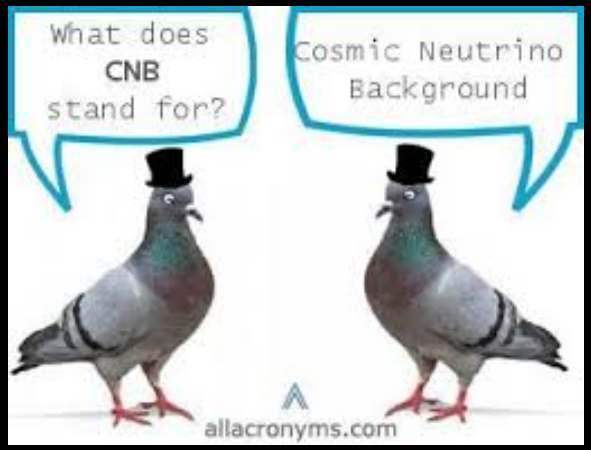
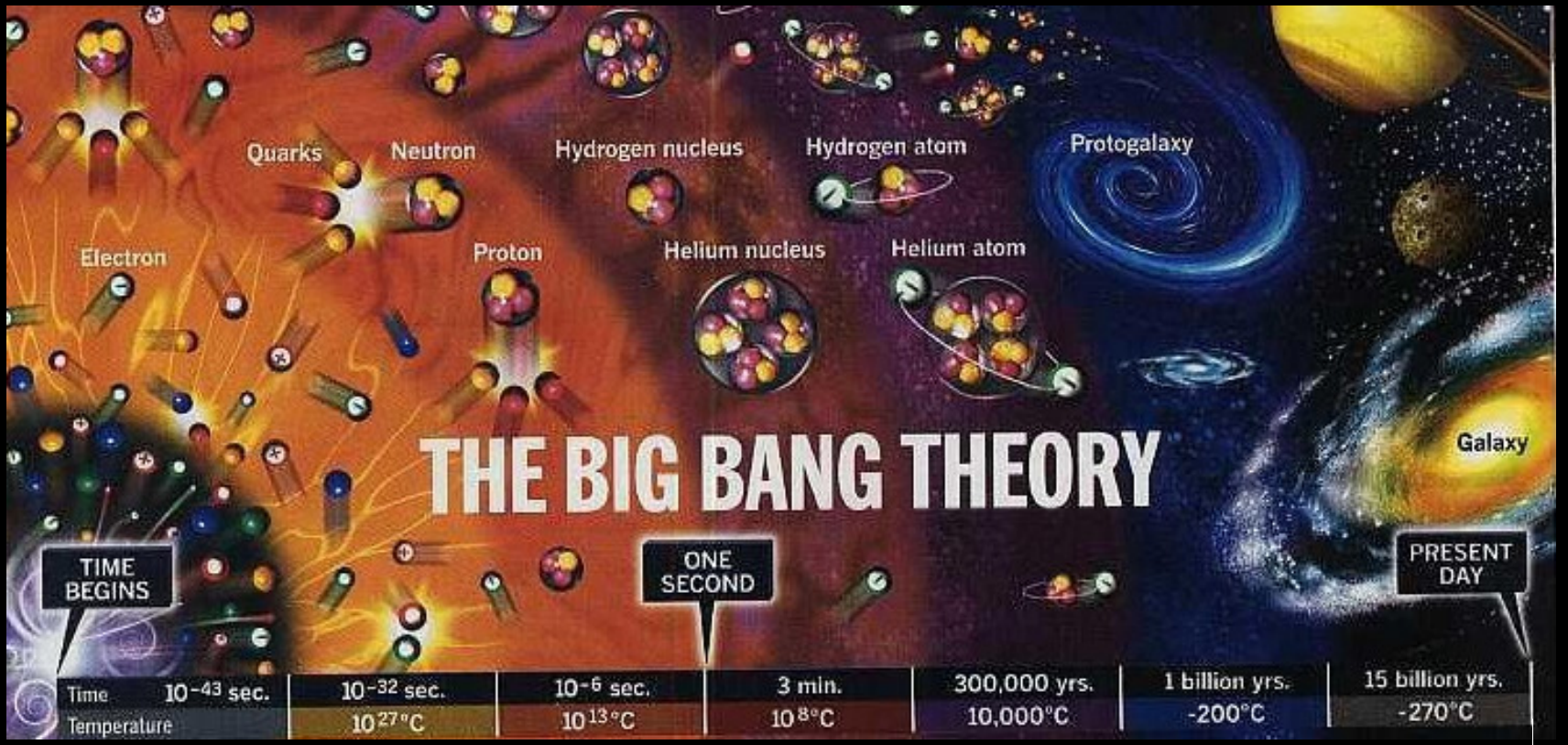
The PTOLEMY *direct* CNB and dark matter detection project



