Secondary production of Cosmic ray anti-Helium3

Ryosuke Sato (Weizmann Institute of Science)

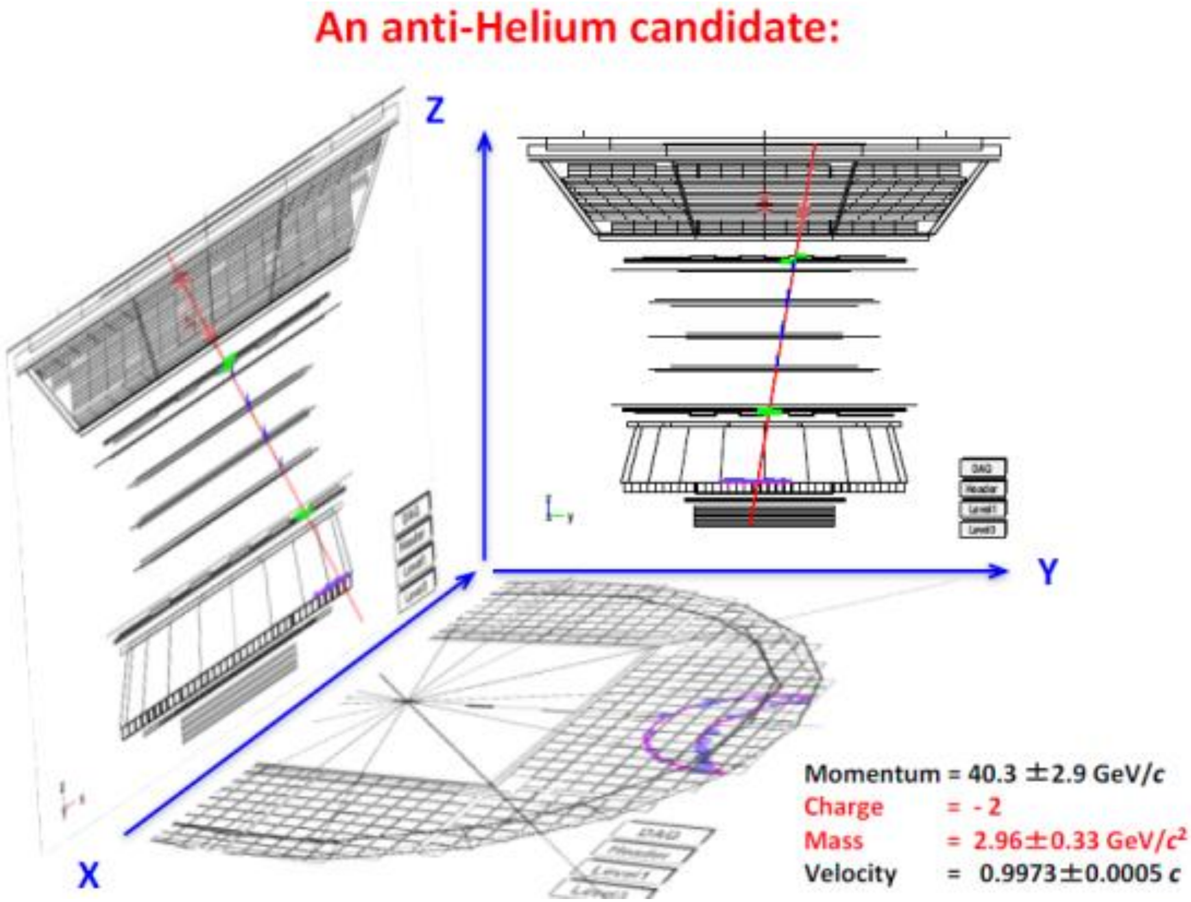
based on arXiv:1704.05431[astro-ph.HE]
Kfir Blum, Kenny C.Y. Ng, RS, Masahiro Takimoto

2017. 8. 9 @ TeVPA 2017

AMS-02 observed Anti-Helium3?

In 2016 Dec, AMS-02 announced,

"we have observed a few events with Z=-2 and with mass around 3He."



[taken from S. Ting's slide]

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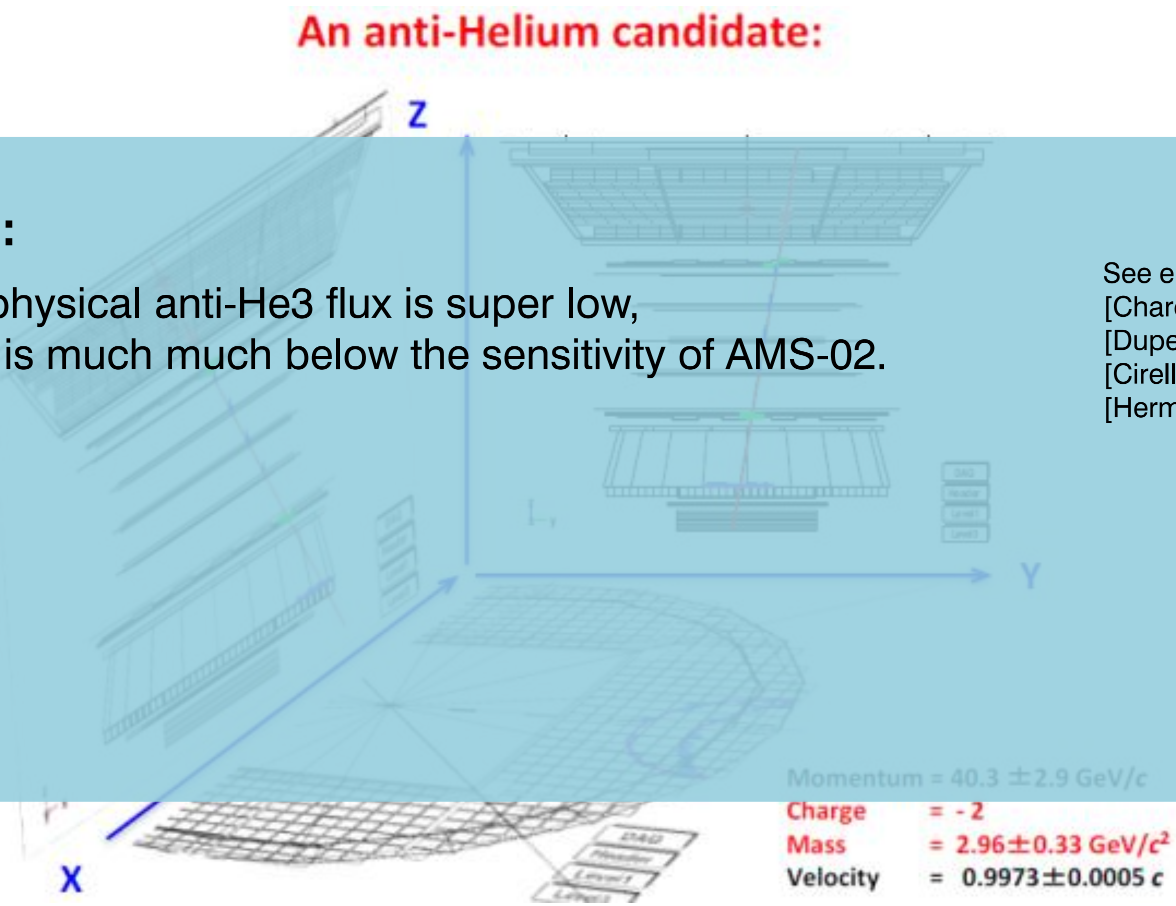

