Title: Secondary Astrophysical Production of Anti-Deuteron and Anti-Helium3 Cosmic Ray

Date: Sep 22, 2017 01:00 PM

URL: http://pirsa.org/17090068

Abstract: <p>Cosmic-ray anti-deuterium and anti-helium have long been suggested as probes of dark matter, as their secondary astrophysical production was thought extremely scarce. But how does one actually predict the secondary flux? Anti-nuclei are dominantly produced in pp collisions, where laboratory cross section data is lacking. We make a new attempt at tackling this problem by appealing to a scaling law of nuclear coalescence with the physical volume of the hadronic emission region. The same volume is probed by Hanbury Brown-Twiss (HBT) two-particle correlations. We demonstrate the consistency of the scaling law with systems ranging from central and off-axis AA collisions to pA collisions, spanning 3 orders of magnitude in coalescence yield. Extending the volume scaling to the pp system, HBT data allows us to make a new estimate of coalescence, that we test against preliminary ALICE pp data. For anti-helium the resulting cross section is 1-2 orders of magnitude higher than earlier estimates. The astrophysical secondary flux of anti-helium could be within reach of a five-year exposure of AMS02.</p>

Anti-deuteron, Anti-Helium3 cosmic ray

Ryosuke Sato (Weizmann Institute of Science)

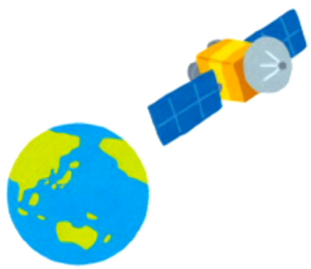
based on arXiv:1704.05431[astro-ph.HE]
Kfir Blum, Kenny C.Y. Ng, RS, Masahiro Takimoto

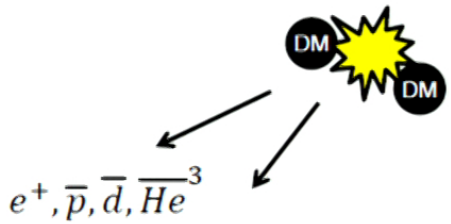
See also 1709.06507 (Blum Sato Waxman)

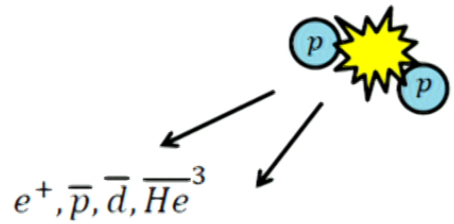
2017. 9. 22 @ Perimeter Institute

Antimatter cosmic ray

Antimatter cosmic ray is an important probe for Dark matter.







To understand its background is very important.

⇩

Astrophysical Secondary production

- Collision between interstellar medium and (primary) cosmic ray

$$p(\mathrm{CR}) + p(\mathrm{ISM}) \rightarrow X$$

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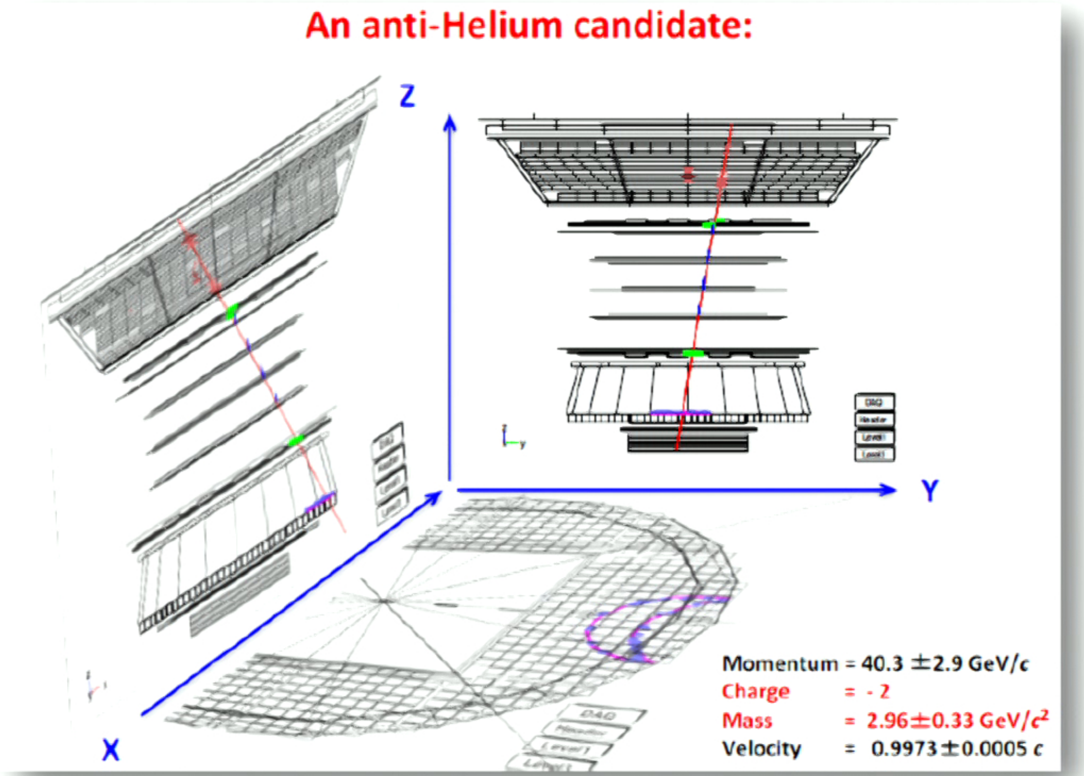
AMS-02 observed Anti-Helium3?

AMS-02 observed 5 events of anti-helium3. [V. Bindi (TeVPA 2017)]



[S. Ting (CERN colloquium, 2016 Dec)]

AMS-02 observed Anti-Helium3?