Carlos de los Heros,
Uppsala University

Partikeldagarna
Lund, Oktober 16-17, 2018



universe transparent to neutrinos

CNB

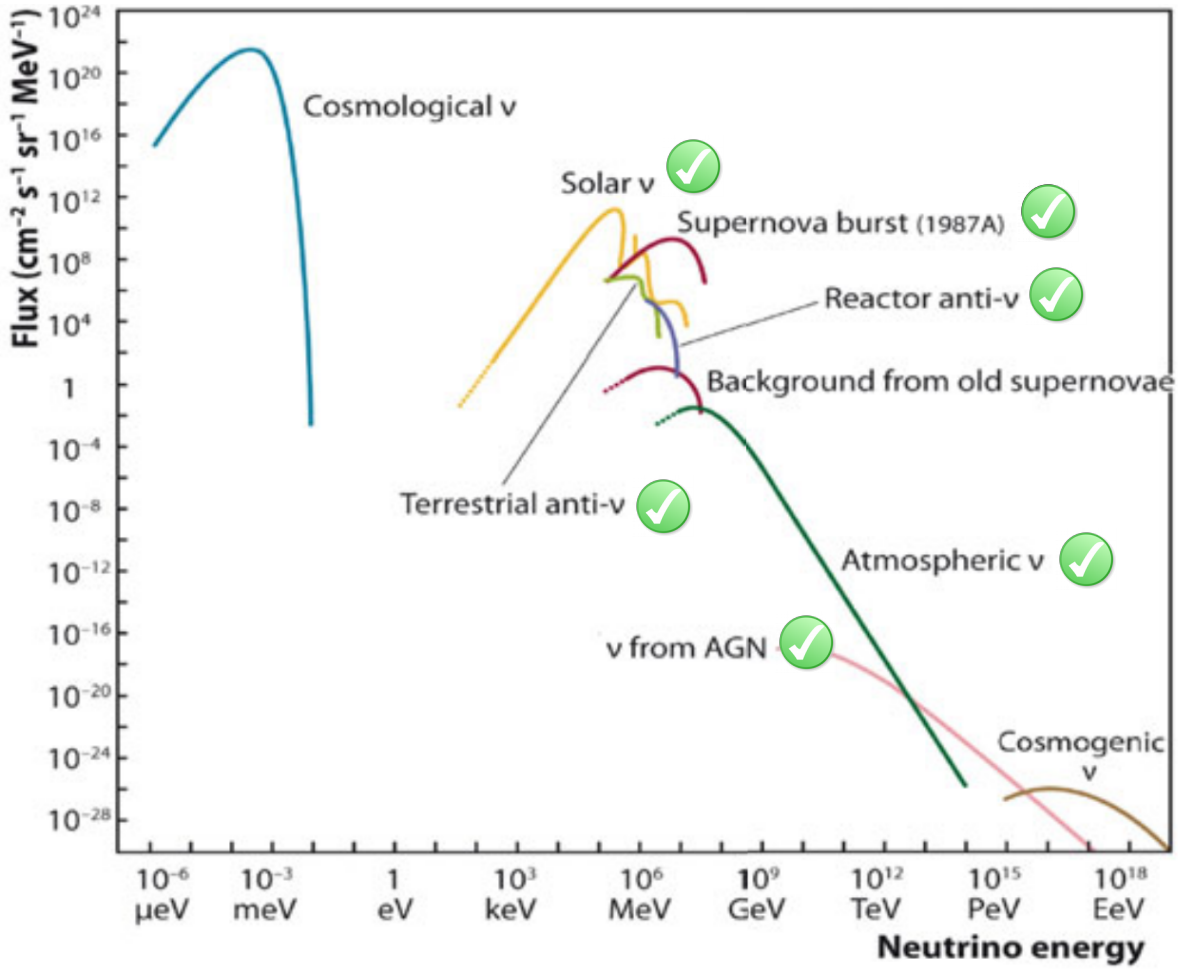
$T \sim 10^{10}$ K ~ 1 MeV

universe transparent to photons

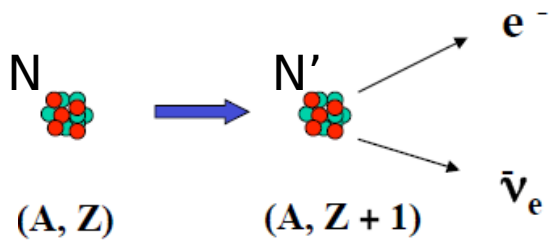
CMB

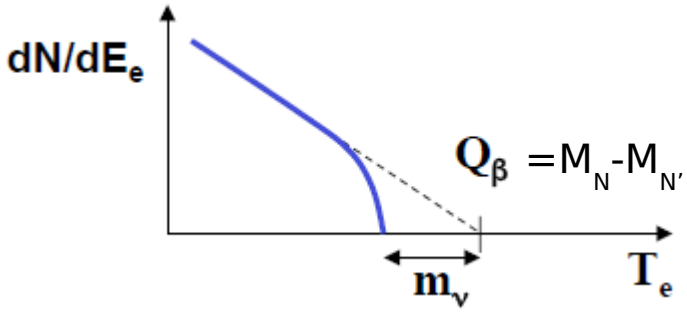
All-permeating sea of relic neutrinos @ E~1 meV

56 cm^{-3} (x 6)


Flux (cm⁻² s⁻¹ sr⁻¹ MeV⁻¹)
10²⁴
10²⁰
10¹⁶
10¹²
10⁸
10⁴
1
10⁻⁴
10⁻⁸
10⁻¹²
10⁻¹⁶
10⁻²⁰
10⁻²⁴
10⁻²⁸
Cosmological ν
Solar ν
Supernova burst (1987A)
Reactor anti-ν
Background from old supernovae
Terrestrial anti-ν
Atmospheric ν
ν from AGN
Cosmogenic ν
10⁻⁶ μeV
10⁻³ meV
1 eV
10³ keV
10⁶ MeV
10⁹ GeV
10¹² TeV
10¹⁵ PeV
10¹⁸ EeV
Neutrino energy

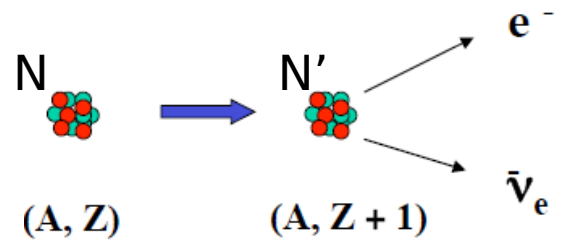
spontaneous nuclear β decay

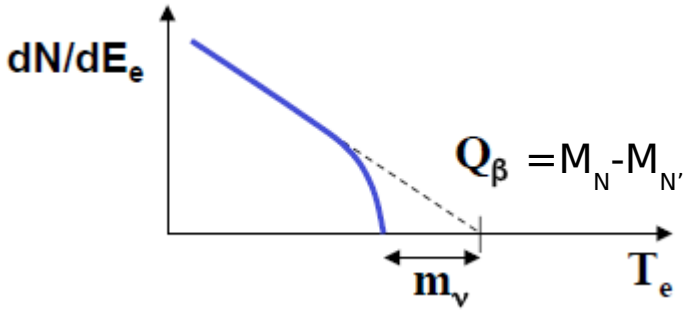




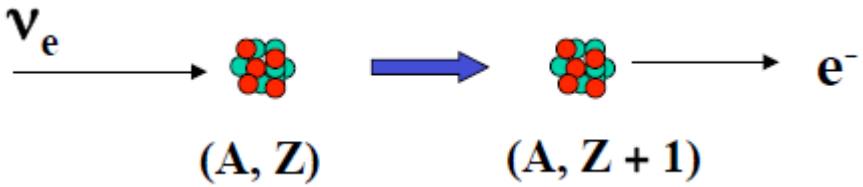
(adapted from A. Cocco ICHEP2018)

