Single transverse spin asymmetry of very forward neutral pion

2022 RHICf Collaboration Meeting

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Outline

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

Introduction

Introduction

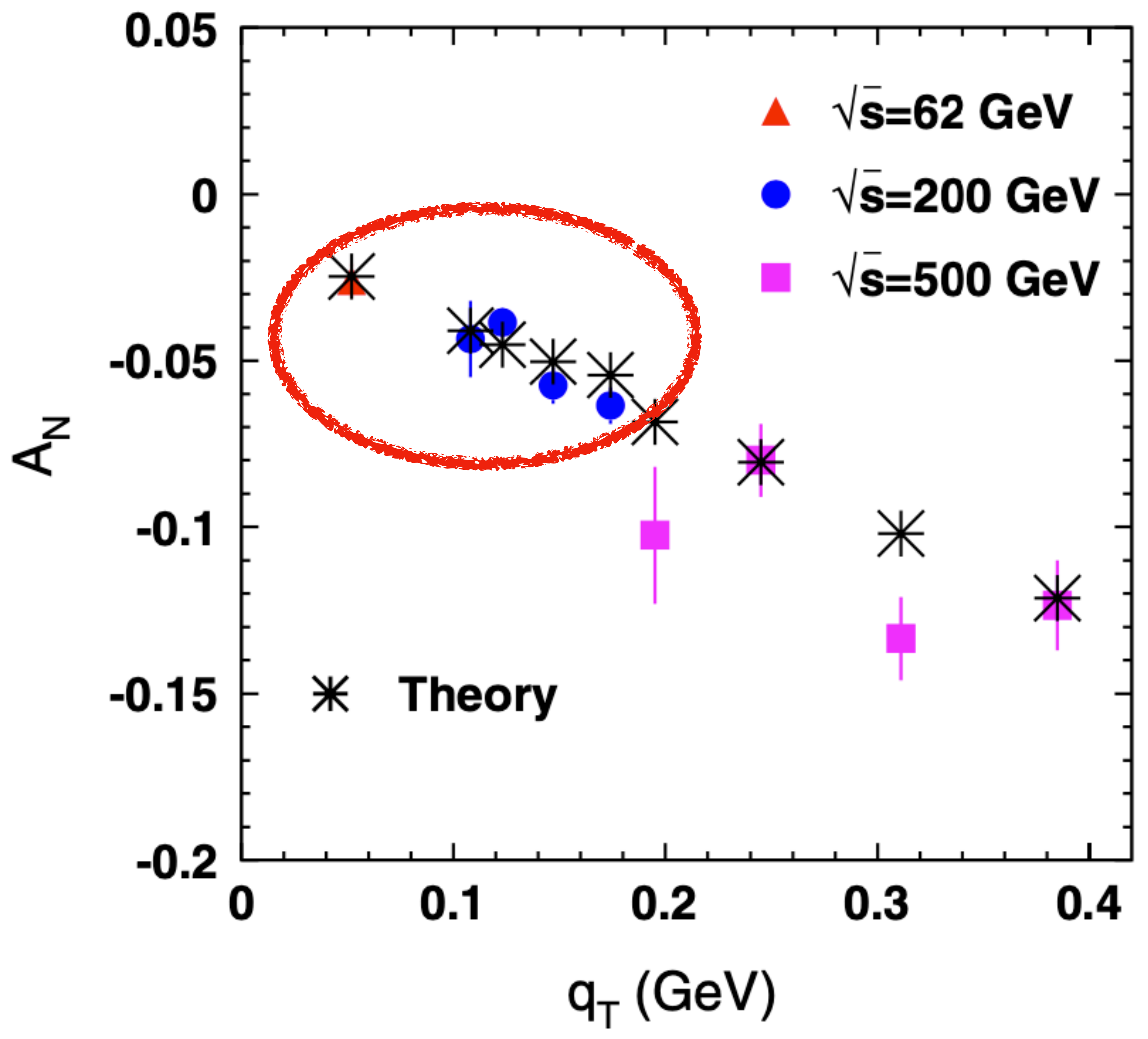
- Single transverse spin asymmetry(SSAs) is one of the interests in high energy reactions, but it has not been well understood yet.
- The significant A_N for pion production was reported for the first time in 1976 [1].
- The SSAs for various very-forward productions(π,n,γ) was measured in 2007 [2] and can not be explained by pQCD calculations(TMD, twist-3, etc).
- Sizable p_T and x_F distributions of A_N for very forward neutron with $\sqrt{s}$ = 62, 210 and 500 GeV was also measured by PHENIX Collaboration [3].
- Recent observations indicate that the diffractive process might account for a large fraction of A_N in the forward direction.

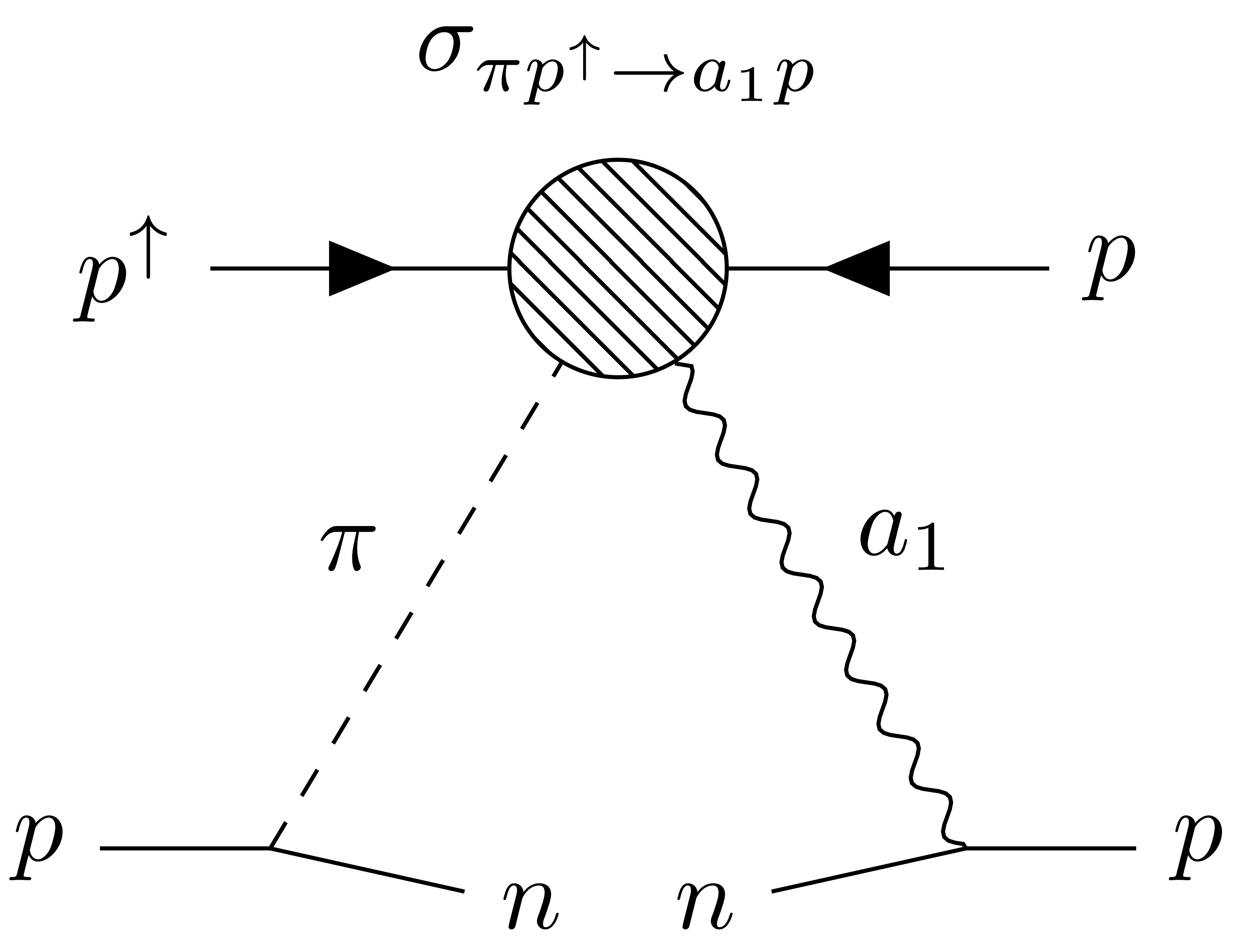
SSAs : $$A_N = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$

