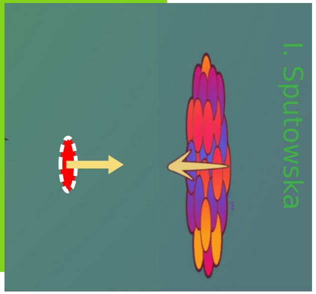
Antiproton stopping in nuclei

Antiproton beams for NA61/SHINE



The physics case

Antiproton data taking

Other experiments

Antineutrons

Andrzej Rybicki, IFJ PAN Kraków

NA61++/SHINE: Physics opportunities from ions to pions

December 17th, 2022

Why antiprotonic beams (1) ?

Strong interactions physics

- NA61/SHINE data are (already now!) very restrictive in terms of phenomenology of transport of baryon number,
- … which is highly informative on quarks, gluons, color exchange, etc in the non-perturbative process,

  but:

- adding baryon number **annihilation** to the process makes a qualitative difference! ---------- > adds up a new element which constrains your model in a powerful way

Why antiprotonic beams (2) ?

Cosmic ray physics

Model building:

- Effect of valence quark on forward emission
- Better visibility for baryon stopping (target nucleons boosted at mid-rapidity, or beyond)
- Particularly interesting if there is the same data for

p+A

$\bar{p}$+A

(From communication between Michael and Tanguy – thanks!)

The importance of data from NA61/SHINE

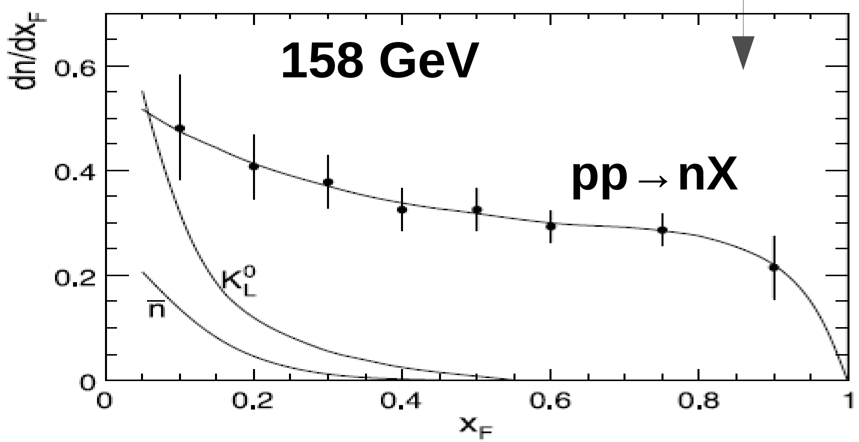
(continuous emergence of data on baryon spectra: NA49 -> NA61/SHINE -> NA61++/SHINE…?)

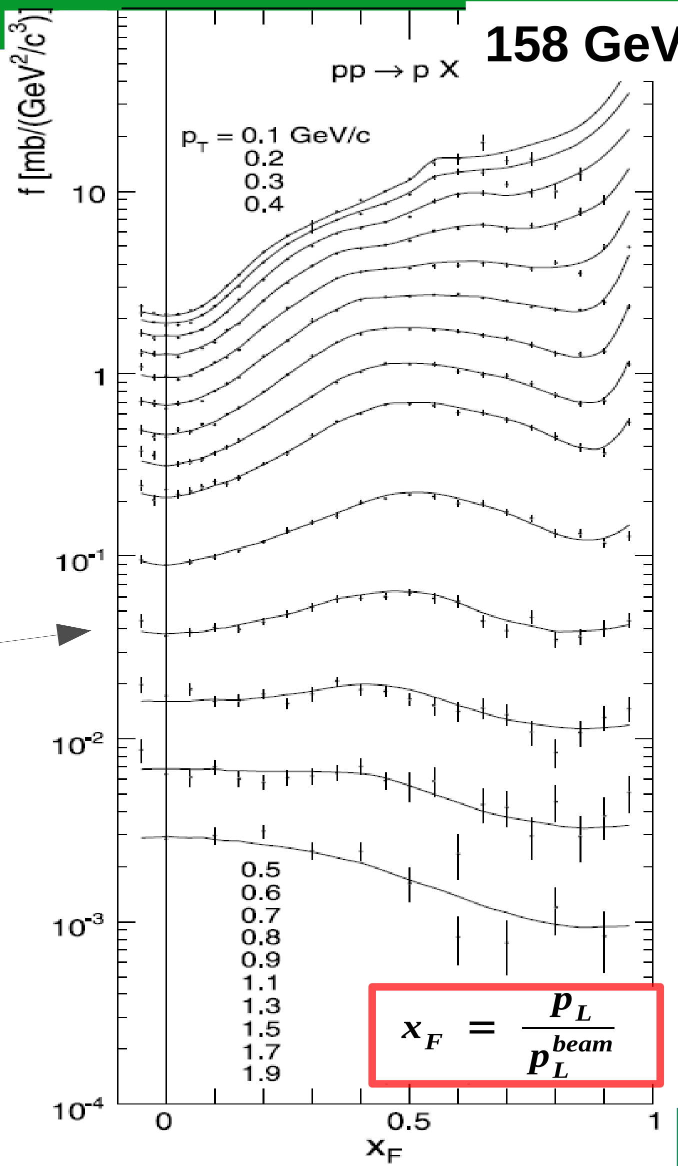
1. Hermeticity (full projectile hemisphere, no p_T-cutoff)