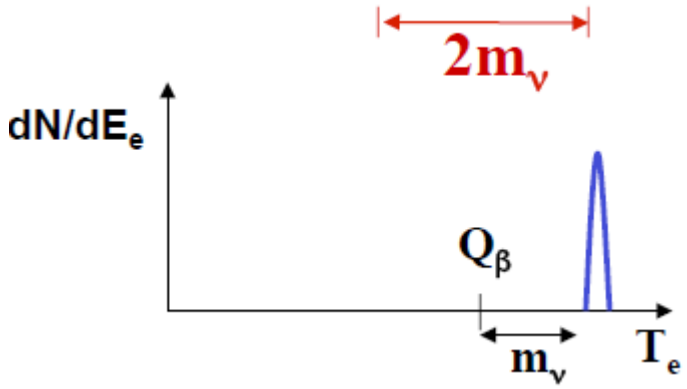
spontaneous nuclear β decay





"induced" nuclear β decay

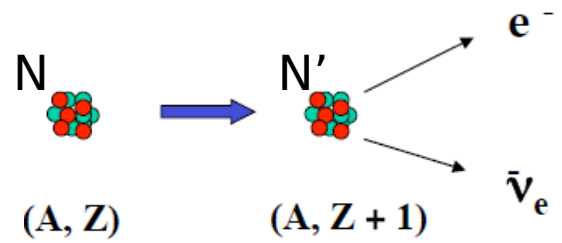


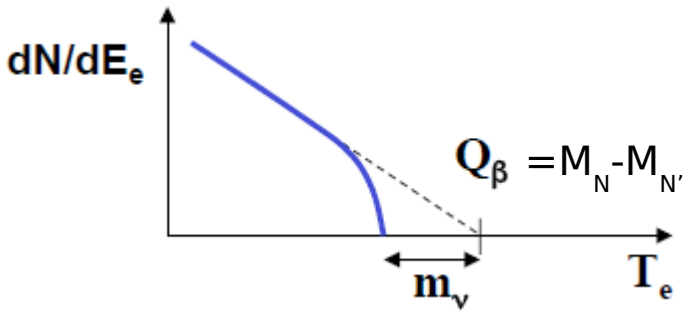


(adapted from A. Cocco ICHEP2018)

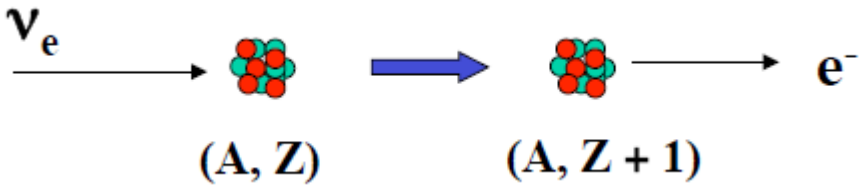
A.G.Cocco, M.Messina and G.Mangano JCAP 06(2007)015

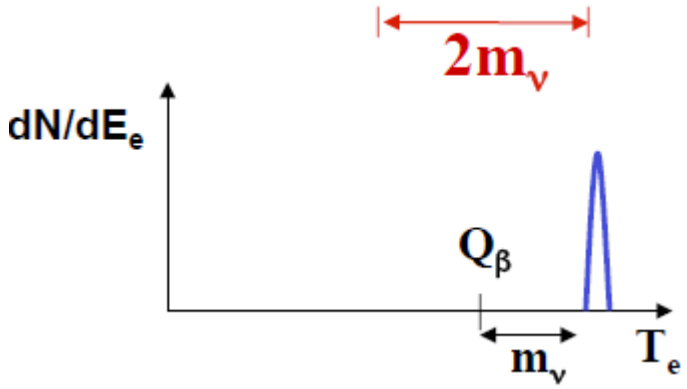
spontaneous nuclear β decay





"induced" nuclear β decay





This process has no energy threshold
The cross section is not vanishing

The electron spectrum from induced neutrino capture has a unique signature: there is a gap of 2 m_ν centered at Q_β between the signal and the "background" electrons from spontaneous β decay

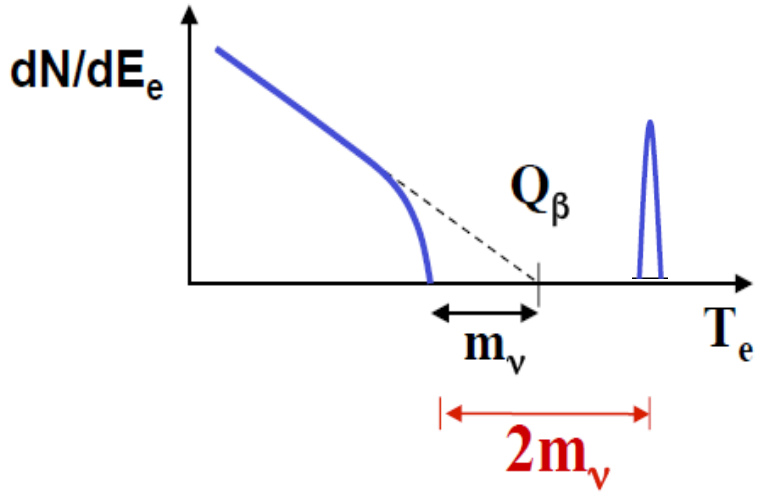
(adapted from A. Cocco ICHEP2018)

