The current-carrying edge channels of the quantum Hall effect are a widely used toolbox to perform a rich variety of quantum electronics experiments in which one seeks, inspired by quantum optics, to coherently manipulate the trajectories of single electronic wave packets [1]. This so-called field of electron quantum optics has recently shown significant progress towards fully quantum coherent electronics using propagating single quasiparticles [2]. However, contrary to photons, electrons are Fermionic particles strongly interacting with their environment because of long-range Coulomb interactions. For excitations close to the Fermi energy, this interaction has been shown to cause decoherence and energy relaxation over micron length scales. Here we show that quasiparticles injected at a well-defined energy in an edge channel - a paradigm of electron quantum optics - undergo unexpectedly a much stronger energy relaxation. On submicron lengths, quasiparticles gush into the Fermi sea with a survival probability decreasing exponentially with their energy. Unmitigated, this relaxation is clearly detrimental to any quantum applications.

Pioneering electron quantum optics experiments [3–5] have been performed in the quantum Hall regime where two edge channels (ECs) co-propagate along the edges of the sample. This is so far the most promising candidate for the coherent manipulation of single electronic excitations [1]. However, at this so-called \( \nu = 2 \) filling factor, short range interactions between the two edge channels can lead to decoherence and energy relaxation, as was demonstrated for electronic excitations that are emitted close to the Fermi sea [6–14]. The fate of quasiparticles emitted well above the Fermi sea seems however to be more complex. Quantum interferometry experiments using such energy-resolved quasiparticles [5, 15–18] showed that the latter retain quantum coherence over propagation lengths of a few microns, but the interpretation of those results is still under debate. Indeed, no one has observed yet how energy-resolved quasiparticles decay as they propagate in this system. Various relaxation mechanisms have been proposed; for instance, quasiparticles could gradually lose momentum and heat up the edge channels [19], or relax by directly exciting collective plasmon modes shared by the two edge channels [20, 21]. To address this fundamental issue of energy relaxation, we have designed an experiment based on energy-resolved emission and spectroscopy of quasiparticles. In this letter, we directly observe, characterize and control their decay.

We have followed the approach proposed in [19, 22], in which one injects quasiparticles at a well-defined energy into an edge channel using a first quantum dot (QD) in the sequential tunneling regime. The injected quasiparticles then propagate over a finite length \( L \), after which we perform a spectroscopy of the energy distribution function \( f(E) \) of the quasiparticles using a second downstream quantum dot as energy filter. This spectroscopy technique was previously used in [4, 9, 23–25], particularly to investigate the energy relaxation of low-energy excitations [9, 23]. A very similar setup was used to investigate charge transfer processes between distant quantum dots in the absence of a magnetic field [25]; furthermore, a recent spectroscopy experiment showed that at vastly higher energies (in the 0.1 eV range), electrons in an edge channel decay by coupling to optical phonons [26].

The devices’ geometry is depicted in Fig. 1a. Samples are realized in a high-mobility GaAs/GaAlAs two-dimension electron gas (2DEG) cooled down to electronic temperatures of \( \sim 20 \) mK, and immersed in a large perpendicular magnetic field to reach filling factor \( \nu = 2 \) of the quantum Hall effect. The two chiral edge channels are depicted as orange lines in Fig. 1a. The quantum dots are defined electrostatically and can be independently controlled using the plunger gate voltages \( V_{P1} \) and \( V_{P2} \). Both QDs are tuned to only transmit the outer edge channel. Quasiparticles in the outer edge channel stemming from the drain electrode are thus transmitted across the first dot QD1, and propagate along the outer edge channel connecting the first dot to the second dot QD2. A length gate, controlled by the voltage \( V_L \), is used to increase the propagation path by diverting the edge channels around the square area delimited by black dashed lines in Fig. 1a (an insulating layer of resist separates the rest of the gate from the surface of the sample). Several samples have been measured, with propagation lengths ranging from \( L = 480 \) nm to 2.17 \( \mu \)m. Fig. 1b depicts the energy configuration of the two dots: a negative voltage \( V_D \) is applied to the drain contact while the contacts connected to the edge channels flowing between the two dots are grounded, defining the zero of energy in our experiment. A narrow single resonance of QD1 is
Figure 1 | Principle and implementation of energy-resolved injection and detection. a, False-colour scanning electron micrograph of a typical sample. The ECs at \( \nu = 2 \) are depicted in orange. The large ohmic contacts located away from the center of the sample are depicted by the gray squares. The scale bar corresponds to 500 nm. b, Energy-scale sketch of the experiment. The two QDs are depicted by a single resonance at energy \( E_1(V_{P1}) \) and \( E_2(V_{P2}) \), respectively. The emitted quasiparticles are depicted by the orange bell-shaped curve. c, Raw transconductance \( \partial I_2/\partial V_{P2} \) of the second QD measured as function of \( E_2(V_{P2}) \) (x-axis) and \( E_1(V_{P1}) \) (y-axis). The thick vertical (resp. horizontal) arrow indicates the span of the drain (resp. source) potential \( V_D \) (resp. \( V_S \)). The \( y = x \) dashed line is a guide for the eye.