2. Numerous data sets (p+p, p+A, A+A) are provided by the same detector

[1] NA49, EPJC 65 (2010) 9
[2] NA49, PRC 83 (2011) 014901
[3] NA49, EPJC 73 (2013) 2364
[4] NA61/SHINE, EPJC 76 (2016) 84
[5] NA61/SHINE, EPJC 76 (2016) 198
[6] NA61/SHINE, EPJC 77 (2017) 671
[7] NA61/SHINE, PRD 100 (2019) 112001
[8] NA61/SHINE, EPJC 81 (2021) 73
[9] ...

4.8M events ← [1]





$$x_F = \frac{p_L}{p_L^{beam}}$$

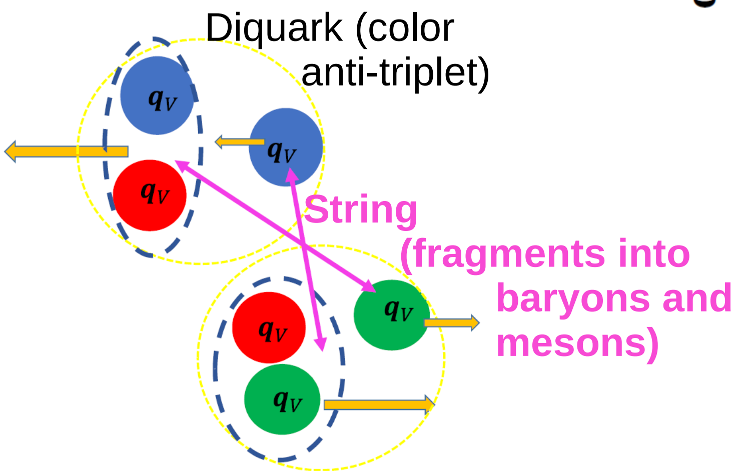
The importance of data from NA61/SHINE

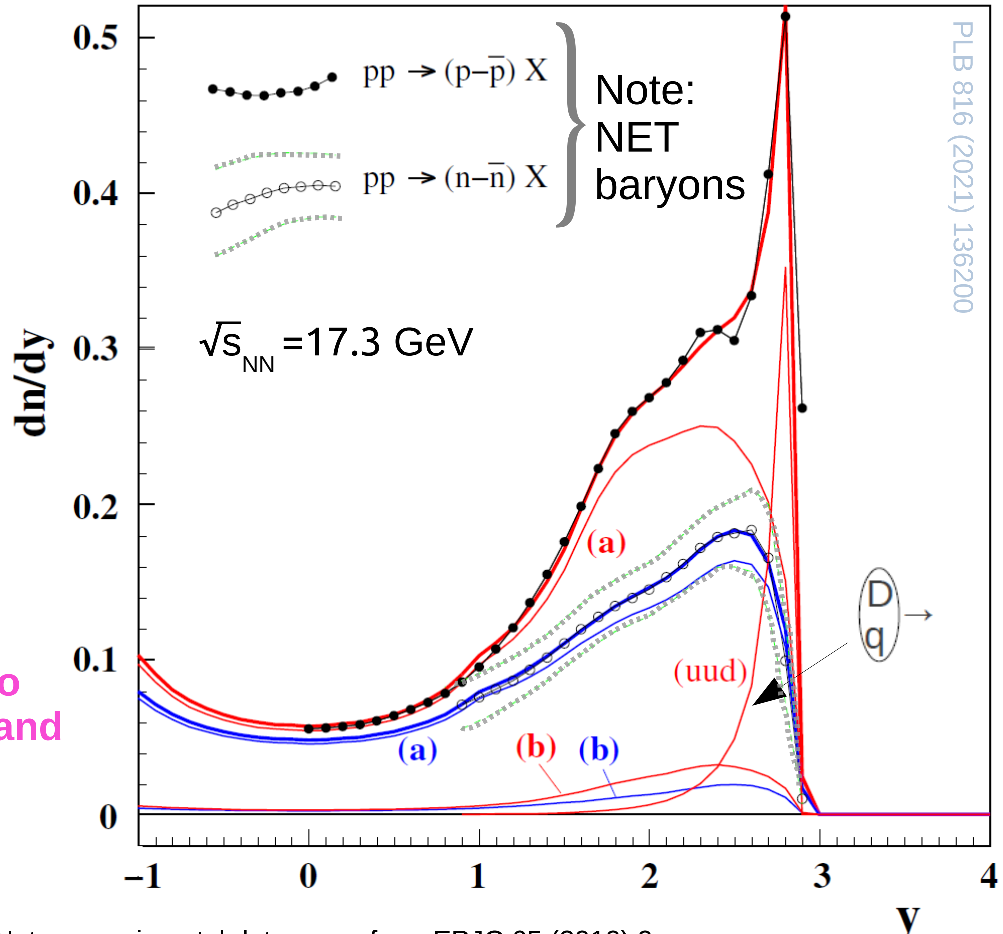
(GEM, the Gluon Exchange Model)