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

Signal to background ratio depends crucially on the energy resolution Δ at the beta decay endpoint

Detection possible only if

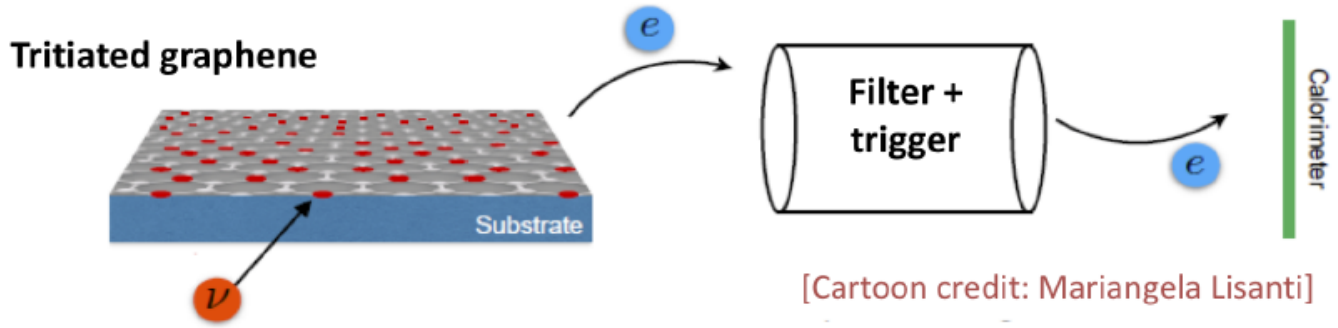
$\Delta < m_\nu$



For a neutrino mass of 0.7 eV and an energy resolution Δ =0.2 eV, a S/B ratio of 3 is obtained. PTOLEMY's target Δ=0.05 eV

For 100 gr of Tritium, one expects ~10 capture events per year

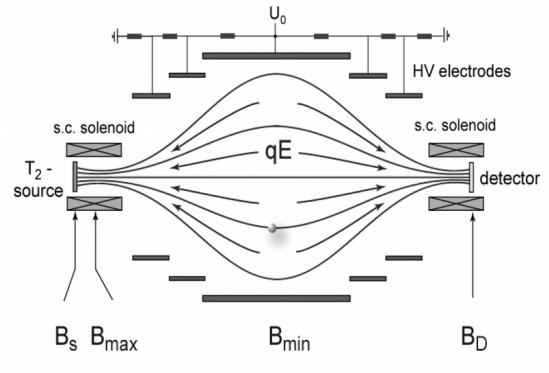
100g of atomically bonded ^3H ; use tritiated graphene (~0.5 kg)



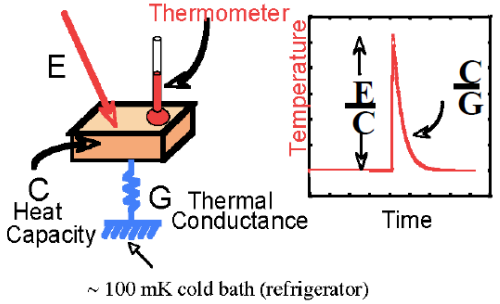
[Cartoon credit: Mariangela Lisanti]

<u>Source</u>:
single atomic layer of T on graphene substrate

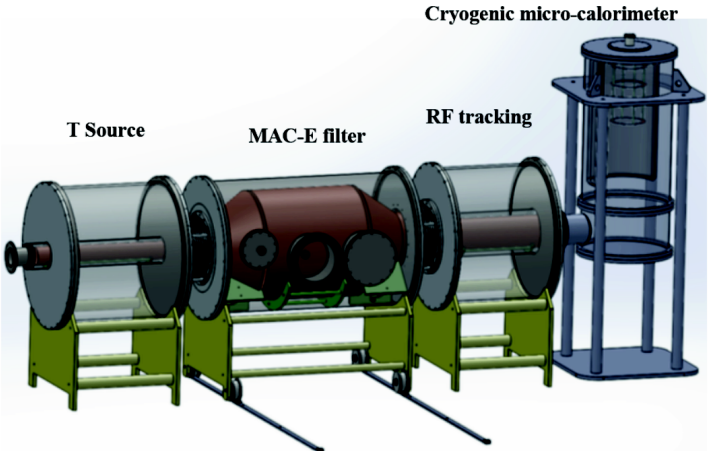
<u>Filter</u>:
MAC-E filter (Magnetic Adiabatic Collimation+Electrostatic)



<u>Calorimeter</u>:
Cryogenic Transition Edge Sensor (TES)