Folklore :

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)]
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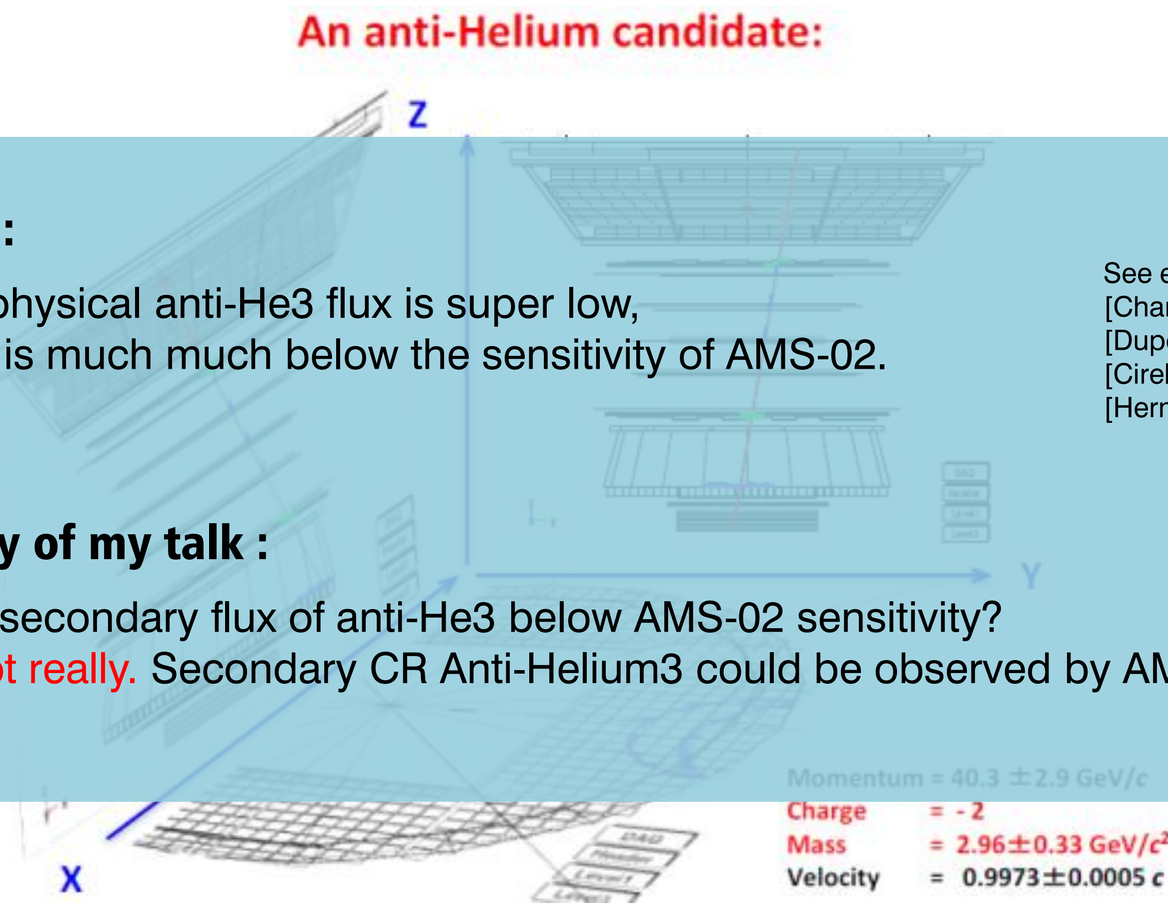

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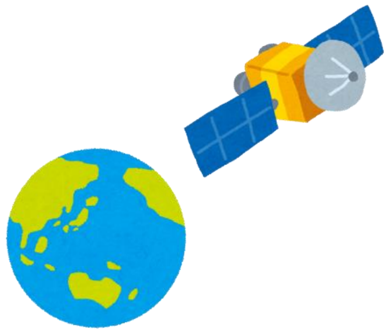
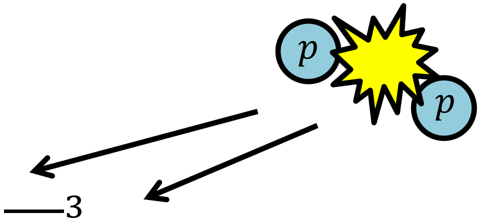
Summary of my talk :

Q : Is secondary flux of anti-He3 below AMS-02 sensitivity?
A : Not really. Secondary CR Anti-Helium3 could be observed by AMS-02.

[taken from S. Ting’s slide]

Secondary production in our galaxy





$e^{+}, \bar{p}, \bar{d}, \overline{He}^{3}, \ldots$

$$\frac{n_{\overline{He^3}}}{n_p} = \frac{X_{esc}/m}{1 + \left(n_{\overline{He^3}}/n_p\right)\sigma_{\overline{He^3}}/m} \times \sigma_{pp\to\overline{He^3}}$$

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

$\sigma_{\overline{He^3}}$: fragmentation cross section of antihelium3

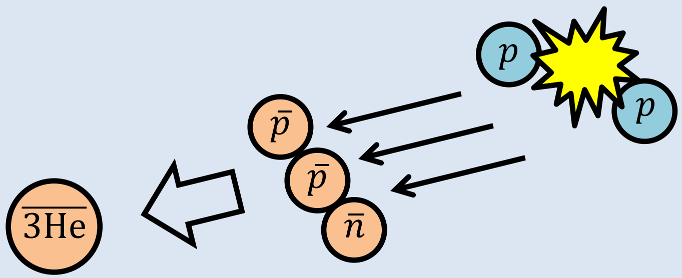
$X_{esc}(R)$ is determined from Boron-Carbon ratio.

The production cross section is important!

Cross section for nuclei production

Coalescence anzats :

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., $\sqrt{s}, p_t, \eta$).
- B_A should be determined from the experiment.

Anti-deuteron : ISR (pp collision at $\sqrt{s} = 53$ GeV)

Anti-Helium3 : No pp collision data ! (except for ALICE 7 TeV preliminary result)
Heavy ion collision gives information.

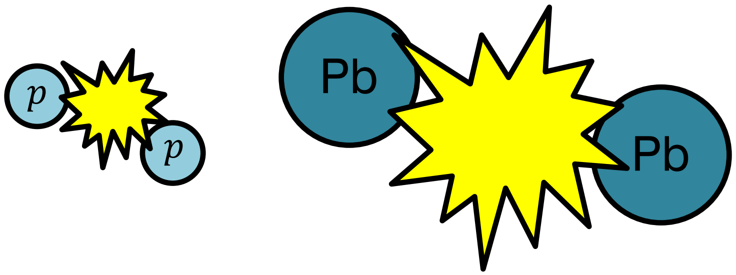
Volume scaling of B_A

[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).

