PTOLEMY

NEUTRINO 2022

XXX International Conference on Neutrino Physics and Astrophysics

Virtual Seoul May 30 (Mon) - June 4 (Sat), 2022

The PTOLEMY NEW Results and Status

M Messina on behalf of the PTOLEMY collaboration

OUTLINE

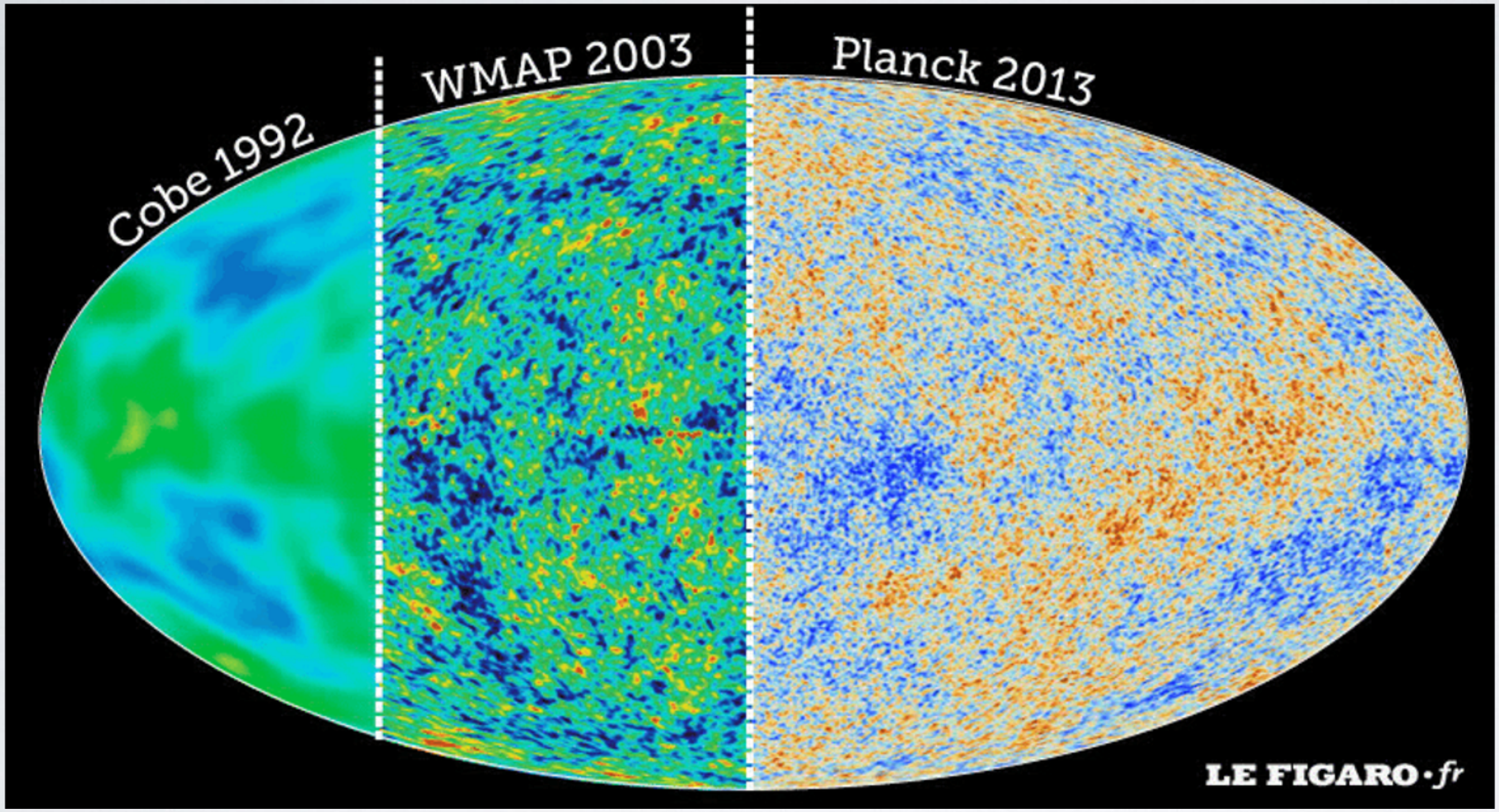
- Short physics introduction

- PTOLEMY detector concept

- Conclusion and Outlook

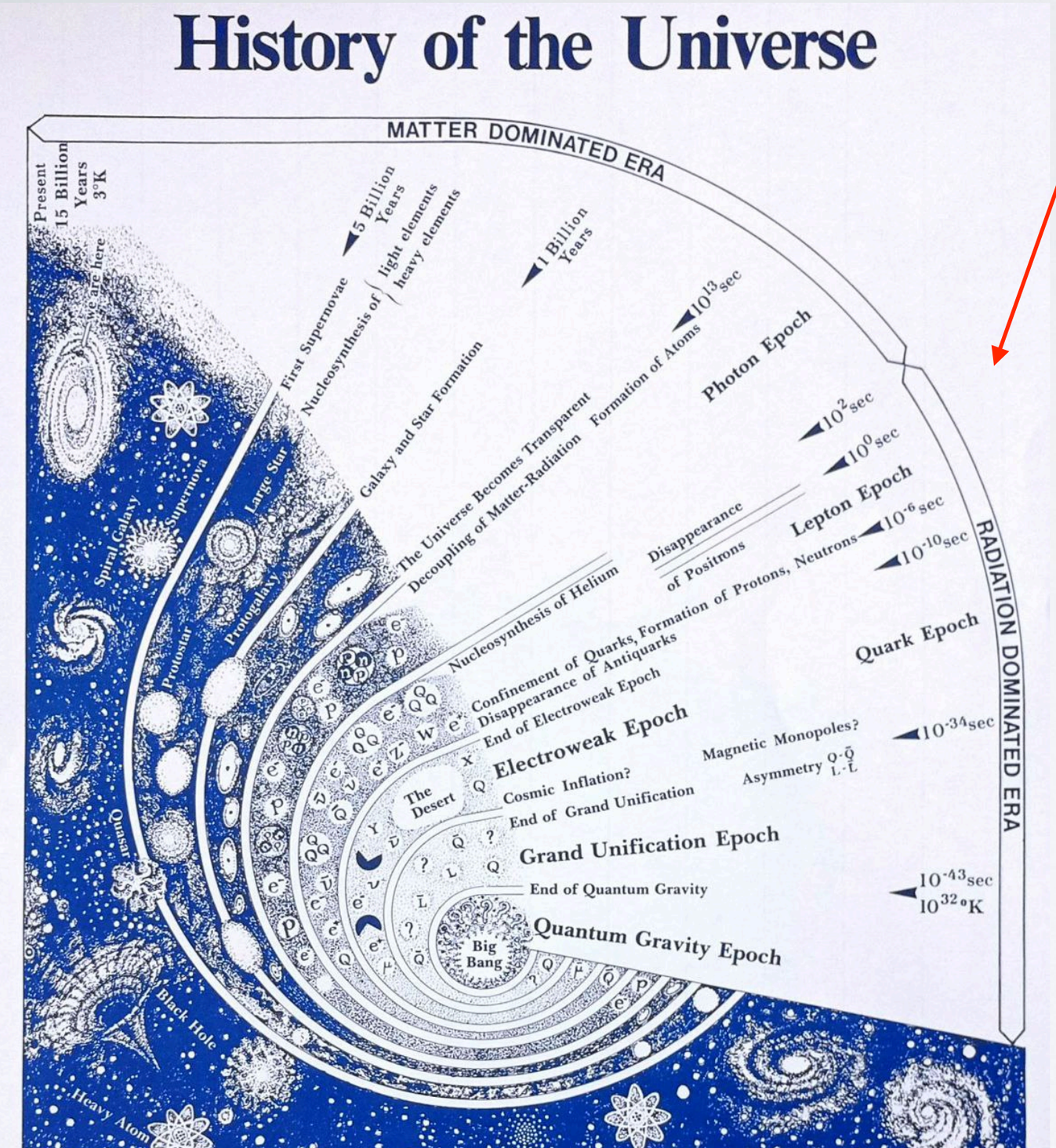
The Gold-mine of Cosmologist

CMB: The oldest electromagnetic radiation in the universe



- Universe is **expanding**: Hubble's law: $v = H_0 D$ (~70 km/s/Mpc), 1919.
- **Cosmic microwave background**, Penzias & Wilson, 1964
- Abundance of **primordial elements**: ^4He, ^2H, ^7Li (?)
- **Galaxies morphology** and stars populations in time
- **Primordial gas cloud** (without heavy elements), 2011

The Big Bang



ν decoupling

The present Universe emerges from an Ultra-dense and high temperature initial state

Time of decoupling:

1 second

neutron/proton ratio

@start of nucleosynthesis

Temperature:

T_ν=1.95 K

Number density:

n_ν=112/cm^3

Velocity distribution:

