Baryon number in proton-proton and proton-nucleus high energy collisions

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See also:
1) APPB 51 (2020) 1207,
2) arXiv:2101.01999

1. Foreword ;

2. The experimental progress ;

3. The Dual Parton Model ;

4. The Gluon Exchange Model (GEM) ;

5. The transport of baryon number ;

6. Summary & Future .

1)
Foreword

- The idea to start this analysis emerged ~1h after the completion of this talk.
- We think this was a good idea.

This talk will be concerned with the future of high energy physics in the sense of NICA, SPS, AFTER @ LHC, ...

- The transport of baryon number from the initial to the final state of a “soft” hadron-hadron or hadron-nucleus collision has been studied since many decades, yet several issues remain unsolved:

→ **role of color ?**
→ **existence / survival of diquarks ?**
→ **BN annihilation ?**
→ **… ?**

- The core of BN transport phenomenology was established about ~**1985** (W. Busza et al., PLB 139, 1984, A. Capella et al., PLB 93, 1980, M.J., J. Karczmarczuk, M. Różańska, ZPC 29, 1985).

- This phenomenology can be improved, in particular with modern exp. data.

2)
The experimental progress

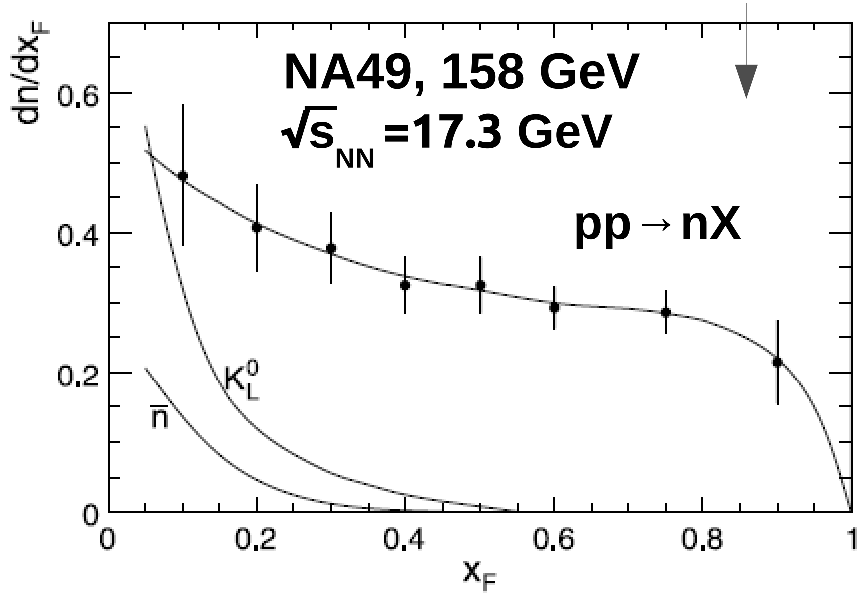
[1] T. Anticic *et al.* [NA49 Collaboration], Eur. Phys. J. **C65**, 9 (2010), **[2]** B. Baatar *et al.* [NA49 Collaboration], Eur. Phys. J. **C73**, 2364 (2013).

1. No need to use protons as a **proxy** for the **total BN** ;

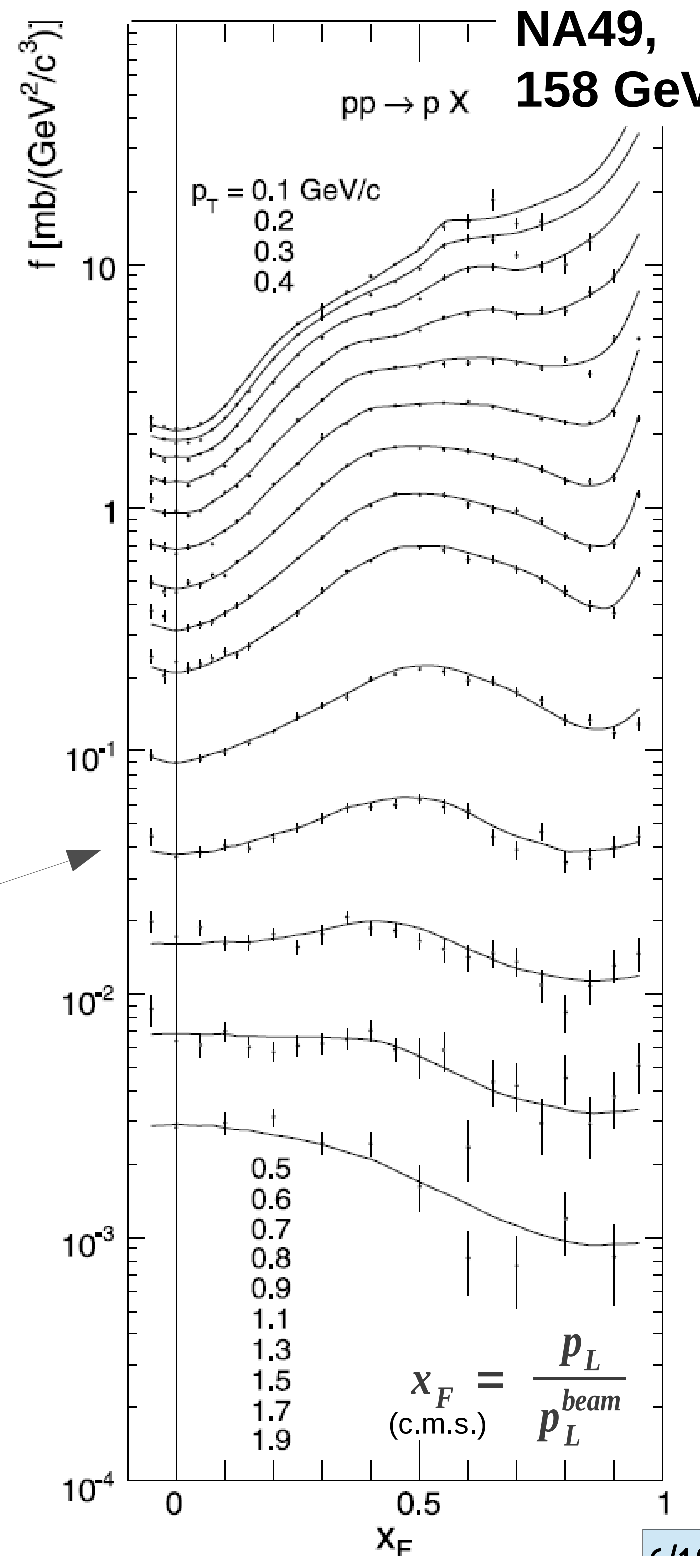
2. Hermeticity (full projectile hemisphere, up to high x_F, no p_T-cutoff)
   → we can use baryon number conservation as a constraint in the verification of our model.

3. Both **p+p and p+A data sets** were provided by the same experiment → allows for the isolation of baryon distributions in the final state of **multiple proton-nucleon collisions.**

Our personal baryon number test: 0.96 (96/100) [excellent!!!]



