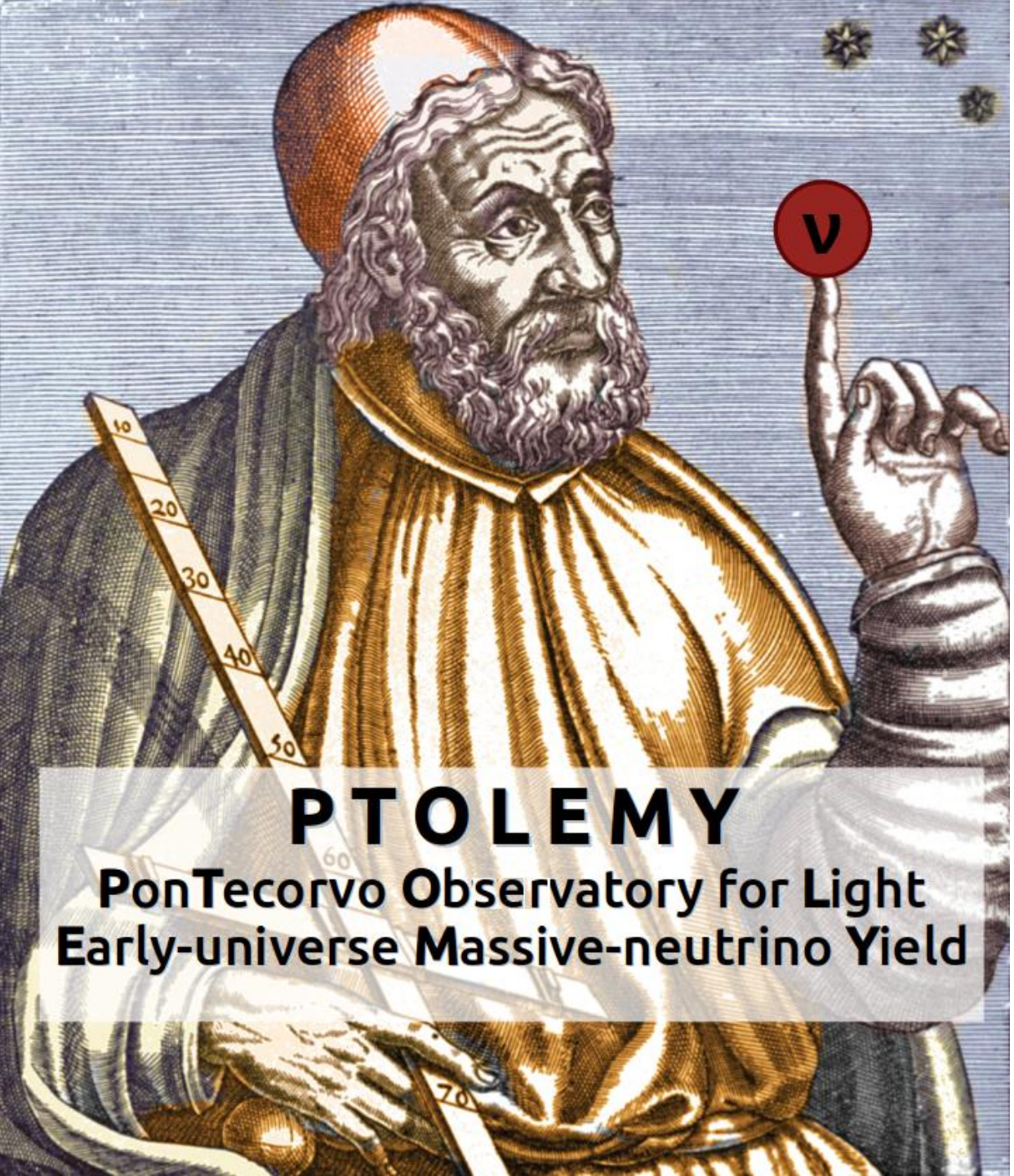


Neutrino mass and Cosmic Neutrino Background with PTOLEMY experiment

Federico Virzi

Università degli studi dell'Aquila

WIN25 10/06/2025

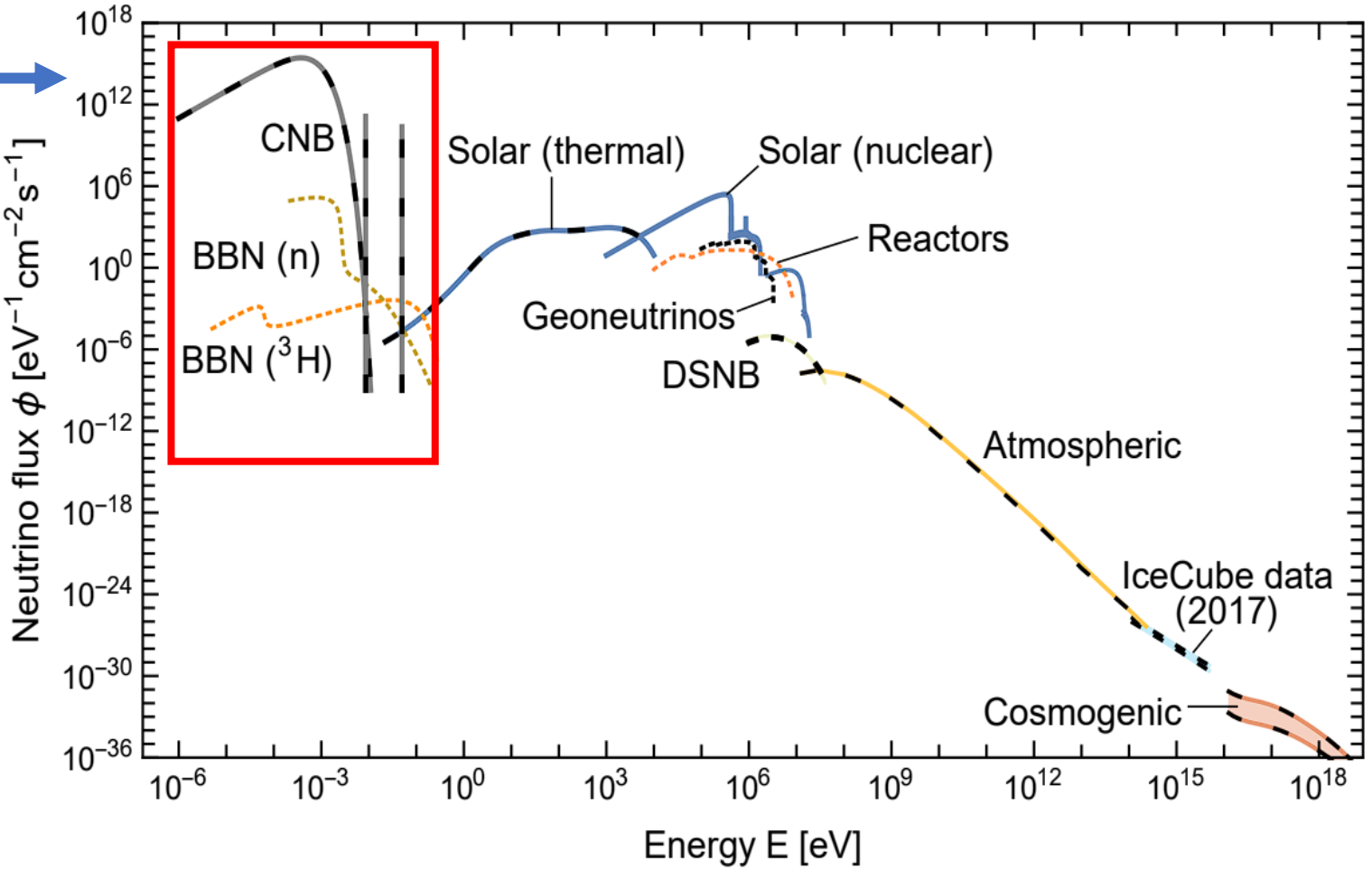
Cosmic Neutrino Background direct detection

- Most abundant neutrino source in the Universe!
- But extremely low Energy

- The only neutrino source at low energy

$K_\nu \approx 10^{-4}$ eV

- Neutrinos do not provide energy for interaction
- Very difficult to detect:



Rev. Mod. Phys. 92, 45006 (2020)

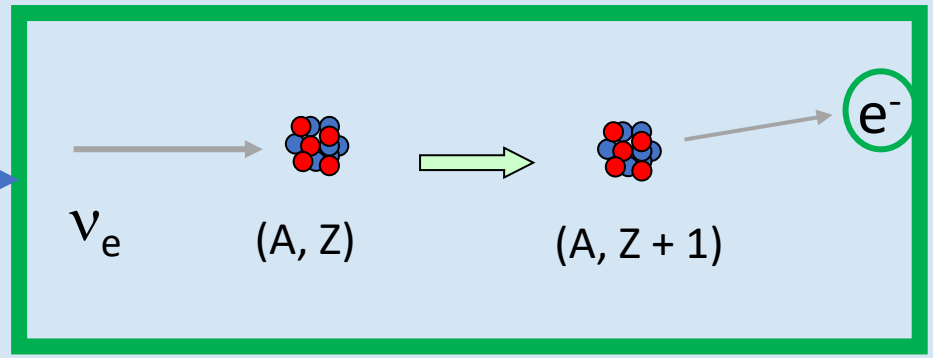
How? → PTOLEMY Project

Cosmic Neutrino Background direct detection: PTOLEMY

- Neutrino capture on beta decaying Nuclei reaction
- Need beta unstable element
- Want maximize interaction with CNB

No energy needed!