$\langle v_\nu \rangle \sim T_\nu/m_\nu$

NEUTRINO FEATURES

- What we <u>do know</u> about neutrinos:

they are massive

well measured Δm_i^2

cosmic neutrino background
should be out there

- What we <u>don't know</u> about neutrinos:

absolute mass scale
$(m_\nu < 0.8$ eV)

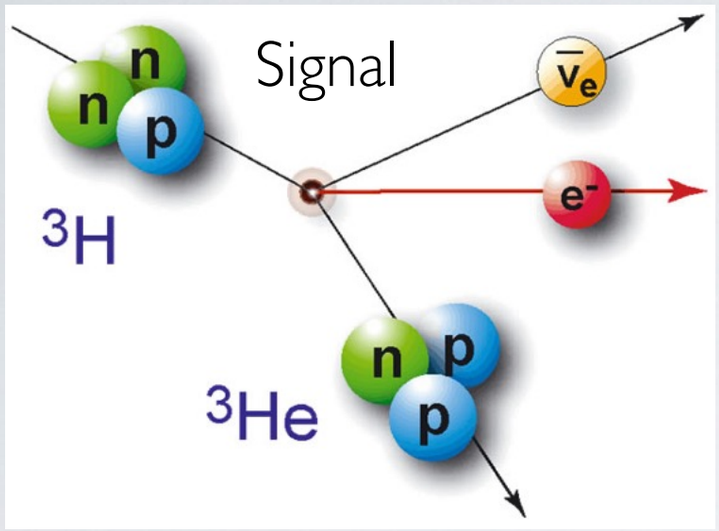
[KATRIN — Nature Phys. 2022, 2105.08533]

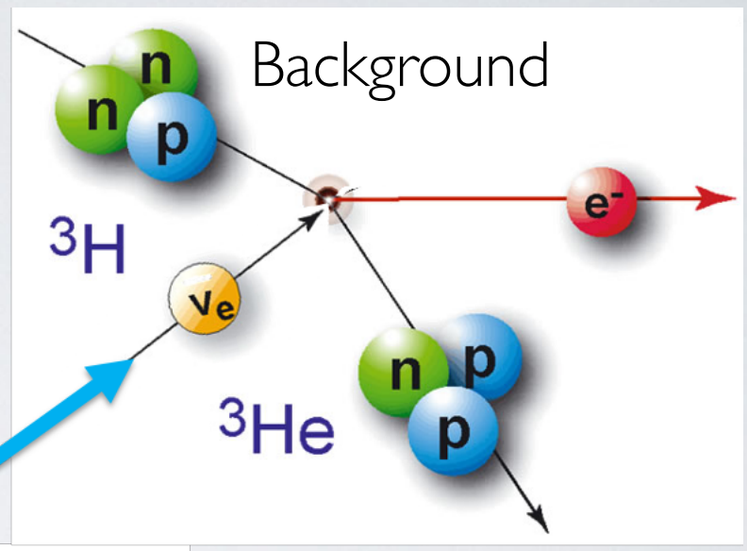
mass ordering
$(50\ meV < m_{\text{light}} \simeq m_e$ or $m_\tau)$

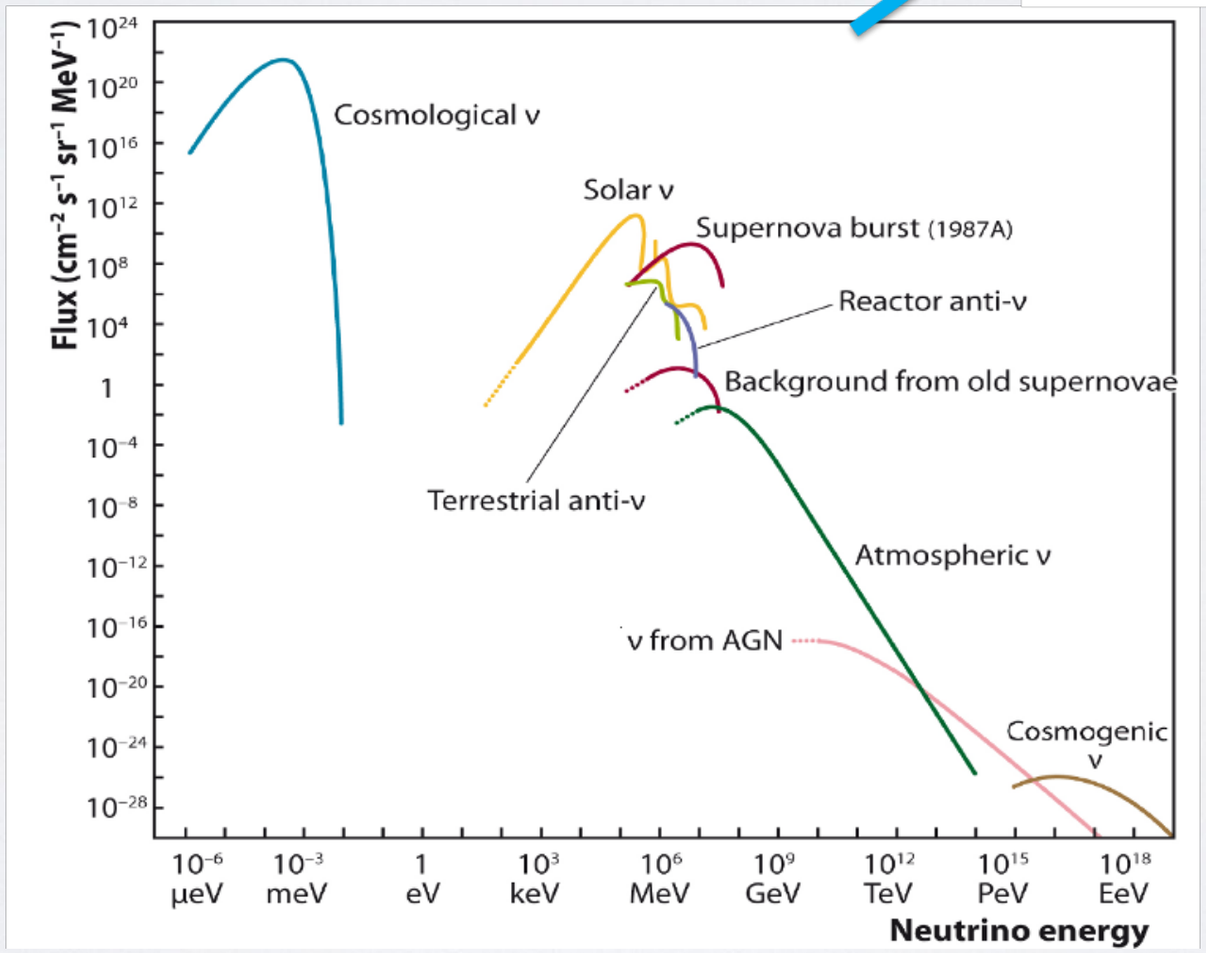
From Cosmology several
limits at 95 % CL on Σm_ν
from 0.56 to 0.11 eV

