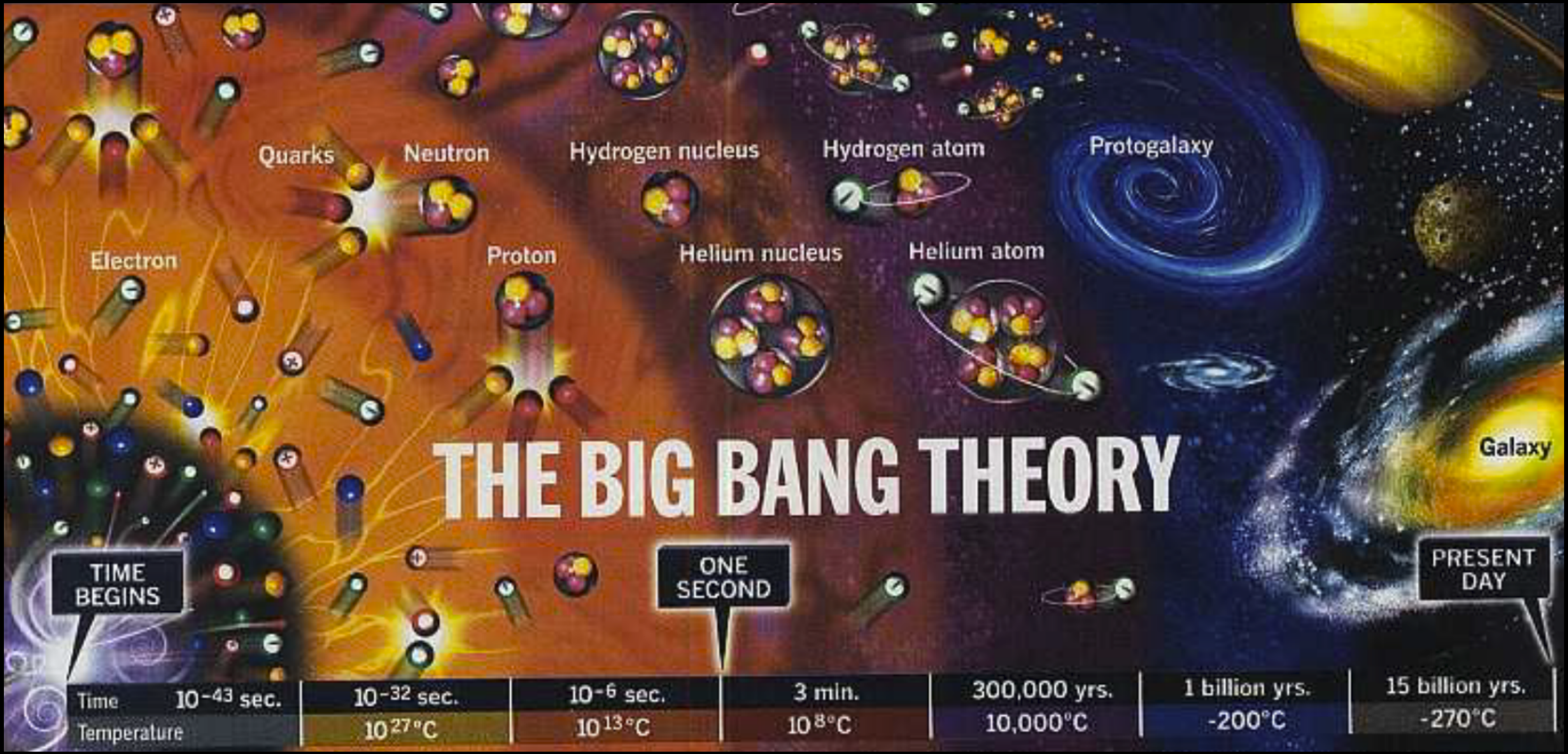
The PTOLEMY experiment to look at the first second of the Universe

Marcello Messina, Primo Ricercatore INFN at LNGS
ICHEP-2020 Prague, Virtual Conference
On behalf of the PTOLEMY Collaboration

Why we believe in Big Bang?