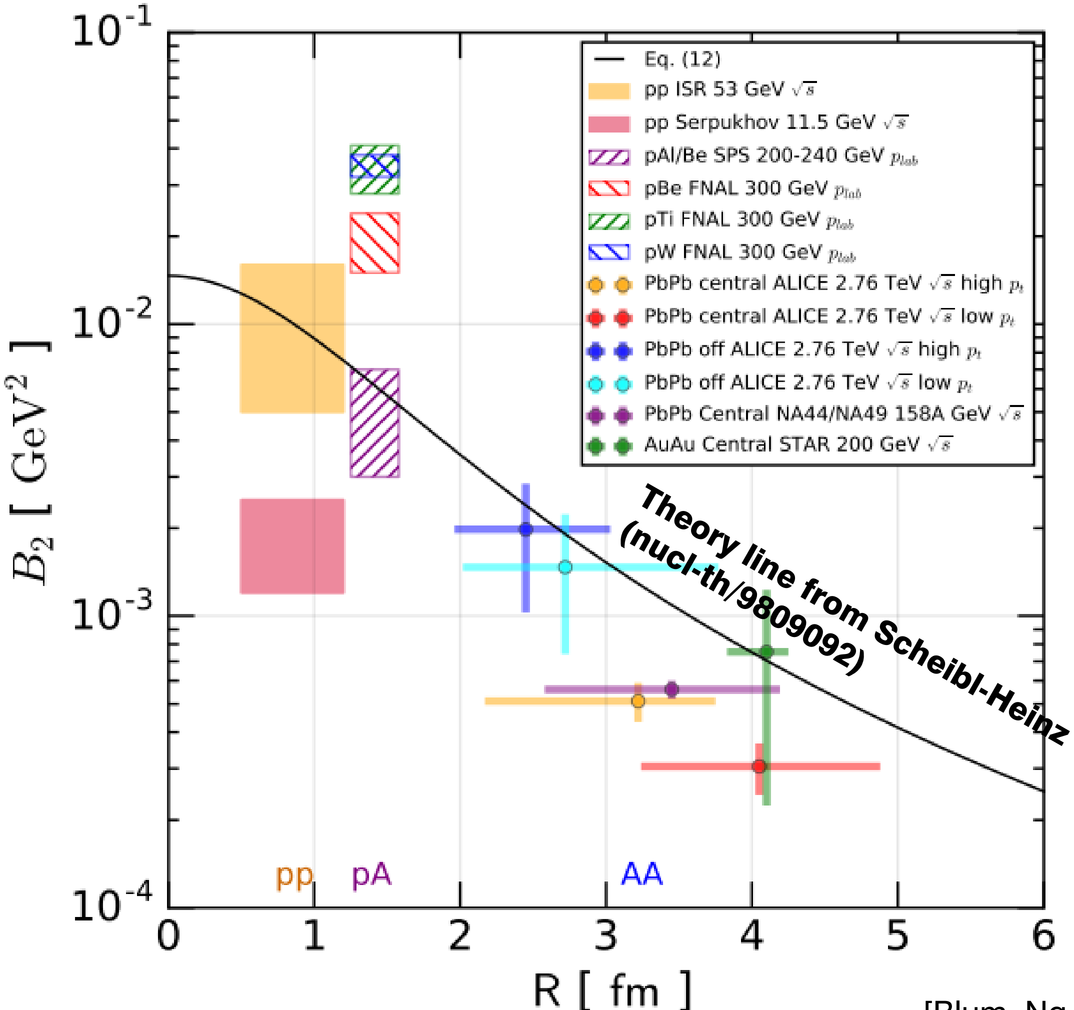
$$B_A \propto \rho^{A-1} \propto V^{-A+1}$$

