# MAC-E filter and RF electron detection

PonTecorvo Observatory for Light, Early-Universe, Massive-Neutrino Yield (PTOLEMY)

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# Experimental Perspective

Too much rate (need to filter)

Need very high energy resolution ($\sigma \sim m_\nu$)

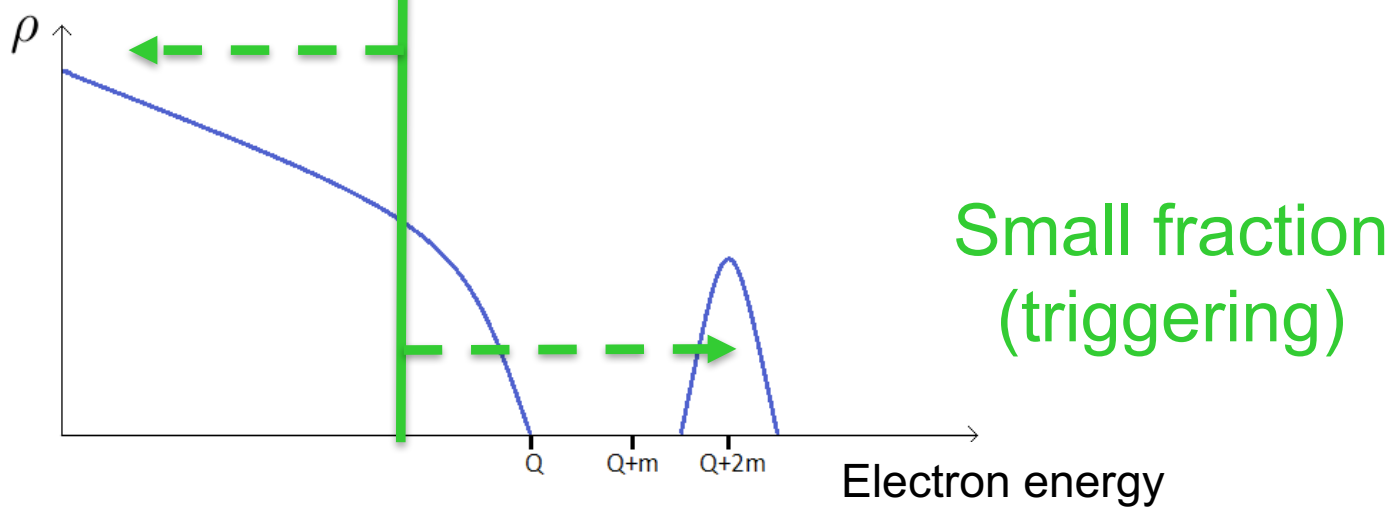
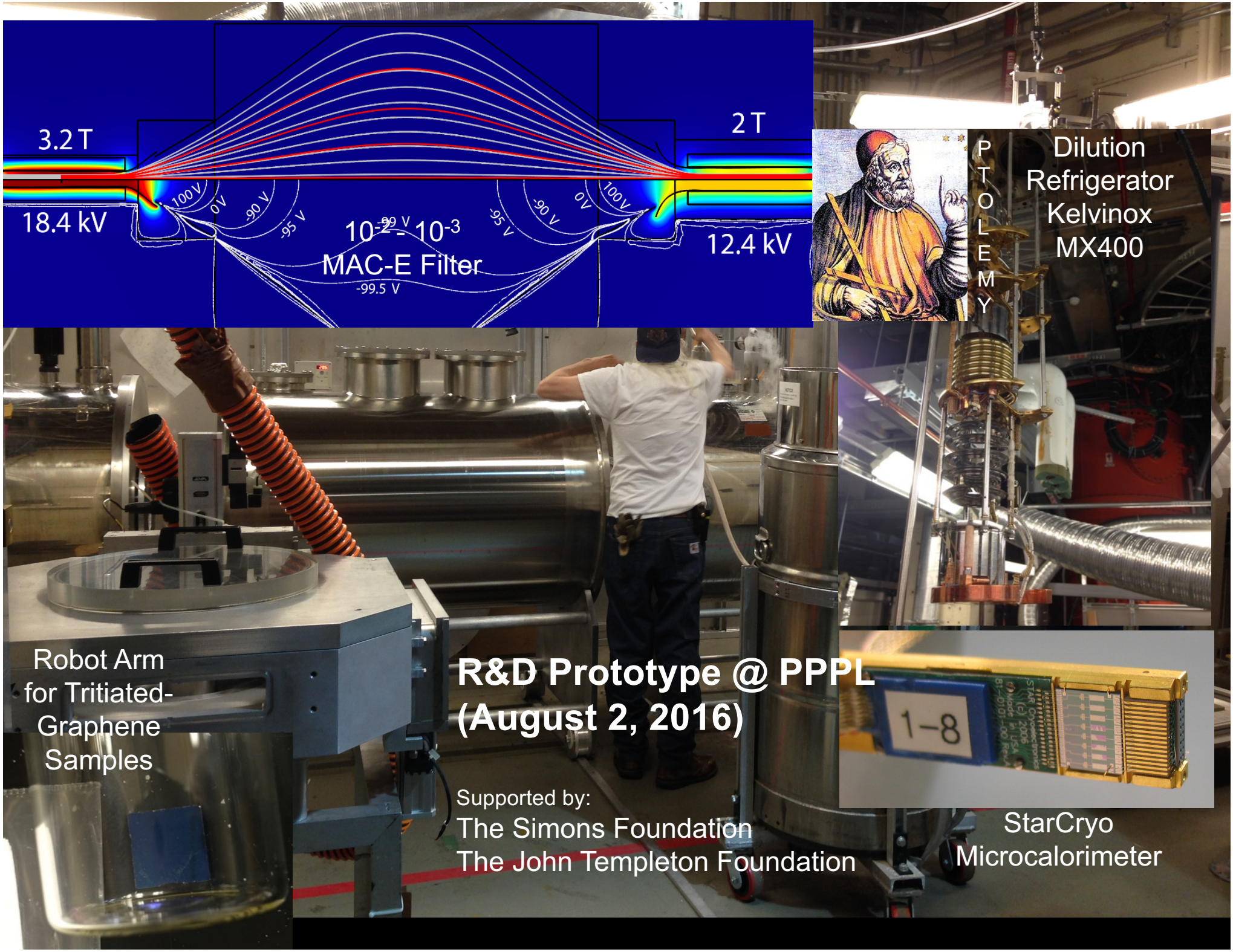


