PING fundamentals

exp023 · 13 May 2026

Abstract

Strips PING down to its biophysical fundamentals and characterises it *in isolation from any task* — no training, no readout, no loss, just a free-running network driven by Poisson input. The E → I → E loop produces gamma at ≈ 30 Hz with the standard $\tau_{\mathrm{AMPA}} + \tau_{\mathrm{GABA}}$ cycle period, and the f–I curves show the loop is dynamic-range compression: PING holds E an order of magnitude below COBA across two orders of magnitude of drive, while COBA saturates near its refractory ceiling.

Method

The architecture characterised here is sketched atop Figure 1. An input layer drives the excitatory population through W_{in}; the E→I→E loop is formed by W_{ei} (E to I) and W_{ie} (I back to E), with no I→I synapse. Disabling the I→E loop (*ei-strength 0*) recovers the COBA reference; engaging it (*ei-strength 1.5*) produces the gamma rhythm.

The full conductance-based model that produces PING is documented in COBANet this notebook is the empirical companion. Two conditions run on the same network — *ei-strength 0* (loop disabled, the COBA reference) and *ei-strength 1.5* (loop engaged, the PING regime) — each driven by uniform Poisson input fed through W_{in} (untrained network). Because PING's loop clamps the E rate while COBA's is unclamped, a single input rate can't show both legibly: the two rasters therefore use **per-condition input rates** — COBA at 5 Hz (a legible ≈ 24 Hz async raster), PING at 45 Hz (into gamma, $f_\gamma \approx 40$ Hz). Population spectra are Welch PSDs on the population-mean E trace (one window per trial of length T, parabolic-interpolated peak; same recipe as exp041 and exp049).

The run scale reports the geometry that actually produced the figures. The two loop conditions (COBA, *ei-strength 0*; PING, *ei-strength 1.5*) are the grid; the raster/PSD input rates are per-condition (COBA 5 Hz, PING 45 Hz) and the free-running f–I panels sweep uniform Poisson drive (2–100 Hz, $T = 400$ ms).

Rate response. The f–I panels of Figure 1 sweep spatially **uniform** Poisson input (all channels at the same rate, no digit structure) on the *untrained, free-running* network, comparing COBA against PING on a shared rate axis — the bare dynamic-range compression of the architecture.

