Experimental Methods

1. Sample:

The conductor is a two-dimensional electron gas (2DEG) with $2 \times 10^6 \, \text{cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$ mobility $\sim 1.4 \times 10^{15} \, \text{m}^2 \cdot \text{s}^{-1}$ density. The 2DEG is buried 100nm under the surface of a GaAs/Ga(Al)As heterojunction. Wet-etching and lithography are used to pattern two $\sim 50\mu$m long electron reservoirs separated by a constriction (Fig. 1). Low resistance AuNiGe ohmic contacts connect the 2DEG to the external circuit. On the middle of the constriction, 300nm gap metallic split gates defined by electron beam lithography are evaporated. Applying negative gate voltage depletes the 2DEG to form a QPC transmitting a single orbital mode whose transmission $D$ is provided by the conductance $G=2e^2/h$.

The distance between the QPC and the Ohmic contacts is $\sim 50\mu$m. The sample size is short enough to avoid the emission of 2D plasmons. Indeed, for 6GHz periodic voltage pulses used, the highest harmonics (24GHz) is well below the first plasmon mode expected at $\sim 80$ GHz.

![Fig. S1 Conductance of the sample versus gate voltage $V_G$ with $G_0 = 2e^2/h$.](image)

2. Experimental set-up:

The samples are mounted in a Cryoconcept® pulse tube dilution refrigerator with $\sim 400\mu$W cooling power and 13mK base temperature.

The broad-band rf-circuit shows minimal microwave reflection up to 40 GHz. The rf-lines connecting the room temperature rf-pulse generator and the L0 signal to the sample are designed in order to give very low loss.

The sample is connected to the coaxial lines via a Printed Circuit Board (PCB). Two coplanar lines on the PCB are designed with the 3D electromagnetic solver CST Microwave studio® in order to have flat transmission up to 40GHz. Each coplanar line connects the coaxial lines on one end and the ohmic contacts of the sample on the other end. Several very short ($\sim 100\mu$m) bonding wires are used in parallel to offer less inductance.
To prevent thermal microwave photons from the hot part of the rf-circuit to reach the sample, attenuators are regularly distributed at the different temperature stages of the refrigerator for a total of ~70dB. An attenuator is also placed at the output of the rf-generator as its rf-noise shows an equivalent noise temperature on 50 Ohms about 30 times higher than the room temperature.

3. **Current noise measurement and noise calibration:**

The current noise is converted into voltage fluctuations across two ~2.5kΩ resistors in series with the sample. For each detection path a 450 kHz bandwidth 2.5 MHz tank circuit combined with a home-made 0.2nV/Hz cryogenic amplifier is used. After further amplification and digitization the cross-correlation voltage noise spectra are calculated in real-time by a computer. The spectra obtained with VLO ON are subtracted from those obtained with VLO OFF and the difference averaged. The whole procedure provides a current noise spectral density resolution of ~3 10^{-30} A^2/Hz accuracy in one minute averaging (or ~1 10^{-30} A^2/Hz after 10mn averaging).

The very accurate calibration of the noise is done using Johnson-Nyquist noise thermometry and using the well-established dc shot noise variation versus a dc voltage bias applied across the sample. Small self-heating effects, well understood both qualitatively and quantitatively, are included in shot noise formula in the form of an electron temperature variation with dc bias, see below and ref 35.

4. **Generation of the Lorentzian pulses V(t) and local sinusoidal wave and rf-calibration:**

The 6GHz Lorentzian pulses with 2W=30ps (W/T=0.09) are synthesized using the appropriate combination of phase and amplitude of the four first harmonics (the lack of the fifth harmonics and higher has negligible impact on pulses carrying a charge lower or equal to 2 and for width W/T down to 0.09). This procedure allows the best control as even the smallest defects in the transmission of the coaxial lines can be compensated. Matching of the amplitude and of the phase is done using the QPC noise as a detector for each harmonics (giving their amplitude) and for a combination of pairs of harmonics (giving information on the relative phase between them). The fundamental harmonic is generated by a high stability frequency synthesizer (Agilent MXGN 5183A). The second harmonics is obtained with a frequency doubler (Marki Microwave AD0512K1304) and the fourth harmonic by cascading a second doubler. For the third harmonic a second synthesizer (R&S®SMF100A) phase locked to the first one generates the 18GHz signal. Variable attenuators and phase shifters are used to tune the harmonics. Once accurate Lorentzian voltage pulses are obtained, as measured in situ at the QPC, the rf-excitation measured at room temperature is monitored by a fast sampling scope and recorded. All along the measurements, the room temperature emitted signal is compared with this reference signal and computer automated correction is performed to compensate for possible drifts of the phase or the amplitude of each harmonics.
For the generation of the local sinusoidal wave $V_{\text{LO}}(t)$ for tomography measurements the output of the 6GHz and 12GHz (first and second harmonics) is derived from the main signal used to generate the Lorentzian pulses using rf-splitters. This procedure ensures temporal phase coherence between the LO excitation and the pulses. The signal is attenuated to control $\eta_{\text{LO}}$ and filtered from unwanted harmonics. A phase shifter is used to control the time-delay $\tau$.

