Single transverse spin asymmetry of very forward neutral pion

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Outline

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- *Born amplitudes*
- *Single transverse spin asymmetry*
- *Results*
- *Summary*

Introduction

Introduction

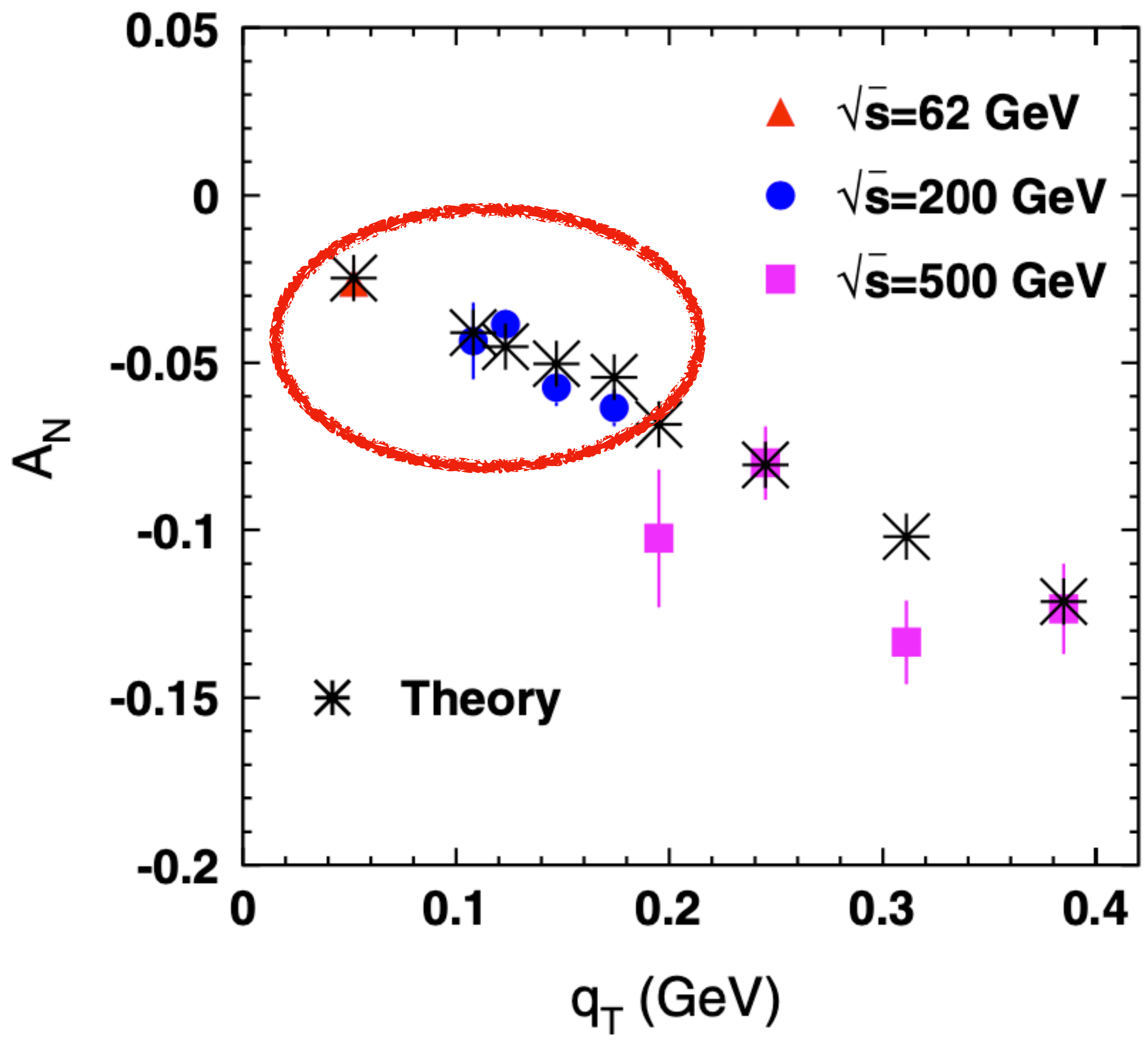
- Single transverse spin asymmetry(SSAs) is one of the interests in high energy reactions, but it has not been well understood yet.
- It is expected that the particle production mechanism in high energy is understood through the SSAs.
- Fermilab experiment reported a nonzero A_N for the first time in 1991 for the pion production [1].
- The SSAs for various very-forward productions(π,n,γ) found to be governed by soft process was measured in 2007 [2].
- The p_T and x_F dependence of A_N for very forward neutron with $\sqrt{s}$ = 62, 210 and 500 GeV was also measured by PHENIX Collaboration [3].

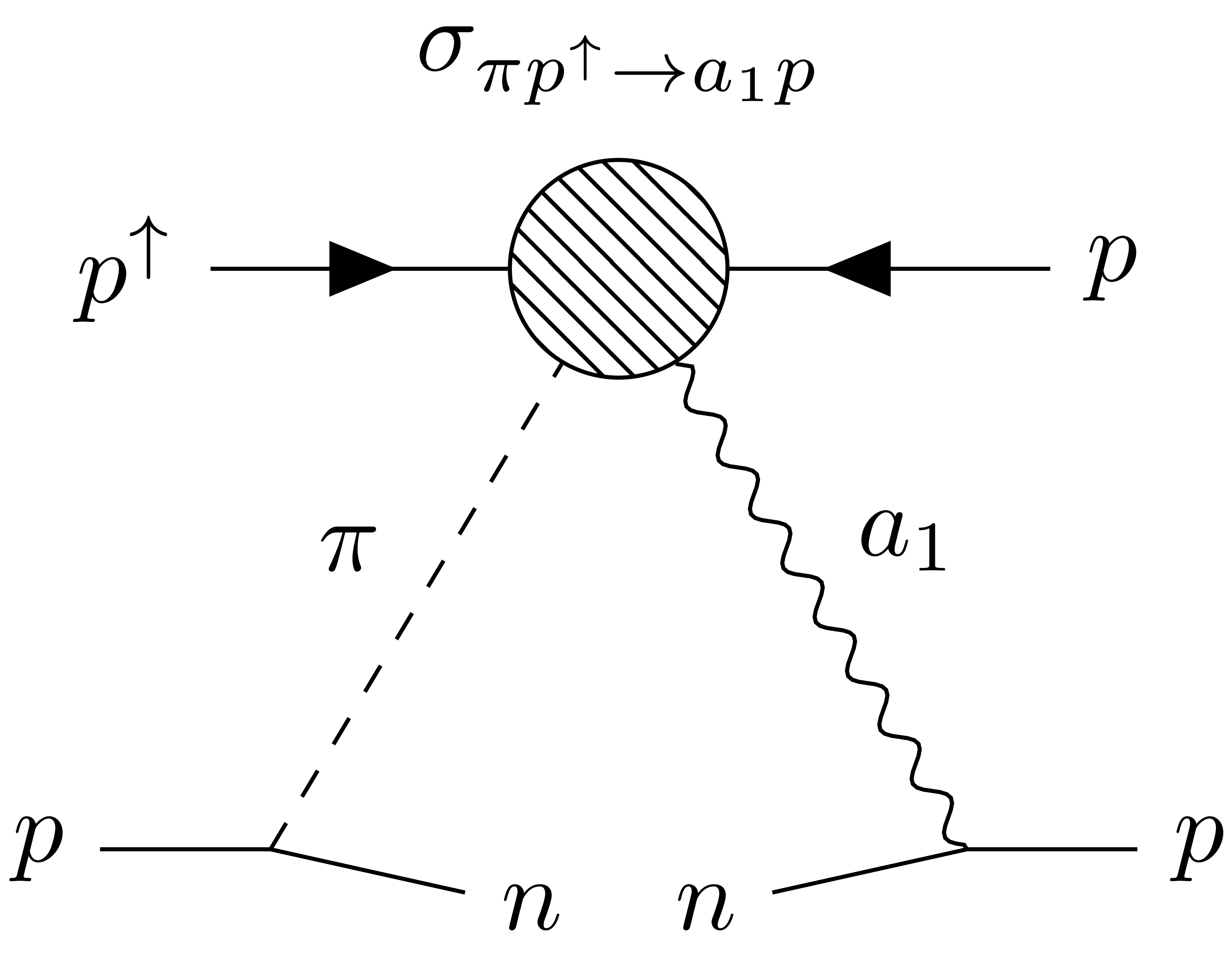
SSAs : $$A_N = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$