Results

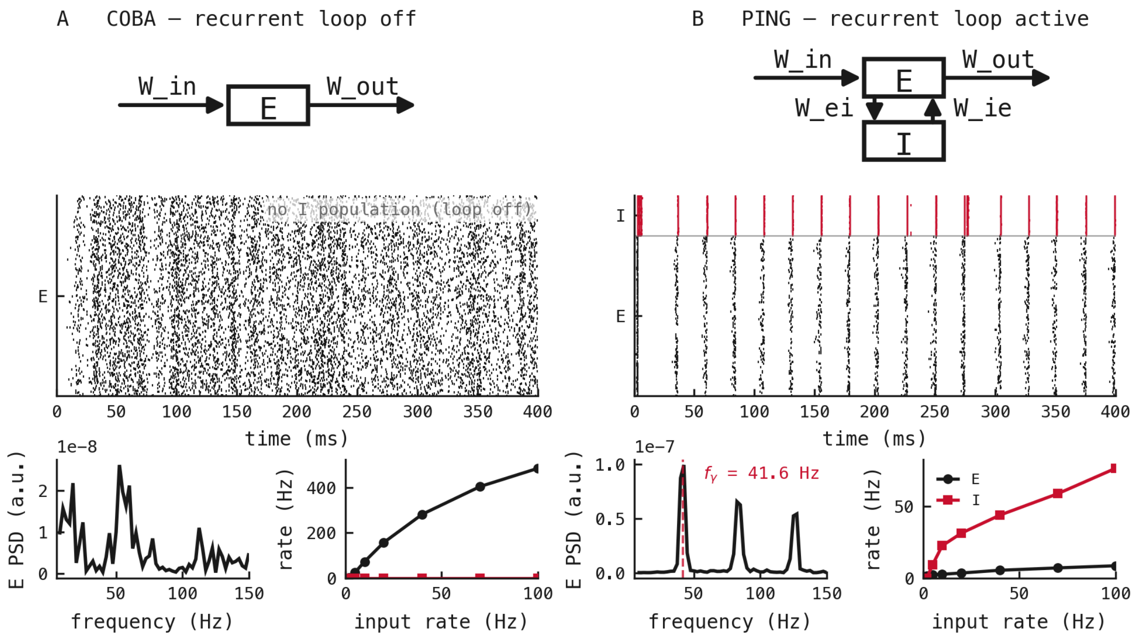

Figure 1: The architecture and its behaviour, off and on, on the same network. Each column carries its schematic on top — **A** COBA (input→E→output, no I population) and **B** PING (the same plus the recurrent E↔I loop, W_{ei} down and W_{ie} up) — directly above the plots it produces. Below each schematic is one combined raster (E black in the lower portion, I red in the upper portion — same axes, no gap) above a bottom row pairing the Welch PSD of the population-mean E trace with the free-running f–I curve (mean per-cell rate vs input rate, E black / I red; each column has its own y-axis — COBA runs to its ≈ 400+ Hz ceiling, PING is on a smaller scale so its loop-clamped E and climbing I are legible). Rasters and spectra are on uniform Poisson input (400 ms) at per-condition rates (COBA 5 Hz, PING 45 Hz — see Methods); the f–I curves sweep that drive on the untrained network. All runs are at $\Delta t =$ 0.1 ms. **A — COBA** (*ei-strength 0*, loop off): asynchronous E firing, no I activity, no recurrent gamma peak, and an E f–I curve that climbs steeply with input rate and saturates toward the refractory ceiling. **B — PING** (*ei-strength 1.5*, loop on): the I population fires a synchronous burst once per cycle and the E raster breaks into vertical bands (the I volley trails each E volley by the AMPA delay); the PSD carries a clean gamma peak (dashed red line; f_γ measured from this raster's E-population PSD, marked on the plot); and its f–I shows the E rate held to single digits across the whole sweep (note the much smaller y-axis than COBA's) while inhibition climbs — the loop's dynamic-range compression. The single E→I→E loop is the only change: it converts asynchronous firing into a gamma rhythm *and* clamps the E rate.

