New estimation of the secondary antideuteron cosmic-ray flux

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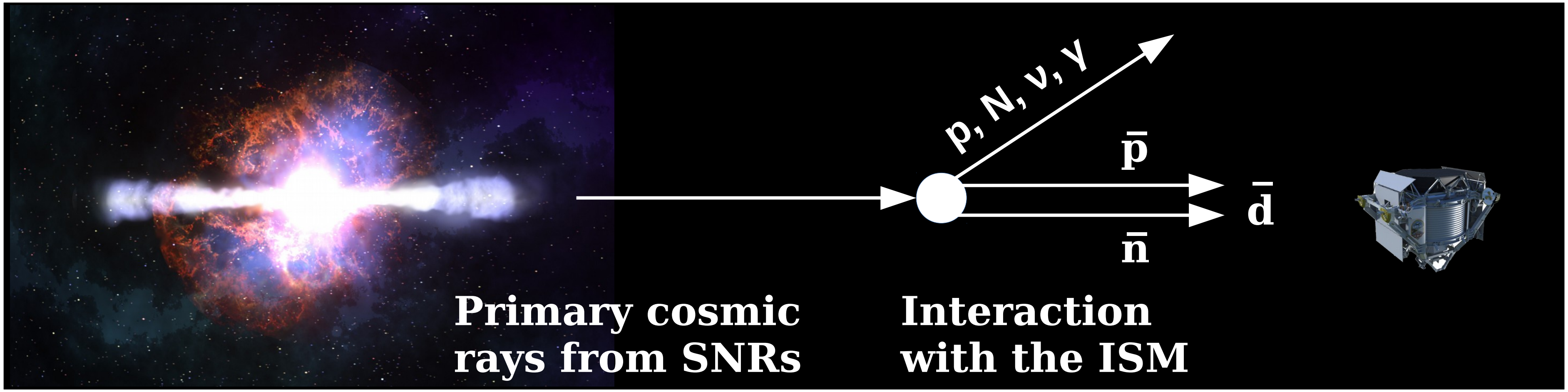
$\bar{d}$19 2th Cosmic-ray
Antideuteron Workshop

Indirect dark matter searches

Expected antideuteron production in cosmic-ray interactions

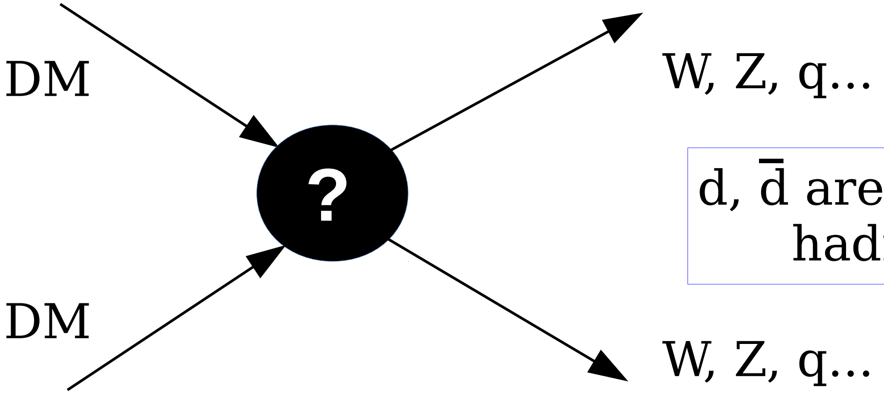


Primary cosmic rays from SNRs

Interaction with the ISM

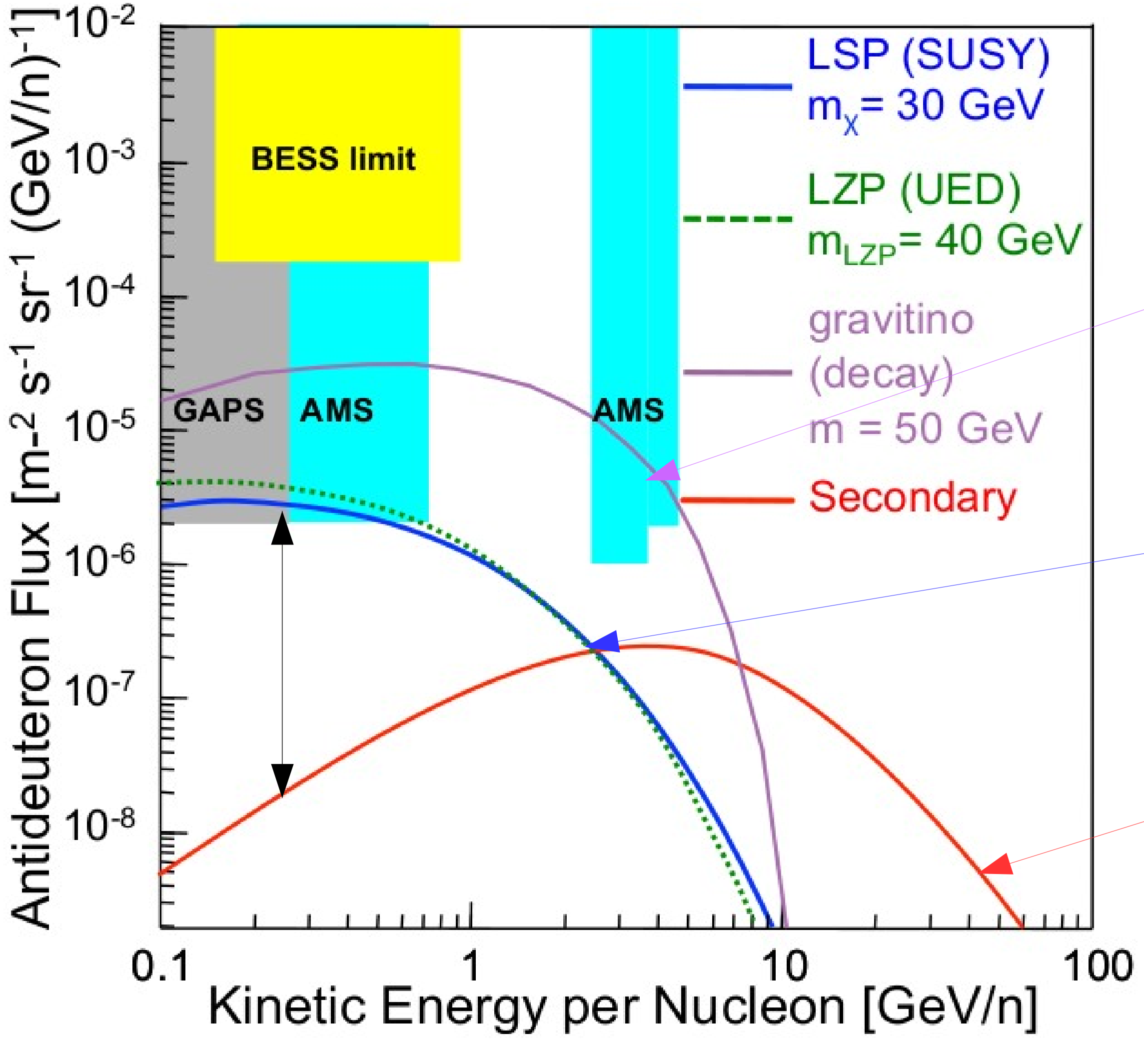
Hypothetical antideuteron cosmic-rays from dark matter

Dark matter candidates



d, d̄ are formed after hadronization

Indirect dark matter searches



Examples of antideuteron signals from dark matter candidates interactions.

