The Pomeron spin-flip and its measurements

Michal Krelina
Boris Kopeliovich

Universidad Técnica Federico Santa María
&
Centro Científico Tecnológico de Valparaíso-CCTVal

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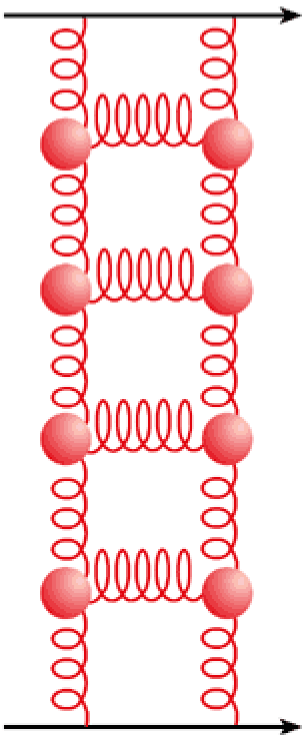
Outline

- Motivation & introduction
- Pomeron spin-flip in *pp* collisions
- Nuclear target case
- Gold nucleus puzzle
- Conclusions



Pomeron and its spin?

- **Pomeron** and differential cross section prediction is one of triumph of Regge theory in 1973.
- However, there is not *general agreement* about the **pomeron spin**.
- In community is a general agreement about the dominant spin non-flip hadronic interaction.
- But, there is no theoretical reason to think that the spin-flip component of the **Pomeron** is zero.
  - If we assume **Pomeron** as Regge pole, we get zero spin asymmetry since the same phase
  - Even if we assume different phase (no Regge pole), we need spin-flip interaction to vary steeply with energy to distinguish them

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Spin-flip Pomeron interaction?

Our goal:

Study the **spin-flip Pomeron** interaction.

Our method:

Study of the single spin asymmetry $A_N(t)$ in the CNI region.

$$A_N \frac{d\sigma}{dt} = 2\mathrm{Im}[\phi_{++}\phi_{+-}^*]$$

$$\frac{d\sigma}{dt} = |\phi_{++}|^2 + |\phi_{+-}|^2$$

ϕ_{++} - Non-flip amplitude

ϕ_{+-} - Spin-flip amplitude

Why CNI region?

Let's assume that **Pomeron** can flip the spin.

Then, due to the same phase factor the hadronic single spin asymmetry will be zero anyway.

Solution is the interference with EM amplitude.

CNI (Coulomb-nuclear interference) region = a kinematical region of very low 4-momentum transfer squared, *-t,* where the interference electromagnetic-hadron terms dominates

B.Z.Kopeliovich, B.G.Zakharov, Phys.Lett. **B**226 (1989) 156

How to calculate it?

Coulomb spin-flip and non-flip amplitude are known, as well as no-flip hadronic amplitude from data.

$$\phi^h = \phi_{++}\left(1 + i\frac{\sqrt{-t}}{m_N}\vec{\sigma}\cdot\vec{n}\, r_5\right)$$

Spin-flip hadron amplitude can be parametrized by factor

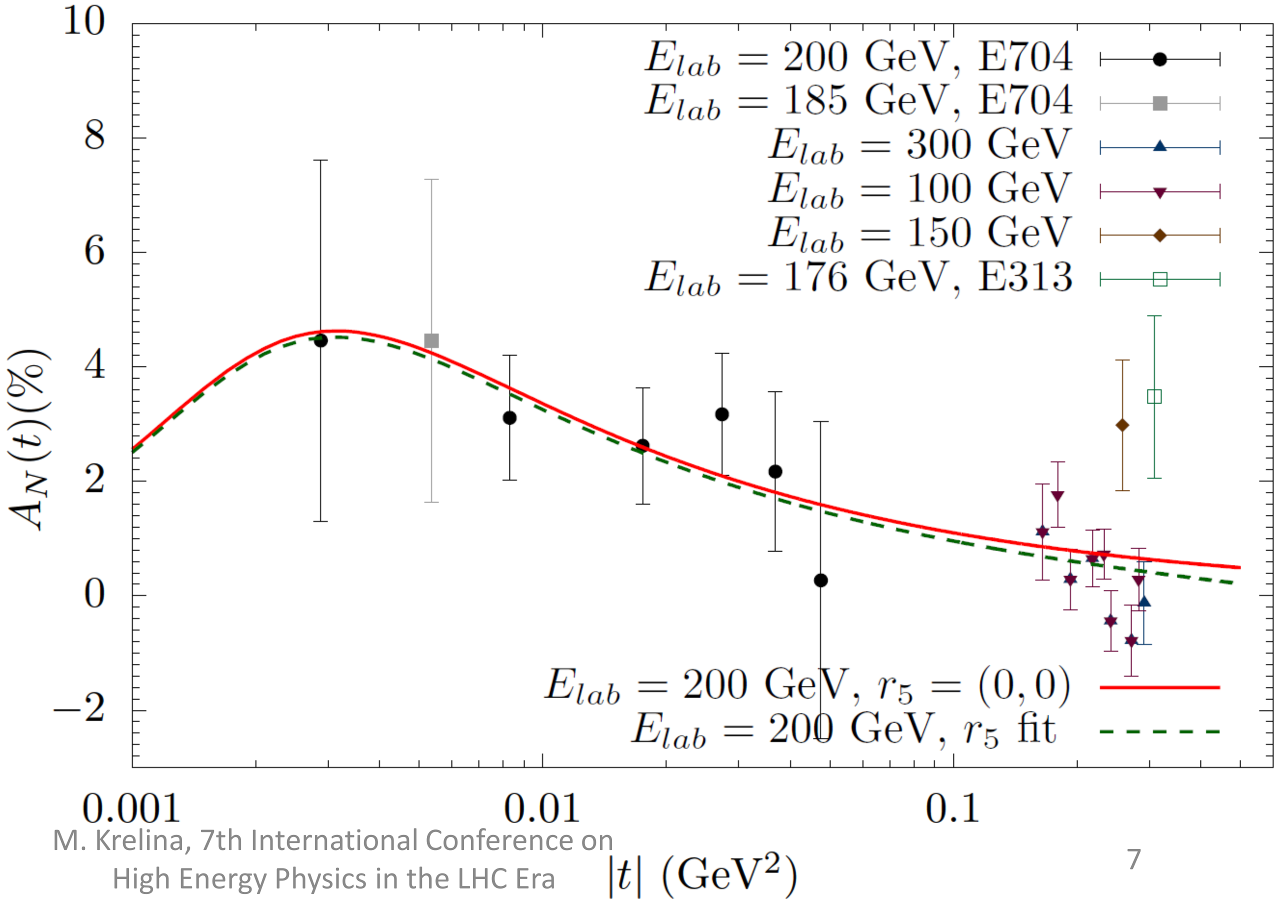
$$r_5 = \frac{m_p\, \phi_{+-}}{\sqrt{-t}\, \mathrm{Im}\, \phi_{++}}$$

Assuming $r_5 = 0$ the asymmetry *$A_N(t)$* can be fully predicted.