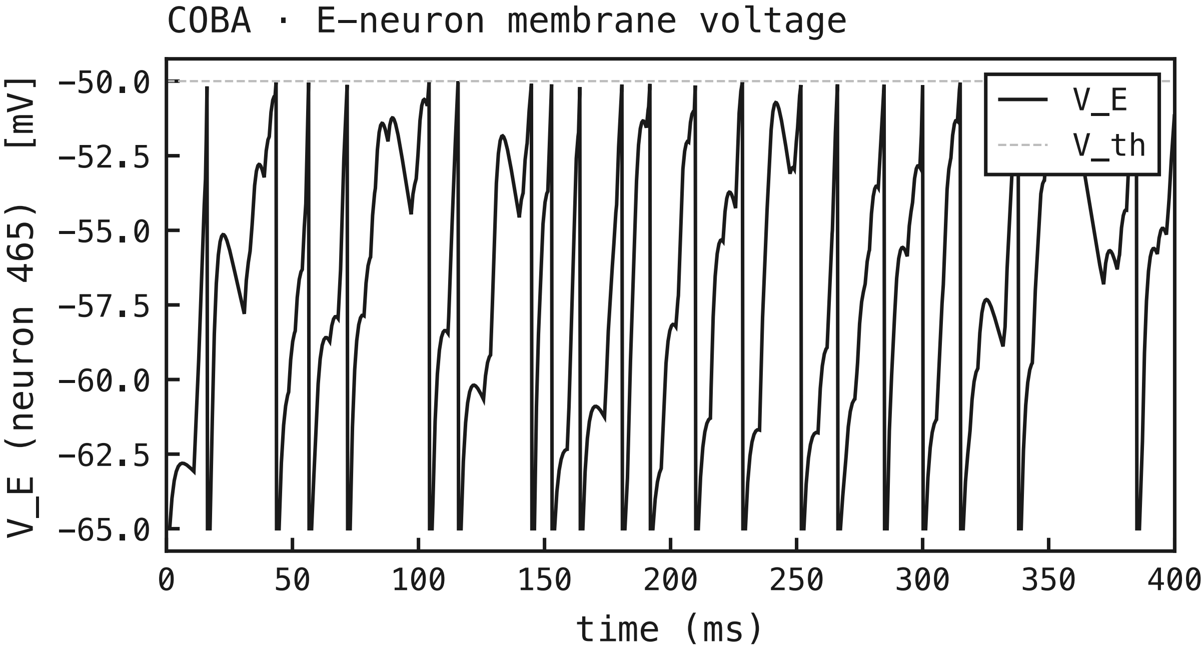

Figure 2: Membrane voltage V_E (black) of the most active E cell, recurrent loop **off** (COBA, *ei-strength 0*). Driven only by feedforward input, the cell charges toward threshold ($V_{\text{th}} = -50$ mV, faint dashed) and hard-resets to $V_{\text{reset}} = -65$ mV each time it fires — irregular, input-paced spiking with no rhythmic structure. The rhythm-free control for Figure 3a.

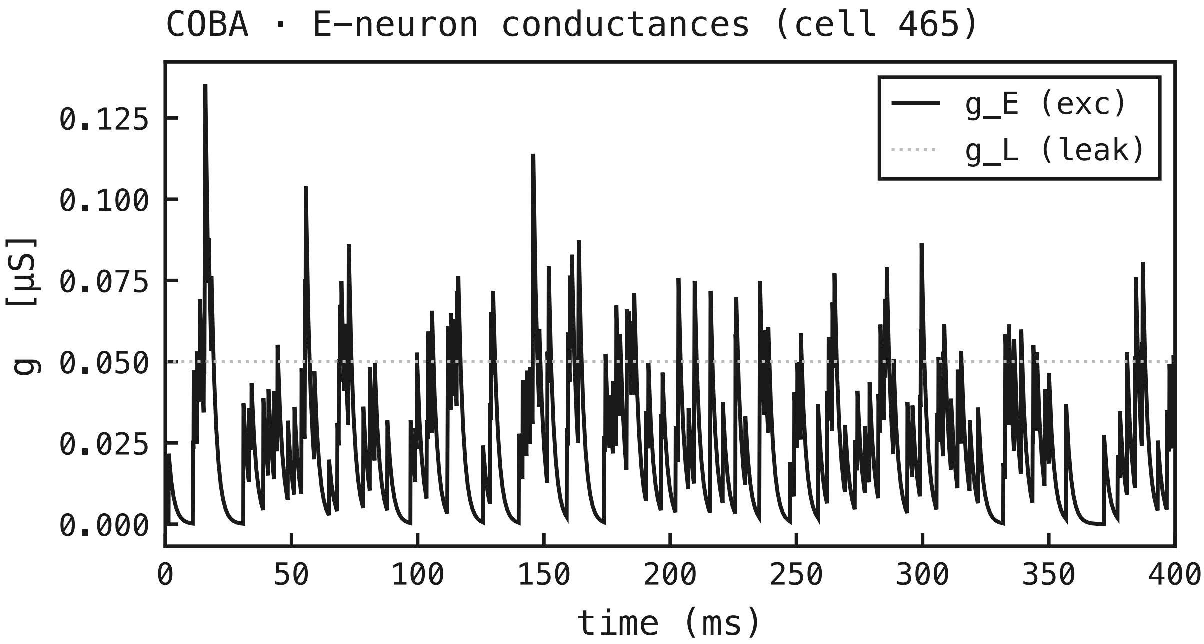

Figure 3: Synaptic and leak conductances on the same E cell, COBA mode. Only the excitatory conductance g_E (black) is active — it steps up with each input spike and decays with τ_{AMPA} — while the leak g_L (faint dotted) is fixed. There is no inhibitory g_I because the I→E loop is off. All conductances are **non-negative**: they count open channels, not current direction or sign.