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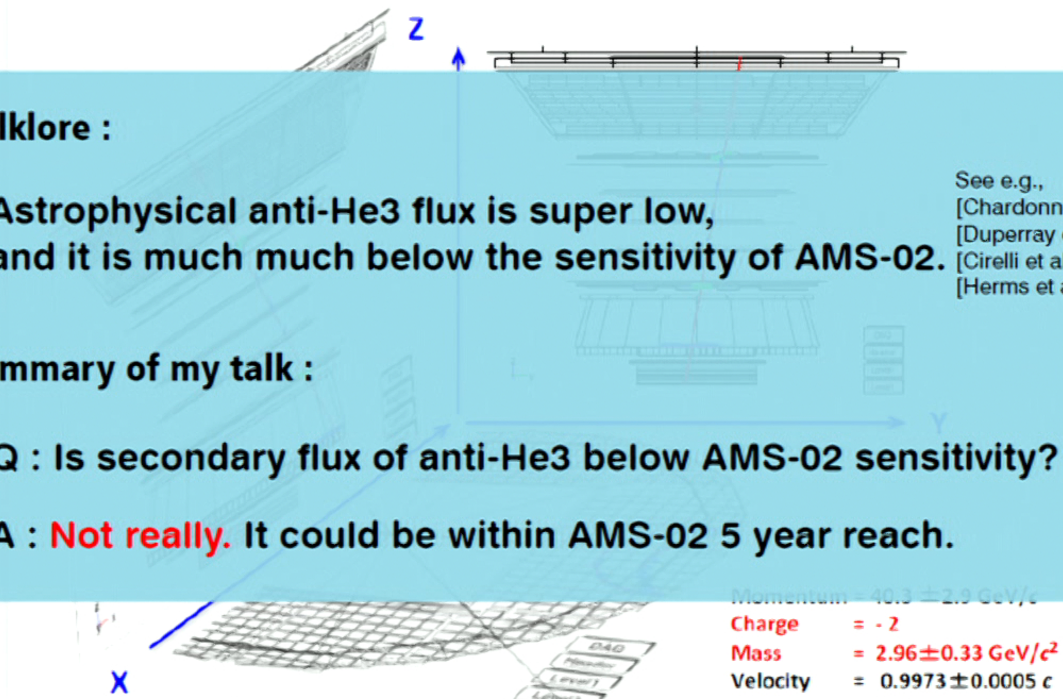
An anti-Helium candidate:



Folklore :

Astrophysical anti-He3 flux is super low, and it is much much below the sensitivity of AMS-02.

See e.g.,
[Chardonnet et al (1997)]
[Duperray et al (2005)]
[Cirelli et al (2014)]
[Herms et al (2016)]

Summary of my talk :

Q : Is secondary flux of anti-He3 below AMS-02 sensitivity?

A : Not really. It could be within AMS-02 5 year reach.

[S. Ting (CERN colloquium, 2016 Dec)]

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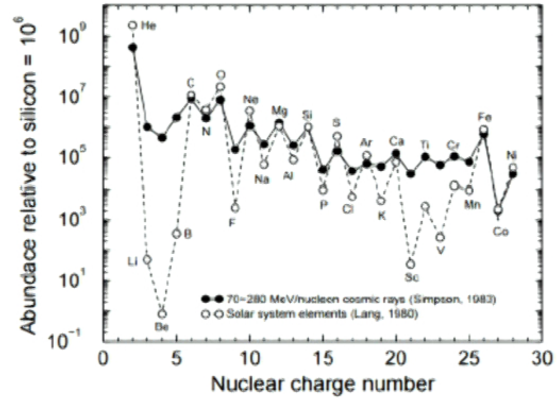
1. Review on secondary production of cosmic ray

For a review, see 1709.06507 (K. Blum, R. Sato, E. Waxman)

Secondary production of Cosmic ray

Composition of CR :

- Similar to solar system "qualitatively"
  Hydrogen, Helium, Carbon, Oxygen are abundant etc.
- Rare elements are much abundant.
  Boron-Carbon ratio is $\sim \mathcal{O}(0.1)$ in CR.



[taken from astro-ph/0008382]

⇨ **Rare elements are produced by collision of ISM and abundant element.**

Primary: $p(\mathrm{H})$, He, C, ...

Secondary: $\begin{cases} \mathrm{Li, Be, B}, \ldots \\ e^+, \overline{p}, \overline{d}, \overline{\mathrm{He}}^3 \end{cases}$

How to calculate secondary CR flux

[Dogiel, Berezinsky, Bulanov, Ptsukin (1990)]
[Gaisser, Schaefer (1992)]
[Blum, Katz, Waxman (2009, 2013)]

Assumptions :

1. Same rigidity ($R = p/Z$) gives same trajectory in magnetic field.
2. Neglect energy loss (I will not discuss e^+ today)
3. Composition is same in every point in which production is active

$n_i(R; x, t) = n_{CR}(x, t) \times f_i(R)$

$$n_B(R; \vec{x}_\odot, t_\odot) = \int dt \int d^3\vec{x}\, \rho_{ISM}(\vec{x}, t) P(R; \{x, t\}, \{\vec{x}_\odot, t_\odot\}) Q_B(R; \vec{x}, t)$$

ρ_{ISM} : ISM density
P : probability to reach the earth
Q_B : source term

$$Q_B = \frac{\sigma_{C\to B}}{m_{ISM}} n_C - \frac{\sigma_B}{m_{ISM}} n_B$$

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$$\frac{n_B(R; \vec{x}_\odot, t_\odot)}{Q_B(R; \vec{x}_\odot, t_\odot)} = \int dt \int d^3\vec{x}\, \rho_{ISM}(\vec{x}, t) P(R; \{x, t\}, \{\vec{x}_\odot, t_\odot\}) \frac{n_{CR}(R; \vec{x}, t)}{n_{CR}(R; \vec{x}_\odot, t_\odot)}$$

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$$n_i(R; x, t) = n_{CR}(x, t) \times f_i(R)$$

We can define $X_{esc}(R)$ $[g/cm^2]$ (grammage) such that

$$\frac{n_B}{Q_B} = \frac{n_{\bar{p}}}{Q_{\bar{p}}} = \frac{n_{\bar{d}}}{Q_{\bar{d}}} = \frac{n_{\overline{3He}}}{Q_{\overline{3He}}} = \frac{X_{esc}(R)}{\rho_{ISM}(x_\odot, t_\odot)}$$