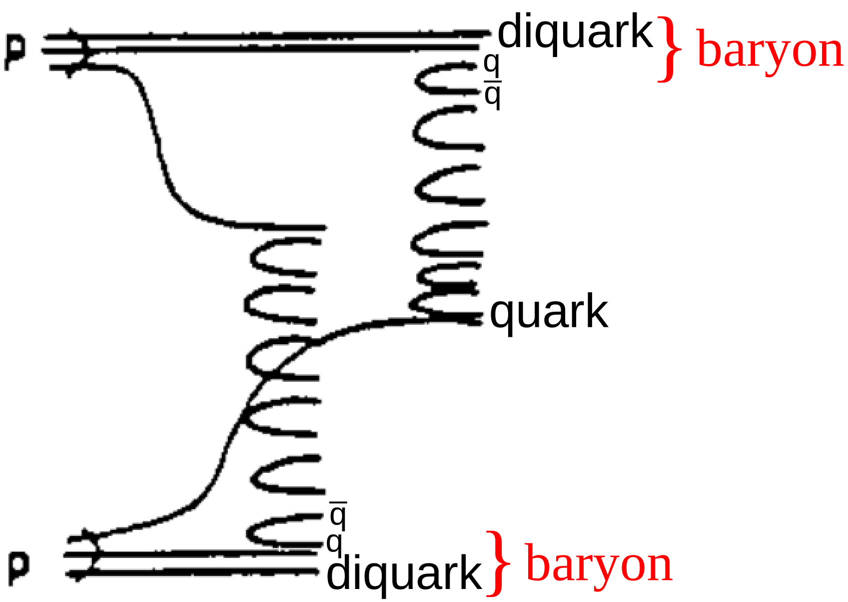
[1]



3)
The Dual Parton Model

The Dual Parton Model

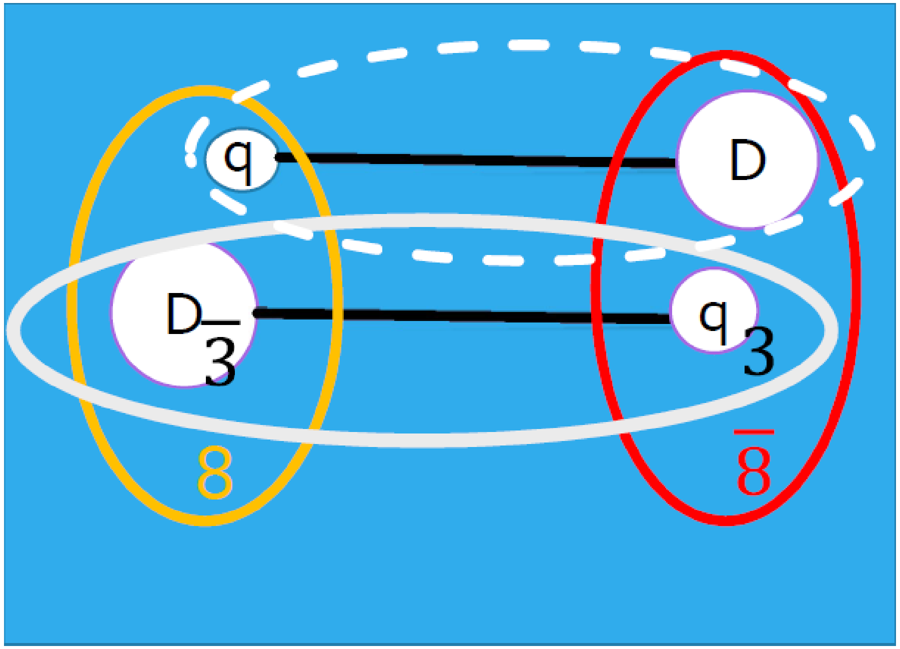
(A. Capella and J. Tran Thanh Van, PLB **93**, 1980,
application to baryons:
M.J., J. Karczmarczuk, M. Różańska, ZPC **29**, 1985)



p+p:

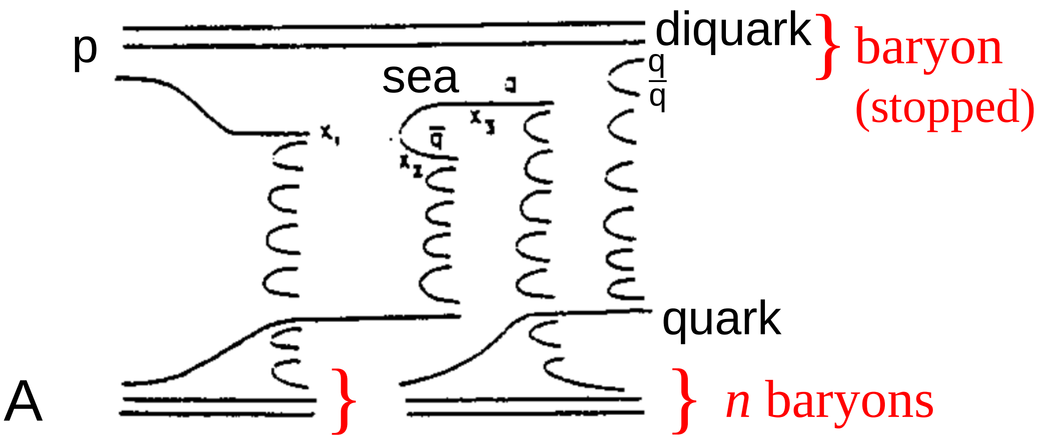
1. color exchange, formation of quark-diquark singlets (strings = “chains”) ;

2. string fragmentation into baryons.



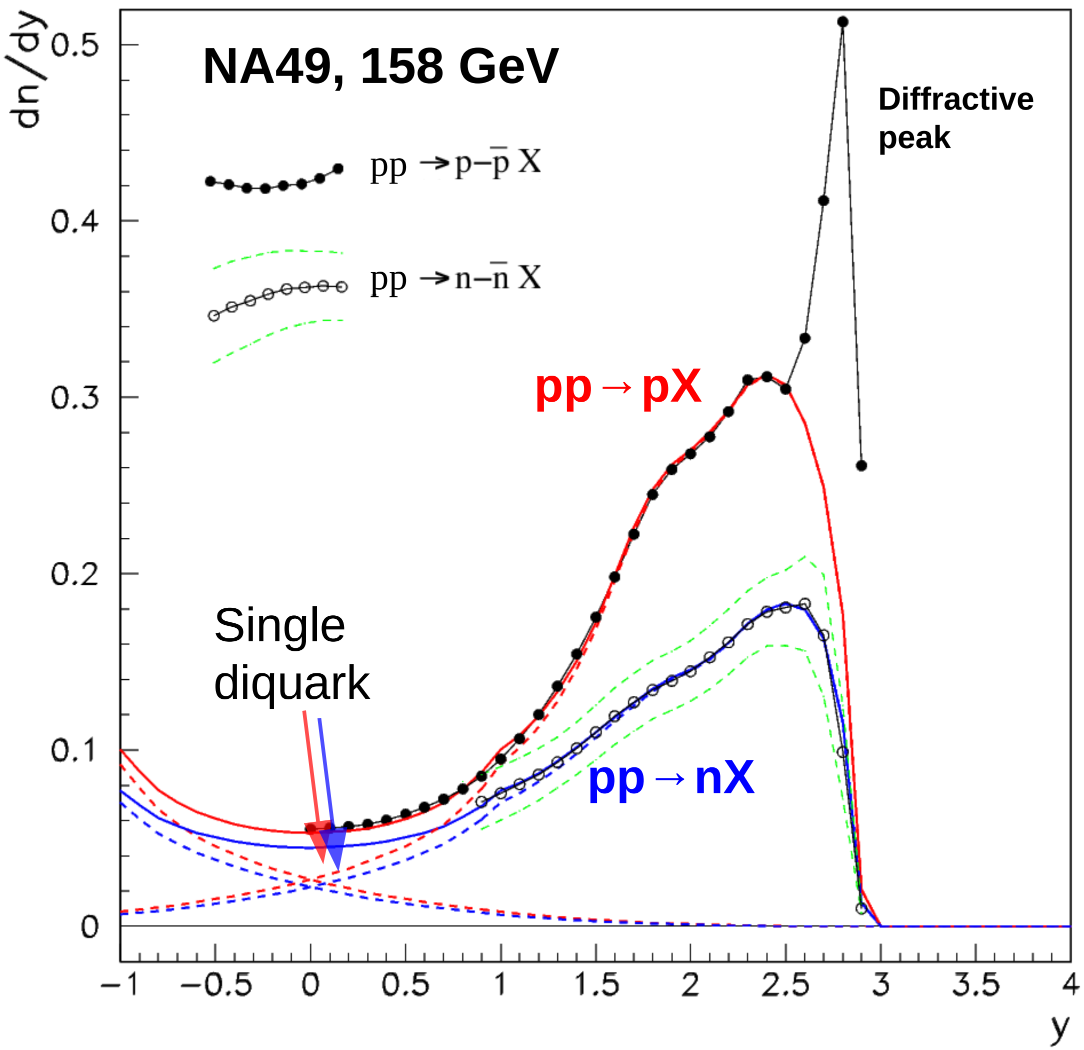
p+A:

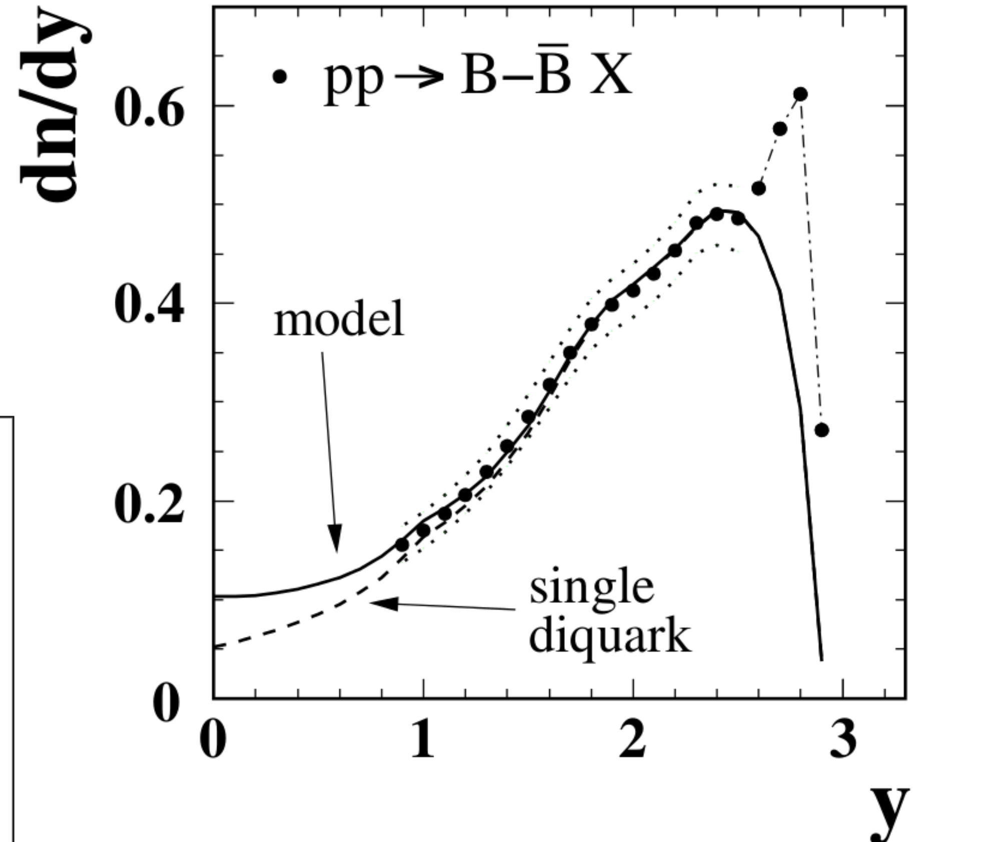
q_s-$\bar{q}_s$ pairs materialize by color exchange
and form extra chains.



The Dual Parton Model in pp collisions

M.J., A.R., APPB 51 (2020) 1207





- Exp. data: different behavior of protons and neutrons ;
- The diffractive peak cannot be described by DPM (→ “no color exchange” ?) ;

→ **Need to extend the DPM .**

4)
The Gluon Exchange Model (GEM)