M. Jeżabek, A.R.:

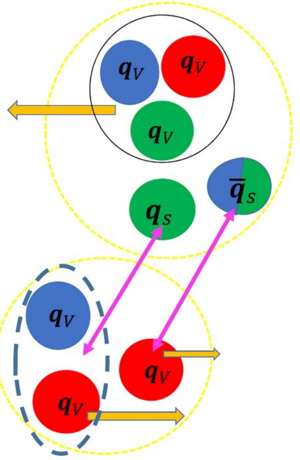
APPB 51 (2020) 1207
PLB 816 (2021) 136200
EPJPlus 136 (2021) 971
APPB 52 (2021) 981
APPB 53 (2022) 7-A3

The interaction proceeds through color (gluon) exchange





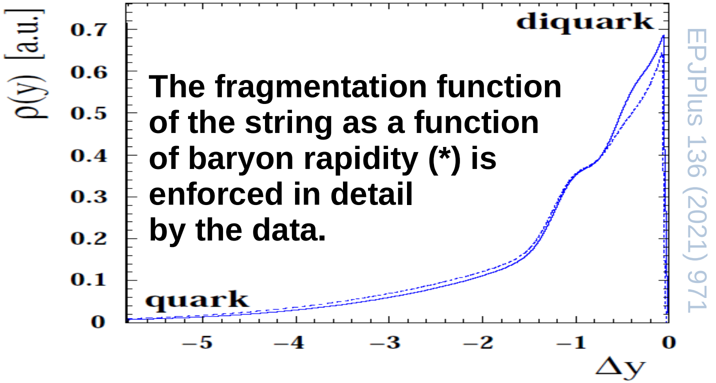
Note: experimental data come from EPJC 65 (2010) 9

