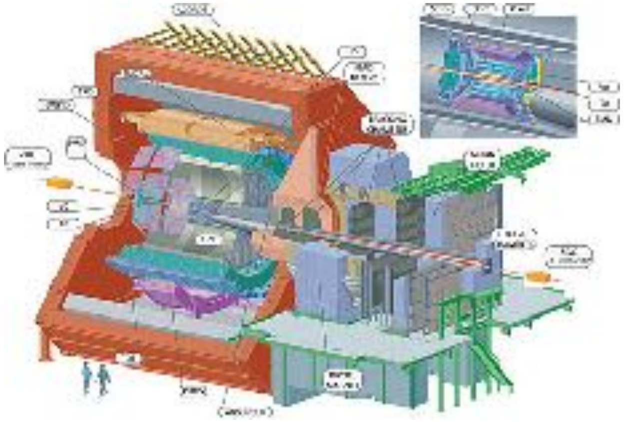
Antimatter Cosmic Rays (and the search for dark matter)

1704.05431, 1709.04953, 1709.06507

Kfir Blum
CERN & Weizmann Institute



GGI, Oct 13 2017

CR antimatter – $\bar{p}$, e^{+}, $\bar{\mathrm{d}}$, and $\overline{^{3}\mathrm{He}}$ – long thought a smoking gun of exotic high-energy physics like dark matter annihilation

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A host of experiments out there to detect it.

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Antiprotons

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=> will try to sort this out

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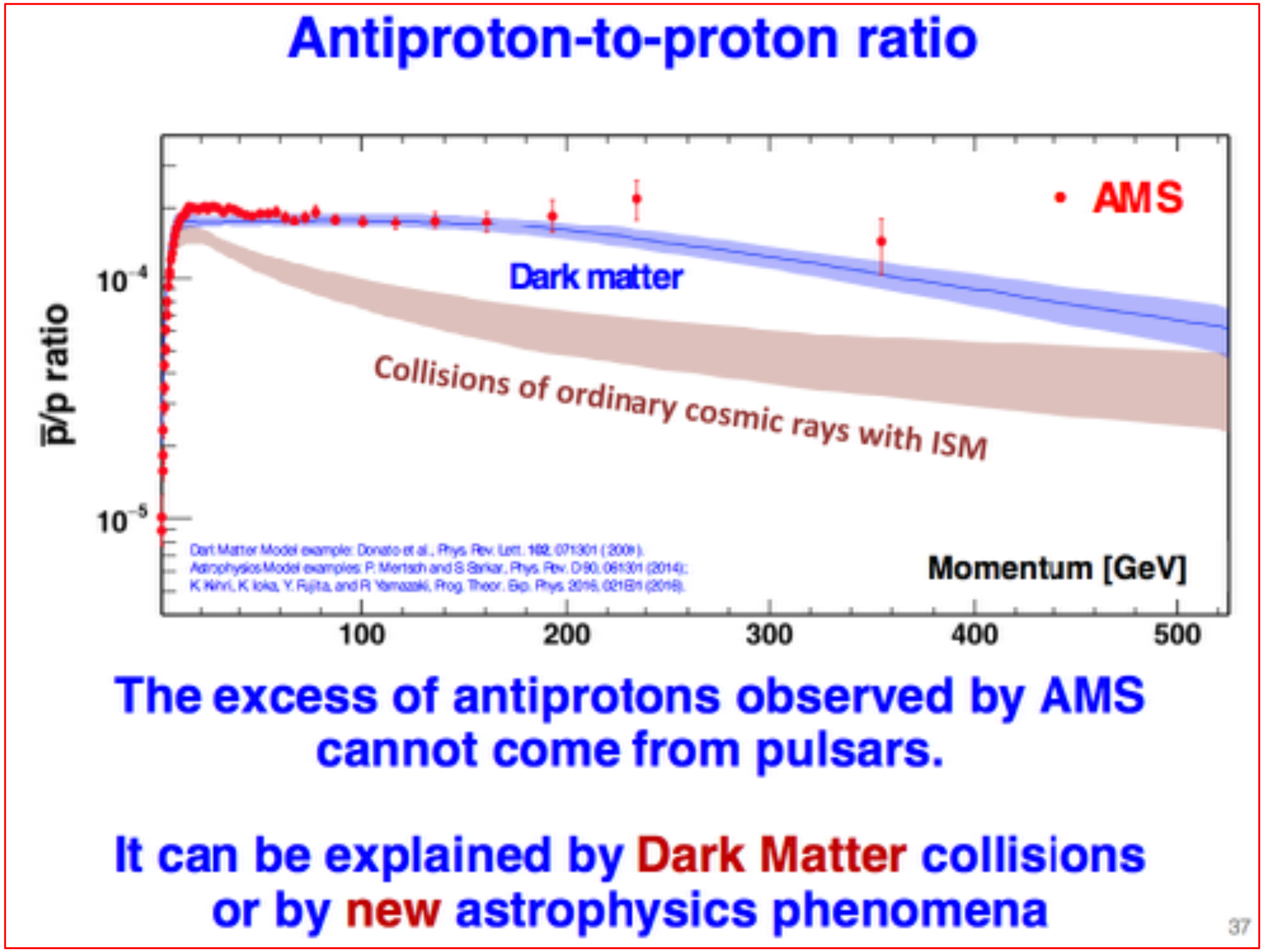
Anti-helium, anti-deuterium
Thought so scarce that a single event would mark new physics.
=> but how does one actually calculate the flux?
will show very recent progress thanks to the LHC ALICE collaboration

AMS02, Dec 2016



antimatter is produced in collisions of the bulk of the CRs
-- protons and He – with interstellar gas

Need to calculate this background to learn about possible exotic sources

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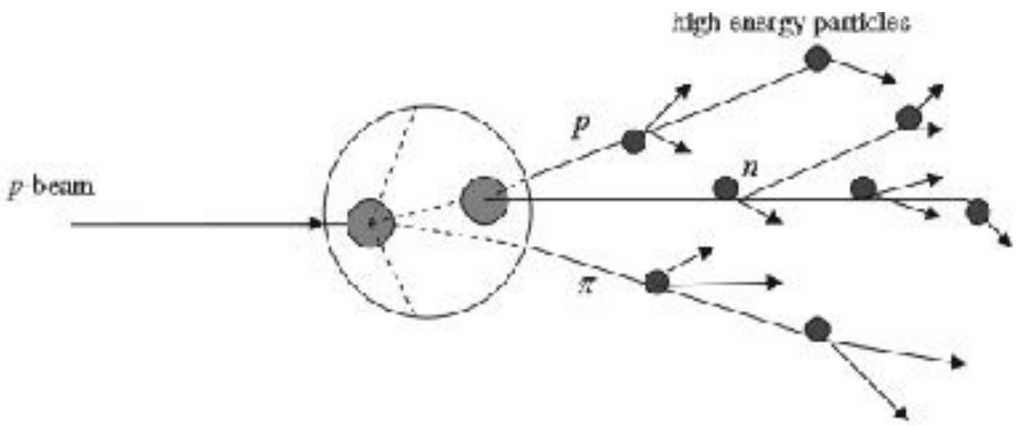
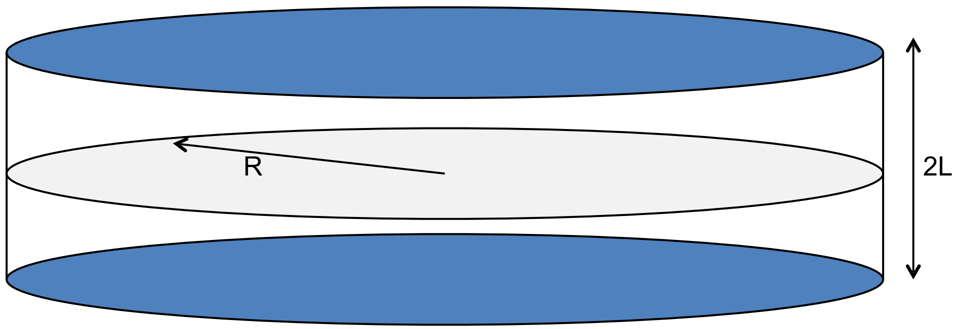
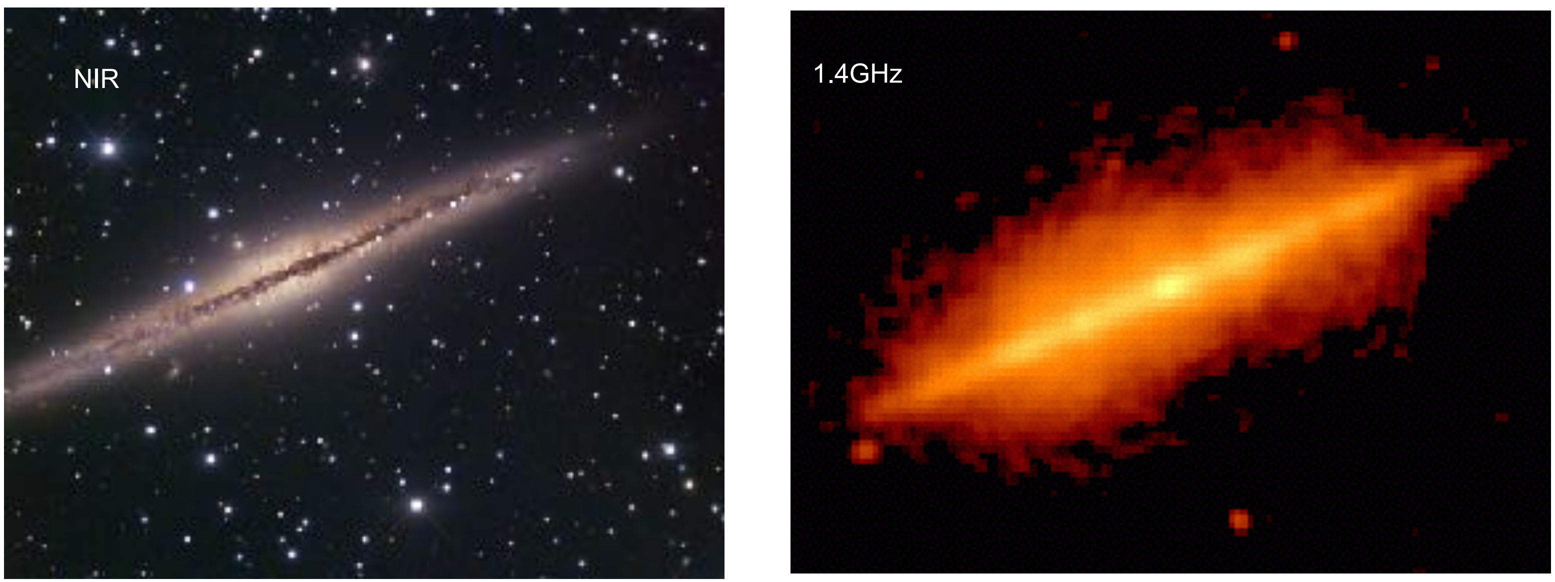


About diffusion models

$K \sim (E/Z)^{\delta}$

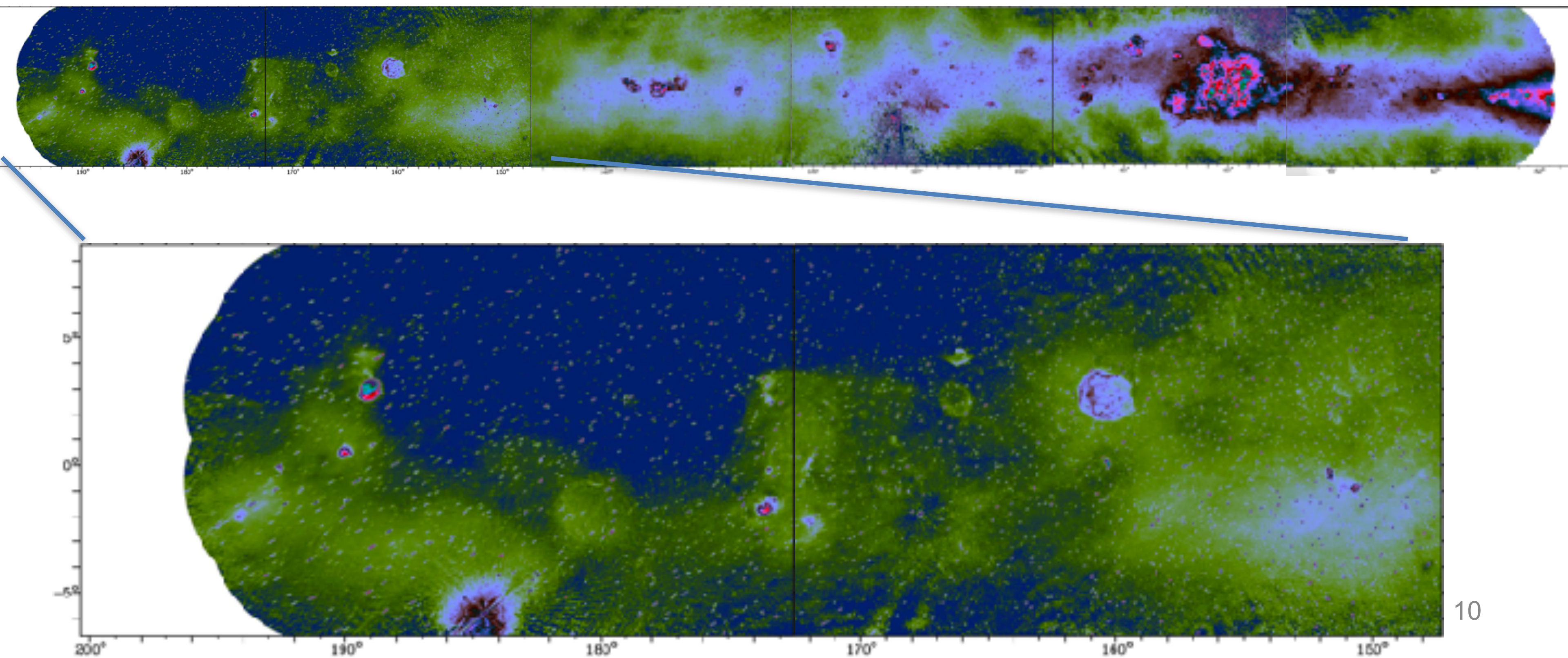


NGC 891

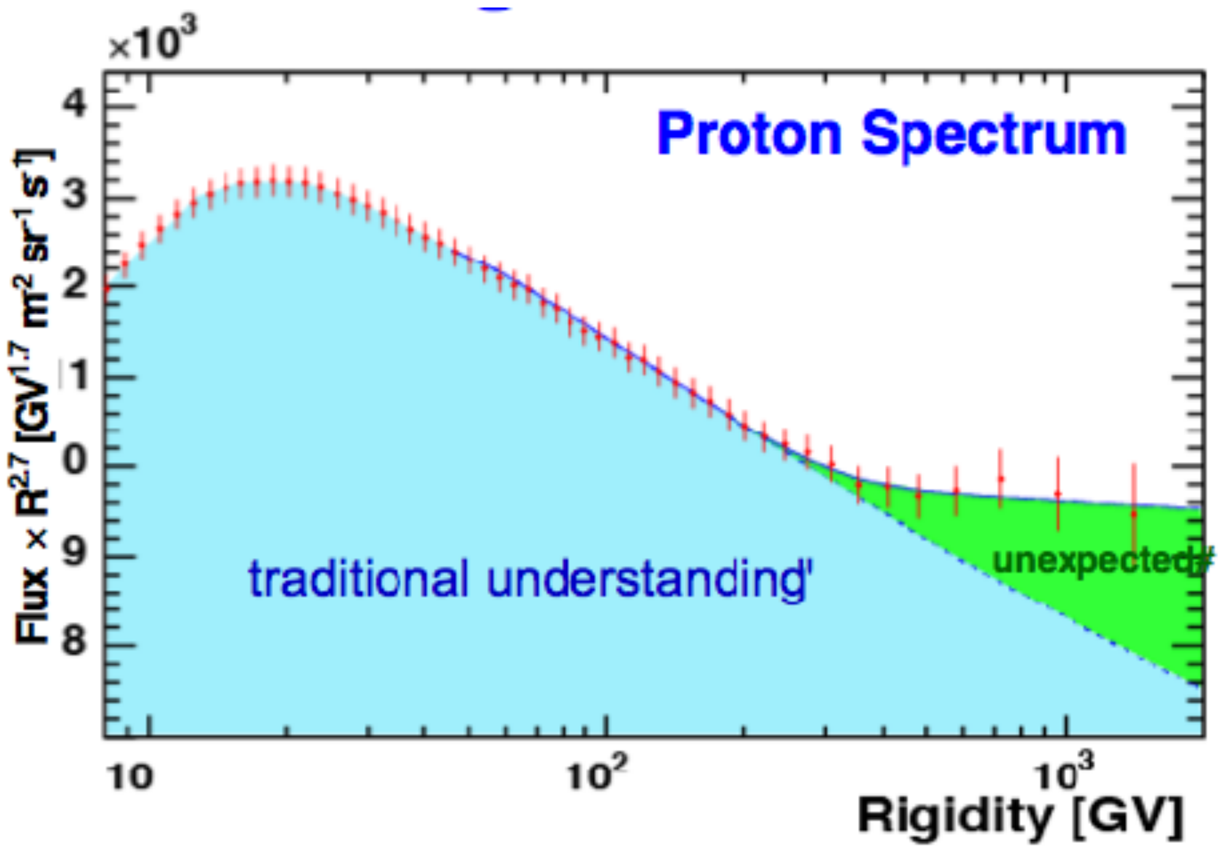


Strong, Moskalenko, Ptuskin, Ann.Rev.Nucl.Part.Sci. 57 (2007) 285-327

https://arxiv.org/pdf/1708.04316.pdf
408MHz (Canadian Galactic Plane Survey)



S. Schael, **Moriond 2016 for AMS02**



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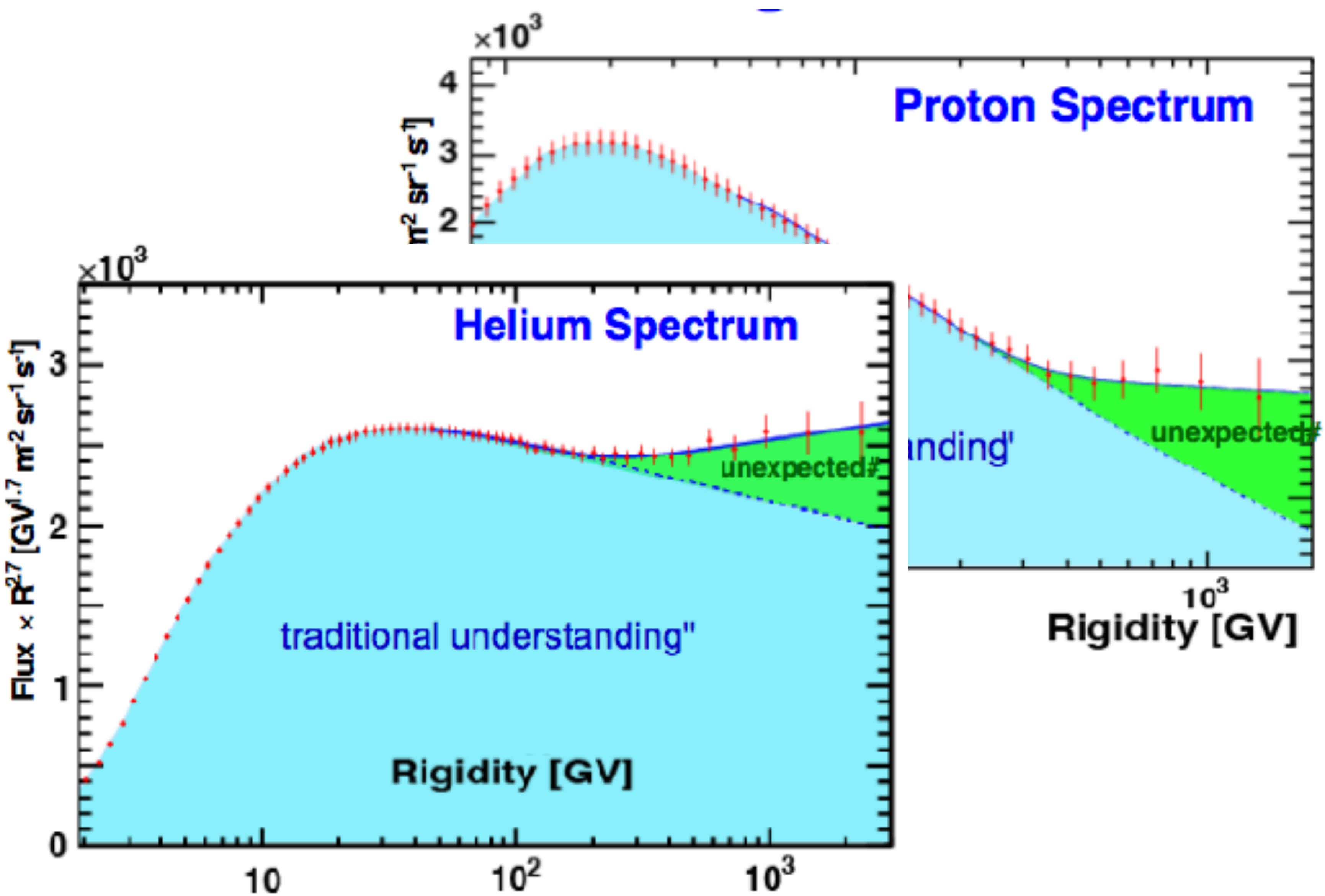

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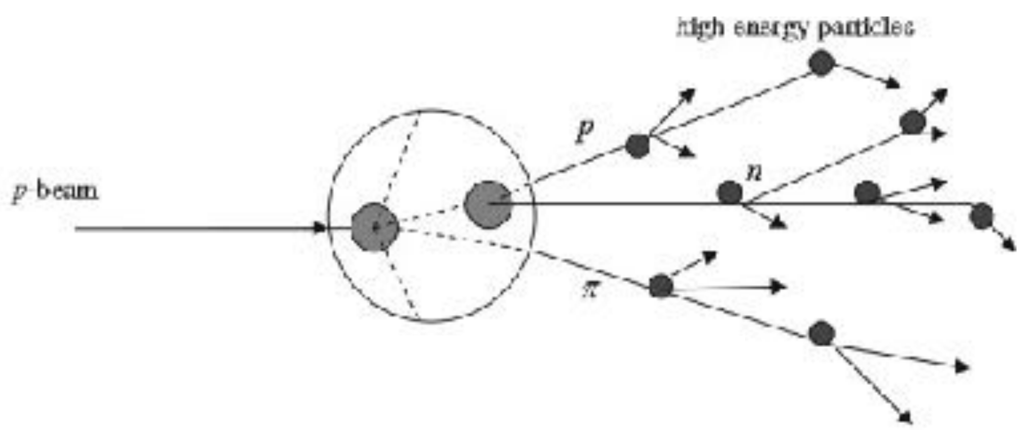

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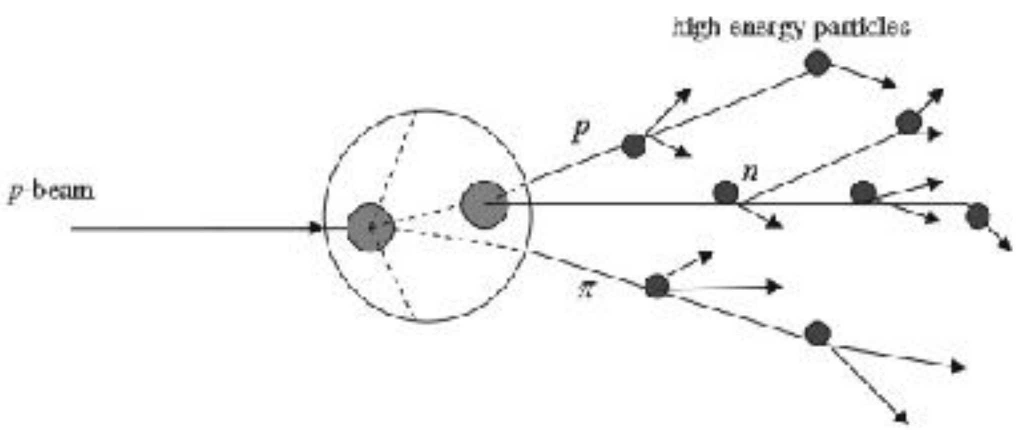
For secondary antimatter we have a handle: particle physics branching fractions

$$\frac{n_a(\mathcal{R})}{n_b(\mathcal{R})} \approx \frac{Q_a(\mathcal{R})}{Q_b(\mathcal{R})}$$