1. Expansion of Universe
2. Light element abundances
3. Cosmic Microwave Background
4. **Cosmic Neutrino Background**



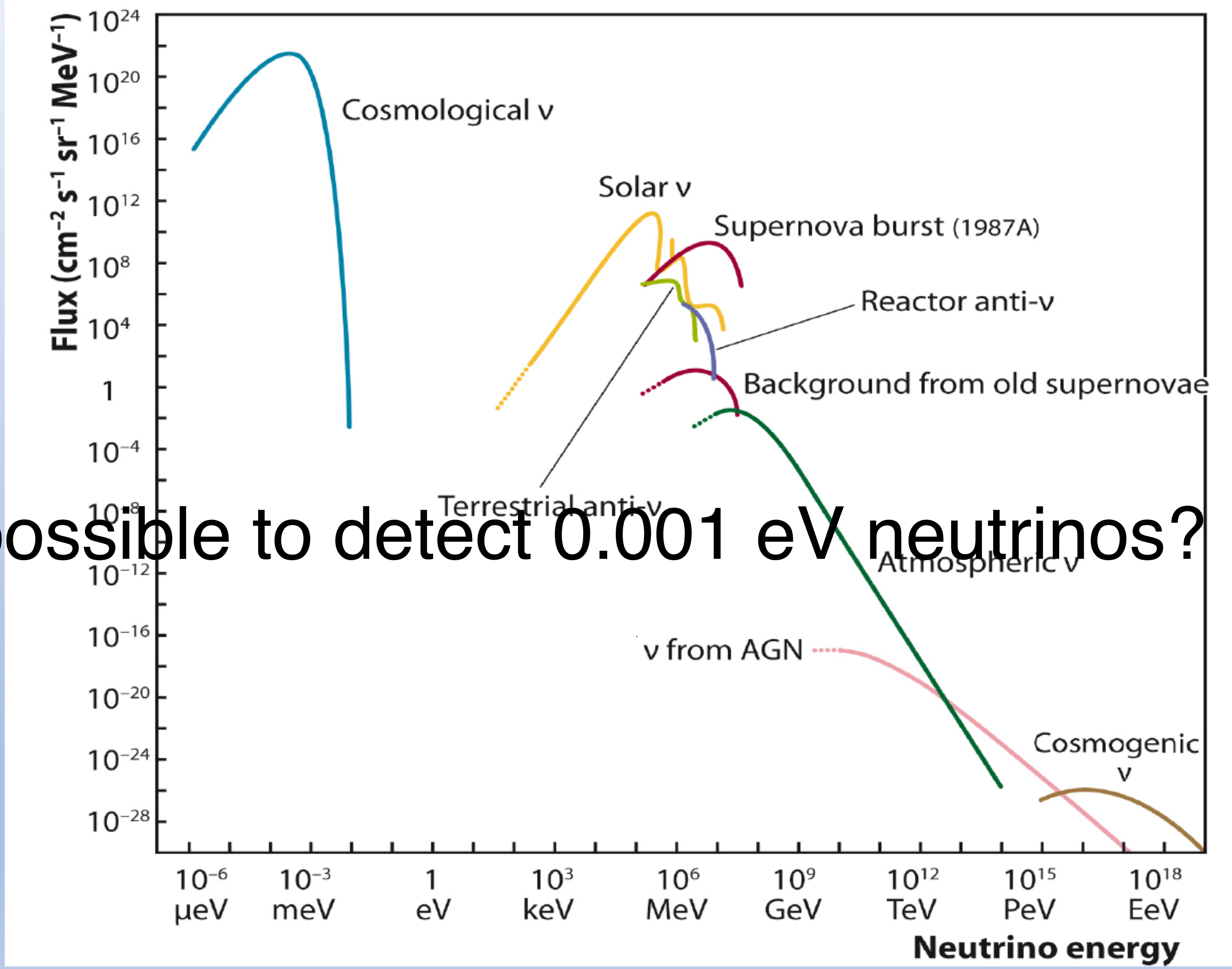
CNB ~ 1 sec

CMB ~ 380k yr

Neutrino flow

$T \approx 1.9\ K \Longrightarrow p_\nu \approx 0.001\ eV$

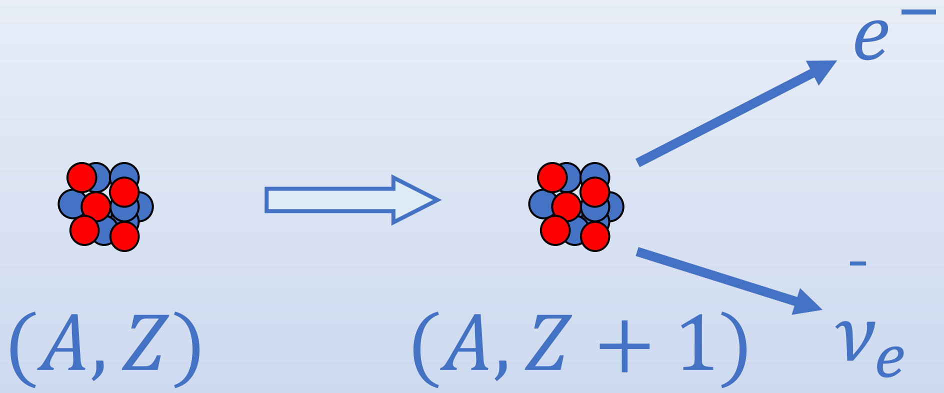
$n \approx 56\ cm^{-3}\ x\ 6$

