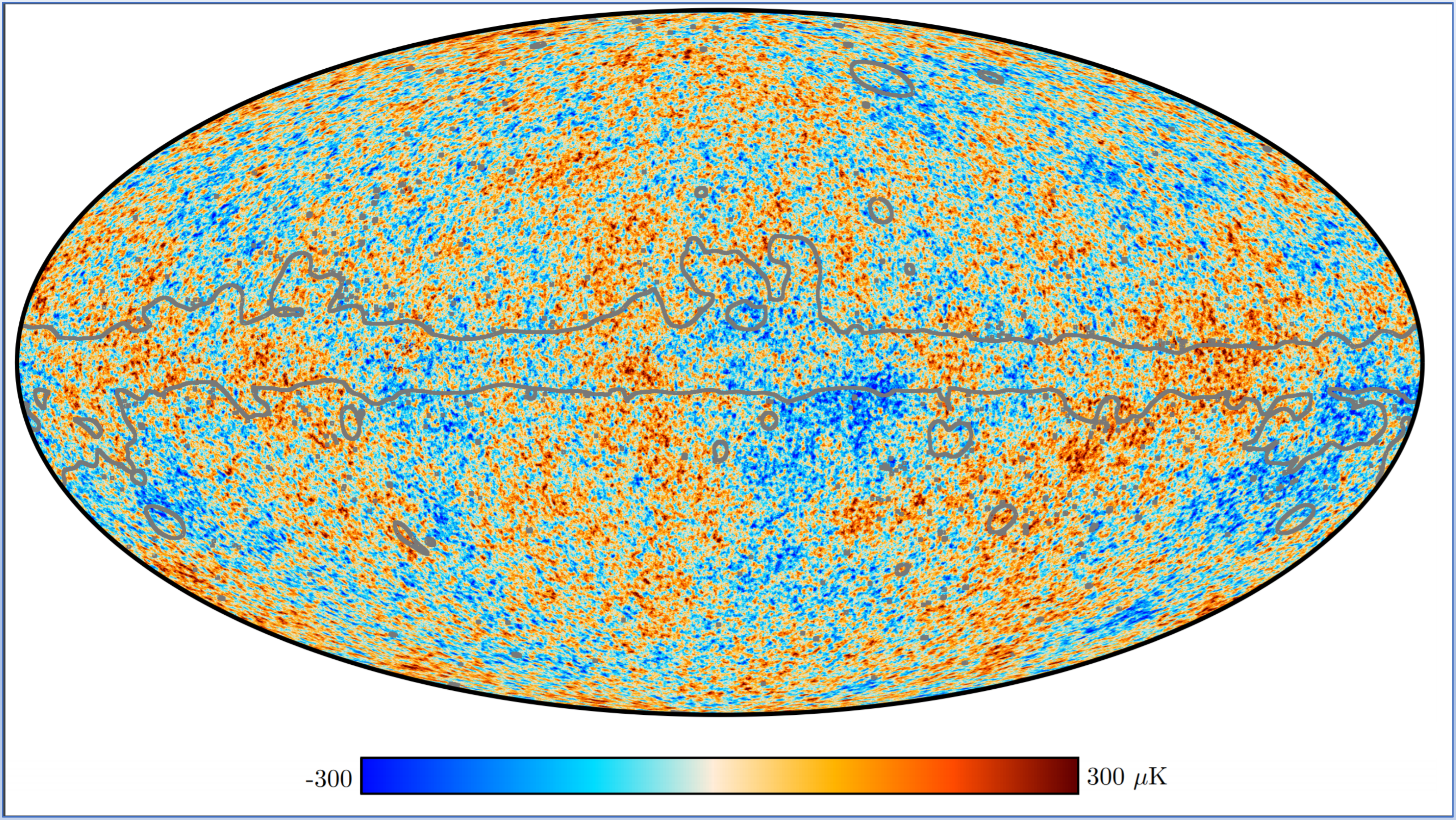
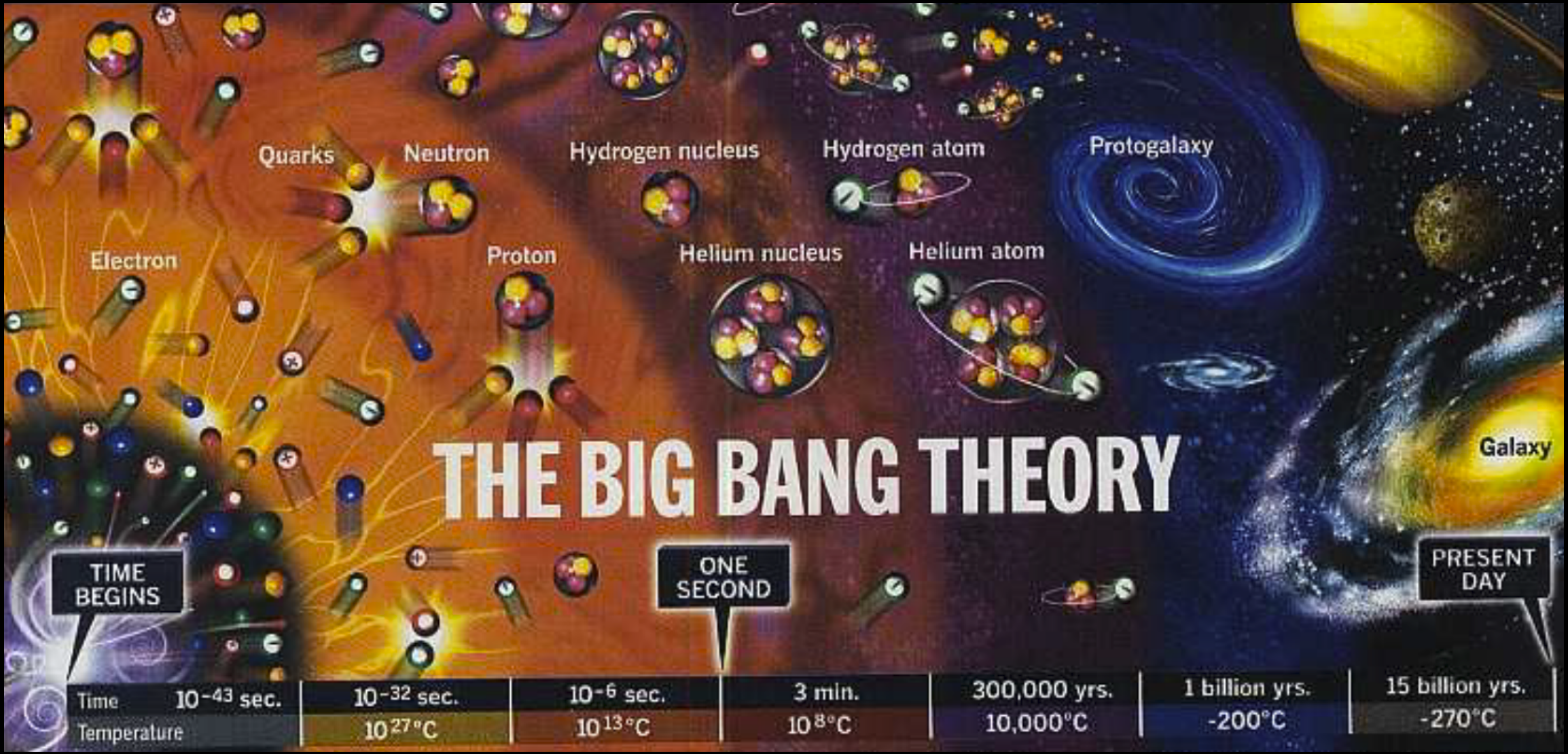
The PTOLEMY experiment, how to have a glance at the first second of the Universe