Tritium
^3H



1. Neutrino mass
2. Dirac/Majorana
3. CNB
4. Sterile neutrino

PTOLEMY concept:
scalable experiment

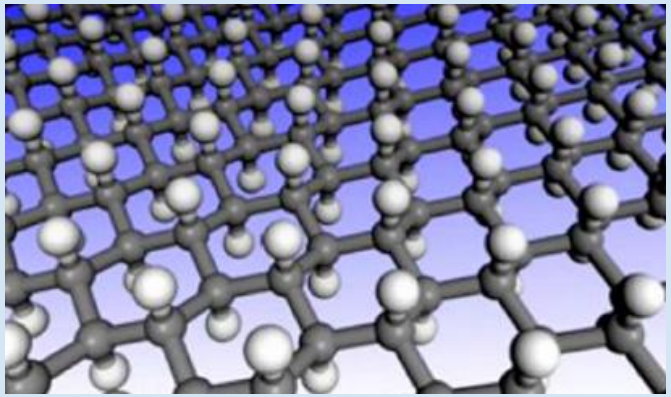
Novel PTOLEMY filter

Solid atomic Tritium

JCAP 0706:015,2007

JCAP 07 (2019) 047

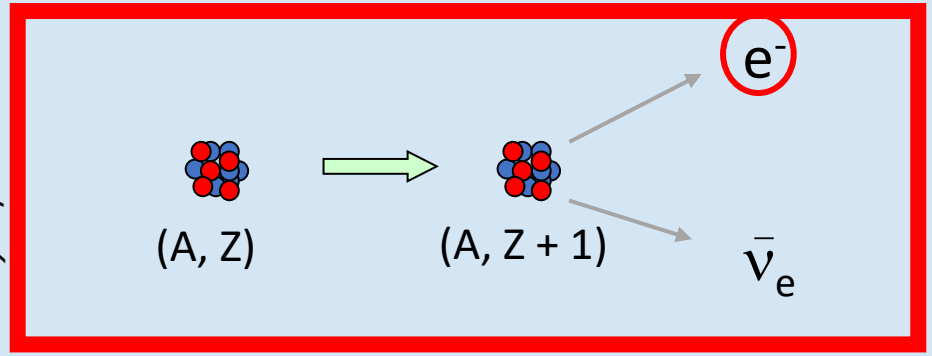
Solid Tritium target



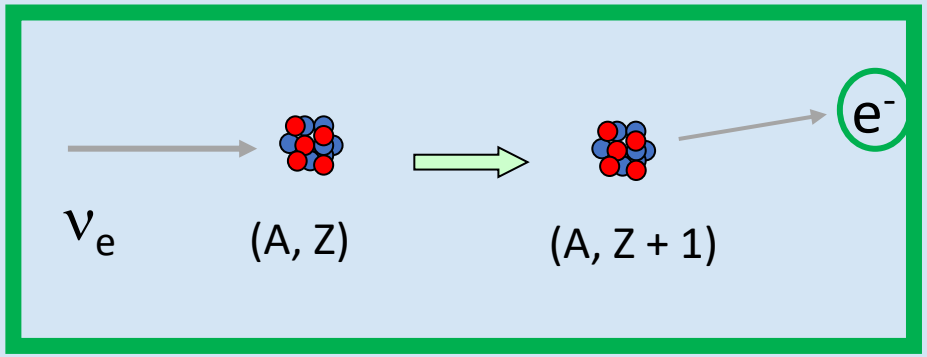
- Atomic Tritium on graphene

- High rate
- Need good energy resolution

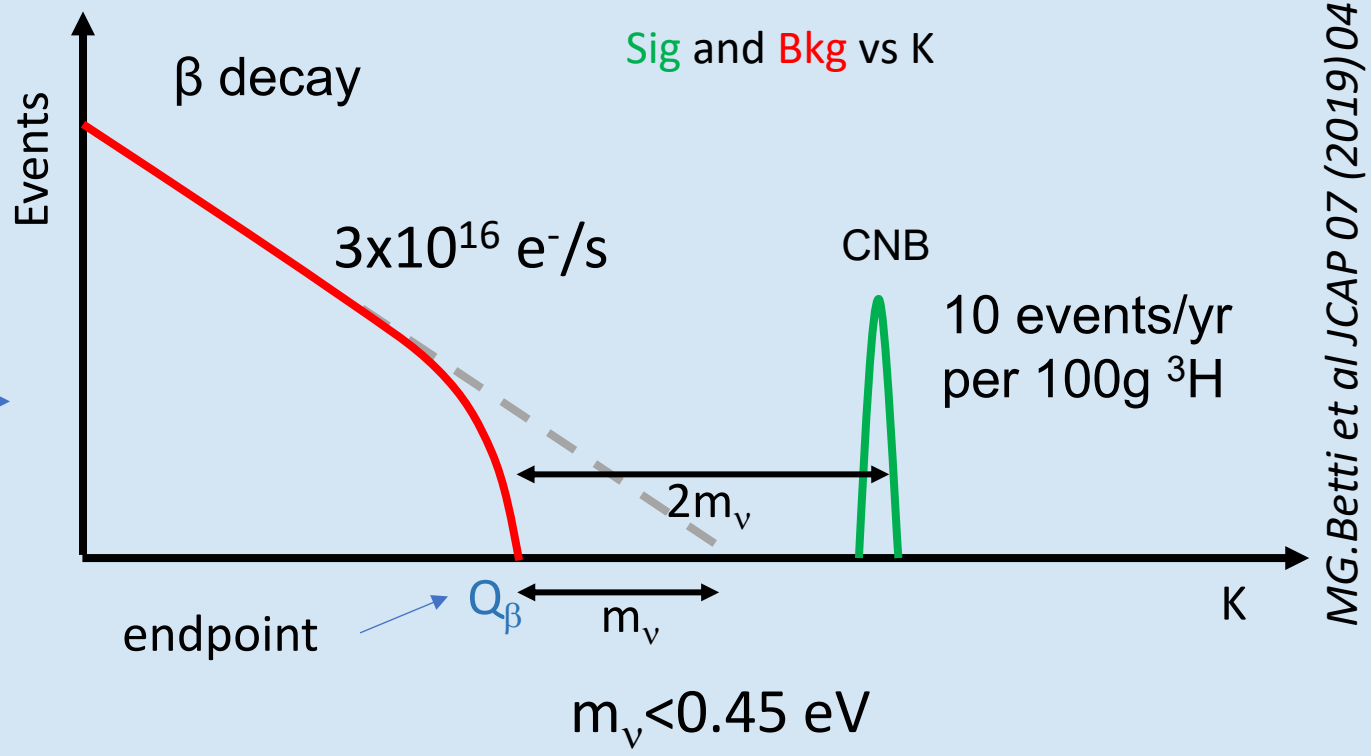
β decay (Background)