Calibration of the rf amplitudes for each harmonics is done by measuring the shot noise under the rf excitation of an harmonics alone. Indeed the photo-assisted shot noise (PASN) for a sine wave is well understood. We follow the method described in the supplementary information of ref. 18 (see Fig. S2 of this reference).

![Figure S2](image_url)

**Figure S2**

Generation of a 6GHz periodic Lorentzian pulses with $w/T=0.09$ (30ps full width at mid height) using the four harmonics technique is shown in Fig. S2 as an example. The red curve is a best fit using the theoretical expression for periodic Lorentzian. The best fit gives $w/T=0.108$ (36ps) a difference which can be attributed to a small broadening due to the finite ~6ps rise time of the fast sampling scope used to record the signal. We emphasize that the actual signal send for measurements is obtained by careful calibrations of each four harmonics using QPC shot noise.
Theoretical description and modeling:

1. **Modeling the effect of periodic voltage pulses on a contact:**

   We consider a periodic voltage \( V(t) \) applied to the left contact. An electron emitted by this contact at energy \( \varepsilon \), in the quantum state \( e^{i k(x)} e^{-i\varepsilon t / \hbar} \), acquires a phase \( \Phi(t) = 2\pi \frac{e^t}{\hbar} \int V(t') dt' \) and arrives at the QPC in a superposition of states with the shifted energies \( \varepsilon + l\hbar v_0 \) and amplitude probabilities \( p_l = \frac{1}{T} \int_0^T e^{-i\Phi(t)} e^{-i 2\pi l / v_0 t} dt \) where \( T = 1/v_0 \) and \( l \) an integer. All transport and noise properties can be calculated from the knowledge of the \( p_l \) using the Floquet scattering theory of refs. 29-30,32-33. It is convenient to introduce the Fermion operator \( \hat{a}(\varepsilon) \) describing an electron arriving at energy \( \varepsilon \) at the QPC. It is related to the Fermion operator \( \hat{a}_L(\varepsilon) \) acting on the states of the left reservoir by \( \hat{a}(\varepsilon) = \sum_l p_l \hat{a}_L(\varepsilon - l\hbar v_0) \). The unitary transformation relating both set of Fermion operators implies: \( \sum_l p_l p^*_l e^{i\delta_{l,k}} = \delta_{k,0} \).

In particular, the sum of the probabilities \( P_l = |p_l|^2 \) for an electron to have its energy shifted by \( l\hbar v_0 \) is unity.

Under the effect of the voltage pulse, the Fermi sea describing right moving electrons arriving at the QPC is a quantum superposition of the initial Fermi sea shifted by the quantity \( l\hbar v_0 \) into positive \((l > 0)\) and negative \((l < 0)\) energy. This situation creates both hole- and electron-like excitations.

Remarkably, for (periodic) Lorentzian pulses carrying unit charge per period one has \( p_l = 0, \ l < 0 \). Only electron-like excitations are created. Each pulse injects one electron per period on top of the Fermi sea: a quasi-particle called leviton.

Defining \( \beta = e^{-2\pi w / T} \), where \( w \) is the full width at half maximum of a single Lorentzian pulse, the probability amplitudes are: \( p_0 = -\beta \) and for \( l > 1 \) \( p_l = (1 - \beta^2) \beta^{l-1} \), see ref. 28 and 34.