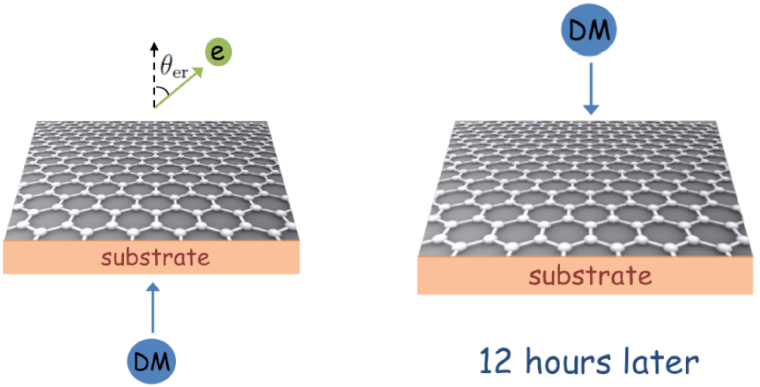


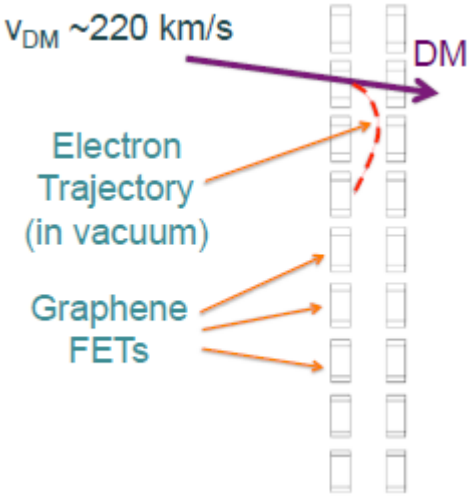
The PTOLEMY prototype
@ Princeton

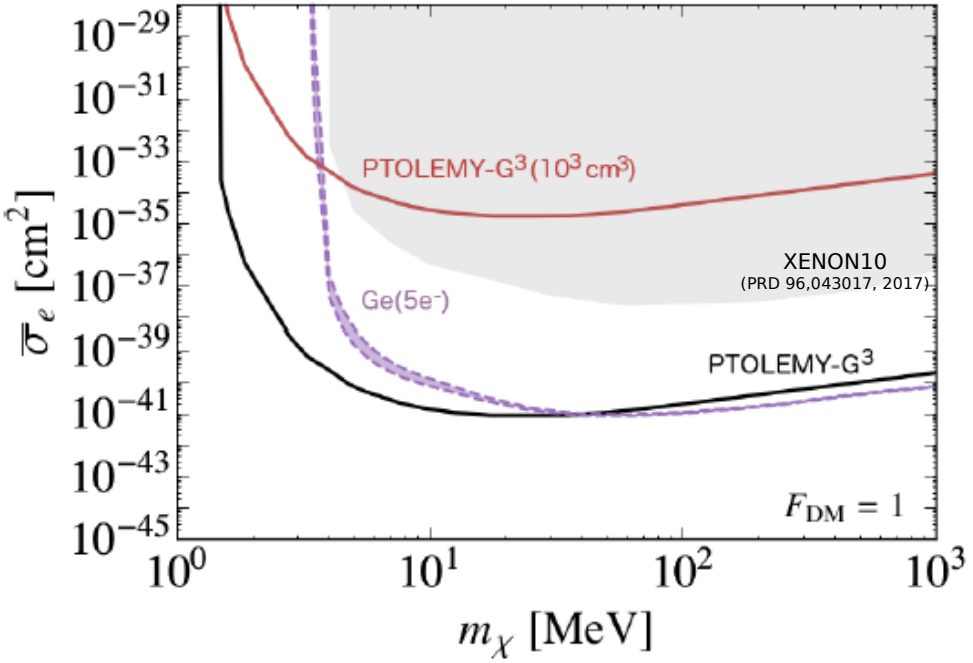


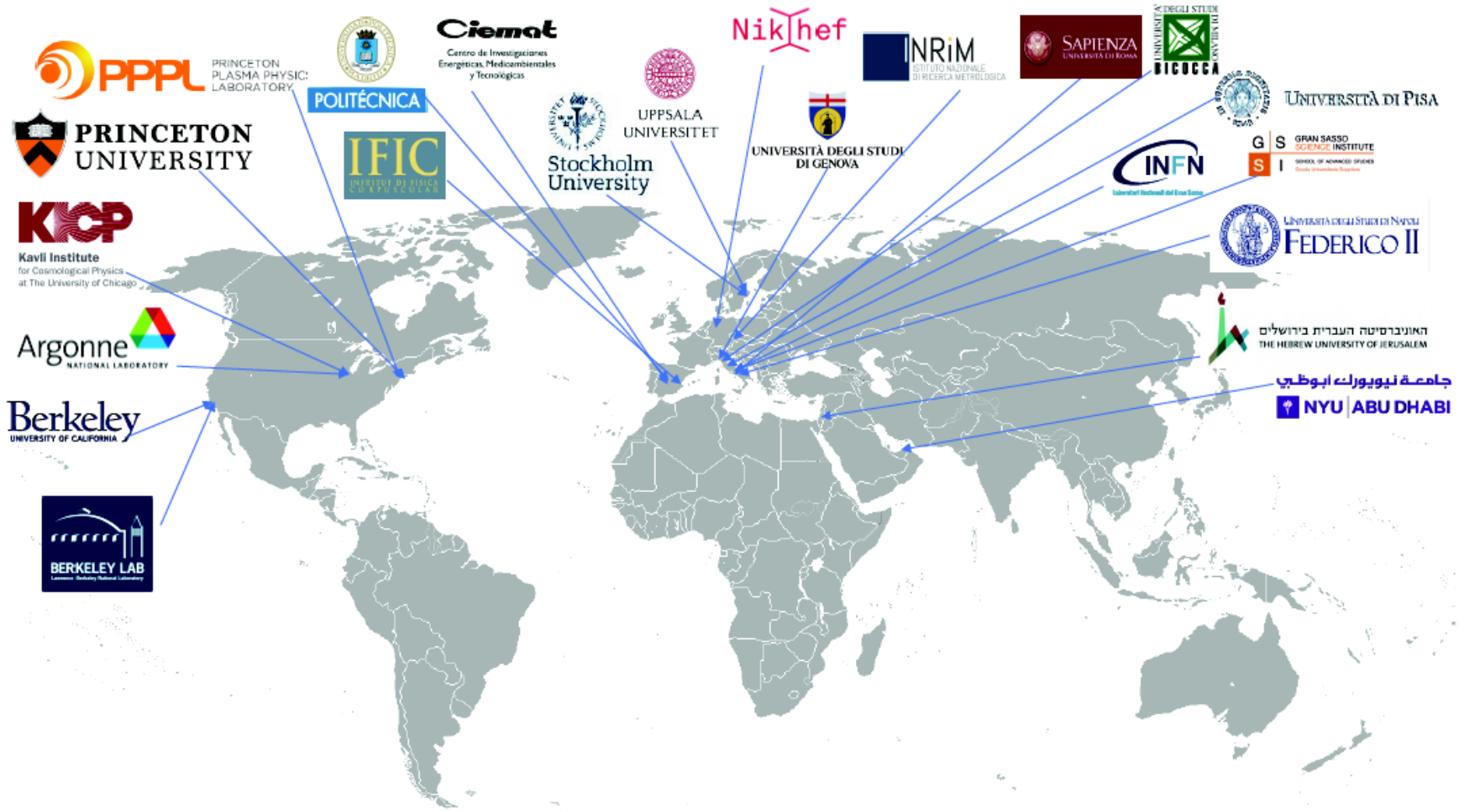
PTOLEMY as a directional DM detector

- PTOLEMY without tritium load and a graphene field effect transistor (FET) target array
- Sensitive to DM+e^- interactions
- FETs provide directionality measurement
- TES provides sensitivity to low e^- energies, ie, to MeV dark matter
- Graphene target can be molded to increase directionality sensitivity (nanotubes, nano-ribbons…)