ρ_{ISM} : ISM density
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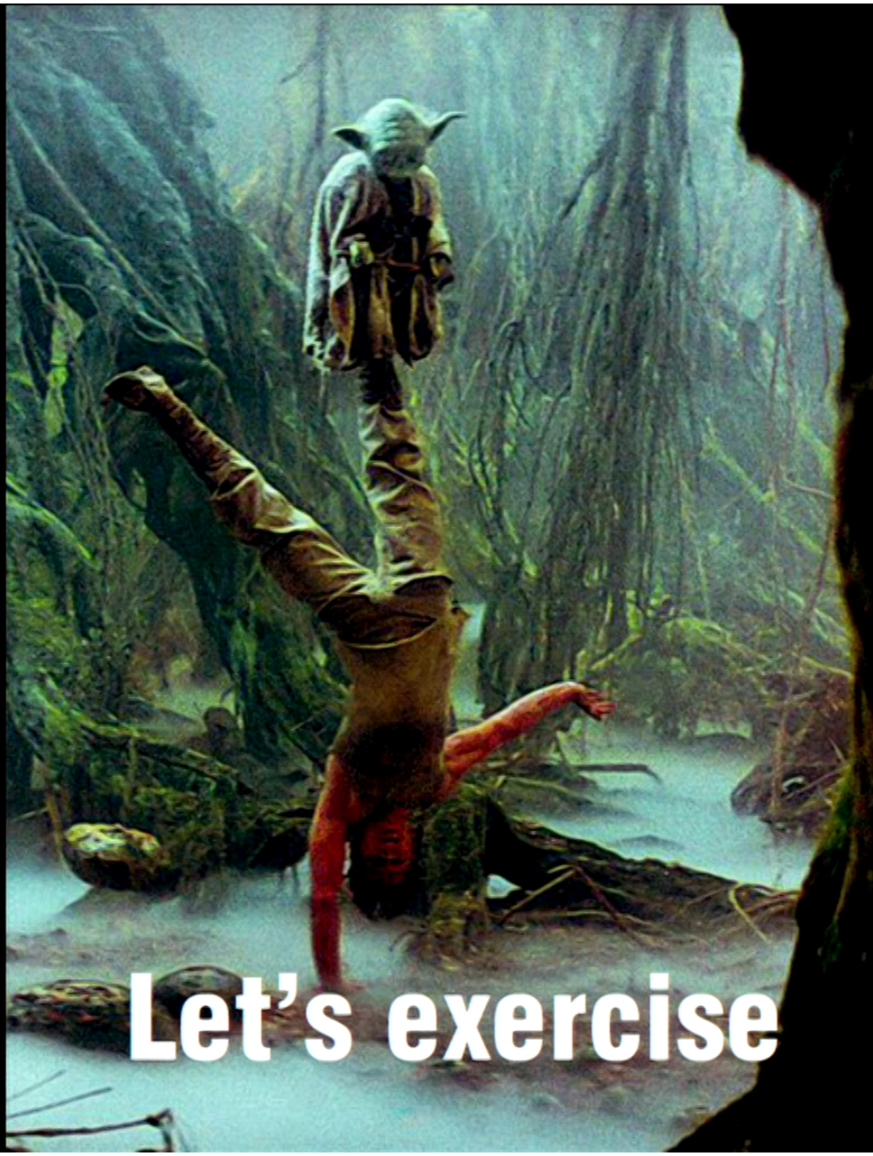
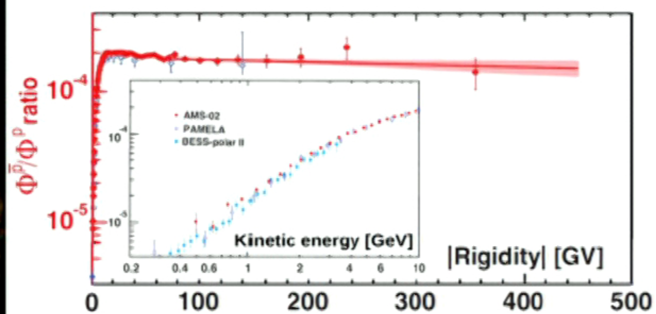
$$Q_B = \frac{\sigma_{C\to B}}{m_{ISM}} n_C - \frac{\sigma_B}{m_{ISM}} n_B$$



AMS-02 Antiproton



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Exercise : antiproton / proton ratio

1. Let us take universal relation :

$$\frac{n_{\bar{p}}(R)}{Q_{\bar{p}}(R)/\rho_{ISM}} = \frac{n_B(R)}{Q_B(R)/\rho_{ISM}} = X_{esc}(R)$$

2. Calculate X_{esc} from B/C data.

$$Q_B(\mathrm{R}) = \frac{\rho_{ISM}}{m_p} n_C(R)\sigma_{C\to B}(R) - \frac{\rho_{ISM}}{m_p} n_B(R)\,\sigma_B(R)$$

$$\Downarrow$$

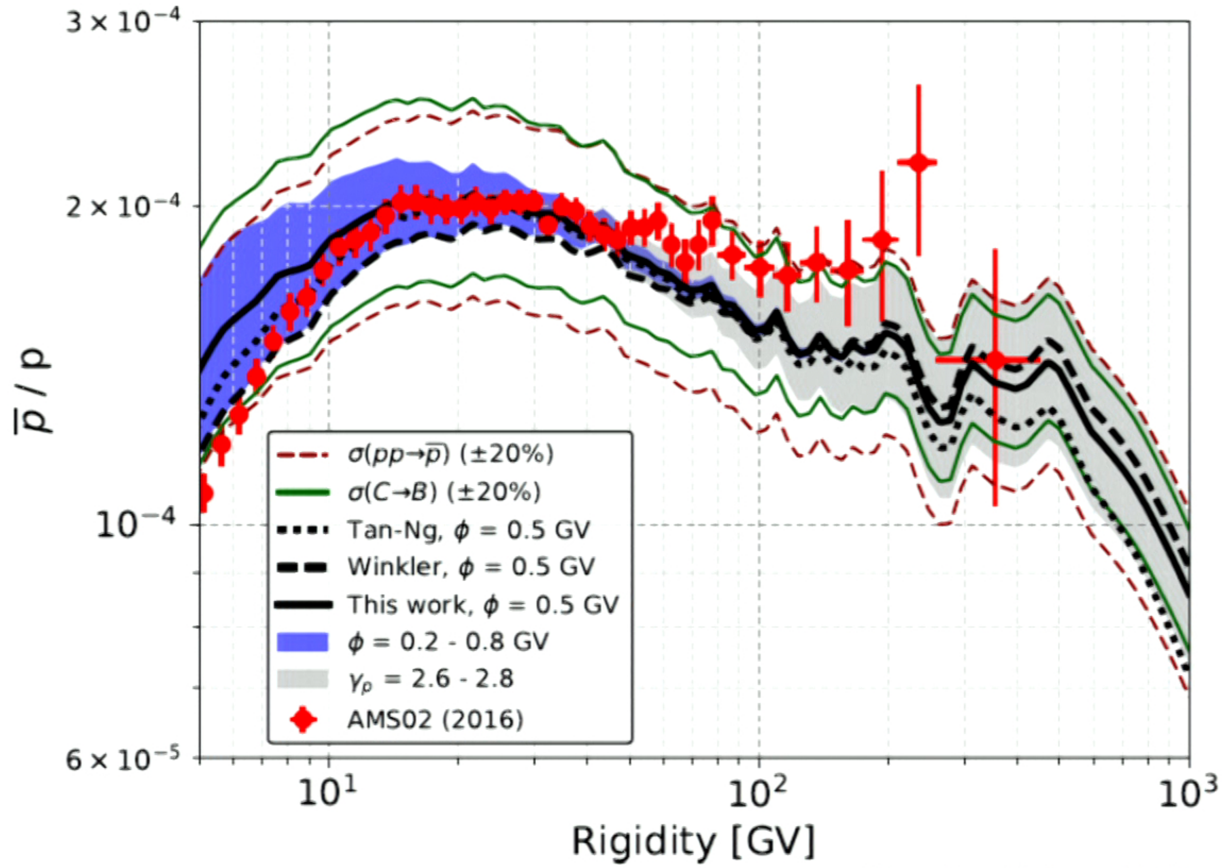
$$X_{esc}(R) = \frac{n_B/n_C}{(\sigma_{C\to B}/m_p) - (n_B/n_C)\sigma_B/m_p}$$