CNB interaction



Phys.Rev.D 106 (2022) 5, 053002



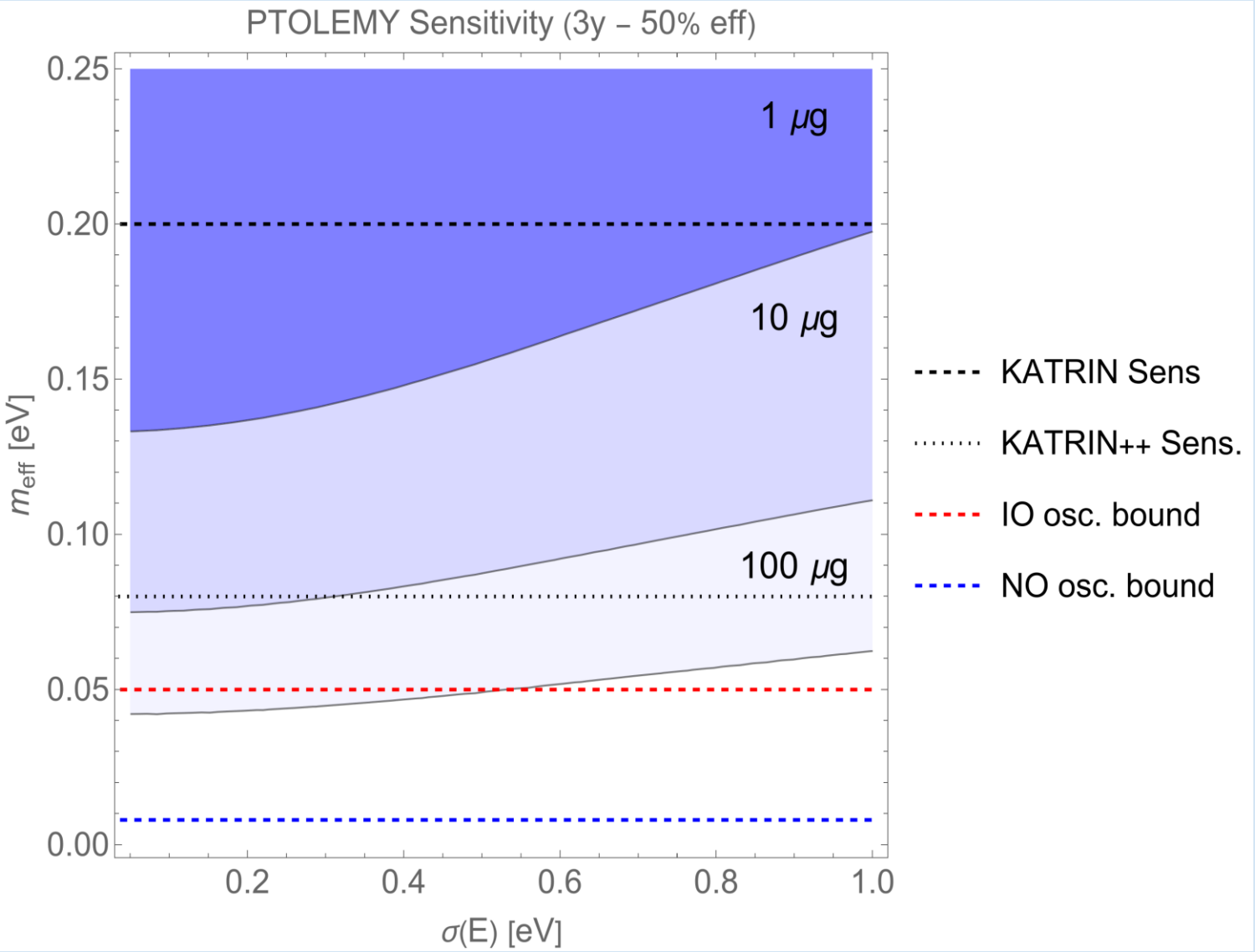
MG.Betti et al JCAP 07 (2019)047

m_ν<0.45 eV

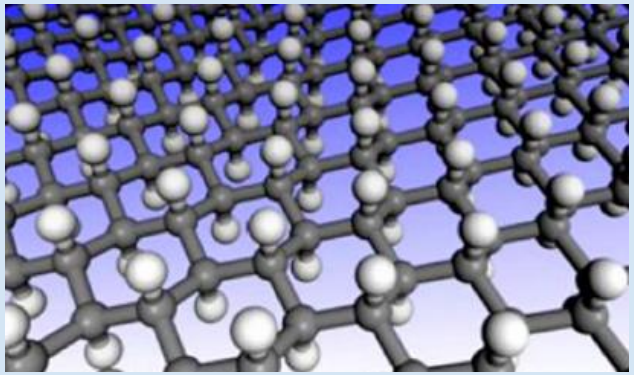
KATRIN *arXiv:2406.13516v1 [nucl-ex] 19 Jun 2024*

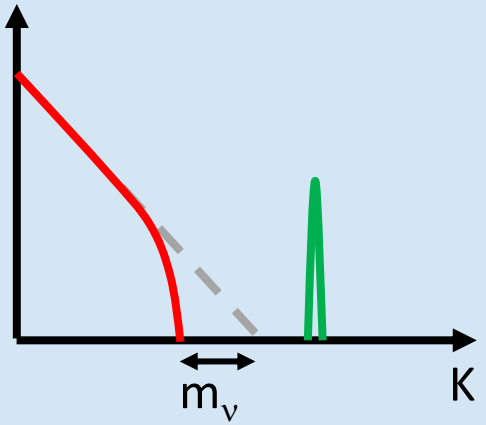
PTOLEMY neutrino mass sensitivity

1 μg=7x7cm^2 of Tritiated graphene



Tritium target

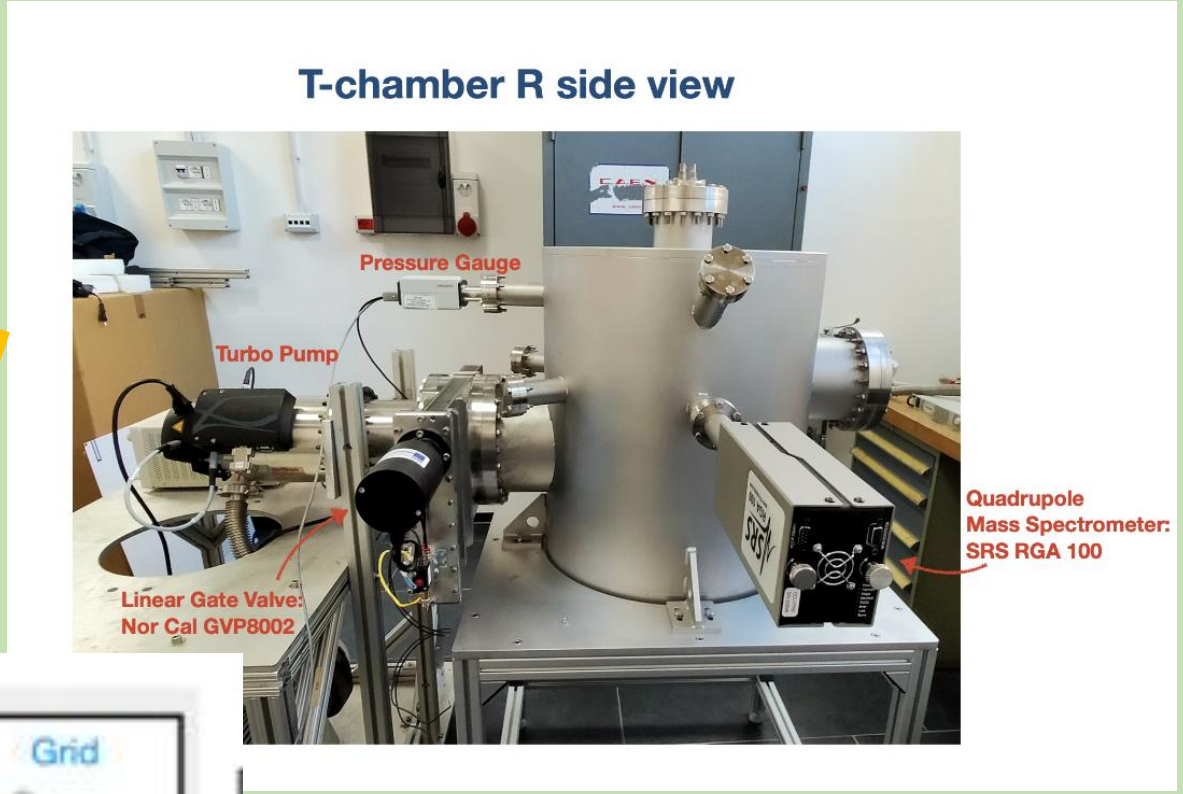


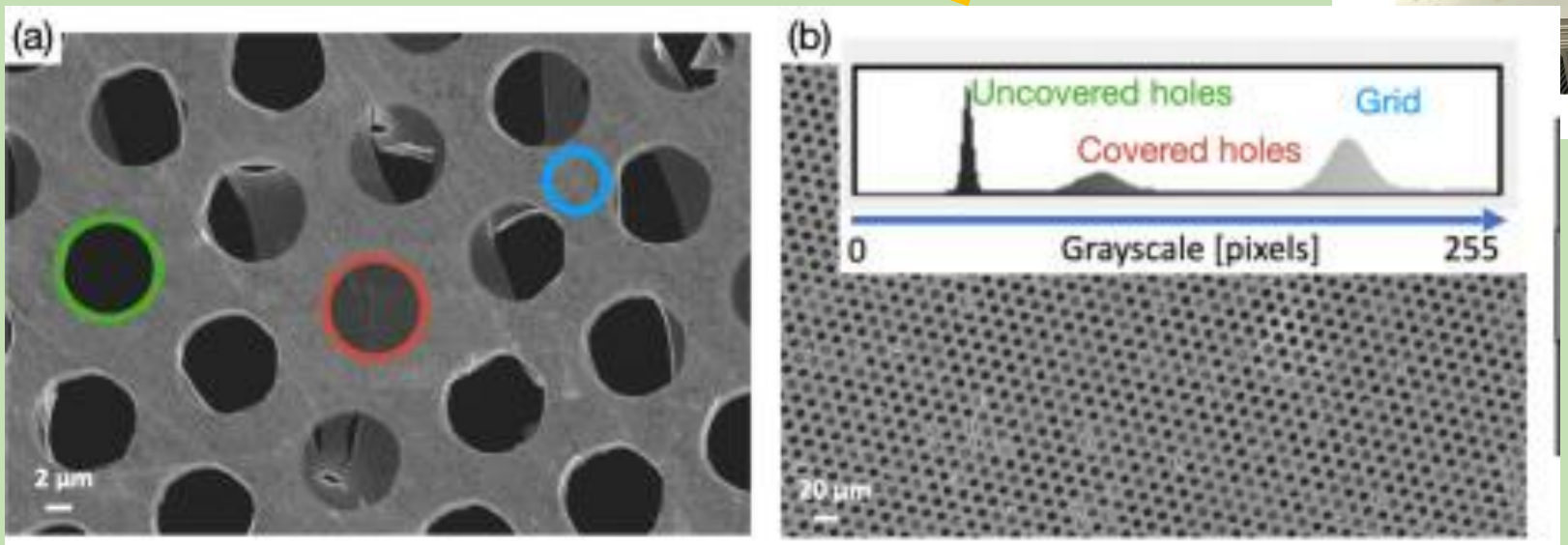


How could be possible to measure this?

Tritium: state of the art

- Tritium @ UKAEA: feasibility study and design requirements of new T loading chamber (quote received)
- Novel Tritium deposition technique Done
- High graphene loading Done
- Tritium Vacuum stability Done





https://arxiv.org/pdf/2504.10238

NanoLett. 2022,22,2971−2977

https://arxiv.org/abs/2504.11853

RF region: filter trigger

Requirements:

- Measurement K , Θ for each electron in the ROI
- O(10 eV) energy resolution
- In O(100 μs)
- Non destructive measurement
- Uniform 1T field

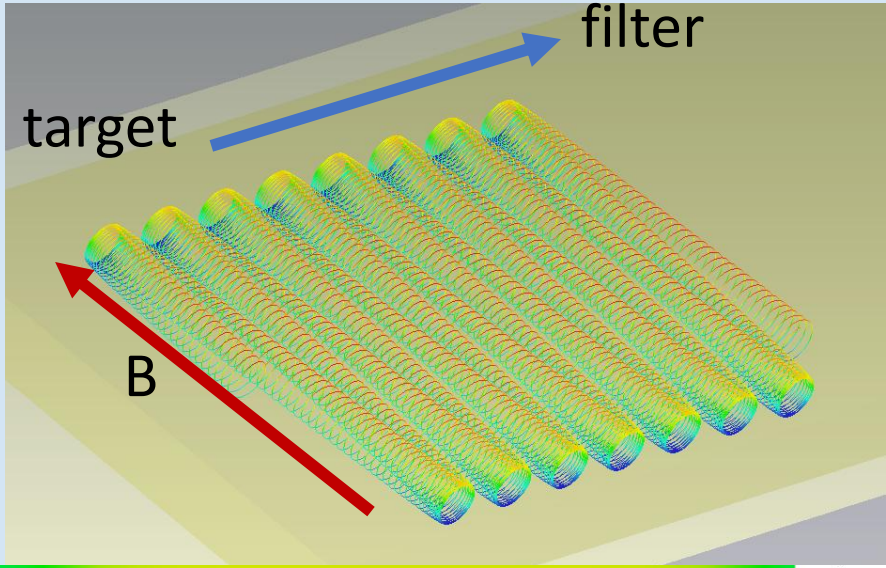
How?