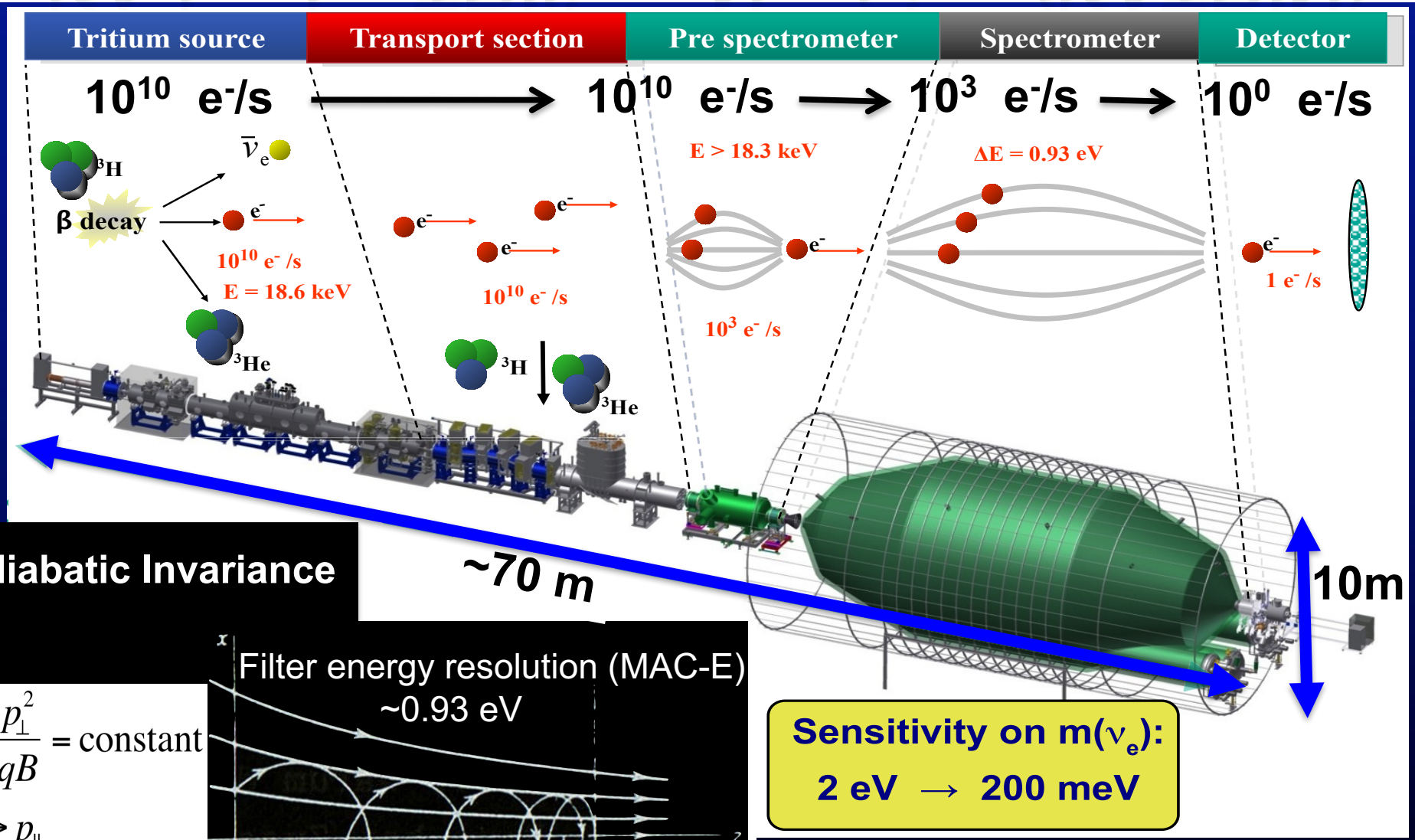

Figure 1: Emitted electron density of states vs kinetic energy for neutrino capture on beta decaying nuclei. The spike at $Q + 2m$ is the CNB signal


# R&D Prototype @ PPPL (August 2, 2016)

Supported by:
The Simons Foundation
The John Templeton Foundation


3.2 T
2 T
18.4 kV
12.4 kV
100 V
0 V
-90 V
-95 V
-99 V
$10^{-2}$ - $10^{-3}$
MAC-E Filter
-99.5 V
PTOLEMY
Dilution
Refrigerator
Kelvinox
MX400
Robot Arm
for Tritiated-
Graphene
Samples
R&D Prototype @ PPPL
(August 2, 2016)
Supported by:
The Simons Foundation
The John Templeton Foundation
1-8
StarCryo
Microcalorimeter

# KArlsruhe TRItium Neutrino (KATRIN)



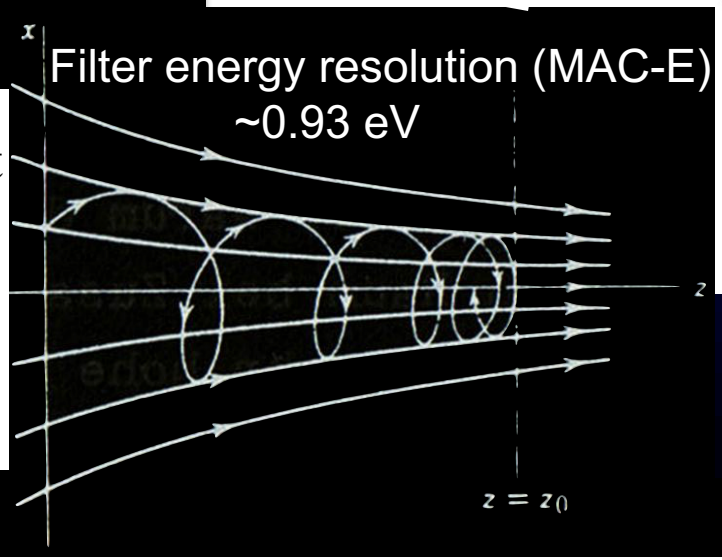

**Adiabatic Invariance**

$$\mu = \frac{p_\perp^2}{qB} = \text{constant}$$

$$p_\perp \rightarrow p_\parallel$$

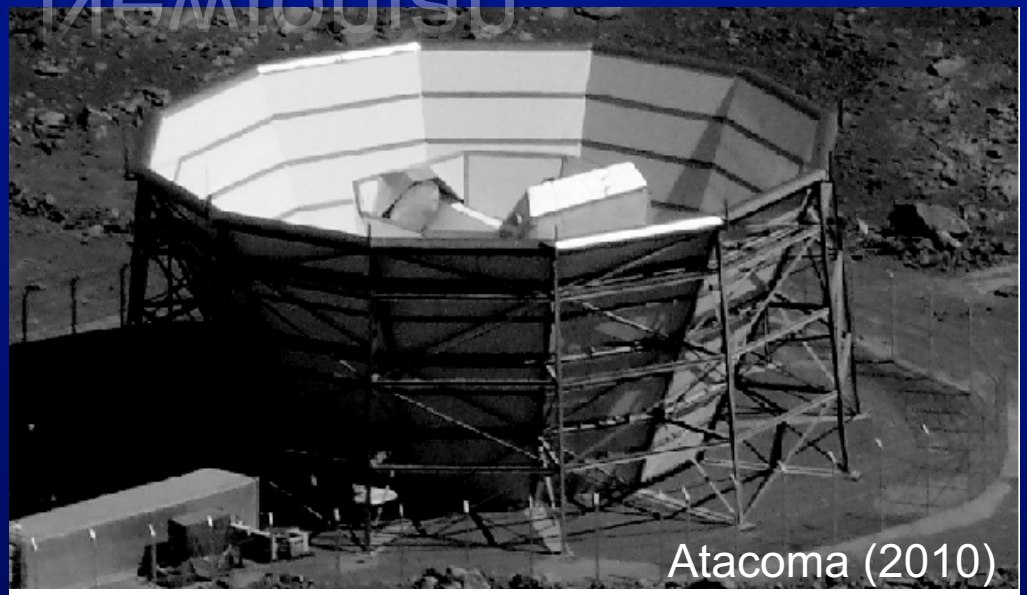
Filter (E - Field)