The generation of levitons, experimentally demonstrated in Ref. 18, is well controlled and is thus suitable to test the feasibility of Quantum Tomography using shot noise\(^1\).
2. **First order coherence, energy density matrix and Wigner function:**

Using the linearized relation dispersion appropriate for energy scale small with respect to the Fermi energy, the Fermion operator measuring the amplitude of probability to find electrons at point x and time t electrons emitted by the left reservoir and incoming on the QPC is

\[ \hat{\psi}(t,x) = \sum_l p_l \hat{a}_l (e - \hbar \nu_0) \]  

in time representation. In energy representation, it is:

\[ \hat{\psi}(e,x) = \sum_l e^{-i\hbar \nu_0 / \nu} p_l \hat{a}_l (e - \hbar \nu_0) . \]

The coherence \[ \left\langle \hat{\psi}(t',x) \hat{\psi}(t,x) \right\rangle \] is here best described in the energy domain, i.e. by the computation of the energy density matrix \[ \left\langle \hat{\psi}(e',x) \hat{\psi}(e,x) \right\rangle = \sum_k \delta(e' - e - k\hbar \nu_0) \sum_l p^*_l p_l e^{-i\hbar \nu_0 / \nu} (\hat{f}_L (e - \hbar \nu_0) - f_L (e)) . \] Here \( \hat{f}_L (e) \) is the Fermi distribution of the left reservoir. The unperturbed Fermi sea contribution of the left reservoir (i.e. when no voltage pulse is applied) has been subtracted. From this expression, we see that a time dependent voltage \( V(t) \) always creates off-diagonal (or coherence) terms in the energy density matrix for energies separated by a multiple of \( \hbar \nu_0 \).

Denoting \[ \left\langle \hat{\psi}(e',x) \hat{\psi}(e,x) \right\rangle = \sum_k \delta(e' - e - k\hbar \nu_0) \tilde{\phi}^* (e + k\hbar \nu_0) \tilde{\phi}(e) \] we get:

\[ \tilde{\phi}^* (e + k\hbar \nu_0) \tilde{\phi}(e) = \sum_l p^*_l p_l (\hat{f}_L (e - \hbar \nu_0) - f_L (e)) \]  

(4)

The \( x \) dependent phase has been integrated in the definition of \( p_l \).

As a result of the periodicity, at zero temperature the function defined in (4) is a step function of the energy: \( \tilde{\phi}(e) \tilde{\phi}(e + k\hbar \nu_0) = \rho_{l,l+k} \) for \( \hbar \nu_0 < e < (l+1)\hbar \nu_0 \). The steps are rounded at finite temperature on the energy scale \( k_B T_e \).

The \( \rho_{l,l+k} \) can be expressed in terms of the Floquet scattering matrix amplitudes \( p_l \):

- For the diagonal term \( k=0 \) (energy density): \( \rho_{0,0} = 1 - \left| p_0 \right|^2 \), \( \rho_{l,l} = 1 - \left| p_0 \right|^2 - \left| p_1 \right|^2 - \cdots - \left| p_l \right|^2 \), \( l > 0 \)
- For the off-diagonal term, \( k > 0 \): \( \rho_{0,k} = - p_0 p_k \), \( \rho_{l,k} = - p_0 p_k - p_1 p_{l+k} - \cdots - p_l p_{l+k} \)

and \( \rho_{l,l+k} = 0 \) for \( l < 0 \).

From the above expressions one can obtain the Wigner Distribution Function (WDF) defined as
\[ W(t,e) = \int_{-\infty}^{+\infty} \left\langle \hat{\psi}^* (\epsilon + \delta / 2) \hat{\psi}(\epsilon - \delta / 2) \right\rangle e^{-i\delta t / \hbar} d\delta = \sum_k \tilde{\phi}^* (\epsilon + k / 2) \tilde{\phi}(\epsilon - k / 2) e^{-i\hbar \nu_0 t} . \]
For levitons, all terms are real and:

\[ W(t, \varepsilon) = \bar{\phi}(\varepsilon)^2 + 2 \cos(2\pi \nu t) \bar{\phi}(\varepsilon + 1/2) \bar{\phi}(\varepsilon - 1/2) + 2 \cos(4\pi \nu t) \bar{\phi}(\varepsilon + 1) \bar{\phi}(\varepsilon - 1) + \ldots \]  

(5)

The WDF restricted to the first two harmonics has been plotted in Figure 4 of the main text. As is well known, one can check that the integration over time gives the energy distribution \( |\bar{\phi}(\varepsilon)|^2 \) and that over energies gives the time dependent probability \( |\phi(t)|^2 \).

