Luminescence of water and ice

a novel detection channel for neutrino telescopes

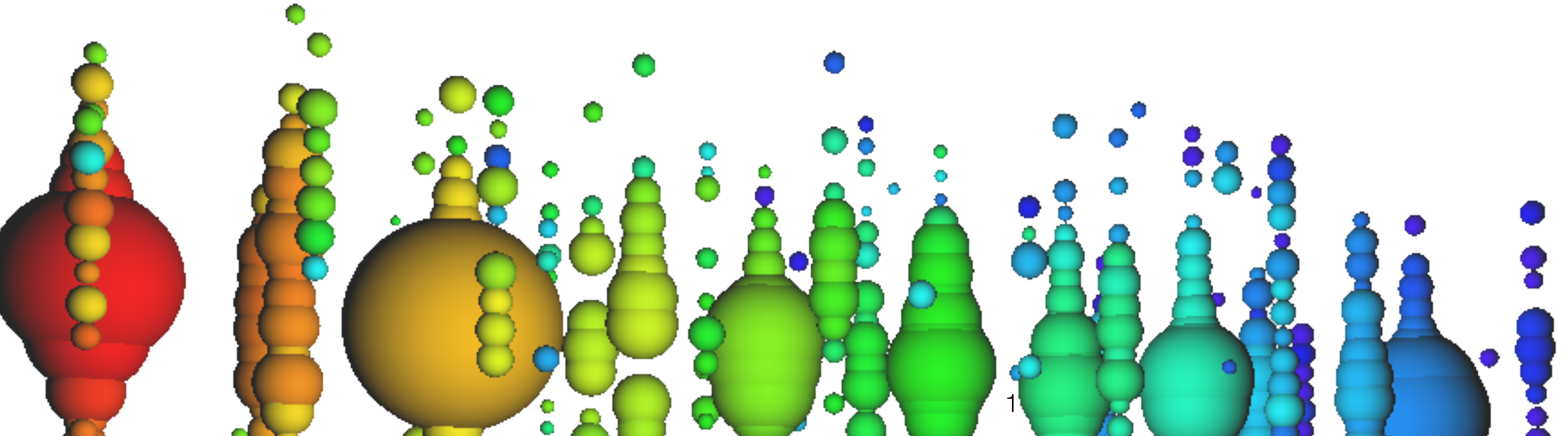
Anna Pollmann

Discussion NU #32
Tue 13 Jul 12:00h 05
POS 1093

SPICEcore

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

BERGISCHE UNIVERSITÄT WUPPERTAL



Neutrino telescopes

- Largest particle detectors on Earth
- Ideal for rare event searches

Working principle

- Large transparent volume instrumented with light sensors
- Particles interact with the natural medium
- Charged particles produce Cherenkov light at relativistic speeds
- Emitted light is detected by sensors

Slow or neutral particles cannot be detected this way!

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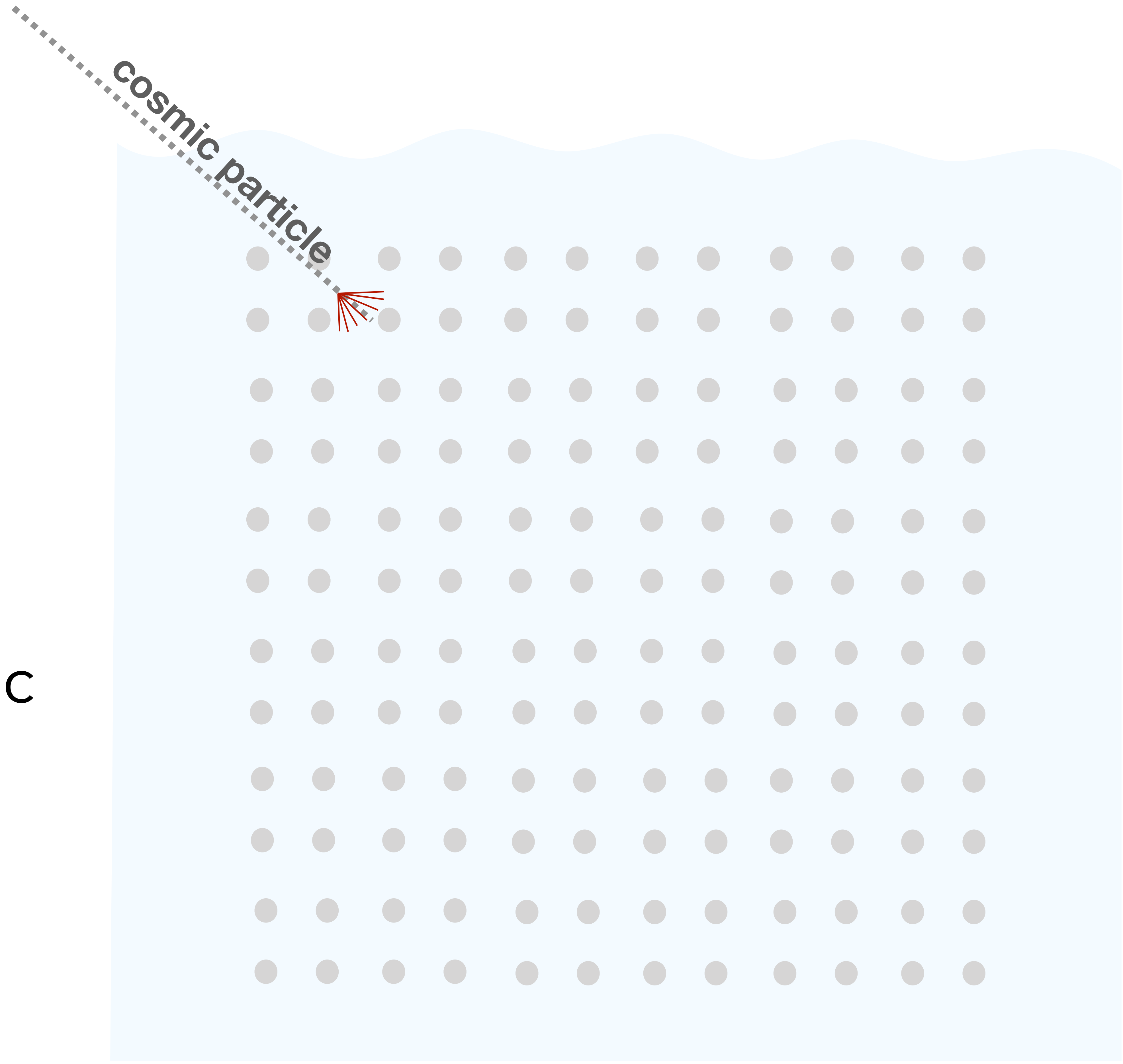

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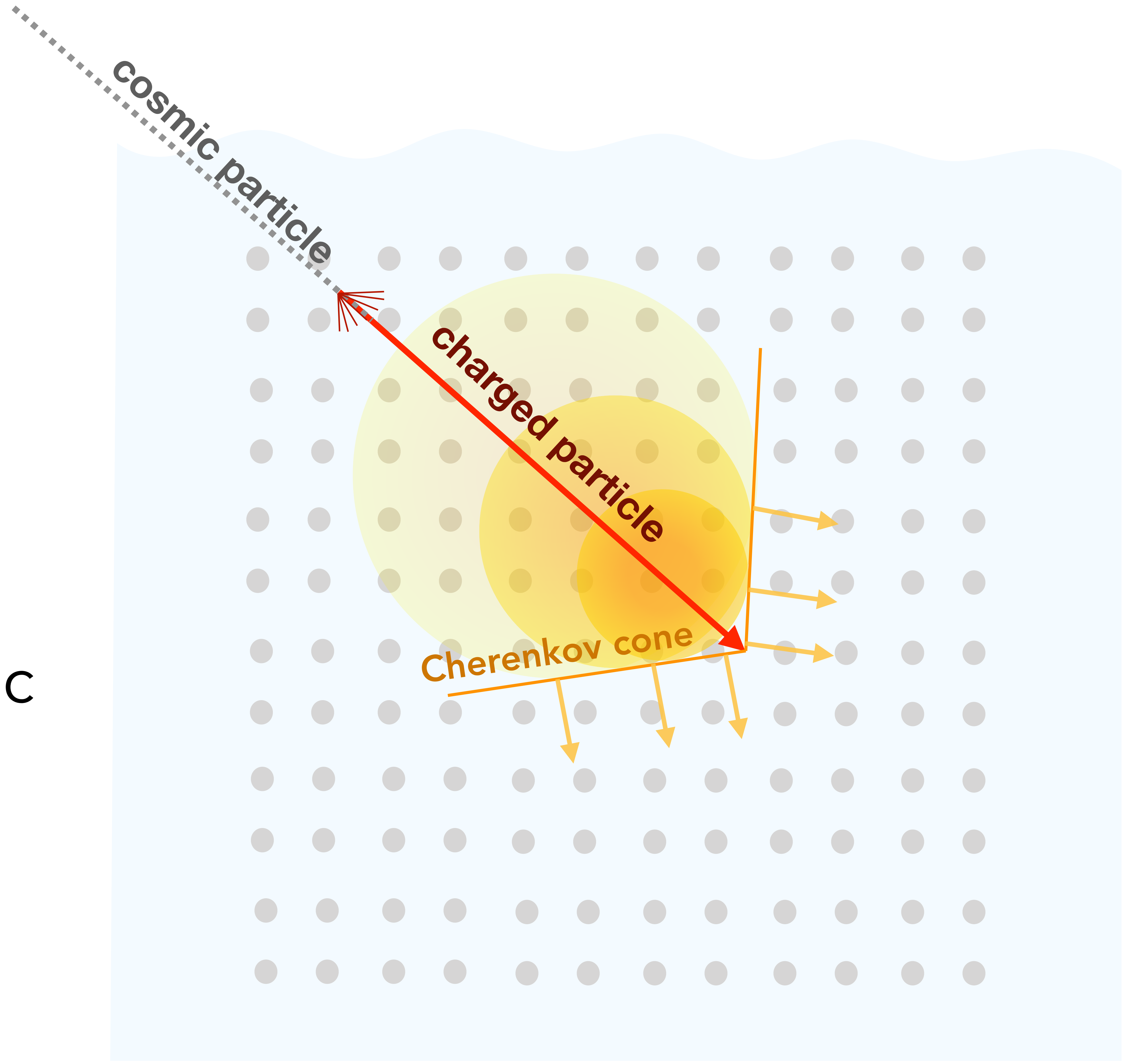

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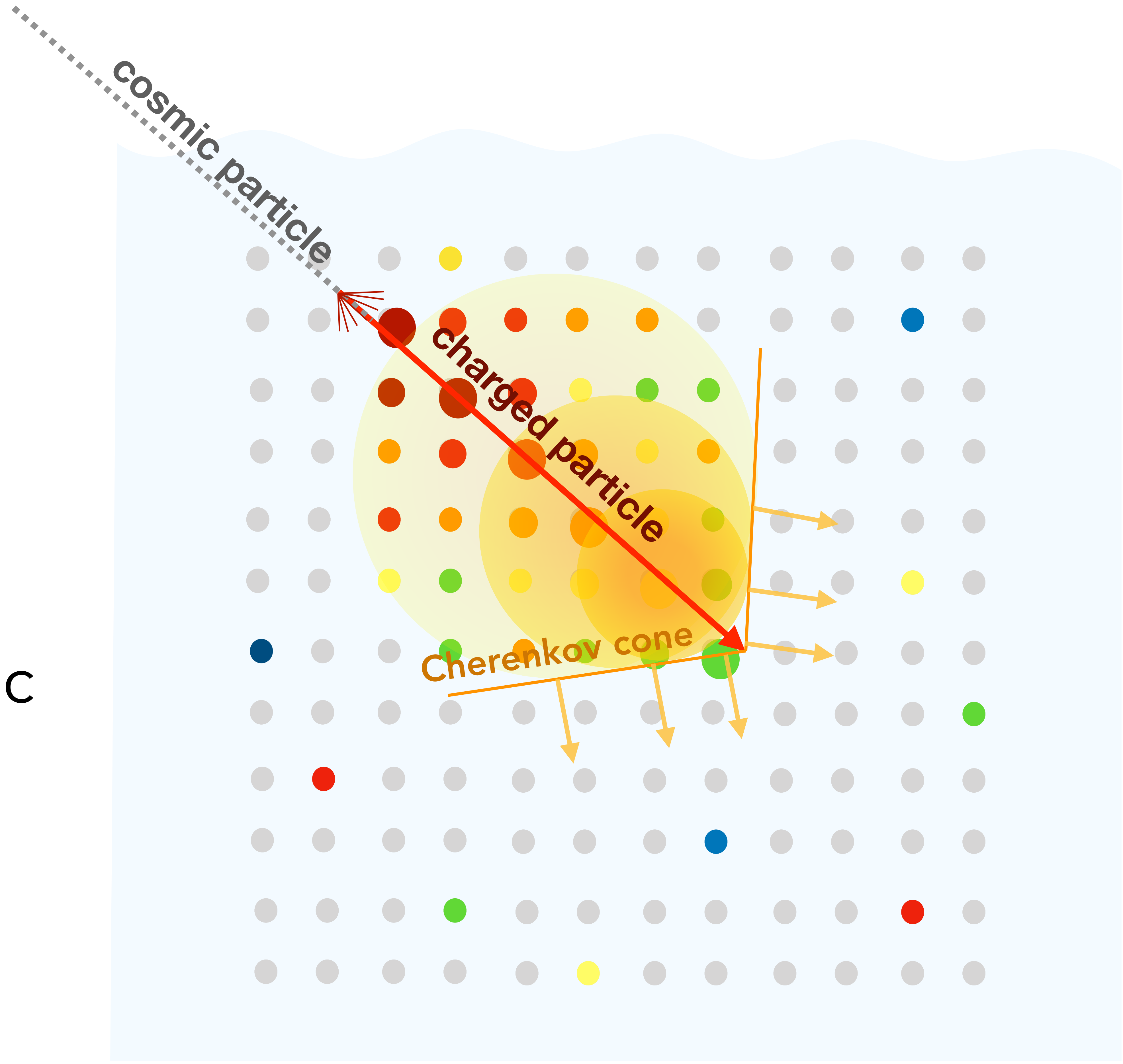

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Luminescence of water and ice

- Passage of ionising radiation through matter
- Excitation of atoms / molecules / lattice
- Relaxation with isotropic light emission

Characterisation

- light yield per deposited energy
- decay kinetics
- wavelength spectrum
- quenching

works for all speeds
works for all ionising radiation

How does it work in water / ice?

Potential dependencies
- temperature
- impurities / solubles
- radiation type

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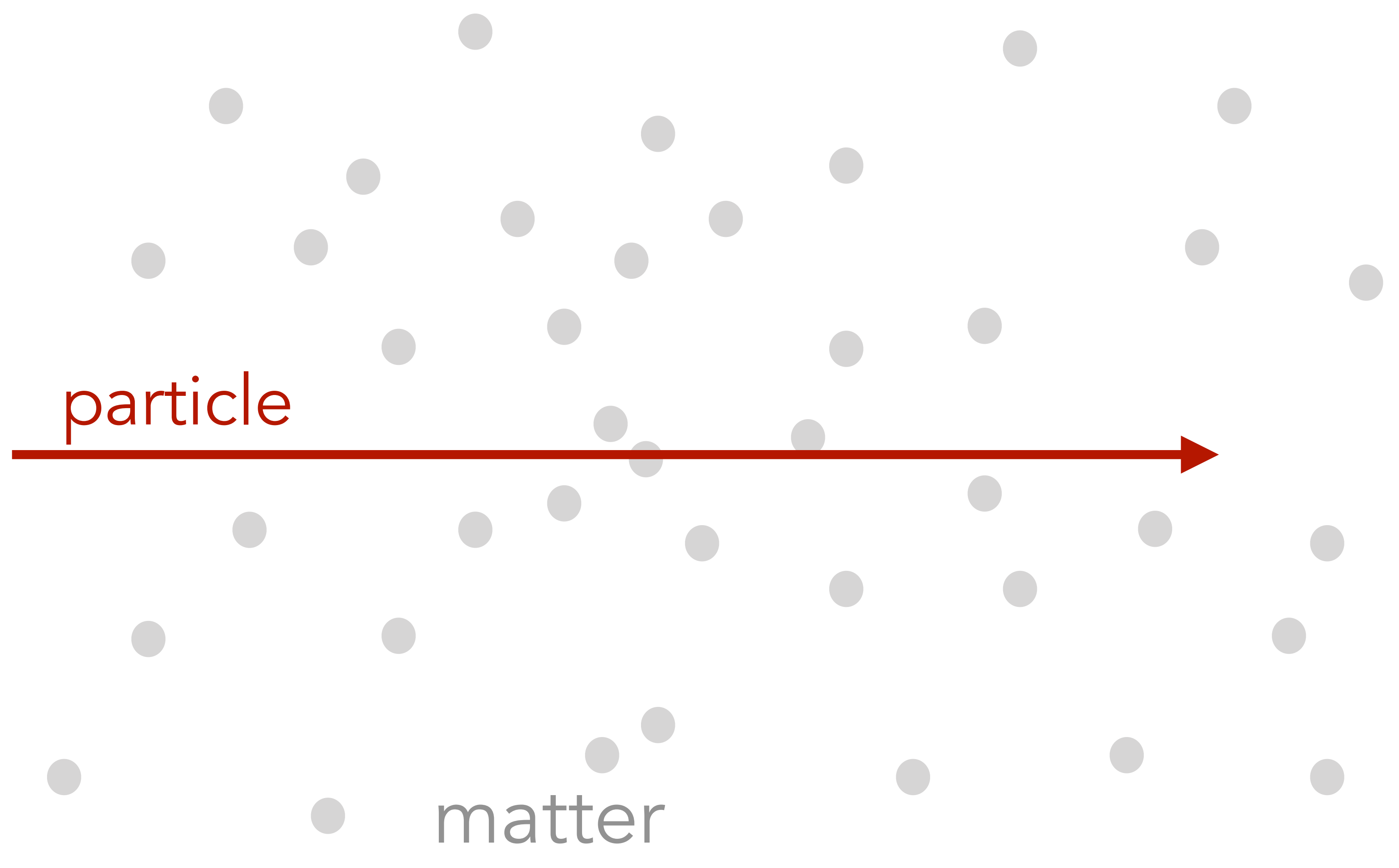

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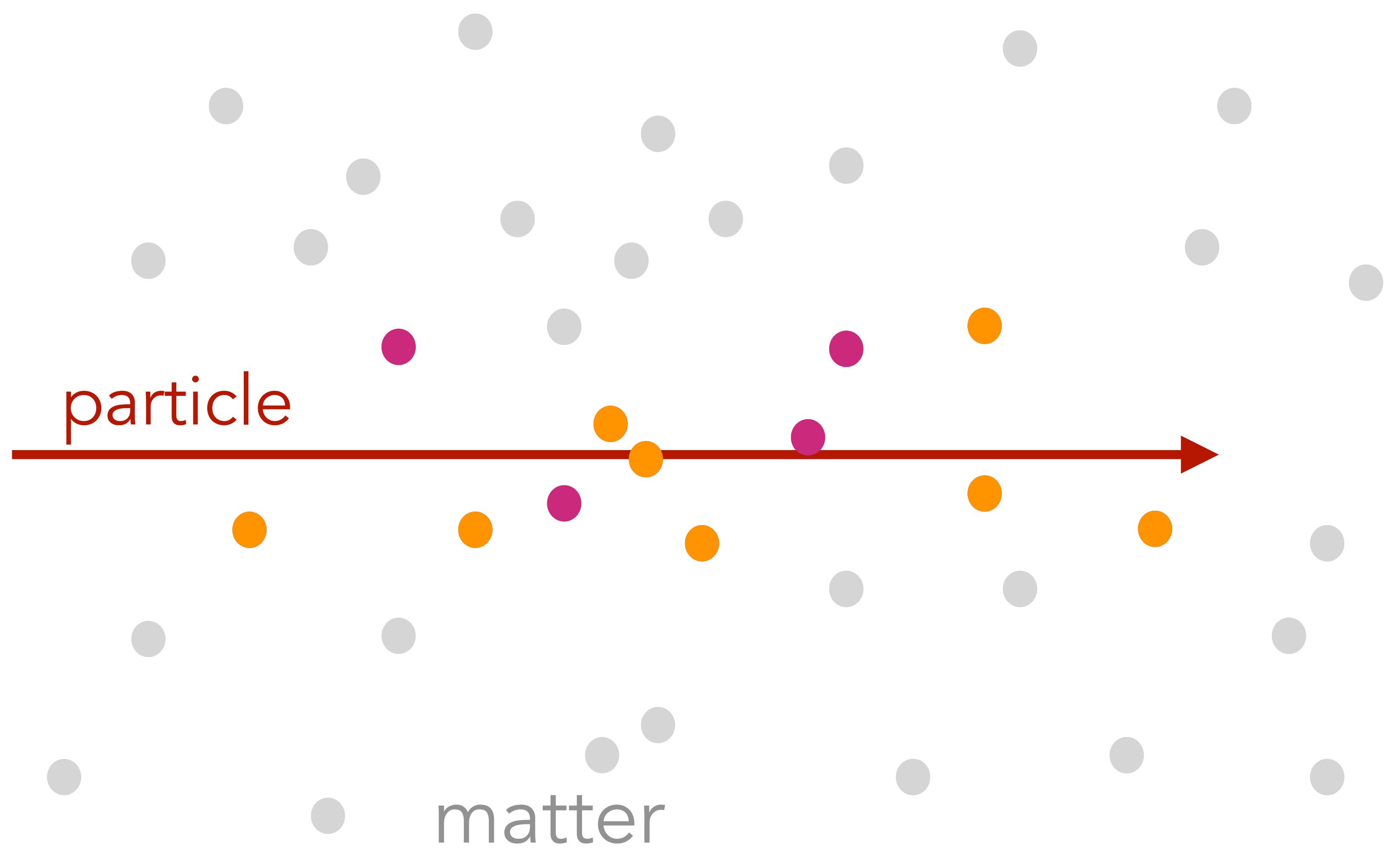