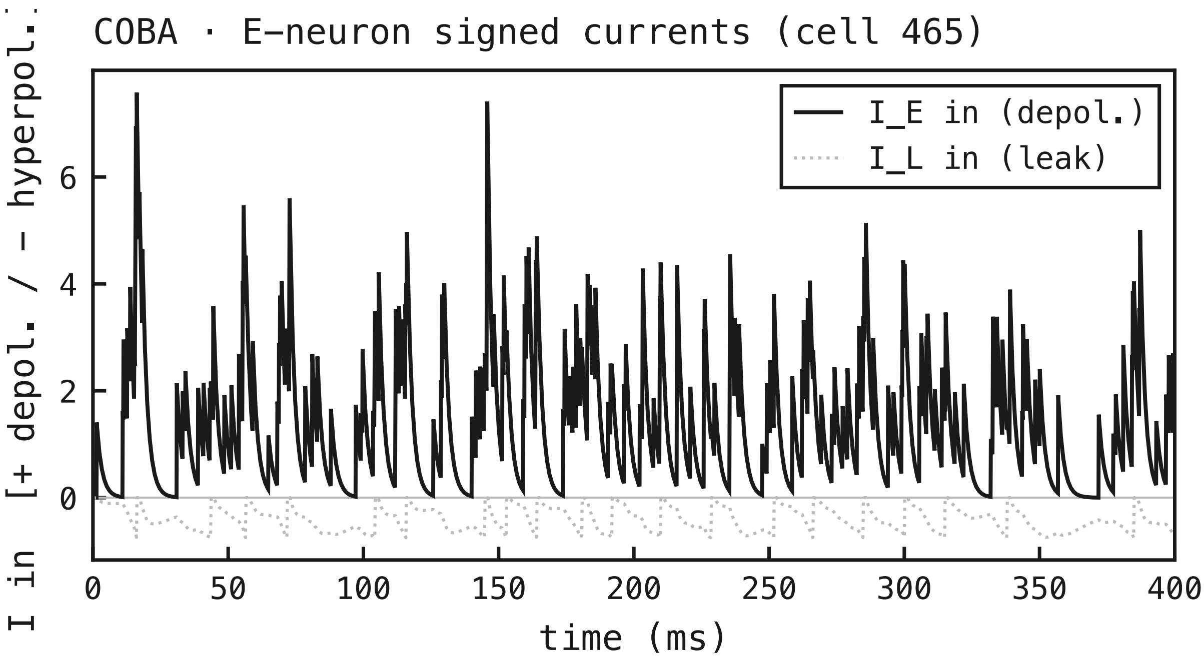

Figure 4: Signed synaptic currents into the E cell, COBA mode, with $I_X^{\text{in}} = -g_X(V - E_X)$ (positive = depolarising). With no inhibition, the only synaptic current is the depolarising excitatory current I_E^{in} (black); the leak current (faint) hovers near zero. Compare Figure 3c, where the loop introduces an inhibitory current of the *opposite* sign.