3. Calculate $\bar{p}/p$ from X_{esc}.

$$\frac{n_{\bar{p}}(R)}{n_p(R)} = \frac{X_{esc}\sigma_{pp\to\bar{p}}/m}{1 + X_{esc}\sigma_{\bar{p}}/m}$$

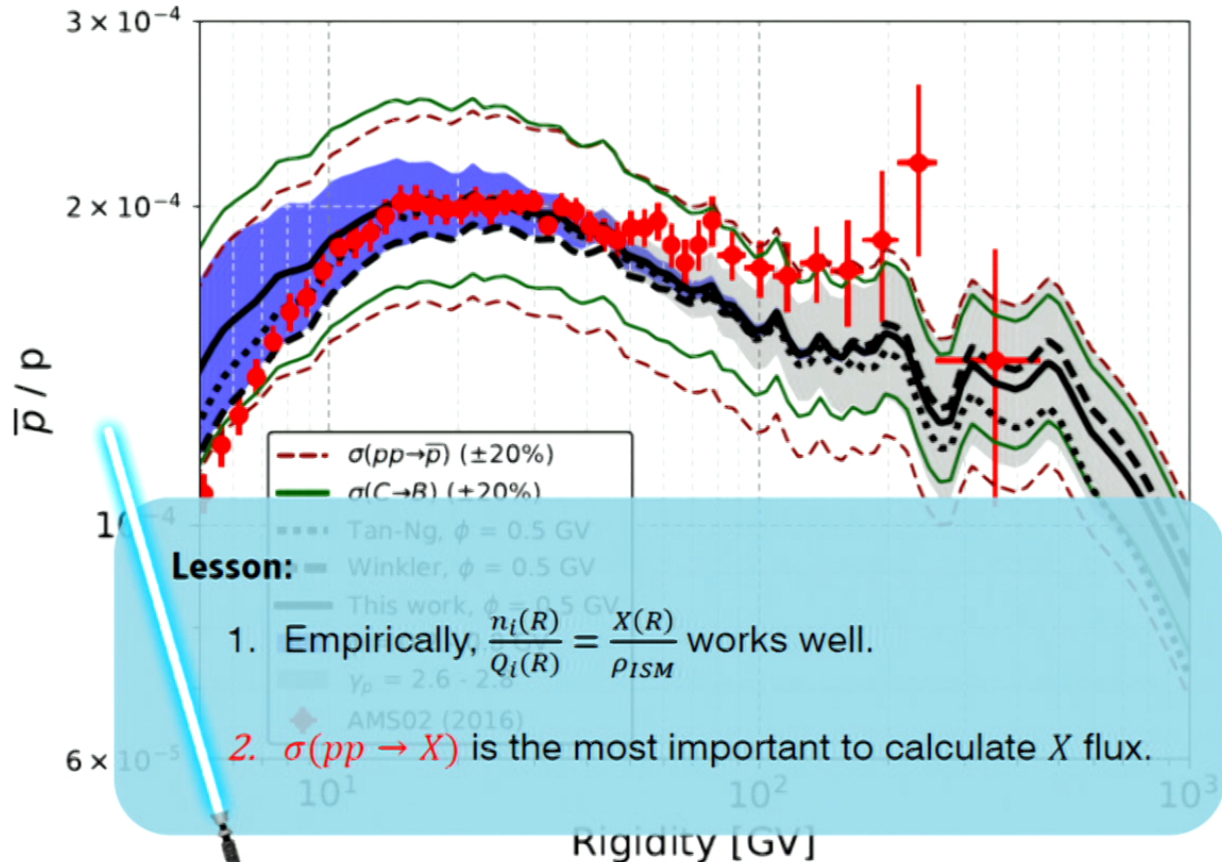
What we need are only B/C ratio and the cross sections!

Exercise : antiproton / proton ratio



[Blum, Sato, Takimoto(2017)]

Exercise : antiproton / proton ratio



Lesson:

1. Empirically, $\frac{n_i(R)}{Q_i(R)} = \frac{X(R)}{\rho_{ISM}}$ works well.
2. $\sigma(pp \to X)$ is the most important to calculate X flux.

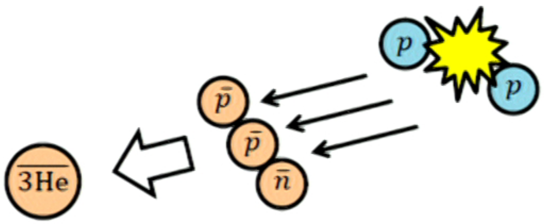
[Blum, Sato, Takimoto(2017)]

2. Cross sections for anti-deuteron, anti-Helium3

Cross section for nuclei production

Coalescence anzats (for nuclei production)

Nucleons (p, n) which travels (almost) same direction forms nuclei



$$E_A \frac{d^3\sigma_A}{dp^3} = B_A \left(E_N \frac{d^3\sigma_N}{dp^3} \right)^A_{p_N = p_N/A}$$

- B_A is (almost) independent on other parameters (e.g., $\sqrt{s}, p_t, \eta$).
- It is impossible to calculate B_A from first principle.
- B_A should be determined from the experiment.

How to get B_A?

$$B_A = E_A \frac{d^3\sigma_A}{dp^3} \Big/ \left[\left(E_N \frac{d^3\sigma_N}{dp^3} \right)^A_{p_N = \frac{p_N}{A}} \right]$$

Anti-deuteron

ISR (pp collision at $\sqrt{s}$ = 53 GeV) $B_2 \sim 10^{-2}\mathrm{GeV}^2$

Anti-Helium3

Anti-He3 measurement at proton-heavy ion, ion-ion collsion.
No pp collision data ! (I will discuss ALICE 7 TeV later.)

We need to extract B_3 from heavy ion collision experiment.