tuned inside the transport window at an energy \( E_1(V_{P1}) \), defining the quasiparticle injection energy. We measure the transconductance \( \partial I_2/\partial V_{P2} \) of QD2 while sweeping the energy \( E_2(V_{P2}) \) of a narrow single resonance in this dot, defining the detection energy. A careful calibration of both QDs is performed to extract their respective lever arms, linking the plunger gates voltages \( V_{P1} \) to the energies \( E_i \) (see Supplementary Information). This allows us, after compensating the small crosstalks between the two plunger gates, to directly probe the dependence of \( \partial I_2/\partial V_{P2} \) with the detection energy \( E_2 \) for different values of the injection energy \( E_1 \). This signal is proportional to \( -\partial(\Delta f(E))/\partial E \), where \( \Delta f(E) = f(E) - f_s(E) \) is the difference of the energy distribution functions on either side of QD2 [4, 9, 23, 24], convoluted with the lineshape of the resonance of QD2. This convolution mostly affects the width of the features in the transconductance (see Supplementary Information). In the following, all widths discussed are convoluted widths. We separate the two contributions of \( f(E) \) and \( f_s(E) \) by applying a positive voltage \( V_S \) to the source contact. This is illustrated in Fig. 1c, which shows a typical measurement of \( \partial I_2/\partial V_{P2} \) as a function of \( E_1 \) and \( E_2 \), for \( L = 480 \) nm. The source and drain potentials, shown as thick arrows in Fig. 1c, are set to \( eV_D = -eV_S = 125 \) µeV, with \( e \approx -1.6 \times 10^{-19} \) C the electron charge. The three main features appearing on this map are i) the blue (negative) vertical line

Figure 2 | Measured distribution functions. Top panel: measured \( f(E) \) for \( L = 480 \) nm. Each curve, offset for clarity, corresponds to an increment of the injection energy \( \delta E_1 \approx 21 \) µeV, from \( E_1 = -21 \) µeV (blue) where no additional quasiparticles are emitted, to \( E_1 = 173 \) µeV (red). The thick gray line is a Fermi function fit of the data at \( E_1 = -21 \) µeV. Bottom panel: measured \( f(E) \) for \( L = 750 \) nm. Each curve corresponds to an increment of the injection energy \( \delta E_1 \approx 9 \) µeV, up to \( E_1 = 121 \) µeV (red). The inset is a zoom on the region delimited by the dashed-line square. In all panels, the vertical offset is equal to \( 5.5 \times 10^4 \delta E_1 \).
at $E_2 = eV_S \approx -125 \, \mu eV$, corresponding to $\partial f_S(E)/\partial E$, ii) the red (positive) vertical line at $E_2 = 0 \, \mu eV$, corresponding to the low-energy part of $\partial f(E)/\partial E$, and iii) the oblique line following a $y = x$ line (black dashed line), corresponding to the emitted quasiparticles which are detected after their propagation. We then integrate the transconductance so as to obtain the energy distribution function $f(E)$, which we discuss in the rest of this paper.