L.I.Lapidus & B.Kopeliovich Sov. J. Nucl. Phys. 19(1974) 114

Problems with spin-flip Pomeron in *pp* at low energies

1) Contribution from Reggeons, $r_5 = r_{5,\mathbb{P}} + r_{5,\mathbb{R}}$ $\Rightarrow$ small r_5 does not mean small $r_{5,\mathbb{P}}$…
2) Large experimental uncertainties

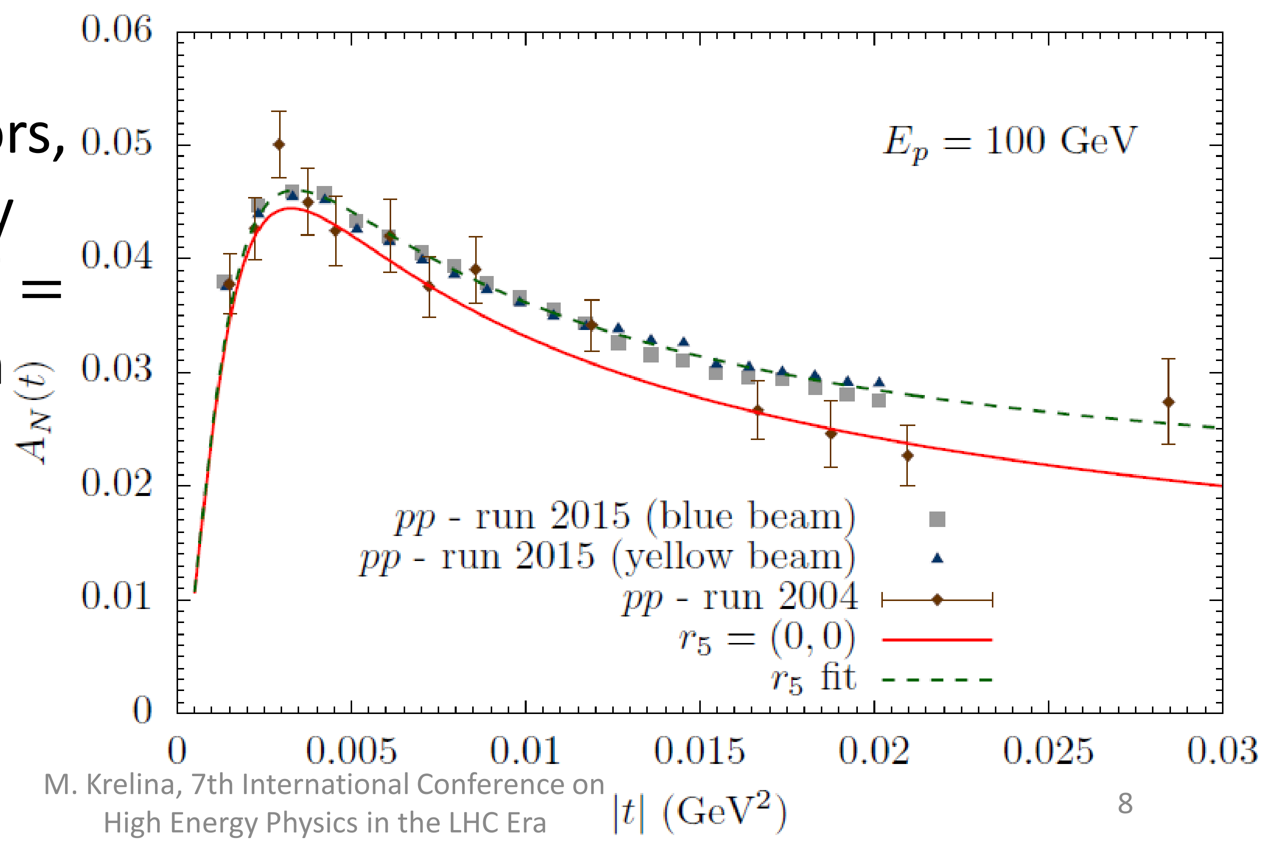


pp data from H-JET

Combined r_5 fit result

$$r_5 = -0.0073 \pm 0.0032 - i0.0289 \pm 0.0128$$

Small experimental errors, however still low energy ($E_{LAB} = 100$ GeV $\approx \sqrt{s} =$ 14 GeV) → contribution from Reggeons



What next?

We want to suppress Reggeons

⇒ Higher energy

⇒ **Nuclear targets**

Why nuclear target?

Two motivations:

Polarimetry – was actual 10 years ago, expected smaller errors at *pA* elastic scattering.

Reggeons – experimental data mostly from RHIC ($E_{LAB} = 100$ GeV $\approx \sqrt{s} = 14$ GeV). Expected a contribution mainly from the iso-vector Reggeons.

If we use the nucleus with zero isospin (e.g. Carbon), these Reggeons are excluded. For other nuclei are suppressed as $1/A$.