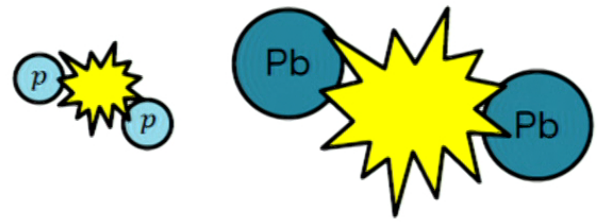
Volume scaling of B_A

[See e.g., Csernai and Kapusta (1986)]

Q : B_A at pp collision and B_A at heavy ion collision should be same?
A : No. It depends on the size of interaction region (fireball).

$$B_A \propto \rho^{A-1} \propto V^{-A+1}$$

ρ : number density of fireball
V : fireball volume



B_A in heavy ion collision $<$ B_A in pp collision

But, is there any way to measure the size of the fireball?

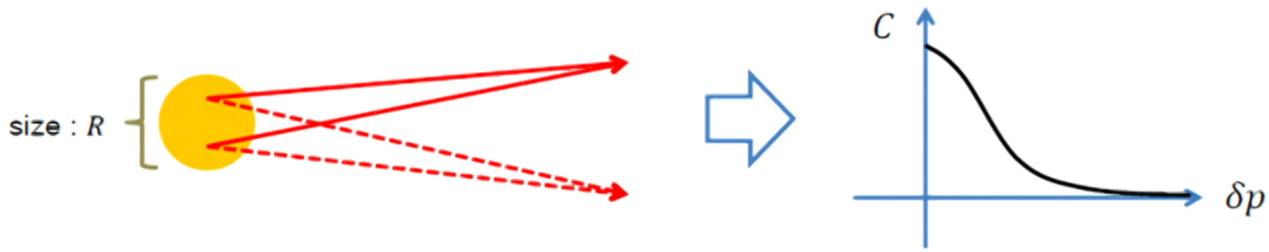
HBT measurement and emission volume

[Hanbury-Brown, Twiss (1954)]

How to measure the size of emission region.

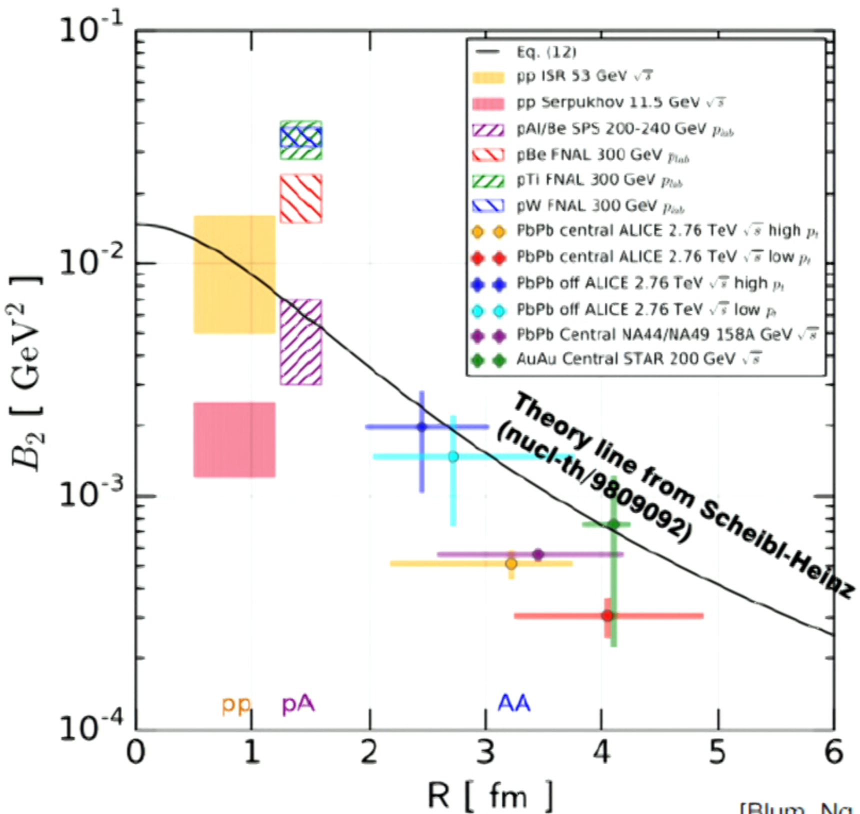
Correlation function of intensity fluctuation : $C = \langle \delta I(p_1) \delta I(p_2) \rangle$

$\delta p \gg 1/R$	different phase space (no interference)	$\rightarrow C = 0$
$\delta p <\sim 1/R$	same phase space (interference)	$\rightarrow C \neq 0$



Intensity corr. of $\pi^{\pm}, K^{\pm}, p, \bar{p}$ etc. at pp, pA, AA collision $\rightarrow$ size of fireball

Volume scaling of B_2 : anti-deuterium



[Blum, Ng, Sato, Takimoto(2017)]

Radius of fireball by HBT measurement

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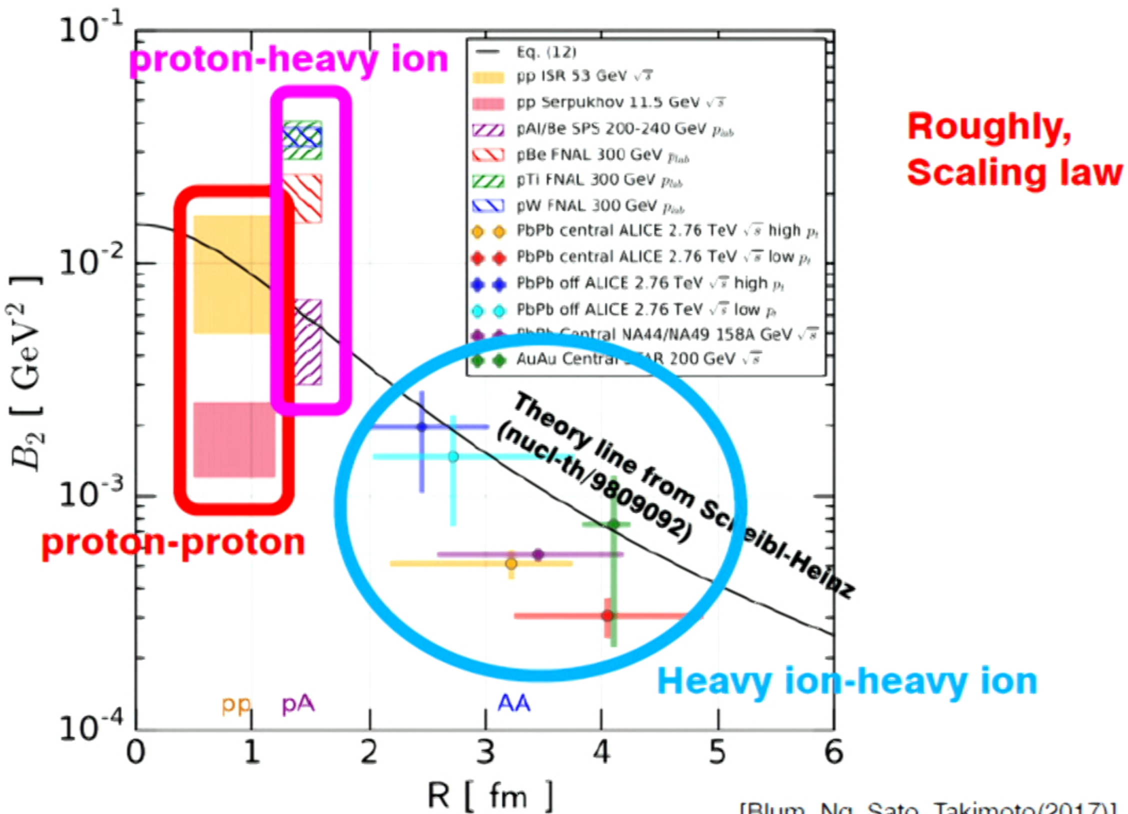
Volume scaling of B_2 : anti-deuterium

