Reviewers' comments:

Reviewer #1 (Remarks to the Author):

In this manuscript, the authors report on conductance and noise (Fano) measurements in a high mobility hBN-encapsulated graphene pn junction in which spin and valley degeneracies of the edge states are lifted by a strong perpendicular magnetic field. Both quantities are measured for different filling factors nu_n and nu_p (in the n and p parts of the junction), ranging from ±1 to ±6. Conductance data show that only interface states with identical spins equilibrate along the np junction (as already reported in previous works). Fano factor data are statistically analyzed to extract the average Fano factor and its standard deviation for each (nu_n,nu_p). The average Fano is compared to different analytical predictions, corresponding to two possible (spin or valley polarized) ground states and to various (coherent, incoherent but quasi-elastic, or inelastic) scattering mechanisms along the np interface. It turns out that the comparison does not yield information about the nature of the ground state but provides some insights into the scattering mechanisms. In particular, a crossover from the incoherent to the coherent regime is observed when the filling factors are increased.

This paper shows for the first time shot noise measurements in a hBN-encapsulated graphene pn junction, for a wide range of filling factors. Similar noise measurements were reported in Refs.[37,38] for graphene samples (deposited on a Si/SiO2 substrate) with lower mobilities. In those samples, spin degeneracy was not lifted and equilibration along the np junction involved all the (spin up and spin down) interface states. Therefore, I believe the noise measurements reported in the present manuscript are worth of interest and can provide important information about the mode-mixing mechanism along the np junction.

However, I am less convinced by the data analysis and the comparison with theory. I am also puzzled by the asymmetric behavior of the junction (comparing e.g. Figs.3a and 3c). I would like to reconsider publication of the manuscript after the authors have addressed the following points:

* In the introduction, it is written that "the shot noise measurements [in Refs.[37,38]] are focused around the lowest filling factor (v = ±2)". This is not completely true: In Ref.[38], the Fano factor is also measured for (nu_n,nu_p)=(2,-6), (6,-2).

* In Fig.1c, it should be mentioned that the energies of Landau levels are plotted as a function of the magnetic field.

* It seems to me that Eq.(1) corresponds to the "excess noise" i.e. the thermal equilibrium noise (at V_sd=0) has already been substracted. It should be made clear in the text.

* In all formulas for t and F, absolute values for |nu_n| and |nu_p| are missing.

* There is no discussion of conductance fluctuations. I wonder whether or not the transmission plotted as a function of V_bg1 and/or V_bg2 shows well resolved conductance plateaus, especially at large nu_n/nu_p. In Fig.1d, only the average transmission is plotted for each plateau and it is not easy to evaluate conductance fluctuations from Fig.1b.

* A related question concerns the calculation of the average value of the Fano factor F=F*/t through the gaussian fits. Is the average value really calculated as <F>=<F*/t> or as <F>=<F*>/<t>? The two quantities are different if the conductance fluctuations are not negligible.

* I do not fully understand the plots shown in Figs. 2a and SI14. If each of them has been obtained for fixed values of V_bg1 and V_bg2, I do not understand the origin of such data spread (leading to an experimental error bar on the evaluation of F*). If on the contrary, each of them

has been obtained by superposing data for various (V_bg1, V_bg2) at fixed (nu_n,nu_p), I find it confusing to show the red fit to Eq.(1) in Fig.2a which is supposed to be done for a given value of (V_bg1, V_bg2).

* There are some values of (nu_p,nu_n) (in particular (-4,1), (-5,2), (-5,3), (-6,2), (-3,1)) for which the histograms of Fano factors are not well fitted by Gaussian fits, so that the estimation of the average Fano and of its standard deviation is imprecise. It would be preferable to improve the statistics with more data (e.g. by varying the magnetic field). If not, it should be made clear in Figs. 3, SI11 and SI12 that some points are less precise than others (maybe with a colorscale encoding the fidelity of the gaussian fits).

* In Fig. SI3, the conductance plateau for nu_p=-5 is indistinguishable. Therefore, I do not understand how data for t and F have been obtained in that case.

* One striking feature of experimental Fano factors is the increase of fluctuations for large filling factors but it is not highlighted by the authors. I believe this is an important argument in favor of a crossover from the incoherent to the coherent regime and that it should be discussed in the main text.

* The Fano factor is a quantity that depends on the length Lnp of the np interface (see Ref.[37]). Therefore, I do not really understand how experimental Fano factors for one fixed length (Lnp=10 microns here) can be compared to theoretical predictions. The comparison can be done in the coherent and quasi-elastic scenarios if Lnp is small enough and inelastic effects are indeed absent in the sample. However the discussion of inelastic effects (at the end of SI6 and following Ref.[SI-8]) makes no sense to me. Could the authors comment on that point?

* I am surprised by the asymmetric behavior of the Fano factor when it is plotted as a function of nu_n at fixed nu_p or as a function of nu_p at fixed nu_n. I think the authors should discuss possible origins of this asymmetry.

Reviewer #2 (Remarks to the Author):

The authors experimentally investigated the Landau transport of graphene p-n interface devices at low temperatures in bipolar regime. They measured the conductance as well as the shot noise. The former shows that the Hall states at the interface follow spin polarized equilibration according to the lift of spin/valley degeneracy at the device edges and p-n interface. The latter says that there is a crossover between incoherent transport at lower filling indices (<2) and coherent transport at higher filling indices (>2). The supplemental material shows sufficient information about the experiment and theoretical model. The conclusion is sound and sheds new insights on the transport of quantum Hall channels of graphene p-n interfaces. The manuscript is scientifically valuable, I think, if the authors consider my following comments.

1. The scale is missing in Fig. 1 (a).

2. In fig. 1 (c), there are two scenarios of the spin/valley splitting. However, I cannot find any information about which scenario is applied for the experimental situation. The authors need to carefully migrate the information in Fig. SI5 of the supplemental material into the main text.

3. I am confused by fig. 1 (c). The spin/valley configuration at N=0 is not identical to that of fig. 2 (c) of Ref [32]. Why?

4. What role doses the valley polarization play? There is nothing about it in the manuscript.

5. The calculation in the supplemental material is based on single channel model. Are the conclusions approximately valid for multi-channel (at least few-channel) cases?

6. In eq (1), what does F* mean? BTW, wide-brackets should be used in the equation.

7. The manuscript says that the Fano factor is more sensitive on the p-side filling index while no explanation is given. Can the authors raise a proposal?

