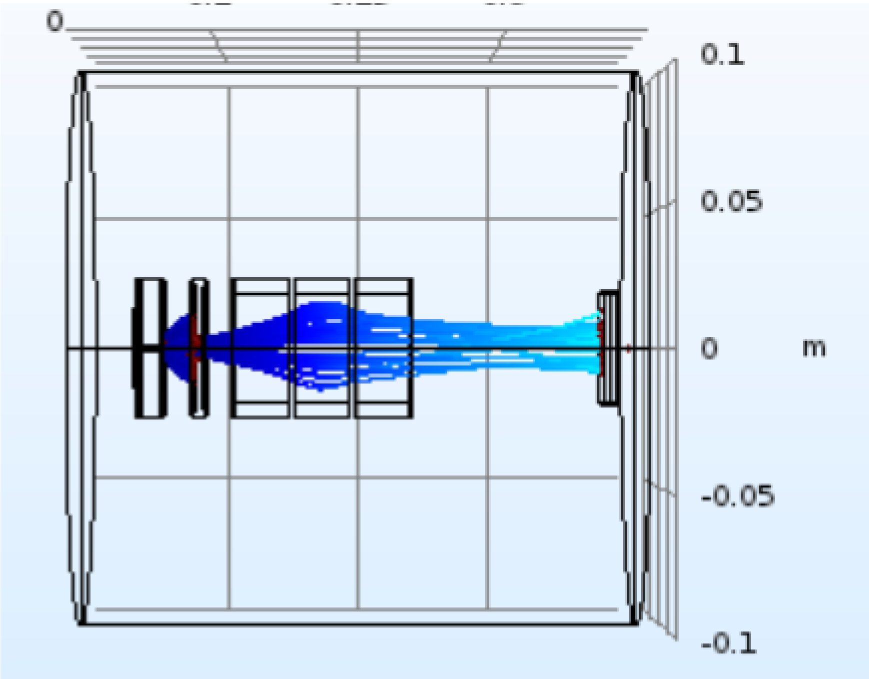
Focusing

Use electrostatic beam optics to focus the beam without changing its energy







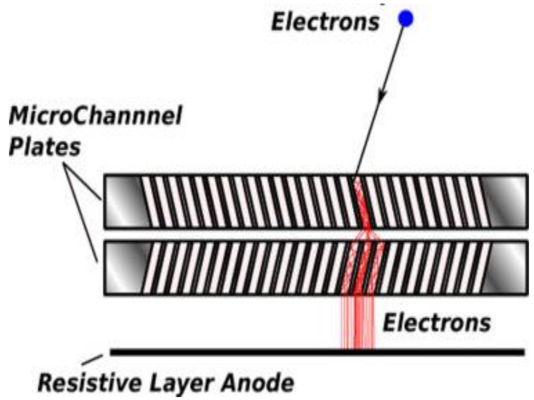


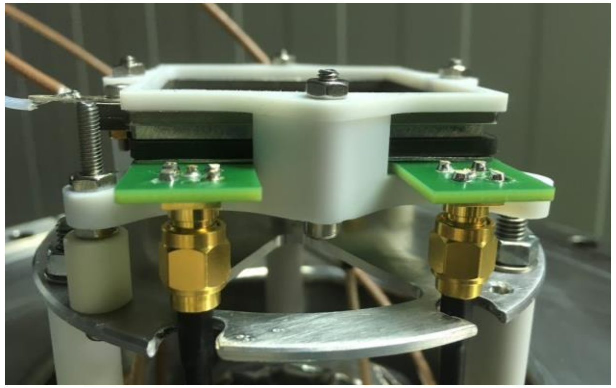
Einzel lens: three coaxial cylinders with *uphill* potential on the middle cylinder