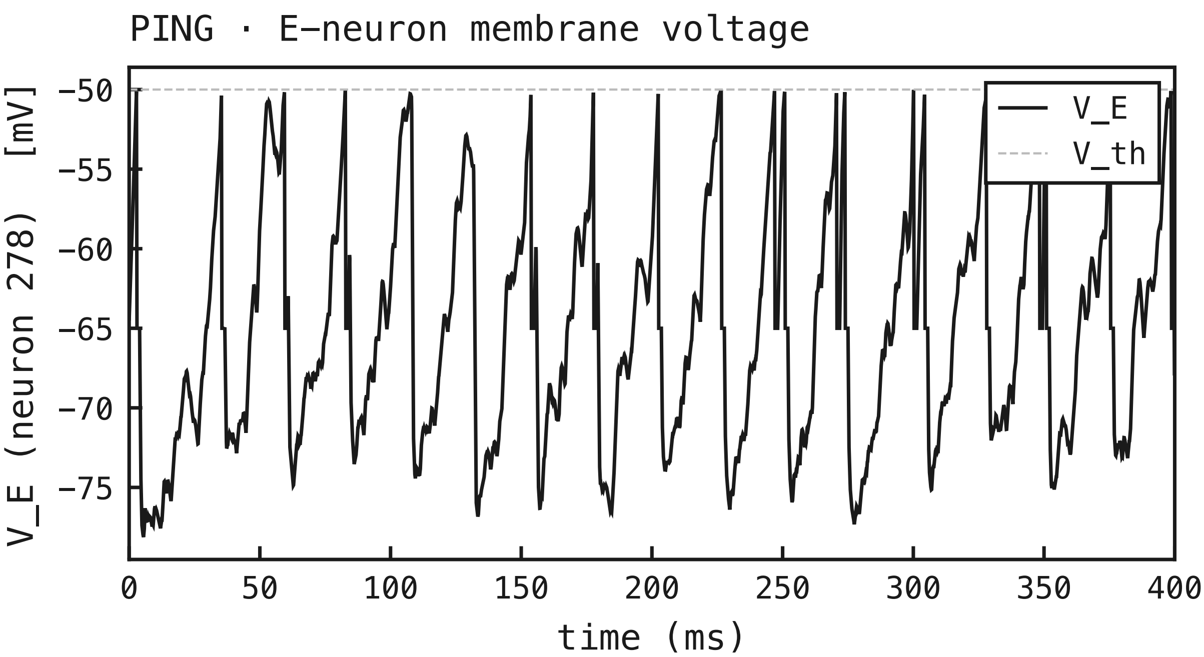

Figure 5: Membrane voltage V_E (black) of the most active E cell, recurrent loop **on** (PING, *ei-strength 1.5*), same input as 2a. Rhythmic inhibitory bursts now hold the cell below threshold most of the time: each I-burst drags V_E toward $E_i = -80$ mV, and the membrane recovers — and can fire — only as the inhibition decays between bursts. The loop has turned the irregular firing of 2a into cycle-gated firing.

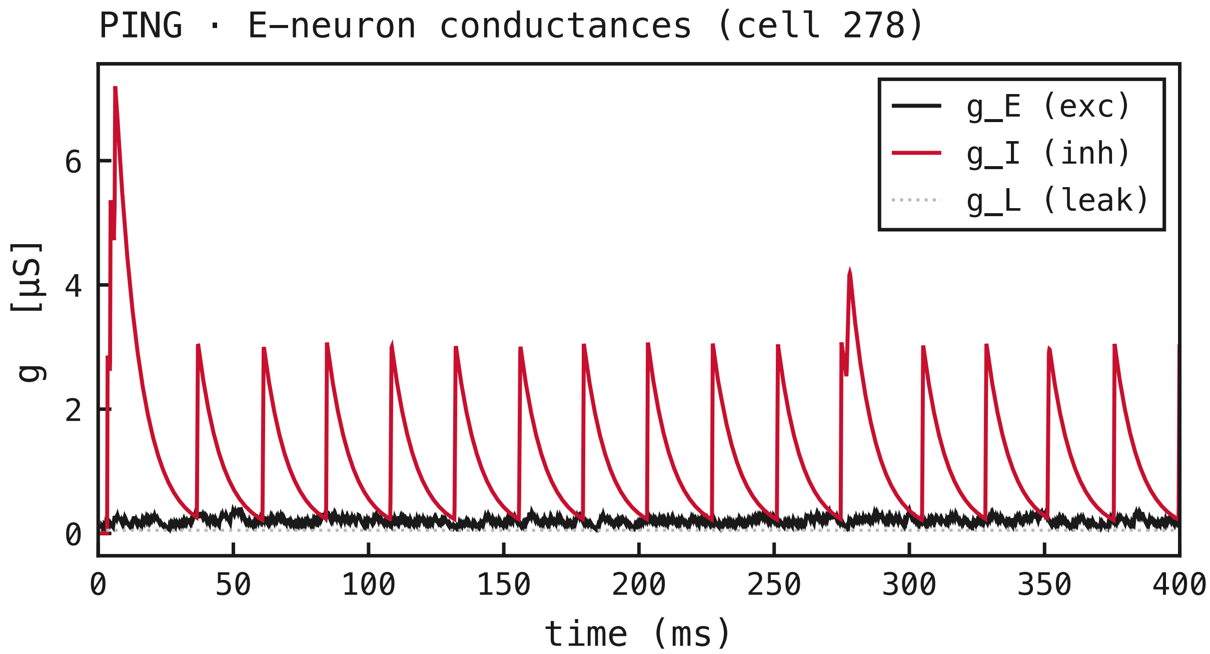

Figure 6: Conductances on the same E cell, PING mode. The inhibitory conductance g_I (red) now dominates — it spikes once per gamma cycle as the synchronous I-burst arrives through W_{ie}, then decays with τ_{GABA} — while g_E (black) carries the smaller feedforward input and g_L (faint) is fixed. All three traces are **non-negative**: g_I is large and positive, and that is what shunts the cell — it carries no sign of its own.