Recipe for an antiproton pie:

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MNRAS 405 (2010) 1458 Katz, Blum, Morag, Waxman

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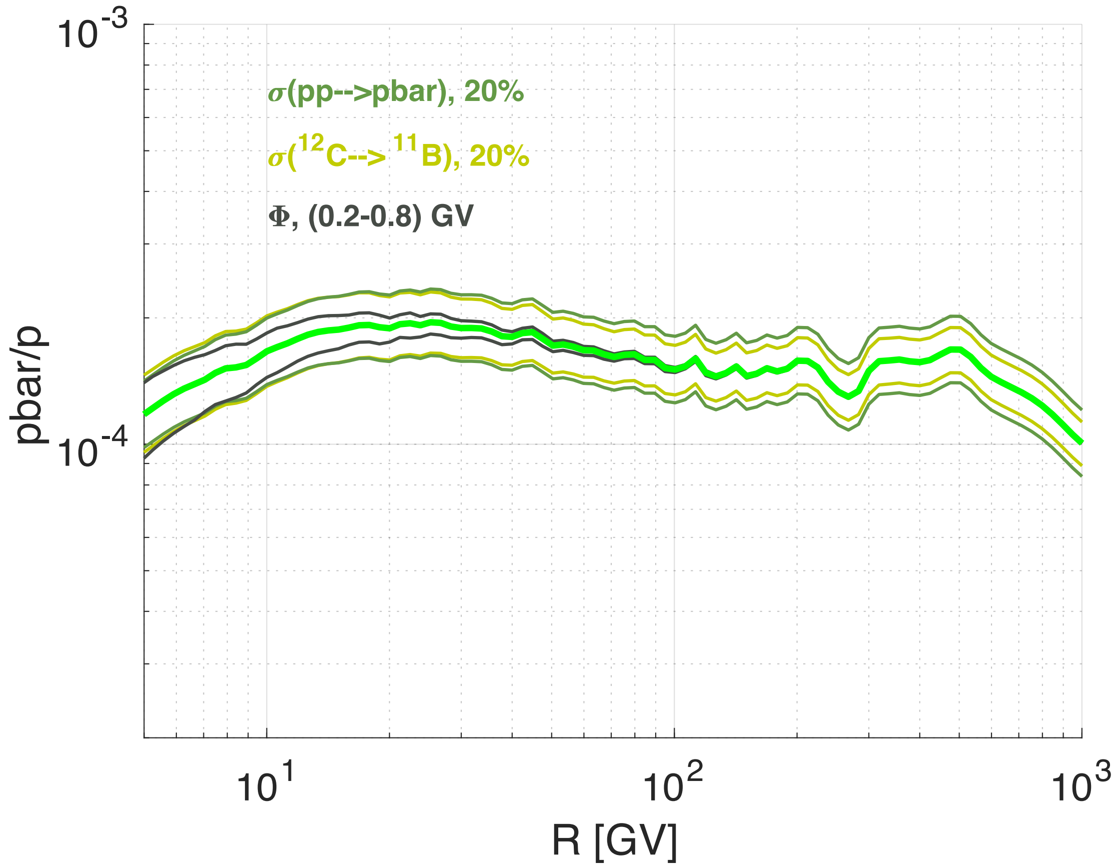

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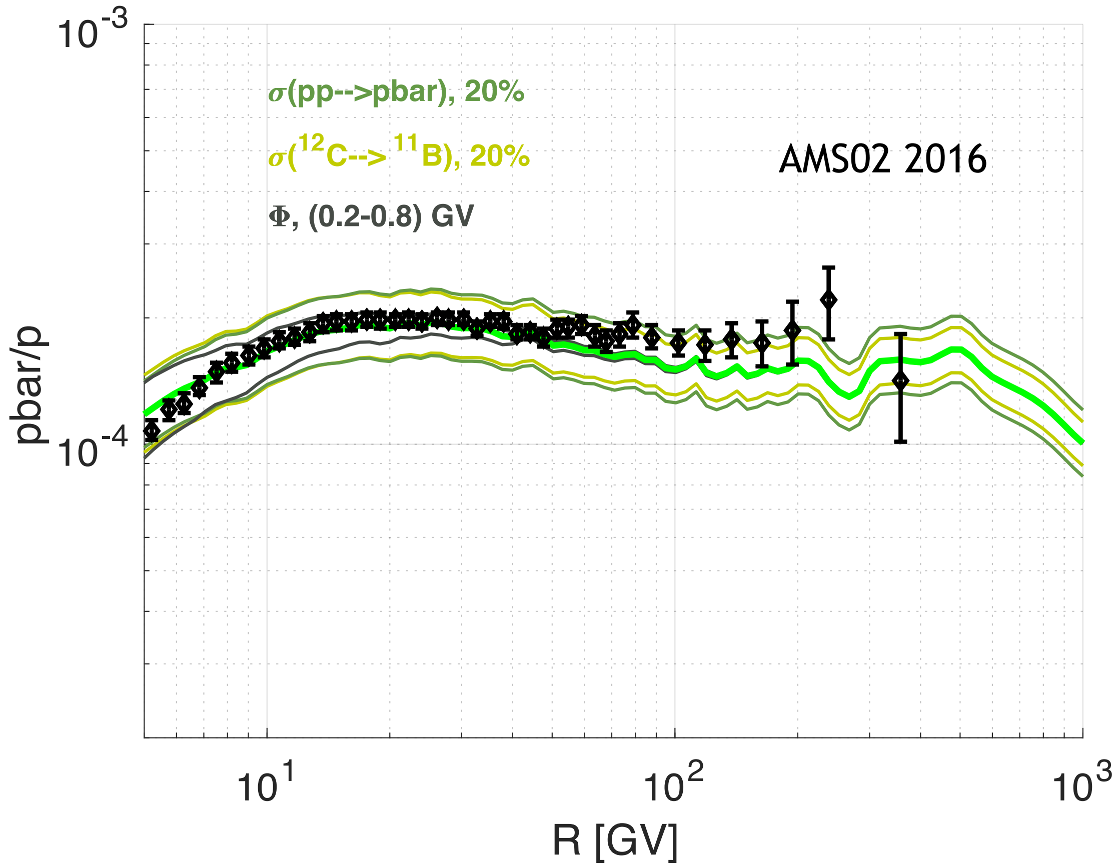

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What about e+ ?

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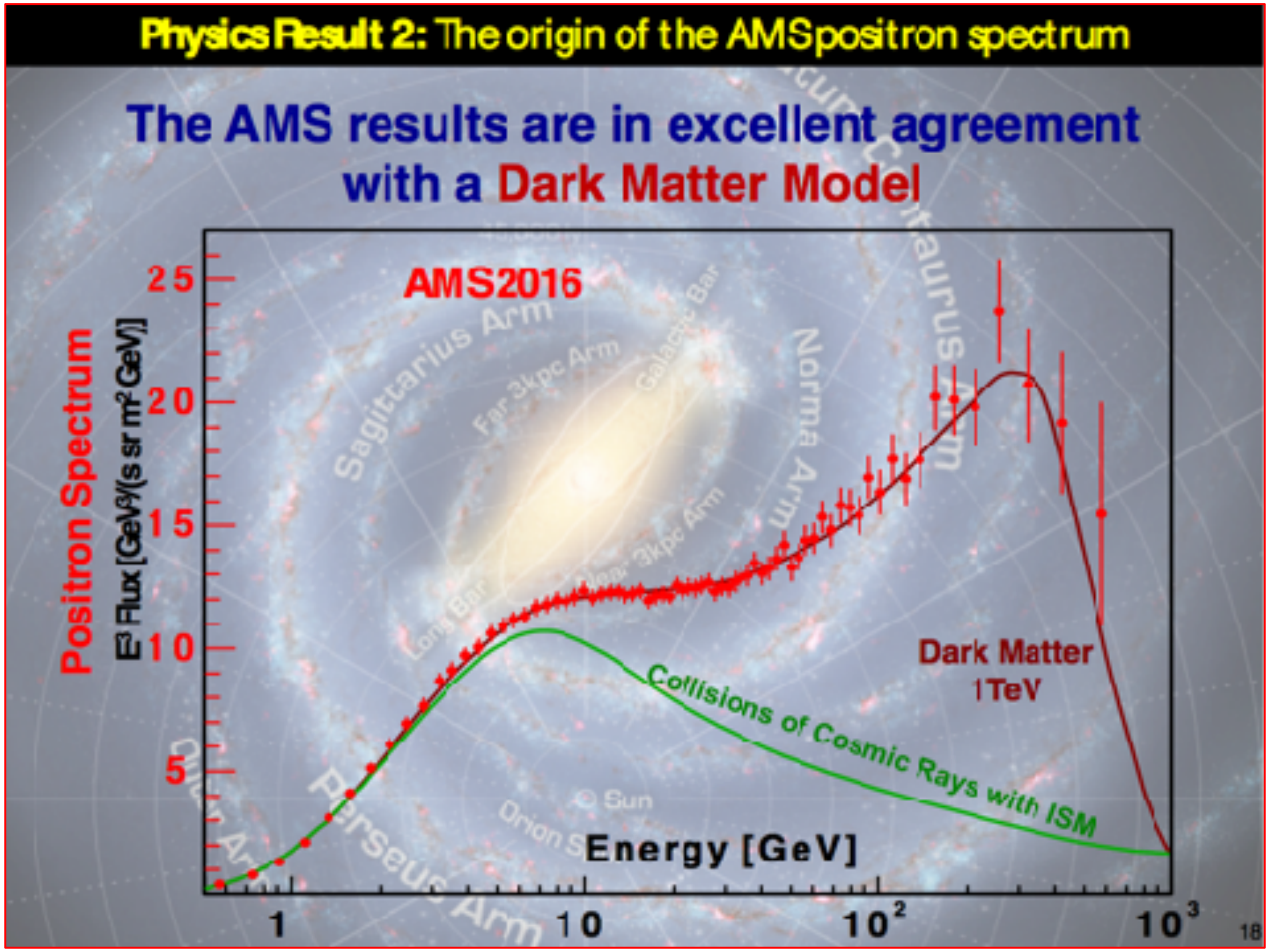
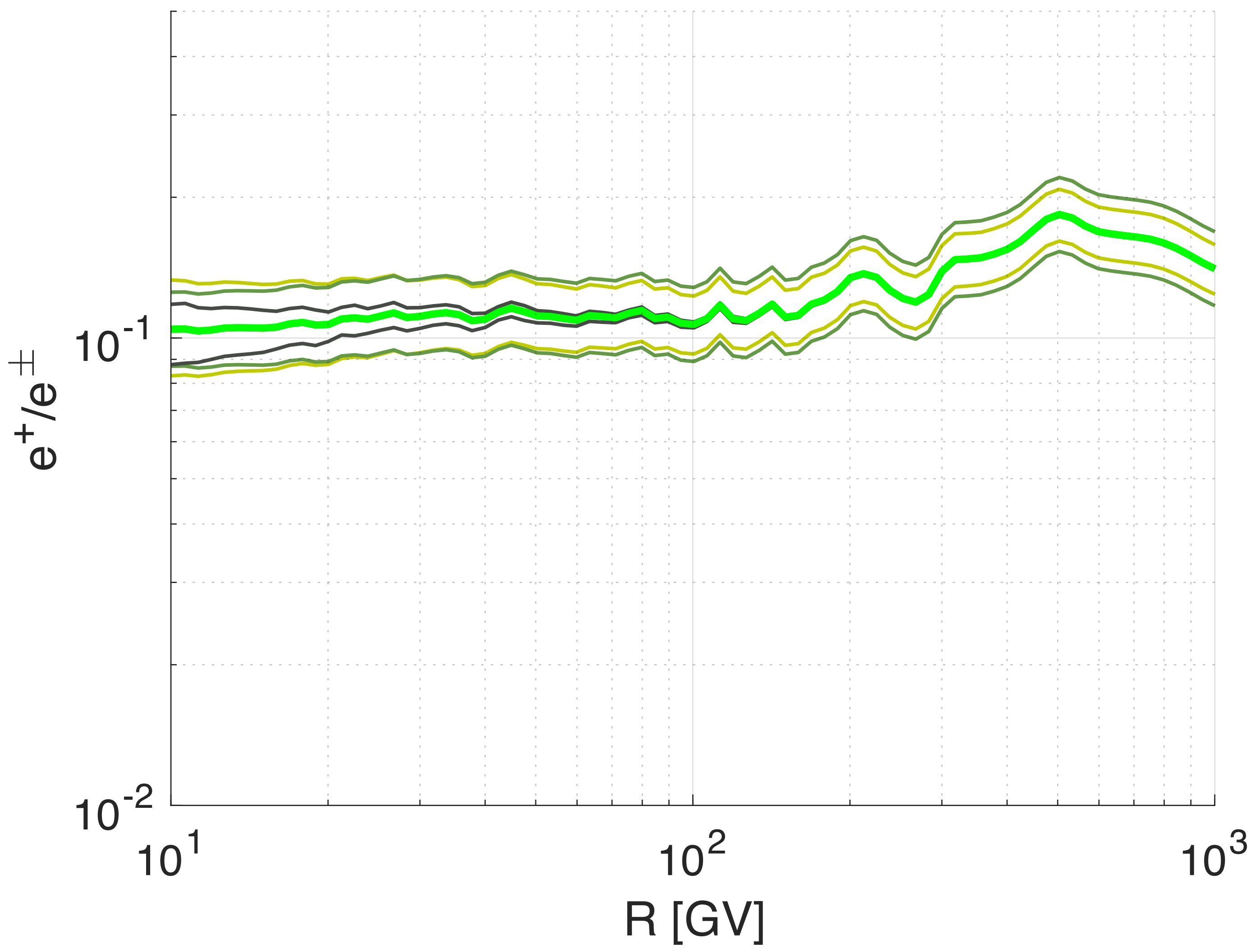
AMS02, Dec 2016



Secondary *upper bound*
(Based on B/C)

$$n_{e^+}(\mathcal{R}) \lesssim \frac{n_{\rm B}(\mathcal{R})}{Q_{\rm B}(\mathcal{R})} Q_{e^+}(\mathcal{R})$$



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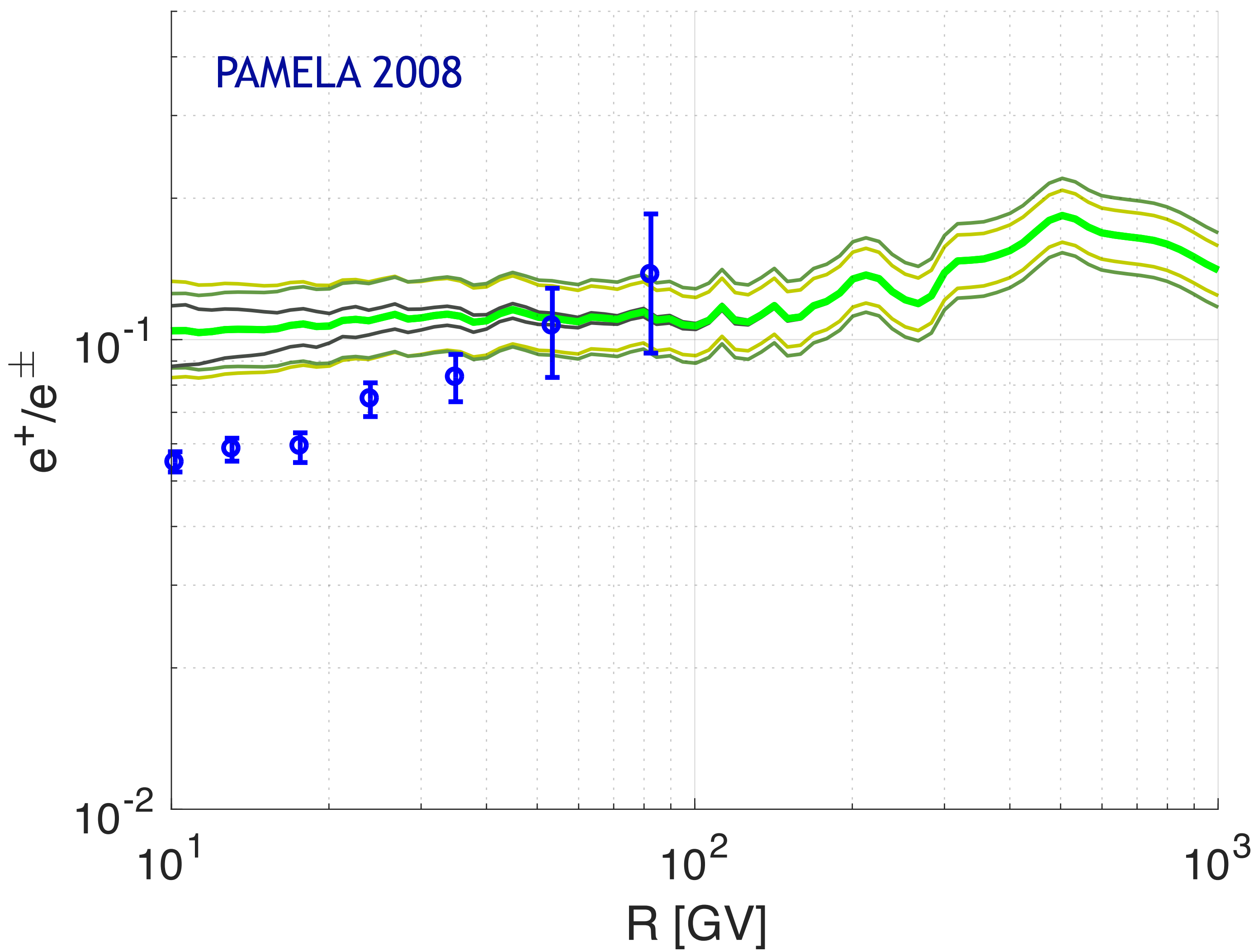

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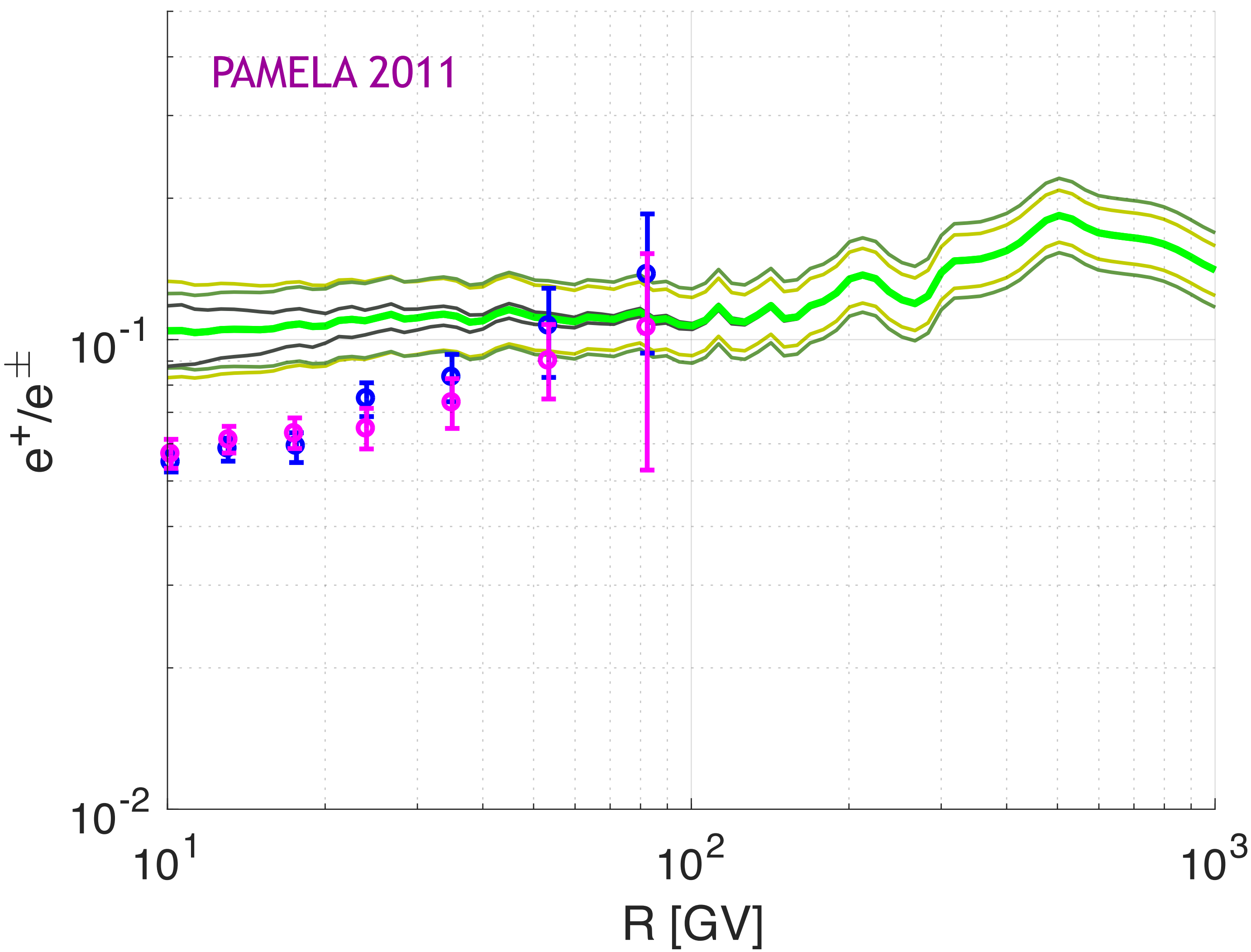

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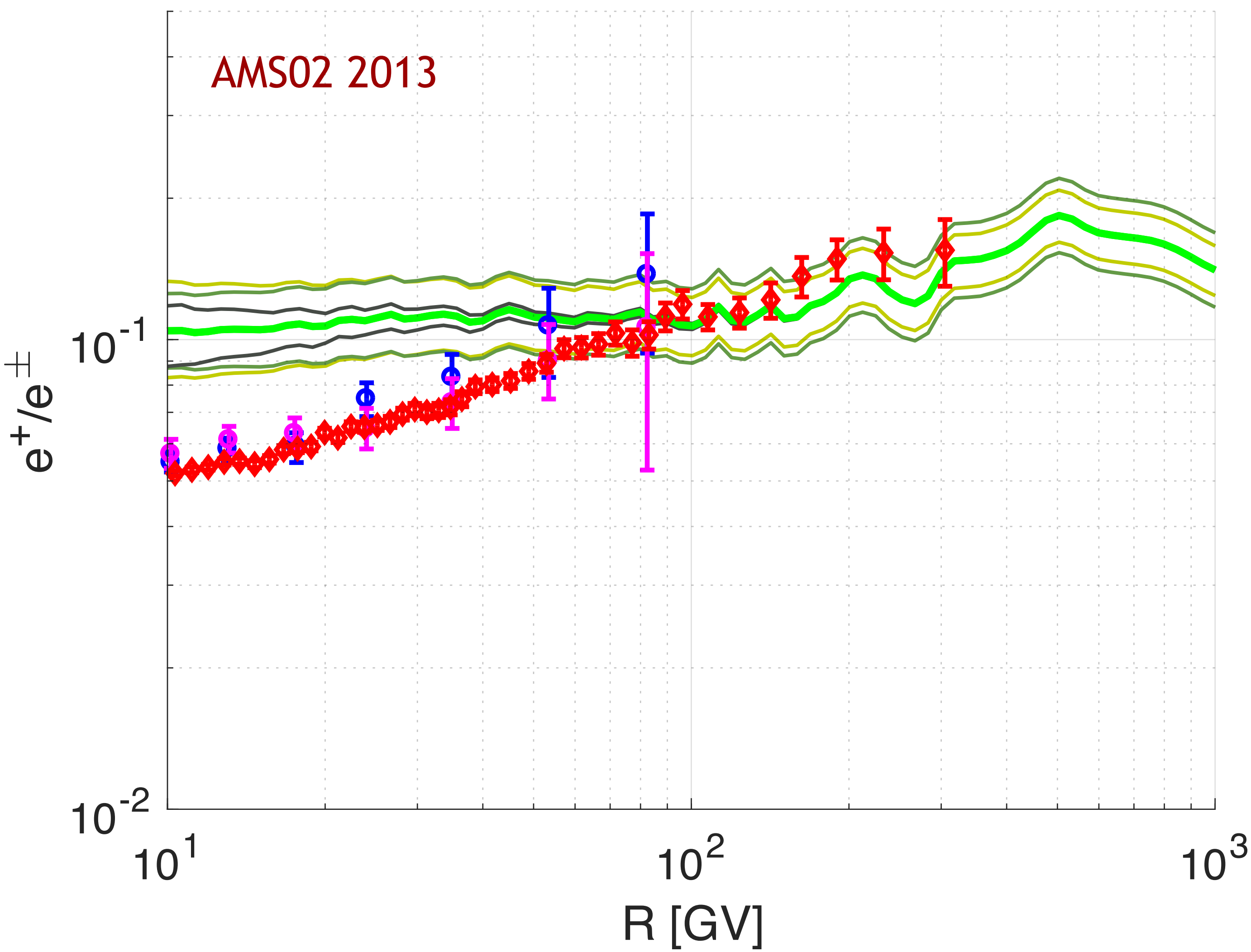

