Stefano Profumo

Santa Cruz Institute for Particle Physics

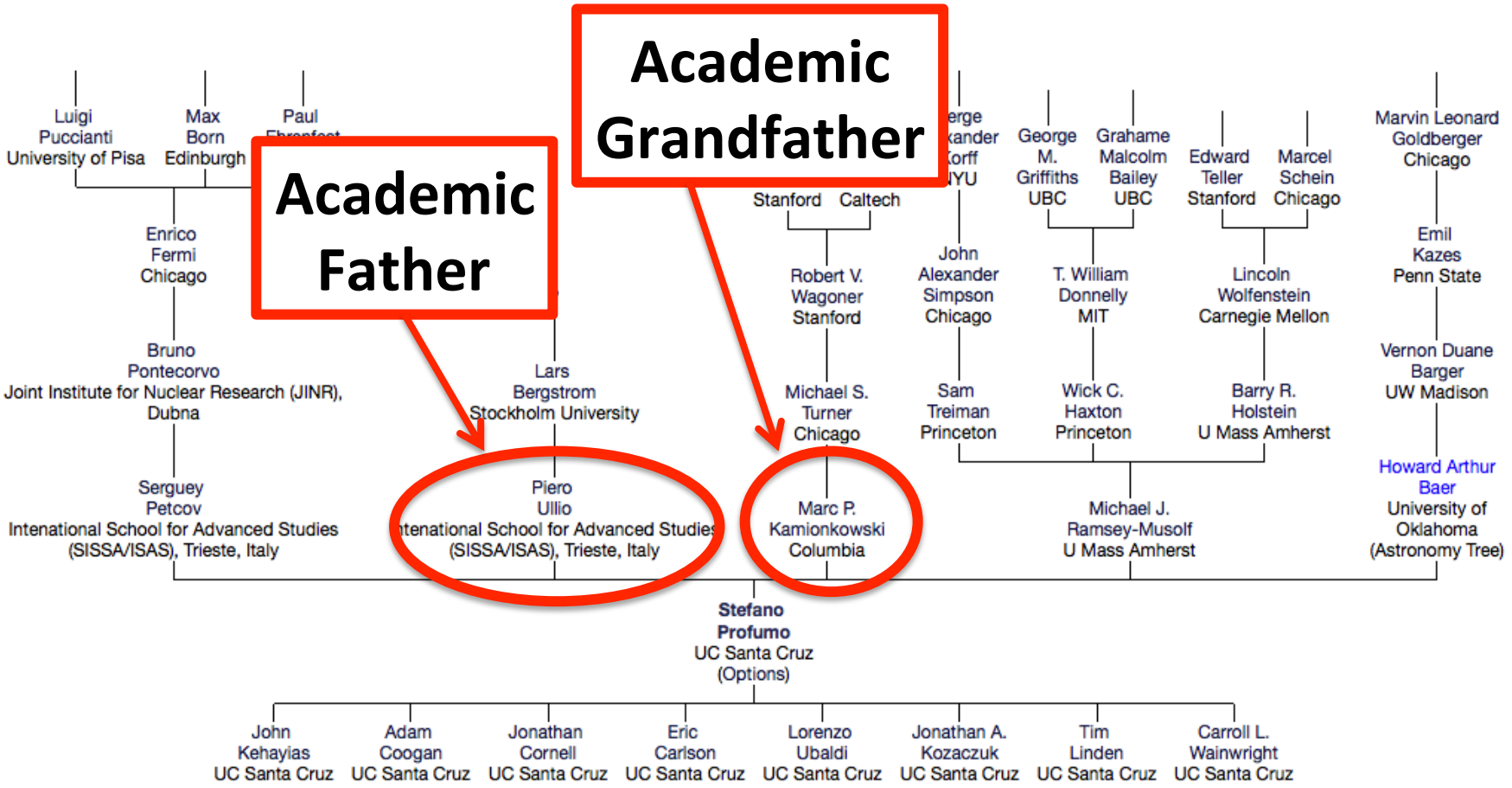
University of California, Santa Cruz

Antihelium from Dark Matter

Antideuteron 2019

UCLA, March 28, 2019

Antideuterons and dark matter run deep in my academic family



17 years ago!

THE ASTROPHYSICAL JOURNAL, 566:604–61[illegible], 2002 February 10

A NOVEL ANTIMATTER DETECTOR BASED ON X-RAY DEEXCITATION OF EXOTIC ATOMS

KAYA MORI,[1] CHARLES J. HAILEY,[1] EDWARD A. BALTZ,[1] WILLIAM W. CRAIG,[2] MARC KAMIONKOWSKI,[3] WILLIAM T. SERBER,[1] AND PIERO ULLIO[4]

Received 2001 July 19; accepted 2001 October 12

ABSTRACT

We propose a novel antiparticle detector. The gaseous antiparticle spectrometer (GAPS) effects particle identification through the characteristic X-rays emitted by antiparticles when they form exotic atoms in gases. GAPS obtains particularly high grasp (effective area–solid angle product) at lower particle energies, where conventional schemes are most limited in their utility. The concept is simple and lightweight, so it can be readily employed on balloon- and space-based missions. An extremely powerful potential application of GAPS is a space-based search for the neutralino through the detection of a neutralino annihilation by-product—the antideuteron. Paradoxically, this space-based search for the neutralino is capable of achieving comparable sensitivity to as yet unrealized third-generation, underground dark matter experiments. And GAPS can obtain this performance in a very modest satellite experiment. GAPS can also provide superior performance in searches for primary antiprotons produced via neutralino annihilation and black hole evaporation and in probing subdominant contributions to the antiproton flux at low energies. In a deep space mission, GAPS will obtain higher sensitivity for a given weight and power than BGO calorimeters.

Subject headings: atomic processes — cosmic rays — dark matter — techniques: spectroscopic

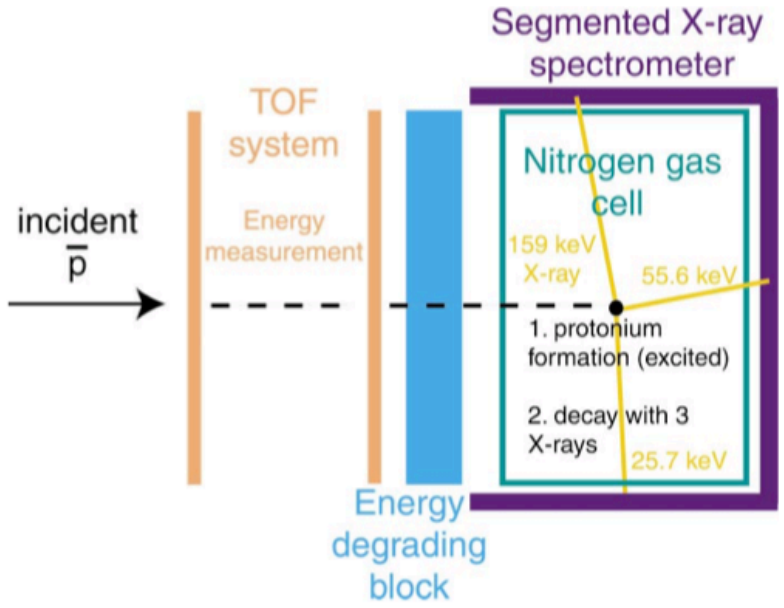


FIG. 5.—Operating principal of the GAPS detector using antiprotons as an example.

...design (and acronym) has significantly evolved (see Sean Quinn's talk earlier today)

...but key science target of opportunity remains the same!

this curve also evolved quite a bit

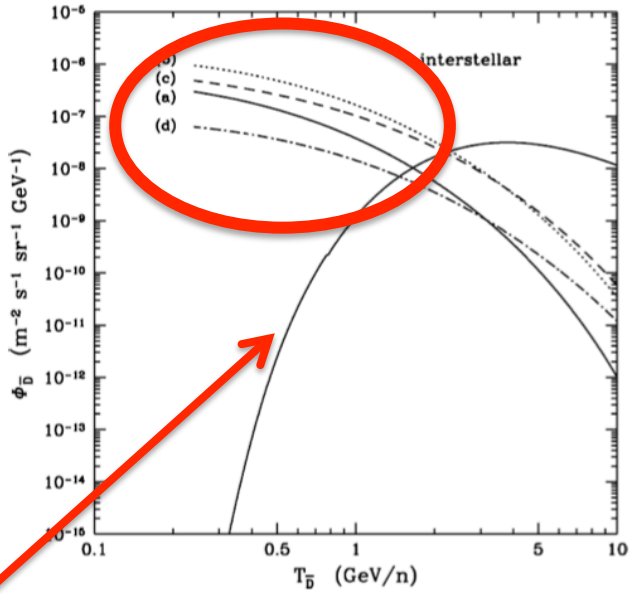


FIG. 3.—Interstellar flux of secondary antideuterons (*heavier solid curve*) decreases at low energy, whereas the energy spectrum of the antideuterons from supersymmetric origin (*curves a–d*) tends to flatten (from Donato et al. 2000).

Mori et al (2002)

The Mori+ 2002 GAPS proposal also mentions anti-Helium searches

** not so difficult anymore:
Alberto Oliva's talk, yesterday:

Anti-Helium Search Status

Currently, AMS observed 8 anti-helium candidates (mass region from 0-10 GeV/c^2) with rigidity <50 GV with respect to a sample of 700 million helium events selected.

The rate of anti-helium is about 1 in 100 million helium

Six candidates are in the mass region of 3He and two in the mass region of ^{4}He.

More events are necessary to augment the significance and ensure that there are no backgrounds.

