$d$, $\bar{p}$ and $\bar{d}$ production cross-section studies for nucleus-nucleus collisions at the NA61/SHINE experiment.

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The NA61/SHINE detector

- **Fixed target** experiment,
- Located at the *SPS* accelerator,
- **Large acceptance** spectrometer – coverage of the full forward hemisphere, down to $p_T = 0$. 
• *dE/dx* method estimates multiplicities of hadrons using **energy loss measurements** in TPCs,

• *tof-dE/dx* method estimates multiplicities of hadrons using **energy loss and particle time of flight measurements** in ToFs,

• *h−* method estimates multiplicities of $\pi^−$ based on the fact that the majority of negatively charged hadrons produced in p+p and A+A collisions are $\pi^-$. 
Physics program at NA61/SHINE

The NA61/SHINE performs a 2D scan over system size and collision energy to study the phase diagram of strongly interacting matter in temperature and baryon density.

![Graph showing system size and beam momentum](image)

- **Data taken,**
- **Large statistics data taken.**

Only strong interaction program datasets marked.
Study of hadrons and light nuclei

This versatile data which was taken by the NA61/SHINE experiment allows for a study of low momentum hadrons and light (anti)nuclei production in a variety of collisions at different energies.

The goal of my analysis is to use different collision systems measurements and a simplified dE/dx PID to study:

- Production cross-sections of different hadrons and light (anti)nuclei,
- Coalescence parameters for deuterons and antideuterons,
- Thermal model predictions,
- Uncertainties in indirect dark matter searches.
Coalescence and thermal models

Production of light nuclei.

Coalescence model

- Nucleons emitted from a fireball with small relative momenta form a nucleus due to attractive nuclear forces.

\[
E_A \frac{d^3 N_A}{d^3 P_A} = B_A \left( E_p \frac{d^3 N_p}{d^3 p} \right)^Z \left( E_n \frac{d^3 N_n}{d^3 p} \right)^{A-Z}
\]

where \( N_A \) invariant yield of clusters with charge \( Z \) and mass number \( A \), \( N_p \) and \( N_n \) proton and neutron yields, \( p = P_A/A \) and \( B_A \) is the coalescence parameter.
Production of light nuclei.

Thermal model

- The ratios of particles’ yields depend on the fireball’s temperature and baryon chemical potential at the chemical freeze-out,
- The model does not describe production mechanism.

\[ N_C = \frac{gV}{\pi^2} m^2 TK_2(m/T) \exp \left( \frac{B\mu_B + q\mu_q}{T} \right) \]

where \( N_C \) is cluster abundance, \( g \) degeneracy factor, \( q \) charge, \( B \) baryon number, \( V \) source volume, \( K_2 \) Bessel function of the second kind, \( \mu_B \) and \( \mu_q \) baryochemical and charge potential.
The NA49 (NA61/SHINE predecessor) experiment published a similar analysis on Pb+Pb collisions at 20A-158A GeV/c.

The contents of the paper:

- PID and yields of $d$, $t$ and $^3$He,
- Study of isospin asymmetry with $t/^3$He ratio,
- Agreement with thermal model of clusters formation,
- **Derivation of coalescence parameter** $B_A$ energy dependence.
Coalescence parameter $B_A$ from central A+A collisions as a function of collision energy - shows energy dependence.
Coalescence parameter ($B_2$) of deuterons and antideuterons as a function of $p_T$ per nucleon in inelastic pp collisions at $\sqrt{s} = 0.9$, 2.76, and 7 TeV.
Simplified $dE/dx$ method

$p+Pb @158$ GeV/c

Clear deuteron and triton signals.
Future steps

- Employ a coalescence afterburner for EPOS MC event generator,
- Introduce a MC correction for experiment acceptance and reconstruction efficiency,
- Calculate production cross-sections,
- Confront results with coalescence and thermal models.
A preliminary analysis has been conducted on measurements of other systems:

- $p+C@31\ \text{GeV/c}$ - 5.4 M events,
- $\pi^+C@350\ \text{GeV/c}$ - 5 M events,
- $\text{Be+Be}@158A\ \text{GeV/c}$ - 2.7 M events,
- $\text{Ar+Sc}@150A\ \text{GeV/c}$ - 2 M events.
Summary

- The NA61/SHINE experiment is a valuable and abundant source of data on low momentum hadrons and light (anti)nuclei production,
- MC corrections are a priority focus,
- Studies of other systems are ongoing.
Thank you for your attention.