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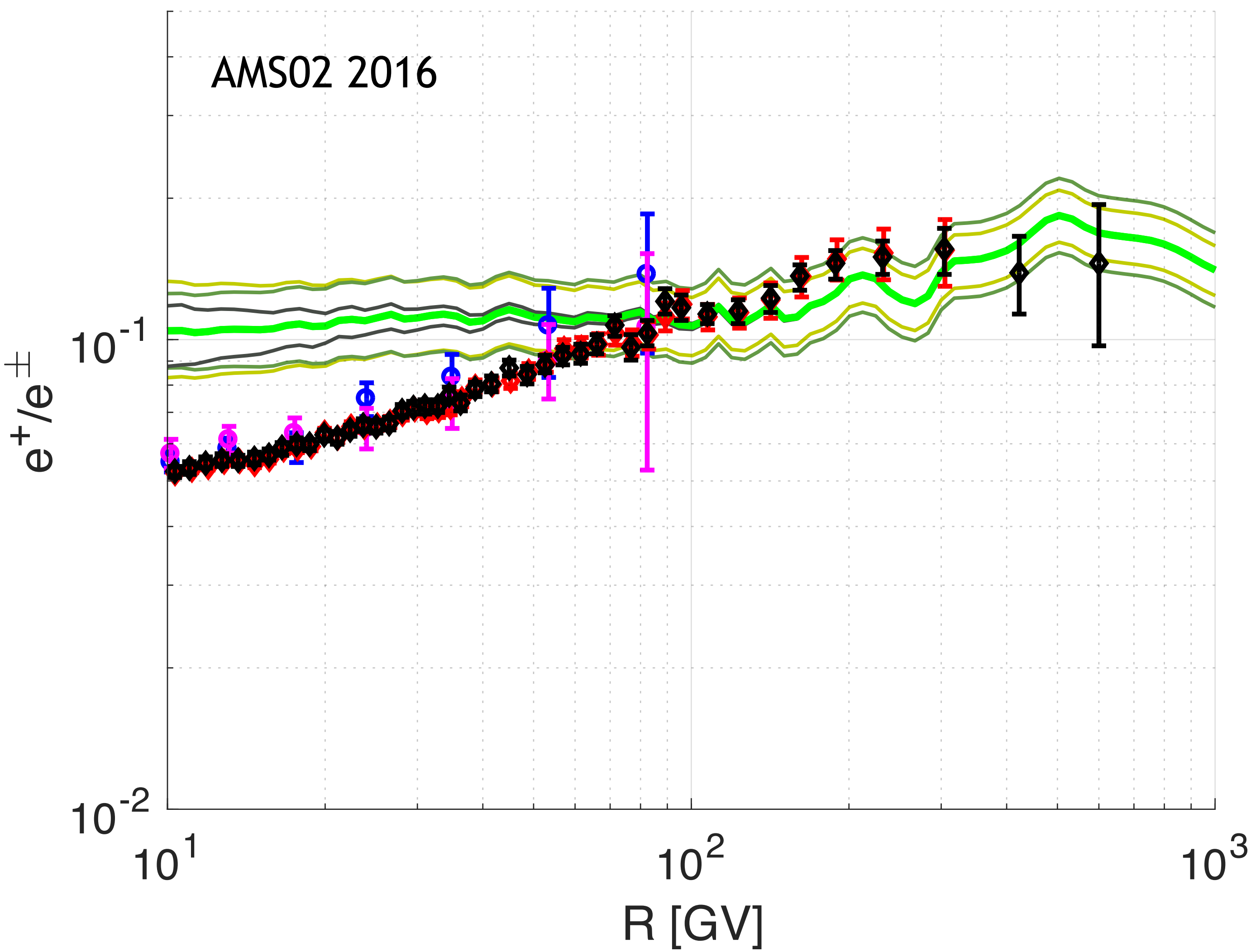

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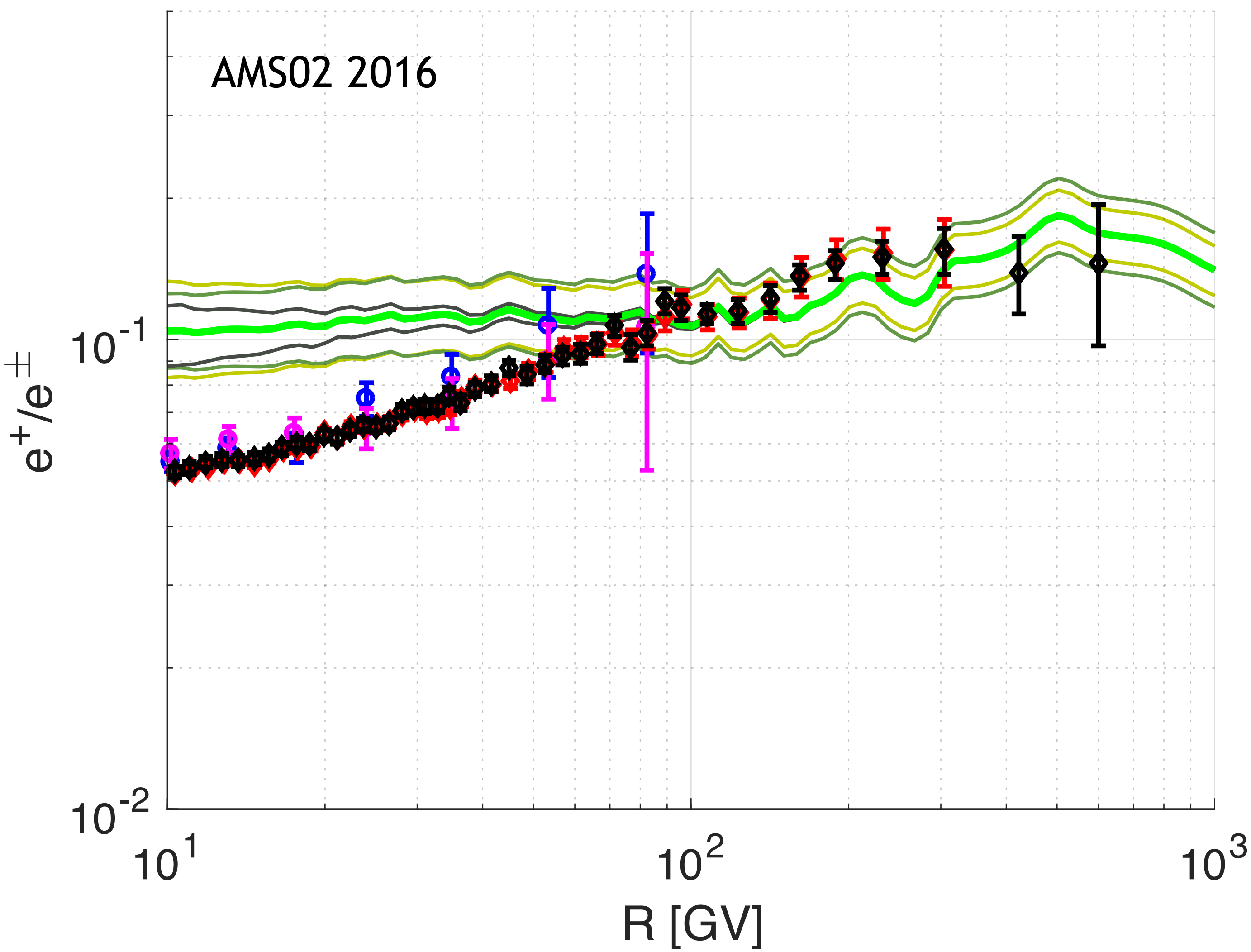
Why would dark matter or pulsars inject ***this*** e+ flux?



Blum, Katz, Waxman, Phys.Rev.Lett. 111 (2013) no.21, 211101

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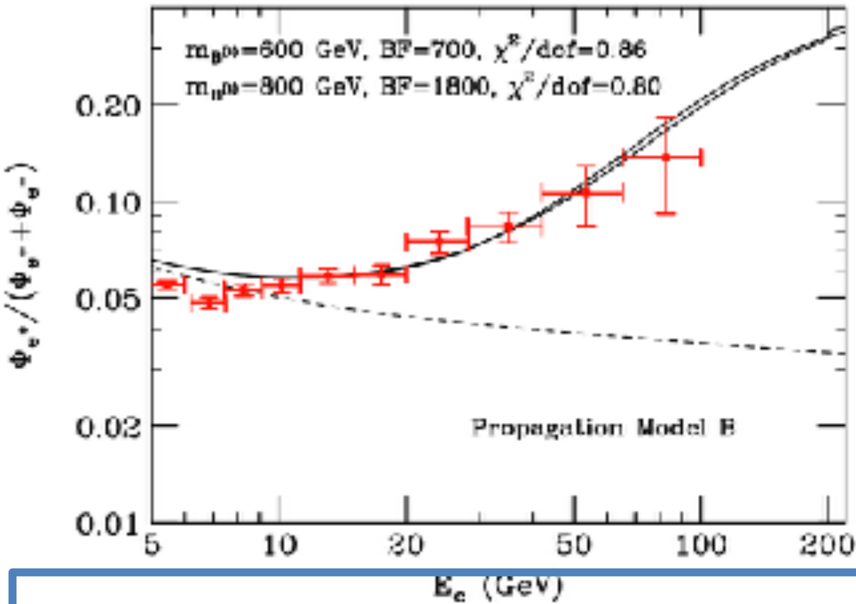

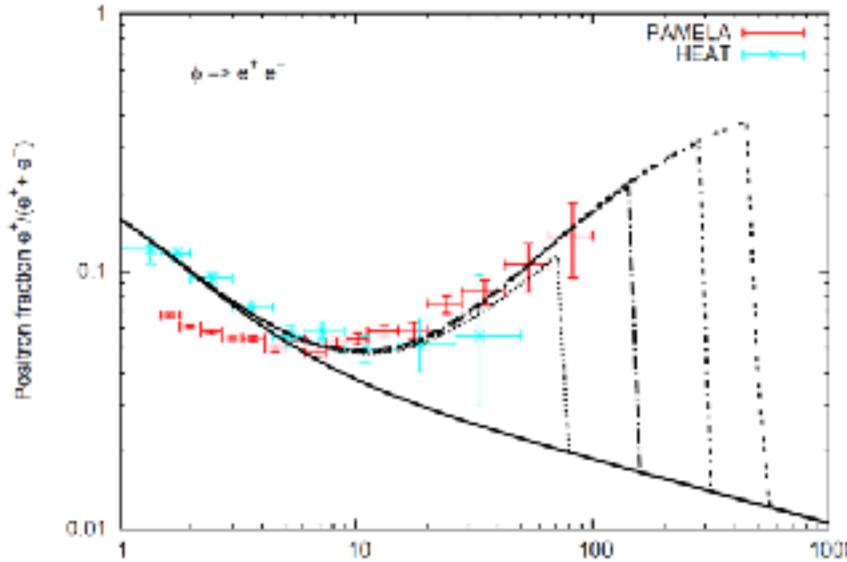

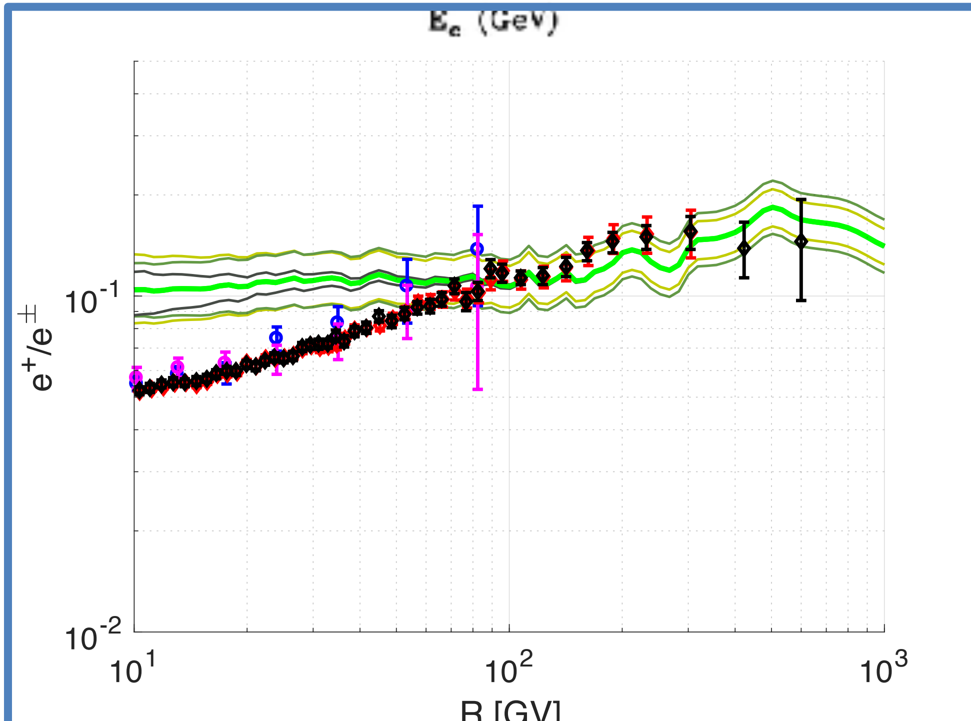

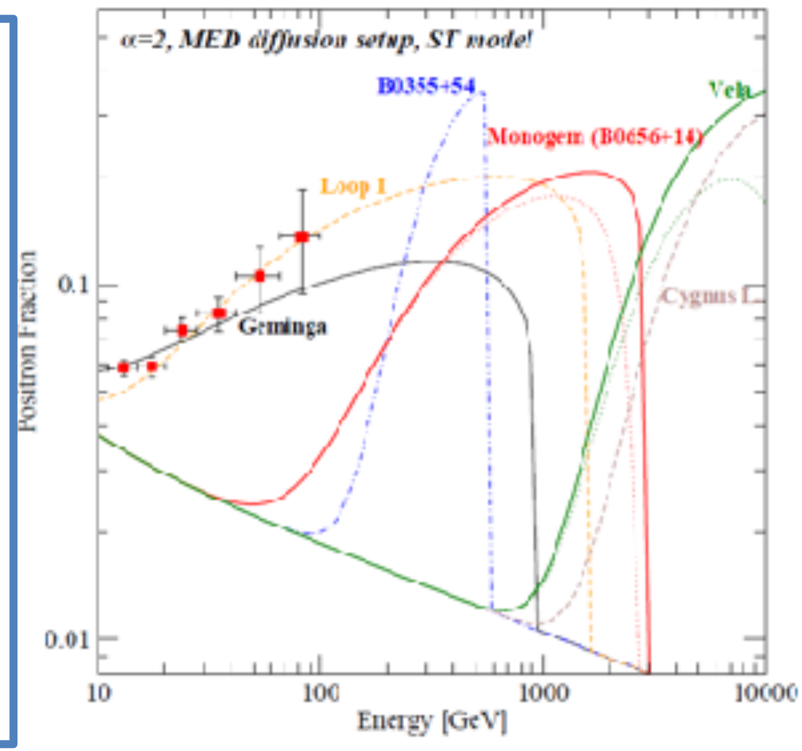

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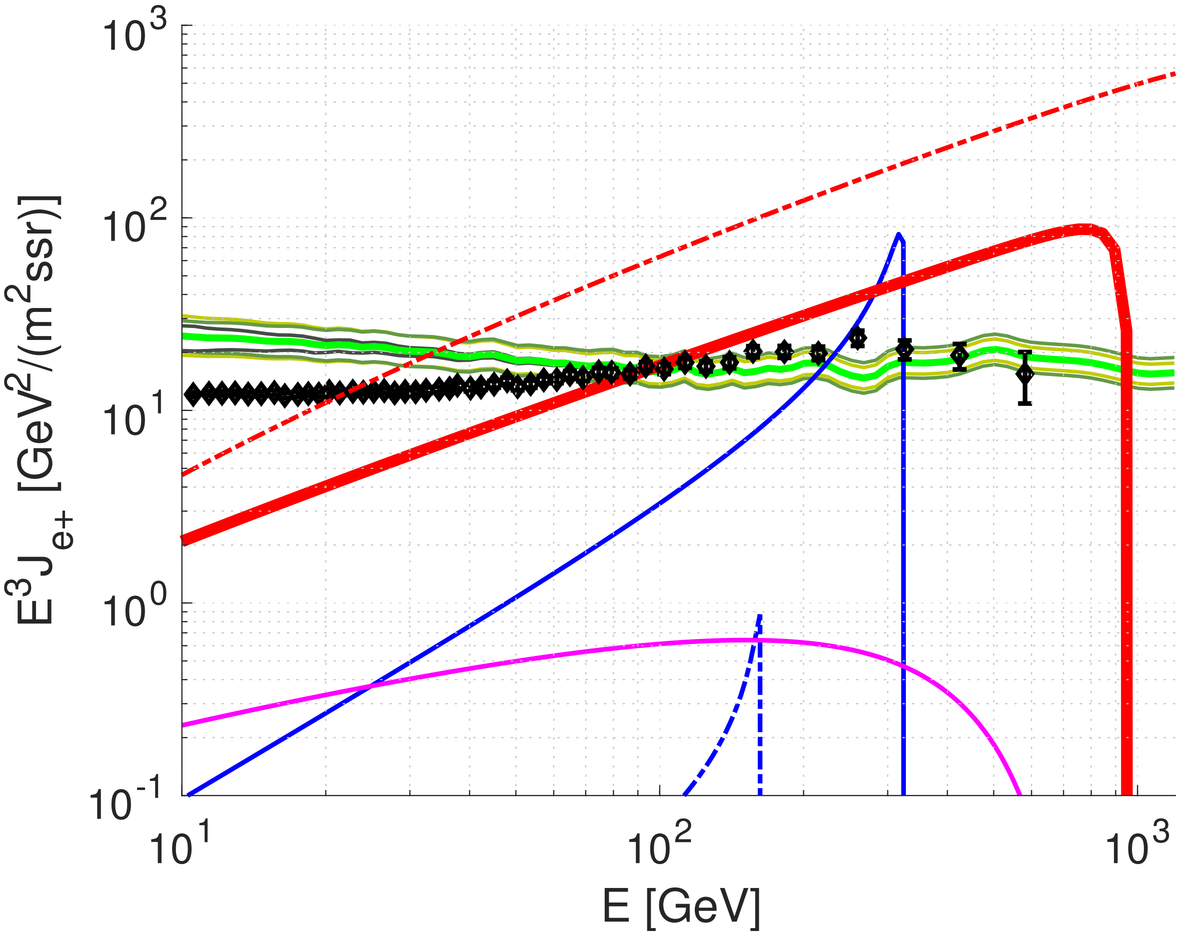


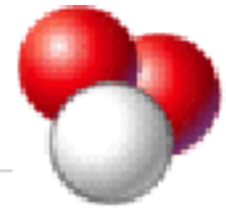
Pulsar model: D. Malyshev, I. Cholis, and J. Gelfand, Phys. Rev. **D80**, 063005 (2009)

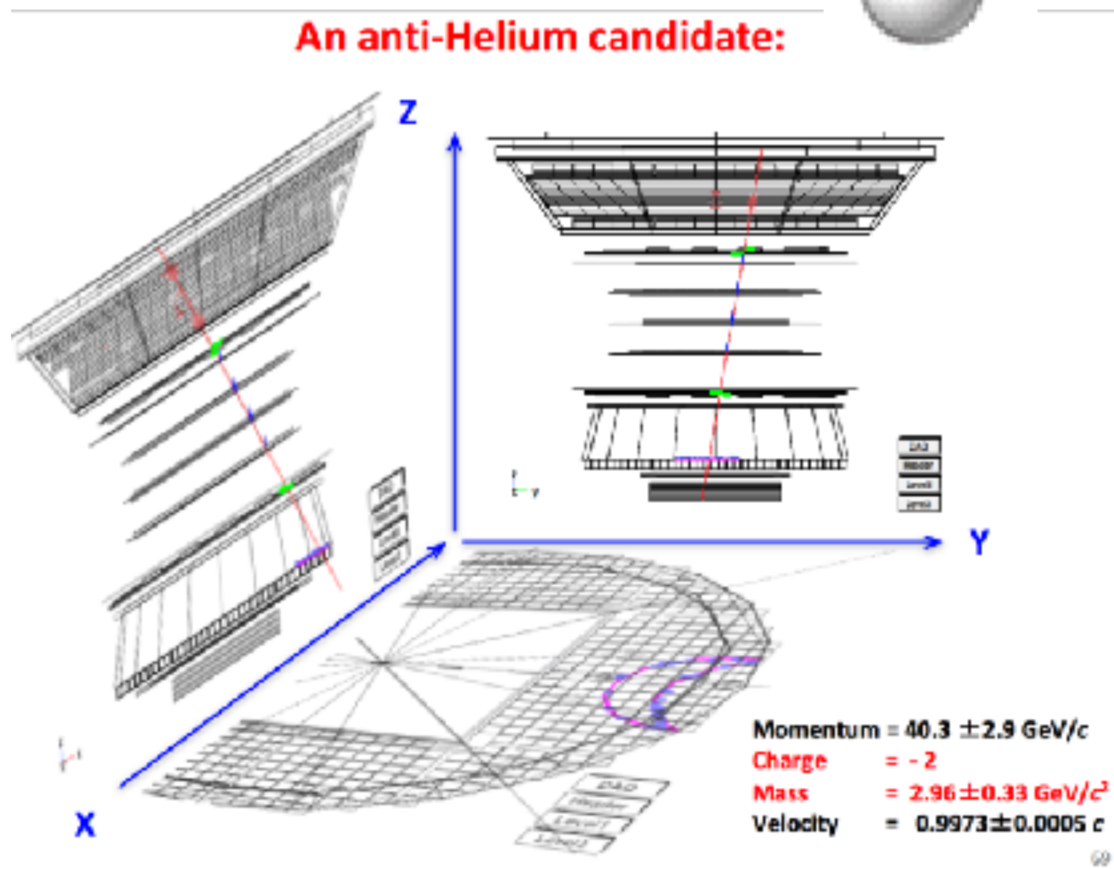
1709.06507

anti He3

anti He3

AMS02, Dec 2016

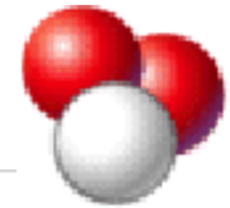


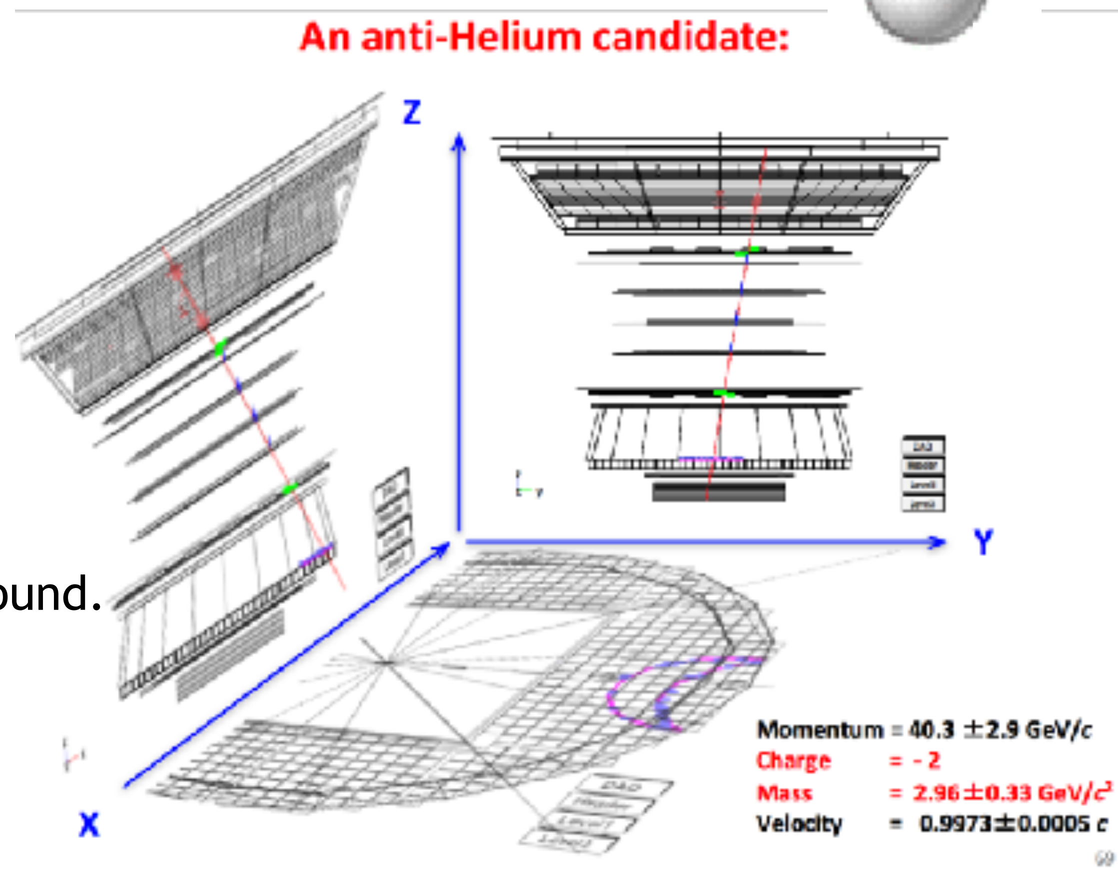


anti He3

Handful of events?