B. Kopeliovich, hep-ph/9801414

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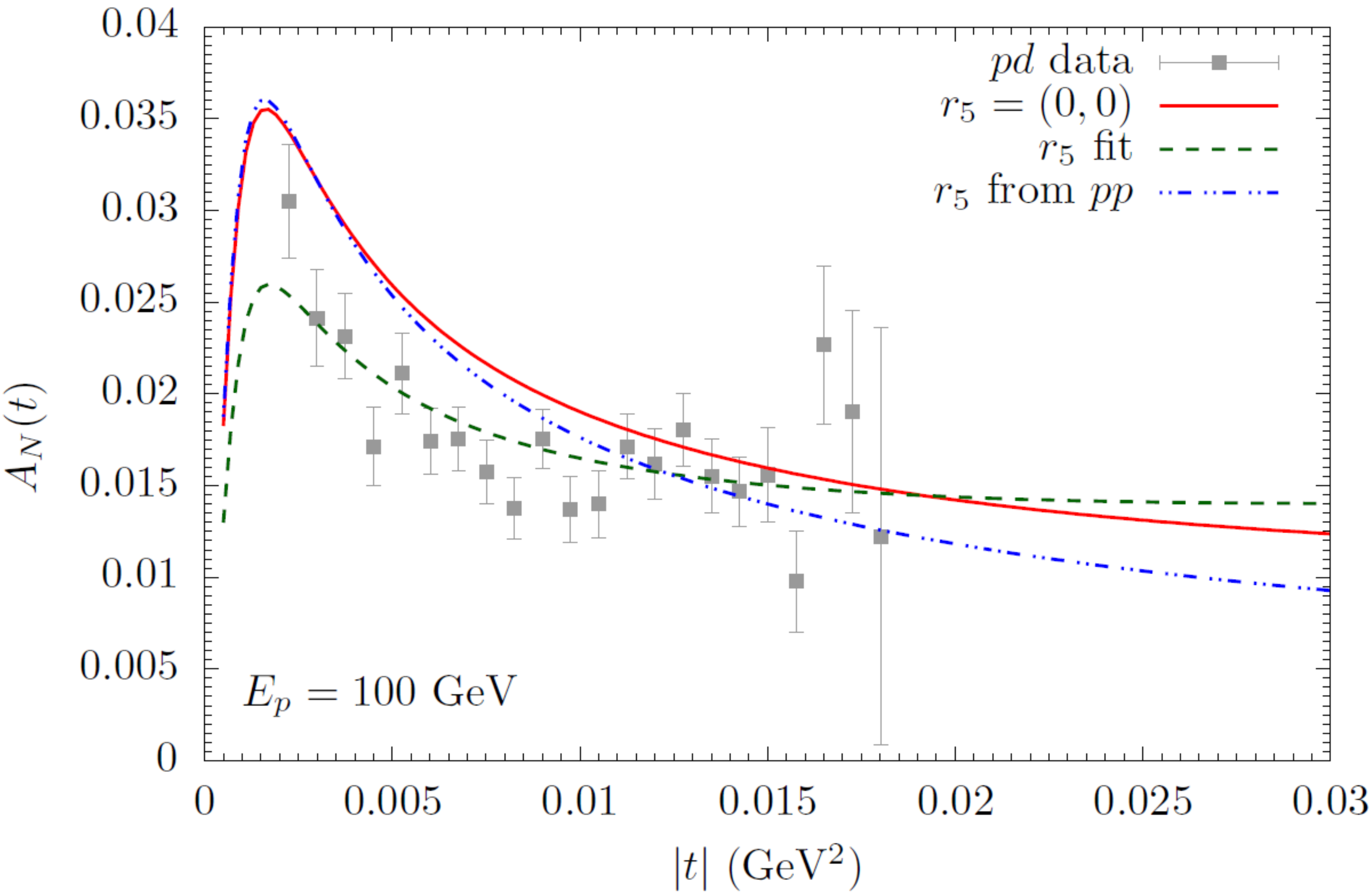
Experimental data for *pd*, *pC*, *pAl*



