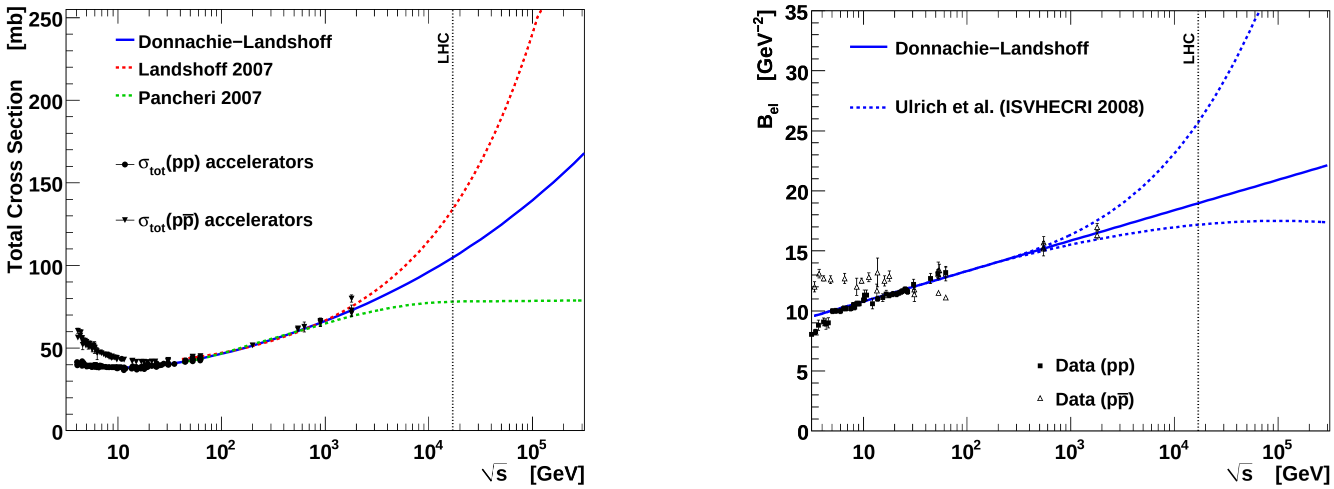

FIG. 1. Compilation of accelerator data of $\sigma_{\rm tot}^{\rm pp}$ and $B_{\rm el}$ [23]. The central line denotes the conventional extrapolation of these data to high energy. The upper and lower lines indicate a set of possible extreme extrapolations. In the left plot the conventional model is the soft pomeron parametrization by Donnachie and Landshoff [24], while the lower curve is by Pancheri et al. [25] and the upper one is the two-pomeron model of Landshoff [26, 27]. The different scenarios in the right plot are from [28].

Not all models are updated regularly and the quality of data description differs between the models.

(B) *smaller* than the actual systematic uncertainties. The existing models are not covering the full phase space of possible interaction scenarios and parameters. Moreover, new physics processes at higher energies, which are unknown now and thus missing in current modelling approaches, could change extrapolations drastically.

Frequently used models for the high-energy range are QGSJet II [29, 30], Epos [31], and the somewhat older QGSJet 01 [32, 33] and Sibyll 2.1 [34]. These models are available in the air shower simulation package CONEX [35] that will be used for calculating the shower observables. Other models for hadronic interactions include neXus [36, 37], HDPM [38], DPMJET [39], and VENUS [40]. These models are older or more limited in the scope of application and not considered here.

Despite the different level of sophistication, the predictions by Sibyll 2.1 and QGSJet 01 are not objectively worse than those by QGSJetII and Epos, as many model aspects are assumptions that cannot be justified by underlying fundamental theoretical constraints. Over the years model predictions and extrapolations have become more alike even though there is no theory for calculating e.g. cross sections from first principles [41]. One has to be careful and should not consider this increasing similarity of model predictions as real convergence and significant decrease of the uncertainties. None of the models is able to consistently describe cosmic ray data (e.g. [7, 9, 42, 43]). In the energy range up to about 10^{15} eV where various measurements on multiparticle production are available good tuning to many different data sets should indeed lead to a convergence of the model predictions. However, at energies beyond that of collider experiments, the extrapolations can only be guided by theoretical end phenomenological assumptions.

In Fig. 1 accelerator data on the total proton-proton cross section $\sigma_{\rm tot}^{\rm pp}$ and the elastic slope parameter $B_{\rm el}$, defined by $d\sigma_{\rm el}/dt|_{t=0} \propto \exp(-|t|B_{\rm el})$, are shown together with different models that extrapolate these data to ultra-high energies. Converting these model extrapolations within the Glauber framework [44, 45] to proton-

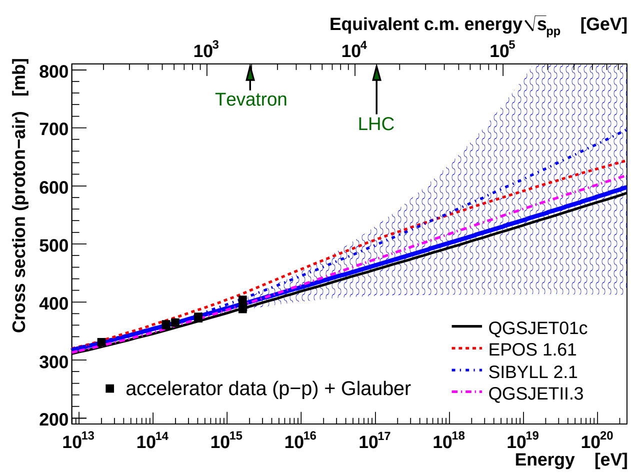

FIG. 2. Uncertainty of the extrapolation of the proton-air cross section for particle production due to different models of the proton-proton cross section as calculated with the Glauber framework [28].