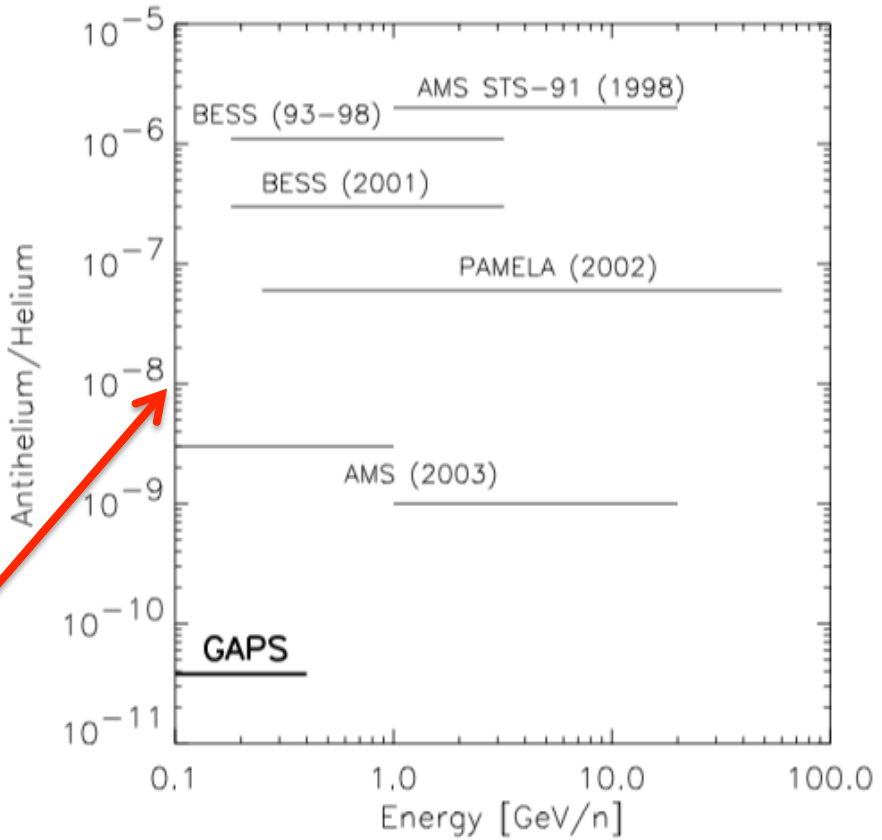


FIG. 11.—Comparison of the upper limits of the ratio $\bar{\text{He}}$/He

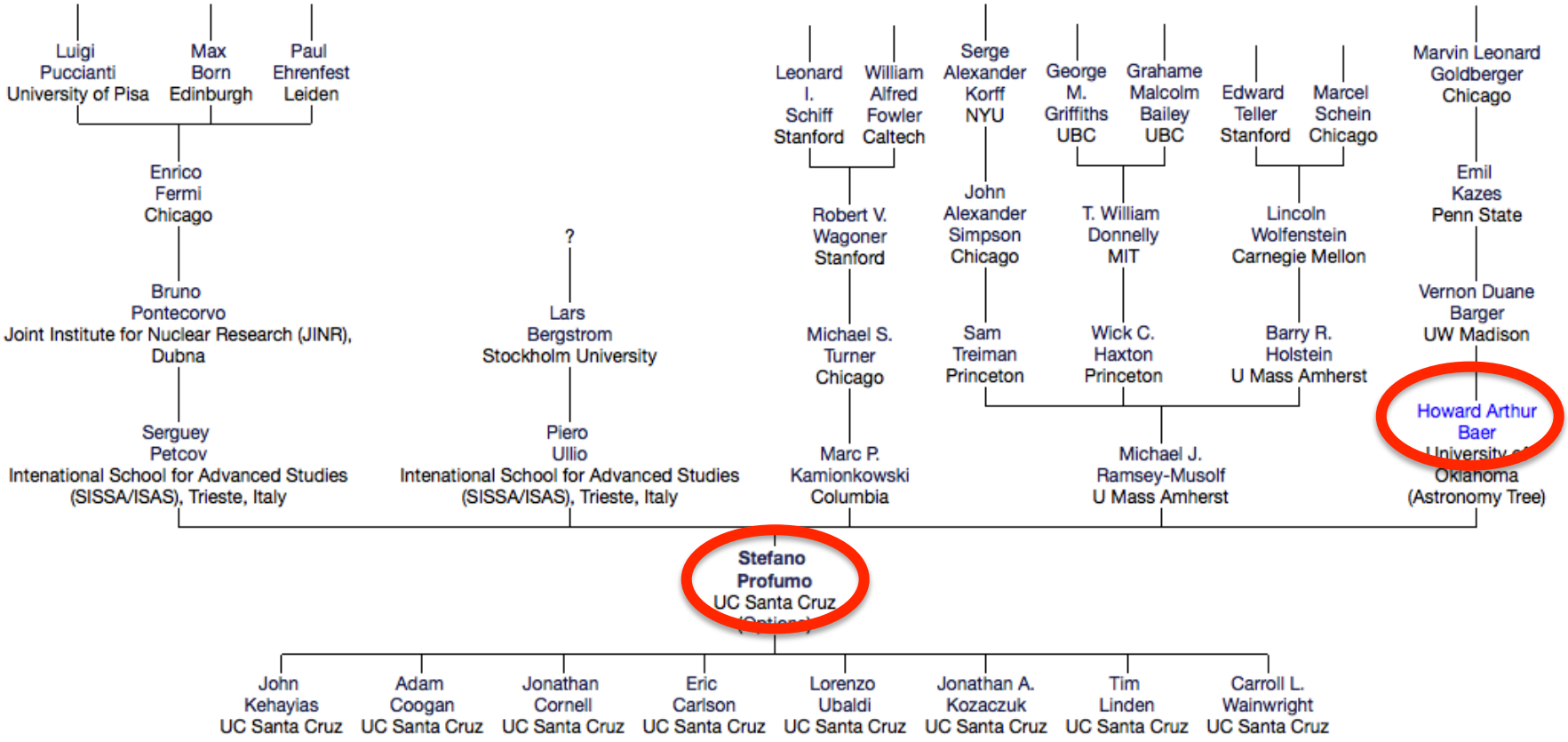
1.3. *Antihelium*

The discovery of a single antihelium atom is compelling evidence for the existence of an antimatter domain* in the universe. Such searches are highly problematic and thus difficult to motivate.** In particular, observational con-

*Scooped Vivian Poulin 17 years ago!

Mori et al (2002)

To anybody who has been working for almost two decades on indirect dark matter searches, a virtually "background-free" channel is a Holy Grail!



Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Low energy antideuterons: shedding light on dark matter

Howard Baer[1] **and Stefano Profumo**[1,2]

[1] Department of Physics, Florida State University, Tallahassee, FL 32306, USA
[2] California Institute of Technology, Mail Code 106-38, Pasadena, CA 91125, USA
E-mail: baer@hep.fsu.edu and profumo@caltech.edu

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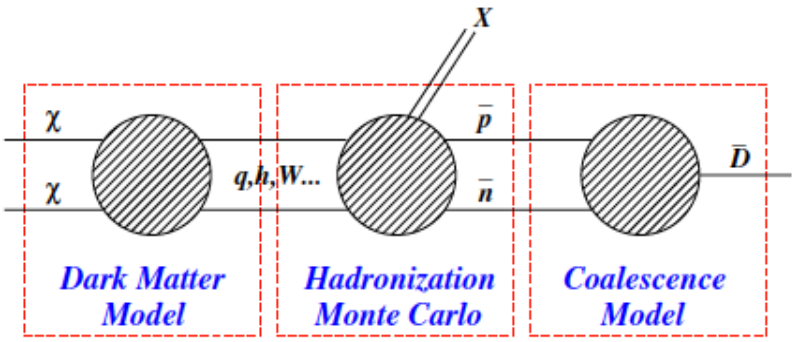
Abstract. Low energy antideuterons suffer a very low secondary and tertiary astrophysical background, while they can be abundantly synthesized in dark matter pair annihilations, therefore providing a privileged indirect dark matter detection technique. The recent publication of the first upper limit on the low energy antideuteron flux by the BESS Collaboration, a new evaluation of the standard astrophysical background, and remarkable progress in the