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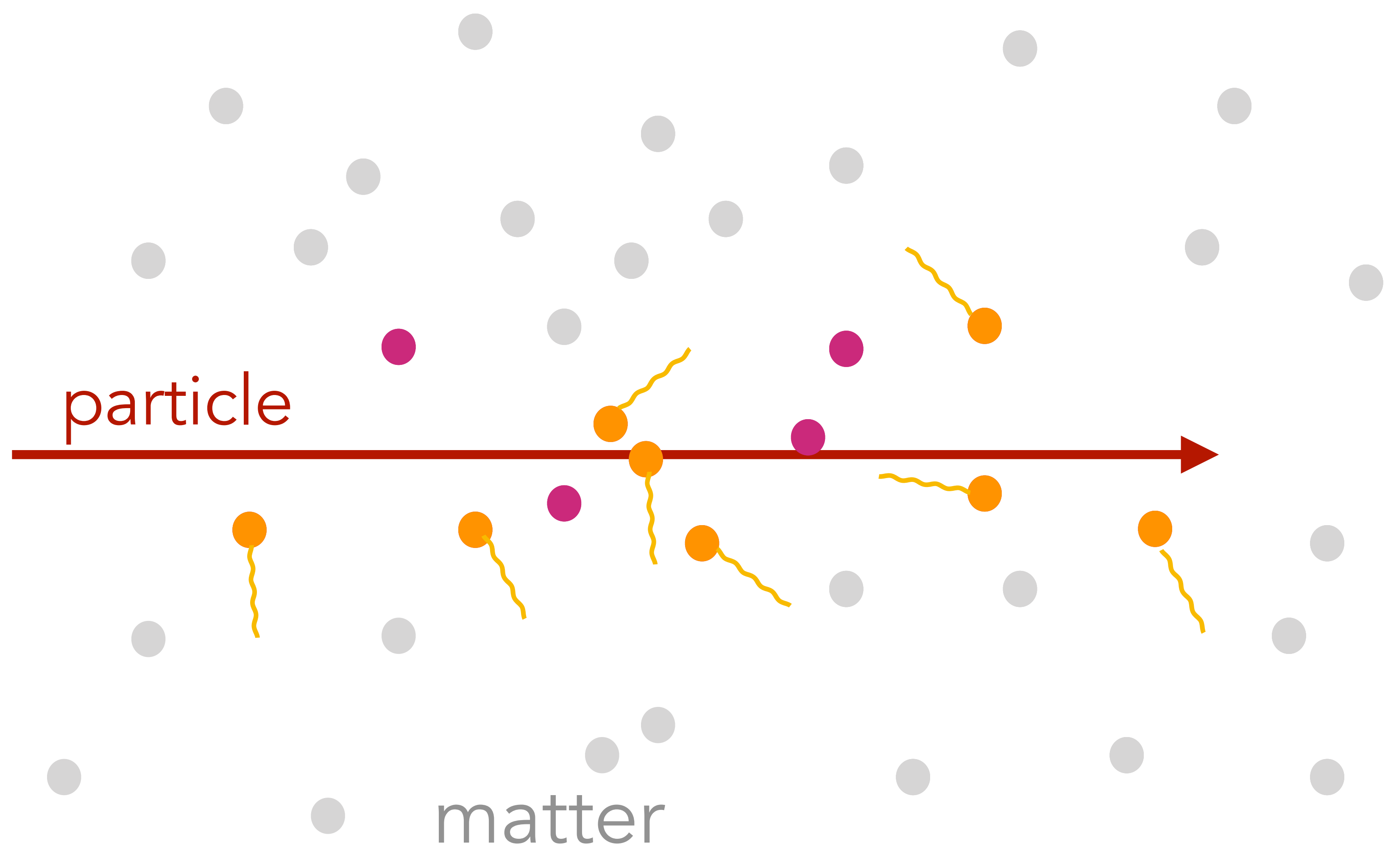

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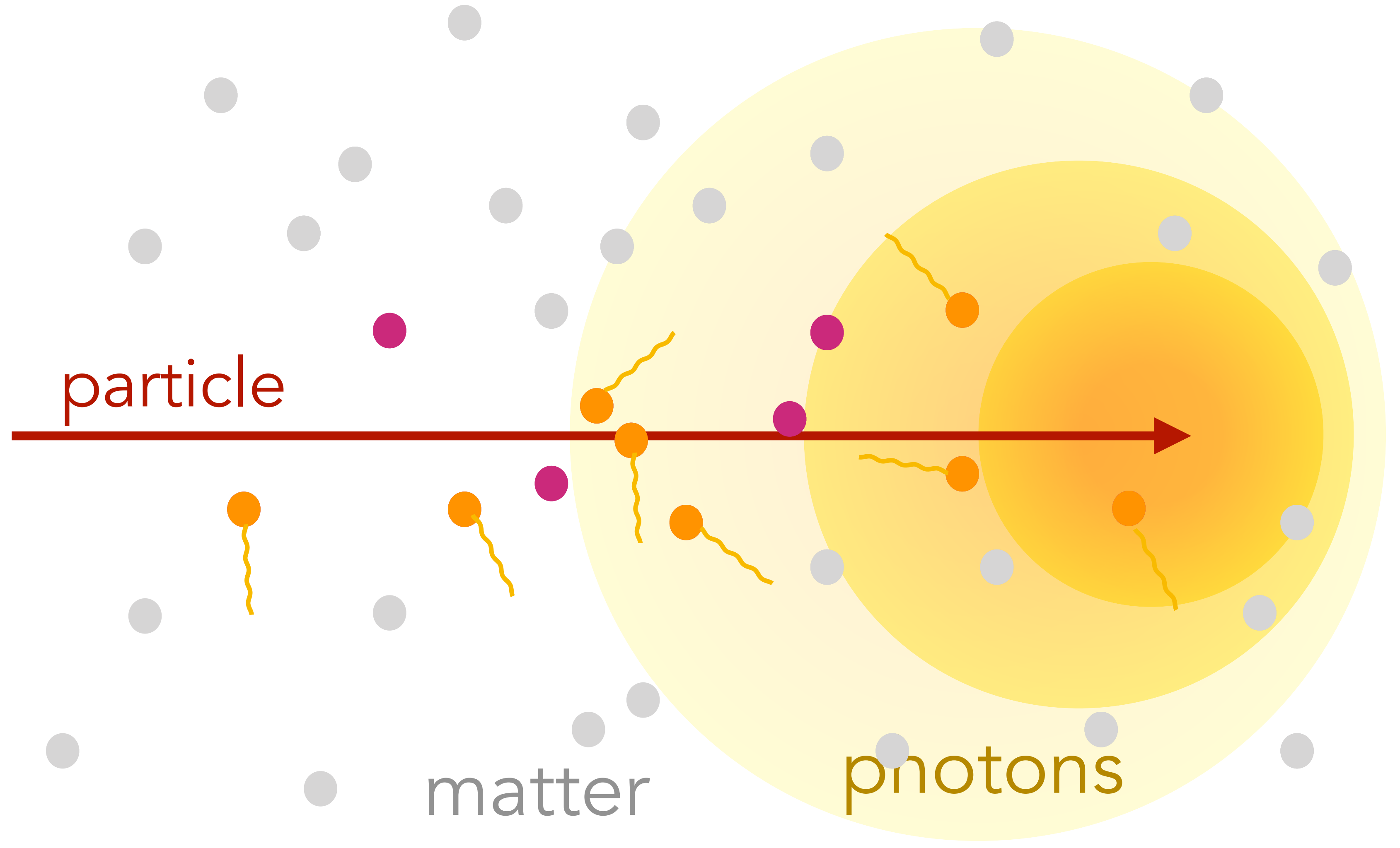
Luminescence light emission pattern

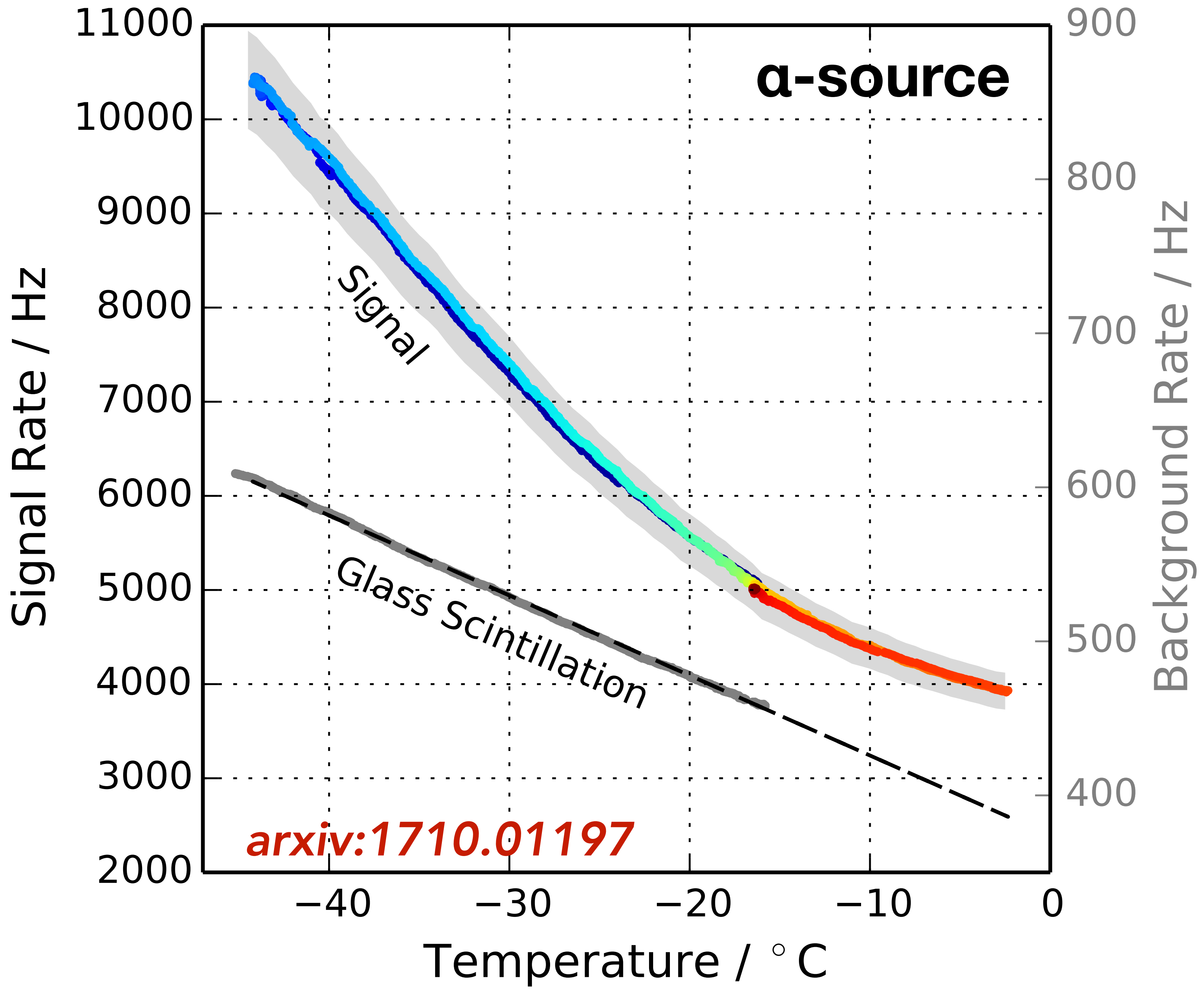


Potential dependencies

- temperature
- impurities / solubles
- radiation type

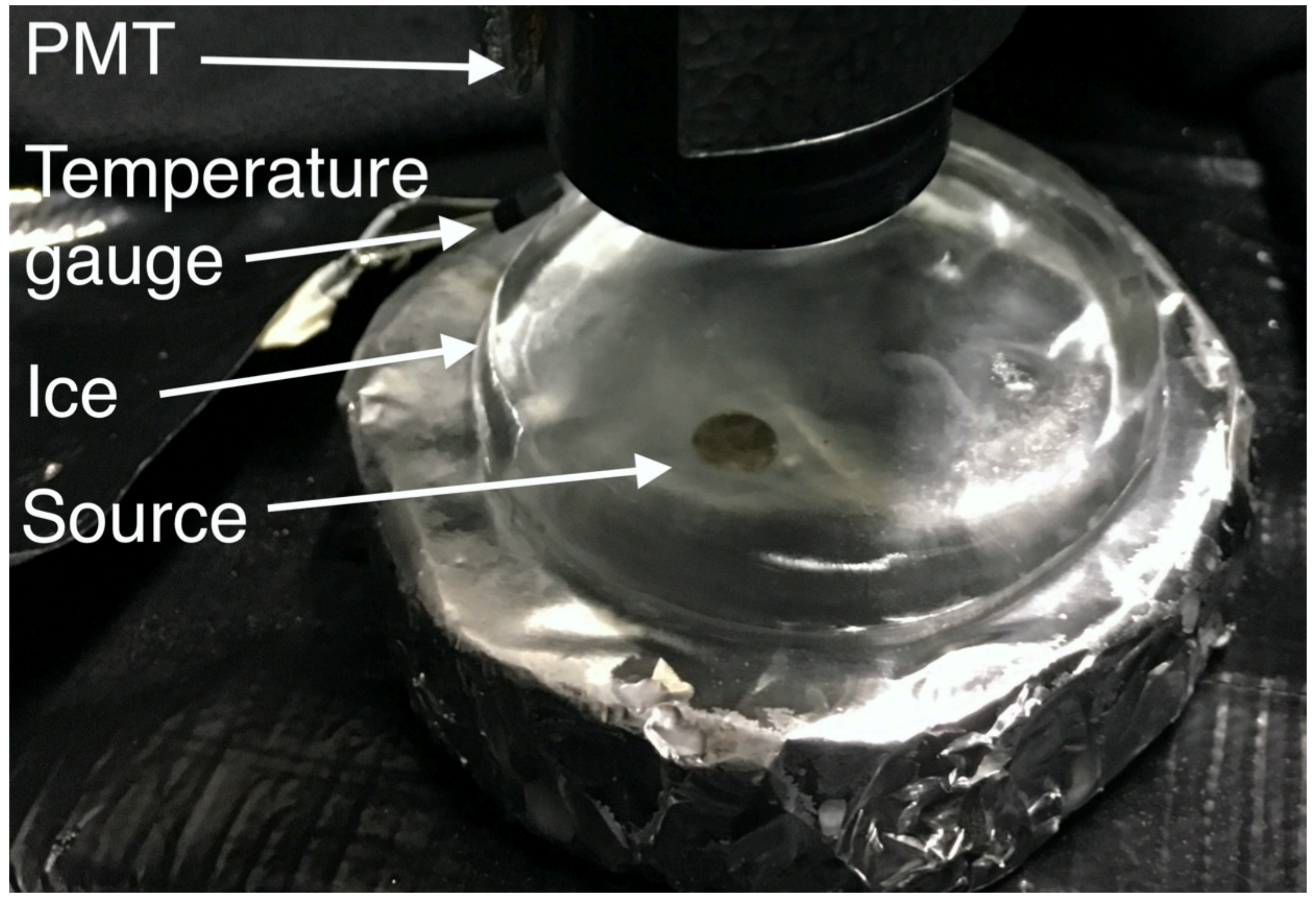
Measurements in laboratory

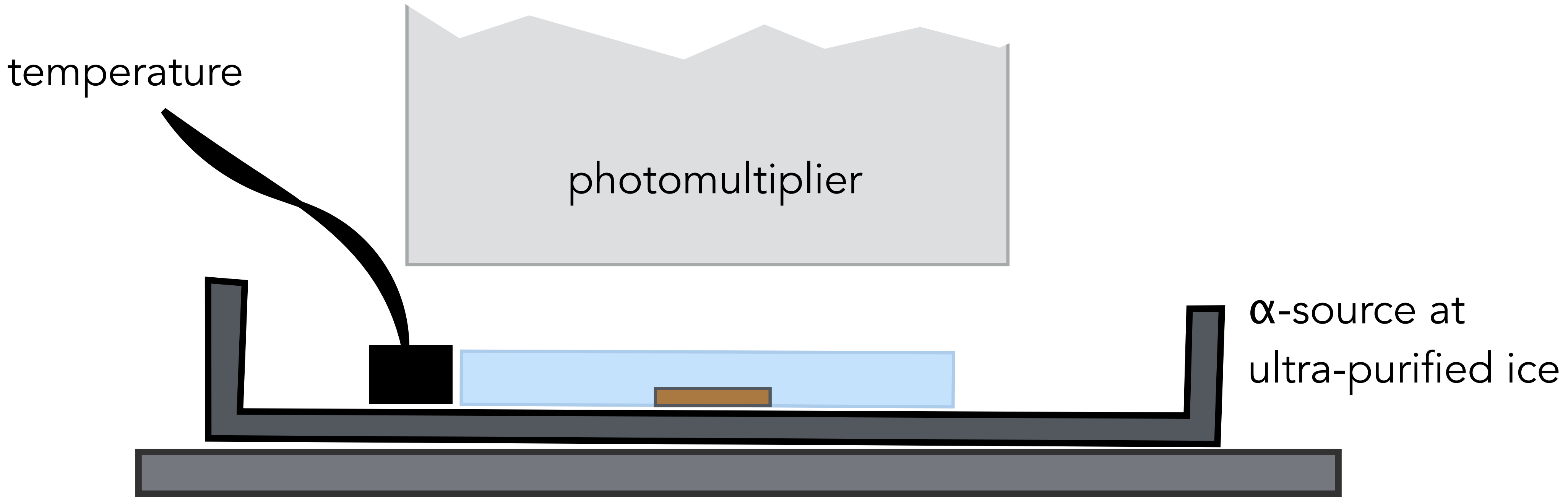
- ultra-pure water* and bubble free ice
- induced luminescence light with radioactive source
- measured single photons with photomultiplier
- probed background
- measured & calculated optics