3. Quantum tomography: practical calculation of the theoretical shot noise:

We first consider the situation of periodic single charge levitons generated at the left contact while no d.c. bias is applied on the right contact. As can be found for example in ref. 28, the zero temperature expression of the shot noise resulting from the partitioning at the QPC is

\[ S_I = S_I^0 \sum_I l|p_I|^2 \]  

where \( S_I^0 = 2(2\varepsilon^2 / h) \hbar \nu \sigma D(1 - D) \), \( D \) being the transmission of the spin degenerate orbital mode transmitted by the QPC.

When increasing the right electro-chemical potential \( \mu_R = eV_R \) the modified shot noise writes

\[ S_I = S_I^0 \sum_I [l-q]|p_I|^2 \]  

with \( q = eV_R / h\nu \). When the small a.c. voltage \( V_{LO}(t) = \eta_{LO} (h\nu / e) \cos(2\pi k \nu (t - \tau)) \) is added to \( V_R \), to first order in the small parameter \( \eta_{LO} \) the noise is obtained by replacing \( p_I \) by \( p_I - \frac{\eta_{LO}}{2}(p_{l+k} e^{i\theta} - p_{l-k} e^{-i\theta}) \) where \( \theta = 2\pi \nu \tau \). This result is readily obtained by remarking that, in the limit of infinitely small sample (i.e. neglecting the propagation time from the contact to the QPC), the unitary Floquet scattering matrix makes the shot noise problem equivalent to the one calculated when applying \( V(t) - V_{LO}(t) \) on the left contact.

- Diagonal term \( (k = 0) \):

The noise difference between \( V(t) \) and \( V(t) \) replaced by its d.c. value \( \bar{V}(t) = h\nu / e \) is measured (as in Ref. 18). This gives

\[ \Delta S_I^{(0)} / S_I^0 = \sum_I |l-q||p_I|^2 - |1-q| \]  

(7)

One can check that this expression is in agreement with Eq. (2) of the main text.

- Off-diagonal measurements \( (k \neq 0) \):

The noise difference when \( V_{LO} \) is ON and OFF is measured. This gives

\[ \Delta S_I^{(k)} / S_I^0 = \eta_{LO} \cos(2\pi \nu \tau) \sum_I |l-q|(p_{l+k} p_{l-k} - p_{l+k} p_{l-k}) \]  

(6)

Here again, one can check that Eq. (6) gives an expression identical to Eq. (3) of the main text.
Including finite temperature is done by the substitution \( |l - q| \rightarrow (l - q) \coth((l - q) h\nu_0 / 2k_B T_e) \).

4. Fitting the data:

For \( k=1 \) and \( 2 \), the fits are aimed to extract the set of parameters \( \Delta P_{l}^{(k)} = (p_l p_{l-k} - p_l p_{l+k}) \) from which the \( \rho_{l,l+k} \) will be obtained (see below). Typically four terms \( l=0 \) to \( 3 \) are kept while the higher terms are considered small.

Practical fitting for \( k=1,2 \) is obtained by remarking that \( \coth(x/2) = 2N(x) - 1 \) where \( N(x) = 1/(\exp(-x) - 1) \) and introducing the function \( F(x) = x N(x) \). At zero temperature \( F \) is zero for \( x<0 \) and is equal to \( x \) for \( x>0 \). At finite temperature the singularity at \( 0 \) is rounded. Using the following sum rules: \( \sum_l \Delta P_{l}^{(k)} = 0 \) and \( \sum_l l \Delta P_{l}^{(k)} = 0 \) for \( \tau=0 \) equation (6) can be written:

\[
\Delta S_{l}^{(k)} / S_{l}^{0} = \eta \sum_l 2 \Delta P_{l}^{(k)} F \left( \frac{(q-l)h\nu_0}{k_B T_e} \right)
\]

This representation of the shot noise difference improves the fitting process as the \( l^{th} \) term does not contribute to the data when \( eV_R \) is few \( k_B T_e \) lower than \( h\nu_0 \).

