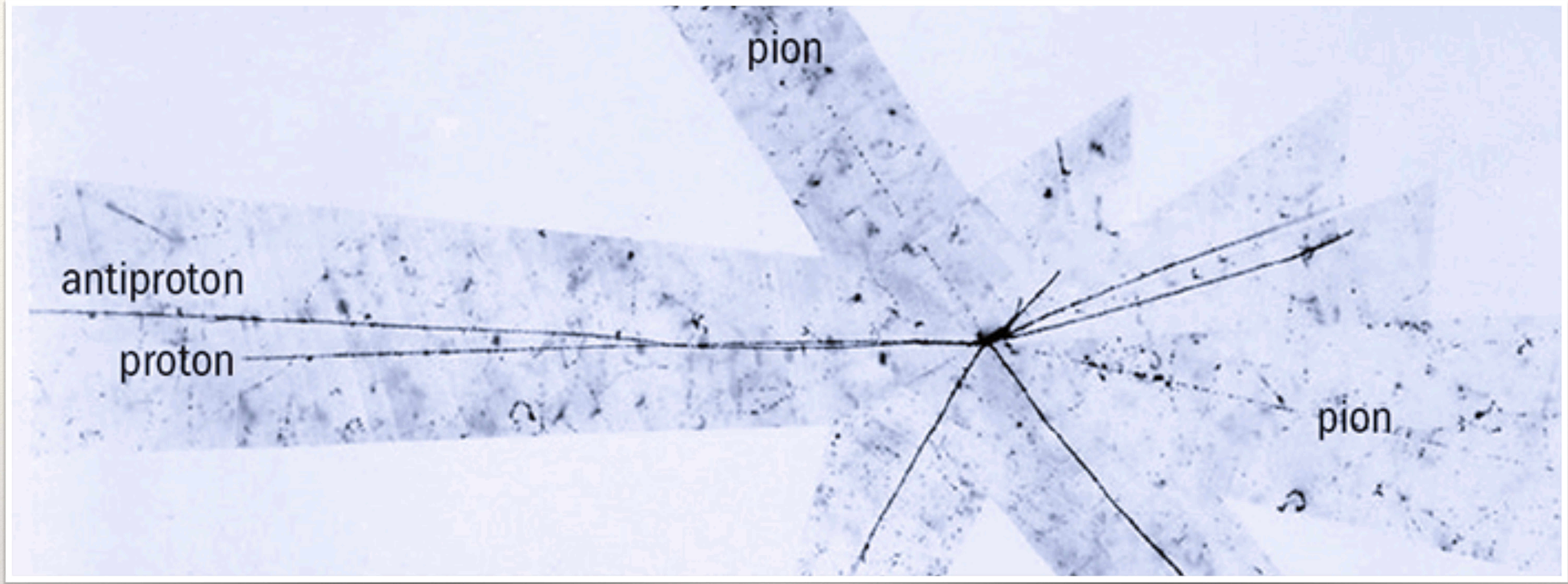
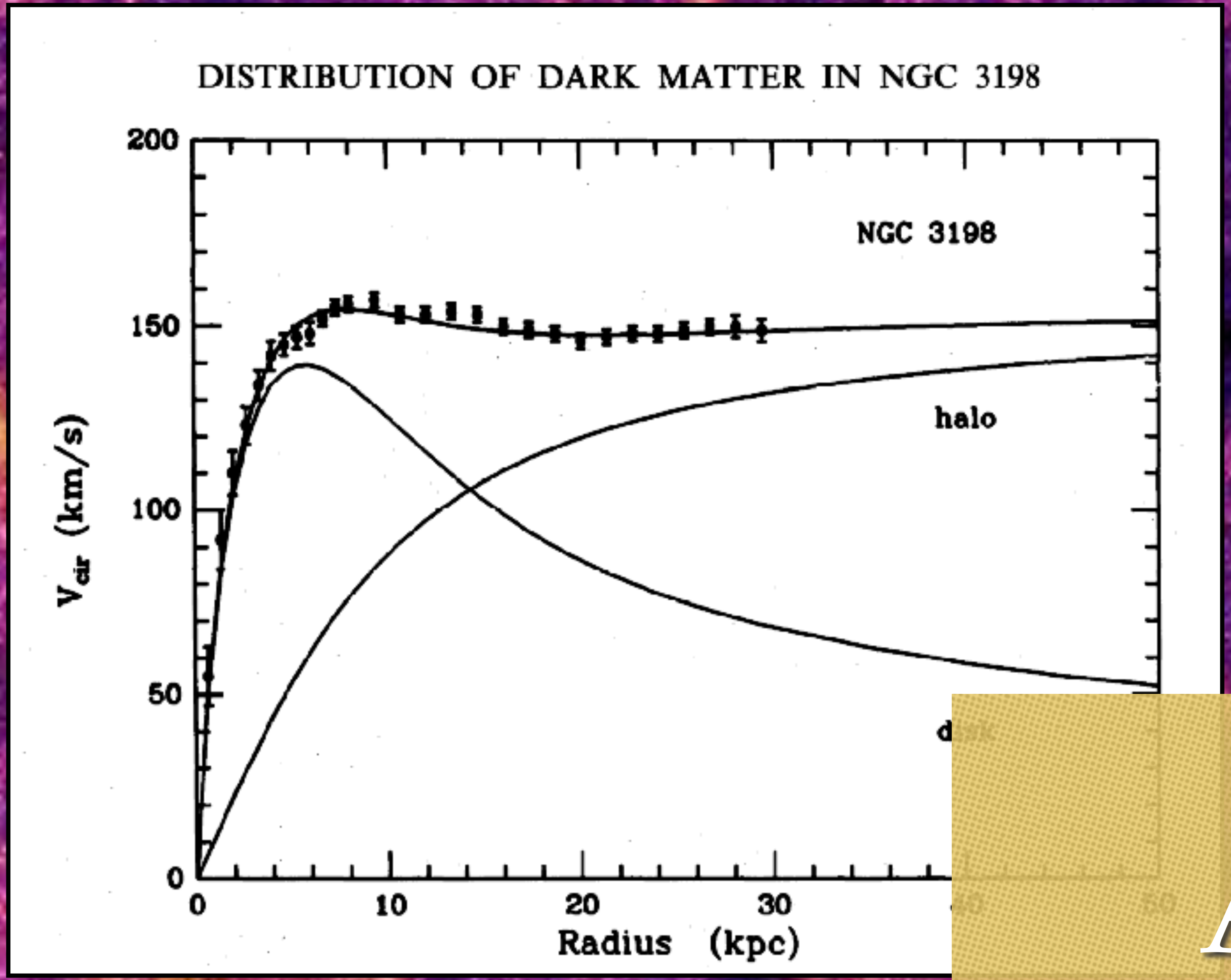


Antinucleons in Cosmic Rays: Using GAPS to Open New Windows on Dark Matter.

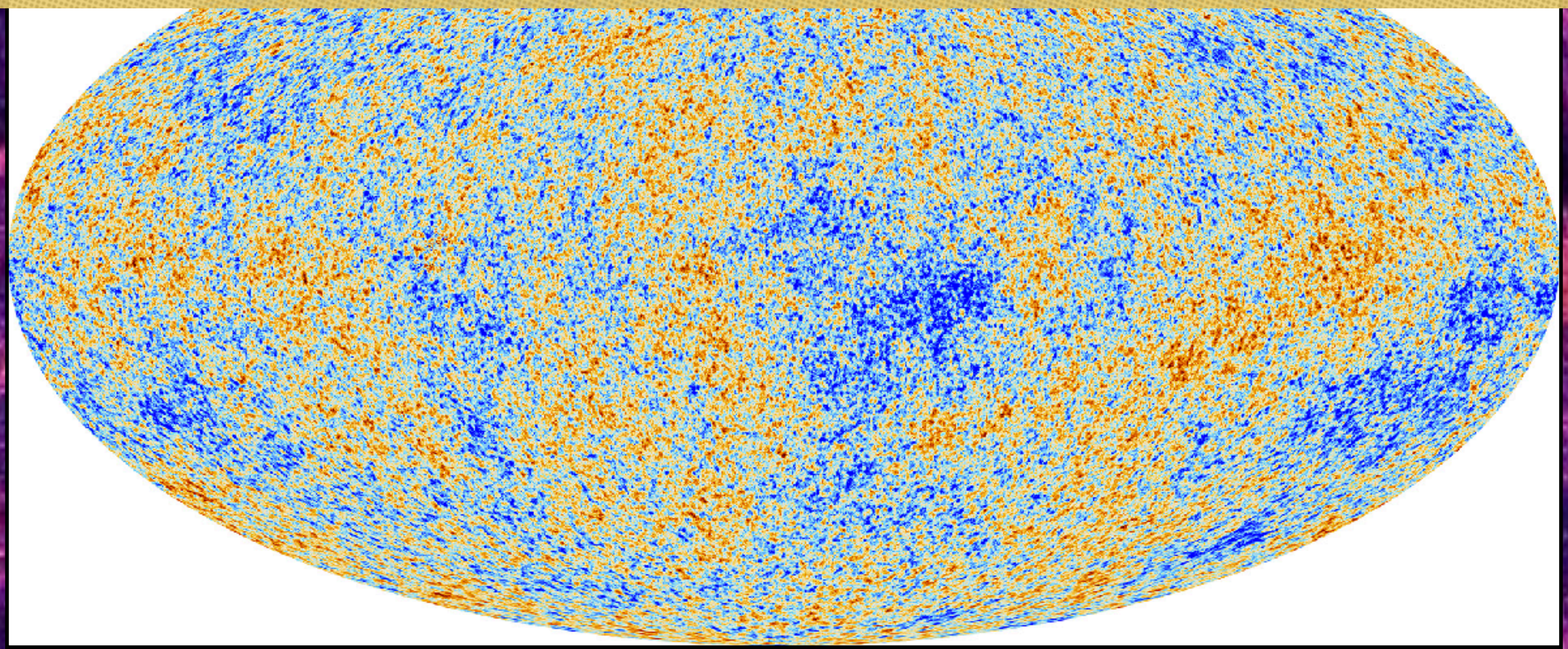
Ralph Bird
ralphbird@astro.ucla.edu
27 August 2018



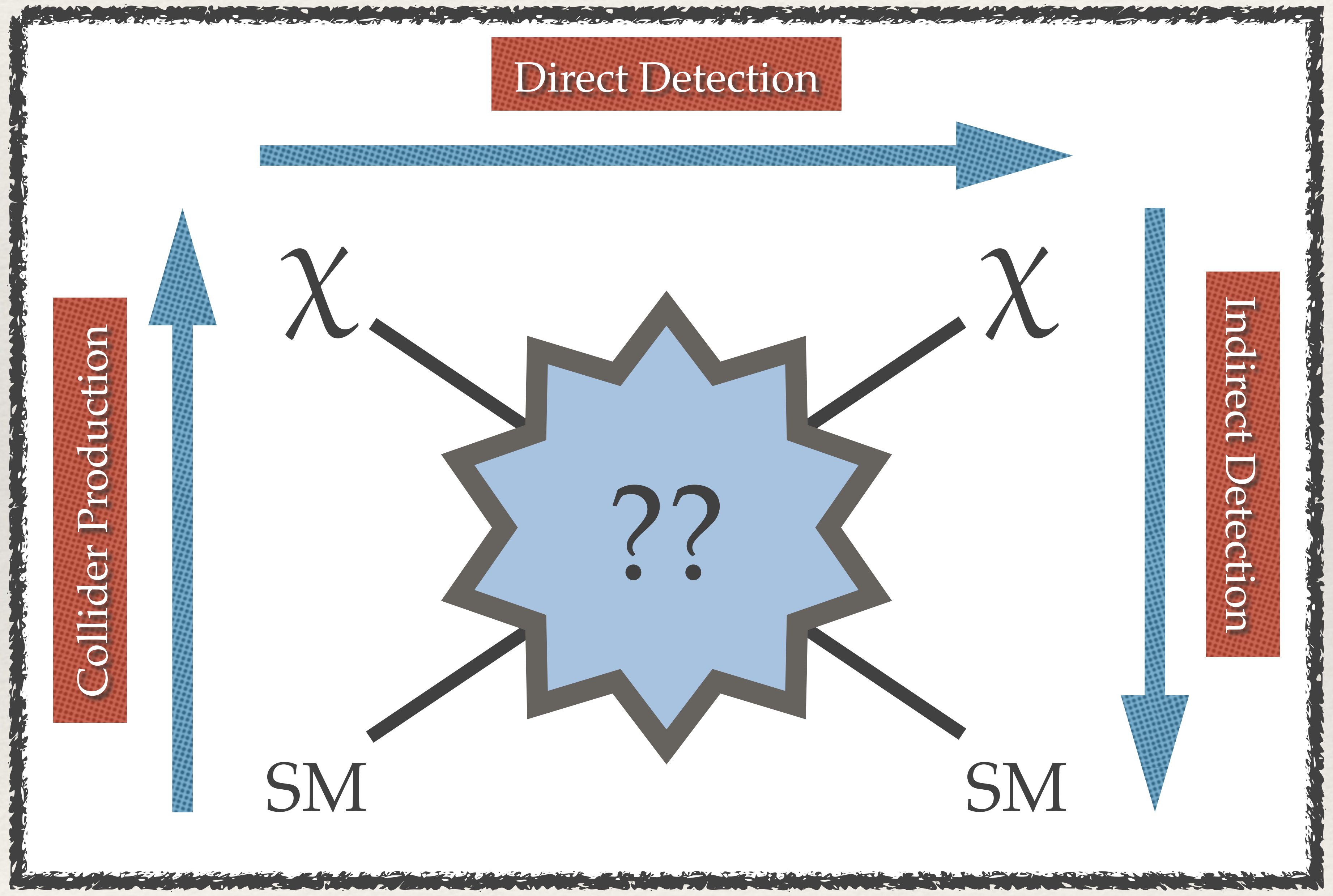
Assumptions for this talk:

Dark Matter Exists.