cosmic neutrino background
yet to be seen

PTOLEMY - RELIC NEUTRINO DETECTION STRATEGY





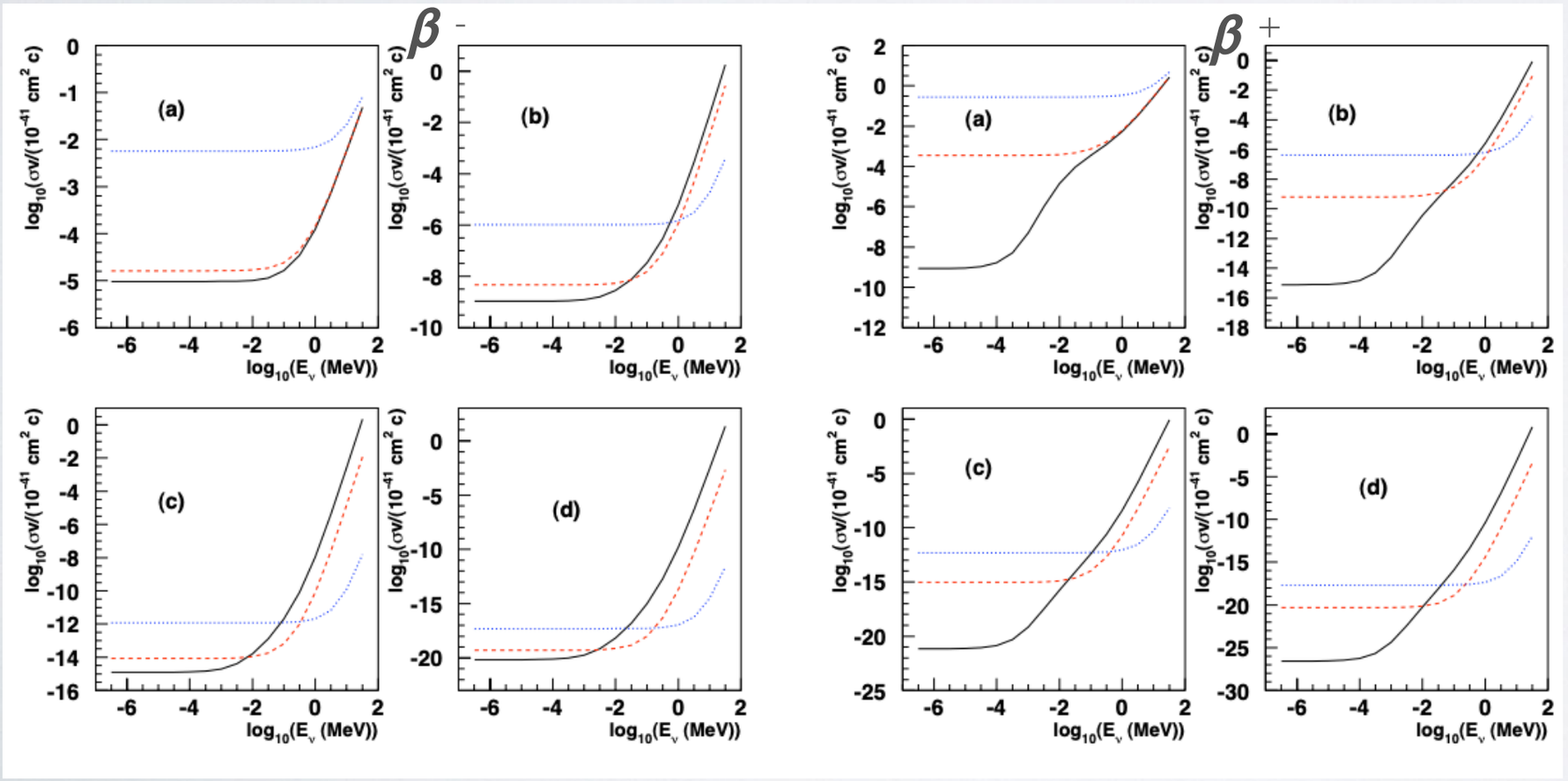


CROSS-SECTION

- Tritium has the largest product of capture cross section and lifetime

$$^3\mathrm{H} \rightarrow {}^3\mathrm{He}^+ + e^- + \bar{\nu}_e$$

$$\nu_e + {}^3\mathrm{H} \rightarrow {}^3\mathrm{He}^+ + e^- \qquad (Q \simeq 18.6\ \mathrm{keV})$$



Detailed evaluation on 2007 of $\sigma \times \tau$ on

JCAP 06 (2007) 015

renewed the dormant discussion on relic neutrino detection and paved the way for a possible experiment.

Several authors confirmed the cross section evaluation and added informations:

J. Phys. G: Nucl. Part. Phys. 35 025001
JCAP 08 (2014) 038

On 1962 Weinberg made the hypothesis of neutrino capture in a different physics framework.

DECAY AND CAPTURE

- Tritium has the largest product of capture cross section and lifetime

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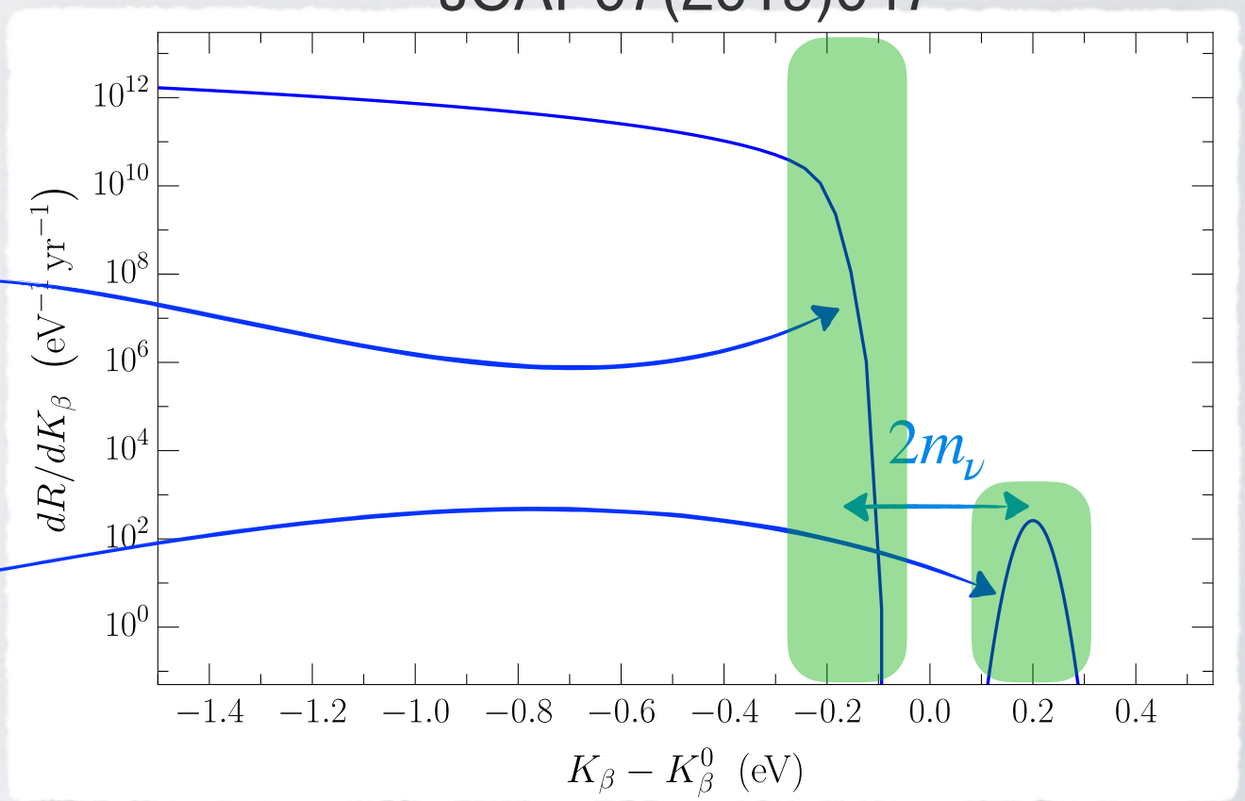
$$\nu_e + {}^3\mathrm{H} \rightarrow {}^3\mathrm{He}^+ + e^- \qquad (Q \simeq 18.6\ \mathrm{keV})$$

- For atomic tritium in vacuum:

measure m_ν from here
need high rate

smoking gun for cosmic neutrino background
need high energy resolution
large instrumented mass