Reviewer #3 (Remarks to the Author):

The authors report on measurements on equilibration processes in graphene pn junctions using conductance and noise measurements. The manuscript contains nice measurements on a high-quality device. However, I am bit uncertain regarding the novelty and broad interest of the results. Therefore I suggest a major revision, where the authors could try to argue about the novelty of their results and on the few of the questions raised below.

High quality pn junctions have been studied widely in the literature, e.g. the spin-dependent equilibration in 3-4 papers, and already noise measurements have been performed on graphene pn junctions, though with lower quality. The question is how much the higher quality adds to the understanding. Here, all degeneracies of the Landau level sequence are lifted, and noise for all different combinations can be studied. The authors are than able to suspect for which plateau which mechanism (regime) might be dominant, but no physical understanding is given. What is the role of the valley, pseudospin? What kind of scattering mechanisms (a bit more concretely) might be at play? Does the electric field/smoothness of the junction matter? Also, since they only have a single device, the determination of different scattering lengths is not possible.
Below, I give some minor comments:
- On Fig1. c it would be nice to show the valley degree of freedom. If I understand well, not both the color and the arrow stands for spin. This is a bit redundant.
- Maybe would be worth showing the idea of the incoherent scattering calculation is the supporting.
- Maybe would be worth to cite some of these papers: L. Veyrat, Nano Lett., 2019, 19, 2, 635–642, S. P. Milovanovic et al., Appl. Phys. Lett. 105, 123507 (2014); P. Makk et al., Phys. Rev. B 98, 035413 , E. Tovari, Nanoscale, 2016, 8, 19910-19916, K. Kolasiński, et al., Phys. Rev. B 95, 045304, Son Te Le et al., arXiv:1904.04726, S. Dubey et al., https://doi.org/10.1016/j.ssc.2016.03.024
- On Fig 1b some conductance oscillations are visible, similarly to the one reported in Ref. 26 (Wei et al., Science Advances). I was wondering if the noise shows any sign of these oscillations.

Reviewer #4 (Remarks to the Author):

I have read the paper by Paul et al “Interplay of filling fraction and coherence in symmetry broken graphene p-n junction”. In this work, Paul and his coworkers carried out conductance and shot noise measurements to investigate the scattering mechanism at the interface of symmetry broken graphene p-n junction (PNJ).

So far, shot noise experiments with PNJ have been done by two groups [37, 38]. Kumada et al qualitatively studied equilibration length dependence of the Fano factor. Matsuo et al evaluated Fano factor at various cases of (v_n, v_p). These results are in good agreement with the incoherent scattering model [17]. However, Si/SiO2 substrates in both experiments prevented them from observing spin-valley symmetry broken conductance.

In this study, the authors measured the hBN encapsulated graphene device, whose mobility is 100 times higher than the previous studies, in two ways: conductance and shot noise measurements. They found that the conductance data agree well with the calculation based on the spin-polarized ground state. In the shot noise experiments, the authors investigated the filling factor dependence of the Fano factor. Firstly, they discovered that the Fano factor in p-region strongly depends on the filling factor, while slowly in n-region. Secondly, they revealed that the Fano factor in the lower p-side filling factor is explained well by the incoherent scattering model, while the Fano factor in the higher filling factor follows the coherent scattering model. Tthe authors attributed the channel number dependence of the Fano factor to the screening effect. These results should induce a strong interest among the mesoscopic community.

The paper is well written, and I do not doubt that the exciting new results it contains deserve publication in Communications Physics. I have minor comments that I think the authors should address before I can recommend the paper for publication.

1. The authors mention that the screening effect from the other channels, which are compressible states, might play a role in increasing coherence of scattering at the PNJ interface. I think that there is another possibility that the filling factor dependence of velocity may explain the enhancement of coherence. The velocity, in general, decreases as the filling factor becomes lower, because edge structure at lower filling factor has flatter confinement than at higher filling factor. Nakamura et al explained that smaller velocity at v=1/3 reduces phase coherence [Nat. Phys. 15, 563 (2019)]. I would like to know the authors' comments about the effect of velocity on the scattering coherence at the PNJ interface.

2. Is there a reason why the Fano factor in n-region slowly depends on the filling factor? Can the screening effect explain the reason?

3. Fano factor distribution at high filling factors show a large variation [the right figure of Fig. 2(b)]. Figures SI14 at (v_n, v_p)= (4, -6) , (5, -6), (6, -6) exhibit larger fluctuation than the other data. Why are these shot noise results at high v_p so noisy?

4. As for gain calibration shown in Supporting Information, the authors should take into account the thermal noise from the impedance of the LC circuit (Z) for more precise calibration [for example, see Phys. Rev. B 101, 115401 (2020)]. The effect of the LC circuit can be ignored when the sample resistance is much lower than the Z. I would like to know whether the LC circuit thermal noise is consicered or not in the paper.

Interplay of filling fraction and coherence in symmetry broken graphene p-n junction (Manuscript COMMSPHYS-20-0337-T)

Arup Kumar Paul[1*], Manas Ranjan Sahu[1*], Chandan Kumar[1], Kenji Watanabe[2], Takashi Taniguchi[2] and Anindya Das[1]

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We thank the reviewers for their criticisms and comments. In this reply, we answer to the reviewer's questions and concerns followed by the list of changes made in the revised manuscript:

Reply to Reviewer 1:

In this manuscript, the authors report on conductance and noise (Fano) measurements in a high mobility hBN-encapsulated graphene pn junction in which spin and valley degeneracies of the edge states are lifted by a strong perpendicular magnetic field. Both quantities are measured for different filling factors nu_n and nu_p (in the n and p parts of the junction), ranging from ± 1 *to* ± 6*. Conductance data show that only interface states with identical spins equilibrate along the np junction (as already reported in previous works). Fano factor data are statistically analyzed to extract the average Fano factor and its standard deviation for each (nu_n ,nu_p). The average Fano is compared to different analytical predictions, corresponding to two possible (spin or valley polarized) ground states and to various (coherent, incoherent but quasi-elastic, or inelastic) scattering mechanisms along the np interface. It turns out that the comparison does not yield information about the nature of the ground state but provides some insights into the scattering mechanisms. In particular, a crossover from the incoherent to the coherent regime is observed when the filling factors are increased.*

paper shows for the first time shot noise measurements in a hBN-encapsulated graphene pn junction, for a wide range of filling factors. Similar noise measurements were reported in Refs.[37,38] for graphene samples (deposited on a Si/SiO2 substrate) with lower mobilities. In those samples, spin degeneracy was not lifted and equilibration along the np junction involved all the (spin up and spin down) interface states. Therefore, I believe the noise measurements reported in the present manuscript are worth of interest and can provide important information about the mode-mixing mechanism along the np junction.