Spin direction of the polarized proton beam

[1] R. Klem et al. Phys. Rev. Lett. 36 (1976) 929
[2] Y. Fukao *et al.*, Phys. Lett. B650 (2007) 325
[3] K. Tanida *et al.*(PHENIX Collaboration), J.Phys.Conf.Ser.295(2011)

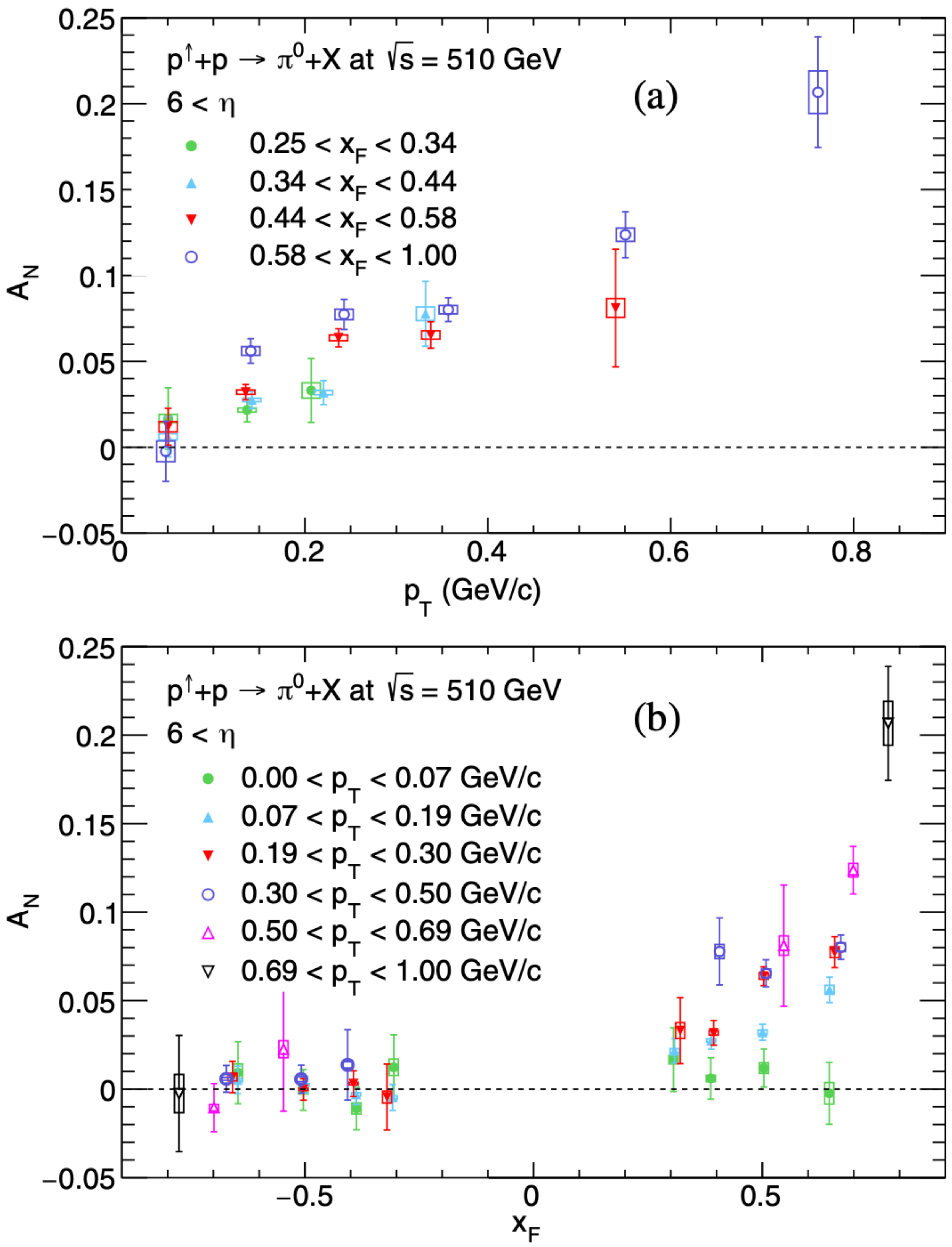
- A theoretical approach to the SSAs for the very forward neutron production was successfully achieved by OBE exchange based on Regge theory [4].