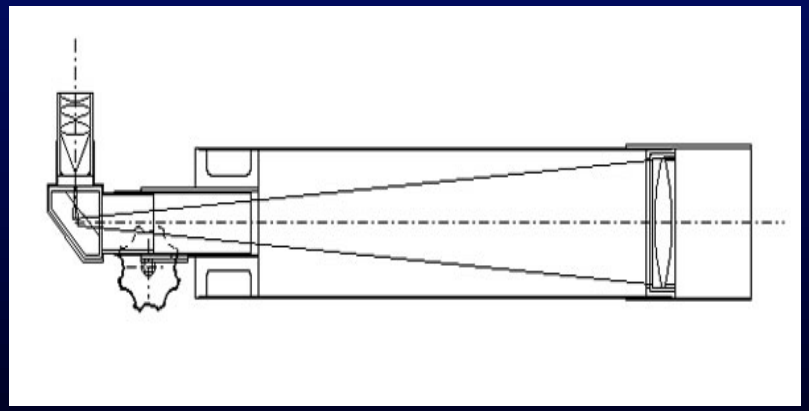
$$p_\parallel \rightarrow p_\perp$$

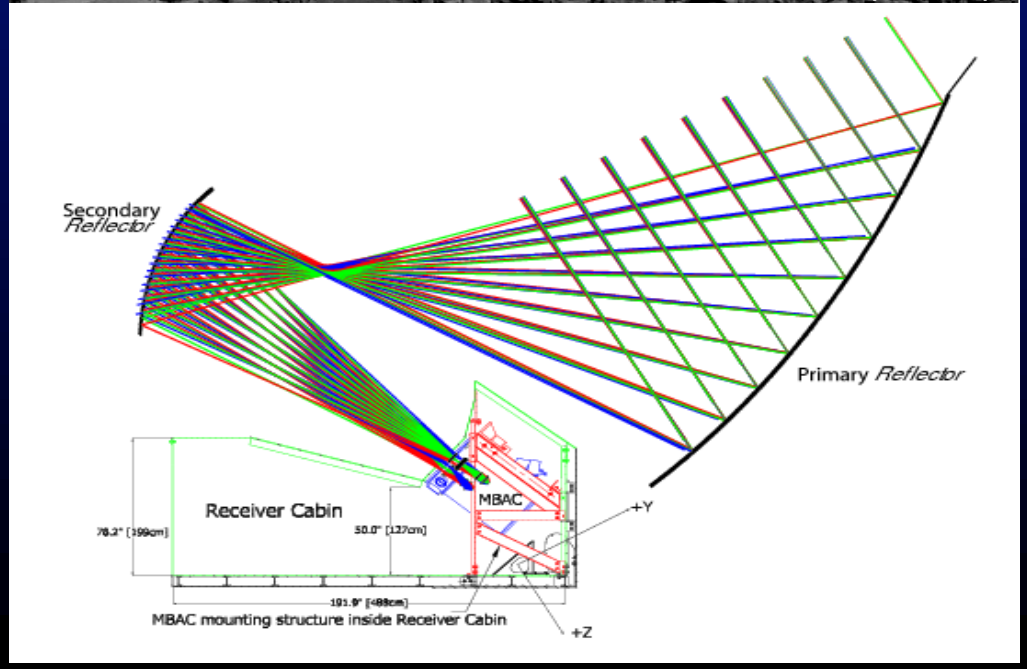



**Sensitivity on m($\nu_e$):**
**2 eV → 200 meV**

# Refractor → Reflector Telescopes
# Galilean → Newtonian

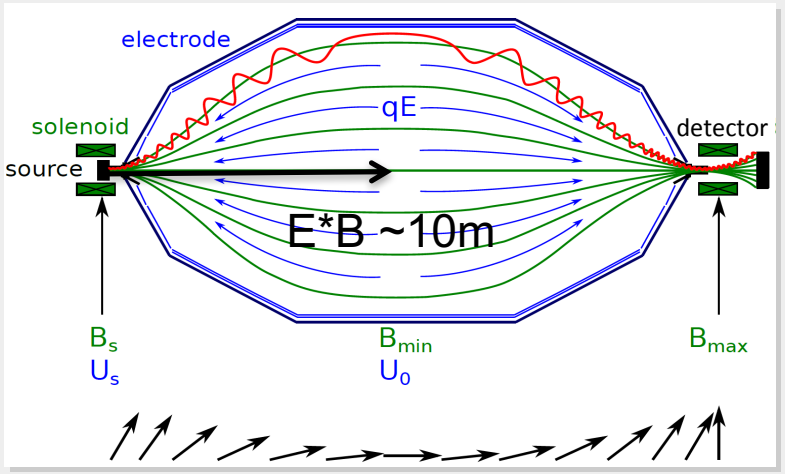





# MAC-E "Telescope"

**MAC-E filter technique**

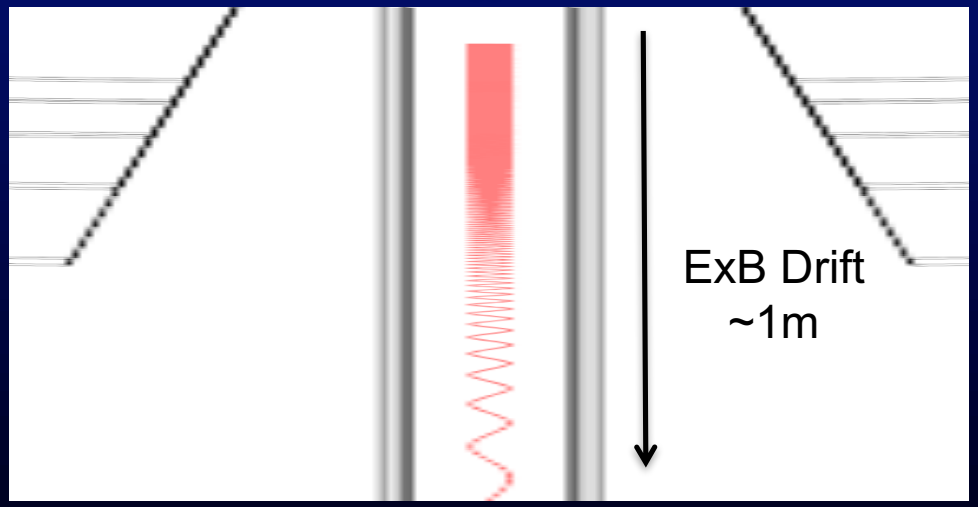
Magnetic Adiabatic Collimation with Electrostatic filter
Picard et al., NIM B63 (1992) 345