However, I am less convinced by the data analysis and the comparison with theory. I am also puzzled by the asymmetric behavior of the junction (comparing e.g. Figs.3a and 3c). I would like to reconsider publication of the manuscript after the authors have addressed the following points:

— We are grateful to the reviewer for the positive and valuable comments. Following are the corrections in the revised manuscript and clarification to the questions, as pointed out by the reviewer.

1.

$\star$ *In the introduction, it is written that "the shot noise measurements [in Refs.[37,38]] are focused around the lowest filling factor (v =* ± 2*)". This is not completely true: In Ref.[38], the Fano factor is also measured for (nu_n,nu_p)=(2,-6), (6,-2).*

— To clarify this point we have modified the revised manuscript with the following line "**Besides, the shot noise measurements are focused around only the filling factors** $\nu = \pm 2$ **and** $\nu = \pm 6$ **with no clear dependence of** F **on filling factors (**ν**).**"

2.

⋆ *In Fig.1c, it should be mentioned that the energies of Landau levels are plotted as a function of the magnetic field.*

— In Figure 1(c) of the revised manuscript we have shown the magnetic field axis.

3.

⋆ *It seems to me that Eq.(1) corresponds to the "excess noise" i.e. the thermal equilibrium noise (at V_sd=0) has already been substracted. It should be made clear in the text.*

— We thank the reviewer for raising this important point. To clarify this we have modified the line "**In general, measured current noise (SI) consists of both thermal and shot noise and follows the expression**" with "**In general, measured excess current noise (SI) with finite temperature broadening follows the expression:**". We have also added the line "**It should be noted that S_I is the excess current noise without the thermal equilibrium noise** ($V_{sd} = 0$)" in the shot noise section of the revised manuscript to further clarify this.

4.

⋆ *In all formulas for t and F, absolute values for |nu_n| and |nu_p| are missing.*

— In the revised manuscript as well as in the supporting information we have used absolute values of filling factor in all the expressions of transmission (t) and Fano factor (F).

5.

⋆ *There is no discussion of conductance fluctuations. I wonder whether or not the transmission plotted as a function of V_bg1 and/or V_bg2 shows well resolved conductance plateaus, especially at large nu_n/nu_p. In Fig.1d, only the average transmission is plotted for each plateau and it is not easy to evaluate conductance fluctuations from Fig.1b.*

— We thank the reviewer for raising this important point. To elucidate on this point, in the Figure 1(d) of the revised manuscript and in Supplementary Figure 5 we have now shown the standard deviation of transmission for each plateau. As it can be seen from the figures, the fluctuations in the transmission is negligible for all the plateau. We do see a slight increase in fluctuation at higher filling factors, however the standard deviation does not exceed 10% of the average values.

6.

$\star$ *A related question concerns the calculation of the average value of the Fano factor F=F*/t through the gaussian fits. Is the average value really calculated as <F>=<F*/t> or as <F>=<F*>/<t>? The two quantities are different if the conductance fluctuations are not negligible.*

— Since the conductance fluctuation is negligible, as described in the last point, we have calculated the average value of Fano as <F>=<F*>/<t>, where <F*> has been obtained from the gaussian fits.

7.

$\star$ *I do not fully understand the plots shown in Figs. 2a and SI14. If each of them has been obtained for fixed values of V_bg1 and V_bg2, I do not understand the origin of such data spread (leading to an experimental error bar on the evaluation of F*). If on the contrary, each of them has been obtained by superposing data for various (V_bg1, V_bg2) at fixed (nu_n,nu_p), I find it confusing to show the red fit to Eq.(1) in Fig.2a which is supposed to be done for a given value of (V_bg1, V_bg2).*

— For a fixed filling factor plateau, multiple noise data (S_I vs I_{in} data) has been taken at different (V_{BG1}, V_{BG2}) points, which in the Fig. 1(b) of the revised manuscript, we have shown by the white dotted points, for filling factor (-2,2). The plots in Fig. 2(a) and Supplementary Figure 14 shows one representative (V_{BG1}, V_{BG2}) point noise data for different filling factor plateaus. In the revised manuscript and Supplementary Information we have now added the gate voltage information in the plots of Fig. 2(a) and Supplementary Figure 14 to clarify this. Each of the (V_{BG1}, V_{BG2}) point noise data has been fitted with Eq. (1), shown as the red fit in Fig. 2(a), to extract out Fano. The Histograms shows the Fano values obtained from all the (V_{BG1}, V_{BG2}) point noise data for a particular filling factor plateau.

8.

$\star$ *There are some values of (nu_p,nu_n) (in particular (-4,1), (-5,2), (-5,3), (-6,2), (-3,1)) for which the histograms of Fano factors are not well fitted by Gaussian fits, so that the estimation of the average Fano and of its standard deviation is imprecise. It would be preferable to improve the statistics with more data (e.g. by varying the magnetic field). If not, it should be made clear in Figs. 3, SI11 and SI12 that some points are less precise than others (maybe with a colorscale encoding the fidelity of the gaussian fits).*

— As the reviewer correctly pointed out, for some of the plateaus, with wide distribution of the Fano values, the Gaussian functions does not capture the Fano variation properly. To clarify this point, as the reviewer suggested, in Figure 2(b) of the revised manuscript and in Supplementary Figure 15 and Supplementary Figure 16, we have now mentioned the "R-squared" (R^2) value of the fittings to show the preciseness of the fitting. Also in Supplementary Figure 11 and Supplementary Figure 12, we have now color-coded the Fano errorbars according to the R-squared (R^2) value of the fittings, to show the plateau-wise preciseness of the fit. We have also mentioned about this in the shot noise section of the main manuscript, by adding the lines "**The variation in Fano values is well captured by the Gaussian function for most of the plateaus,**

except for some plateaus with large Fano variation. To quantify how well the Gaussian fitting is, we have quoted the "R-squared" value of the fitting (also see Supplementary Fig. 11, 12, 15 and 16).

9.

⋆ *In Fig. SI3, the conductance plateau for nu_p=-5 is indistinguishable. Therefore, I do not understand how data for t and F have been obtained in that case.*

— In the trans-resistance plot of Figure 1(a) of main text the plateau corresponding to $\nu_p = -5$ is clearly visible, even though it is indistinguishable in the conductance plot of Fig. SI3. We have used Fig. 1(a) as reference for taking t and Fano data for $\nu_p = -5$ plateau.

