UNIVERSIDAD TECNICA FEDERICO SANTA MARIA

Centro Científico Tecnológico de Valparaíso

FACULTY OF NUCLEAR SCIENCES AND PHYSICAL ENGINEERING CTU IN PRAGUE

The Pomeron spin-flip and its measurements

Michal Krelina

in collaboration with Boris Kopeliovich

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

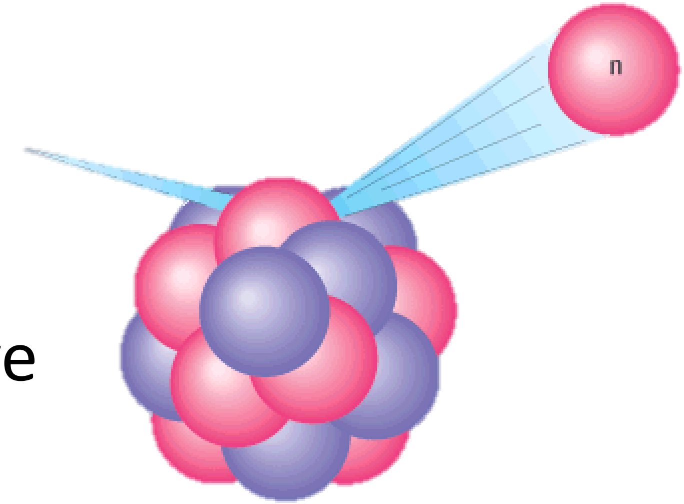
&

FNSPE, Czech Technical University in Prague

23rd International Spin Symphosium, 11 Sept., Ferrara, Italy

Outline

- Motivation & introduction
- Little of theory
- Nuclear target case and Gold nucleus puzzle
- STAR data with a new perspective
- Conclusions



Hadron spin-flip interaction?

- **Hadronic spin-flip interaction** is well known from low energies via Reggeons such as ρ or a_2.
- But at higher energies the **Pomeron** is dominant, at least a general agreement is about the dominant spin non-flip hadronic interaction in the community.
- However, there is not *general agreement* about the **pomeron spin**.

  ⇐ **This is our motivation!**

- But can we measure the **Pomeron** spin-flip interaction at intermediate energies of RHIC in fix-target configuration where data are available?

Hadron spin-flip interaction?

Answer:

- Not sure, since no one is able reliable calculate the contribution from Reggeons.

- But, maybe we can use other targets, some with zero isospins.
- For example a nucleus such as Carbon.
- However, previous theoretical attempts fail to explain the recent data from the RHIC on polarized proton-gold scattering, exposing a nontrivial t-dependence of single spin asymmetry.

  $\Leftarrow$ **This is our next motivation!**

Why nuclear target?

Two main motivations:

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

Reggeons – experimental data mostly from RHIC ($E_{LAB} = 100\ \mathrm{GeV} \approx \sqrt{s} = 14\ \mathrm{GeV}$). Can be expected a significant contribution 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

Spin-flip hadronic 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.

$\phi = \phi^h + \phi^{em}$ Dominant term: $A_N \sim \mathrm{Im}\phi^{\mathrm{h}}_{++}\mathrm{Re}\phi^{\mathrm{em}}_{+-}$

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 non-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

Let us check the *pp* elastic scattering.

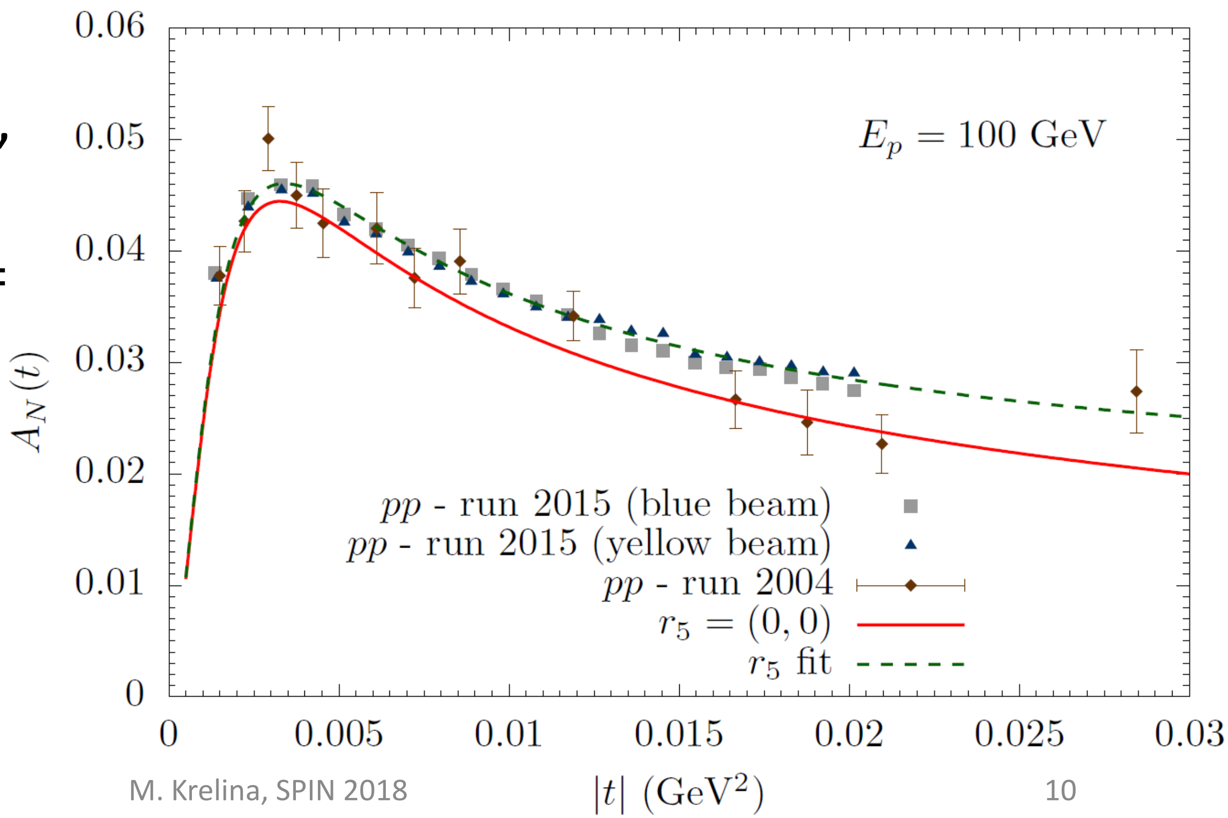
At fix-target lower energy configurations.