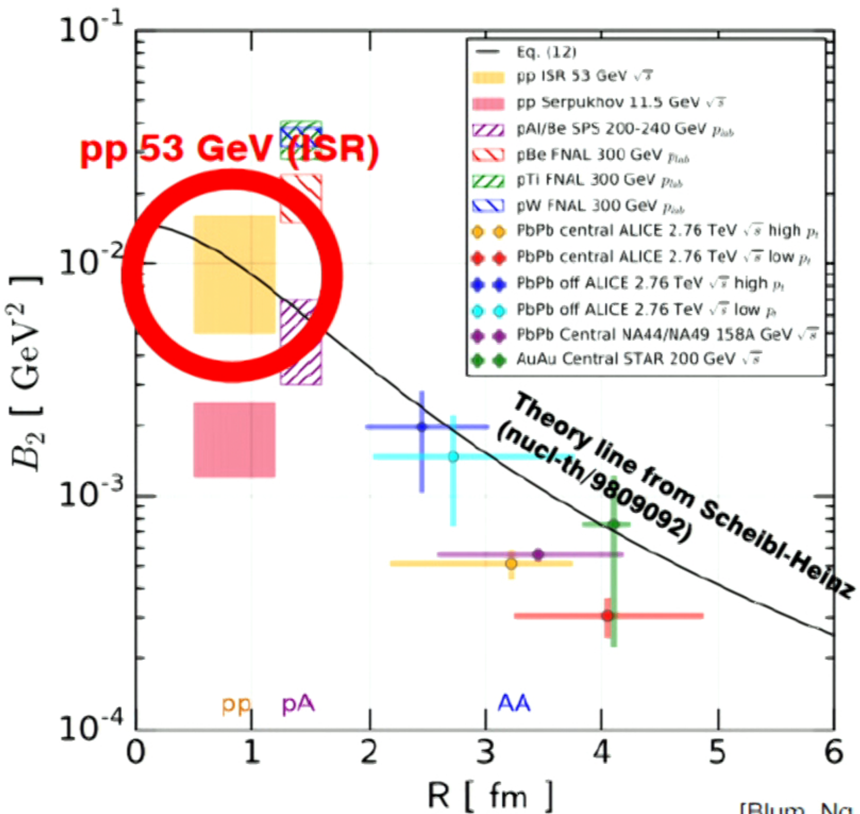


[Blum, Ng, Sato, Takimoto(2017)]

Radius of fireball by HBT measurement

Roughly,
Scaling law for B_2 works.

Radius measurement & anti-deuterium



[Blum, Ng, Sato, Takimoto(2017)]

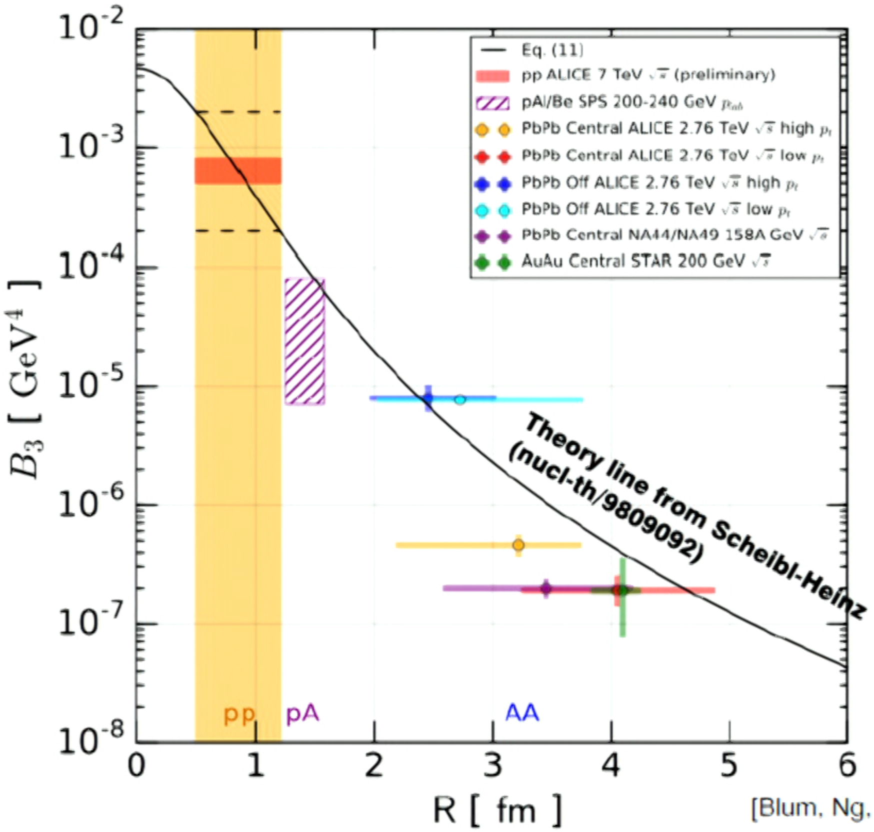
Radius of fireball by HBT measurement

Roughly,
Scaling law for B_2 works.