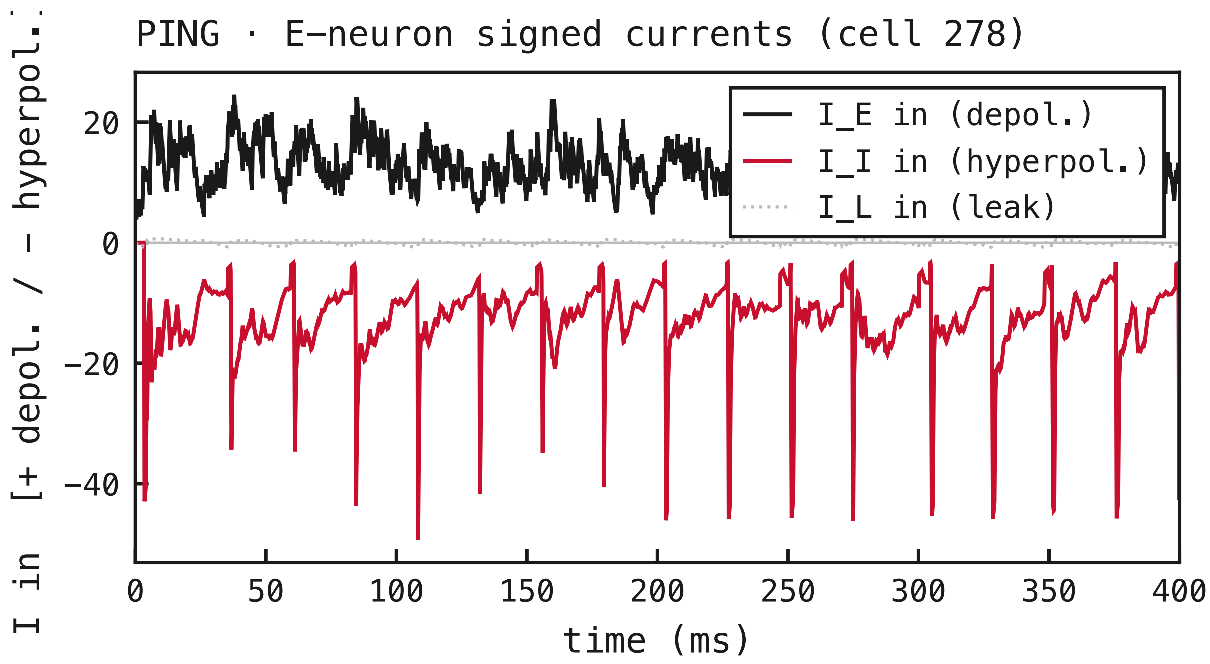

Figure 7: The load-bearing panel. Signed currents into the E cell, PING mode. The excitatory current $I_E^{\text{in}} = -g_E(V - E_E)$ (black) is depolarising; the inhibitory current $I_I^{\text{in}} = -g_I(V - E_I)$ (red) is **negative (hyperpolarising) even though g_I is positive** (Figure 3b) — the minus sign comes entirely from the driving force $(V - E_I) > 0$ whenever V sits above $E_i = -80$ mV. The COBA principle made literal: *the sign lives in the driving force, never in the conductance.* The sharp negative pulses are the per-cycle inhibitory kicks that gate the rhythm.