Spin direction of the polarized proton beam

[1] D.L. Adams *et al.*, Phys. Lett. B264 (1991) 3,4
[2] Y. Fukao *et al.*, Phys. Lett. B650 (2007) 325
[3] K. Tanida *et al*.(PHENIX Collaboration), J.Phys.Conf.Ser.295(2011)

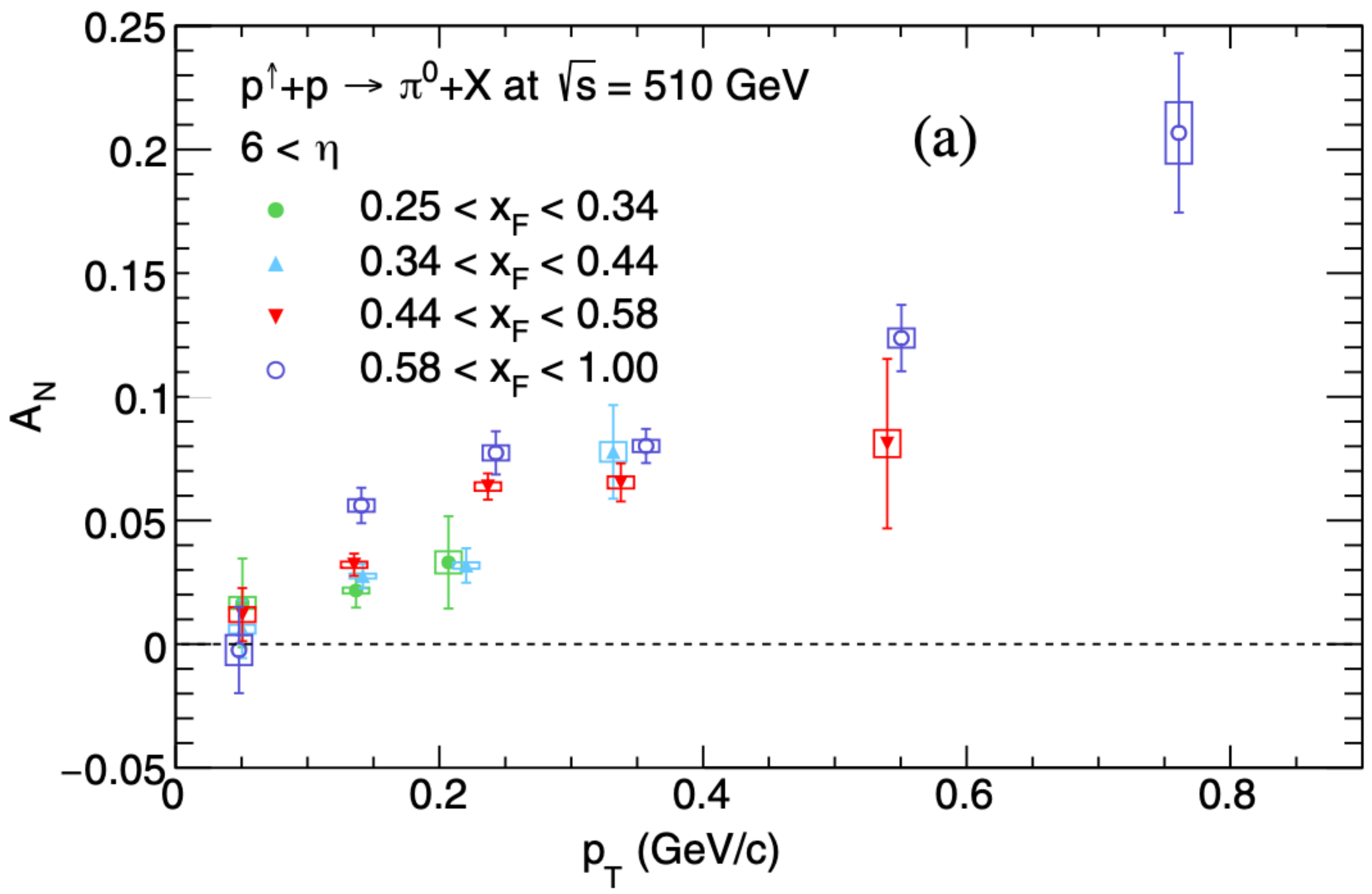
- A theoretical approach to the SSAs for the very forward neutron production was successfully achieved by OBE exchange based on Regge theory [4].

