The Gluon Exchange Model, or solving the puzzle of nuclear stopping power

Marek Jeżabek and Andrzej Rybicki

Institute of Nuclear Physics, Polish Academy of Sciences

Cracow, Poland

1. Introduction ;

2. The Gluon Exchange Model ;

3. Baryon stopping as a function of the number of collisions ;

4. Conclusions.

5. (Homework).

Based on:

APPB 51 (2020) 1207
PLB 816 (2021) 136200
EPJPlus 136 (2021) 971
APPB 52 (2021) 981
arXiv:2111.03401

1)
Introduction

a

This talk will be concerned with "soft" proton-proton and proton-nucleus collisions at √s ~ 20 GeV.

The implications touch all the high energy scale (LHC, cosmic), and also nucleus-nucleus (heavy ion) physics.

The main problem which we will address is the following:

- in a proton-nucleus (pA) collision, how does the proton *encode* knowledge on the number of nucleons which it collides with ?

"The puzzle of nuclear stopping power"

a

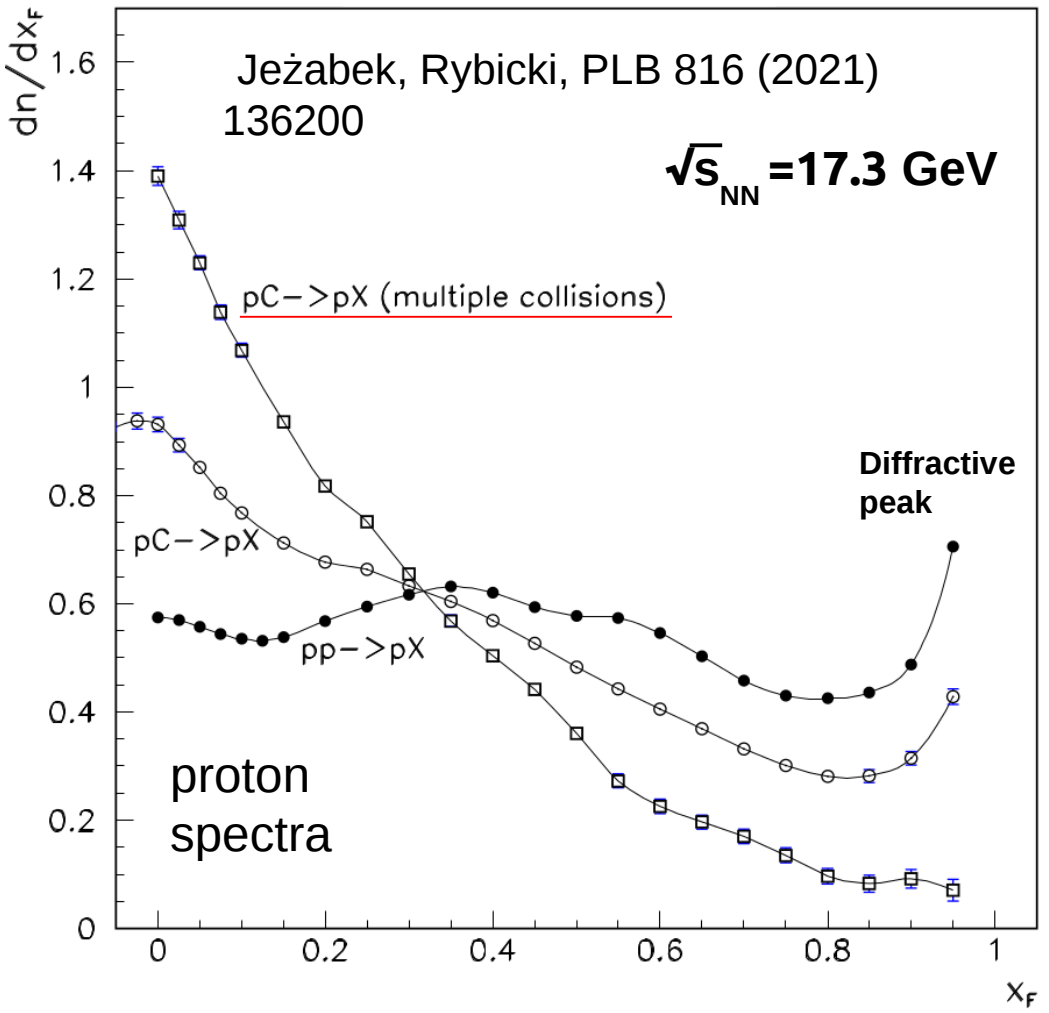
Proton-proton vs proton-nucleus collisions

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

1. pp and pC data from the same NA49 experiment (Eur. Phys. J. **C65**, 9 (2010), Eur. Phys. J. **C73**, 2364 (2013)).

2. **P(1)** - probability of proton collision with one wounded nucleon.

3. **Advantage**: we can extract pC collisions in which the proton collides with **multiple** (more than one) nucleons.



a

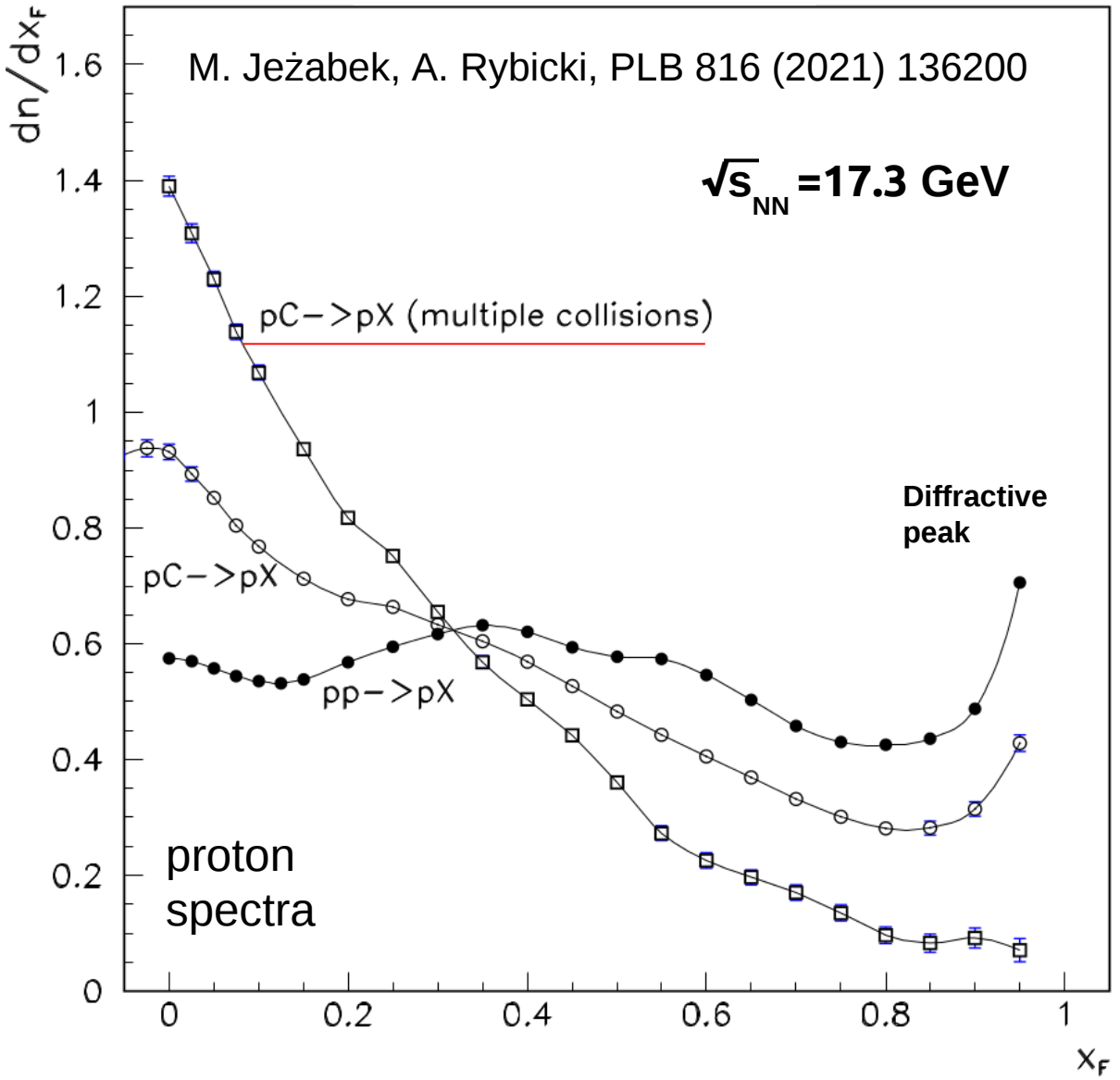
Qualitative difference between single and multiple proton-nucleon collisions!

How does the projectile know about the number of wounded nucleons ?

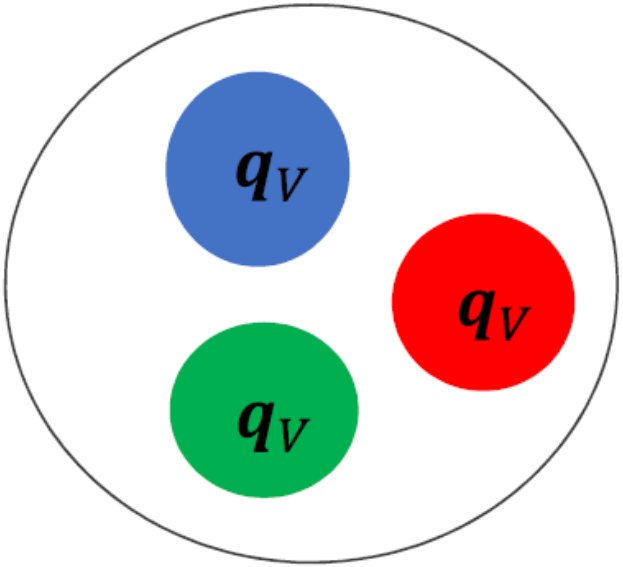
→ The Gluon Exchange Model :

→ The projectile is a system of constituents : valence quarks (color triplets) and sea quark-antiquark pairs (color octets).

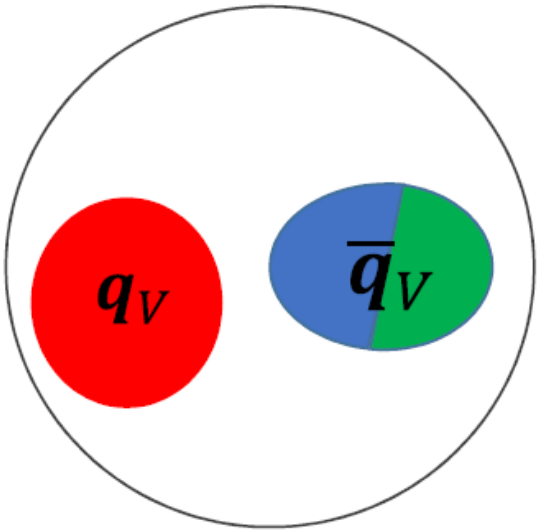
→ The interaction is governed by the number of exchanged color octets (gluons).