JCAP12(2005)008

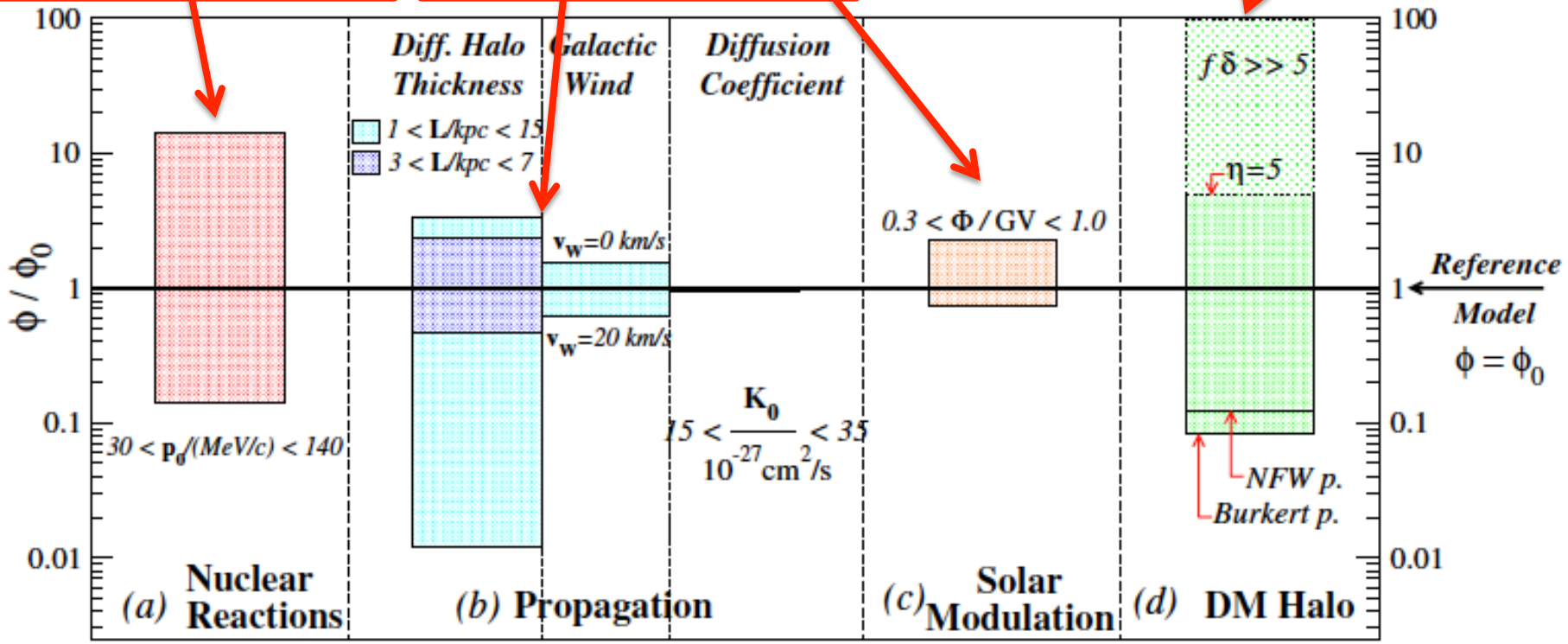


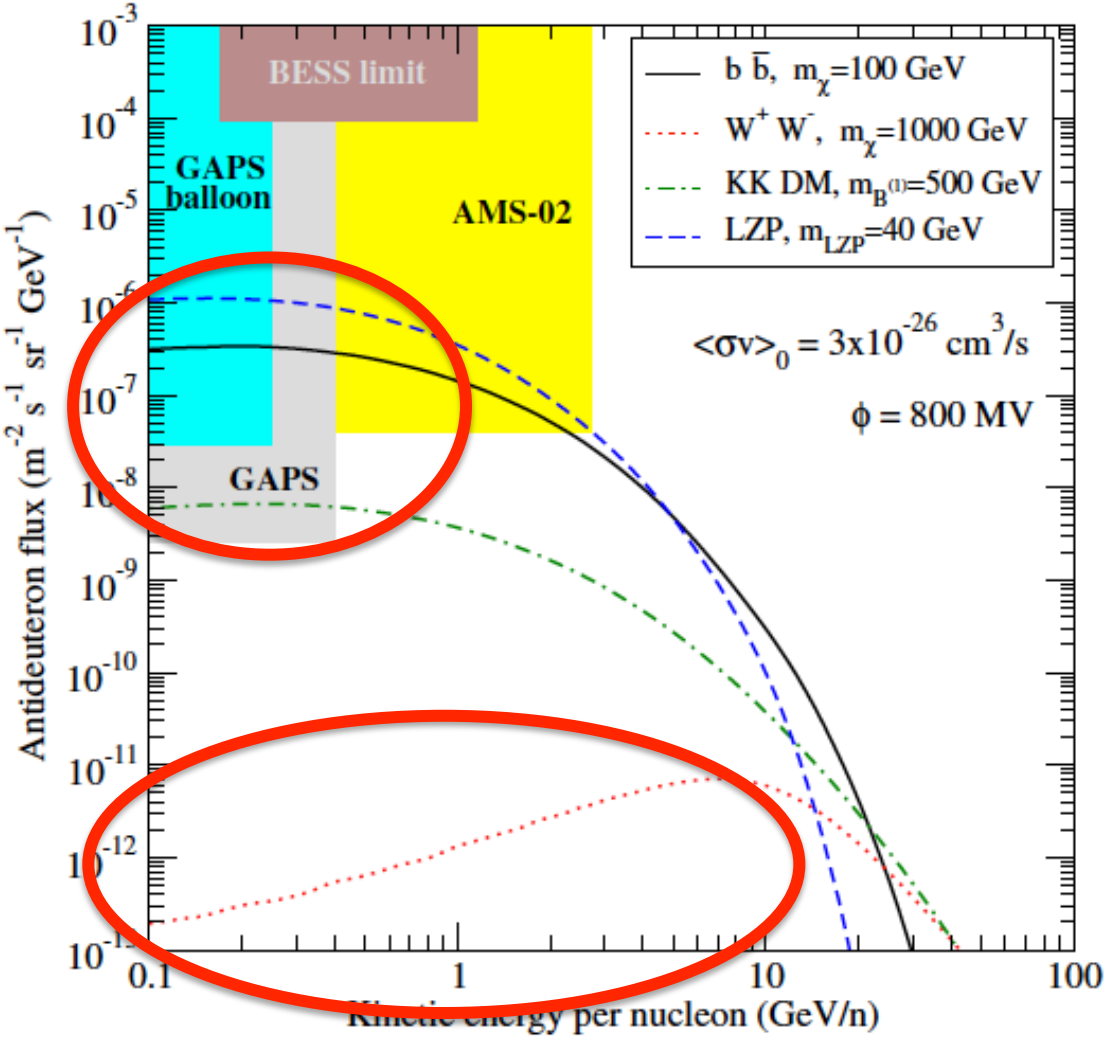
Bottom line: there exist large overall uncertainties on predicting signals from DM models!

Probably too pessimistic (Ng's talk)

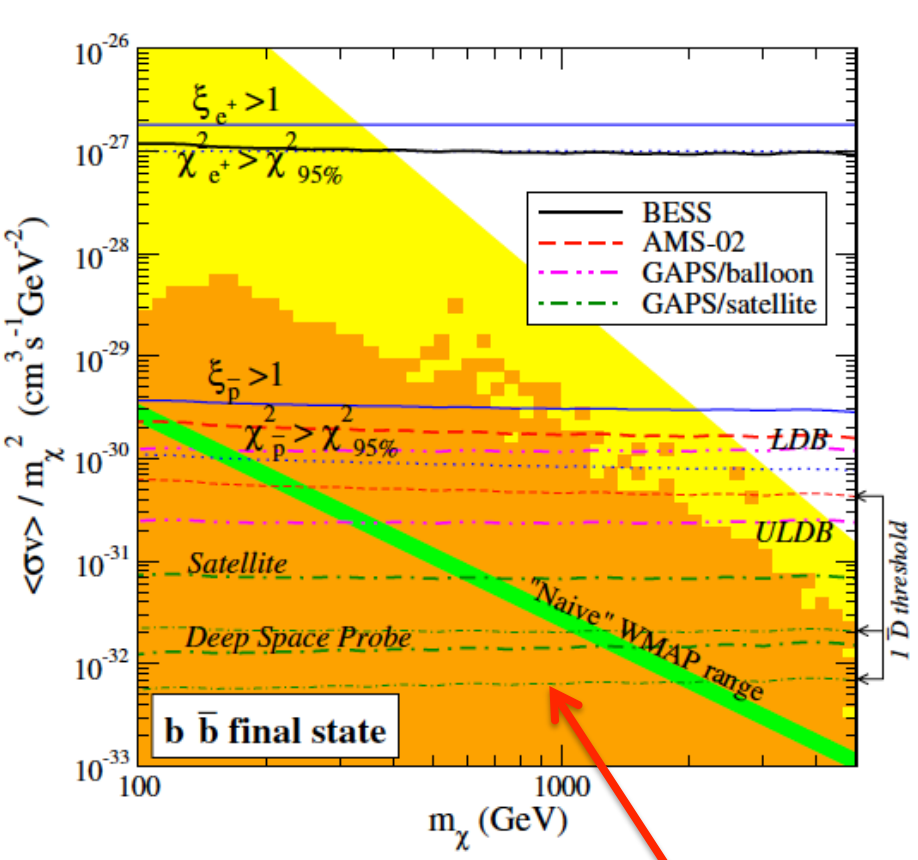
Probably a bit pessimistic (Salati, Moskalenko)

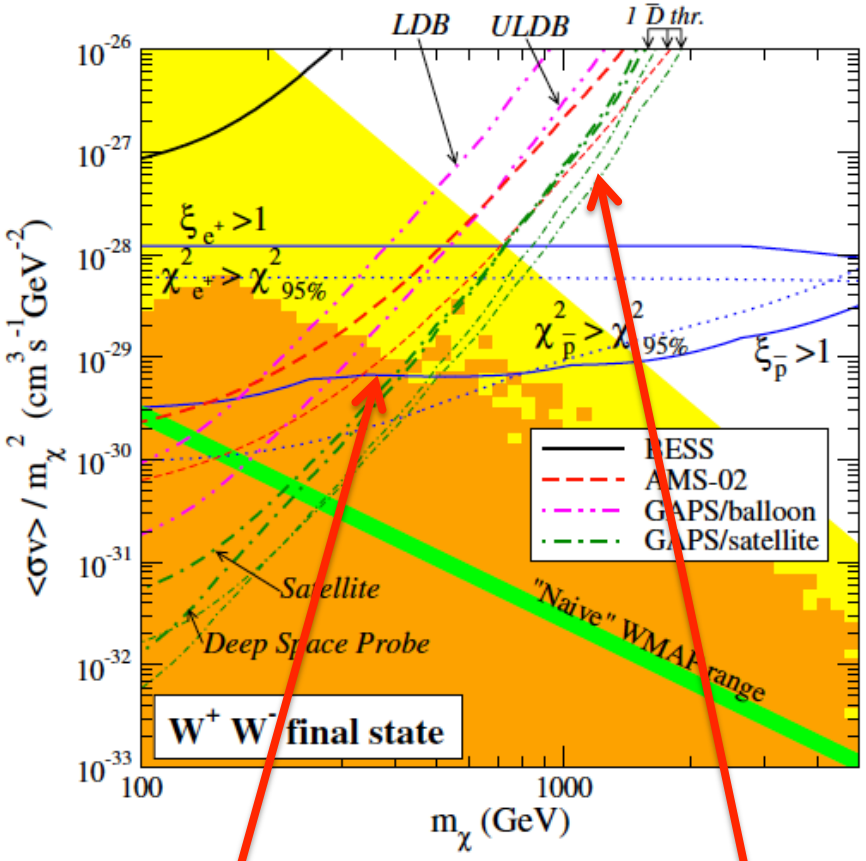
Probably about right?