pp data from H-JET

Combined r_5 fit result

$$r_5 = -0.0077 \pm 0.0031 - i0.0294 \pm 0.0126$$
$$r_5 = -0.0068 \pm 0.0032 - i0.0285 \pm 0.0130$$

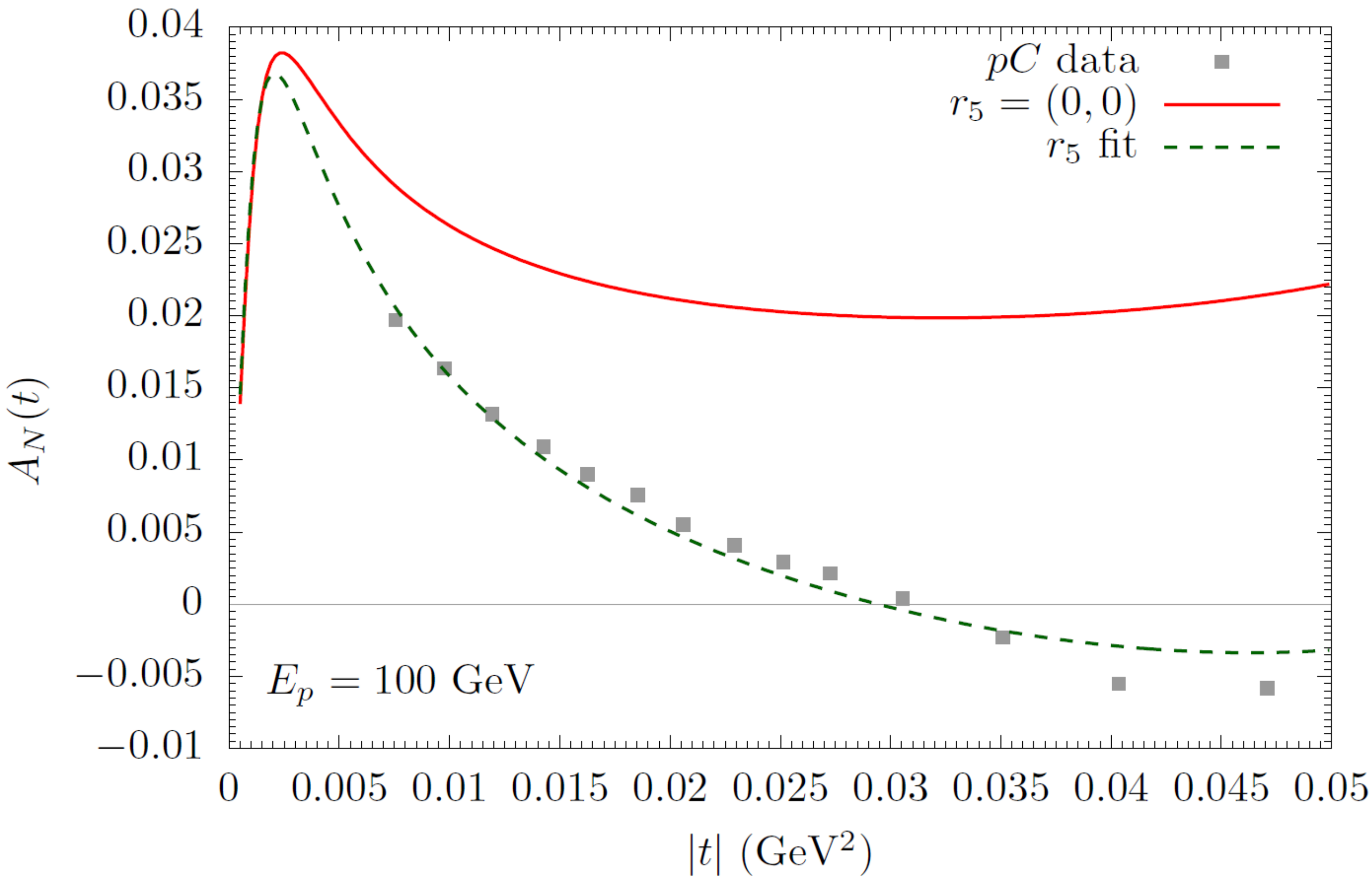
Small experimental errors, however still low energy ($E_{LAB} = 100$ GeV $\approx \sqrt{s} = 14$ GeV) → possible contribution from Reggeons



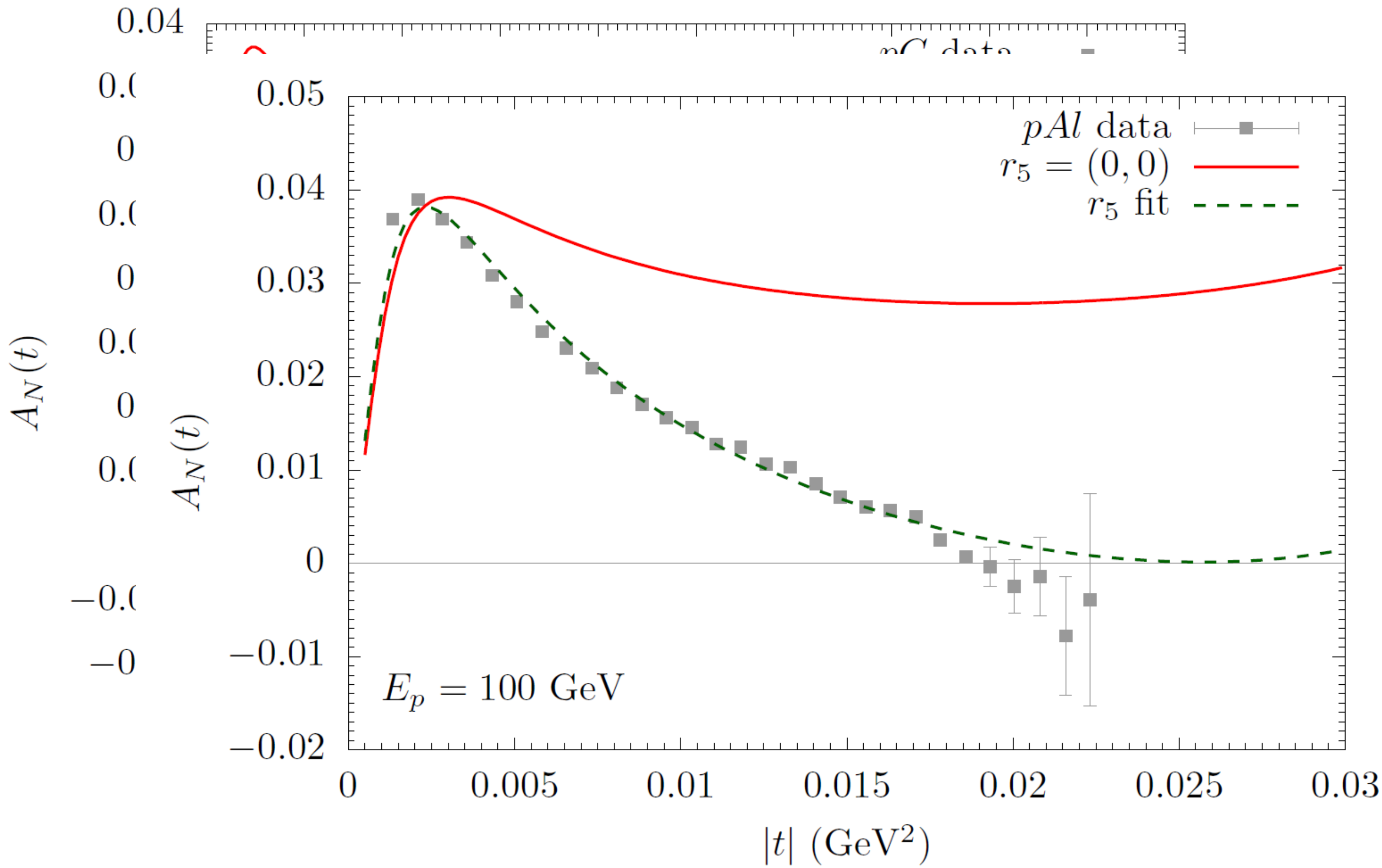
Now, let’s check *pA*.

