COMMENTS (from April 20th)

I. The LUXE project is aimed at experimental studying of the regime when the Lorentz invariant quantum parameter chi=(E/E_c)gamma is above unity. Within the present project the LUXE team plans to see abundant electron-positron pair creation in the collisions of the ultra-relativistic 17.5 GeV electrons from the DESY XFEL with high intensity electromagnetic wave generated by short pulse laser. The 40 TW fs laser is available for the first stage of the project. Then it will be upgraded to 350 TW power level. The expectation of this specific regime of the electron-positron pair creation is based on the nonlinear QED theory originally developed by H. Reiss, N. B. Narozhnyi, A. I. Nikishov (his name is misspelled in the project text) and V. I. Ritus. As widely known, the first experiments on demonstration of gamma photon generation in the multiphoton Compton scattering and electron positron pair creation through the Breit-Wheeler mechanism have been carried out at SLAC in famous E144 campaign. The E144 experiment has demonstrated theoretically foreseen physics in the limit of small but finite parameter chi (less than unity), when the probability of the pair creation is exponentially small.

For the parameter chi above unity the pair creation probability is not exponentially small. In this limit, the process of prolific generation of pairs in the interaction of high power laser light with charged particles has been actively discussed after publication by A. R. Bell and John G. Kirk, Phys. Rev. Lett. 101, 200403 (2008), which is surprisingly not mentioned in the LUXE proposal whose central goal is in reaching this regime with the upgraded relatively high power laser.

The LUXE project also plans to see the electron-positron pair creation in the collision of the bremsstrahlung gamma photons, which are generated in the interaction of ultrarelativistic electrons with high Z material, with the focused laser pulse. The expected efficiency of this process is substantially lower than in the case of the gamma rays produced via the nonlinear Compton scattering.

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Commented [BK1]: It is power-law suppressed, and does not depend on chi, but rather on xi and eta. The parameter regime the referee is referring to, is when xi>>1 and probabilities become functions of chi, and when also eta <<1, there is an exponential suppression.

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Commented [SD2]: ((In addition to xi=O(1000) the generation of avalanche type cascades as described by Bell and Kirk requires the reacceleration of the particles, which usually requires the collision of several laser pulses. One could say that LUXE might explore the formation of shower-type cascades at its largest possible xi-values. The trident pair production could be considered one of the most simple of those shower-processes. But the general idea is that the produced pair can also emit photons, i.e. do nonlinear Compton scattering. I have no good feeling for how likely those proceses are for LUXE parameters, but they should already be included in the MC simulations.))

Commented [BK3]: LUXE's goal is to measure the transition from the perturbative, multi-photon physics, as measured in E144, to the fully non-perturbative physics, when xi is of order 1. The regime of the paper of Bell and Kirk is xi>>1 (they specifically mention 10^24 Wcm^-2 , which is xi O(1000) in the abstract, whereas LUXE will achieve, at most, xi=20).

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Commented [BK4]: This would be the first gamma-gamma collider type experiment to measure nonlinear Breit-Wheeler. It thereby separates the process from nonlinear Compton scattering, unlike in E144 allowing, e.g. photon polarisation studies, which are linked to Light-by-Light scattering and possible studies of the one-step trident process.

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Another experiment planned by the LUXE team is devoted to the problem of observing the axions in the process known as “the light shining through the wall”. Similar experiments are in the programs of other facilities, e.g. at the ELI-NP laser facility where the 10 PW lasers come into operation.

II. Successful accomplishing of the LUXE project will undoubtedly make a significant impact to fundamental science. Unfortunately, in formulating the scientific goal the LUXE team describes a physical picture which cannot be accepted because through the proposal it uses not-adequate terminology as the redundant promising to exceed the Schwinger limit electric field, saying that the Schwinger process of the electron-positron pair creation from vacuum will be demonstrated and the electron-photon interaction will be in the non-perturbative regime.