Quenching:
Use different radioactive sources

Decay kinetics:
Time between subsequent pulses is recorded





* HLPC grade: TOC < 5 ppb, > 18MΩ

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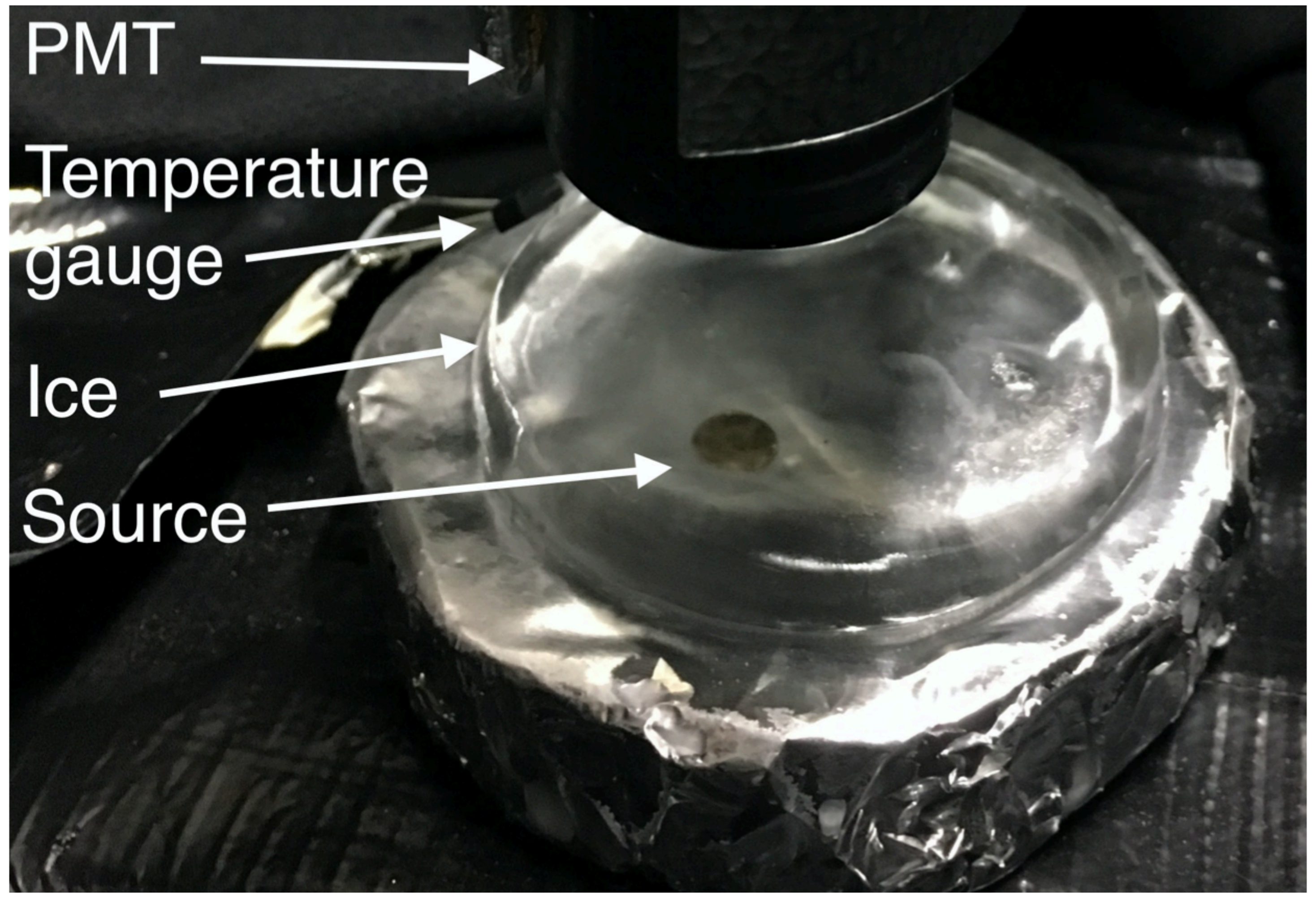

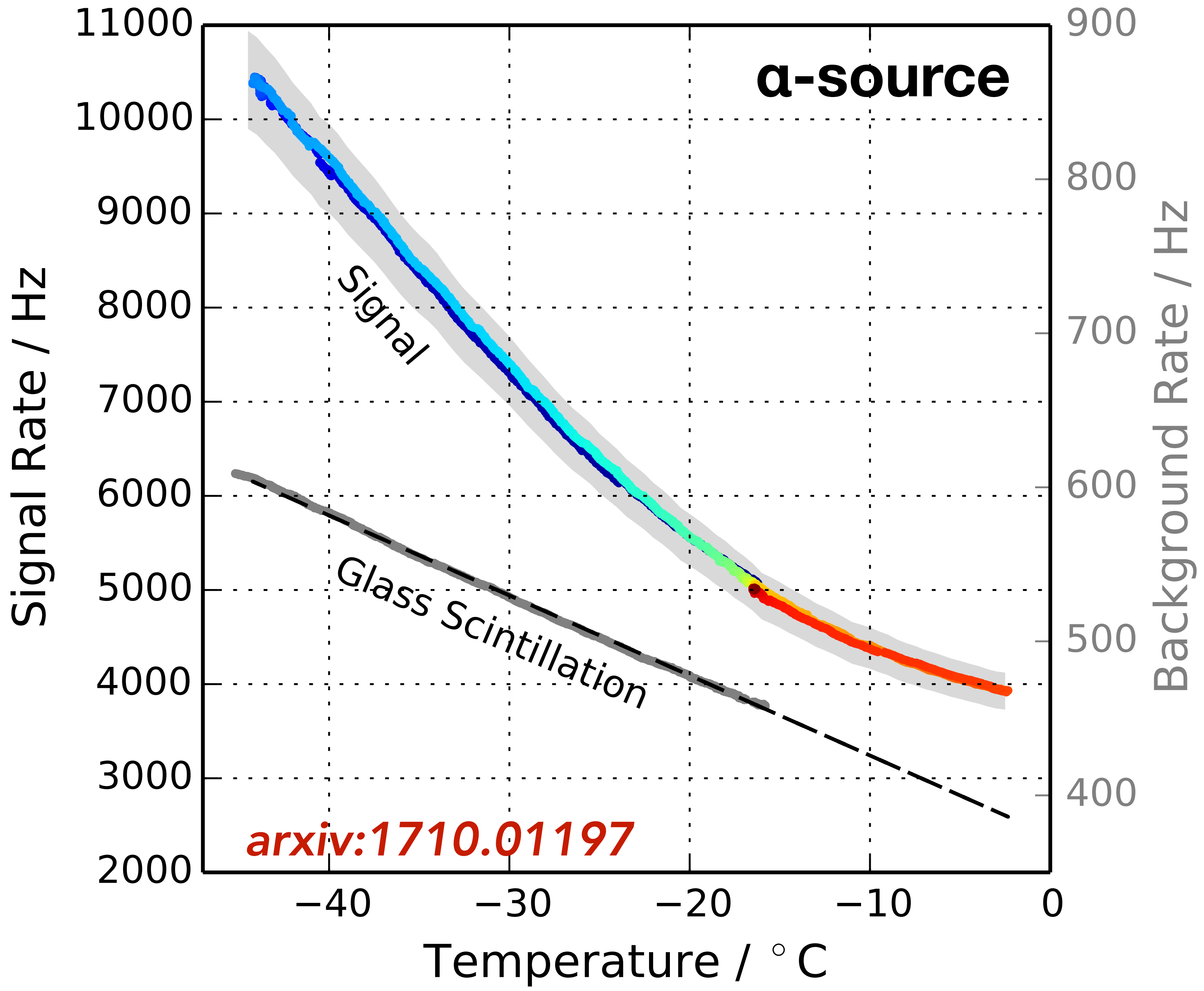

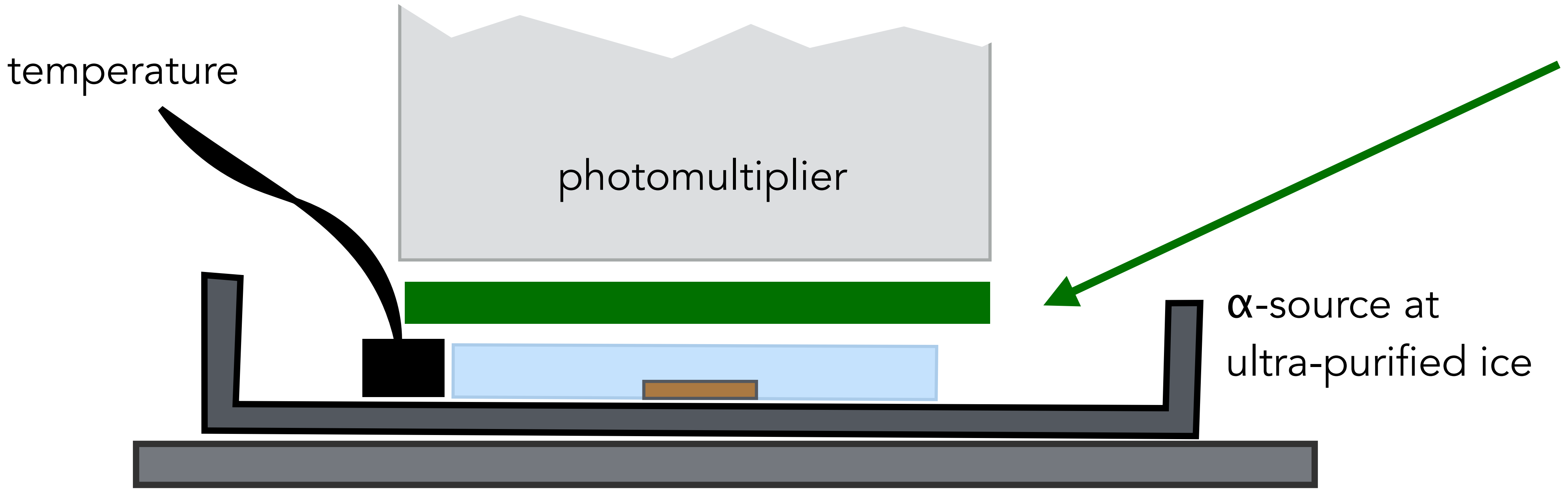

Quenching:
Use different radioactive sources

Decay kinetics:
Time between subsequent pulses is recorded

Spectrum:
A disk with filters is rotating in the light pathway

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South Pole
IceCube
1 km
SPICEcore
⦰191.8 mm
118 m -
130 m -
135 m -
210 m -
⦰177.8 mm
⦰129.6 mm
⦰126.0 mm
1500 m
1751 m -
1850 m
2500 m
IceCube Sensors detecting a passing muon
Tilted ice layers
Ice quality TOC ~ 7 ppb
Environ. Sci. Technol. 2011, 45, 2, 673–678
Casing
Deployment
Bottom Camera
114m, Estisol Surface
Side Camera
~700m

Measurements in ice

Irradiate ice with β-source and measure back-scattered light

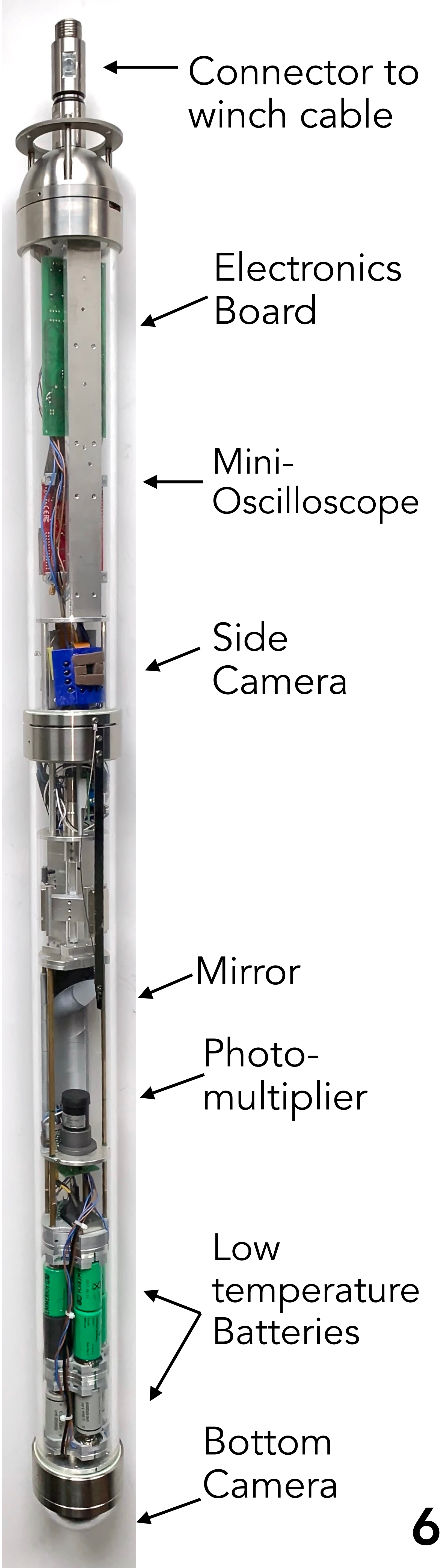
Logger

- small diameter: 92 mm
- source on spring, moved by magnets
- mirror for reflection onto PMT
- environmental sensors and cameras
- live control and read-out of on-board oscilloscope
- movable filter holder

Second experiment

Upgrade Camera Logger

(see POS 1047, same session)



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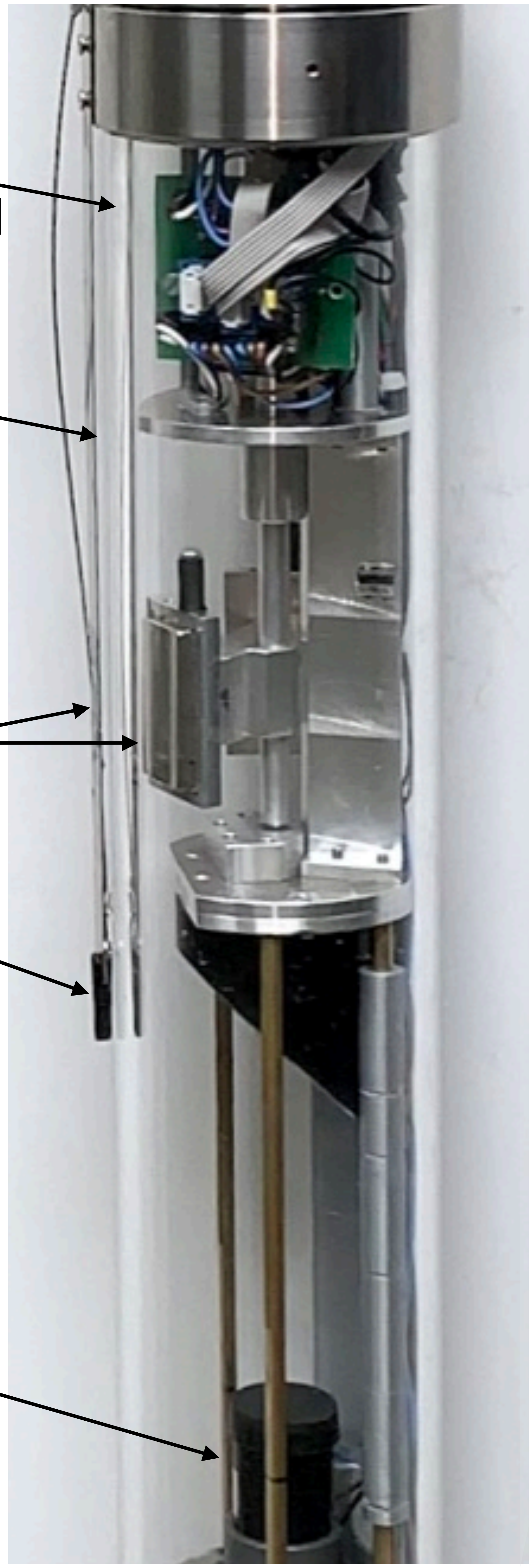

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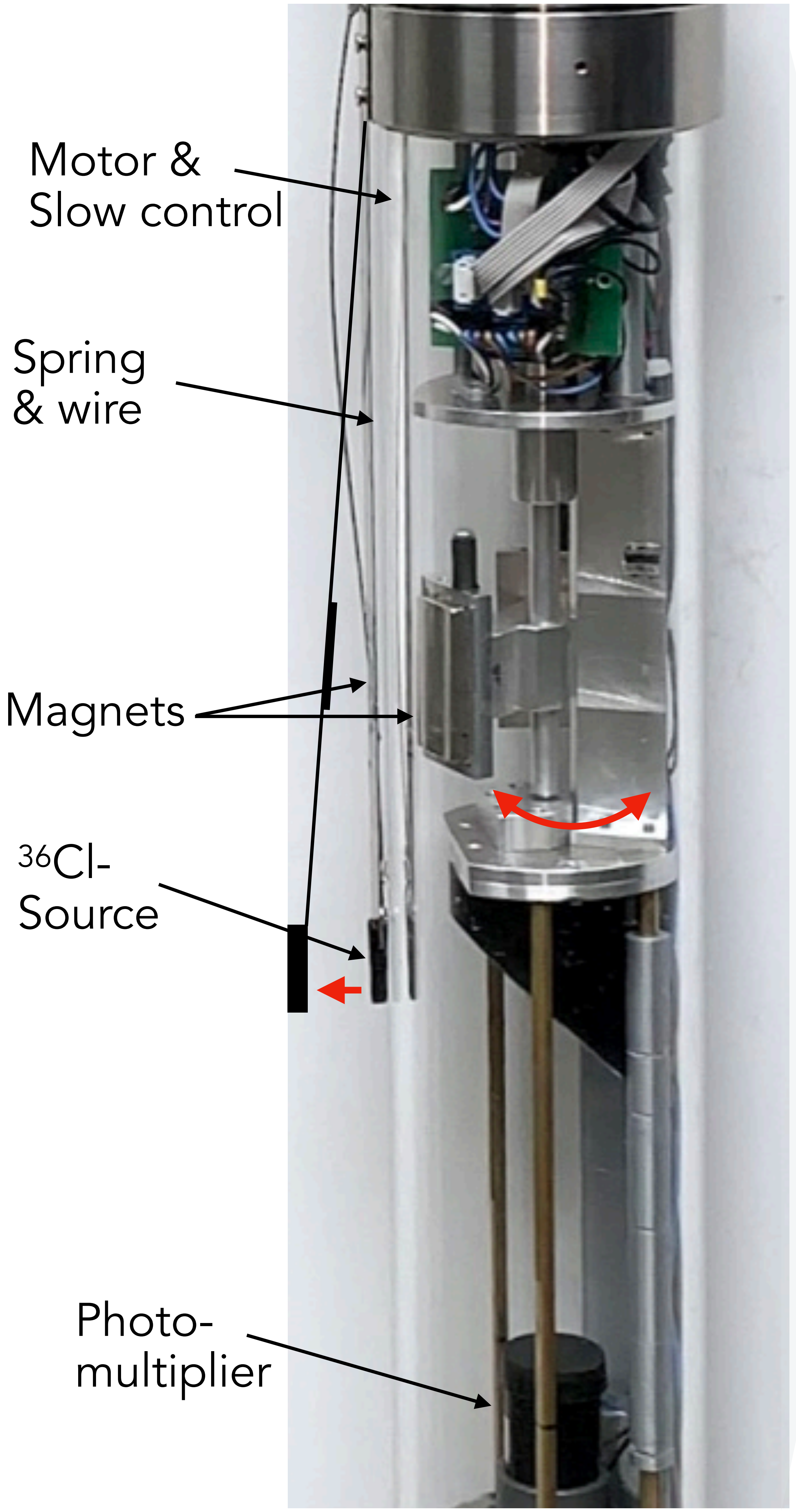