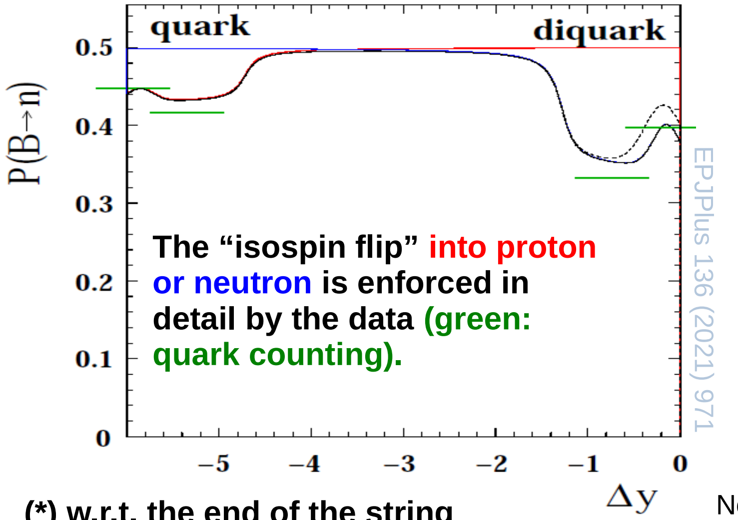


Inelastic diffraction

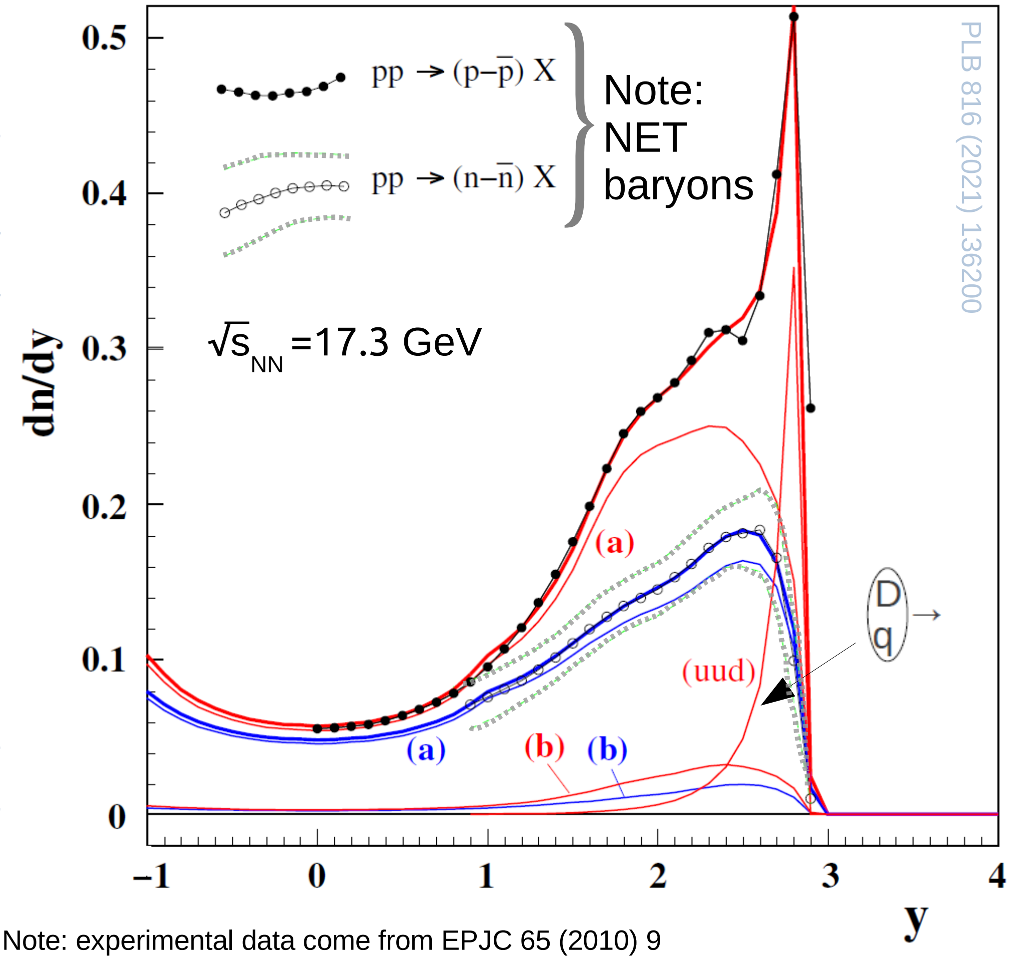
The importance of data from NA61/SHINE

(no freedom with this data!)





(*) w.r.t. the end of the string



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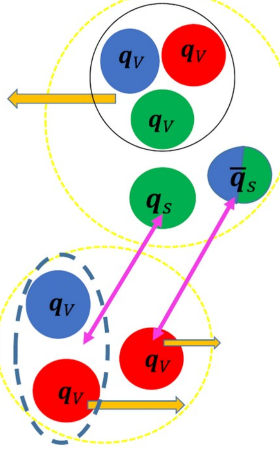


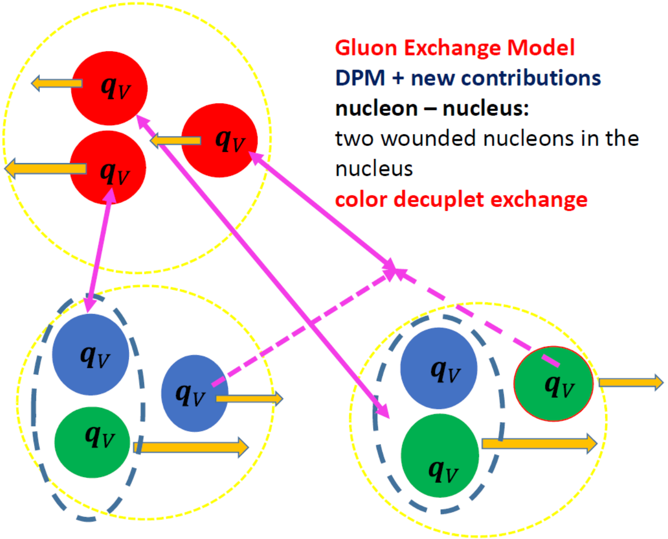
Inelastic diffraction

The importance of data from NA61/SHINE
(state of the art)

1. In p+A collisions, **multiple gluon exchange** increases the size (dimension) of color representations for constituent valence and sea quarks ;