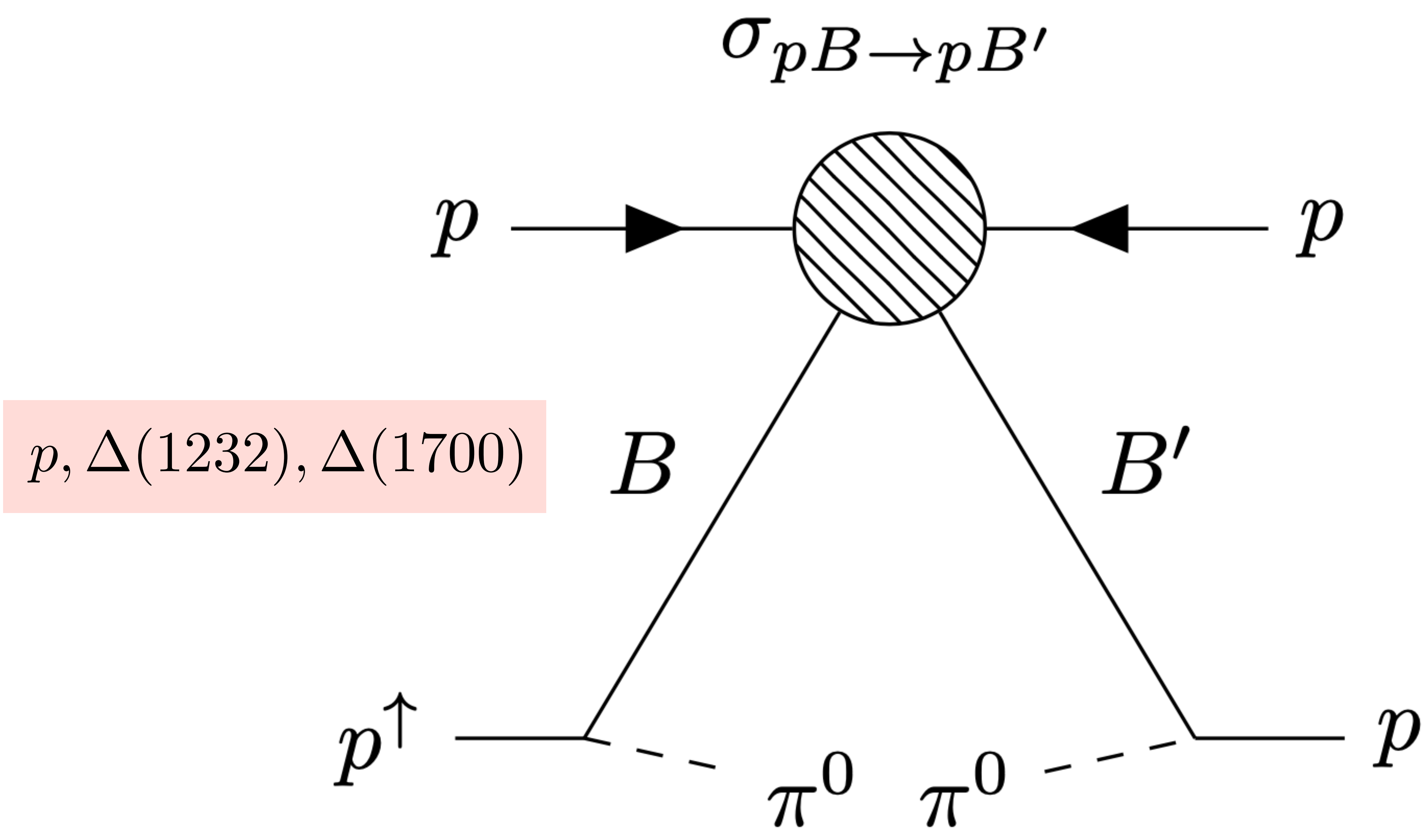




- The contribution of the π-a_1 interference for A_N matches the experiment results very well.

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





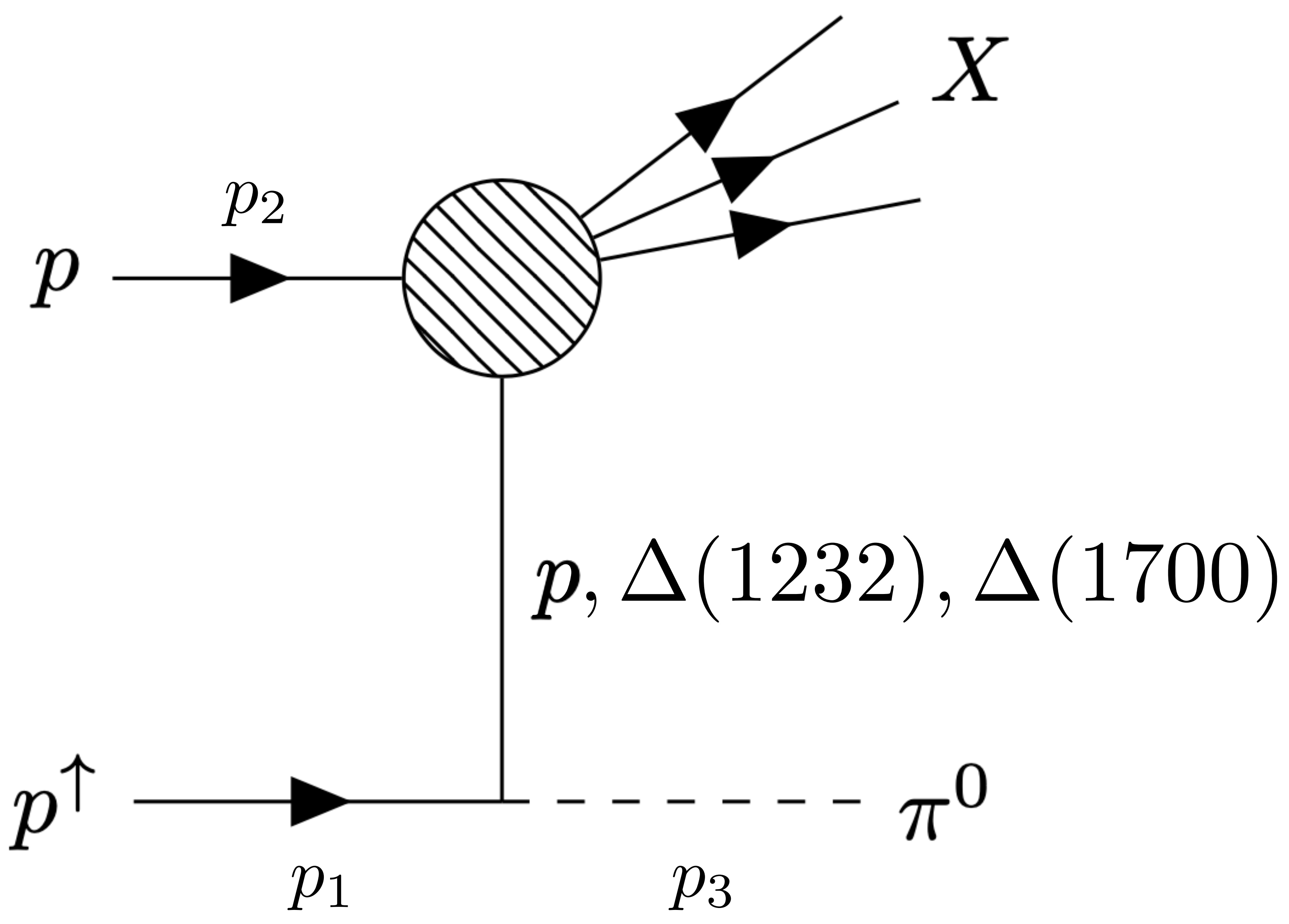
- We take into account the interferences between the proton and *Δ*(1700).
- The p-*Δ*(1700)-*π* triple-Regge process plays an essential role for production of TSSA.

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

Born amplitudes

Born approximation

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



- Kinematics for single diffractive(SD) process

$$p_1 = (E_1, 0, 0, p_z), \quad p_2 = (E_2, 0, 0, -p_z), \quad p_3 = (E_3, \boldsymbol{p}_T, p'_z)$$

$$M_X^2 \equiv (p_1 + p_2 - p_3)^2$$

$$x_F \simeq 1 - \frac{M_X^2}{s}, \quad t \simeq (1 - x_F) m_N^2 - \frac{\mathbf{p}_T^2}{x_F}$$

The SD processes can be described in terms of s, x_F, and p_T^2.