10.

⋆ *One striking feature of experimental Fano factors is the increase of fluctuations for large filling factors but it is not highlighted by the authors. I believe this is an important argument in favor of a crossover from the incoherent to the coherent regime and that it should be discussed in the main text.*

— We thank the reviewer for pointing this out. To emphasized on this point we have added "**The coherent nature is further manifested as increase in Fano errorbar, showing wider spread of Fano values at higher filling factors. This can be qualitatively understood from the increased mesoscopic conductance fluctuations of the junction, observed at higher filling factors plateaus. As the coherence increases, conductance fluctuation increases[23,31] as can be seen in Fig. 1b and 1d. Since the Fano depends on the transmittance, it shows the variation[31] with increased coherence.**" at the end of the 3rd paragraph of the discussion section of the revised manuscript.

11.

⋆ *The Fano factor is a quantity that depends on the length Lnp of the np interface (see Ref.[37]). Therefore, I do not really understand how experimental Fano factors for one fixed length (Lnp=10 microns here) can be compared to theoretical predictions. The comparison can be done in the coherent and quasi-elastic scenarios if Lnp is small enough and inelastic effects are indeed absent in the sample. However the discussion of inelastic effects (at the end of SI6 and following Ref.[SI-8]) makes no sense to me. Could the authors comment on that point?*

— Theoretically calculated Fano values, without considering any inelastic energy loss, gives the upper limit of Fano for different scattering mechanisms (coherent and quasi-elastic). In presence of inelastic energy loss Fano factor reduces exponentially with increasing length, as has been shown in ref. [44]. In our experiment as we have shown that for (-2,2) the experimental Fano is very close to the maximum value predicted for quasi-elastic scattering and for higher filling factors experimental Fano factor even exceeded the quasi-elastic scattering. Therefore, to understand the unusual filling factor dependence we have compared our experimental Fano with theoretical values for quasi-elastic and coherent scattering, and it shows that inelastic effects are indeed absent in our sample. The discussions of inelastic scattering process in the SI is just to show its allowed values for the completeness of the discussion. We have added the following sentence in the revised manuscript "**For the completeness, we also mention the Fano values for inelastic scattering as described by Abanin et. al.[24], which is very similar in magnitude with the quasi-elastic case as shown in Supplementary Fig. 10(e).**"

12.

⋆ *I am surprised by the asymmetric behaviour of the Fano factor when it is plotted as a function of nu_n at fixed nu_p or as a function of nu_p at fixed nu_n. I think the authors should discuss possible origins of this asymmetry.*

— We agree with the referee that we do not fully understand the origin of the asymmetric behaviour of the Fano. In the 4th paragraph of the discussion section of the revised manuscript we have added a plausible origin of the asymmetric filling factor dependence of Fano, based on velocity dependent phase coherence of the edge states and different steepness of the confinement potential on either side of the pn junction : "**One plausible reason for the observed crossover with increasing filling factor is the velocity-dependent phase coherence of the edge states[49]. The velocity, hence the phase coherence of the edge-states, increases with a higher filling factor, as the confining potential becomes steeper. It qualitatively explains the observed crossover from incoherent to coherent scattering regime with increasing filling factor. Also, the asymmetric dependence of the Fano factor on p and n side filling factors (Fig. 3) can be qualitatively understood, by considering different steepness of the confining potential on either side of the pn junction[14]. In our device, the graphite gate $BG2$ is closer ($\sim$ 20nm) to the graphene flake, than the graphite gate $BG1$ ($\sim$ 40nm). Hence at the p doped side of the junction the confinement potential is steeper compared to that at n doped side. As a result, the phase coherence of the edge states at the p side will change more rapidly than that for edge states at the n side. One more possibility could be that the screening might be playing a big role in dynamics as observed in GaAs based 2DEG[47,50,53]. The coherent scattering dominates as the screening increases with more number of participating edges at PNJ. However, it does not explain the asymmetry observed in Fig. 3.**"

Reply to Reviewer 2:

The authors experimentally investigated the Landau transport of graphene p-n interface devices at low temperatures in bipolar regime. They measured the conductance as well as the shot noise. The former shows that the Hall states at the interface follow spin polarized equilibration according to the lift of spin/valley degeneracy at the device edges and p-n interface. The latter says that there is a crossover between incoherent transport at lower filling indices (<2) and coherent transport at higher filling indices (>2). The supplemental material shows sufficient information about the experiment and theoretical model. The conclusion is sound and sheds new insights on the transport of quantum Hall channels of graphene p-n interfaces. The manuscript is scientifically valuable, I think, if the authors consider my following comments.

— We are grateful to the reviewer for the positive and valuable comments. Following are the changes and answer to the questions as raised by the reviewer:

1.

1. The scale is missing in Fig. 1 (a).

— Fig. 1(a) is a schematic of the device and measurement set-up. In Supplementary Figure 1(b), which is the actual optical image of the measured device, we have now added a scale-bar.

2.

2. In fig. 1 (c), there are two scenarios of the spin/valley splitting. However, I cannot find any information about which scenario is applied for the experimental situation. The authors need to carefully migrate the information in Fig. SI5 of the supplemental material into the main text.

— Throughout the main manuscript we have only considered spin-polarized ground state for comparison with experimental data (for both transmission and Fano). We have clarified this at the end of conductance measurement section of the main manuscript.

3.

3. I am confused by fig. 1 (c). The spin/valley configuration at N=0 is not identical to that of fig. 2 (c) of Ref [32]. Why?

— We thank the reviewer for raising this point. Here we would like to clarify that the spin/valley configuration in Fig. 1(c) in our manuscript is exactly the same as that of fig. 2(c) of Ref. [32] (In the revised manuscript Ref. [39]). However, we understand the confusion have arose due the our choice of different color for different spin. For this reason in the revised manuscript we have used red and black color to represent two different valley degree of freedom and the two spins are denoted by up and down arrow as usual.

4.

4. What role doses the valley polarization play? There is nothing about it in the manuscript.

— Valley-isospin becomes important in case of clean pn junction without disorder, as has been shown by Tworzydlo et al (ref. 23). However, it has been shown in ref. 27 that the presence of disorders at the interface (junction) as well as at the physical boundary of the sample suppress the the effect of Valley-isospin. Experiments on pn junction also agrees with it. Thus, valley-isospin degree of freedom of the edge states does not provide any protection against scattering via disorders. The only importance it has in our measurement, when both the valley and spin degeneracy are lifted completely, and spin polarized edge states are created. The spin configuration of these edge states depends on which order the spin and valley degeneracy are lifted, as we have described for two possible ground states in Fig. 1(c).

