TRIFORCE: *a PTOLEMY project*

TRItium-endpoint From $\mathcal{O}$(fW) Radio-frequency Cyclotron Emissions

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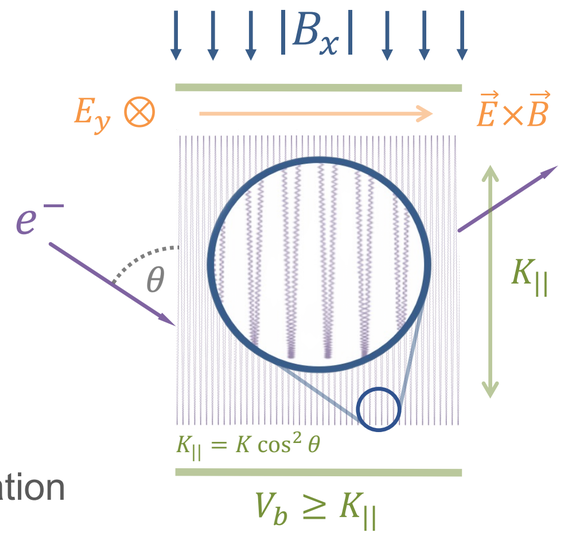
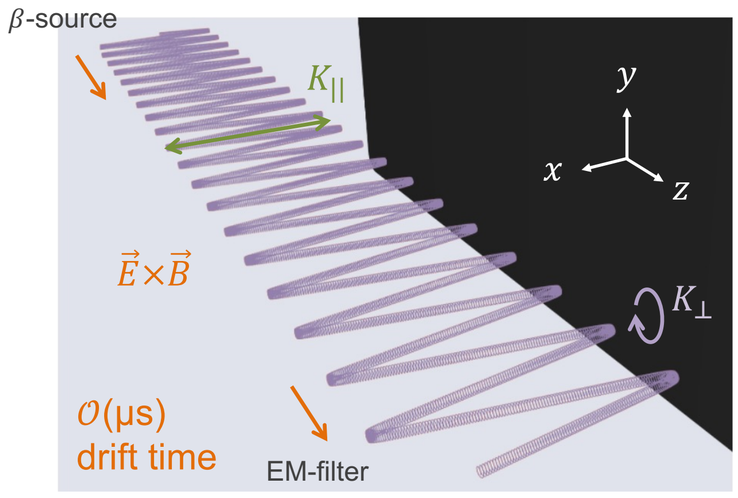
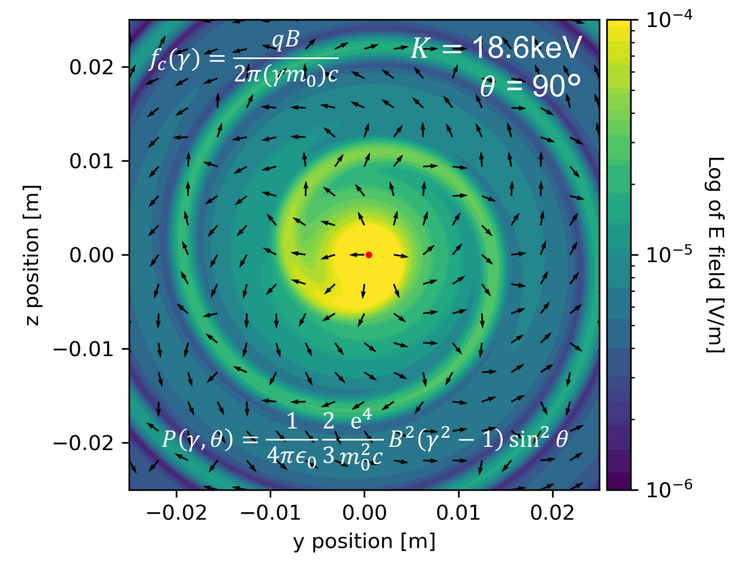
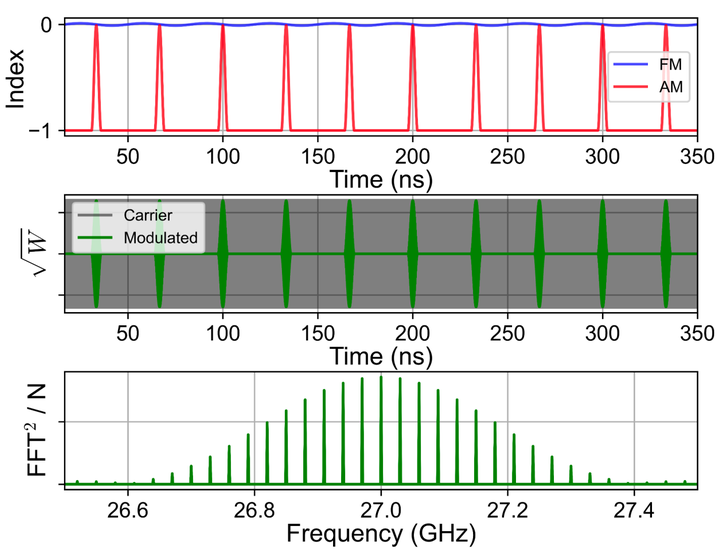
- ***Aims***
  - Cyclotron radiation electron spectroscopy [1]
  - Non-destructive electron tracking [2]
  - Large θ acceptance for isotropic β-source
- ***PTOLEMY trigger***
  - $\mathcal{O}(10^{15})$ electrons per g of tritium per second
  - Trigger on electrons with $(Q_\beta - K) \sim \mathcal{O}(\mathrm{eV})$
  - Real-time analysis of CR signal provides measurement of $K_{||}$ for online filter reconfiguration