M.J., A.R., arXiv:2101.01999

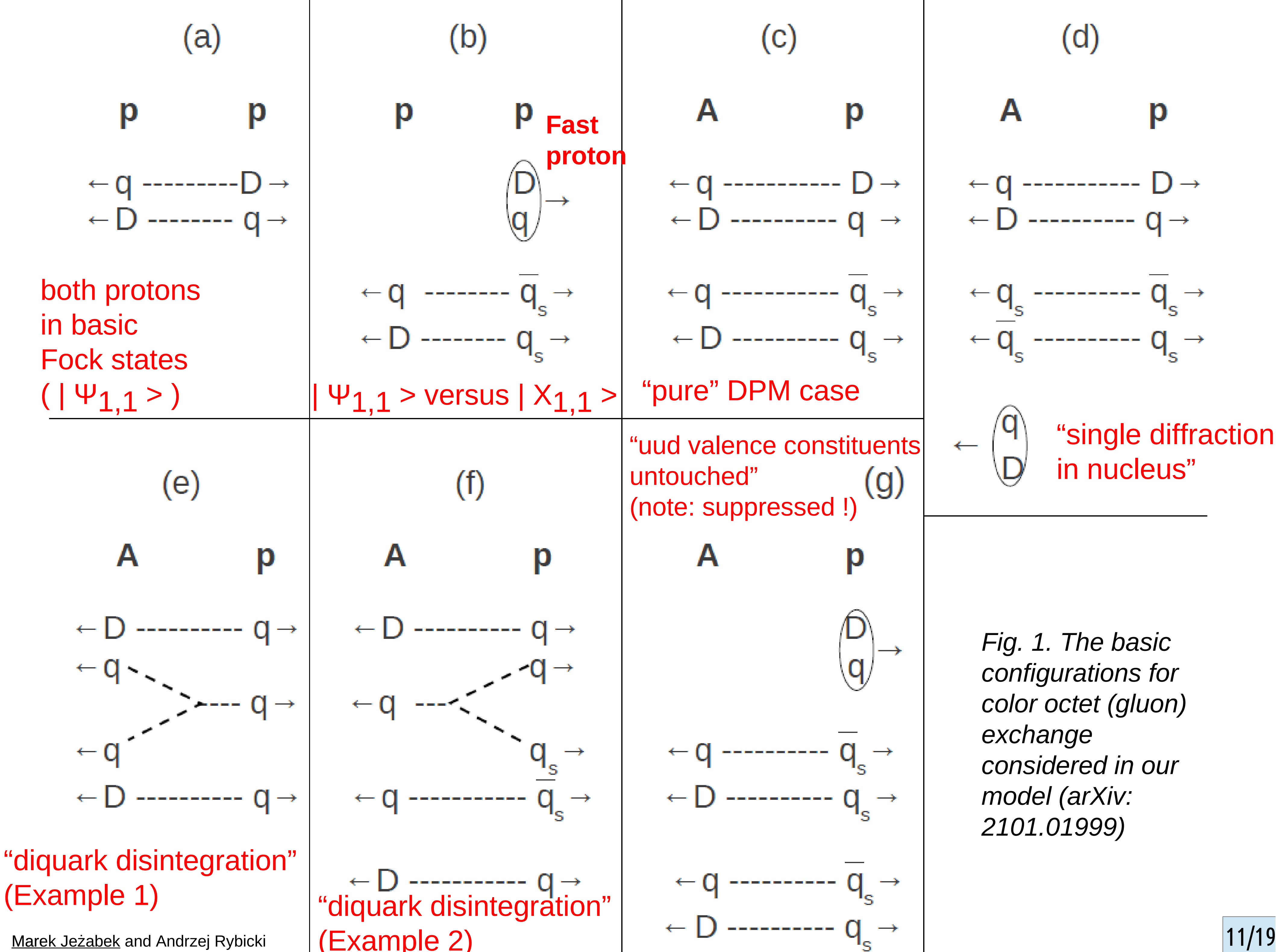
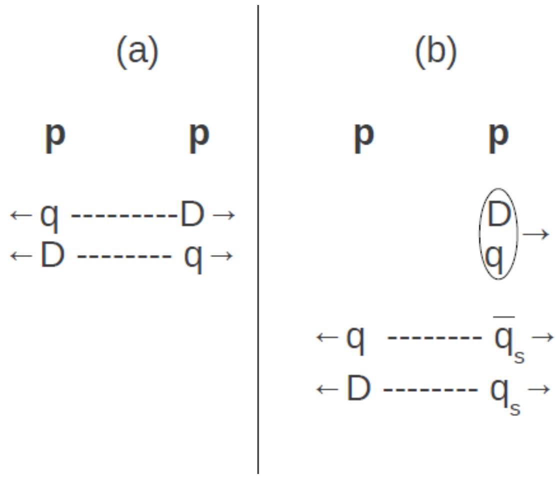
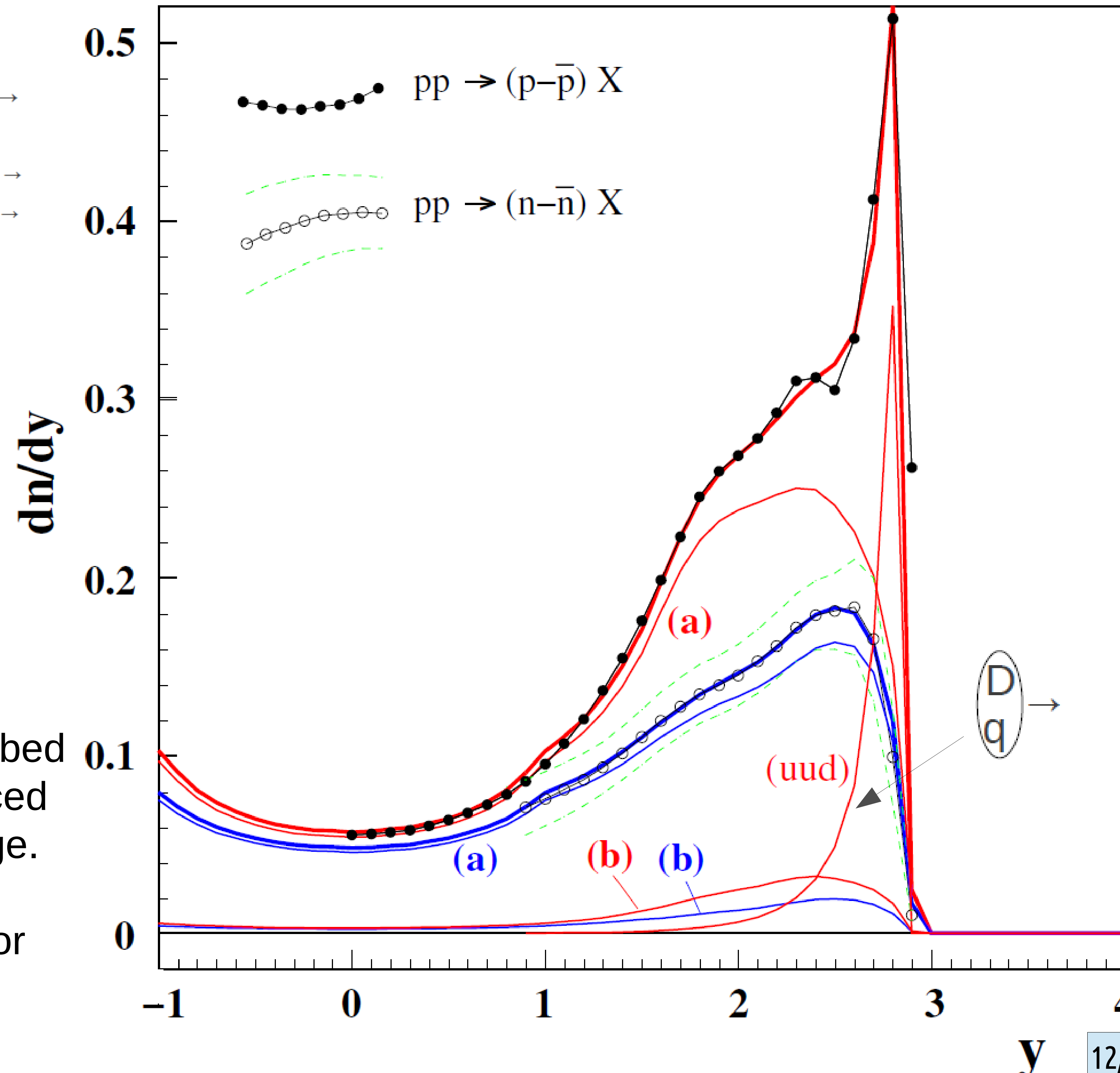


Fig. 1. The basic configurations for color octet (gluon) exchange considered in our model (arXiv: 2101.01999)



The GEM Model in pp collisions

arXiv:2101.01999



- Good description for the entire proton and neutron spectrum ;
- Diffractive peak described by a mechanism induced by color octet exchange.
- Relative probability *r* for diagram (b): *r* ≈ 8%.