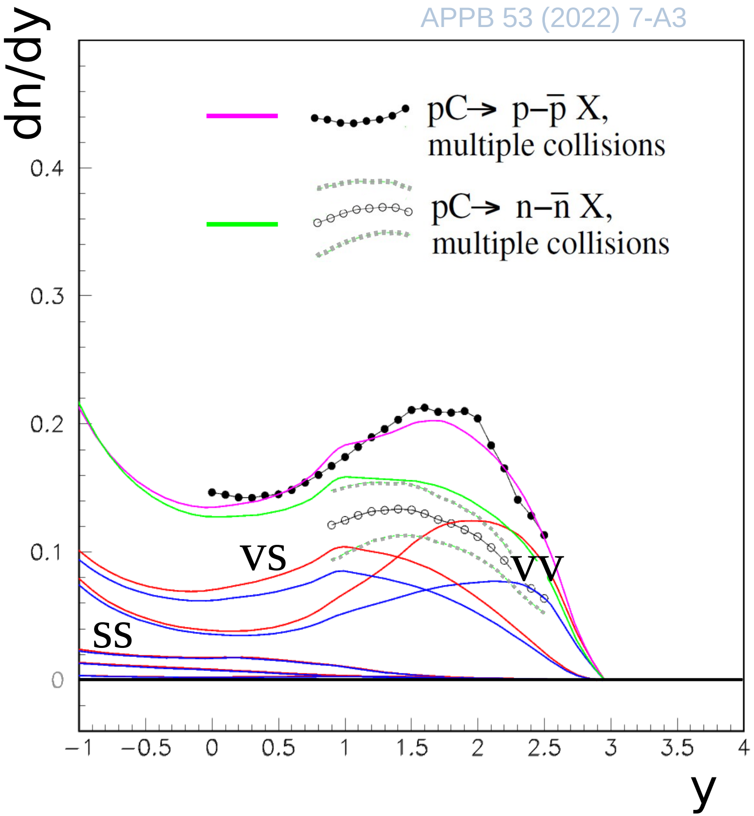
2. We have diquarks (color anti-triplets) made of **valence-valence**, **valence-sea**, and **sea-sea** quarks ;

3. We have a new "**no diquark**" configuration (see below) ;



4. The best way to ~~kill~~ verify such a model is to add up **annihilation**.

APPB 53 (2022) 7-A3



Experimental data from EPJC 65 (2010) 9, EPJC 73 (2013) 2364

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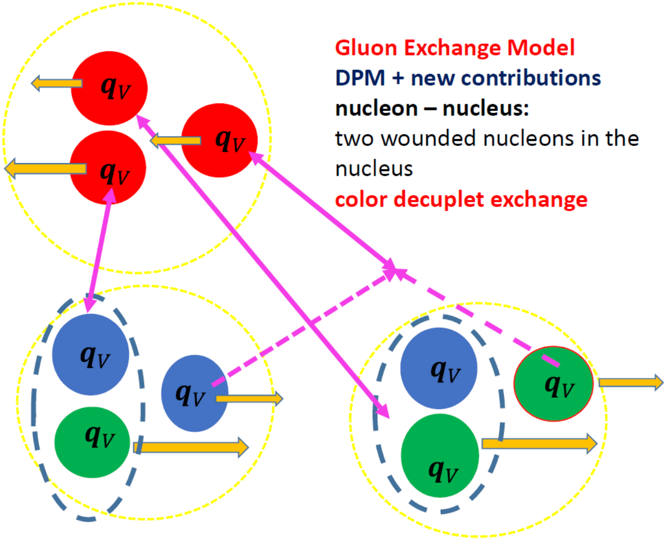

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5. In $\bar{p}$+A, each diquark will annihilate with its own, calculable probability.