The Quantum Electrodynamics providing an underlying theoretical basis is a combination of Quantum Mechanics and Special Relativity. It operates with the Lorentz invariant parameters such as parameters $\xi=eE/m_e\omega_0 c$, $\chi=(E/E_S)\gamma_e$, $\eta=(E/E_S)(\hbar\omega_\gamma/m_e c^2)$ with E_S being the Schwinger field and the Poincare invariants *F* and *G*.

The LUXE team statement that for chi>1 in the frame of reference where the electron is at rest the electric field is above the Schwinger field sounds at least strangely, even similar statements can be found in some recent publications by other teams. According to Special Relativity the electric field is not Lorentz invariant. Depending on the frame of reference it can be arbitrarily strong or arbitrarily small. The above written expression chi=(E/E_S)gamma is qualitative. If one writes it rigorously as chi= $c=\sqrt{-(F_{mn}p^n)^2}/m_e cE_s$ he finds that the parameter value, in particular, when it is larger or smaller than unity, depends on the electromagnetic configuration. There is a case when arbitrarily high energy electron moves along the electric field of the amplitude arbitrarily close to the Schwinger field but the parameter remains below unity. There is a case of chi>1 when the electron moves across the magnetic field (the electric field may vanish) emitting photons. Etc, etc, etc,…

Commented [BK5]: The BSM part of LUXE uses a process of “secondary production”, where high-energy photons generated by nonlinear Compton scattering collide with high-Z dump material and thereby achieve centre-of-momentum energies of the order of 100s of MeV. We are unaware of planned experiments at ELI-NP that will probe ALPs in this mass range and welcome the referee to provide references.

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Commented [SD6]: So all of this Section II is about our ‘improper’ use of the words ‘nonperturbative’ and ‘Schwinger-effect’?

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Commented [BK7]: LUXE comprises specialists from a range of fields. The term “Schwinger pair creation” is used by different communities in different ways. We agree with the referee, that if one uses the strict definition of what Schwinger presented in the famous paper: Phys. Rev. 82, 5 (1951), which was pair creation in a constant electric field, then LUXE will not measure this process. However, as the referee points out, other teams also use this terminology to refer to a pair creation process where the fundamental coupling is in the denominator of the exponent. This also occurs in the tunneling limit of nonlinear Breit-Wheeler pair-creation, and it was meant in these terms. We agree that one can be more specific here, and indeed in Chapter 2 and in the Appendix of the CDR, we give technical details for what form of pair-creation LUXE will measure.

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Commented [BK8]: Whilst it is of course true that the electric field is not a Lorentz invariant, the electric field in the rest frame *is* a good approximation to the Lorentz invariant when the particle [[DS: colliding with the laser pulse]] is highly relativistic, as is the case in LUXE. (In fact, this is exactly what is being used to turn the dependency on chi (which is a Lorentz invariant) into chi \approx E*/E_cr, where E* is the rest-frame electric field.)

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Commented [BK9]: Yes, the referee is right, the correspondence chi \approx E*/Ecr is dependent on the field configuration. For the LUXE parameters, the electrons will be moving perpendicular to field lines, and the Lorentz gamma factor is large (>1000), and therefore the focussed laser background will appear crossed in the rest frame of the electron and hence chi \approx E*/Ecr should be a good approximation.

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For abundant electron-positron pair creation via the Breit-Wheeler process the parameter should be larger than unity. In this case one cannot say about the electric field in the "gamma photon rest frame".

Having seen some formal analogy between the expressions for the probabilities of electron-positron pair generation by Breit-Wheeler mechanism in the small limit and in the case of so-called "Schwinger process" (it is known after the publications by Sauter and by Heisenberg and Euler) the LUXE team redundantly and erroneously repeats about the "equivalence" of these processes. Those who are minimally aware of Quantum Electrodynamics know well that in the probability of the Schwinger process is determined by the invariants F and G, but not by or .