Late decays of unstable gravitinos

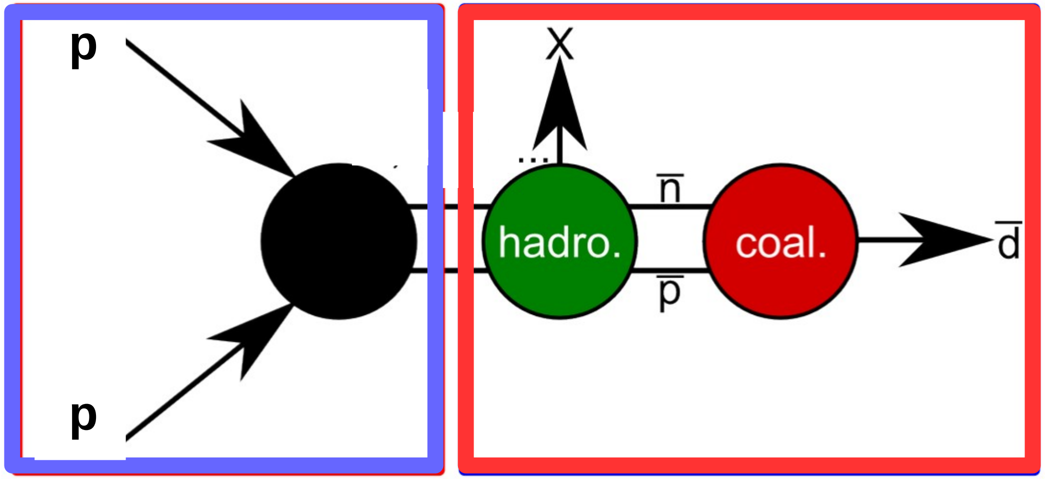
Neutralino:
SUSY lightest supersymetric particle, decay into bb

Astrophysical background:
Cosmic-ray collisions with the interstellar medium

Antideuterons are an important unexplored indirect detection technique.

T. Aramaki et al., Phys. Rept. 618, 1 (2016), arXiv:1505.07785 [hep-ph].

Antideuteron formation model



p+p, p+He, He+p, pbar+p collisions

Coalescence

Coalescence Model

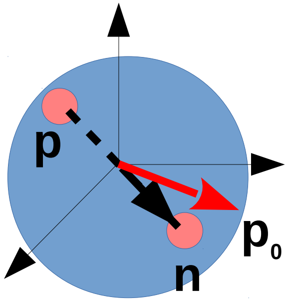
Deuterons and antideuterons can be formed by a pair p-n or p-n close in phase space.

$$\gamma_d \frac{d^3N_d}{dp_d^3} = \frac{4\pi}{3}\boxed{p_0^3}\left(\gamma_p \frac{d^3N_p}{dp_p^3}\right)\left(\gamma_n \frac{d^3N_n}{dp_n^3}\right)$$

p_0 is extracted from this comparison

Collisions are simulated with **Monte Carlo** generators, to produce p-n and $\bar{p}$-$\bar{n}$ pairs.

Afterburner



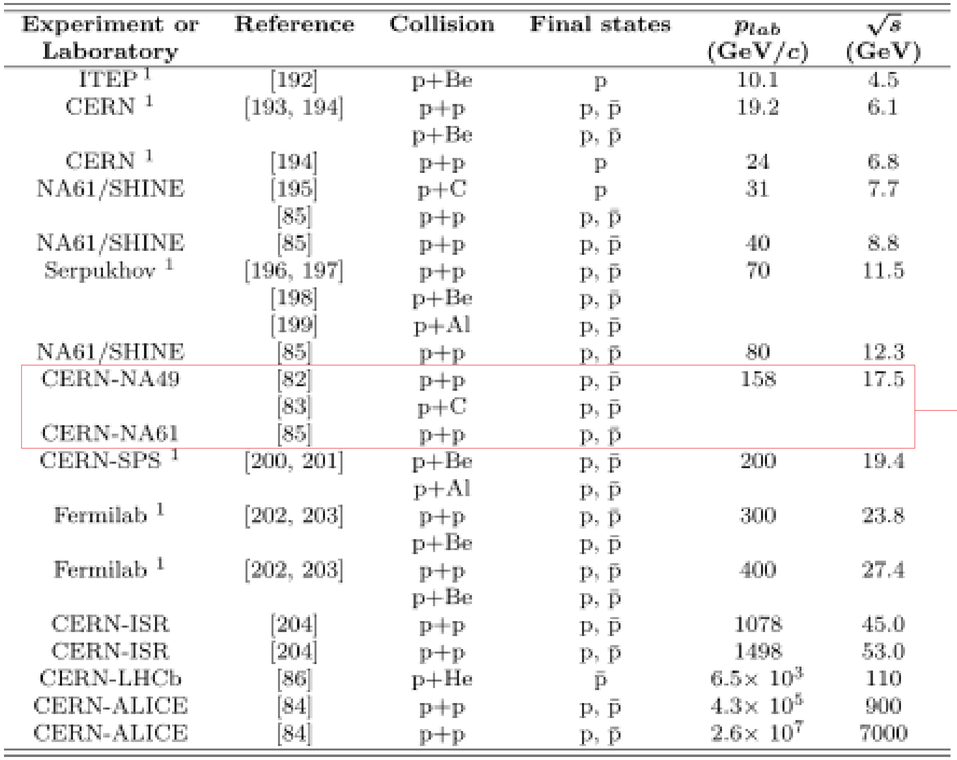
d and $\bar{d}$ are created from the pairs event by event

The results from simulations are compared to data

Antiproton production simulation

- To generate a correct prediction of antideuterons using MC, it is necessary to have a proper description of antiprotons.

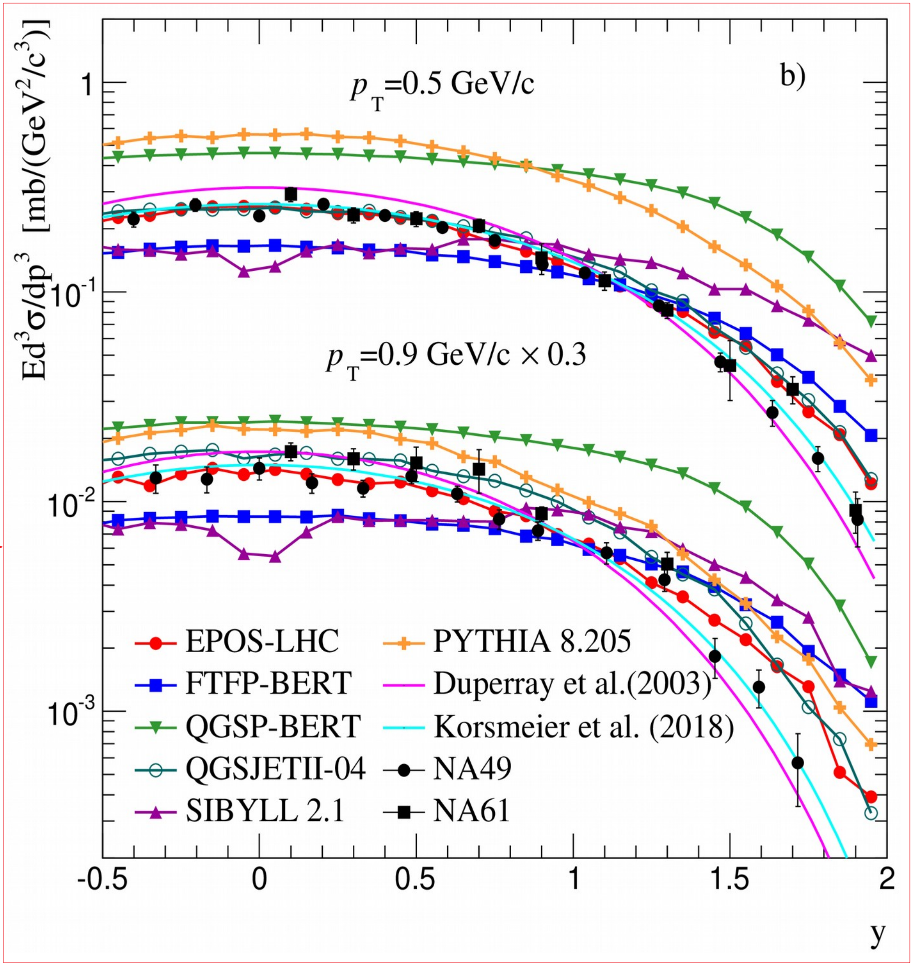
- High energy MC are suggested by M. Kachelriess et al. 2015.