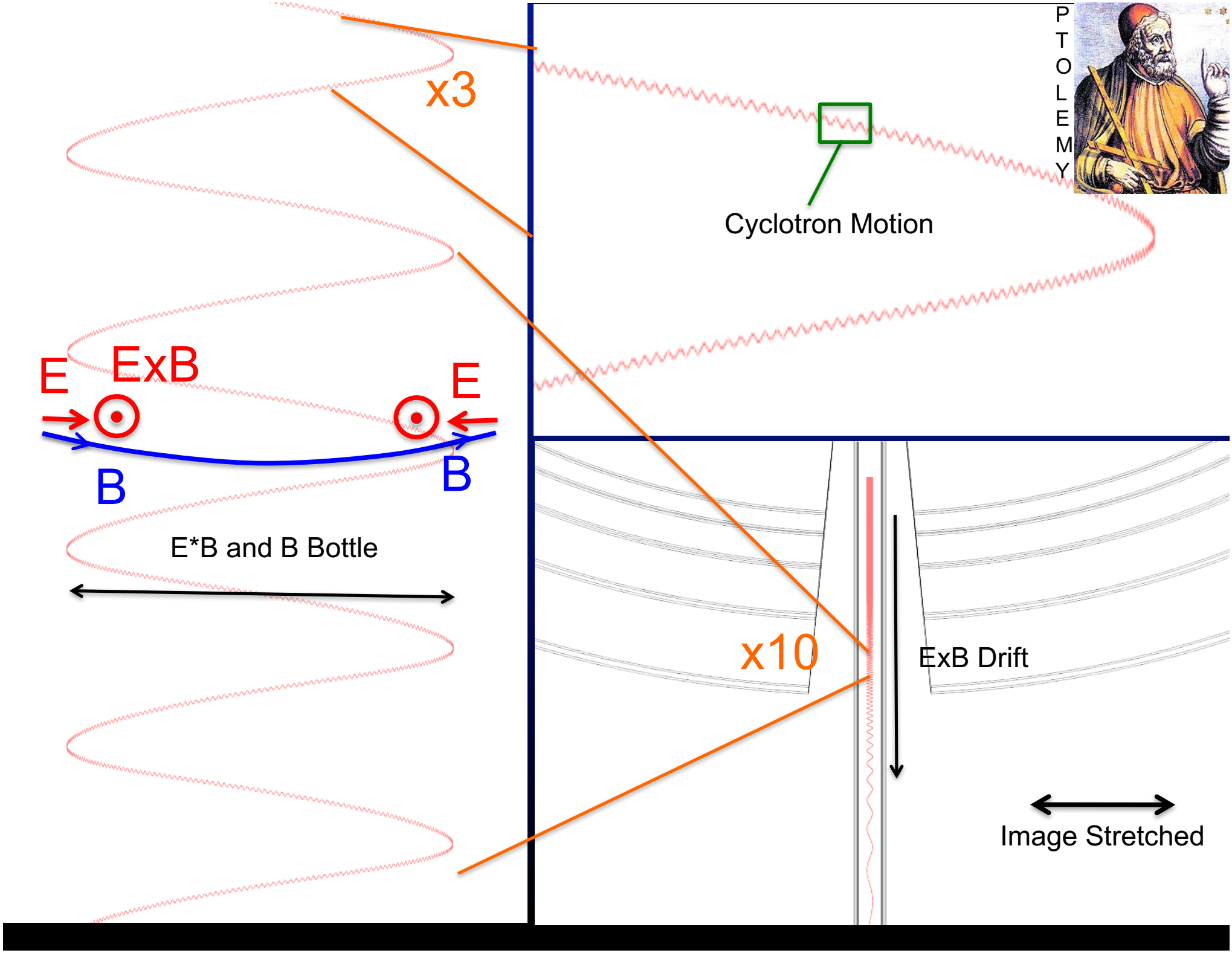

$$\mu = \frac{E_\perp}{B} = \text{const.}$$

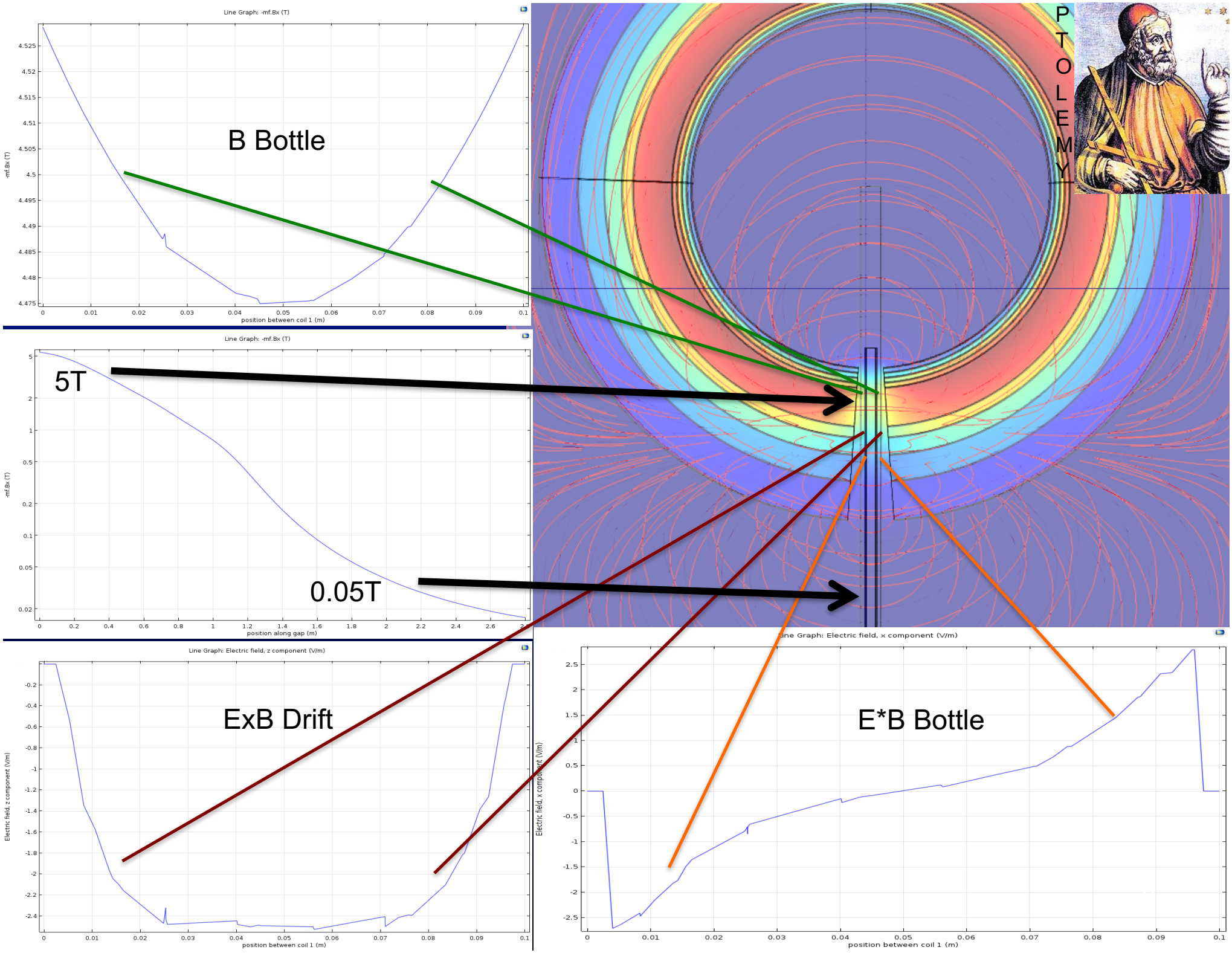
PTOLEMY implements a "reflector" method that is four orders of magnitude more compact along the direction of the B field

E*B ~1cm
↔



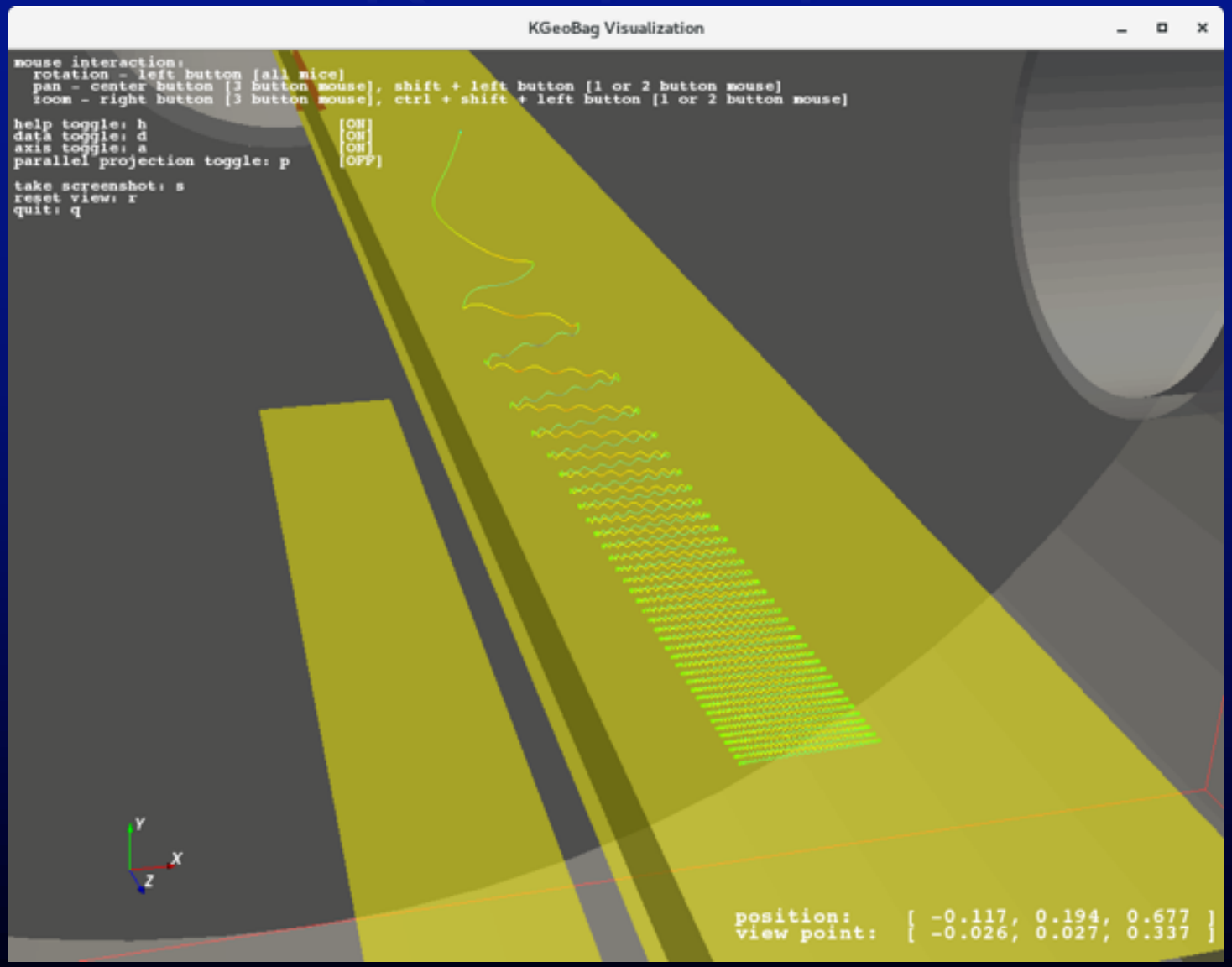

Filtering of the energy is in the vertical direction


x3
Cyclotron Motion
PTOLEMY
E
ExB
E
B
B
E*B and B Bottle
x10
ExB Drift
Image Stretched


Line Graph: -mf.Bx (T)
B Bottle
-mf.Bx (T)
position between coil 1 (m)
Line Graph: -mf.Bx (T)
5T
0.05T
-mf.Bx (T)
position along gap (m)
Line Graph: Electric field, z component (V/m)
ExB Drift
Electric field, z component (V/m)
position between coil 1 (m)
Line Graph: Electric field, x component (V/m)
E*B Bottle
Electric field, x component (V/m)
position between coil 1 (m)
PTOLEMY