AMS02, Dec 2016





At this point it is not clear
if AMS02 is seeing true CR events,
or some rare experimental background.

Need to reject freak background
events at a level of ~ 1:100M…

We take it as motivation for theory examination of what
the astro anti-He3 flux is.

anti He3

Handful of events

"coalescence": $$E_A \frac{dN_A}{d^3p_A} = B_A\, R(x) \left(E_p \frac{dN_p}{d^3p_p} \right)^A$$

The difficult part is to get the cross section right:
We need B_3.

anti He3

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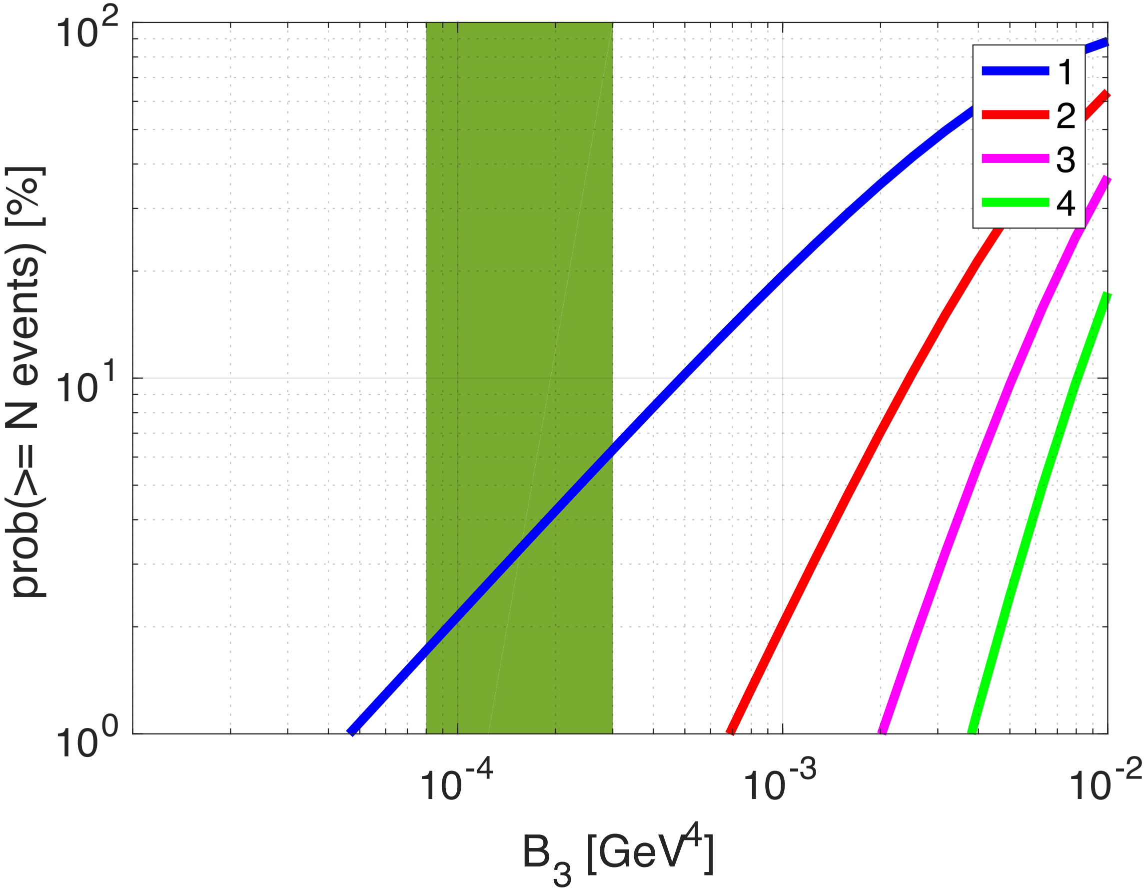
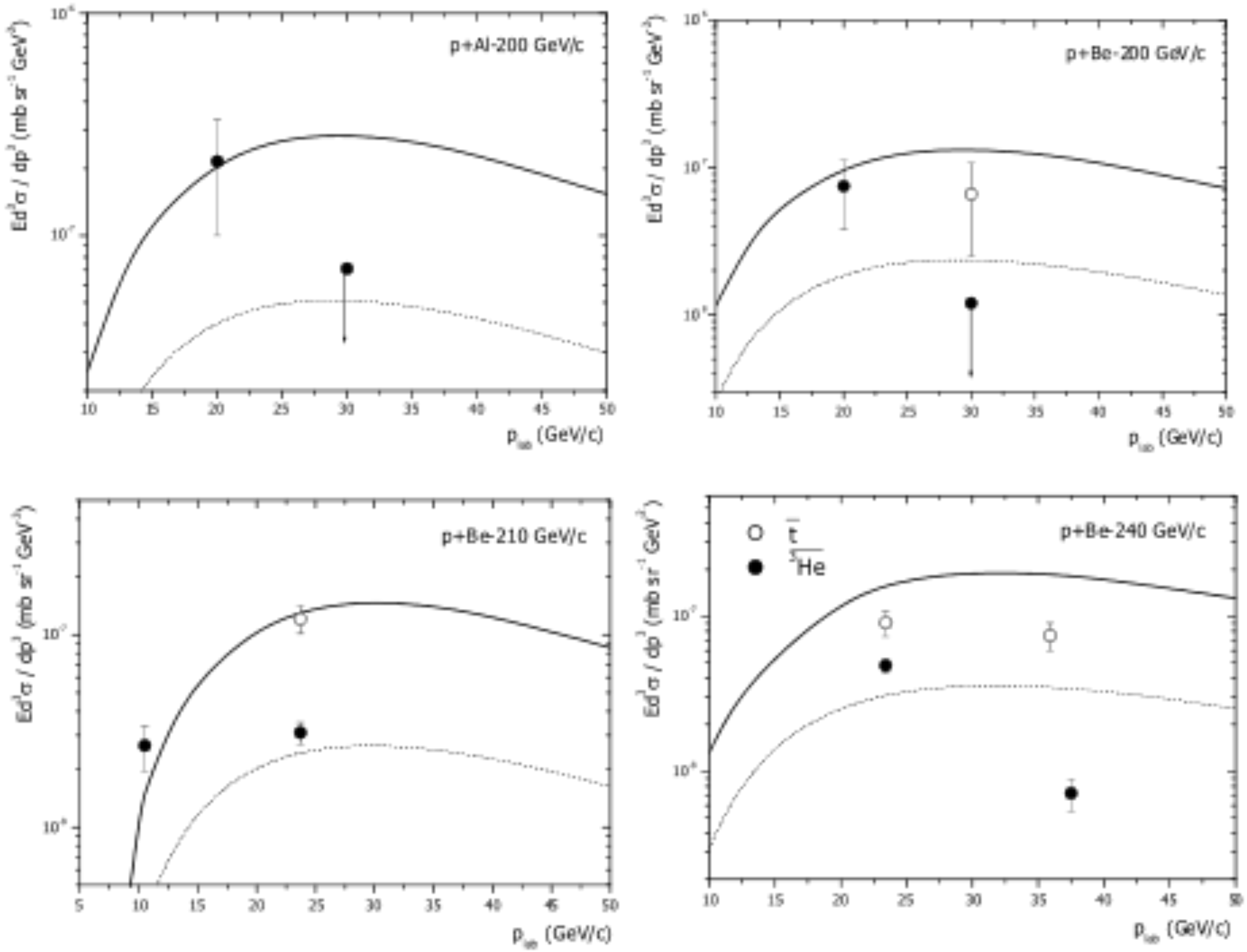


Duperray et al, PRD71 083013 (2005), **pA data** from SPS (1980's)

B_3=1.4x10^{-5} GeV^4



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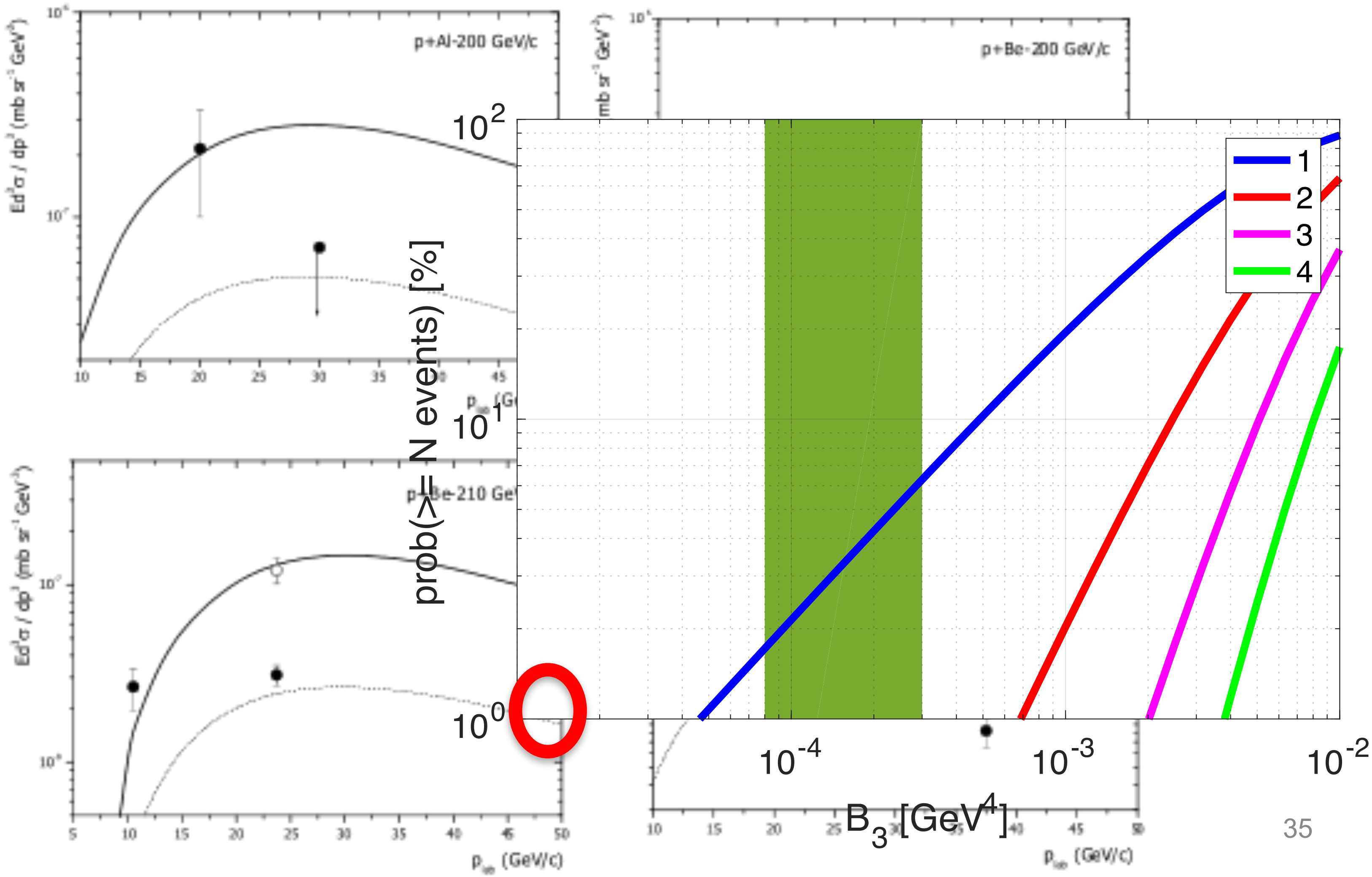
If true, then anti-helium @AMS02 = new physics



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Complimentary AA, pA, and related pp data exists elsewhere.

Let's take a step back and try to see the bigger picture

$$E_A \frac{dN_A}{d^3p_A} = B_A \, R(x) \, \left(E_p \frac{dN_p}{d^3p_p} \right)^A$$

Hadrons emitted from a finite size emission region.
Typical scales O(fm) ~ 1/(100 MeV)

Natural scaling law: $\boxed{B_A \propto V^{1-A}}$

Emission region scale size is probed by two-particle correlations:

Hanbury Brown-Twiss (HBT) data

Scheibl & Heinz, Phys.Rev. C59 (1999) 1585-1602

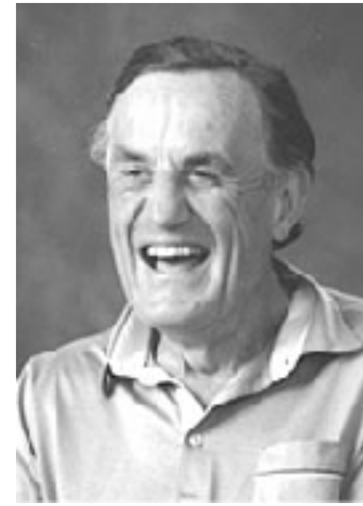
Hanbury Brown-Twiss (HBT)

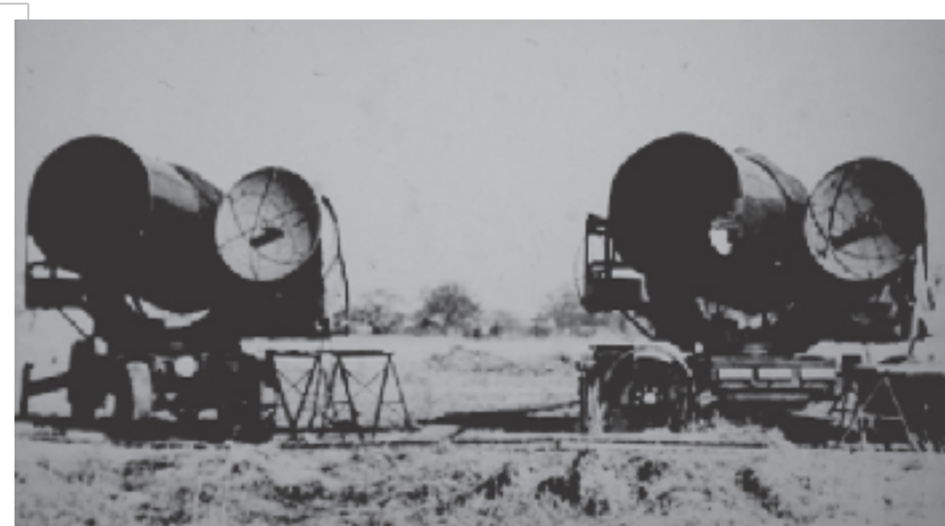
Nature **178**, 1046-1048 (10 November 1956) | doi:10.1038/1781046a0

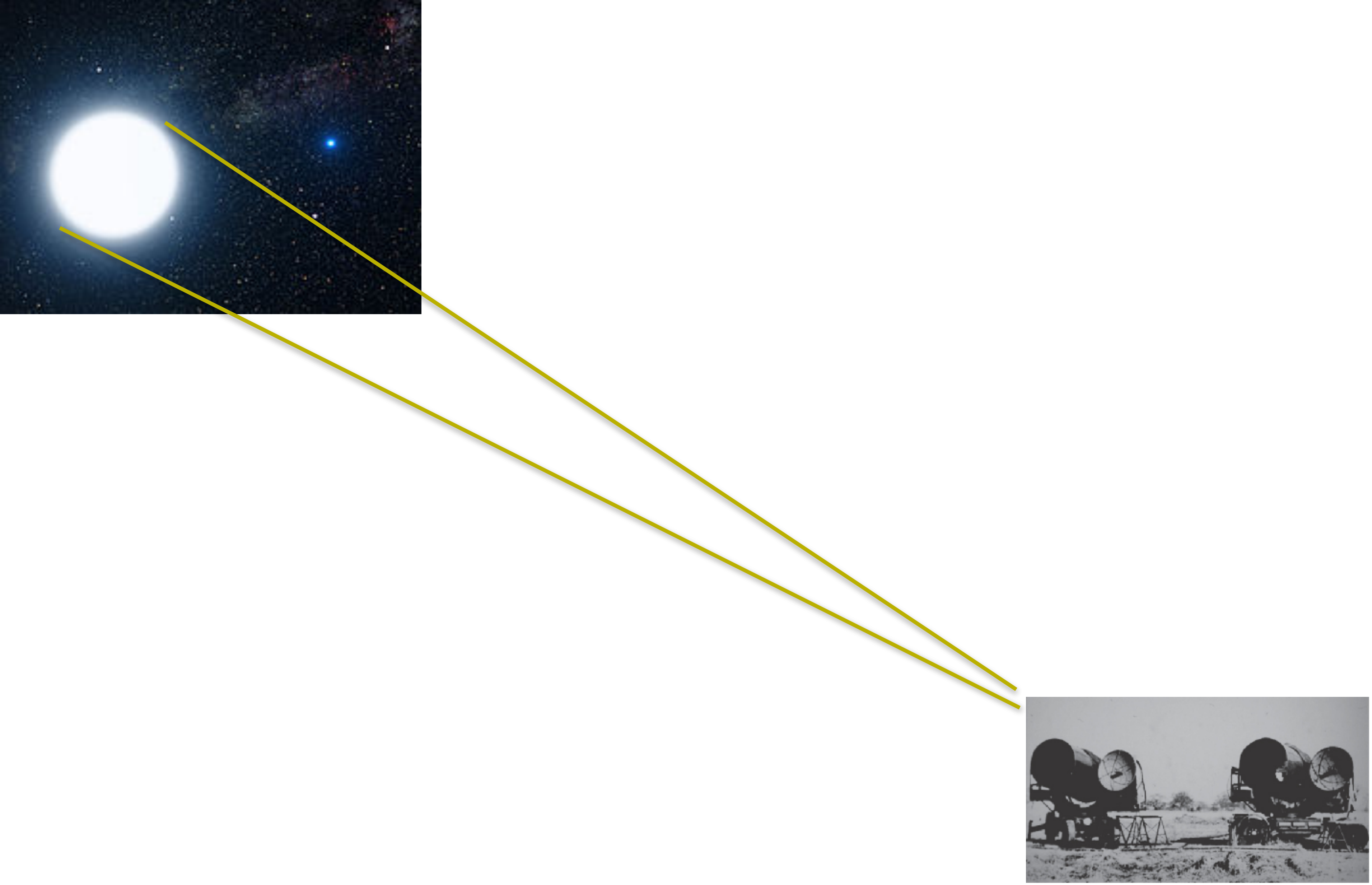
A Test of a New Type of Stellar Interferometer on Sirius