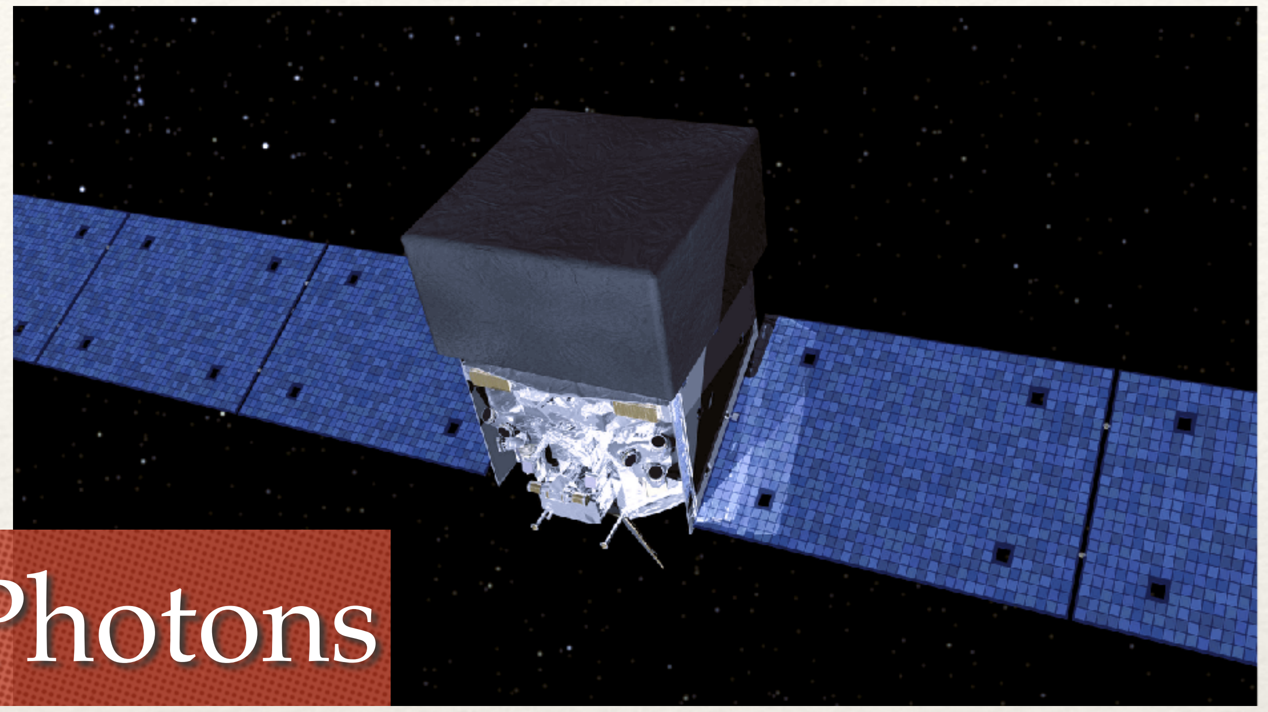
(At least some of) It is a WIMP.



A Multimessenger Search



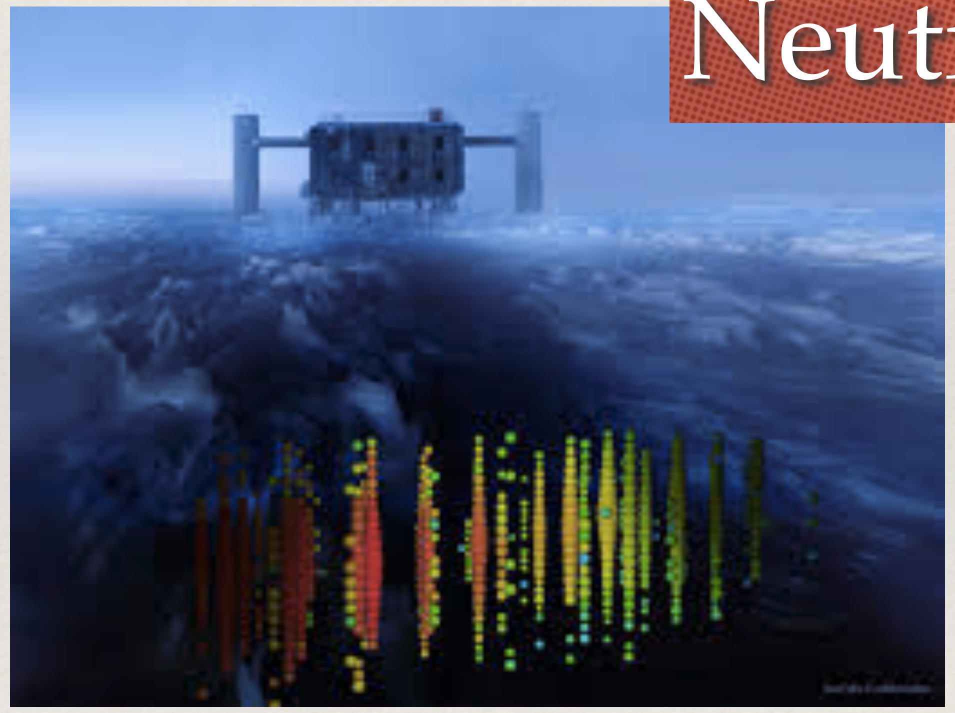
Photons



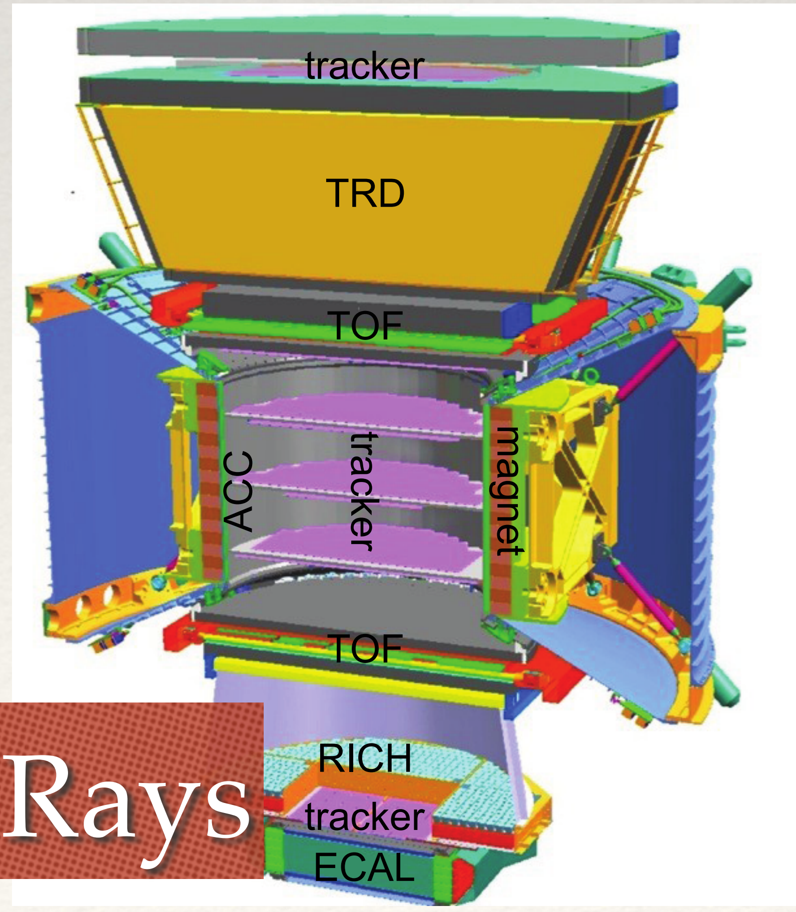
Galactic Center: High flux, astrophysical background.
Dwarf Galaxies: Low flux, low/no background.

Neutrinos

Hard to detect, atmospheric background.