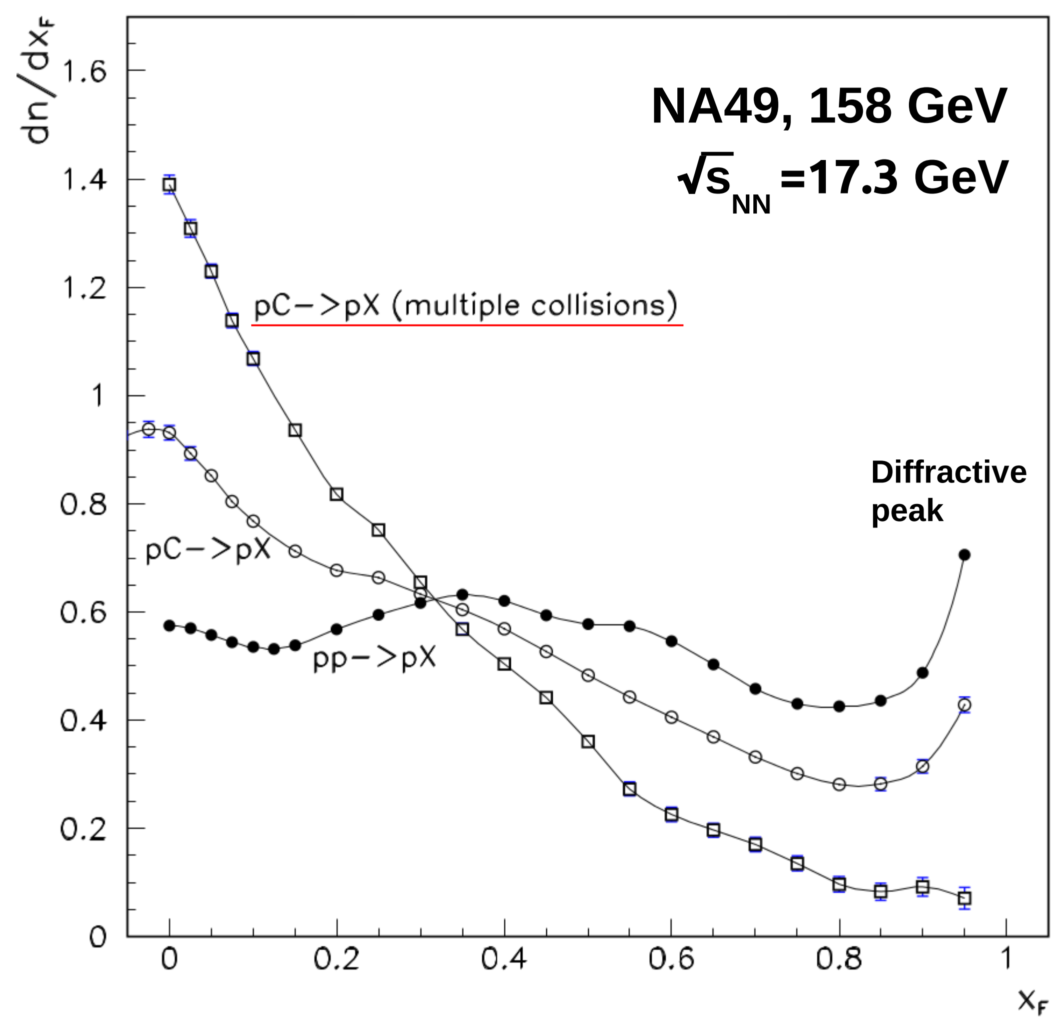
5)
The transport of baryon number in proton-nucleus collisions

arXiv:2101.01999

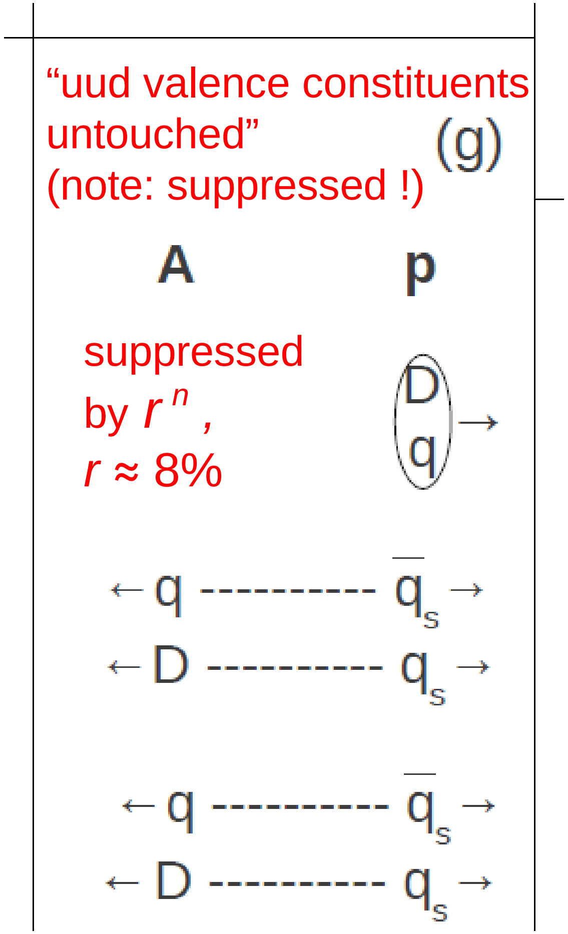
Proton-carbon collisions

$$\frac{dn}{dy}(pC_{\text{multiple collisions}} \to pX) = \frac{1}{1-P(1)}\left(\frac{dn}{dy}(pC \to pX) - P(1)\cdot\frac{dn}{dy}(pp \to pX)\right)$$

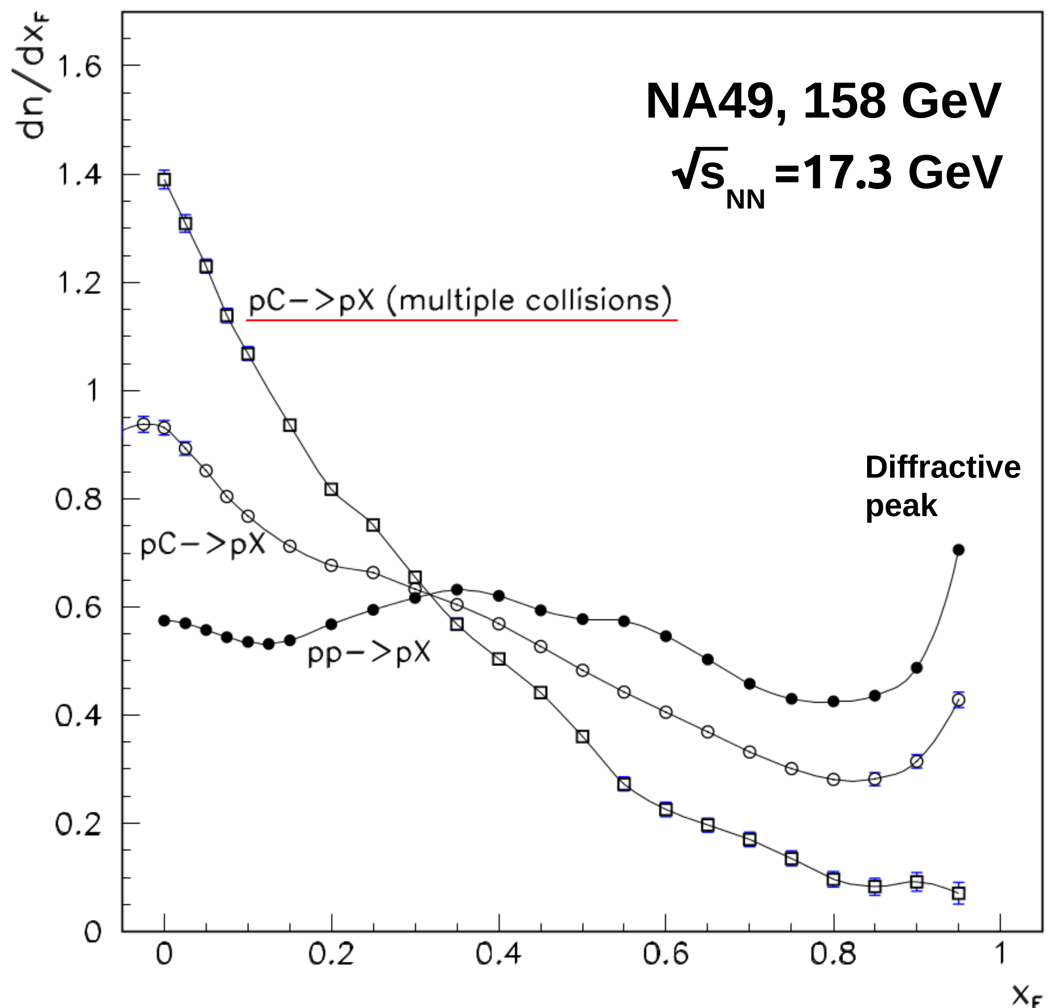
1. pC data from the same NA49 experiment (EPJC 73, 2013);
2. Glauber simulation → **P(1)** (EPJC 49, 2007) ;
3. Extraction of pC collisions in which the proton collides with **two or more** carbon nucleons ;
4. Note: in this “multiple collision” sample, the diffractive peak is strongly suppressed.