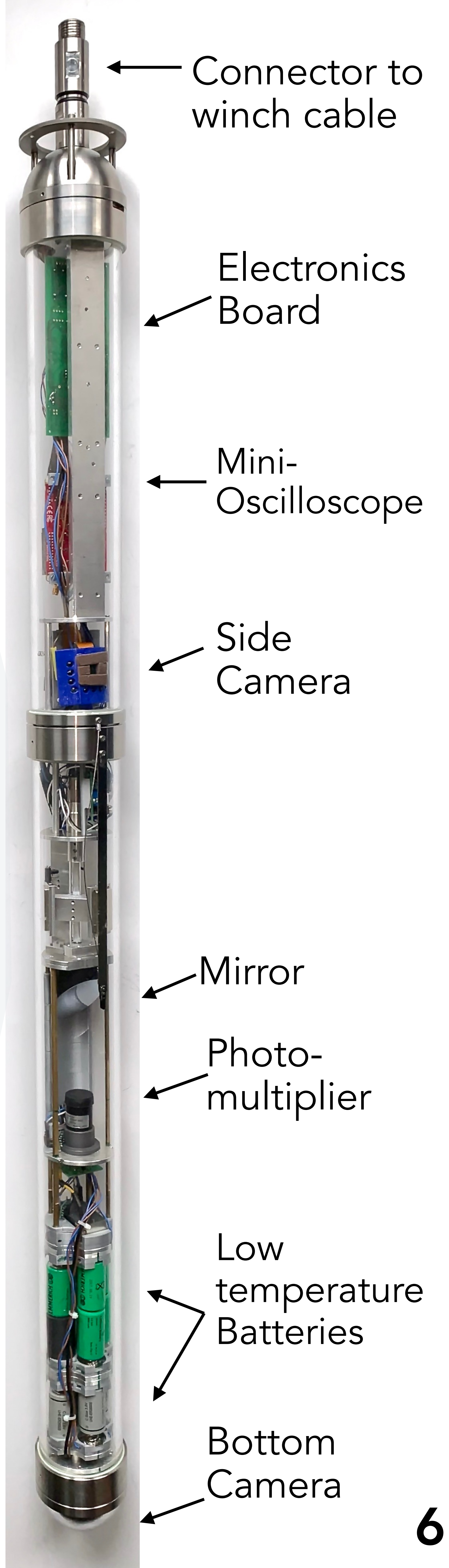

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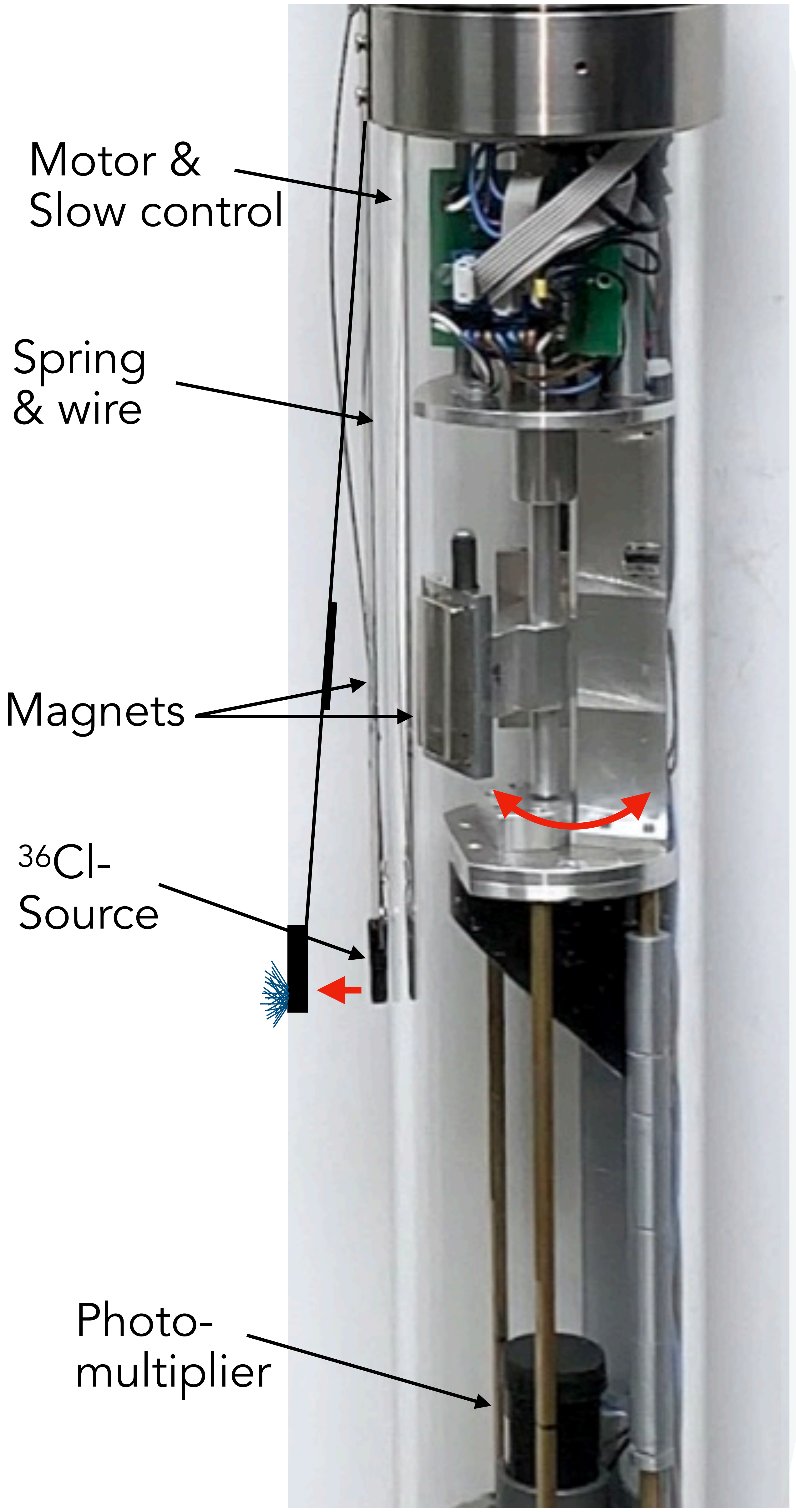

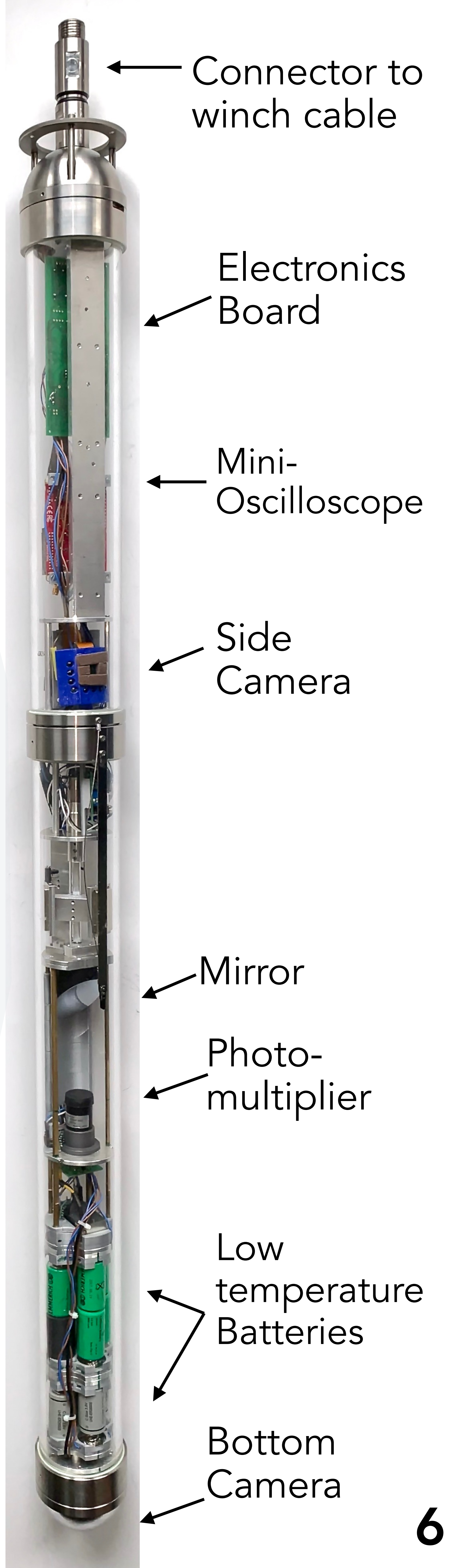

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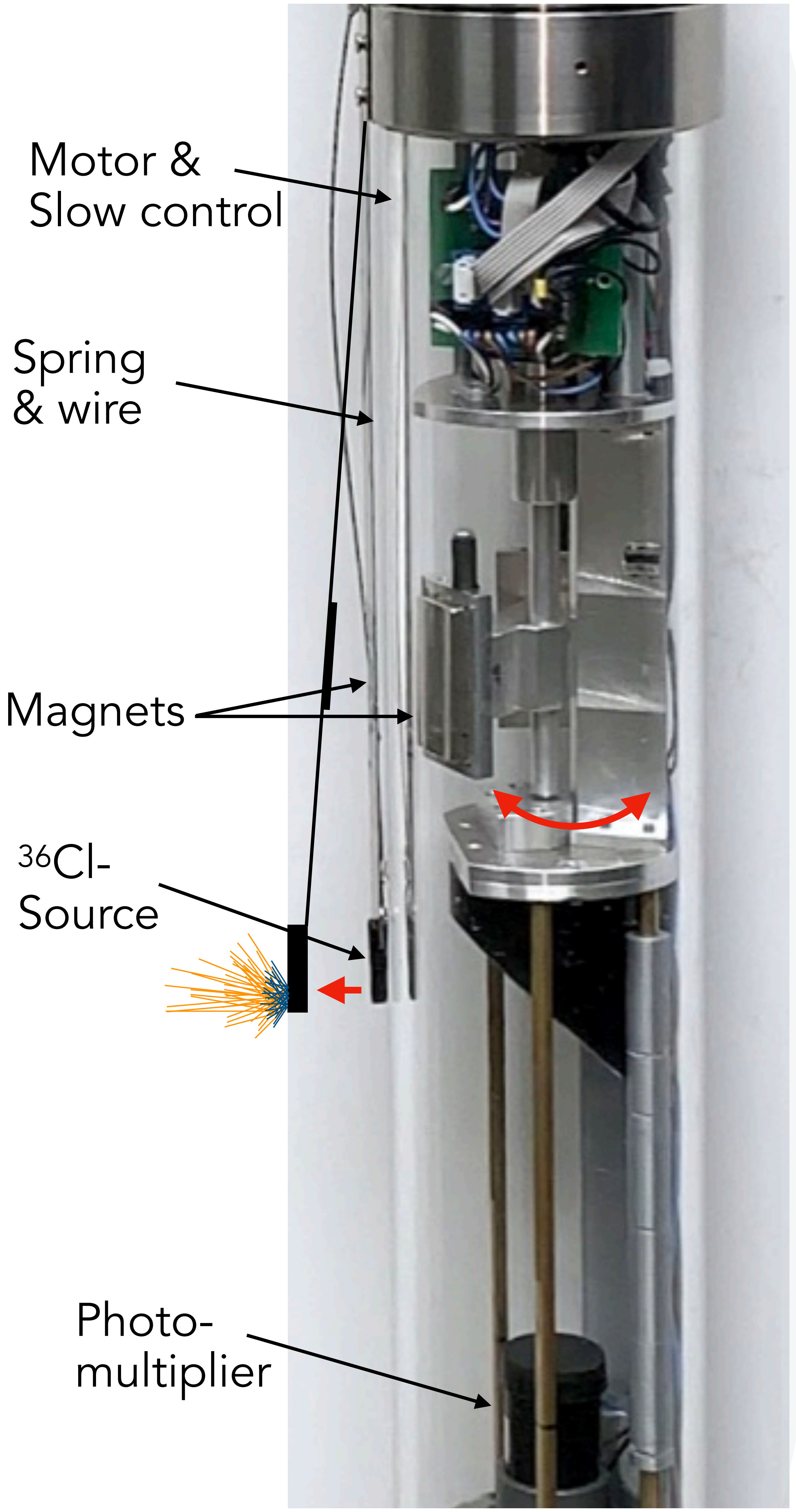

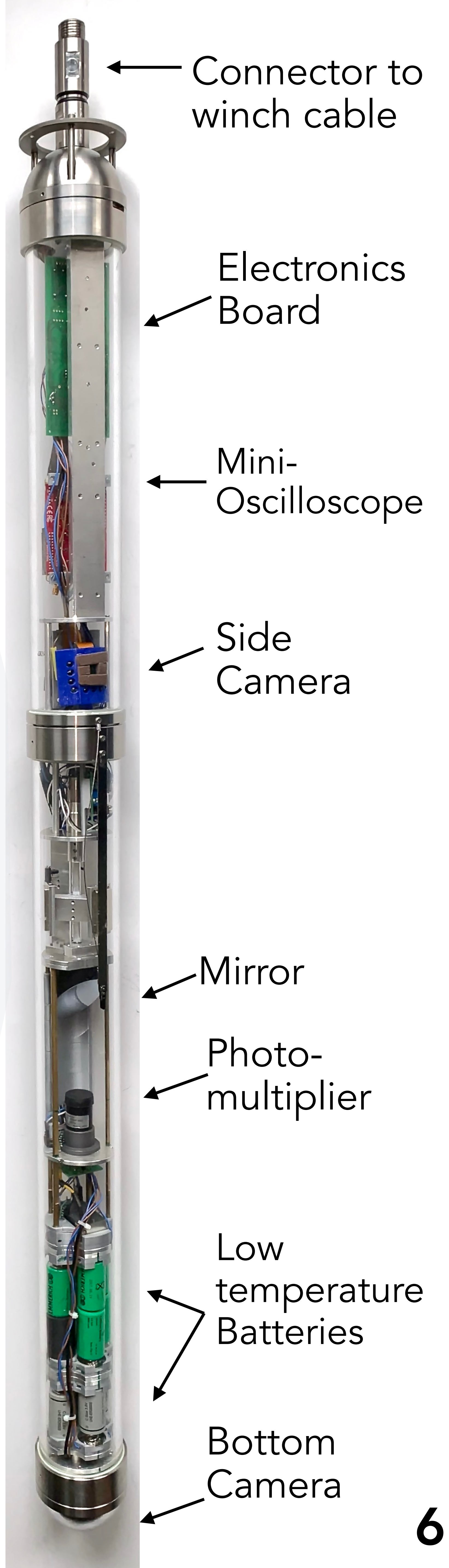

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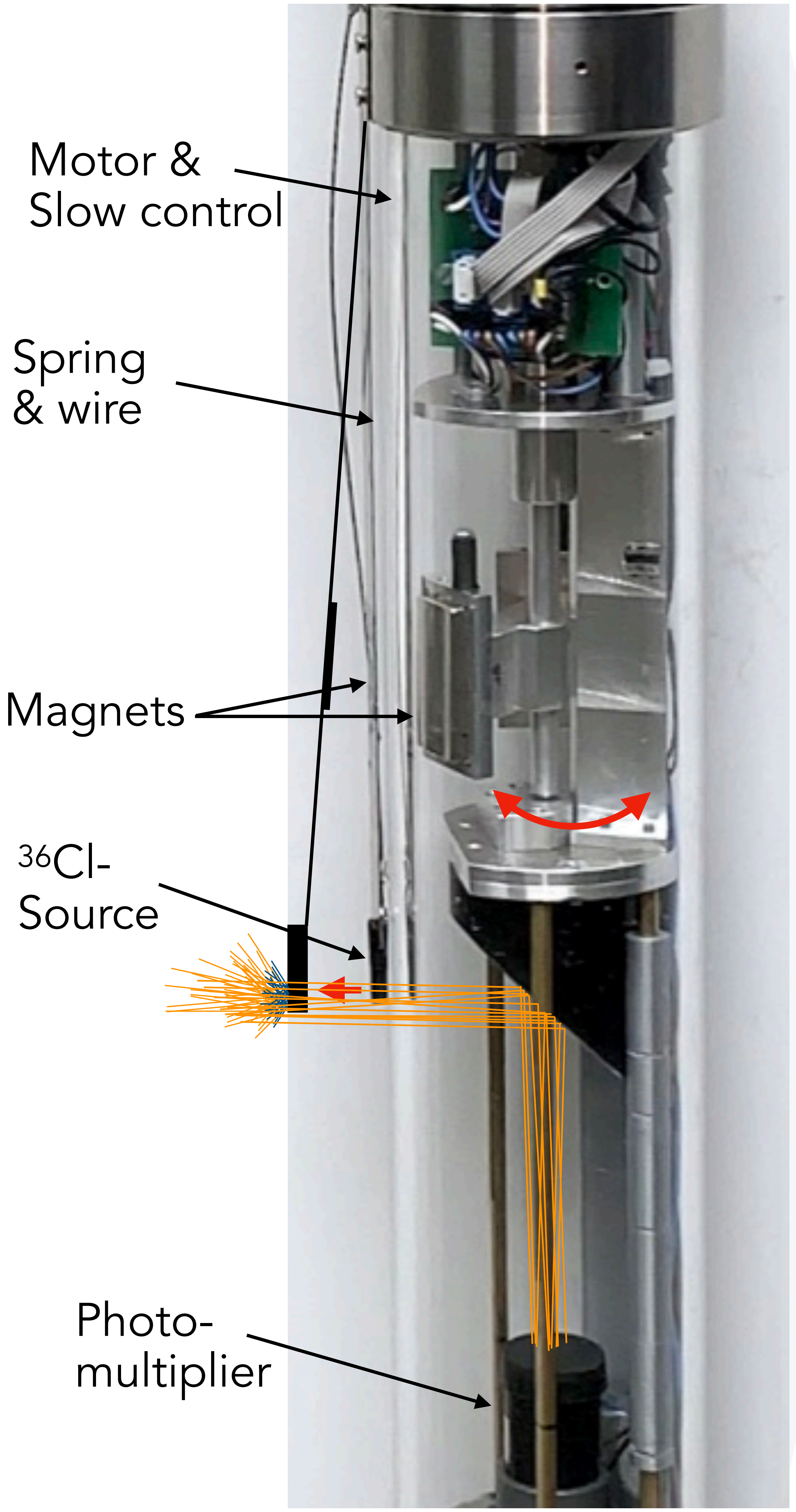

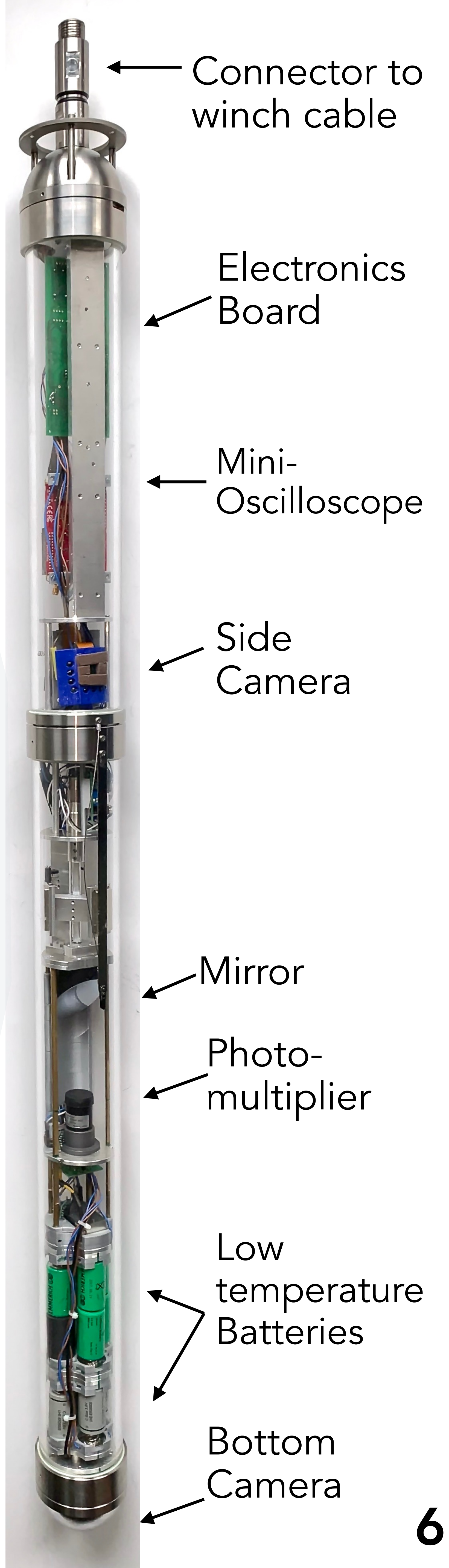

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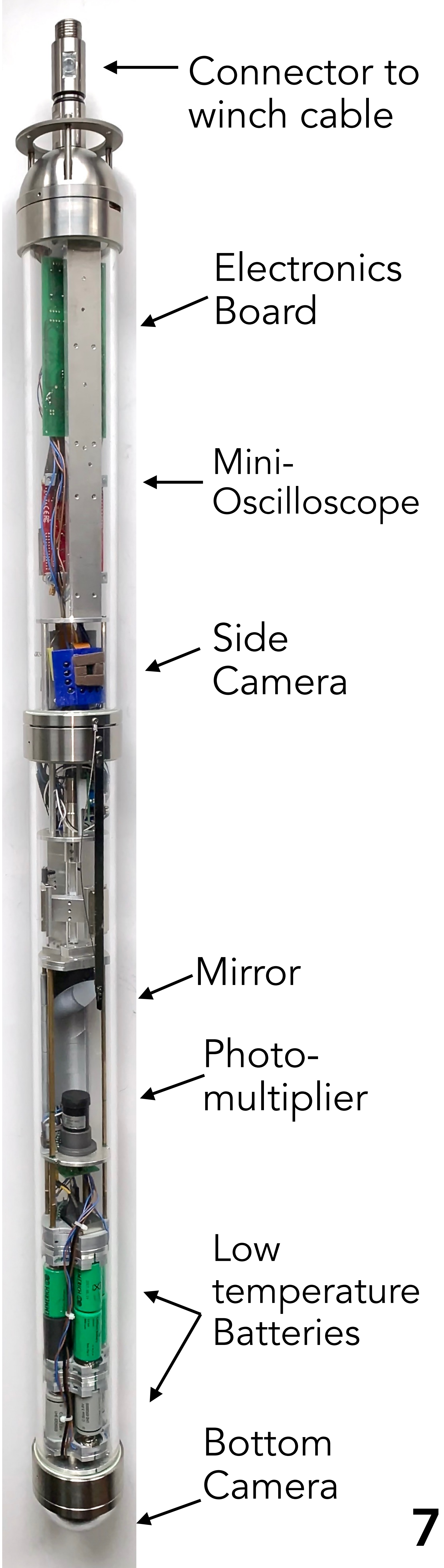