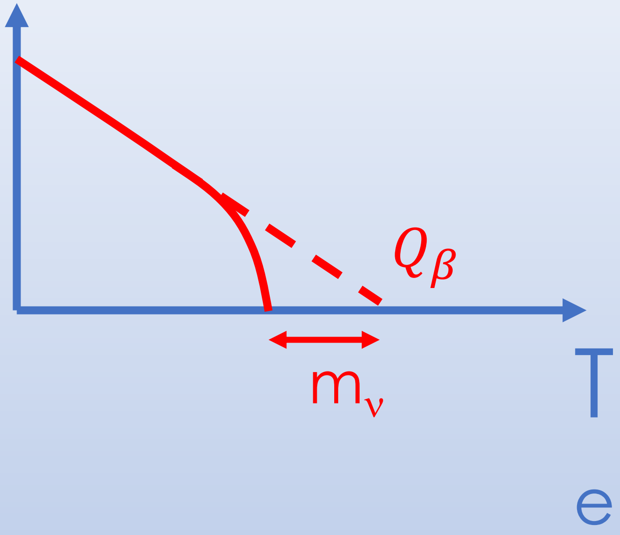


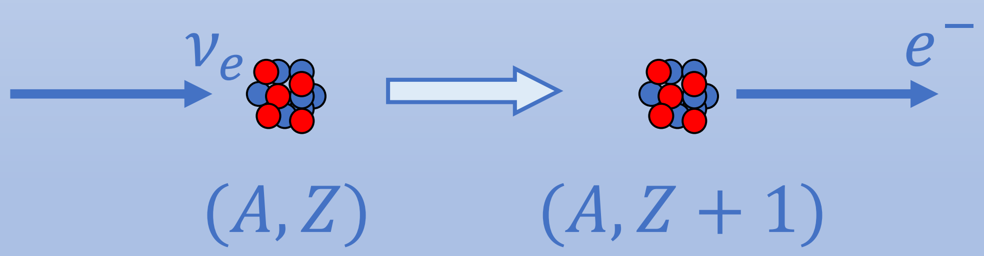
Is it possible to detect 0.001 eV neutrinos?

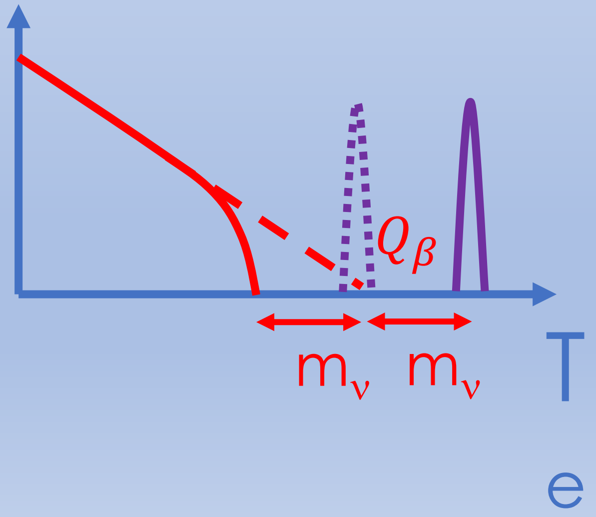
Detection principle

A new idea







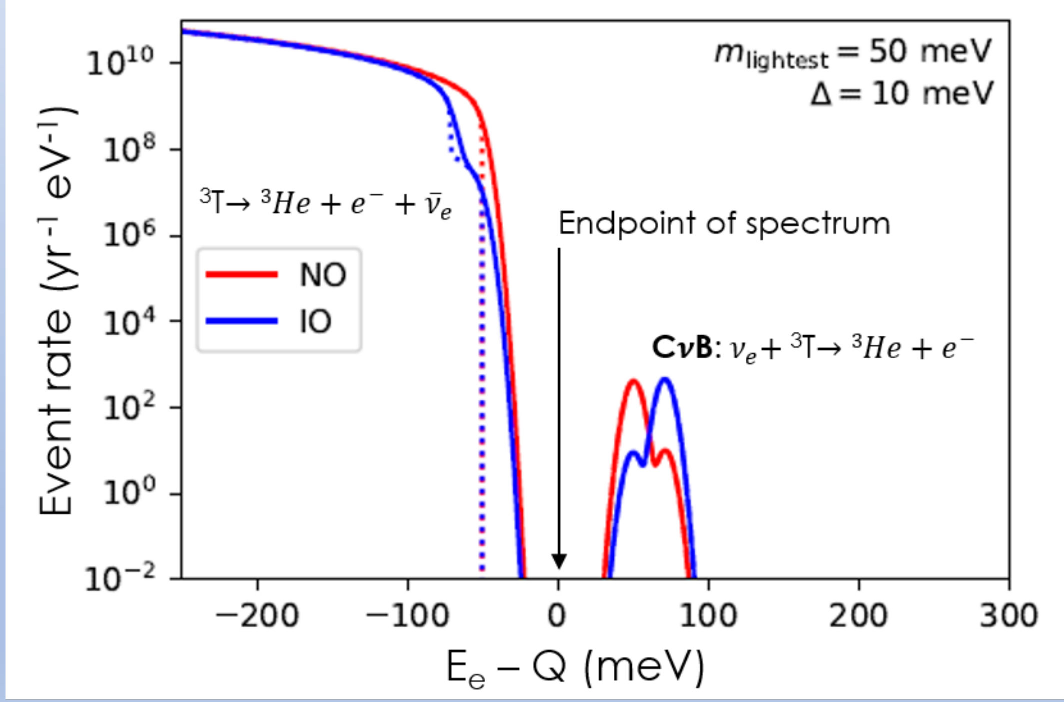


A.G.Cocco, G.Mangano and M.Messina JCAP 06(2007) 015

Why Tritium target?

