EPJ Web of Conferences **182**, 02049 (2018) https://doi.org/10.1051/epjconf/201818202049
ICNFP 2017

Precision RENORM / MBR Diffraction Predictions Tested by Recent LHC Results

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Abstract. Diffractive, elastic, and precision total pp cross-section predictions, based on the pre-LHC RENORM/MBR model, are compared to recent experimental results. Discrepancies among results by different experiments present a challenge to testing the model. Suggestions for analyses/measurements to understand and resolve the experimental discrepancies are discussed.

1 Introduction

We present an updated comparison between the precision RENORM / MBR model [1] diffraction predictions and LHC experimantal results, presented at ICNFP-2016, to cover new measurements. Below, we provide a brief historical background of the evolution of the model to a precision tool for data collection and analysis.

In DIS-2015 (Spring 2015) we summarized [2] the pre-LHC predictions of the total, elastic and total-inelastic, as well as the single diffractive (SD) and double diffractive (DD) components of the proton-proton cross section at high energies based RENORM / MBR [1]. We compared the measurements of the SD and DD cross sections from the Tevatron and the LHC with the predictions of the model and found excellent agreement. Good agreement was also observed between the model predictions and the total, elastic and total inelastic cross sections obtained at the Tevatron at $\sqrt{s} = 1.8$ TeV, and at the LHC at $\sqrt{s} = 7$ and 8 TeV.

The confirmation of the predictions of all the above cross sections at the Tevatron and the LHC up to $\sqrt{s} = 8$ TeV prompted a calculation/extrapolation to $\sqrt{s} = 13$ TeV, the nominal foreseen colliding-beam energy at the LHC for Summer 2015. For $\sigma_{\rm tot}$, $\sigma_{\rm el}$ and $\sigma_{\rm inel}$, we predicted 108 mb, 32 mb, and 77 mb, respectively, with uncertainties of $\sim 11\%$ in all cases, mainly due to the uncertainty in the energy-squared scale parameter s_0 of the model.

In Summer 2015 we updated the energy-squared scale parameter s_0 of RENORM / MBR to a more precise value based on a tensor glueball interpretation of the Axial Field Spectrometer (AFS) exclusive charged di-pion data [3–5]. This change in RENORM / MBR decreases the uncertainties in the predictions of the total, elastic, and total-inelastic cross sections to less than 2% from Tevatron to LHC energies, with little or no effect on the mean values. The predictions were compared with measurements by ATLAS at $\sqrt{s} = 7$ TeV and by TOTEM at $\sqrt{s} = 7$ and 8 TeV at Moriond QCD in March 2016 [6] and found to be in good agreement.

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At ICNFP-2016 (July 2016) we presented an update of [6] to include the new measurements of the total inelastic cross section at $\sqrt{s}$ = 13 TeV by ATLAS and CMS reported at DIS-2016 (April 2016) [7]. All measured cross sections were in good agreement within the experimental uncertainties of the data and the theoretical uncertainties of the model, reaching down to the ~1% level (Table 1). However, there were some disagreements among the measurements themselves and with the RENORM /MBR predictions at the $\sim 2\sigma$ level.

We recalled that in RENORM the total inelastic cross section is calculated as the difference between the total and the elastic cross sections, and thus, a measured lower $\sigma_{\rm el}$ would result in a higher $\sigma_{\rm inel}$. As can be seen in Table 1, at ICNFP-2016 the MBR $\sigma_{\rm el}$ was larger than the TOTEM and CMS measurements by ~ 2 mb at $\sqrt{s}$=7 TeV, which would imply a higher MBR prediction for $\sigma_{\rm el}$ at 13 TeV by ~ 2 mb as well. We recommended that the interplay between $\sigma_{\rm el}$ and $\sigma_{\rm inel}$ be carefully taken into consideration as more measurements of both $\sigma_{\rm el}$ and $\sigma_{\rm tot}$ at $\sqrt{s}$ = 8 TeV and $\sqrt{s}$ = 13 TeV with reduced luminosity and extrapolation uncertainties became available.