ρ : number density of fireball
V : fireball volume



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

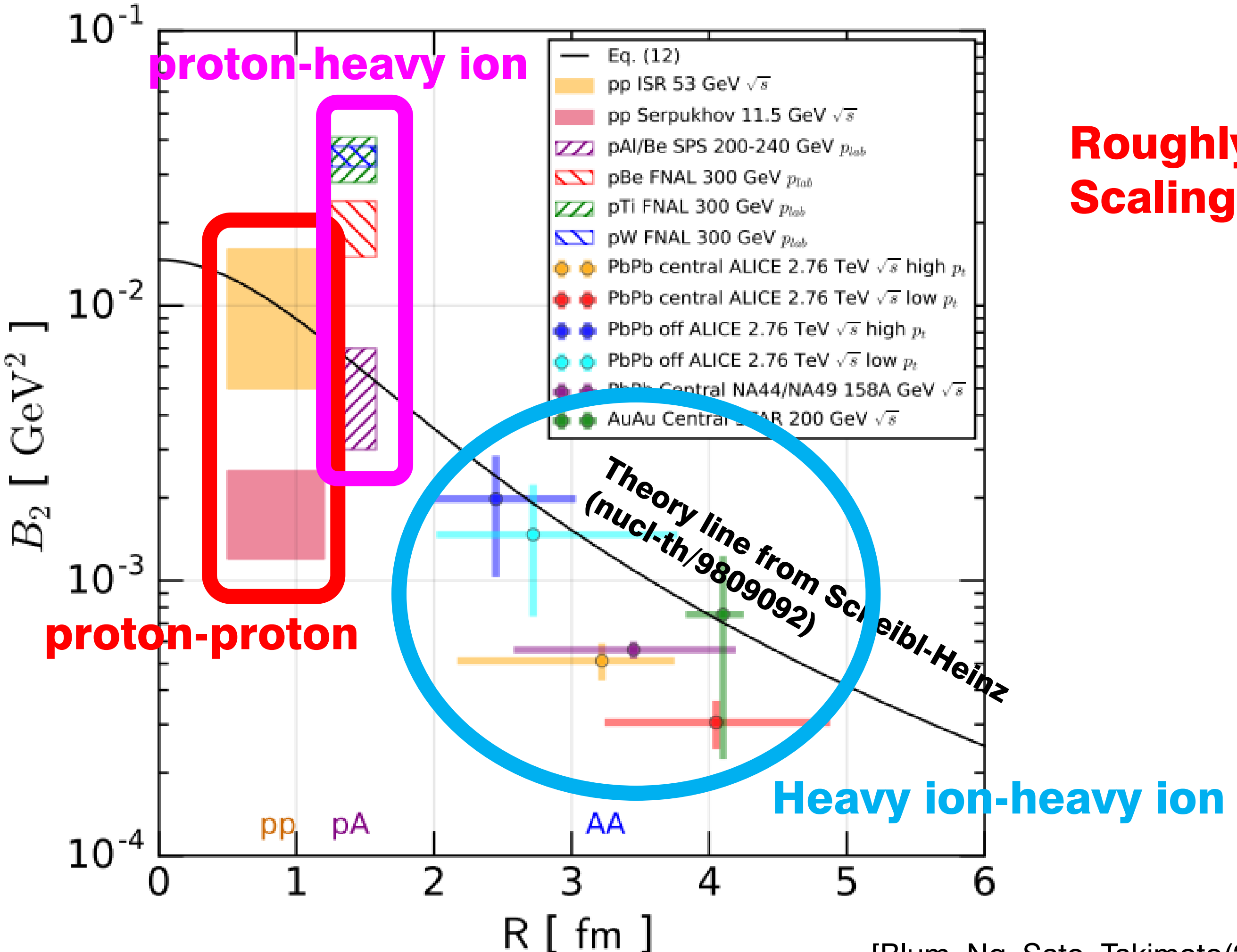
Volume scaling of B_2 : anti-deuterium



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

Radius of fireball by HBT measurement

Volume scaling of B_2 : anti-deuterium

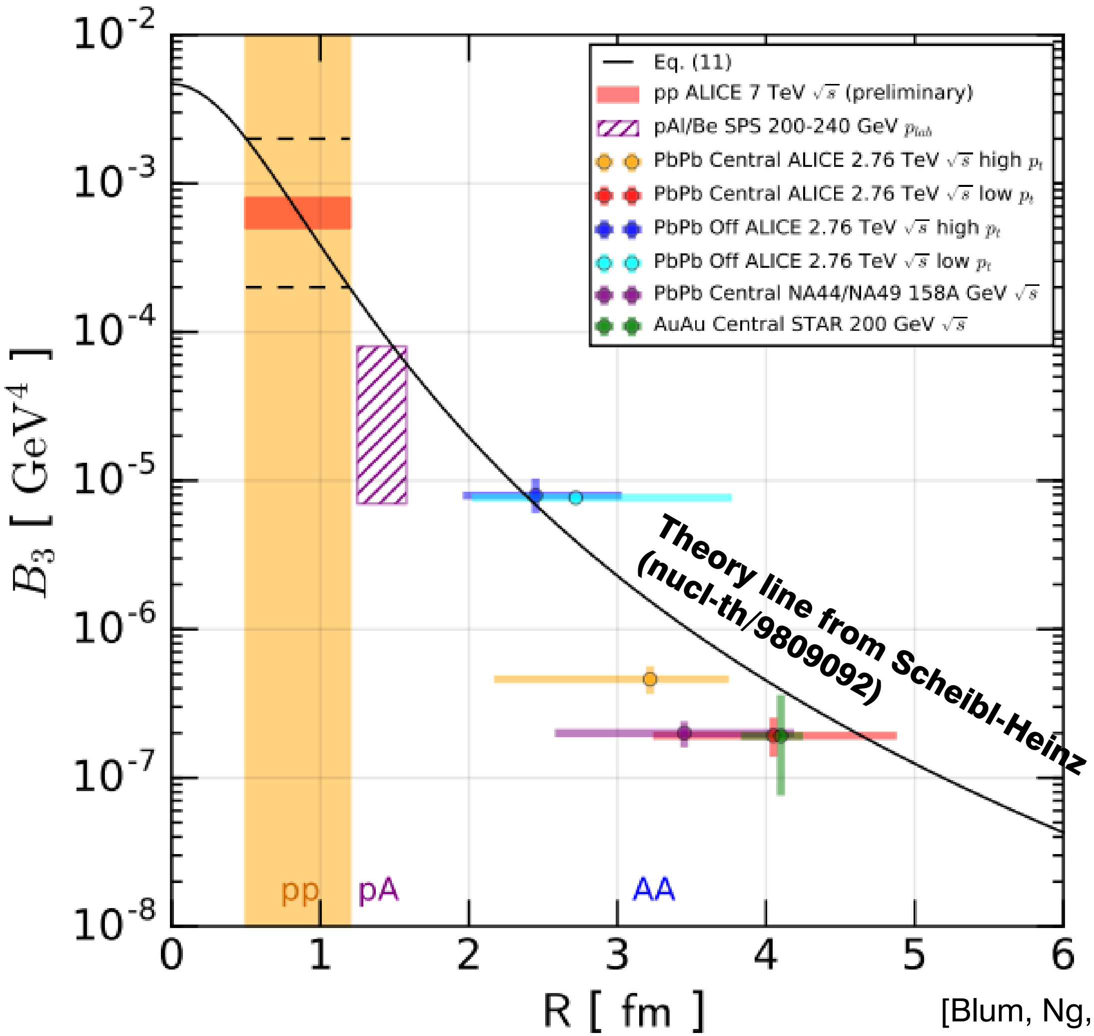


Roughly,
Scaling law for B_2 works.

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

Radius of fireball by HBT measurement

Volume scaling of B_3 : anti-Helium 3



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

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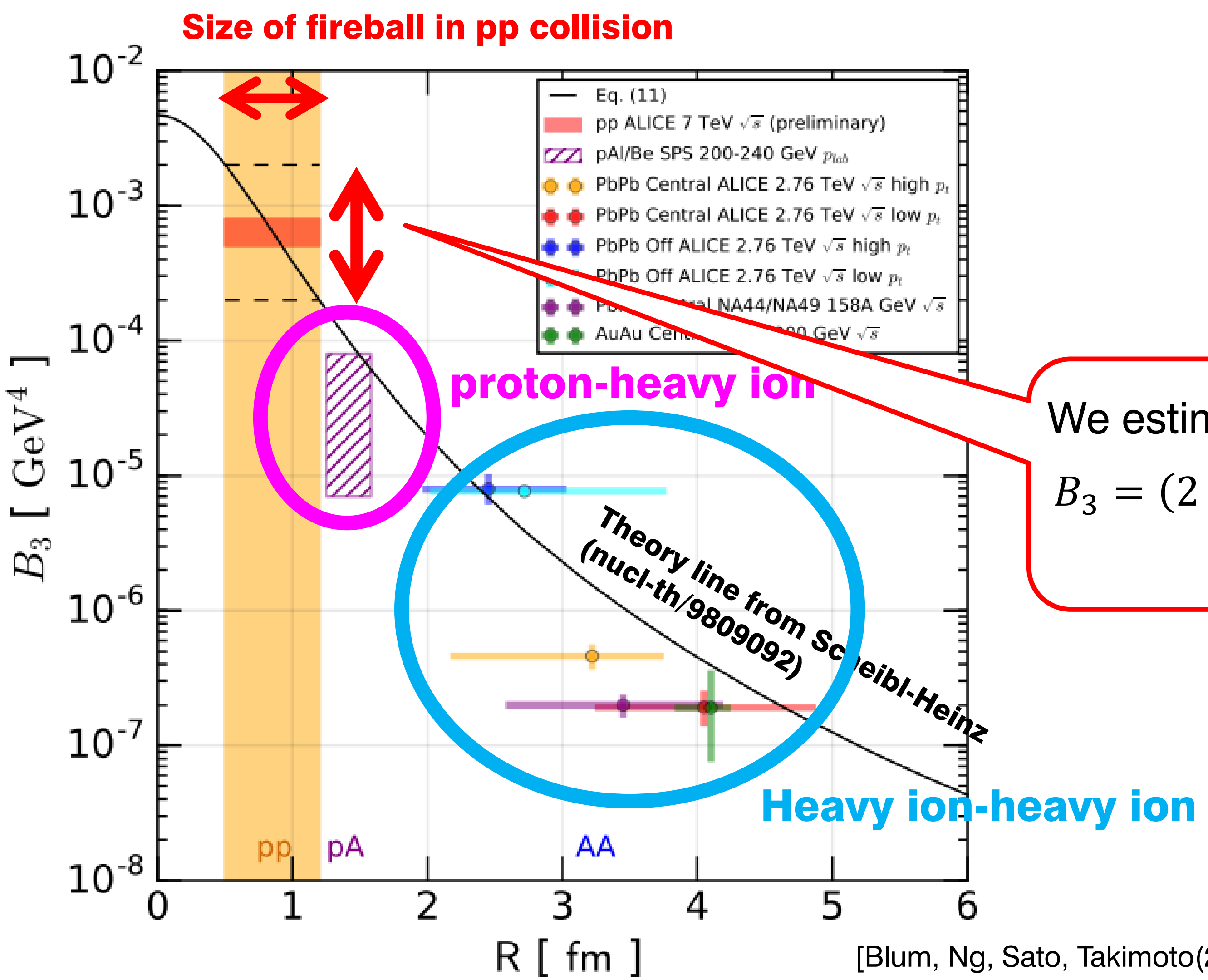