2)
the Gluon Exchange Model (GEM)

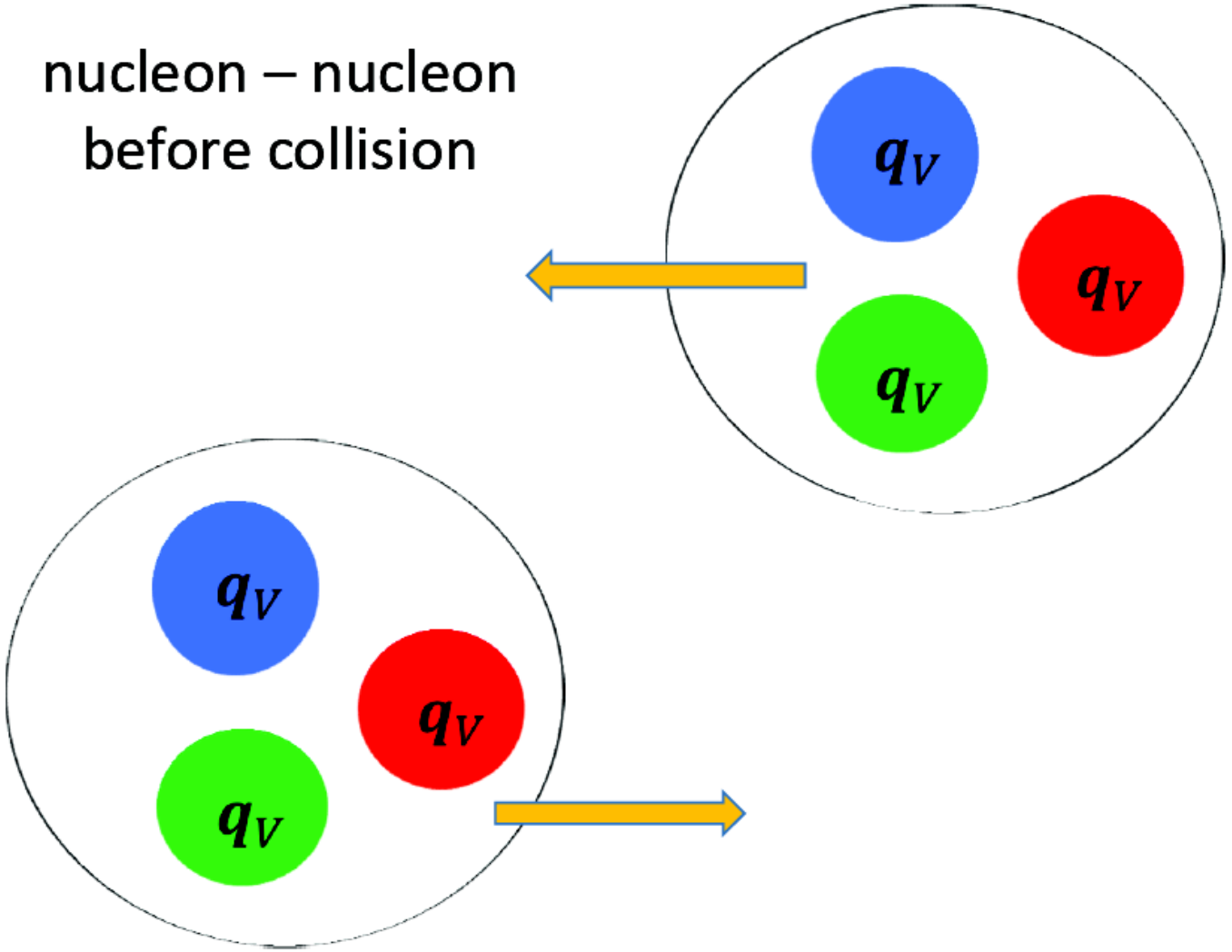


Baryon

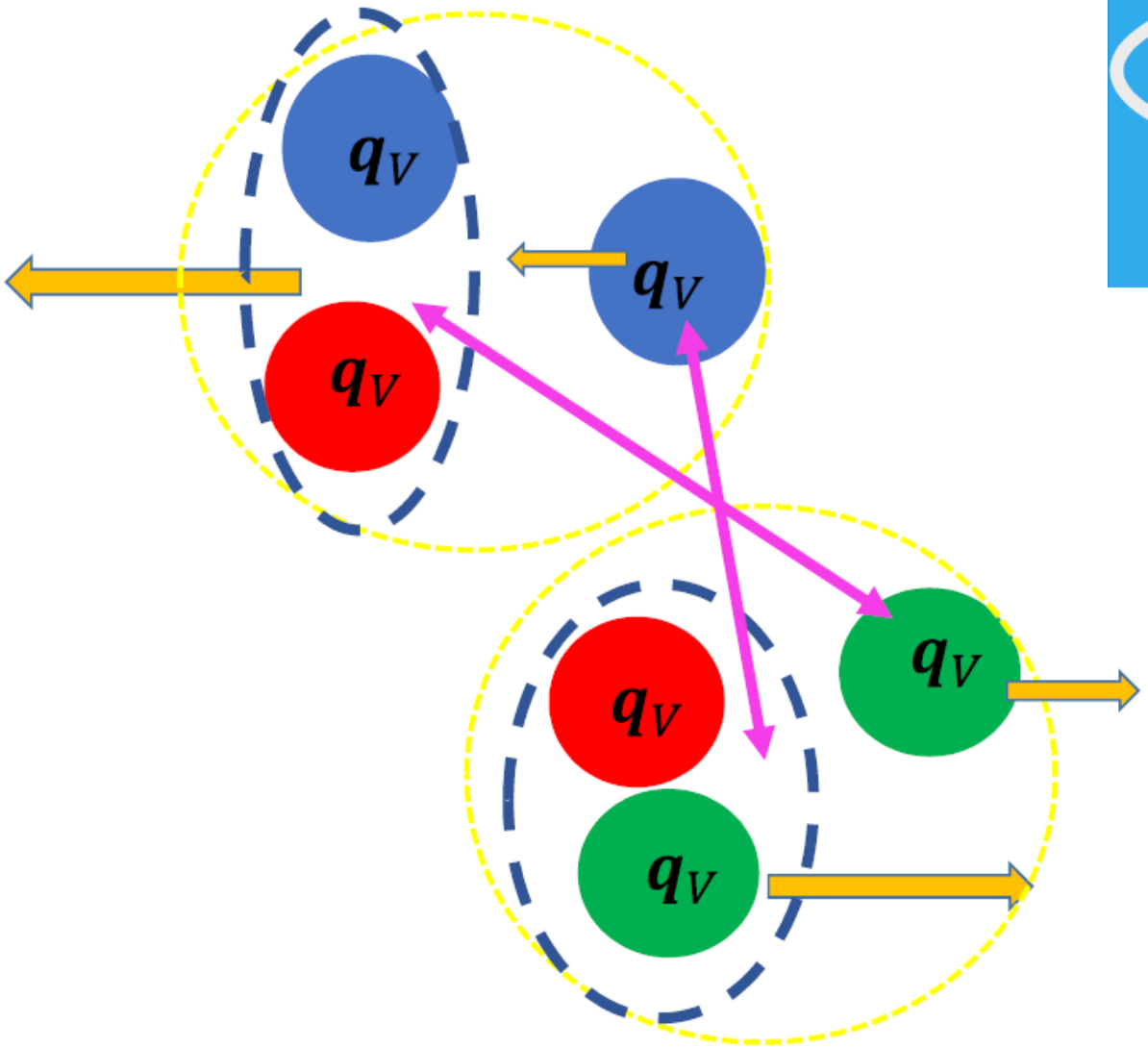


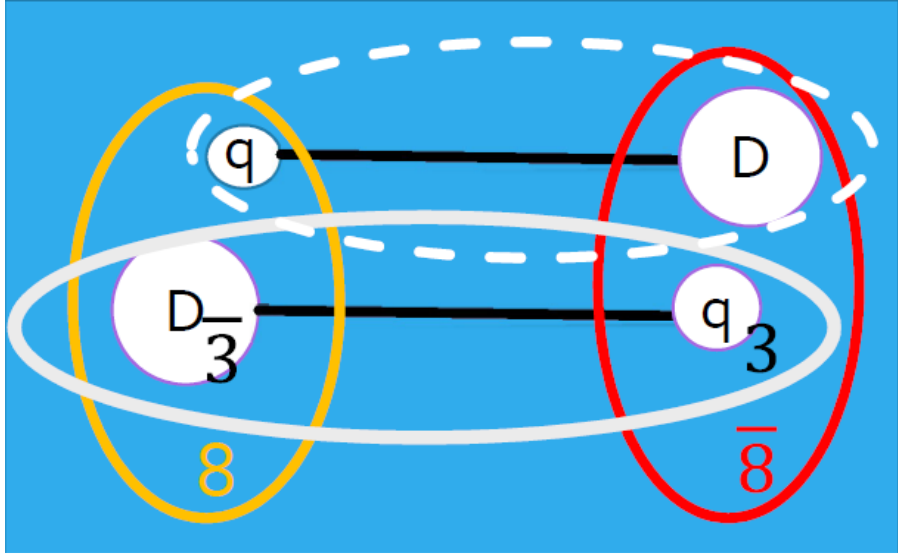
Meson

nucleon – nucleon
before collision



nucleon – nucleon
after collision

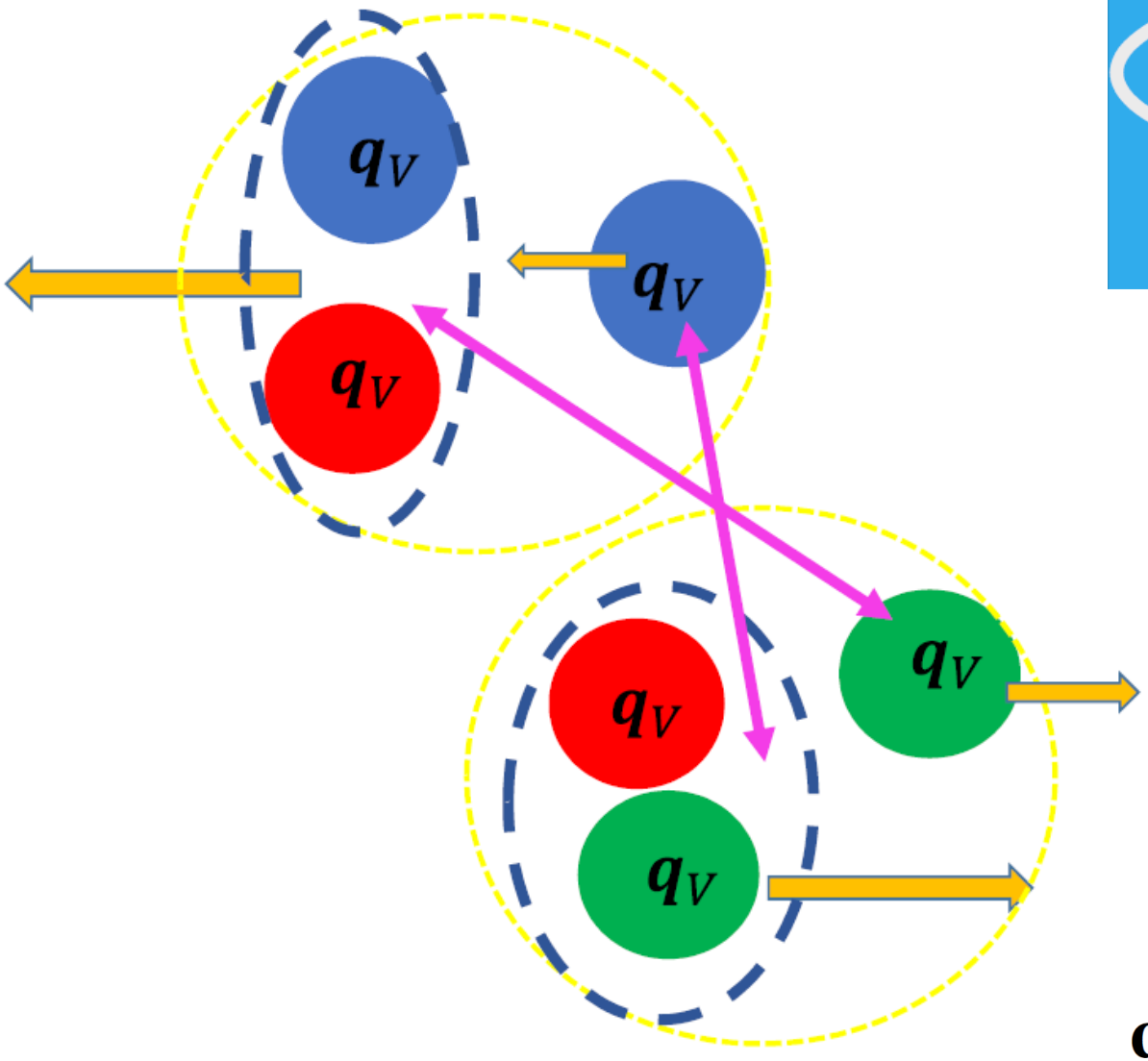


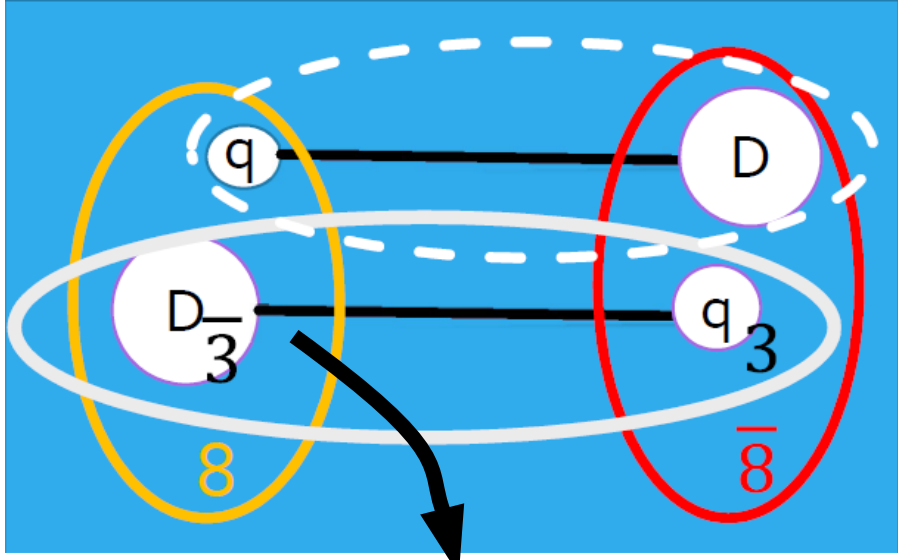


Note: this is like in the Dual Parton Model.

A. Capella and J. Tran Thanh Van, PLB **93**, 1980,