After INNFP-2016, preliminary new results were presented at ICHEP-2016 (August) [8] (cf. Table 1). Notable among them are the updated measurements at $\sqrt{s}$ = 13 TeV by ATLAS of $\sigma_{\rm inel}^{\rm ATLAS} = 79.3 \pm 0.6({\rm exp}) \pm 2.5({\rm extr}) \pm 1.3({\rm lum})$ and CMS $\sigma_{\rm inel}^{\rm CMS} = 71.3 \pm 0.5({\rm exp}) \pm 2.7({\rm extr}) \pm 2.1({\rm lum})$. The new results are compatible at the 2σ level of all the uncertainties combined in quadratute.

A new measurement by TOTEM of $\sigma_{\rm tot}$, $\sigma_{\rm el}$ and $\sigma_{\rm inel}$ at $\sqrt{s}$=2.76 TeV was presented at DIS-2017 (April 2017) [9] (cf. Table 1). The data are in excellent agreement with the RENORM / MBR predictions down to the ~ 1% level.

2 RENORM cross sections

The total, elastic, and total-inelastic cross sections in the RENORM / MBR model depend on the value of the energy-squared scale parameter, s_0. Quoting verbatim from Ref. [2],

"The total cross section ($\sigma_{\rm tot}$) is expressed as [10]

$$\sigma_{\rm tot}^{p^{\pm}p} = 16.79 s^{0.104} + 60.81 s^{-0.32} \mp 31.68 s^{-0.54} \quad \text{for } \sqrt{s} \leq 1.8 \text{ TeV}, \tag{1}$$

$$\sigma_{\rm tot}^{p^{\pm}p} = \sigma_{\rm tot}^{\rm CDF} + \frac{\pi}{s_0}\left[\left(\ln\frac{s}{s_F}\right)^2 - \left(\ln\frac{s^{\rm CDF}}{s_F}\right)^2\right] \quad \text{for } \sqrt{s} \geq 1.8 \text{ TeV}, \tag{2}$$

where s_0 and s_F are the energy and (Pomeron flux) saturation scales, $s_0 = 3.7 \pm 1.5$ GeV^2 and $\sqrt{s_F}$ = 22 GeV, respectively. For $\sqrt{s} \leq 1.8$ TeV, where there are Reggeon contributions, we use the global fit expression [11], while for $\sqrt{s} \geq 1.8$ TeV, where Reggeon contributions are negligible, we employ the Froissart-Martin formula [12–14]. The two expressions are smoothly matched at $\sqrt{s} \approx 1.8$ TeV. The $\sigma_{\rm el}$ for $\sqrt{s} \leq 1.8$ TeV is obtained from the global fit [11], while for $1.8 < \sqrt{s} \leq 50$ TeV we use an extrapolation of the global-fit ratio of $\sigma_{\rm el}/\sigma_{\rm tot}$, which is slowly varying with $\sqrt{s}$, multiplied by σ_{tot}. The total non-diffractive cross section is given by $\sigma_{\rm ND} = (\sigma_{\rm tot} - \sigma_{\rm el}) - (2\sigma_{\rm SD} + \sigma_{\rm DD} + \sigma_{\rm CD})$."

2.1 Tensor glueball exchange predictions vs. measurements

The partial wave analysis of the AFS exclusive $\pi^{\pm}$ data [5], performed in terms of a fit with a model with S-wave and D-wave amplitudes as a function of the di-pion mass up to 2.3 GeV, leads to the results presented in Figure 1.

