



UHE cosmic ray measurements and asymptotic regime for NN total-cross section

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Asymptotics for σ_{tot}

The high (Froissart–Martin) bound for hadronic scattering

$$\sigma_{\text{tot}}(s) \leq \pi \ln^2 \varepsilon / m^2,$$

M. Froissart, Phys. Rev. 123, 1053 (1961); A. Martin, Il Nuovo Cim. A42, 930 (1966).

The low bound for hadronic cross-section

$$\sigma_{\text{tot}}(s) \geq \delta \varepsilon^{-6},$$

H. Cornille, Nuovo Cim. A4, 549 (1971).

Here m is the pion mass, δ – parameter, $\varepsilon \equiv s/s_0$, $s = (p_1 + p_2)^2$ is the Mandelstam invariant, $s_0 = 1 \text{ GeV}^2$, $p_{1,2}$ are incoming particle momenta.

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Why study σ_{tot} at UH energies

- The total cross-section is one of the most important physical observables. Its energy dependence is in the focus of intense theoretical and experimental investigations to create the complete theory of strong interactions.
- The study of nucleon-nucleon total cross-section at (ultra)high energies is crucially important for search for onset of asymptotic region for strong interaction reactions.
- The energy dependence of σ_{tot} allows us to search for possible signatures of new physics beyond the Standard Model (SM).

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AQFT model

The following parameterization for $\sigma_{\text{tot}}(s)$ was suggested within the model based on the general principles (unitarity, analyticity and crossing-symmetry) of the Axiomatic Quantum Field Theory (AQFT) for nucleon-nucleon scattering:

$$\sigma_{\text{tot}}(s) = \delta \varepsilon^{(-6-\gamma)} + (\beta \varepsilon^{-\alpha} / \sqrt{2}) \times (\pi \ln^2 \varepsilon / m^2),$$

where α , β , γ and δ are free parameters.

S.D. Campos, V.O., Int. J. Mod. Phys. A25, 5333 (2010).

The first term on the right-hand side responses for the description of low-energy data and second term is the leading one at high energies. Furthermore the Froissart–Martin factor is clearly shown for the last case.

The AQFT model describes the experimental results for global scattering parameters (σ_{tot} and ρ) with statistically acceptable fit quality in wide energy domain $\sqrt{s} \geq 5 \text{ GeV}$ for both the proton-proton and the antiproton-proton collisions.

S.D. Campos, V.O., Int. J. Mod. Phys. A25, 5333 (2010);

V.O., S.D. Campos, arXiv: 1704.02135 [hep-ph], 2017.

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Observable and data sample

The present analysis is focused on the energy behavior of $\sigma_{\text{tot}}(s)$ in nucleon-nucleon scattering.

The data sample considered here and denoted as DB17+ includes

- database DB14+ for nucleon-nucleon total cross-section

V.O., S.D. Campos, arXiv: 1704.02135 [hep-ph], 2017;