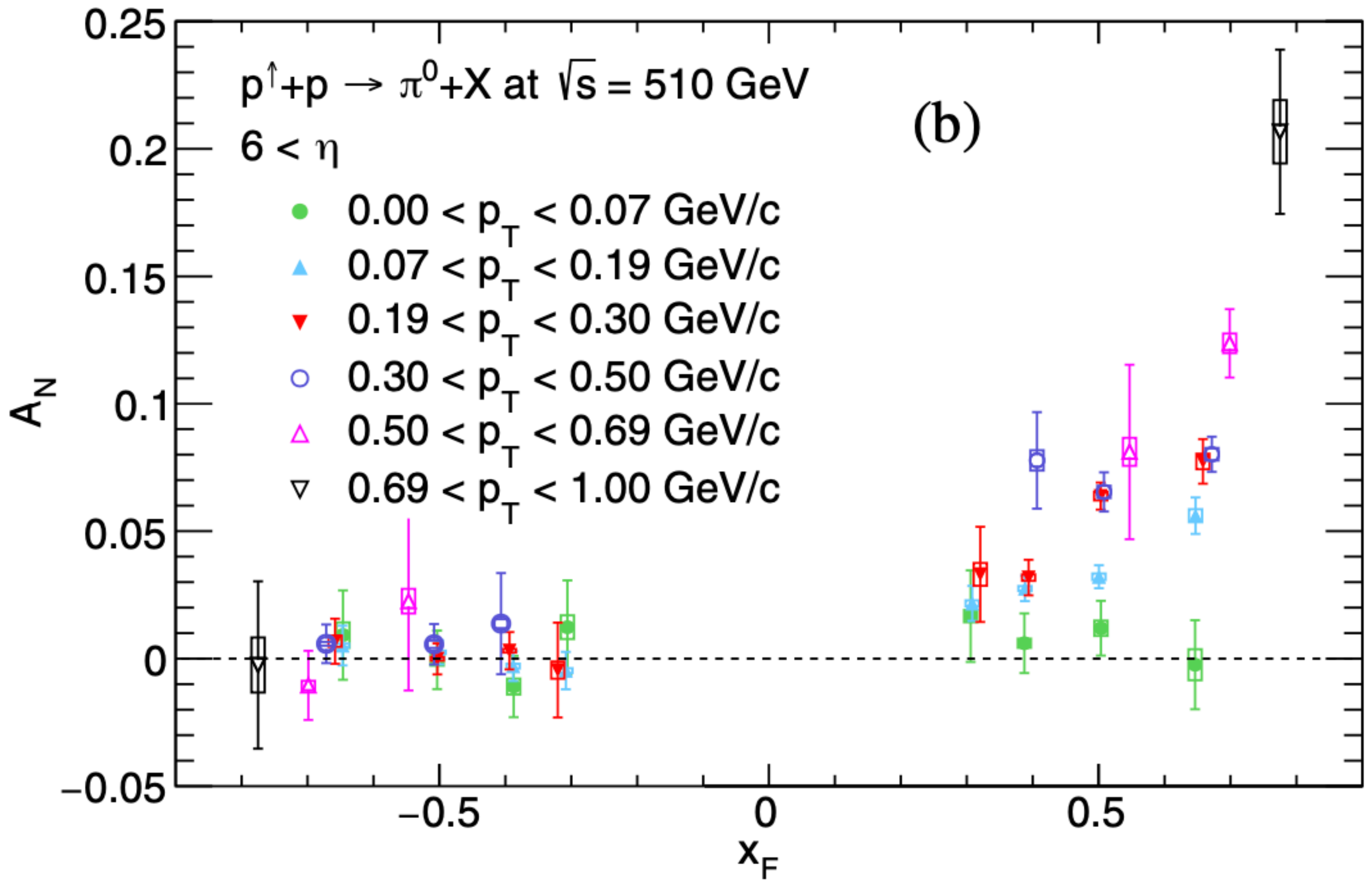


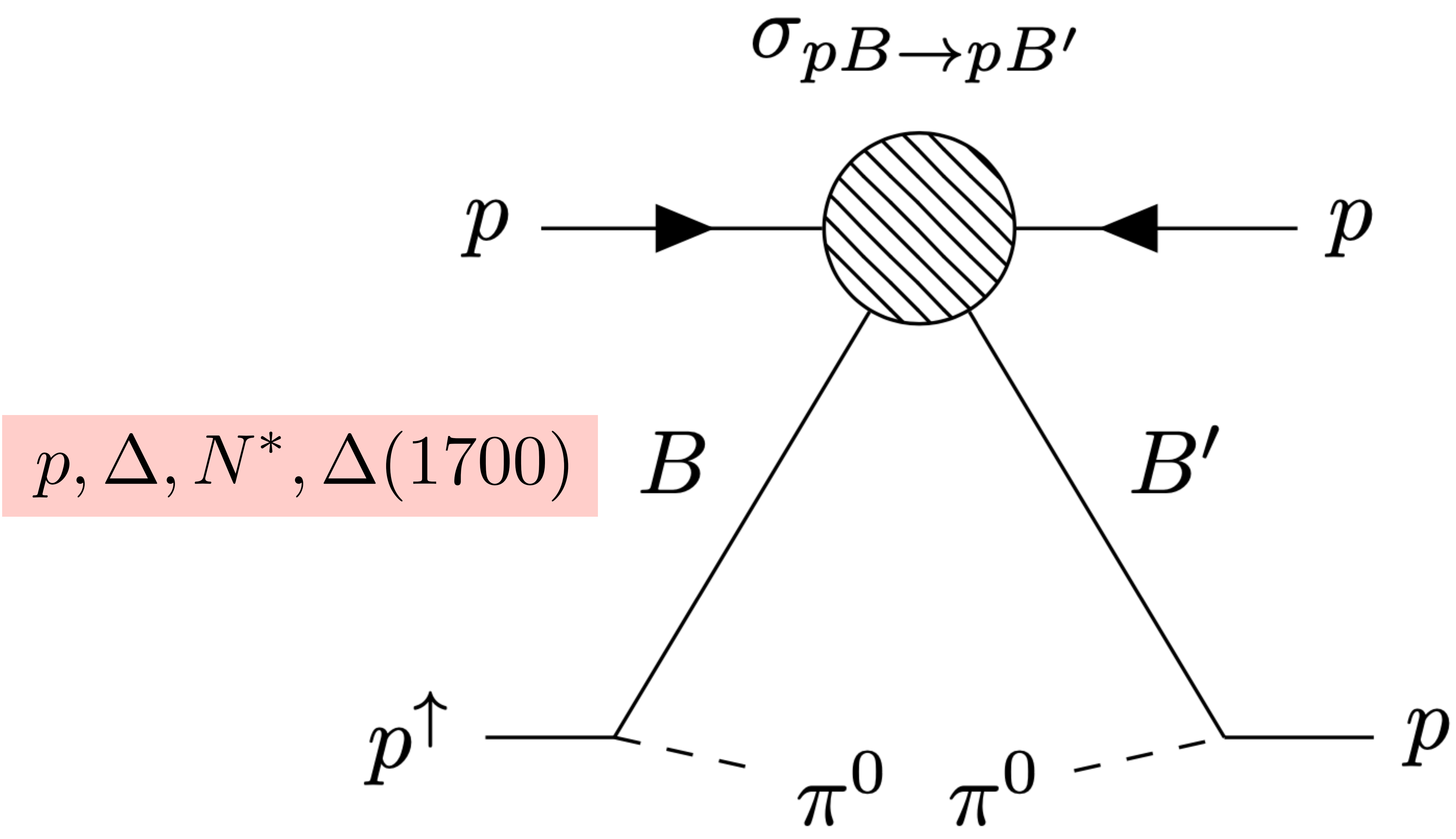


- The contribution of the π-a_1 interference for A_N matches the experiment results very well.

- Recently the SSAs of very forward neutral pion was measured in RHICf experiment [5].