The D-wave dominates at masses above ~ 2 GeV, and according to the presumed interpretation in Ref. [5] it corresponds to a spin-2 tensor glueball of mass $M_{\rm tgb}$. A Gaussian fit to this enhancement yields $M_{\rm tgb} = 2.10 \pm 0.68$ GeV. Identifying $M^2_{\rm tgb}$ with the saturated glueball-like enhancement of the MBR parameter s_0 (see Eq. 2) yields $s_0 = 4.42 \pm 0.34$ GeV^2. Using this value in Eq. 2 we predicted

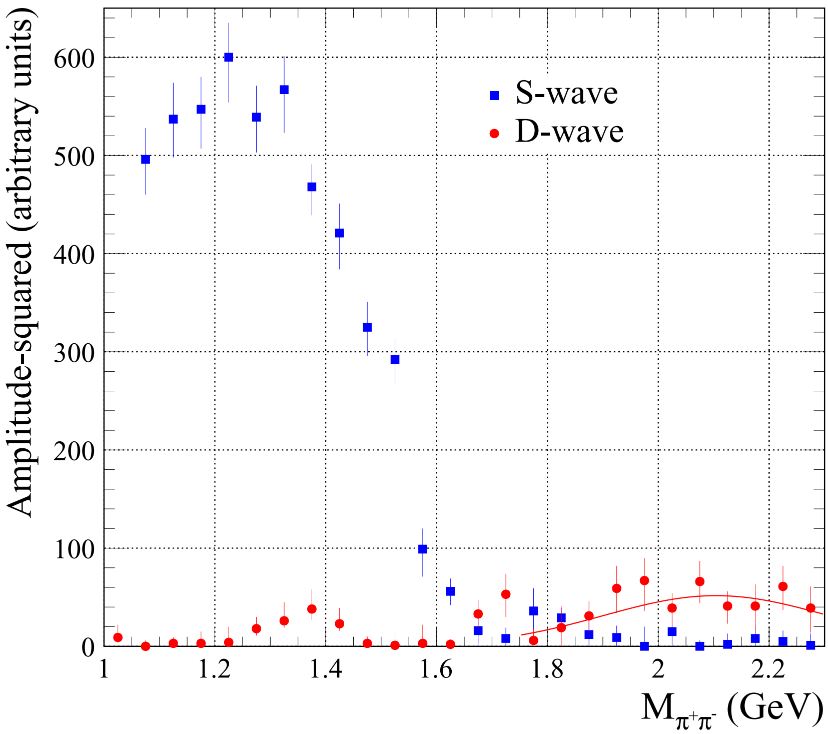

Figure 1. Extraction of tensor-glueball-exchange parameters from a Gaussian fit to the exclusive $\pi^{\pm}$ Axial Field Spectrometer data. The fit yields a mean mass value $\langle M_{\pi^+\pi^-}\rangle = 2.10$ GeV of width $\Delta = \pm 0.68$ GeV.

for $\sigma_{\rm tot}$, $\sigma_{\rm el}$, and $\sigma_{\rm inel}$ at 13 TeV cross sections of 103.7 ± 1.9 mb, 30.2 ± 0.8 mb, and 73.5 ± 1.3 mb, respectively. The ATLAS- and TOTEM-measured cross sections at $\sqrt{s}$ = 7 and 8 TeV [15–17] are shown in Table 1 along wiith the MBR predictions.

The ICNFP-2016, ATLAS and CMS cross-section are imported from Ref. [7]. Details of the ATLAS results, as presented in [7], are listed below:

1. Elastic cross section:
   $\sigma_{\rm el}^{\rm ALFA}$(7 TeV) = 24.00 ± 0.19 (stat) ± 0.57 (syst) mb

2. Nuclear slope:
   $b^{\rm ALFA}$(7 TeV) = 19.73 ± 0.14 (stat) ± 0.26 (syst) GeV^{-2}

3. Total cross section
   $\sigma_{\rm tot}^{\rm ALFA}$(7 TeV = 95.35 ± 0.38 (stat) ± 1.25 (exp) ± 0.37 (extr) mb

4. Inelastic cross section:

   - $\sigma_{\rm inel}^{\rm ALFA}$(7 TeV) = 71.34 ± 0.36 (stat) ± 0.83 (syst) mb
   - $\sigma_{\rm inel}^{\rm MBTS}$(7 TeV) = 69.4 ± 2.4 (exp) ± 6.9 (extr) mb
   - $\sigma_{\rm inel}^{\rm MBTS}$(13 TeV) = 73.1 ± 0.9 (exp) ± 3.8 (extr) ± 6.6 (lum) mb