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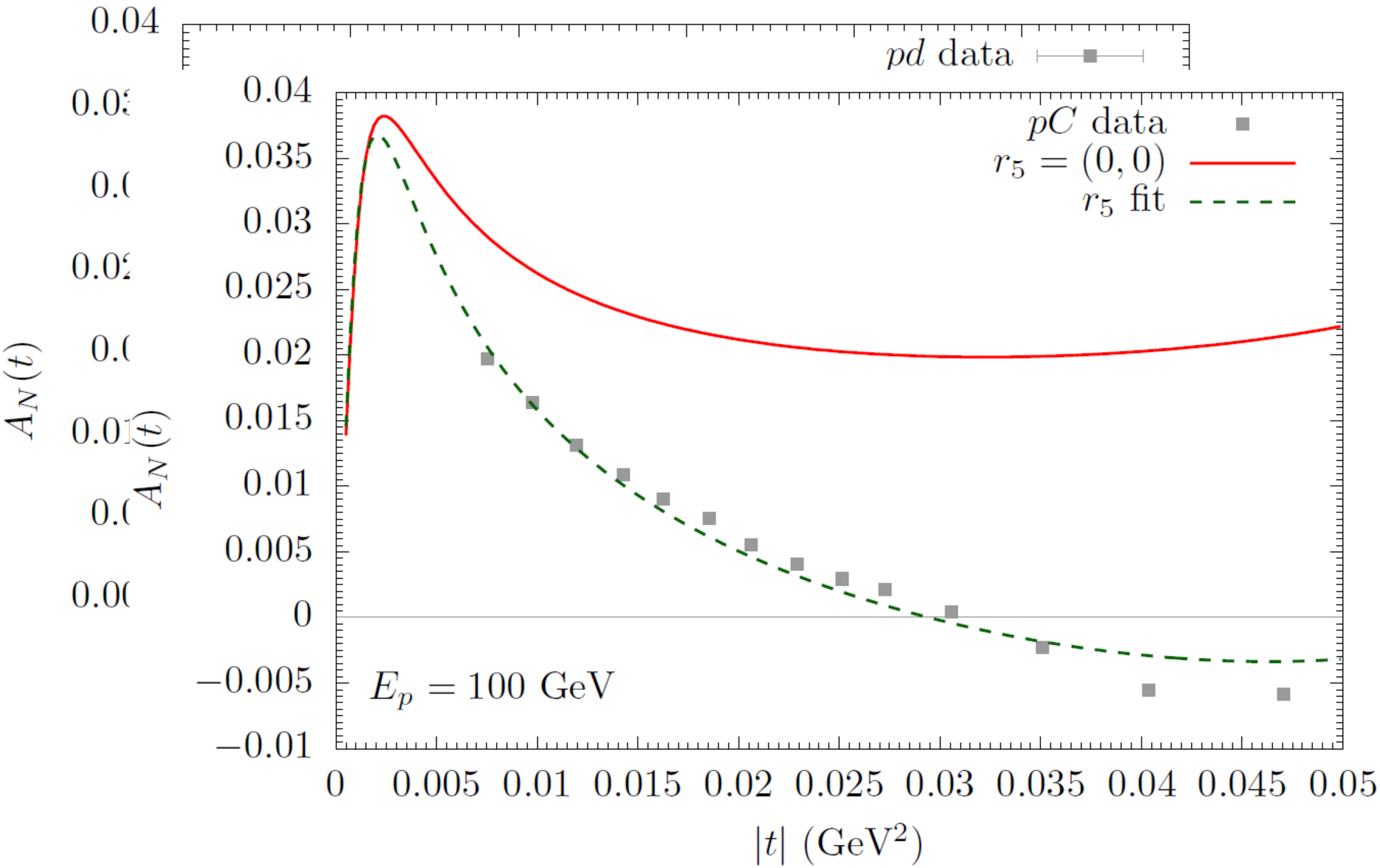
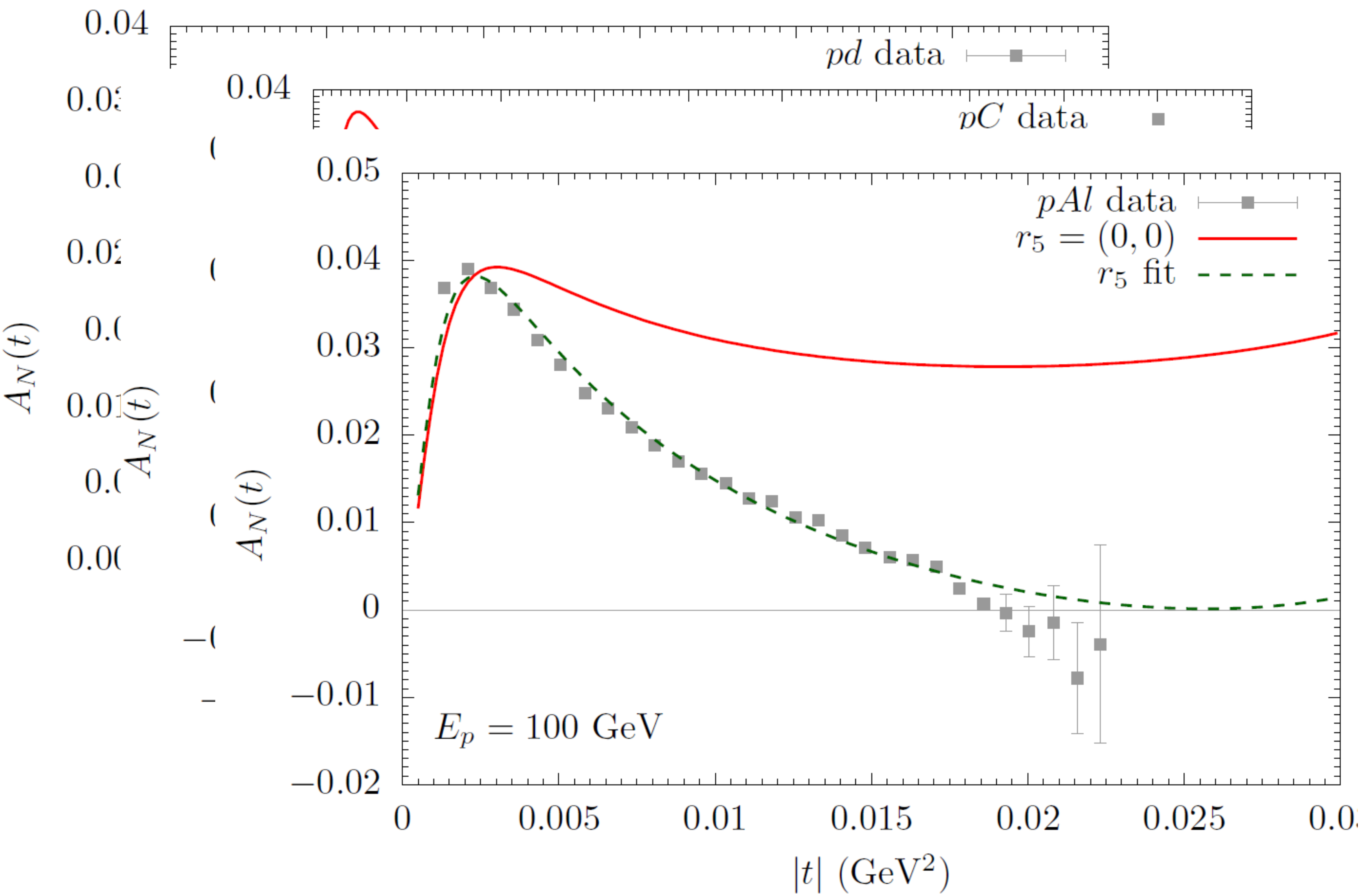
Experimental data for *pd, pC, pAl*