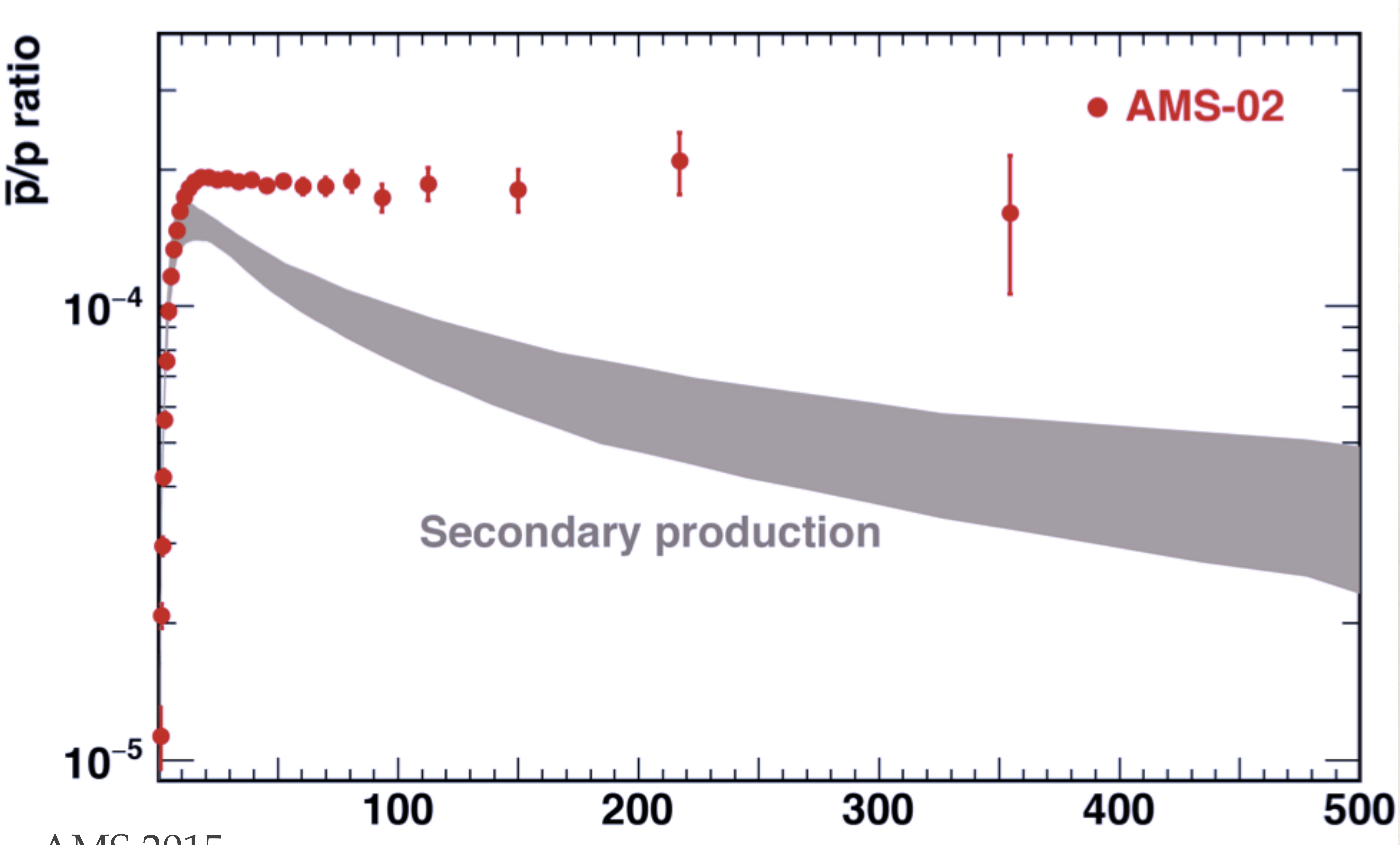


Cosmic Rays



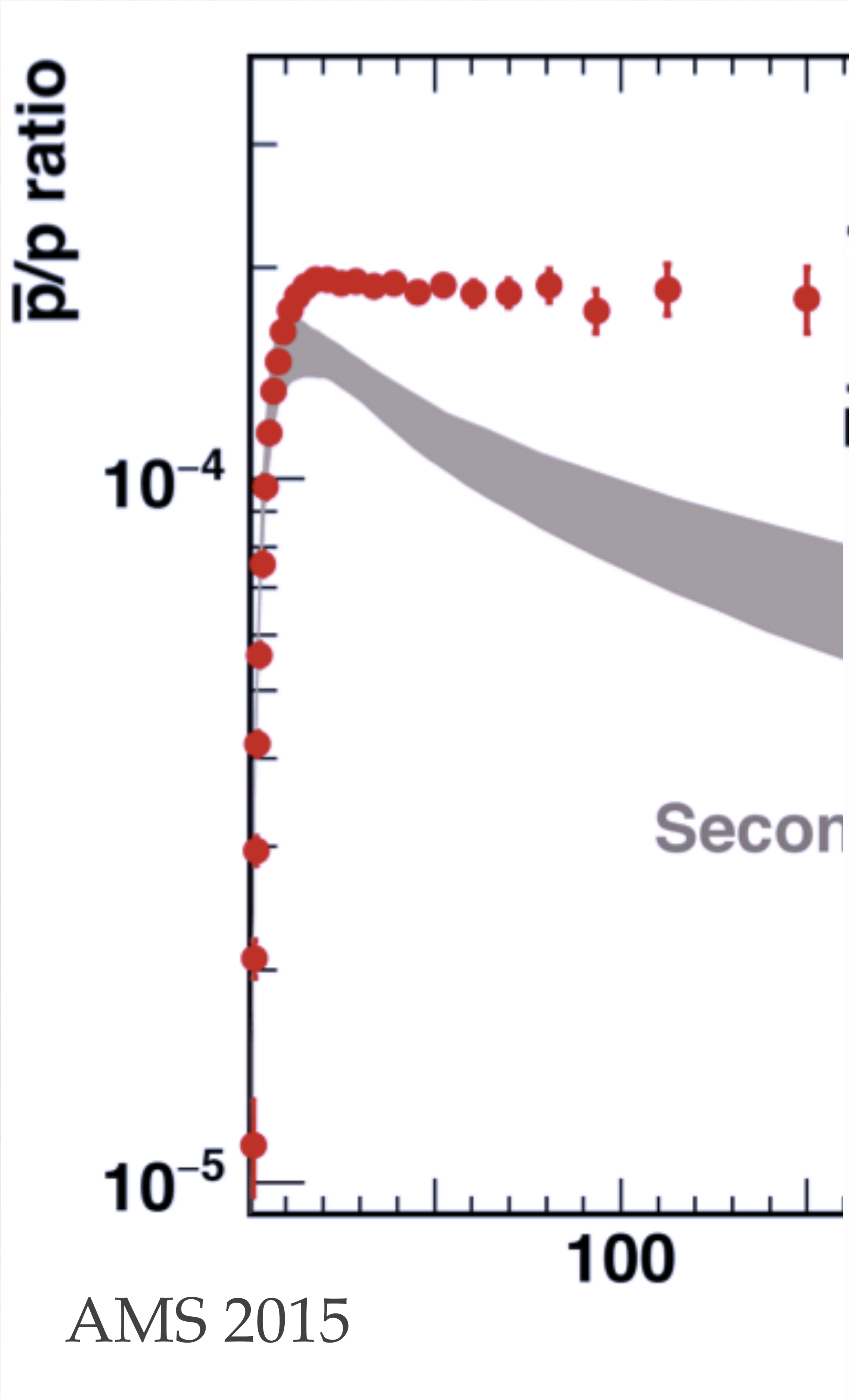
Many pathways, different backgrounds

Antiprotons ($\bar{p}$)

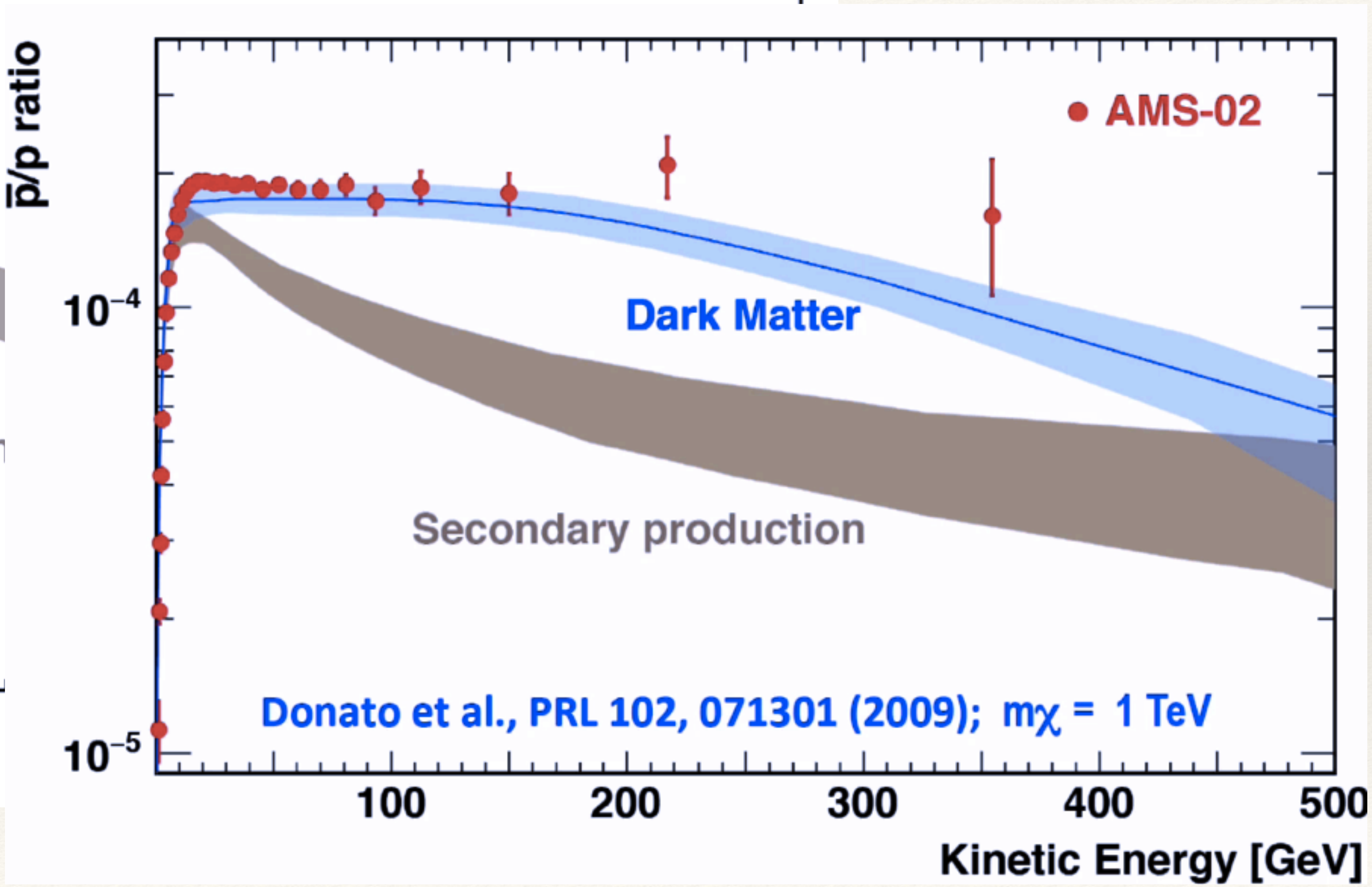


AMS 2015

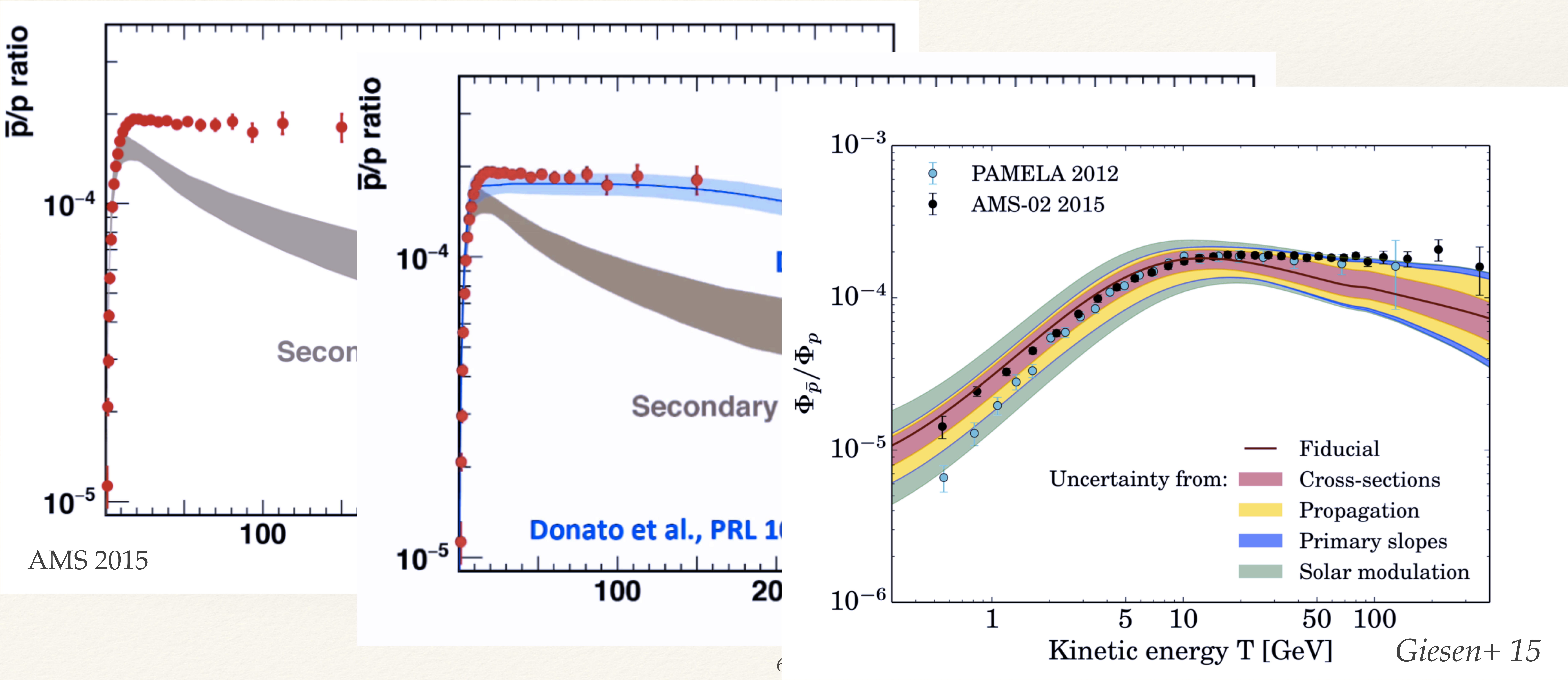
Antiprotons ($\bar{p}$)



AMS 2015



Antiprotons ($\bar{p}$)

