Triple Regge exchange mechanisms of four-pion continuum production in the $pp \to pp\pi^+\pi^-\pi^+\pi^-$ reaction (Phys. Rev. D 95 094020 (2017)) @ QCD - Old Challenges and New Opportunities

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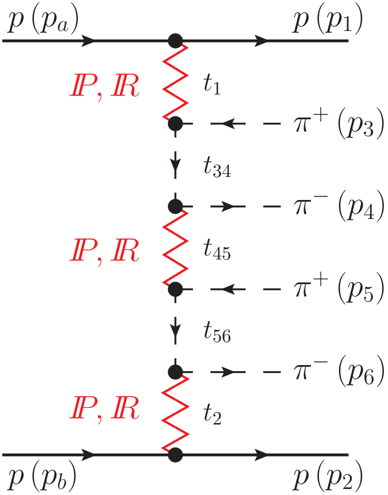
September 27, 2017

Outline

The model $pp \to pp\pi^+\pi^-\pi^+\pi^-$

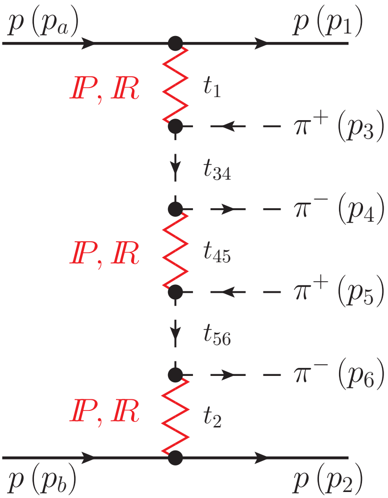
The model



$$\mathcal{M}_{\{3456\}} = A_{\pi p}(s_{13}, t_1)\,\frac{F_\pi(t_{34})}{t_{34} - m_\pi^2}\,A_{\pi\pi}(s_{45}, t_{45})\,\frac{F_\pi(t_{56})}{t_{56} - m_\pi^2}\,A_{\pi p}(s_{26}, t_2)$$

+ symmetrization of pions.

The model



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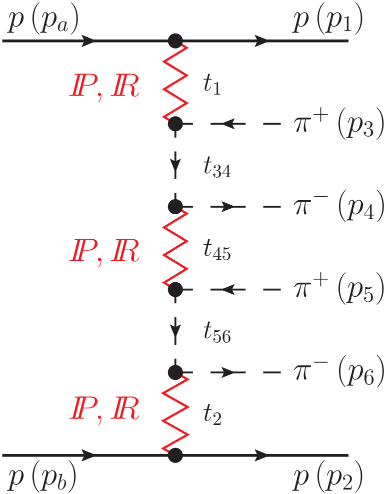

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+ symmetrization of pions.

The model - details

$$
\begin{aligned}
\mathcal{M} = \frac{1}{2}&\left(\mathcal{M}_{\{3456\}} + \mathcal{M}_{\{5436\}} + \mathcal{M}_{\{3654\}} + \mathcal{M}_{\{5634\}}\right) \\
+ \frac{1}{2}&\left(\mathcal{M}_{\{4356\}} + \mathcal{M}_{\{4536\}} + \mathcal{M}_{\{6354\}} + \mathcal{M}_{\{6534\}}\right) \\
+ \frac{1}{2}&\left(\mathcal{M}_{\{3465\}} + \mathcal{M}_{\{5463\}} + \mathcal{M}_{\{3645\}} + \mathcal{M}_{\{5643\}}\right) \\
+ \frac{1}{2}&\left(\mathcal{M}_{\{4365\}} + \mathcal{M}_{\{4563\}} + \mathcal{M}_{\{6345\}} + \mathcal{M}_{\{6543\}}\right) .
\end{aligned} \tag{1}
$$

The model - details

$$\mathcal{M}_{\{3456\}} = A_{\pi p}(s_{13}, t_1)\,\frac{F_\pi(t_{34})}{t_{34}-m_\pi^2}\,A_{\pi\pi}(s_{45}, t_{45})\,\frac{F_\pi(t_{56})}{t_{56}-m_\pi^2}\,A_{\pi p}(s_{26}, t_2).$$