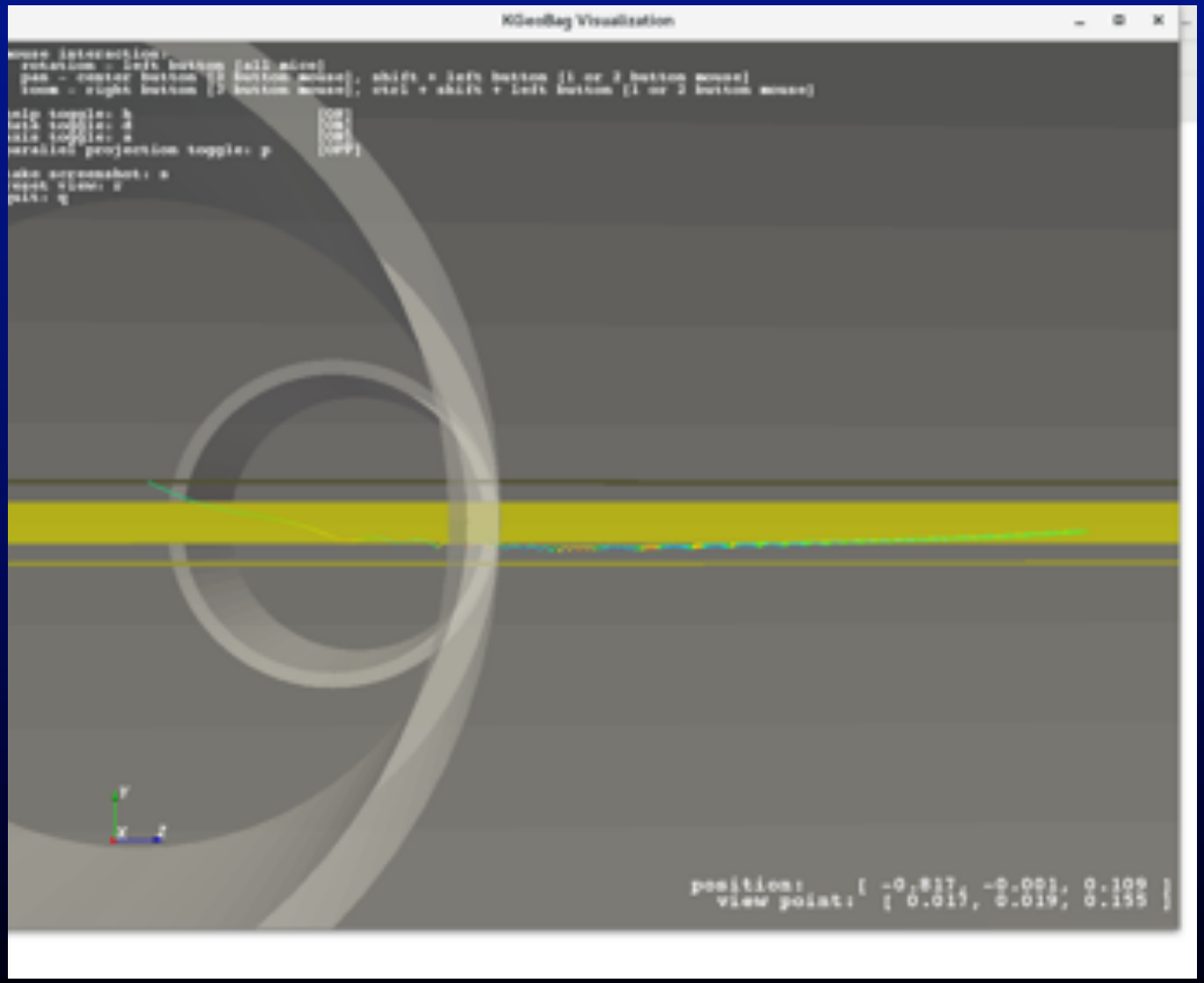
# Kassiopeia

A. Cocco



# Vertical Drift

A. Cocco



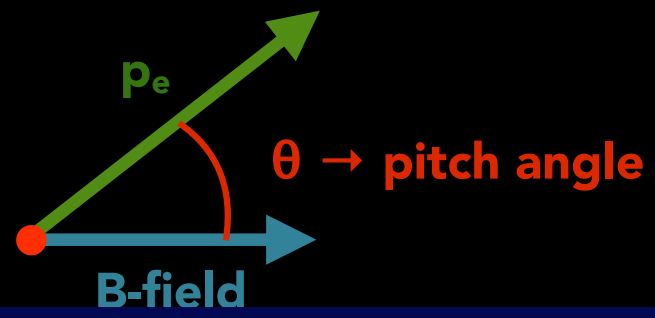
# Cyclotron Radiation Emission Spectroscopy (Project 8) → RF Trigger

Larmor formula

$$P(\gamma,\theta) = \frac{1}{4\pi\varepsilon_0}\frac{2}{3}\frac{q^4 B^2}{m_e^2}(\gamma^2-1)\sin^2\theta$$

Emitted power

- 1.1 fW for 18 keV $e^-$ at 90°

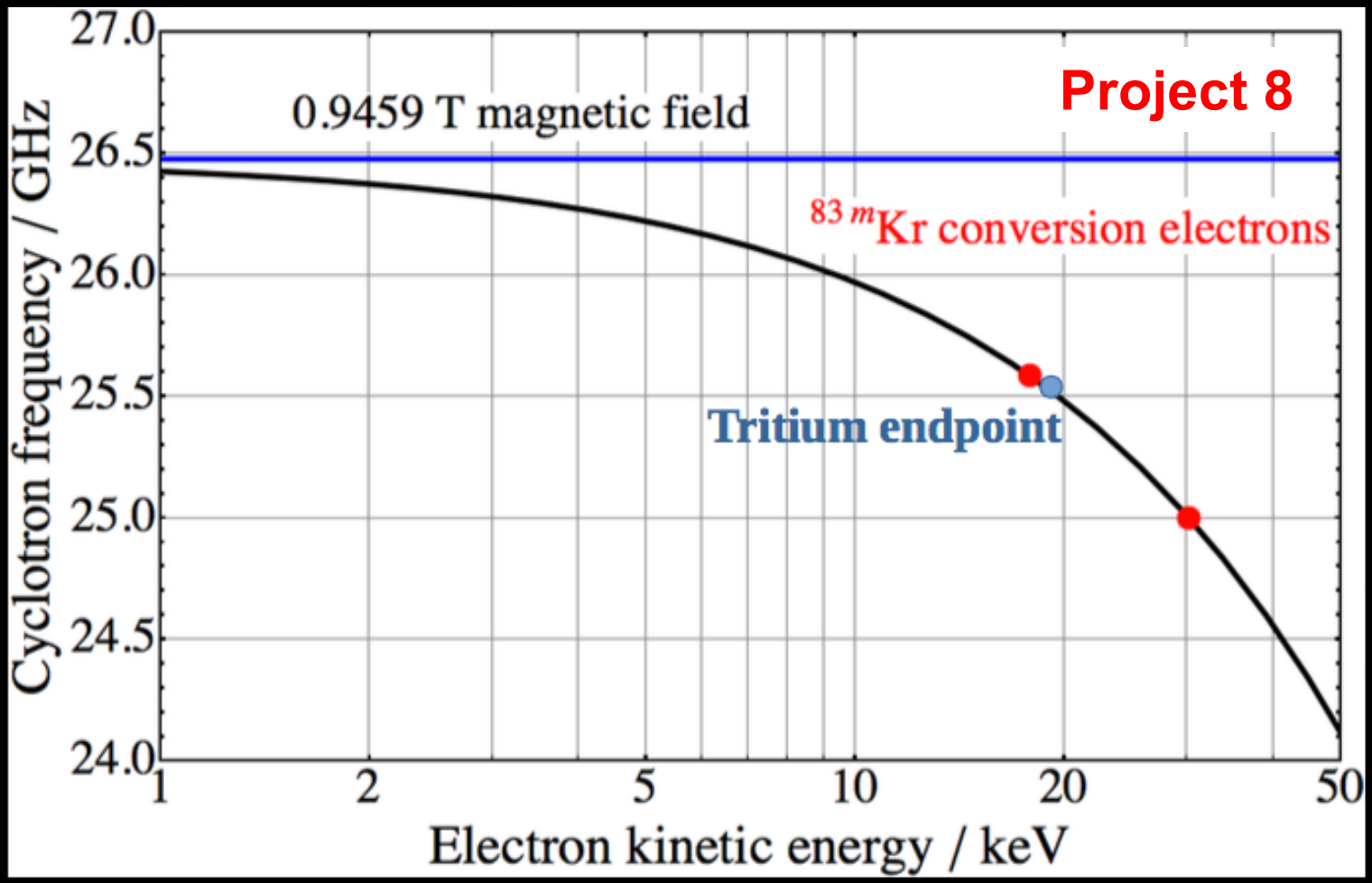



PTOLEMY ExB Filter is a natural harmonic trap

- B field is dropping adiabatically as the electrons drift radially
- Drift velocity has to be adjusted so that number of bounces is roughly ~20,000 per FFT/Trigger decision