M. M. on behalf of the POTLEMY collaboration

GSSI Science Fair

Who told the history of the Universe so far?





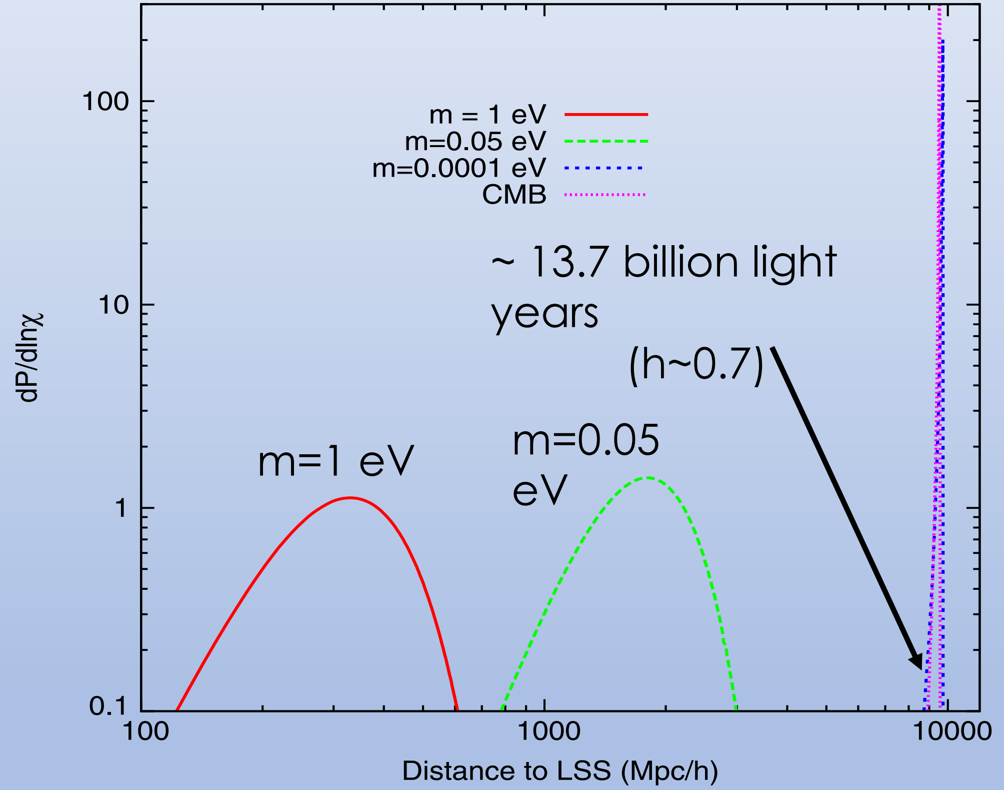
CNB ~ 1 sec

CMB ~ 380k yr

Neutrino Mass and Future Observations

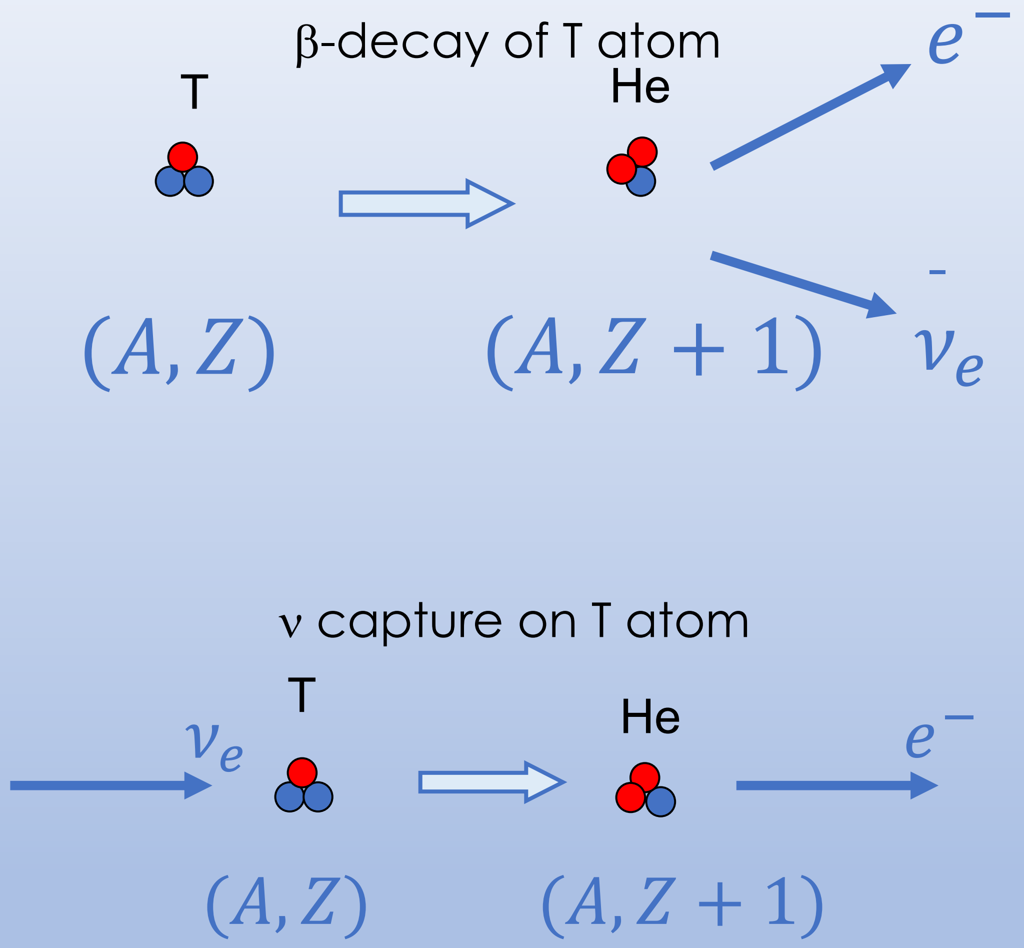
At less than 1 second after the Big Bang, nearly 50% of the total energy density of the Universe was in the form of neutrino kinetic energy. This is the time when neutrinos thermally decoupled from matter and began free-streaming through the Universe.