In our analysis for anti-d,
We use ISR 53 GeV data:

$$B_2 \approx (0.5 - 1.6) \times 10^{-2}\mathrm{GeV}^2$$

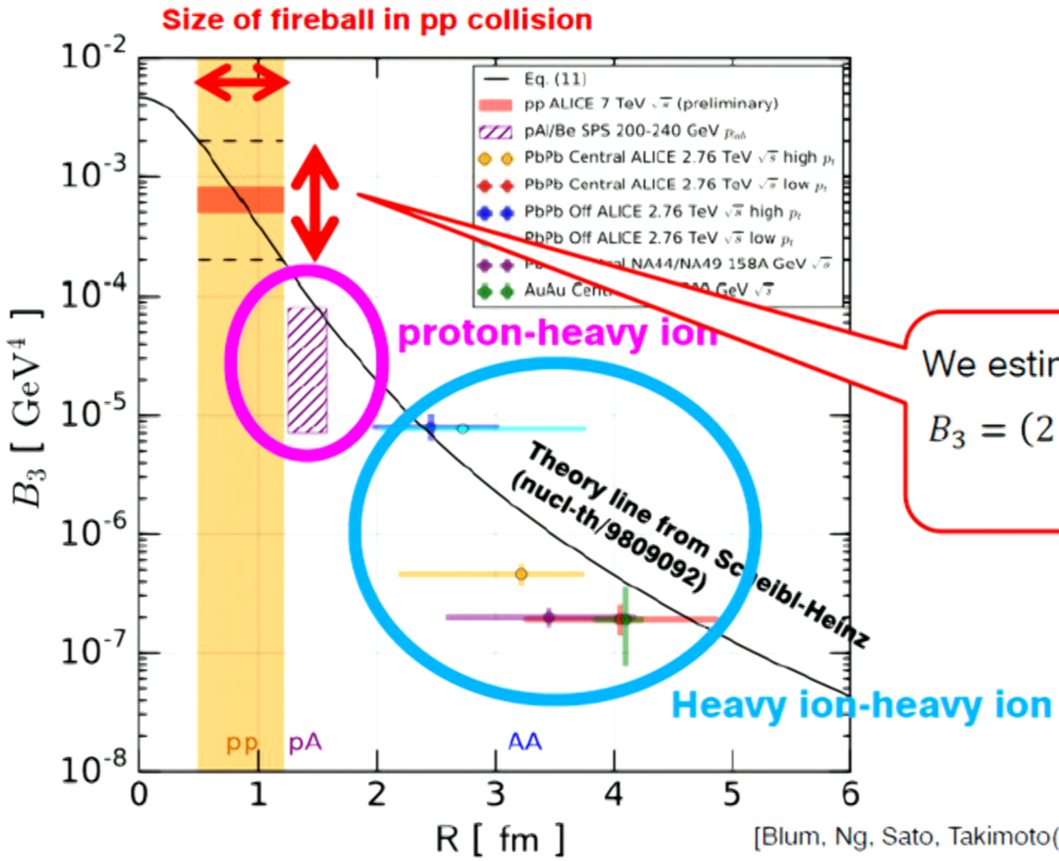
Volume scaling of B3 : anti-Helium 3



[Blum, Ng, Sato, Takimoto(2017)]

Radius of fireball by HBT measurement

Volume scaling of B3 : anti-Helium 3



We estimate

$B_3 = (2 - 20) \times 10^{-4}\ \mathrm{GeV}^4$

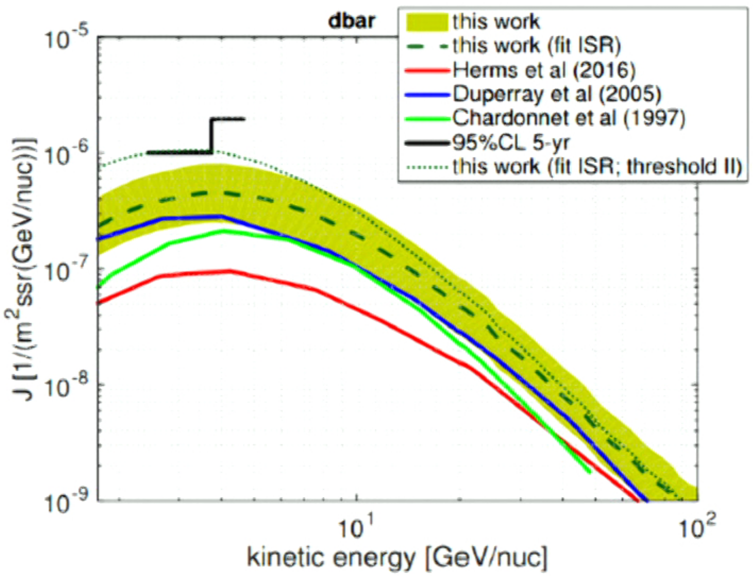
for pp collision

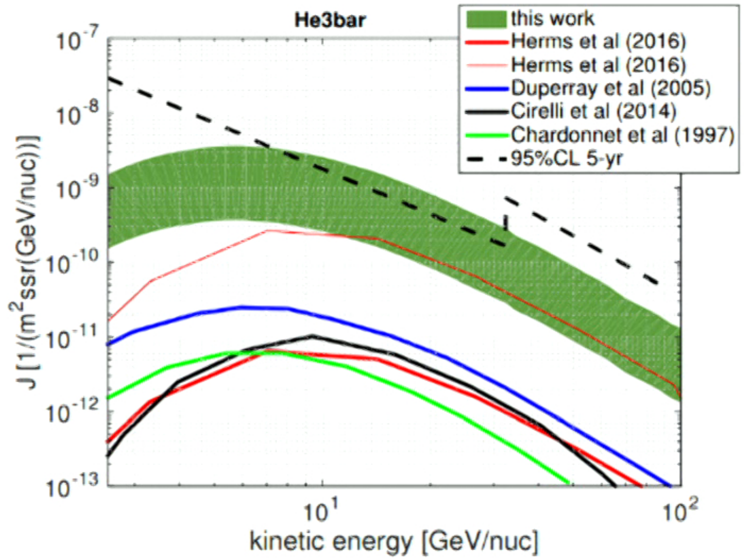
[Blum, Ng, Sato, Takimoto(2017)]