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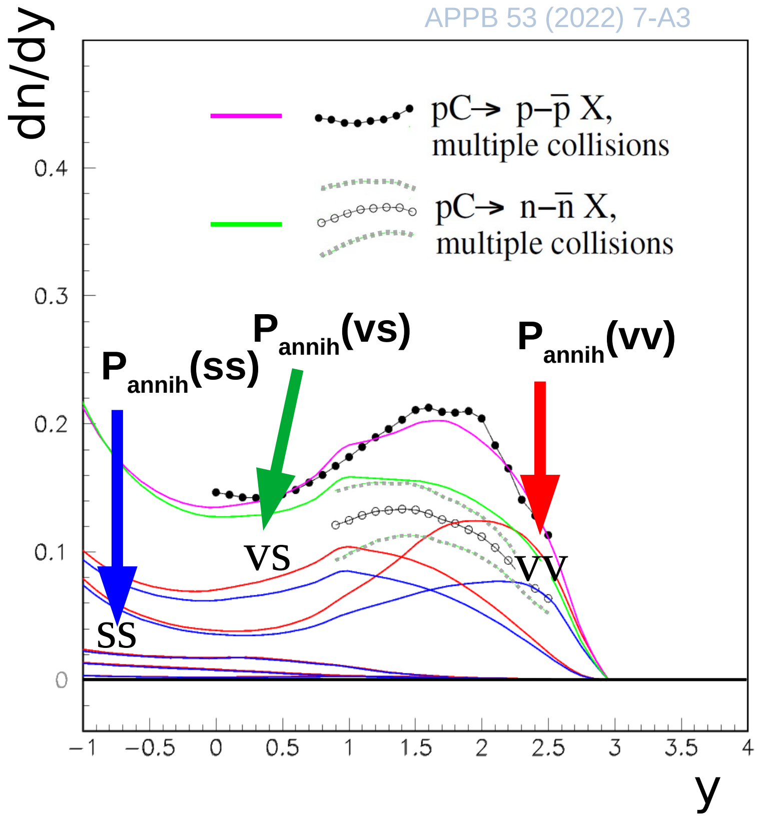

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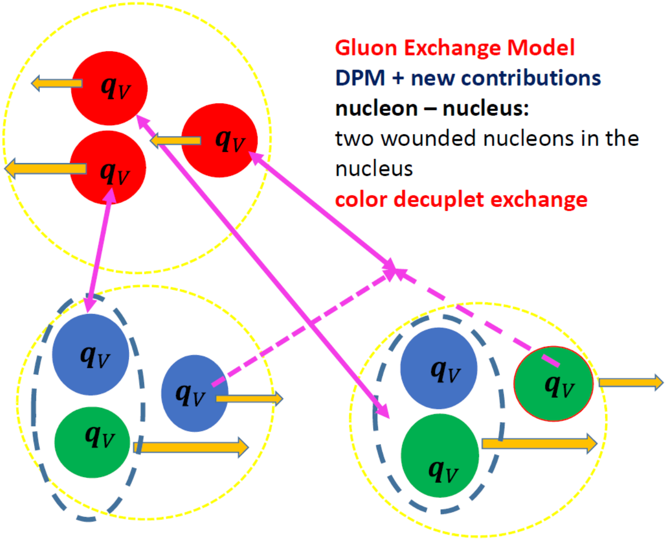

4. The best way to ~~kill~~ verify such a model is to add up **annihilation**.

5. In $\bar{p}$+A, each diquark will annihilate with its own, calculable probability.

6. (Bonus) the p-$\bar{p}$ spectrum will show the fate of target nucleons.

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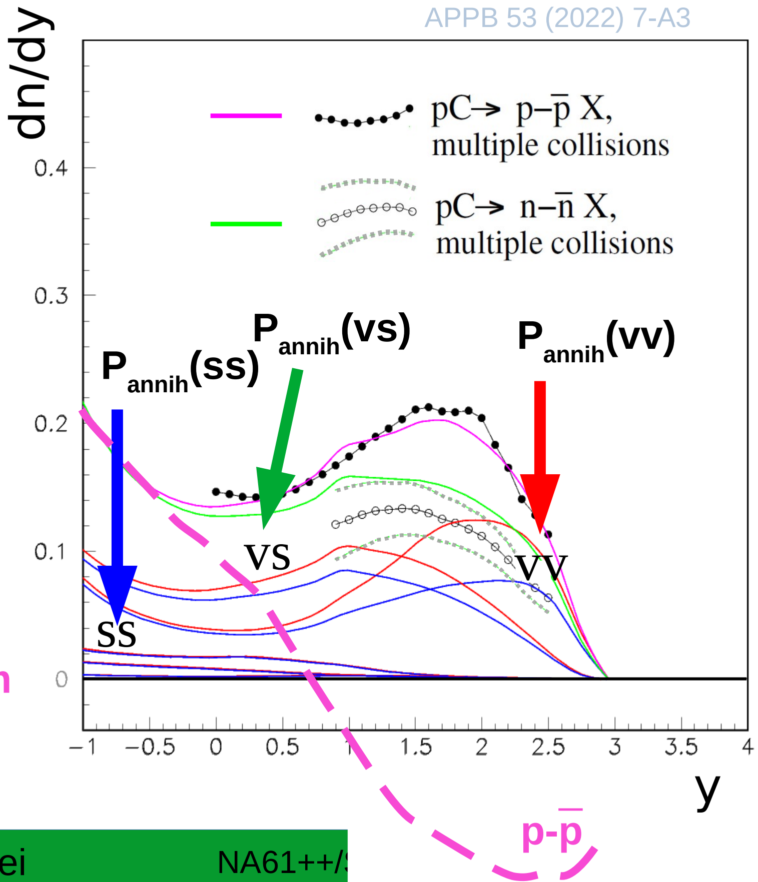


