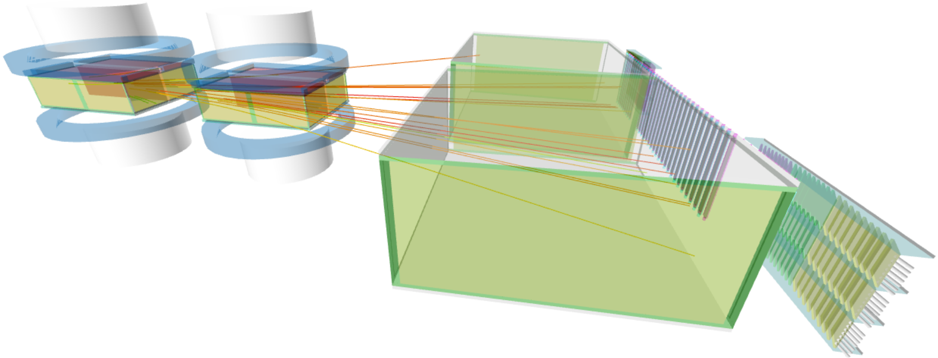

Reference measurements for indirect dark matter searches with p+C collisions at the NA61/SHINE experiment

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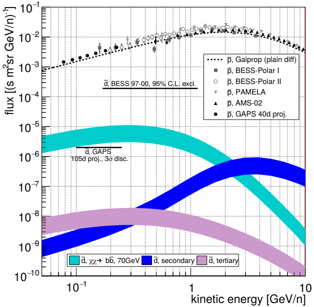
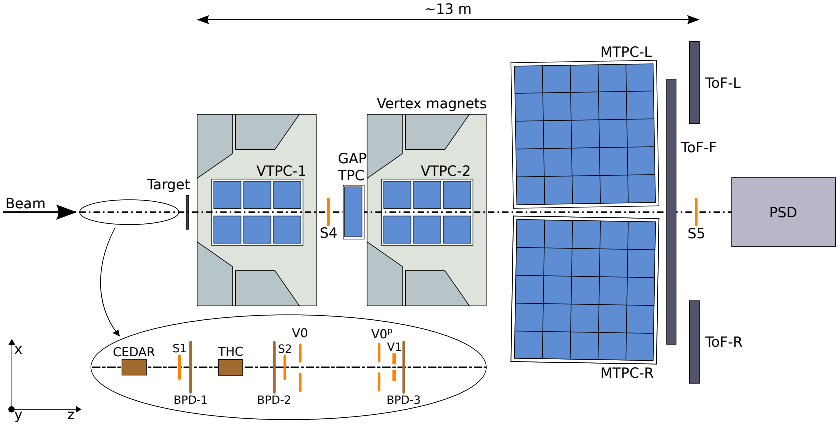
Motivation



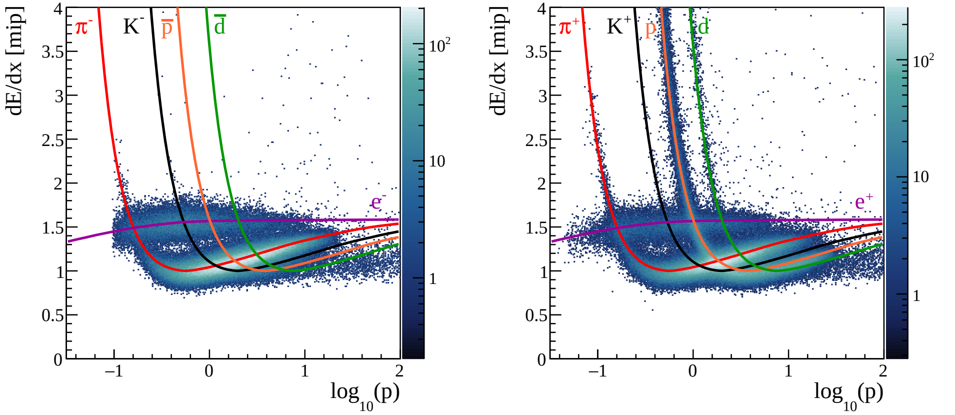
- Possible use in **support of indirect dark matter signal searches.** Antiparticles may be a signal with **low background**,
- Carbon target is interesting since it is the major building component of the AMS-02. Studying p+C collisions can **lower the uncertainty** of detecting particles from interaction in the detector material.
- **SPS energy range** ideal for cosmic ray studies as the peak for $\bar{d}$ production is expected in the range $10 - 100$ GeV.

NA61/SHINE experiment



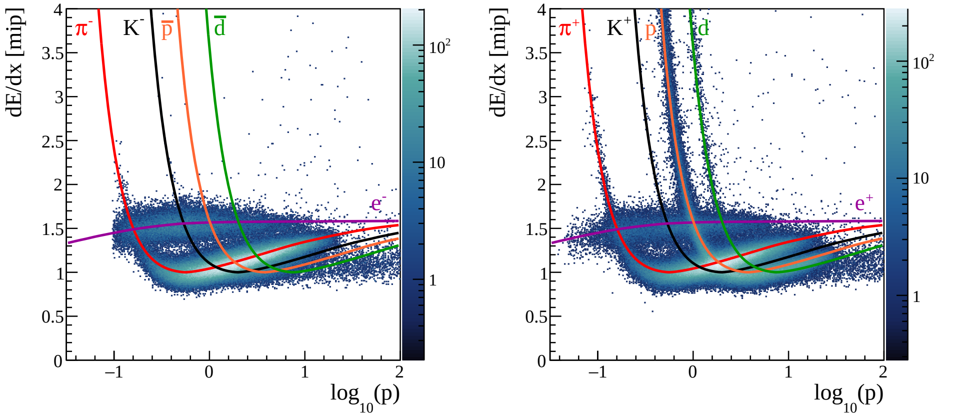
- Large-acceptance, fixed target experiment at **CERN SPS**,
- Studies final states of collisions in a **range of beam momenta** (from 13*A* to 150*A* GeV/c) and **variety of systems** (from *p*+*p* through *p*+C or Ar+Sc to Pb+Pb).