Sweden:

A. Ferella, J. Gudmundsson, J. Conrad, C-F Strid (SU), C. de los Heros (UU)

Working on the static electromagnetic filter simulation and on the optimisation of the source-filter coupling

Letter of Intent to the Laboratori Nazionali del GranSasso (Italy)

PTOLEMY: A Proposal for Thermal Relic Detection of Massive Neutrinos and Directional Detection of MeV Dark Matter

E. Baracchini[3], M.G. Betti[11], M. Biasotti[5], F. Calle-Gomez[15], G. Cavoto[10,11], C. Chang[22,23], A.G. Cocco[7], A.P. Colijn[13], J. Conrad[18], N. D'Ambrosio[2], M. Faverzani[6], A. Ferella[18], P. Fernandez de Salas[16], E. Ferri[6], P. Garcia[14], G. Garcia Gomez-Tejedor[15], S. Gariazzo[17], F. Gatti[5], C. Gentile[25], A. Giachero[6], J. Godmundsson[18], Y. Hochberg[1], Y. Kahn[26], M. Lisanti[26], C. Mancini-Terracciano[10], G. Mangano[7], L.E. Marcucci[9], C. Mariani[11], G. Mazzitelli[4], M. Messina[20], A. Molinero-Vela[14], E. Monticone[12], A. Nucciotti[6], F. Pandolfi[10], S. Pastor-Carpi[17], C. Pérez de los Heros[19], O. Pisanti[7,8], A. Polosa[10,11], A. Puiu[6], M. Rajteri[12], R. Santorelli[14], K. Schaeffner[3], C.G. Tully[26], Y. Raitses[25], N. Rossi[10], F. Zhao[26], K.M. Zurek[21,22]

[1]Racah Institute of Physics, Hebrew University of Jerusalem, Jerusalem, Israel
[2]INFN Laboratori Nazionali del Gran Sasso, L'Aquila, Italy
[3]Gran Sasso Science Institute (GSSI), L'Aquila, Italy
[4]INFN Laboratori Nazionali di Frascati, Frascati, Italy
[5]Università degli Studi di Genova e INFN Sezione di Genova, Genova, Italy
[6]Università degli Studi di Milano-Bicocca e INFN Sezione di Milano-Bicocca, Milano, Italy
[7]INFN Sezione di Napoli, Napoli, Italy
[8]Università degli Studi di Napoli Federico II, Napoli, Italy
[9]Università degli Studi di Pisa e INFN Sezione di Pisa, Pisa, Italy
[10]INFN Sezione di Roma, Roma, Italy
[11]Università degli Studi di Roma La Sapienza, Roma, Italy
[12]Istituto Nazionale di Ricerca Metrologica (INRiM), Torino, Italy
[13]Nationaal instituut voor subatomaire fysica (NIKHEF), Amsterdam, Netherlands
[14]Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
[15]Consejo Superior de Investigaciones Cientificas (CSIC), Madrid, Spain
[16]Universidad Politécnica de Madrid, Madrid, Spain
[17]Instituto de Física Corpuscular (IFIC), Valencia, Spain
[18]Stockholm University, Stockholm, Sweden
[19]Uppsala University, Uppsala, Sweden
[20]New York University Abu Dhabi, Abu Dhabi, UAE
[21]Lawrence Berkeley National Laboratory, University of California, Berkeley, CA, USA
[22]Department of Physics, University of California, Berkeley, CA, USA
[23]Argonne National Laboratory, Chicago, IL, USA
[24]Kavli Institute for Cosmological Physics, University of Chicago, Chicago, IL, USA
[25]Princeton Plasma Physics Laboratory, Princeton, NJ, USA
[26]Department of Physics, Princeton University, Princeton, NJ, USA

Submitted: March 19th, 2018

GS Scientific Committee green light: May 31st

A lot of R&D to be done

What was “impossible” a few years ago is now just “challenging”