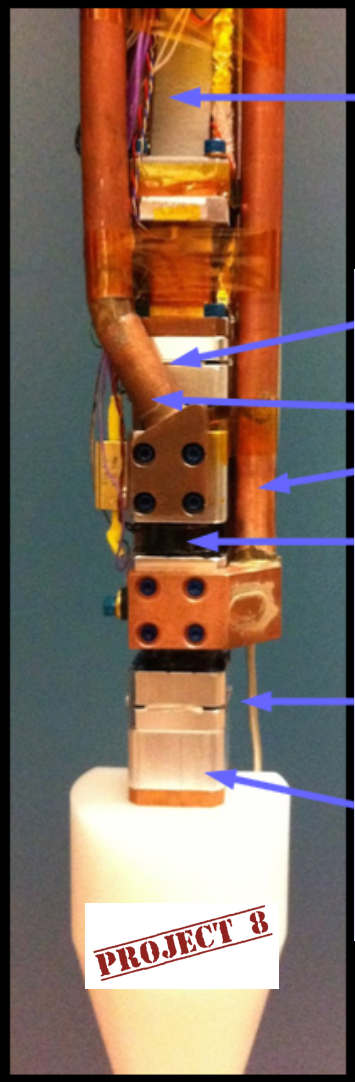
# Relativistic Correction to Cyclotron Frequency

magnetic field of 1T → cyclotron frequency in K-Band

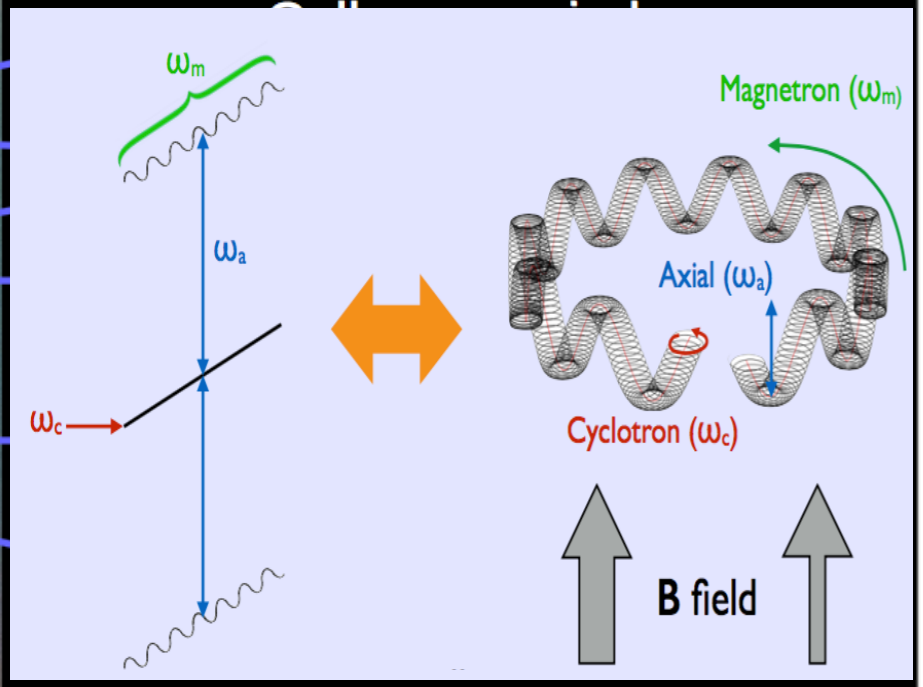



$^{83m}$Kr provides electrons close to tritium endpoint

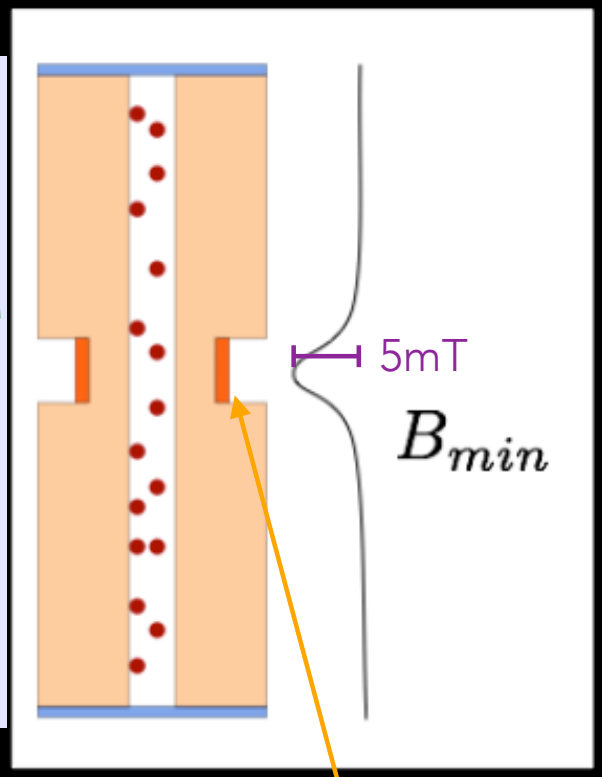
# Project 8 Prototype (Harmonic Trap)