Particle identification



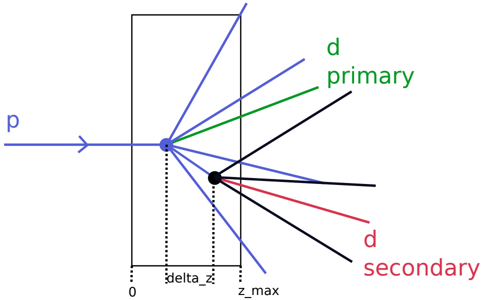
- Based on the particle **specific energy loss** in TPCs (dE/dx) parametrized by the **Bethe-Bloch curves**,
- Applied to **low-momentum particles only** – p and d are easily distinguishable (the same region is applied to antiparticles),

Particle identification



- Applying the same acceptance regions as for p and d to their respective antiparticles yields only 27 and 9 entries, respectively,
- This translates to statistical uncertainty of 20% in case of $\bar{p}$ and 30% in case of $\bar{d}$.

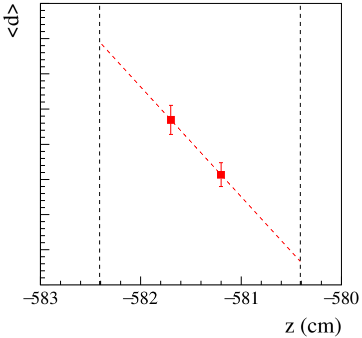
Data driven correction



- Correction for production of **deuterons in secondary processes**,
- Contributions of particles produced **before and after target center** are compared,

$$\langle d \rangle = \underset{\substack{\| \\ \text{const.(z)}}}{\langle d \rangle_{\text{prim}}} + \underset{\substack{\| \\ \alpha \cdot \Delta_z}}{\langle d \rangle_{\text{sec}}}$$

Data driven correction - performance check



$$\langle d \rangle = \langle d \rangle_{\text{prim}} + \langle d \rangle_{\text{sec}}$$

$$\langle d \rangle_{\text{prim}} = \text{const.(z)}, \qquad \langle d \rangle_{\text{sec}} = \alpha \cdot \Delta_z$$

- The contribution of primary *d* constant along target width,
- The contribution of secondary *d* decreasing linearly with the target width,
- The contribution of primary *d* can be extracted from the intersection with the end of the target.

MC correction – coalescence

- Ordinary event generators do not produce deuterons,
- **Coalescence model** has to be applied as an afterburner in order to produce light (anti)nuclei from p, $\bar{p}$, n and $\bar{n}$,

$$|\vec{k_1} - \vec{k_2}| < 2p_0 \tag{1}$$

where

$$p_0 = \frac{A}{1 + \exp B - \ln(T/C)} \tag{2}$$

with T being collision energy in GeV, $A = 89.6$, $B = 6.6$ and $C = 0.73$ (different parametrization for antiparticles).

See: A. Shukla et al. ”Large-scale Simulations of Antihelium Production in Cosmic-ray Interactions”. In: *Phys.Rev.D 102 (2020) 6, 063004*.

MC correction

The MC-based **correction on detector geometry** can be calculated as the ratio of generated (coalesced) d in full solid angle to d reconstructed in detector acceptance:

$$\langle d_{\text{final}} \rangle = c \cdot \langle d_{\text{raw, common acc}} \rangle$$

$$c = \frac{\langle d \rangle_{\text{gen}}}{\langle d_{\text{sel, common acc}} \rangle} = 61.18$$

- Statistical uncertainty is negligible.

Calculating the cross-section

Based on the NA61/SHINE published data on p+C data:

$$\sigma_d = \frac{\sigma_{\text{trig}}}{f_{\text{prod}}(1-\epsilon)} \left(\frac{n_d^I}{N_{\text{trig}}^{\text{I}}} - \epsilon \frac{n_d^R}{N_{\text{trig}}^{\text{R}}} \right),$$

with:

- $\sigma_{\text{trig}} = 305.7 \pm 2.7$ mb,
- $N_{\text{trig}}^{\text{I}}$ and $N_{\text{trig}}^{\text{R}}$ are the numbers of trigger events with the target inserted and removed, respectively,
- n_d^{I} and n_d^{R} number of deuterons produced with target inserted and removed, respectively,
- $\epsilon = 0.123 \pm 0.004$ is the ratio of the interaction probabilities for operation with the target removed and inserted,
- $f_{\text{prod}} = 0.993$ is the fraction of production events.

Conclusions

- Using the proposed analysis method it is feasible to obtain the cross-section value for primary deuterons, but more detailed analysis is necessary,
- Similar analysis performed for $\bar{p}$ and $\bar{d}$ gives 27 and 9 entries, respectively. This amounts to **unsatisfactory statistical uncertainty** of 20% and 30%, respectively.
- In order to decrease the uncertainty below 10% amount of data should **increase twelvefold** in case of $\bar{d}$ and **fourfold** in case of $\bar{p}$.
- The results from N61/SHINE are a valuable source of data for reference measurements,
- Large-scale p+p data sets for $\bar{p}$ and d production are being analyzed and results are forthcoming.

Thank you for your attention.