Experimental data for *pd, pC, pAl*



Experimental data for *pd, pC, pAl*

pd: $r_5 = -0.005 \pm 0.003 + i0.267 \pm 0.056$

pC: $r_5 = -0.051 \pm 0.001 - i0.014 \pm 0.014$

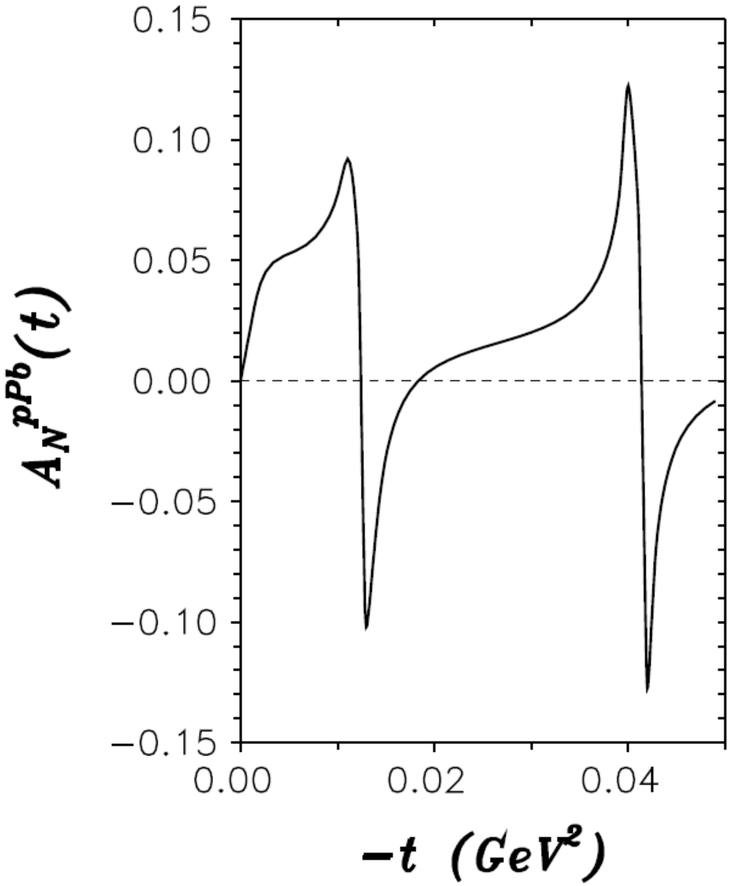
pAl: $r_5 = -0.100 \pm 0.003 - i0.183 \pm 0.096$

pC and ***pAl*** indicates higher $\boldsymbol{r_5}$ then ***pp*** $\Rightarrow$ significant contribution from Reggeons in ***pp***.

Remember result from *pp:*

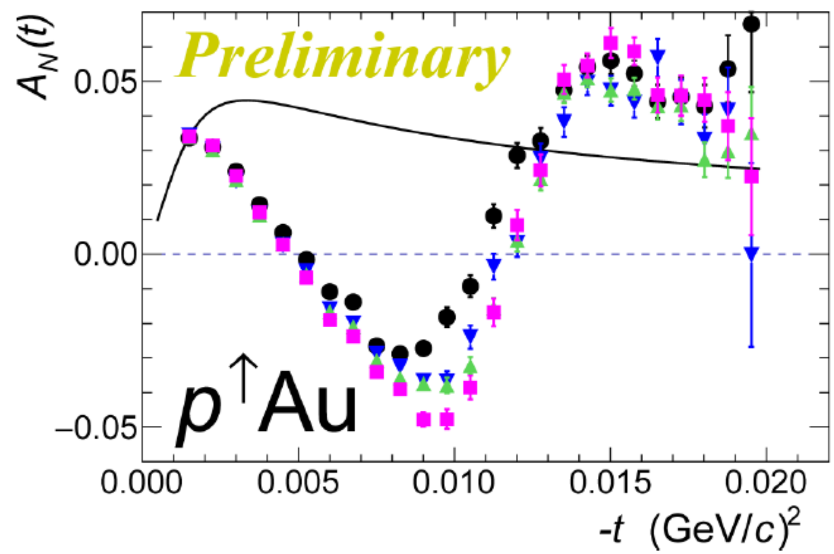
$$r_5 = -0.0073 \pm 0.0032 - i0.0289 \pm 0.0128$$

…but the Gold is the challenge



B. Kopeliovich, hep-ph/9801414

Estimation of $r_{5,\mathbb{P}}$ form Carbon is sufficient, for Gold the situation is more complicated. However, take a look at it…



From a talk by Andrei Poblaguev (SPIN2016)

Data has nearly inverse trend than theoretical calculations.

Mistakes in formulas

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We want to understand the *t* dependence ⇒ need to revise the calculation. We start from the Glauber. We found some mistakes in signs in original formulas.

B.Z. Kopeliovich and T.L. Trueman, Phys. Rev. D64, 034004 (2001)

$$\frac{16\pi}{(\sigma_{tot}^{pA})^2}\frac{d\sigma_{pA}}{dt} = \left[\frac{t_c}{t}F_A^{em}(t)\right]^2 + \left[\mathrm{Im}F_A^h(t)\right]^2\left(\rho_{pA}^2(t) + 1 - \frac{t}{m_N^2}|r_5|^2\right)$$
$$+ 2\frac{t_c}{t}F_A^{em}(t)F_A^h(t)\left(\rho_{pA}(t) + \delta_{pA}\right),$$

$$\frac{16\pi}{(\sigma_{tot}^{pA})^2}\frac{d\sigma_{pA}}{dt}A_N^{pA}(t) = \frac{\sqrt{-t}}{m_N}\mathrm{Im}F_A^h(t)\Big\{2\mathrm{Im}F_A^h(t)(\mathrm{Re}r_5 - \mathrm{Im}r_5\rho_{pA}(t))$$
$$+ F_A^{em}(t)\frac{t_c}{t}\left[(\mu_p - 1)(1 - \delta_{pA}\rho_{pA}(t)) - 2(\mathrm{Im}r_5 - \delta_{pA}\mathrm{Re}r_5)\right]\Big\}$$

However, wrong signs were at not dominant terms and have no effect for the Gold description.