We estimate

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

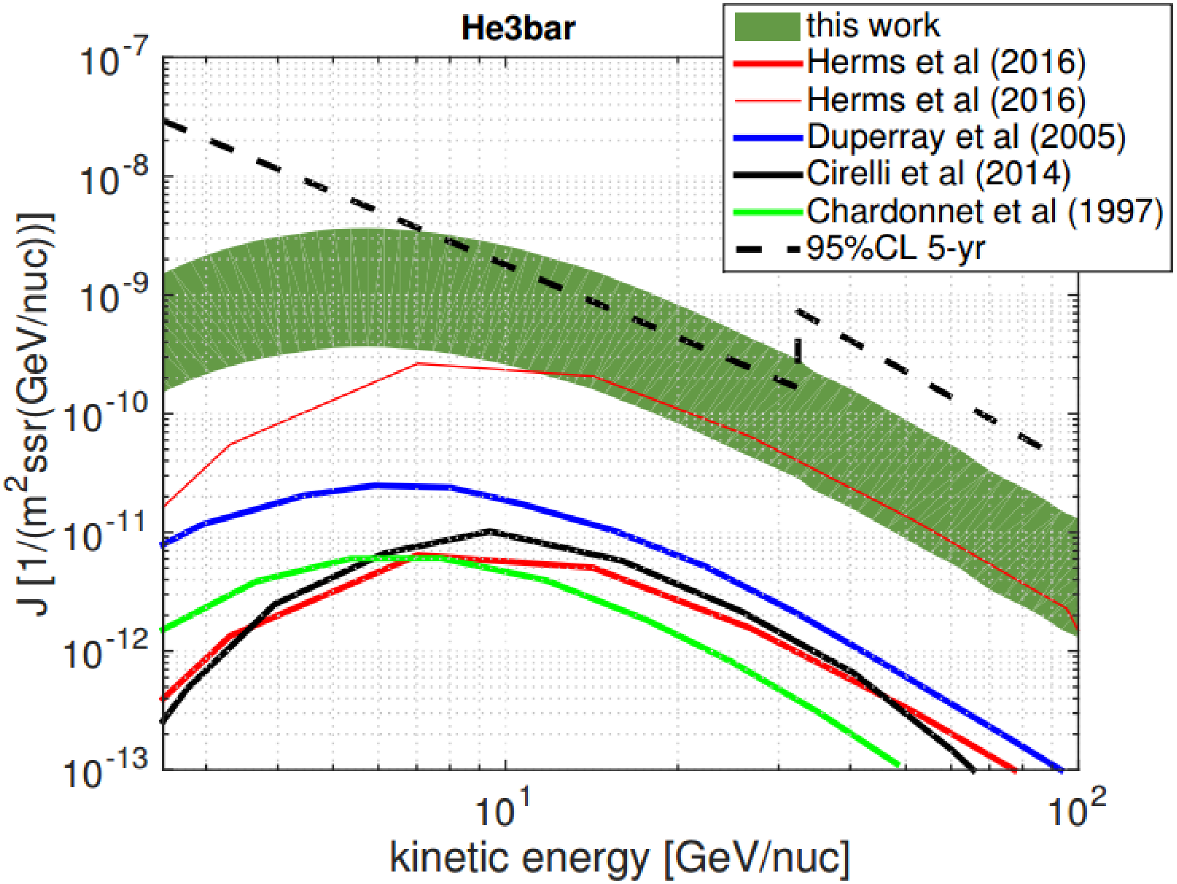
for pp collision

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

Radius of fireball by HBT measurement

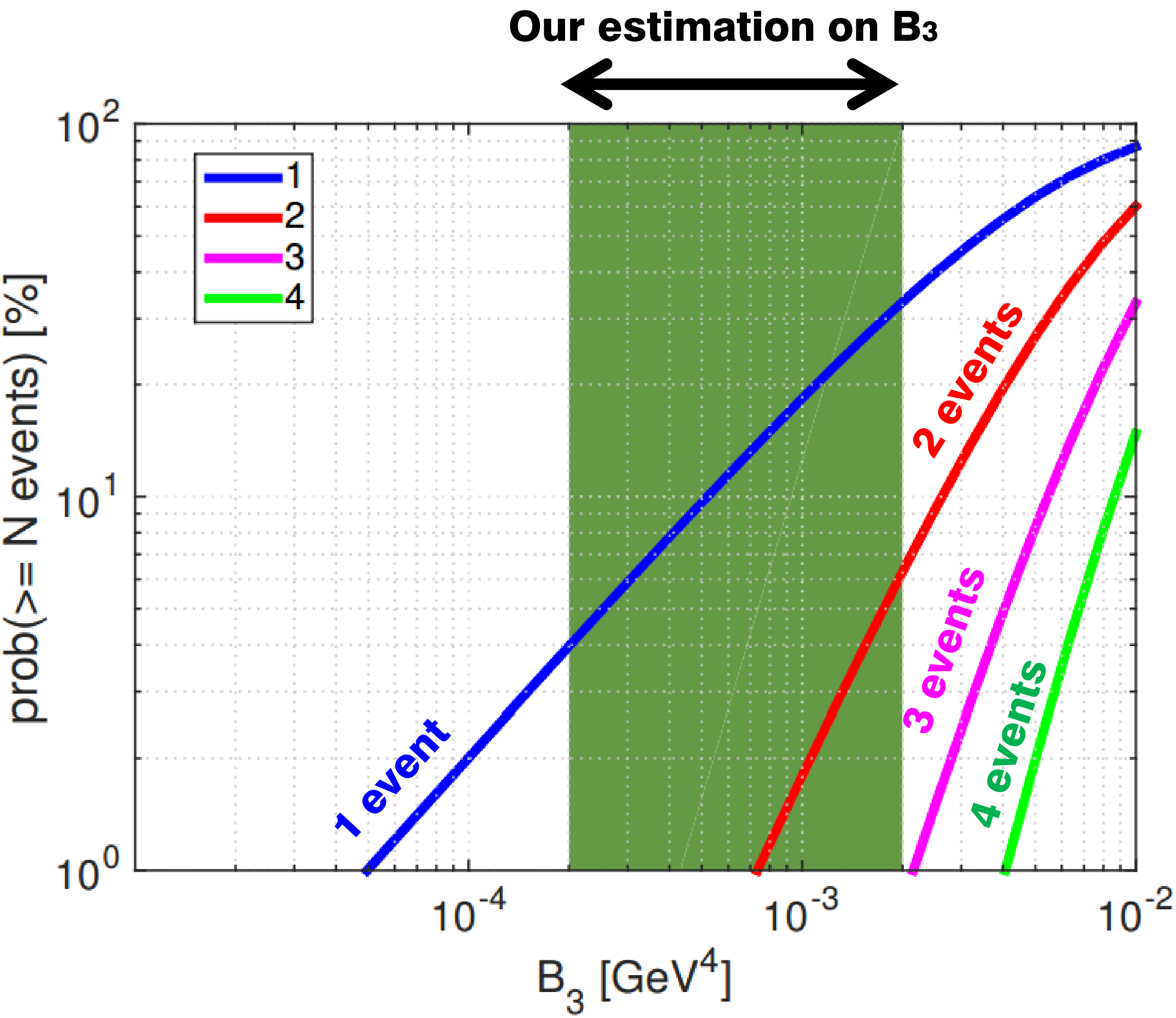
Anti-Helium3 flux

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



Chardonnet 1997 : p_c which is derived from d for $\mathrm{He3}$. 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



Summary

Secondary production of 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.