Fig. 2 shows measurements of $f(E)$ for $L = 480$ nm (top panel) and $L = 750$ nm (bottom panel). The injection energy $E_1$ is gradually increased from negative values (blue curves), where the resonance of QD1 is outside the bias window, to large positive values $E_1 > 100 \, \mu eV$ (red curves), where we expect to detect quasiparticles at high energy. The measured $f(E)$ evolve from a Fermi function at low temperature (the apparent temperature of this Fermi function is increased to $\sim 40$ mK by the convolution with the resonance of QD2, see Supplementary Information) to strongly out-of-equilibrium distribution functions showing a distinct quasiparticle peak at finite energy. This is particularly striking for the shortest distance, where the quasiparticle peak clearly appears even at the largest $E_1 = 173 \, \mu eV$. The position of this peak increases linearly with $E_1$; furthermore, its amplitude gradually decreases with $E_1$. In contrast, for a path only 50 % longer, the peak amplitude becomes much more strongly suppressed as $E_1$ increases; nonetheless it remains visible, and even grows back, at large $E_1 > 100 \, \mu eV$ (see inset in the bottom panel of Fig. 2).

Plotting the data in semi-log scale, as illustrated in Fig. 3a for the $L = 480$ nm data shown previously in Fig. 2, allows us to quantitatively analyze the quasiparticle peak. We consistently observe that the quasiparticle peak is reasonably well fitted by a Lorentzian peak, shown as dashed black lines in Fig. 3a. Remarkably, the position $E_{\text{peak}}$ of the peak matches the injection energy $E_1$; furthermore, its full width at half maximum (FWHM) remains constant as $E_1$ is increased. This is in direct contradiction with the predictions of [19]. Our analysis allows us to emphasize and quantify the drastic effect of propagation length on the relaxation. We plot in Fig. 3b the extracted Lorentzian peak heights as a function of $E_1$, for $L = 480$ and 750 nm. The peak heights are normalized by their extrapolation at zero $E_1$ (see Supplementary Information). The green pentagons correspond to the $L = 480$ nm data shown in Fig. 2 and Fig. 3a (referred to as resonance A), and the red circles to data obtained for the same sample, using another slightly broader resonance (resonance B) for QD1. Both follow an exponential decay, with a characteristic energy $E_d = 56 \, \mu eV$ for the resonance A, and $66 \, \mu eV$ for the slightly broader resonance B. In contrast, the $L = 750$ nm data, corresponding to the measurements shown in the bottom panel of Fig. 2, displays a much faster exponential decay, with $E_d = 18 \, \mu eV$. Strikingly, for $E_1 > 80 \, \mu eV$, the peak height increases with $E_1$, highlighting the behavior observed in the linear-scale plots shown in Fig. 2. We emphasize that in all the data shown here, (as well as in all the data we obtained where the quasiparticle peak can be observed), the peak position is preserved...
Figure 4 | Controlling energy relaxation with an electrostatic gate. a, b, c, False-colour scanning electron micrographs of a typical sample, depicting the trajectories of the ECs for $V_L = 0.2$ V (a, length gate highlighted in red), $V_L = -0.1$ V (b, gate highlighted in violet), and $V_L = -0.5$ V (c, gate highlighted in dark blue). In a, the ECs copropagate along a $L \approx 750$ nm long path. In b, the ECs are spatially separated (orange dotted lines) as they flow below the length gate. In c, the ECs copropagate along a $L \approx 2.17$ µm long path. d, e, f, Measured $f(E)$ for the configurations depicted in resp. a, b, and c. Each curve, offset for clarity, corresponds to an injection energy increment $\delta E_1 \approx 9$ µeV, from $E_1 \approx -26$ µeV (blue) to $E_1 \approx 122$ µeV (red, d) / $E_1 \approx 98$ µeV (red, e and f). The inset in d is a zoom on the region delimited by the black dotted square.

during propagation, and the FWHM is independent of $E_1$ (see Supplementary Information). The revival of the quasiparticle peak at intermediate $E_1$ was consistently observed at $L = 750$ nm (see e.g. Fig. 4d); while we did not observe it for shorter $L$, it is not unlikely that it would occur at significantly higher $E_1$, not accessible to our experiment.