Electron detection

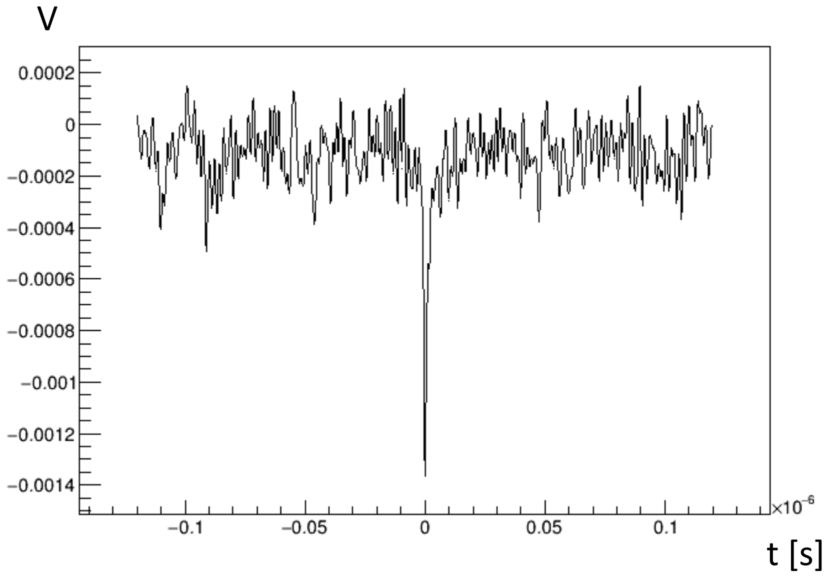
Microchannel plate detector

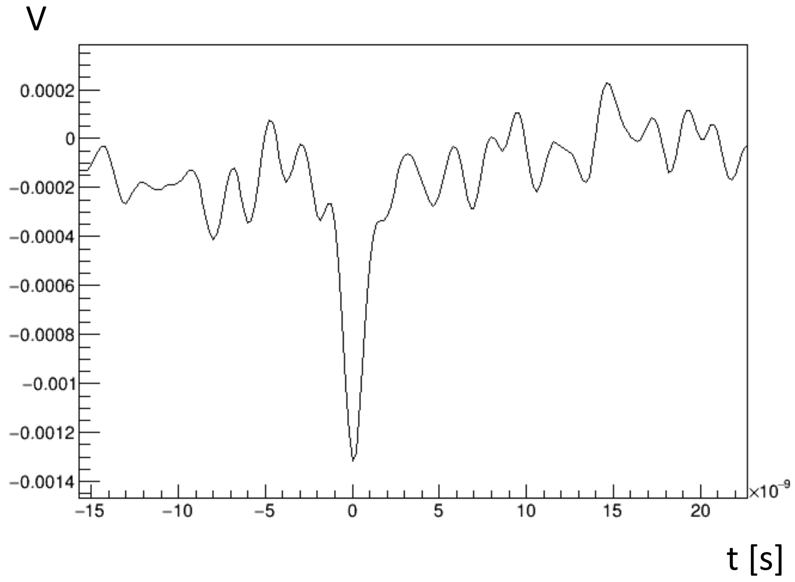
- 2 stacks of multichannel plates in parallel
- Four 2 cm x 2 cm channels
- Gain 10^5
- Dark count rate with 1800 V across MCP: 1 Hz
- Rise up: 2.5 ns
- Fall time: 4 ns