Radius of fireball by HBT measurement

Antimatter flux

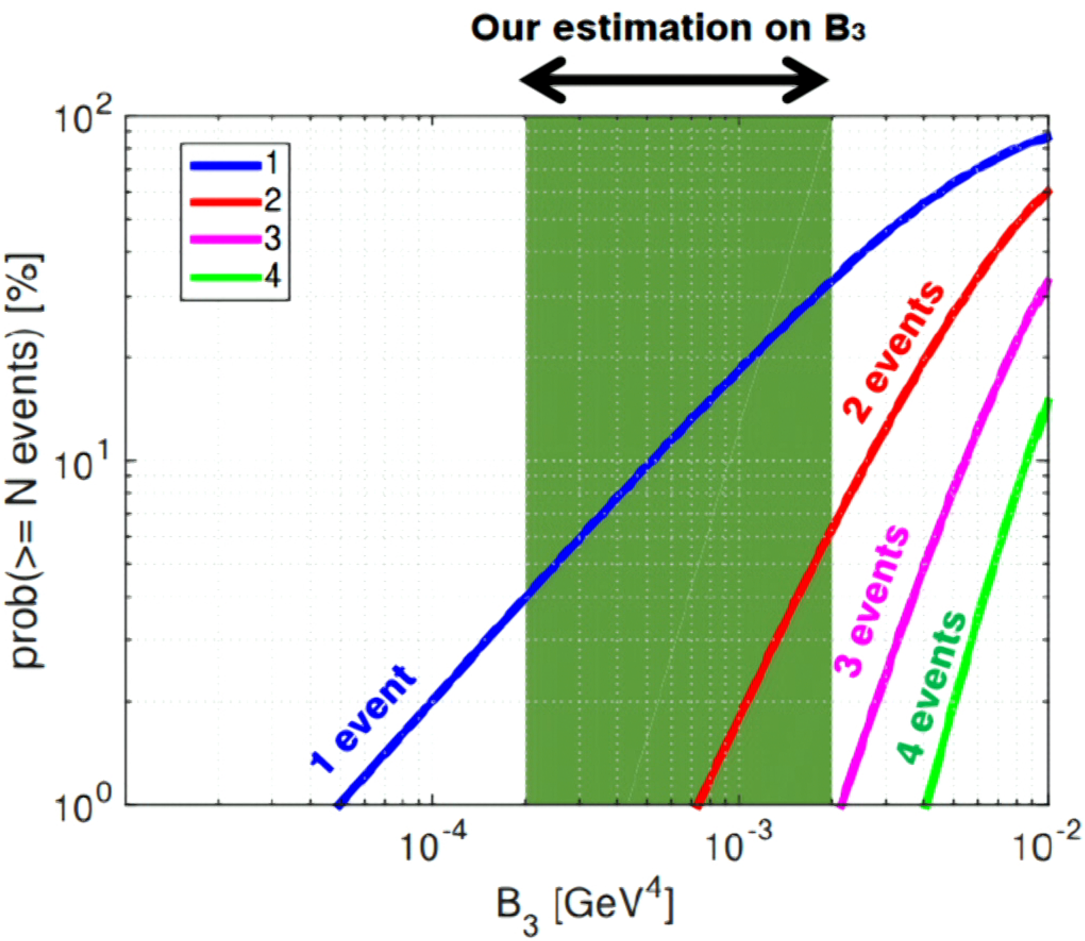
[Blum, Ng, Sato, Takimoto(2017)]





Chardonnet 1997	: p_c which is derived from d for He3. using different $pp \to \bar{d}X$ data.
Duperray 2005	: B parameter from pA/AA collisions.
Cirelli 2014	: PYTHIA
Ibarra-Wild 2012	: PYTHIA & DPMJET-III
Herms 2016	: PYTHIA & DPMJET-III

Number of anti-Helium3 events at AMS-02 5 yrs

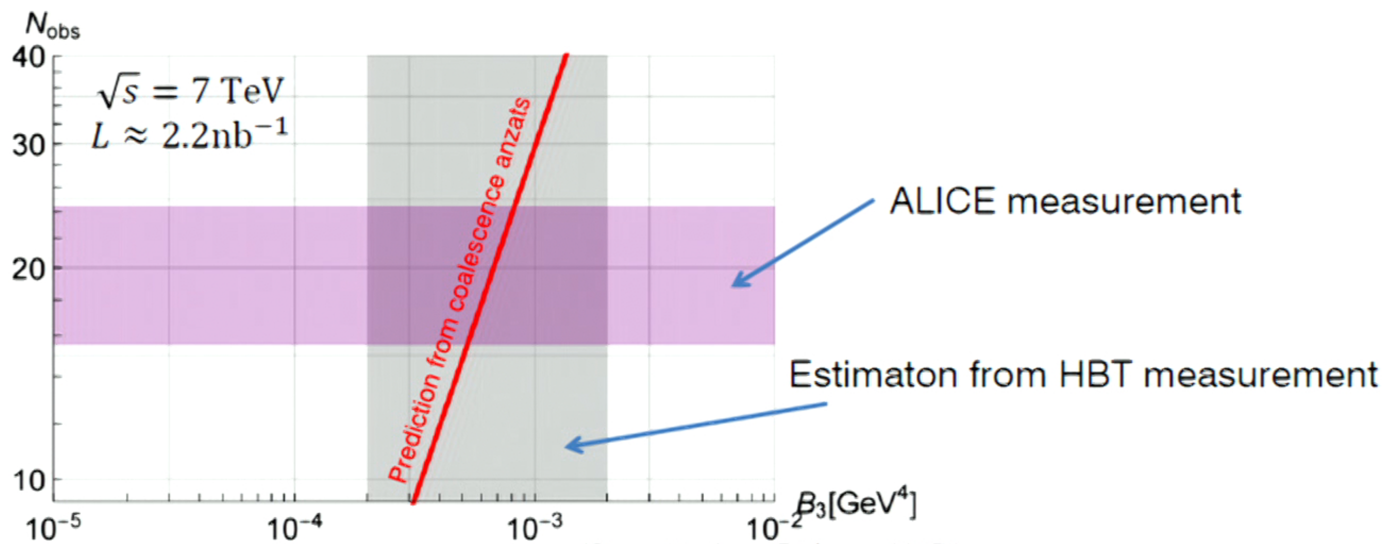


Anti-Helium3 at the LHC

We estimated $B_3(pp)$ from $B_3(AA)$. Direct measurement on $B_3(pp)$?

ALICE preliminary analysis (1109.4836) says,...

The raw spectra of $d(\bar{d})$, $t(\bar{t})$, and $^3He(^3\overline{He})$ are obtained for pp collisions at $\sqrt{s} = 7$ TeV and for Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. We observed about 20k antideuterons, 20 antitritons, and 20 $^3\overline{He}$ candidates for the pp collisions collected in 2010.



[Blum, Ng, Sato, Takimoto(2017)]

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Summary

Secondary production of anti-d and anti-He3 is reconsidered

Coalescence parameter of pp collision should be smaller than AA

Astrophysical antiHe3 could be within the reach of 5-yr AMS-02

Stay tuned for official AMS-02 paper.

We need direct measurement on B_3!

To calculate antinuclei flux coalescence parameter B_A is the most important.
ALICE and LHCb could be important to measure B_3.

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