We illustrate the effect of the length gate in Fig. 4. For positive $V_L \approx 0.2$ V, the gate does not affect the trajectory of the edge channels, which flow directly between the two QDs (Fig. 4a). The corresponding $f(E)$ measured for $L = 750$ nm are shown in Fig. 4d, and are similar to the data shown in Fig. 2. For intermediate values $V_L \approx -0.1$ V, the electrostatic potential generated by the gate allows separating the two edge channels [27], as depicted in Fig. 4b: spectacularly, in that case all data show a very clear quasiparticle peak up to large $E_1$ (Fig. 4e). Contrarily, for large negative values $V_L \approx -0.5$ V, both edge channels are diverted around the gate and follow a longer ($L = 2.17$ µm, Fig. 4c) path, leading to the full disappearance of the quasiparticle peak even at low $E_1$ (Fig. 4f). Despite the absence of a quasiparticle peak in this case, the measured $f(E)$ remain out-of-equilibrium and cannot be fitted by a hot-electron Fermi function. We emphasize that the low-energy parts of all measured $f(E)$ are qualitatively similar, regardless of injection energy (see e.g. Fig. 3a) or propagation length; this suggests that the low-energy excitations generated by the relaxation of finite-energy quasiparticles are much more long-lived. The length gate allows us to tune $E_d$ from values below $20$ µeV for $L = 2.17$ µm, to large values $E_d \approx 110$ µeV when the edge channels are spatially separated (although the small decrease of the peak with energy in that configuration does not allow us to clearly identify an exponential decay). Strikingly, this last value is almost twice as large as the largest $E_d$ obtained when both edge channels copropagate along the shortest path (see above). Note finally that we obtained similar large values of $E_d$ when separating the two edge channels in a $L = 480$ nm sample (see Supplementary Information), which we explain by the finite, ungated co-propagation length between the QDs and the length gate. These results, in agreement with previous works [23, 28], clearly point towards the coupling between the two co-propagating edge channels as one of the dominant mechanism for energy relaxation.

Comparing our findings to existing experiments and theories allows shedding light on several issues. We observe that energy-resolved quasiparticles relax over much shorter lengths compared to all previous experimental works [3–5, 8, 9, 13, 15–18, 23, 28]. This fast decay generates low-energy excitations, which in turn relax in a
manner comparable to the aforementioned studies. This is compatible with theoretical models predicting that energy-resolved quasiparticles first decay into low-energy collective modes distributed on the two edge channels, which then propagate coherently over micron-size lengths \cite{20, 21}. The preserved width and position of the quasiparticle peak, as well as its revival observed for intermediate lengths, is also compatible with these models (but not with ref. \cite{19}). Note however that the remarkable exponential decay was not predicted (see Supplementary Information), indicating that the underlying physics is not fully understood. Finally, we are able to spatially separate the two edge channels, leading to a strong reduction of relaxation, again in qualitative agreement with \cite{20, 21}. This, combined with other gating schemes \cite{23, 28, 29}, provides a powerful toolkit to limit relaxation and decoherence in quantum Hall edge channels, potentially enabling quantum coherent electronics using propagating electrons.

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**Author contributions**

R.H.R. performed the experiments, with help from F.D.P., P.R. & Pat.R.; R.H.R., F.D.P. & Pat.R. analyzed the data, with inputs from D.M. & F.P.; U.G. & A.C. grew the 2DEG; D.M. fabricated the devices, with inputs from R.H.R., F.D.P. & Pat.R.; R.H.R., F.D.P., U.G., D.M. & Pat.R. wrote the manuscript, with inputs from all other coauthors; Pat.R. supervised the project.

**Methods**

The samples were realized in GaAs/GaAlAs two-dimensional electron gas injector with typical density $\sim 2.5 \times 10^{11}$ cm$^{-2}$ and mobility $\sim 2 \times 10^{6}$ cm$^2$V$^{-1}$s$^{-1}$. The 200 nm insulating resist layer separating the length gate from the surface of the sample is made of SU-8 photoresist. Perpendicular magnetic fields of about 5 T were applied to the surface of the sample is made of SU-8 photoresist. Perinsulating resist layer separating the length gate from the dimension electron gases with typical density

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Supplementary Information for
Strong energy relaxation of propagating quasiparticles in the quantum Hall regime

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Measured samples

All data discussed in the main text were measured in two samples (#1 and #2). A complete set of curves (referred to in the following as a spectrum), as shown in the figures of the main text is obtained using a unique pair of resonances of the QDs. Supplementary table I summarizes the resonances implemented in the emitter (QD1) and the detector (QD2) for each spectrum (S1 to S6), the corresponding figure of the main text, the propagation length \( L \), the respective transmission \( T_1, T_2 \) and width \( \Gamma_1, \Gamma_2 \) of emitter and detector resonances (see below), the characteristic decay energy \( E_d \), and the average width (FWHM) of the detected QP peak.