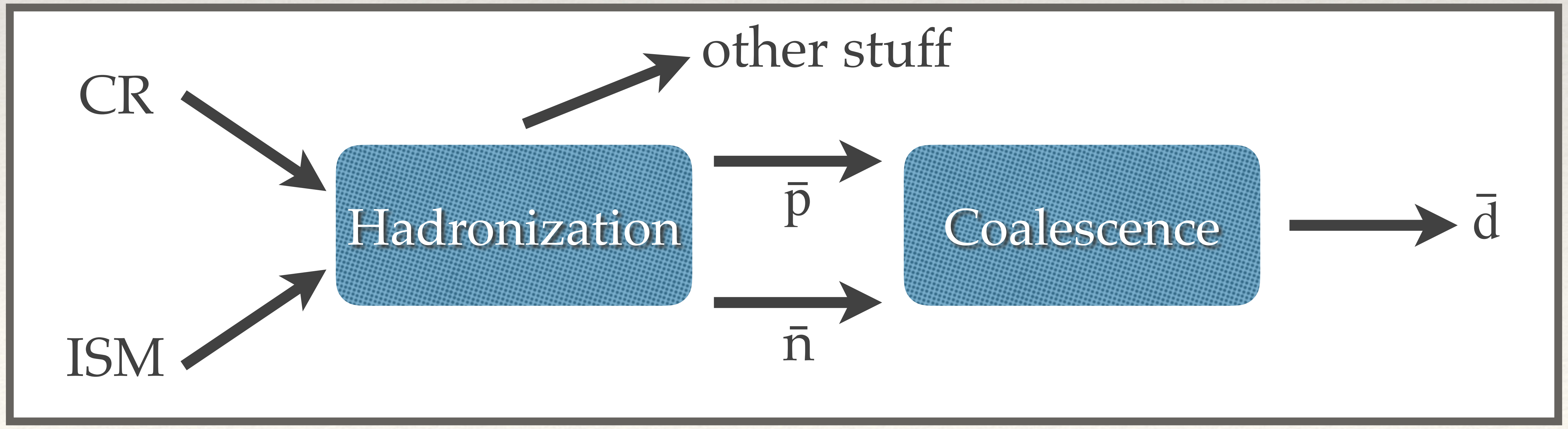


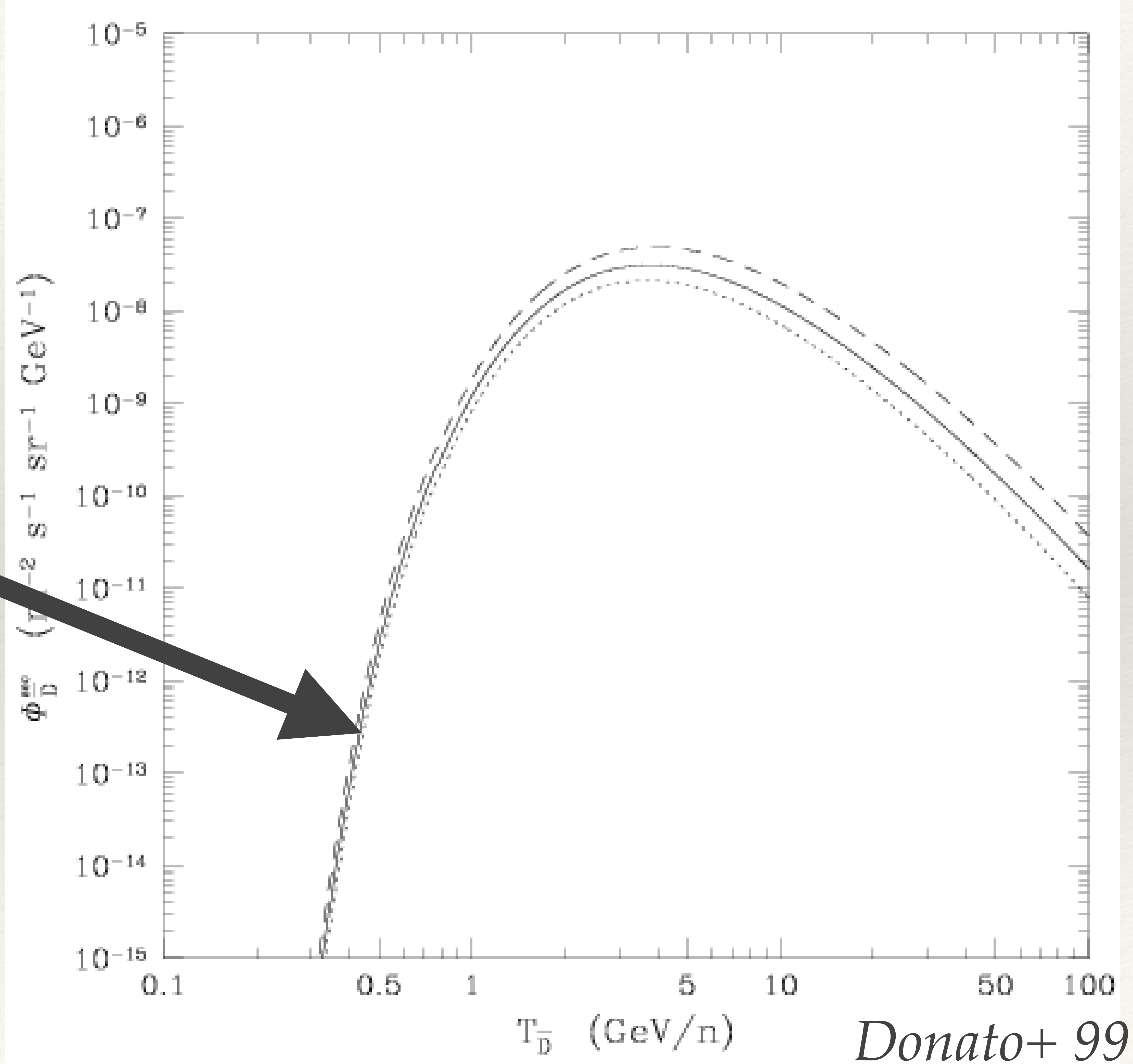
Why Antideuterons?

Astrophysical Antideuterons

Collision kinematics → Momentum threshold for production.

Low binding energy → inelastic scatter ≈ destruction.





Donato+ 99

Why Antideuterons?

Dark Matter Antideuterons

Production is via annihilation or a decay.

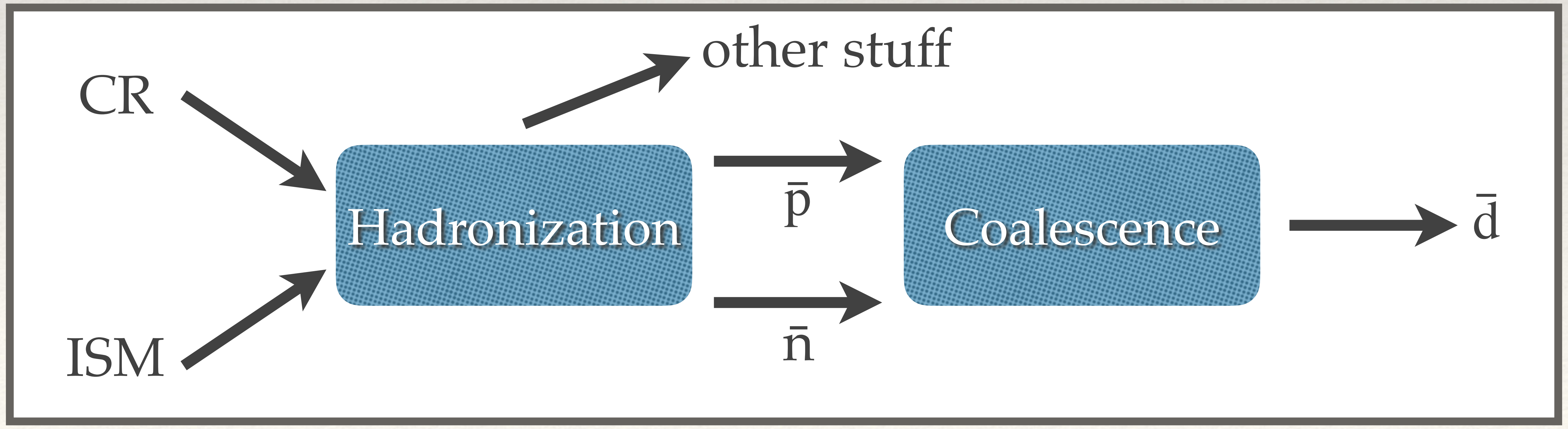
→ No kinematic threshold.

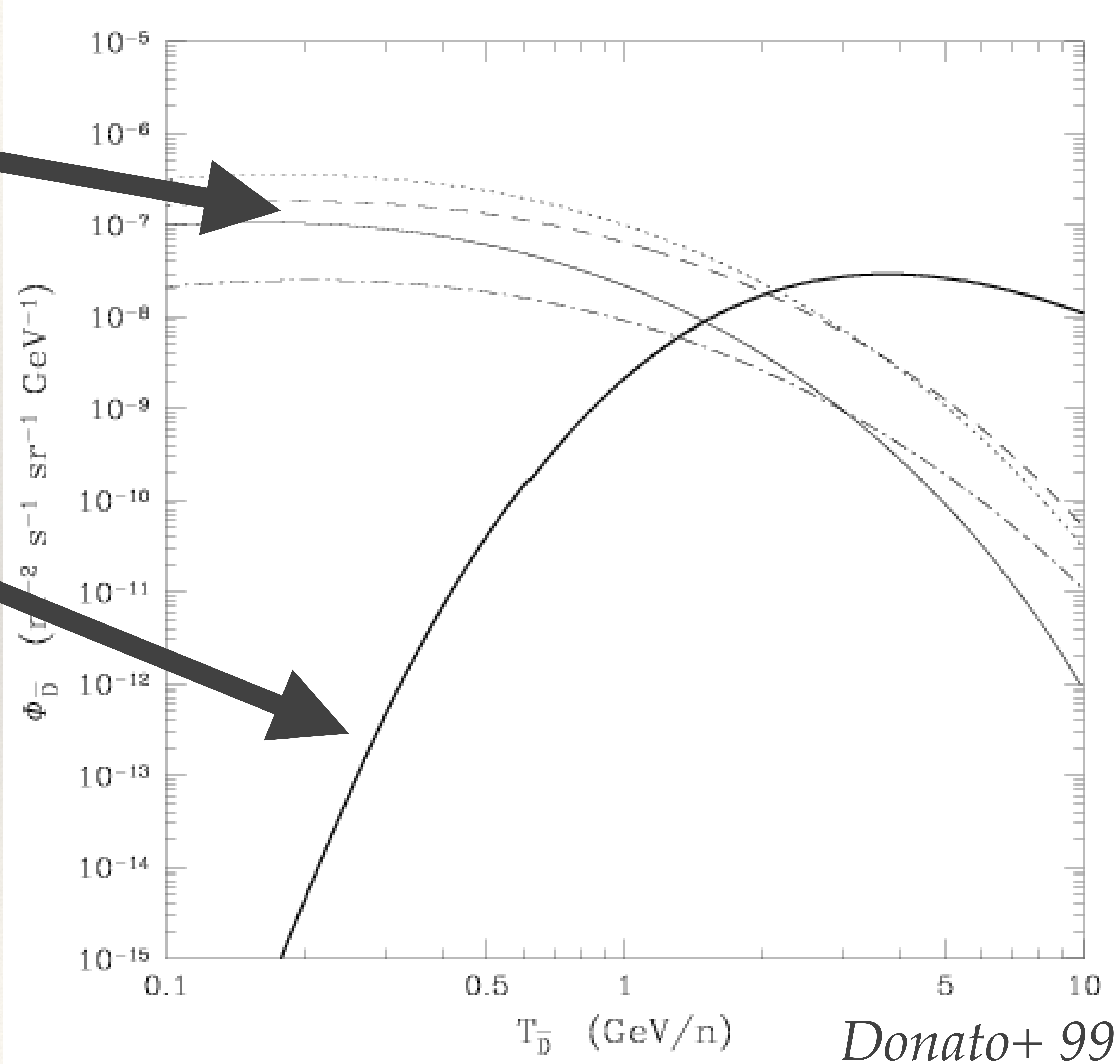
→ No low energy cutoff!

Astrophysical Antideuterons

Collision kinematics → Momentum threshold for production.

Low binding energy → inelastic scatter ≈ destruction.