R. HANBURY BROWN & , DR.R. Q. TWISS

1. Jodrell Bank Experimental Station, University of Manchester
2. Services Electronics Research Laboratory, Baldock







HBT in heavy ion and pp collisions

Lisa et al, Ann.Rev.Nucl.Part.Sci. 55 (2005) 357-402
Scheibl & Heinz, Phys.Rev. C59 (1999) 1585-1602
Baym, Acta Phys. Polon. B29 (1998) 1839-1884
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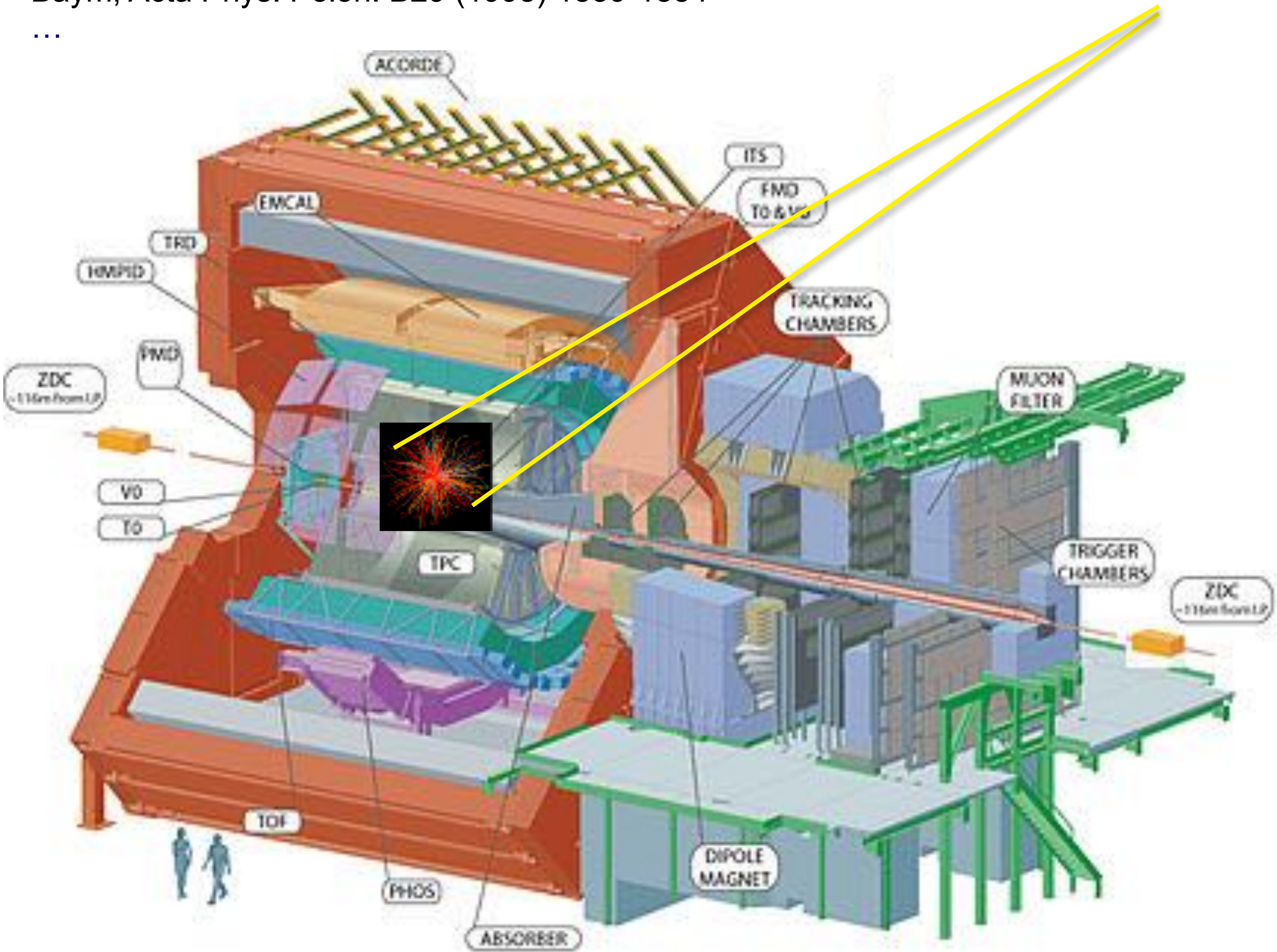
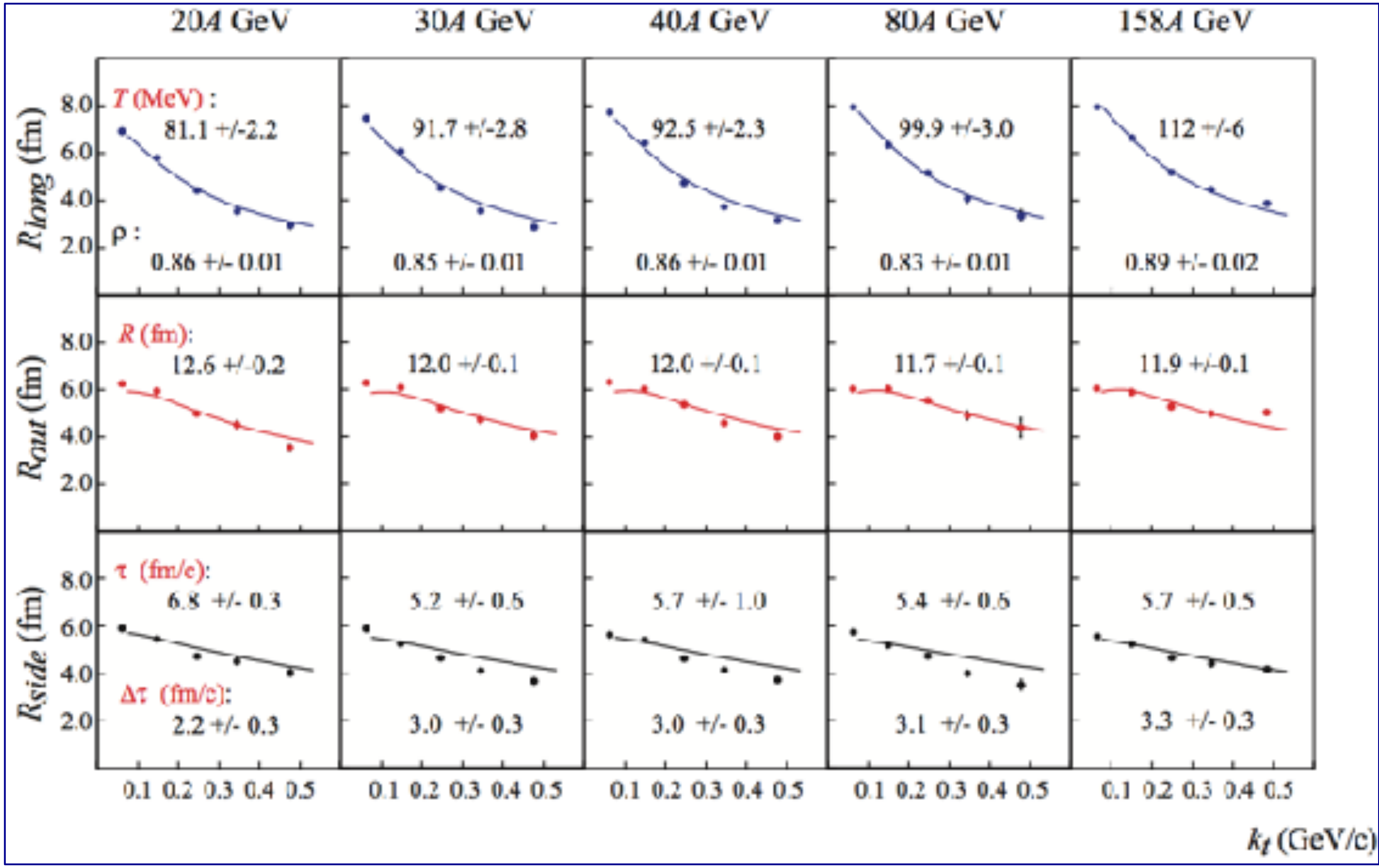


HBT in heavy ion and pp collisions

Example: CERN SPS, **PbPb** 20, 30, 40, 80, 158A GeV



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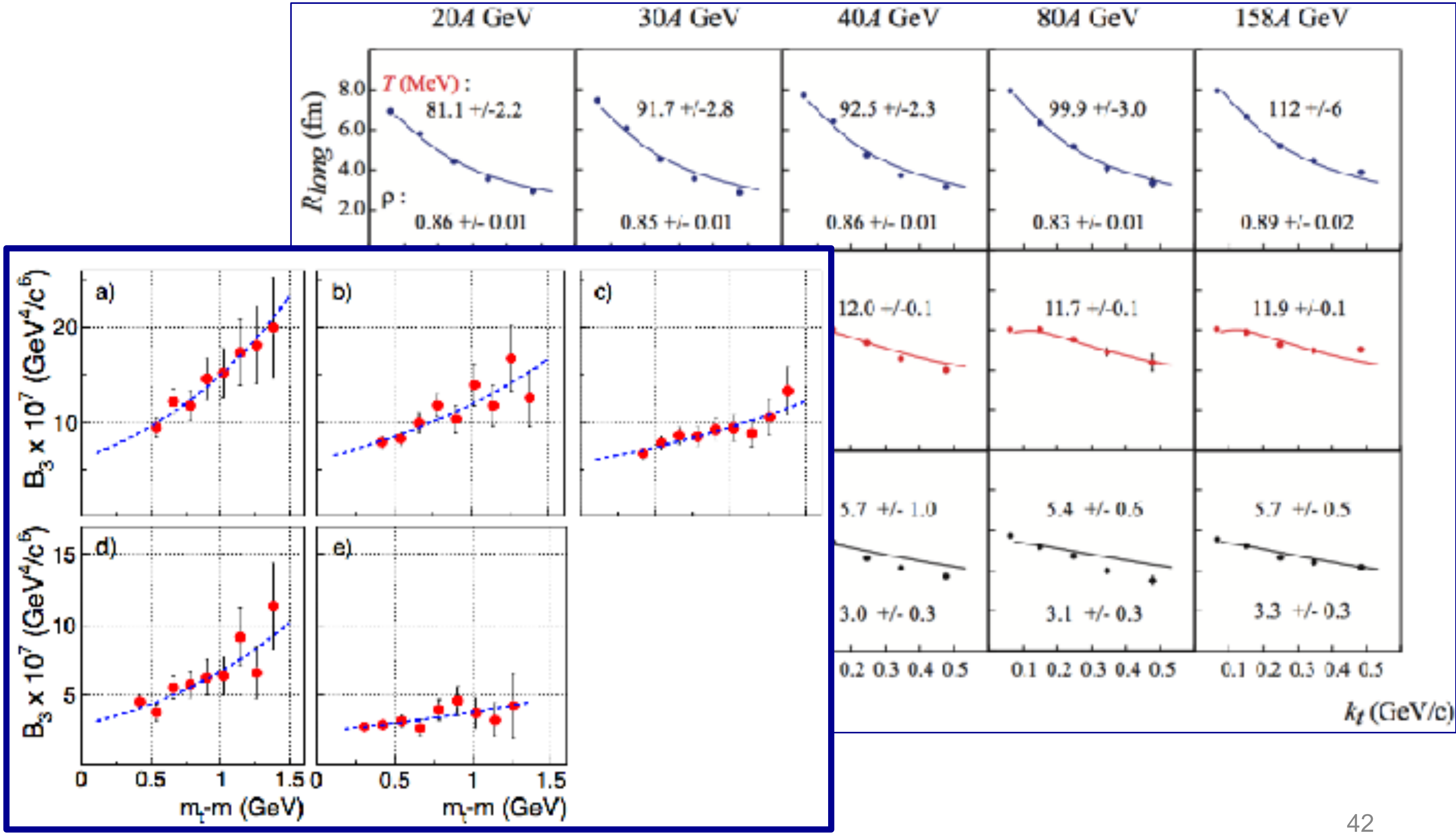
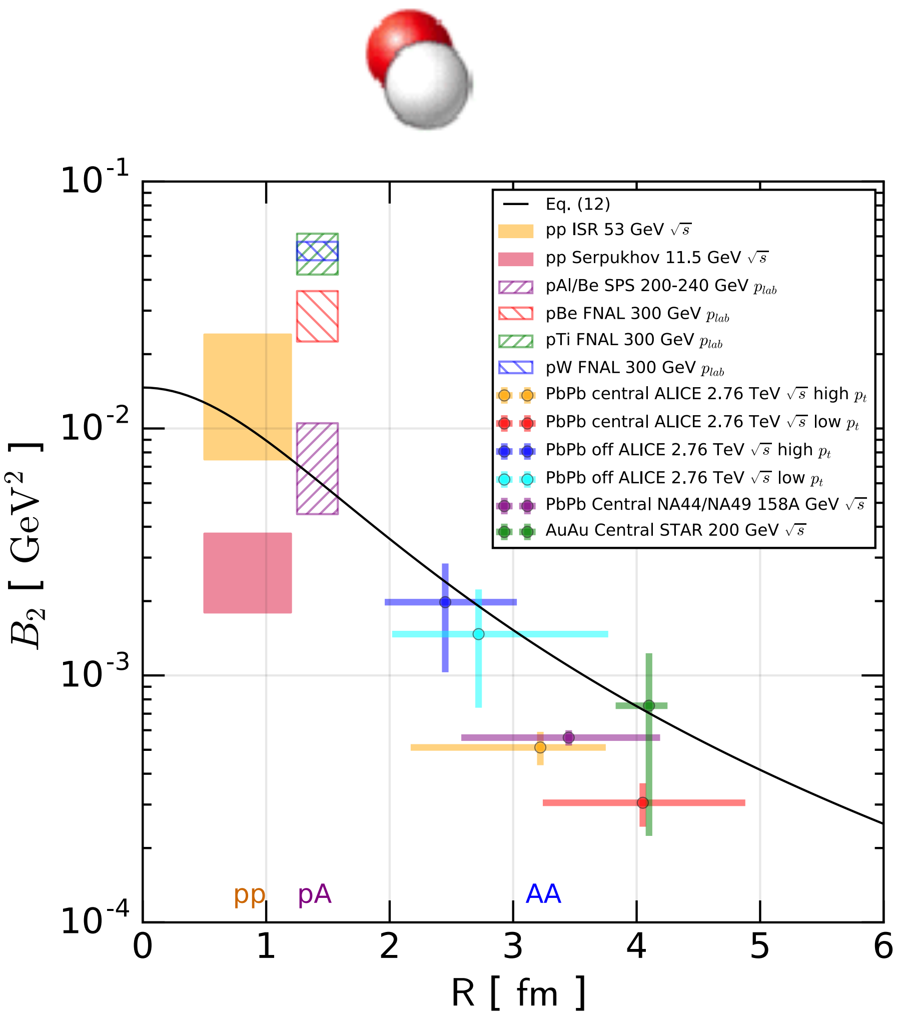
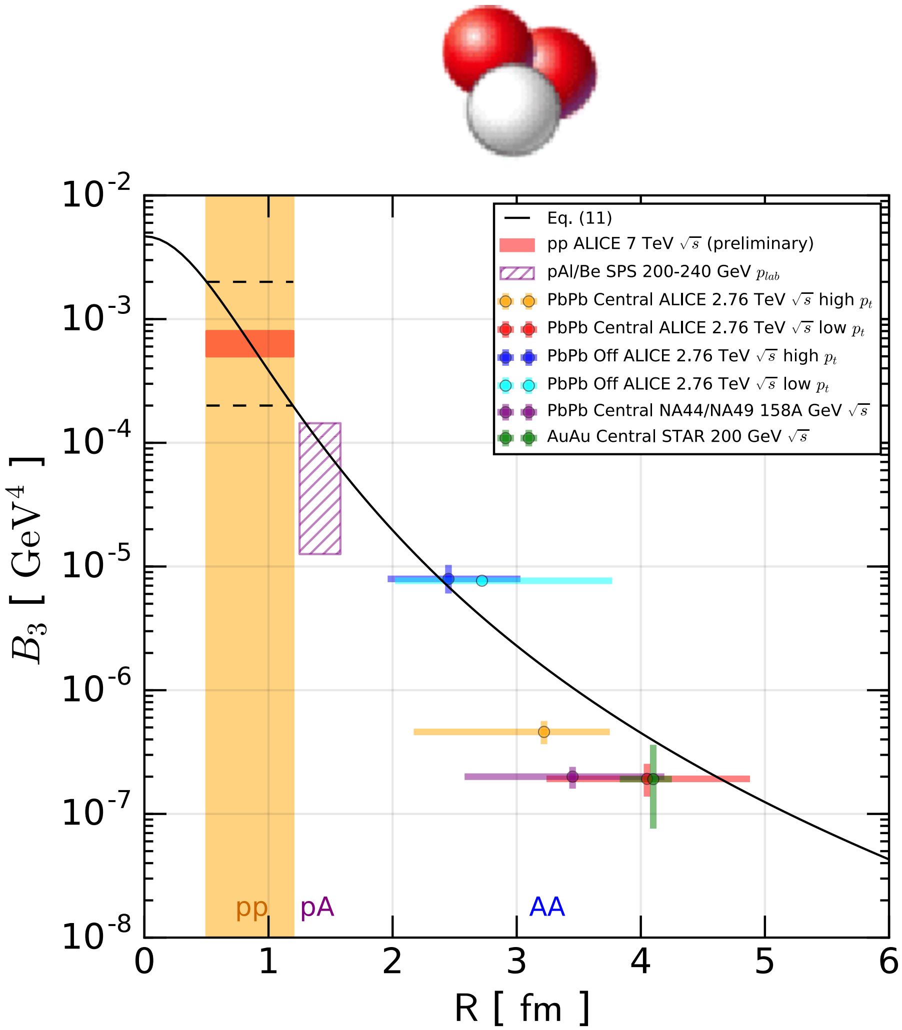


- Collected all systems for which we find nuclear yield & HBT data





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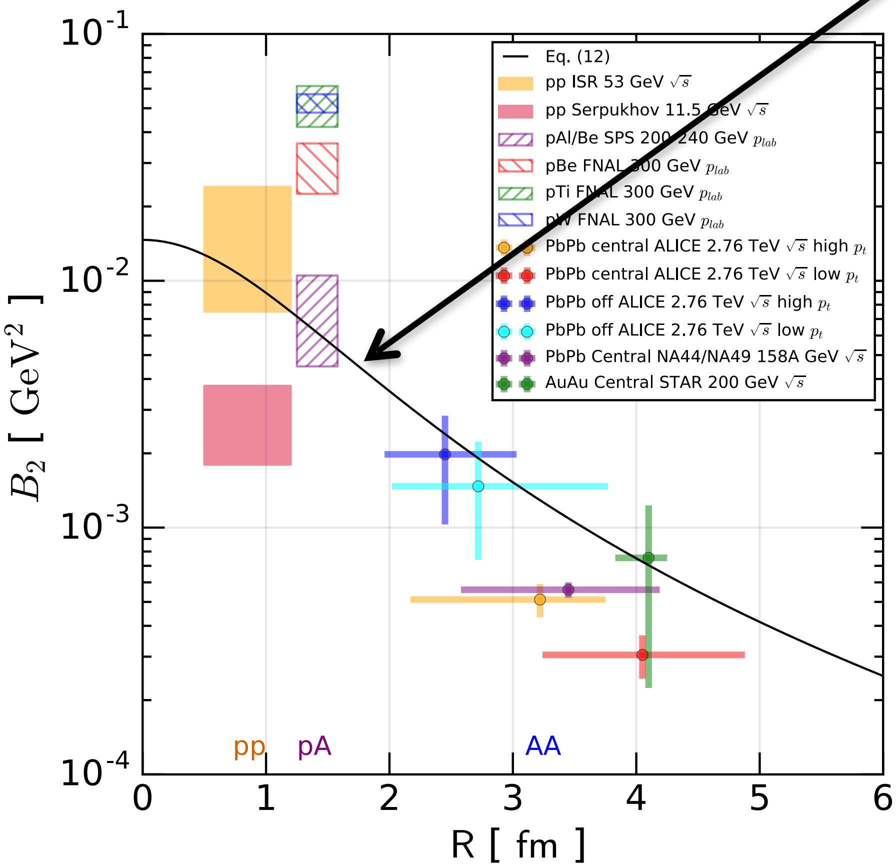

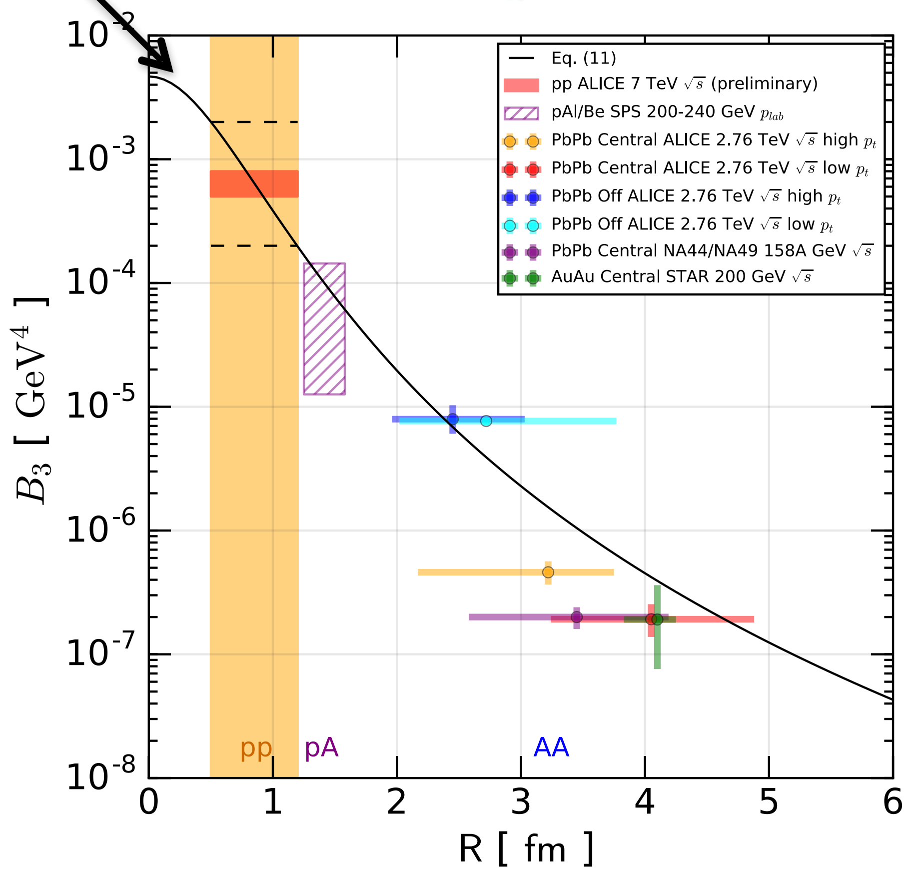

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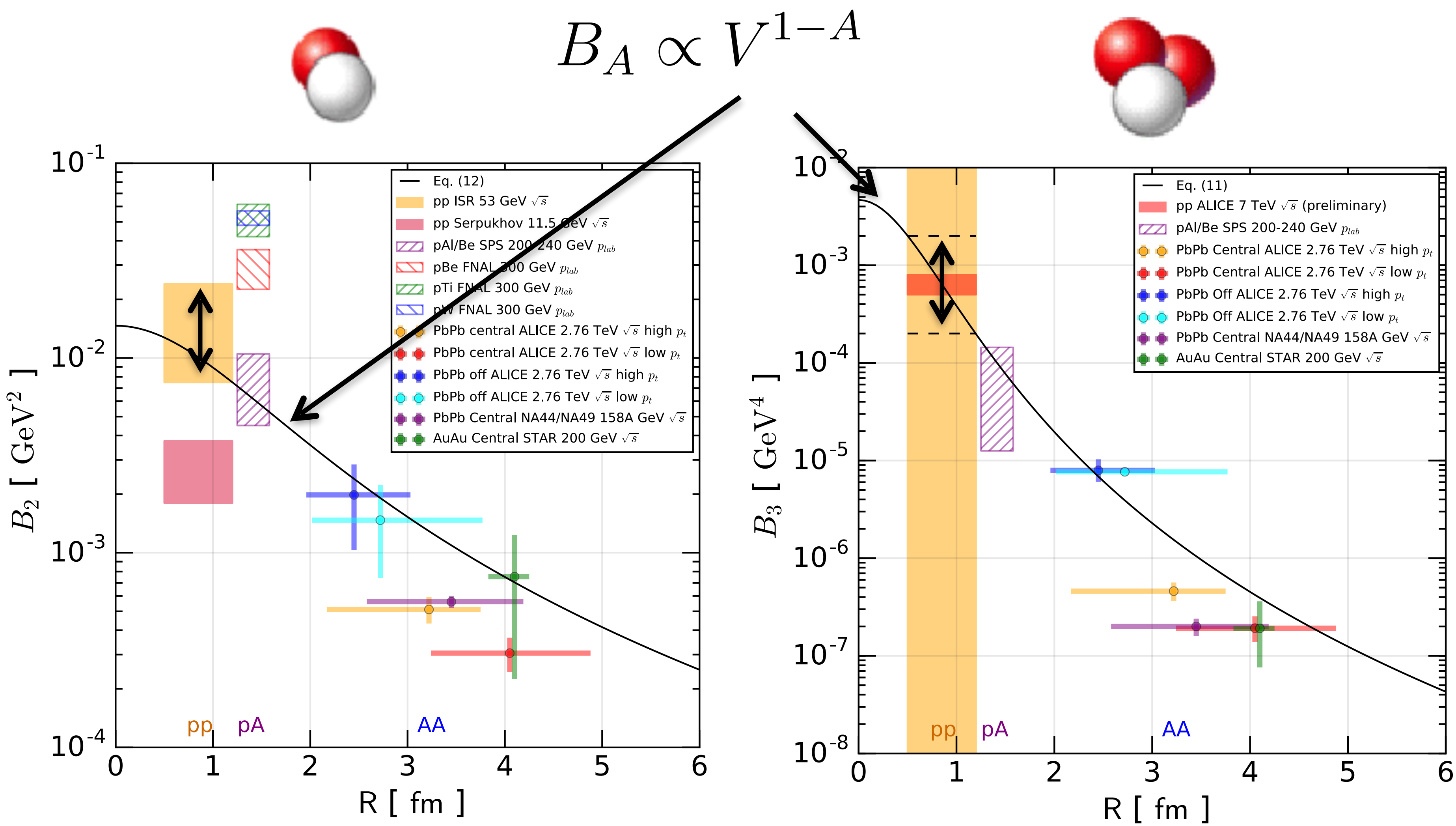