At RHIC fix-target configuration.

Experimental data for *pC*, *pAl*



Experimental data for *pC*, *pAl*



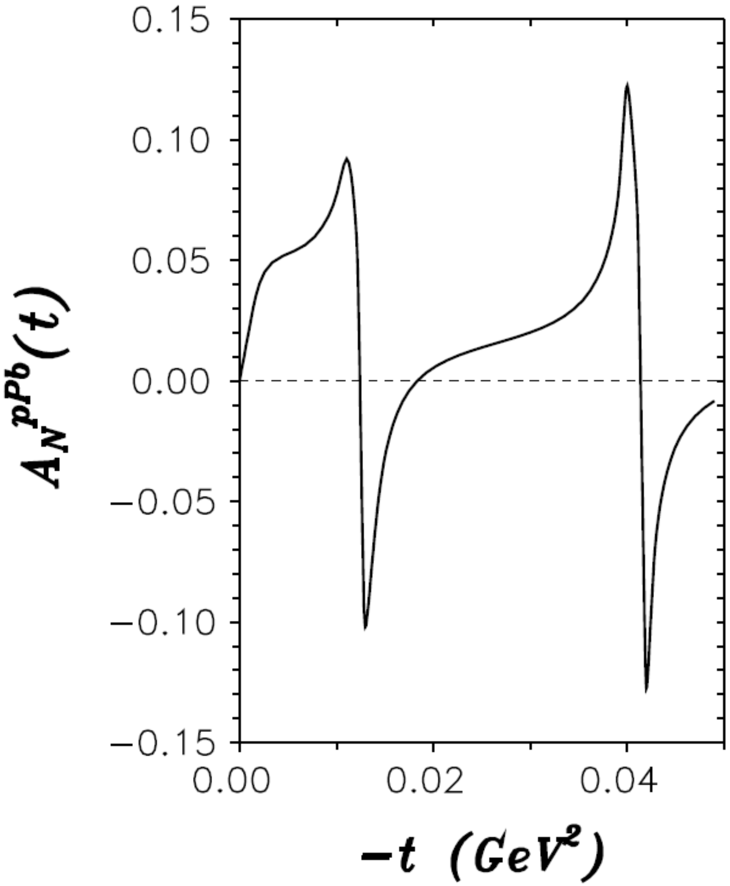
Experimental data for *pC*, *pAl*

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

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

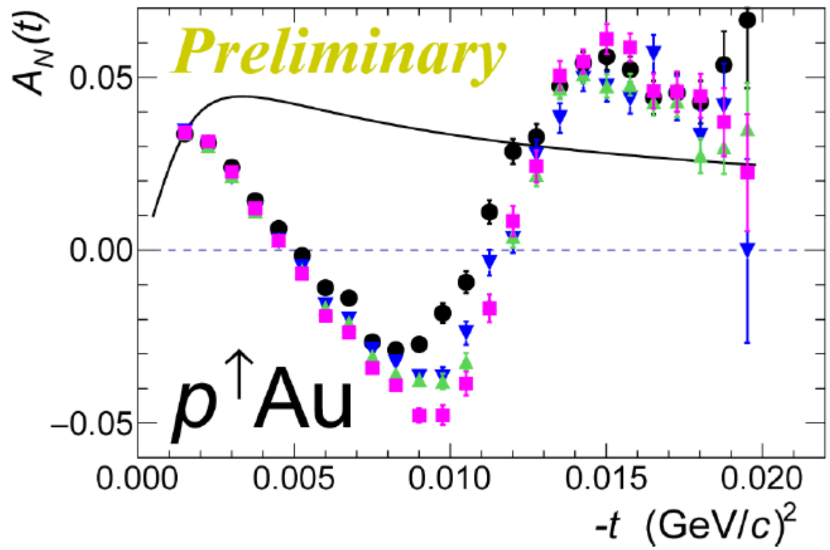
- With the current theory we can find such r_5 that fit the data
- With $r_5 = 0$ we are above the experimental data!?
  - Compare with *pp!*
- One could expect r_5 closer to each other.