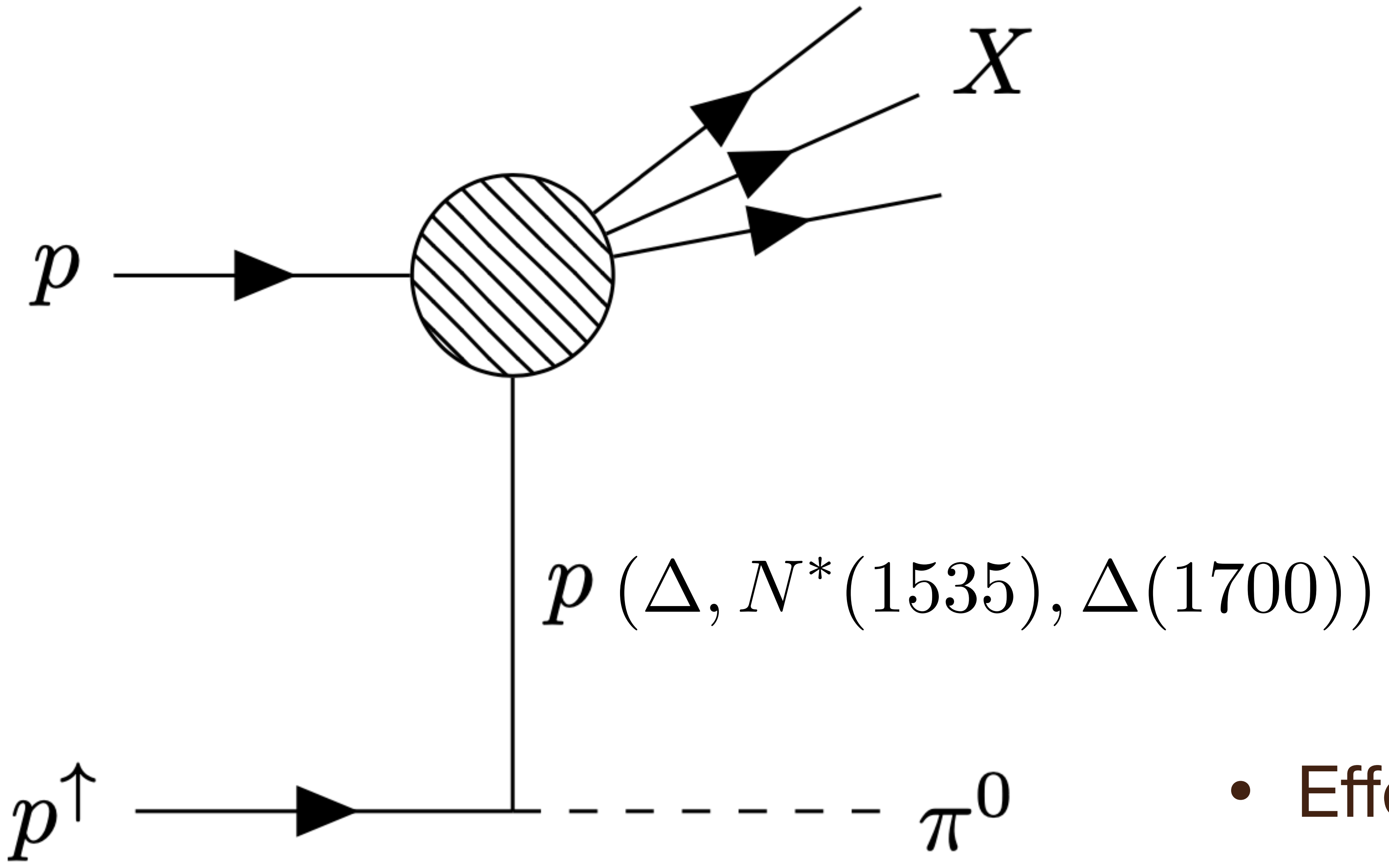
- We take into account four Reggeons in the calculation of the SSAs by using interferences between them.
- The cross section for $pB \to pB'$ will be used as fitting parameters.

[5] M.H. Kim *et al.*, Phys. Rev. Lett. 124 (2020) 124

Born amplitudes

Born diagrams

- Born diagram for the $p + p^{\uparrow} \to \pi^0 + X$:



- Effective Lagrangians:

$$\mathcal{L}_{NN\pi} = -g_{\pi NN}\bar{\psi}\gamma_\mu\gamma_5\boldsymbol{\tau}\cdot\partial^\mu\boldsymbol{\pi}\psi,$$

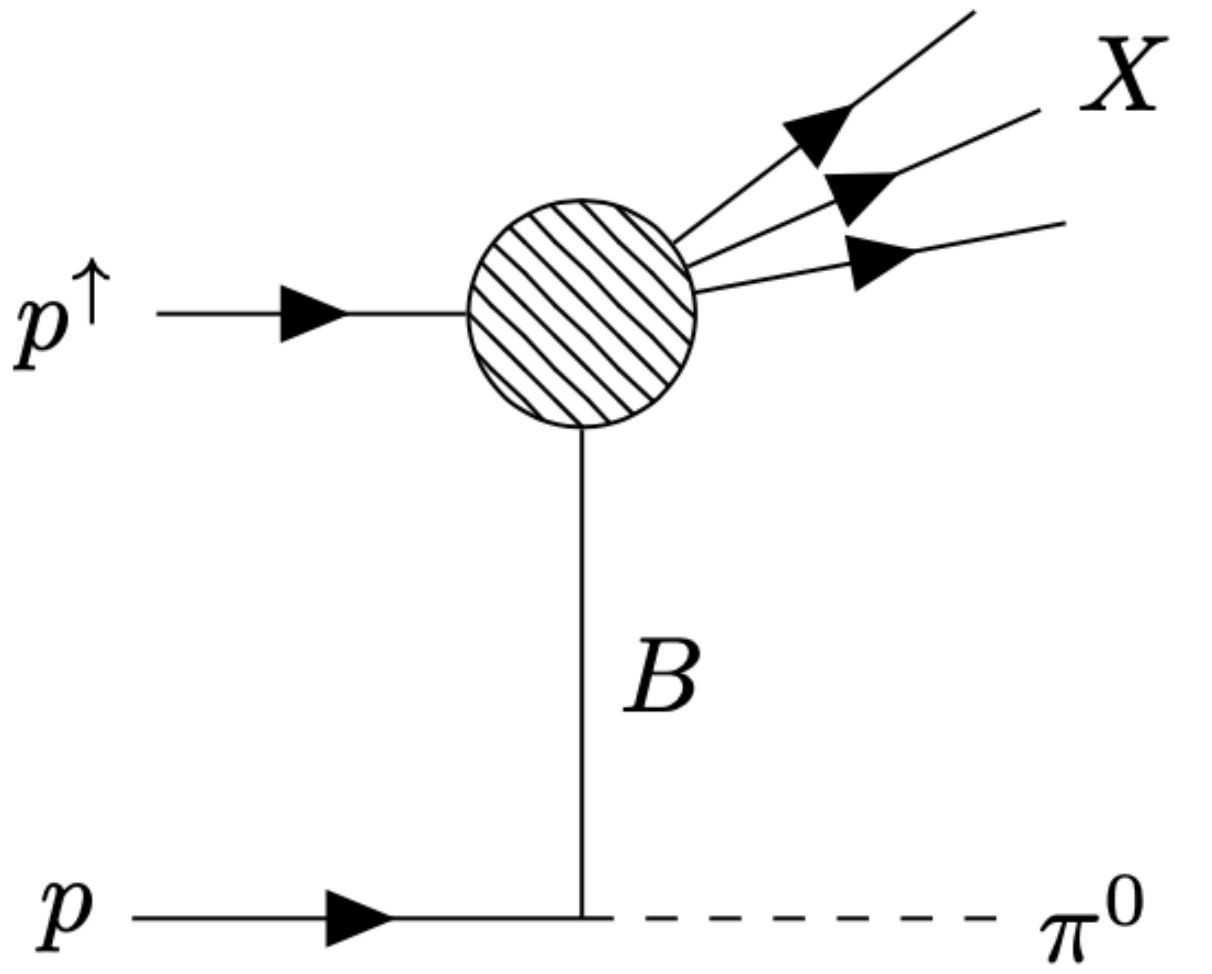
$$\mathcal{L}_{N\Delta\pi} = -g_{\pi N\Delta}\bar{\psi}^\mu_\Delta(g_{\mu\nu} + a\gamma_\mu\gamma_\nu)\boldsymbol{T}\cdot\partial^\nu\boldsymbol{\pi}\psi,$$

$$\mathcal{L}_{NN^*\pi} = -g_{NN^*\pi}\bar{\psi}_{N^*}\gamma_\mu\boldsymbol{\tau}\cdot\partial^\mu\boldsymbol{\pi}\psi,$$

$$\mathcal{L}_{N\Delta^*\pi} = ig_{\pi N\Delta^*}\bar{\psi}^\mu_{\Delta^*}(g_{\mu\nu} + a\gamma_\mu\gamma_\nu)\gamma_5\boldsymbol{T}\cdot\partial^\nu\boldsymbol{\pi}\psi.$$