The reason why the LUXE team claims that the project aims at studying the QED in non-perturbative regime also lays beyond the sciences. The LUXE team perfectly knows that H. Reiss, N. B. Narozhnyi, A. I. Nikishov and V. I. Ritus have built the nonlinear QED theory within the scope of the perturbation theory using the Furry picture based on the Volkov states as it is notices in Pages 12 and 22 of the LUXE project. Sometimes in recent publications this approach is called as semi-non-perturbative. Narozhny and Ritus have foreseen that the non-perturbative regime will come into play at alpha chi^2/3 >1, i. e. at chi>1500, which is unreachable for the LUXE project parameters.

RECOMMENDATION

Apparently the notes written above are well known for a major part of the LUXE team. A part of this team formulated the LUXE goal as to exceed the Schwinger limit and to demonstrate non-perturbative regime for non-expert and public community to strengthen the project importance. The LUXE project being enough strong does not need such the strengthening which could make an opposite effects causing unwanted criticism of the obtained results and making the unneeded obstacles for

Commented [BK10]: It is the electric field in the rest frame of the created pair that is being referred – not the rest frame of a photon.

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Commented [SD11]: ((It is of course correct that the Schwinger and BW processes depend on different parameters. I think the "equivalence" is that in the "Schwinger regime" of Breit-Wheeler the process has tunnelling characteristics, with the typical tunnelling exponent exp(-#/e) since chi~e. The big difference is that Schwinger calculated the pair production probability in a constant electric field, and in BW one always has the high frequency photon))

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Commented [BK12]: The issue of the Ritus-Narozhny (RN) conjecture that the referee points to, is an exciting and new (revived) avenue of research, which is being hotly debated in the theory literature. The non-perturbativity in the RN conjecture is of a different nature – rather it is about the resummation of the perturbation series in the quantised photon field. LUXE will measure signatures of the non-perturbativity in the interaction of the charge with the laser (classical) background. This is also non-perturbative: if one formulates a perturbative expansion and truncates it, then the predictions of the mass-shift effect in the Compton harmonics and the deviation from power-law behaviour in pair-creation will be completely missed.

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those scientific teams (not excluding the LUXE people) who will make next steps in the future towards studying really non-perturbative physics and towards reaching the Schwinger limit. I recommend to rewrite introduction reformulating the project goal.

Commented [BK13]: We take on board the suggestion of the referee, and will rewrite the introduction.

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COMMENTS

In what it concerns the lasers planned to use, at the first stage with 40 TW laser pulse colliding with 17.5 GeV electrons the quantum parameter will not exceed unity. In other words, at the first stage, which could be considered as an introductory phase for the LUXE project, will reproduce the E144 results. The introductory phase is important in acquiring an experience on the laser pulse focusing, on the experiment parameters characterization, on the laser and electron beam synchronization, etc. The limit chi>1 is expected to be reached with the upgraded 350 TW laser.

Commented [BK14]: The E144 experiment observed the Breit-Wheeler process in the perturbative, multi-photon region with, approximately 0.1<xi<0.35. Already in phase-0 of the LUXE project, we will reach xi>1, and thereby reach the all-order dependency on xi, for which we will measure signals in the Compton and Breit-Wheeler processes, which was beyond what E144 could achieve, which had a weaker laser.

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Commented [BK15]: Whilst we agree that chi approx. 1 is a useful measure of when pair-creation will become probable, the LUXE experiment, by virtue of having: i) a well-characterised electron beam; ii) a wide focus (for xi=1, the focal waist is >25*wavelength) and wide photon source (bremsstrahlung) giving a large overlap and iii) performing long-duration data-taking runs, will be able to measure pair-creation rates down to chi approx. 0.2 (10^-4 pairs per photon).

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RECOMMENDATION

In working on the laser pulse focusing it would be good to pay more attention to increasing the Strehl ratio.

For approaching physical limit of the focused laser beam the laser experts in the LUXE team could use a well-established method, e.g. described in A. S. Pirozhkov, et al., “Approaching the diffraction-limited, bandwidth-limited Petawatt”, Optics Express, 25, 20486 (2017).

The electron beam synchronization with the laser pulse providing their overlapping in the 4 volume of the size micron-cube fs requires additional attention. It would be nice if the team proposes a method of the in citu measurement of the laser-electron beam overlapping.