Experiment or Laboratory	Reference	Collision	Final states	p_{lab} (GeV/c)	$\sqrt{s}$ (GeV)
ITEP [1]	[192]	p+Be	p	10.1	4.5
CERN [1]	[193, 194]	p+p	p, $\bar{p}$	19.2	6.1
		p+Be	p, $\bar{p}$		
CERN [1]	[194]	p+p	p	24	6.8
NA61/SHINE	[195]	p+C	p	31	7.7
	[85]	p+p	p, $\bar{p}$		
NA61/SHINE	[85]	p+p	p, $\bar{p}$	40	8.8
Serpukhov [1]	[196, 197]	p+p	p, $\bar{p}$	70	11.5
	[198]	p+Be	p, $\bar{p}$		
	[199]	p+Al	p, $\bar{p}$		
NA61/SHINE	[85]	p+p	p, $\bar{p}$	80	12.3
CERN-NA49	[82]	p+p	p, $\bar{p}$	158	17.5
	[83]	p+C	p, $\bar{p}$		
CERN-NA61	[85]	p+p	p, $\bar{p}$		
CERN-SPS [1]	[200, 201]	p+Be	p, $\bar{p}$	200	19.4
		p+Al	p, $\bar{p}$		
Fermilab [1]	[202, 203]	p+p	p, $\bar{p}$	300	23.8
		p+Be	p, $\bar{p}$		
Fermilab [1]	[202, 203]	p+p	p, $\bar{p}$	400	27.4
		p+Be	p, $\bar{p}$		
CERN-ISR	[204]	p+p	p, $\bar{p}$	1078	45.0
CERN-ISR	[204]	p+p	p, $\bar{p}$	1498	53.0
CERN-LHCb	[86]	p+He	$\bar{p}$	6.5×10^3	110
CERN-ALICE	[84]	p+p	p, $\bar{p}$	4.3×10^5	900
CERN-ALICE	[84]	p+p	p, $\bar{p}$	2.6×10^7	7000

Proton and antiproton data list on p+p and p+A collisions to be compared to simulations. D. Gomez-Coral et al. 2018.

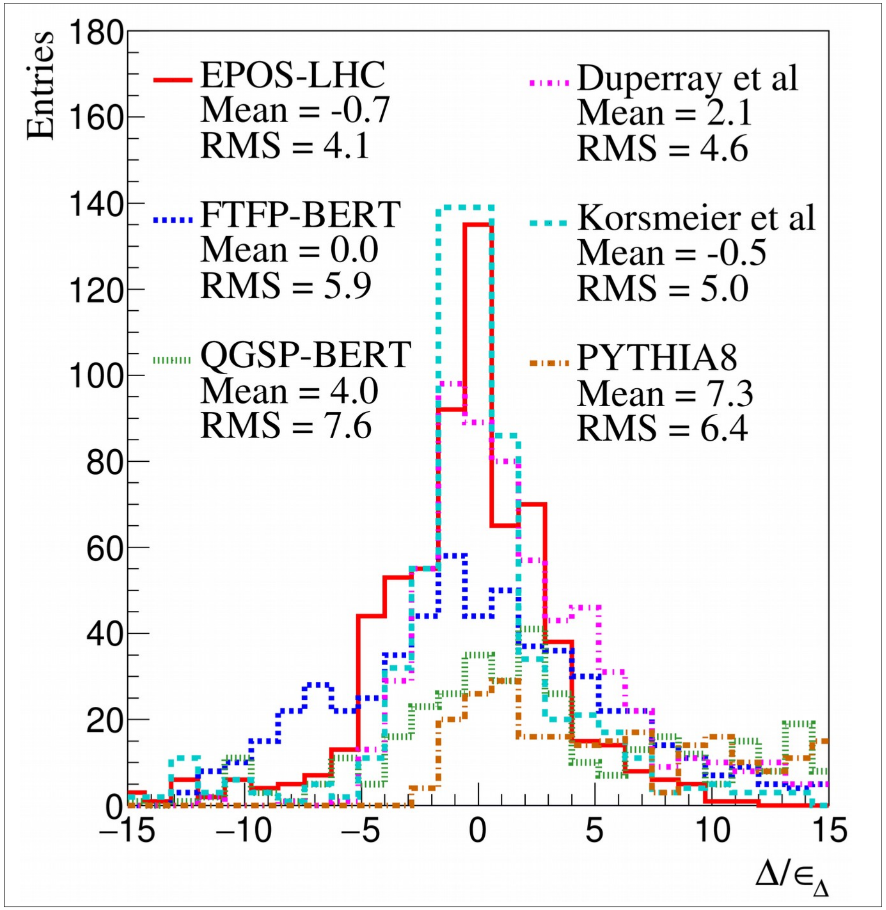
Invariant differential cross section for **antiprotons** in p+p collisions at 158 GeV/c, as function of rapidity

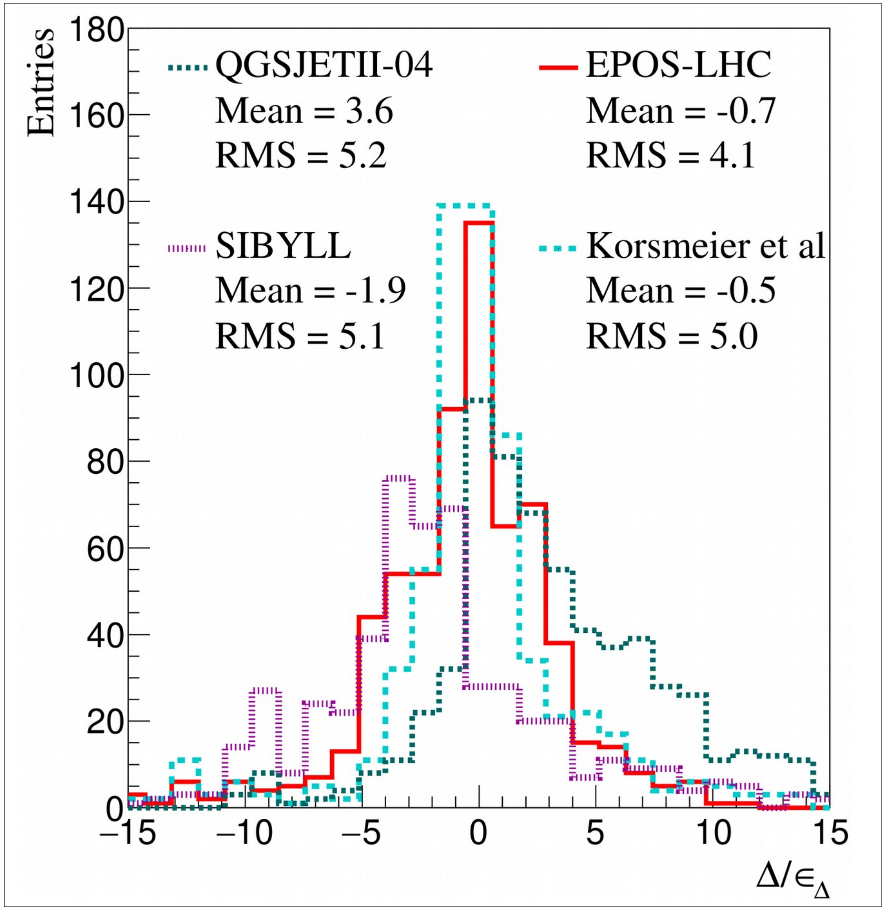


Antiproton production simulation

- The most reliable MC model is selected from the comparison to data.

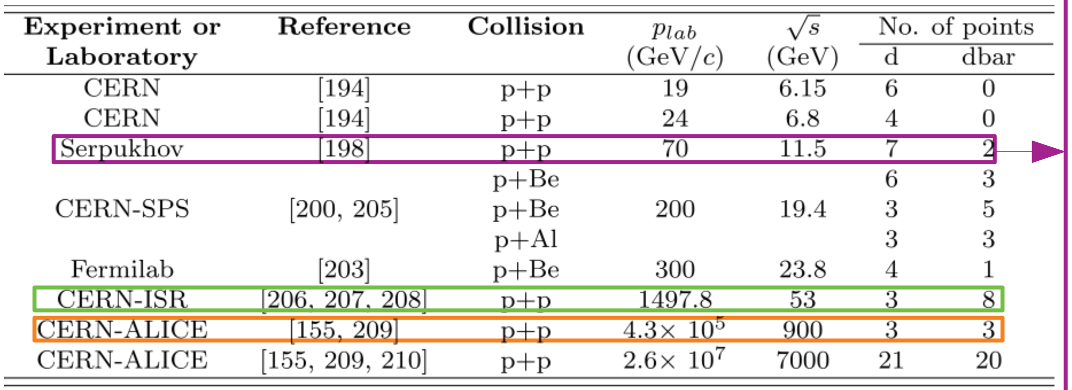
$$\frac{\Delta}{\epsilon_\Delta} = \frac{\left(E\frac{d^3\sigma}{dp^3}^{sim} - E\frac{d^3\sigma}{dp^3}^{data}\right)}{\sqrt{(\epsilon_{sim})^2 + (\epsilon_{data})^2}}$$