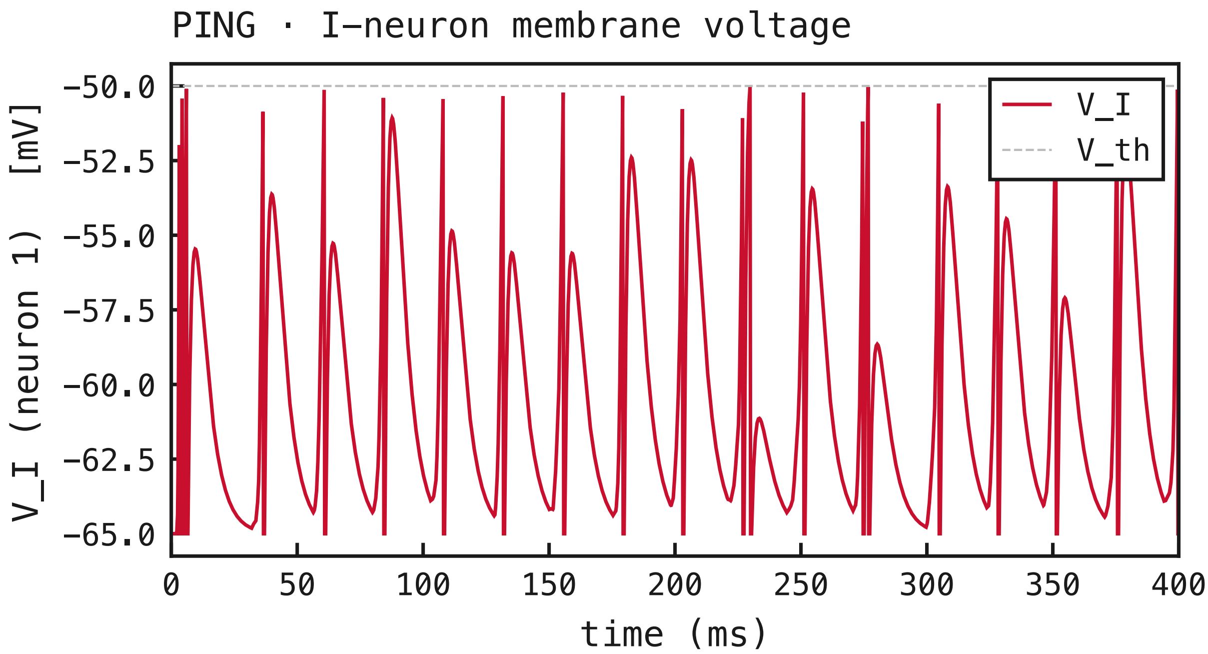

Figure 8: Membrane voltage V_I (red) of the most active I cell, PING mode. The I cell integrates the excitatory volley from the E population and fires once per gamma cycle, so V_I tracks the E-burst envelope — ramping up as E cells fire, crossing threshold ($V_{\text{th}} = -50$ mV, faint dashed), resetting, and waiting for the next volley. This single I-spike per cycle delivers the inhibitory burst seen on the E cell in 3b–3c.

