Extracting Nuclear Form Factors from Coherent Neutrino Scattering

Emilio Ciuffoli IMP, CAS, Lanzhou

Based on a work in collaboration with J. Evslin, Q. Fu and J. Tang [1]

CEνNS

Coherent Elastic Neutrino-Nucleus Scattering (CEνNS) was observed recently by the COHERENT collaboration, using neutrinos created via pion Decay At Rest (πDAR) [2].
The CEνNS cross section is given by

$$\frac{d\sigma(E_\nu, E_r)}{dE_r} = \frac{G_F^2[N-(1-4\sin^2\theta_w)Z]^2F^2(Q^2)M^2}{4\pi} \times \frac{1}{M}\left(1-\frac{E_r}{E_{max}}\right)$$

Since at these energies $(1-4\sin^2\theta_w) \simeq 0.045$, the proton contribution is strongly suppressed; in particular the form factor depends almost exclusively on the neutron distribution. Studying CEνNS it is possible to extract important information on the electroweak form factor and the neutron distribution [3].

Facilities: At China Spallation Neutron Source (CSNS) during Phase I a 1.6 GeV, 100 kW pulsed proton beam hits a fixed target, creating neutrinos via πDAR as by-products of the collision; the time structure of the beam (frequency 25 Hz) will reduce significantly the steady state background. Neutrinos will also be produced at the CIADS facility, currently under construction as part of the China - Accelerator Driven System (C-ADS) project: here the energy will be lower (500 MeV) but, due to the higher power (2.5 MW), the neutrino flux will be around 5 times larger, however the beam will be continuous, not pulsed, and the background considerably higher. In the following calculations, the neutrino beam that will be produced at CSNS is used.