### Supplementary Table I

| Sample | Data | Res-QD1 | Res-QD2 | Fig. | \( L \) \( \mu \text{m} \) | \( T_1 \) \( \mu \text{eV} \) | \( \Gamma_1 \) \( \mu \text{eV} \) | \( T_2 \) \( \mu \text{eV} \) | \( \Gamma_2 \) \( \mu \text{eV} \) | \( E_d \) \( \mu \text{eV} \) | FWHM \( \mu \text{eV} \) |
|--------|------|---------|---------|------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| #1     | S1   | 1A      | 2A      | 2a, 3a| 0.48            | 0.44            | 12.8            | 0.3             | 5.9             | 56              | 19              |
| #1     | S2   | 1B      | 2B      | 3b   | 0.48            | 0.60            | 18.7            | 0.50            | 11.25           | 66              | 30              |
| #2     | S3   | 1C      | 2C      | 2b   | 0.75            | 0.54            | 16.3            | 0.34            | 9.6             | 18              | 29              |
| #2     | S4   | 1C      | 2C      | 4d   | 0.75            | 0.54            | 16.3            | 0.34            | 9.6             | 18              | 29              |
| #2     | S5   | 1D      | 2D      | 4e   | 0.75            | 0.40            | 11.8            | 0.55            | 4.9             | 110             | 18              |
| #2     | S6   | 1E      | 2E      | 4f   | 2.17            | 0.43            | 17.0            | 0.20            | 27.0            | –               | 18              |

Supplementary Table I | Measured samples and the corresponding data discussed in the main text. The column Res-QD1 (Res-QD2) refers to the resonance in the emitter (detector) QD used to measure each spectrum. Spectrum S5 corresponds to the \( L = 750 \) nm dataset with separated ECs.

Quantum dots calibration

### Supplementary Figure 1 | QD calibration.

The color map is a typical transconductance measurement of a QD in the Coulomb blockade regime. The inset is the linearisation from which we obtain the lever arm \( \alpha \).

The resonances used in the emitter \((i = 1)\) and detector \((i = 2)\) QDs were characterized by measuring the transconductance \( \partial I_i / \partial V_{Pi} \) as a function of the respective bias voltage \((V_D \text{ for } i = 1 \text{ and } V_S \text{ for } i = 2)\) and the plunger gate voltage \( V_{Pi} \). It is in particular crucial to work with resonances devoid of excited states, so as to be sure that quasiparticles are emitted at a single well defined energy [1]. These usually are easily identified when measuring Coulomb
diamonds plots. The color plot in Supplementary Fig. 1 shows a typical measurement in the sequential tunneling regime. The red and blue oblique lines, separated by $\Delta V_{P1}$, define the boundaries of the Coulomb blockade regime. A linear fit of $\Delta V_{P1}$ as a function of the bias voltage allows us to extract the lever arm $\alpha_i$ as shown in the plot at the right hand side. Supplementary table II summarizes the lever arm obtained from the calibration of each of the resonances used in this work. The transmission and widths of the resonances (see Supplementary Table I) are extracted from the differential conductance $\partial I/\partial V_{D, S}$ at zero bias voltage. In our experiment, we have tried to work, for both QDs, with very thin resonances (with widths ideally smaller than the temperature) so as to maximize energy resolution, and with close to unity transmission (corresponding to symmetric barriers), so as to maximize signal-to-noise ratio. In practice, this turns out to be quite challenging, especially when dealing with quantum dots sharing a common depletion gate. The data shown in the main text and in the supplementary information correspond to the best experimental conditions we could achieve. When measuring the distribution function $f(E)$ obtained by sweeping $V_{P2}$, we have simultaneously corrected the cross-talk between $V_{P1}$ and $V_{P2}$ in order to keep a constant injection energy $E_1(V_{P1})$. Typically, for a step $\delta V_{P2}$ in QD2, we correct the plunger gate voltage in the QD1 by $\delta V_{P1} \approx -\delta V_{P2}/20$.