Once the \( \Delta P_{l} \) are extracted, the off-diagonal terms \( \phi(\varepsilon)\phi(\varepsilon + k h\nu_0) = \rho_{l,l+k} \) are readily obtained:

For \( k=1 \), one have \( \rho_{0,1} = \Delta P_{0}^{(1)} \), \( \rho_{1,2} = 2\Delta P_{0}^{(1)} + \Delta P_{1}^{(1)} \), \( \rho_{2,3} = 3\Delta P_{0}^{(1)} + 2\Delta P_{1}^{(1)} + \Delta P_{2}^{(1)} \) and \( \rho_{3,4} = 4\Delta P_{0}^{(1)} + 3\Delta P_{1}^{(1)} + 2\Delta P_{2}^{(1)} + \Delta P_{3}^{(1)} \).

For \( k=2 \), one have \( \rho_{0,2} = \Delta P_{0}^{(2)} \), \( \rho_{1,3} = \Delta P_{0}^{(2)} + \Delta P_{1}^{(2)} \), \( \rho_{2,4} = 2\Delta P_{0}^{(2)} + \Delta P_{1}^{(2)} + \Delta P_{2}^{(2)} \) and \( \rho_{3,5} = 2\Delta P_{0}^{(2)} + 2\Delta P_{1}^{(2)} + \Delta P_{2}^{(2)} + \Delta P_{3}^{(2)} \).

In Figure 3, main text, the error bars of \( \tilde{\phi}(\varepsilon)\tilde{\phi}(\varepsilon + k h\nu_0) = \rho_{l,l+k} \) include the quadratic sum of the error associated to each \( \Delta P_{l}^{(k)} \) with a weight taking into account the above relations linking the set of \( \rho_{l,l+k} \) to the set of \( \Delta P_{l}^{(k)} \).

A similar procedure can be done for \( k=0 \). Because of the different ON-OFF noise difference acquisition procedure, we define the \( \Delta P_{l}^{(0)} = |p_l|^2 - \delta_{l,1} \) and fit the data using the finite temperature extension of Eq. (7):

\[
\Delta S_{l}^{(0)} / S_{l}^{0} = \sum_l 2 \Delta P_{l}^{(0)} F \left( \frac{(q-l)h\nu_0}{k_B T_e} \right) \]
Here, error bars are smaller as the noise signal is about ten times higher than for the measurement of off-diagonal terms.

5. Taking self-heating effects into account:

Heating effects can be taken into account. The procedure is similar to the one used in Ref. (18). The ac and dc excitations generate an electrical power \( G(V(t) - V_R - V_{LO}(t))^2 / 2 \) which is dissipated in the 2DEG leads few inelastic lengths away from the QPC. Using the Wiedemann-Franz law which relates the 2D leads thermal conductance to the 2D-lead conductance and assuming the temperature of the ohmic contacts at base temperature, it is possible to calculate the electronic temperature \( T_e \) as a function of the excitation and plug its values in the finite temperature shot noise formula. The electronic temperature is given by:

\[
T_e(V_{dc})^2 = T_e(0)^2 + \frac{24}{\pi^2} \frac{G}{G_m} (1 + \frac{e}{2k_B} G_m) \left( \frac{e}{2k_B} G_m \right)^2 \left( V(t) - V_R - V_{LO}(t) \right)^2 \]

with \( G_m \sim 150 \) Ohms, the (measured total conductance) of all leads in parallel\(^{35}\). This electron temperature modeling is first checked by measuring the shot noise when only a dc bias is applied across the sample. Typically, \( T_e \sim 35\)mK (no excitation, \( V_R=0 \)) and \( T_e \sim 48\)mK (for \( V_R \sim 3hV_0/e \)). The weak amplitude of \( V_{LO} \) does not change appreciably the electronic temperature.

Within the signal to noise ratio, inclusion of the heating effect does not change significantly the extracted \( \rho_{ij,j+k} \). From modeling, changes are expected well below the error bars.