Antideuteron production simulation

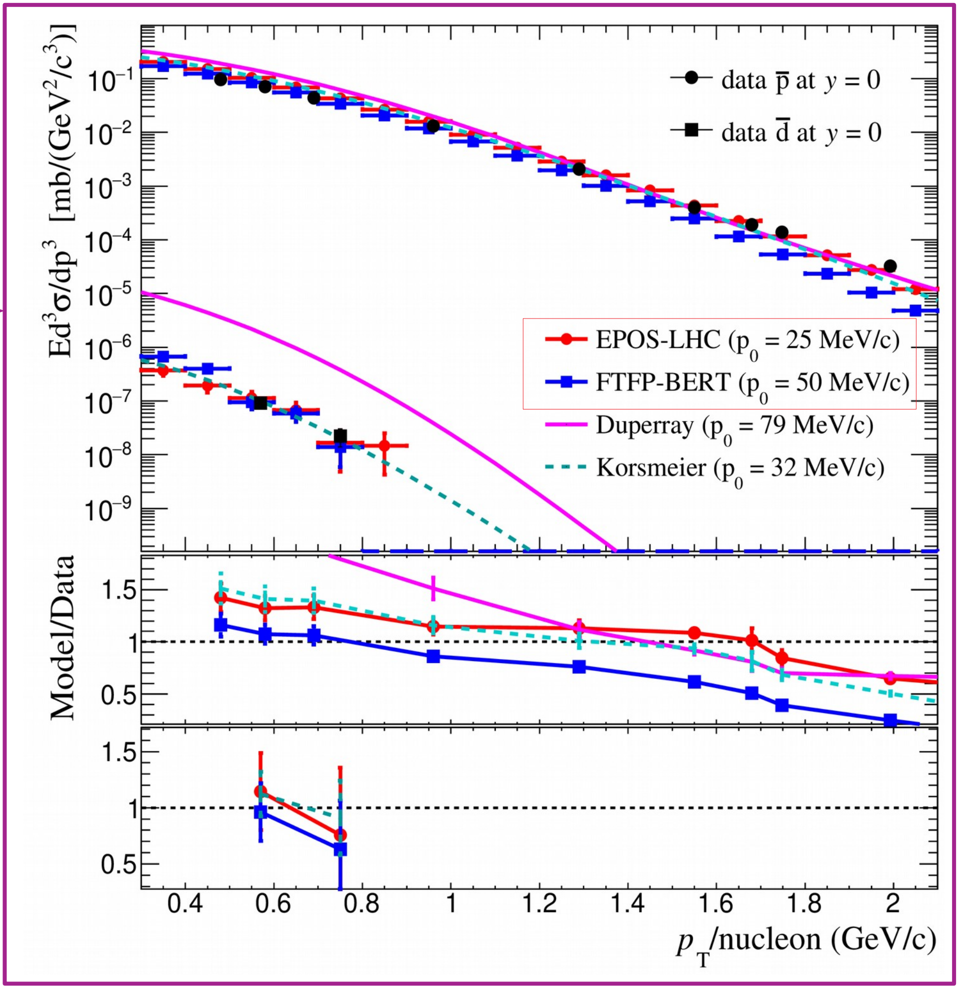
- The coalescence momentum (p_0) is determined from the fit of simulations to data.



Experiment or Laboratory	Reference	Collision	p_{lab} (GeV/c)	$\sqrt{s}$ (GeV)	No. of points d	No. of points dbar
CERN	[194]	p+p	19	6.15	6	0
CERN	[194]	p+p	24	6.8	4	0
Serpukhov	[198]	p+p	70	11.5	7	2
CERN-SPS	[200, 205]	p+Be	200	19.4	6	3
		p+Be			3	5
		p+Al			3	3
Fermilab	[203]	p+Be	300	23.8	4	1
CERN-ISR	[206, 207, 208]	p+p	1497.8	53	3	8
CERN-ALICE	[155, 209]	p+p	4.3×10^5	900	3	3
CERN-ALICE	[155, 209, 210]	p+p	2.6×10^7	7000	21	20

Deuteron and antideuteron data list on p+p and p+A collisions to be compared to simulations. D. Gomez-Coral et al. 2018.

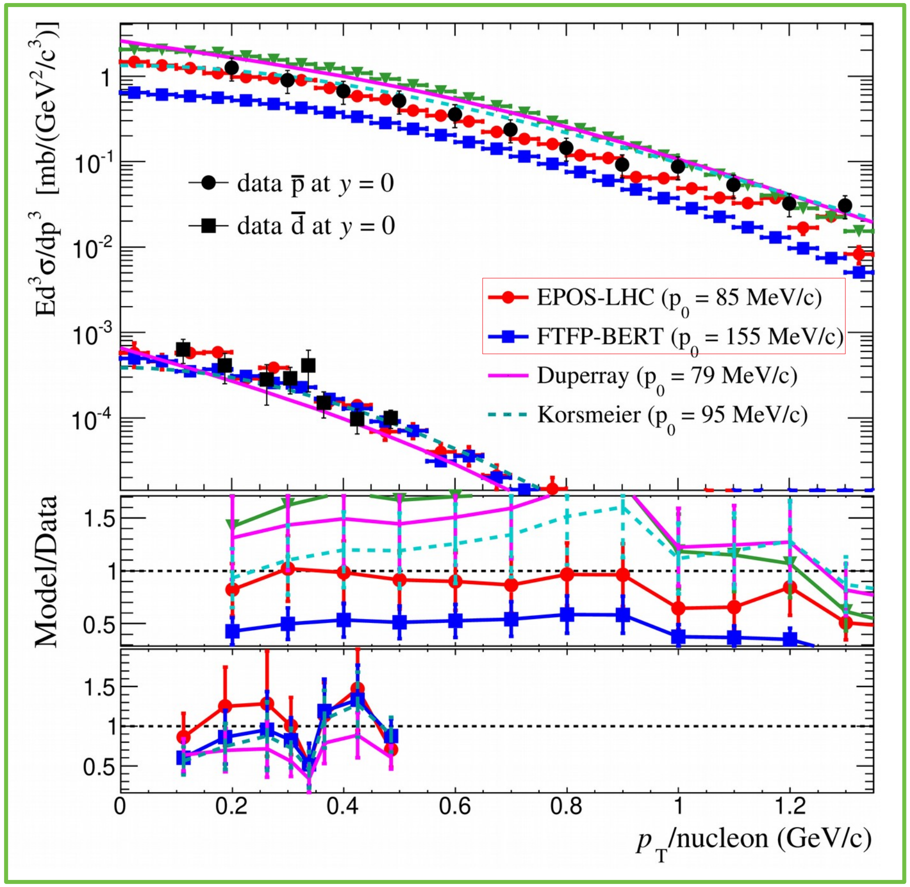
p+p at √s = 11.5 GeV



Antideuteron invariant differential cross section in p+p collisions at 70 GeV/c, as function of p_T