Baer & Profumo, 2005





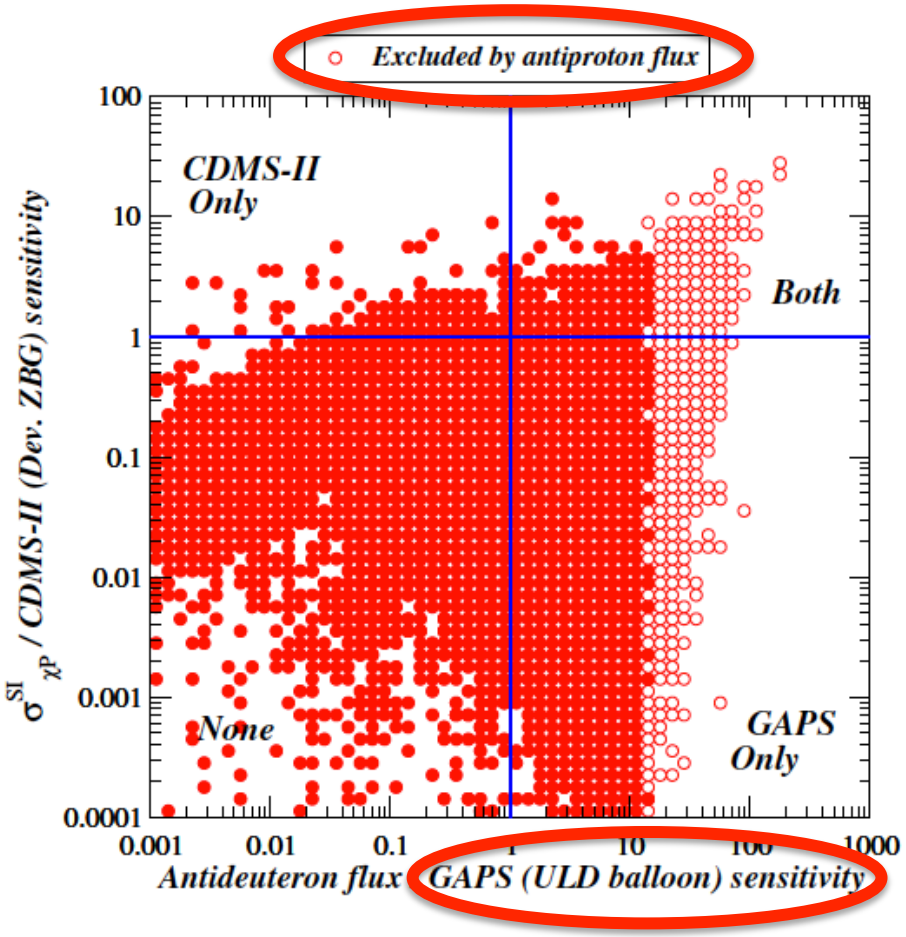
Old paper! (SUSY=DM)

soft nucleon spectrum = great at large masses!

Detecting antideuterons implies a feature in antiprotons!

hard nucleon spectrum = tougher!

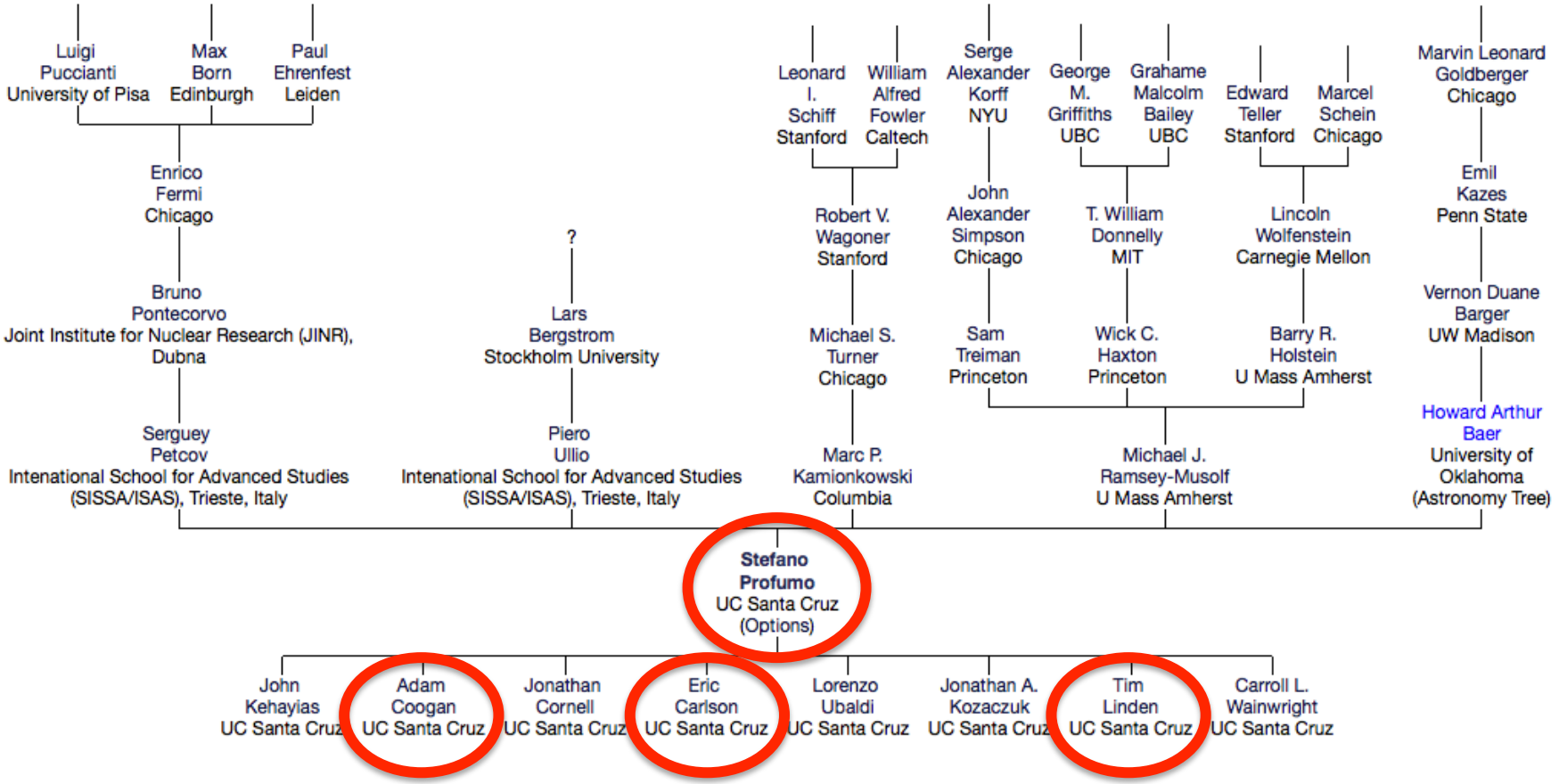
Baer & Profumo, 2005



Broadly, these results on complementarity remain true (some of the points might have been killed by LHC)

Baer & Profumo, 2005

...the family tradition continues...



First calculation of antihelium from DM (soon followed by Cirelli+ 2014)

PHYSICAL REVIEW D **89,** 076005 (2014)

Antihelium from dark matter

Eric Carlson,[1,2,*] Adam Coogan,[1,2,†] Tim Linden,[1,2,3,4,‡] Stefano Profumo,[1,2,§] Alejandro Ibarra,[5,¶] and Sebastian Wild[5,**]

[1]*Department of Physics, University of California, 1156 High Street, Santa Cruz, California 95064, USA*
[2]*Santa Cruz Institute for Particle Physics, Santa Cruz, California 95064, USA*
[3]*Department of Physics, University of Chicago, Chicago, Illinois 60637, USA*
[4]*Kavli Institute for Cosmological Physics, Chicago, Illinois 60637, USA*
[5]*Physik-Department T30d, Technische Universität München, James-Franck-Straße, 85748 Garching, Germany*

(Received 9 January 2014; published 8 April 2014)

Cosmic-ray antinuclei provide a promising discovery channel for the indirect detection of particle dark matter. Hadron showers produced by the pair annihilation or decay of Galactic dark matter generate antinucleons which can in turn form light antinuclei. Previous studies have only focused on the spectrum and flux of low energy antideuterons which, although very rarely, are occasionally also produced by cosmic-ray spallation. Heavier elements ($A \geq 3$) have instead entirely negligible astrophysical background and a primary yield from dark matter which could be detectable by future experiments. Using a Monte Carlo event generator and an event-by-event phase space analysis, we compute, for the first time, the production spectrum of $^3\overline{\mathrm{He}}$ and $^3\bar{\mathrm{H}}$ for dark matter annihilating or decaying to $b\bar{b}$ and W^+W^- final states. We then employ a semianalytic model of interstellar and heliospheric propagation to calculate the $^3\overline{\mathrm{He}}$ flux as well as to provide tools to relate the antihelium spectrum corresponding to an arbitrary antideuteron spectrum. Finally, we discuss prospects for current and future experiments, including GAPS and AMS-02.