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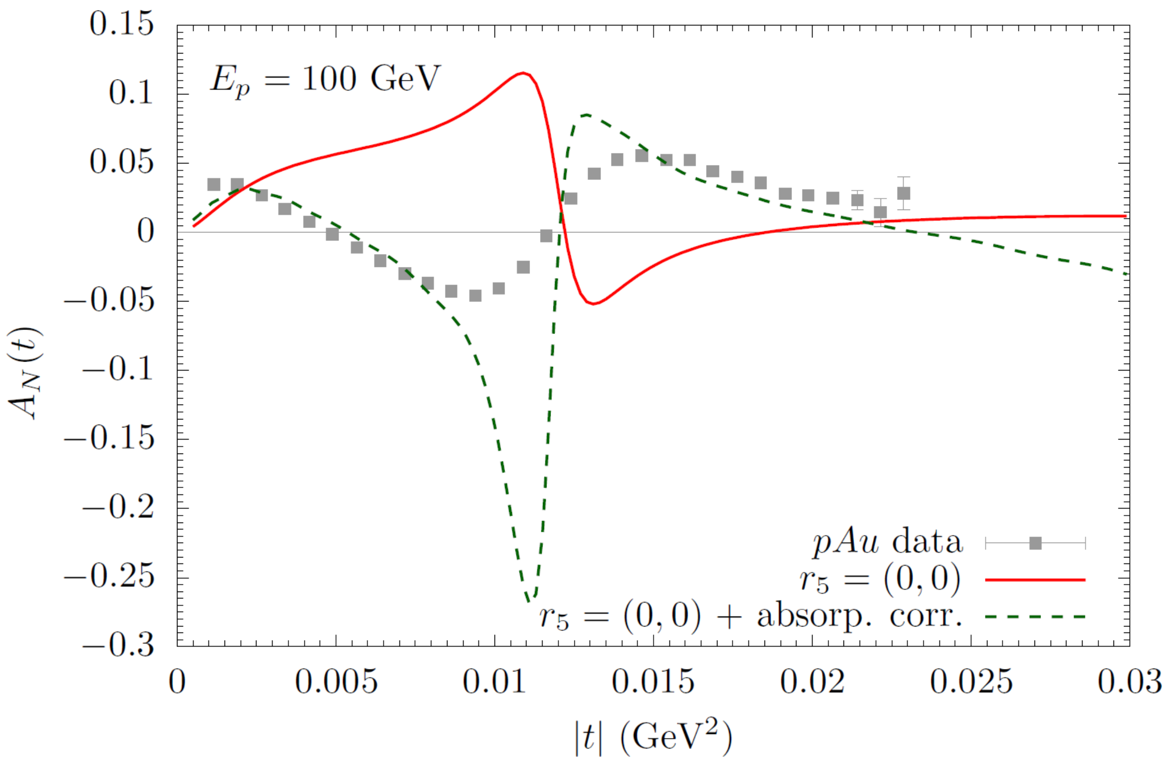
Wrong EM form factor

We found that the source of the trouble is the incorrect electromagnetic form factor, where we discovered the importance of the absorption

$$\phi_{\text{em}}(q) = \sqrt{\pi} Z \alpha_{em} \left(\frac{2}{q^2} + \frac{\mu_p - 1}{q} \right) F_A^{em}(q^2) e^{i\delta_{pA}} \otimes \boldsymbol{e^{-\frac{1}{2}\sigma_{tot}^{pp} T_A(b)}}$$



The electromagnetic amplitude gets the main contribution from the ultra-peripheral collisions, $b > R_A$, while the hadronic amplitude is non-zero only at small impact parameters, $b < R_A$.

Due to the coherence in the momentum space.

Other corrections

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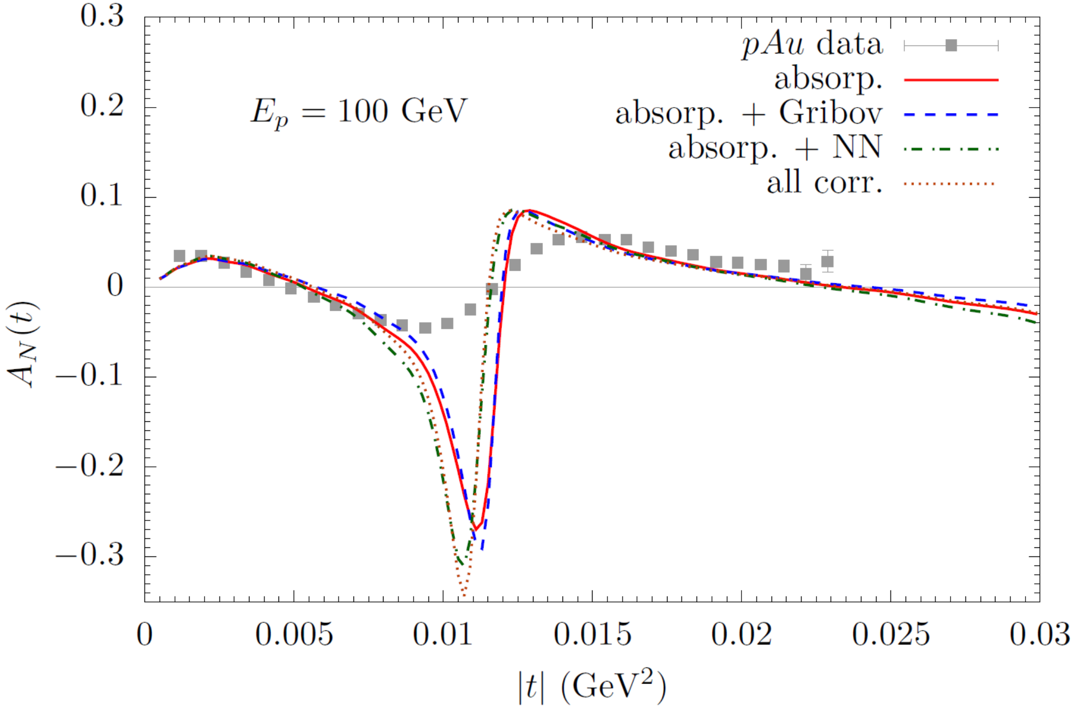
To have a full description we should add other correction such as Gribov correction or nucleon-nucleon correlations.

Gribov corrections – effectively increase the *pA* cross section

B. Z. Kopeliovich, Int. J. Mod. Phys. A31 no. 28n29, (2016) 1645021, arXiv:1602.00298 [hep-ph].
B. Z. Kopeliovich, I. K. Potashnikova, and I. Schmidt, Phys. Rev. C73 (2006) 034901, arXiv:hep-ph/0508277 [hep-ph].

NN correlations – effectively reduce the nuclear thickness function

M. Alvioli, C. Ciofi degli Atti, B. Z. Kopeliovich, I. K. Potashnikova, and I. Schmidt, Phys. Rev. C81 (2010) 025204, arXiv:0911.1382 [nucl-th].