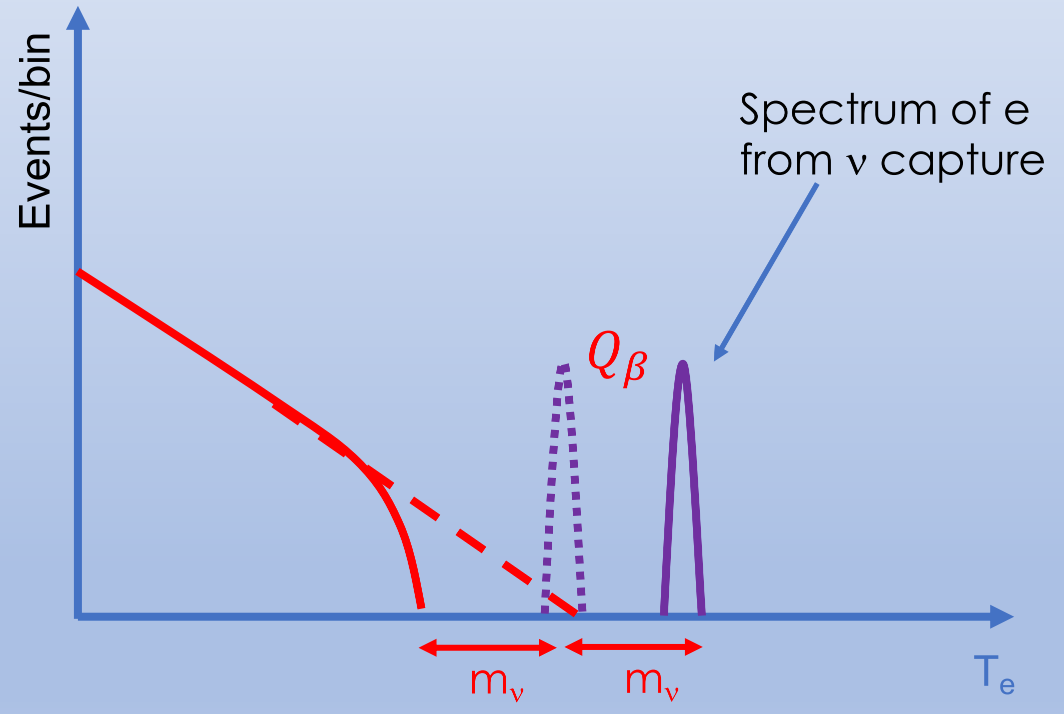
S. Dodelson and M. Vesterinen,
"Cosmic Neutrino Last Scattering Surface (LSS),"
http://doi.org/10.1103/PhysRevLett.103.171301



Due the finite mass of the neutrinos and Hubble expansion, the relic neutrinos that arrive at Earth today (after 13.7 billion years of waiting for them) originate from distances less than 2 billion light years away.
With extensive galaxy cluster survey data seen with optical and infra-red, we can directly compare to the original seeds of structure recorded by the neutrinos – two images of the same location in space separated by over 10 billion years.

Detection principle

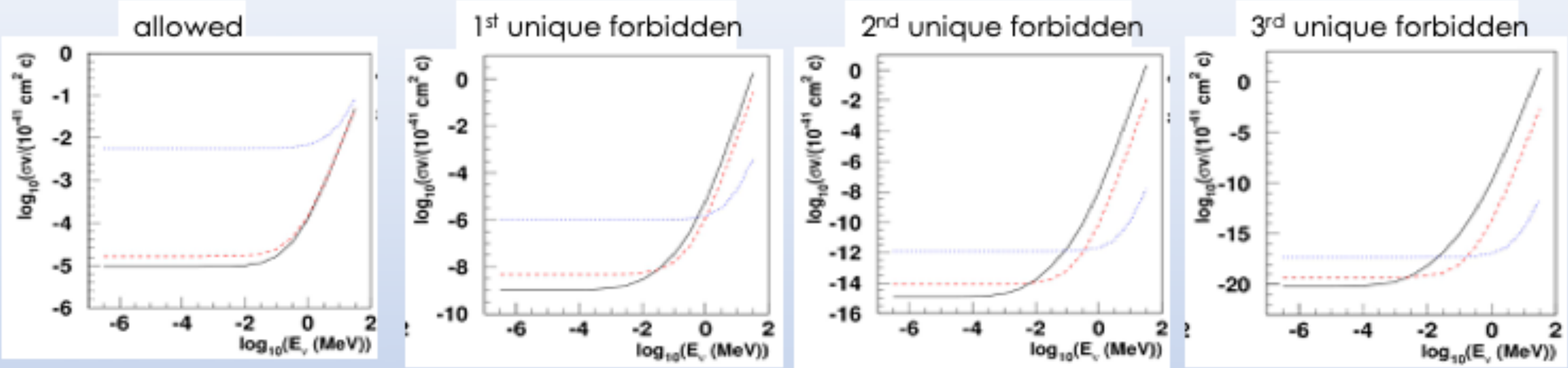




A.G. Cocco, G. Mangano and M. Messina, JCAP 06 (2007) 015
S Weinberg, *Phys. Rev.* (1962) 128:3, 1457

NCB Cross Section

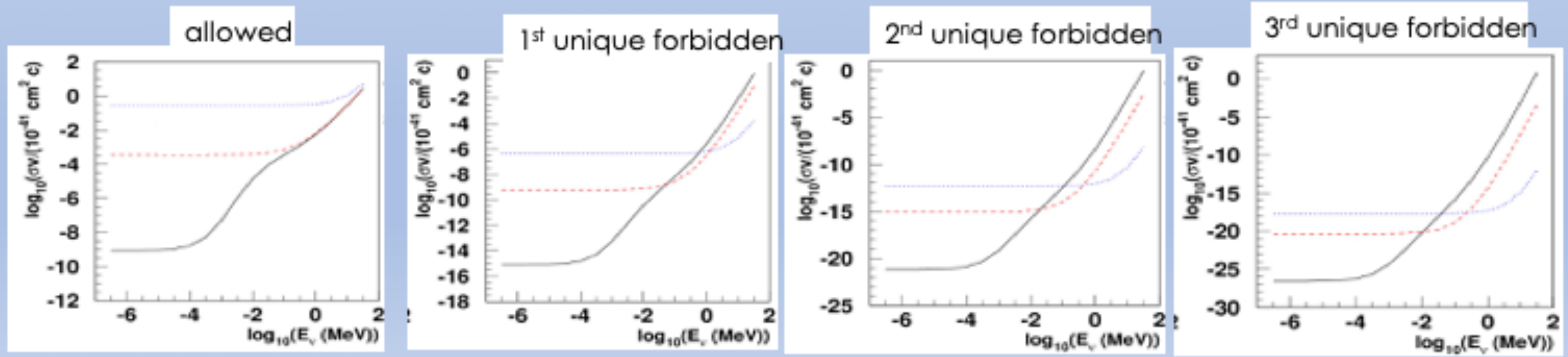
as a function of E_ν, Q_β for different nuclear spin transitions