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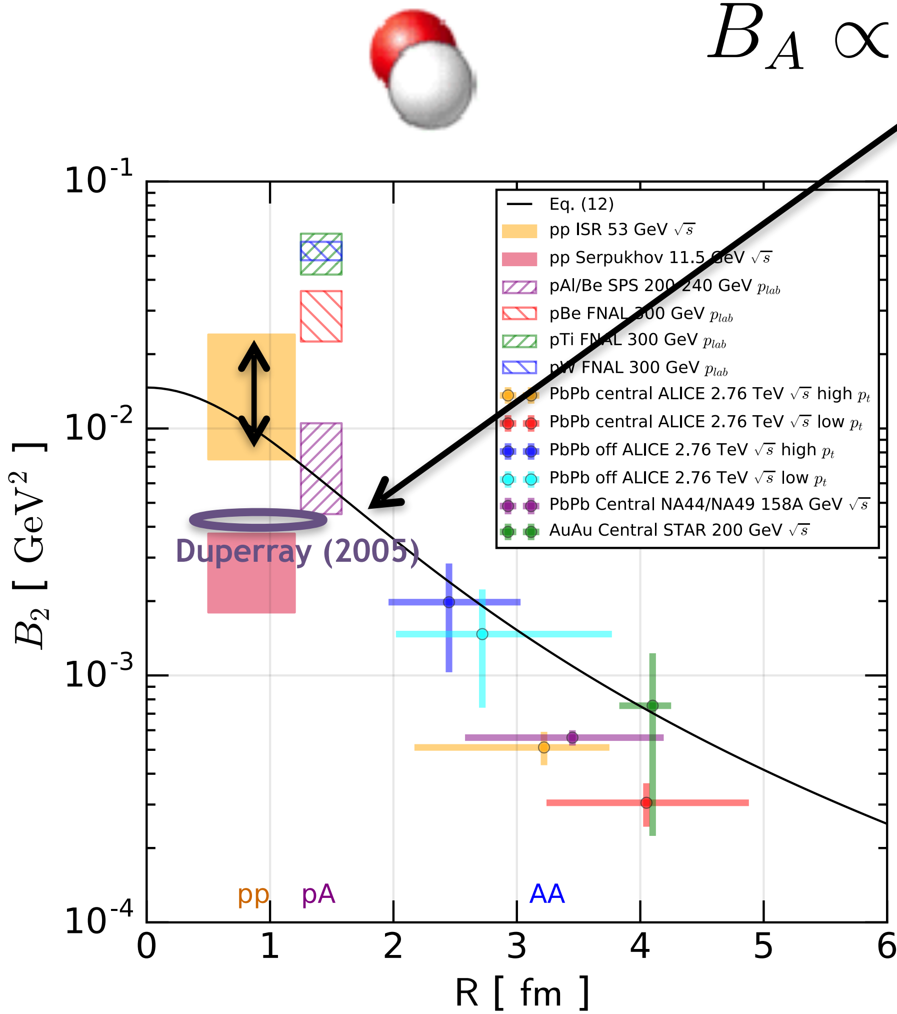

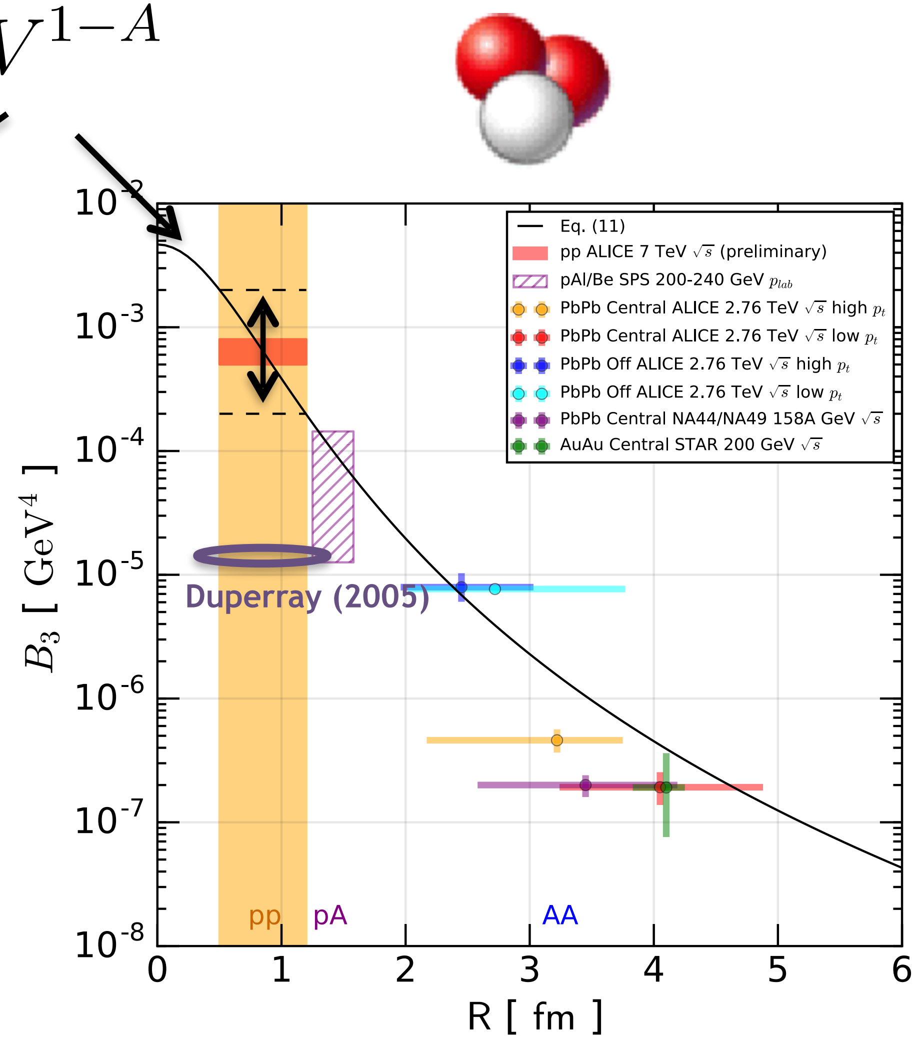

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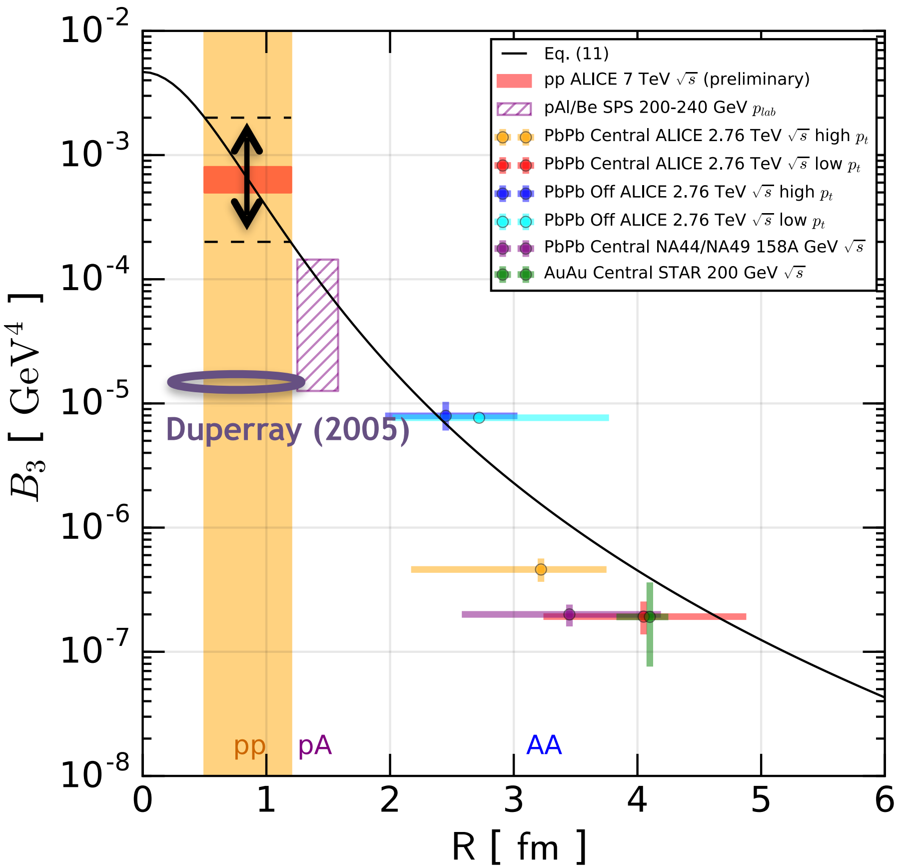

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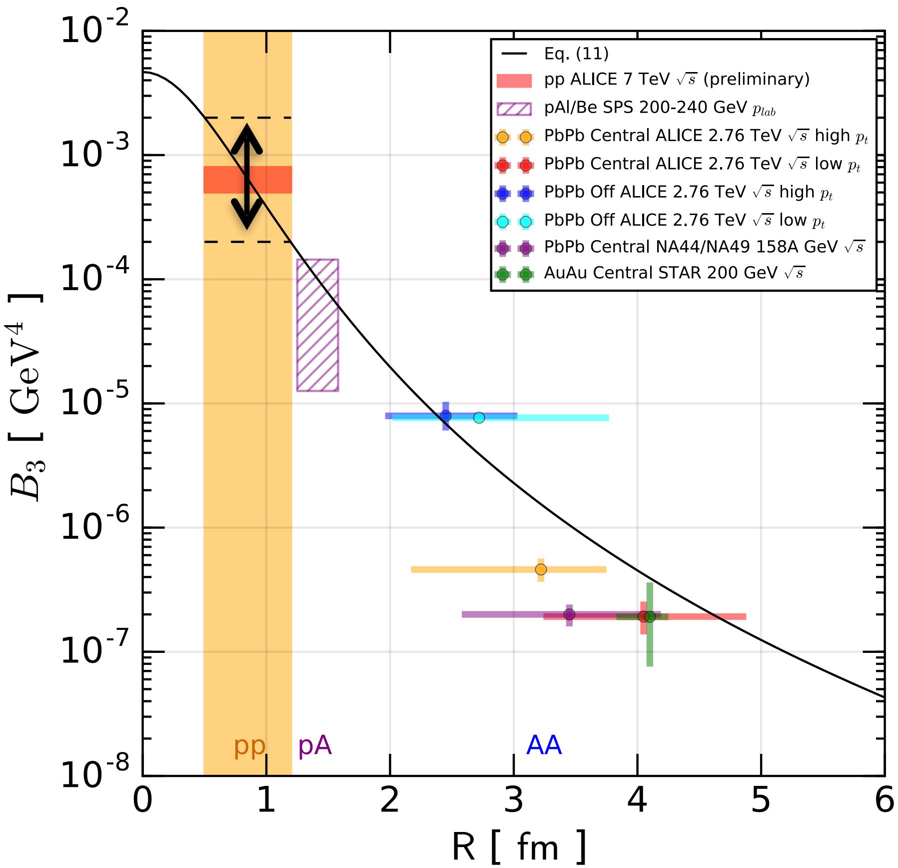

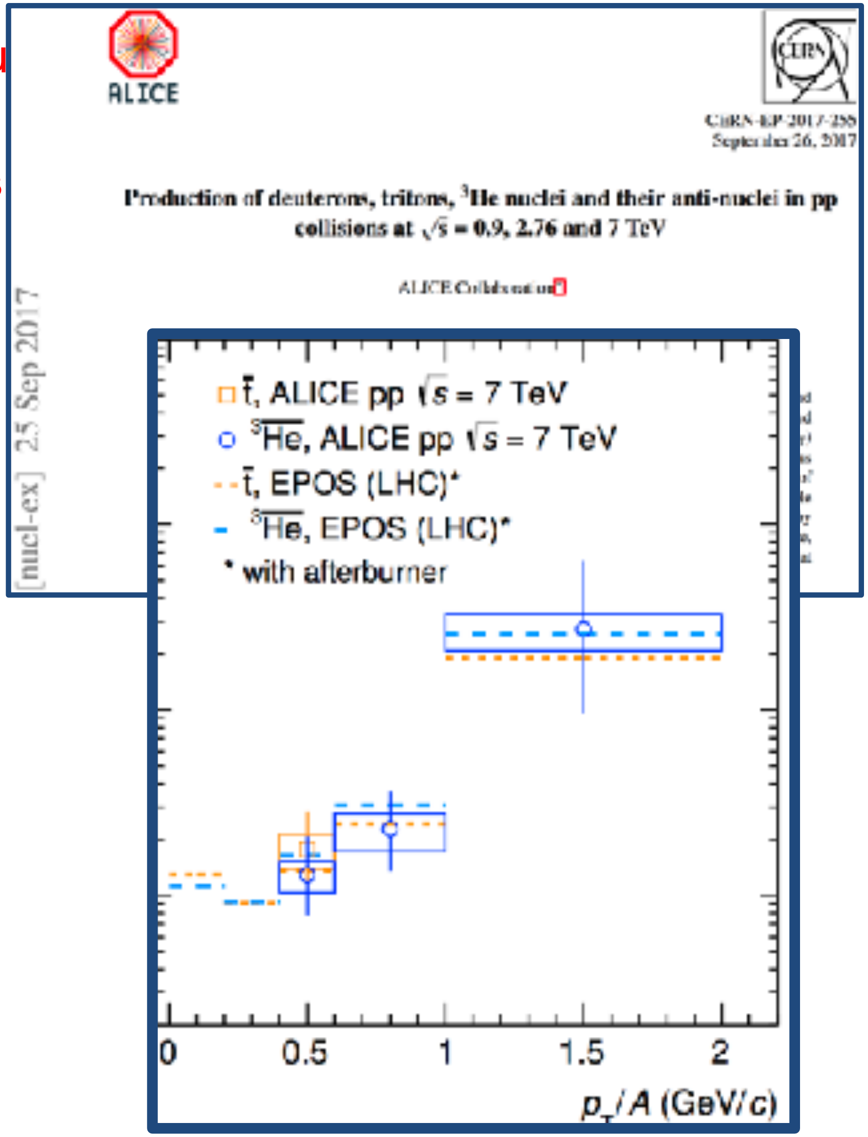

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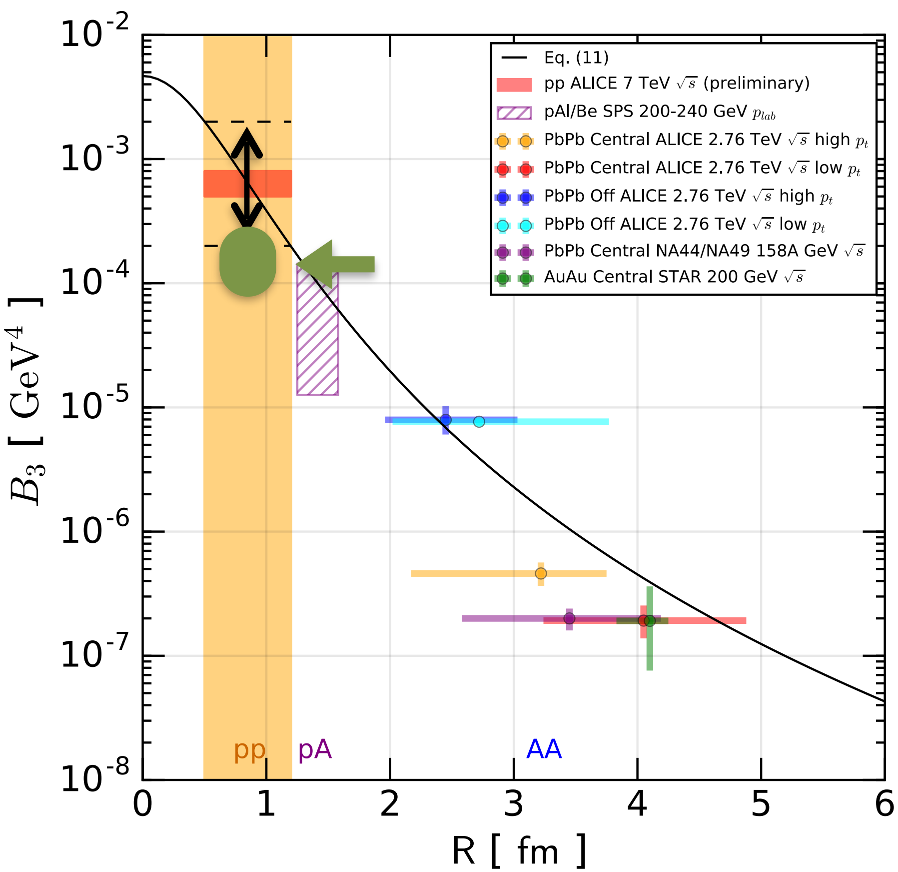
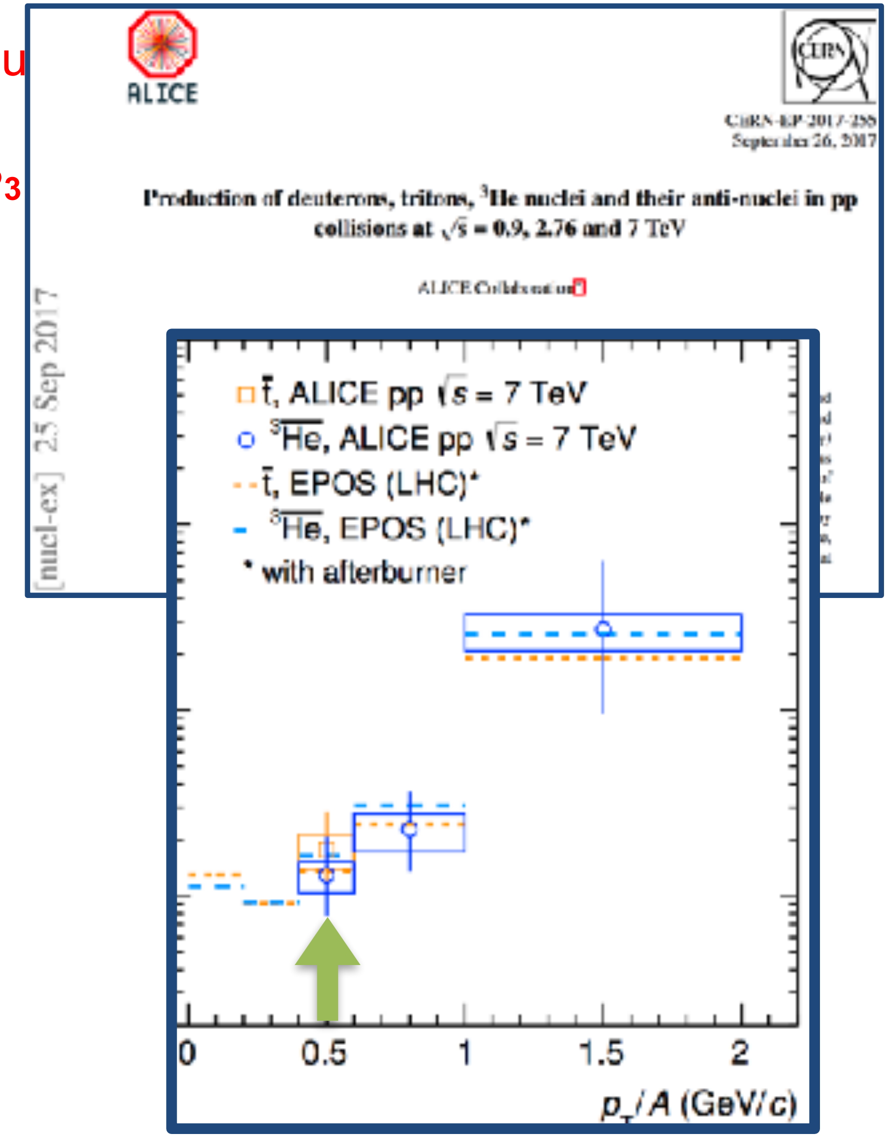
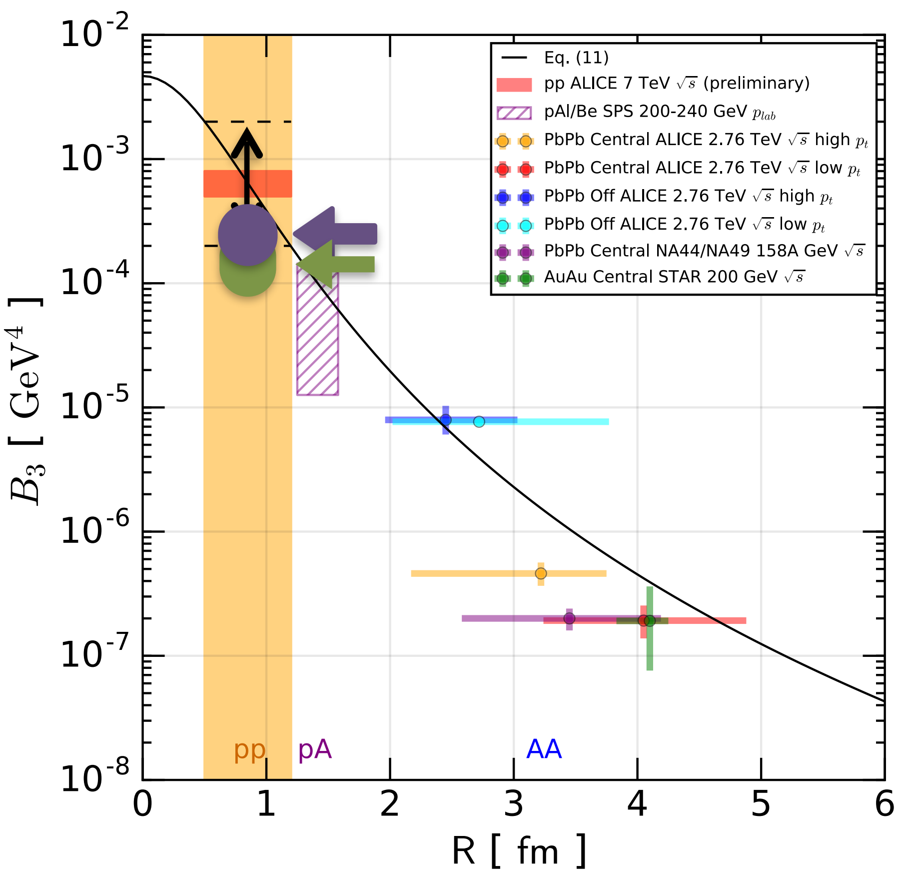
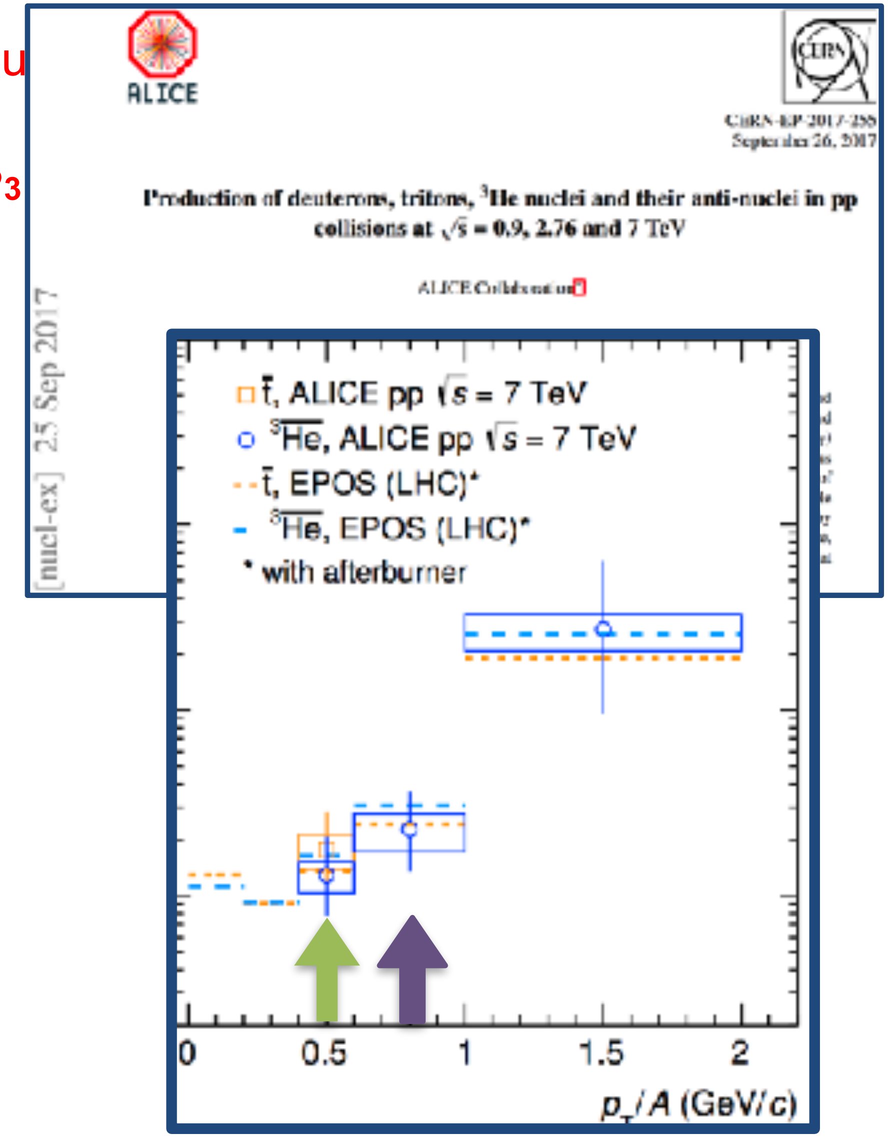