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

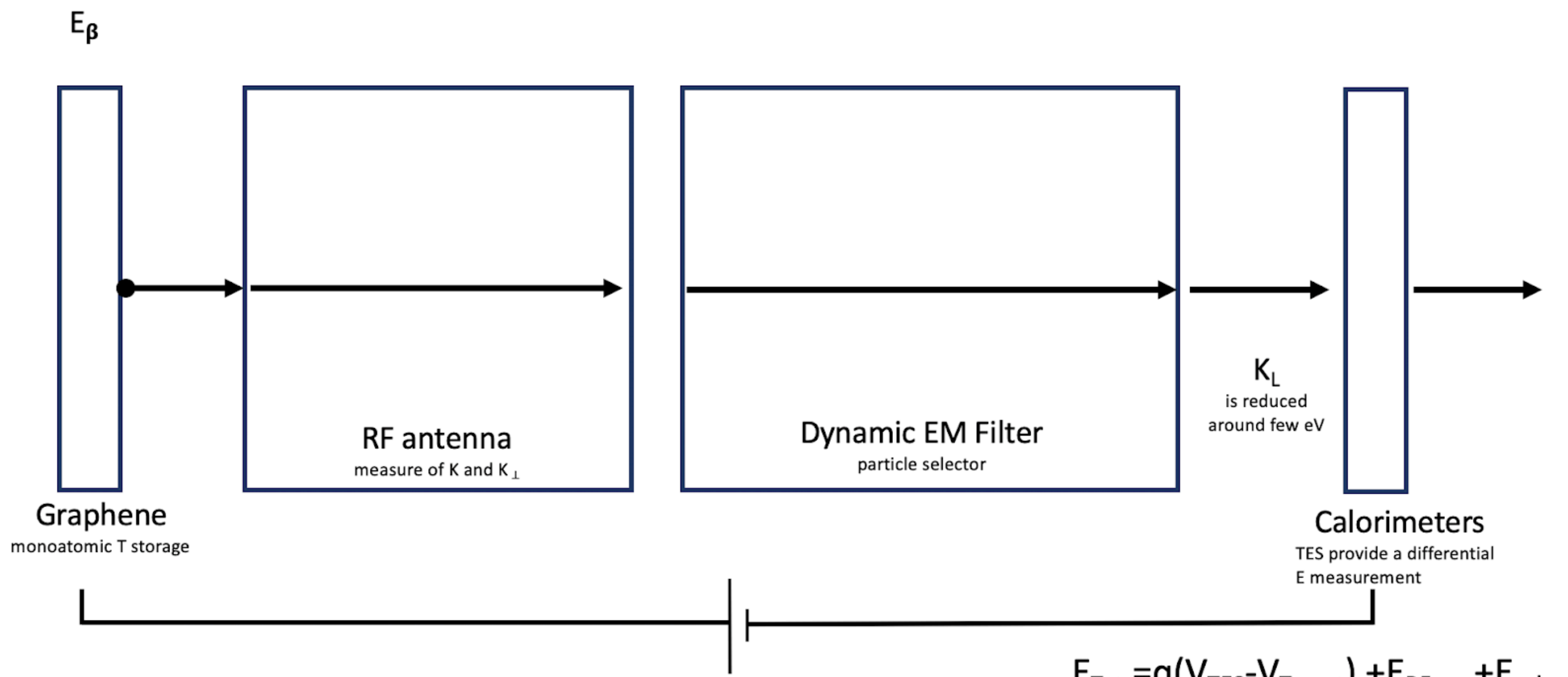
PTOLEMY collaboration JCAP07(2019)047



PTOLEMY experiment

- Goal:
  1. Find evidence for CνB
  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

PTOLEMY: experiment layout



$$E_{Tot} = q(V_{TES} - V_{Target}) + E_{RFcorr} + E_{cal}$$

PTOLEMY: measurement principle

M. G.Betti et al., Progress in Particle and Nuclear Physics, **106** (2019),120-131

Step 1

A new way of storing atomic T

Step 2

Electron RF emission is detected

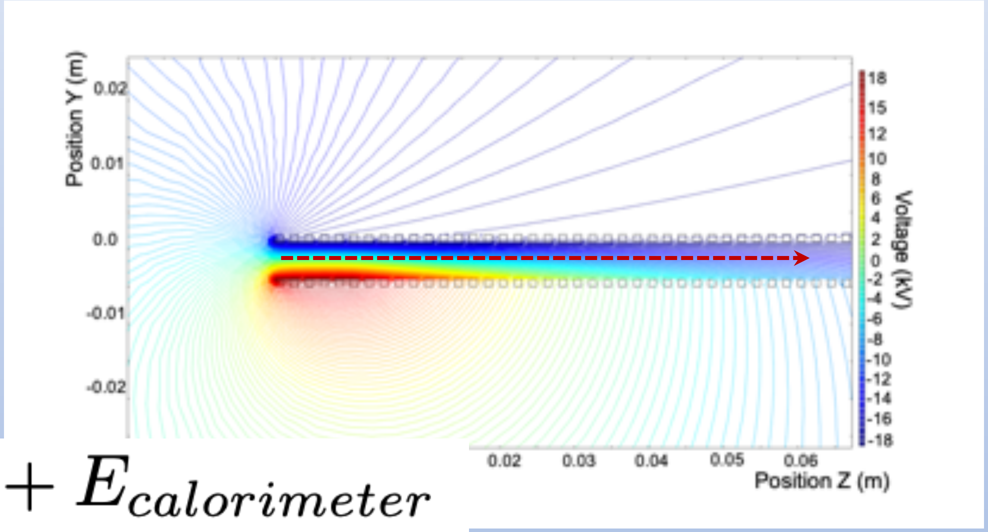
Trigger good particles and give a preliminary evaluation of E and P_T

$$2\pi f_c = \frac{qB}{m_e c^2} \cdot \frac{1}{\gamma}$$

$$P_{tot} = \frac{1}{4\pi\epsilon_0} \frac{8\pi^2 q^2 f_c^2}{3c} \frac{\beta_\perp^2}{1-\beta^2}$$

Step 3

Field properly set on ms time scale: the transverse kinetic energy is removed by pushing the particle on an electrostatic potential hills. Thus particle in the ROI moves on a straight trajectory while those out of ROI will end up on one of the electrodes.