β^- (top)

β^+ (bottom)

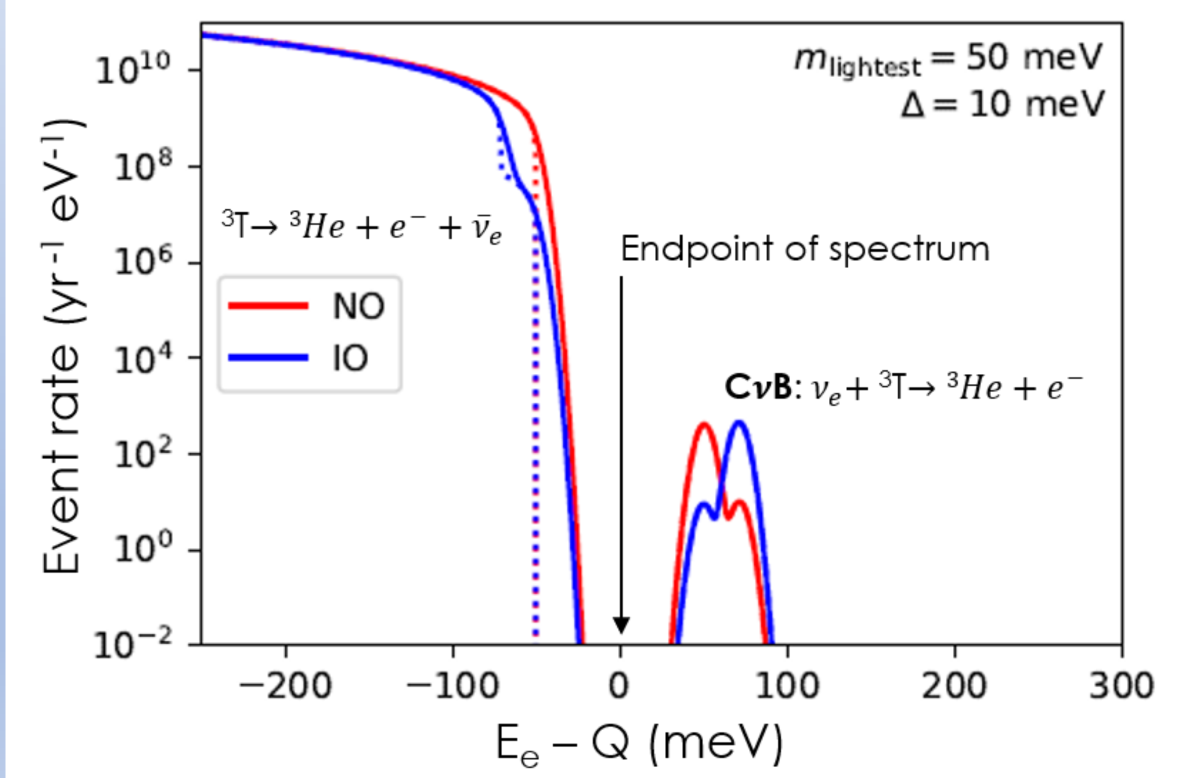
solid black line	Q_β = 1 keV
dashed red line	Q_β = 100 keV
thin orange line	Q_β = 10 MeV



Why Tritium target?

- High cross-section for neutrino capture
- Sizeable lifetime
- Low Q-value
- **Tritium beta decay ~10^{15} Bq/gram**

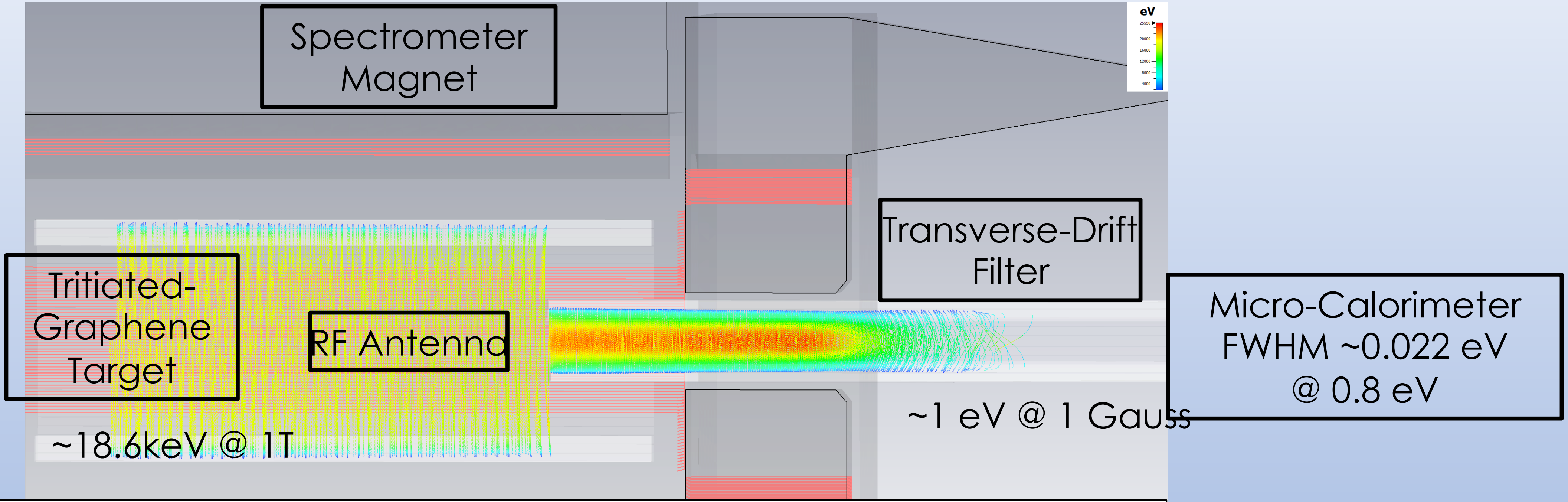
PTOLEMY collaboration **JCAP 1907 (2019) 047**