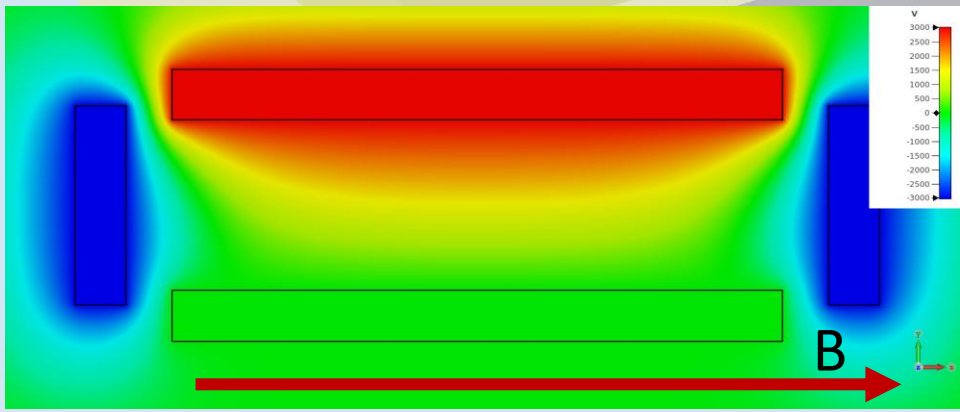
Electron spectroscopy with cyclotron radiation (CRES)

- Cyclotron radiation
- In uniform 1T
- Bouncing motion

PROJECT 8
Thank you!

f_c = 27GHz
P=1fW



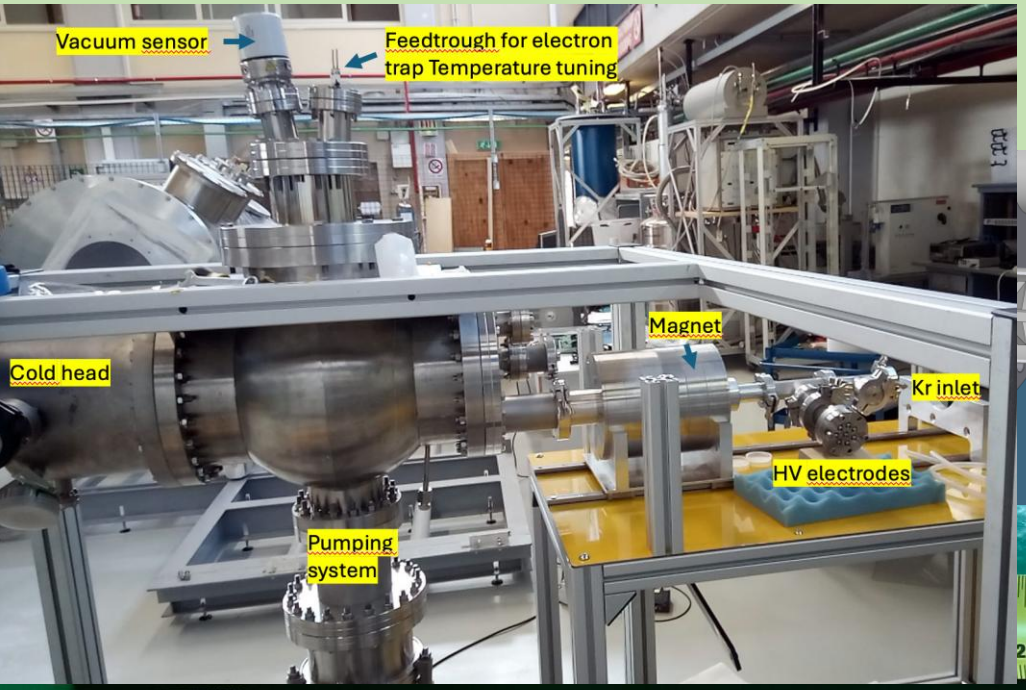


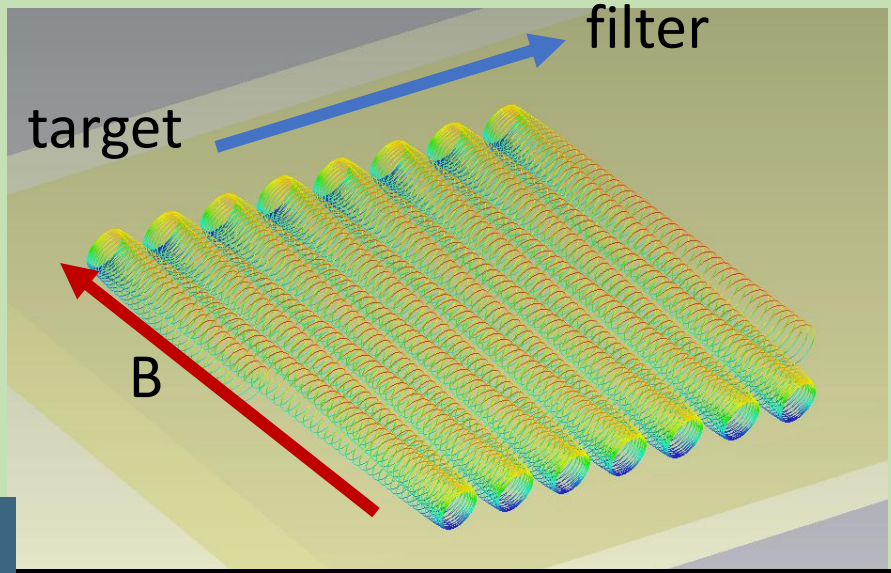
$$f_c = \frac{1}{2\pi}\frac{|q|B}{m}\frac{1}{K/m+1}$$

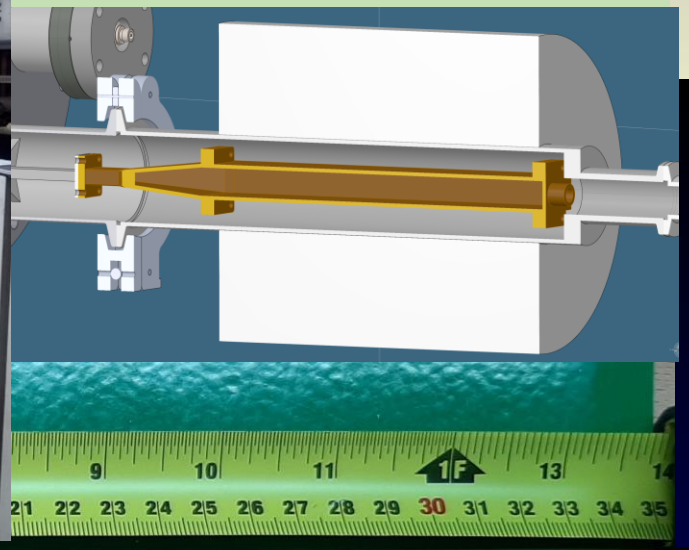
Electron Trap: test setup for RF Region

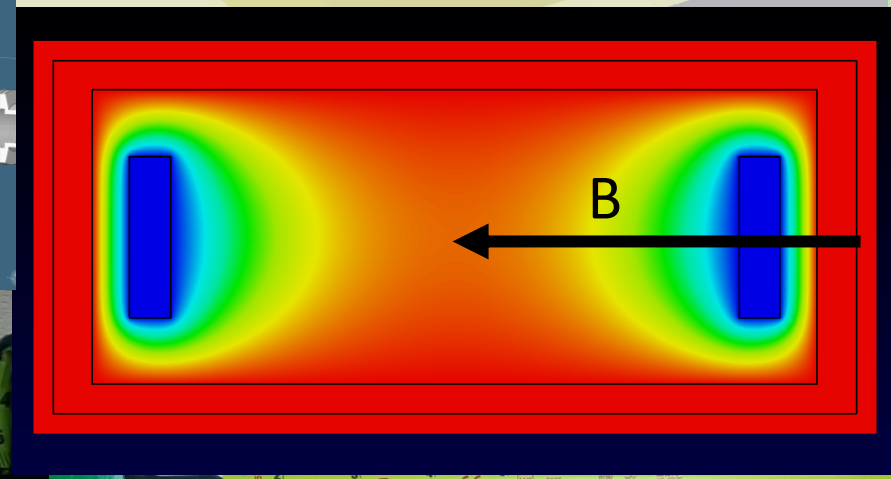
Ongoing measurements @ LNGS

- ^{83m}Kr source
- 0.98T dipole permanent magnet
- Detection of RF emitted by electron in bouncing motion