For such a complicated model many choices have to be made, e.g.,:

- **Q**: What is exact form of $A_{p\pi}$ and $A_{\pi\pi}$ amplitudes? **A**: Take parametrization by Lebiedowicz and Sczurek [2], however, different choices are possible (...more fundamentally, how QCD and the Regge phenomenology are connected?).
- **Q**: What is the choice of form factor $F_\pi(t_{ij})$? **A**: We selected common choice $F_\pi(t) = \exp\left(\frac{t-m_\pi^2}{\Lambda_{off,E}^2}\right)$, where $\Lambda_{off,E} = 1 - 1.5GeV^{-2}$ (educated guess from fit functions and upper and lower limits for $\Lambda_{off,E}$).
- **Q**: How remove regions where the Regge theory does not apply ($s_{ij} < 2GeV^2$)? **A**: We can take smooth cut function or the Heaviside theta function (does anyone know how to include non-Regge region?).

The model - details

$$\mathcal{M}_{\{3456\}} = A_{\pi p}(s_{13}, t_1) \frac{F_\pi(t_{34})}{t_{34} - m_\pi^2} A_{\pi\pi}(s_{45}, t_{45}) \frac{F_\pi(t_{56})}{t_{56} - m_\pi^2} A_{\pi p}(s_{26}, t_2).$$

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Cross section

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We selected the following cuts:

- Full Phase Space:

$$p_{t,p} < 2 \text{ GeV}\,, \quad |y_{4\pi}| < 6, \tag{2}$$

- ATLAS:

$$|t_1|, |t_2| < 1 \text{ GeV}^2\,, \quad |y_\pi| < 2.5\,, \quad p_{t,\pi} > 0.5 \text{ GeV}\,, \tag{3}$$

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Table : The integrated Born level (no absorption effects) cross section for the four-pion continuum production. Results were calculated for two different values of the cut-off parameter $\Lambda_{off,E}$.

	$\Lambda_{off,E}$ [GeV]	σ @ $\sqrt{s} = 7$ TeV	σ @ $\sqrt{s} = 13$ TeV
Full PS	1.0	7.21 μb	8.97 μb
Full PS	1.5	42.86 μb	51.78 μb
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ALICE cuts practically reject detection possibility.

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Experimental characteristics

Experimental characteristics - rapidity gap

Focus on the pion subsystem and do:

- Order pion system according to rapidity: $y_1 < y_2 < y_3 < y_4$.
- The following classes of ordering are possible:
  - Class A:
  $$\pi^+(y_1), \pi^-(y_2), \pi^+(y_3), \pi^-(y_4);$$
  $$\pi^-(y_1), \pi^+(y_2), \pi^-(y_3), \pi^+(y_4);$$
  - Class B:
  $$\pi^-(y_1), \pi^+(y_2), \pi^+(y_3), \pi^-(y_4);$$
  $$\pi^+(y_1), \pi^-(y_2), \pi^-(y_3), \pi^+(y_4);$$
  - Class C:
  $$\pi^+(y_1), \pi^+(y_2), \pi^-(y_3), \pi^-(y_4);$$
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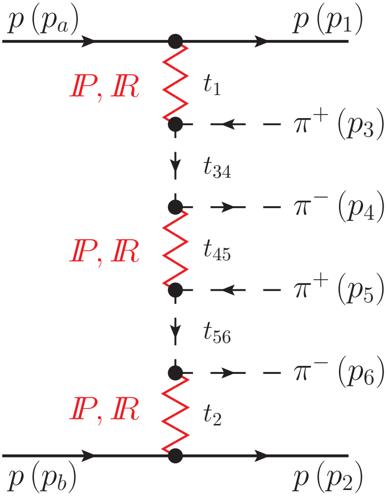
Experimental characteristics - rapidity gap