6. Linearity of sample response:

Non-linearity effects are not expected for the rf-set-up, but they could arise from possible rectification effects of the ac current by the QPC. To prevent this we have chosen QPC transmission and energy range such that the energy dependence of the transmission is negligible. This is checked by \( dI/dV(V) \) measurements and by looking at the photo-current (if the I-V characteristic is non-linear a weak dc photo-current appears when pulses and sine-waves are applied). In case of intermodulation due to an unexpected non-linear sample response, the \( k=0 \) noise (figure 2a) would be partly replicated in the noise measured for \( k=1 \) and \( k=2 \), but clearly the shape of noise curve versus \( V_R \) are different. For example the curve at \( k=2 \) (figure 3d) shows a maximum at \( eV_R=2hV_0 \) while the noise at \( k=0 \) is maximum at \( eV_R = hV_0 \). Finally, the noise measured at \( k=1 \) and \( k=2 \) shows linear response to excitation. We can safely rule out intermodulation.

7. Coherence versus thermal broadening

The tomographic noise measurements for levitons (and for the 2-electron sine-wave pulses shown below) are in good agreement with a model including only thermal effects. This rises question about possible observation of decoherence effects due to electron interaction affecting the first order coherence. The Landau quasi-particle lifetime of an electron launched with some energy \( \Delta \) above the Fermi sea has been calculated for 2D electron gas in refs. 36 and 37 and measured in ref. 38. For \( \Delta=2hV_0 \) we find an electron-electron collision rate \( 1/\tau_{ee} \sim 0.4 \times 10^9 \text{s}^{-1} \) which is smaller than the thermal broadening \( k_B T_e/h \sim 1.05 \times 10^9 \text{for} 50\text{mK} \). This is
only for $\Delta = 4\hbar v_0$ ($1/\tau_{\text{ee}} \sim 1.6 \times 10^9 \text{ s}^{-1}$) that decoherence effects can be expected while the present measurements probe smaller energy range.

Additional data:

**Shot noise tomography of sine-wave electron pulses:**

The noise quantum tomography method has been also tested on a state very different from the single charge leviton state. We have chosen sine-wave pulses carrying two electrons. The sine-wave pulse is simple and well understood. Contrary to levitons it is not a minimal excitation state and show a large contain of neutral electron-hole pairs excitations accompanying the injected charge pulse. The number of electron-hole has been experimentally measured. The energy spectrum (diagonal part of the energy density matrix) has been measured and Hong Ou Mandel correlation have been done. All data have been found in excellent agreement with theoretical predictions. Here we provide quantum tomography shot noise measurements for $k=2$.

The voltage of 2-electron periodic sine pulses is $V(t) = 2\frac{h v_0}{e} (1 - \cos(2\pi v_0 t))$. The probability amplitudes are real and given by $p_l = J_{l-2}(2)$, where $J_l(x)$ is an integer Bessel function. Contrary to levitons the $p_l$ are no longer zero for $l<0$. According to the Bessel function property they show the identity $p_{n-l} = (-1)^l p_{l+n}$ ($n$ the electron number, $n=2$ here). This makes $\Delta P_l^{(k=2)}$ anti-symmetrical with respect to $l=2$, i.e. $\Delta P_l^{(k=2)} = (p_l p_{-k} - p_{l-k} p_{l+k}) = -\Delta P_{4-l}^{(k=2)}$. The $k=2$ tomographic shot noise is also anti-symmetrical with respect to $q = eV_R / \hbar v_0 = n = 2$ at all temperature, i.e. $\Delta S_l^{(k=2)}(eV_R) = -\Delta S_{4-l}^{(k=2)}(n\hbar v_0 - eV_R)$. These features and the negative values of $\Delta S_l^{(k=2)}(eV_R)$ for sine wave pulses contrast with the positive value found for the leviton case.

In figure S2 below, the upper graph shows the oscillatory variation of the measured noise versus time delay. The data are analogous to figure 3b of the main text but for sine-wave pulses with same repetition rate (6GHz) and similar $\eta_{LO}^{(k=2)} = 0.05$ and for $eV_R = 0.83 \hbar v_0$. A doubling of the period with time delay is also found as expected for the second harmonics. Figure S3, lower graph, shows $\Delta S_l^{(k=2)}$ versus the dc right voltage, while zero time delay has been chosen to maximize the signal. A clear negative part of the excess noise is found. The expected symmetry with respect to $eV_R = 2\hbar v_0$ is clear, contrasting with the case of levitons. The data compare well with theory including the finite temperature and further validate the shot noise approach of ref. 16 for quantum tomographic measurements.
Supplementary Information

References:


34. C. Grenier et al., Fractionalization of minimal excitations in integer quantum Hall edge channels *Phys. Rev. B* **88**, 085302 (2013)