Typical electron signal

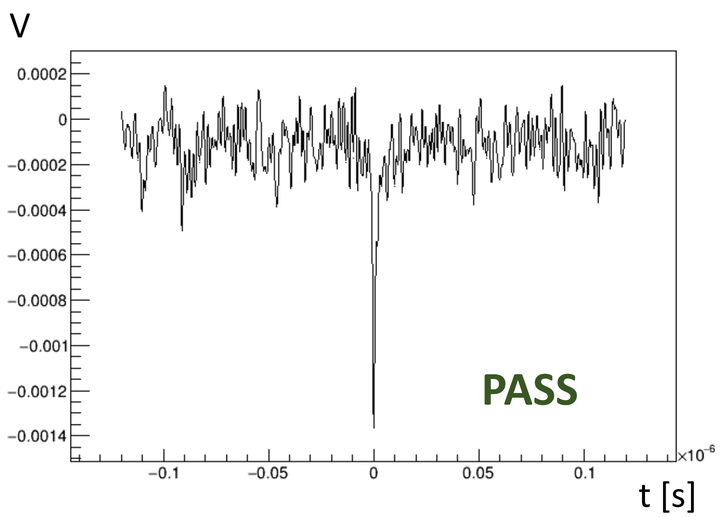


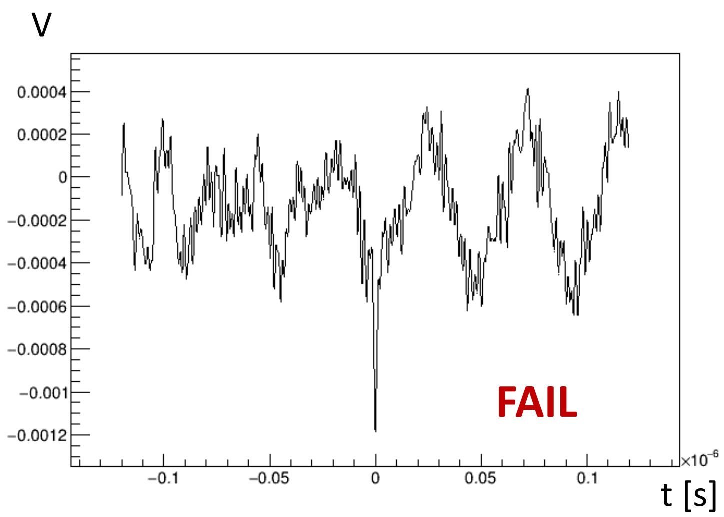


Electron detection

Event selection

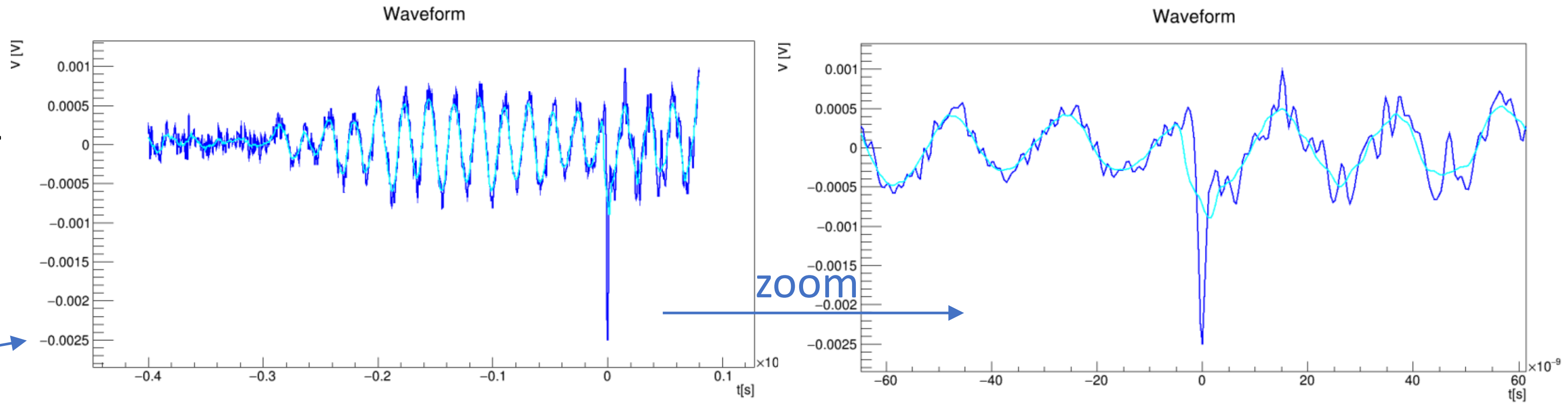
Selection #1:
Peak hight > 5 x baseline RMS





Selection #2:
SNIP filter following the noise pattern with short window for signal peak

Event passing selection #2 requirement
but not selection #1



Status summary

- Electron extraction
  - Extraction from metal tip observed
  - Preparation towards photoextraction started
- Electron transport
  - Earth’s magnetic field contribution measured
  - Helmholtz coil assembled
  - Einzel lens focusing design ongoing
- Electron detection
  - Detector characterized
  - Event selection designed

Electrons from the copper tip measured at 5 and 15 cm distance, with energies from 500 eV

Outlook and prospects

	2020	2021				2022	
	Q4	Q1	Q2	Q3	Q4	Q1	Q2
Electron extraction							
• Photoextraction optimization	●	●					
• Optical connections	●	●					
Electron transport							
• Einzel lens focusing tests	●						
• Magnetic field guiding	●						
• Pulsing the beam		●	●				
Electron detection							
• ADC based DAQ			●	●			
Energy measurement							
• Time of flight simulations and tests			●	●			
• Electron back scattering rate and/or cross section measurements				●	●	●	