Backup

HBT measurement and emission volume

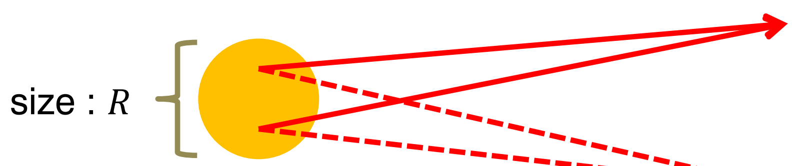
[Hanbury-Brown, Twiss (1954)]

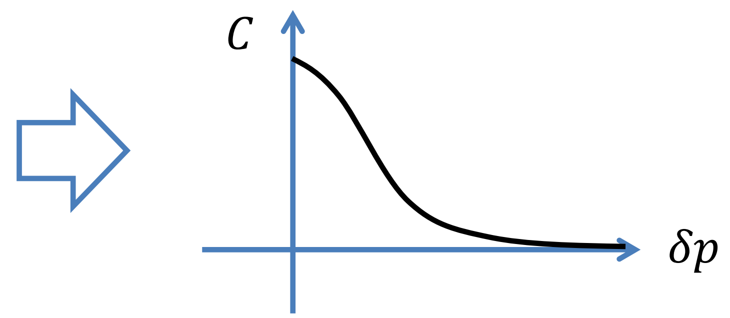
How to measure the size of emission region.

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) $\rightarrow C \neq 0$

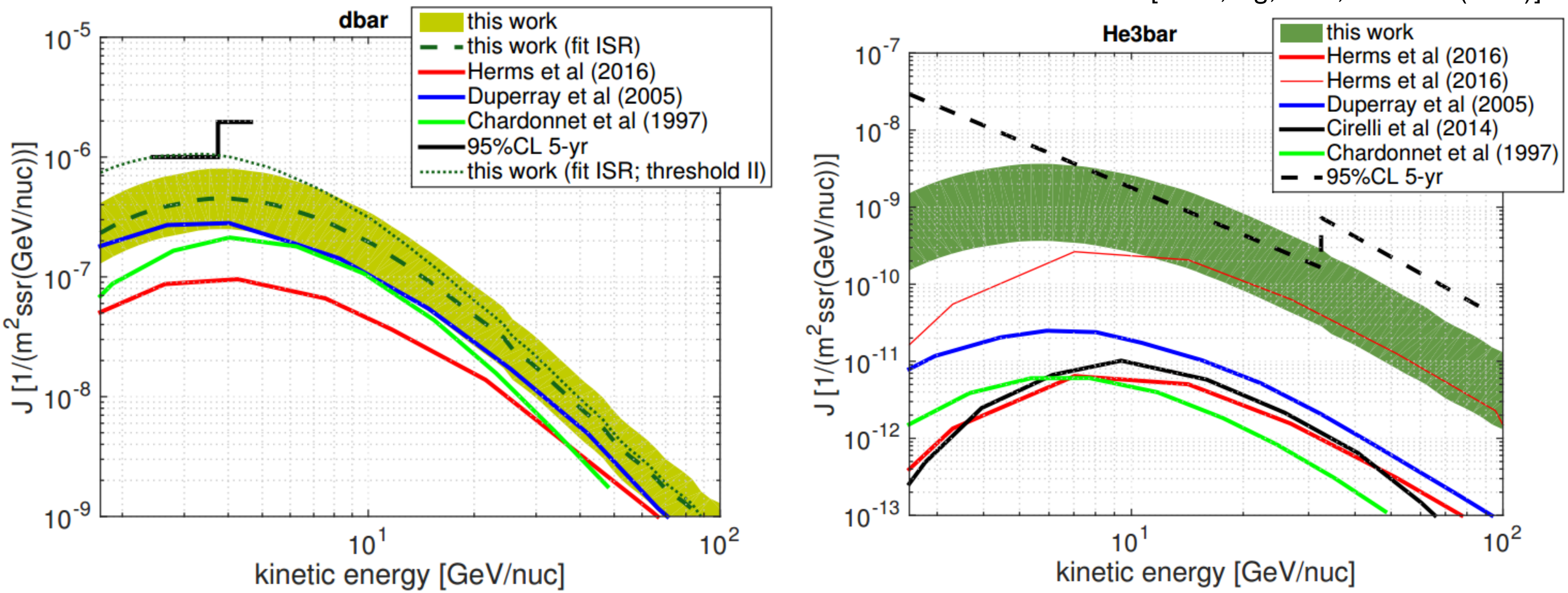




Intensity corr. of $\pi^{\pm}, K^{\pm}, p, \bar{p}$ etc. at pp, pA, AA collision $\rightarrow$ size of fireball

Antimatter flux

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



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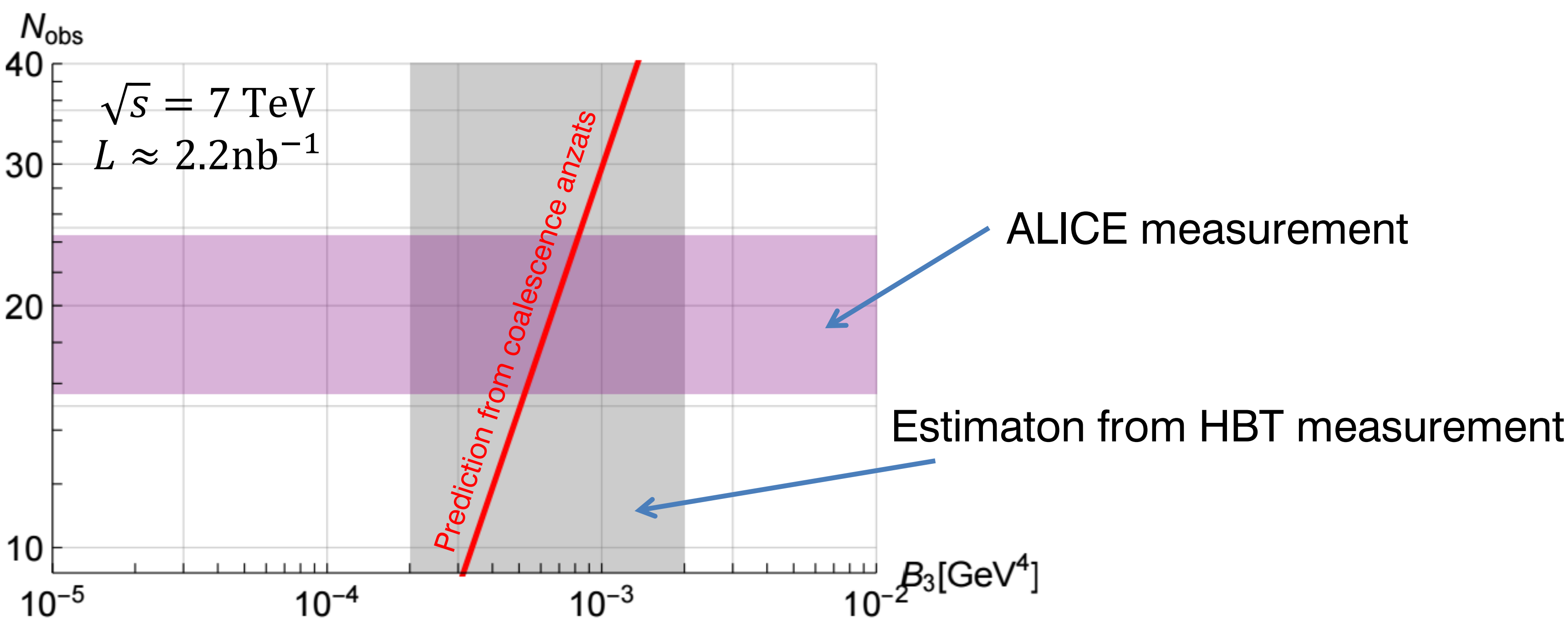
Anti-Helium3 at the LHC