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

$$\mathbf{V}_D = \mathbf{V}_\perp = \left(qE + F - \mu\nabla B - m\frac{d\mathbf{V}}{dt}\right) \times \frac{\mathbf{B}}{qB^2}$$

$$\frac{dT_\perp}{dt} = -qE \cdot V_D = -qE\,(qE - \mu\nabla(B)) \times \frac{B}{qB^2} \qquad \mu = \frac{mv_\perp^{*2}}{2B}$$

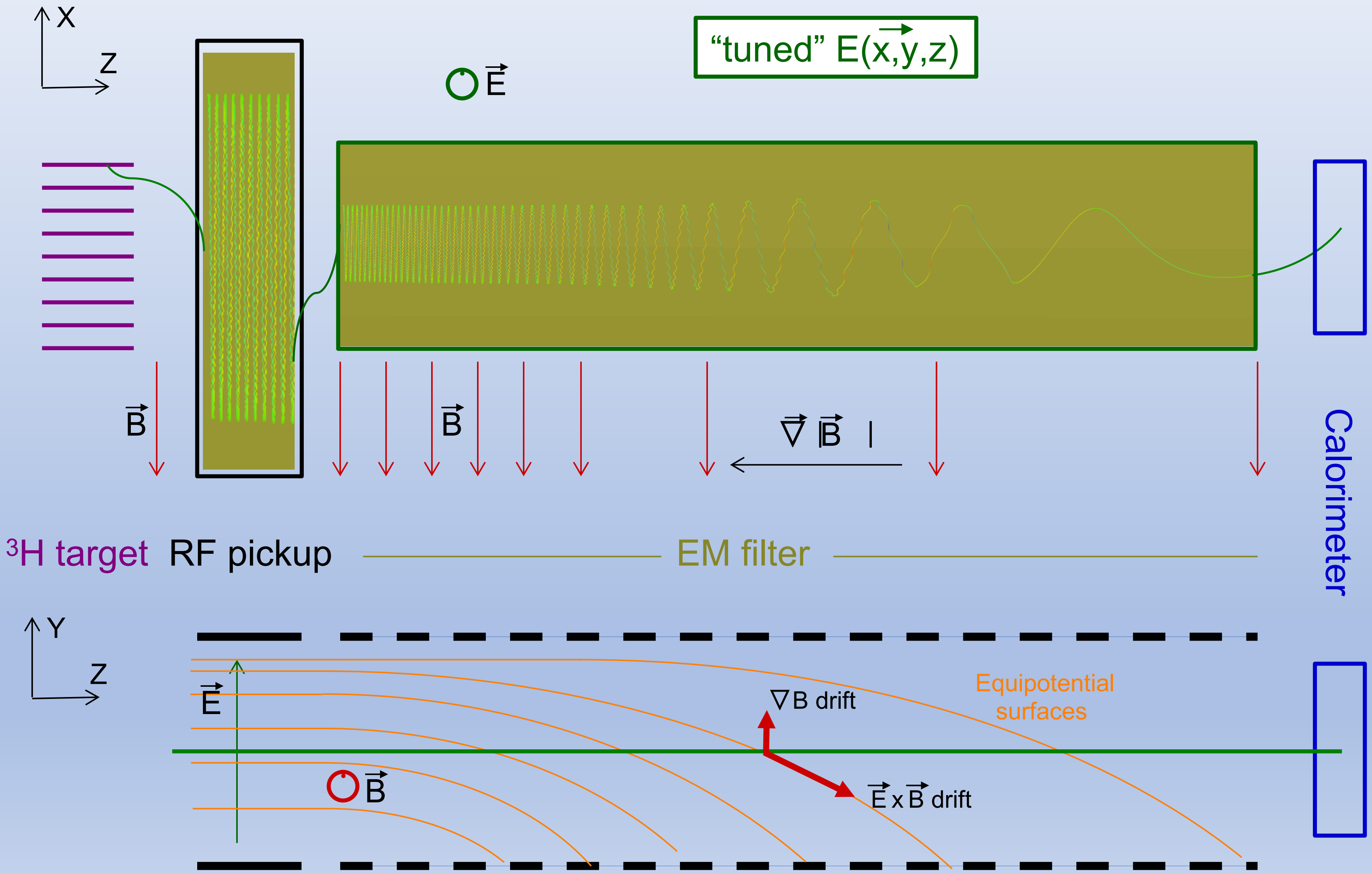
Between Step 3-4

Electrostatic barrier will reduce T_L

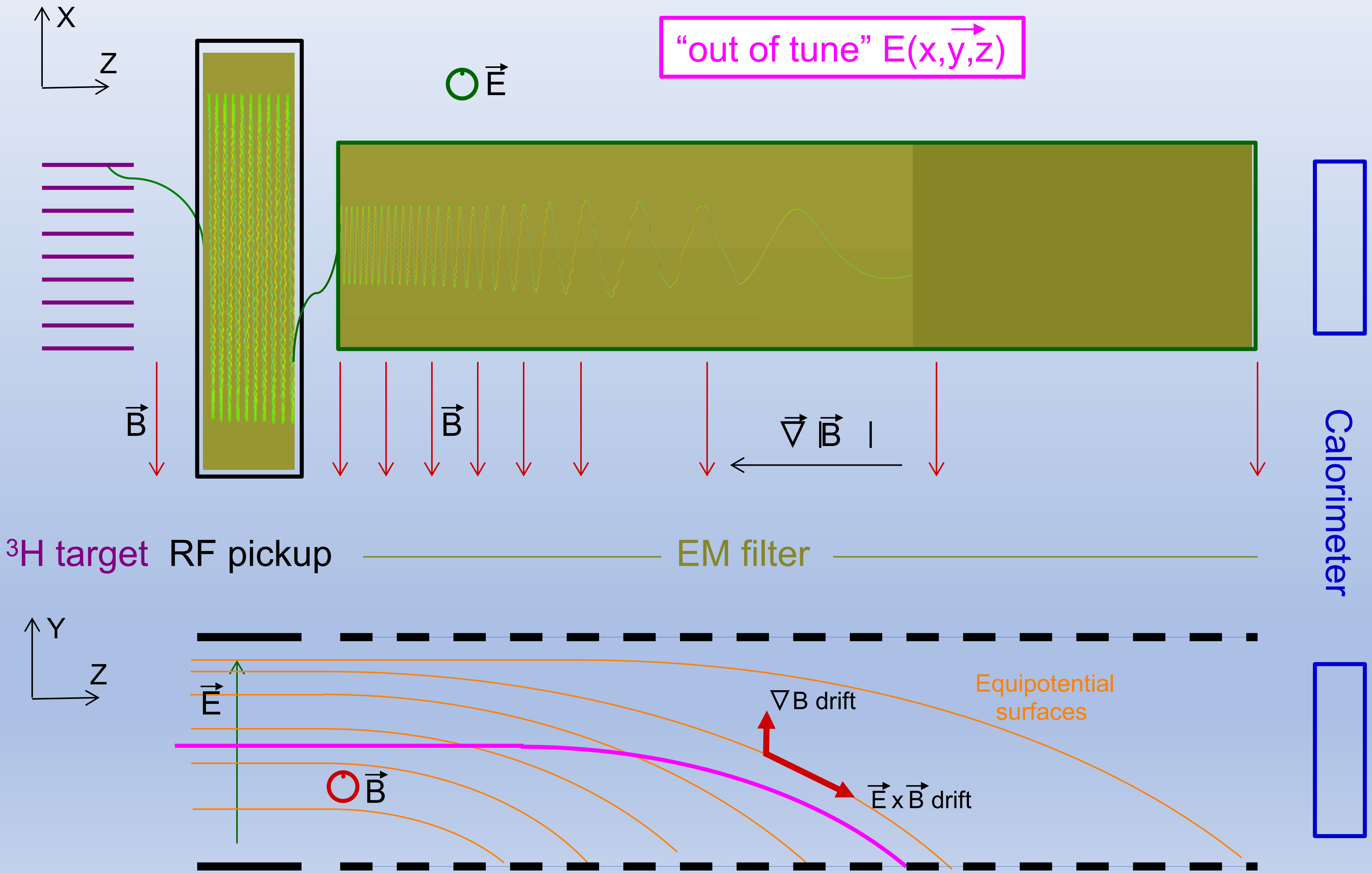
Step 4

The particle is driven into the TES: $T_{tot}=q(V_{anode} - V_{source}) + E_{cal}$