arXiv:2101.01999



$$\frac{dn}{dy}(pC_{\text{multiple collisions}} \to pX) = \frac{1}{1-P(1)}\left(\frac{dn}{dy}(pC \to pX) - P(1)\cdot\frac{dn}{dy}(pp \to pX)\right)$$

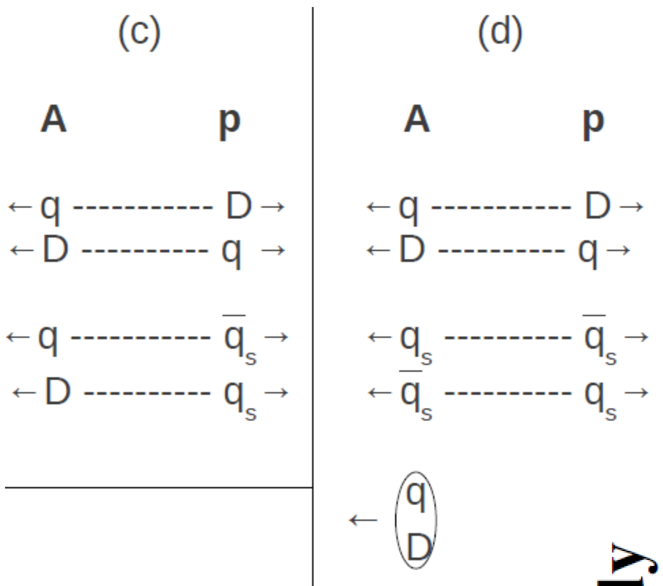


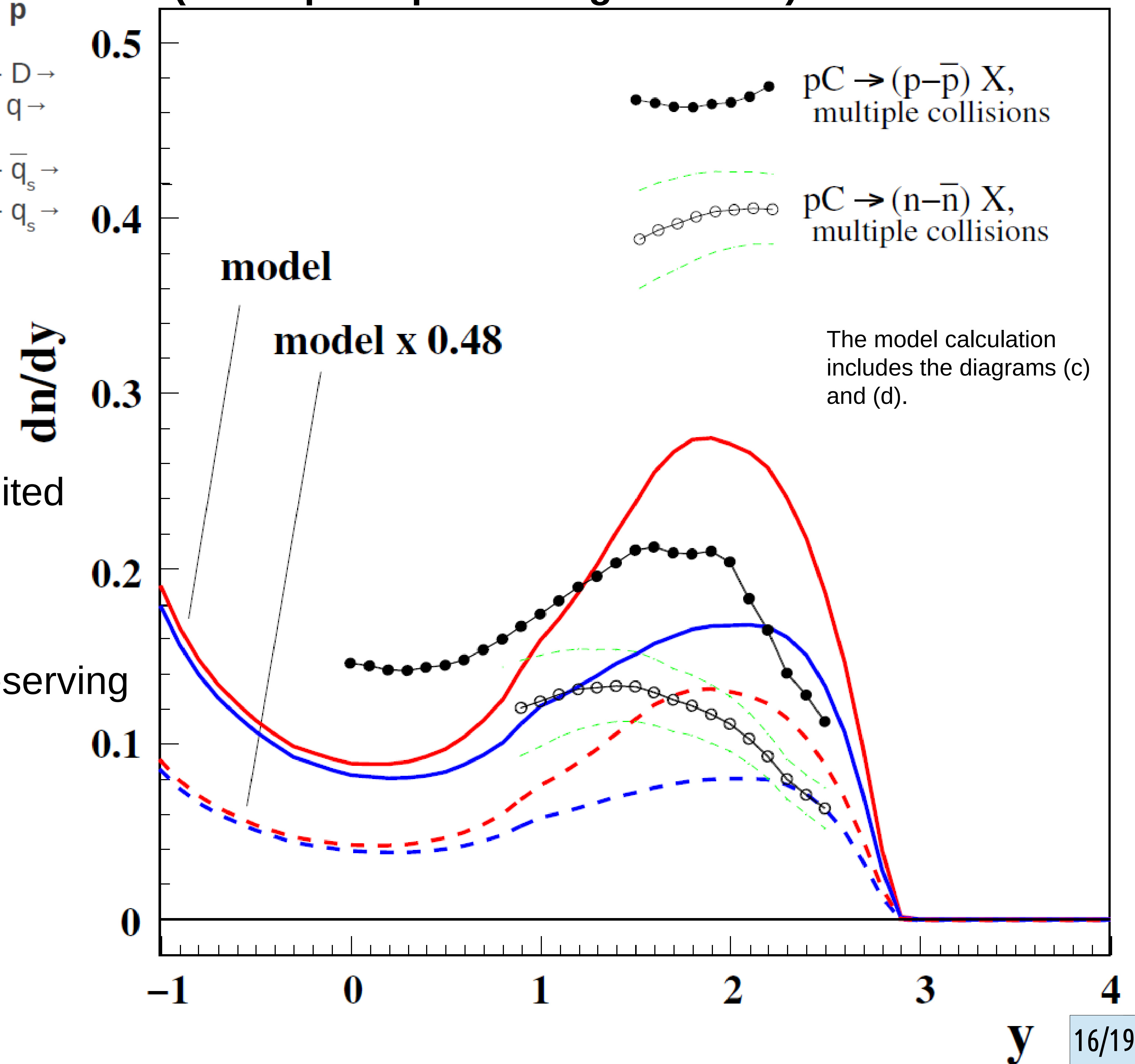
arXiv:2101.01999

4. Note: in this “multiple collision” sample, the diffractive peak is strongly suppressed.

arXiv:2101.01999

The GEM model in pA collisions (the diquark-preserving scenario)