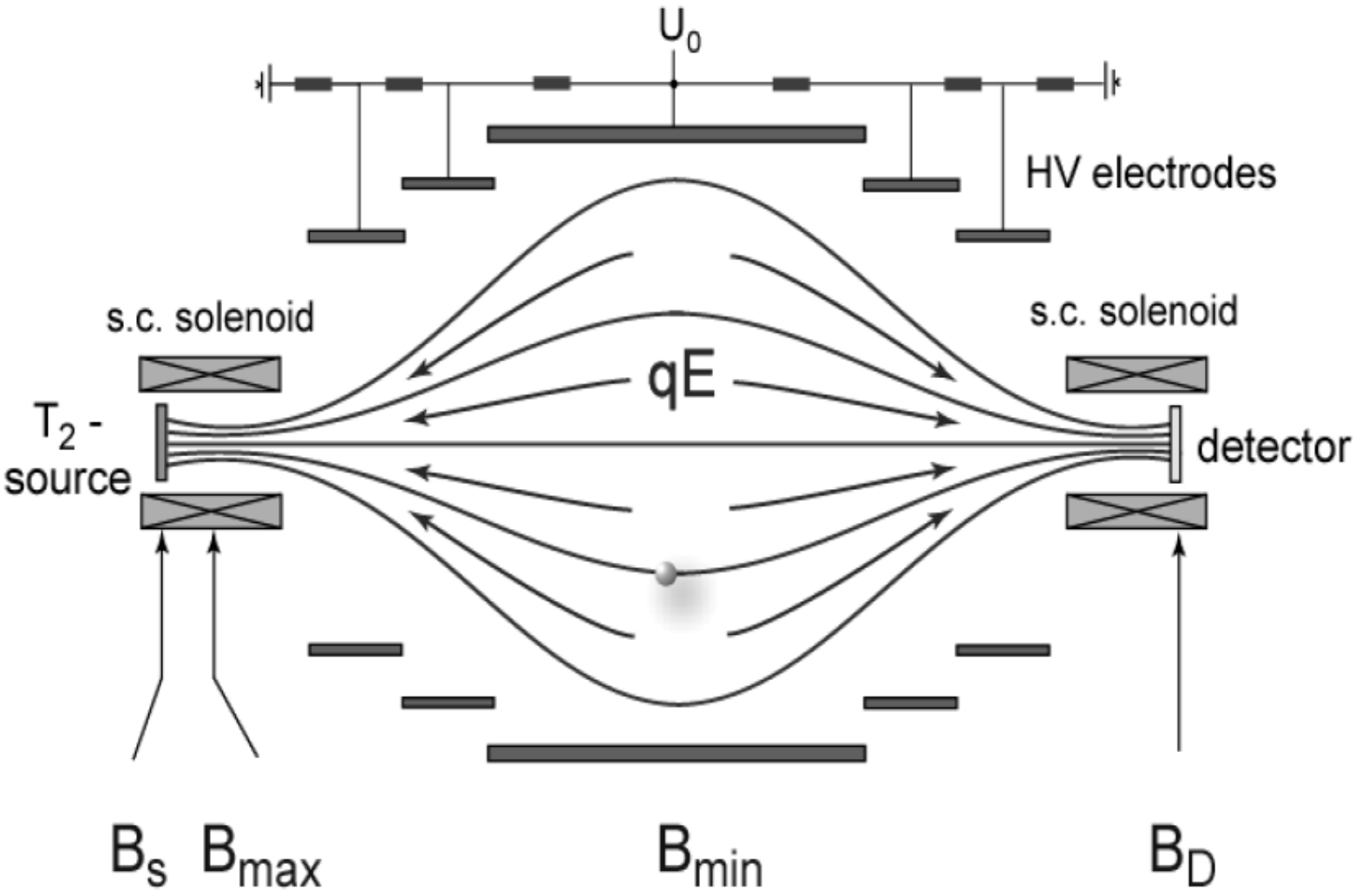
PTOLEMY has become an LNGS experiment and a prototype installation is starting at the lab

A first phase of PTOLEMY will be to look for light Dark Matter with directional sensitivity

The second phase, with a Tritium source, will be devoted to measure the CNB

New collaborators welcome. Chance to contribute from the first stages of the experiment

(Magnetic Adiabatic Colimation+Electrostatic)



From arxiv:0909.2104

Phase I

Proof-of-principle @ LNGS:

TES, Graphene, background level (3 to 5 years)

Phase II

Technical design for a scalable detector

Phase III

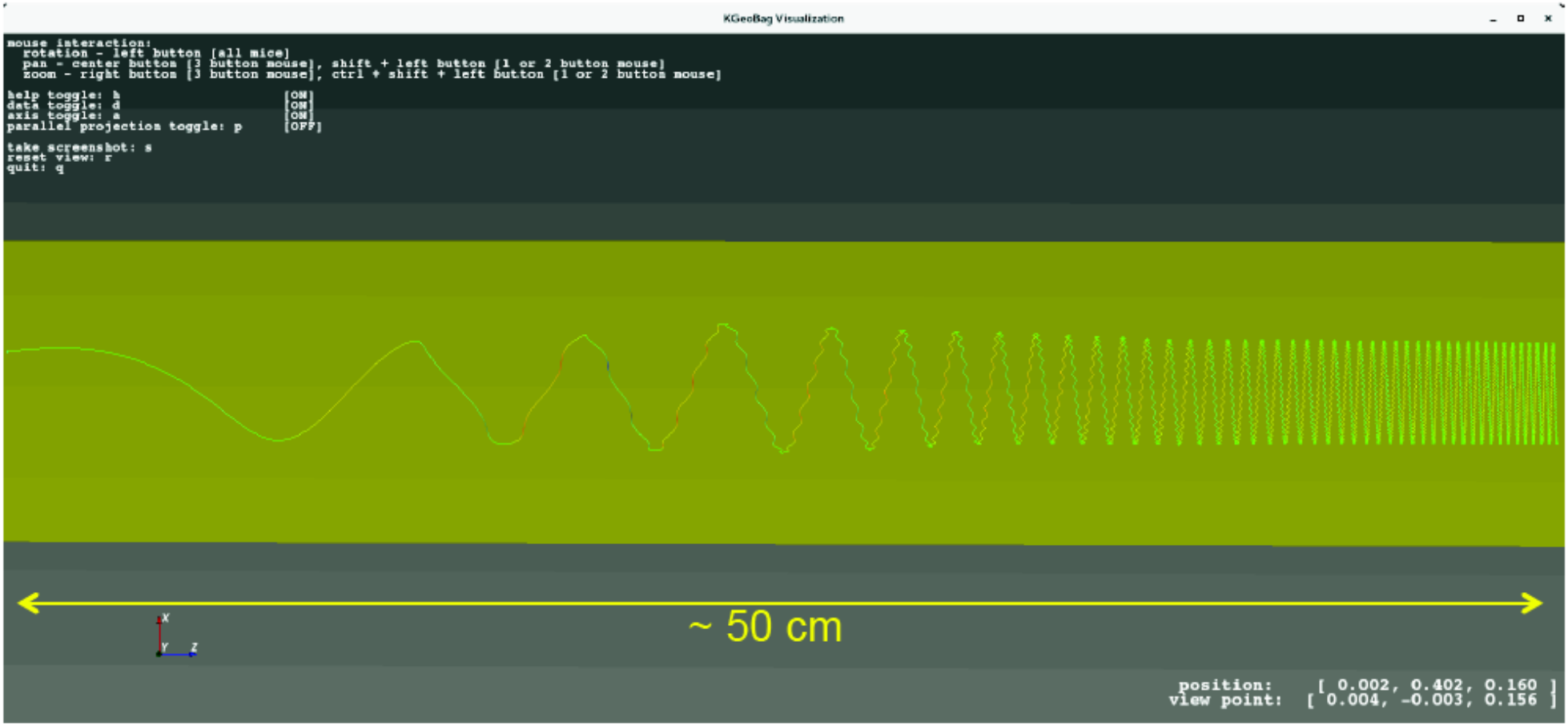
Full detector construction and search for relic neutrino