Table 1. The total, elastic, and total inelastic MBR predictions (in mb) at $\sqrt{s}$ = 7, 8 and 13 TeV presented at ICNFP-2016 vs. measurements at the LHC by TOTEM and ATLAS. Also shown are updated results by ATLAS for $\sqrt{s}$ = 8 and 13 TeV and CMS for $\sqrt{s}$ = 13 TeV presented at ICHEP-2016, and TOTEM results for $\sqrt{s}$ = 2.6 TeV presented at DIS-2017.

$\sqrt{s}$ (TeV)	MBR Experiment	$\sigma_{\rm tot}$ (mb)	$\sigma_{\rm el}$ (mb)	$\sigma_{\rm inel}$ (mb)
7	MBR	95.4 ± 1.2	26.4 ± 0.3	69.0 ± 1.0
	TOTEM	98.3 ± 2.9	24.8 ± 1.3	73.7 ± 1.7
	TOTEM_Lum_ind	98.0 ± 2.5	25.2 ± 1	72.9 ± 1.5
	ATLAS	95.35 ± 1.36	24.00 ± 0.60	71.34 ± 0.90
8	MBR	97.1 ± 1.4	27.2 ± 0.4	69.9 ± 1.0
	TOTEM	101.7 ± 2.9	27.1 ± 1.4	74.7 ± 1.7
	ATLAS-ICHEP16	96.1 ± 0.9	27.1 ± 1.4	74.7 ± 1.7
13	MBR	103.7 ± 1.9	30.2 ± 0.8	73.5 ± 1.3
	ATLAS	xxx	xxx	73.1 ± 0.9(exp)±3.8(extr)±6.6(lum)
	ATLAS-ICHEP16	xxx	xxx	79.3 ± 0.6(exp)±2.5(extr)±1.3(lum)
	CMS-ICHEP16	xxx	xxx	71.3 ± 0.5(exp)±2.7(extr)±2.1(lum)
2.6	MBR	85.2 ± 1.2	21.7 ± 0.3	63.5 ± 1.1
	TOTEM-DIS17	84.7 ± 3.3	21.8 ± 1.4	62.8 ± 2.9

Shown in Table 1 is also a measurement of the total inelastic cross section by ATLAS at $\sqrt{s}$ = 13 TeV [18], $\sigma_{\rm inel} = 73.1 \pm 0.9$ (exp) ± 3.8 (extr) ± 6.6 (lum) mb, which, apart from the extrapolation and luminosity uncertainties, is in excellent agreement with MBR. All the other measurements are also in good agreement with the predictions. The tensor-glueball-based prediction of $\sigma_{\rm inel}$ at $\sqrt{s}$ = 13 TeV agrees with the ATLAS measurement at the 1% level.

Following ICNFP-2016, new results were presented at ICHEP-2016 [8] by ATLAS and CMS, and at DIS-2017 [7] by TOTEM (cf. Table 1). As discussed in the introduction, these results confirm the predictions of RENORM / MBR.

3 Summary and conclusions

We present the predictions of the total, elastic scattering, and total-inelastic proton-proton cross sections at $\sqrt{s}$ = 7, 8 and 13 TeV of the RENORM / MBR MBR model, based on a Regge-theory inspired tensor-glueball implementation of the RENORM model for hadronic diffraction, and compare them with experimental results by the TOTEM, ATLAS, and CMS Collaborations. All measured cross sections are in good agreement within the experimental uncertainties of the data and the theoretical uncertainties of the model, reaching down to the ∼1% level.

Acknowledgments

Warmly acknowledged are Dr. Michael Albrow for providing a copy of the thesis of Peter C. Cesil, where the tensor-Pomeron data and analysis are discussed, and Dr. Robert Ciesielski for extracting the tensor-Pomeron parameters from the data and for many invaluable discussions.

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