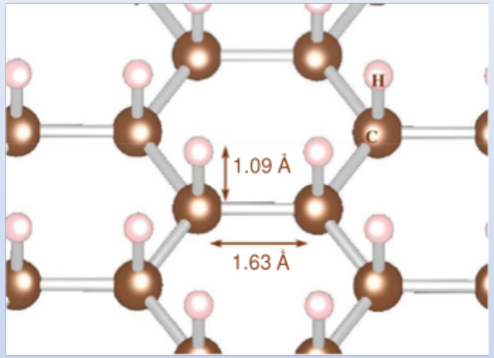
New concept EM filter
Dynamic tuning



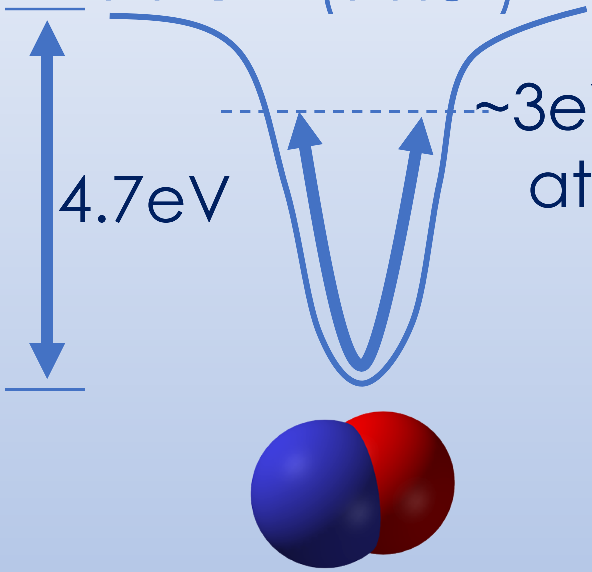
New concept EM filter
Dynamic tuning



Features of T storage



T-T → $(T\text{-}He^3)^*$

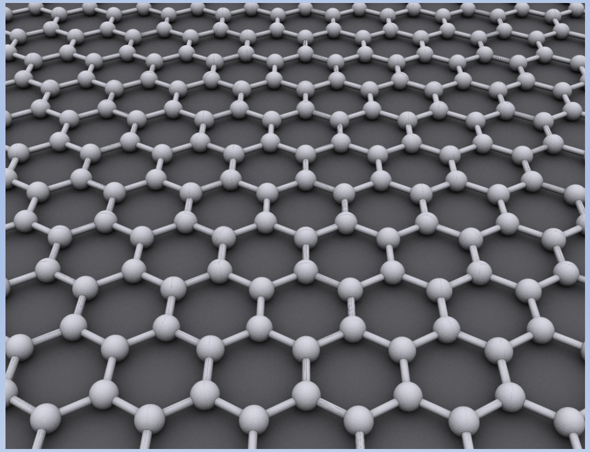


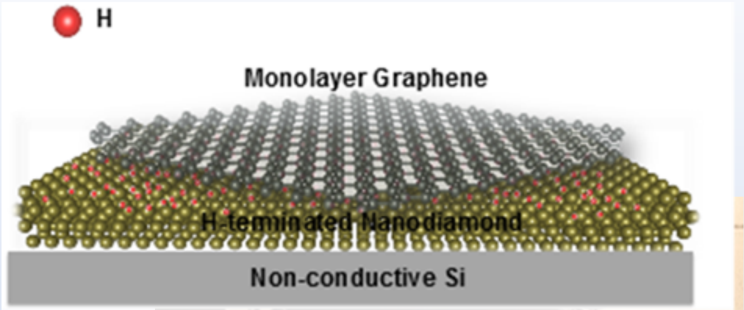
4.7eV

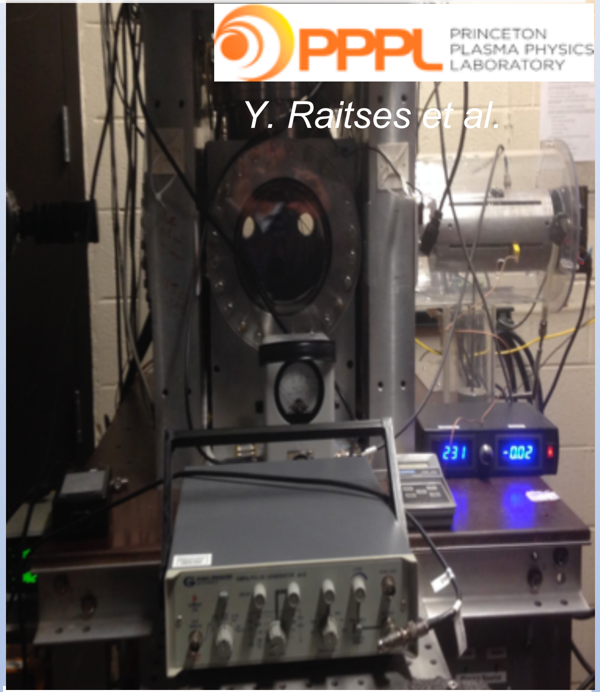
~3eV He^3 recoil at endpoint

<3eV binding energy

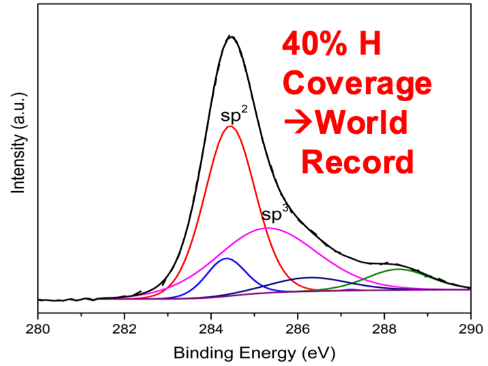
Graphene



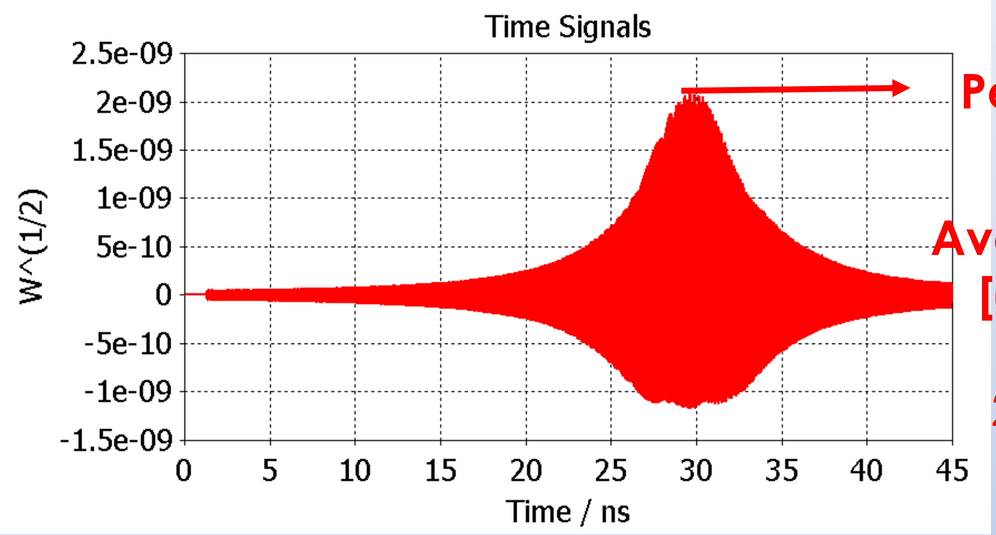




XPS Hydrogenation Results from Princeton



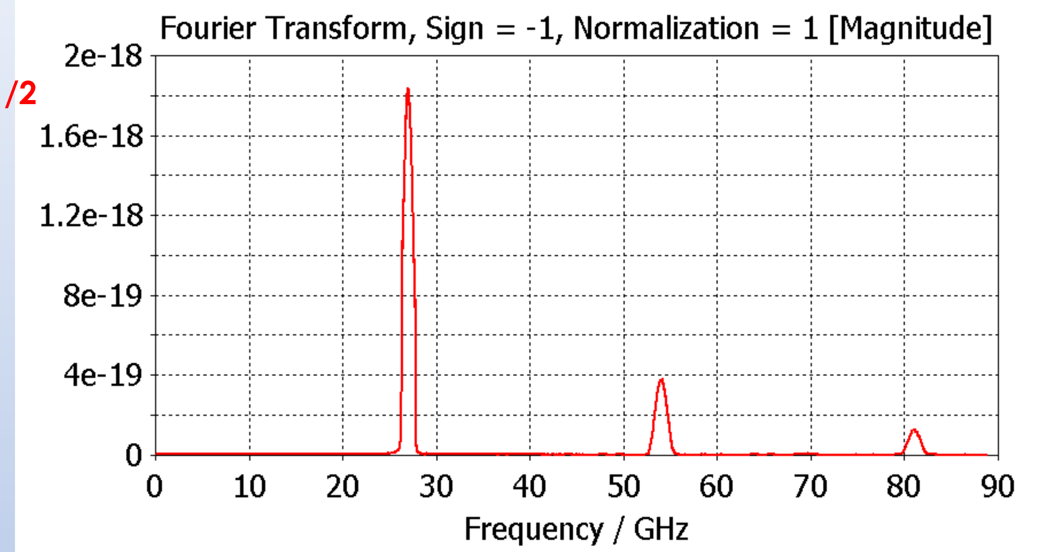
PIC – Outgoing power from the waveport in the fundamental mode