MJ, J. Karczmarczuk, M. Różańska, ZPC **29**, 1985.

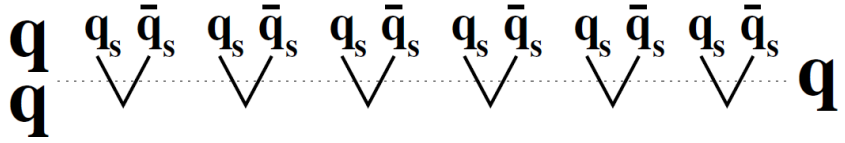
nucleon – nucleon
after collision

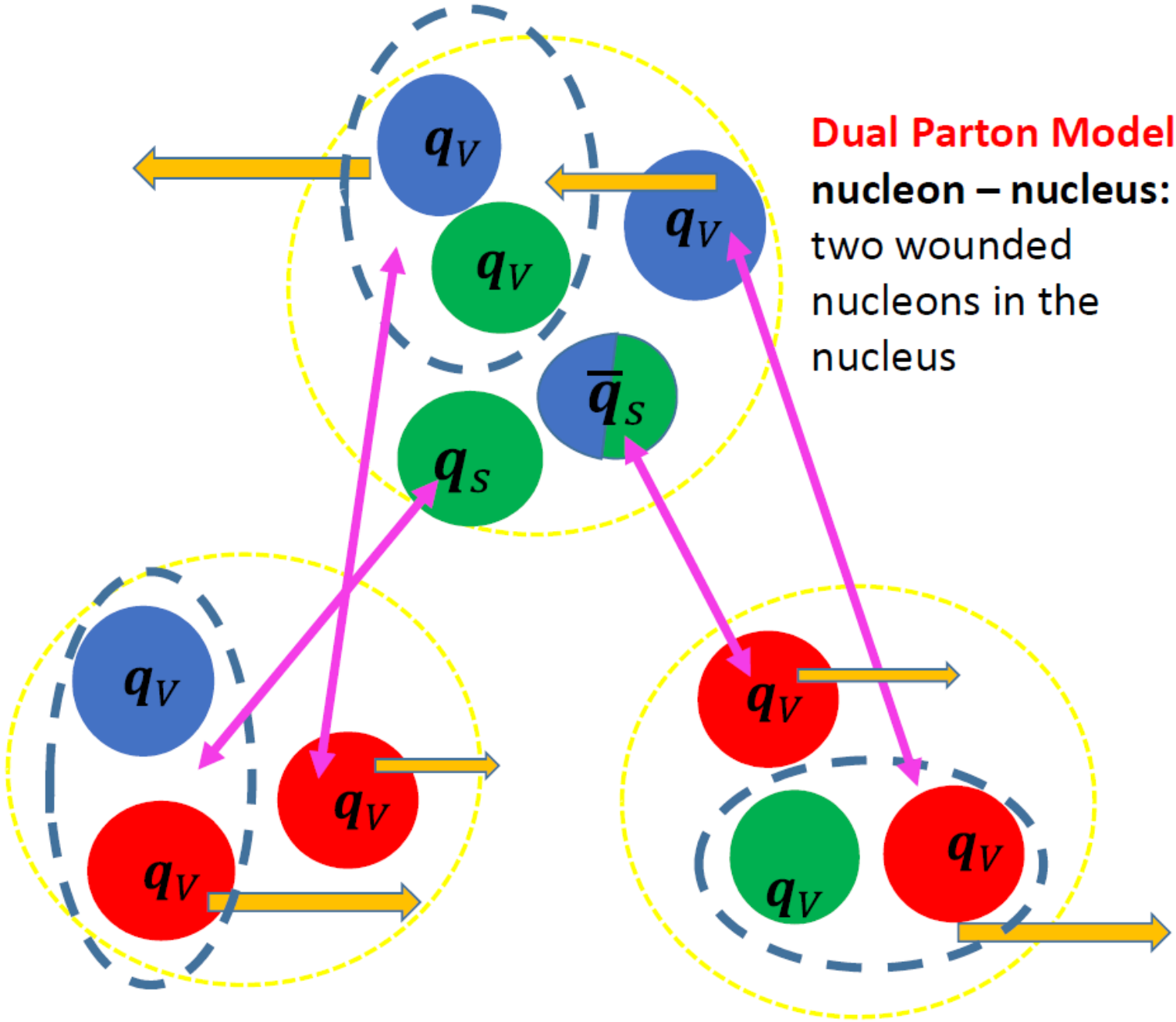




Note - we will concentrate on <u>diquarks</u> :

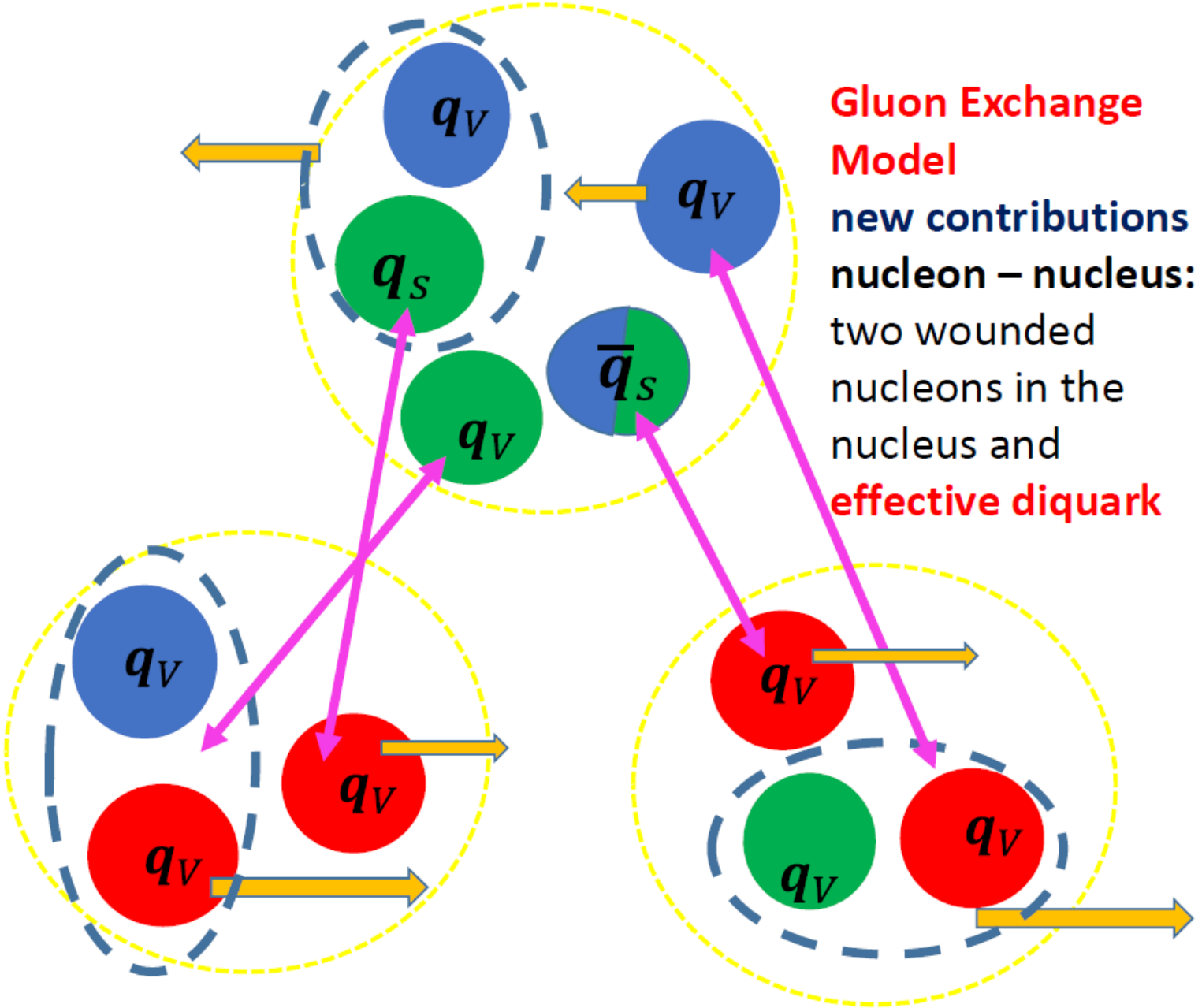
- D's carry most of the strings' energy/momentum,
- string fragmentation proceeds through q-$\bar{q}$ pairs thus it “starts” from the diquark.