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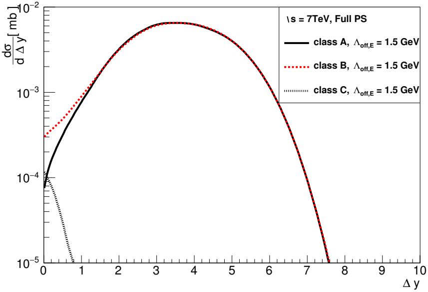
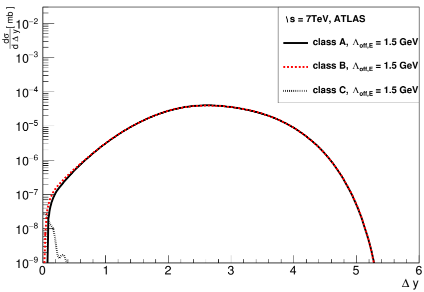
+ symmetrization

Experimental characteristics - rapidity gap

Differences between these classes is visible in $\Delta y := y_3 - y_2$.





Experimental characteristic - comparison with 2σ

Comparison with $pp \to pp\sigma\sigma$ process recently discussed in [3] which gives (via $\sigma \to \pi^+\pi^-$) the same final state.

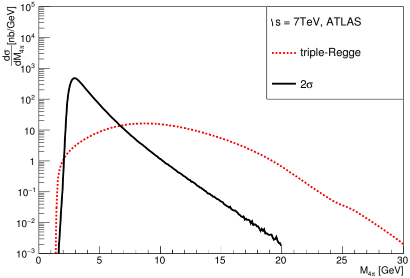
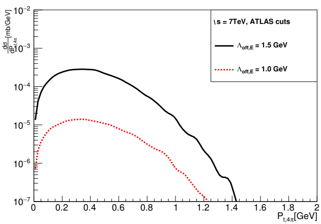


Figure : Four-pion invariant mass distribution ($M_{4\pi}$) with the ATLAS kinematical cuts (3) for $\sqrt{s} = 7$ TeV. The results correspond to the Born level calculations. The dotted line represents the triple Regge exchange mechanism obtained for $\Lambda_{off,E} = 1.5$ GeV. The solid line represents the contribution from $\sigma\sigma$ mechanism discussed in [3].

Other characteristics - ATLAS

Other characteristics - p_t



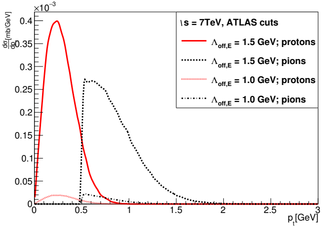


Figure : Distribution in transverse momentum of the four-pion system (P_t) (left panel) and for the transverse momenta of individual particles (protons or pions) (right panel) with the ATLAS cuts (3).

Other characteristics - $M_{4\pi}$

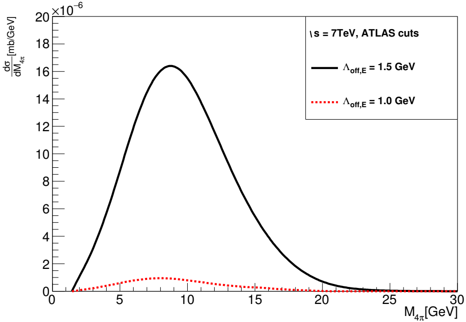


Figure : Four-pion invariant mass distribution ($M_{4\pi}$) with the ATLAS cuts (3) for $\Lambda_{off,E} = 1$ GeV (lower curve) and $\Lambda_{off,E} = 1.5$ GeV (upper curve).

Other characteristics - y

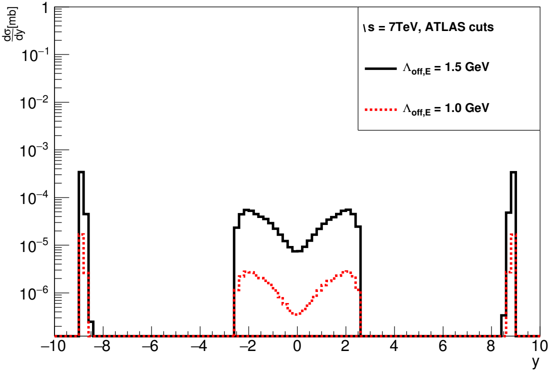


Figure : Distribution in rapidity of pions and protons for the ATLAS cuts (3).