…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…



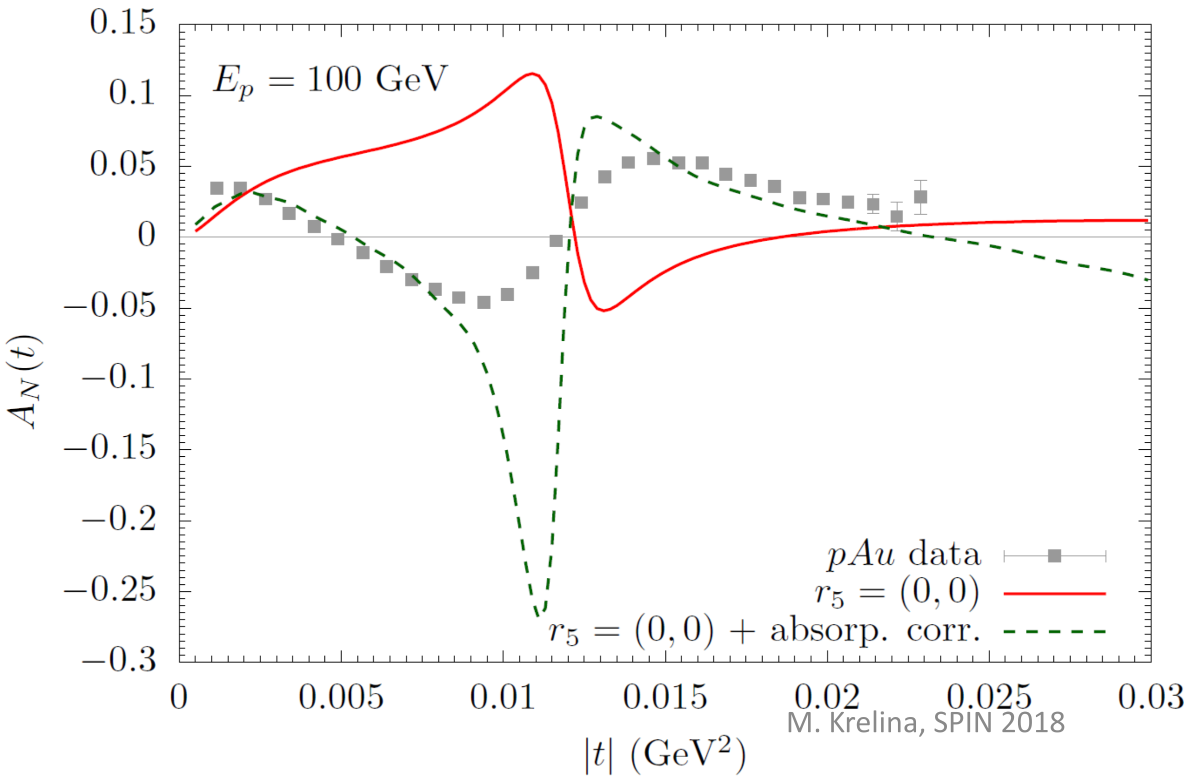
From a talk by Andrei Poblaguev (SPIN2016)

Data has nearly inverse trend than theoretical calculations.

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

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



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.

Absorptive correction

- Absorptive correction on inelastic collisions is a natural part of the Glauber formula
- But EM formfactor corresponds to *eA* collisions where we have no correction on inelastic collisions
  - Significant only for small distance in the range of Pomerons
- Can be applied also for *pp*!!

Other corrections

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

Gribov corrections – effectively increase the *pA* cross section

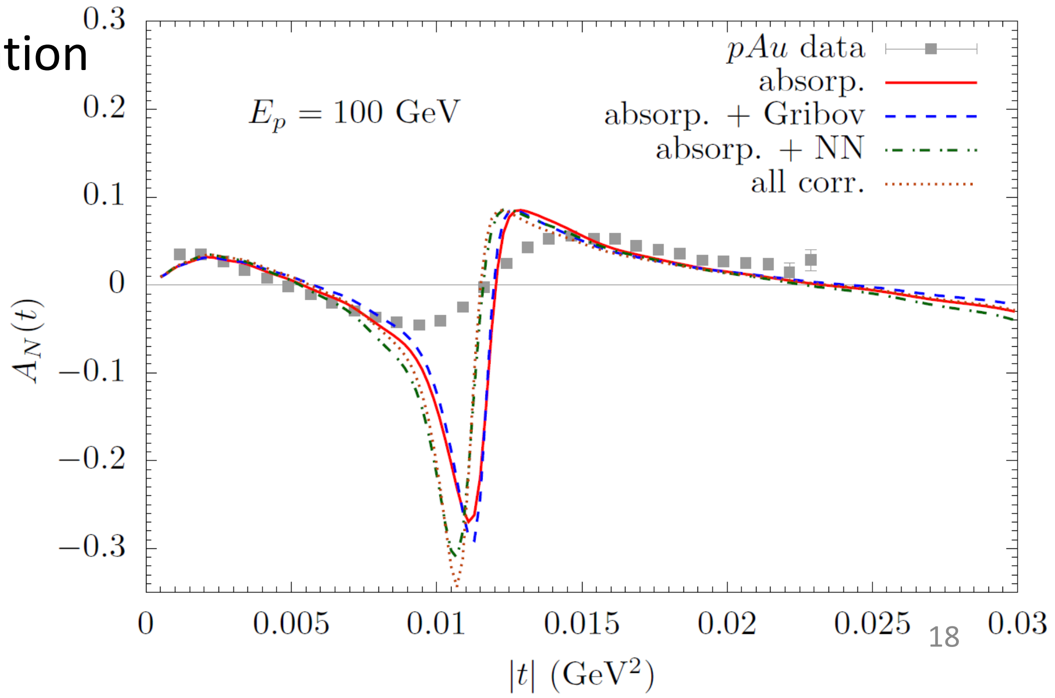
B. Z. Kopeliovich, Int. J. Mod. Phys. A31 no. 28n29, (2016) 1645021, arXiv:1602.00298 [hep-ph].
B. Z. Kopeliovich, I. K. Potashnikova, and I. Schmidt, Phys. Rev. C73 (2006) 034901, arXiv:hep-ph/0508277 [hep-ph].

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].