JCAP07(2019)047



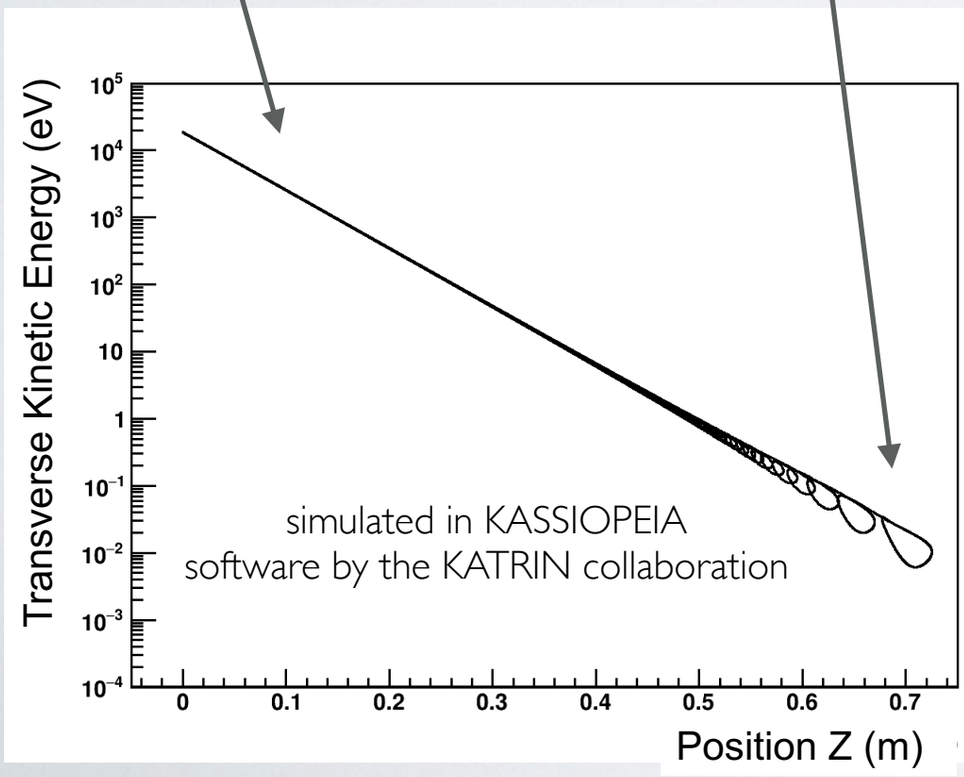
DETECTOR CONCEPT

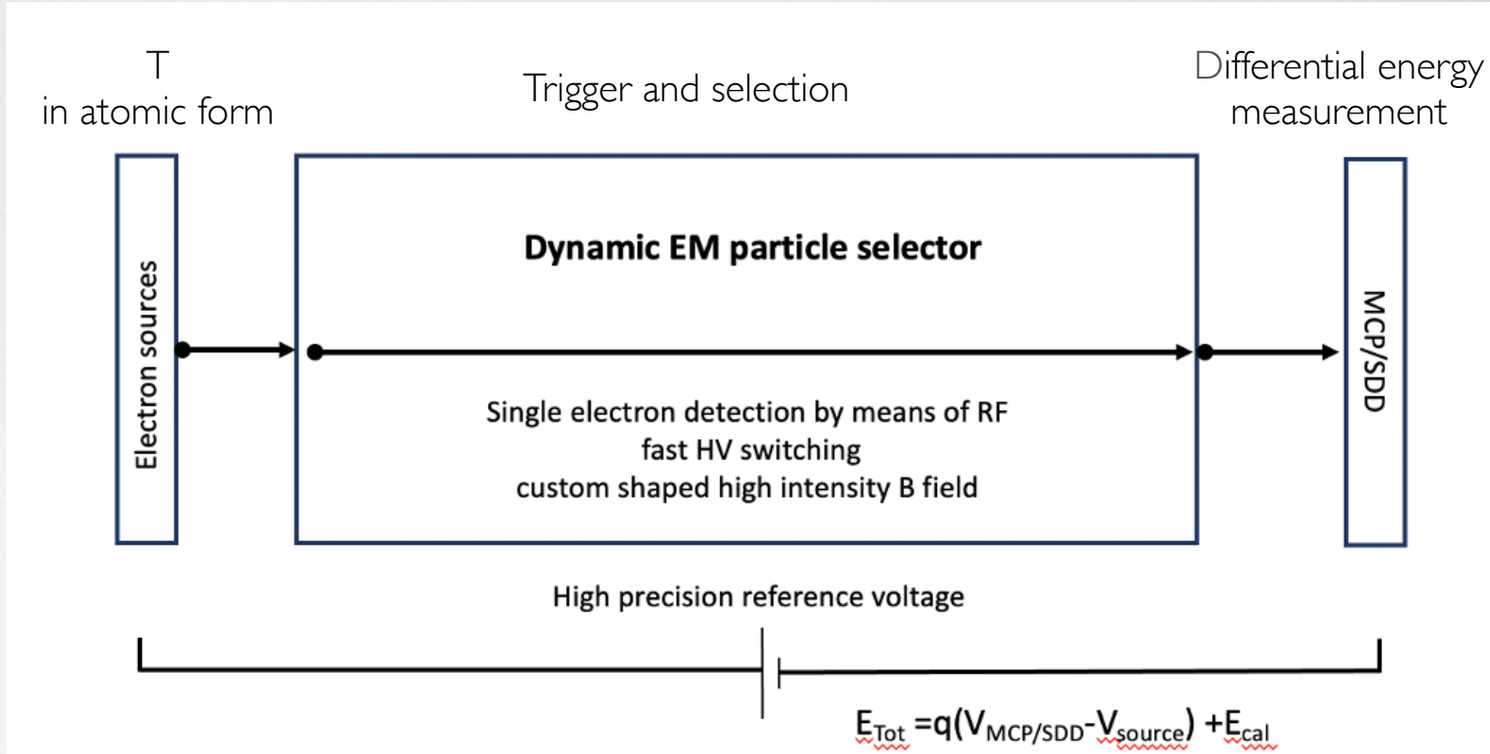
$$\frac{dT_\perp}{dt} = \frac{\mu}{B^2}\boldsymbol{E}\cdot(\boldsymbol{\nabla}B\times\boldsymbol{B})$$

Prog.Part.Nucl.Phys. 106 (2019) 120-131

JINST 17 (2022) 05, P05021

New concept: **Transverse drift filter**
18.6 keV ➠ 0.01 keV in 0.7 meters



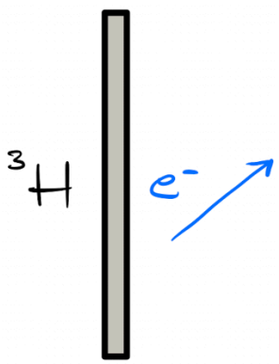


- PTOLEMY aims at using TES detectors with an envisaged resolution of $\Delta E \simeq 0.05$ eV
- However:
  1. TES' perform best with energies $O(10\text{ eV})$ need to slow the electrons down
  2. TES' are slow response detectors need to reduce the number of electrons coming from β-decay

PTOLEMY: THE IDEA

JINST 17 (2022) 05, P05021

- A new electromagnetic filter idea based on RF detection and dynamic E setting



By A. Esposito

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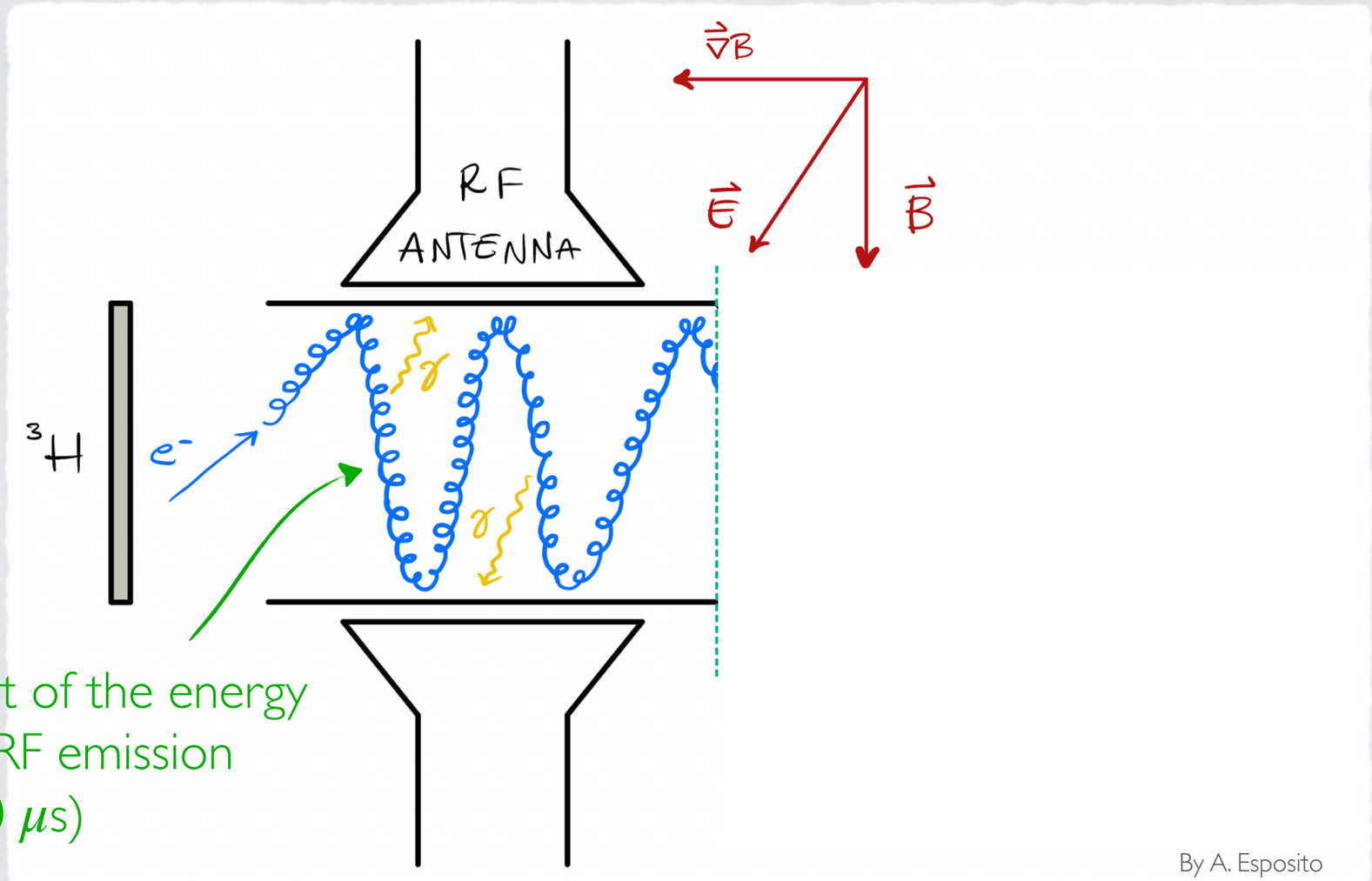

first measurement of the energy
via cyclotron RF emission
($\sim 10\ \mu s$)