PTOLEMY experiment

- Goal:
  1. Find evidence for CvB
  2. Accurate measurement of neutrino mass
  3. Light DM detection (not discussed in this talk)
- Key challenges:
  1. Extreme energy resolution is required
  2. Extreme background rates from the target

Block Diagram of the PTOLEMY Spectrometer

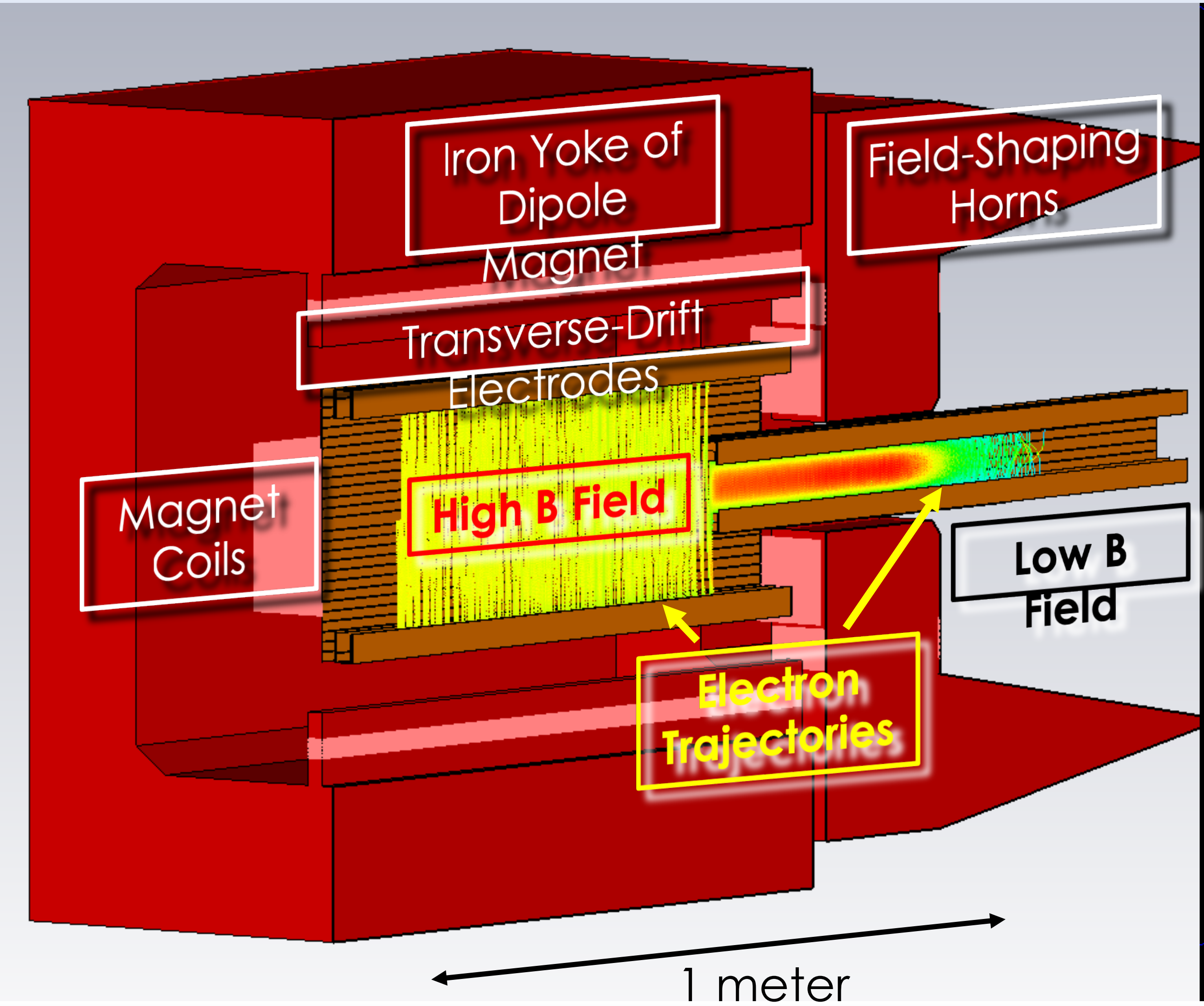


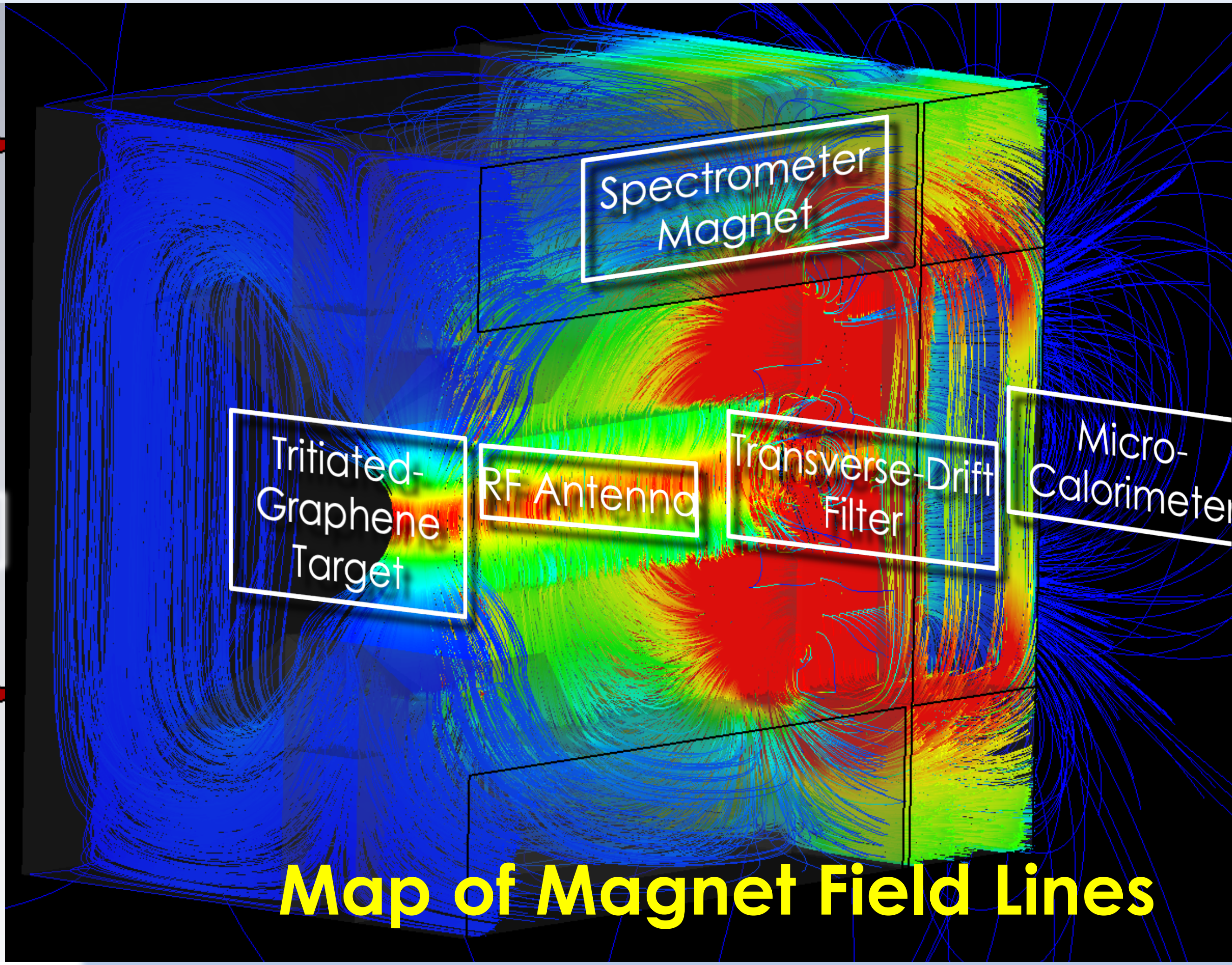
Principle of Operation:

1. Electrons from weakly-bound tritium originate from a cold target surface.
2. Electrons drift through an RF Antenna region where the electron momentum components are measured to ~ few eV resolution.
3. Filter electrodes are set ~ 1 msec in advance of electrons entering filter.
4. Kinetic energy of electrons drained as they climb a potential under gradient-B drift.
5. Electrons of ~ few eV in a low B field region are transported into a micro-calorimeter.

R&D Program:
Small-scale resolution studies and Filter Concept evaluation

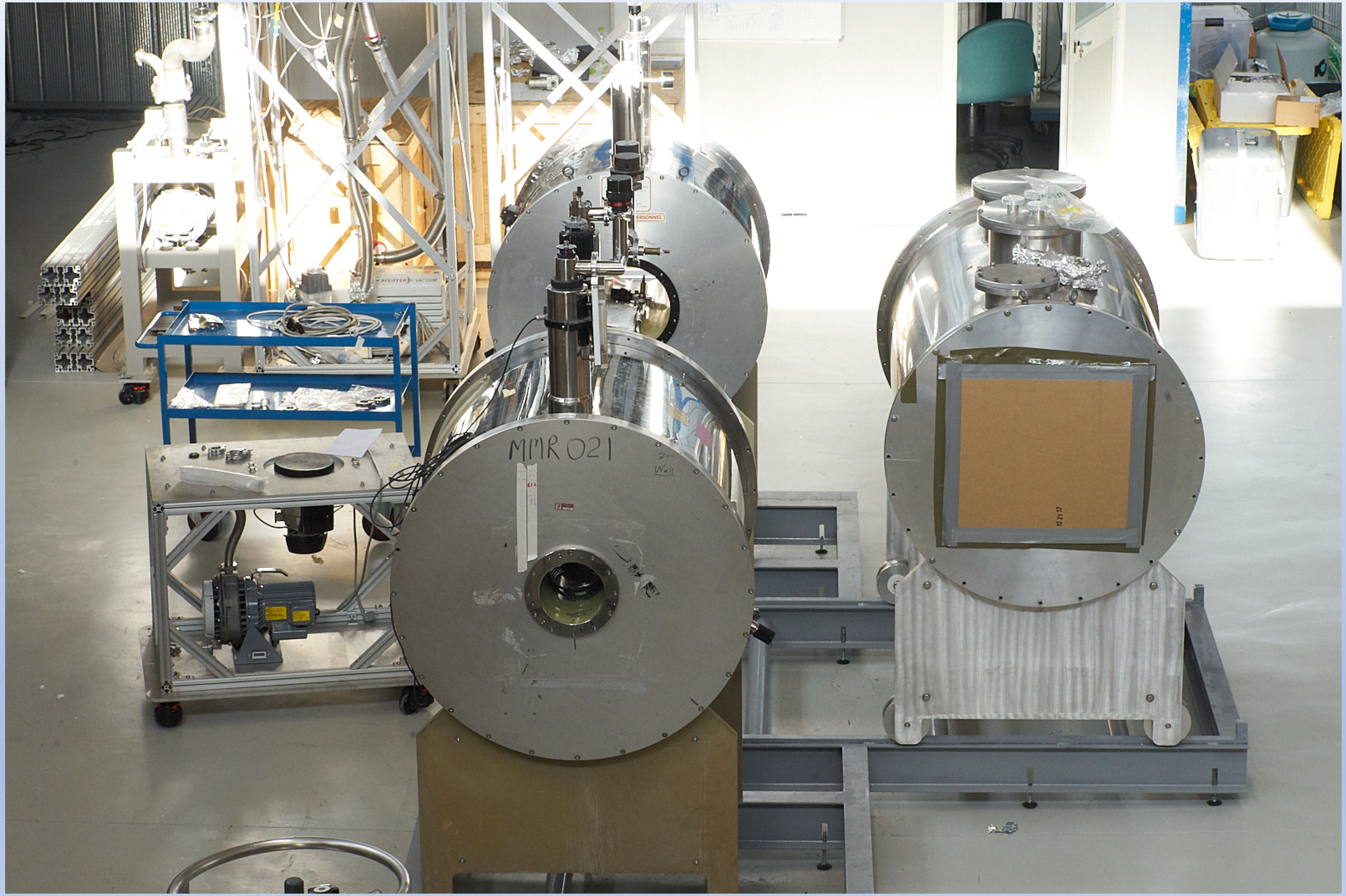
Physical Layout of First Spectrometer