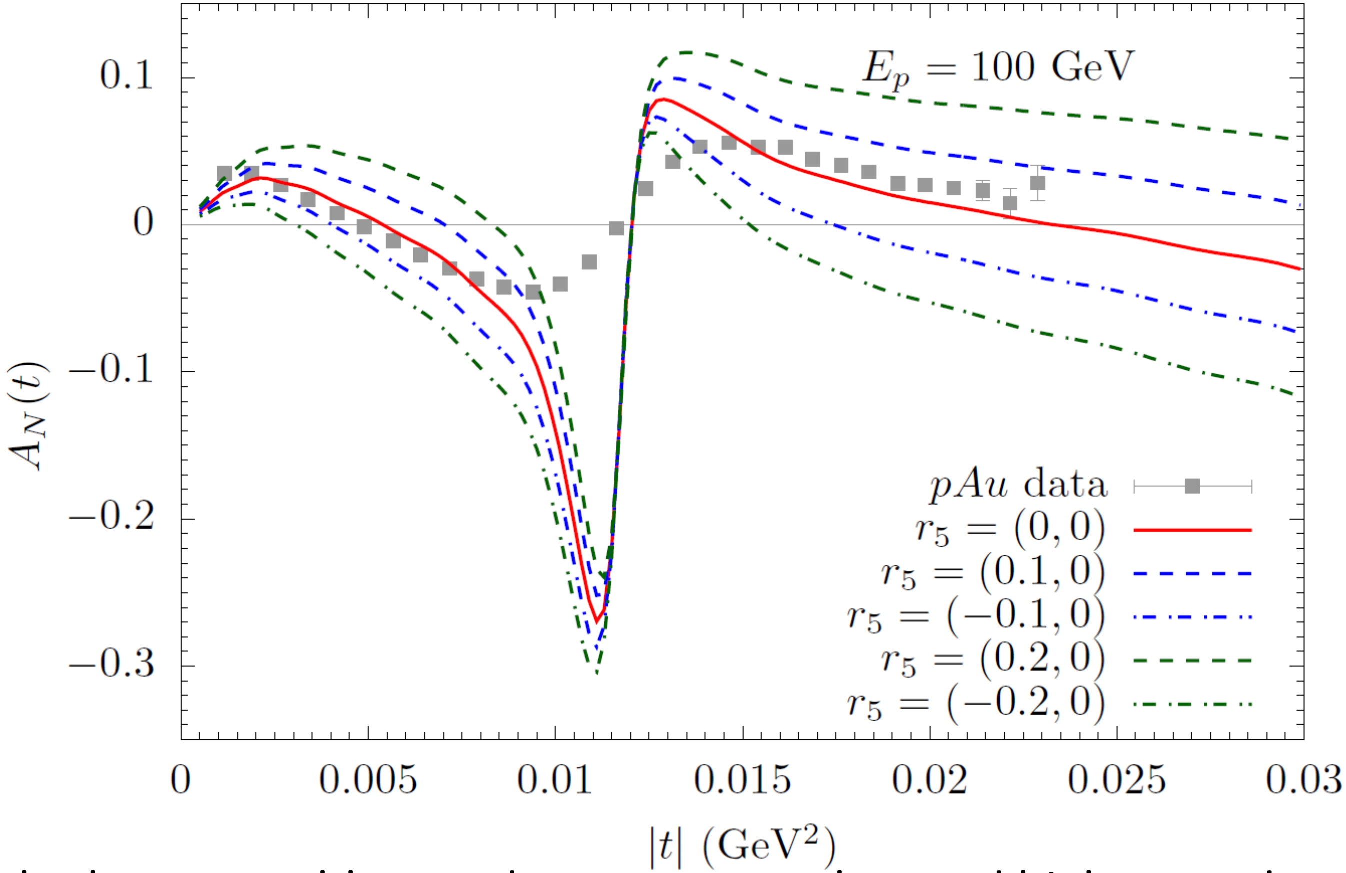
Odderon – only Born approximation

B. G. Zakharov, Sov. J. Nucl. Phys. 49, 860 (1989), [Yad. Fiz.49,1386(1989)]



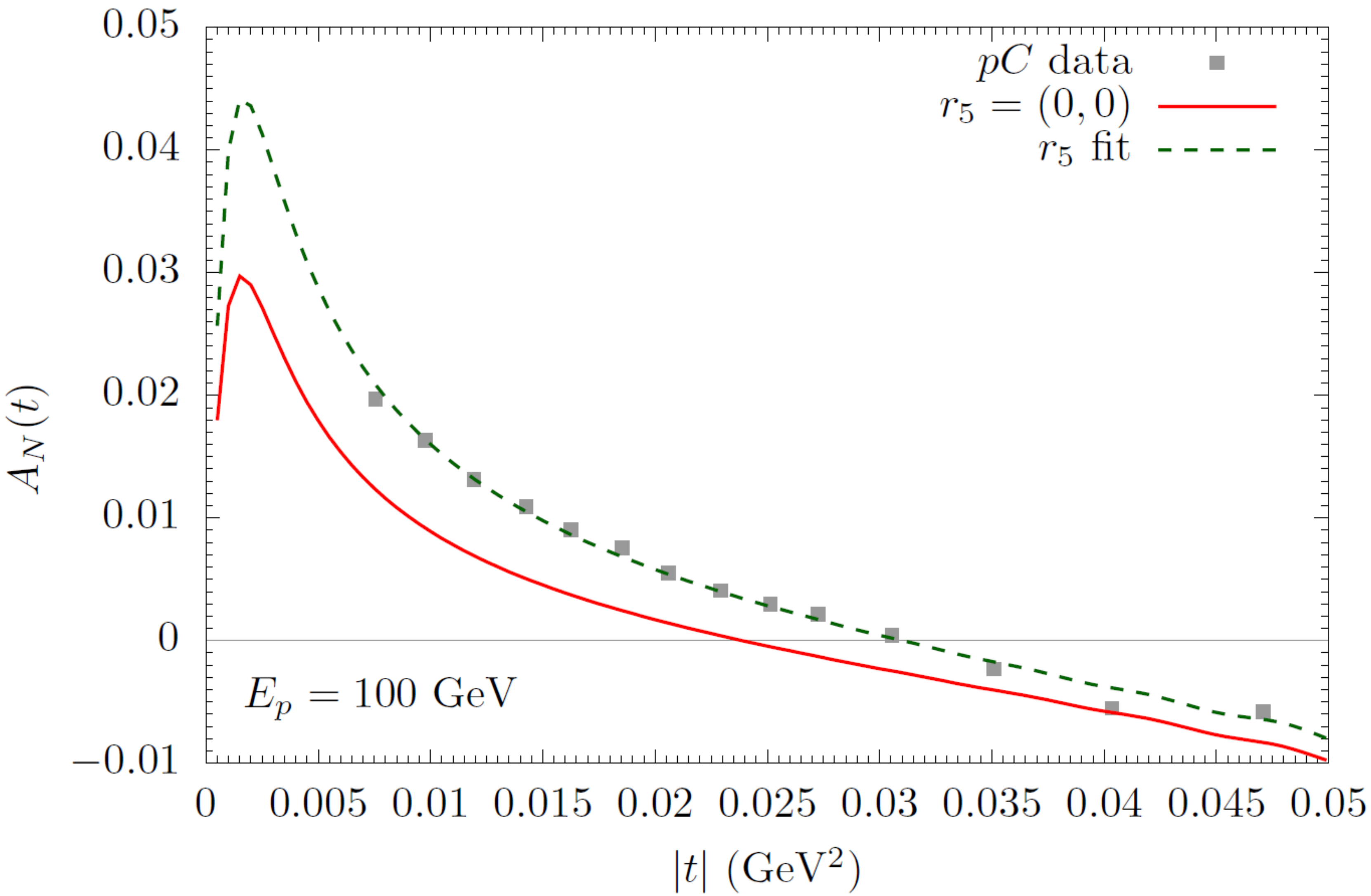
Further adjustments

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

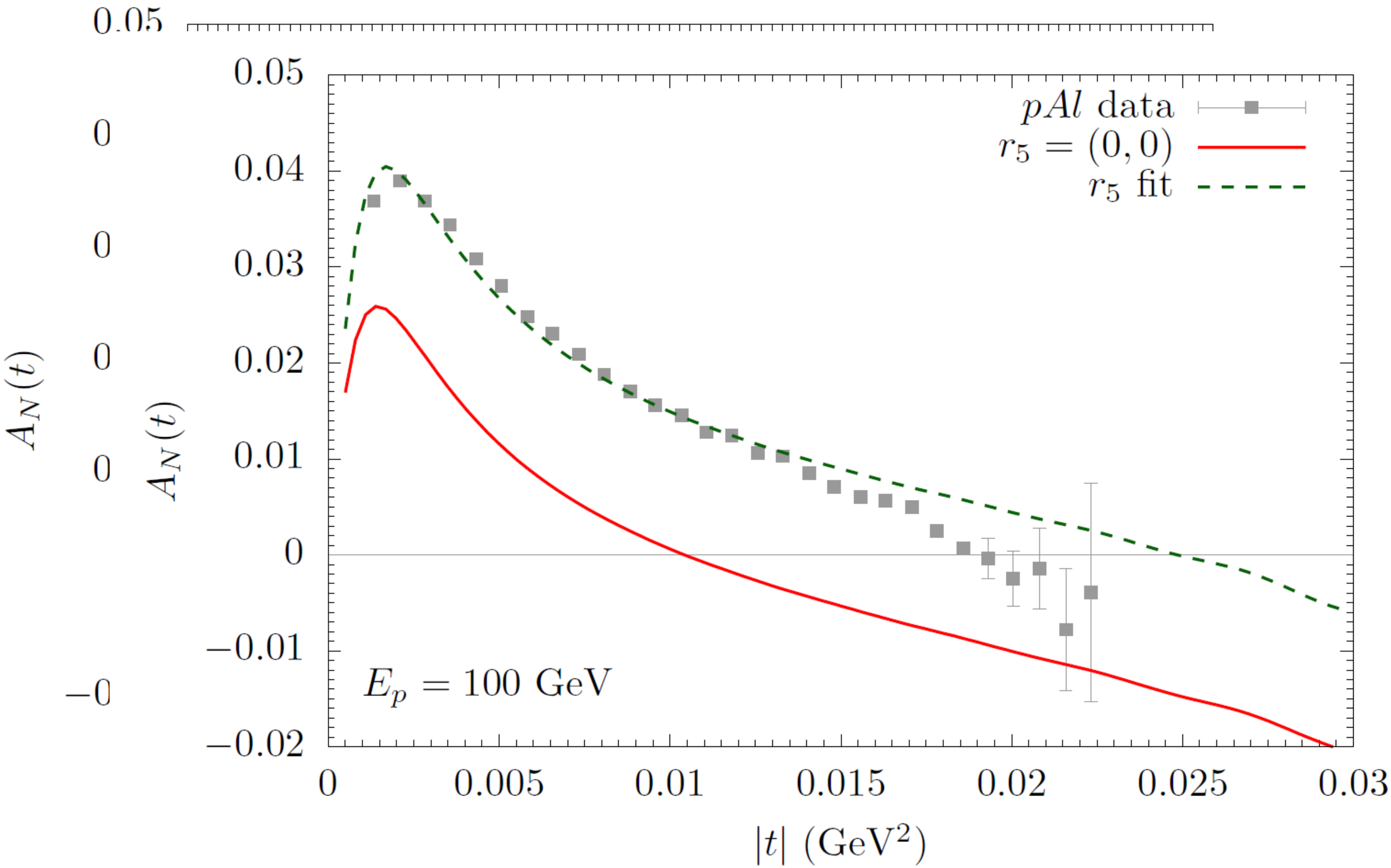


The result looks reasonable, good agreement at low and high *t*, good position of the cross points.

pC, pAl with absorption correction



pC, pAl with absorption correction



Finally, let's see the data from STAR.

Results from STAR at $\sqrt{s} = 200$ GeV are enough high to **not expect** any **Reggeons**.