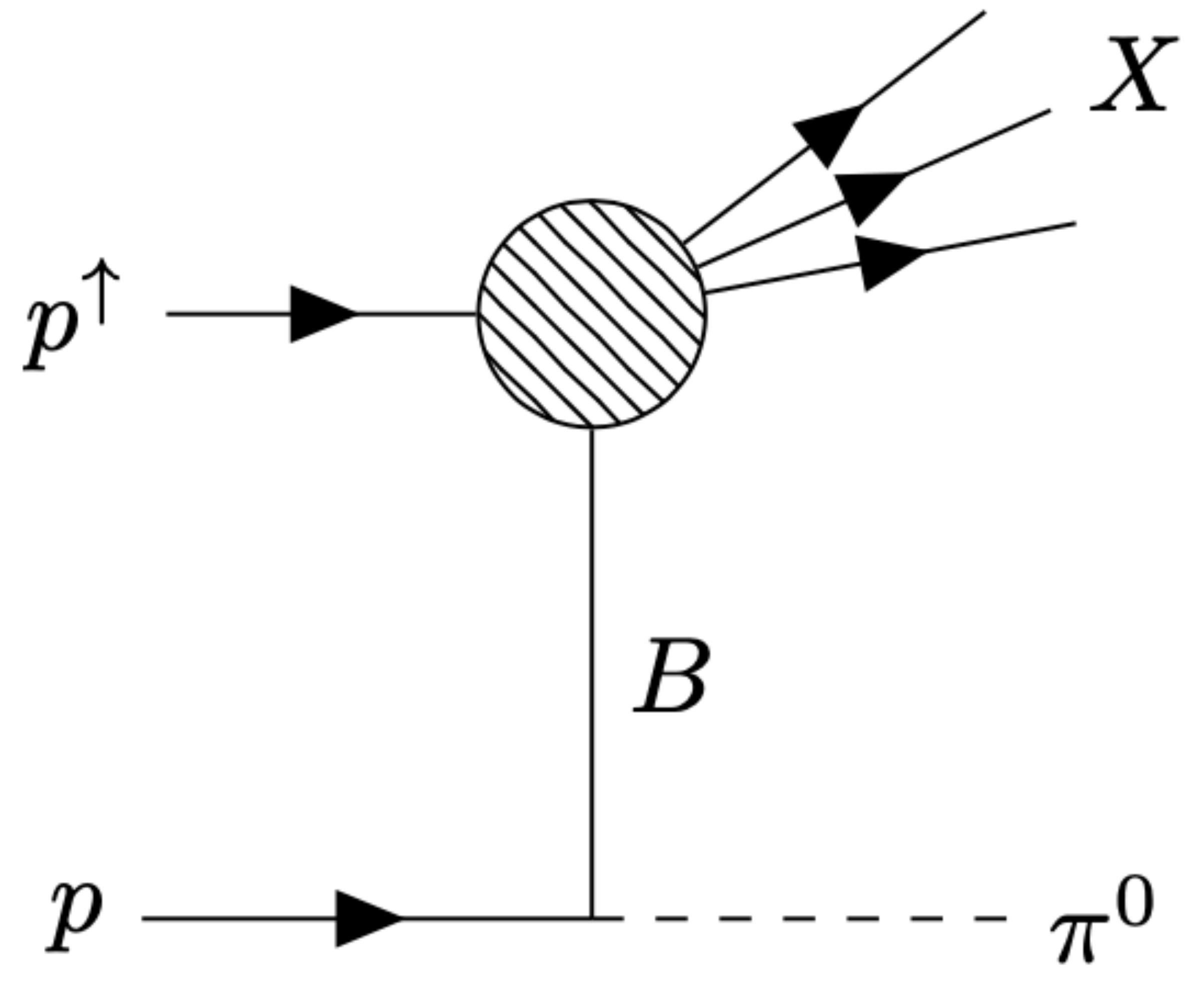
- Effective Lagrangians

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

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

Born amplitudes

$$A^N_{p\to\pi^0}(s,s') = g_{NN\pi}\beta_N(s,s';p_T)\phi_N(p_T,x_F),$$
$$A^\Delta_{p\to\pi^0}(s,s') = g_{N\Delta\pi}\beta_\Delta(s,s';p_T)\phi_\Delta(p_T,x_F),$$
$$A^{\Delta^*}_{p\to\pi^0}(s,s') = g_{N\Delta^*\pi}\beta_{\Delta^*}(s,s';p_T)\phi_{\Delta^*}(p_T,x_F).$$



(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

$$\alpha_p(t) = -0.30 + 0.96t,$$
$$\alpha_\Delta(t) = 0.16 + 0.89t,$$
$$\alpha_{\Delta^*}(t) = -1.30 + 0.96t$$

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

Single transverse spin asymmetry

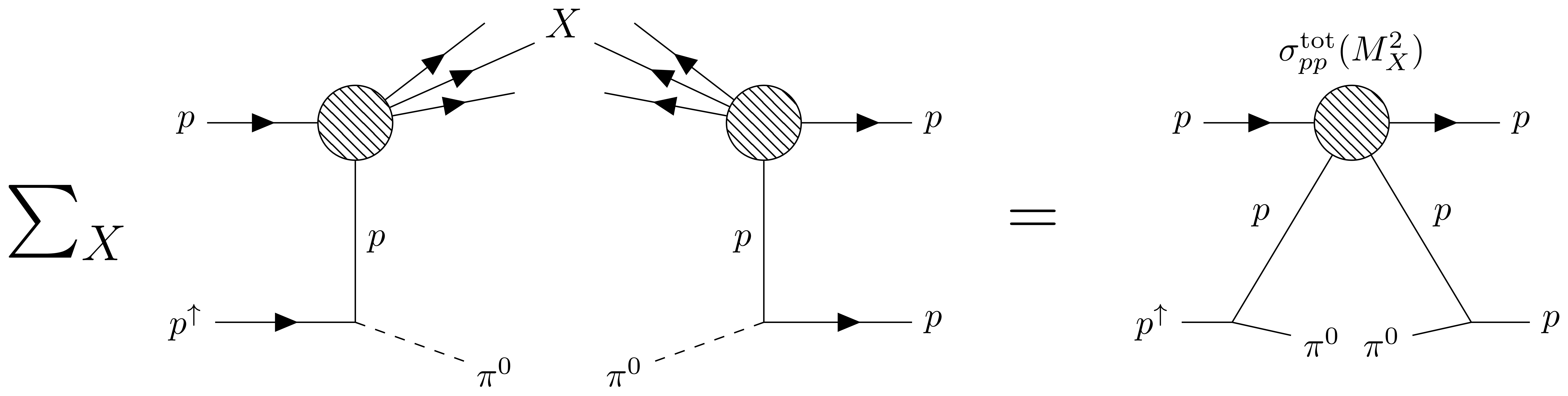
Single transverse spin asymmetry(SSAs)

- SSAs

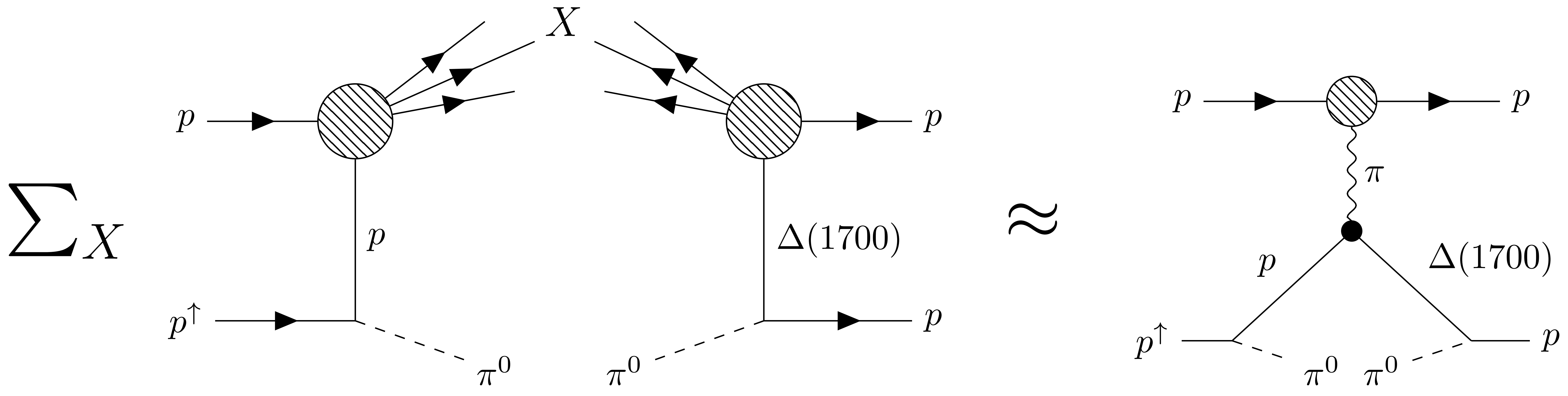
$$A_N = \frac{i(A^{+*}_{p\to\pi^0} A^{-}_{p\to\pi^0} - A^{-*}_{p\to\pi^0} A^{+}_{p\to\pi^0})}{|A^{+}_{p\to\pi^0}|^2 + |A^{-}_{p\to\pi^0}|^2}$$

- In order to avoid producing nonzero A_N at $p_T=0$, we exclude the interference between natural and unnatural parity states: $\mathrm{Natural} = \{p, \Delta(1700)\}$
- 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 and pΔ→pΔ differential cross sections.