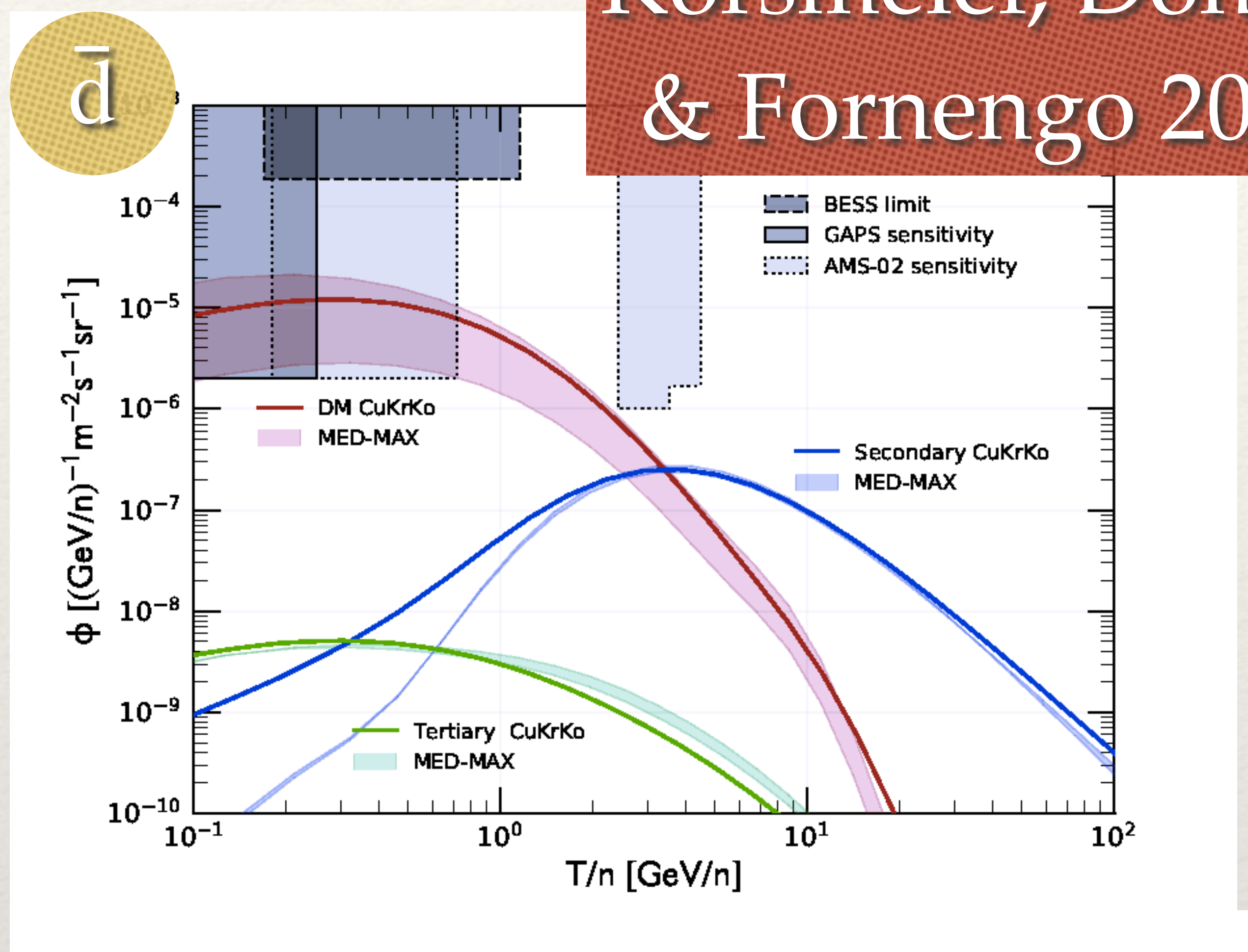


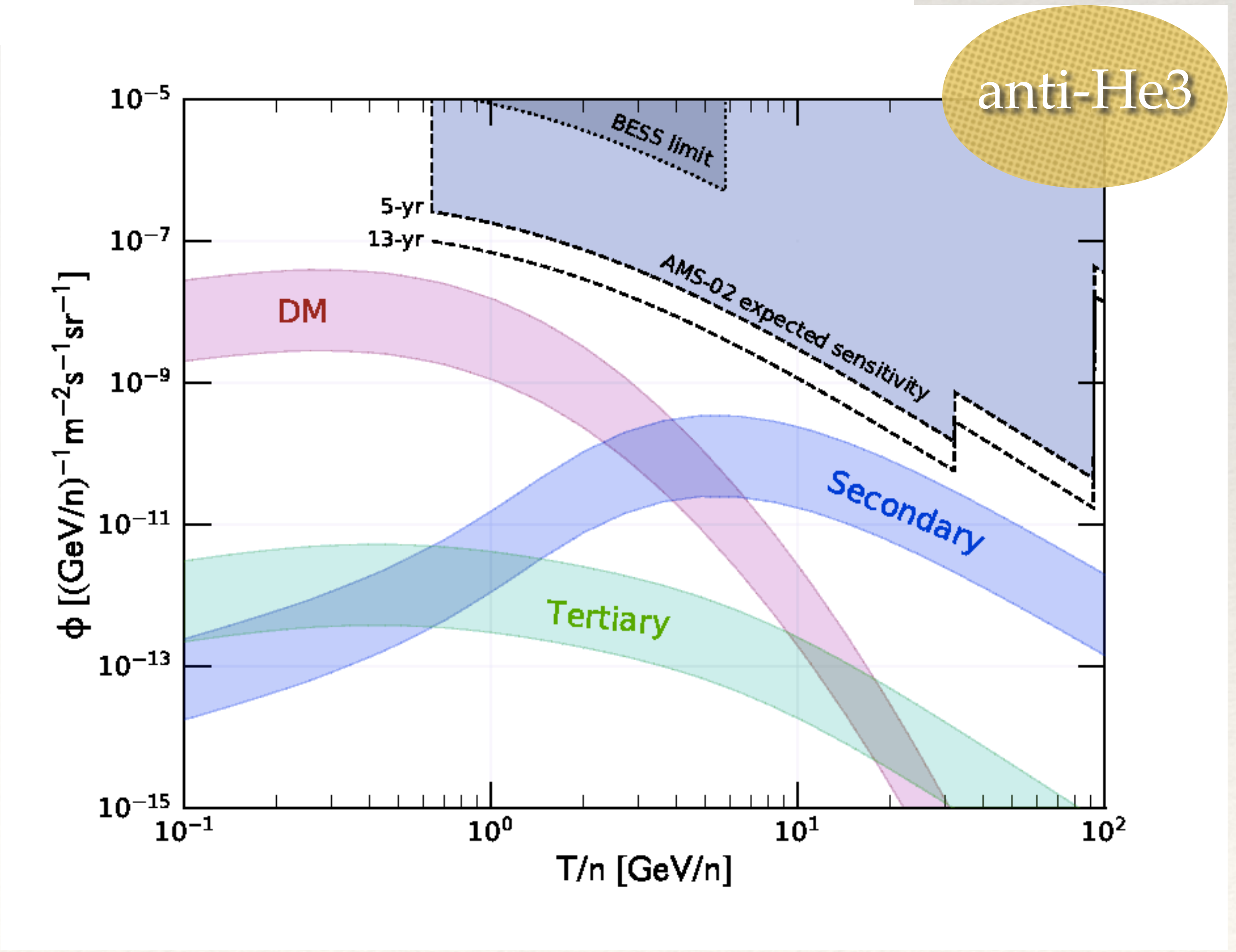


Donato+ 99

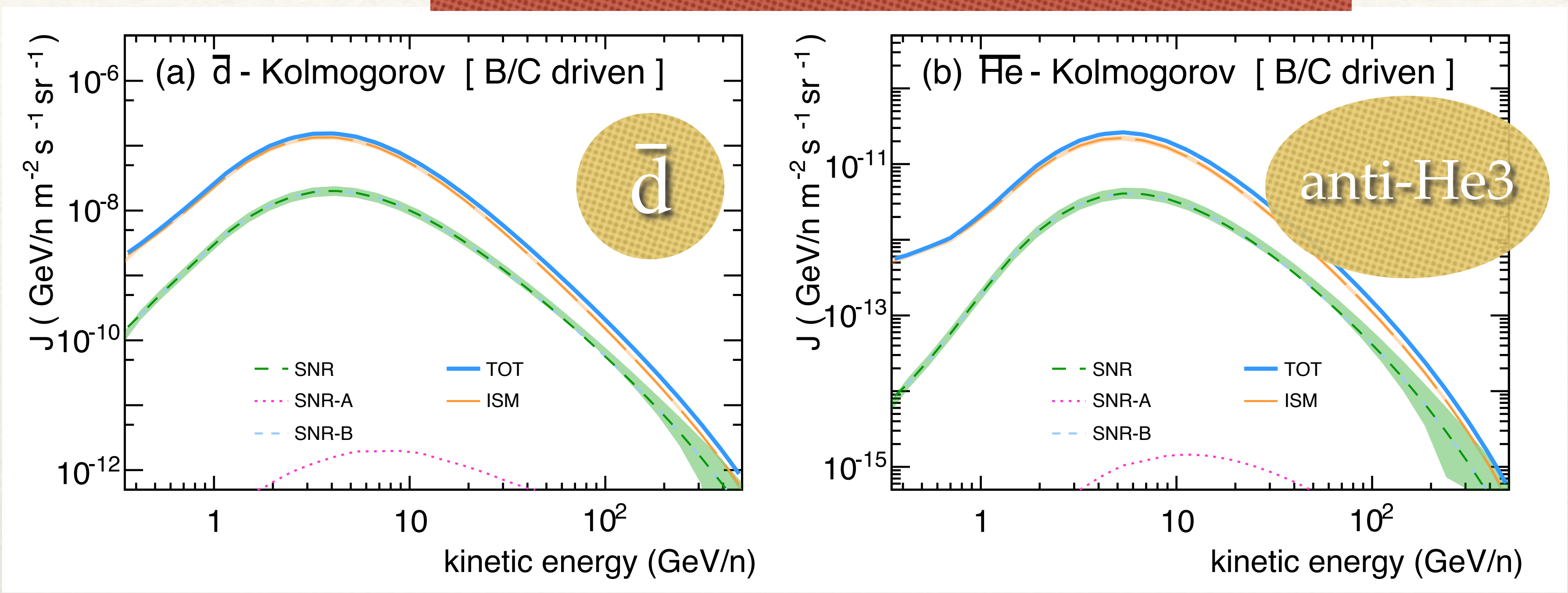
Significant Ongoing Theoretical Work

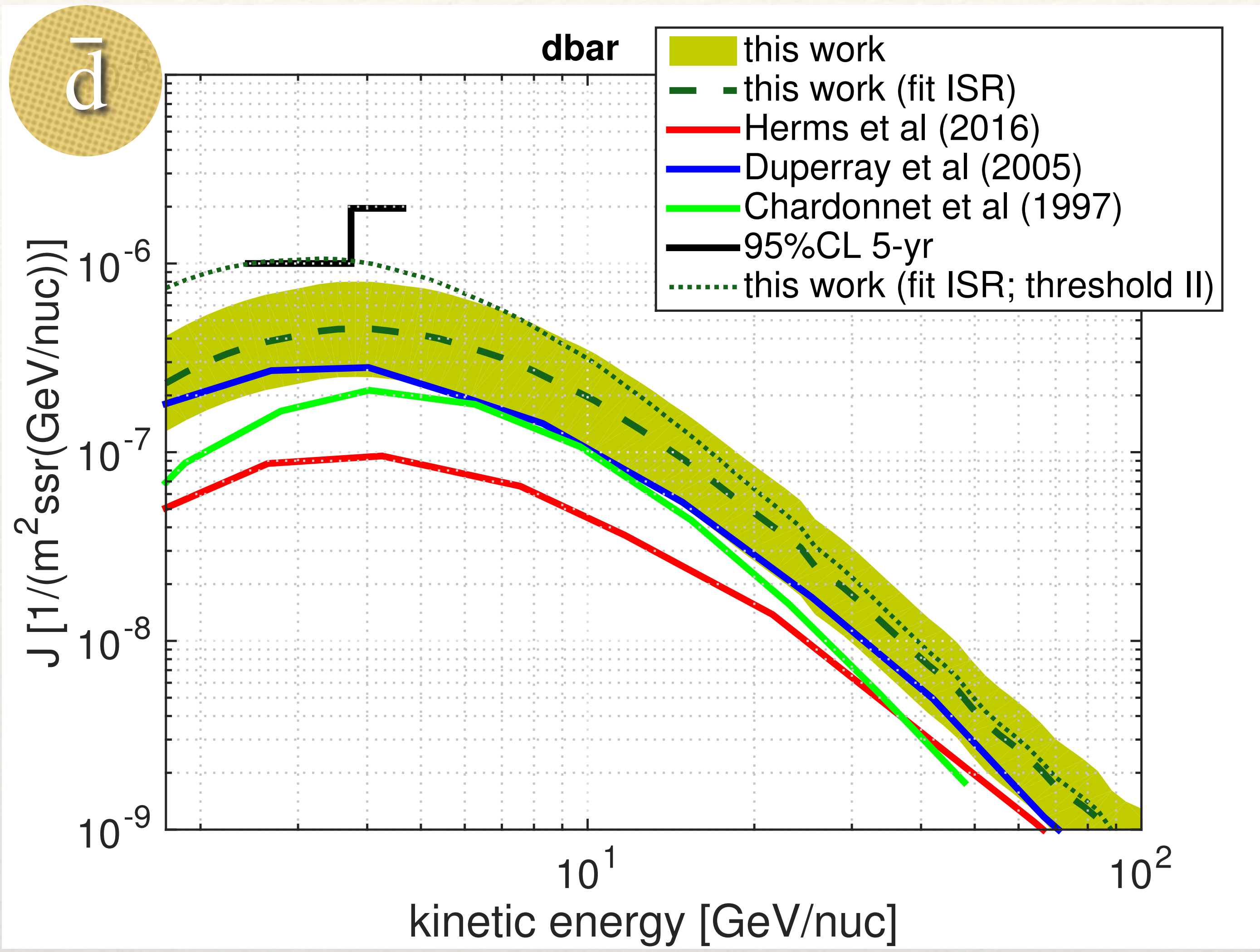
Korsmeier, Donato & Fornengo 2018



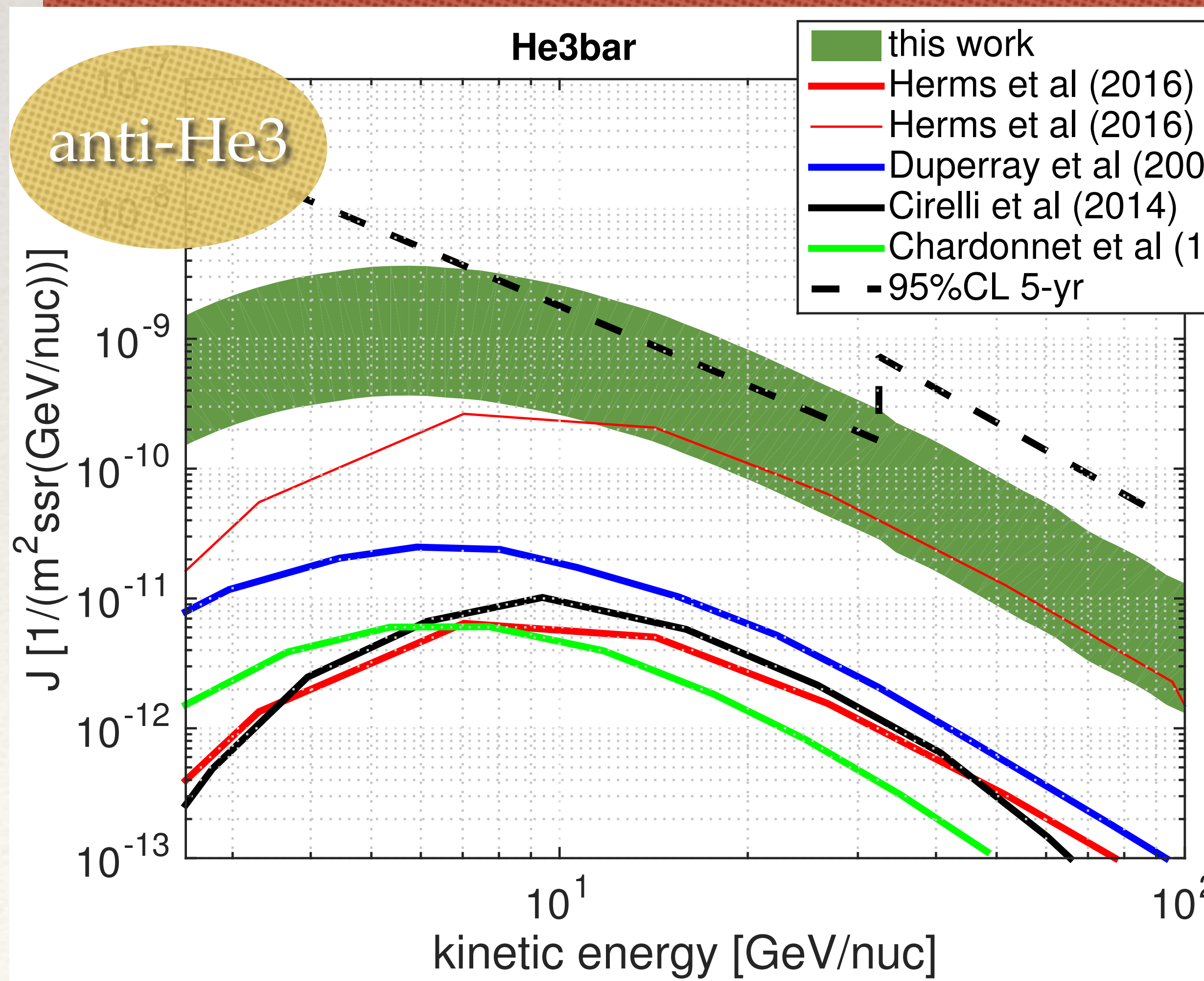


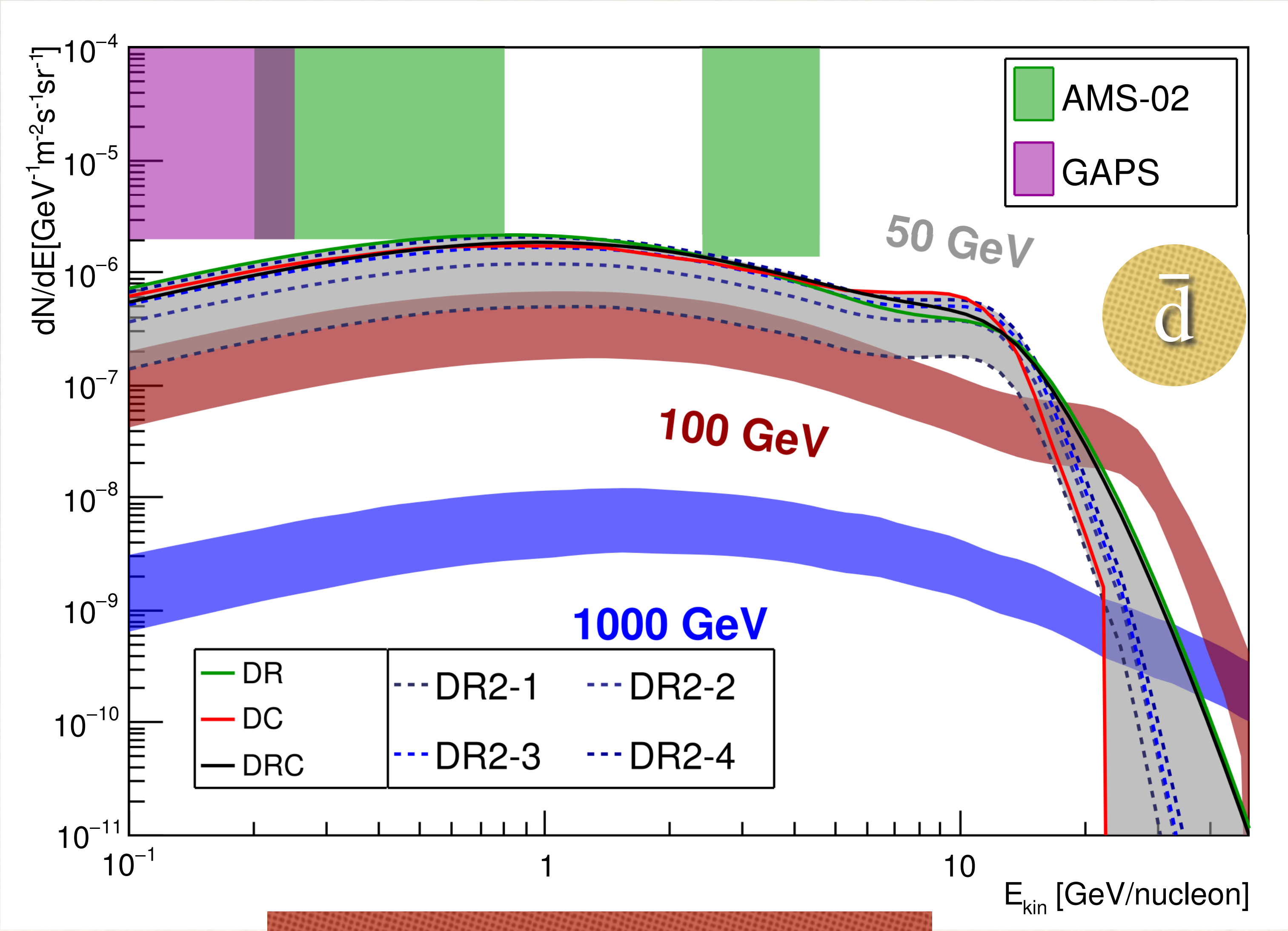
Tomassetti & Oliva 2017





Blum, Sato & Waxman 2017

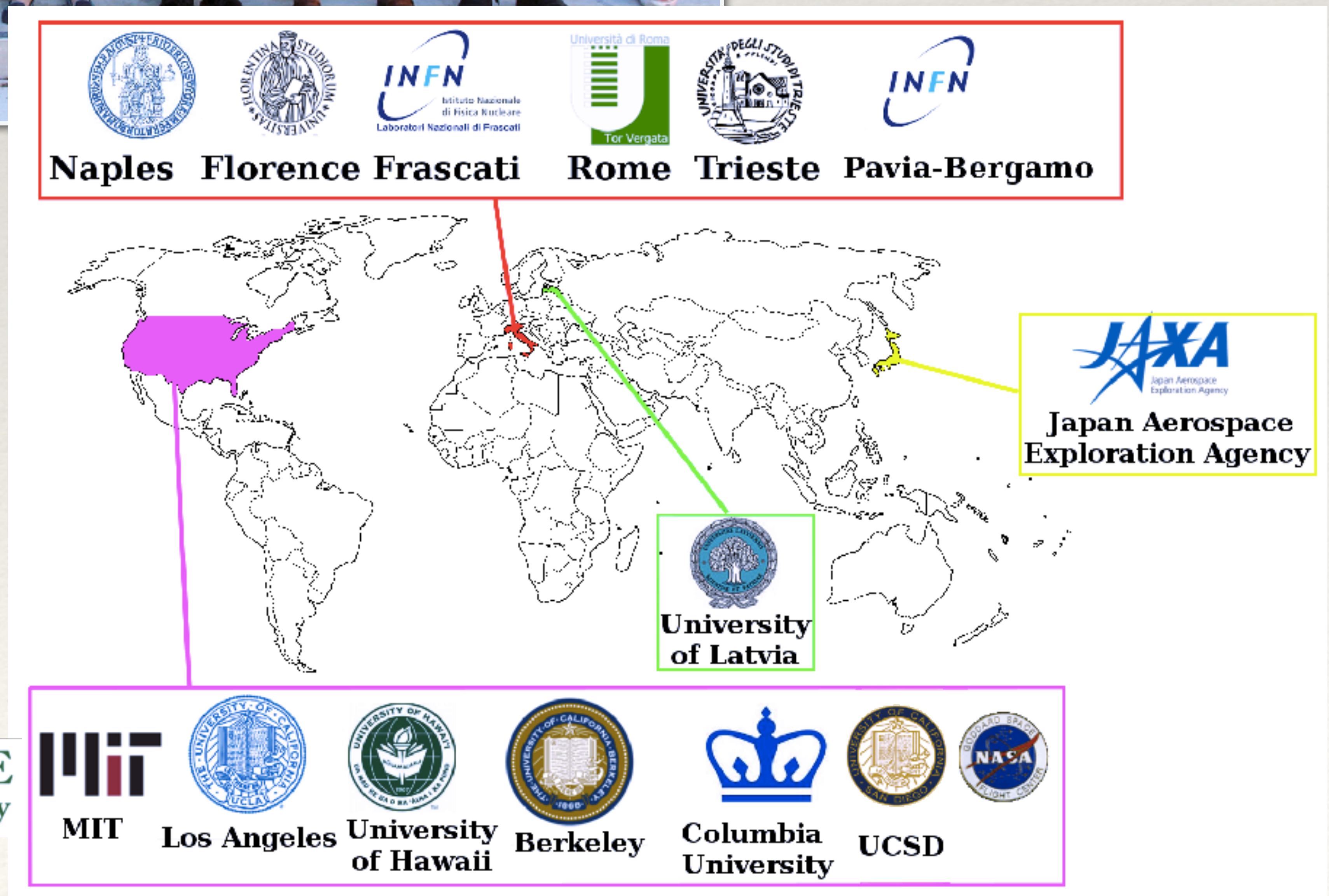




Lin, Bi & Yin 2018