- Collected all systems for which we find nu
- For **pp**, *until Sep 26, 2017*, we **had no B_3**





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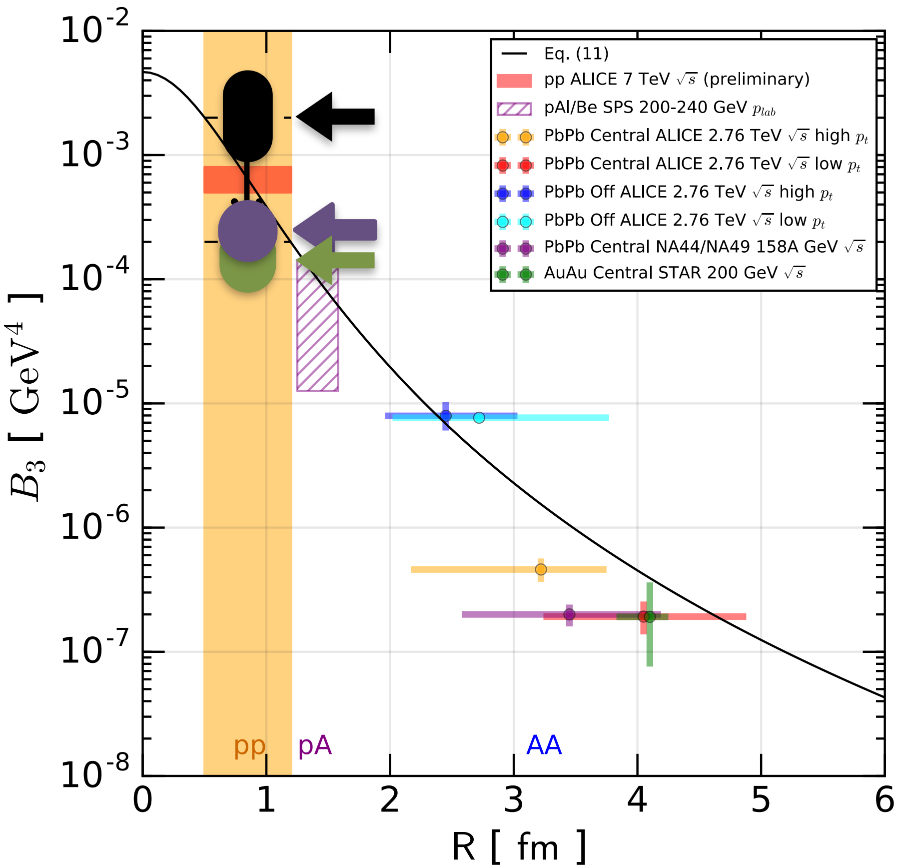
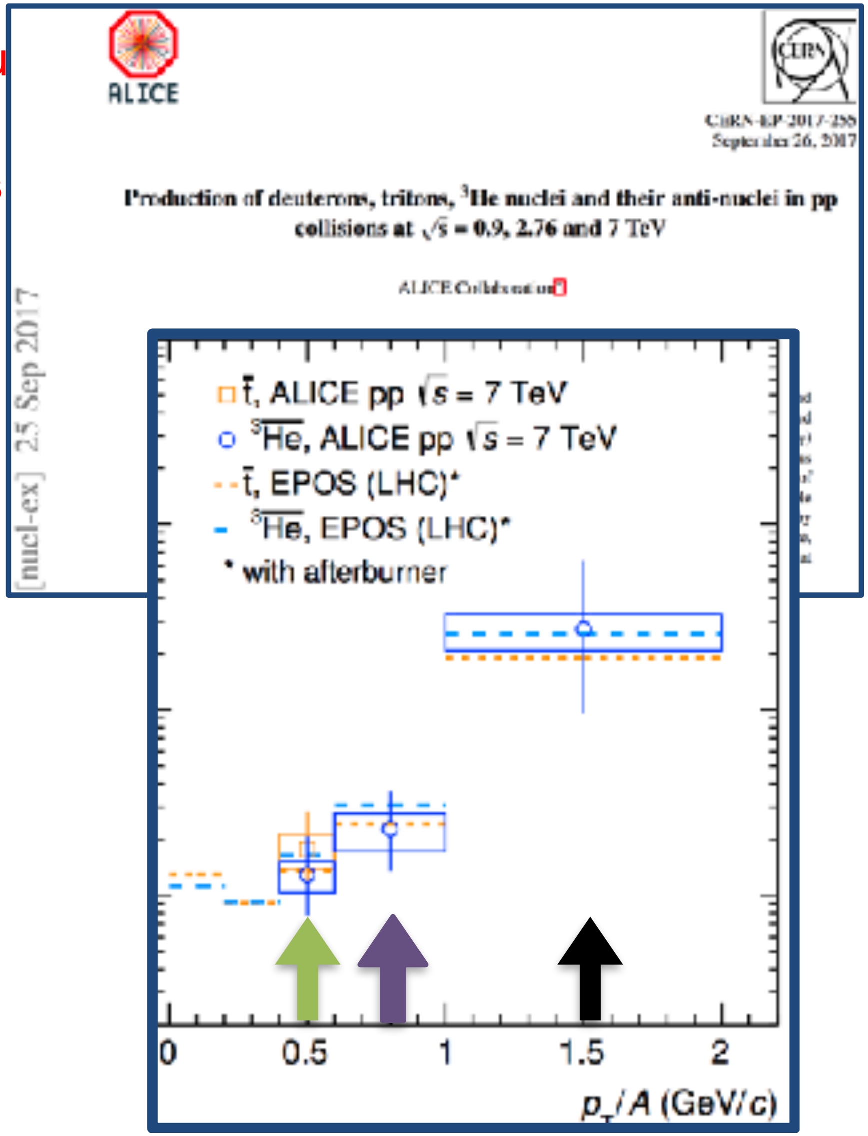
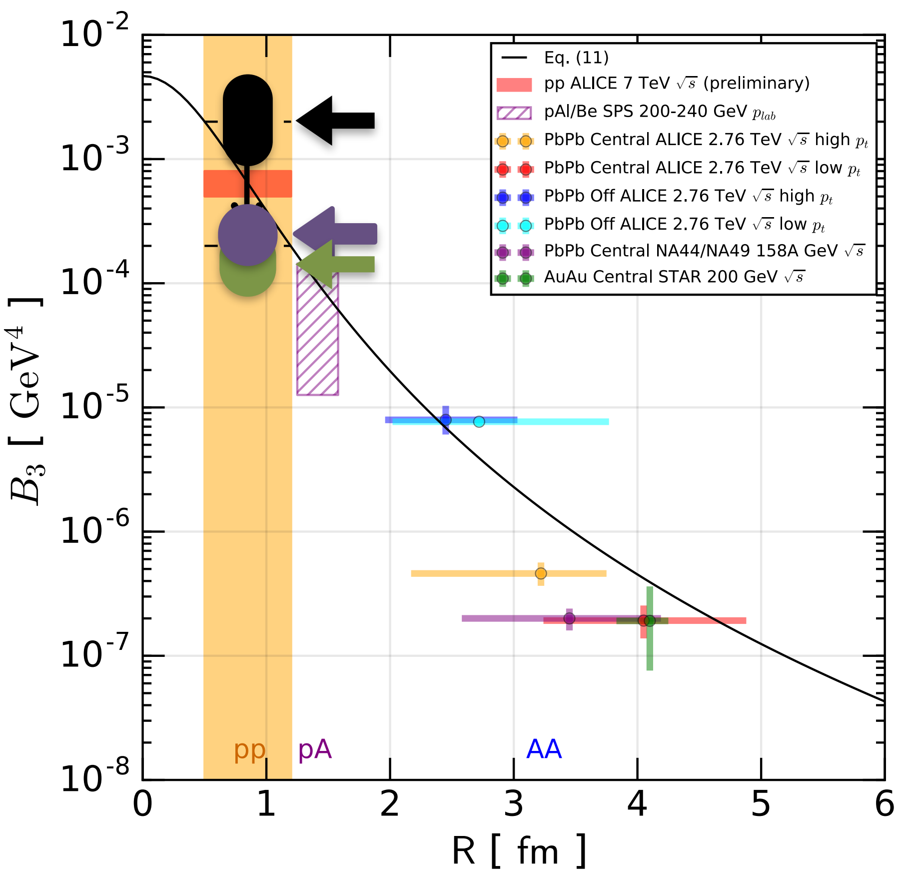


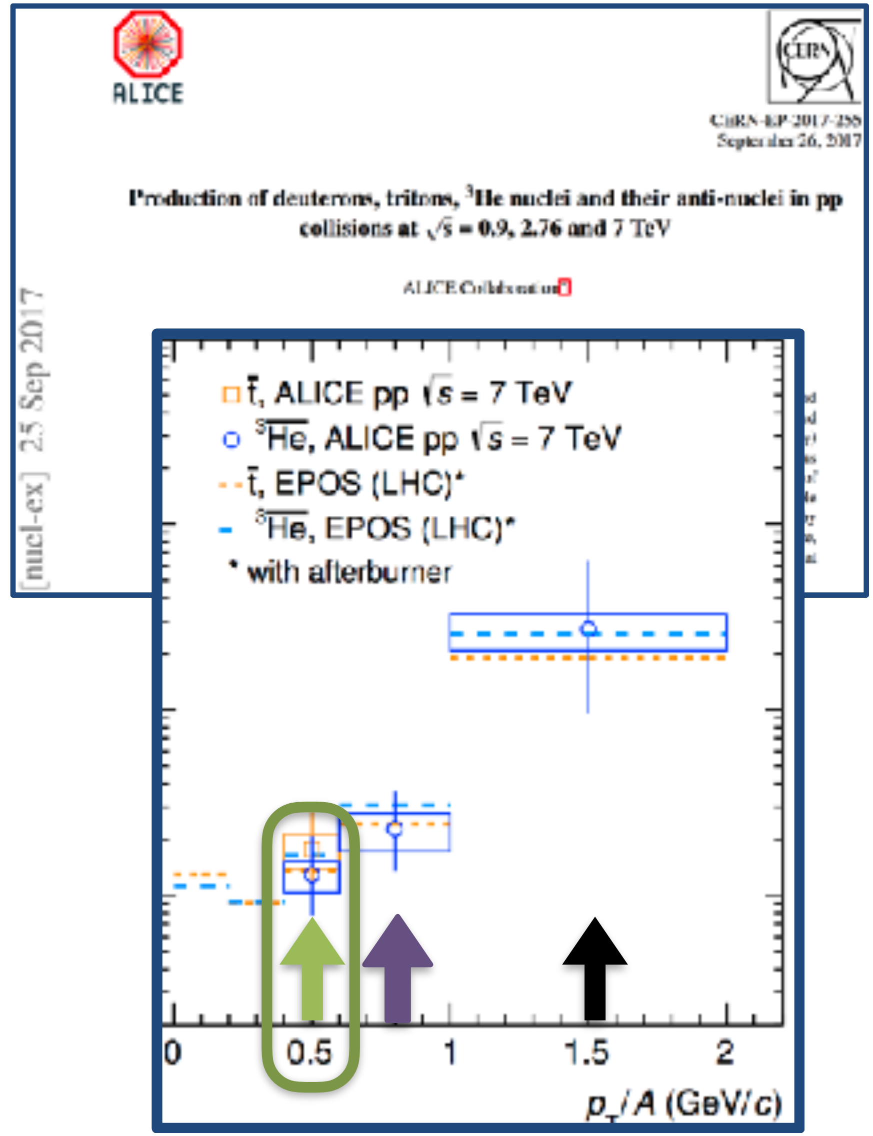


We got the basic picture more or less right.

But we have detailed data now: significant pT dependence in B3.

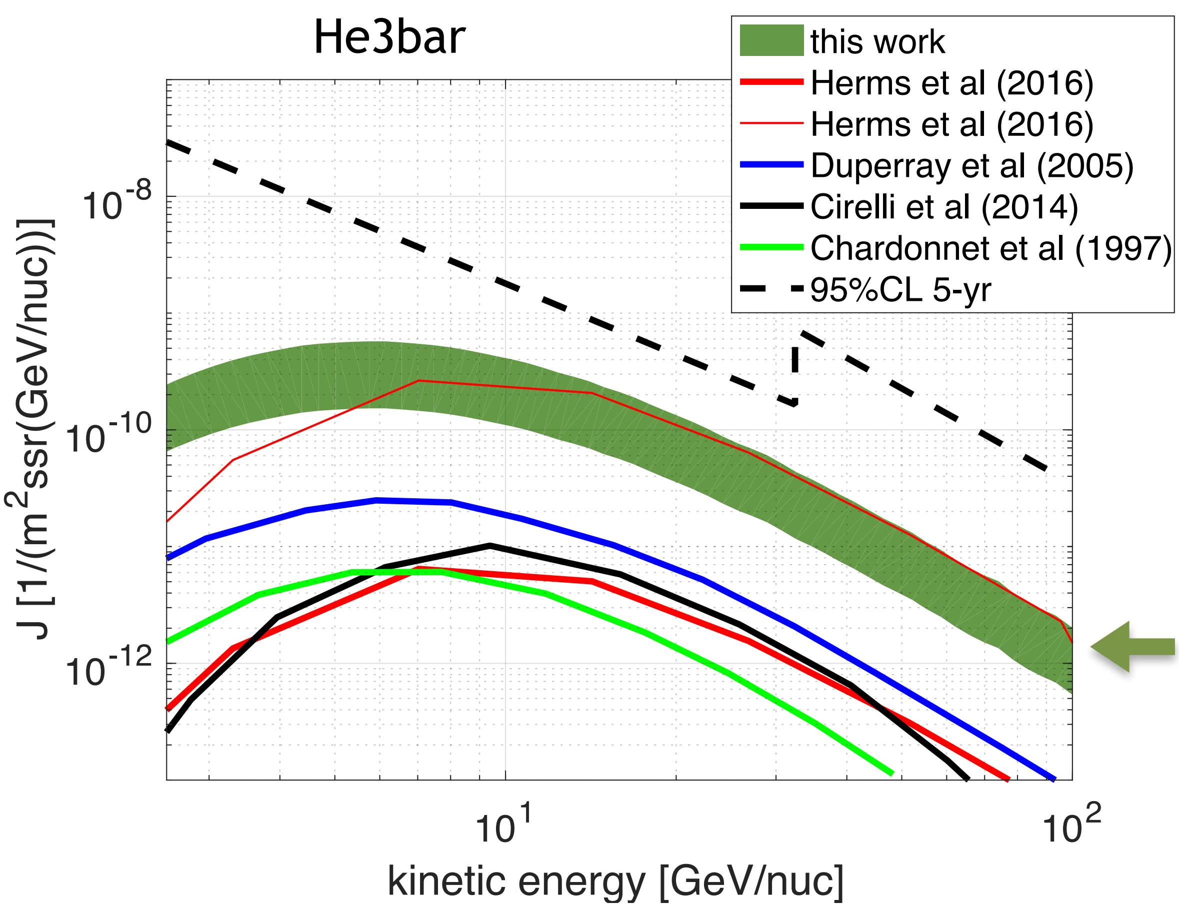
Most relevant for astro is pT/A < 0.5 GeV

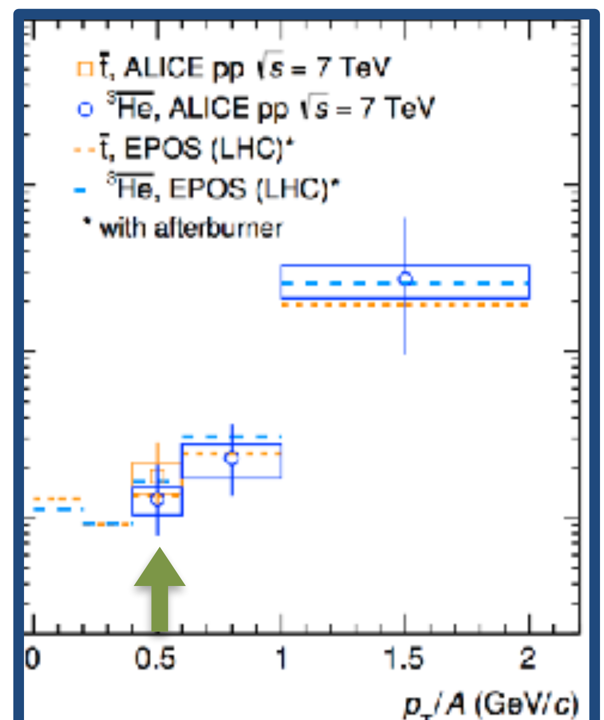




Implication of ALICE results for astrophysics.

He3bar: secondary production by pp collisions
unlikely to explain 1 event/yr at AMS02.



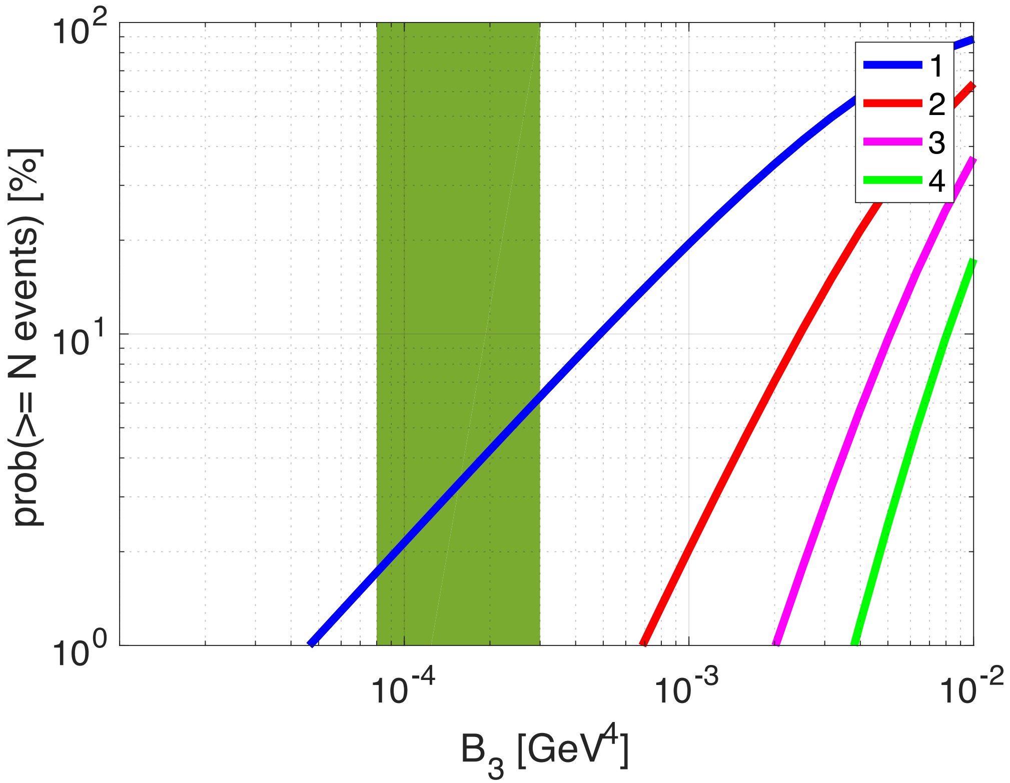


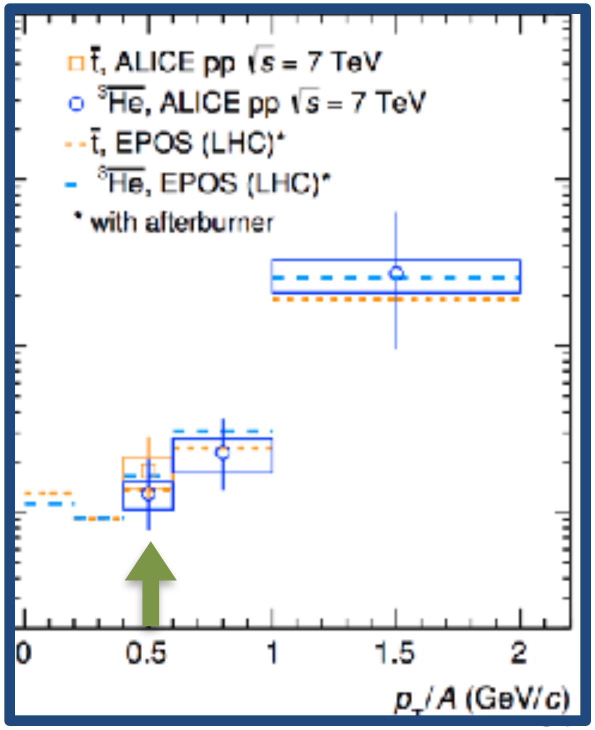
Implication of ALICE results for astrophysics.

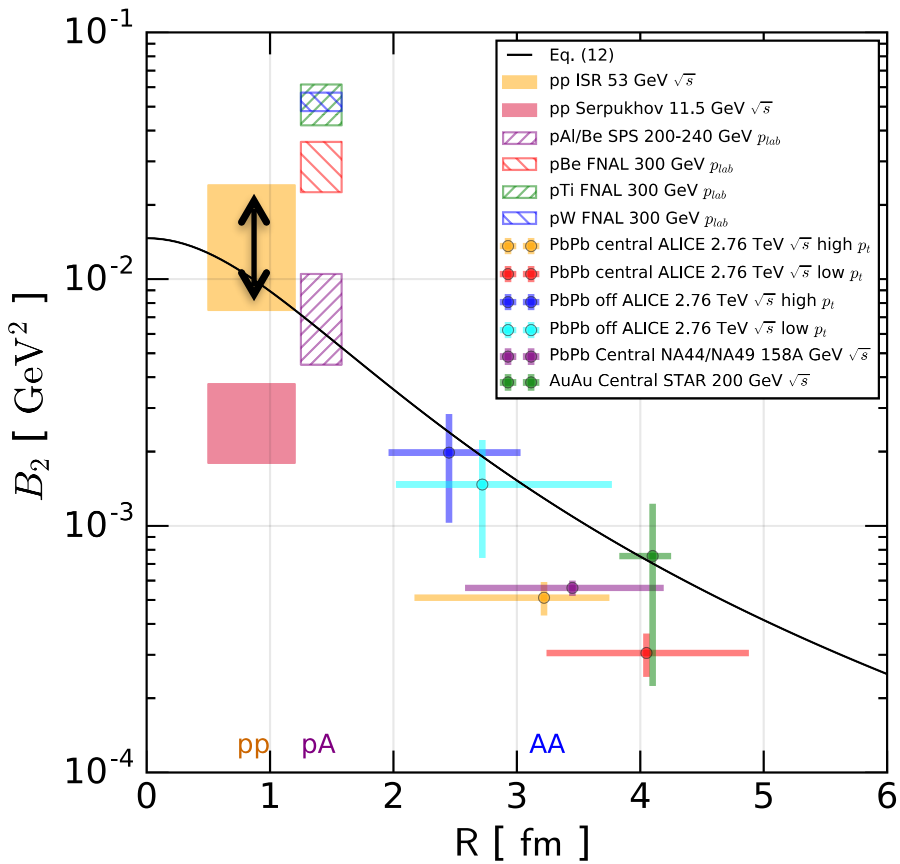
He3bar: secondary production by pp collisions
unlikely to explain 1 event/yr at AMS02.