| Spectrum | $\alpha_1$ (10$^{-2}$ meV/mV) | $\alpha_2$ (10$^{-2}$ meV/mV) |
|----------|-----------------|-----------------|
| S1       | 3.64 ± 0.02     | 3.97 ± 0.02     |
| S2       | 3.55 ± 0.03     | 0.406 ± 0.001   |
| S3       | 4.80 ± 0.03     | 6.35 ± 0.03     |
| S4       | 4.80 ± 0.03     | 6.35 ± 0.03     |
| S5       | 4.79 ± 0.03     | 4.97 ± 0.02     |
| S6       | 4.09 ± 0.02     | 3.97 ± 0.02     |

**Supplementary Table II** | Measured lever arm $\alpha_i$ for the resonances used in each QD ($i = 1, 2$) to obtain the spectra discussed in the main text.

**Convolution**

The transmitted current $I_2(E_2)$ through the detector QD2 in the sequential tunneling regime reads:

$$I_2(E_2) = \frac{e}{h} \int L_2(E, E_2)[f(E) - f_S(E)]dE$$  \hspace{1cm} (1)

where $f(E)$ is the distribution function to be probe, $f_S(E)$ the equilibrium distribution function at the source of the detector, and $L_2(E, E_2)$ is the intrinsic lineshape of the resonance on QD2. A simple model of electrostatic confinement for the electrons in the QD gives $L_2(E, E_2)$ as a Lorentz function centered in $E_2$

If the resonance of the detector is thin enough, namely its intrinsic width $\Gamma_2 \ll k_B T$, the lineshape can be approximated by a normalized delta function $L_2(E, E_2) \sim L_0 \times \delta(E - E_2)$, with $L_0 = \int L_2(E, E_2)dE$ a constant characteristic of the detector. Thus the current $I_2(E_2)$ is directly proportional to $\Delta f(E) = f(E) - f_S(E)$.

In other cases, as for most of the resonance used in our experiment, the measured signal, obtained from $\partial I_2/\partial V_{P2}$, is convoluted with the lineshape of QD2 following Eq. 1. In this case, the detected Fermi sea is widened and the effective electronic temperature $T_{eff}$, which is obtained by fitting a Fermi function, is larger than the 2DEG electronic temperature $T$, that is measured with a much thinner resonance. This is the case of the Fermi sea in all the spectra presented in the main text. The table III summarizes the measured $T_{eff}$, $T$ and the base temperature $T_{ph}$ for the different spectra. A comparison between $T_{eff}$ and $T$ provides a method to estimate the linewidth $\Gamma_2$ of the detector. An equivalent approach can be follow to further characterize the emitter QD.

The convoluted distribution shows also some deviation from an actual Fermi function, mainly by the development of a long tail. In such a case the convoluted distribution function is better described by an arctangent function with a characteristic width $T_{atn}$:

$$f(E) \approx \frac{1}{2} - \frac{1}{\pi} \arctan \left( \frac{E}{k_B T_{atn}} \right)$$  \hspace{1cm} (2)
Notice that this functional form is the same as that predicted for a metastable state, which is expected to occur in the relaxation process of a double step distribution function generated by a QPC at low transmission [2]. Thus the effects of the convolution can hamper the experimental investigation of the predicted metastable state [3].

Moreover, the injected QP peak in our experiment is also affected by the convolution at the detector QD. Let us consider the case when the injected QP peak is a Lorentz peak $L_1(E, E_1)$ centered at the injection energy $E_1$, with amplitude $T_1$ and width $\Gamma_1$. After the convolution with the QD2 lineshape, $L_2(E, E_2)$, the QP peak maintains its Lorentzian form but with an increased width: $\Gamma_1 + \Gamma_2$, and a reduced height: $T_1\Gamma_1/(\Gamma_1 + \Gamma_2)$. Importantly, since the characteristics of the detector are the same for all the curves of the same spectra, the exponential decay of the peak height discussed in the main text is not affected by the convolution. As can be seen in Supplementary Table I, the extracted widths of the Lorentzian fits correspond within less than 10 % to the sum $\Gamma_1 + \Gamma_2$.