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



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

Volume scaling

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

Non-relativistic case

$$W(p,x) = (2\pi)^3 \frac{d^6N}{dx^3dp^3} \quad \Rightarrow \quad W(p,x) = \frac{(2\pi)^3}{V}\frac{d^3N}{dp^3}$$

If we can neglect the size of particles,

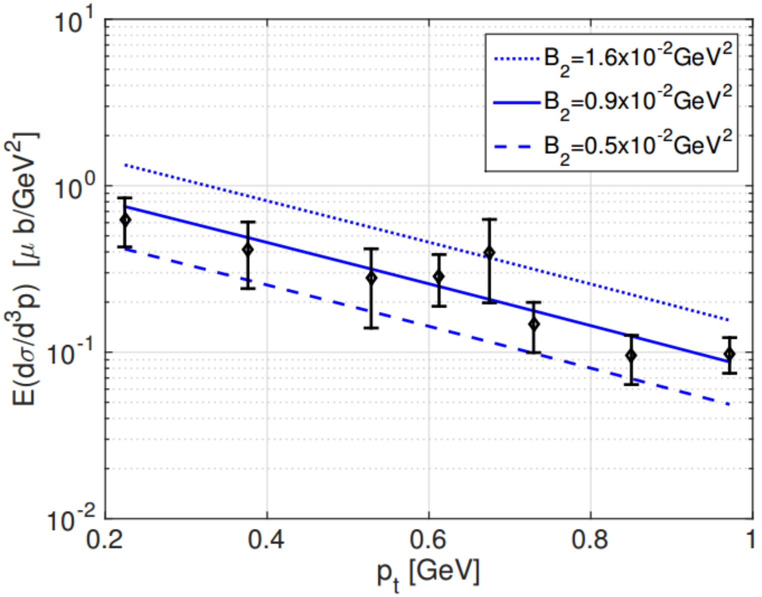
$$W(p,x) = c\big(W_p(p/A,x)\big)^Z\big(W_p(p/A,x)\big)^N$$

$$\Downarrow$$

$$\frac{d^3N}{dp^3} = c\left(\frac{(2\pi)^3}{V}\right)^{A-1}\left(\frac{d^3N}{dp^3}\right)^Z\left(\frac{d^3N}{dp^3}\right)^N$$

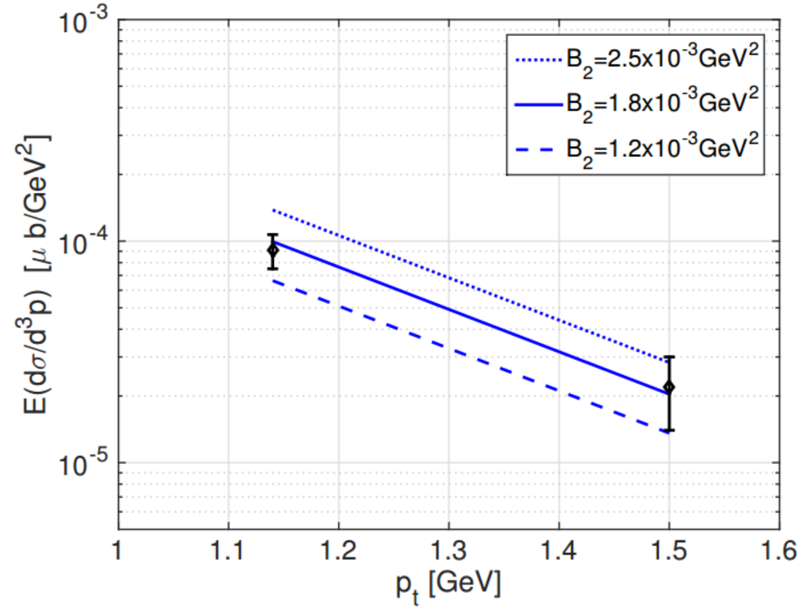
Anti-d observation at pp collision

ISR (1970's)



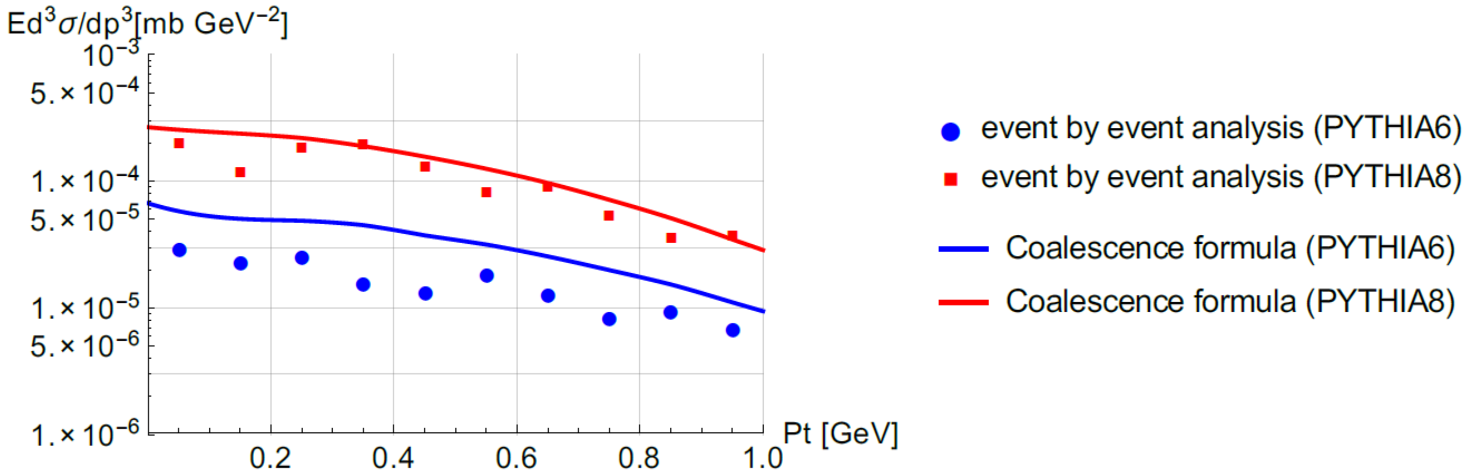
- $\sqrt{s} = 53$ GeV
- $p_t < 1$ GeV
- $B_2 \approx 0.9 \times 10^{-2}\text{GeV}^2$