- preliminary TOTEM result for pp collisions at $\sqrt{s} = 2.76$ TeV

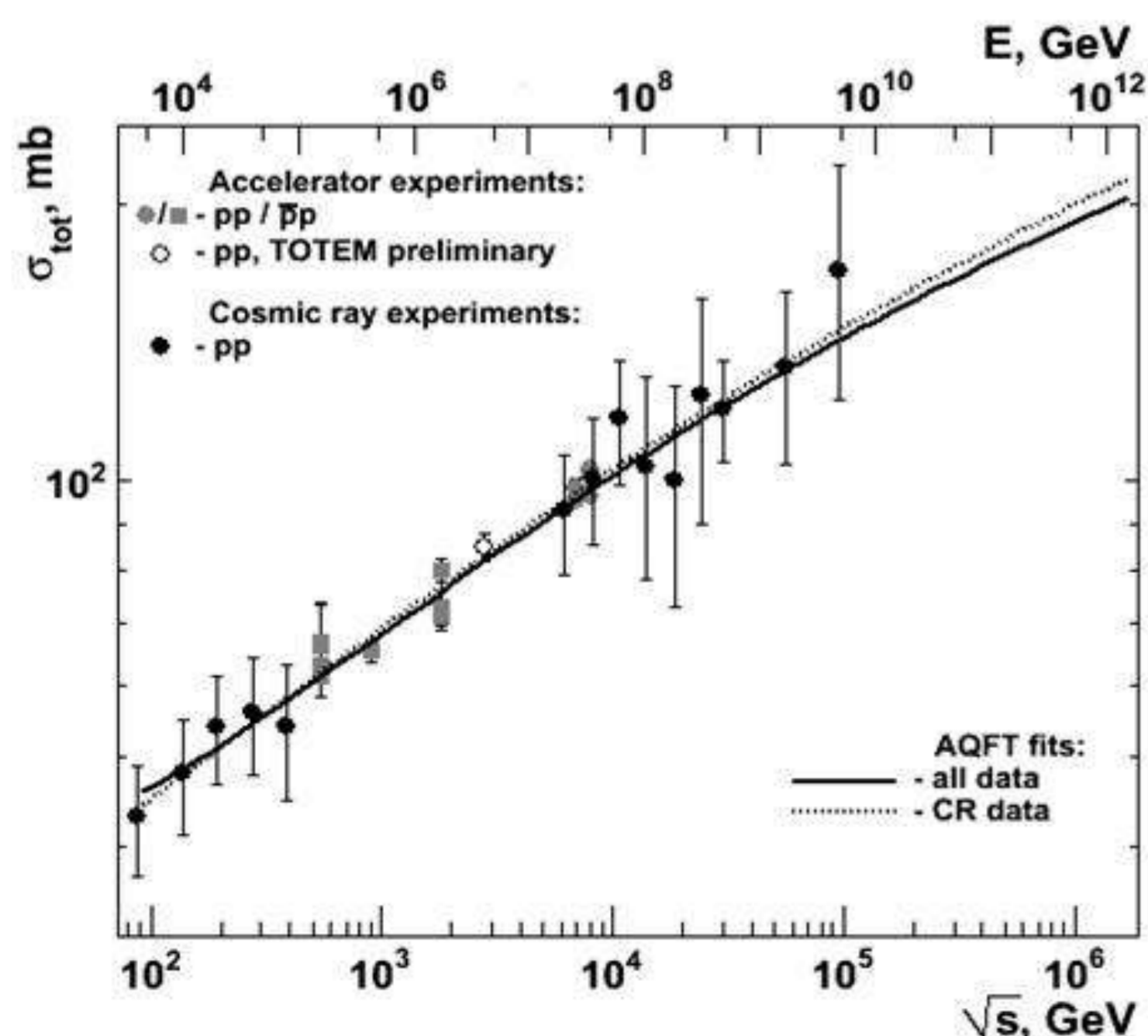
N. Turini, TOTEM status report, presentation on the LHCC session 22.02.2017.

Thus the DB17+ is most complete data sample for nucleon-nucleon σ_{tot} at the moment. Also the subset is analyzed with only cosmic ray measurements. It should be noted that the subset with cosmic ray results extends up to the much higher energy ($\sqrt{s} = 95$ TeV) than the subset with accelerator measurements ($\sqrt{s} \leq 8$ TeV).

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AQFT fits for data subsets

The subset of cosmic ray measurements is fitted separately. The data from DB14+ is approximated just in the same energy domain $\sqrt{s} > 86$ GeV for correct comparison.



Parameter	all data	CR data
$\alpha \times 10^4$	121 ± 71	10 ± 8
γ	-5.89 ± 0.03	-5.99 ± 0.05
χ^2/ndf	1.01	0.16