**Electrochemical potential shift**

An important check in our experiments consists in verifying that the charge current remains conserved in the edge channel, i.e. that no charge tunnels from one edge channel to the other. This can be done by calculating the electrochemical potential shift $\mu$ in the outer edge channel at the detector, given by the integral of the measured distribution function, and comparing it either to the amount of current $I_1$ stemming from the drain that is transmitted by QD1 (note that in practice we measure the reflected current $1 - I_1$), or to the shift given by the emitter’s resonance parameters, namely $\Delta \mu = \pi \Gamma_1 T_1$ for a Lorentzian shaped resonance. This is illustrated in Supplementary Fig. 2 for the $L = 480$ nm data shown in main text Fig. 2. We systematically observe a good agreement, indicating that charge current is always conserved in the outer edge channel in our experiments.

![Supplementary Figure 2](image-url)
Additional data and analysis

Supplementary Figure 3 | Quasiparticle peak analysis for $L = 480$ nm, resonance B. Measured $f(E)$ in sample #1, plotted in semi-log scale. The inset shows the peak center (blue circles) and the peak width (red diamonds), determined from the Lorentz fit (black dash line) of the peak, as a function of the injection energy $E_1$.

Supplementary Figure 4 | Quasiparticle peak analysis for $L = 750$ nm, resonance B. Measured $f(E)$ in sample #2, plotted in semi-log scale. The inset shows the peak center (blue circles) and the peak width (red diamonds), determined from the Lorentz fit (black dash line) of the peak, as a function of the injection energy $E_1$.

Supplementary Fig. 3 shows the spectrum S2 ($L = 480$ nm, res. B) in semi-log scale, along with the Lorentzian fits, the normalized heights of which are shown as red circles in main text Fig. 3b. The peak positions and FWHM are shown in the inset. Supplementary Fig. 4 shows the spectrum S3 ($L = 750$ nm) in semi-log scale, along with the Lorentzian fits, the normalized heights of which are shown as blue diamonds in main text Fig. 3b. The peak positions and FWHM are shown in the inset. Similarly, the data at $L = 750$ nm when the ECs are separated (see main text Fig. 4e) is shown in semilog scale in Supplementary Fig. 5. Along with the peak position and FWHM, we show the evolution of the peak height versus $E_1$ used to extract $E_d$ (see below). Note that in that case the exponential character of the decay is less clear, as the peak height only decreases by 50%.

The exponential decay of the quasiparticle peak height consistently observed in our data can be directly compared to recent theoretical works predicting the evolution of electronic wave packets emitted at finite energy in an edge channel capacitively coupled to a neighboring one [4–6]. In these works, the peak height, referred to as elastic scattering probability, displays a decaying behavior as a function of the product $E_1 \times L$ given by a squared 0th-order Bessel function ($J_0(E_1L/v))^2$. We show in Supplementary Fig. 6 a tentative adjustment of our data at $L = 750$ nm with such a function, where the only fit parameter is the value of $E_1$ at which the peak height reaches a minimum. The discrepancy between this predicted function and our data is unambiguously larger than the uncertainty on the measurements. Furthermore, it is not possible to accurately match our data with such a function, regardless of the
**Supplementary Figure 5** Quasiparticle peak analysis for $L = 750$ nm with separated ECs. Left panel: measured $f(E)$ in semilog scale (symbols), with Lorentzian fits (black dashed lines). The extracted peak positions and FWHM are shown in the inset. Right panel: absolute peak heights (blue hexagons) extracted from the Lorentzian fits shown in the left panel, plotted in linear scale versus $E_1$. The blue dashed line is the exponential fit used to extract $E_d$.

**Supplementary Figure 6** | Comparison data-theoretical predictions. Normalized peak height extracted from the Lorentzian fits plotted versus $E_1$, for $L = 480$ (red circles) and 750 nm (blue diamonds - same data as in the main text). The grey hexagons are predictions extracted from ref. [4], and the blue line is a squared Bessel function fit.