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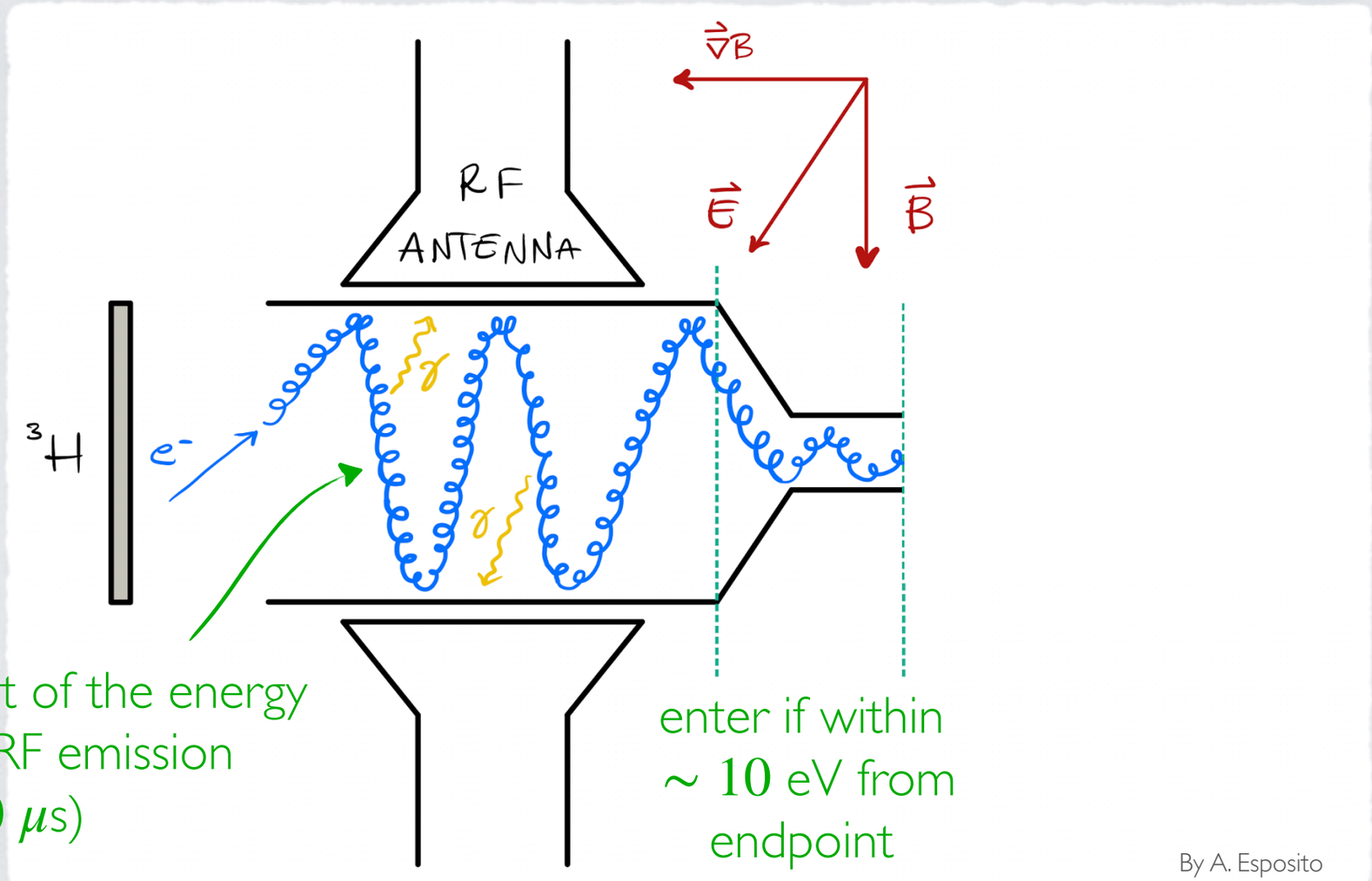

PTOLEMY: THE IDEA

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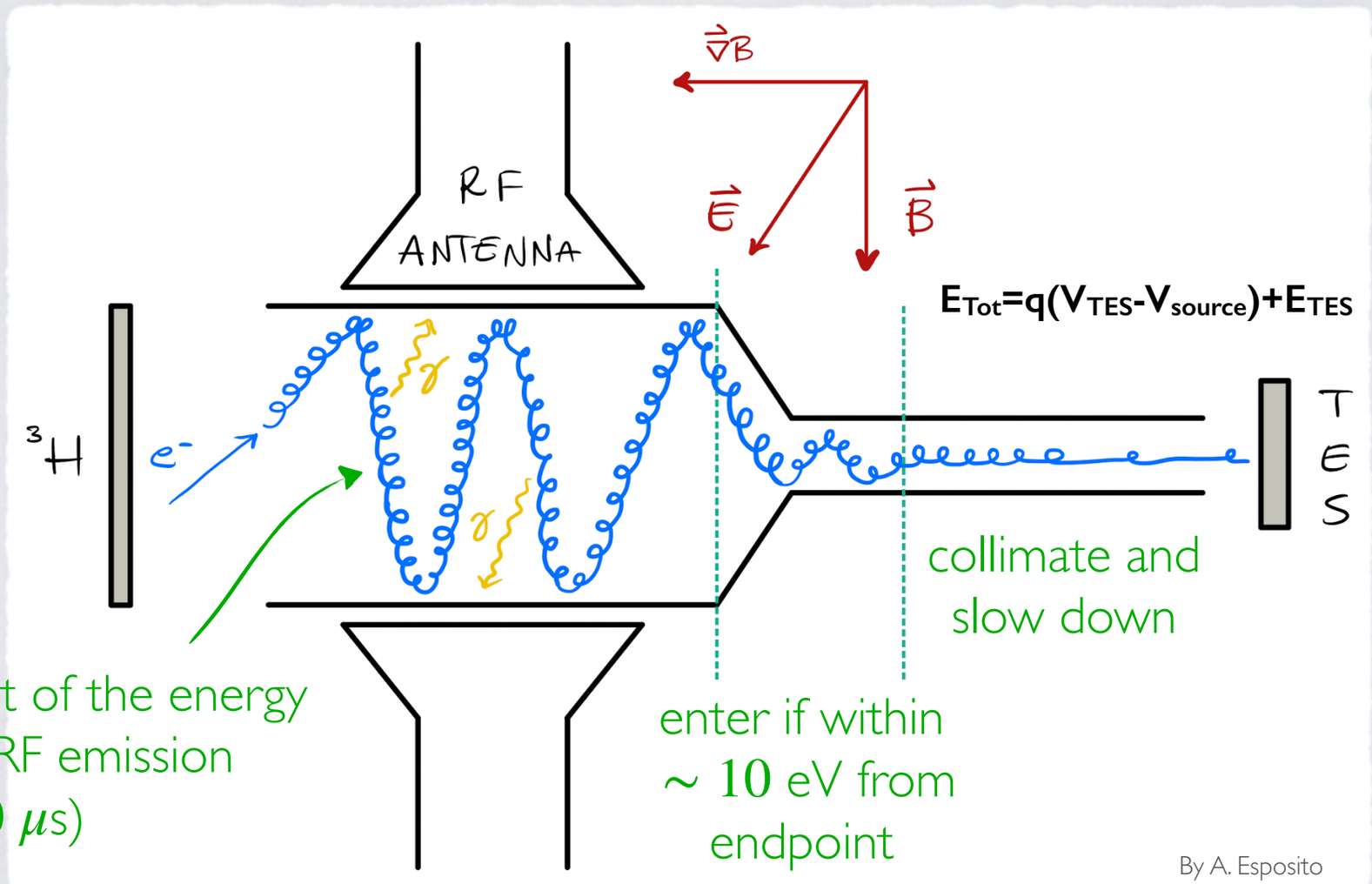
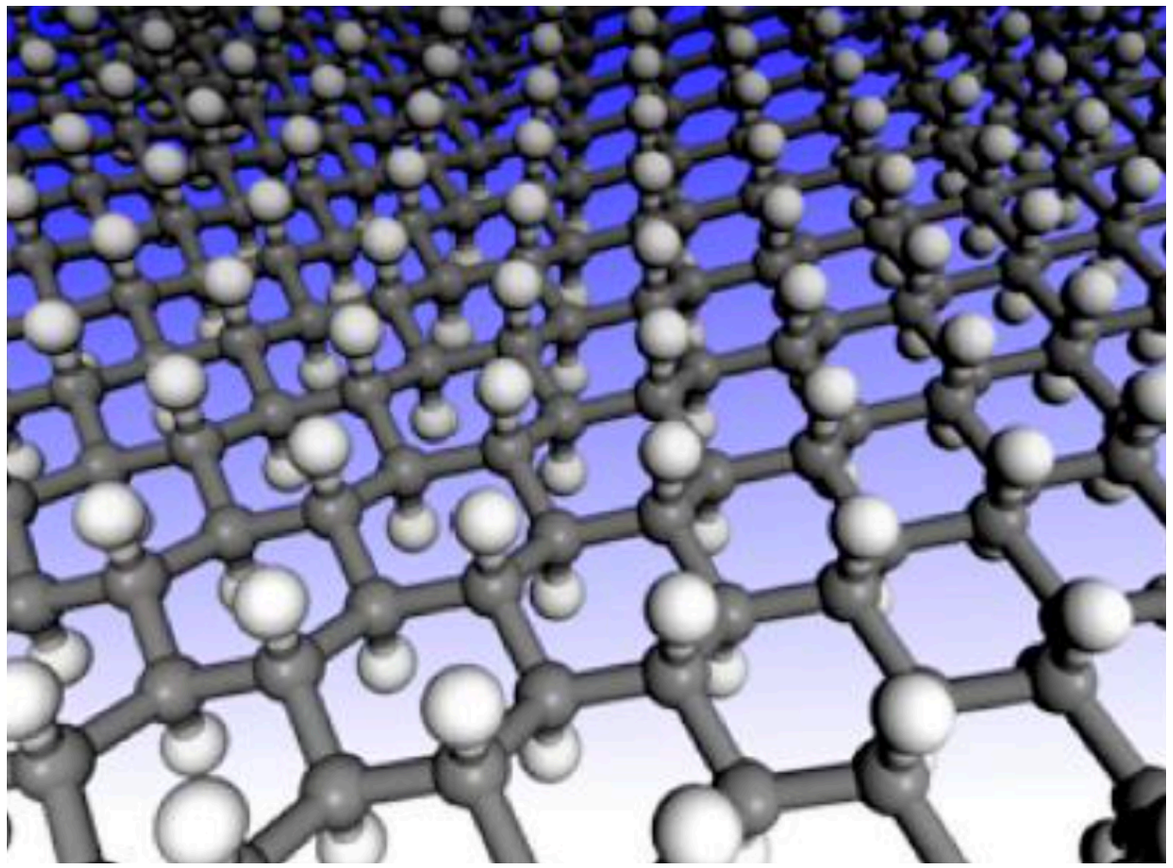
ΔV known to 1 ppm precision