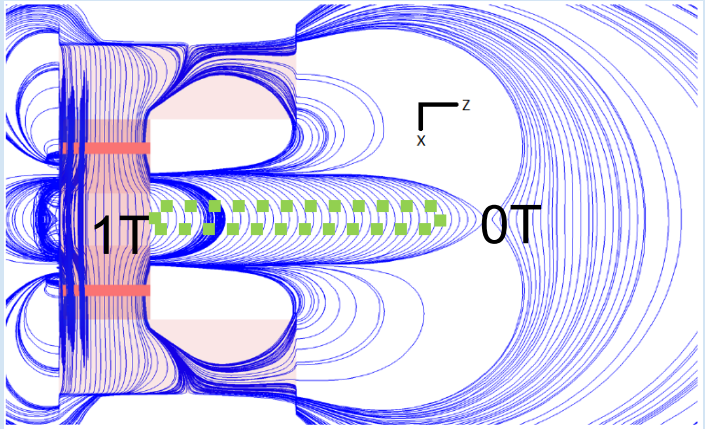


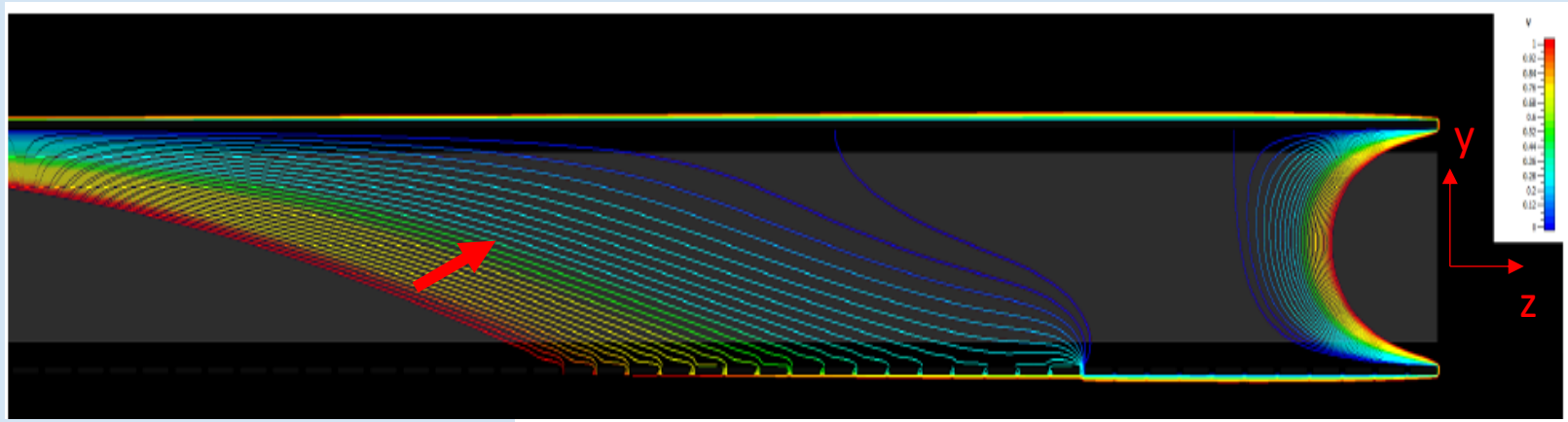




PTOLEMY filter

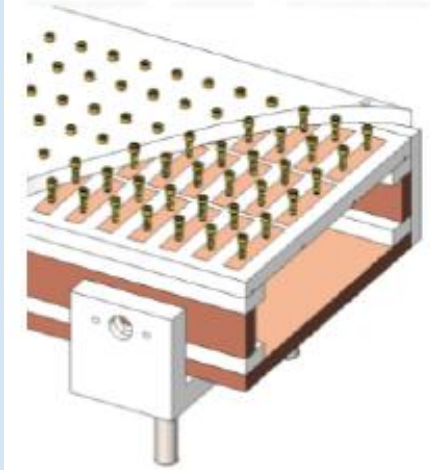
- Exponential decaying magnetic field
- Exponential decaying electric field





$$B_x = B_0 \cos\left(\frac{x}{\lambda}\right) e^{-z/\lambda},$$
$$B_y = 0,$$
$$B_z = -B_0 \sin\left(\frac{x}{\lambda}\right) e^{-z/\lambda}.$$

$$E_x = 0,$$
$$E_y = E_0 \cos\left(\frac{y}{\lambda}\right) e^{-z/\lambda},$$
$$E_z = -E_0 \sin\left(\frac{y}{\lambda}\right) e^{-z/\lambda}.$$



$$\boldsymbol{V}^{y}_{E\times B}(z)|_{x,y=0} = \frac{\boldsymbol{E}\times\boldsymbol{B}}{B_x^2} = \frac{E_z B_x \hat{\boldsymbol{y}}}{B_x^2} = \frac{E_z}{B_x}\hat{\boldsymbol{y}}$$

$$\boldsymbol{V}_{\nabla B-C} = \frac{1}{2} m(v_\perp^2 + 2v_\parallel^2)\frac{\boldsymbol{B}\times\boldsymbol{\nabla}_\perp B}{qB^3} = (T_\perp + 2T_\parallel)\frac{\boldsymbol{B}\times\boldsymbol{\nabla}_\perp B}{qB^3}$$

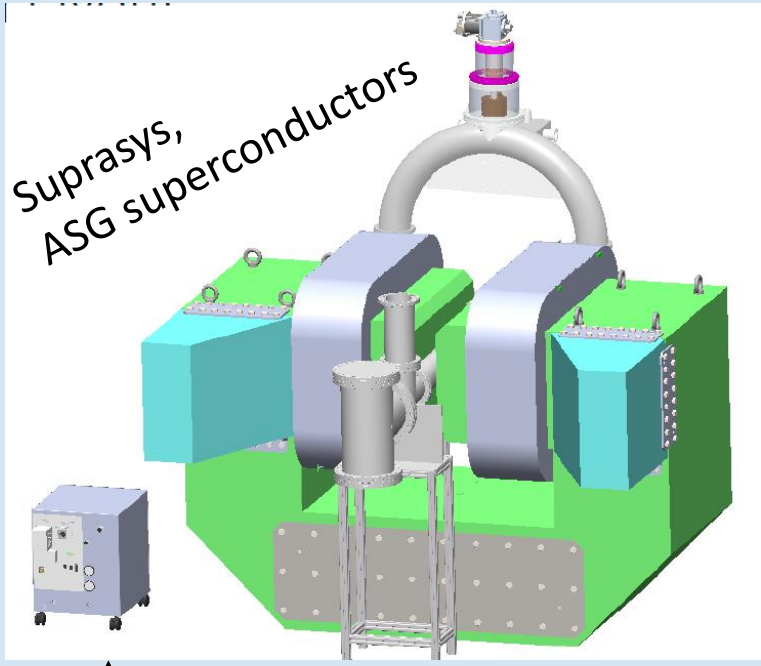
arXiv:2108.10388v2 [physics.ins-det] 24 Jan 2022

Dynamic EM Filter

Pitch angle Θ =angle between e^- velocity and B

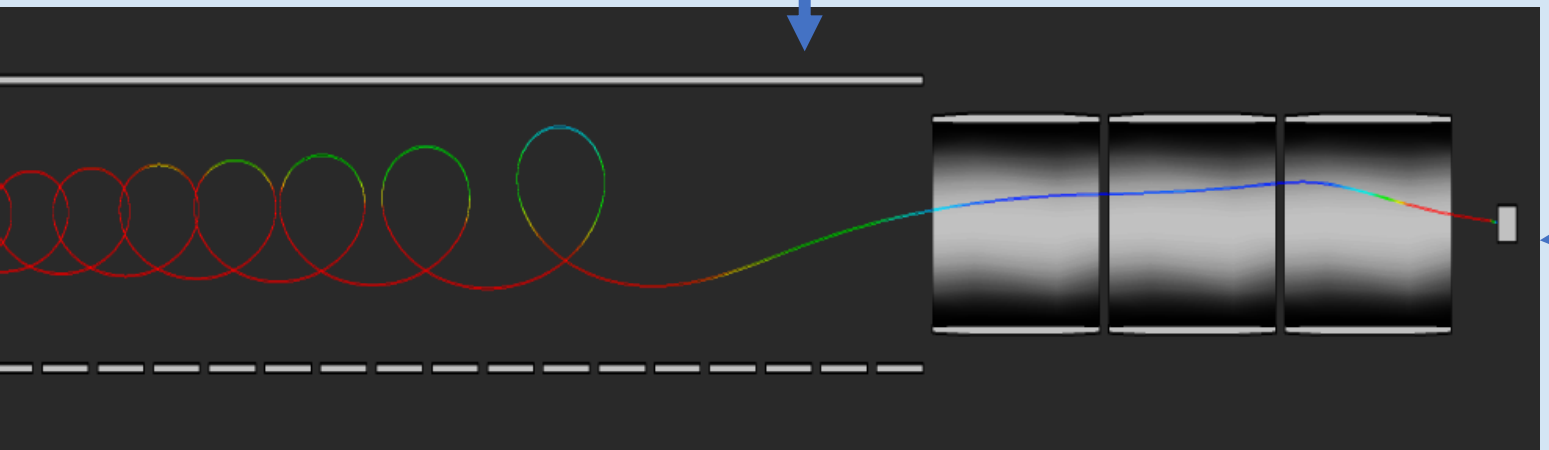
- Electron decelleration:
  Drain K, Θ
  K up to O(100 eV) on TES