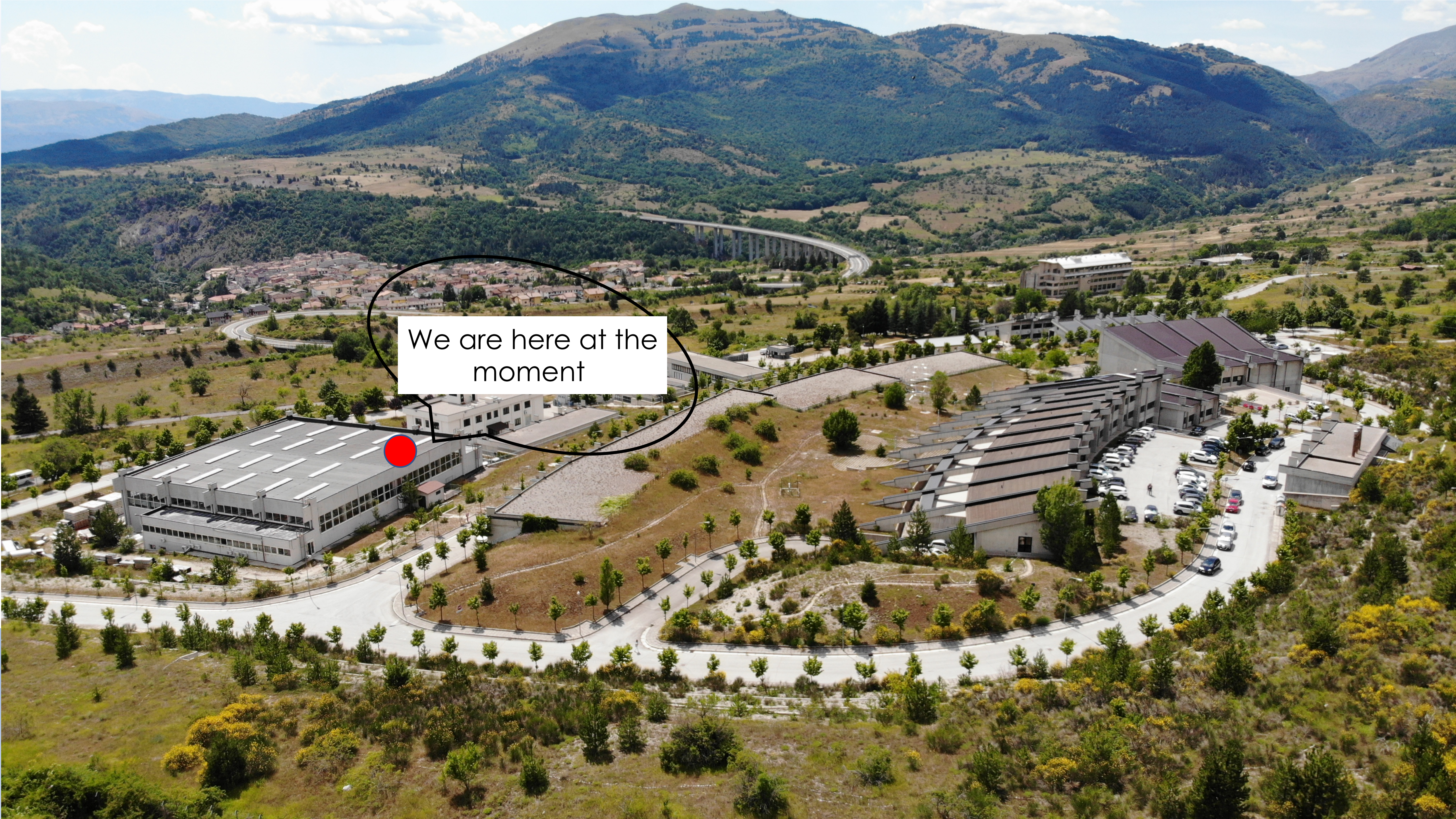




(Left) Cross-Sectional View (Sliced in Half): Red – Iron Yoke, Pink – Current Coils, Brown – Electrodes, Rainbo

Experimental site at LNGS




We are here at the moment

Light Dark Matter search

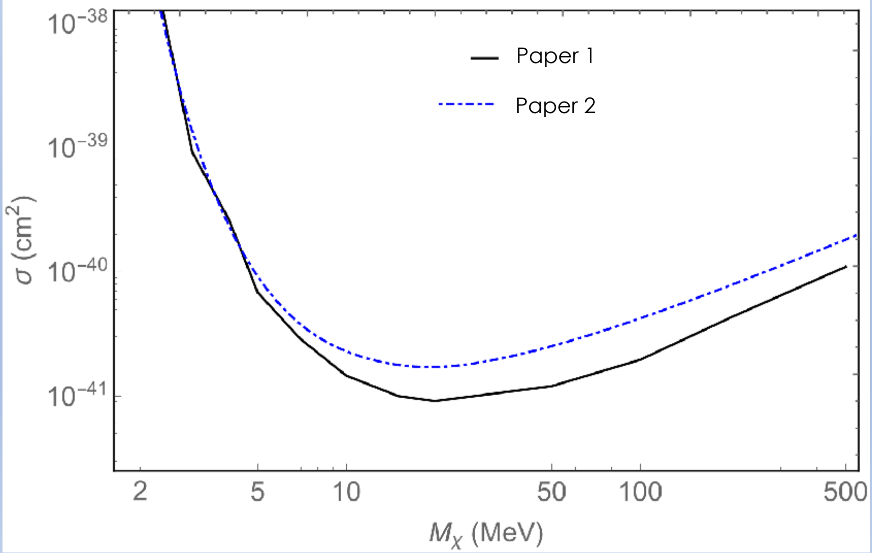
Side project potentially very much interesting

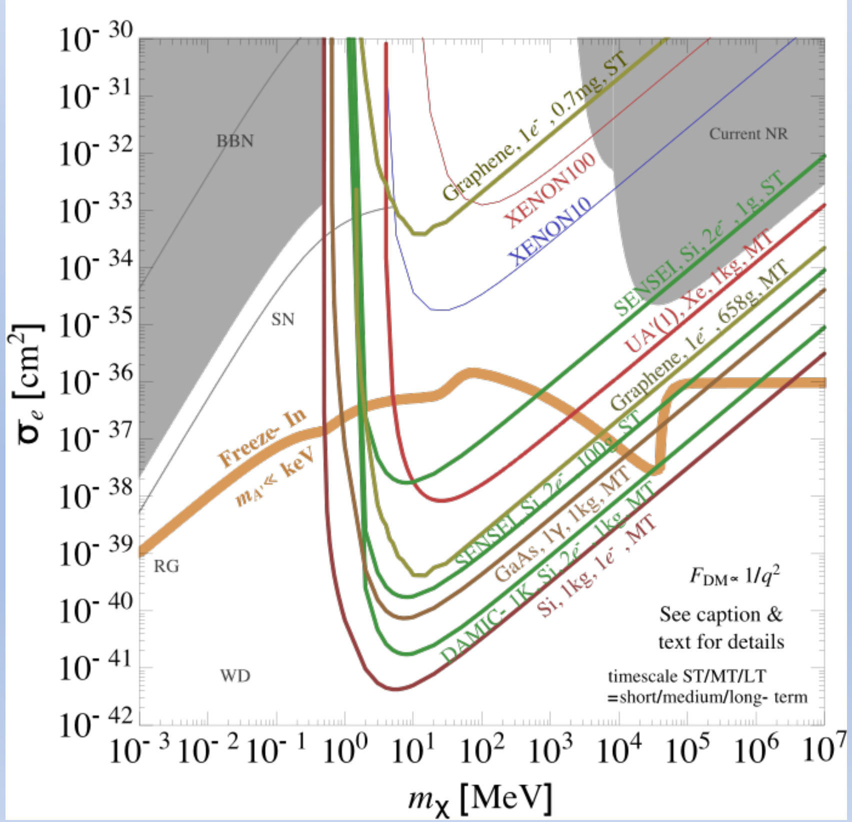
1. Hochberg, et. al, 2016. "Directional Detection of Dark Matter with 2D Targets", Phys. Lett. **B772,** (2017), 239.
2. GL Cavoto et. Al, "Sub-GeV Dark Matter Detection with Electron Recoils in Carbon Nanotubes "Phys.Lett. **B776** (2018) 338-344