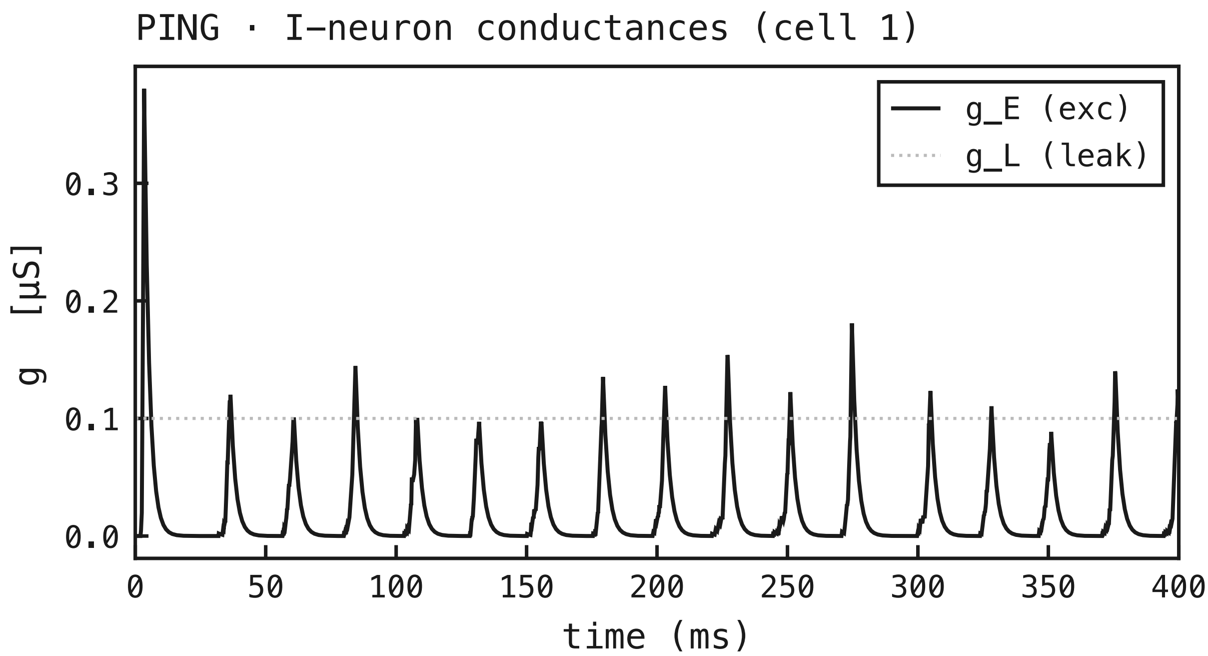

Figure 9: Conductances on the I cell, PING mode. The I cell receives **only excitation**: g_E (black) is the arriving E-spike envelope (delivered via W_{ei}) and g_L (faint) is the fixed leak. There is no inhibitory conductance — the architecture has no I→I synapse — which is exactly why the I population can synchronise into the sharp once-per-cycle bursts that clock the loop.

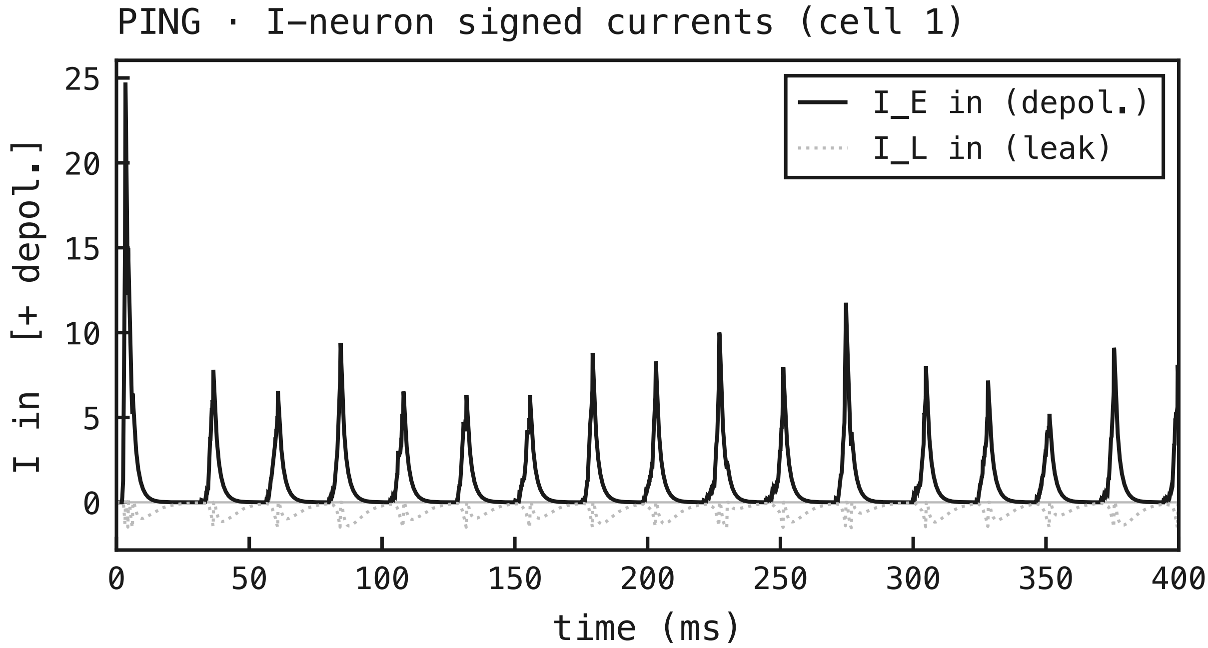

Figure 10: Signed currents into the I cell, PING mode. With no inhibitory input, only the depolarising excitatory current I_E^{in} (black) and a small leak current contribute — the I cell is driven purely up to threshold. Read 3a–3f together and the loop is in cross-section: E spikes ramp g_E on I (3e–3f) → I fires once per cycle (3d) → that spike delivers the inhibitory burst g_I on E (3b) → its negative current shuts E down (3c, 3a) → g_I decays → E refires. That delayed E→I→E loop is PING.