Further adjustments

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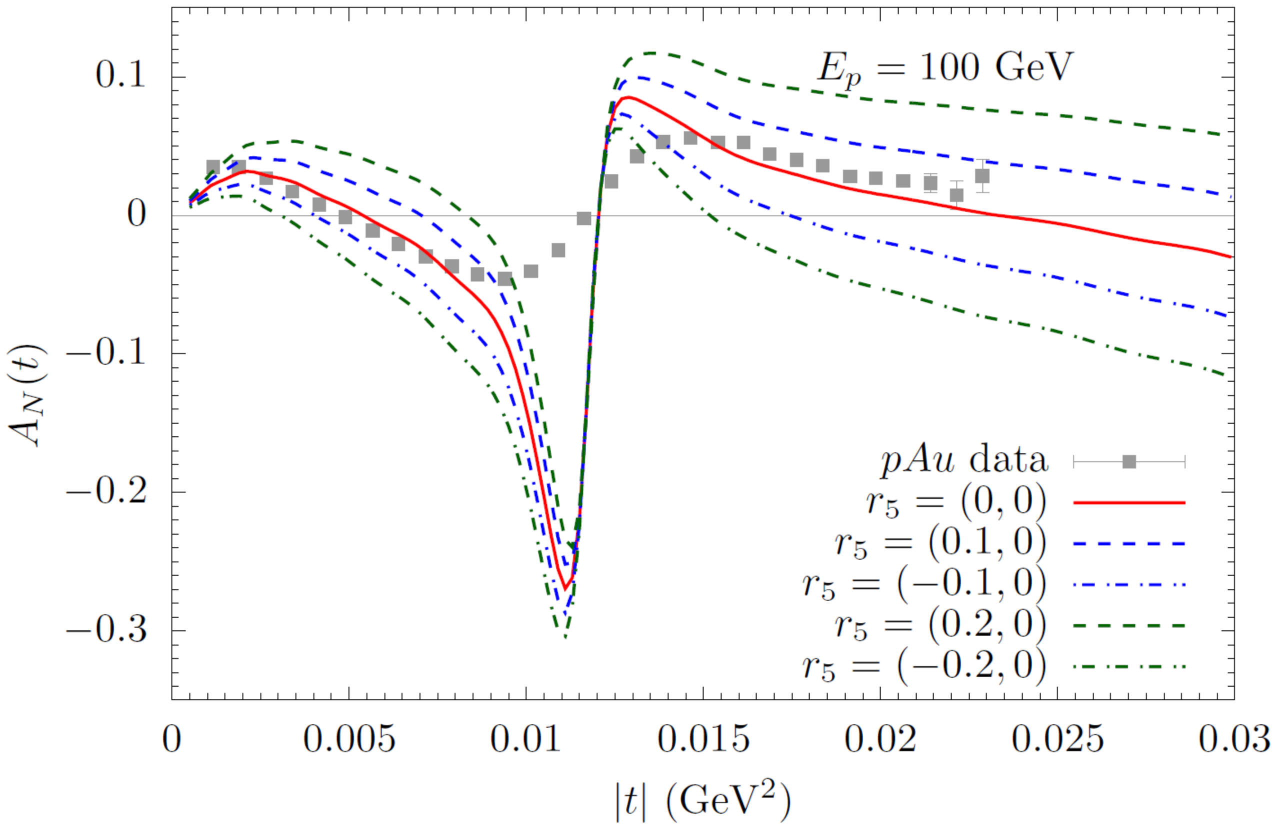
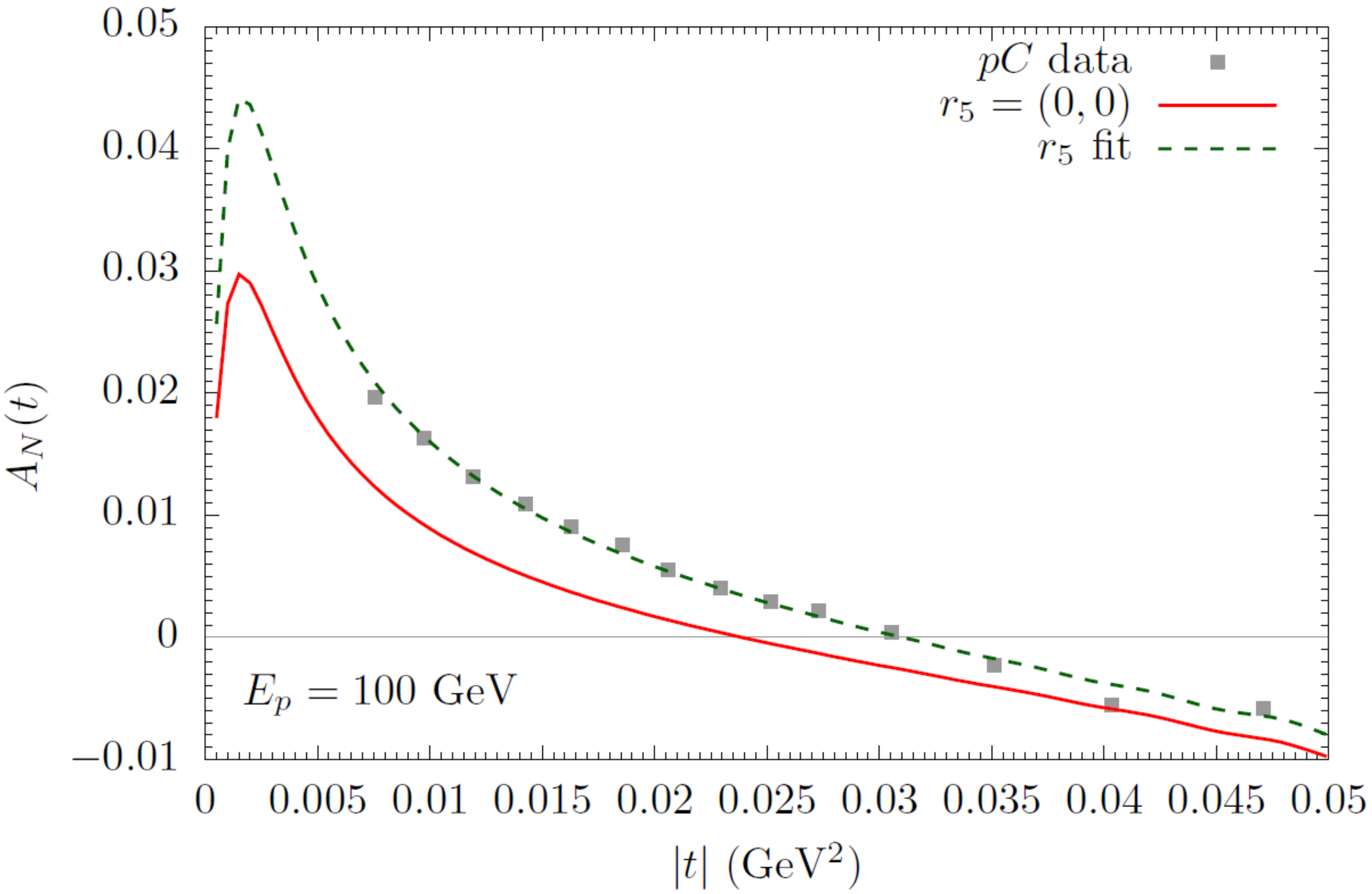
Finally, we can make some adjustment by non-zero r_5