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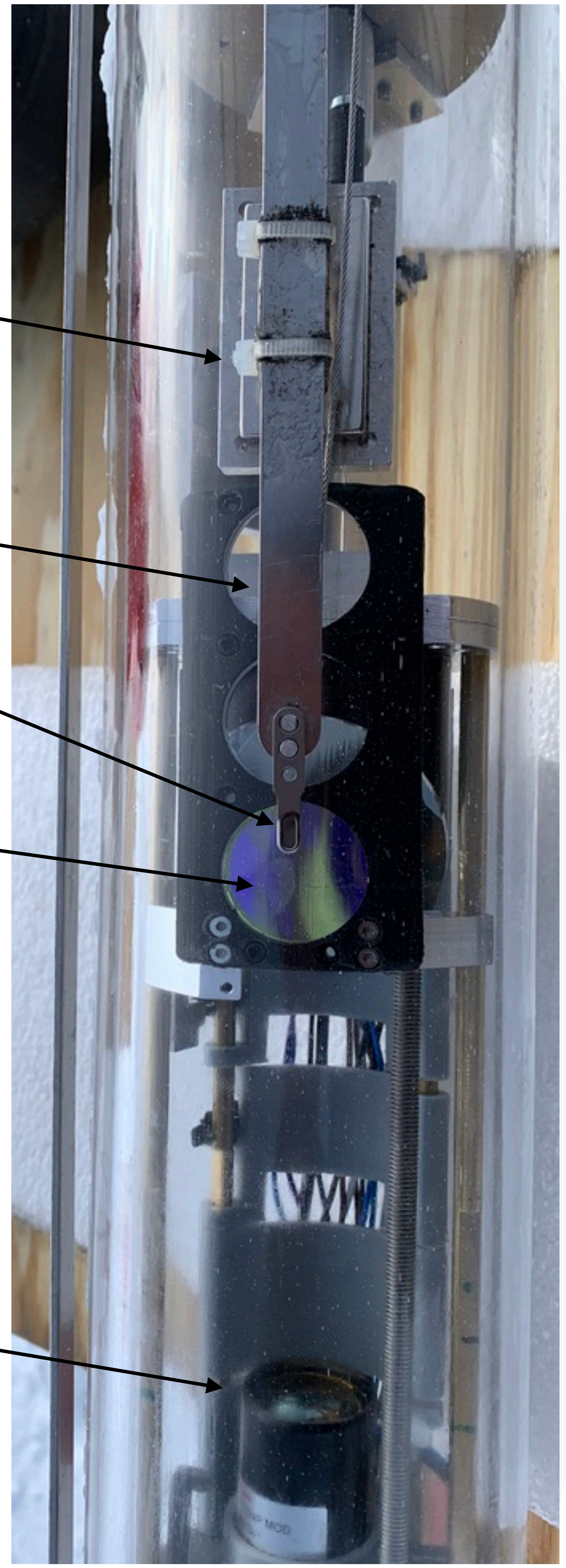
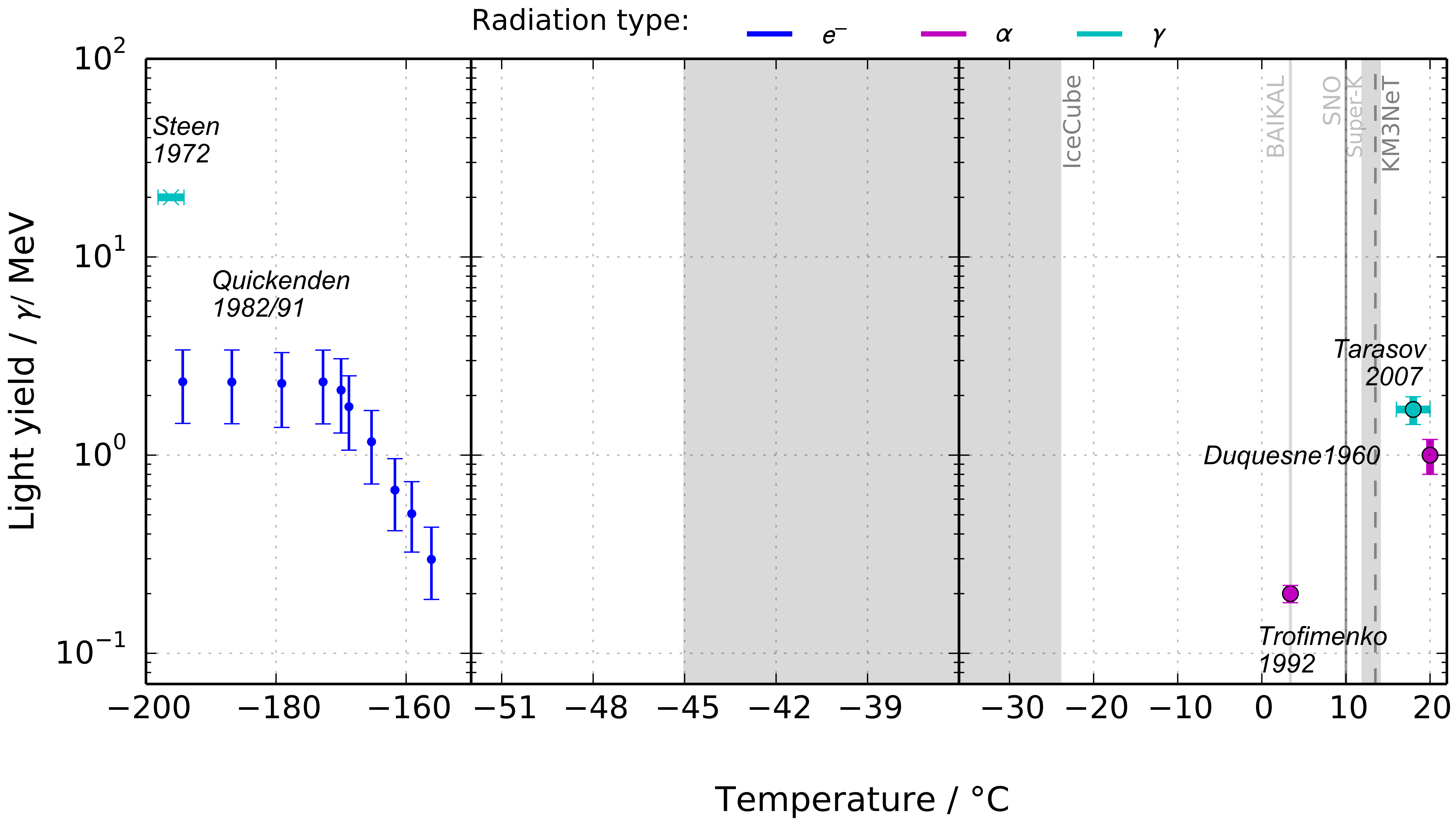


Light yield (Lab + in-situ)

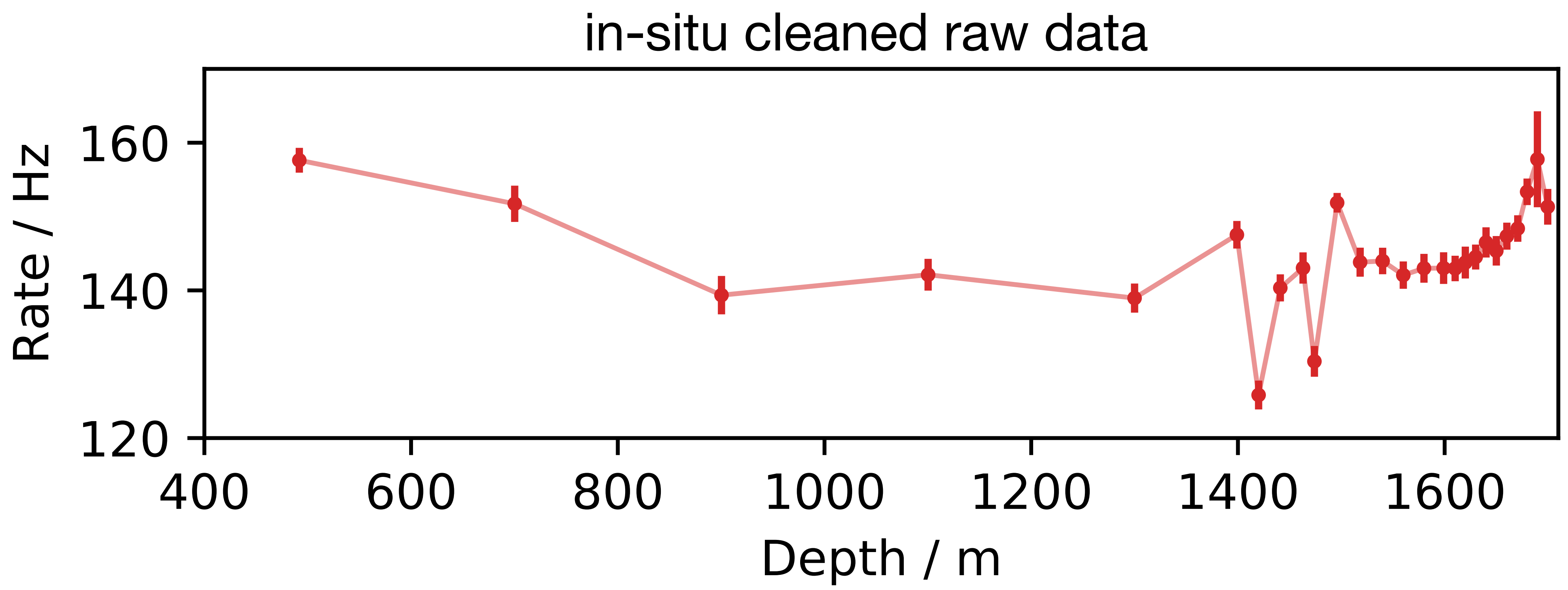
Method

- optical properties measured in lab
- in-situ scattering modelled with GEANT
- rate cleaned and corrected with temperature and **background**
  - PMT noise
  - Estisol luminescence (in-situ only)
  - Cherenkov light
- in-situ: 30 different depths
  lab: 5 different ice samples



Results

- temperature dependence at higher values
- clear indication of quenching or solubles
- in-situ: correlation with $\delta^{18}O$ isotope ratio (part of O_2 molecule)



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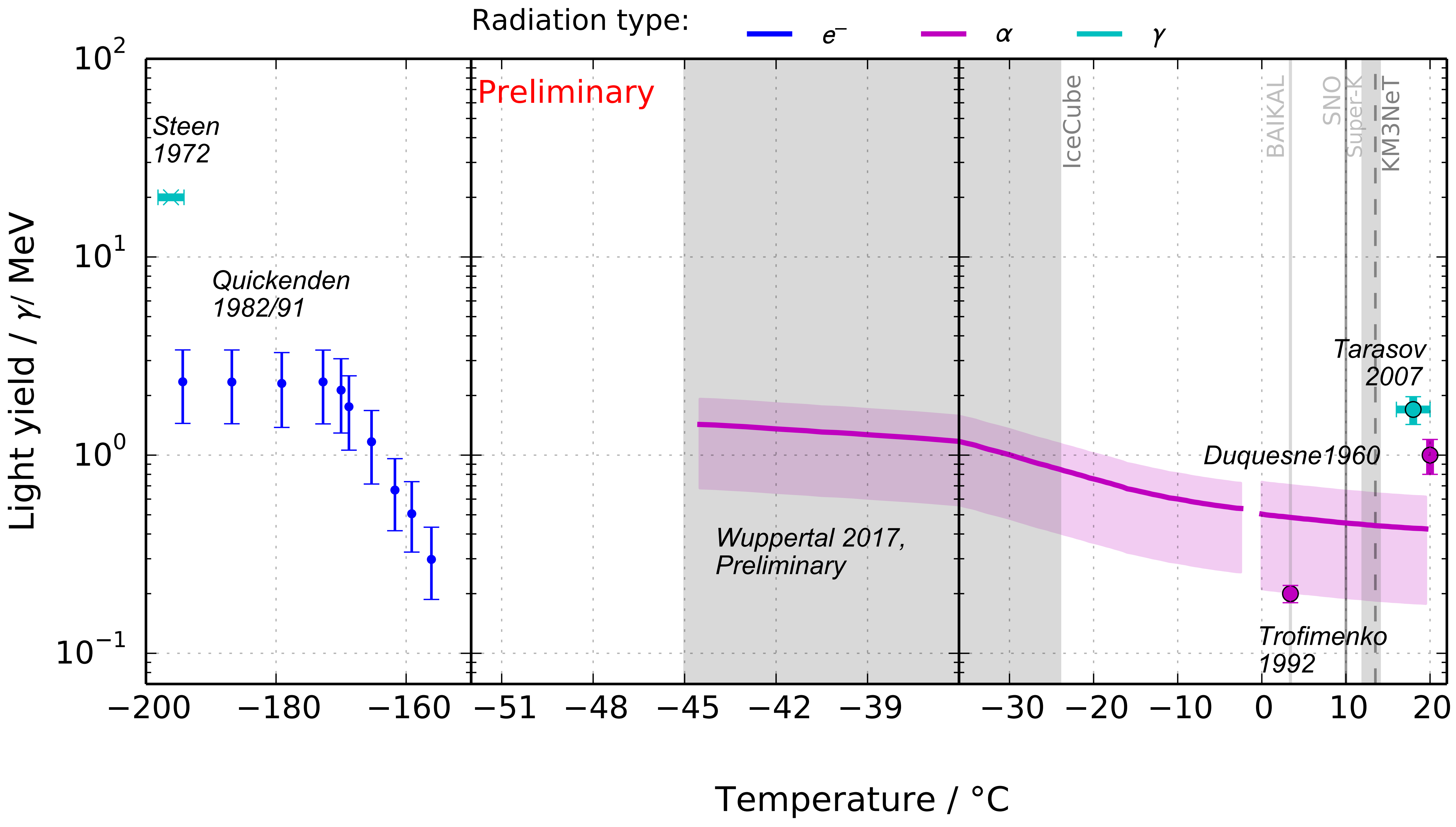

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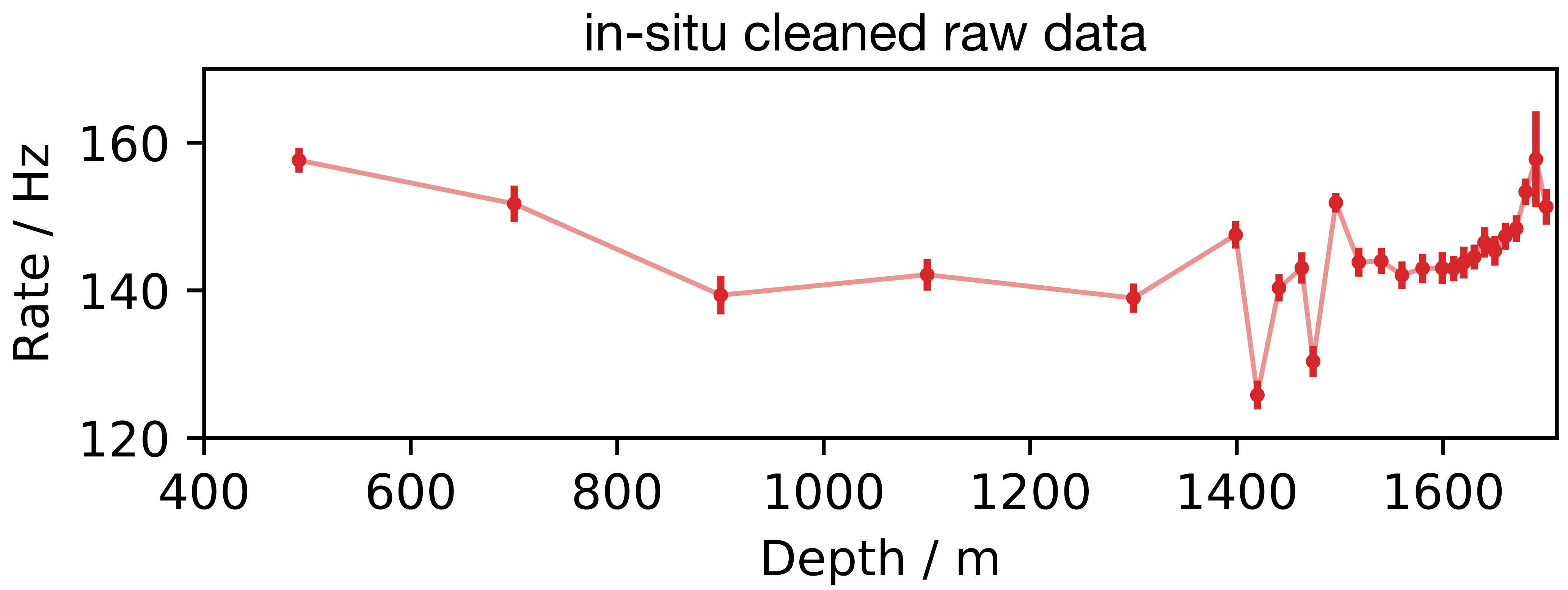

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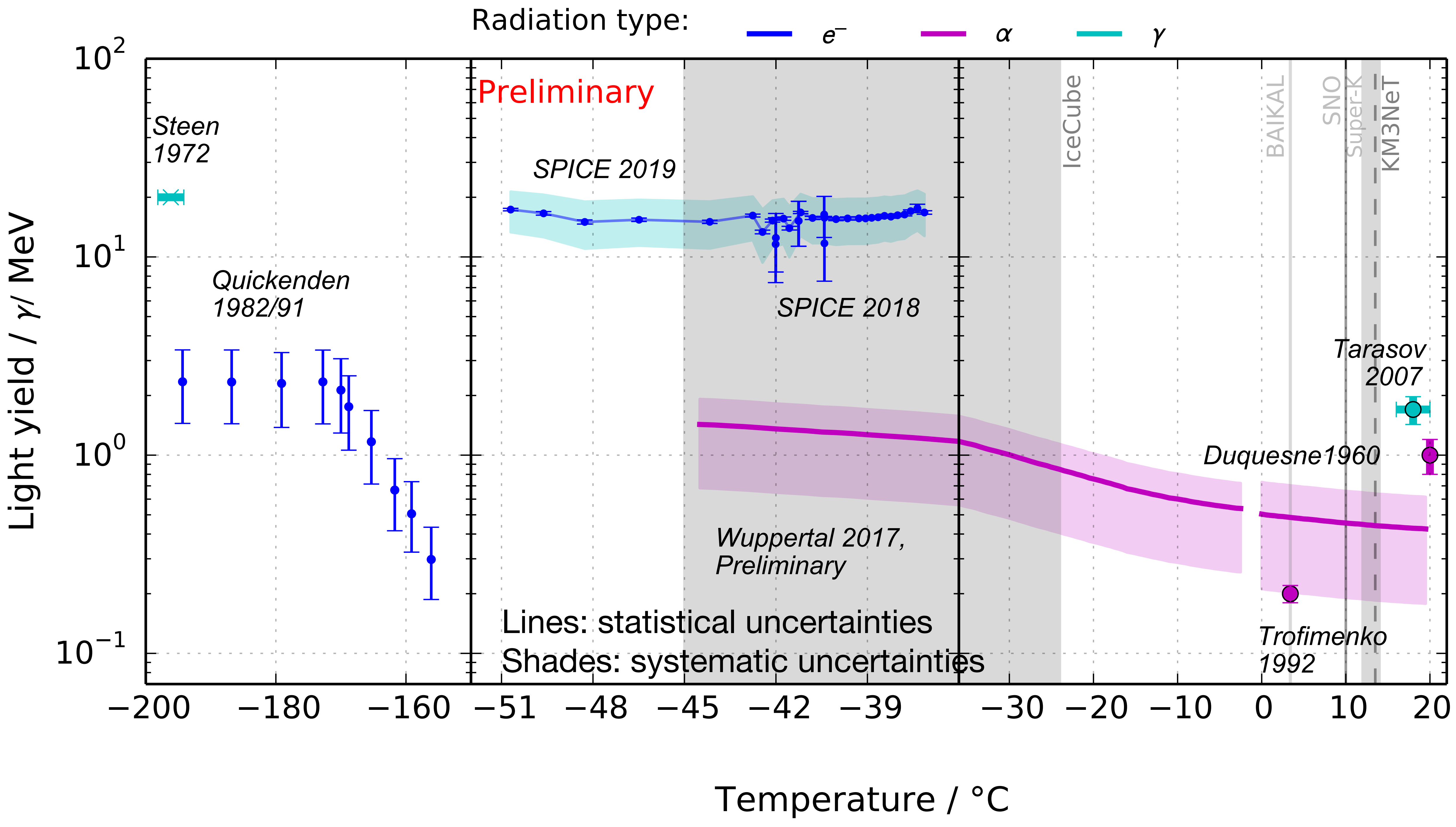