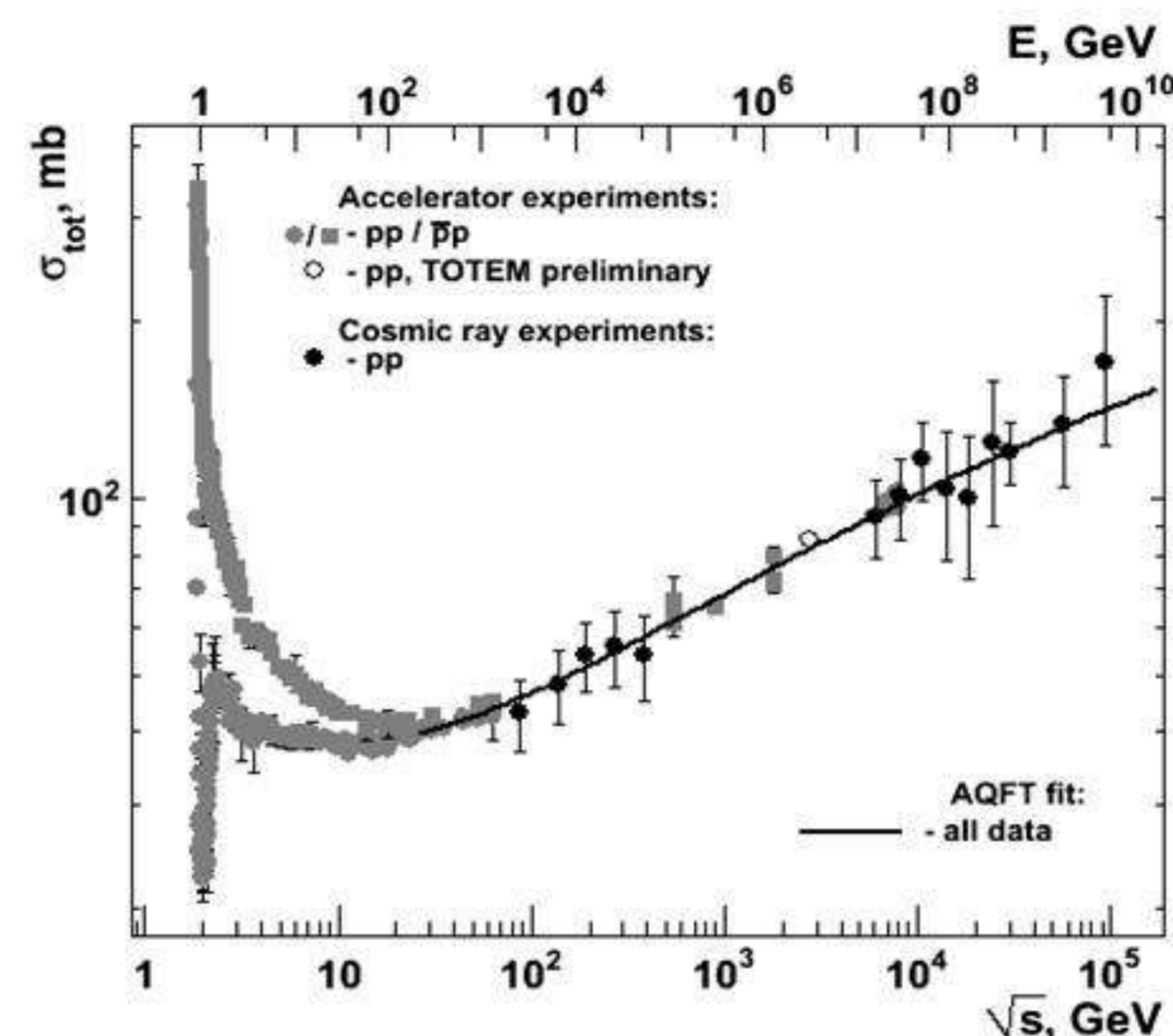
The γ coincides with its asymptotic value for CR data subset while the γ smaller noticeably than asymptotic value (-6) for all data.

Experimental results from DB17+ and AQFT fit curves for full data sample (solid line) and for cosmic ray measurements (dashed line) at $\sqrt{s} > 86$ GeV.

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Energy dependence of σ_{tot}

The preliminary TOTEM point is excluded from the fitted data sample, i.e. data sample is identical to the DB14+ in the case of fit procedure. The fit is simultaneously made for proton-proton and antiproton-proton scattering at energies above some low boundary s_{min} .



The AQFT model agrees rather well over a wide energy region with the experimental data of σ_{tot} measured in NN scattering.

As expected, the fit quality worsens at the decrease of s_{min} , i.e. for expansion of fit range towards the lower collision energies.

Total cross-section energy dependence for NN collisions. The solid line is the AQFT fit at $\sqrt{s} \geq 25$ GeV. Experimental data are from DB17+.

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Summary

1. The AQFT model describes the nucleon-nucleon total cross-section rather well in wide energy domain $\sqrt{s} \geq 25$ GeV.
2. The cosmic ray measurements show some faster increase than all data for identical fit ranges. For the first case some model parameter reaches its asymptotic value ($\gamma = -5.99 \pm 0.05$).
3. The results for cosmic ray measurements at ultra high energies can be considered as possible indication on the onset of asymptotic behavior of NN total cross-section at energies no less than $O(100)$ TeV.
4. The new precision measurements for ultra high energy cosmic rays are essential for verification of the suggestion and further study of asymptotic behavior for physical observables. Perhaps, such measurements will be made much earlier than in future accelerator experiments.

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