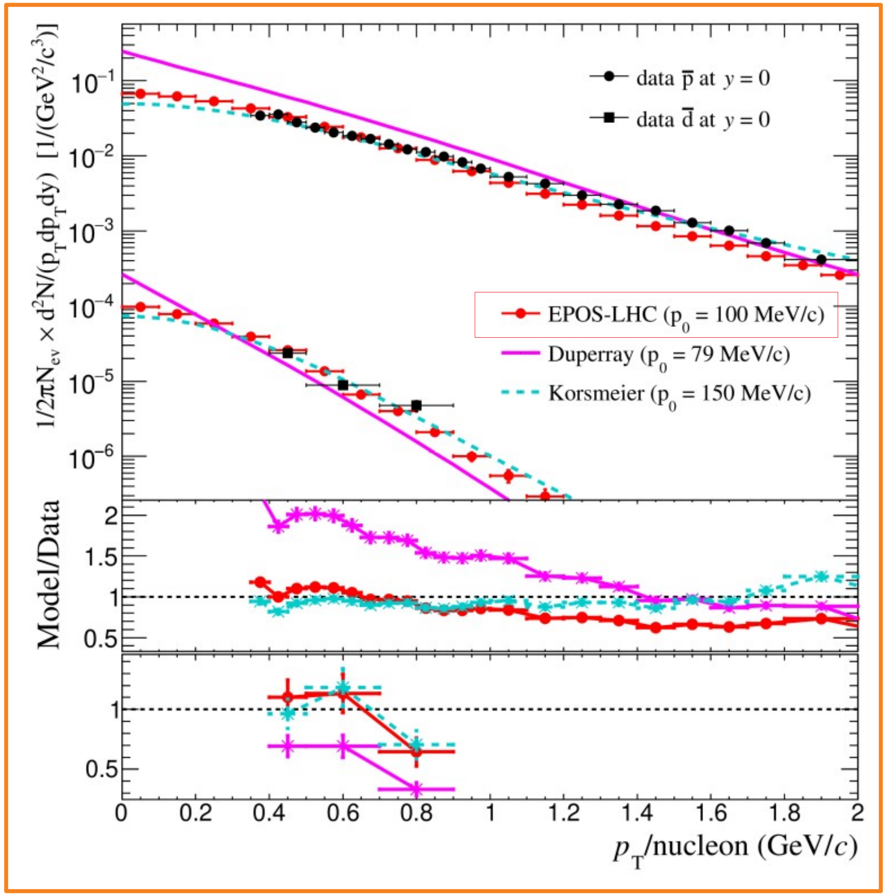
Antideuteron production simulation

p+p at √s = 53 GeV



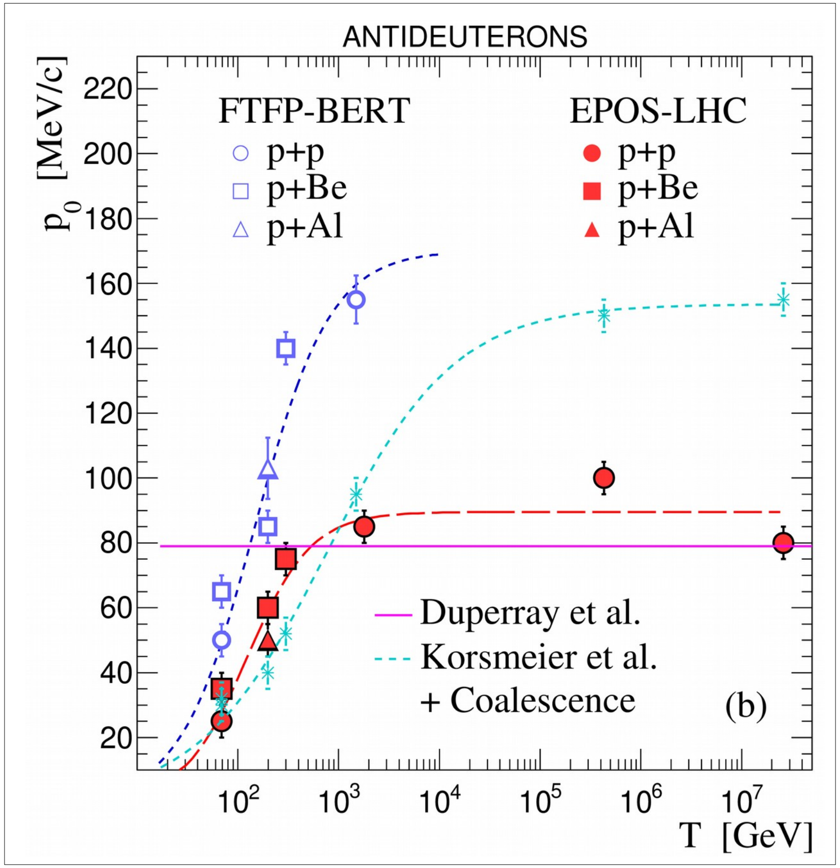
Antideuteron invariant differential cross section as function of p_T compared to ISR data.

p+p at √s = 900 GeV

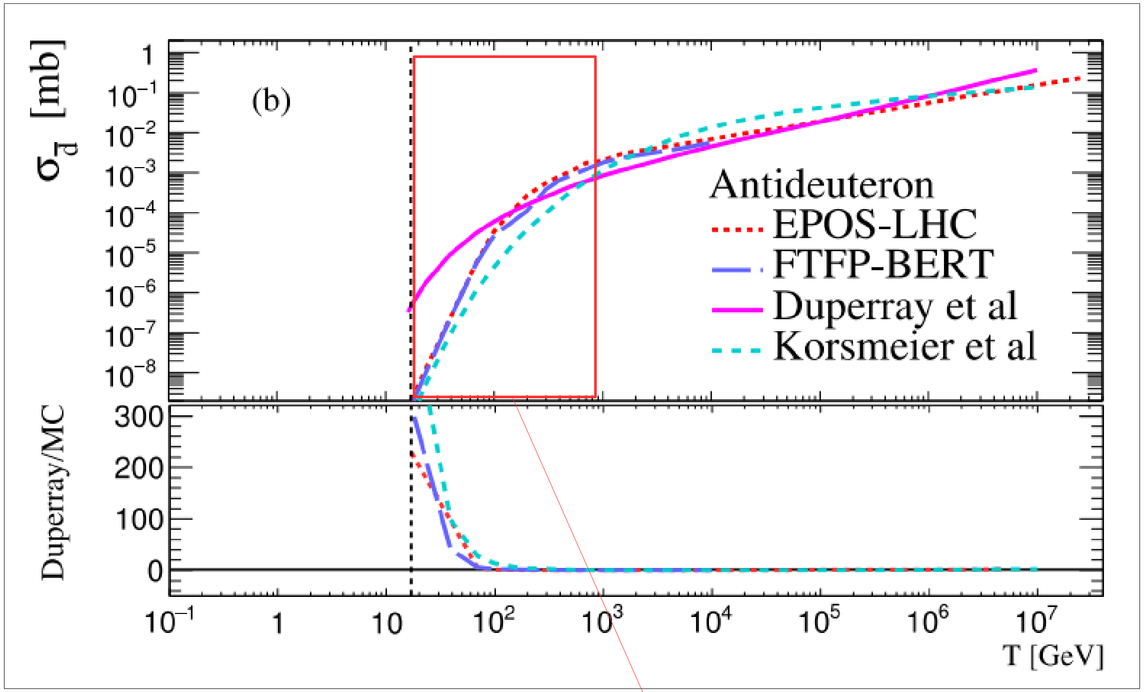


Antideuteron invariant differential cross section as function of p_T compared to ALICE-LHC data.

Coalescence momentum (p_0) and production cross section



p+p → X + dbar



- p_0 is parameterized as function of the projectile kinetic energy.
- p_0 is similar for p+p and p+Be collisions.