5.

5. The calculation in the supplemental material is based on single channel model. Are the conclusions approximately valid for multi-channel (at least few-channel) cases?

— The calculation in SI are indeed for multi-channel cases. For example for filling factor (-2,2) (Supplementary Figure 8), two edge-channel from each side enter into the pn junction and co-propagate along the junction.

6.

6. In eq (1), what does F mean? BTW, wide-brackets should be used in the equation.*

— F* is normalized noise magnitude, which we have defined as $S_I/2eI_{in}$, in the shot noise measurement section of the main manuscript. We have also changed the size of the brackets in the revised manuscript.

7.

7. The manuscript says that the Fano factor is more sensitive on the p-side filling index while no explanation is given. Can the authors raise a proposal?

— We agree with the referee that we do not fully understand the origin of the asymmetric behaviour of the Fano. In the 4th paragraph of the discussion section of the revised manuscript we have added a plausible origin of the asymmetric filling factor dependence of Fano, based on velocity dependent phase coherence of the edge states and different steepness of the confinement potential on either side of the pn junction : "**One plausible reason for the observed crossover with increasing filling factor is the velocity-dependent phase coherence of the edge states[49]. The velocity, hence the phase coherence of the edge-states, increases with a higher filling factor, as the confining potential becomes steeper. It qualitatively explains the observed crossover from incoherent to coherent scattering regime with increasing filling factor. Also, the asymmetric dependence of the Fano factor on p and n side filling factors (Fig. 3) can be qualitatively understood, by considering different steepness of the confining potential on either side of the pn junction[14]. In our device, the graphite gate $BG2$ is closer ($\sim$ 20nm) to the graphene flake, than the graphite gate $BG1$ ($\sim$ 40nm). Hence at the p doped side of the junction the confinement potential is steeper compared to that at n doped side. As a result, the phase coherence of the edge states at the p side will change more rapidly than that for edge states at the n side. One more possibility could be that the screening might be playing a big role in dynamics as observed in GaAs based 2DEG[47,50,53]. The coherent scattering dominates as the screening increases with more number of participating edges at PNJ. However, it does not explain the asymmetry observed in Fig. 3.**"

Reply to Reviewer 3:

Reply to Reviewer 3:

The authors report on measurements on equilibration processes in graphene pn junctions using conductance and noise measurements. The manuscript contains nice measurements on a high-quality device. However, I am bit uncertain regarding the novelty and broad interest of the results. Therefore I suggest a major revision, where the authors could try to argue about the novelty of their results and on the few of the questions raised below.

— First, we would like to thank the reviewer for the criticisms and positive comments, and also for bringing many relevant publications to our attentions. In the revised manuscript, we have cited some of those references mentioned by the reviewer. In short, the previous shot noise studies (ref. 44 and 45) on graphene pn-junction, have only shown the effect of incoherent scattering process in equilibration of co-propagating edge states along the junction. Understanding of the equlibration dynamics is important for designing electron interferometer, where a pn-junction could be used as a beam-splitter. It is a general consensus that disorders along the pn interface facilitate the equilibration of the edge states. However the effect of disorders on equilibration between higher filling factor edge states remains an open question to this date. Moreover in presence of spin polarization how the equlibration dynamics modifies, is also not known. As we have mentioned in the introduction, in this work we have tried to demystify this two points, by performing conductance and shot-noise on a high quality graphene- pn junction. Our conductance measurement reveals spin selective nature of edge-state equlibration, which is in agreement with previous works. Interestingly, the analysis of Fano factor from our shot noise data, reveals an interesting behaviour: Fano factor increases with increasing filling factor. As we have shown in the manuscript, this increasing behaviour can be understood as a crossover of scattering mechanism from incoherent to coherent scattering regime. This indicates towards possibilities like varying effect of interface disorder on higher filling edge states due to screening, velocity dependent phase coherence length of edge states, etc playing important role in equlibrtion at a graphene pn- junction. To the best of our knowledge there is no previous report of this kind, which makes our work novel and hence will add to the fundamental understanding of the mesoscopic device physics.

1.

High quality pn junctions have been studied widely in the literature, e.g. the spin-dependent equilibration in 3-4 papers, and already noise measurements have been performed on graphene pn junctions, though with lower quality. The question is how much the higher quality adds to the understanding.

— To this, we would like point out that, the observation of the entire QH spectrum (from integer to fractional), in grpahene, is made possible only with increasing device quality. Thus increase in device quality, even slightly, always increases the probability of new observation. As we have mentioned in the earlier point, our observation hints towards role of new effects, in the equlibration physics at a graphene pn junction, whereas in the earlier shot noise studies only the role of incoherent process have been seen.

2.

Here, all degeneracies of the Landau level sequence are lifted, and noise for all different combinations can be studied. The authors are than able to suspect for which plateau which mechanism (regime) might be dominant, but no physical understanding is given.

— One plausible reason for the crossover could be the enhanced screening of the pn-interface at higher filling factors. This we have mentioned in the manuscript. In the revised manuscript we have now added another plausible explanation based on velocity dependent phase coherence of the edge states at the end of the discussion section : "**One plausible reason for the observed crossover with increasing filling factor is the velocity-dependent phase coherence of the edge states[49]. The velocity, hence the phase coherence of the edge-states, increases with a higher filling factor, as the confining potential becomes steeper. It qualitatively explains the observed crossover from incoherent to coherent scattering regime with increasing filling factor. Also, the asymmetric dependence of the Fano factor on p and n side filling factors (Fig. 3) can be qualitatively understood, by considering different steepness of the confining potential on either side of the pn junction[14]. In our device, the graphite gate $BG2$ is closer ($\sim$ 20nm) to the graphene flake, than the graphite gate $BG1$ ($\sim$ 40nm). Hence at the p doped side of the junction the confinement potential is steeper compared to that at n doped side. As a result, the phase coherence of the edge states at the p side will change more rapidly than that for edge states at the n side.**"

3.

What is the role of the valley, pseudospin?