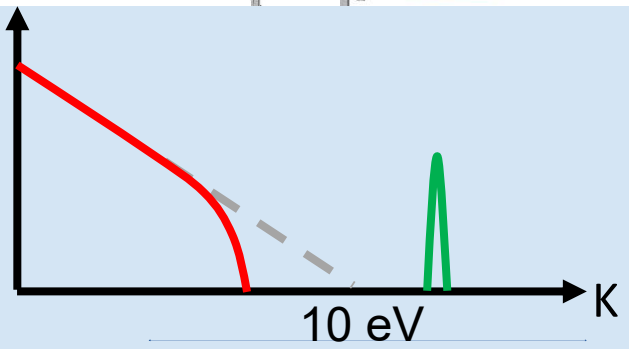
Energy Drain ✓



- If electron has:
  $K<Q_\beta$ → Discarded TES
  $K \sim Q_\beta$ →

Background rejection ✓





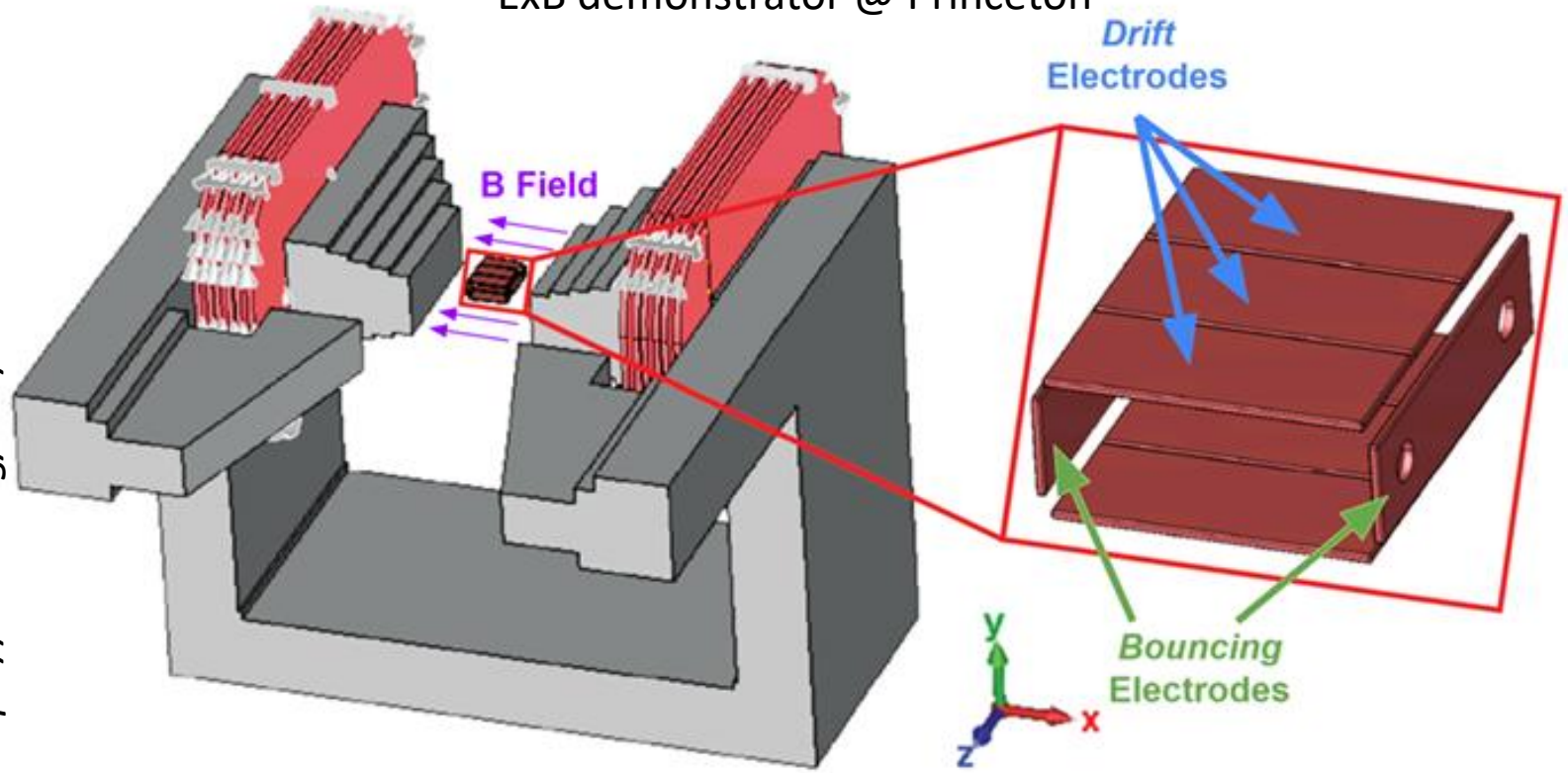
Event by event basis
If K , Θ known
→ RF Region

PTOLEMY filter: state of the art

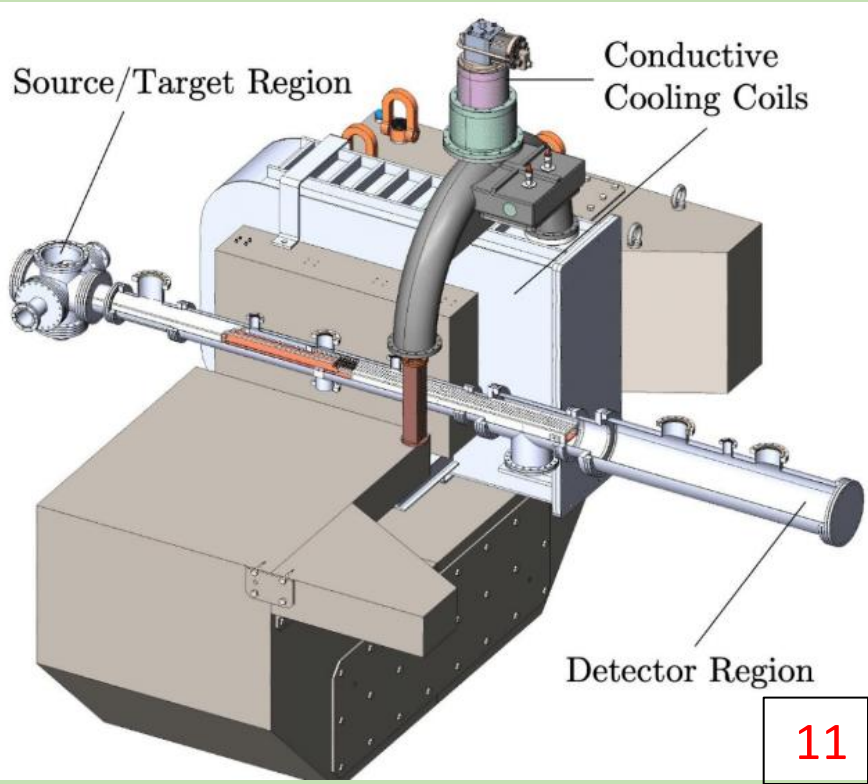
- ExB demonstrator at Princeton: slow electron drift
- PTOLEMY magnet under construction: shipment to LNGS nov ‘25

Done

ExB demonstrator @ Princeton



https://arxiv.org/abs/2503.10025

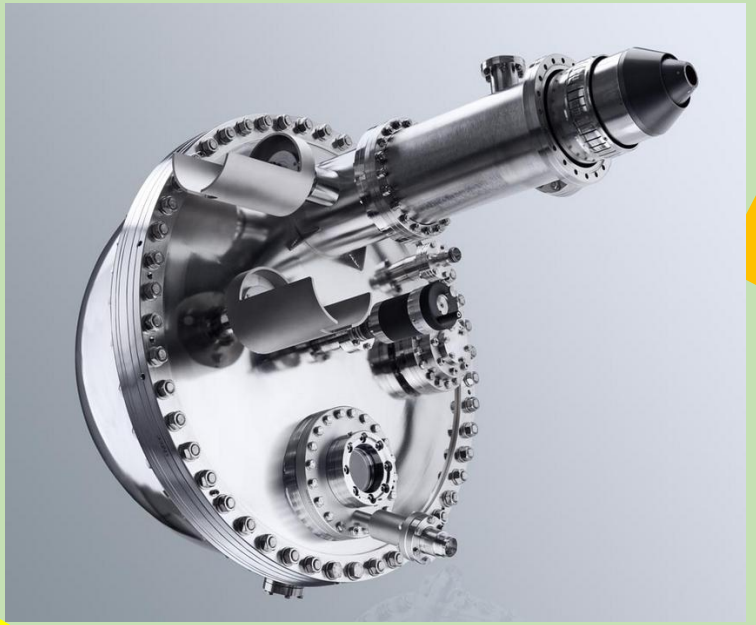


Obtaining desired energy resolution

Option A

Hemispherical electron analyser

- Typically used in spectroscopy
- Capability to reach σ_K=50meV
- Room temperature