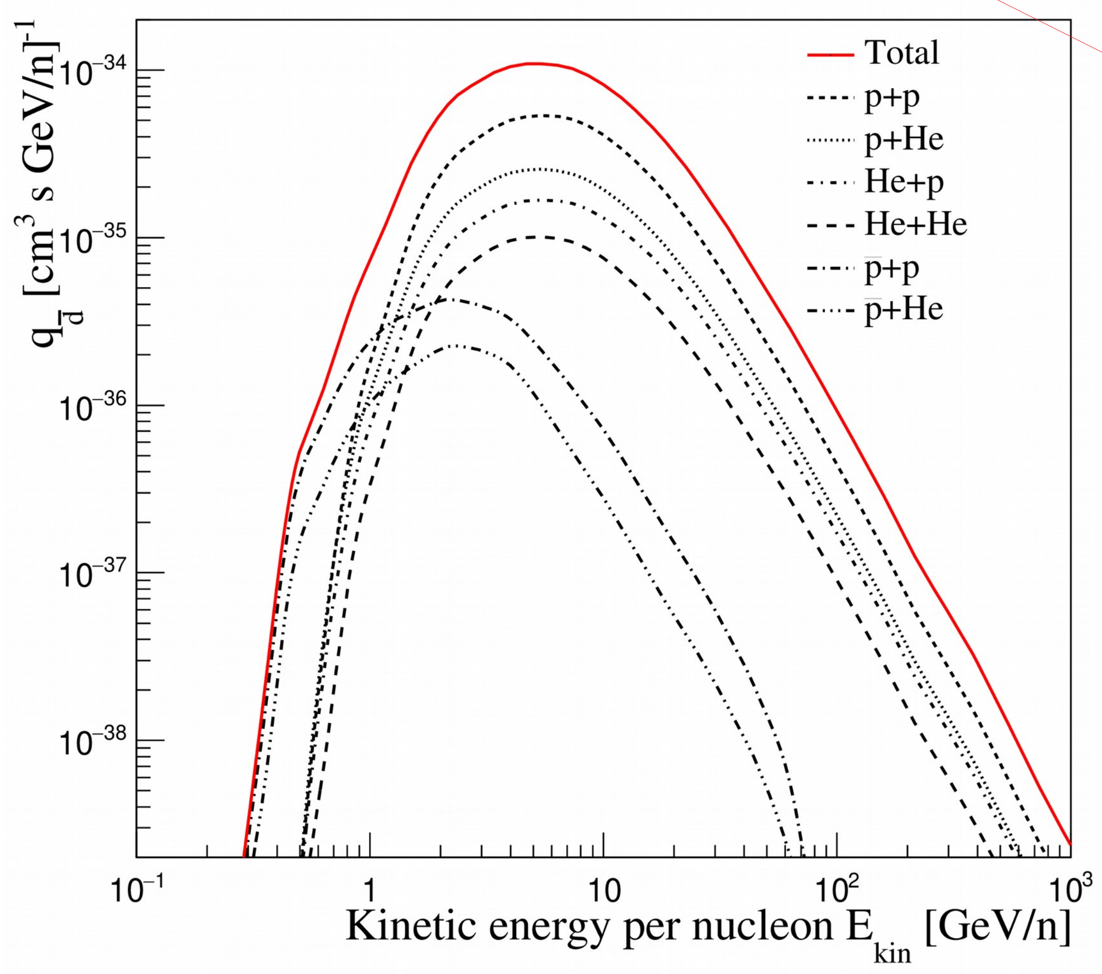
- p_0 changes in the energy region of major importance for cosmic ray production.

Antideuteron source term

$$q_{\bar{\mathrm{d}}}^{sec}(E_{kin}^{\bar{\mathrm{d}}}) = \sum_{i=\mathrm{p,He},\bar{\mathrm{p}}} \; \sum_{j=\mathrm{p,He}} 4\pi n_j \int_{T_{min}}^{\infty} \mathrm{d}T_i \left(\frac{d\sigma}{dE_{kin}^{\bar{\mathrm{d}}}}\right)_{ij} \Phi_i(T_i)$$

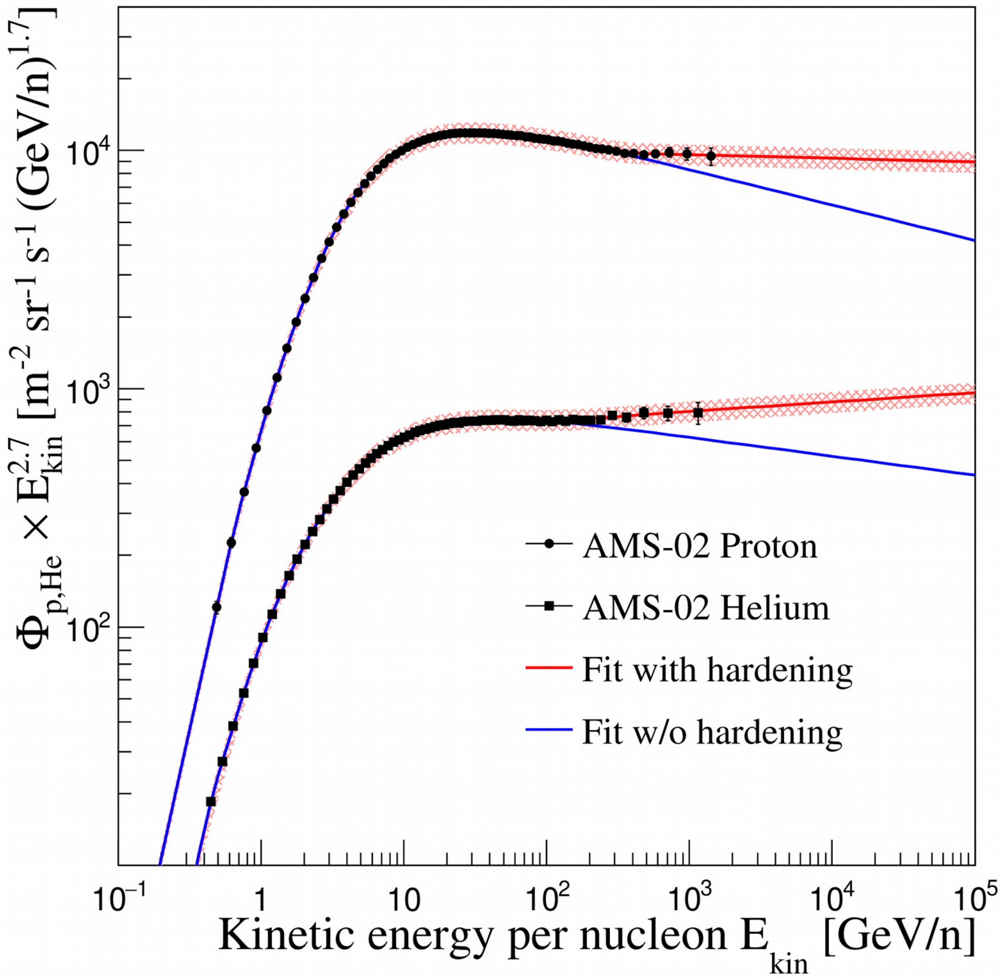
p, He Fluxes

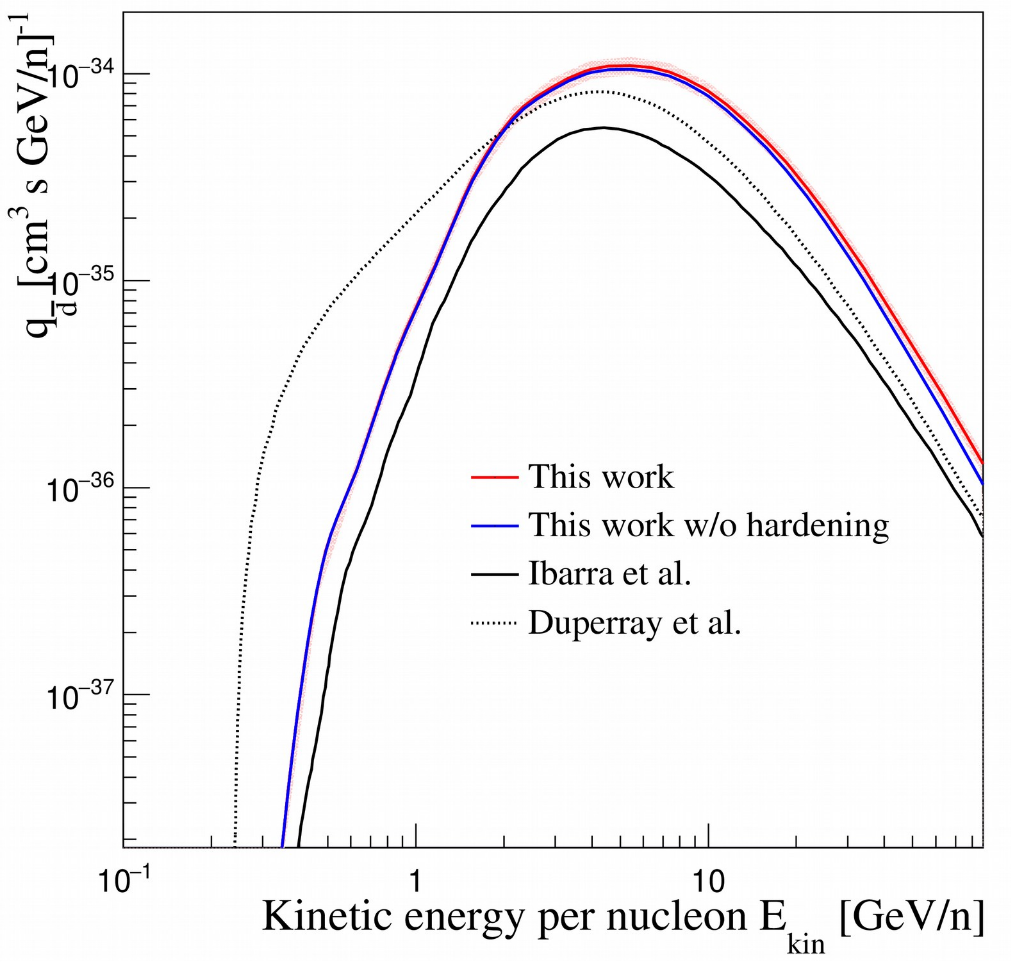
EPOS-LHC cross-section



Antideuteron source term

- Proton and helium fluxes with and without hardening are inserted in the convolution.