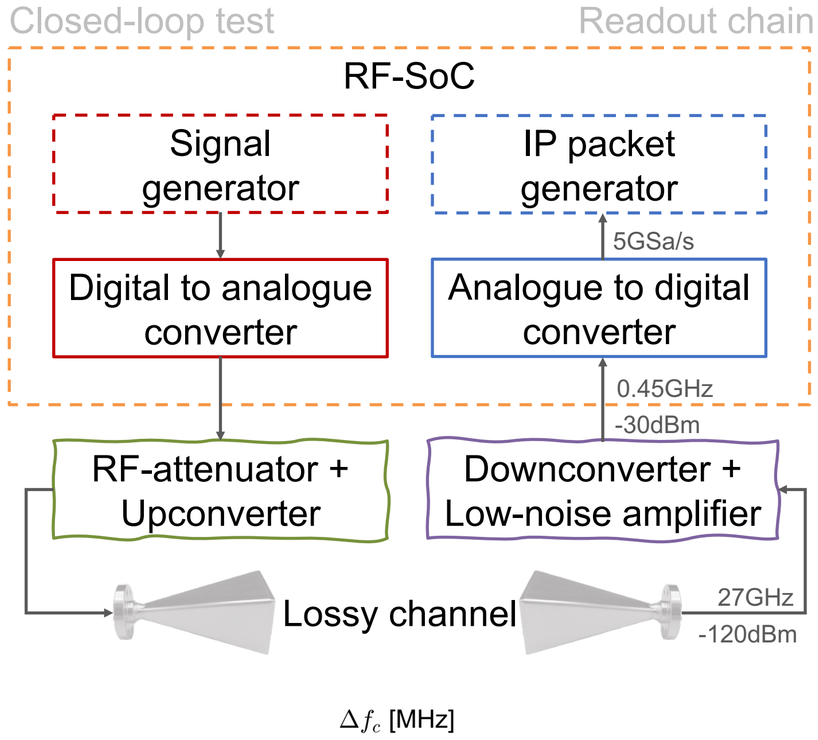
- ***EM-filter requirements***
  - $K_{||}$ reconstruction for the adaptive θ acceptance of the transverse drift filter [3]
  - Fast $K_{||}$ extraction $\sim \mathcal{O}(\mu\mathrm{s})$, providing time enough to adjust voltages on the filter
  - $\sigma(K_{||}) \sim \mathcal{O}(\mathrm{eV}) \Rightarrow \Delta K_\perp \sim \mathcal{O}(100\mathrm{meV})$
- ***Offline trajectory reconstruction***
  - Constrain uncertainty on correction to K from cyclotron radiative losses $\sim \mathcal{O}(\mathrm{meV})$