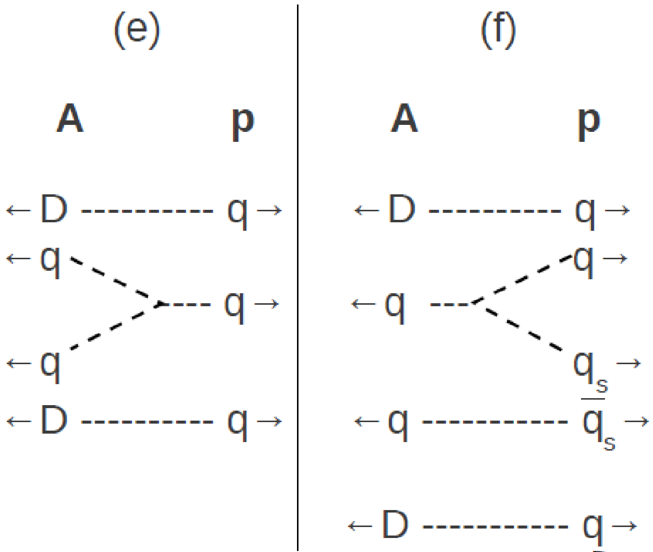


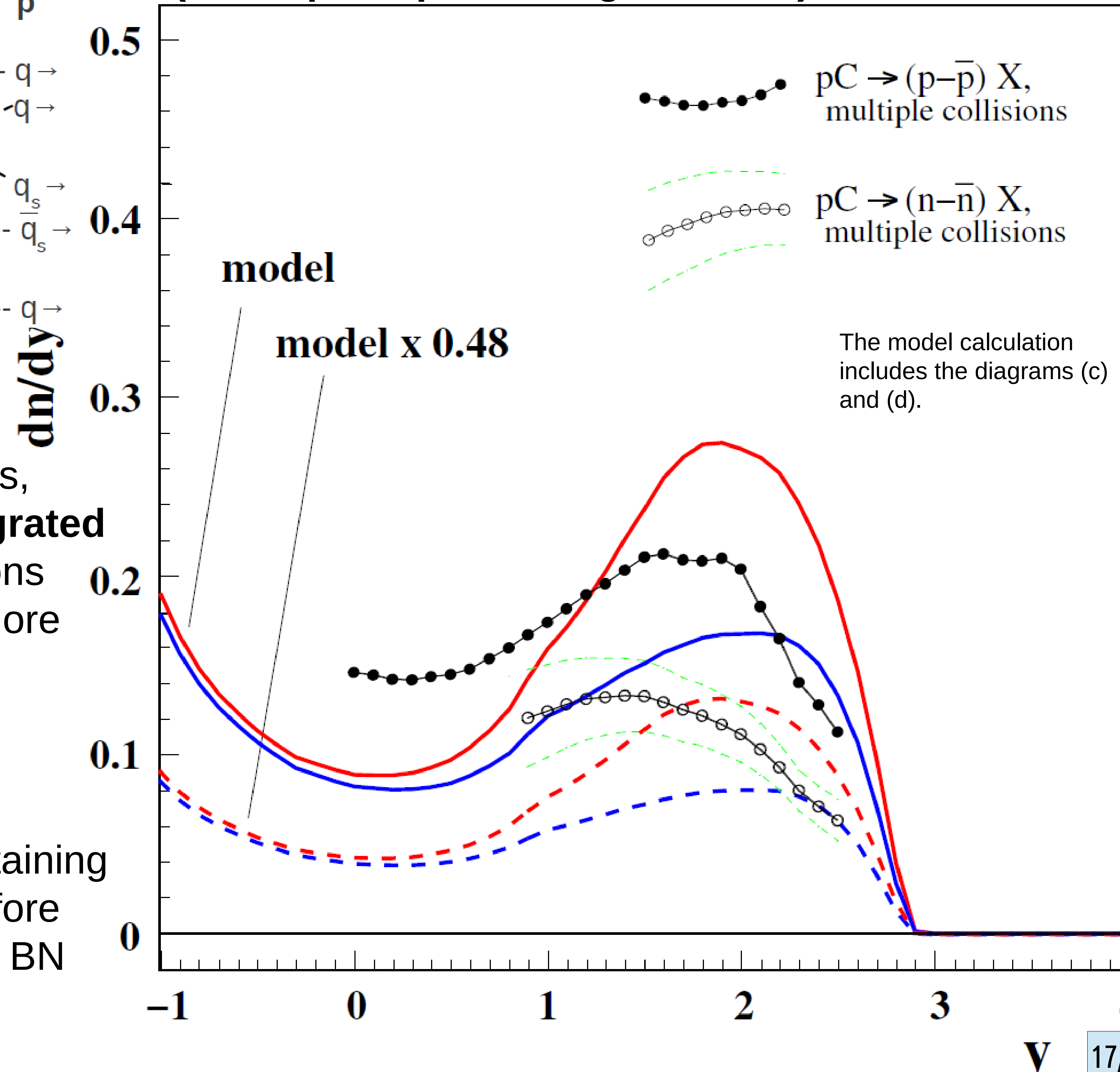


- GEM calculation is limited to diquark-preserving diagrams (c,d) ;
- Exp. data: diquark-preserving diagrams cannot be responsible for 100% of baryon “stopping” ;
- Upper limit for this contribution : **48%** .

arXiv:2101.01999

The GEM model in pA collisions (the diquark-preserving scenario)





- Already in pC reactions, the diquark is **disintegrated** in about **half** of collisions of a proton with 2 or more nucleons ;
- This will result in color singlets of a new type, **softer** then these containing the diquark, and therefore to **longer transfers** of BN in rapidity.

5) Summary

We presented a new model for soft processes in hadron-hadron and hadron-nucleus collisions, the Gluon Exchange Model (GEM).

While formally it can be regarded as a generalization of the Dual Parton Model, it is fundamentally based on the number of exchanged color octets (gluons) and extends the Fock space of states available for the participating protons and nucleons.

In pp collisions, GEM provides a complete description of the final state proton and neutron distribution in the projectile hemisphere.

What is remarkable is that unlike the DPM, GEM successfully describes the proton diffractive peak at high x_F as a specific case of color octet exchange.

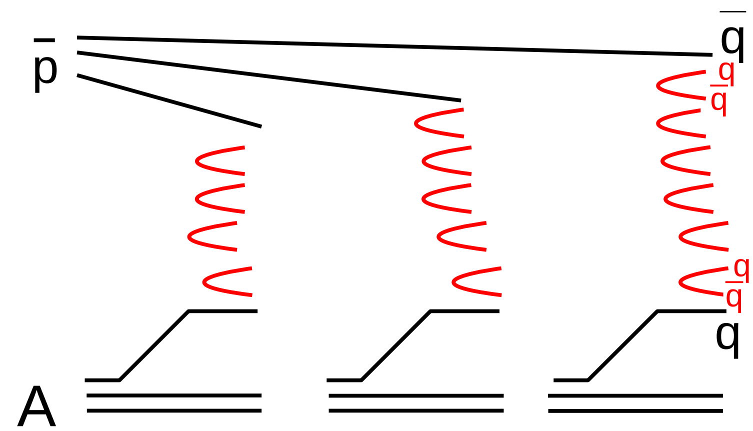
In pA collisions where the proton interacts with more than one nucleon, our study made with GEM shows that the projectile proton diquark cannot survive in more than about half of such processes.