Normalization of the pp→X amplitude : $\sum_X \left|A_{pp\to X}(M_X^2)\right|^2 = M_X^2 \sigma_{pp}^{\rm tot}(M_X^2)$



The triple-Regge diagram:

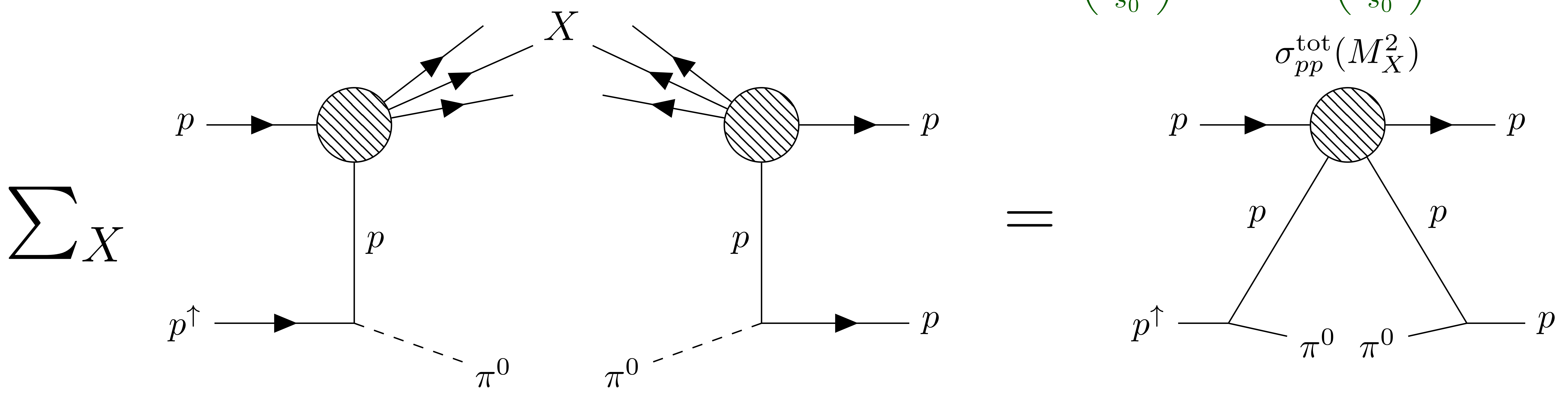


[7] J.R. Cudell *et al.* (COMPETE Collaboration) *Phys.Rev.Lett.* 89 (2002) 201801

Normalization of the pp→X amplitude : $\sum_X \left| A_{pp\to X}(M_X^2) \right|^2 = M_X^2 \sigma_{pp}^{\mathrm{tot}}(M_X^2)$

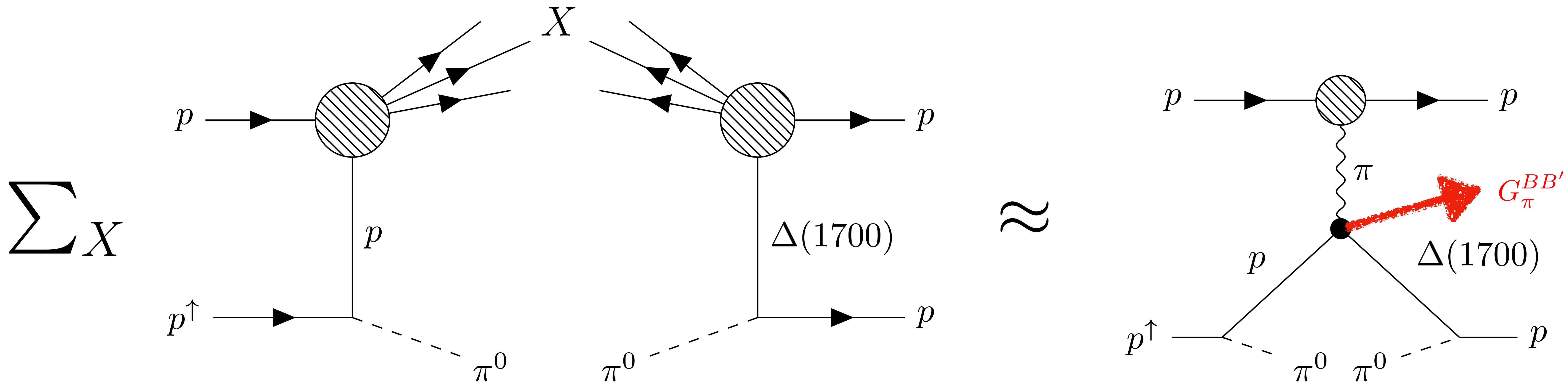
[7]

$$\sigma_{pp}^{\mathrm{tot}}(M_X^2) = 42.6 \left(\frac{M_X^2}{s_0}\right)^{-0.46} - 33.4 \left(\frac{M_X^2}{s_0}\right)^{-0.545} + 35.5 + 0.307 \log^2 \left(\frac{M_X^2}{29.1}\right) \quad [\mathrm{mb}]$$



pΔ scattering : $C_{\Delta\Delta} \equiv \dfrac{\sigma_{p\Delta}^{\mathrm{tot}}(M_X^2)}{\sigma_{pp}^{\mathrm{tot}}(M_X^2)}$

The triple-Regge diagram:

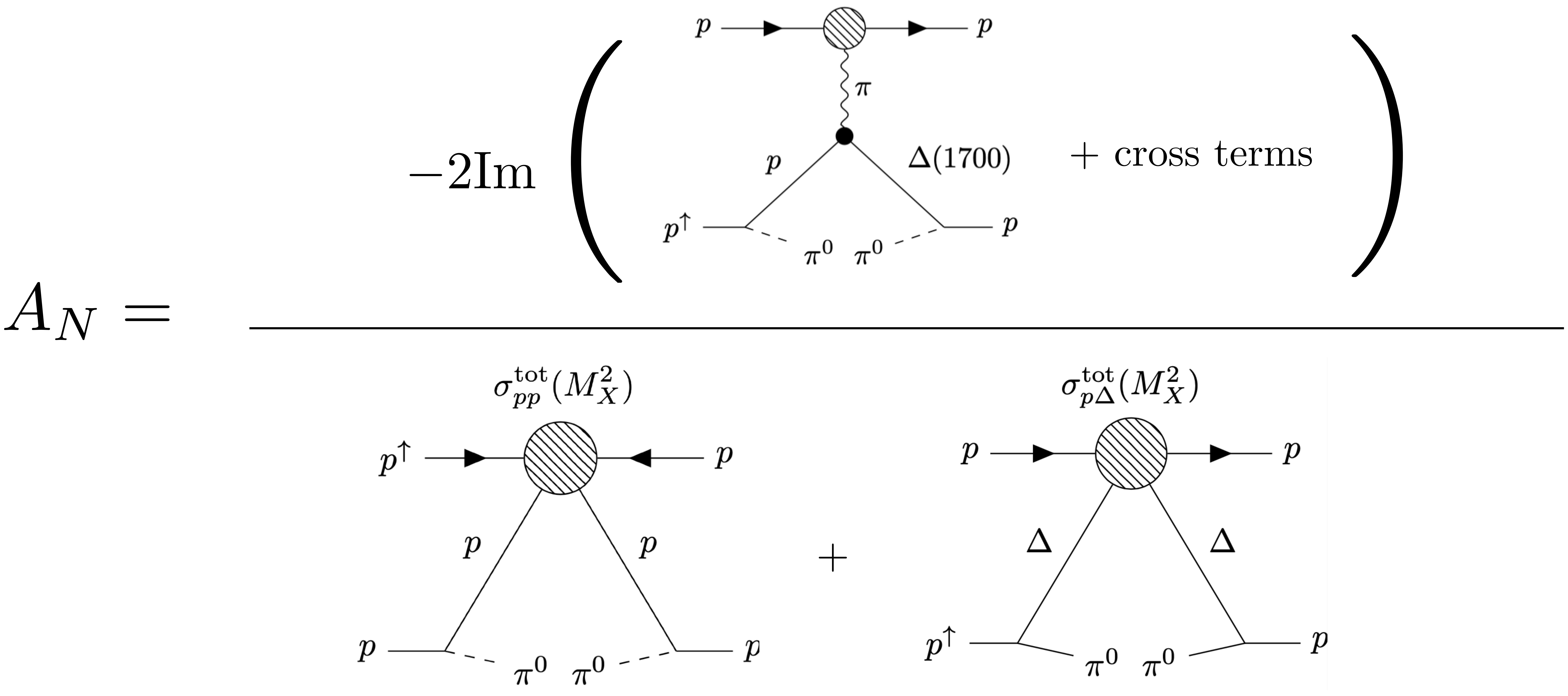


[8]

$$G_\pi^{BB'}(t) = g_\pi^{BB'} \frac{|t|}{m_\pi^2} \exp\left\{-b_\pi^{BB'}|t|\right\}.$$

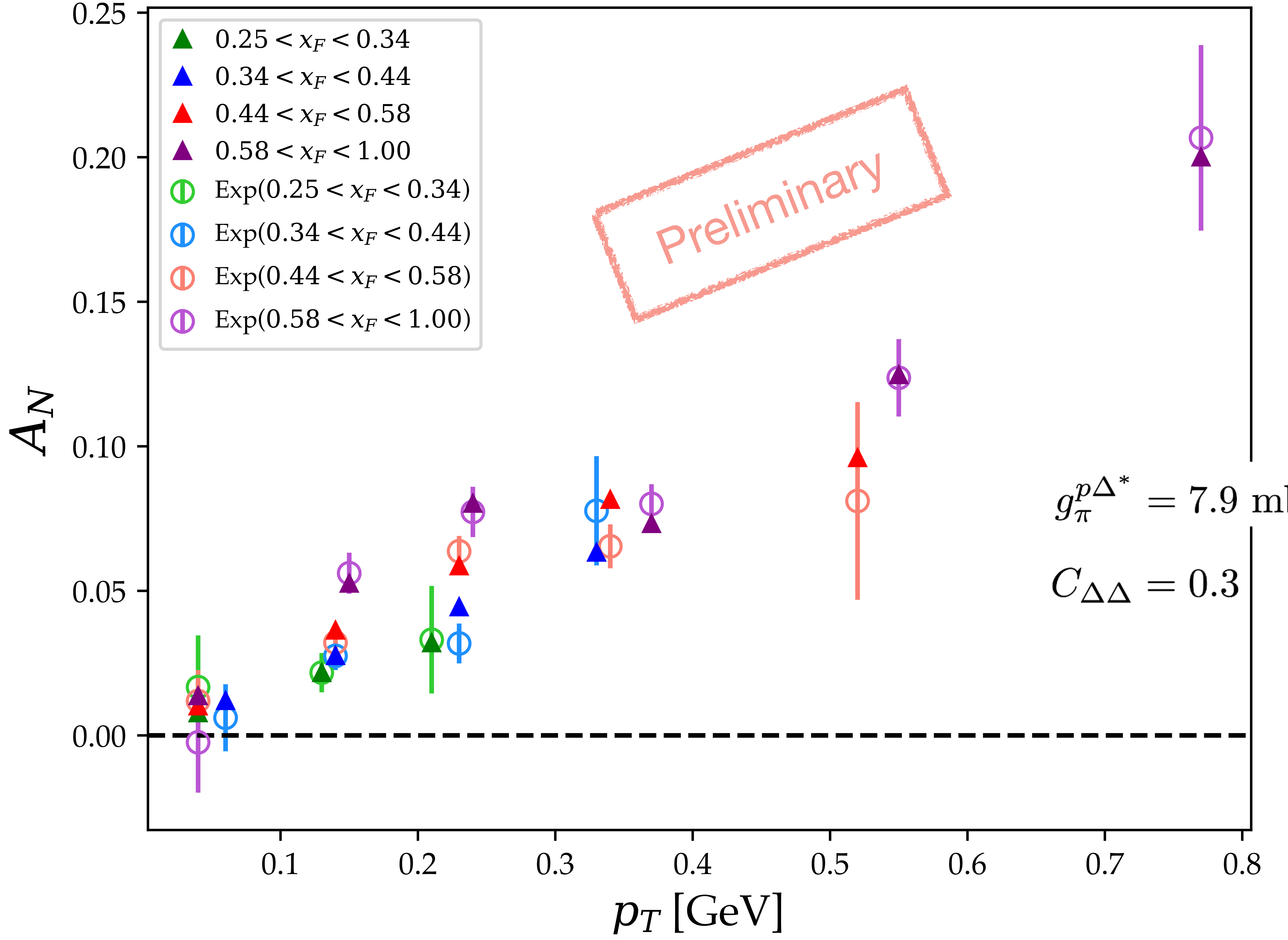
[8] P. D. B. Collins, An Introduction to Regge Theory and High Energy Physics