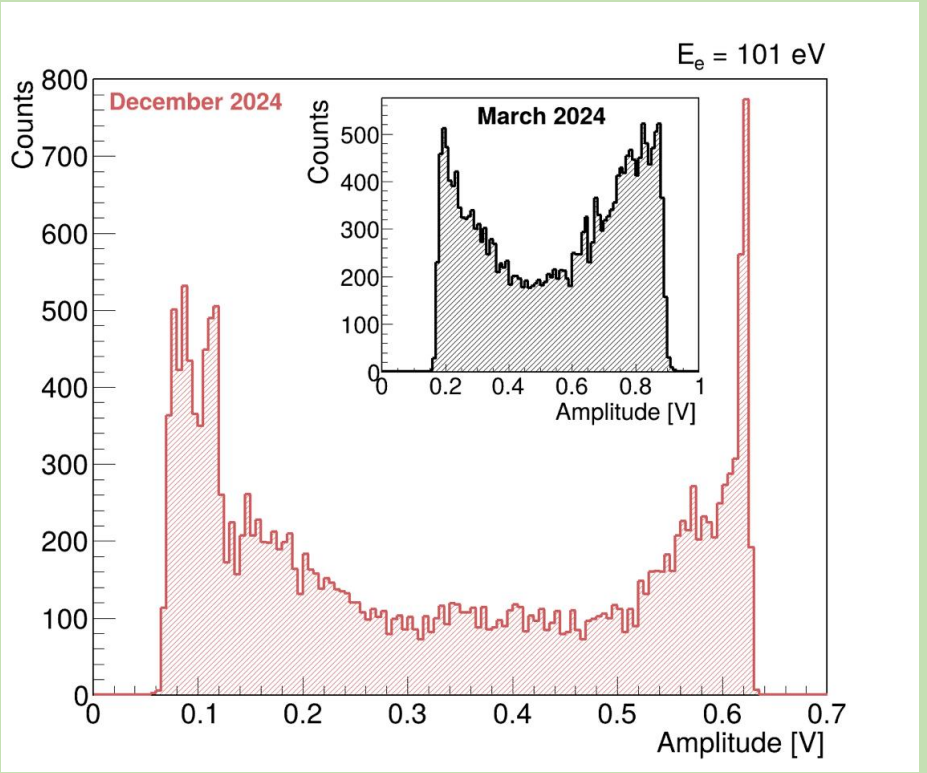
Commercial availability

Option B

TES for electrons

Done

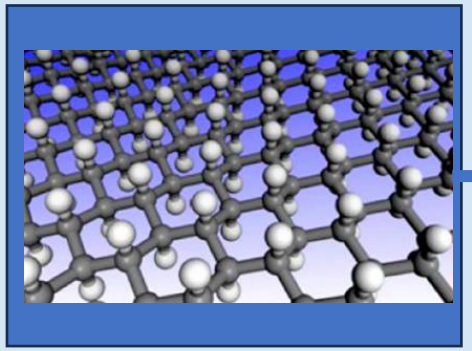
- Typically used for photons
- First time used for electrons in our energy ROI



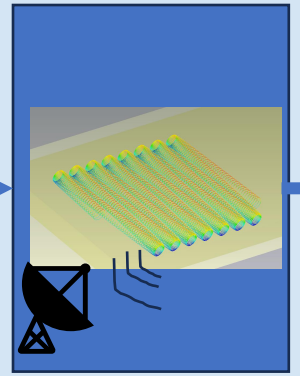
arXiv:2405.19475v1 [physics.ins-det] 29 May 2024

PTOLEMY Concept

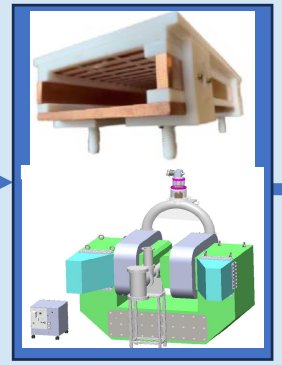
Tritium target



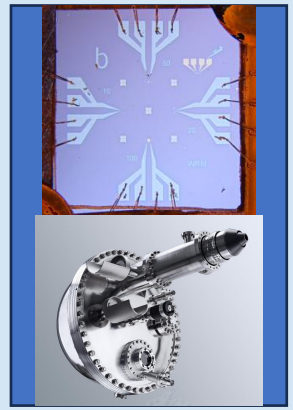
RF region

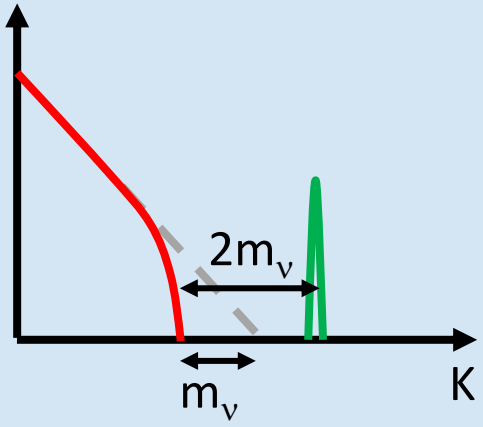


Filter



High energy resolution measurement





Filter trigger
K and Θ, fast and rough measurement

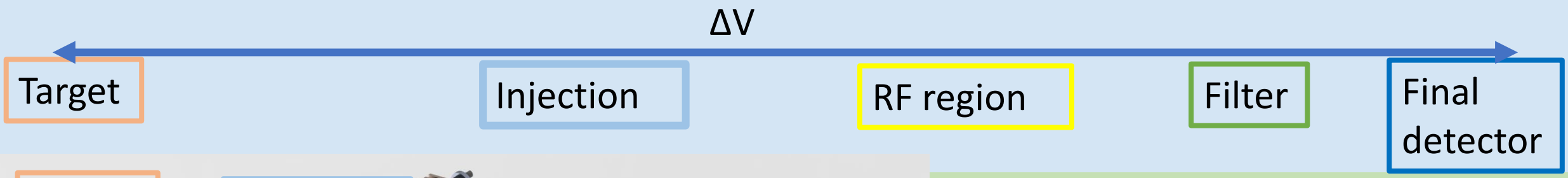
Energy Drain +filter

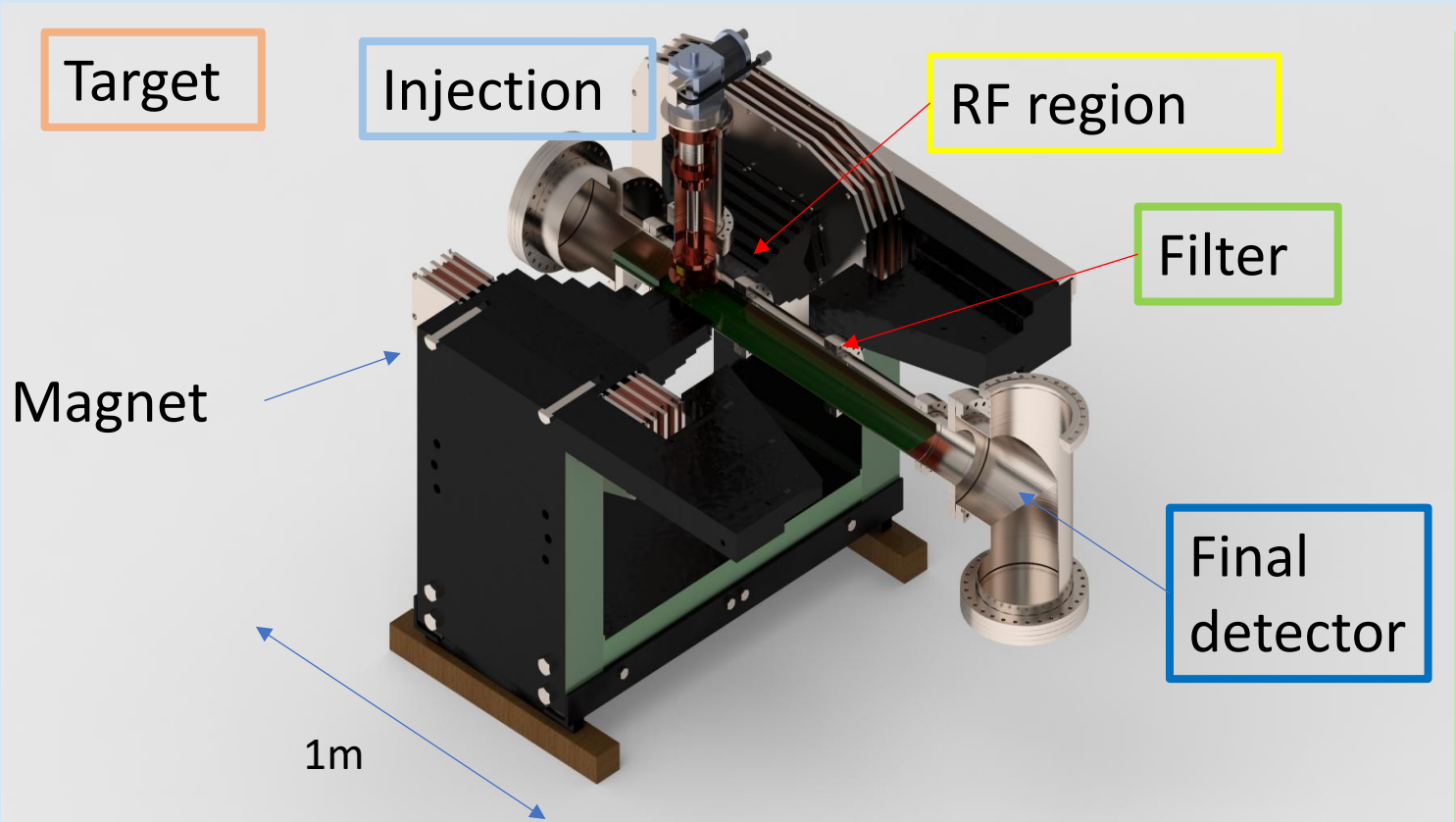
σ_K=50 meV

TOF information combined with RF

PTOLEMY Concept

How to reconstruct target's electron kinetic energy K_i? → $K_i = q\Delta V + E_{RF,corr} + E_{final}$