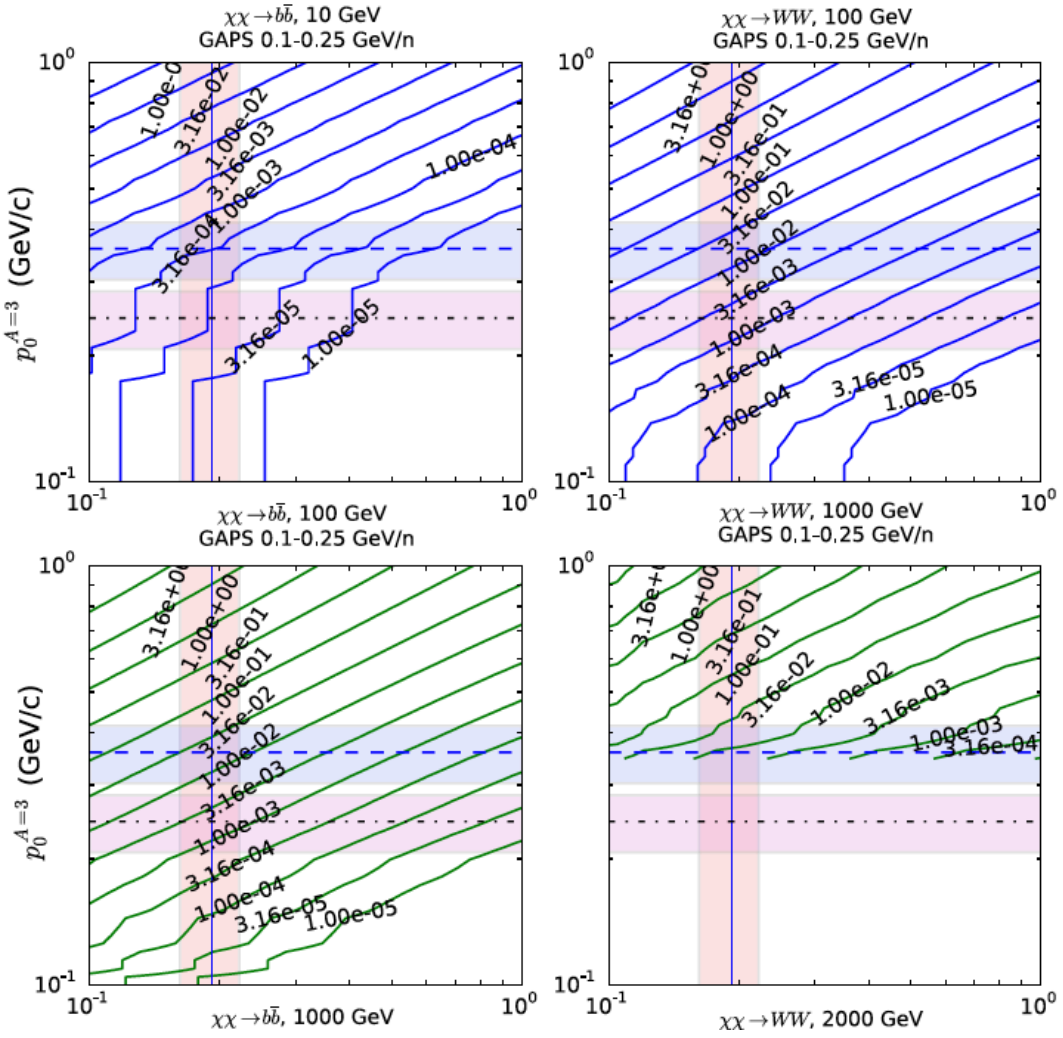
DOI: 10.1103/PhysRevD.89.076005 PACS numbers: 95.35.+d

I. INTRODUCTION

Within the paradigm of weakly interacting massive particle (WIMP) dark matter, the pair-annihilation or decay of dark matter particles generically yields high-energy

decay of WIMPs to hadronic final states—generic to models coupling WIMPs to the weak gauge bosons or quarks (e.g. W^+W^- or $b\bar{b}$). While large astrophysical backgrounds often prohibit the clean disentanglement of

It was critical to assess (1) systematics from coalescence picture (2) relative Dbar and ^{3}Hebar ratio



$$p_0 \sim \sqrt{B}$$

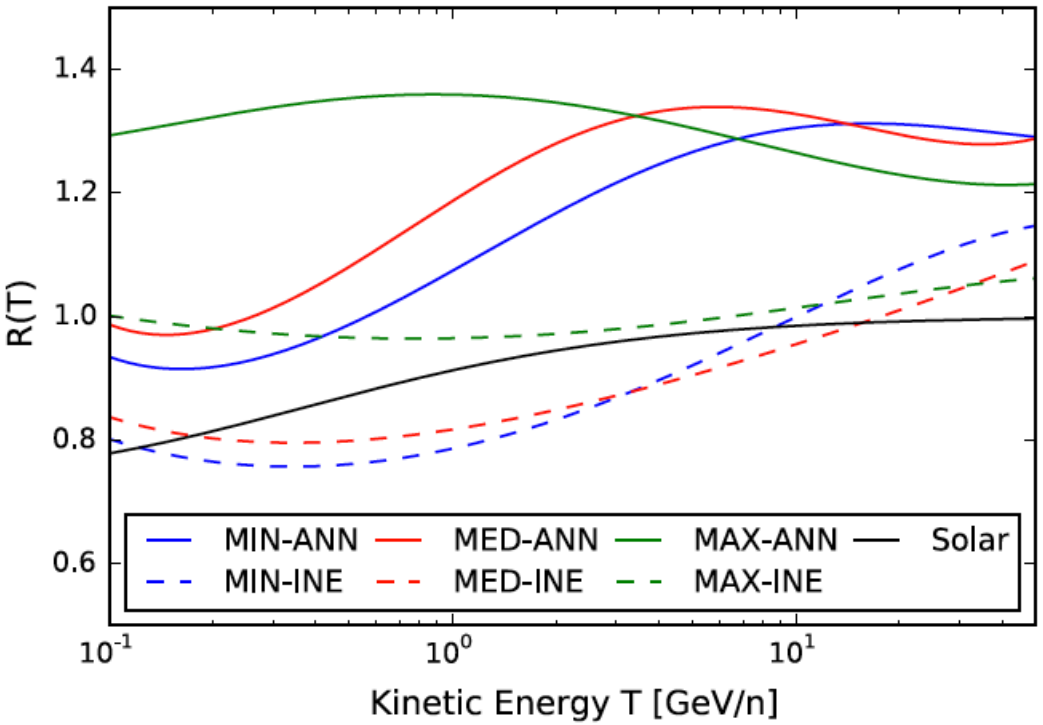
$$p_0^{A=3} = \sqrt{B_{^3\overline{\mathrm{He}}}/B_{\bar{D}}}\, p_0^{A=2} = 0.357 \pm 0.059 \text{ GeV}/c$$

$$p_0^{A=3} = 1.28\, p_0^{A=2} = 0.246 \pm 0.038 \text{ GeV}/c.$$

- Ratio depends on annihilation mode and DM mass
- Can be anywhere from O(0.1) to O(10^{-4})

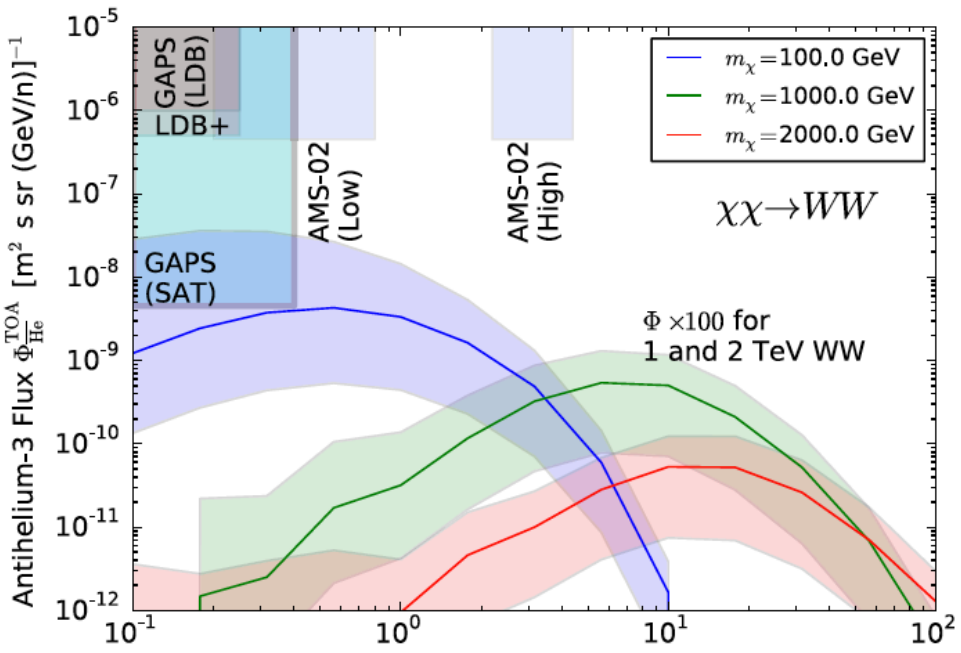
Carlson+ 2014

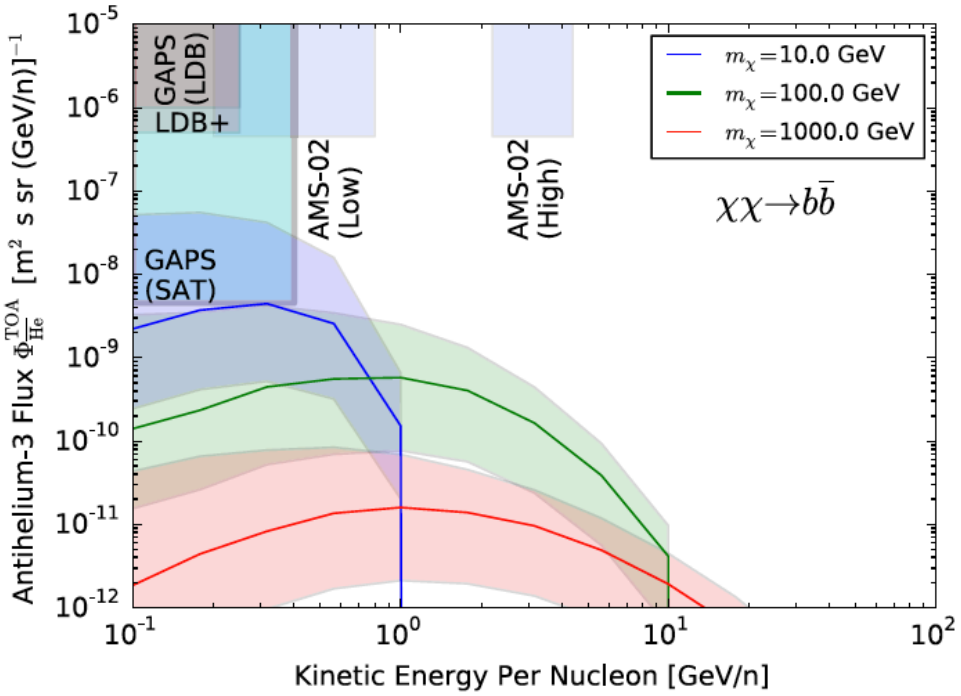
Comparatively, the uncertainty from propagation is small (~20%)



$$R(T) = P^{\overline{\mathrm{He}}}_{\mathrm{num}} / P^{\bar{\mathrm{D}}}_{\mathrm{num}}$$

Carlson+ 2014





- **Thermal cross section; only propagation uncertainties shown (not coalescence)**
- **WW final state, and large masses, are a long shot! (x100!)**
- **^{3}He detection not unreasonable for canonical DM density and annihilation cross sections, and low masses, at GAPS (SAT)**

Carlson+ 2014

Sam Ting's Alpha Magnetic Spectrometer was delivered to space in 2011 on the next-to-last space shuttle flight.