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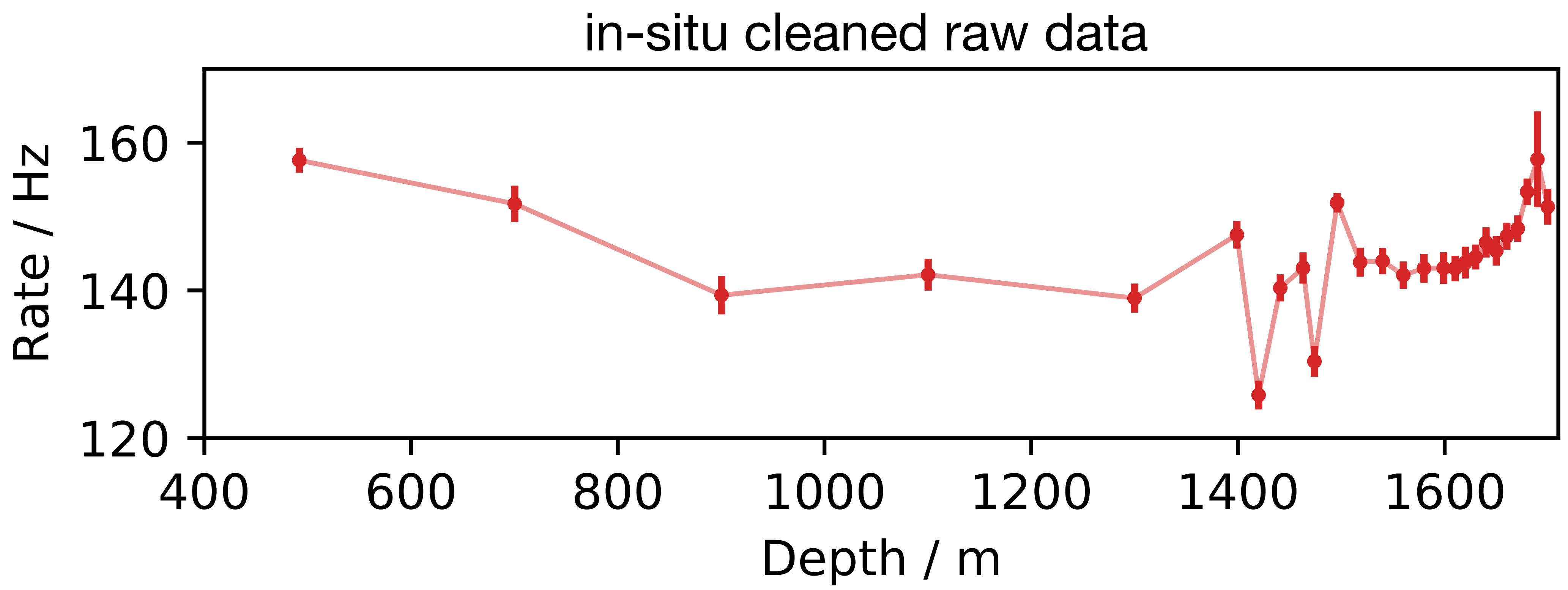

Spectrum (Lab + in-situ)

Method

- long pass filters give integrated spectrum
- subtract Estisol and Cherenkov contribution (modelled)

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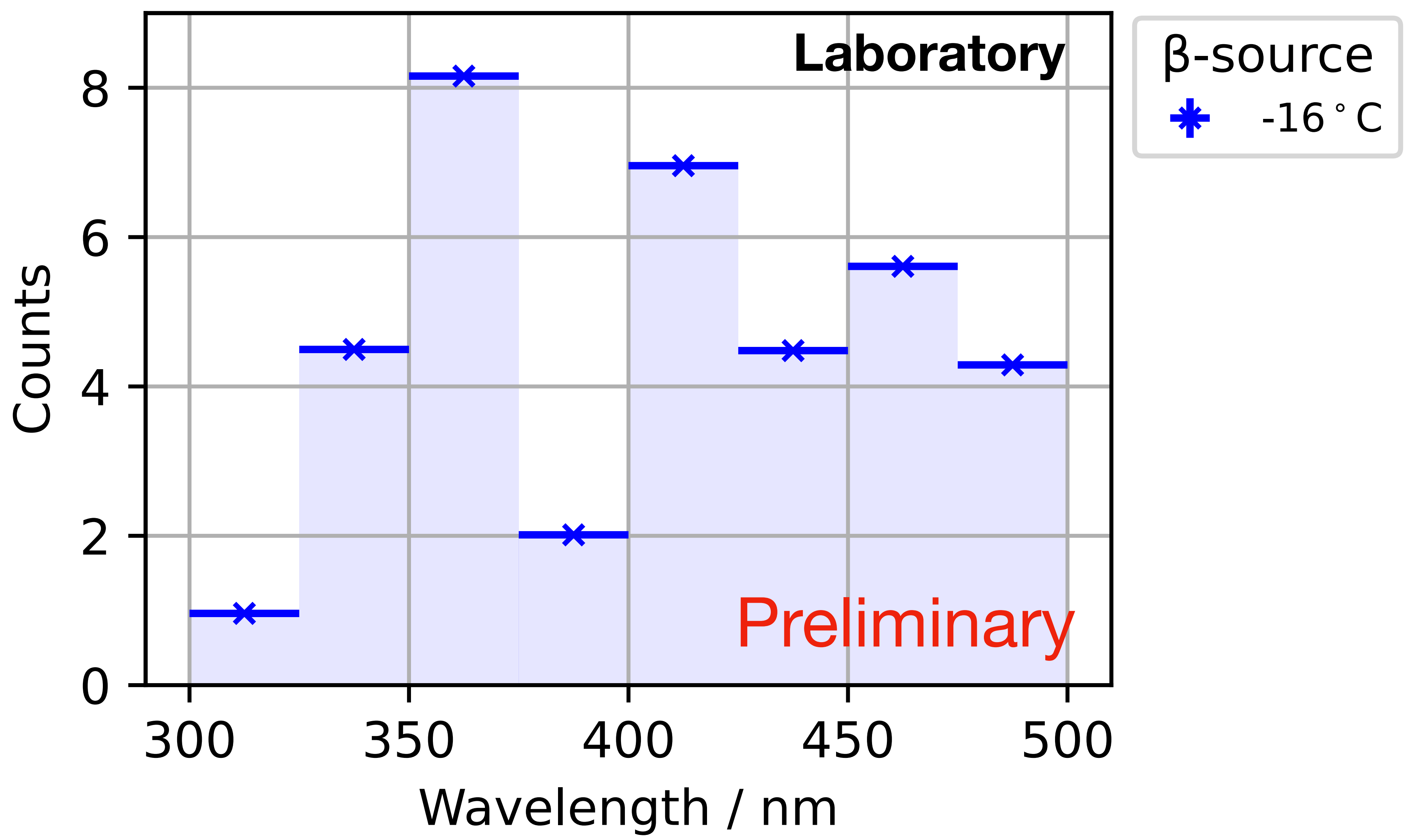
- clear difference to Cherenkov Spectrum
- lab: deviation due to
  - temperature ~15%
  - quenching significant
- in-situ: deviation due to
  - ice properties significant at 400-475nm
- both: deviation due to
  - ice properties significant at 365nm



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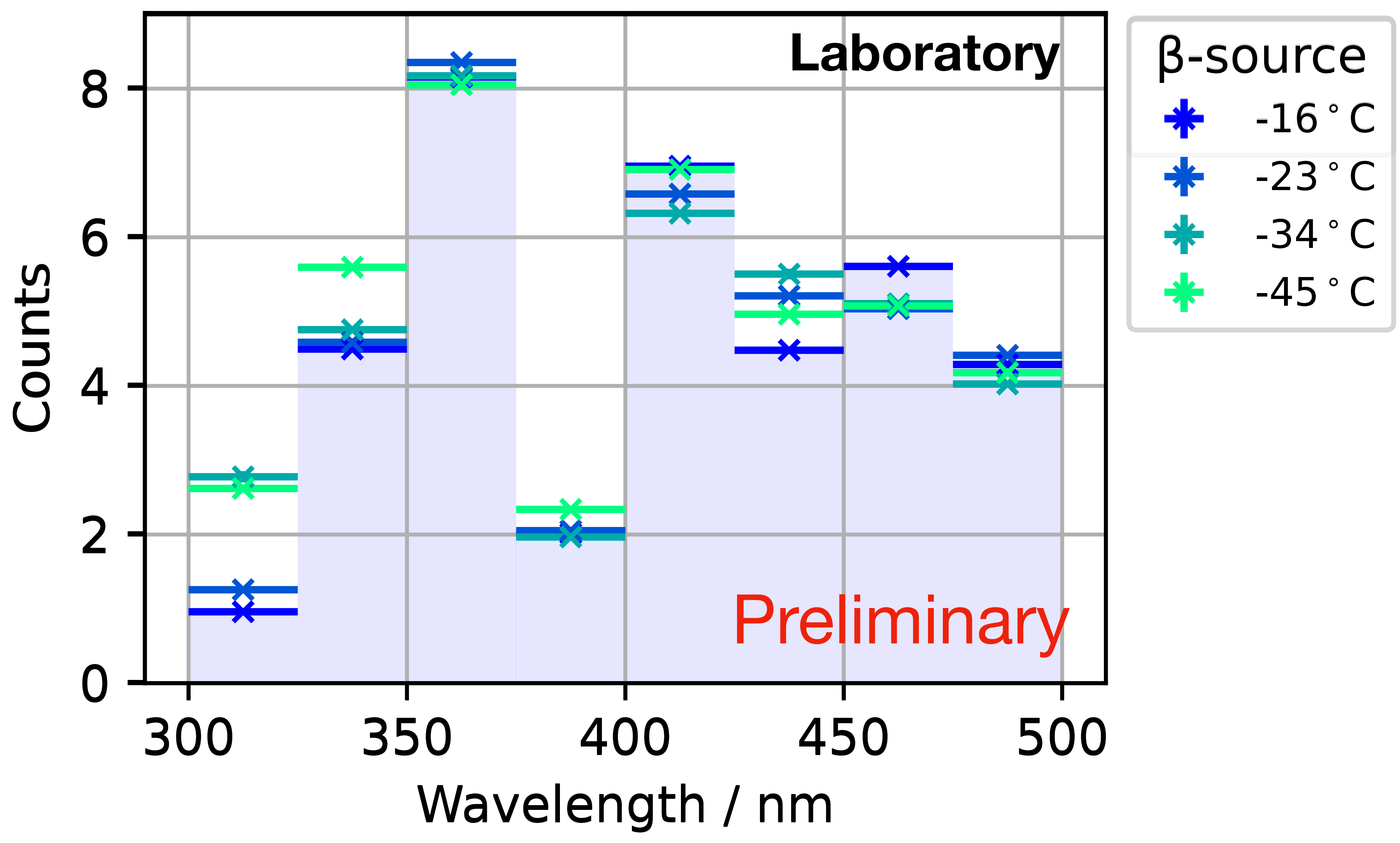

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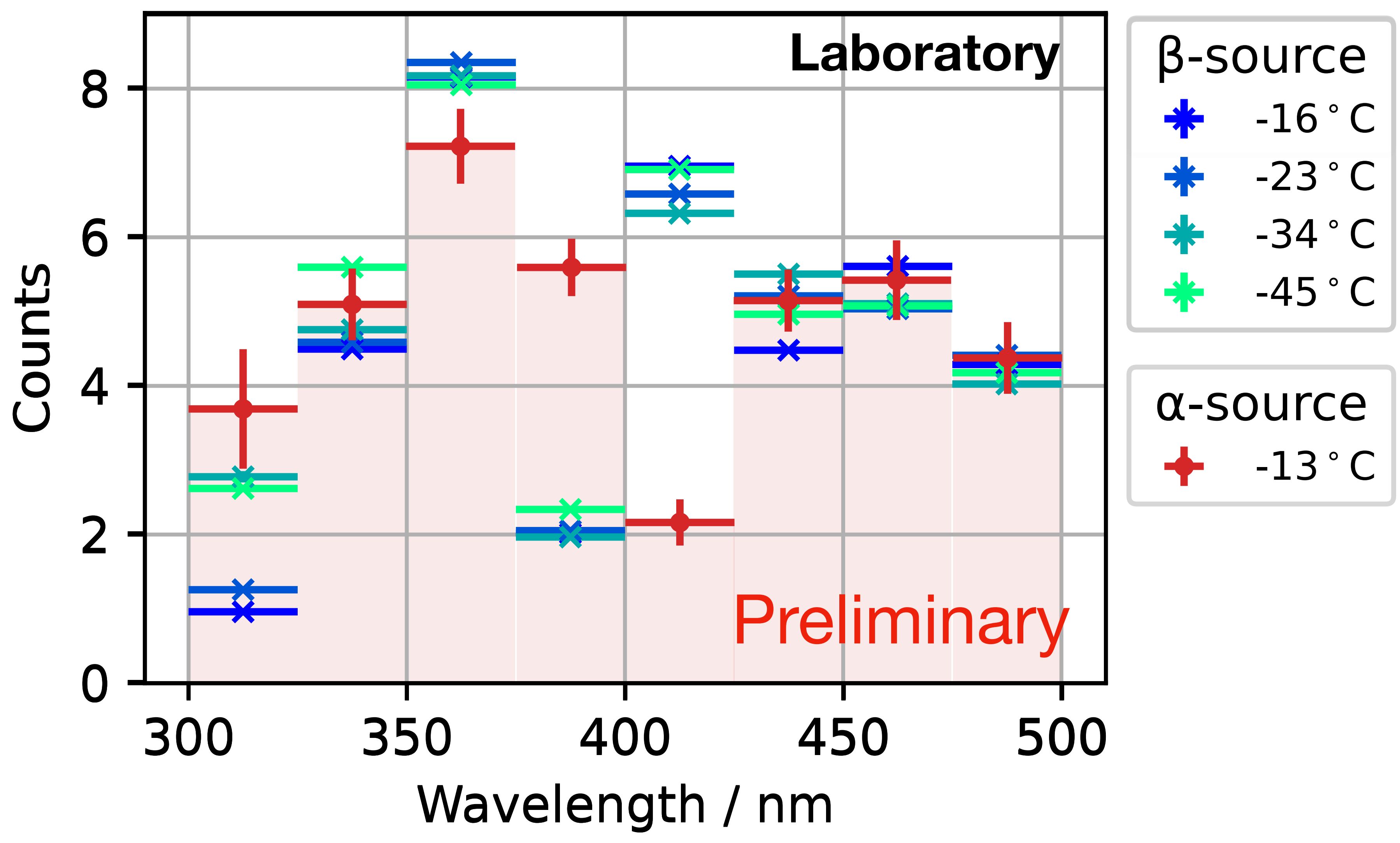

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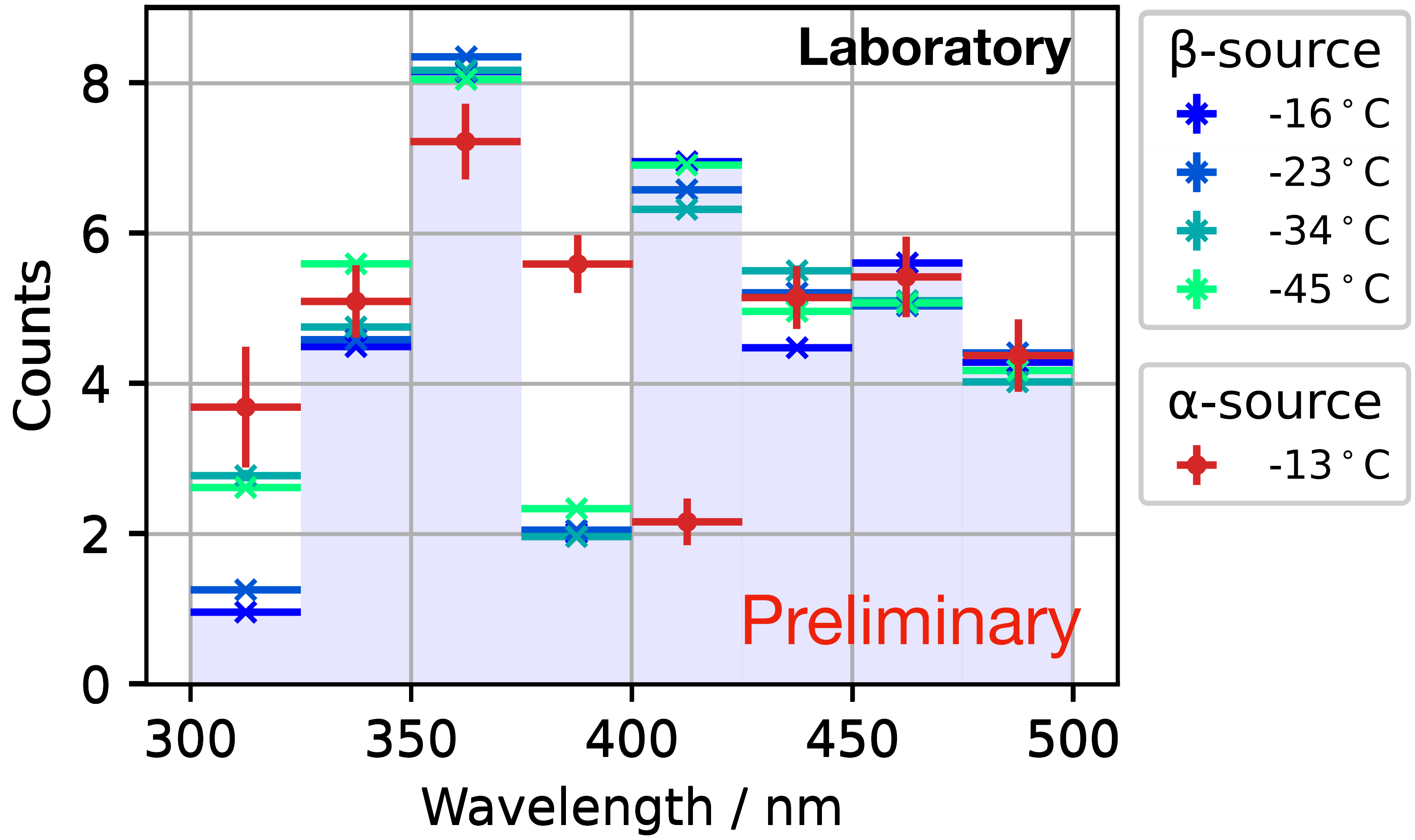