**Peak height normalization**

Supplementary Fig. 7 shows the absolute peak height (without normalization) for the same data presented in Fig. 3b. of the main text. Since relaxation is suppressed at low energies, the peak height at low energy is proportional to the transmission of QD1, thus varying in different spectra, as seen in Supplementary Fig. 7. Therefore for a better comparison of the exponential decay between different spectra it is convenient to look at the peak height normalized by its extrapolation to zero $E_1$ as done in Fig. 3b. of the main text. The table IV summarizes the values of the peak height extrapolation to zero $E_1$, defined as $A_0$, for the data presented in Supplementary Fig. 7. In one case the extrapolated value is larger than 1, which could be misinterpreted as suggesting that the height of the injected peak at low energy was larger than 1. However one must remember that the actual amplitude of the injected peak, and
Supplementary Figure 7 | Peak height. Absolute peak heights extracted from Lorentzian fits, plotted versus $E_1$. The data correspond to the normalized one shown in Fig. 3b of the main text.

the transmission of QD1, at low energy is renormalized by the occupation of the Fermi sea, ensuring that the total distribution function remains limited by 1.

| Spectrum | Symbol  | $A_0$       |
|----------|---------|-------------|
| S1       | pentagons | 0.44 ± 0.02 |
| S2       | circles  | 0.47 ± 0.01 |
| S3       | diamonds | 1.35 ± 0.06 |

Supplementary Table IV | Peak heights extrapolated to zero $E_1$, used to obtain the normalized peak height.

Tuning energy relaxation with the length gate

Supplementary Figure 8 | Length gate. Scanning electron microscope side view of the side gate, showing the insulating SU-8 resist bridge separating the gate from the surface of the sample. The imprint of the gate on the 2DEG is highlighted by the white dashed line.
Supplementary Figure 9 | Tuning $E_d$. Evolution of $E_d$ vs the length gate voltage $V_L$. Plot (a) corresponds to sample #1 (b) where the short distance between the QDs was $L = 480$ nm ($L = 750$ nm).

Supplementary Figure 10 | Spectrum at maximal decoupling in sample #1. Measured distribution function $f(E)$ for $L = 480$ nm at length gate voltage $V_L = -0.12$ V, for which $E_d = 80\mu$eV is maximal. Each curve, offset for clarity, corresponds to an increment of the injection energy $\delta E_1 \approx 21\mu$eV, from $E_1 \approx -21\mu$eV (blue), to $E_1 \approx 190\mu$eV. The vertical offset is equal to $5.5 \times 10^{-3}$ $\delta E_1$.

A side view of the length gate is shown in Supplementary Fig. 8, displaying the 200 nm-thick SU-8 resist layer separating the left part of the length gate from the surface of the sample. Supplementary Fig. 9 shows the continuous change of the characteristic energy $E_d$ as a function of the voltage $V_L$ applied to the length gate. The data in Supplementary Fig. 9a were obtained from sample #1 with propagation distance $L = 480$ nm, while the data in Supplementary Fig. 9b were taken with sample #2 with propagation distance $L = 750$ nm, including the data shown in Fig. 4 of the main text. In both cases $E_d$ reaches a maximum value at intermediate $V_L$, when the ECs are maximally decoupled. At more negative voltages $V_L$, the ECs propagate following a longer path, increasing the relaxation of the QP peak. Since the QP peak is not well defined in the detected distribution, the values of $E_d$ at the most negative side of Supplementary Fig. 9 were not obtained from the height of the fit of the QP peak. Instead, we directly used the value of the distribution function $f(E)$ evaluated at the injection energy $E = E_1$. The behavior of $f(E_1)$ vs. $E_1$ provides an upper limit for the characteristic energy $E_d$.

In principle, the characteristic energy $E_d$ can be scaled with the propagation distance $L$ in order to obtain a characteristic speed $v$ for the propagation of the excitations [4, 5]: $E_d = h v / L$. However, our experimental data does not follow such scaling law, which can be understood by the fact that $E_d$ is strongly affected by the electrostatic environment as seen in Fig S9.
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