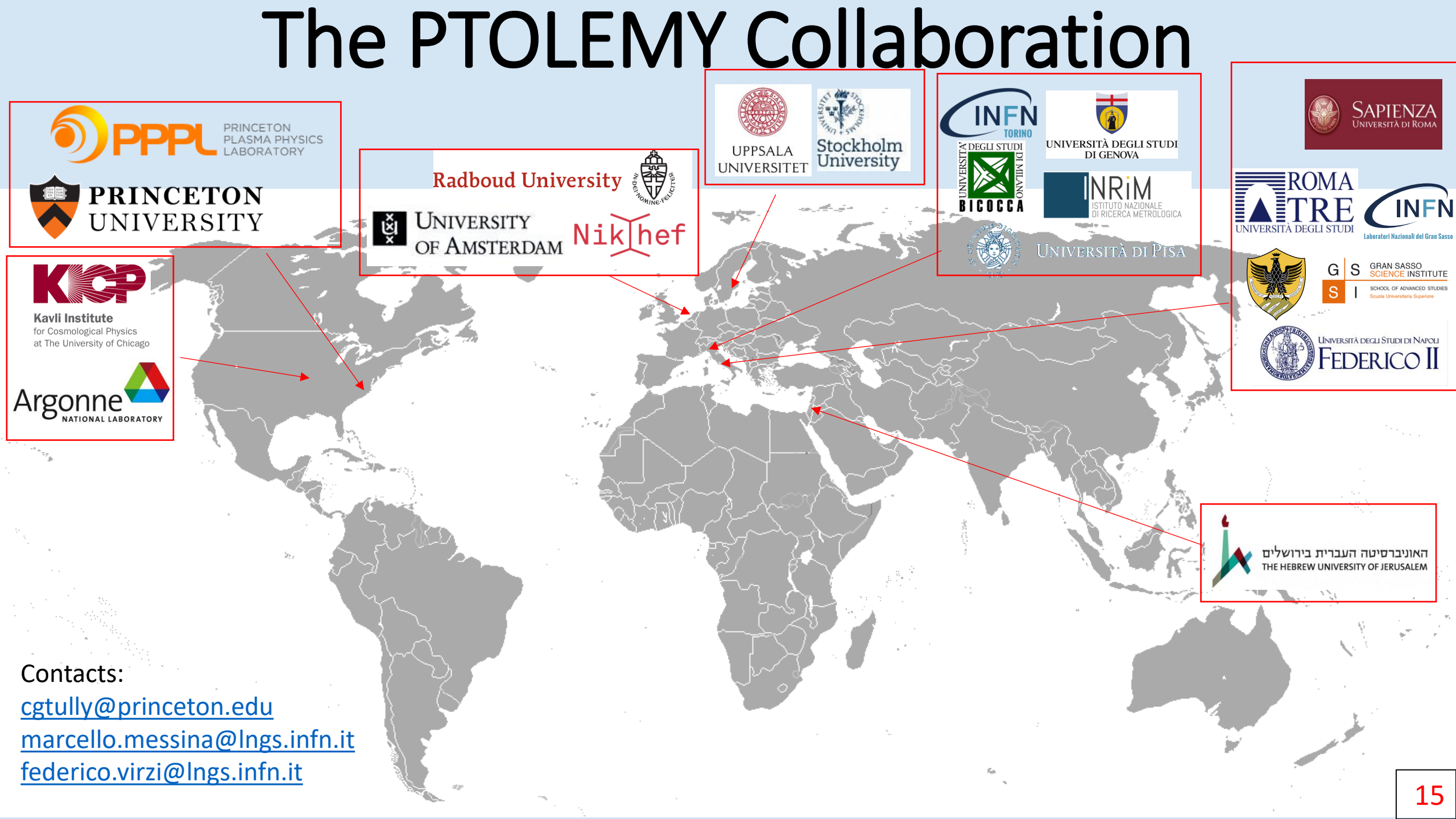




High stability HV @ LNGS

Done

The PTOLEMY Collaboration



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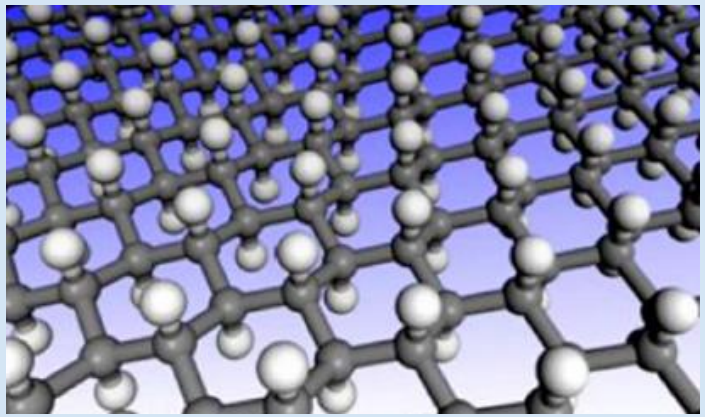
federico.virzi@lngs.infn.it

Conclusion and outlook

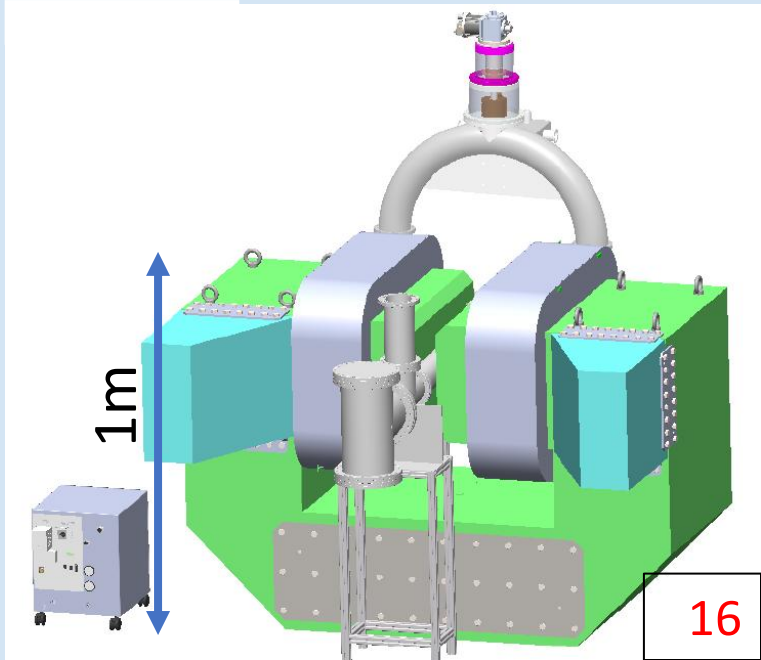
PTOLEMY experimental method

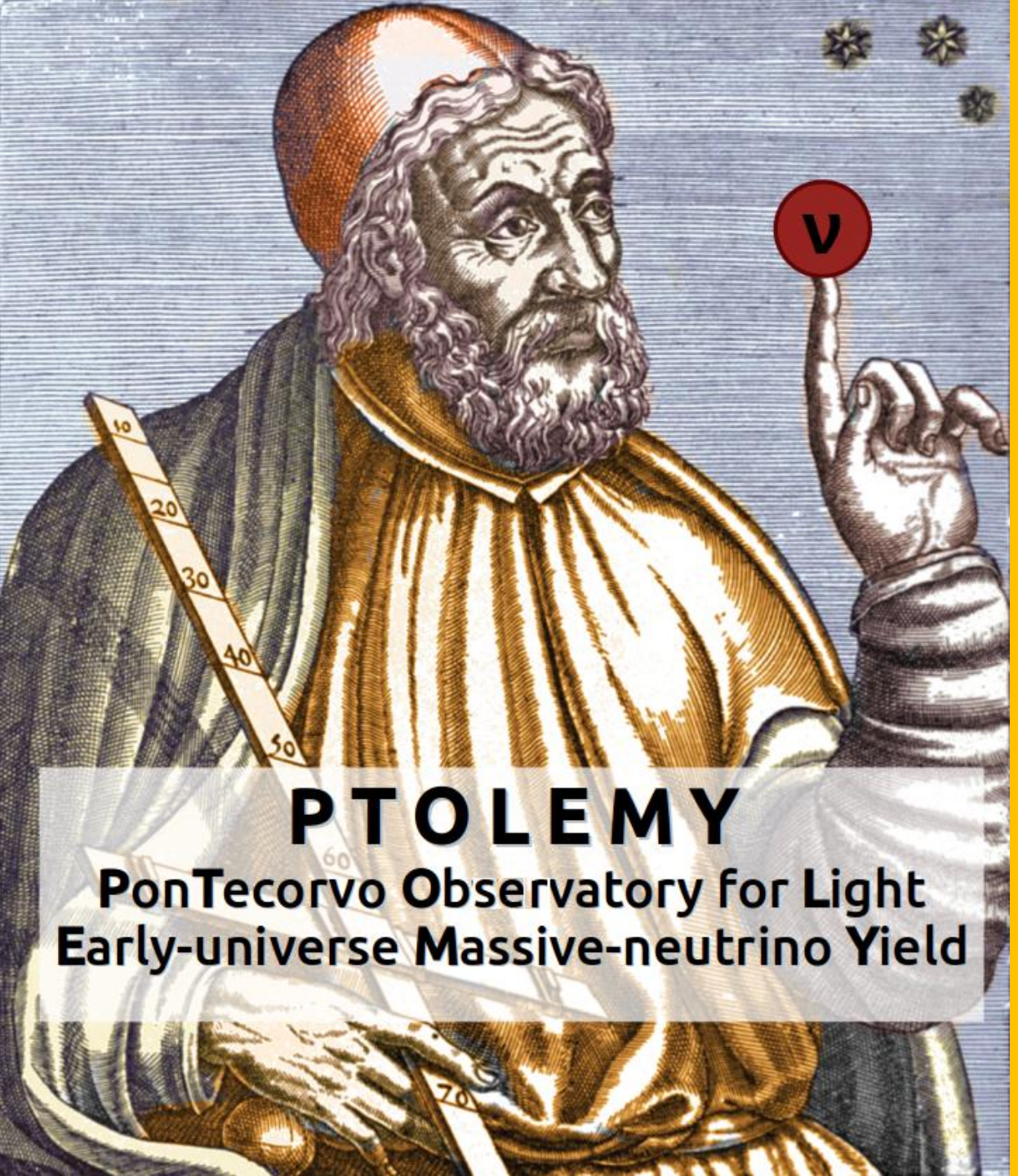
Atomic, solid Tritium target	Background rejection by realtime filter + small size detector	High precision energy measurement

Keys for future high Tritium mass experiment



Phase 0) Demonstrator @ LNGS
Phase 1) Measurement m_ν
Phase 2) Mid Scale demonstrator
Phase 3) Measurement CNB





Backup slides

b