SAM TING'S LAST TEASE

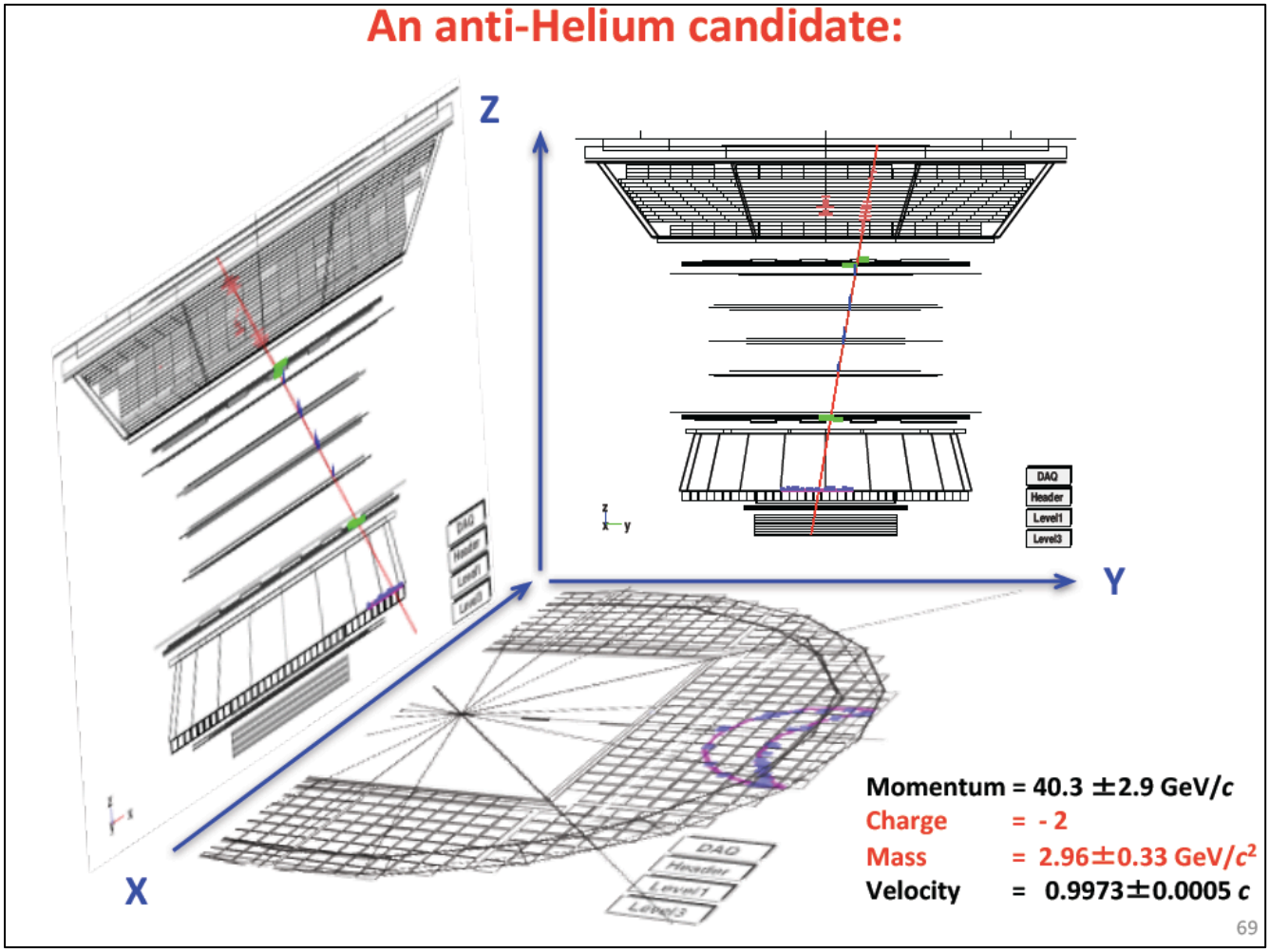
How the physicist's aging space magnet, in a final flourish, may have trapped heavy antimatter

By **Joshua Sokol**

Sam Ting speaks softly and deliberately as he gets ready to deliver some juicy news to his audience. finally delivering on the promise of its original name, when "AM" stood for "antimatter."

So far, the AMS has measured the masses that the AMS may have trapped a bigger and weirder form of antimatter. The AMS, he says, has seen a handful of candidate

Science, April 2017



See Alberto's presentation today!

PHYSICAL REVIEW D 96, 083020 (2017)

Origin of the tentative AMS antihelium events

Adam Coogan* and Stefano Profumo†

Department of Physics and Santa Cruz Institute for Particle Physics, University of California, Santa Cruz, California 95064, USA

(Received 31 May 2017; published 31 October 2017)

We demonstrate that the tentative detection of a few antihelium events with the Alpha Magnetic Spectrometer (AMS) on board the International Space Station can, in principle, be ascribed to the annihilation or decay of Galactic dark matter, when accounting for uncertainties in the coalescence process leading to the formation of antinuclei. We show that the predicted antiproton rate, assuming the antihelium events came from dark matter, is marginally consistent with AMS data, as is the antideuteron rate with current available constraints. We argue that a dark matter origin can be tested with better constraints on the coalescence process, better control of misidentified events, and with future antideuteron data.

DOI: 10.1103/PhysRevD.96.083020

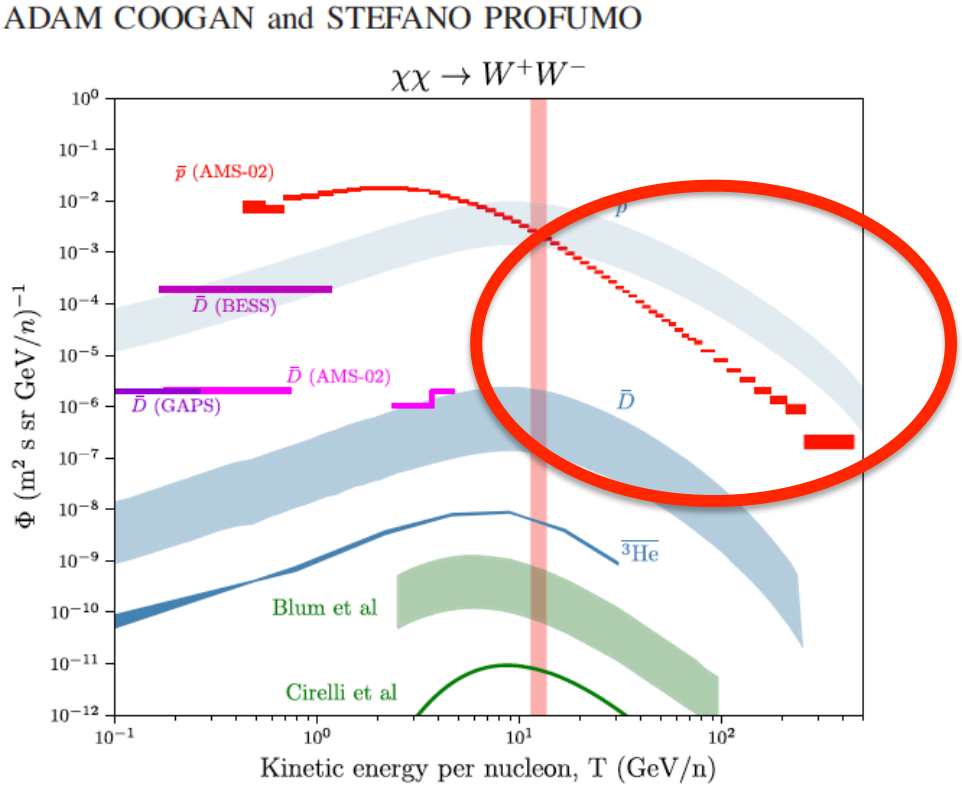
I. INTRODUCTION

Background-free processes are the Holy Grail of astrophysical searches for dark matter (DM): in numerous recent examples, ranging from the Galactic center excess to the positron fraction excess to the 3.5 keV line, possible DM signals have well-known, plausible astrophysical counterparts. Conclusively discriminating between a DM origin

cautiously states that "it will take a few more years of detector verification and to collect more data to ascertain the origin of these events" [5].