Waveguide to amplifiers



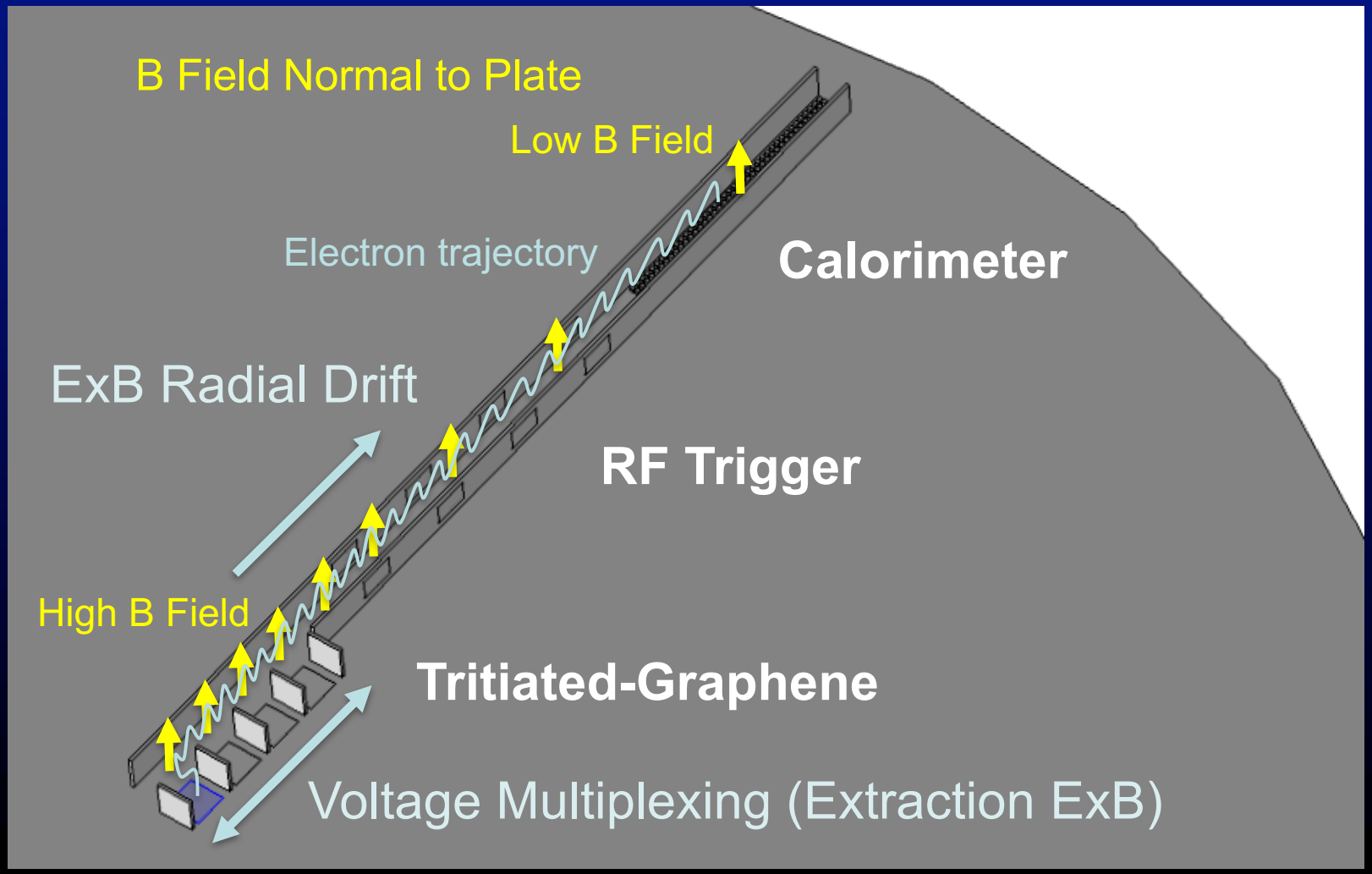

Harmonic $e^-$ trap



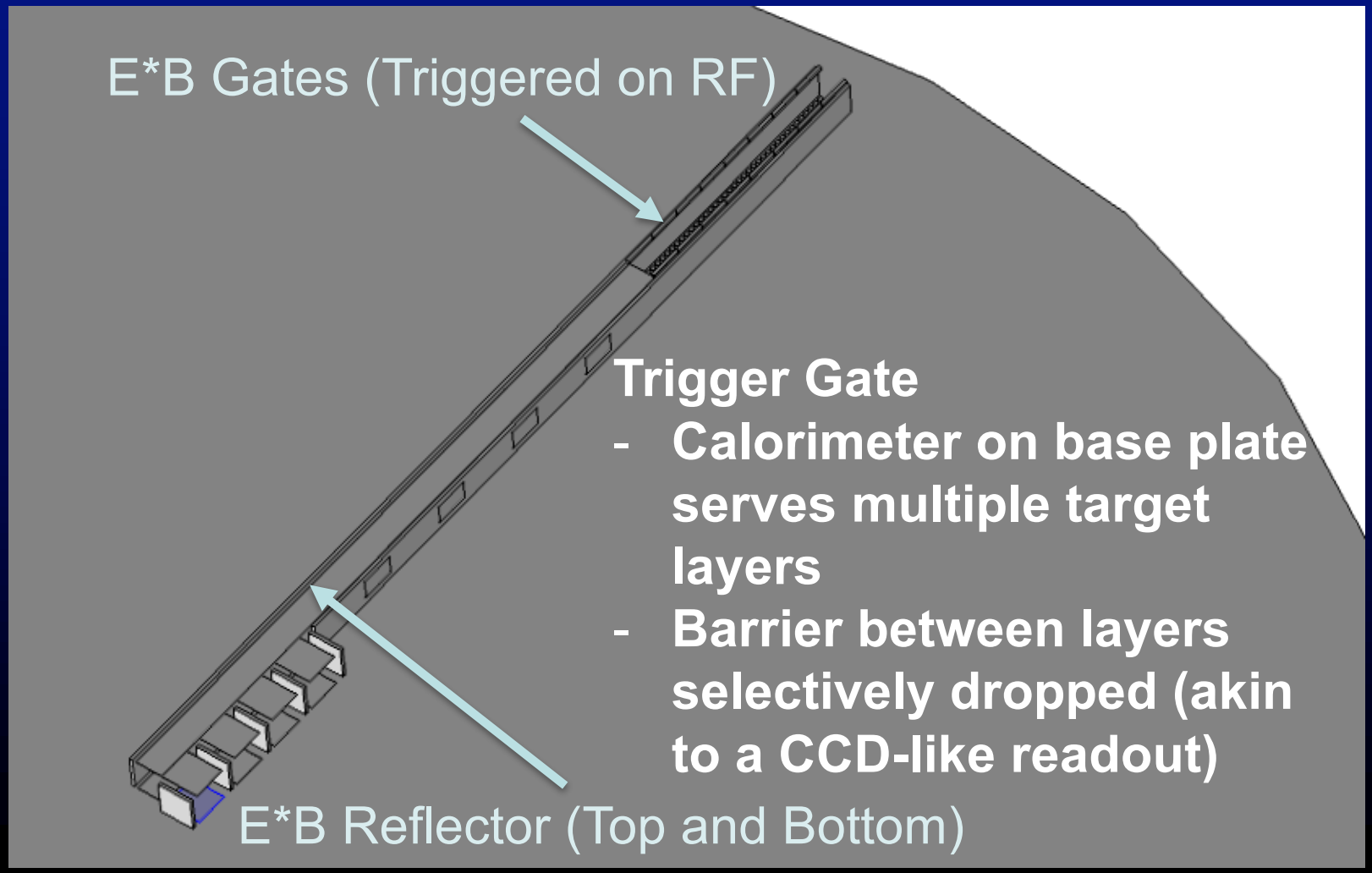

Magentic bottle coil

# Step 2: Scalable Design

- Minimal path from target to measurement
  - Can this be done in ~1 meter ?
  - Can a location be found to host a large-scale



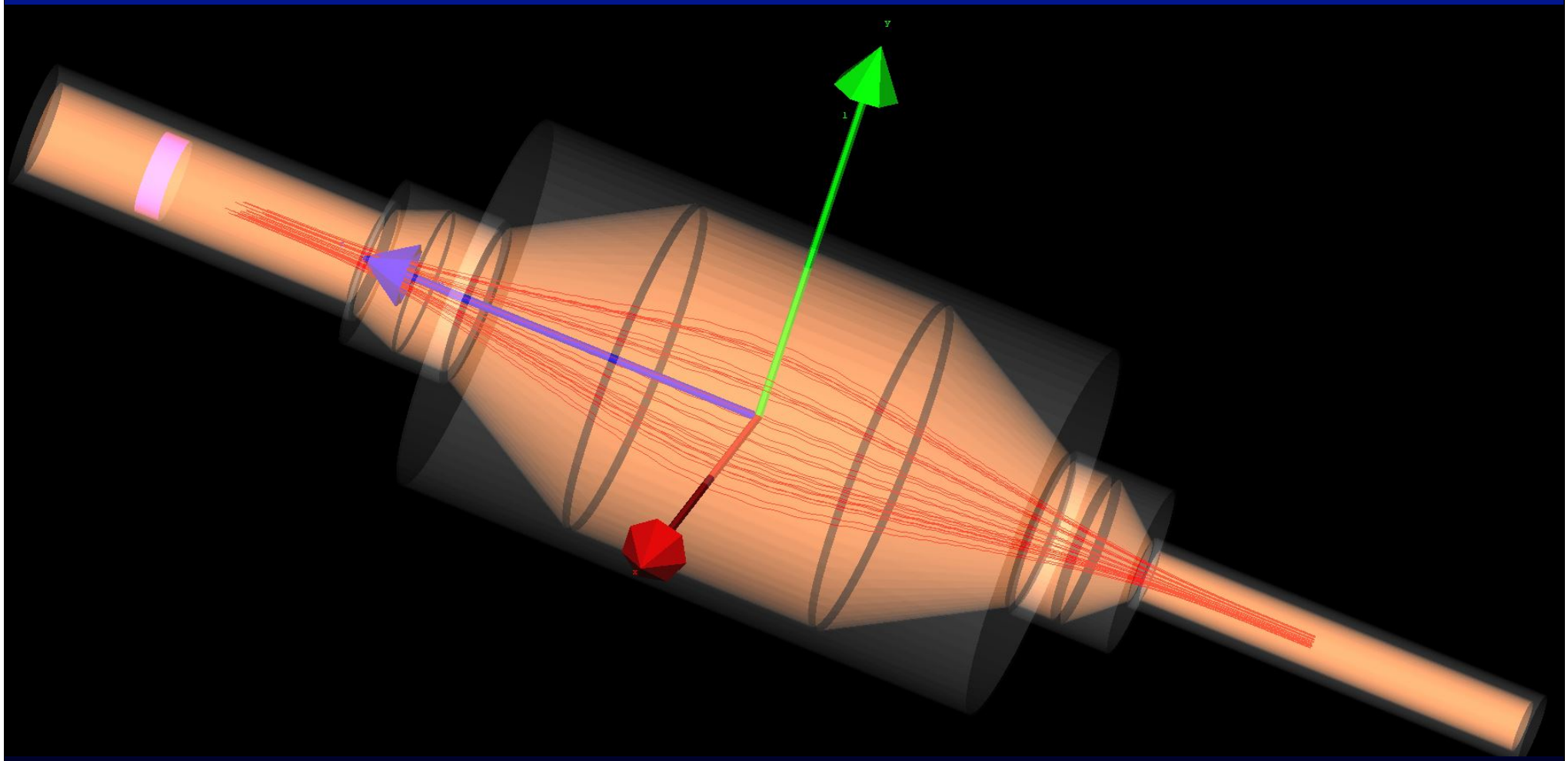
# E*B Reflector and Trigger Gate to Calorimeter