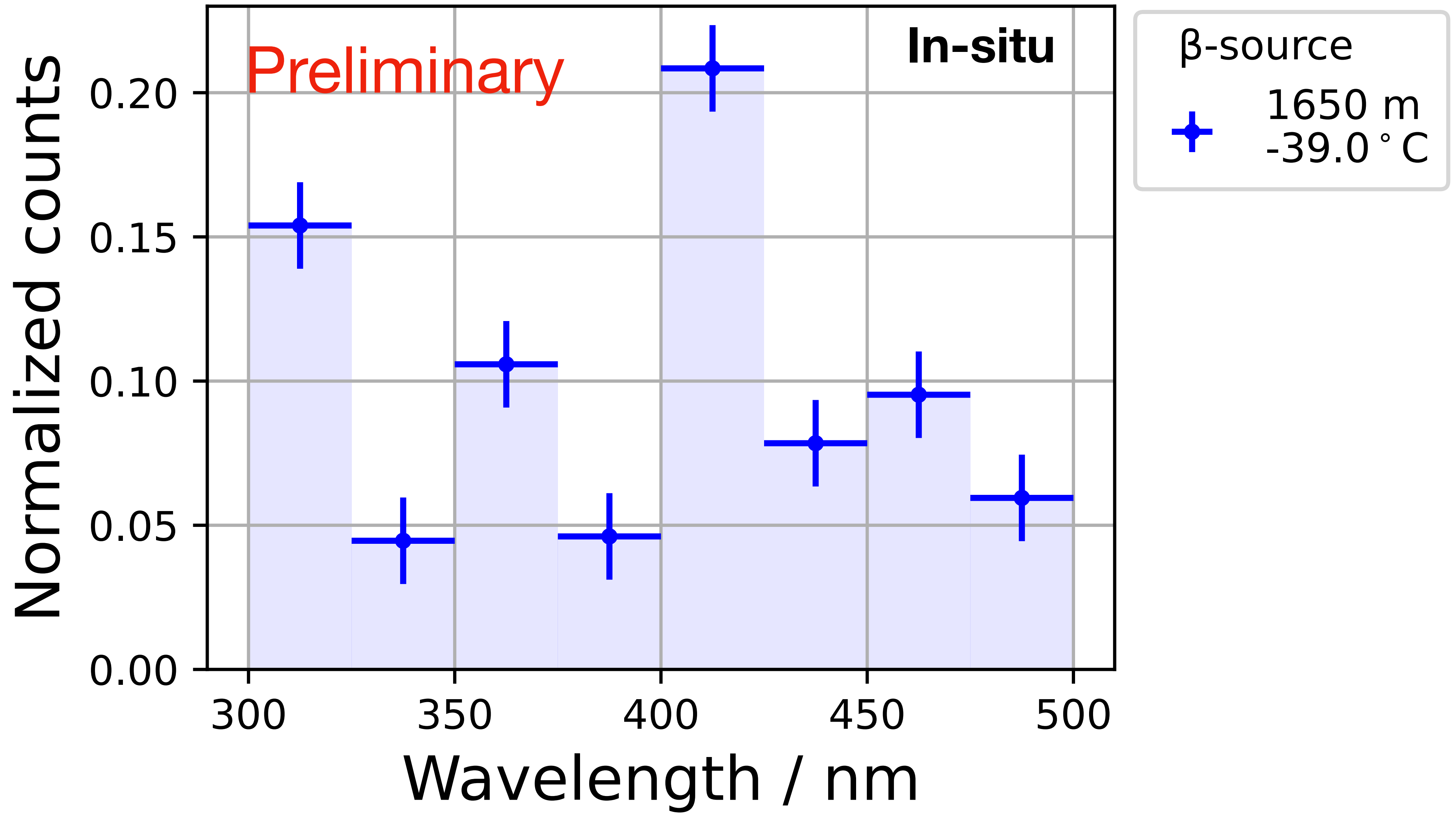

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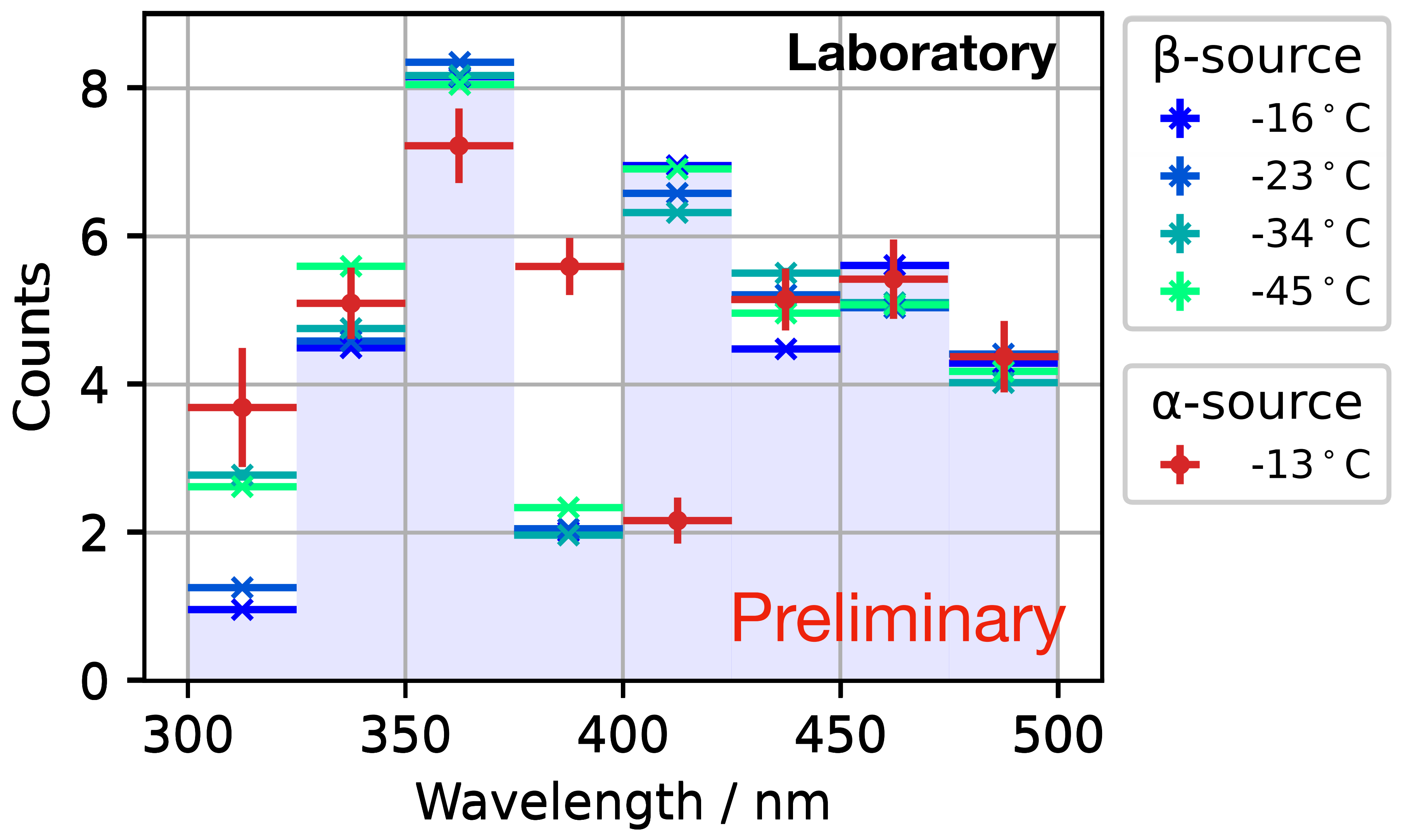

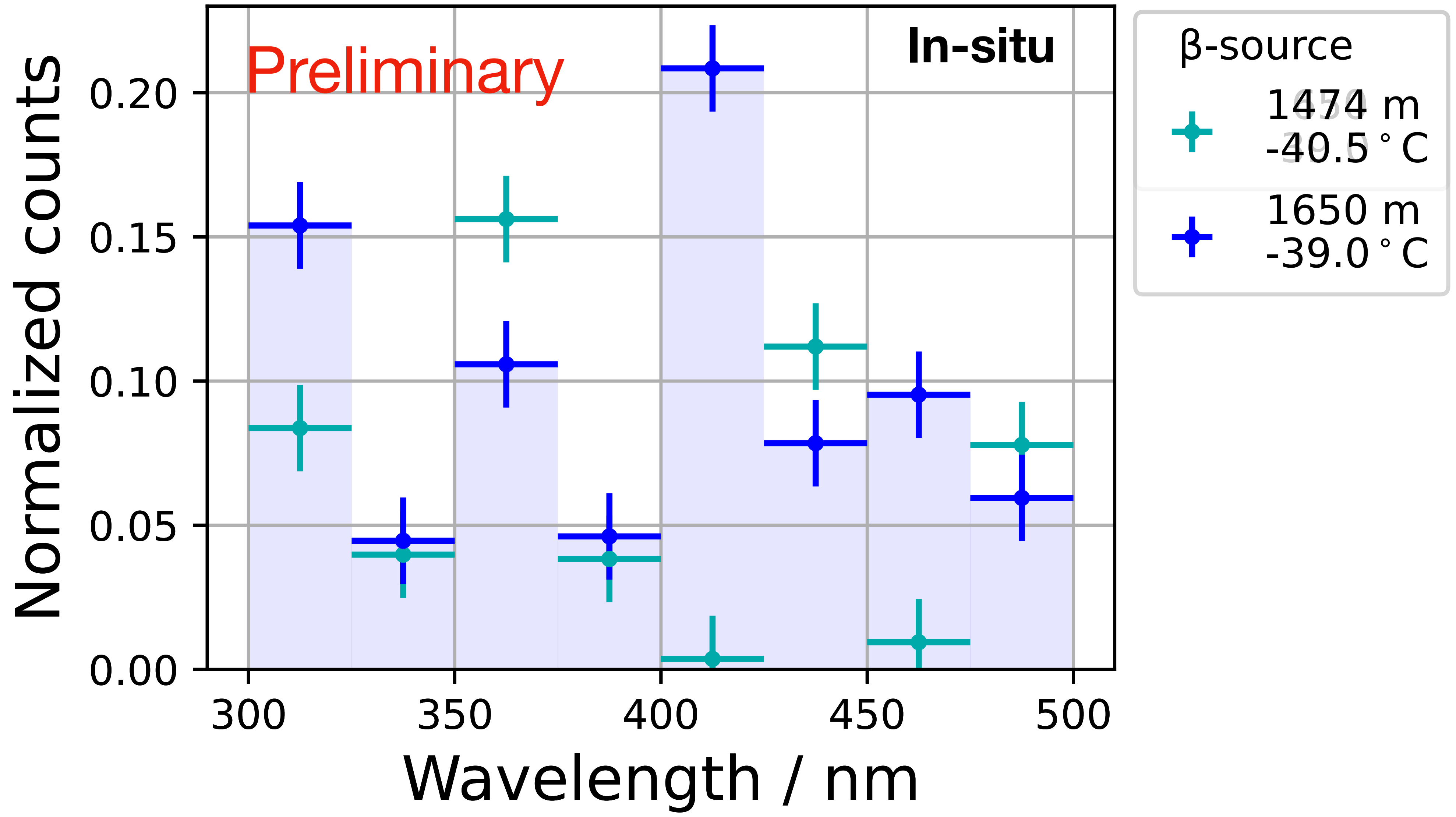

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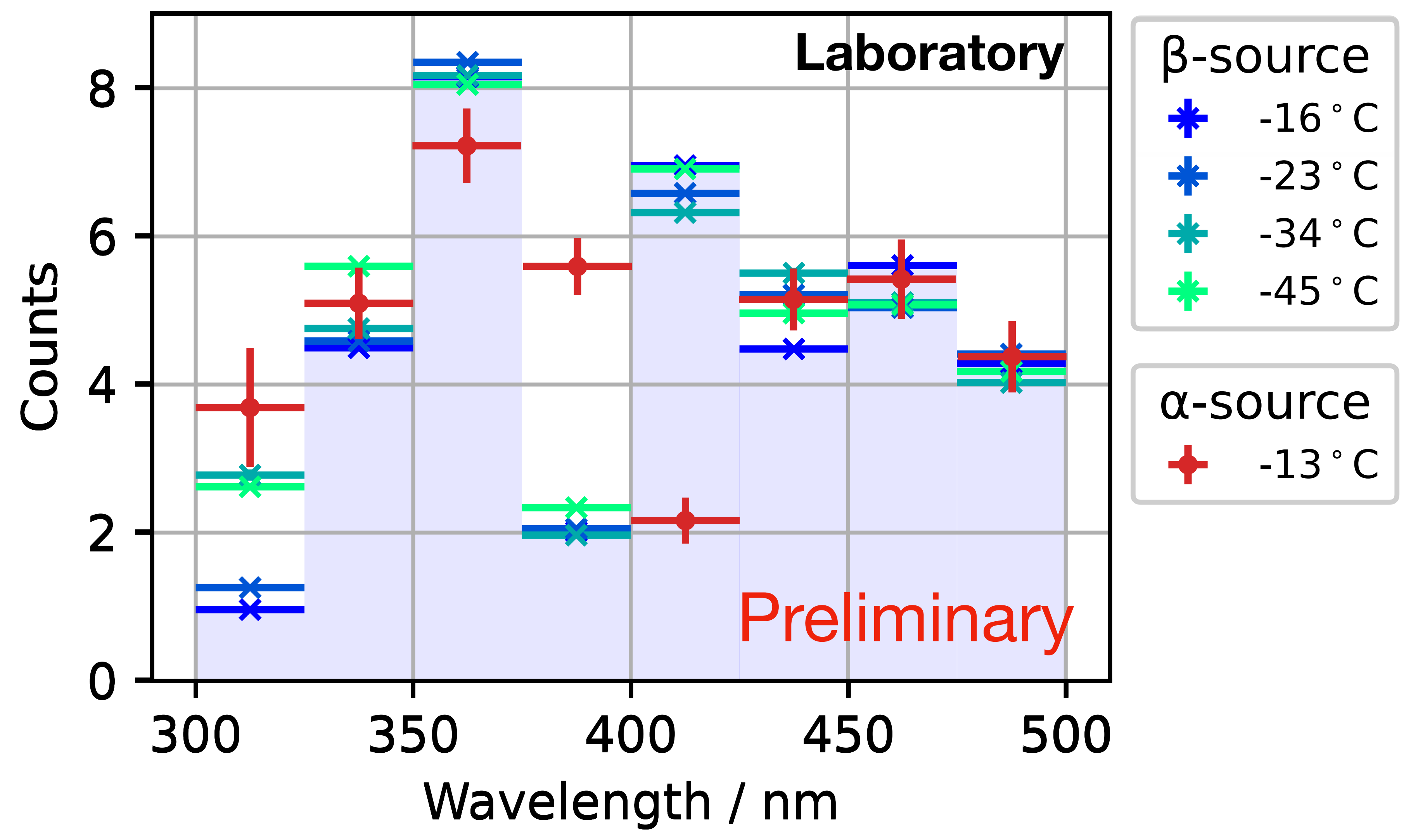
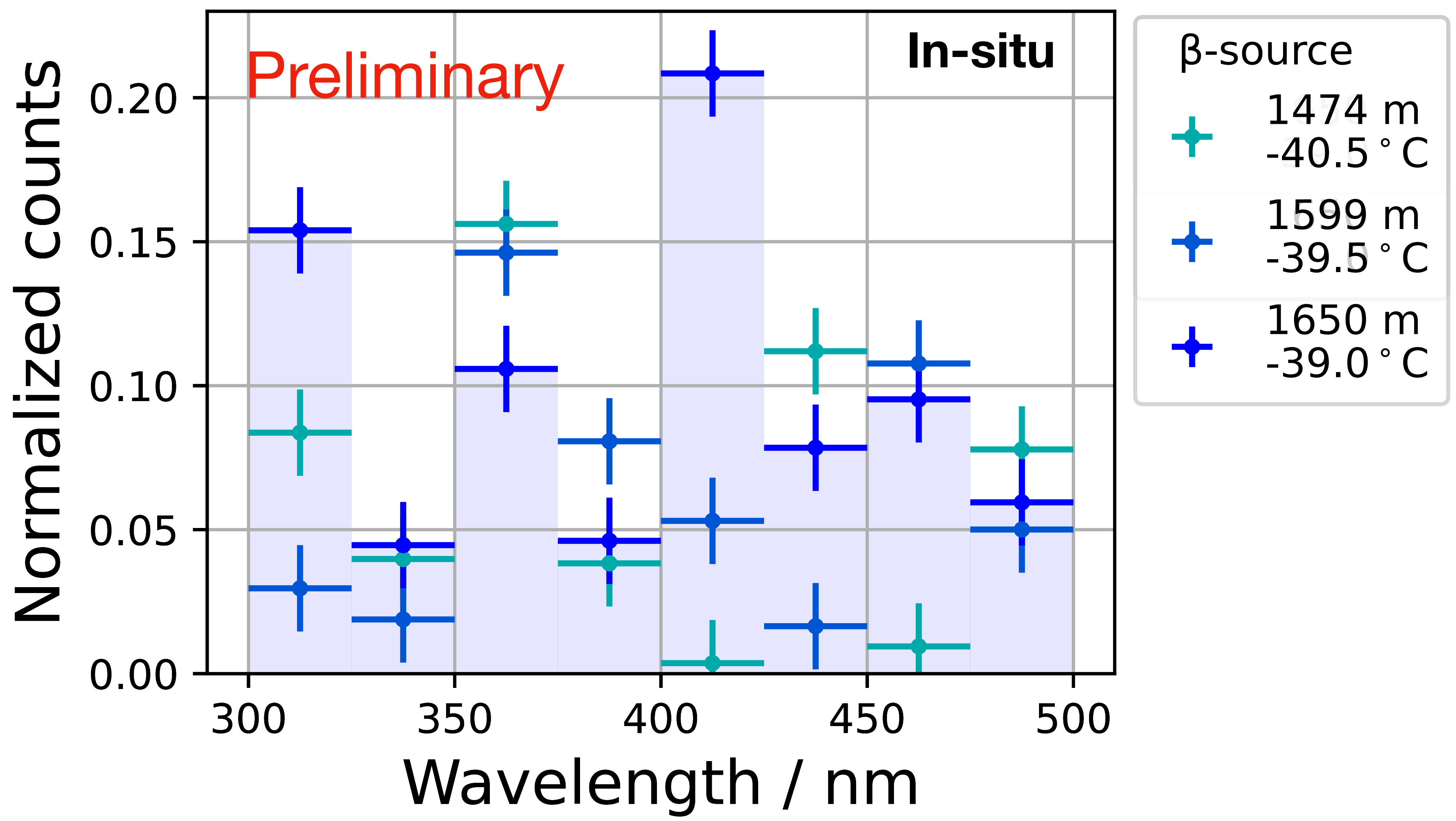
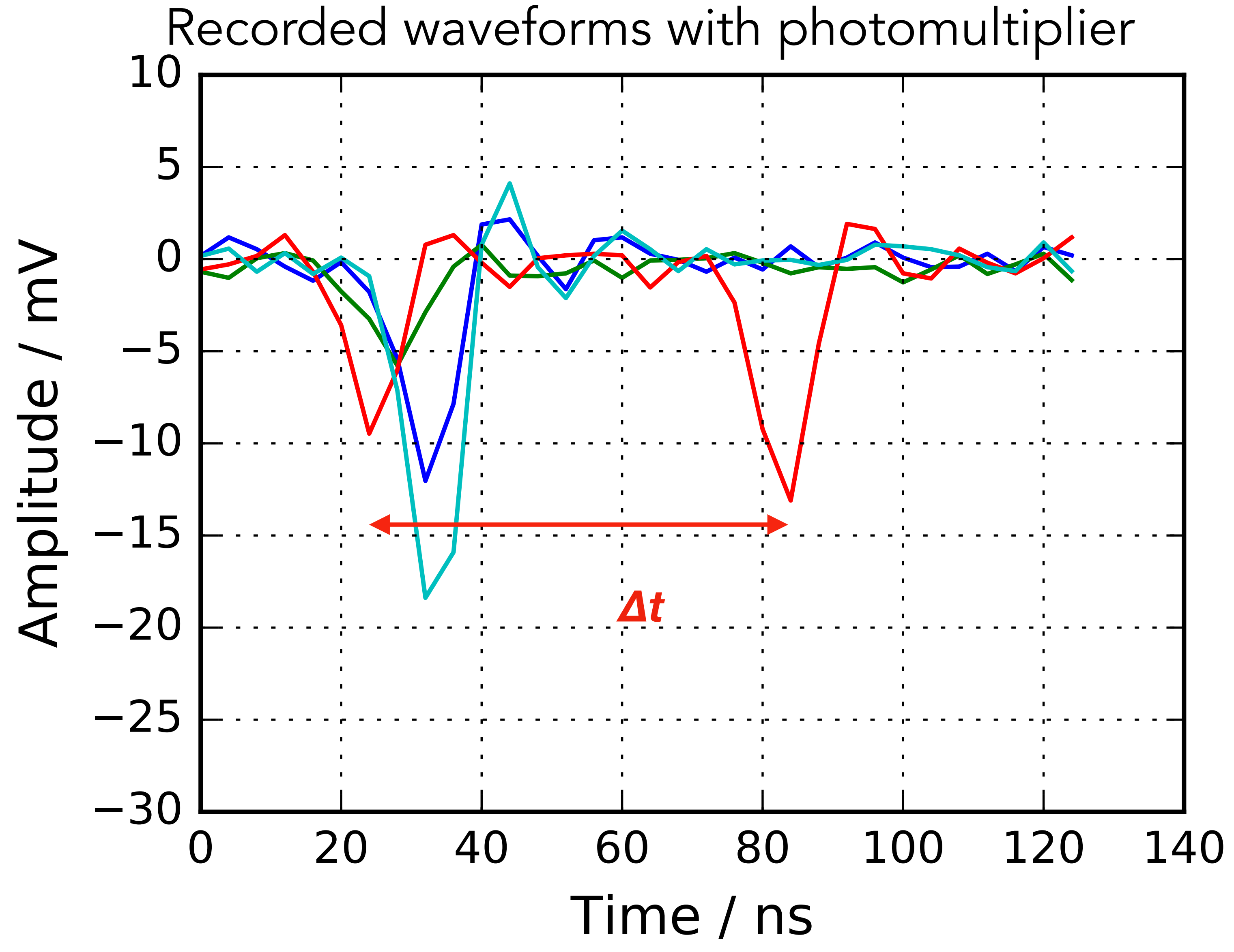




Decay kinetics (in-situ)