- Diagrammatic representation of the SSAs for the pion production



Results

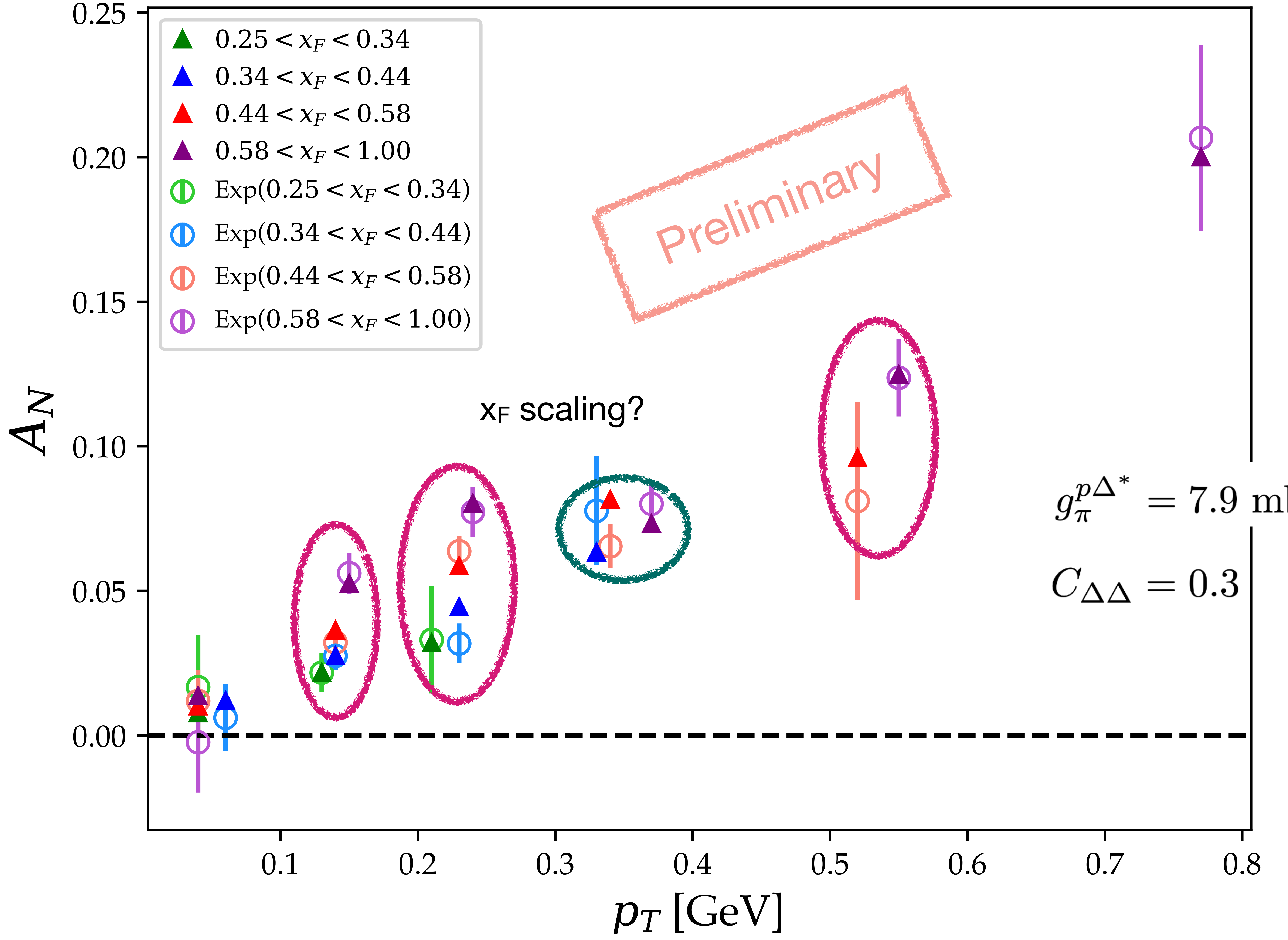
SSAs vs p_T



$$g_\pi^{p\Delta^*} = 7.9 \text{ mb TeV}^2, \quad b_\pi^{p\Delta^*} = 4 \text{ GeV}^{-2}$$

$$C_{\Delta\Delta} = 0.3$$

SSAs vs p_T



$$g_\pi^{p\Delta^*} = 7.9 \text{ mb TeV}^2, \quad b_\pi^{p\Delta^*} = 4 \text{ GeV}^{-2}$$

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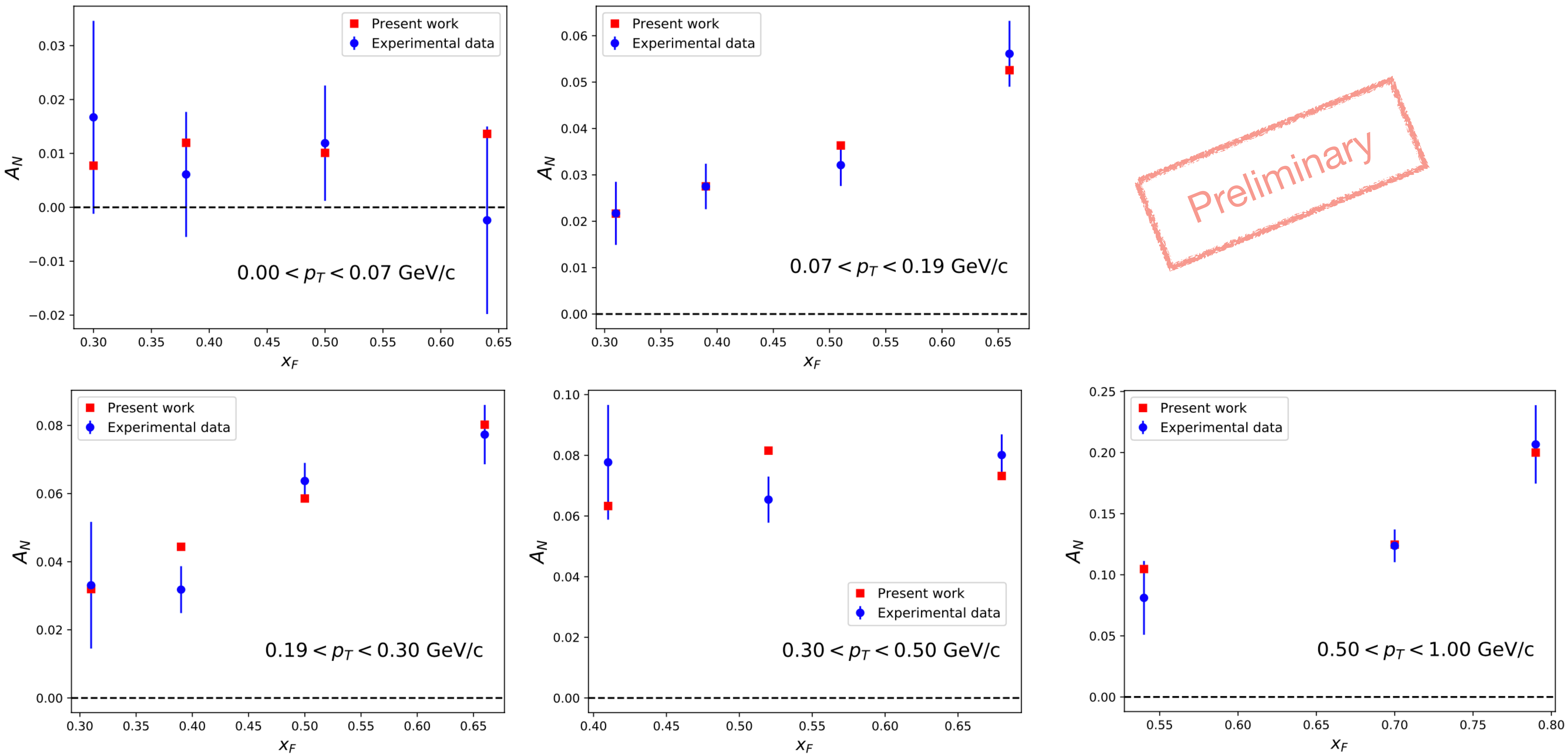
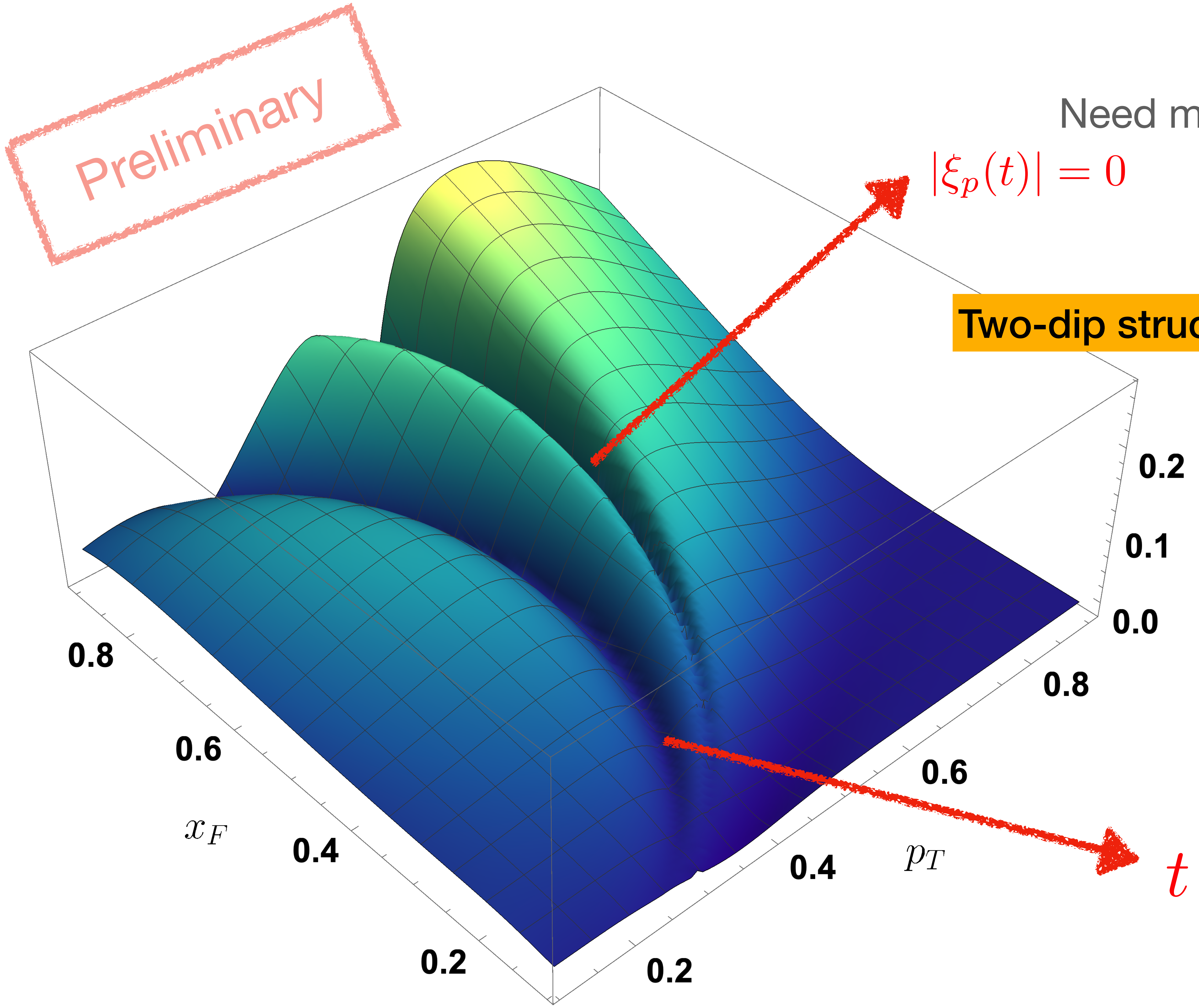
SSAs vs x_F