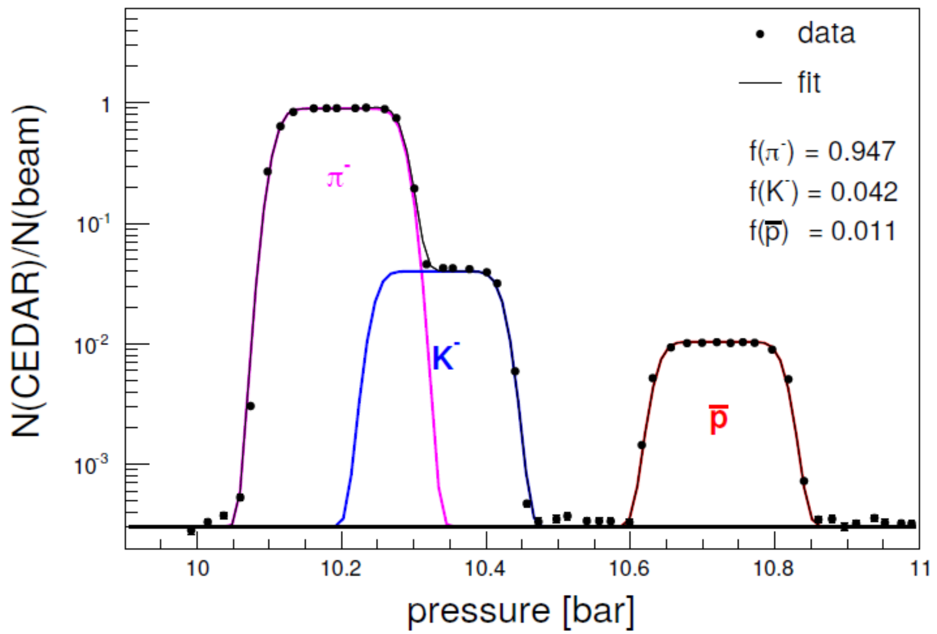
Experimental data from EPJC 65 (2010) 9, EPJC 73 (2013) 2364

Antiproton data taking with NA61/SHINE

How much data can we take?

NA61/SHINE capabilities for $\overline{p}$ program

Secondary hadron beam at 158 GeV/c



Assuming:

- average SPS super cycle: 40 s
  flat top: 4.8 s
- **$\overline{p}$ content in the beam of $\approx 1\%$**
- target of 5% interaction probability
- maximum intensity of the beam for momenta of interest at H2: 200 kHz (limited by off-time beam particles)
- and typical efficiencies summarized in NA61/SHINE Addendum 2018, Sec 9.3

Mean number of recorded interactions: ≈600k events per day

Szymon Puławski
Nikolaos Charitonidis

Data taking estimates

1. Assuming 158 GeV/*c* beam

2. $\bar{p}$+p and $\bar{p}$+A (A=9, 12, 45, 208)　　6M events per sample:　5 x 10 days

3. p+p and p+A (A=9, 12, 45, 208)　　6M events per sample:　5 x 1 day?

----

55 days

8 weeks of data taking to fulfill a ~maximum plan at one energy

1. Assuming 158 GeV/*c* beam

2. $\bar{p}$+p and $\bar{p}$+A (A=12, 208)　　6M events per sample:　3 x 10 days

3. p+p and p+A (A=12, 208)　　6M events per sample:　3 x 1 day?

----

33 days

5 weeks of data taking to fulfill a ~minimum plan at one energy

Other experiments

SPS (1985)

R. Bailey et al., Z. Phys. C **29** (1985), 1

1. ACCMOR, beam: 120 GeV/*c*

2. p+A and $\bar{p}$+A : (Be, Cu, Ag, W, U)