Born amplitudes

$$A^{N}_{p\to\pi^0}(s,s') = g_{NN\pi}\bar{u}_N(s',q)\not{k}\gamma_5 u_p(s,p)\phi_N(p_T,x_F),$$
$$A^{\Delta}_{p\to\pi^0}(s,s') = g_{N\Delta\pi}\bar{u}^{\mu}_{\Delta}(s',q)(k_\mu + a\gamma_\mu\not{k})u_p(s,p)\phi_\Delta(p_T,x_F),$$
$$A^{N^*}_{p\to\pi^0}(s,s') = g_{NN^*\pi}\bar{u}_{N^*}(s',q)\not{k}u_p(s,p)\phi_{N^*}(p_T,x_F),$$
$$A^{\Delta'}_{p\to\pi^0}(s,s') = -ig_{N\Delta'\pi}\bar{u}^{\mu}_{\Delta}(s',q)(k_\mu + a\gamma_\mu\not{k})\gamma_5 u_p(s,p)\phi_{\Delta'}(p_T,x_F),$$



(Reggeized) Baryon amplitude :

$$\phi_B = \frac{\alpha'_B}{2}(1 \pm \exp\{-i\pi(\alpha_B(t) - J_B)\})\Gamma(J_B - \alpha_B(t))(1 - x_F)^{-\alpha_B(t)+J_B} A_{pB\to X}$$ [6]

provides the correct Regge poles.

$$\frac{s}{M_X^2} \approx (1 - x_F)^{-1}$$

Regge trajectories

$$\alpha_p(t) = -0.384 + 0.996t$$
$$\alpha_\Delta(t) = 0.157 + 0.892t$$
$$\alpha_{N^*}(t) = -1.763 + 0.967t$$
$$\alpha_{\Delta'}(t) = -1.50 + 1.05t$$

[6] M. Guidal et al. Nucl. Phys. A 627 (1997)

Single transverse spin asymmetry

Single transverse spin asymmetry(SSAs)

- SSAs

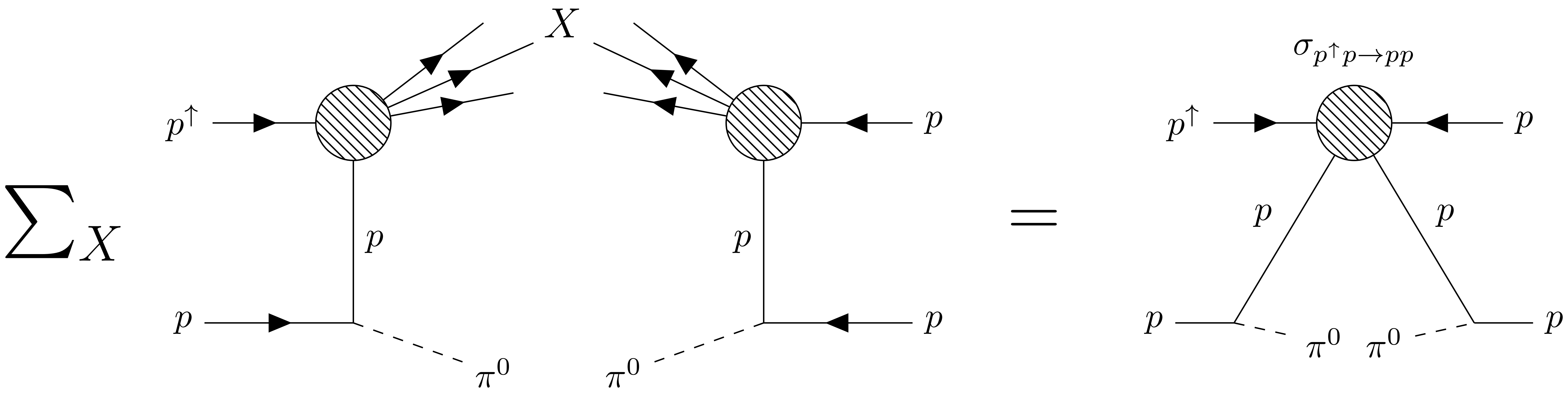
$$A_N = \frac{i(A^{+*}_{p\to\pi^0} A^{-}_{p\to\pi^0} - A^{-*}_{p\to\pi^0} A^{+}_{p\to\pi^0})}{|A^{+}_{p\to\pi^0}|^2 + |A^{-}_{p\to\pi^0}|^2}$$

  - In order to avoid producing nonzero A_N at $p_T=0$, we exclude the interference between natural and unnatural parity states.

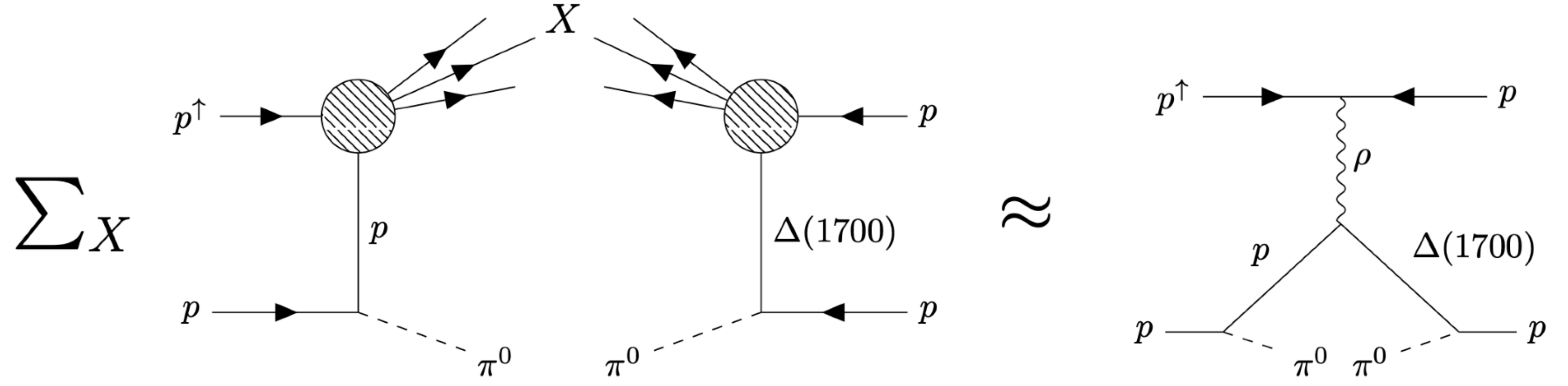
$$\text{Natural} = \{p, \Delta(1700)\}, \quad \text{Unnatural} = \{N^*(1535), \Delta(1232)\}$$