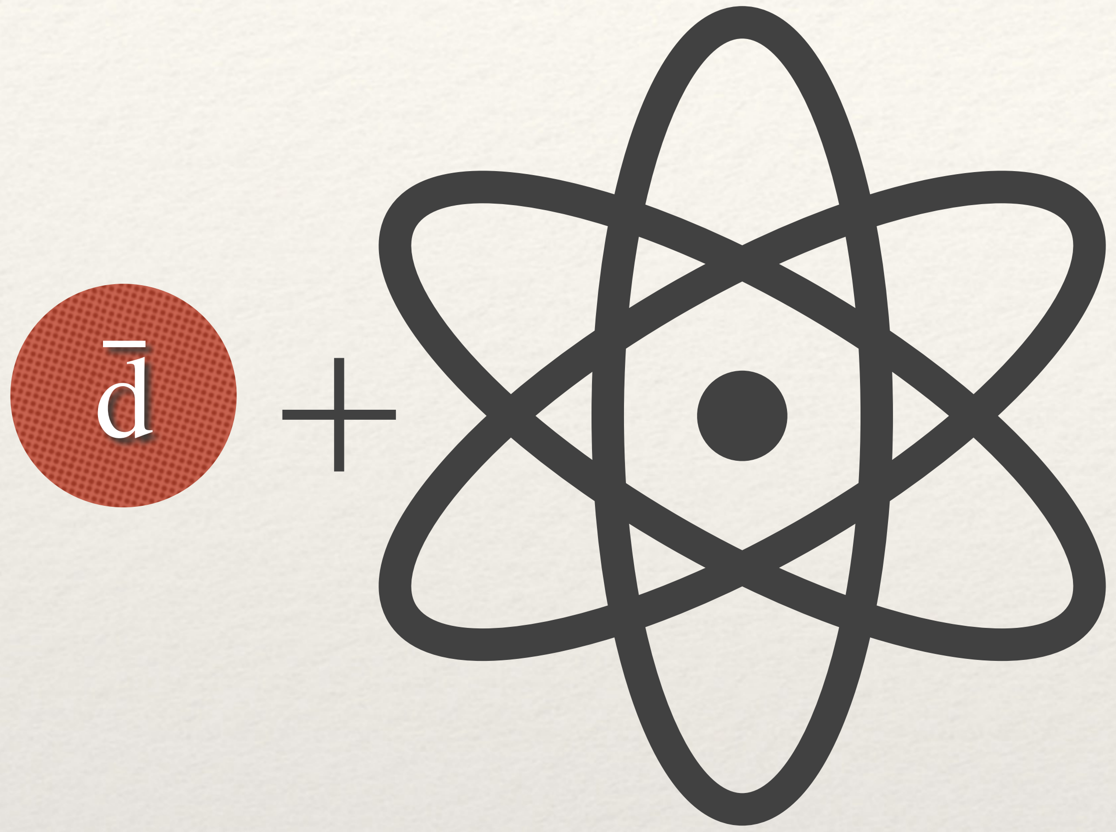
GAPS - General Antiparticle Spectrometer

- Antinucleons provide an excellent window for dark matter searches.
- With an almost background free signal they provide a very "clean" window.
- However, existing techniques (rigidity based) have problems:
  - Energy threshold.
  - (Anti)proton suppression.
- Solution:
  - Exotic atom technique → no background.
  - Antarctic balloon → low energy threshold.