Consequently, the diquark must be frequently disintegrated, leading to longer transfers of baryon number in rapidity.

5') Future

> – A comparatively simple experiment would consist in a comparison of the fast proton spectra in pA collisions with fast antiproton spectra in $\bar{p}$A collisions at the same energy. Our calculations show that also this measurement can give the necessary informations about the evolution of the intranuclear process.
>
> APPB 11 1980

M.J., K. Zalewski, 40 years ago (!)



→ the usage of a $\bar{p}$ projectile offers new possibilities of studying the properties of the non-perturbative process by, e.g., **the annihilation of baryon number from the disintegrated anti-diquark over multiple nucleons.**

→ the limitations of the earlier data sets are largely lifted for modern experimental data if only proper precision, hermeticity, and measurement of different baryon types (p, n, Λ, ...) can be ensured.

→ several options come to mind:

- →SPS (SHINE) ;
- →NICA (MPD) ?
- →AFTER@LHC ?

... thank you !

Acknowledgments

We acknowledge the work of Hans Gerhard Fischer on the release of the experimental data which made this study possible.

This work was supported by the National Science Centre, Poland (grant no. 2014/14/E/ST2/00018).

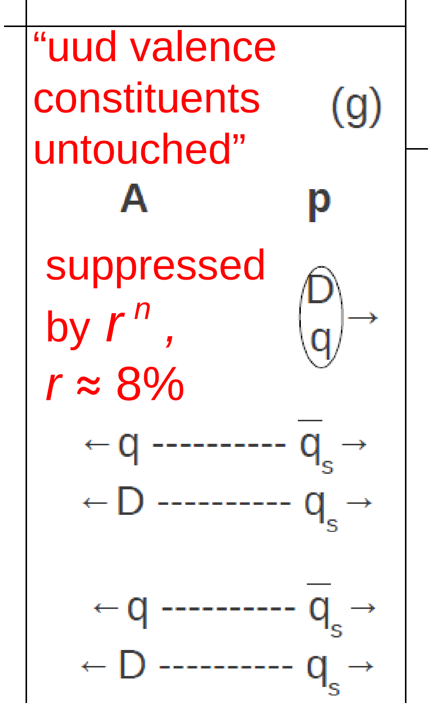
Extra slides

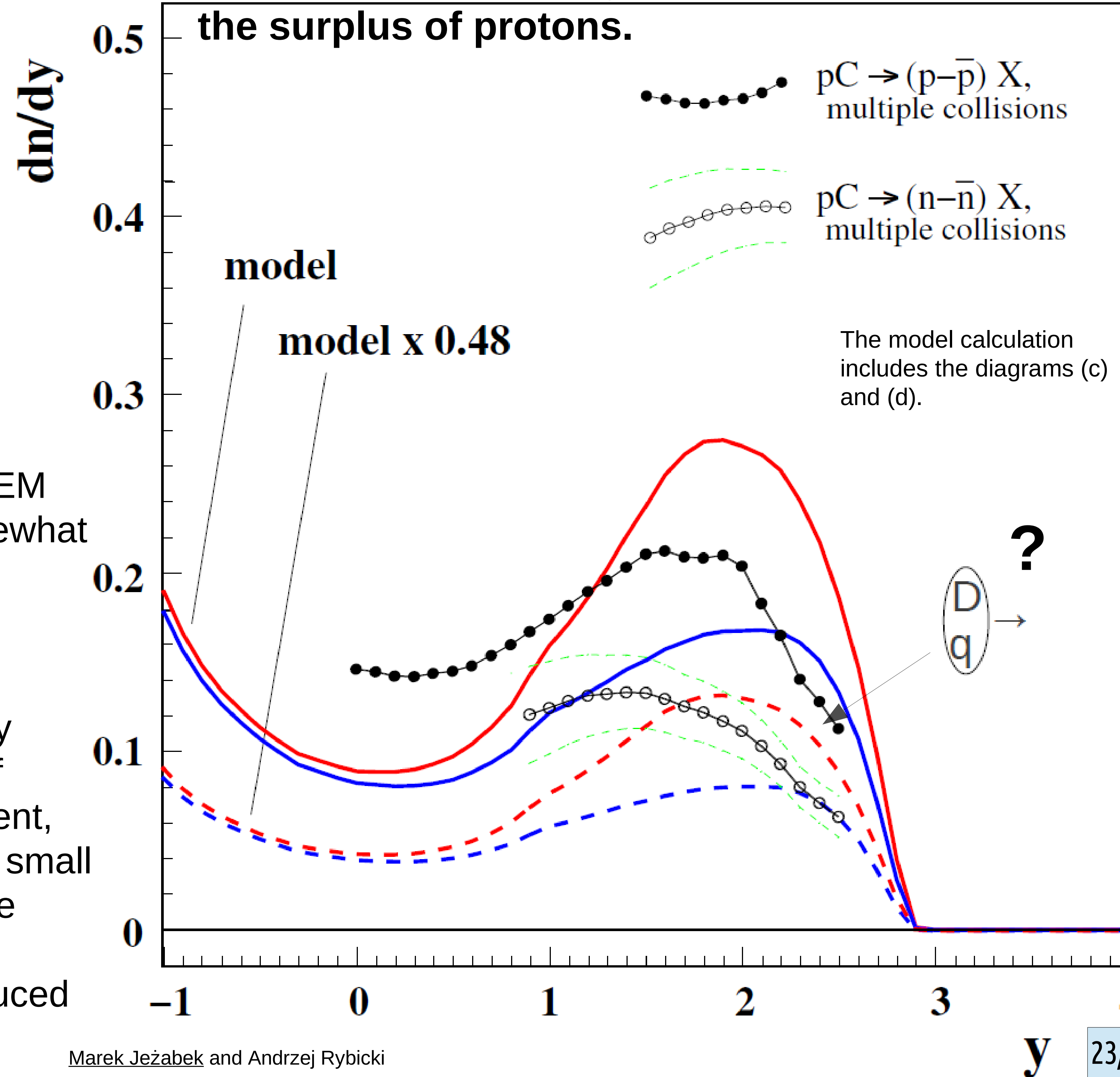
Constituent distribution in GEM (x_{q_i}, x_i - momentum fractions, μ-sea quark mass):

$$\rho_m(x_{q_1}, x_{q_2}, x_{q_3}, x_1, ..., x_{2m}) =$$

$$C_m (x_{q_1} + x_{q_2})^{1/2} x_{q_3}^{-1/2} \prod_{i=1}^{2m} (x_i^2 + 4\mu^2/s)^{-1/2} \cdot \delta\left(1 - x_{q_1} - x_{q_2} - x_{q_3} - \sum_{i=1}^{2m} x_i\right)$$

The GEM model in pA collisions (the diquark-preserving scenario) : the surplus of protons.





- Interestingly, unlike for neutrons, the scaled GEM proton calculation somewhat underestimates the spectrum of protons at forward rapidity.
- With caution induced by the systematic errors of the neutron measurement, we tend to attribute the small surplus of protons to the (strongly reduced) uud singlet component, induced by the diagram (g).