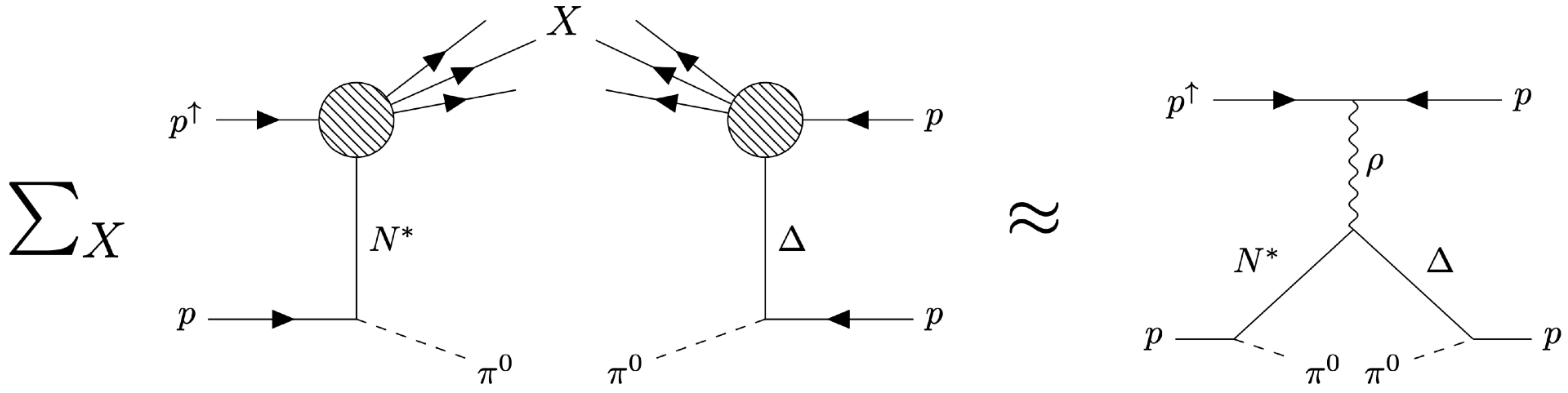
- The inclusive part of the interference terms can be approximated as the triple-Regge process.
- The inclusive part of the denominator is normalized in terms of the pp→pp differential cross section.

Normalization of the pp→X amplitude : $$\sum_X \left|A_{pp\to X}(M_X^2)\right|^2 \approx 4\sqrt{\pi} M_X^2 \sqrt{\frac{d\sigma(pp\to pp)}{dt}}$$

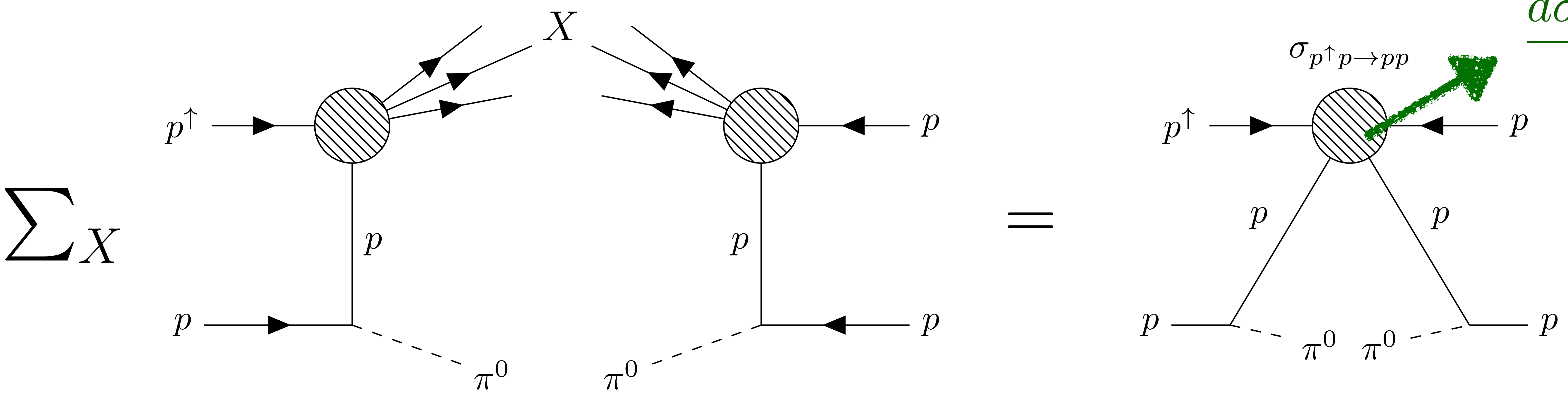


Triple-Regge diagrams :





Normalization of the pp→X amplitude : $\sum_X \left|A_{pp\to X}(M_X^2)\right|^2 \approx 4\sqrt{\pi} M_X^2 \sqrt{\frac{d\sigma(pp\to pp)}{dt}}$



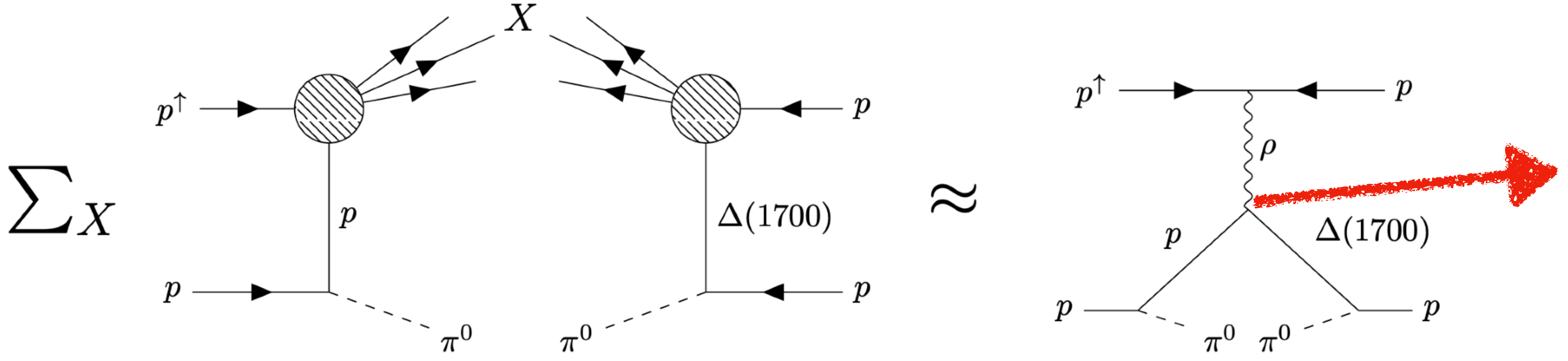
$$\frac{d\sigma(pp\to pp)}{dt}(p_T^2, x_F) = Ae^{Bt}$$

$$A = B\sigma_{\rm el} = 201.5\ \mathrm{mb/GeV^2}$$

$$B = 15.5\ \mathrm{GeV^{-2}}$$ [7]