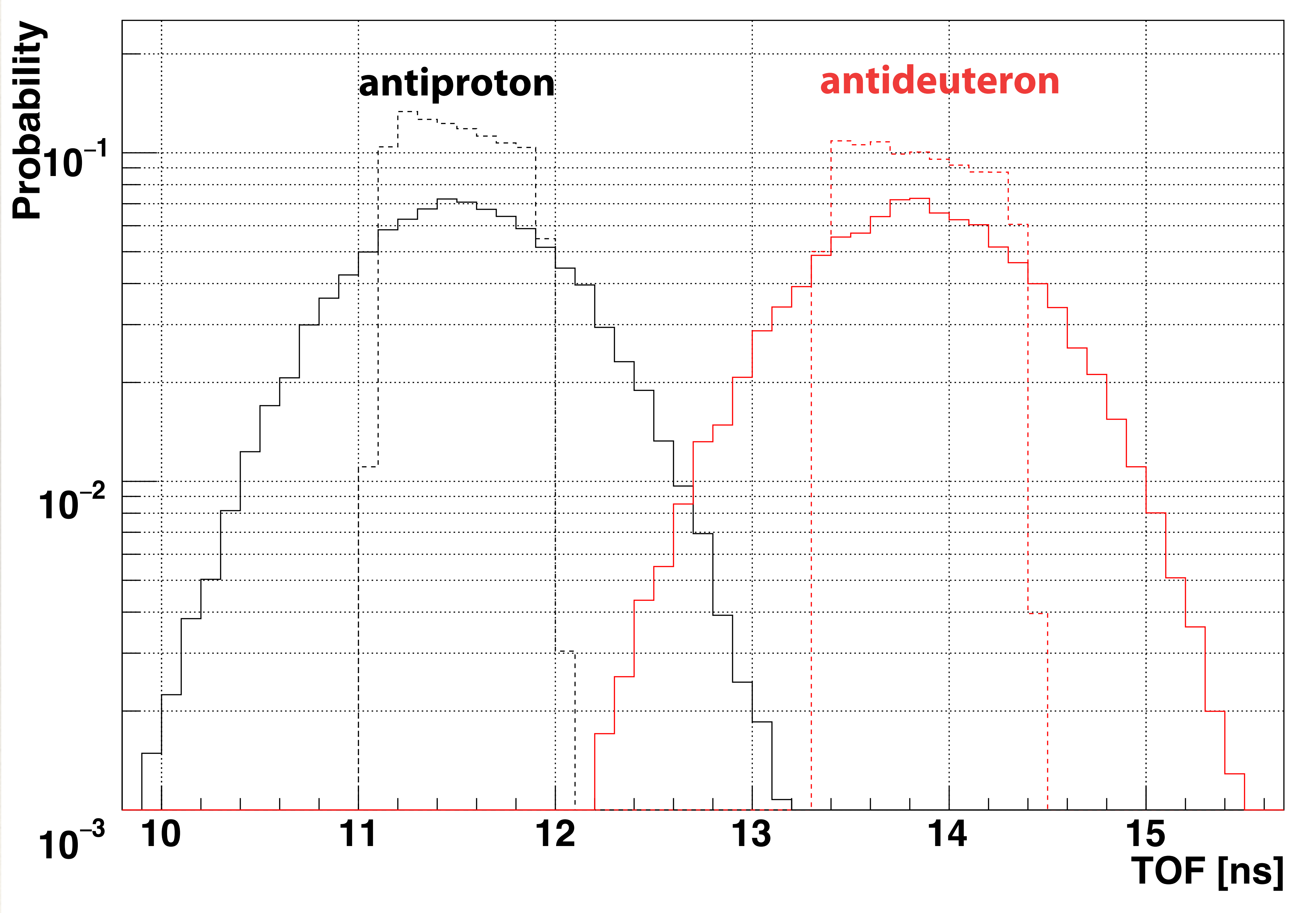


OAK RIDGE National Laboratory

Stopping Depth

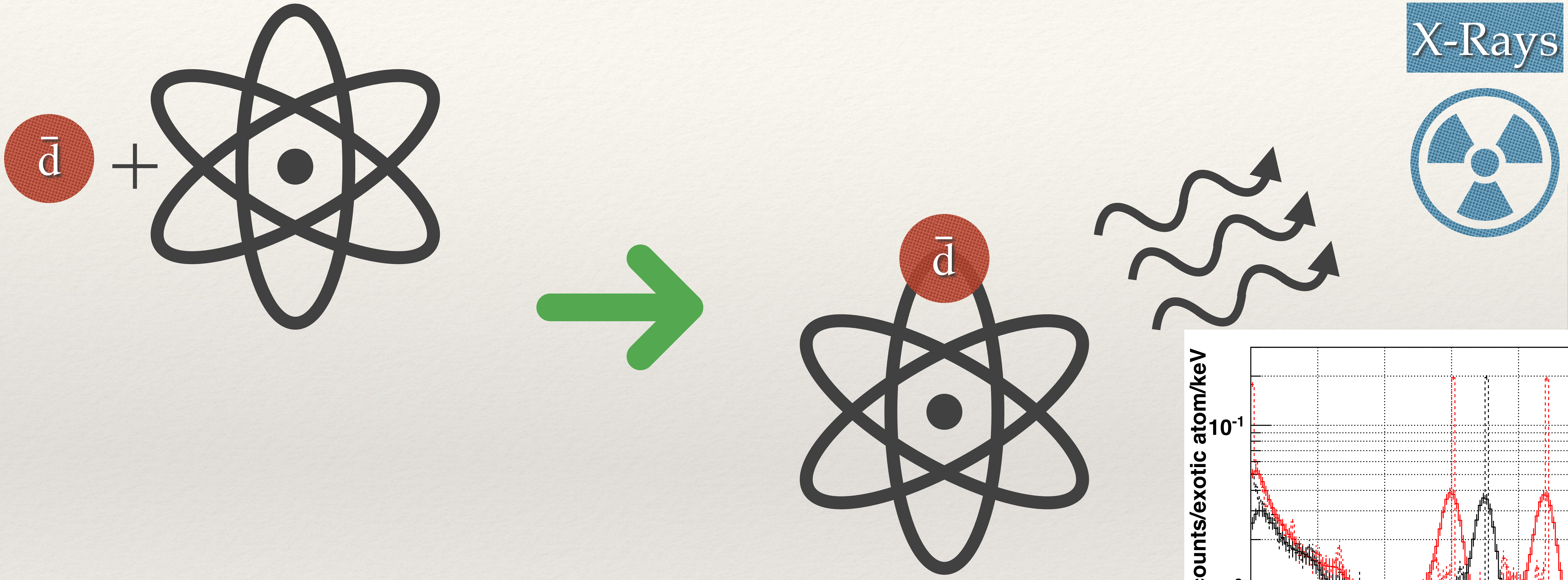


→ More likely to stop

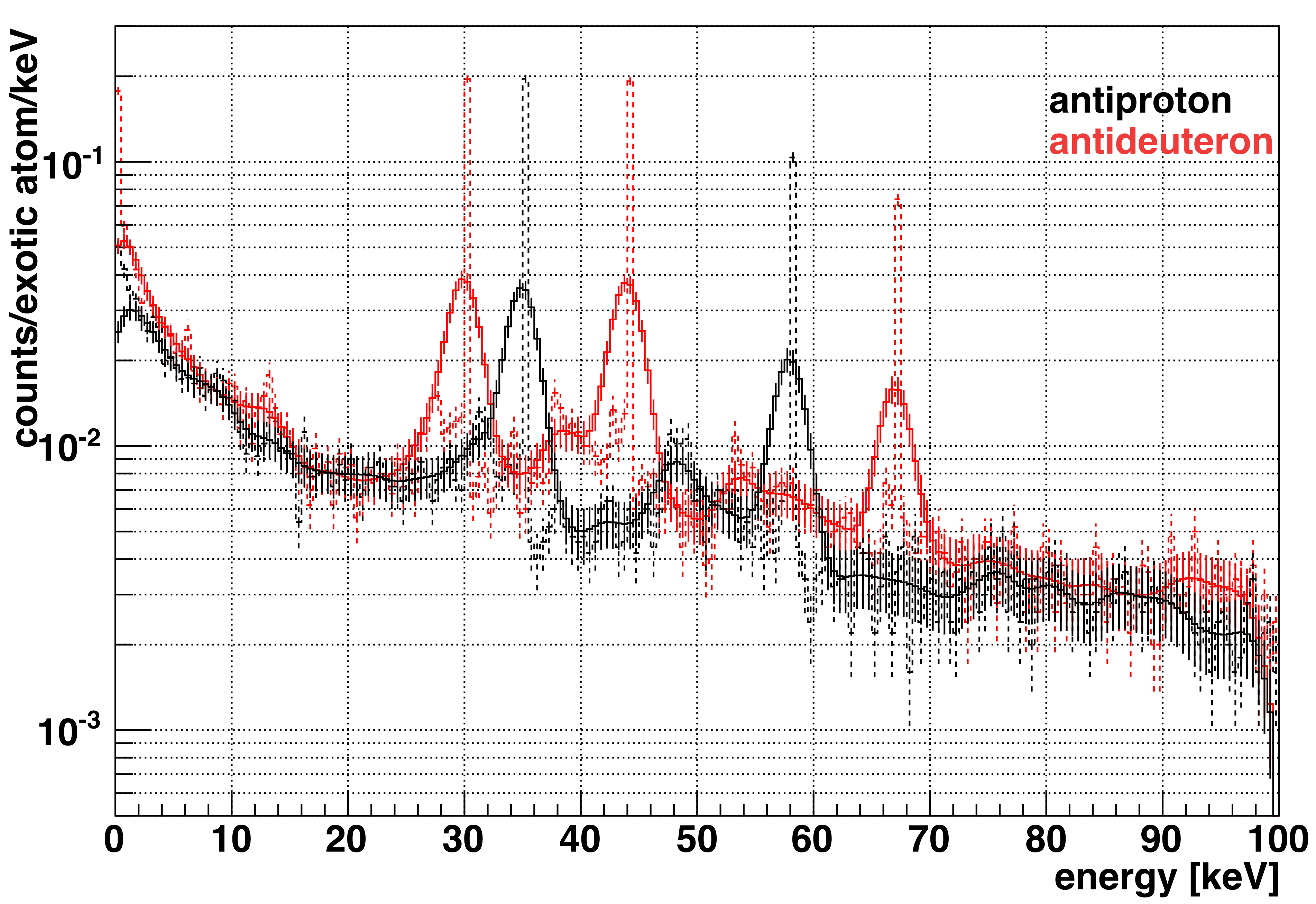


→ Slower