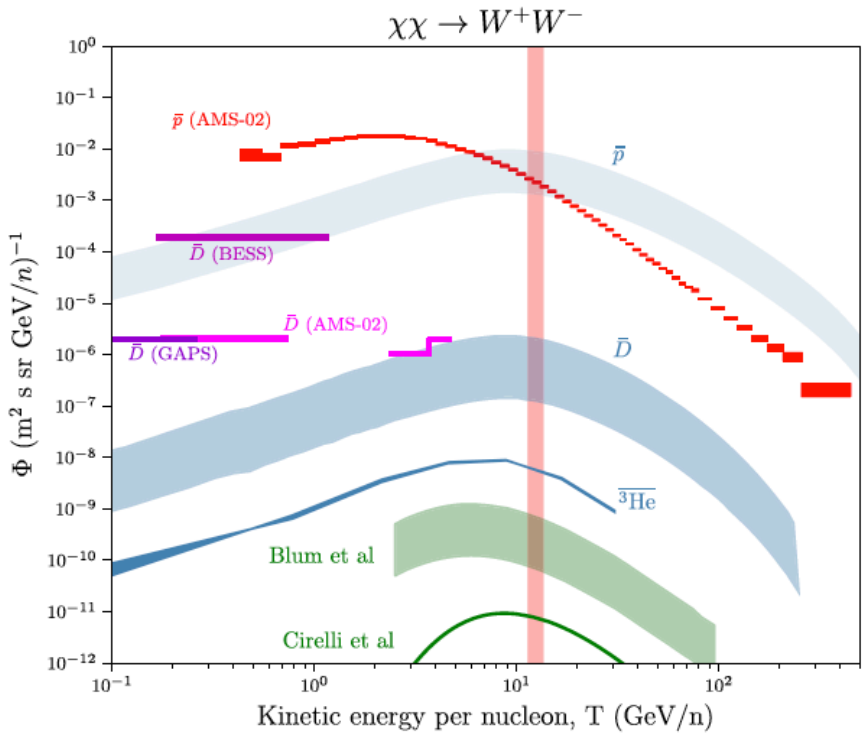
Event misidentification notwithstanding, in this study we consider the possibility that one or all of the tentatively detected antihelium events stem from DM annihilation or decay (for definiteness, we will hereafter focus on annihilation, but our results would apply directly to decaying

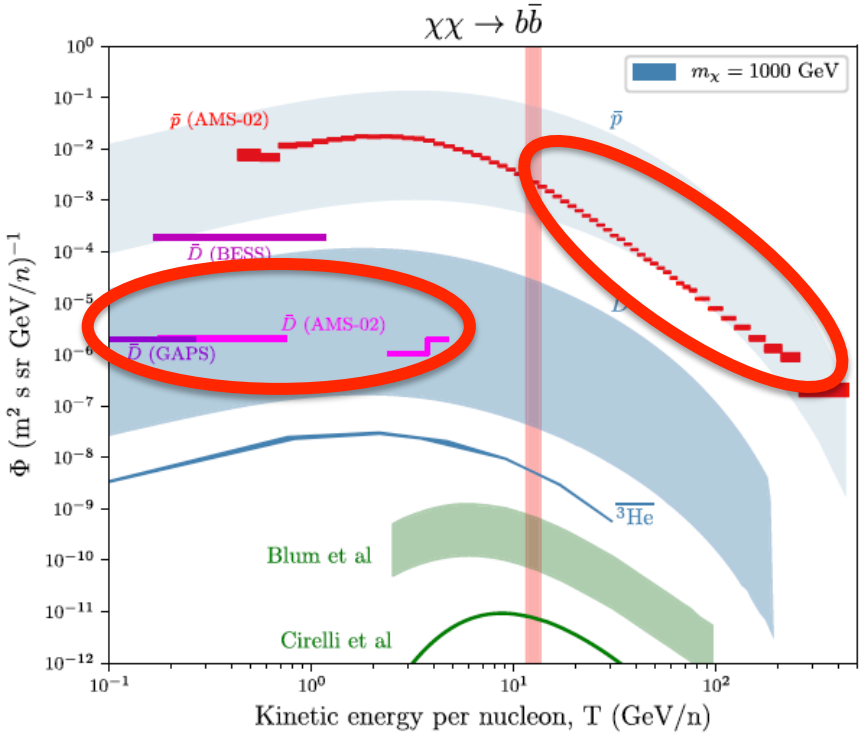
Coogan and Profumo (2017)



One event with 40 GeV momentum in 5 years

Coogan and Profumo (2017)

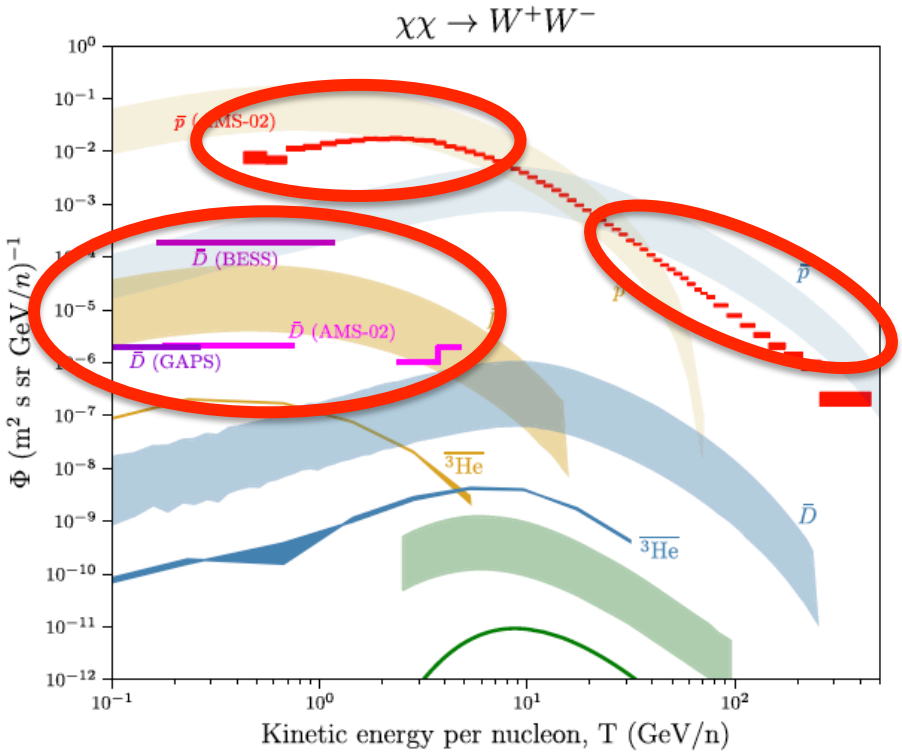




One event with 40 GeV momentum in 5 years

Coogan and Profumo (2017)

No bueno



one ^{3}He per year

Coogan and Profumo (2017)

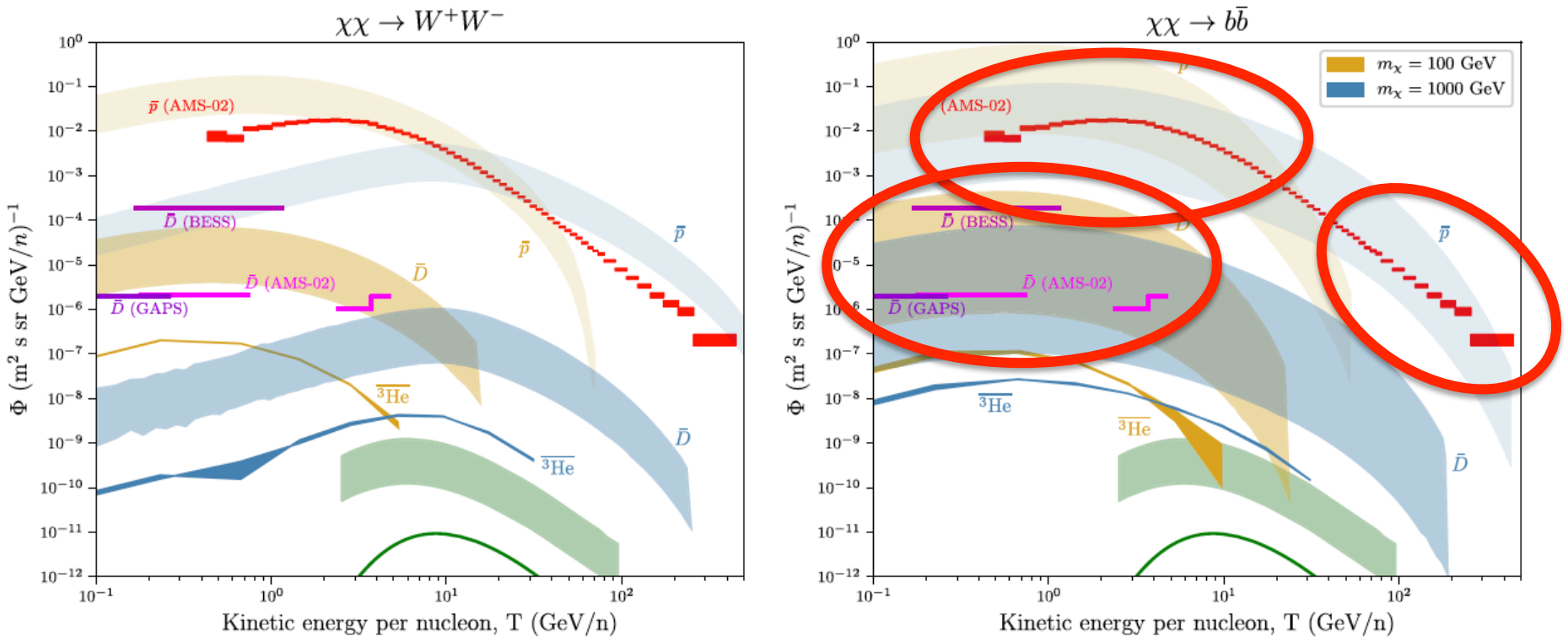


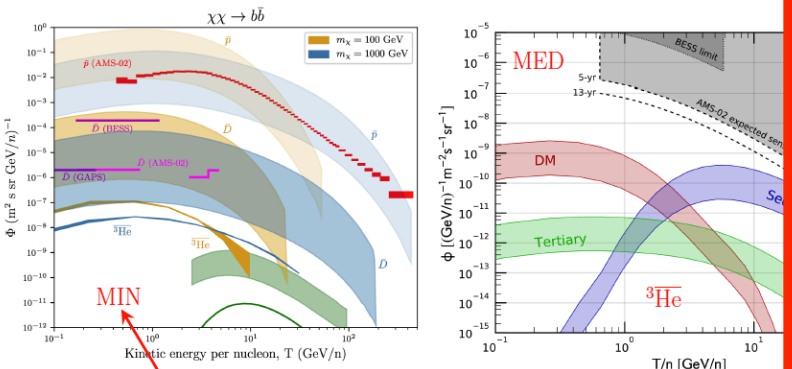
FIG. 2. As in Fig. 1, but for the predicted antiproton and antideuteron fluxes for 100 GeV (yellow lines) and 1 TeV (blue lines) dark matter particles pair-annihilating into W^+W^- (left panel) and $\bar{b}b$ (right panel), normalized to yield one ^{3}He per year overall. Spectra are computed using $\phi_F = 500$ MV, MethodAnn and MAX propagation.

one ^{3}He per year

Coogan and Profumo (2017)

4) A word on dark matter

Could anti-helium ($^3\overline{\text{He}}$) events be produced by DM?