- Hardening increases dbar flux by less than 10%
- dbar production is higher than in previous works.

Propagation with Galprop56

Set 1 DR
Without convection

z [kpc]	$D_0/10^{28}$ [$cm^2\ s^{-1}$]	δ	V_{alf} [$km\ s^{-1}$]
6	4.37	0.494	7.64

Proton

R1	R2	γ1	γ2	γ3
5.78 GV	304 GV	1.74	2.35	2.178

Helium

R1	R2	γ1	γ2	γ3
5.78 GV	304 GV	1.69	2.29	2.12

T. A. Porter et al., 2017

Set 2 DCR
With convection

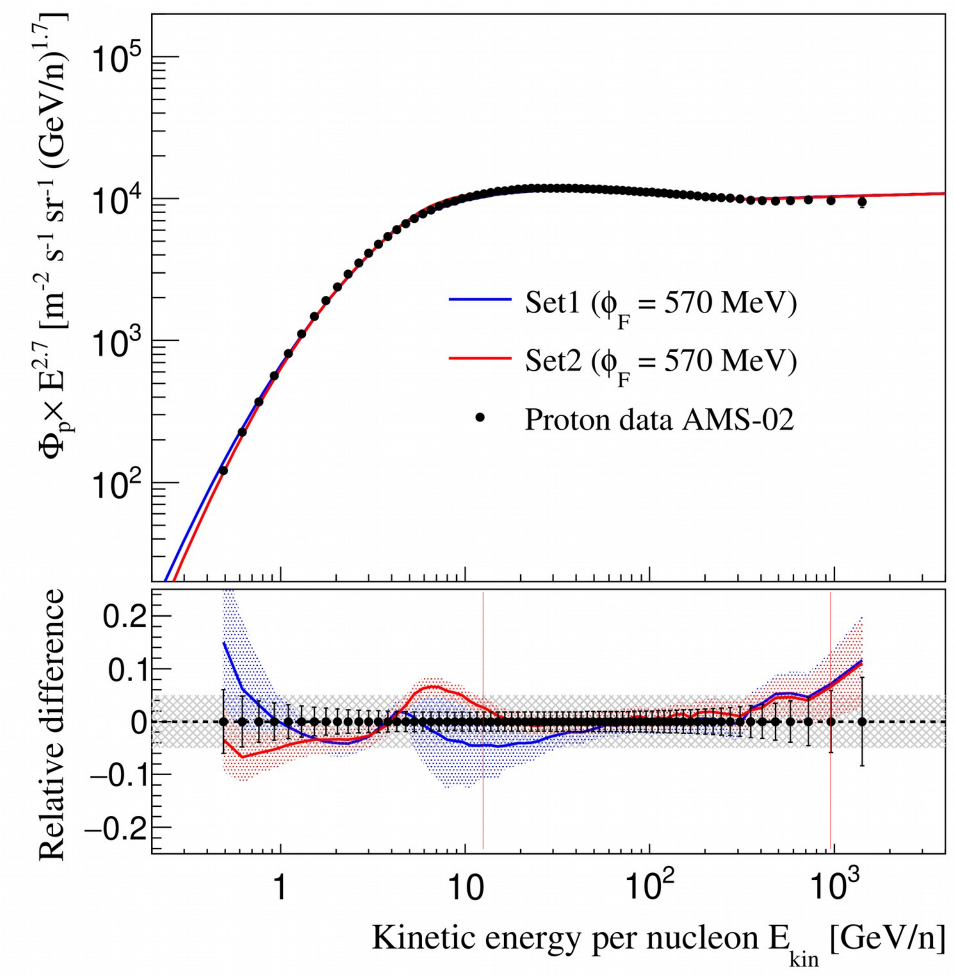
z [kpc]	$D_0/10^{28}$ [$cm^2\ s^{-1}$]	δ	V_{alf} [$km\ s^{-1}$]	V_{conv} [$km\ s^{-1}$]	dV/dz_{conv} [$km\ s^{-1}\ kpc^{-1}$]
4	4.3	0.395	28.6	12.4	10.2

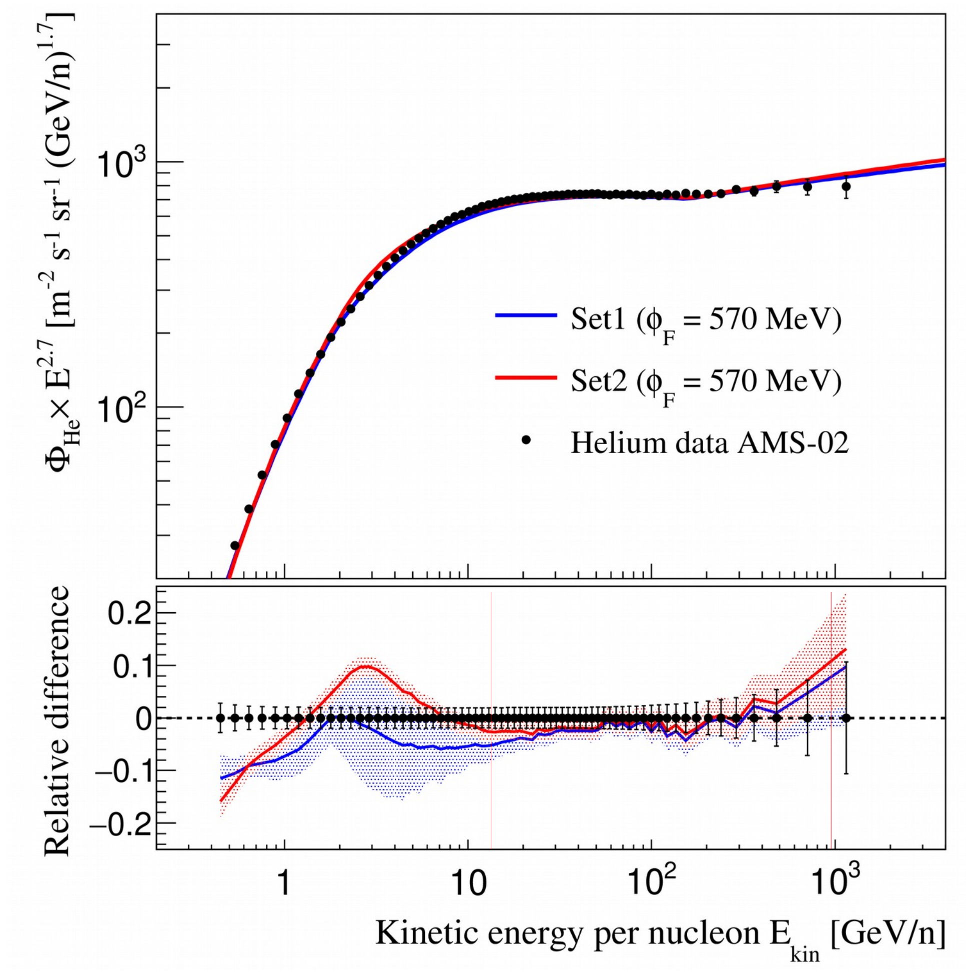
R1	R2	γ1	γ2	γ3
7 GV	360 GV	1.69	2.44	2.28