Dual Parton Model

nucleon – nucleus: two wounded nucleons in the nucleus



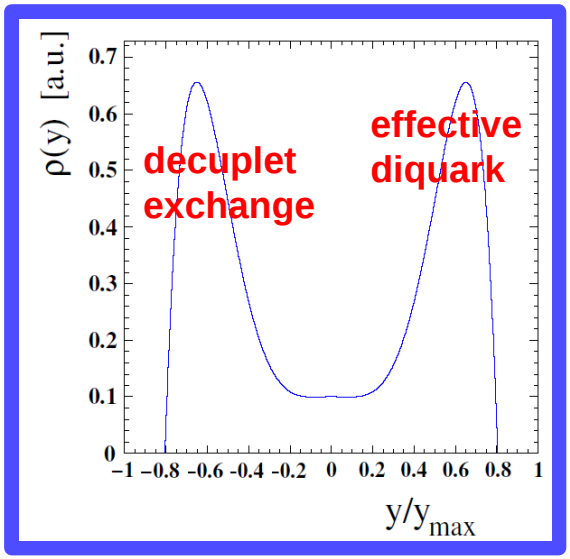
Gluon Exchange Model

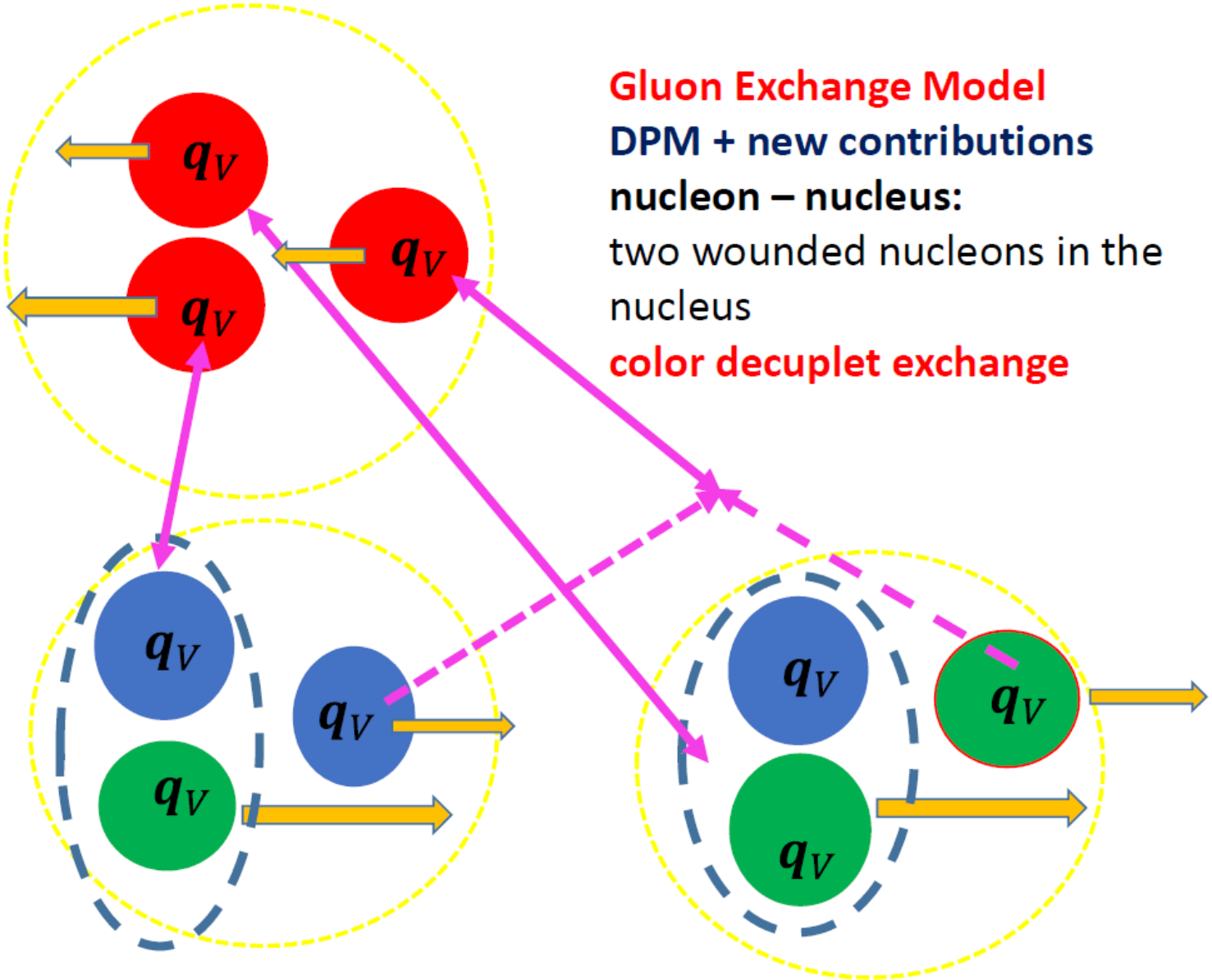
new contributions

nucleon – nucleus:

two wounded nucleons in the nucleus and

effective diquark





Gluon Exchange Model

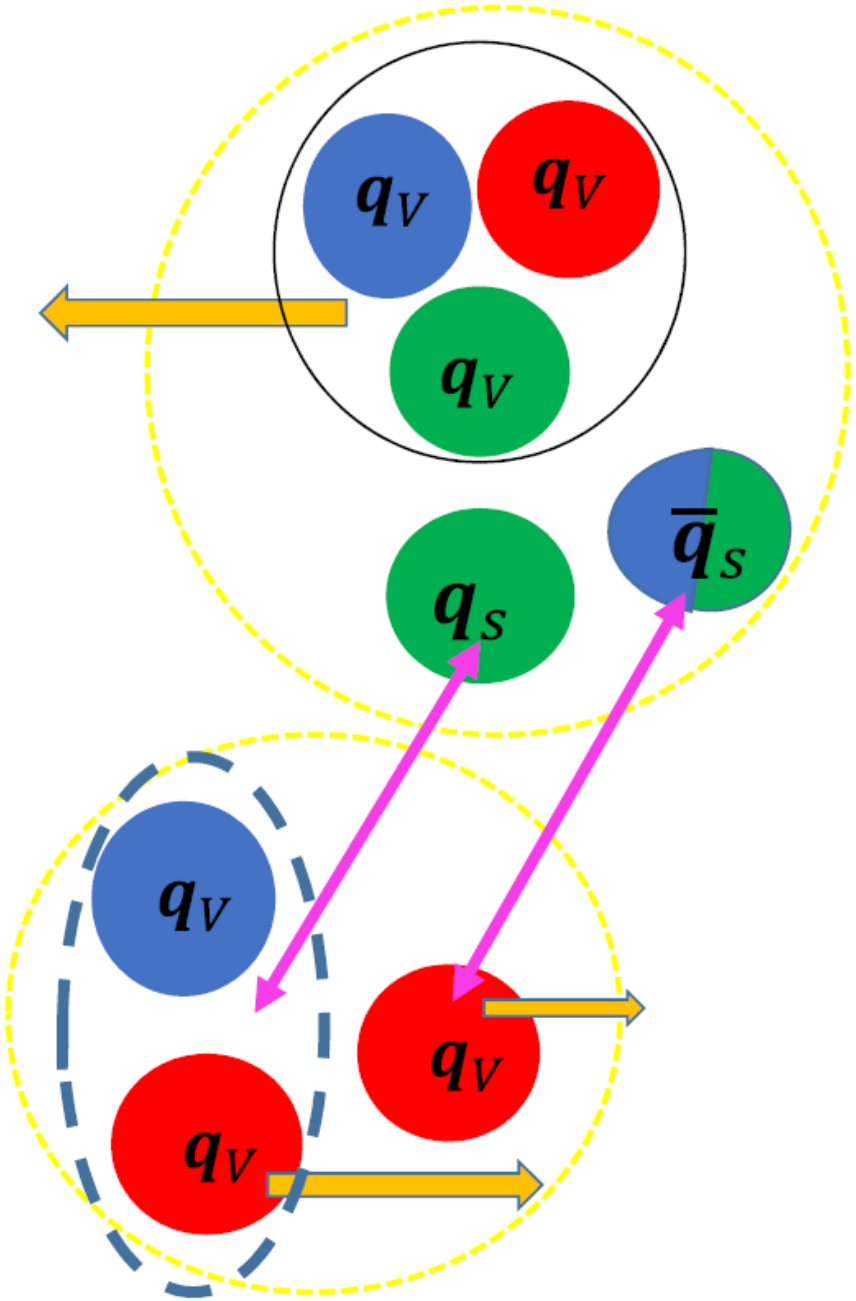
DPM + new contributions

nucleon – nucleus:

two wounded nucleons in the nucleus

color decuplet exchange

Bonus...



Gluon Exchange Model

DPM + new contributions

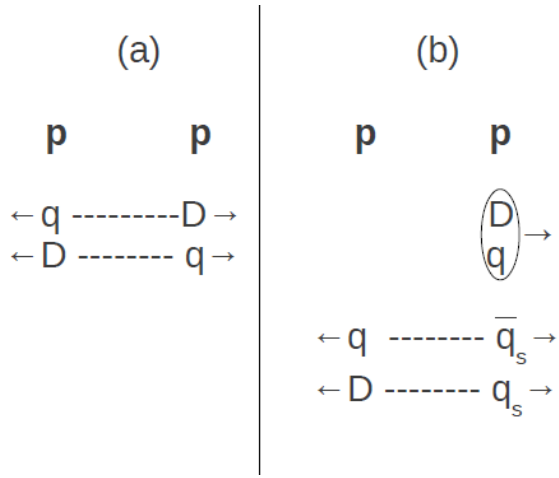
nucleon – nucleon:

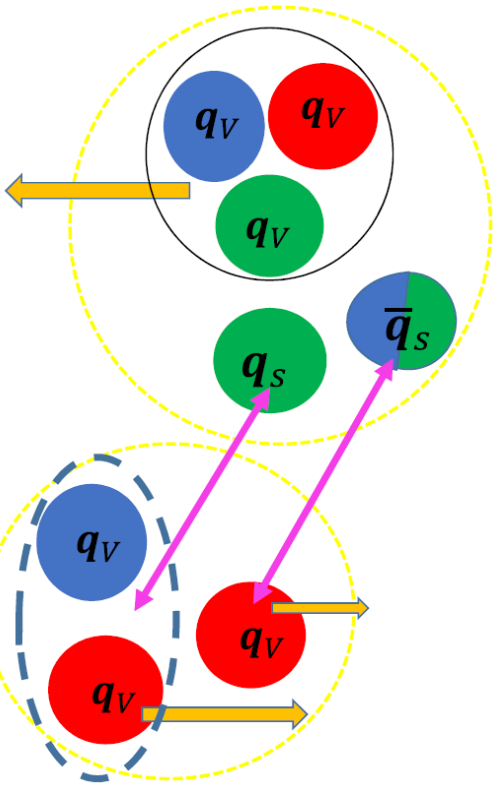
inelastic diffraction

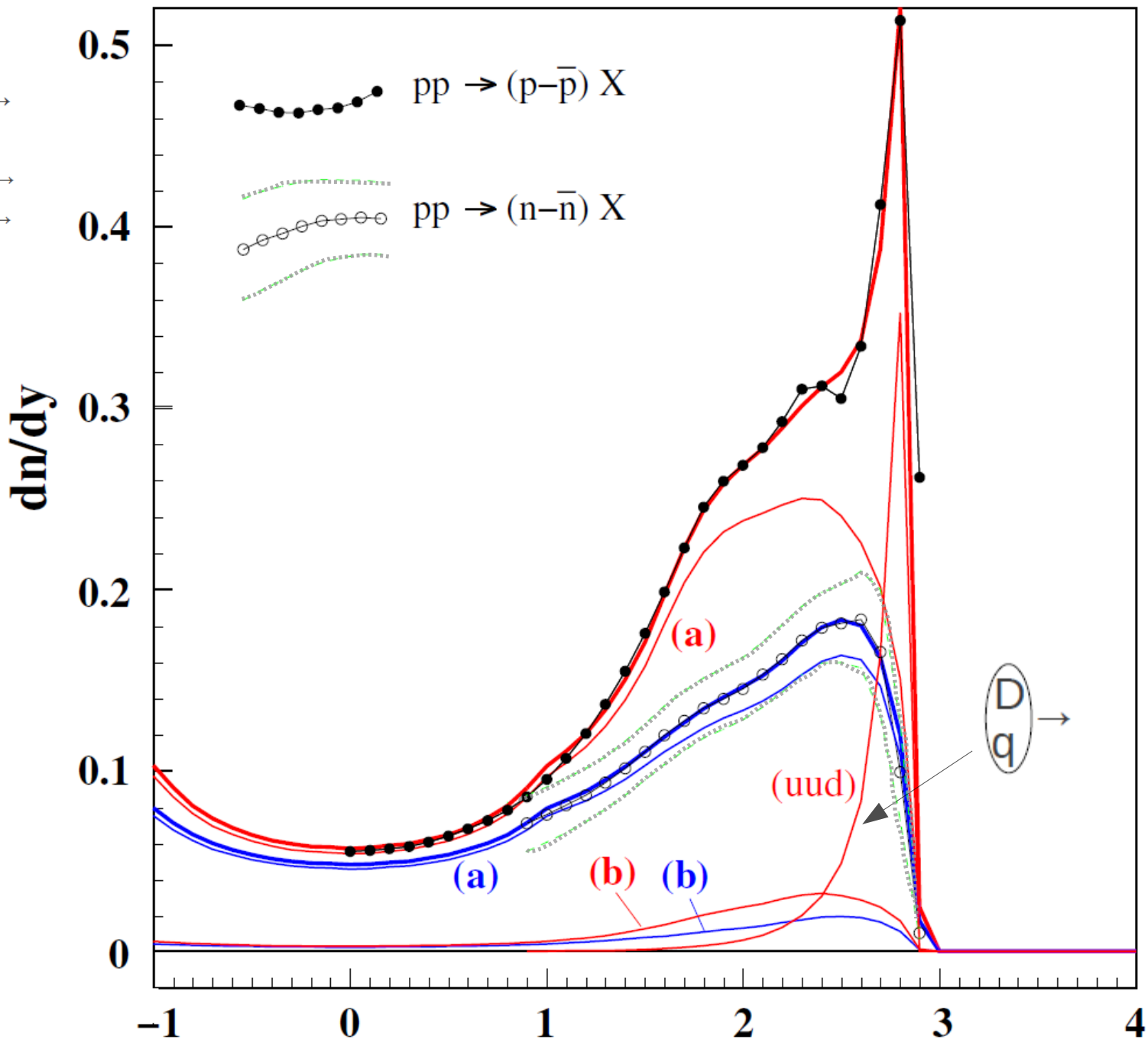
- Note!
- Below we will discuss NET baryon spectra.
- Baryon-antibaryon pair production has been subtracted from all the distributions!
- Unlike at the LHC, at the SPS the $\bar{p}/p$ ratio is ~0.25 at y(c.m.s.)=0 .