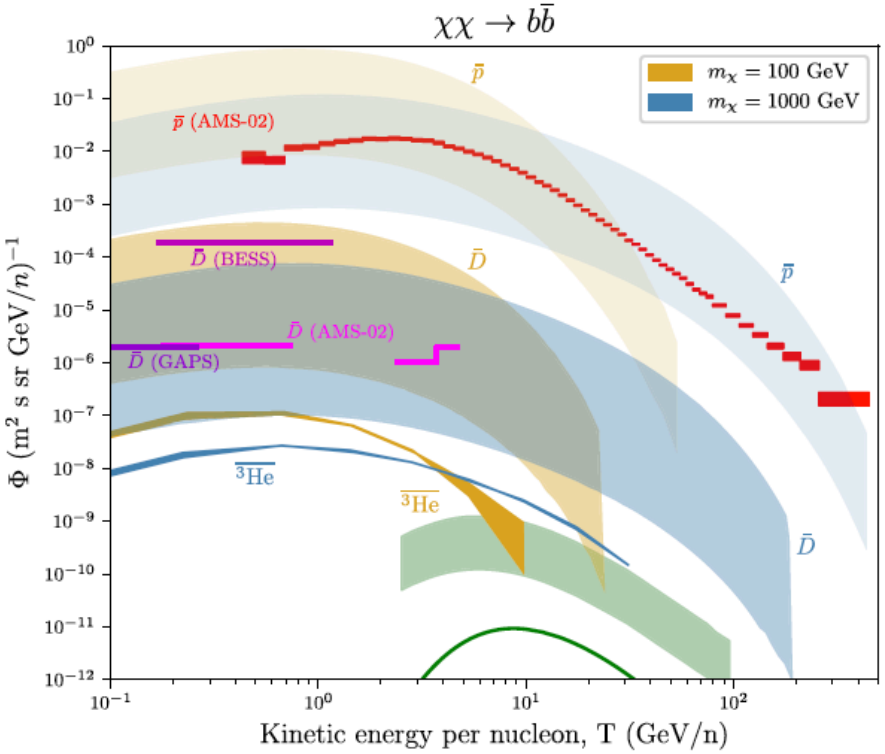


A. Coogan & S. Profumo,
Phys. Rev. D96 (2017) 083020

M. Korsmeier et al., Phys. Rev. D9

- If AMS-02 $\overline{\text{He}}$ events are from DM, beware of $\bar{p}$ flux.
- To evade the $\bar{p}$ constraint, p_{coal} exceedingly large.

Salati (yesterday) MIN is excluded by positrons



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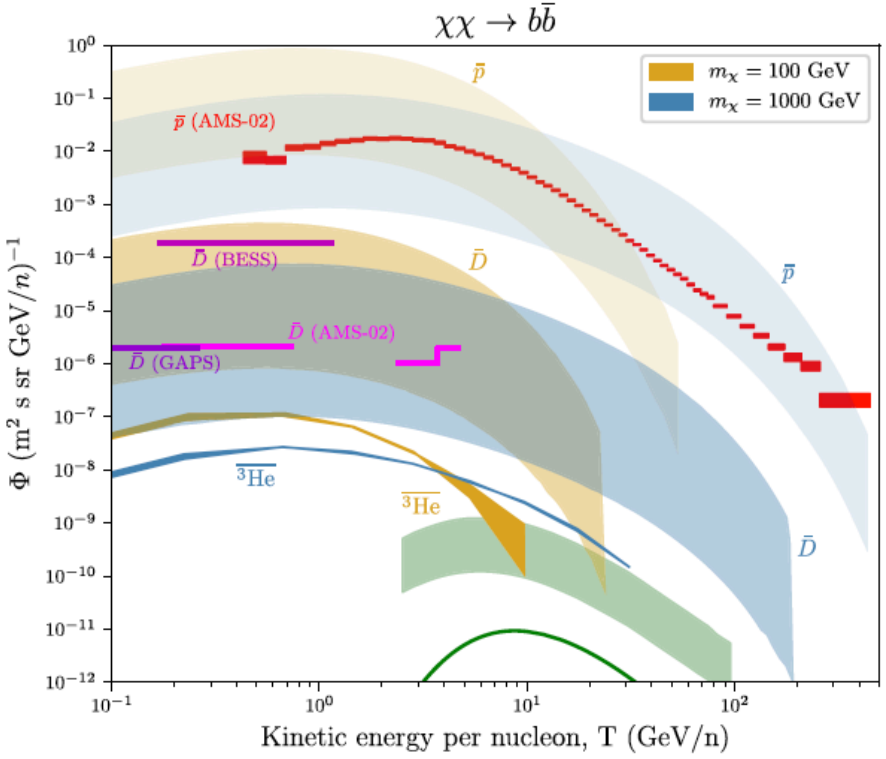
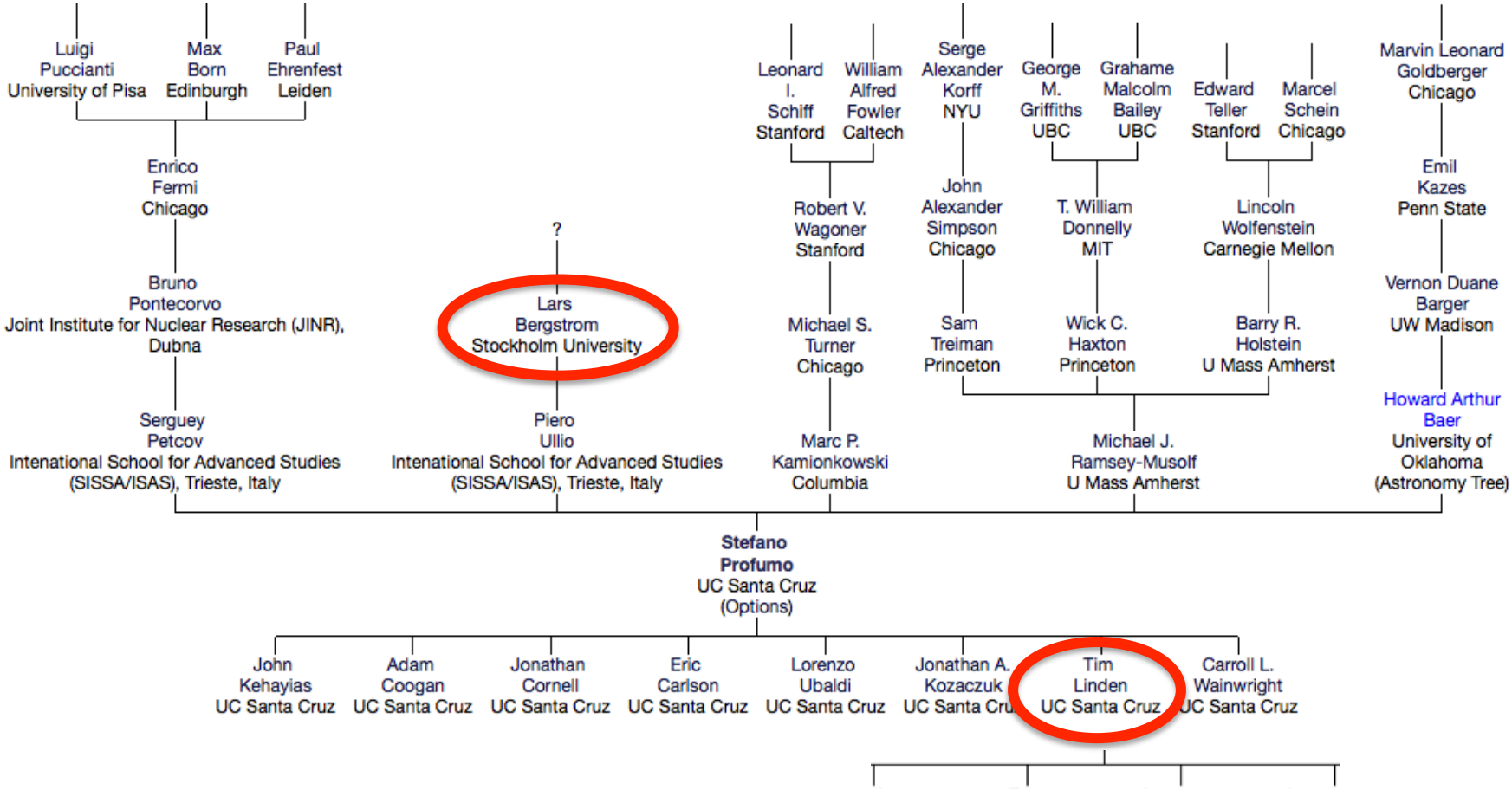
one ^{3}He per year

Coogan and Profumo (2017)



- 3He from DM: a potentially self-consistent picture
- Can be tested with better constraints on coalescence momentum
- Predicts features in pbar and Dbar – better statistics and control over misidentified events will allow sharper predictions
- To do: GeV (<10) DM!

Coogan and Profumo (2017)



...more antimatter warriors to come!