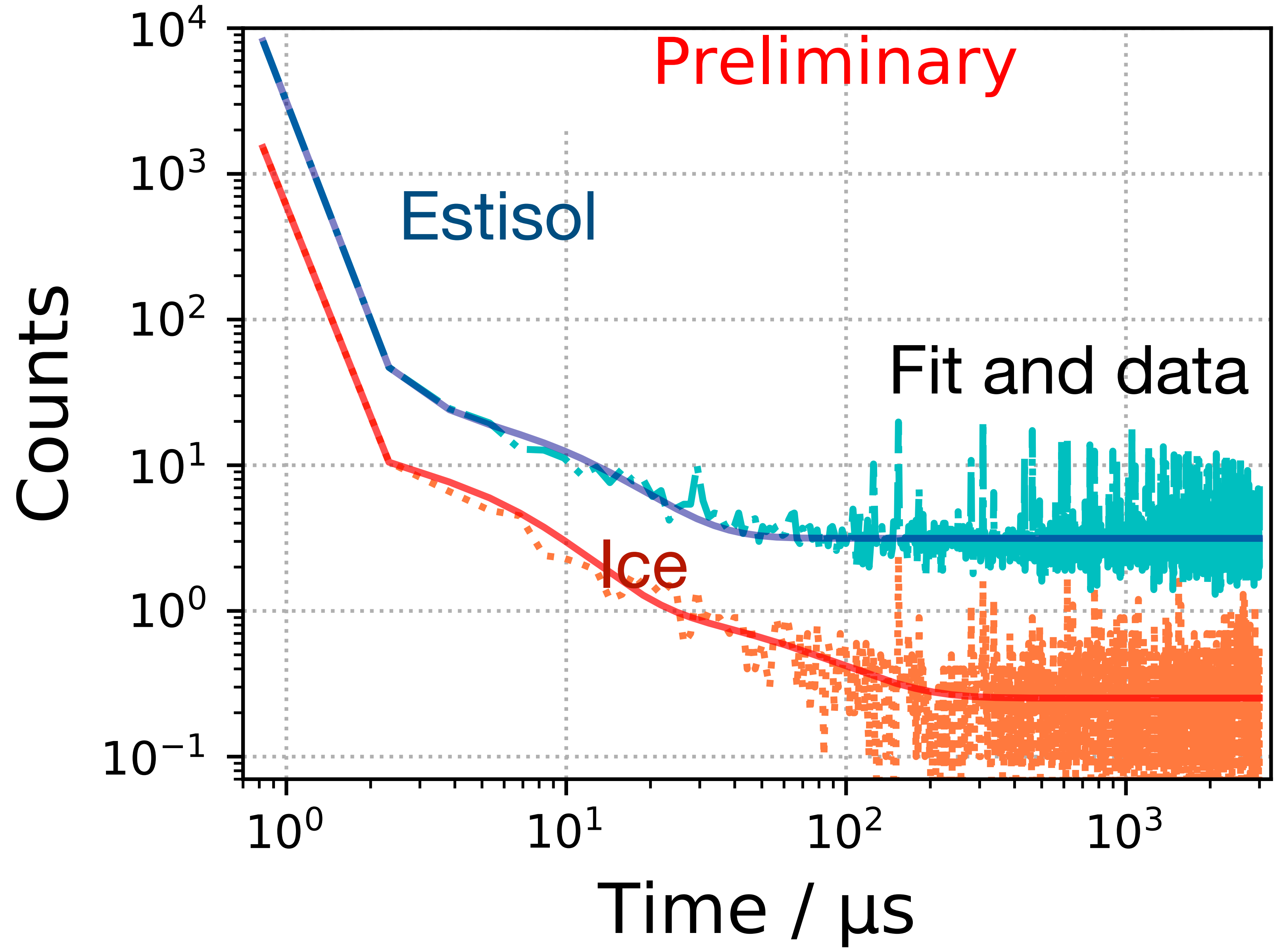
Method

- time difference between a pulse and all subsequent pulses
- subtract Estistol contribution (modelled)
- short < 120 ns:
  - obtained from waveform
  - corrected for PMT effects
- long > 120 ns:
  - obtained from trigger timestamps



Results

- little depth dependence



Decay times of ice

$\tau_1 \approx 2.44$ ns

$\tau_2 \approx 196$ ns

$\tau_3 \approx 5.03$ µs

$\tau_4 \approx 56.1$ µs

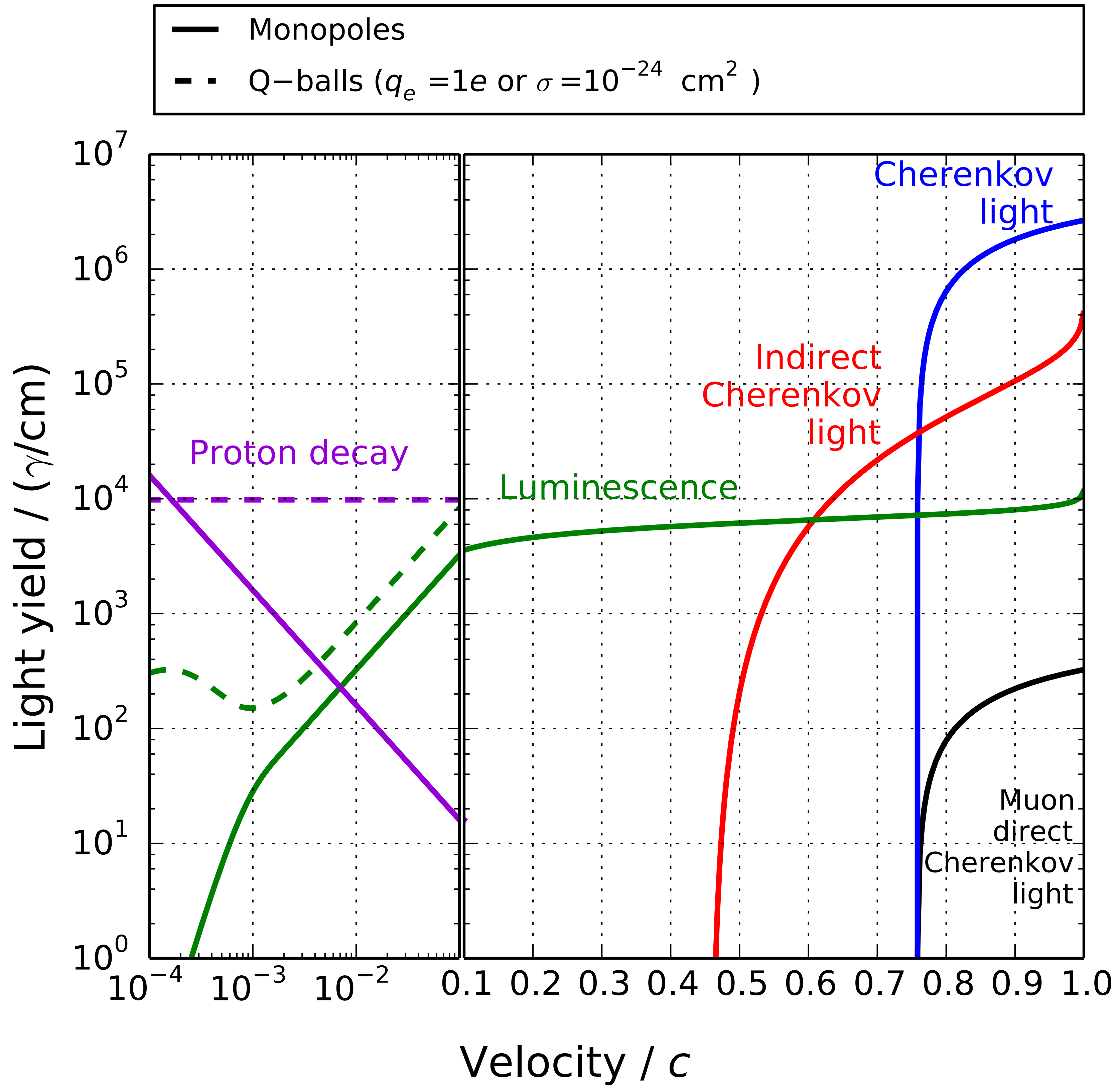
Application

Search for massive Big Bang relics

- Q-balls:
  - predicted in supersymmetry
  - coherent states of squarks, sleptons, Higgs field
  - candidates for Dark Matter
  - charged Q-balls emit luminescence light
- Magnetic monopoles:
  - predicted in GUT, further unifying theories and electroweak theory
  - topologically stable defect in vacuum
  - carry at least an isolated magnetic charge
  - **see first search ever: <u>POS 534</u> <u>(DM 16 Jul 18:00h)</u> using light yield and decay time**
- Nuclearites
  - stable states in SM in thermodynamic processes
  - lumps of u-, d-, s-quarks (neutron stars)
- Super heavy neutral Dark Matter

Charged Q-Ball & Noise

0.001 *c*,
Z=137
Q=10^20



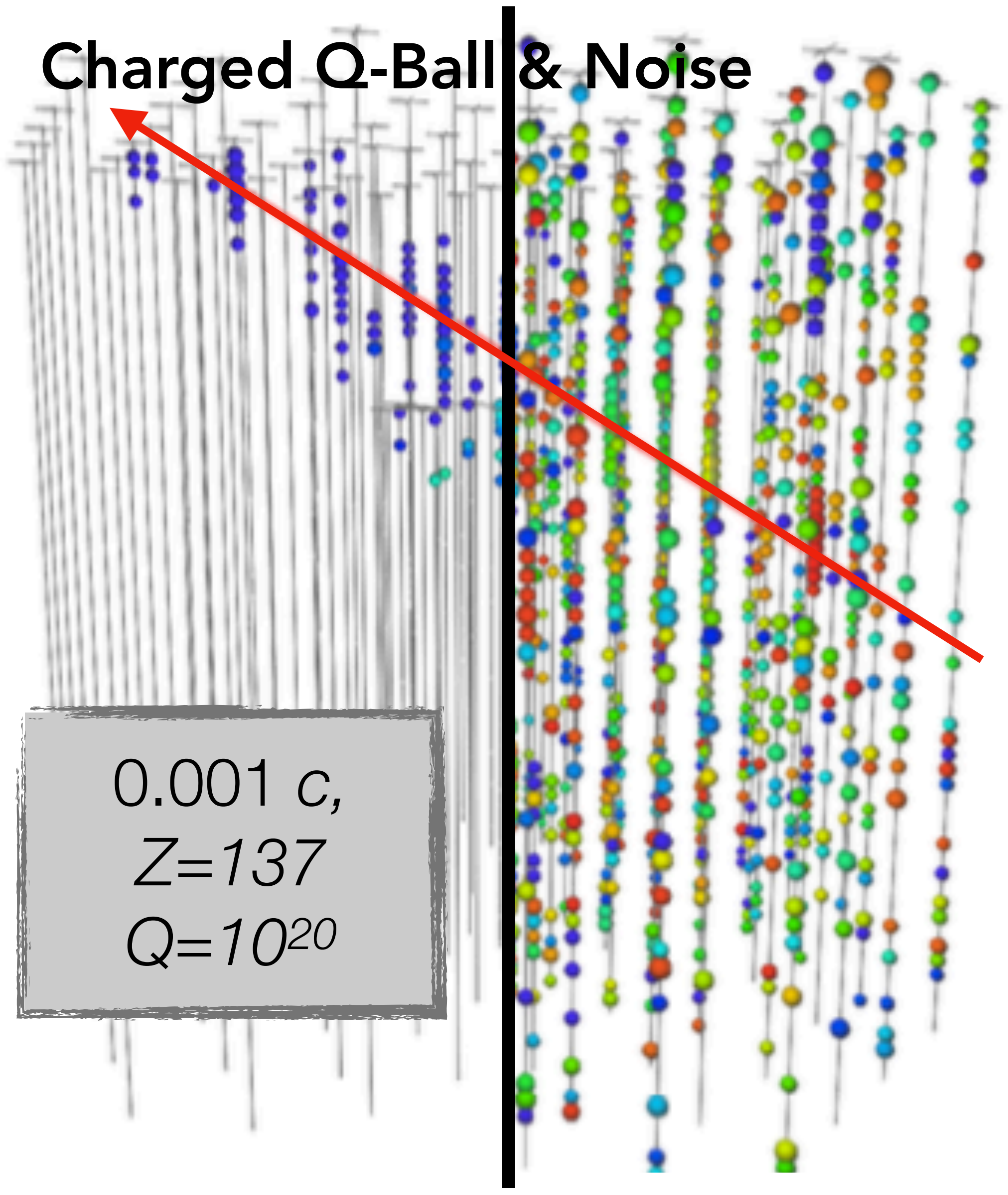
Standard model particles

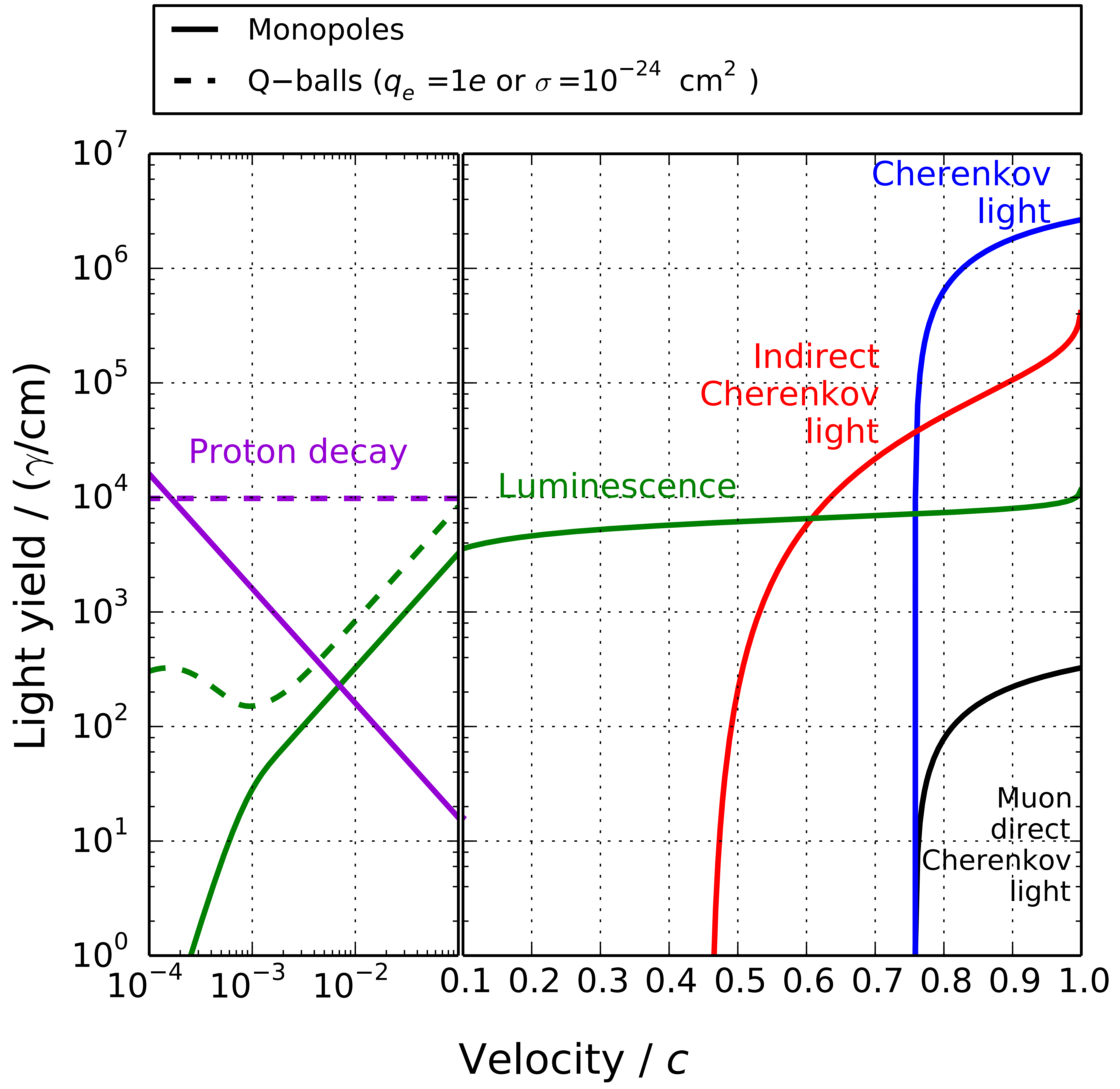
- energy reconstruction
- reconstruction of signature features

Application

Search for massive Big Bang relics

- Q-balls:
  - predicted in supersymmetry
  - coherent states of squarks, sleptons, Higgs field
  - candidates for Dark Matter
  - charged Q-balls emit luminescence light
- Magnetic monopoles:
  - predicted in GUT, further unifying theories and electroweak theory
  - topologically stable defect in vacuum
  - carry at least an isolated magnetic charge
  - **see first search ever: POS 534 (DM 16 Jul 18:00h) using light yield and decay time**
- Nuclearites
  - stable states in SM in thermodynamic processes
  - lumps of u-, d-, s-quarks (neutron stars)
- Super heavy neutral Dark Matter





Standard model particles

- energy reconstruction
- reconstruction of signature features

Summary & outlook

- Properties of luminescence of pure water and ice measured in lab and in-situ
- First search at neutrino telescope conducted, see POS 534 (DM 16 Jul 18:00h)
- Ready for use for various applications in water and ice
- Analysis of exited molecule species ongoing

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Luminescence of water and ice

a novel detection channel for neutrino telescopes

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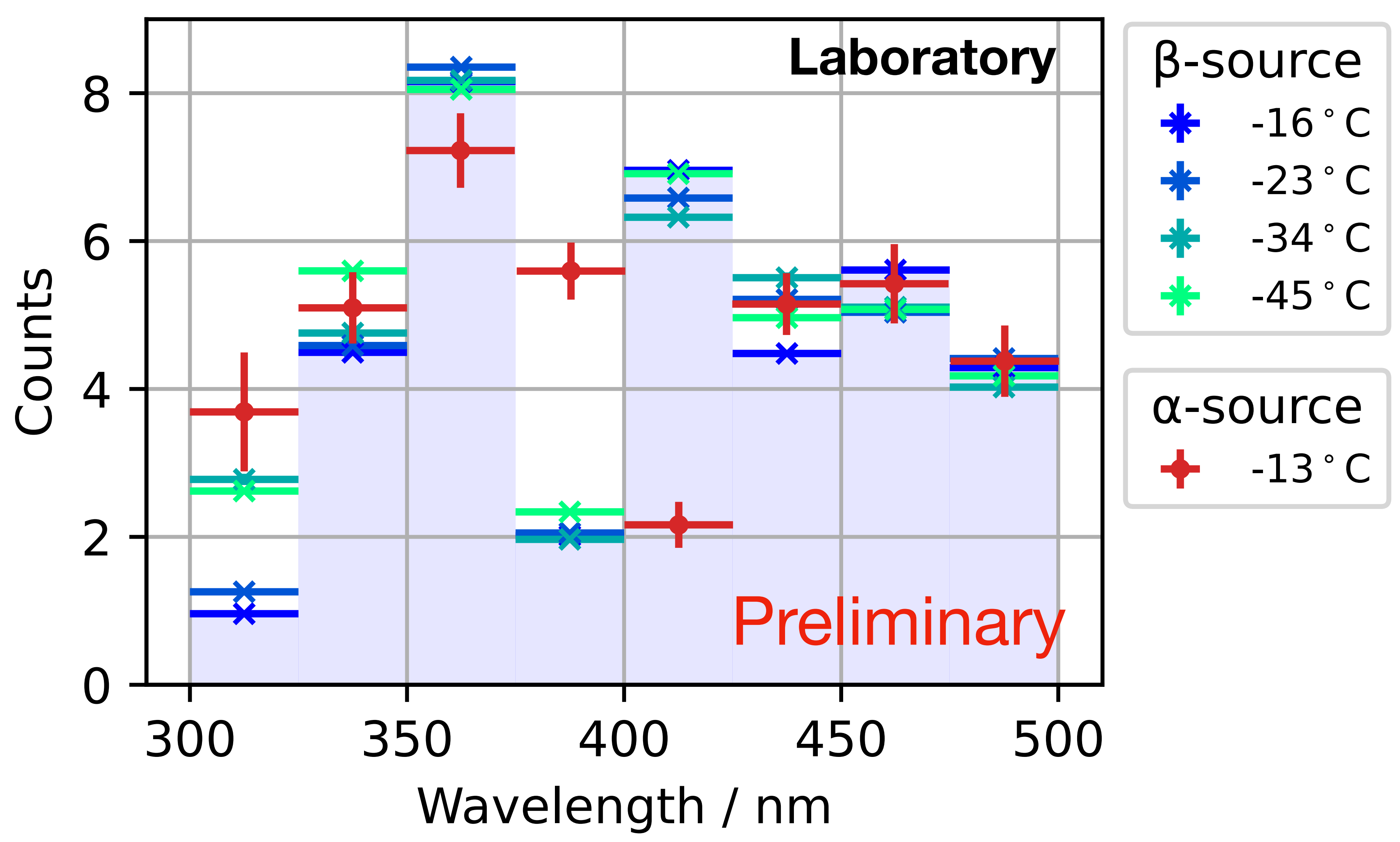
What is it about:
Measurements of luminescence properties in water and ice @ South Pole and in laboratory

- light yield
- decay kinetics
- spectrum
- quenching

Spectrum of luminescence of ice



Why relevant:

- the huge volume of large neutrino telescopes makes them ideal for rare event searches
- but these water-Cherenkov detectors rely on Cherenkov light only
- luminescence light would enable searches for other particles in other parameter ranges

Conclusions:

- Simulations of Magnetic Monopoles and Q-balls show that luminescence is a suitable new detection channel
- First search for Magnetic Monopoles yielded World leading sensitivities (POS 534, DM 16 Jul 18:00h)