—Valley-isospin becomes important in case of clean pn junction without disorders, as has been shown by Tworzydlo et al (ref. 23). However, it has been shown in ref. 27 that the presence of disorders at the interface (junction) as well as at the physical boundary of the sample suppress the the effect of Valley-isospin. Experiments on pn junction also agrees with it. Thus, valley-isospin degree of freedom of the edge states does not provide any protection against scattering via disorders. The only importance it has in our measurement, when both the valley and spin degeneracy are lifted completely, and spin polarized edge states are created. The spin configuration of these edge states depends on which order the spin and valley degeneracy are lifted, as we have described for two possible ground states in Fig. 1(c).

4.

What kind of scattering mechanisms (a bit more concretely) might be at play?

— As we have shown in the manuscript both coherent and quasi-elastic scattering process can play a role depending on the number of co-propagating channels, along the pn junction.

5.

Does the electric field/smoothness of the junction matter? Also, since they only have a single device, the determination of different scattering lengths is not possible. Below, I give some minor comments:

—We agree with the reviewer that electric filed, junction smoothness can have important effect in our observation. As we have mentioned in a earlier point, in the revised manuscript we have given a plausible effect of the steepness of the confining potential at the junction.

Regarding one single device we would like to note the following: Theoretically calculated Fano values, without considering any inelastic energy loss, gives the upper limit of Fano for different scattering mechanisms (coherent and quasi-elastic). In presence of inelastic energy loss Fano factor reduces exponentially with increasing length, as has been shown in ref. [44]. In our experiment as we have shown that for (-2,2) the experimental Fano is very close to the maximum value predicted for quasi-elastic scattering and for higher filling factors experimental Fano factor even exceeded the quasi-elastic scattering. Therefore, to understand the interesting filling factor dependence we have compared our experimental Fano with theoretical values for quasi-elastic and coherent scattering and it fairly agrees with our experimental data. It also shows that inelastic effects are indeed absent in our device. Thus, with a single clean device it was possible to see the different scattering mechanism by varying the number of edges.

6.

- On Fig1. c it would be nice to show the valley degree of freedom. If I understand well, not both the color and the arrow stands for spin. This is a bit redundant.

— We thank the reviewer for pointing this problem. In the revised manuscript we have shown the two valley degree of freedom in red and black color and the spins are shown by up and down pointing arrows.

7.

- Maybe would be worth showing the idea of the incoherent scattering calculation is the supporting.

— The main aim of the calculations shown in SI is to extend the scattering matrix idea for different process given in SI ref.4 and SI ref.5, to the spin selective case. This is relatively simple for case of coherent scattering, where we show that as long as the two spin channels does not interact with each other, the total noise power (auto-correlation term) can be written as the sum of individual noise powers for the two spin channels. In case of incoherent scattering, the introduction of the fictitious contact makes the calculation complicated, as the resultant auto-correlation term for incoherent scattering consists contribution form both the intrinsic correlations for 4-terminal configuration and contribution due to the conductance of the fictitious probe with other contacts. For now, this calculation is beyond the scope of our work. However, by examining the matrix methods given for incoherent scattering in SI ref.4 and SI ref.5, it appears that as long as the two spin channels do not interact with each other, the same spin matrix elements of the intrinsic correlation and conductance terms, can be segregated out, similar to the case of coherent scattering. Thus qualitatively, the idea of addition of noise power shown for coherent scattering will be applicable. This is what we have shown for quasi-elastic scattering, for which we have introduced two parallel voltage probes (SI 10(d)), each for one spin. it is assumed that there will be no particle as well as energy exchange between the two probes. On the other hand if inelastic process and energy losses are involved then the two parallel probe model becomes invalid, as the two spin channel can exchange energy. In this case how the scattering matrix elements can be defined is not clear and it also remains a open question.

8.

- Maybe would be worth to cite some of these papers: L. Veyrat, Nano Lett., 2019, 19, 2, $635-642$*, S. P. Milovanovic et al., Appl. Phys. Lett. 105, 123507 (2014); P. Makk et al., Phys. Rev. B 98, 035413 , E. Tovari, Nanoscale, 2016, 8, 19910-19916, K. Kolasinski, et al., Phys. Rev. B 95, 045304, Son Te Le et al., arXiv:1904.04726, S. Dubey et al., https://doi.org/10.1016/j.ssc.2016.03.024*

— In the revised manuscript we have cited the publications mentioned by the reviewer.

9.

- On Fig 1b some conductance oscillations are visible, similarly to the one reported in Ref. 26 (Wei et al., Science Advances). I was wondering if the noise shows any sign of these oscillations.

— As the reviewer correctly pointed out the effect of conductance oscillation, is indeed visible in the noise measurement. It can be seen as the increase in standard deviation of the experimental Fano, with increasing filling factor. In the revised manuscript, we have now mentioned about this effect at the end of 3rd paragraph of the discussion section: "**The coherent nature is further manifested as increase in Fano errorbar, showing wider spread of Fano values at higher filling factors. This can be qualitatively understood from the increased mesoscopic conductance fluctuations as well as interference effect**[26] **of the junction, observed at higher filling factors plateaus. As the coherence increases, conductance fluctuation increases**[23,31] **as can be seen in Fig. 1b and 1d. Since the Fano depends on the transmittance, it shows the variation**[31] **with increased coherence.**"

Reply to Reviewer 4:

I have read the paper by Paul et al "Interplay of filling fraction and coherence in symmetry broken graphene p-n junction". In this work, Paul and his coworkers carried out conductance and shot noise measurements to investigate the scattering mechanism at the interface of symmetry broken graphene p-n junction (PNJ).

So far, shot noise experiments with PNJ have been done by two groups [37, 38]. Kumada et al qualitatively studied equilibration length dependence of the Fano factor. Matsuo et al evaluated Fano factor at various cases of (v_n, v_p)*. These results are in good agreement with the incoherent scattering model [17]. However, Si/SiO2 substrates in both experiments prevented them from observing spin-valley symmetry broken conductance.*

In this study, the authors measured the hBN encapsulated graphene device, whose mobility is 100 times higher than the previous studies, in two ways: conductance and shot noise measurements. They found that the conductance data agree well with the calculation based on the spin-polarized ground state. In the shot noise experiments, the authors investigated the filling factor dependence of the Fano factor. Firstly, they discovered that the Fano factor in p-region strongly depends on the filling factor, while slowly in n-region. Secondly, they revealed that the Fano factor in the lower p-side filling factor is explained well by the incoherent scattering model, while the Fano factor in the higher filling factor follows the coherent scattering model. Tthe authors attributed the channel number dependence of the Fano factor to the screening effect. These results should induce a strong interest among the mesoscopic community.