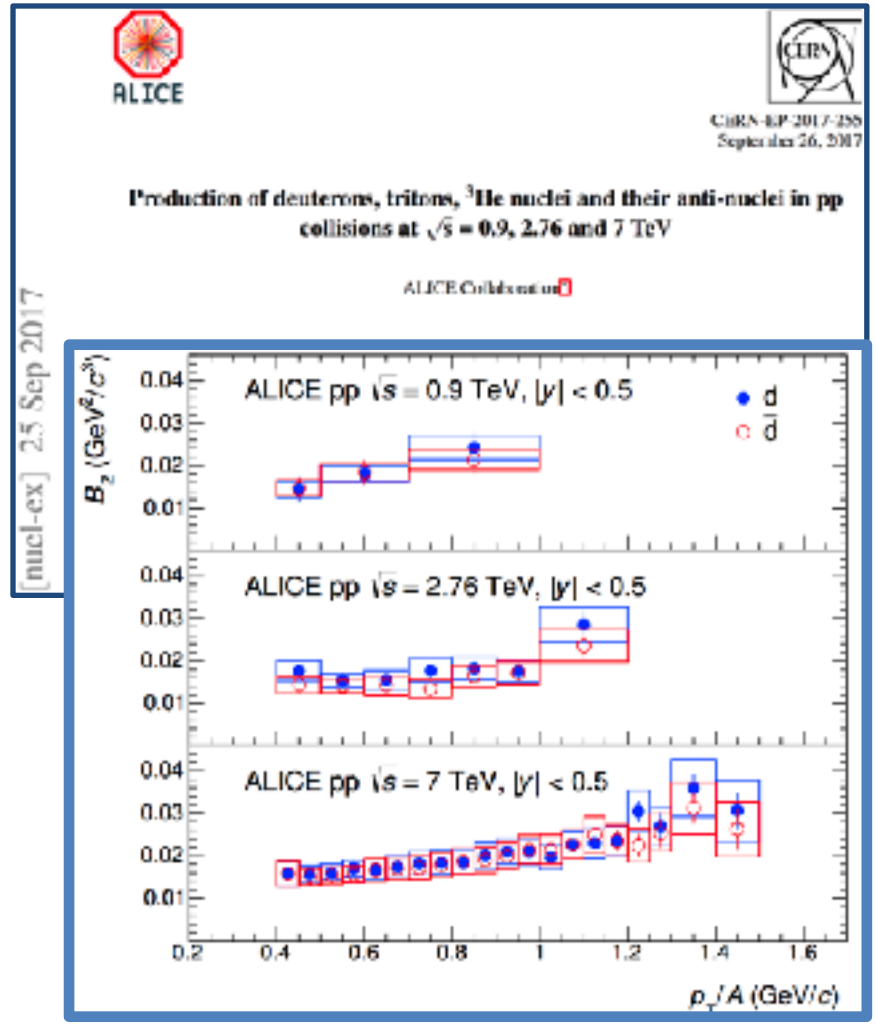
1 event/5yr we could live with, but 1 event/yr unlikely.

What about p-pbar collisions?
Are we missing a very large contribution in forward region?
…is AMS02 seeing background?






Eq. (12)
pp ISR 53 GeV $\sqrt{s}$
pp Serpukhov 11.5 GeV $\sqrt{s}$
pAl/Be SPS 200-240 GeV p_{lab}
pBe FNAL 300 GeV p_{lab}
pTi FNAL 300 GeV p_{lab}
pW FNAL 300 GeV p_{lab}
PbPb central ALICE 2.76 TeV $\sqrt{s}$ high p_t
PbPb central ALICE 2.76 TeV $\sqrt{s}$ low p_t
PbPb off ALICE 2.76 TeV $\sqrt{s}$ high p_t
PbPb off ALICE 2.76 TeV $\sqrt{s}$ low p_t
PbPb Central NA44/NA49 158A GeV $\sqrt{s}$
AuAu Central STAR 200 GeV $\sqrt{s}$
pp
pA
AA
B_2 [GeV^2]
R [fm]


ALICE
Production of deuterons, tritons, ^{3}He nuclei and their anti-nuclei in pp collisions at $\sqrt{s}$ = 0.9, 2.76 and 7 TeV
ALICE pp $\sqrt{s}$ = 0.9 TeV, |y| < 0.5
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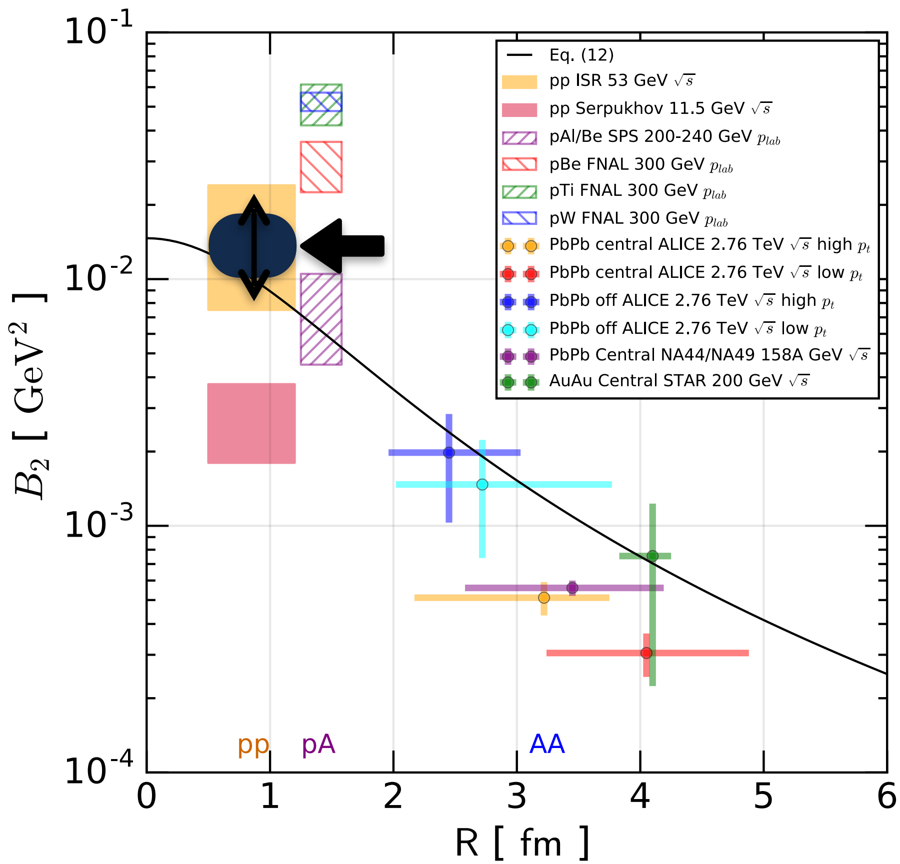
d
$\bar{d}$
B_2 (GeV^2/c^3)
p_T/A (GeV/c)



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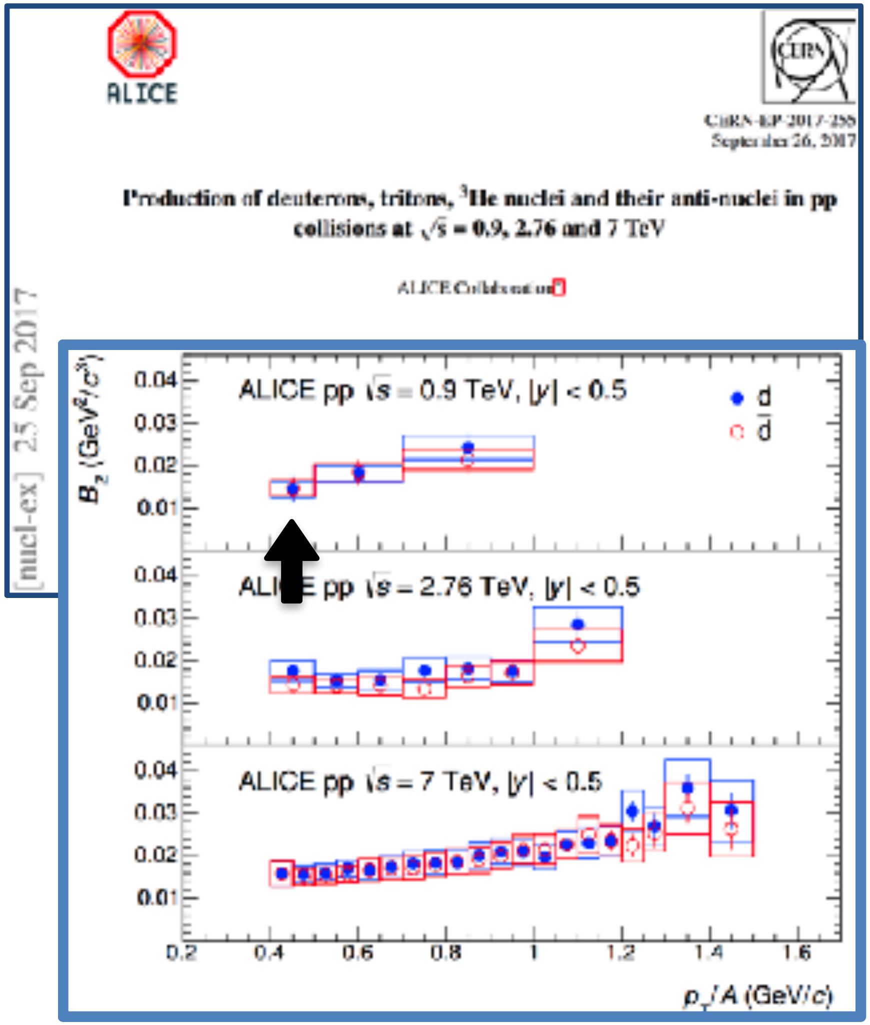

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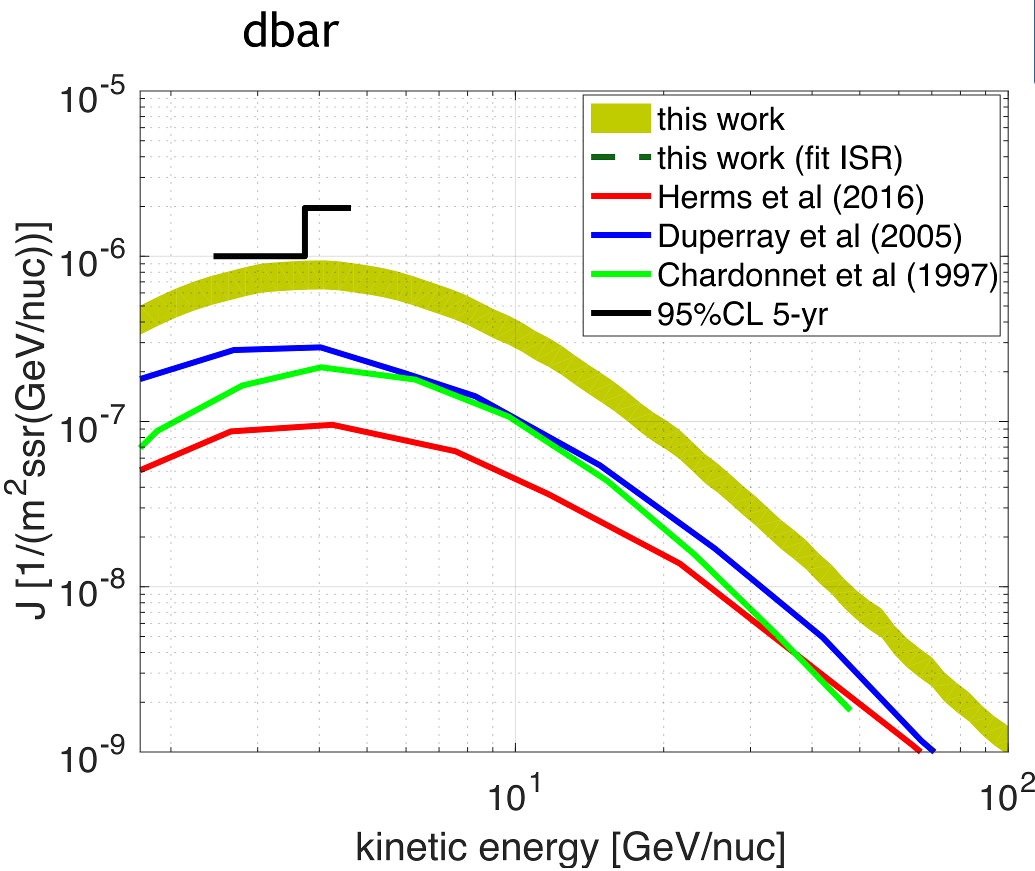
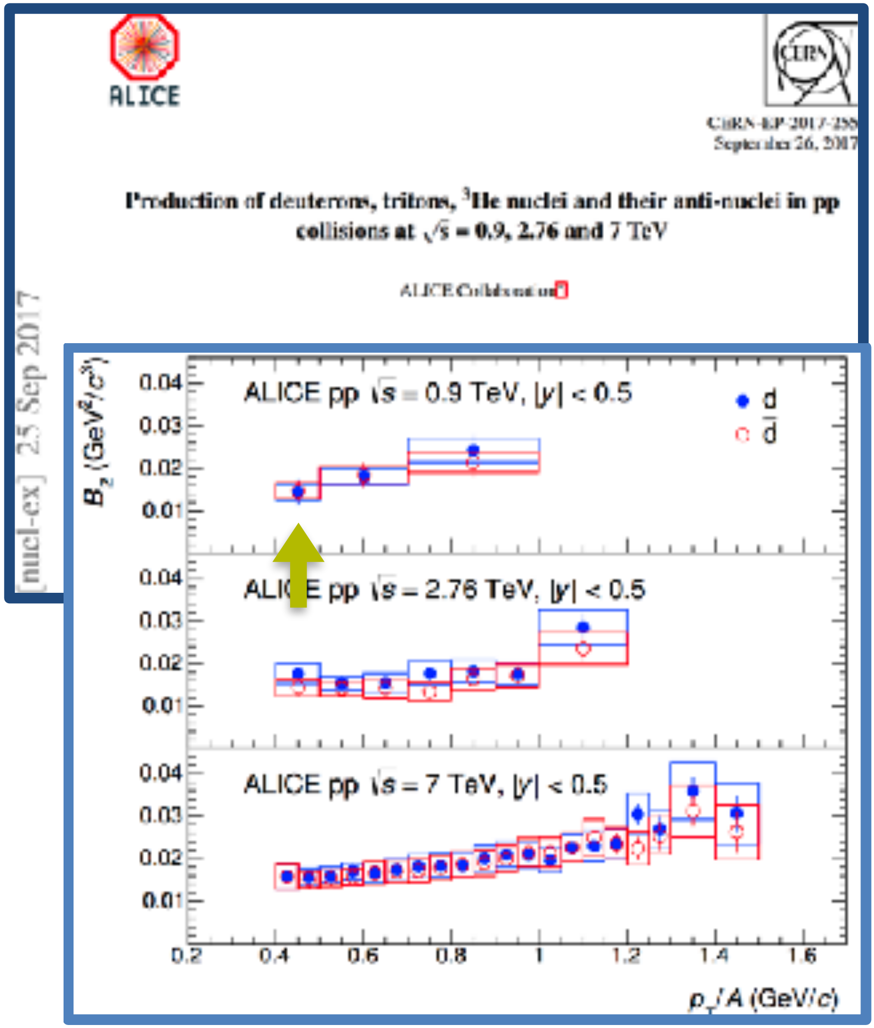
$\bar{d}$
B_2 (GeV^2/c^3)
p_T/A (GeV/c)

Implication of ALICE results for astrophysics.

dbar: secondary production by pp collisions **may** be seen at AMS02 5yr exposure.





Summary

Summary

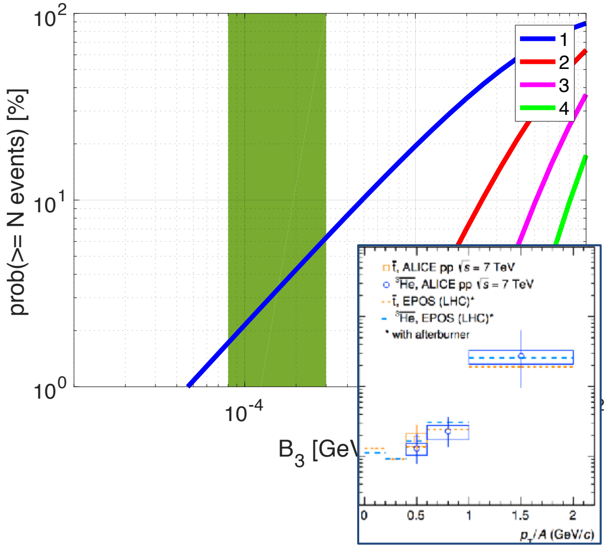
- Antiprotons consistent w/ secondary.

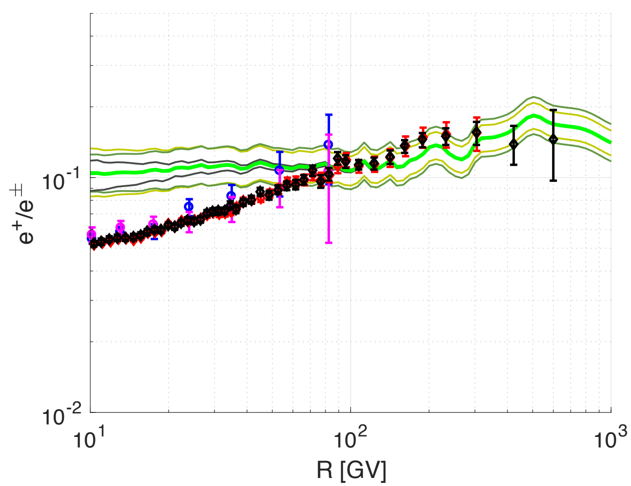
- **Positrons consistent with secondary.**

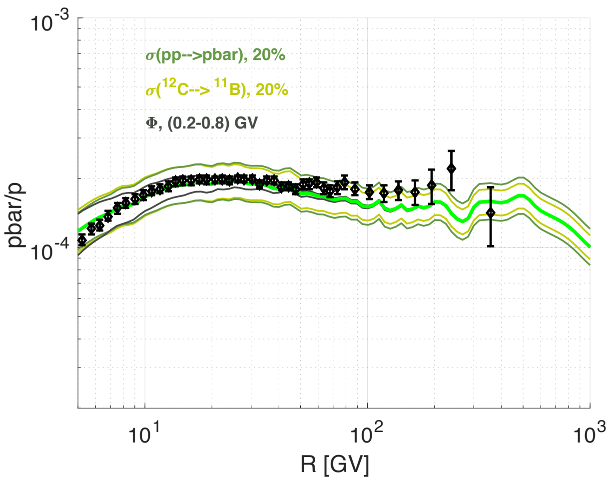
CR propagation more interesting than supposed in simplified diffusion models

- ***Secondary*** anti-He3, anti-d events in 5-year of AMS02?

1 anti-He3 event plausible. 5 events unlikely from (the naively dominant) pp collisions
Anti-d events: not much below, possibly in reach.







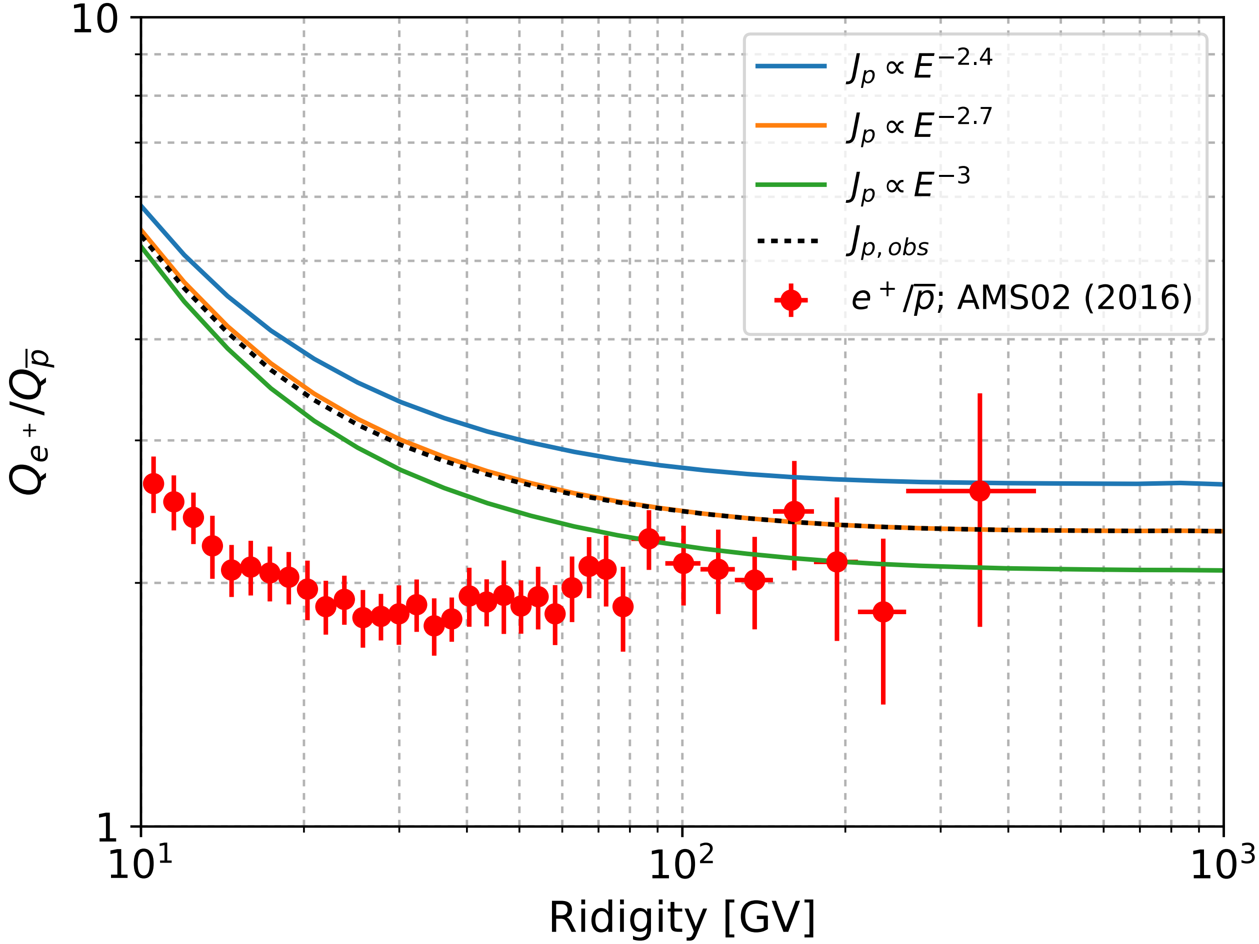
Xtra

$$\frac{n_{e^+}}{n_{\bar{p}}} = f_{e^+}(\mathcal{R})\frac{Q_{e^+}(\mathcal{R})}{Q_{\bar{p}}(\mathcal{R})}$$

Secondary upper bound

$$\boxed{f_{e^+}(\mathcal{R}) \leq 1}$$

More robust (no need to go via B/C):



MNRAS 405 (2010) 1458 Katz, Blum, Morag, Waxman

1709.04953, 1709.06507