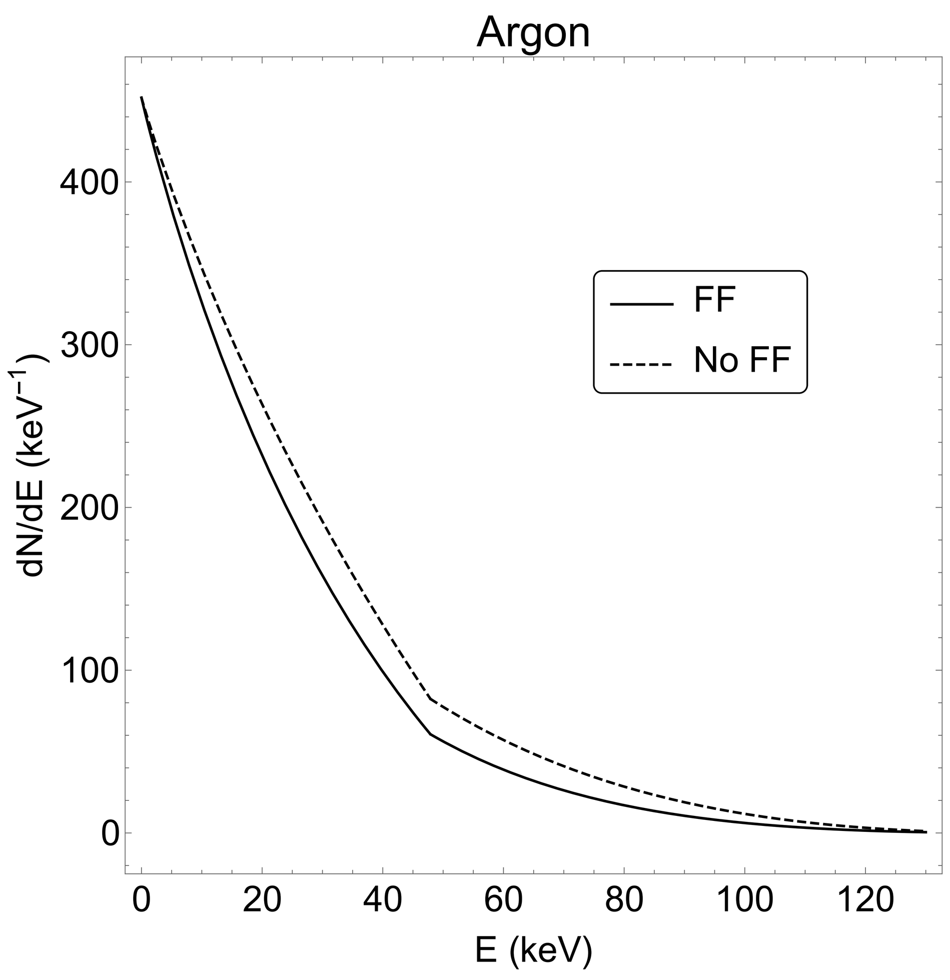

Figure 1: Expected spectrum for 1 ton LAr detector, 1 year lifetime

Neutron Distribution

We used the Helm model to describe the neutron distribution inside the nucleus; it is a two-parameters model that depends on the distribution radius R and the neutron skin thickness s. In this energy range the dependence on s is negligible: the sensitivity to the form factor is expressed as the 1-σ bound on R

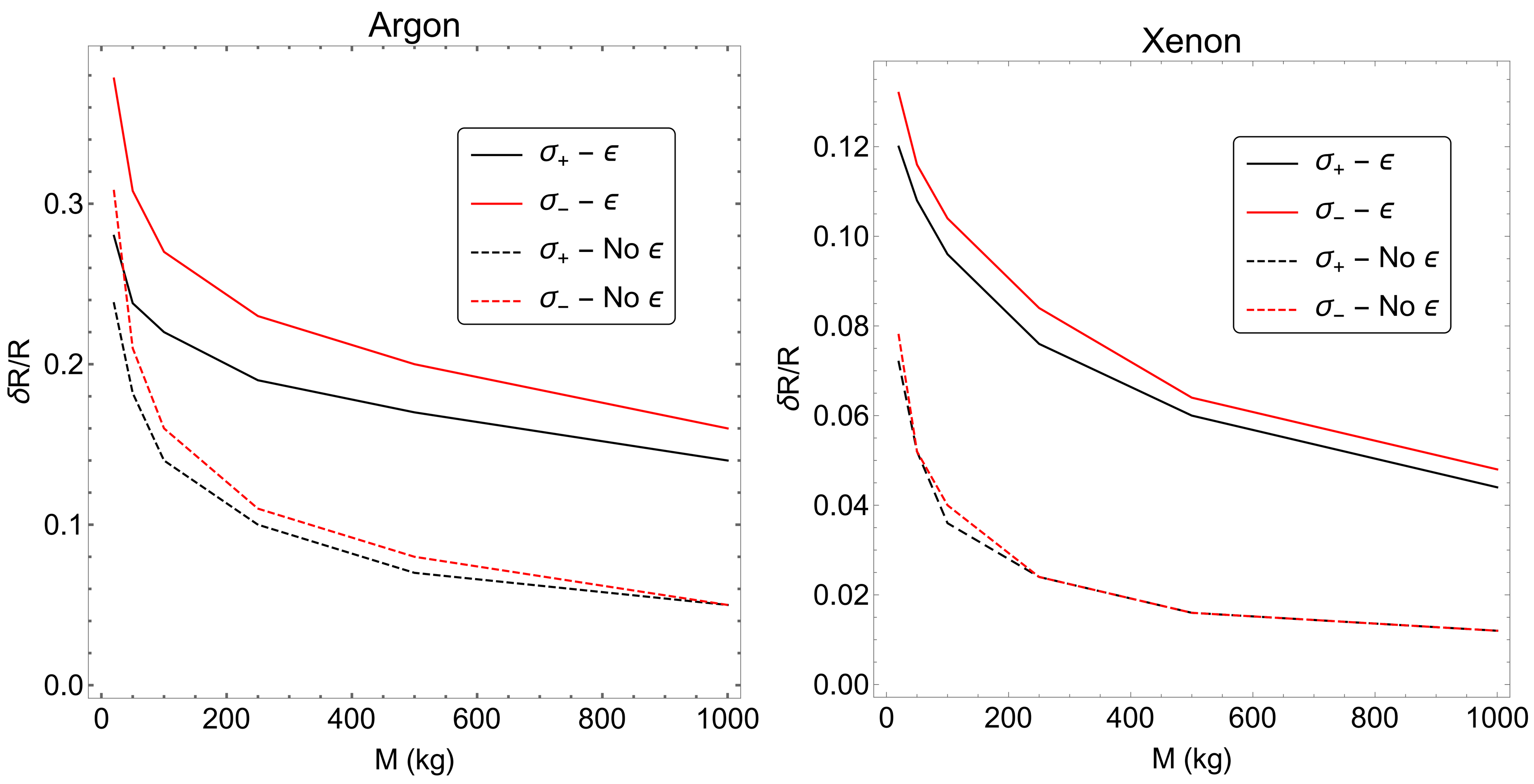

Figure 2: Sensitivity to R assuming the CSNS neutrino beam and 1 year lifetime

Quenching Factor

We considered a simple linear model to describe the uncertainty on the quenching factor (QF):