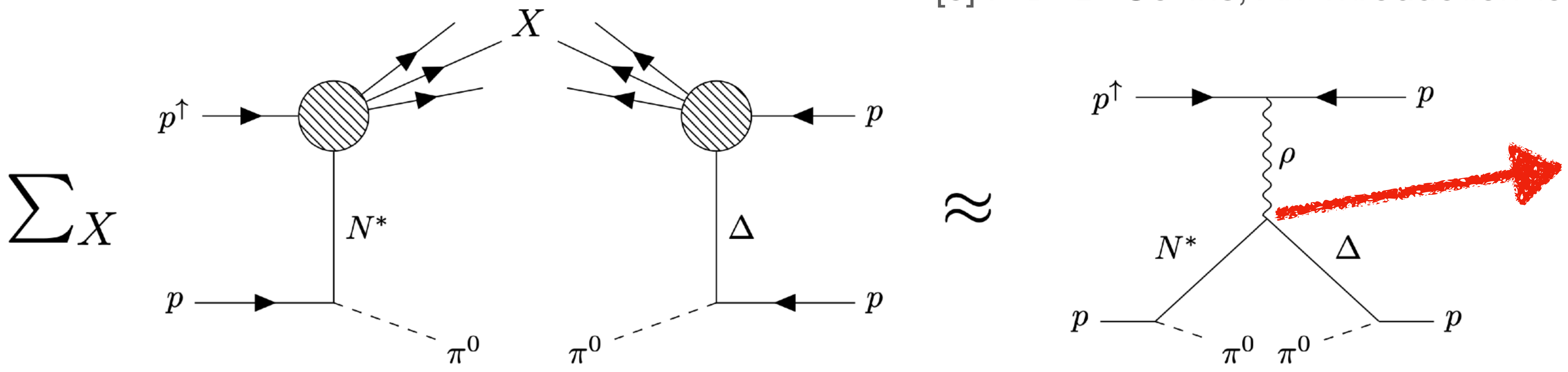
[7] T. Csörgő (TOTEM Collab.) EPJ Web Conf. 205 (2019) 06004

Triple-Regge diagrams :



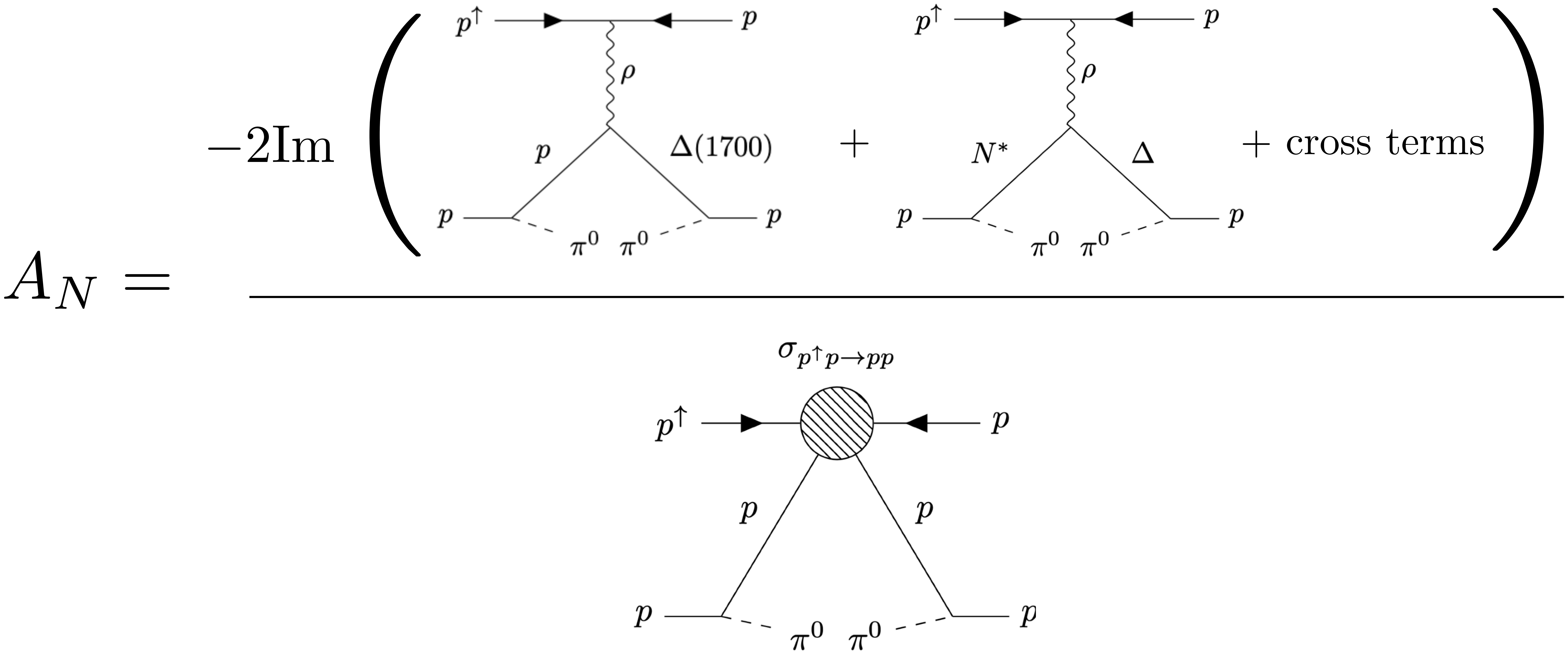
$$G_{p\Delta^*}(t) = G_{p\Delta^*}(0)e^{b_{p\Delta^*}t}$$ [8]