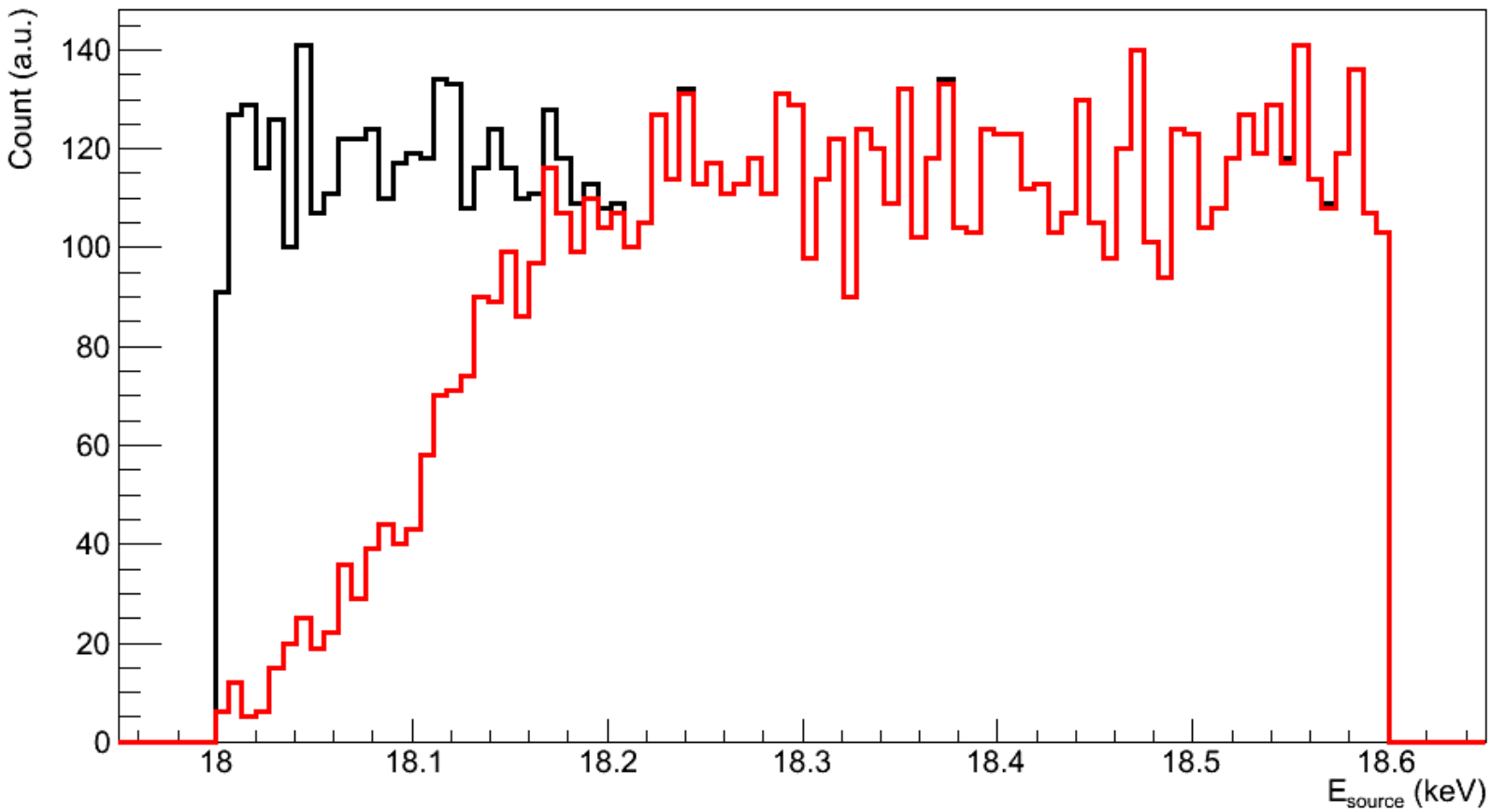

**Trigger Gate**

- **Calorimeter on base plate serves multiple target layers**
- **Barrier between layers selectively dropped (akin to a CCD-like readout)**

# GEANT4

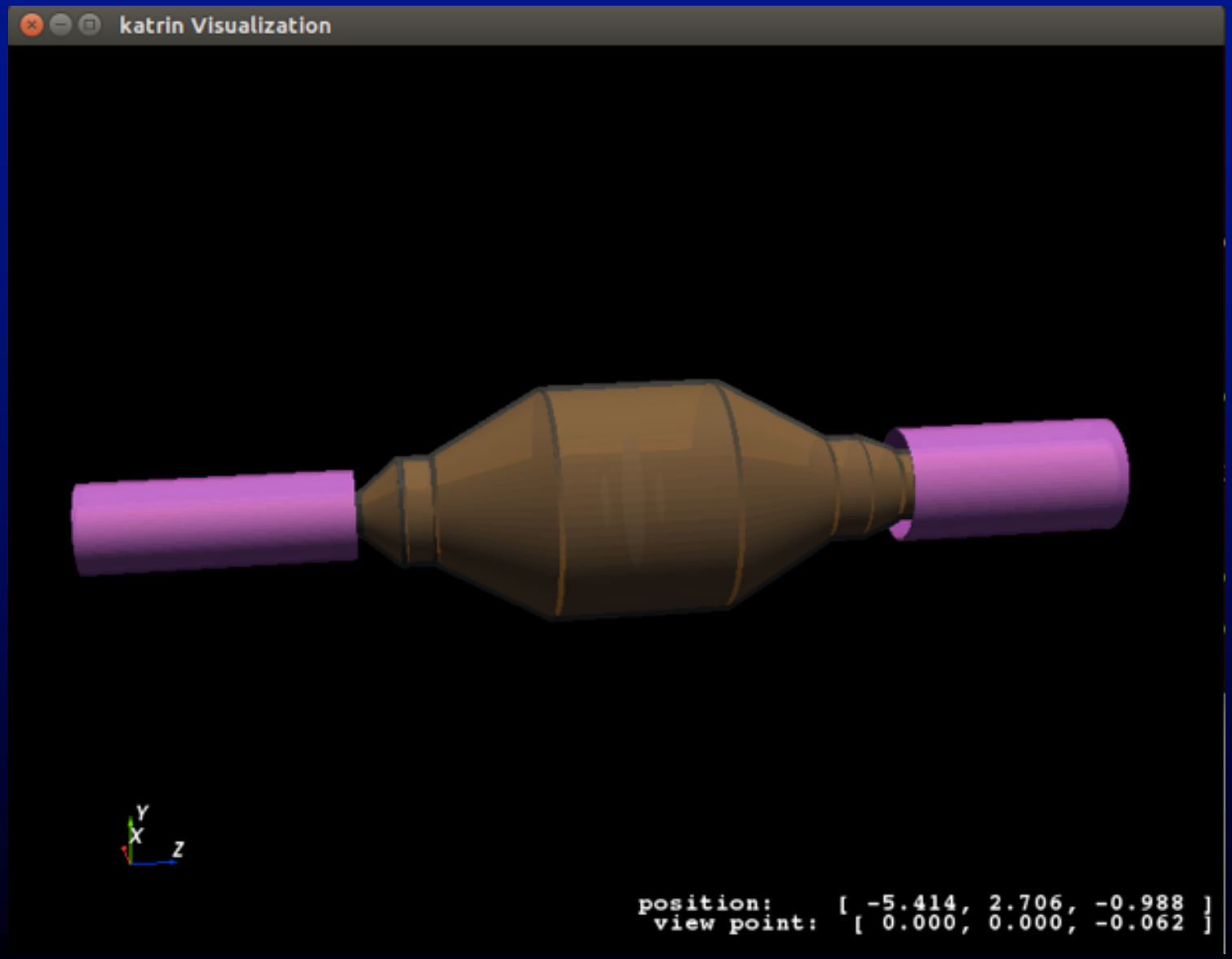


# Prototype Filter



# Kassiopeia

A. Cocco



# Overview/R&D Plan

- MAC-E for existing prototype needs further studies to understand electron transport between target (or e-Gun) and microcalorimeter for R&D evaluation
- Disk design needs more detailed studies of:
  - Electron transport properties
  - Target interface (to get electrons into the filter)
  - Design for an RF antenna integrated into the filter
  - Trigger system for selecting endpoint electrons for measurement by the calorimeter