(7 events/100 g Tritium expected)

(from A. Cocco ICHEP2018)

New E×B filtering design

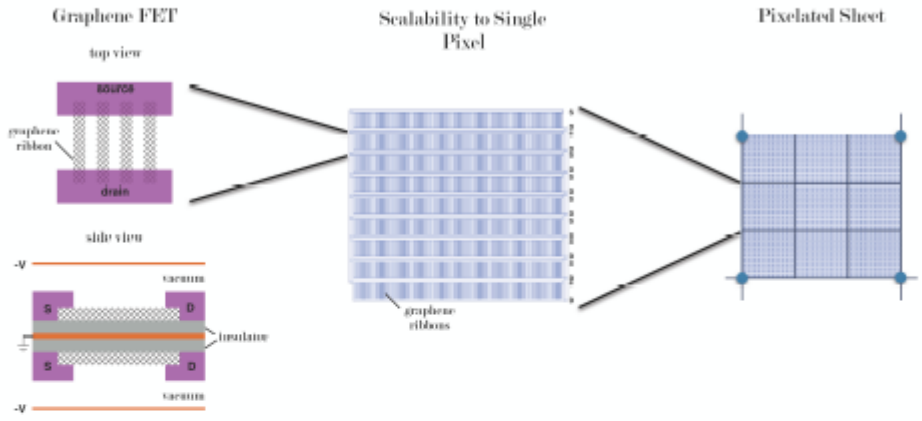
(Top view)

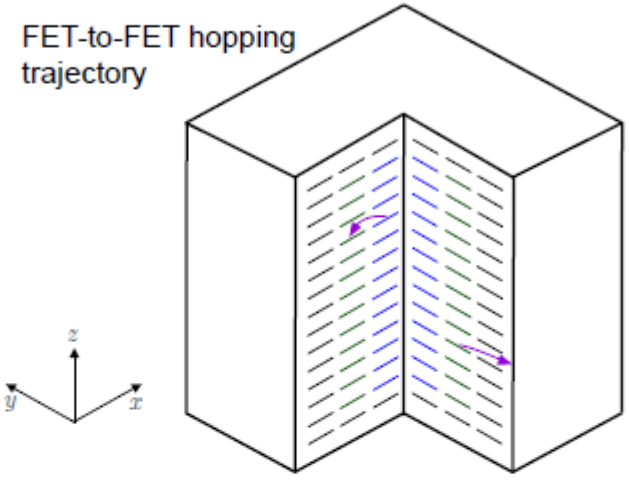


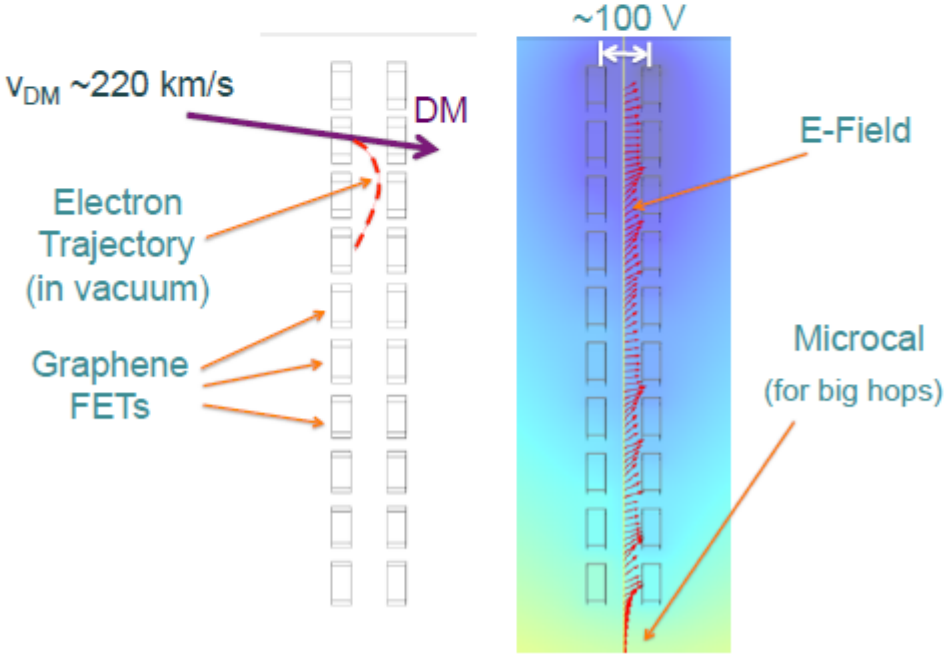
Example of 15 keV electron loosing transverse energy as the B field intensity decrease (drift is from the right to the left)

(from A. Cocco ICHEP2018)

PTOLEMY-G^3
Detector configuration







- Scaling up ~mm to ~cm
- Stacked planar arrays of G-FETs
  1kg ~ 10^{10}cm^2 ~ 10^9 cm^3
  Individually vacuum-sealed wafers
  Cryogenically cooled (4.2K)
  Cryopumping of gas contaminants on G3 surface - no line-of-sight trajectories
  Low mass substrates with ALD dielectric

What is special about Graphene?

- Geim et al. in 2004 noted gaphene sensitivity to a single electric charge (added or removed) in a Field-Effect Transistor configuration - here at room temperature
- It is a semimetal: Dirac point provides a resistivity spike at a single gate voltage and the height is set by the inverse of the mobility
- Mobility increases by an order of magnitude at cryogenic temperatures
- Small band gap (meV) induced in Graphene could provide clean on/off transitions