Present work
Experimental data
$0.00 < p_T < 0.07$ GeV/c
$0.07 < p_T < 0.19$ GeV/c
$0.19 < p_T < 0.30$ GeV/c
$0.30 < p_T < 0.50$ GeV/c
$0.50 < p_T < 1.00$ GeV/c
A_N
x_F
Preliminary

3D plot

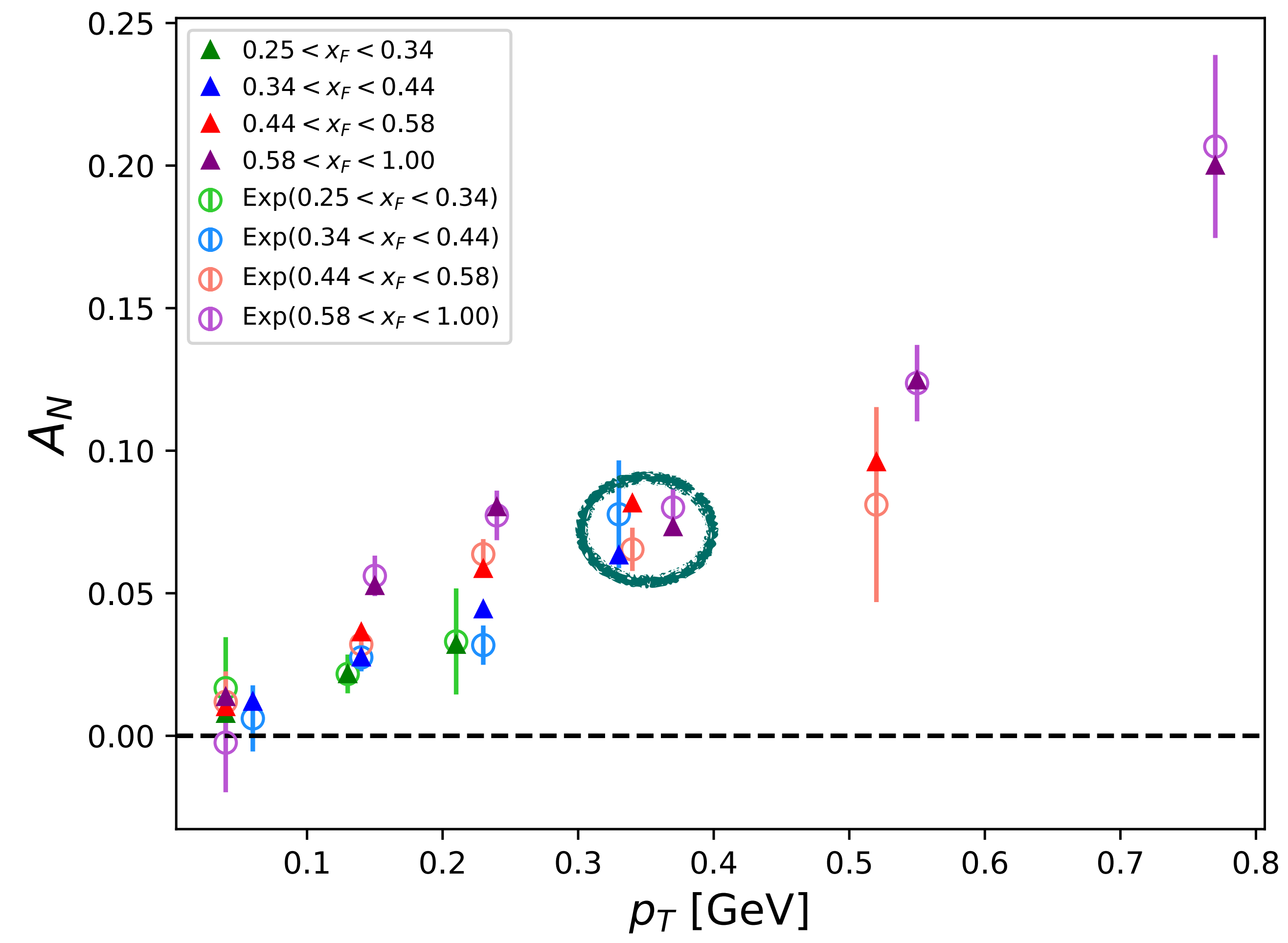
Need more data points at 0.4 < p_T < 0.5 GeV.



$t = 0$

Two-dip structure

Explain the vanishing of x_F scaling effect at a specific p_T range.



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 pΔ total cross sections and the triple-Regge coupling 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.
- We found that the very forward neutral pion A_N is produced through the diffractive processes.

Thank you