PTOLEMY: ATOMIC T TARGET

- PTOLEMY has to deal with large instrumented mass. Distribute atomic tritium on a solid state substrate (e.g. graphene)



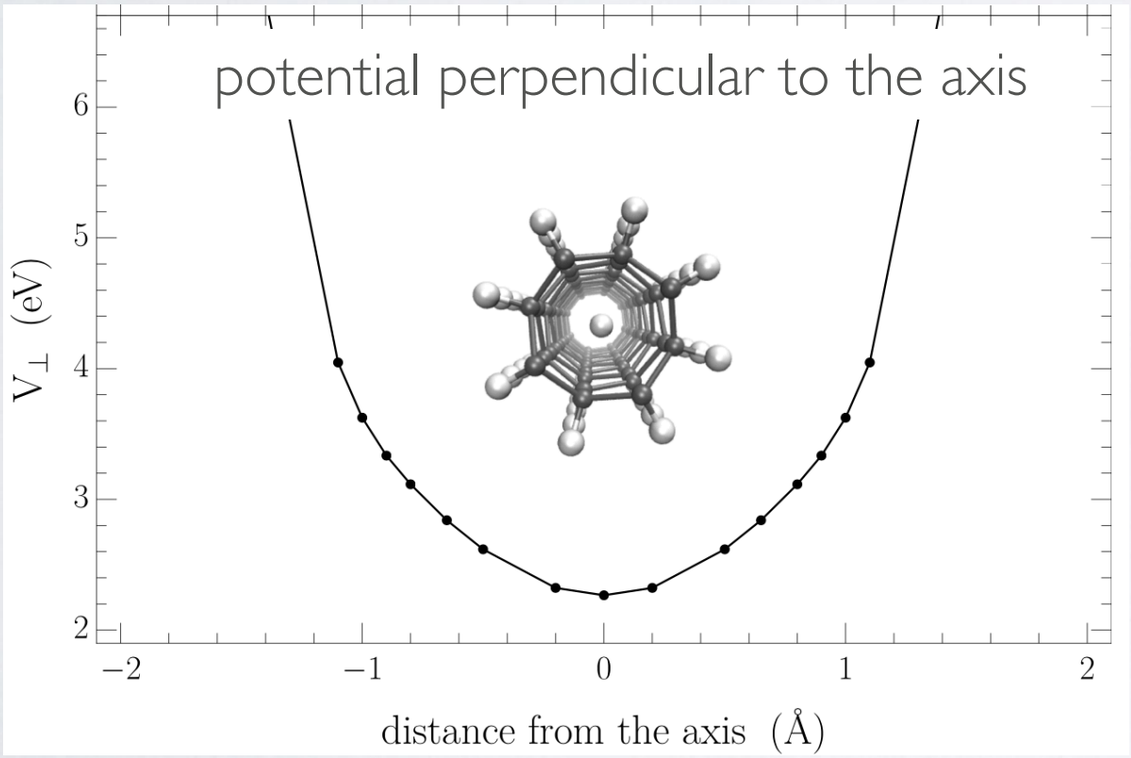
90% H loading demonstrated in the framework of the PTOLEMY R&D by Rome group (unprecedented value).
[see Betti et al. – Nano Lett. 2022]

ALTERNATIVES

- Preliminary studies show that this is a feasible solution
- When passivated with hydrogen,

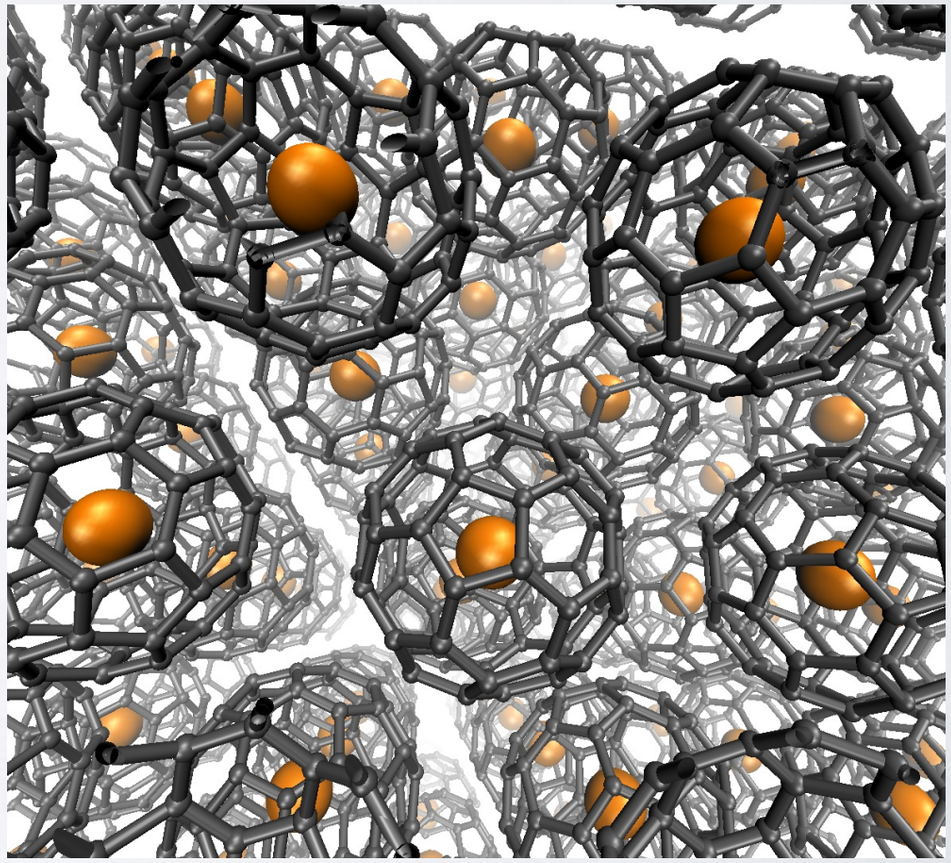
  the nanotube potential looks like

[PTOLEMY – 2203.11228]