$$E_{obs} = E_{real}(1+\epsilon)$$

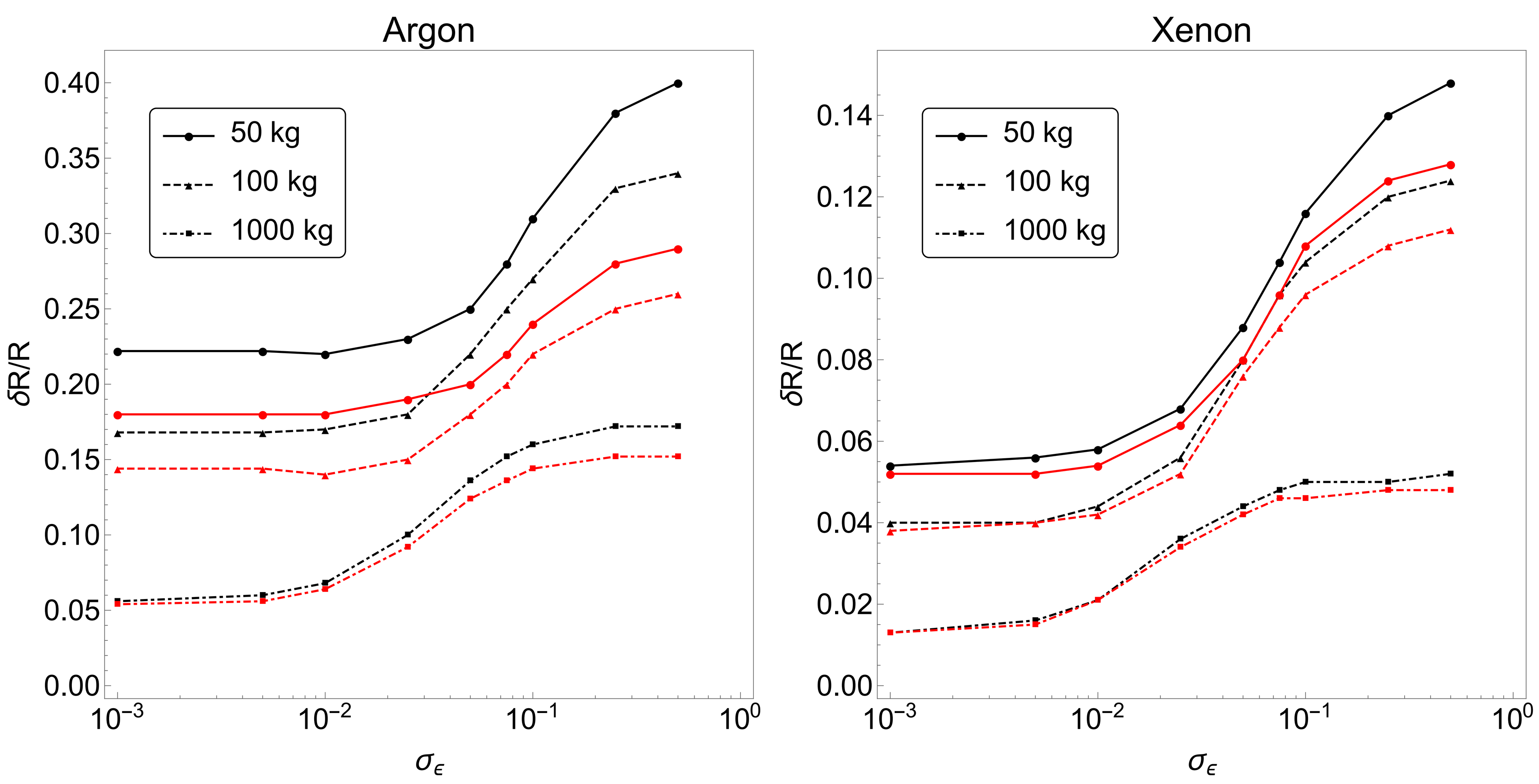

Figure 3: Precision as a function of the QF uncertainty

Model-Independent Analysis

For a model-independent analysis, we considered a Taylor expansion of $F^2(Q^2)$; each term Q^{2n} is multiplied by a factor proportional to the 2n-th momentum of the radius distribution, $\langle R^{2n}\rangle$. We calculated the 1σ region in the $\langle R^2\rangle$-$\langle R^4\rangle$ plane for a 1-ton Argon detector, considering at first only the uncertainty on the total flux normalization, then taking into account also the $\langle R^6\rangle$ term and the uncertainty on the QF.