GEM in pp collisions

PLB 816 (2021) 136200



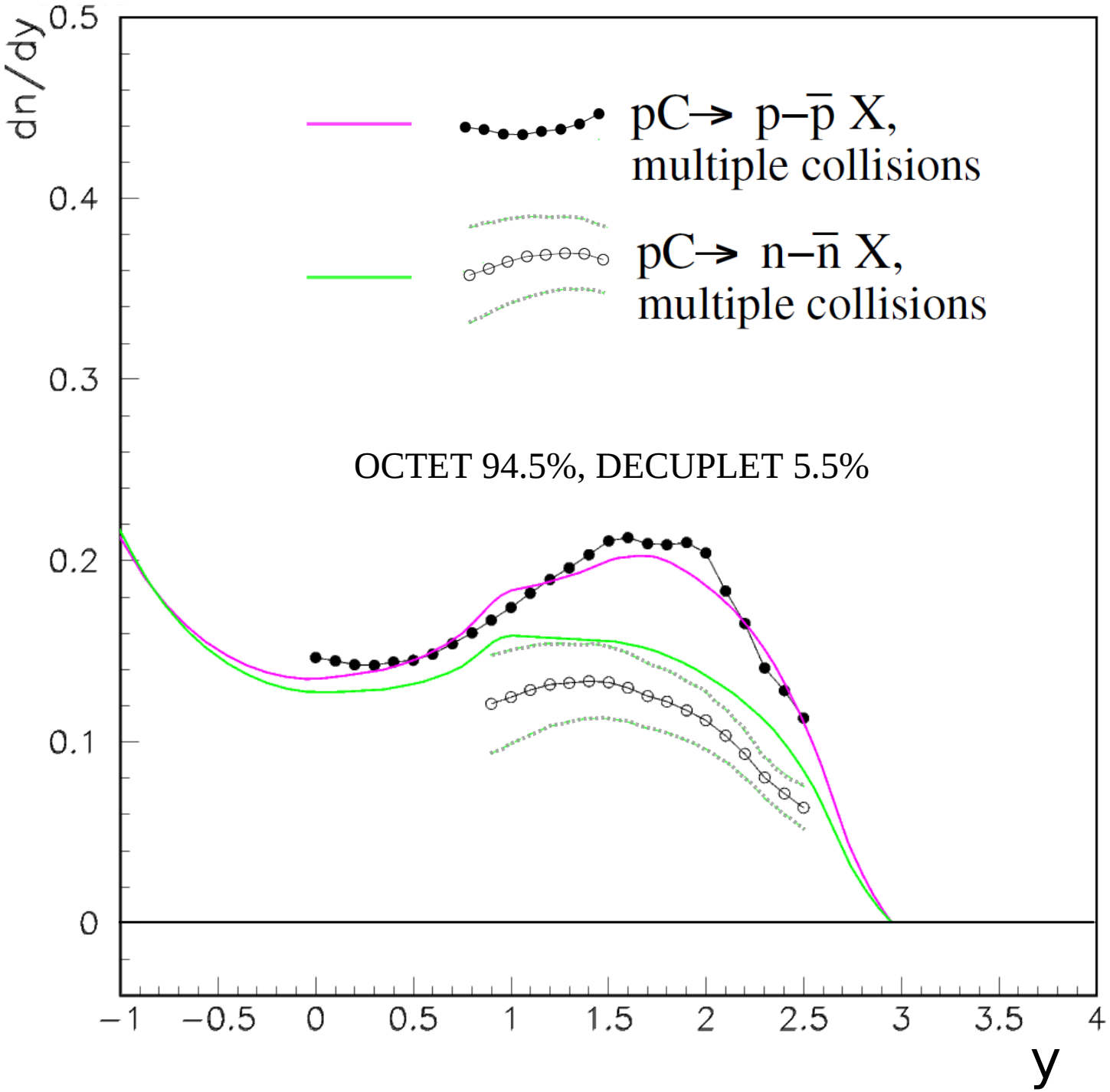


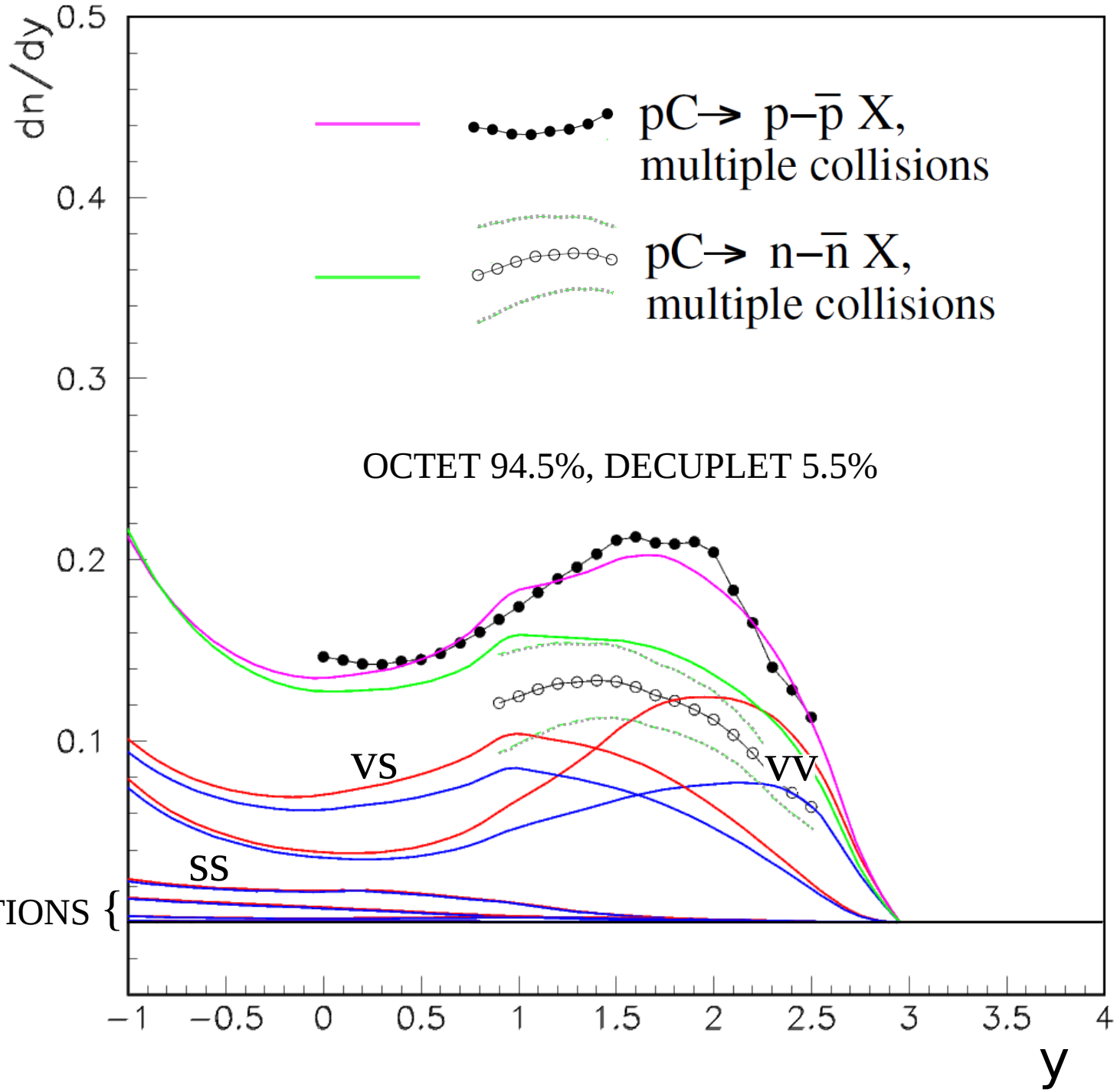


Octet

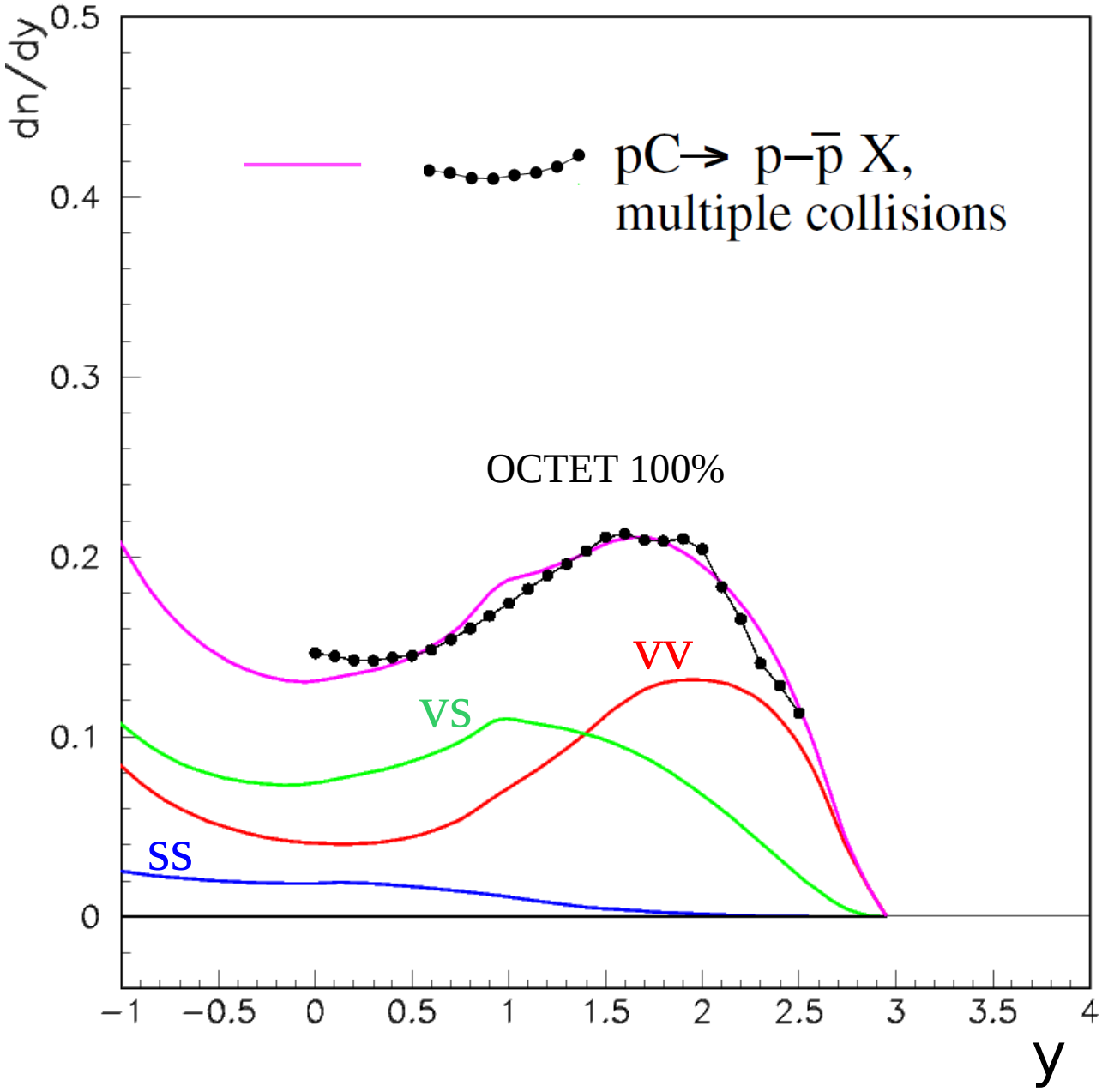
Decuplet

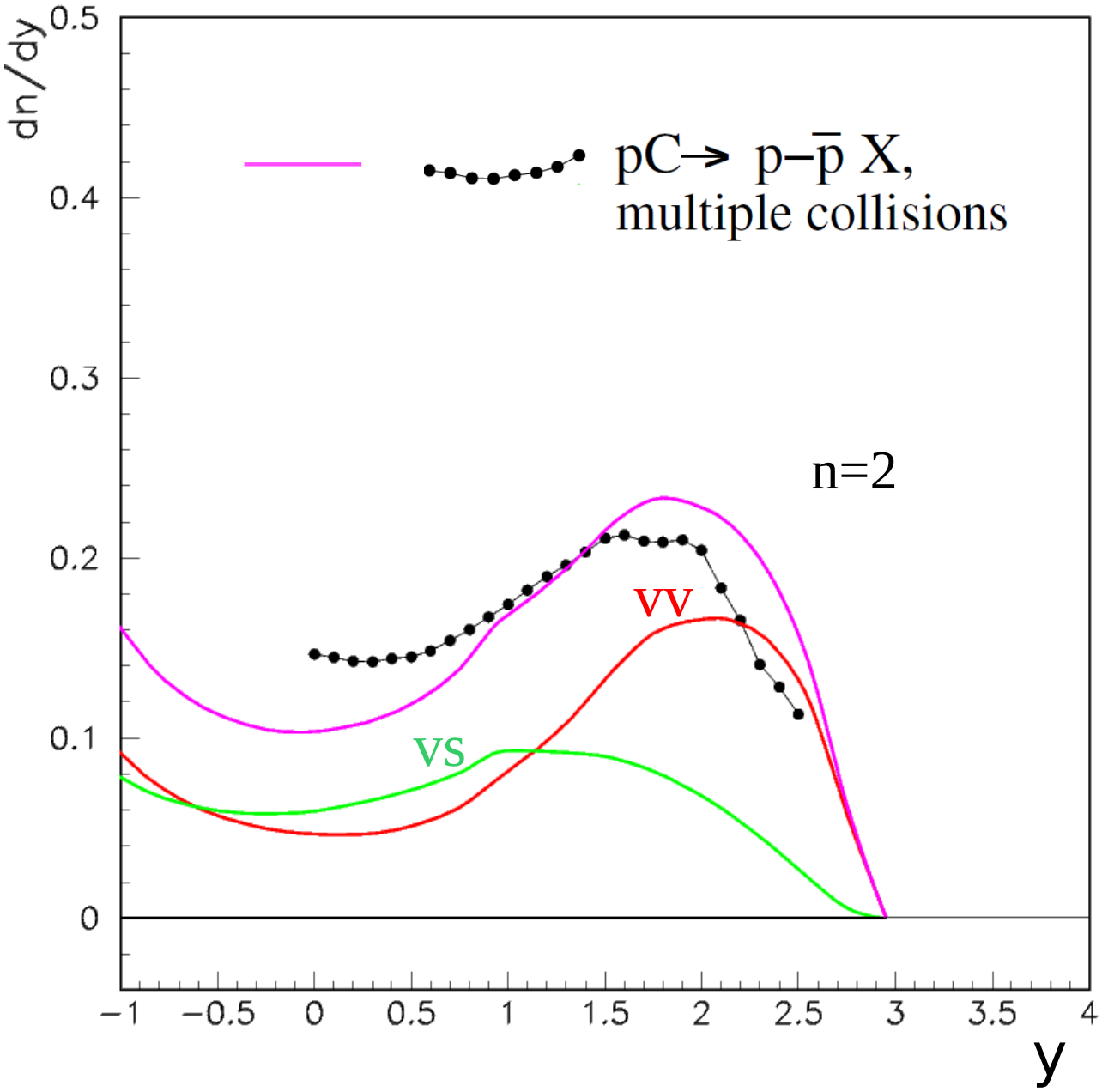
	$\underline{8} \otimes \underline{3^{N-1}}$			$\underline{10} \otimes \underline{3^{N-2}}$		
N	V V	V S	S S	0	V S	S S
1	1	-	-	-	-	-
2	0.5917	0.4083	-	1	-	-
3	0.3740	0.5223	0.1037	0.5	0.5	-
4	...	...	...	...	...	0.1429
5	...	...	...	...	...	...
6	0.1319	0.4908	0.3773	0.0444	0.5733	0.3823
7	...	...	...	...	...	...
8	...	...	...	...	...	...
9	0.0644	0.3989	0.5367	0.0030	0.4366	0.5604

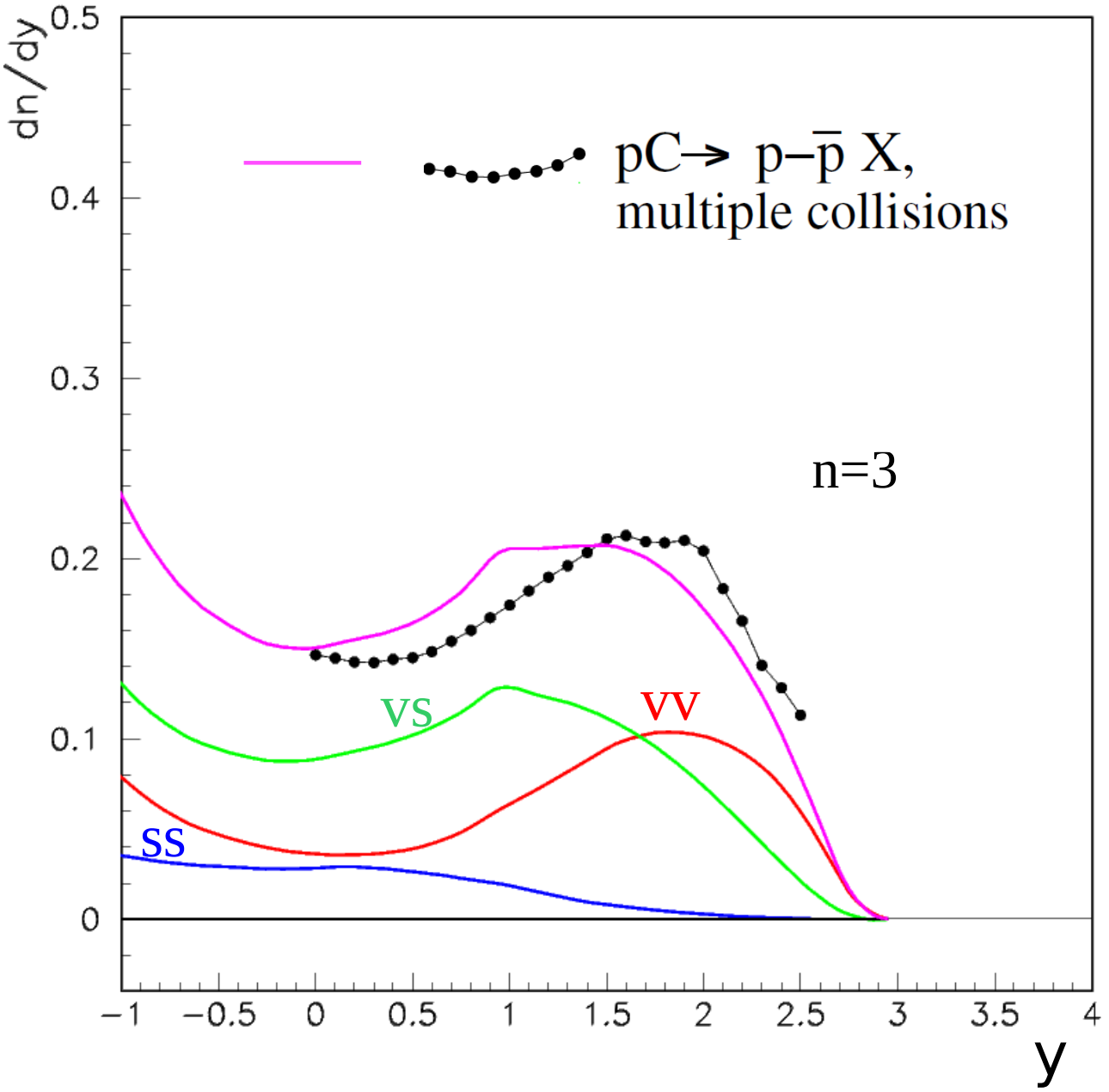

dn/dy
0.5
0.4
0.3
0.2
0.1
0
pC→ p–p̄ X,
multiple collisions
pC→ n–n̄ X,
multiple collisions
OCTET 94.5%, DECUPLET 5.5%
−1
−0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
y