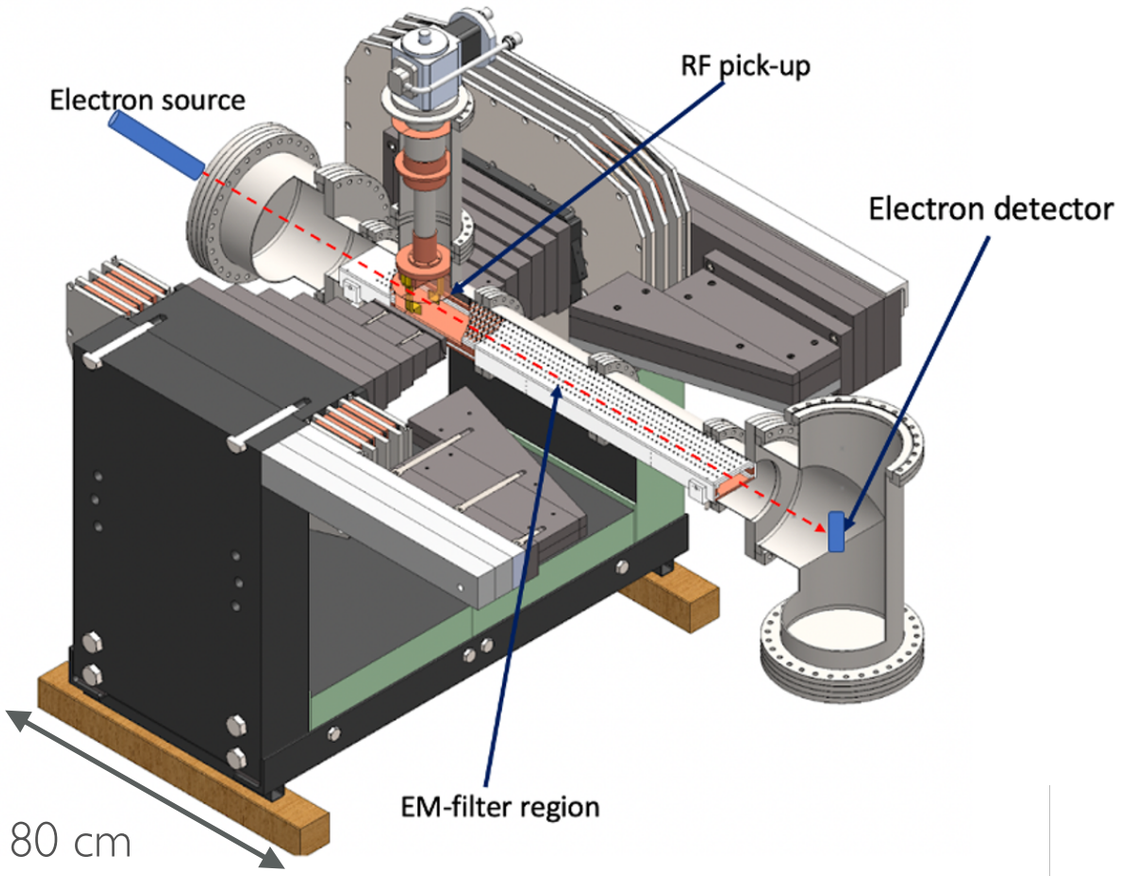
external B-field could also **prevent the formation of molecules** if two atoms are in the same nanotube

Fullerene sphere with **single T** atom
very promising even though prototypal idea

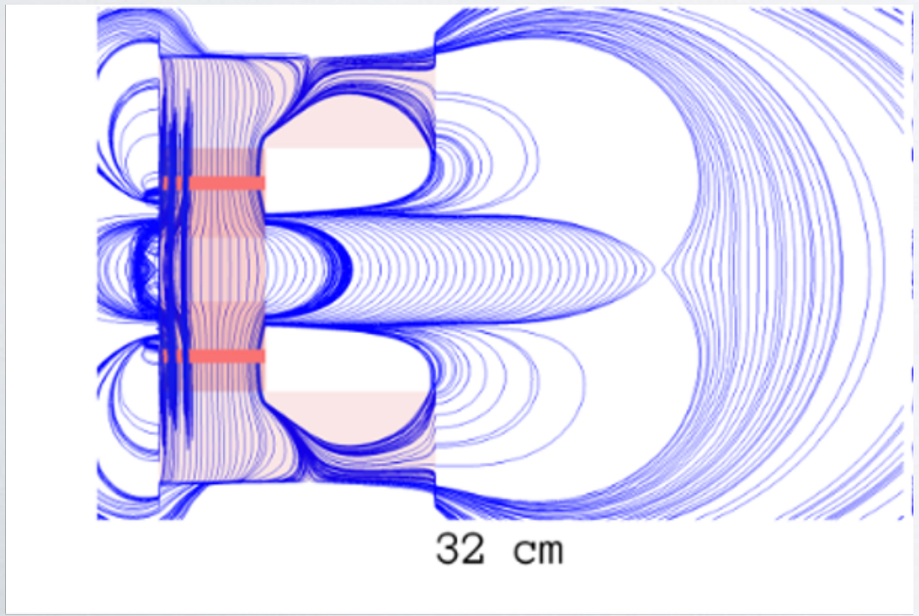


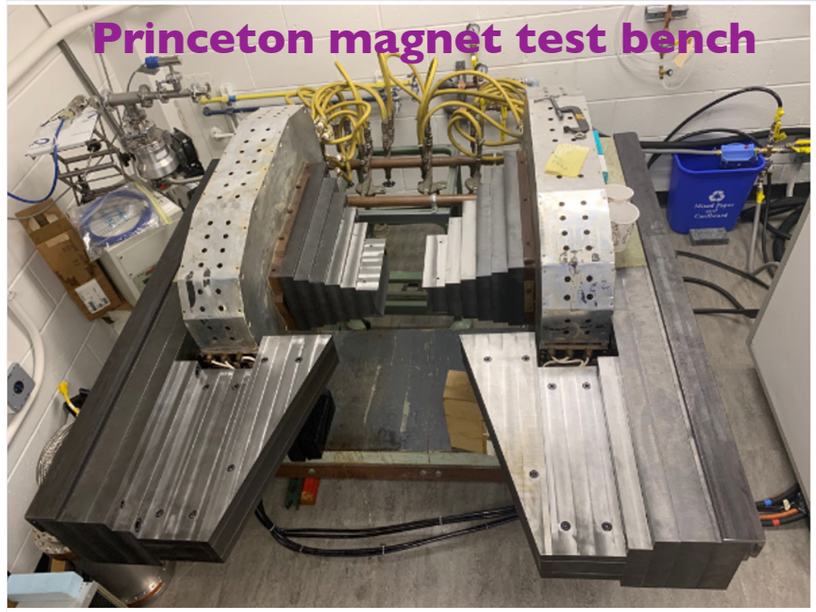
DEMONSTRATOR MAGNET

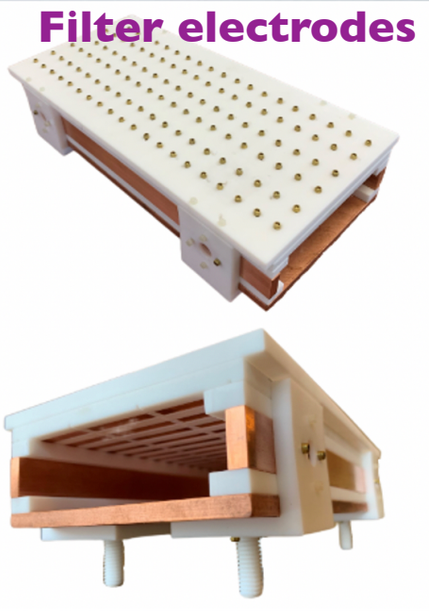
BEING REBUILT AT LNGS IN A LARGER SIZE.



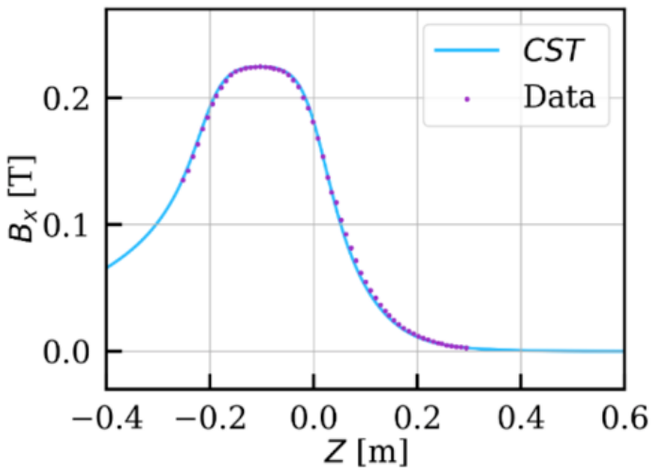
Simulated B-map

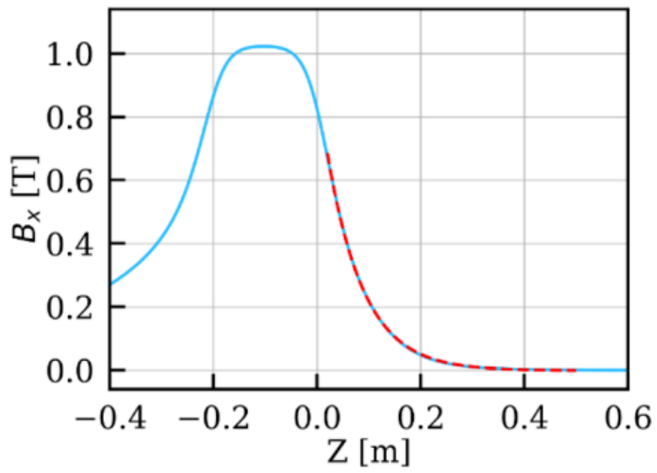






Measured B field shape as expected





CALORIMETER

$E\_e=q(V_{TES}-V\_source\ )+E\_cal$

Now: 0.11 eV @ 0.8 eV and 106 mK and 10x10 μm²
TiAuTi 90nm [Ti(45nm) Au(45nm)] (τ ~137 ns)