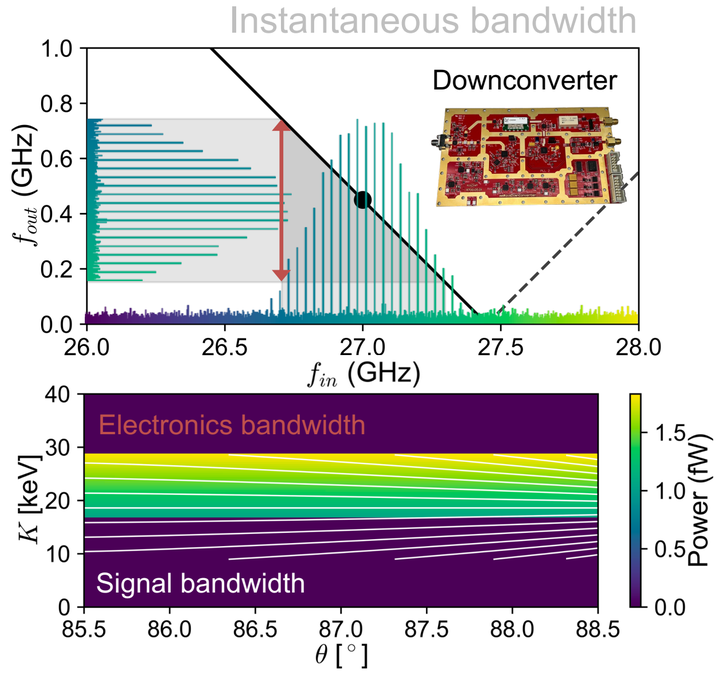


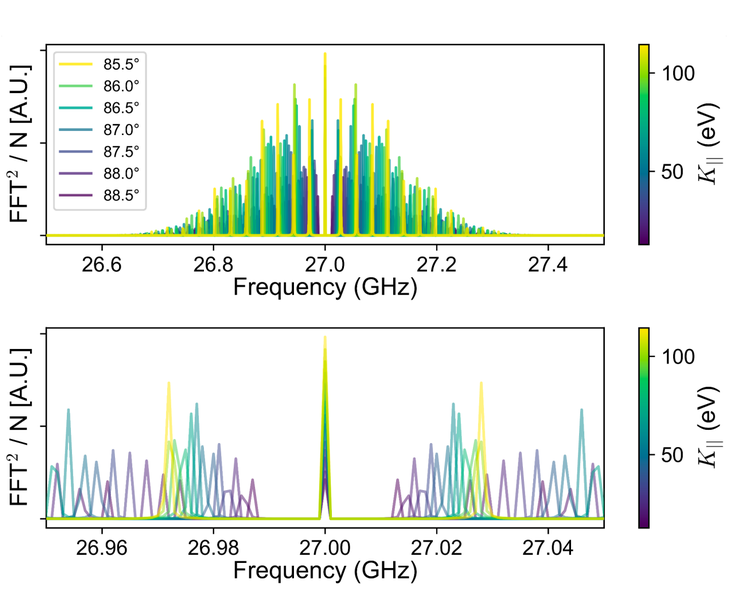


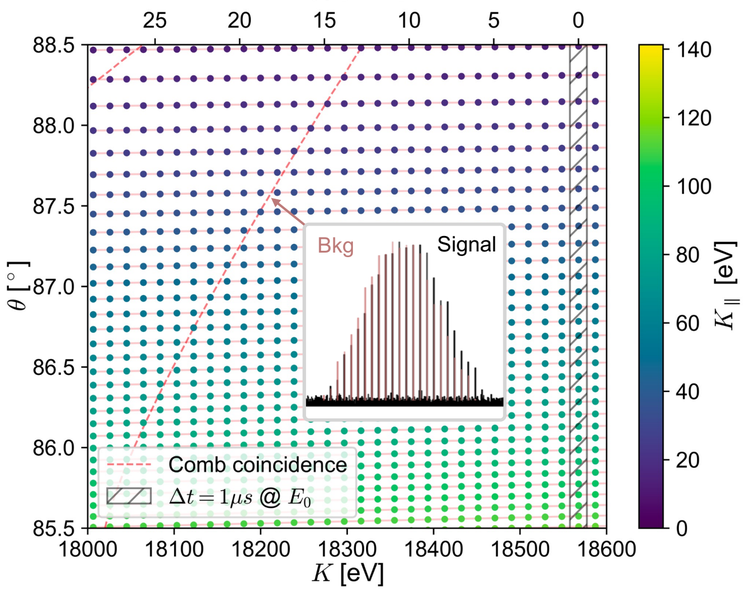


- ***Electron transport***
  - Dipole magnet aligned along x-axis
  - 'Bounce': V_b contains $\{e^- | \theta > 85°\}$
  - 'Drift': V_d results in E_y producing v_z akin to magnetron motion
- ***Cyclotron emissions***
  - B-field acts on $K_\perp \Rightarrow$ orbital r = 0.46mm
  - Power from single electron ~ 1fW
  - Frequency for K = 18.6keV ~ 27GHz
- ***Modulated RF signal***
  - AM dominated by bounce trajectory
  - $K_{||} \Rightarrow$ frequency comb tooth spacing
  - FM influence dependant on phase
- ***Readout chain***
  - HEMT low-noise amplifier (4K):
    - Noise temp. ~10K; BW 15GHz
  - Proprietary downconverter:
    - Adjustable instantaneous 0.6GHz BW between 24.0–27.5GHz
    - Mixes central frequency → 450MHz
- ***Loop test***
  - FPGA transmits & receives synthetic signal across a given channel
  - Antenna & readout characterisation
  - Reconstruction algorithm development









- ***Matched filtering***
  - FFT templates convolved with spectra
  - 5ns pulse $\Rightarrow$ 0.2GHz comb width
  - Broader signal reduces № comb templates for same $K_{||}$ discrimination or greater θ range acceptance & $\therefore$ rate
- ***Future work***
  - Move to JTWPA for B-tolerance & SNR
  - Downconverter-v2 with 2GHz BW
  - Multi-band ADC for broadband readout

[1] Project-8 collaboration, "Real-time Signal Detection for Cyclotron Radiation…" (2023) [arXiv:2310.02112]
[2] Iwasaki, et al, "CRES-Based Non-destructive Electron Momentum Estimati…" (2024) [arXiv:2404.00817]
[3] Chung, et al, "Implementation and Optimization of the PTOLEMY Transver…" (2022) [arXiv:2108.10388]
[4] Withington, et al, "Quantum Noise Limited Phased Arrays for Single-Electr…" (2024) [arXiv:2401.03247]

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