R1	R2	γ1	γ2	γ3
7 GV	330 GV	1.71	2.38	2.21

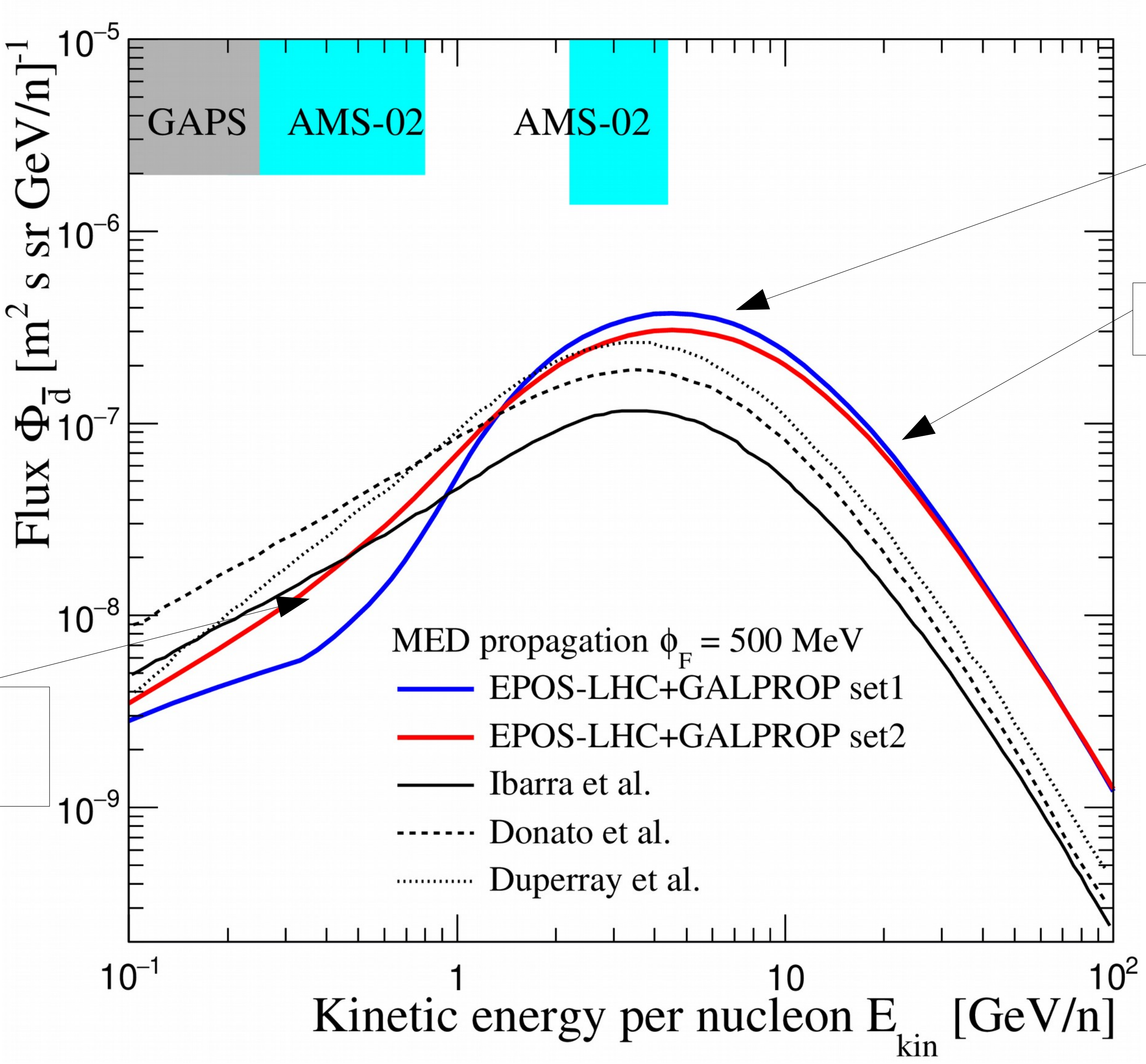
M. J. Boschini et al 2017
PoS(ICRC2017)278

Proton and Helium fluxes





Secondary Antideuteron Flux



Maximum is shifted.

Increase at high energy.

Adiabatic
energy loss

Summary

- A new study on the secondary antideuteron production was presented, using a high-energy MC generator (EPOS-LHC) and the coalescence model.

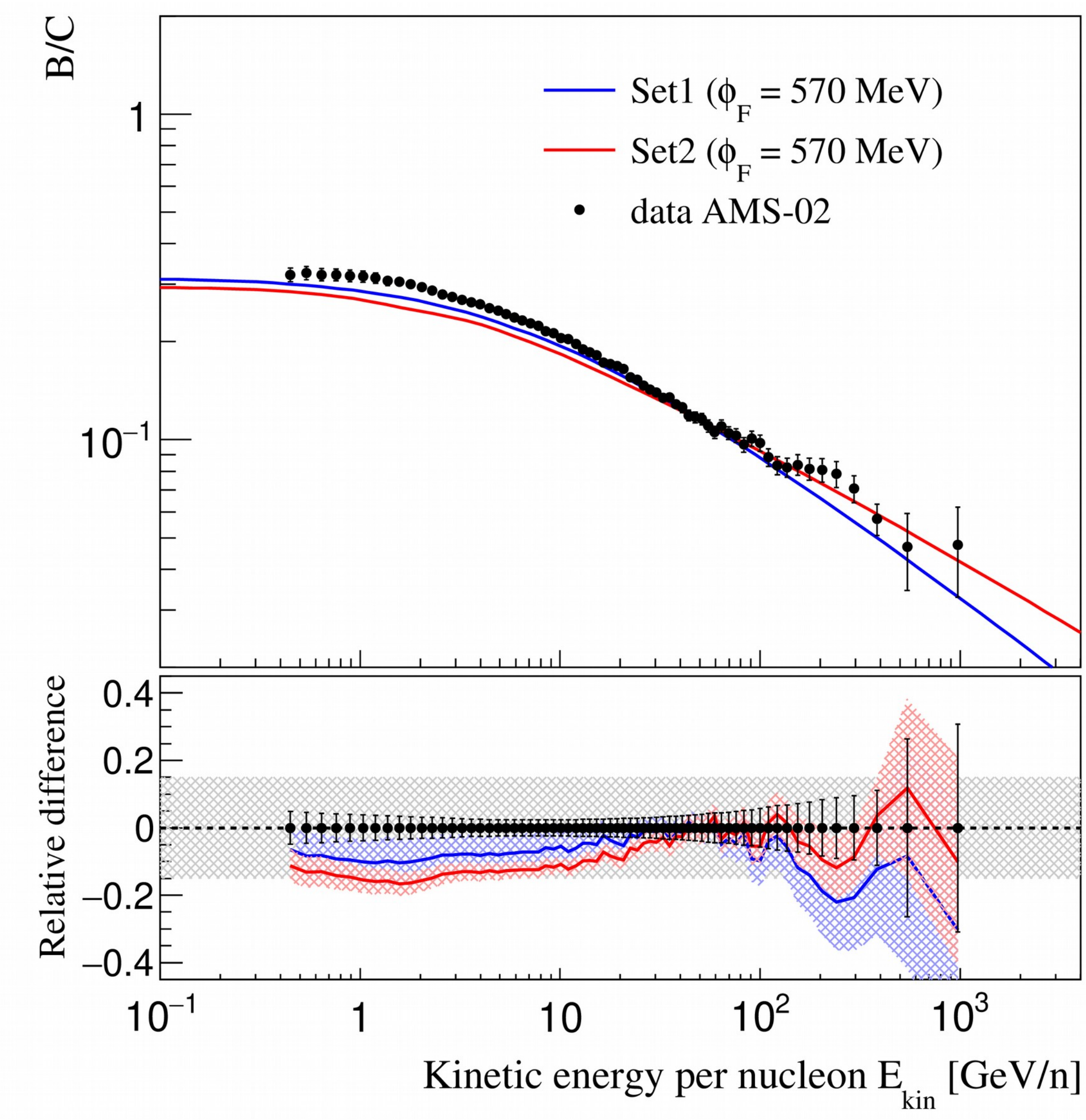
- Simulations were compared to an extensive data set, including new measurements from NA61 and ALICE-LHC.

- From the comparison to data, it seems the coalescence momentum (p_0) depends on the collision energy. As consequence:

    - Antideuteron production cross section shows important differences with respect to previous calculations.
    - Antideuteron flux maximum is shifted and it increases above 4 GeV/n in comparison with other works.

Thank you!

Boron to Carbon ratio



Antiproton production simulation