Design Goal (PTOLEMY): ΔE_{FWHM} = 0.05 eV @ 10 eV

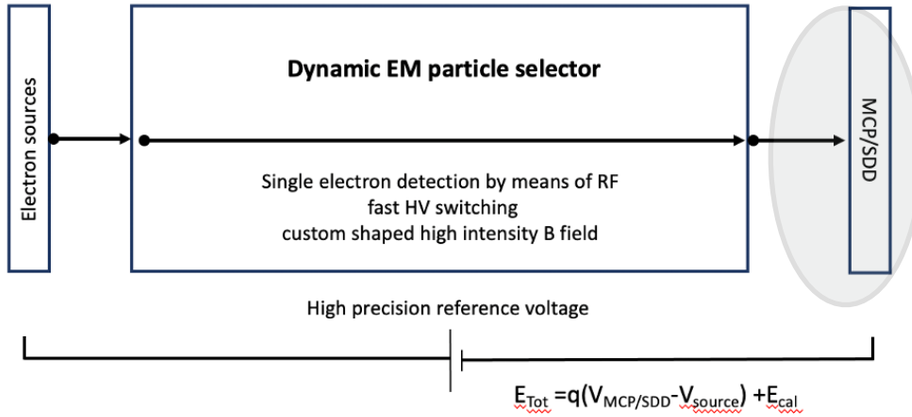
translates to $\Delta E \propto E^{\alpha}$ $(\alpha \leq 1/3)$

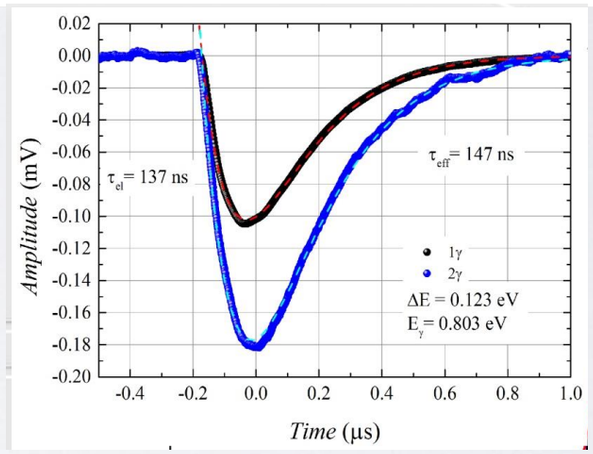
ΔE_{FWHM} = 0.022 eV @ 0.8 eV

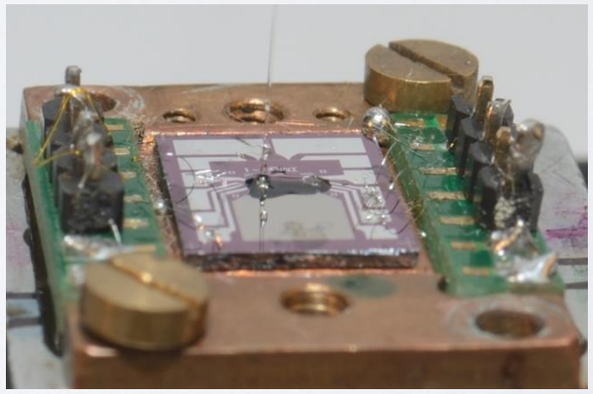
$$\Delta E_{FWHM} \approx 2.36 \sqrt{4 k_B T_c^2 \frac{C_e}{\propto} \sqrt{\frac{n}{2}}}$$

$\Delta E \propto T^{3/2}$ ⇨ T_c= 36 mK @10x10 μm² (t=90 nm)

⇨ T_c= 46 mK @10x10 μm² (t=45 nm)



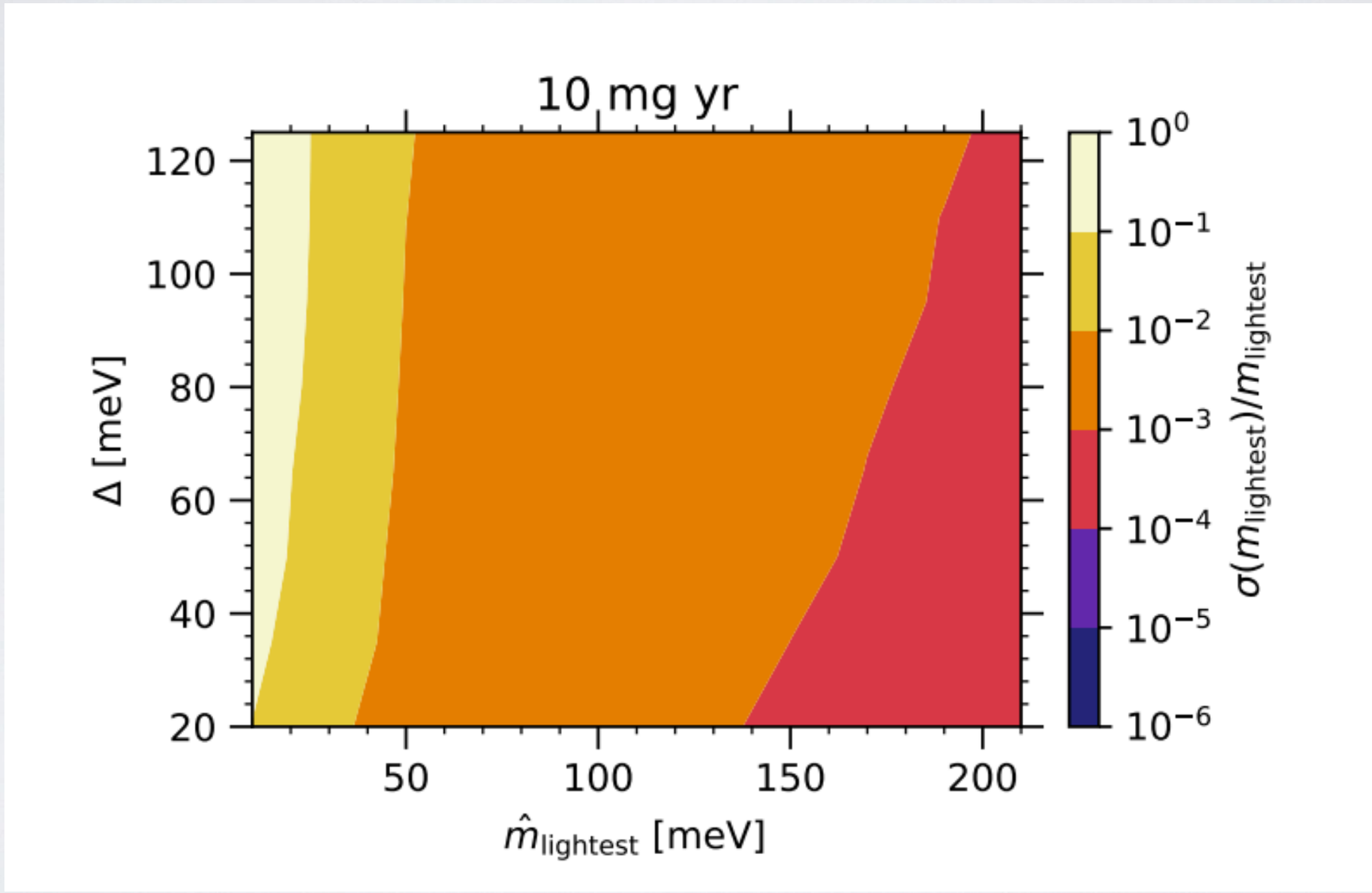




INRiM
ISTITUTO NAZIONALE
DI RICERCA METROLOGICA

A taste of the results that PTOLEMY can achieve

Even in absence of capture events spectral analysis will allow to achieve mass measurement with the percentage uncertainty reported below:
energy resolution versus lights neutrino mass for 10 mg x yr of exposures



CONCLUSION

- PTOLEMY aims at eventually detect cosmic neutrino background on a long term time scale
- The detector prototype will be ready at LNGS by the next year
- Prototype baseline option is: T embedded on graphene; New concept EM filter in final configuration; electron energy resolution measured in several steps (MCP/SDD). Ultimately operate TES with sub-eV energy resolution.
- Possible intermediate results from Prototype on neutrino mass measurement
- Ultimate goals of demonstrator: instrumented mass ~ hundreds of μg, energy resolution 50-100 meV, T storage solution will come from optimisation of atomic T support structure. Time scale 5 years.