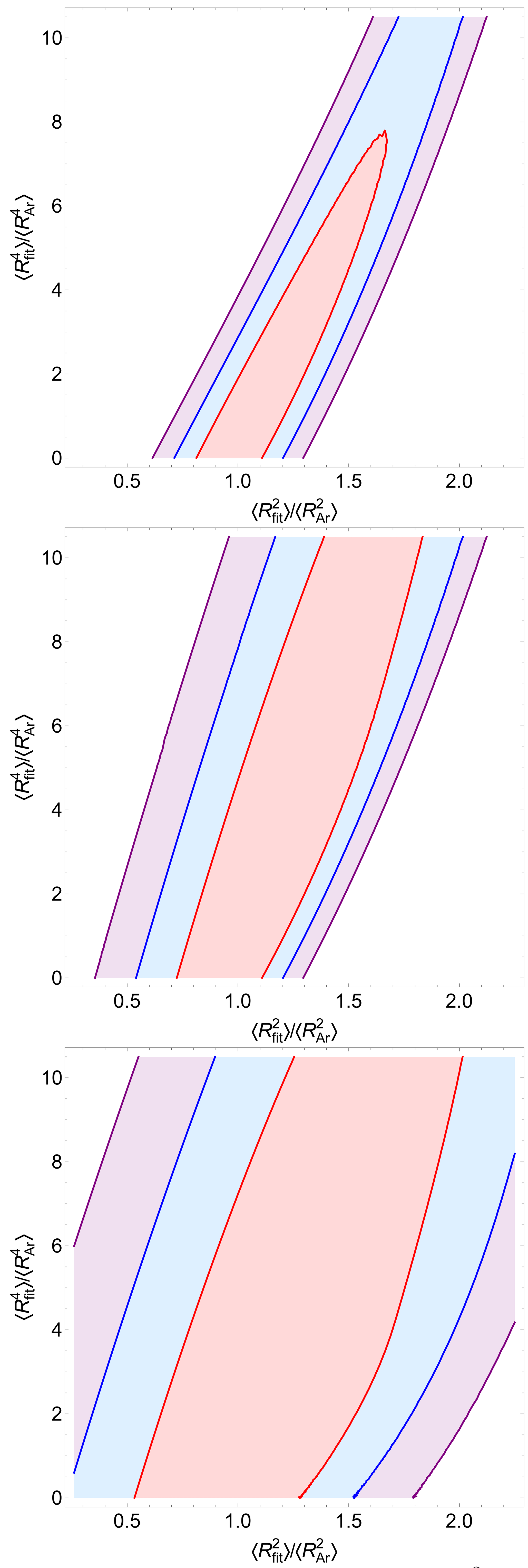

Figure 4: 1-, 2- and 3-σ's regions in the $\langle R^2\rangle$-$\langle R^4\rangle$ plane. Upper panel: only total flux uncertainty taken into account. Central panel: expansion up to $\langle R^6\rangle$ (treated as a pull parameter). Lower panel: best-fit values for $\langle R^6\rangle$ and ϵ are used

References

[1] E. Ciuffoli, J. Evslin, Q. Fu, Qiang and J. Tang, arXiv:1801.02166 [physics.ins-det]

[2] D. Akimov *et al.* Science, 357(6356):1123-1126, 2017.

[3] M. Cadeddu, C. Giunti, Y. F. Li, and Y. Y. Zhang, Phys. Rev. Lett., 120(7):072501, 2018.