The result looks reasonable, good agreement at low and high *t*, good position of the cross points.

pC, pAl with absorption correction



pC, pAl with absorption correction

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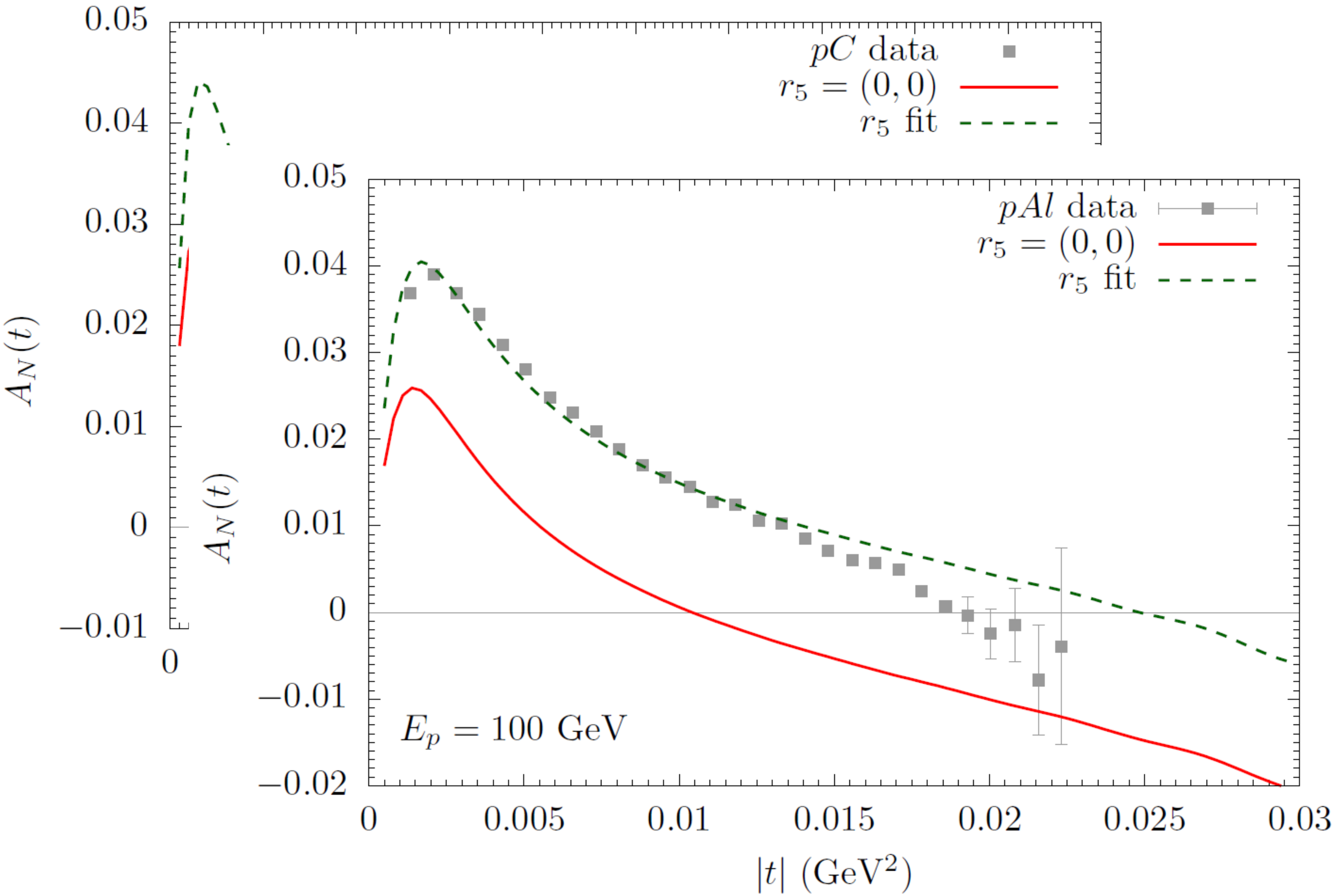

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pC, *pAl* with absorption correction

***pC*:** $r_5 = -0.031 \pm 0.001 - i0.384 \pm 0.017$

***pAl*:** $r_5 = -0.074 \pm 0.002 - i0.376 \pm 0.029$

- Very different spin asymmetry for zero r_5
- ***pC*** and ***pAl*** closer to each other
- High sensitivity for real part of r_5

Remember result from *pp:*

$$r_5 = -0.0073 \pm 0.0032 - i0.0289 \pm 0.0128$$

Conclusions

- We study the CNI region to see the effect of spin-flip hadronic amplitude.
- Indicated small r_5 in pp at RHIC does not report about Pomeron spin-flip interaction, it is combination of Pomeron and Reggeon.
- We are interested into the nuclear target because of exclusion or suppression of Reggeons.
- Data for *pC* indicated higher r_5 then in *pp*. It can be interpreted that the pomeron r_5 is suppressed in *pp*. Similar situation for *pAl*.
- More complex situation in case of Gold target. Unexpected experimentally measured *t* dependence.
- Wrong signs found in the original formulas.
- A novel mechanism of interference of electromagnetic UPC with central hadronic collisions is proposed attempting at explanations of *pAu* data for CNI generated $A_N(t)$
- We included other expected correction. Finally we have good agreement at low and high *t*, good position of the crossing points.
- Nevertheless, an accurate determination of r_5 from *pAu* data is not possible so far.

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Thank you for your attention

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