[8] P. D. B. Collins, An Introduction to Regge Theory and High Energy Physics



$$G_{N^*\Delta}(t) = G_{N^*\Delta}(0)e^{b_{N^*\Delta}t}$$

- Diagrammatic representation of the SSAs for the pion production



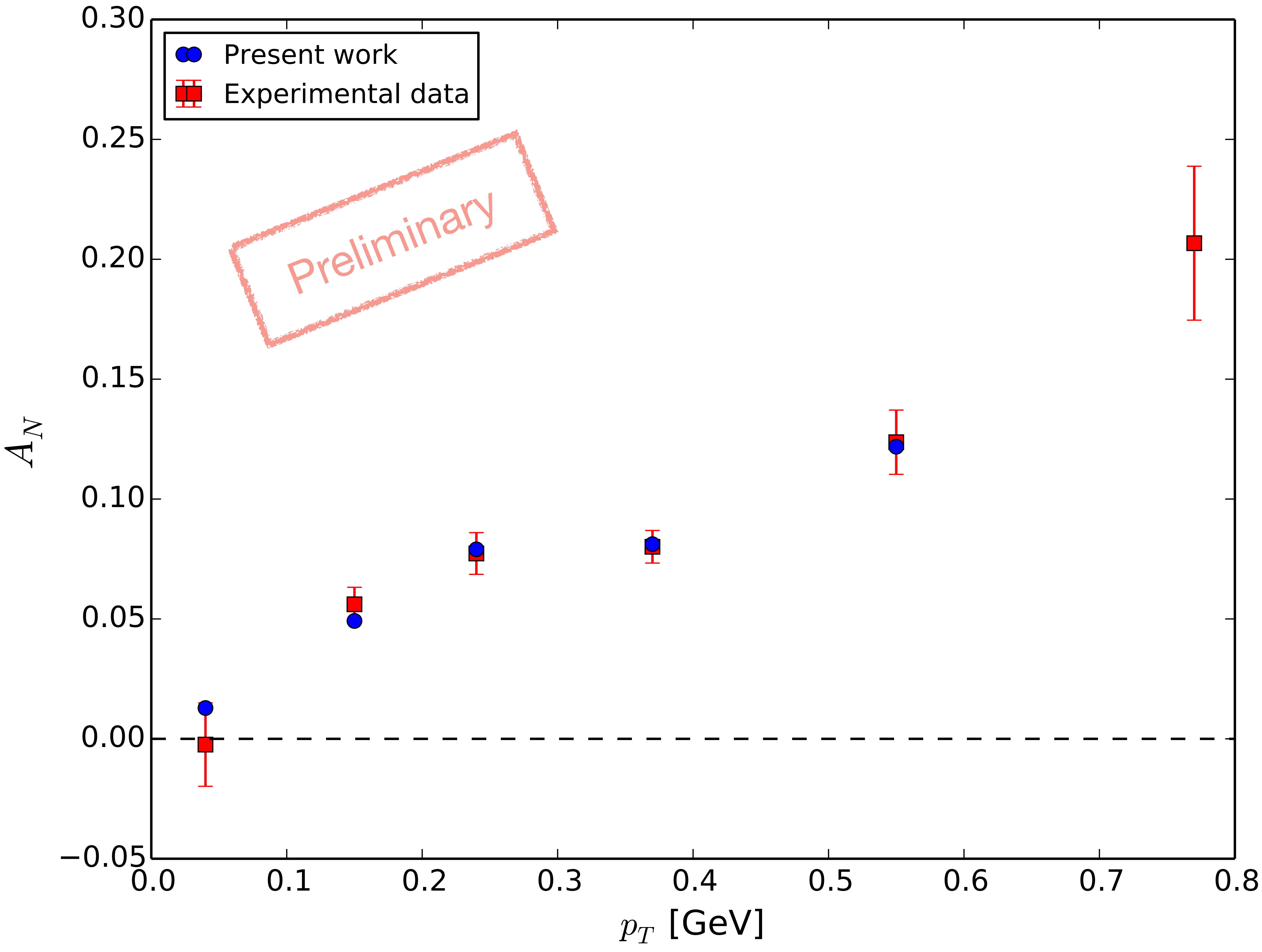
Results

SSAs vs p_T

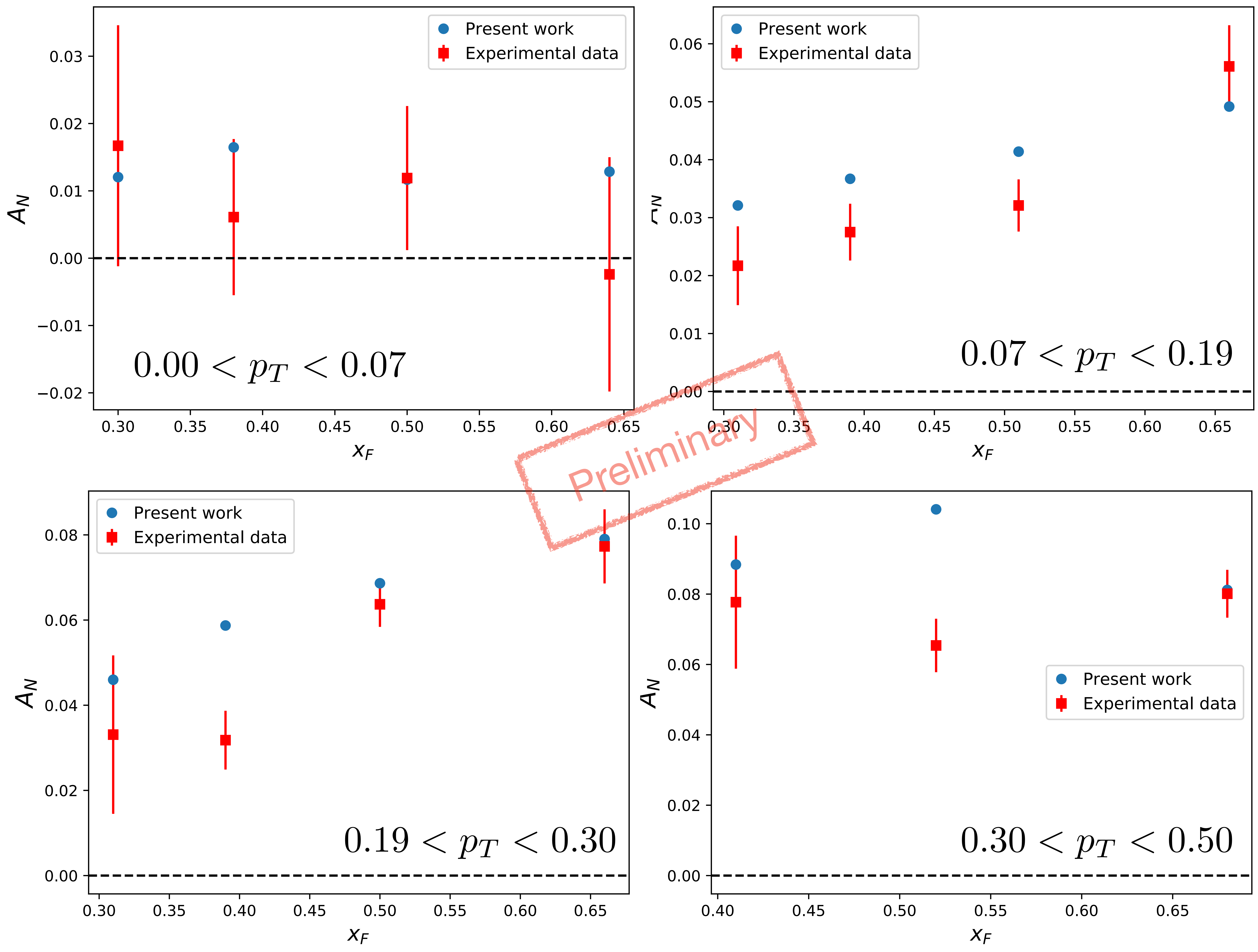
$$G_{p\Delta^*}(0) = G_{N^*\Delta}(0) = 1\ \mathrm{mb}$$

$$b_{p\Delta^*}(0) = 5.5\ \mathrm{GeV}^{-2}$$

$$b_{N^*\Delta}(0) = 5.7\ \mathrm{GeV}^{-2}$$



SSAs vs x_F



Present work
Experimental data
$0.00 < p_T < 0.07$
$0.07 < p_T < 0.19$
$0.19 < p_T < 0.30$
$0.30 < p_T < 0.50$
A_N
x_F
Preliminary

Summary

Summary

- We investigated the SSAs for forward neutral pion through the Reggeon exchange processes.
- The interference between Reggeon exchanges are approximated as the triple-Regge processes.
- The pp differential cross section and the triple-Regge couplings are parametrized due to the lack of experimental data.
- Our results match the RHICf data of both transverse momentum and x_F distribution quite well.
- The spin asymmetry can be explained by Regge exchange processes.
- We will improve the transverse momentum distribution by adopting other processes in the denominator.

Thank you