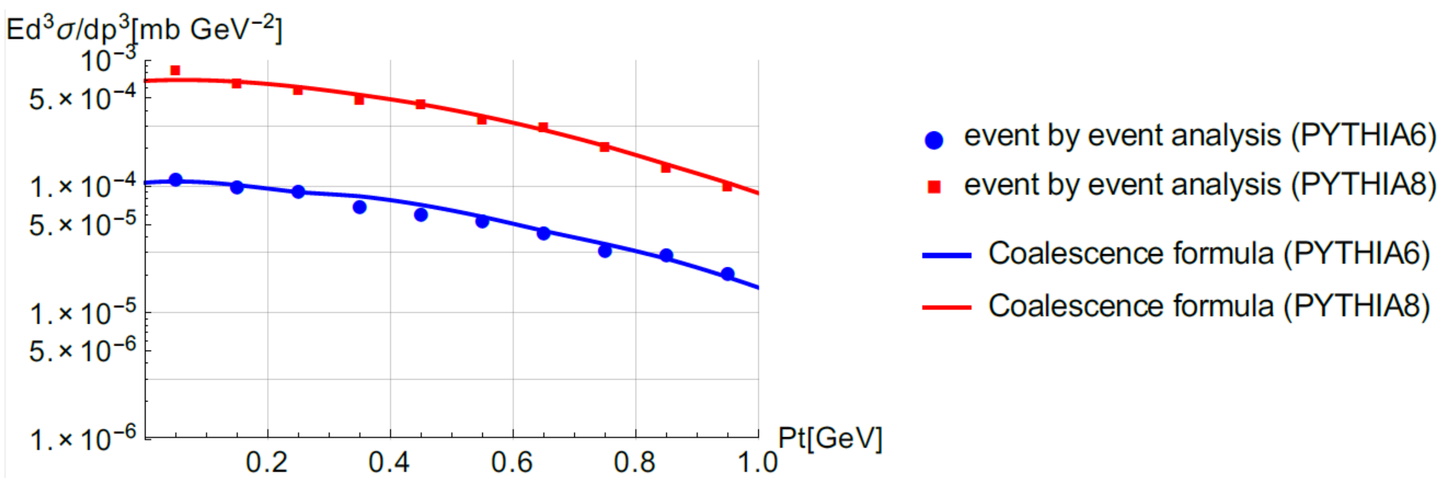
Serpukhov (1987)



- $\sqrt{s} = 11.6$ GeV
- $p_t > 1$ GeV
- $B_2 \approx 0.18 \times 10^{-2}\text{GeV}^2$

Pythia versus Coalescence formula





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

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

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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universal for all elements (function of R)

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

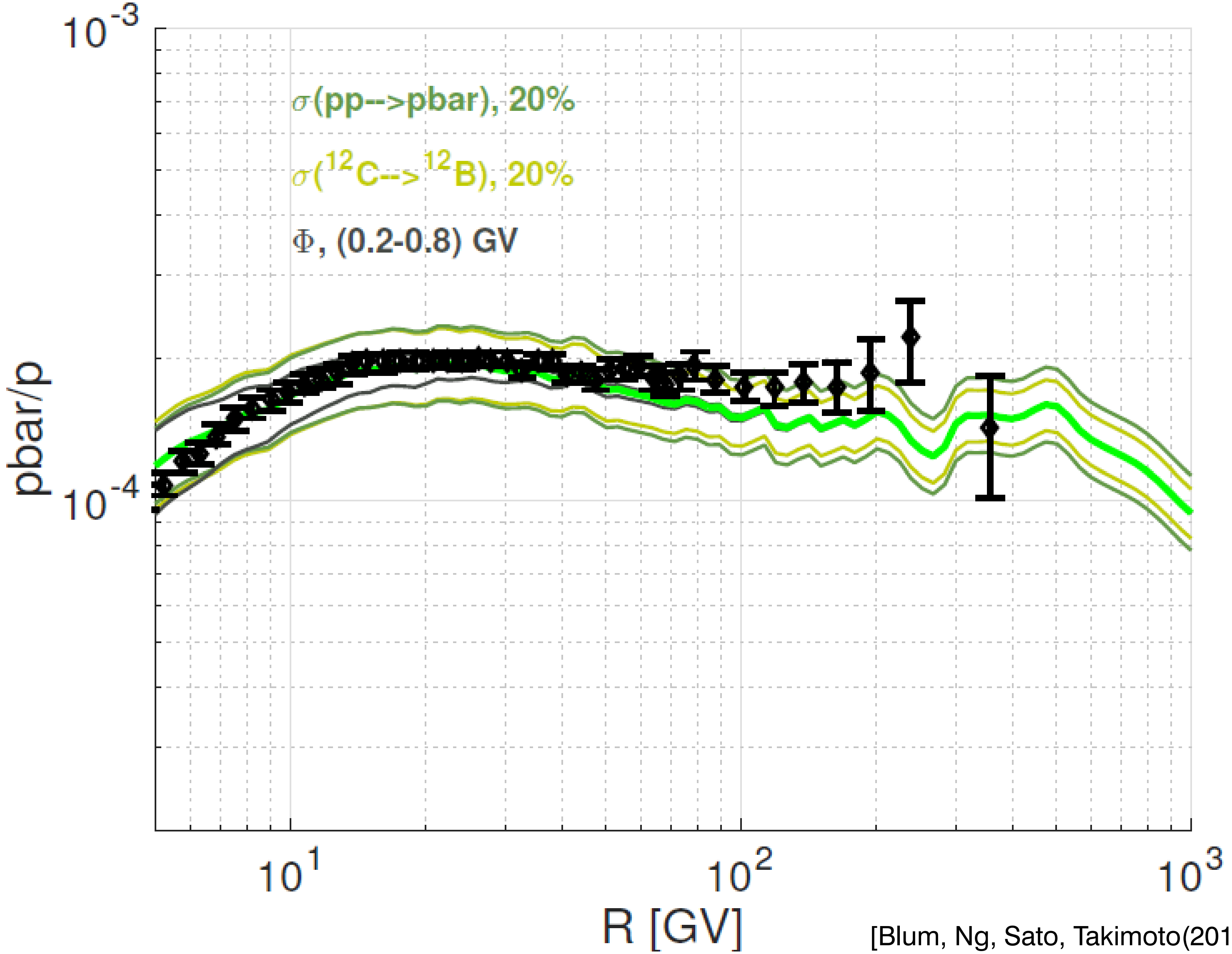
We can define $X_{esc}(R)$ $[g/cm^2]$ such that

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

This relation is

- model-independent relation.
- supported by the measurement of stable nuclei. [Webber, McDonald, Lukasiak (2003)]

Exercise : antiproton / proton ratio



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