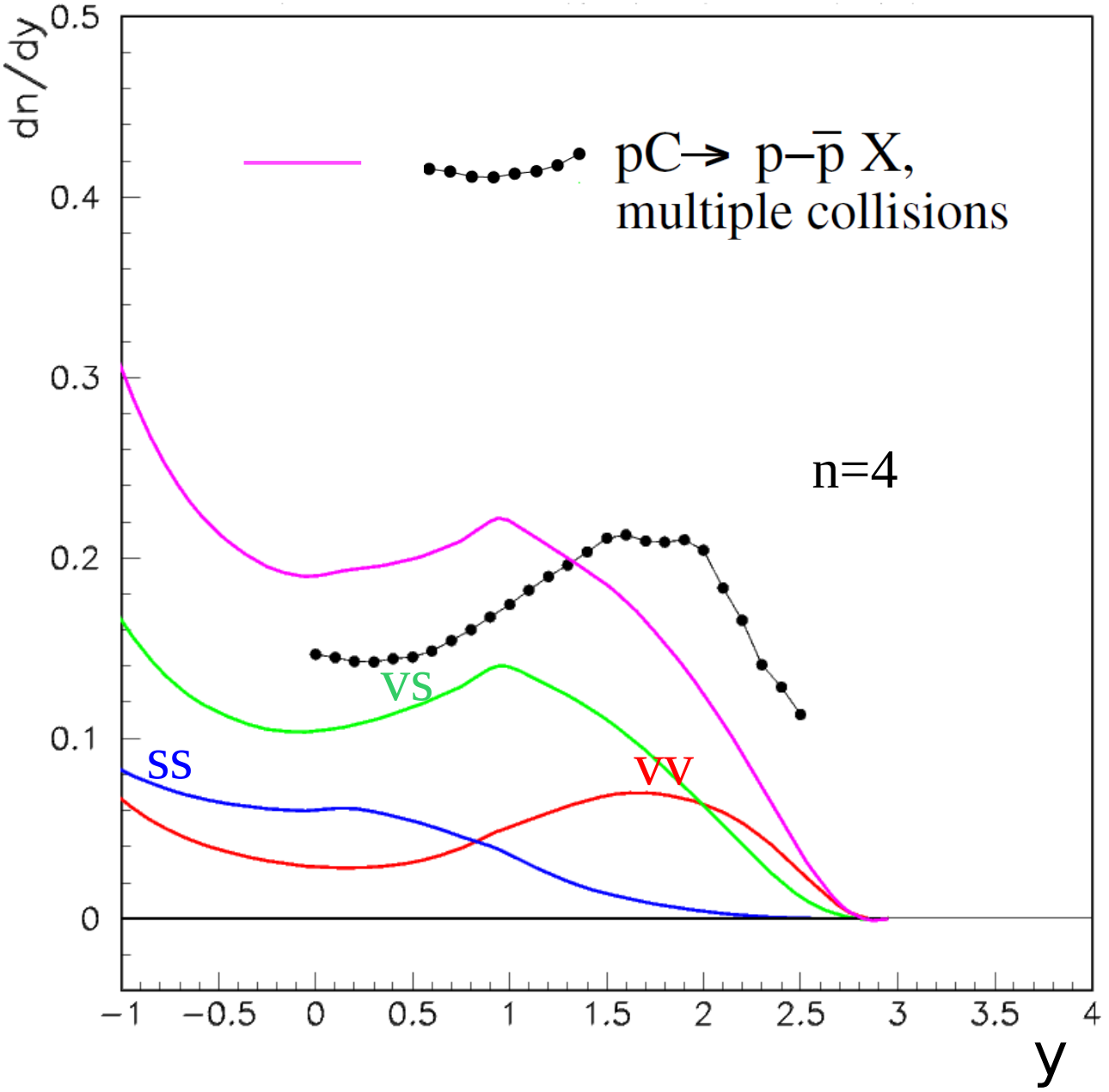

dn/dy
0.5
0.4
0.3
0.2
0.1
pC→ p–p̄ X,
multiple collisions
pC→ n–n̄ X,
multiple collisions
OCTET 94.5%, DECUPLET 5.5%
VS
VV
SS
DECUPLET
CONTRIBUTIONS {
−1
−0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
y

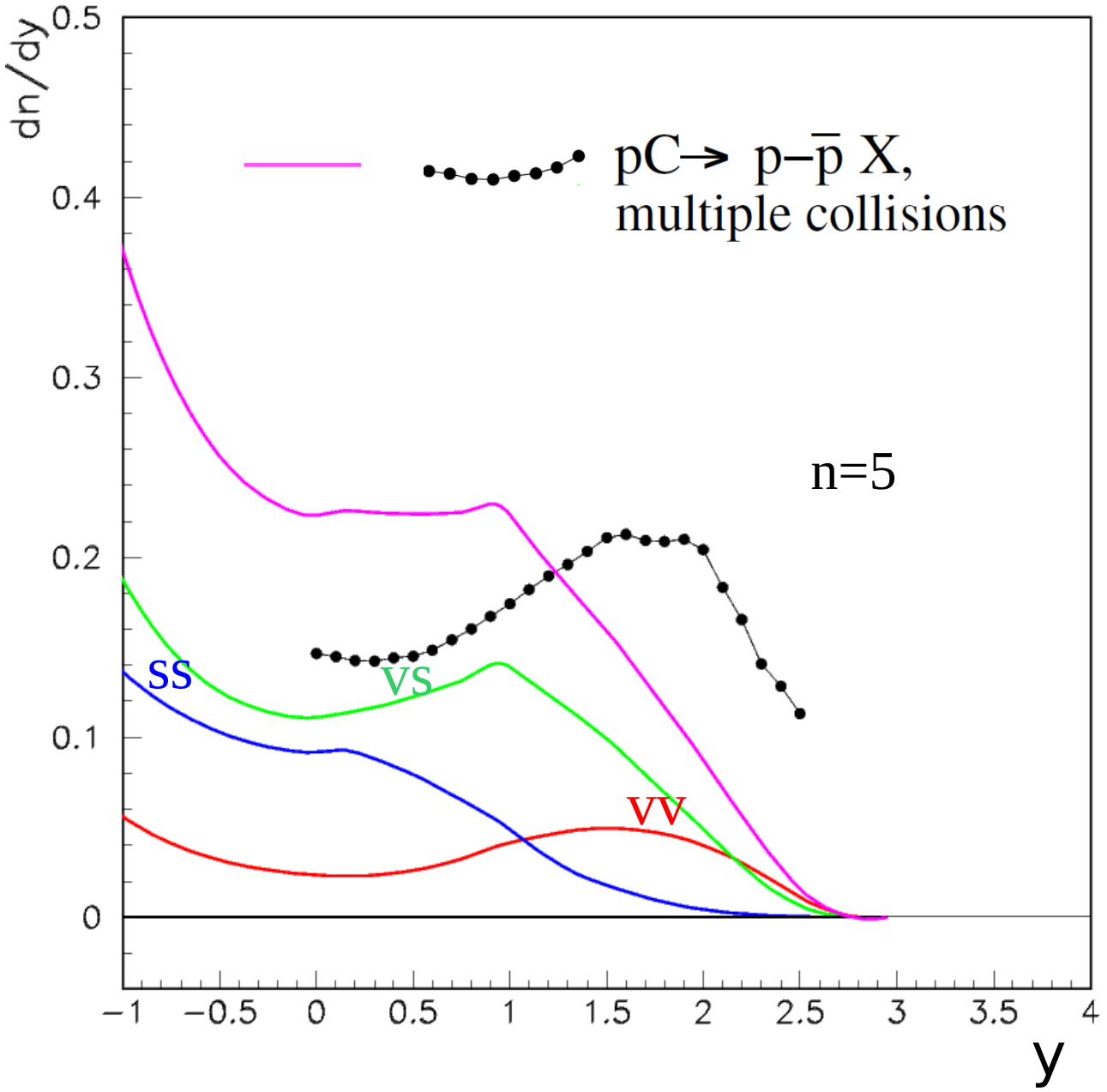
3)
Baryon stopping as a function of the number of collisions

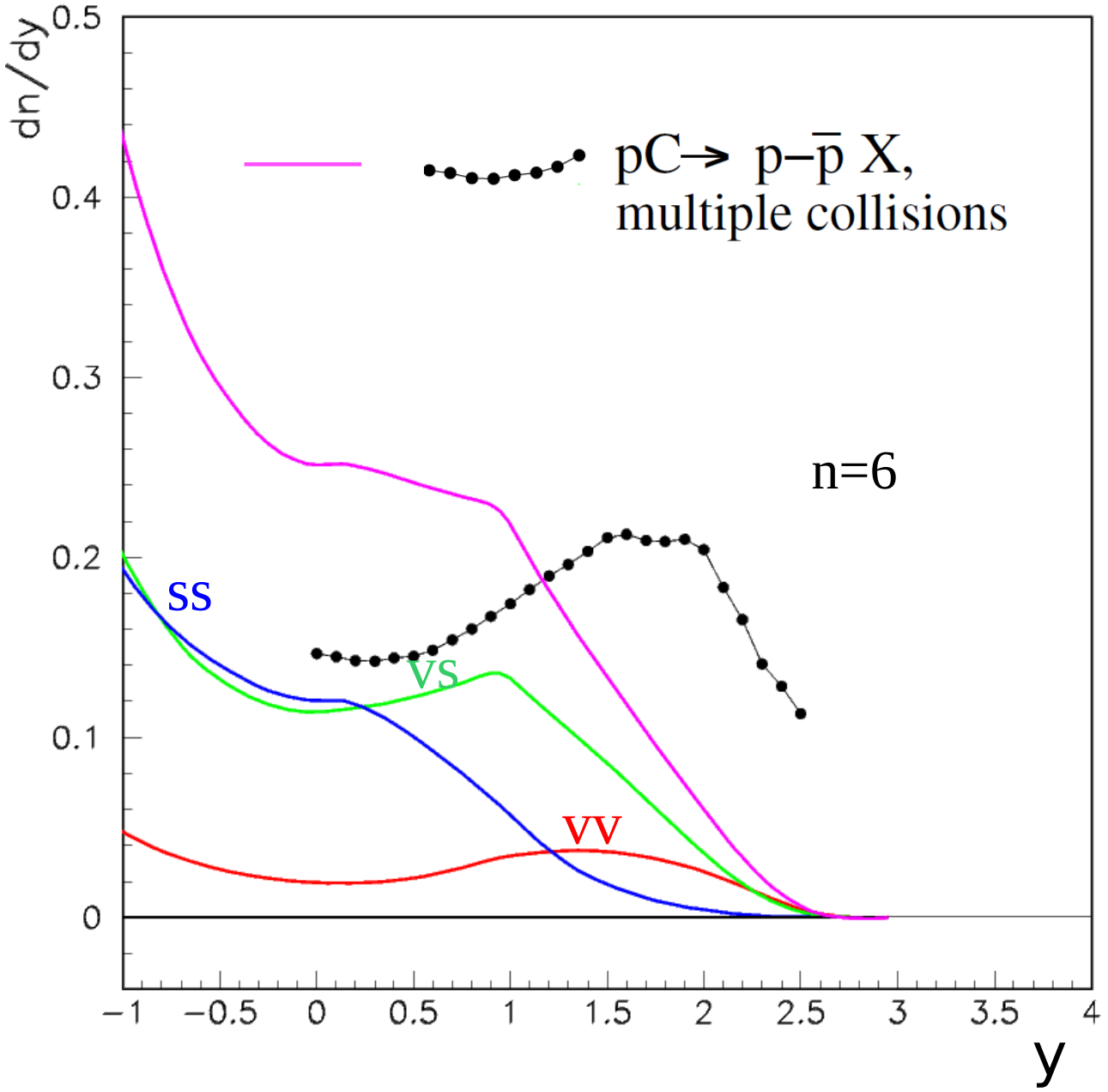

dn/dy
0.5
0.4
0.3
0.2
0.1
0
pC→ p−p̄ X,
multiple collisions
OCTET 100%
VV
VS
SS
−1
−0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
y


dn/dy
0.5
0.4
0.3
0.2
0.1
0
pC→ p−p̄ X,
multiple collisions
n=2
VV
VS
−1
−0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
y