The paper is well written, and I do not doubt that the exciting new results it contains deserve publication in Communications Physics. I have minor comments that I think the authors should address before I can recommend the paper for publication.

— We thank the reviewer for the positive comments and for bringing a very relevant publication to our attention. Following are the answer to questions, raised by the reviewer

1.

1. The authors mention that the screening effect from the other channels, which are compressible states, might play a role in increasing coherence of scattering at the PNJ interface. I think that there is another possibility that the filling factor dependence of velocity may explain the enhancement of coherence. The velocity, in general, decreases as the filling factor becomes lower, because edge structure at lower filling factor has flatter confinement than at higher filling factor. Nakamura et al explained that smaller velocity at Î½=1/3 reduces phase coherence [Nat. Phys. 15, 563 (2019)]. I would like to know the authors' comments about the effect of velocity on the scattering coherence at the PNJ interface.

— After going through the publication, suggested by the reviewer, we think that the velocity dependent phase coherence might be an important factor behind our observation. In the revised manuscript we have highlighted about this possibility in the 4th paragraph of the discussion section : "**One plausible reason for the observed crossover with increasing filling factor is the velocity-dependent phase coherence of the edge states[49]. The velocity, hence the phase coherence of the edge-states, increases with a higher filling factor, as the confining potential becomes steeper. It qualitatively explains the observed crossover from incoherent to coherent scattering regime with increasing filling factor. Also, the asymmetric dependence of the Fano factor on p and n side filling factors (Fig. 3) can be qualitatively understood, by considering different steepness of the confining potential on either side of the pn junction[14]. In our device, the graphite gate $BG2$ is closer ($\sim$ 20nm) to the graphene flake, than the graphite gate $BG1$ ($\sim$ 40nm). Hence at the p doped side of the junction the confinement potential is steeper compared to that at n doped side. As a result, the phase coherence of the edge states at the p side will change more rapidly than that for edge states at the n side. One more possibility could be that the screening might be playing a big role in dynamics as observed in GaAs based 2DEG[47,50,53]. The coherent scattering dominates as the screening increases with more number of participating edges at PNJ. However, it does not explain the asymmetry observed in Fig. 3.**"

2.

2. Is there a reason why the Fano factor in n-region slowly depends on the filling factor? Can the screening effect explain the reason?

— As of now, we do not fully understand the origin of the asymmetric behaviour of the Fano. As we have highlighted in the previous answer, following the suggestion by the referee, velocity dependent phase coherence of the edge states depending on the different slope of the confinement potential on either side of the pn junction could be the reason behind the asymmetry.

3.

3. Fano factor distribution at high filling factors show a large variation [the right figure of Fig. 2(b)]. Figures SI14 at (v_n, v_p)= (4, -6) , (5, -6), (6, -6) exhibit larger fluctuation than the other data. Why are these shot noise results at high v_p so noisy?

— We believe that the increasing fluctuation of Fano is related to the coherent nature of the scattering. To highlight this point, in the revised manuscript we have added "**The coherent nature is further manifested as increase in Fano errorbar, showing wider spread of Fano values at higher filling factors. This can be qualitatively understood from the increased mesoscopic conductance fluctuations of the junction, observed at higher filling factors plateaus. As the coherence increases, conductance fluctuation increases[23,31] as can be seen in Fig. 1b and 1d. Since the Fano depends on the transmittance, it shows the variation[31] with increased coherence.**" at the end of the 3rd paragraph of the discussion section. The increase in conductance fluctuation can be seen in the Figure 1(d) of the revised manuscript and in the supplementary Figure 5, where we have added errorbars for the plateau wise transmission value.

4.

4. As for gain calibration shown in Supporting Information, the authors should take into account the thermal noise from the impedance of the LC circuit (Z) for more precise calibration [for example, see Phys. Rev. B 101, 115401 (2020)]. The effect of the LC circuit can be ignored when the sample resistance is much lower than the Z. I would like to know whether the LC circuit thermal noise is consicered or not in the paper.

— We have used a coil made of superconducting wire as the L. At resonance the effective impedance of the LC circuit is of the order of $10M\Omega$, which is much larger than the sample resistance. Thus we can safely ignore the effect of the LC resonant circuit in gain measurement.

List of changes:

1. References no: 11, 15, 16, 19, 20, 21, 22,and 49 has been added to the main manuscript
2. Page 1/introduction/paragraph# 2/7 to 9th line :

   we have replaced the "**Besides, the shot noise measurements are focused around the lowest filling factor ($\nu = \pm 2$) and hence the dependence of F on filling factors (ν) is lacking.**" line in the introduction with "**Besides, the shot noise measurements are focused around only the filling factors $\nu = \pm 2$ and $\nu = \pm 6$ with no clear dependence of F on filling factors (ν).**"
3. Throughout the entire manuscript we have replaced abbreviation of "Supporting information figure (SI)" with "Supplementary Figure"
4. Page 3/Figure 1(b) :

   We have replaced the white dashed boxes with white dots.
5. Page 3/Figure 1(c) :

   We have now shown the magnetic field axis. Also the red and black color has been reassigned to represent the two valley degrees of freedom.
6. Page 3/Figure 1(d) :

   We have added errorbars to the transmission data to show the conductance fluctuation.
7. Page 3/Figure 1/captions :

   We have added the line "**Red and black color indicates valley degrees of freedom**"
8. We have now replaced all the filling factor terms, ν_p, ν_n, $\nu_{n\uparrow}$, $\nu_{n\downarrow}$, $\nu_{p\uparrow}$ and $\nu_{p\downarrow}$ with $|\nu_p|$, $|\nu_n|$, $|\nu_{n\uparrow}|$, $|\nu_{n\downarrow}|$, $|\nu_{p\uparrow}|$ and $|\nu_{p\downarrow}|$, respectively.
9. Page 4/paragraph# 1/Conductance measurement/8th to 10th line :

   We have added the lines "**The errorbars in Fig. 1(d) and Supplementary Fig. 5 show the conductance fluctuation of different plateaus. It can be seen that though the conductance fluctuation increases with higher filling factor, but the magnitude of the fluctuation remains negligible compared to the average transmission values.**
10. Page 4/paragraph# 2/Shot noise measurement/3rd line :

    The line "**In general, measured current noise (S_I) consists of both thermal and shot noise and follows the expression** has been replaced with "**In general, measured excess current noise (S_I) with finite temperature broadening follows the expression:**
11. Page 4/Equation 1:

    The bracket size have been changed

12. Page 4/paragraph# 2/Shot noise measurement/5th to 7th line :

    The line "**For $eV_{sd} > k_BT$ shot noise dominates over thermal noise and S_I becomes linear with I_{in} as shown in Figure 2(a) for (ν_p, ν_n) = $(-2, 2)$, $(-3, 3)$ and $(-4, 4)$ filling factor plateaus.**" has been replaced with "**For $eV_{sd} > k_BT$ shot noise dominates over thermal broadening and S_I becomes linear with I_{in}. This can be seen in Figure 2(a), showing one representative S_I vs. I_{in} noise data for (ν_p, ν_n) = $(-2, 2)$, $(-3, 3)$ and $(-4, 4)$ filling factor plateaus.**"

13. Page 4/paragraph# 2/Shot noise measurement/7th line :

    We have added the line "**It should be noted that S_I is the excess current noise without the thermal equilibrium noise ($V_{sd} = 0$)**"

14. Page 4/paragraph# 2/Shot noise measurement/12th line :

    We have added "(V_{BG1}, V_{BG2})".

15. Page 4/paragraph# 2/Shot noise measurement/17th to 19th line :

    We have added the line "**The variation in Fano is well captured by the Gaussian function for most of the plateaus except for some plateaus with large Fano variation. To quantify how well the Gaussian fitting is, we have quoted the "R-squared" value of the fitting (also see Supplementary Fig. 11, 12, 15 and 16).**"

16. Page 5/Figure 2(a):

    We have added the gate voltage information to the noise data.

17. Page 5/Figure 2(b):

    We have added R-square information to the to the histogram plots.

18. Page 5/Figure 2/Caption :

    We have added the line "**The R-square value shows the quality of the fitting.**"

19. Page 6/paragraph# 2/Discussion/line 17 :

    The line "**Note that the calculated values of Fano using inelastic scattering as described by Abanin et. al.[24] are very similar in magnitude with quasi-elastic case (SI-10(e))**" has been modified to "**For the completeness, we also mention the Fano values for inelastic scattering as described by Abanin et. al.[24], which is very similar in magnitude with the quasi-elastic case as shown in Supplementary Fig. 10(e).**"

20. Page 6/paragraph# 3/Discussion/line 8 to 12:

    We have divided this third paragraph into two, in the revised manuscript and at the end we have added "**The coherent nature is further manifested as increase in Fano errorbar, showing wider spread of Fano values at higher filling factors. This can be qualitatively understood from the increased mesoscopic conductance fluctuations of the junction, observed at higher filling factors plateaus. As the coherence increases, conductance fluctuation increases[23,31] as can be seen in Fig. 1b and 1d. Since the Fano depends on the transmittance, it shows the variation[31] with increased coherence.**"

21. Page 6/paragraph# 4/Discussion:

    We have added a new paragraph "**One plausible reason for the observed crossover with increasing filling factor is the velocity-dependent phase coherence of the edge states[49]. The velocity, hence the phase coherence of the edge-states, increases with a higher filling factor, as the confining potential becomes steeper. It qualitatively explains the observed crossover from incoherent to coherent scattering regime with increasing filling factor. Also, the asymmetric dependence of the Fano factor on p and n side filling factors (Fig. 3) can be qualitatively understood, by considering different steepness of the confining potential on either side of the pn junction[14]. In our device, the graphite gate $BG2$ is closer ($\sim$ 20nm) to the graphene flake, than the graphite gate $BG1$ ($\sim$ 40nm). Hence at the p doped side of the junction the confinement potential is steeper compared to that at n doped side. As a result, the phase coherence of the edge states at the p side will change more rapidly than that for edge states at the n side. One more possibility could be that the screening might be playing a big role in dynamics as observed in GaAs based 2DEG[47,50,53]. The coherent scattering dominates as the screening increases with more number of participating edges at PNJ. However, it does not explain the asymmetry observed in Fig. 3.**"

22. Supplementary Information/Supplementary Figure 1(b):

    We have now added a scale-bar

23. Supplementary Information/Supplementary Figure 5:

    We have added error bars to the transmission data to show the conductance fluctuation

24. Supplementary Information/Supplementary Figure 11 and Supplementary Figure 12:

    We have color-coded the Fano errorbars according to the r-square values of the Gaussian fitting to show the preciseness of the fitting, corresponding to a plateau.

25. Supplementary Information/Supplementary Figure 14 :

    We have added the gate voltage information in the noise data.

26. Supplementary Information/Supplementary Figure 15 and Supplementary Figure 16 :

    We have added R-square information to the to the histogram plots.

REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

The authors have convincingly replied to all my questions and comments and have modified the text accordingly. I recommend publication of the manuscript in Communications Physics, after the following minor corrections have been addressed:

* In Figs.1(d) and SI5, some error bars are missing, probably because they are smaller than the symbol width. If yes, it should be mentioned that they have been omitted for clarity. If not, they should be shown.
* The sentence "Since the Fano depends on the transmittance, it shows the variation with increased coherence" sounds confusing to me. It should be rephrased or removed.

Reviewer #2 (Remarks to the Author):

The authors replied my comments clearly and the manuscript was improved magnificently. I think the paper now can be accepted for publication.

Reviewer #3 (Remarks to the Author):

The authors have addressed most of the points quite extensively and convincingly, therefore I suggest publication as it is.

Reviewer #4 (Remarks to the Author):

I am satisfied with the author's reply to my questions and comments, as well as with the changes made in the manuscript. I think the paper should be published in Communications Physics in its present form.

Interplay of filling fraction and coherence in symmetry broken graphene p-n junction (Manuscript COMMSPHYS-20-0337A)

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We thank all the reviewers for their criticisms, comments and suggestions, which have helped us immensely in improving the manuscript.

Reply to Reviewer 1:

The authors have convincingly replied to all my questions and comments and have modified the text accordingly. I recommend publication of the manuscript in Communications Physics, after the following minor corrections have been addressed:

— We are grateful to the reviewer for the valuable suggestions. Following are the corrections in the revised manuscript:

** In Figs.1(d) and SI5, some error bars are missing, probably because they are smaller than the symbol width. If yes, it should be mentioned that they have been omitted for clarity. If not, they should be shown.*

— In the revised manuscript we have clarified this by adding the sentence **"We note that for clarity we have removed the errorbars which are smaller than the width of the symbol used."** in the conductance measurement section.

** The sentence "Since the Fano depends on the transmittance, it shows the variation with increased coherence" sounds confusing to me. It should be rephrased or removed.*

— In the revised manuscript we have removed the sentence.