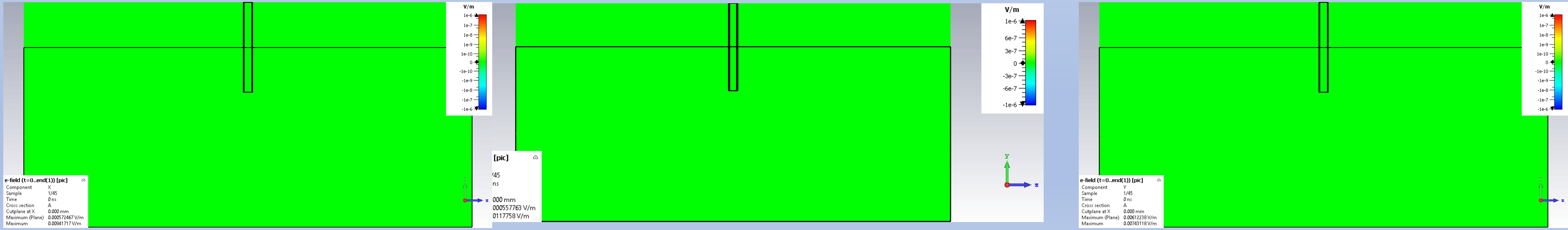
Peak: 2e-09 $W^{1/2}$

Average Power: [(Peak)^2]/2

2e-18 Watt

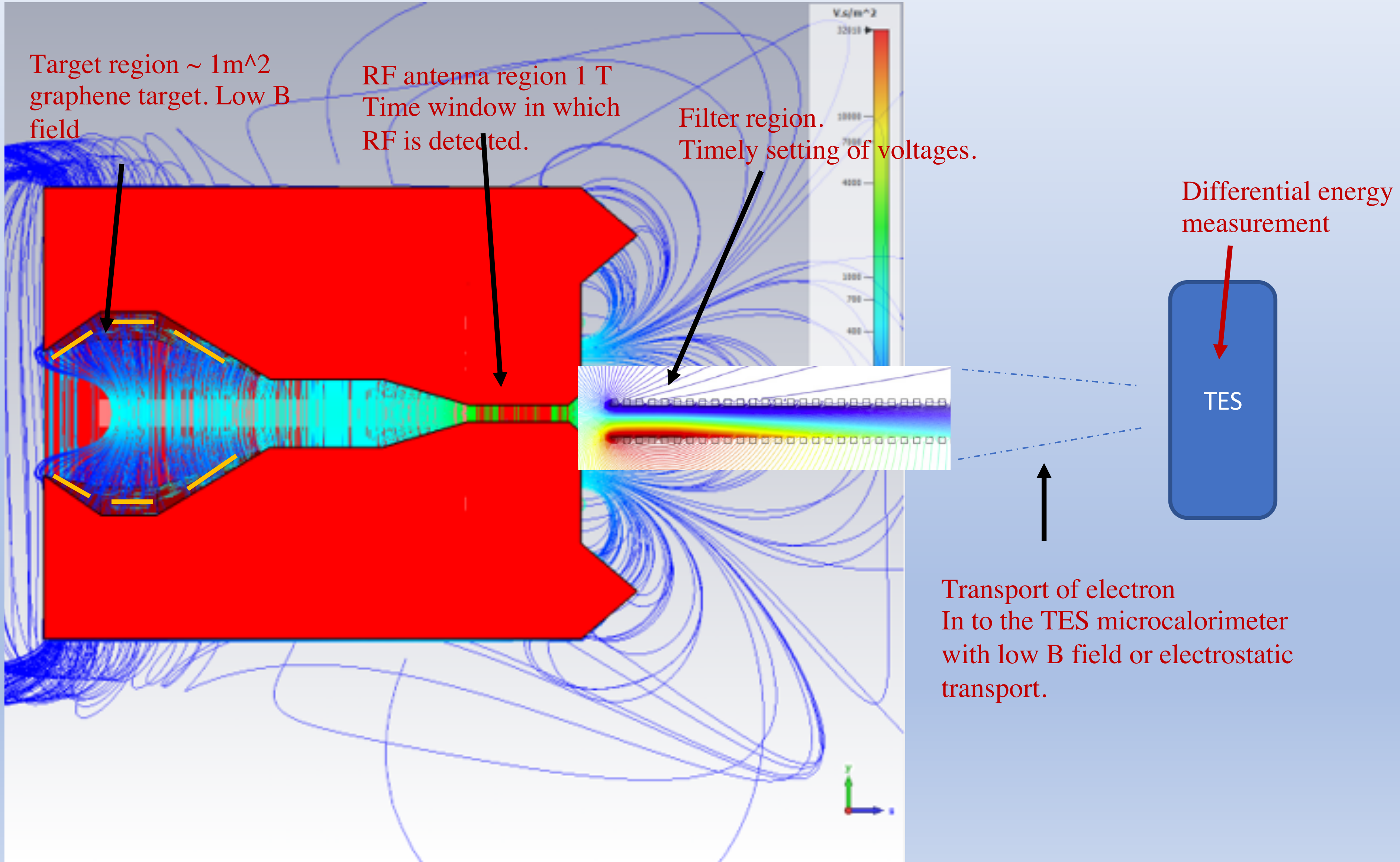


Electric field cartesian components, yz plane (medium plane), <u>one frame every 1 ns</u>

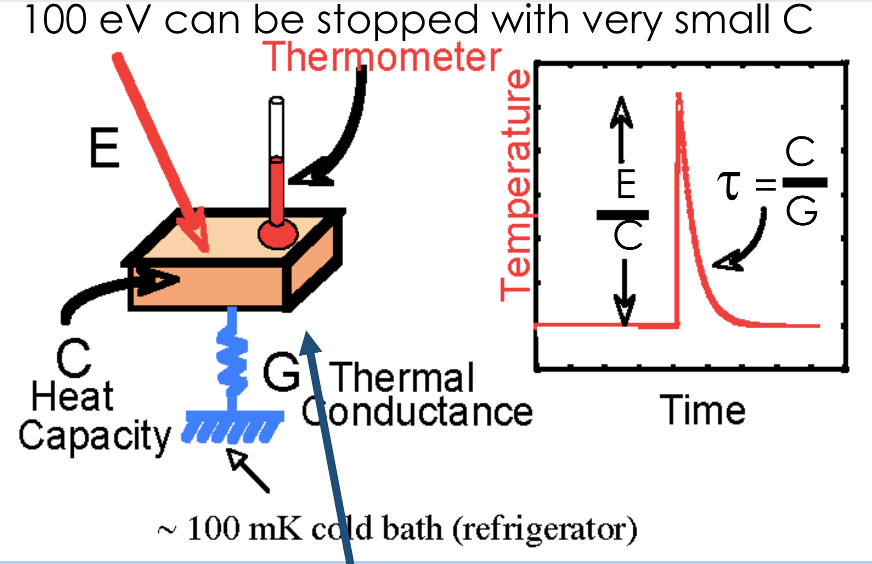


Magnet geometry under study

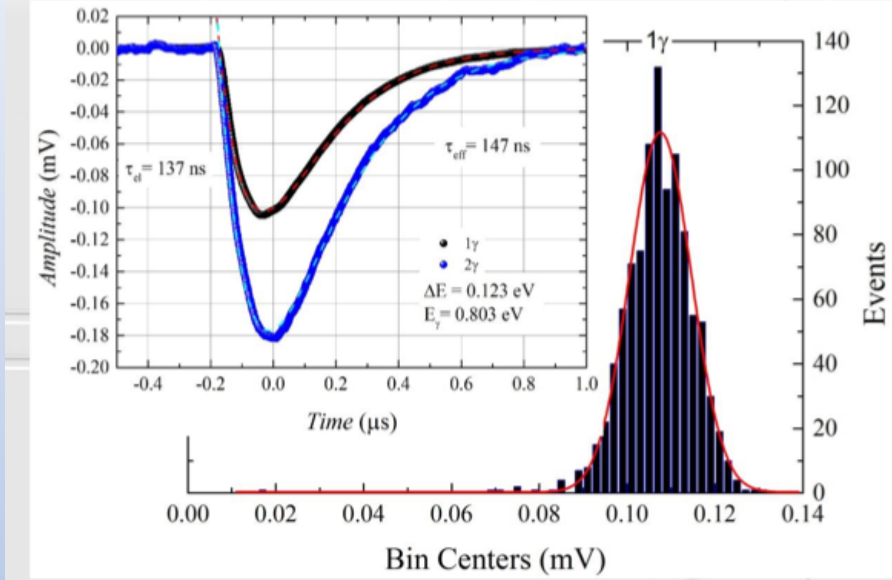
This is a key ingredient to realize efficiently the whole elector transport form graphene support to the RF region then to the filter and finally to the TES.