Other characteristics - $M_{\pi\pi}$

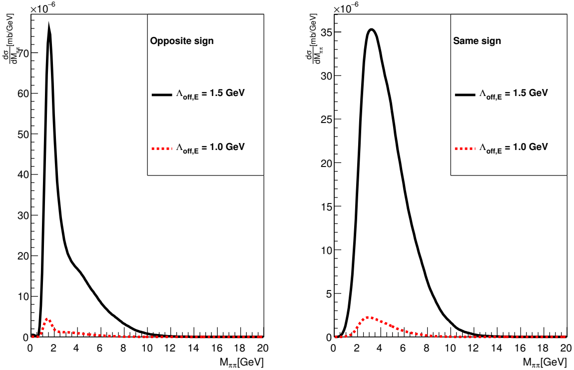


Figure : Dipion invariant mass distribution for the opposite-sign (left panel) and same-sign (right panel) pions with the ATLAS cuts (3) for different values of $\Lambda_{off,E}$.

More details

The model was studied in many aspects. For full details see our paper:
R. Kycia, P. Lebiedowicz, A. Szczurek, and J. Turnau, *Triple Regge exchange mechanisms of four-pion continuum production in the* $pp \to pp\pi^+\pi^- pi^+\pi^-$ *reaction* Phys. Rev. D 95, 094020 (2017) https://arxiv.org/abs/1702.07572.

Bibliography

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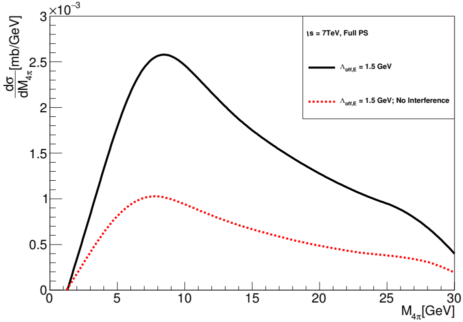
- P. Lebiedowicz and A. Szczurek, Phys. Rev. **D81** (2010) 036003.
- P. Lebiedowicz, O. Nachtmann, and A. Szczurek, Phys. Rev. **D94** (2016) 034017.
- R. A. Kycia, J. Chwastowski, R. Staszewski, and J. Turnau, arXiv:hep-ph/1411.6035.

Thank You for Your Attention

Backup

Interference effect - Full Phase Space

$$|\mathcal{M}_{\text{no interference}}|^2 = \frac{1}{4}\left(|\mathcal{M}_{\{3456\}}|^2 + |\mathcal{M}_{\{5436\}}|^2 + \dots\right) + \dots .$$



Pomeron Reggeon influence - Full Phase Space

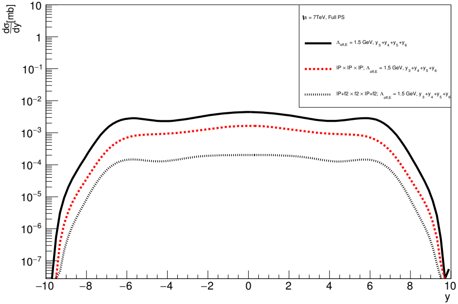


Figure : Rapidity distribution of pions for $(\mathbb{P}+f_{2\mathbb{R}})\times(\mathbb{P}+f_{2\mathbb{R}})\times(\mathbb{P}+f_{2\mathbb{R}})$ (upper curve), $\mathbb{P}\times\mathbb{P}\times\mathbb{P}$ (middle curve) and $(\mathbb{P}+f_{2\mathbb{R}})\times f_{2\mathbb{R}}\times(\mathbb{P}+f_{2\mathbb{R}})$ (lower curve) exchanges for $\Lambda_{off,E}=1.5$ GeV.