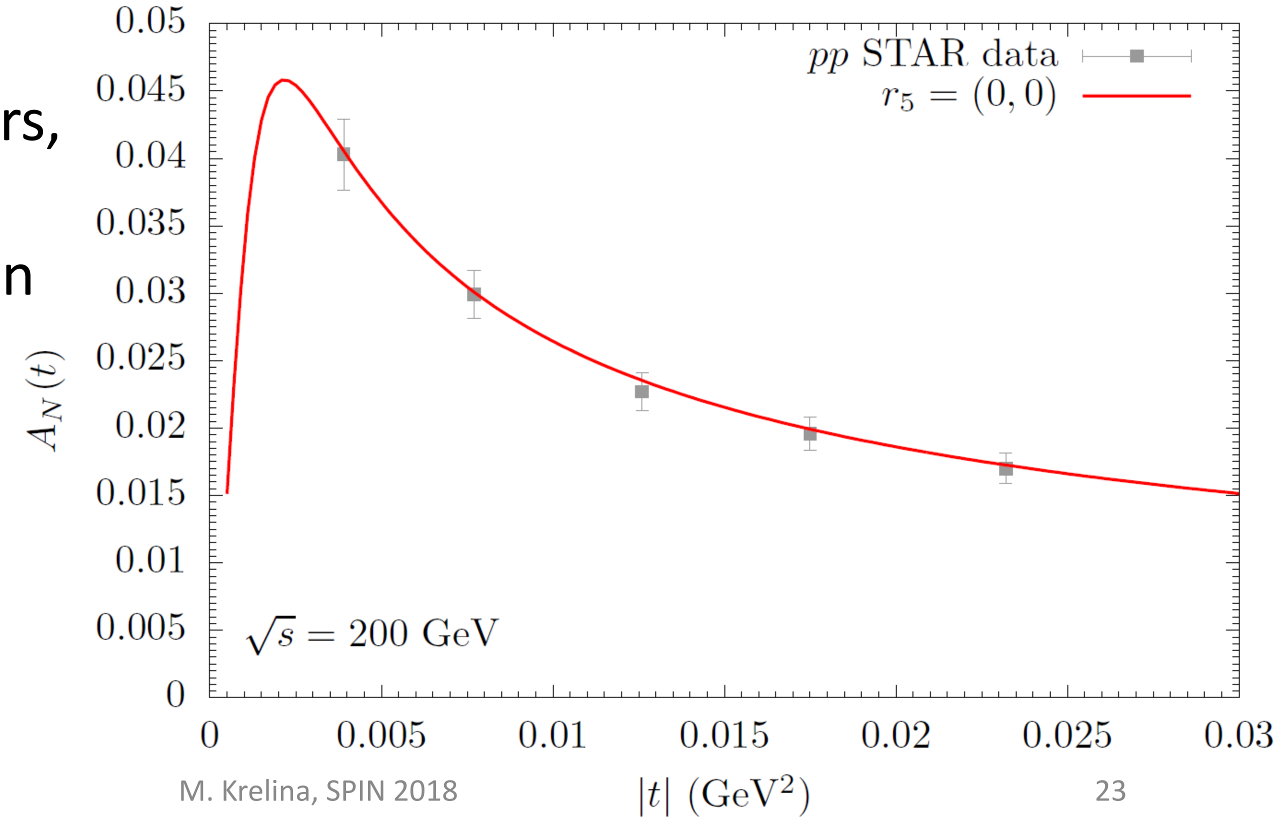
pp data from STAR

Combined r_5 fit result

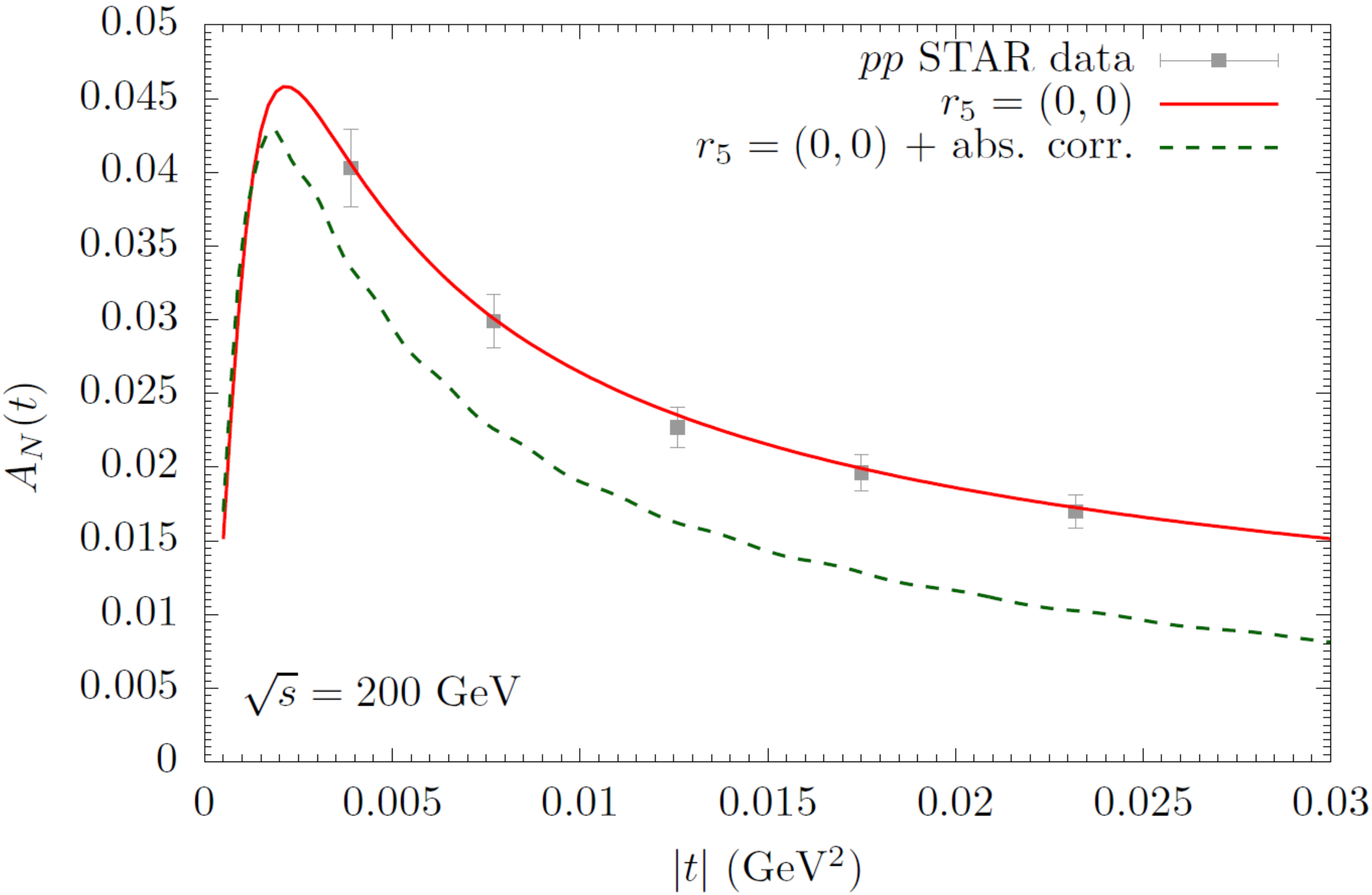
$$r_5 \approx 0$$

Zero r_5 ?! No Pomeron spin flip interaction?!

Small experimental errors, high energy ($\sqrt{s} =$ 200 GeV) → contribution from Reggeons are not expected



pp with absorption correction



We are finishing.

Let’s see final results and conclusion!

Global results

mode	Energy	note	Re r_5 (+abs.corr.)	Im r_5 (+abs.corr.)
pp	21,321	STAR	-0.0330 ± 0.0011	-0.1272 ± 0.0137
pp	255	2018, blue	-0.0272 ± 0.0011	-0.0735 ± 0.0073
pp	255	2018, yellow	-0.0285 ± 0.0010	-0.0670 ± 0.0066
pp	200	E704	-0.0142 ± 0.0175	-0.0512 ± 0.1751
pp	100	2015, blue	-0.0360 ± 0.0016	-0.0529 ± 0.0073
pp	100	2015, yellow	-0.0235 ± 0.0024	-0.1055 ± 0.0112
pp	100	2018, blue	-0.0348 ± 0.0023	-0.0350 ± 0.0103
pp	100	2018, yellow	-0.0348 ± 0.0020	-0.0791 ± 0.00911
pC	100	2008	0.031 ± 0.001	-0.384 ± 0.017
pAl	100	2015	0.074 ± 0.002	-0.376 ± 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

Conclusions

- We study the CNI region to see the effect of spin-flip hadronic amplitude.
- Indicated small $\boldsymbol{r_5}$ 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 at low energies.
- More complex situation in case of Gold target. Unexpected experimentally measured *t* dependence.
- 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 $\boldsymbol{r_5}$ from *pAu* data is not possible so far.
- Importance of the absorption correction also for *pp*.
- Zero $\boldsymbol{r_5}$ from STAR at high energy without absorption.