3. leading proton and antiproton spectra in a wide range of x_F

4. A-dependence of annihilation x-section

5. statistics: up to ~30k events per sample

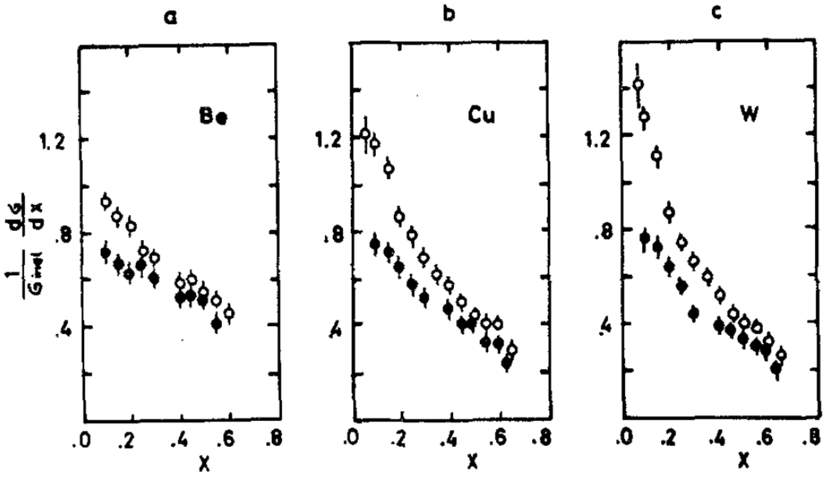


Fig. 6a–c. Inclusive $p/\bar{p}$ Feynman x distributions. **a** Be, **b** Cu, **c** W, ○—$(1/\sigma_{inel})\cdot d\sigma/dx(pA \to p + \text{anything})$, ●—$(1/\sigma_{inel})\cdot d\sigma/dx(\bar{p}A \to \bar{p} + \text{anything})$

FAIR (-?-)

1. Beam: up to 15 GeV/*c*

2. Statistics: ∞ events?

3. Ability to measure spectra ?

Antineutrons

Last remarks

Antineutrons

1. p+A and $\bar{p}$+A reactions:

    Leading protons / antiprotons

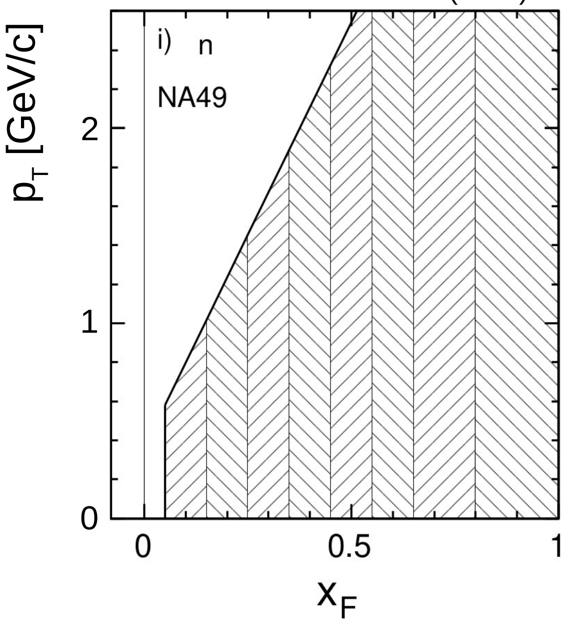
    Leading neutrons / antineutrons

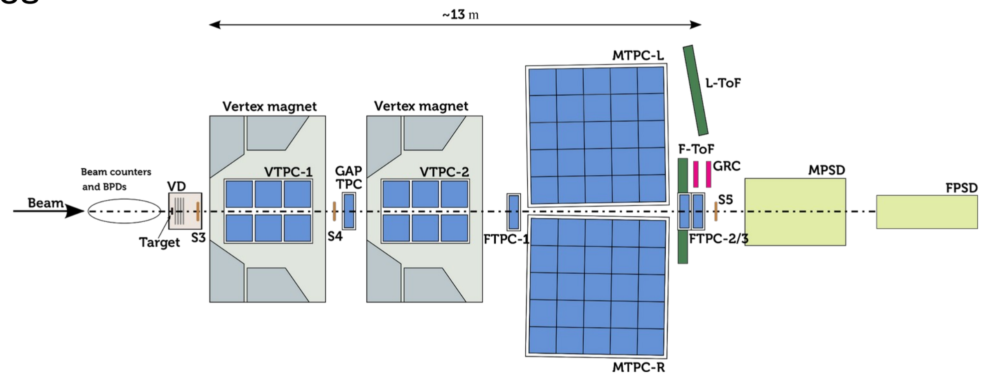
2. Neutron measurements are extremely interesting for studies of baryon stopping

3. First discussions indicate that such measurements would be doable with the MPSD/FPSD system

-> need for veto for charged particles

EPJC 65 (2010) 9





Summary

- A possible comparative analysis of

  p+p and p+A versus $\bar{p}$+p and $\bar{p}$+A interactions

  could significantly improve the understanding of the fate of quarks and gluons in the collision

- NA61++/SHINE:

  decent statistics from data taking with high energy antiproton beams

  coverage of the entire projectile hemisphere

  all the **p+p / p+A / $\bar{p}$+p / $\bar{p}$+A** reactions measured in identical experimental conditions

  measurement potentially not limited to (anti)protons but including other (anti)baryons

Thank you !