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Referee statement regarding Mr Jiri Procházka's doctoral thesis

Dear colleagues,

Please find below my statement regarding Mr Procházka's doctoral thesis entitled "Elastic proton-proton collisions at high energies". I have read the doctoral thesis, and I have gone through the publications and documents associated to it.

The thesis focuses on analysis of the elastic proton-proton collision data from CERNs Large Hadron Collider (LHC) and Intersecting Storage Rings (ISR), the only pre-LHC proton-proton collider, as well as the interpretation of the differential elastic cross-section measurements at these colliders within different descriptions of the elastic hadron collision process. Data from the TOTEM experiment at the LHC, of which the author of thesis is a member, has been used. TOTEM is a dedicated forward physics experiment, focused on the measurement of total cross section and elastic scattering over a wide momentum transfer range, and the study of diffractive processes, providing new significant information about the structure of the proton and strong interaction at low momentum transfer.

The thesis contains a review of the TOTEM measurements based on Run 1 (2009-2013) data to which the author of thesis contributed mainly to the results on the elastic scattering and their interpretation and the usage of the luminosity. In addition, the models used to describe elastic hadron collisions and extract characteristics of proton-proton collisions are described in detail with their advantages and disadvantages. Furthermore, a particular description, to whom the author of the thesis has contributed, is used for extracting the characteristics of proton-proton collisions using ISR and LHC data at proton-proton centre-of-mass energies of 52.8 GeV and 8 TeV, respectively. Finally whether elastic proton-proton collisions are dominantly central or peripheral, i.e. more or less head-on, is discussed.

Some more detailed comments below:

1. New scientific results and insights

The main scientific insight of the thesis is to highlight the problems and consequences of the standard description of elastic hadron collisions and show that same data can be described by an alternative, where elastic collisions can be dominantly peripheral instead of central. In addition, to being more intuitive, this is of importance since inappropriate descriptions of the elastic hadron collisions might lead to incorrect extractions of the characteristics of the collisions from the data. In the thesis, the author shows that there is some dependence on the extracted characteristics e.g. the total proton-proton cross section, whether elastic collisions are assumed to be peripheral or central. However the data is currently not sensitive enough to uniquely distinguish these two options and it is not obvious whether such data can be taken in



the future. The author also demonstrates that using an electromagnetic description of the colliding protons instead of a purely electric one, doesn't alter the results in any significant way.

2. *Importance for the research area and possible applications to other areas*

The work of the thesis author is of importance for the research field, touching the basic description of elastic hadron collision. New LHC elastic scattering data is being published all along as the analysis of the Run 2 data at 13 TeV centre-of-mass energy are being finalized and more is expected to come with potential LHC runs at a lower centre-of-mass energy in 2018 and ultimately at 14 TeV in 2021. A proper description of elastic collisions should be used to avoid conclusions from the data that are not solid. Material from the thesis has been published in well renowned scientific journals like European Physics Journal and Nuclear Physics. Any direct applications of the research in other areas is not easy to envisage although similar methods could be usable for describing collisions of (light) nuclei.

3. *Comments on submitted thesis*

The structure of the thesis follows a logical flow. The thesis is well written with only limited number of English language faults. The text conforms to scientific standards. The author demonstrates excellent familiarity of the relevant literature of the subject, shown through out the thesis by the complete set of references and description of their main results. The results are obtained following methods that are well established in the scientific community. The author also shows a solid knowledge of mathematics and its application in physics. However, some choices (questions) are only partially motivated (answered) in the thesis. E.g. why the particular functional form of the elastic hadronic phase of eq. (4.5) is chosen over other ones (giving similar behaviour) and how does this choice influence the results? How are the values chosen to which the elastic root-mean-squared impact parameter ("rms b") is constrained to in the fits to data? What is the maximal difference on basic proton-proton collision quantities like the total cross section and the rho parameter compared to a central description if in the peripheral description the value of the elastic rms b is allowed to vary over its whole acceptable range?

4. *The ability of the author for scientific work*

The author has made independent and original contributions to the so-called eikonal model approach to describe elastic hadron collisions and also applied it to describe elastic scattering data from ISR at 52.8 GeV centre-of-mass energy and from LHC at 8 TeV. In the thesis, he has also shown a good ability to critically review his own and other peoples scientific work.

In conclusion, the submitted thesis is sufficient for a PhD thesis both in terms of scientific content and as a scientific manuscript. The scientific work of the author is of importance for the field and he has demonstrated sufficient ability for such work. Therefore, **I recommend the Faculty of Mathematics and Physics to approve the doctoral thesis of Mr Jiri Procházka.**

Yours sincerely,

Kenneth Österberg
Professor in Experimental Particle Physics