Thank you for your attention

Back slide – formulas - pp

$$\frac{d\sigma}{dt} = 2\pi \left\{ |\phi_1|^2 + |\phi_2|^2 + |\phi_3|^2 + |\phi_4|^2 + 4|\phi_5|^2 \right\},$$

$$A_N \frac{d\sigma}{dt} = -4\pi \mathrm{Im} \left\{ (\phi_1 + \phi_2 + \phi_3 - \phi_4)\phi_5^* \right\}$$

$$\phi_1(s,t) = \langle + + |M| + + \rangle$$

$$\phi_2(s,t) = \langle + + |M| - - \rangle$$

$$\phi_3(s,t) = \langle + - |M| + - \rangle$$

$$\phi_4(s,t) = \langle + - |M| - + \rangle$$

$$\phi_5(s,t) = \langle + + |M| + - \rangle$$

Back slide – formulas - pp

$$\phi_1^h = \frac{\sigma_{tot}^{pp}}{8\pi}(\rho_{pp} + i)e^{-\frac{1}{2}B|t|},$$

$$\phi_2^h = r_2\frac{\sigma_{tot}^{pp}}{4\pi}(\rho_{pp} + i)e^{-\frac{1}{2}B|t|} = r_5^2\frac{t}{m_p^2}\frac{\sigma_{tot}^{pp}}{8\pi}(\rho_{pp} + i)e^{-\frac{1}{2}B|t|} \approx 0,$$

$$\phi_3^h = \frac{\sigma_{tot}^{pp}}{8\pi}(\rho_{pp} + i)e^{-\frac{1}{2}B|t|},$$

$$\phi_4^h = -r_4\frac{t}{m_N^2}\frac{\sigma_{tot}^{pp}}{8\pi}(\rho_{pp} + i)e^{-\frac{1}{2}B|t|} \approx 0,$$

$$\phi_5^h = r_5\frac{\sqrt{-t}}{m_N}\frac{\sigma_{tot}^{pp}}{8\pi}e^{-\frac{1}{2}B|t|},$$

$$e^{i\delta_{pp}}\phi_1^{em} = -\frac{\alpha_{em}}{|t|}G^2(t)e^{i\delta_{pp}},$$

$$e^{i\delta_{pp}}\phi_2^{em} = \frac{\alpha_{em}(\mu_N - 1)^2}{|t|}G^2(t)e^{i\delta_{pp}} \approx 0,$$

$$e^{i\delta_{pp}}\phi_3^{em} = -\frac{\alpha_{em}}{|t|}G^2(t)e^{i\delta_{pp}},$$

$$e^{i\delta_{pp}}\phi_4^{em} = -\frac{\alpha_{em}(\mu_N - 1)^2}{|t|}G^2(t)e^{i\delta_{pp}} \approx 0,$$

$$e^{i\delta_{pp}}\phi_5^{em} = -\frac{\alpha_{em}(\mu_N - 1)}{2m_N\sqrt{-t}}G^2(t)e^{i\delta_{pp}},$$

Back slide – formulas - pA

$$A_N \frac{d\sigma^{pA}}{dt} = 2\mathrm{Im}(f_{++}^{pA} f_{+-}^{pA,*}),$$

$$\frac{d\sigma^{pA}}{dt} = |f_{++}^{pA}|^2 + |f_{+-}^{pA}|^2.$$

$$f_{++}^{pA,h} = \sqrt{\pi}\frac{\sigma_{tot}^{pA}}{4\pi} F_A^h(q^2),$$

$$f_{+-}^{pA,h} = \sqrt{\pi} r_5 \frac{q}{m_N} \frac{\sigma_{tot}^{pA}}{4\pi} \mathrm{Im} F_A^h(q^2),$$

$$e^{i\delta_{pA}} f_{++}^{pA,em} = \sqrt{\pi}\frac{2Z\alpha_{EM}}{q^2} F_A^{em}(q^2) e^{i\delta_{pA}},$$

$$e^{i\delta_{pA}} f_{+-}^{pA,em} = \sqrt{\pi}\frac{Z\alpha_{EM}}{m_N q}(\mu_p - 1) F_A^{em}(q^2) e^{i\delta_{pA}}.$$

Back slide – formulas - pA

$$F_A^h(q^2) = \frac{2i}{\sigma_{tot}^{pA}} \int d^2b\, e^{i\vec{q}\cdot\vec{b}} \left[1 - e^{-\frac{1}{2}\sigma_{tot}^{NN}(1-i\rho_{pp})T_A^h(b)}\right]$$

$$= \frac{4i\pi}{\sigma_{tot}^{pA}} \int db\, b J_0(qb) \left[1 - e^{-\frac{1}{2}\sigma_{tot}^{NN}(1-i\rho_{pp})T_A^h(b)}\right]$$

$$T_A^h(b) = \frac{2}{\sigma_{tot}^{hN}} \int d^2s\, \frac{\sigma_{tot}^{hN}}{4\pi B_{hN}} \exp\left(-\frac{s^2}{2B_{hN}}\right) T_A(\vec{b} - \vec{s})$$

Back slide – formulas - absorption

$$f^{em,pA}(b) = \sqrt{\pi} Z \alpha_{em} \left[2G_1(b^2) + \frac{\mu_p - 1}{m_N} G_2(b^2) \right],$$

$$G_1(b^2) = \int d^2q e^{i\vec{b}\cdot\vec{q}} \frac{1}{q^2} F_A^{em}(q^2) e^{i\delta_{pA}(q^2)}$$

$$G_2(b^2) = \int d^2q e^{i\vec{b}\cdot\vec{q}} \frac{1}{q} F_A^{em}(q^2) e^{i\delta_{pA}(q^2)}$$

$$f^{em,pA}(b) = \sqrt{\pi} Z \alpha_{em} \left[2G_1(b^2) + \frac{\mu_p - 1}{m_N} G_2(b^2) \right] S(b)$$

$$= \sqrt{\pi} Z \alpha_{em} \left[2G_1(b^2) + \frac{\mu_p - 1}{m_N} G_2(b^2) \right] e^{-\frac{1}{2}\sigma_{tot}^{pp} T_A^{eff}(b)}$$

$$f^{em,pA}(q^2) = \frac{1}{2\pi} \int d^2b e^{-i\vec{b}\cdot\vec{q}} f^{em,pA}(b)$$