Calorimetric measurement
based on Transition Edges Sensors technology



100 eV electron can be stopped in a very small absorber absorber i.e. small C



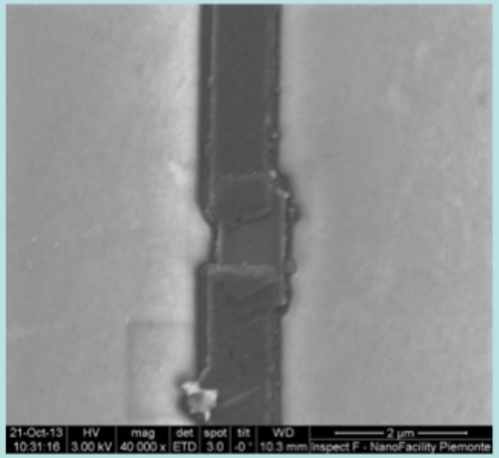
τ_{etf} = 147ns

ΔE_{FWHM} = 0.12 eV @ 1545nm

Results from INRIM (Torino) - Istituto Nazionale di Ricerca Metrologica

$\sigma_E = 0.05\,\mathbf{eV}$

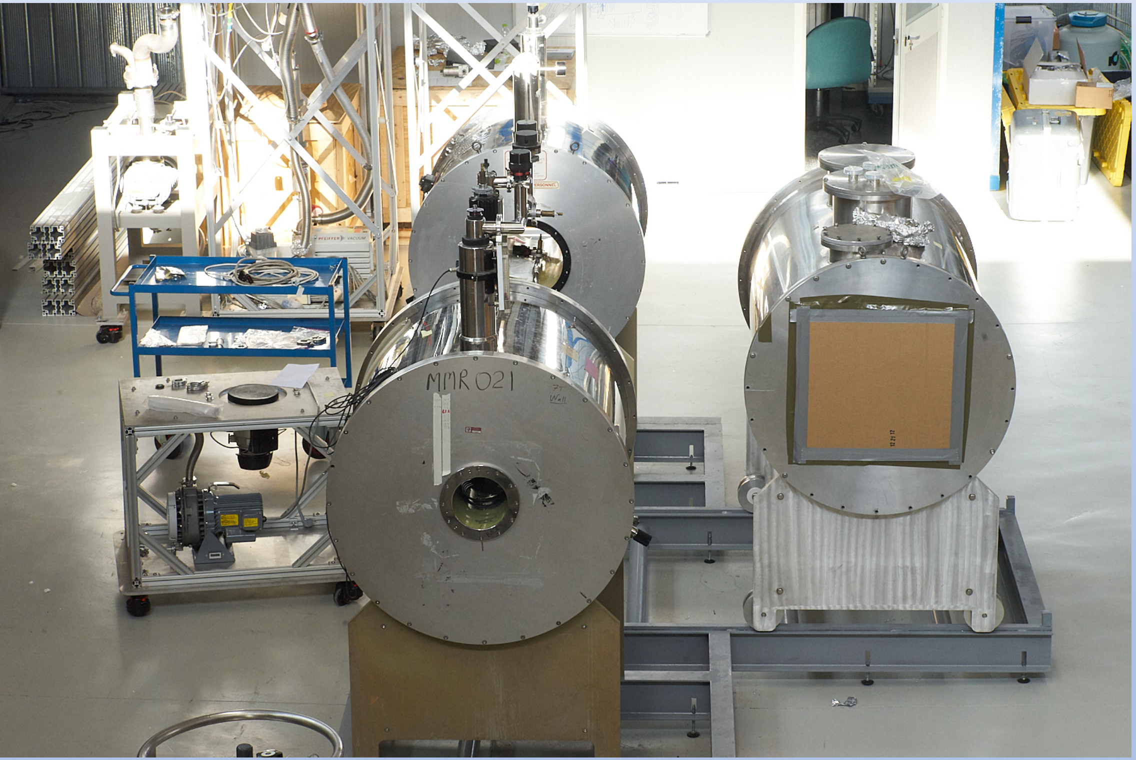
1 µm × 1 µm



C. Portesi *et al*, IEEE Trans App Supercond, 25, 3, (2015)

Experimental site at LNGS

detection idea under development



7 countries 23 institutes and 55 physicists

Germany

KIT

Israel

The Racah Institute of Physics

Italy

INFN Laboratori Nazionali del Gran Sasso
GSSI
Torino INFN and INRiM
Universita' di Genova and INFN-GE
Universita' di Milano-Bicocca and INFN-Milano-Bicocca
Universita' di Napoli Federico II and INFN-NA
Universita' di Pisa
Universita' di ROMA La Sapienza and INFN-RM1
Universita' di ROMA3 and INFN
INFN Torino

Spain

CIEMAT
Consejo Superior de Investigaciones Cientificas (CSIC)
Instituto de Fisica Corpuscular (IFIC)
Universidad Politecnica Madrid

Sweden

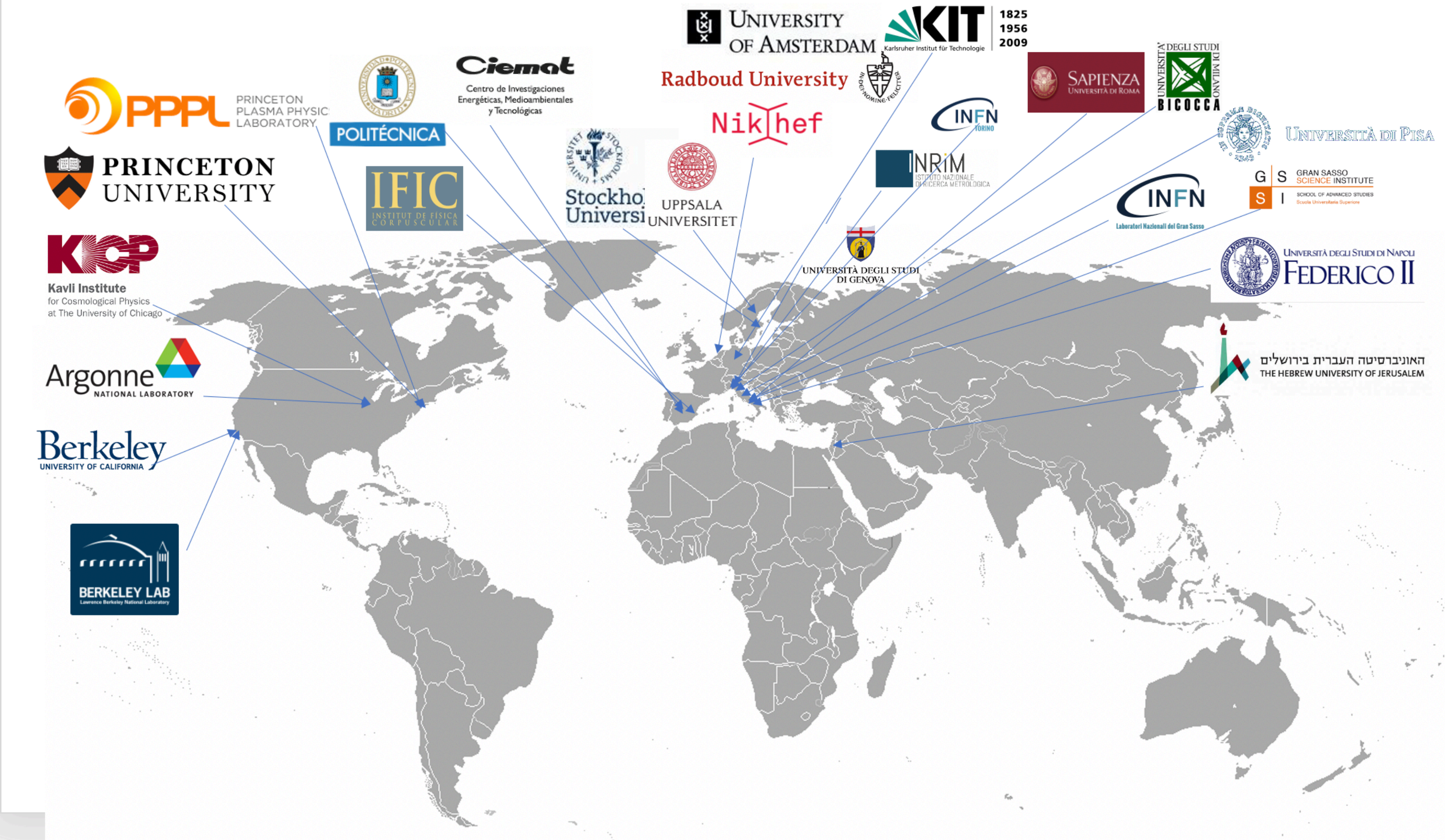
Stockolm University
Uppsala University

The Netherland

Nikhef
Univeristy of Amsterdam

USA

Argonne National laboratory(ANL) and Kavli Institute(KICP)
University of California Berkeley and Berkeley National Laboratory (BNL)
Princeton Plasma Physics laboratory (PPPL)
Princeton University



To Conclude

1. Something completely different

2. Physics program: **Relic Neutrino's, Light DM, Neutrino mass**

3. Technological challenge: **New support for T**, **extreme high rate, extreme energy resolution**

1) M. G.Betti et al.,
"A design for an electromagnetic filter for precision energy measurements at the tritium endpoint",
Progress in Particle and Nuclear Physics, **106 (**2019),120-131

2) M. g. Netti et al.,
"Neutrino Physics witht eh PTOLEMY prtoject",
JCAP_047P_0219