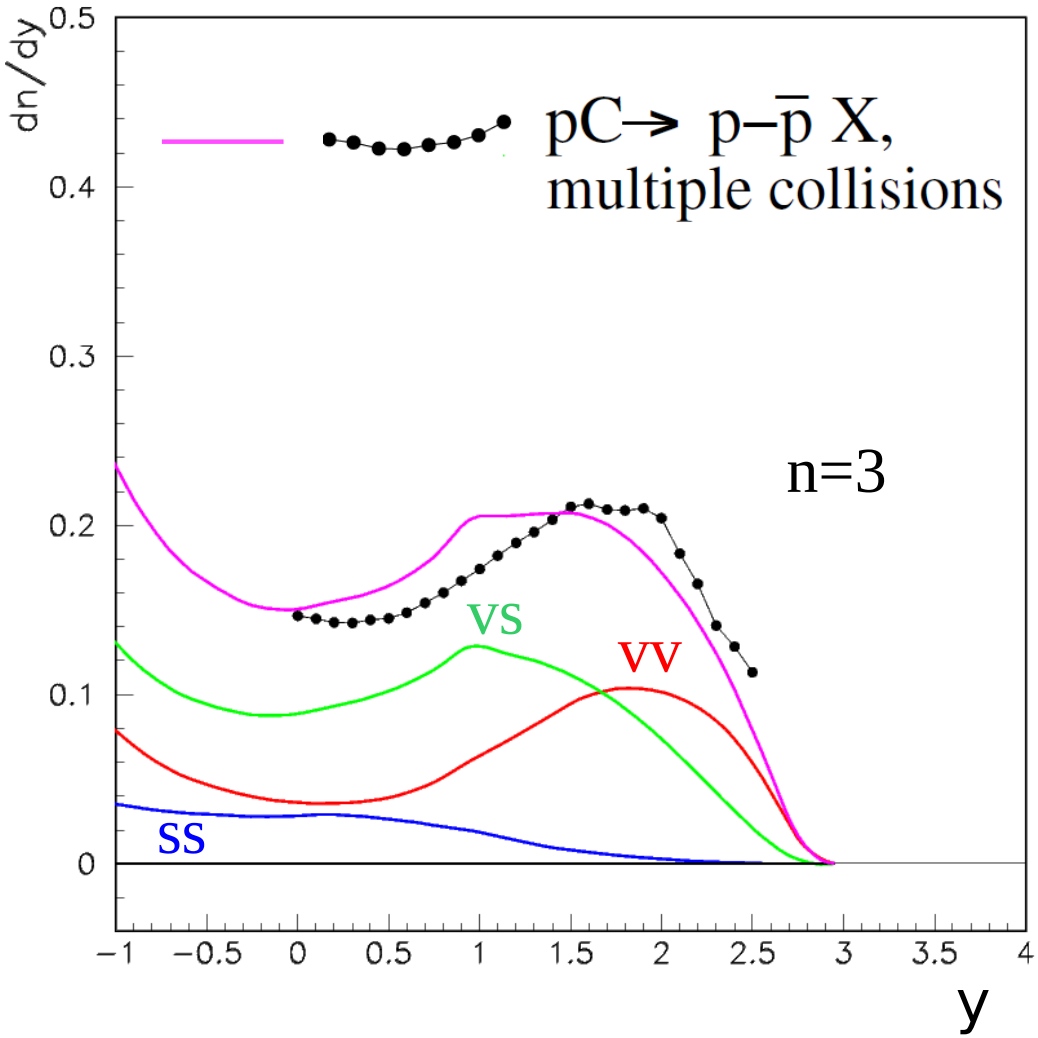

dn/dy
0.5
0.4
0.3
0.2
0.1
0
pC→ p−p̄ X,
multiple collisions
n=3
VS
VV
SS
−1
−0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
y

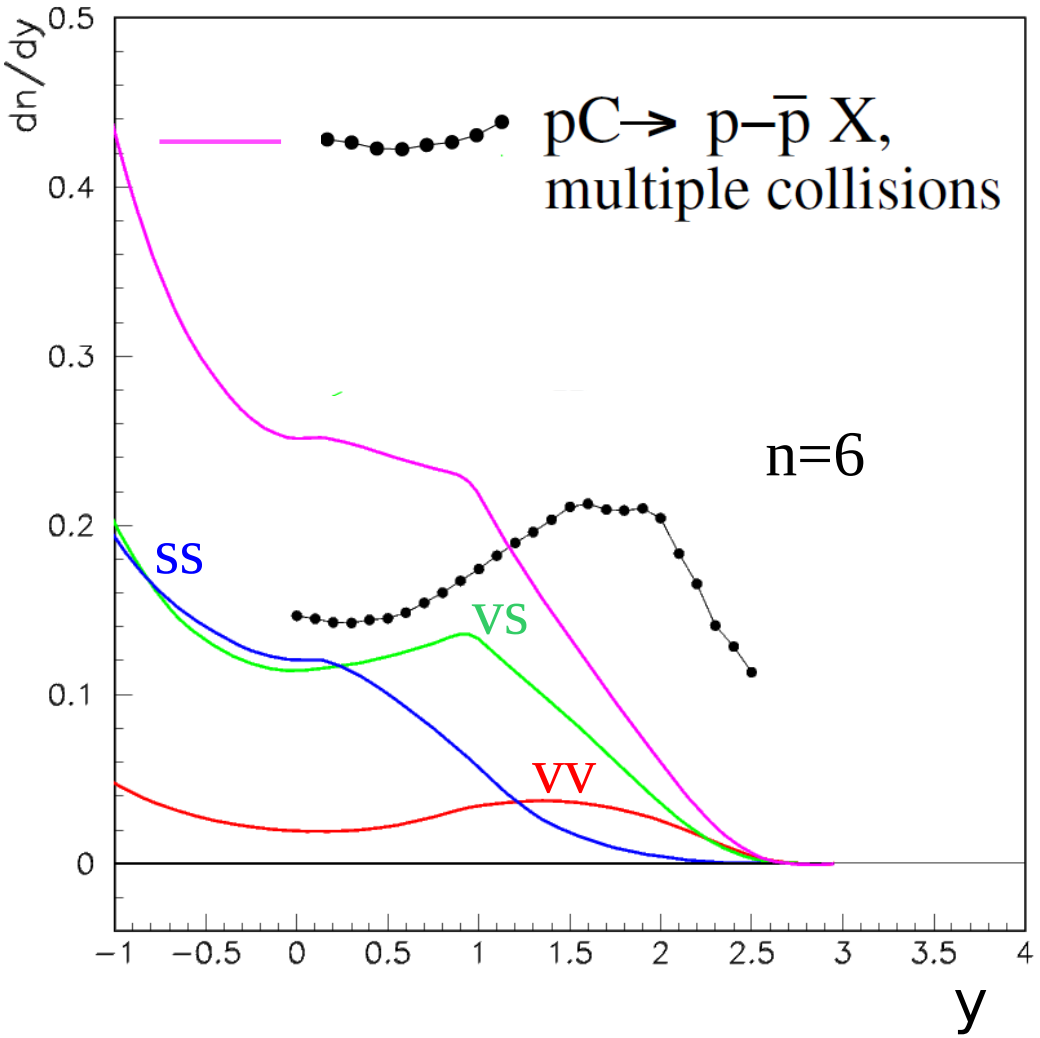

dn/dy
0.5
0.4
0.3
0.2
0.1
0
pC→ p−p̄ X,
multiple collisions
n=4
VS
SS
VV
−1
−0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
y


dn/dy
0.5
0.4
0.3
0.2
0.1
0
pC→ p−p̄ X,
multiple collisions
n=5
SS
VS
VV
−1
−0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
y


dn/dy
0.5
0.4
0.3
0.2
0.1
0
pC→ p−p̄ X,
multiple collisions
n=6
ss
vs
vv
−1
−0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
y

arXiv:2111.03401





The process of baryon stopping is governed by the different color configurations of constituents (valence-valence, valence-sea, sea-sea), **which emerge as a function of the number of collisions.**

a

4) Conclusions

1. There is a **qualitative difference** between single and multiple proton-nucleon collisions;

2. Spectra of baryons are governed by **color configurations** of constituents (valence, sea);

3. These configurations depend on the **number of exchanged gluons** and are richer in the multiple collision process, which results in **stronger baryon stopping**.

4. Thus, baryon stopping is strongly connected to the **number of collisions** but much less, if at all, to the **energy deposit** by the projectile.

… thank you !

Homework:

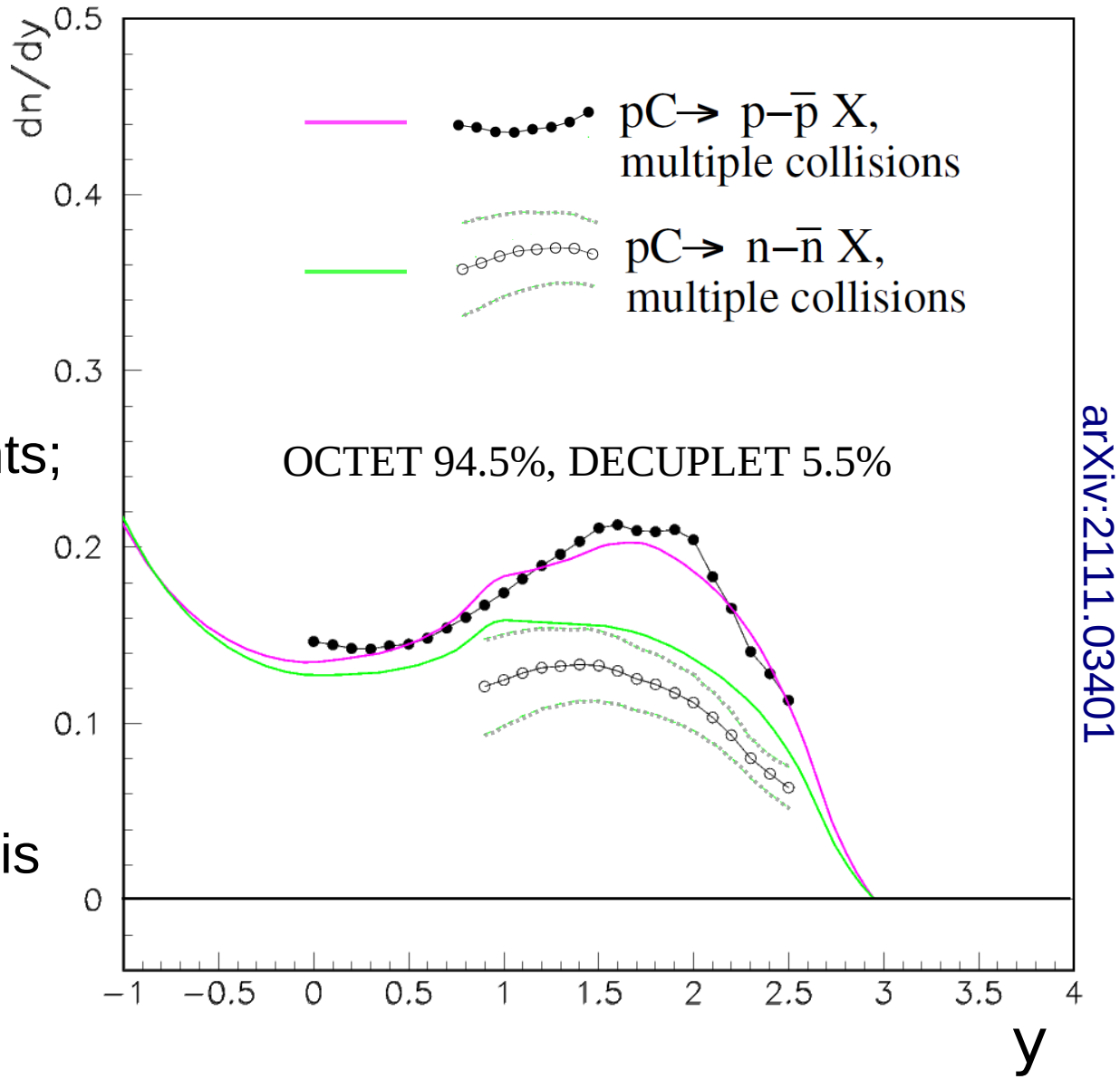
1. Isospin effects are **powerful** in the baryon stopping process;

2. They directly reflect the **flavor** of valence constituents;

3. Most probably **unknown** before 2013 (no data);

4. GEM inherits most of IE from pp to pA but the effect is still somewhat **weak**;

5. **Work in progress.**



… thank you (2).