In both papers the interaction of light DM with electrons in C nano-structure are discussed. With two different approaches, some directionality features of C nano-ribbon or nano-tube structure are shown. Thus a technical run of the PTOLEMY detector without T would provide interesting results in a region of sensitivity lacking of DM hunting activity. Any electron popping up form C nano-structure could be signature of DM interaction.

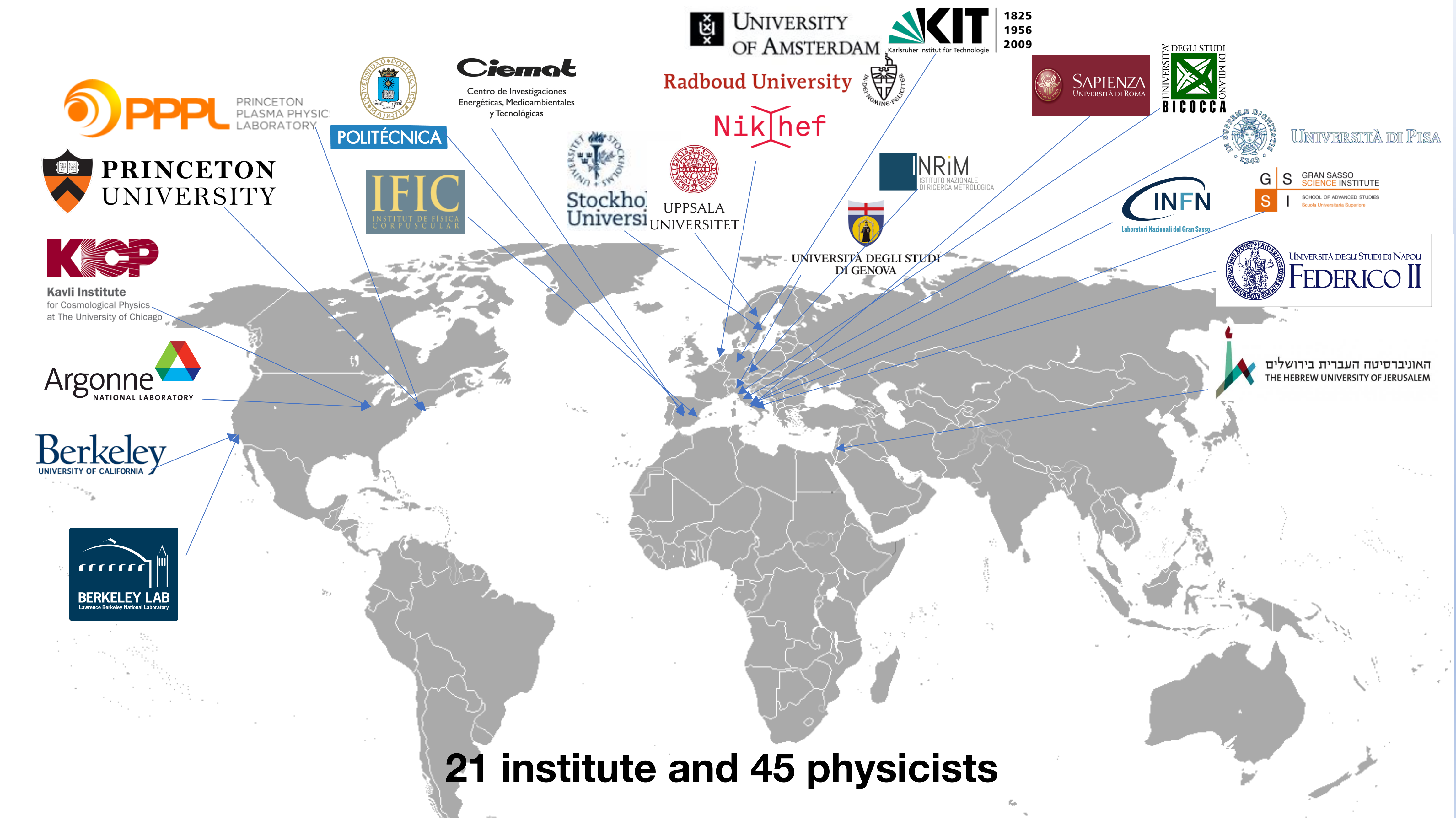
The requirements crucial for the PTOLEMY CNB detection project could be also very much beneficial for Light DM search:

- C with with ^{14}C contamination at better than one per 10^{18}
- electron selection capability
- and very high energy resolution





World-map of the PTOLEMY Collaboration



21 institute and 45 physicists

Recent Publications

[PTOLEMY COLLABORATION] http://ptolemy.lngs.infn.it

New ExB Filter concept:

A design for an electromagnetic filter for precision energy measurements at the tritium endpoint, M.G. Betti et al., Prog. Part. Nucl. Phys. **106** (2019) 120-131, https://doi.org/10.1016/j.ppnp.2019.02.004, e-Print: arXiv:1810.06703

TES Microcalorimeters for PTOLEMY, M. Rajteri, M. Biasotti, M. Faverzani, E. Ferri, R. Filippo, F. Gatti, A. Giachero, E. Monticone, A. Nucciotti, A. Puiu, J. Low Temp. Phys. (2019). https://doi.org/10.1007/s10909-019-02271-x

Physics Program (CNB, Mass, Sterile):

Neutrino physics with the PTOLEMY project, M.G. Betti et al., JCAP **07** (2019) 047, https://doi.org/10.1088/1475-7516/2019/07/047, e-Print: arXiv:1902.05508

To Conclude

Being a protagonist in the proof of principle of the PTOLEMY concept can be a great opportunity to engage yourself in interesting challenge in many fields of physics with enormous publications opportunity.

One day you might be among those that moved forward the threshold of knowledge towards the discovery of Relic Neutrinos.

Do not forget to take the Jackson from your book shelf and make it your Bible.