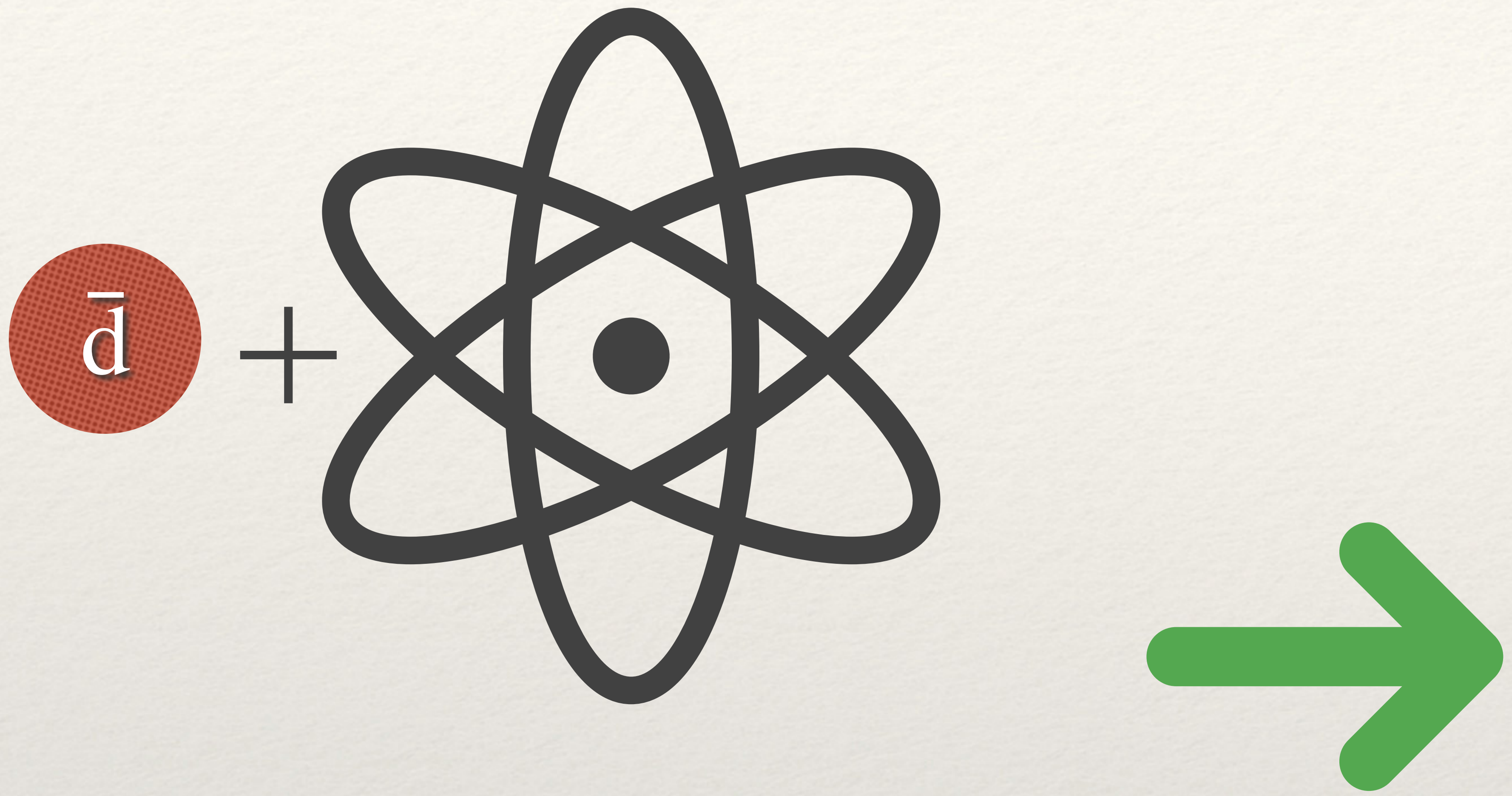
Characteristic X-Rays

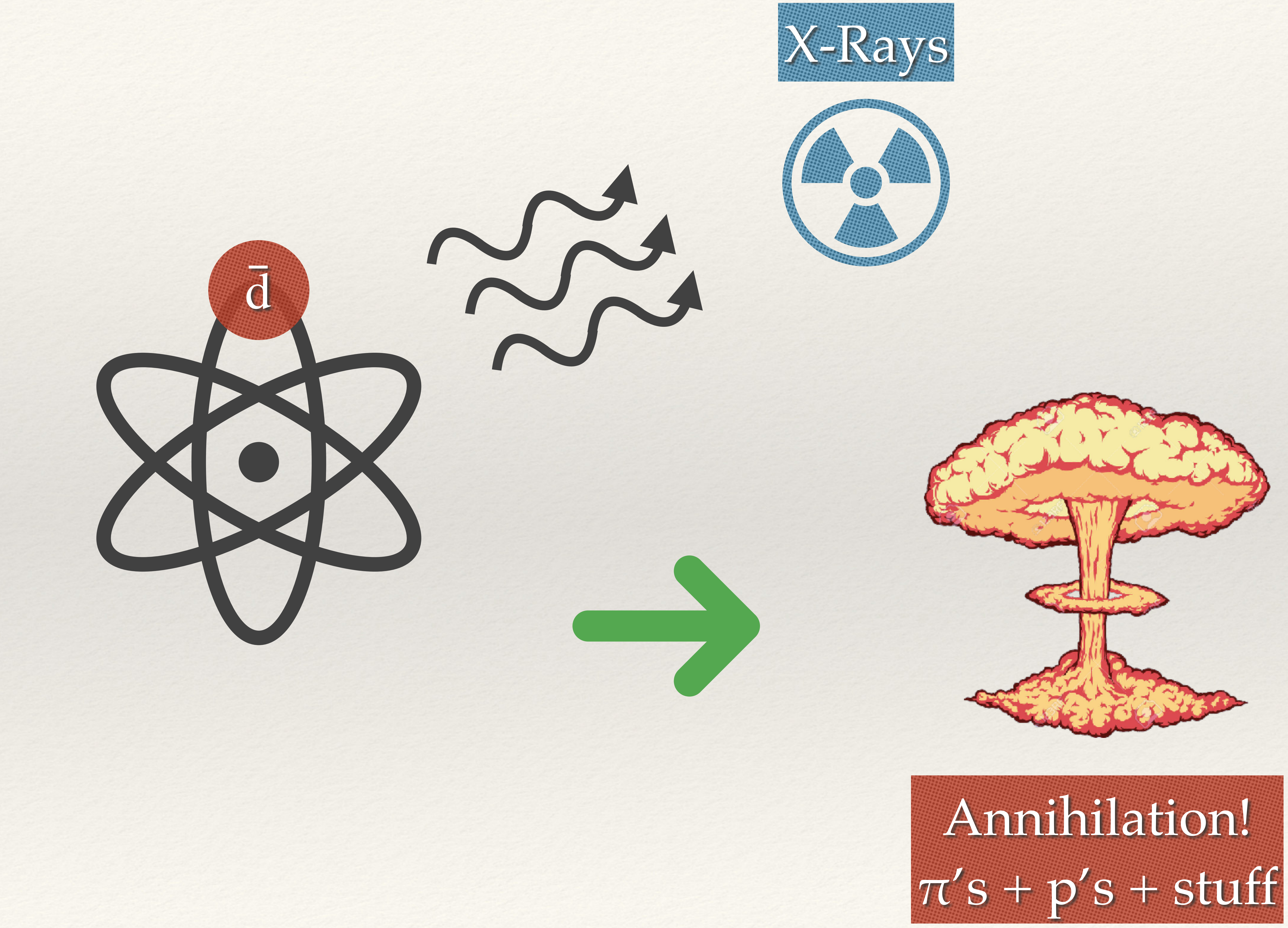


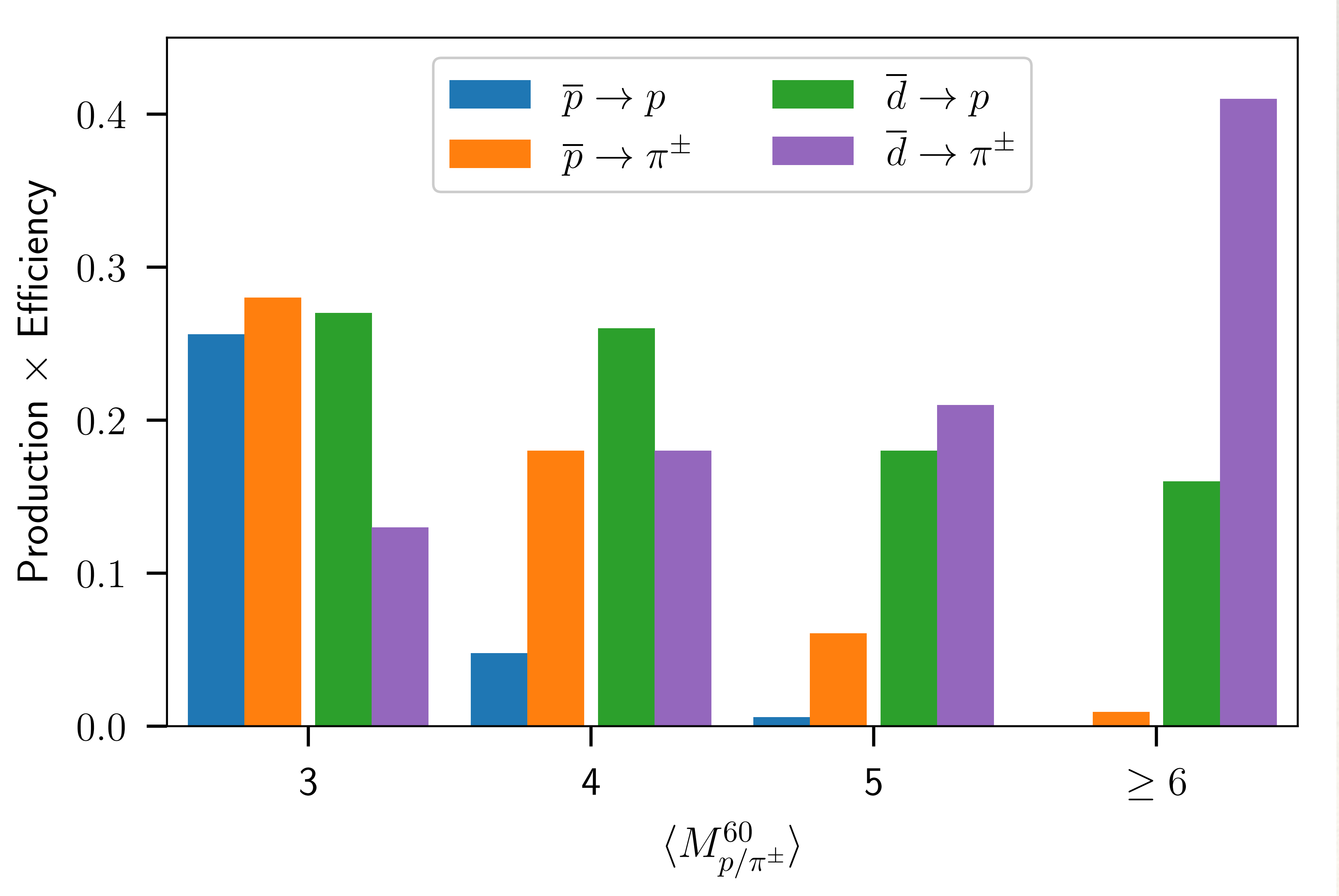
Simulation checked against data measured at KEK in 2004



Pion & Proton Production

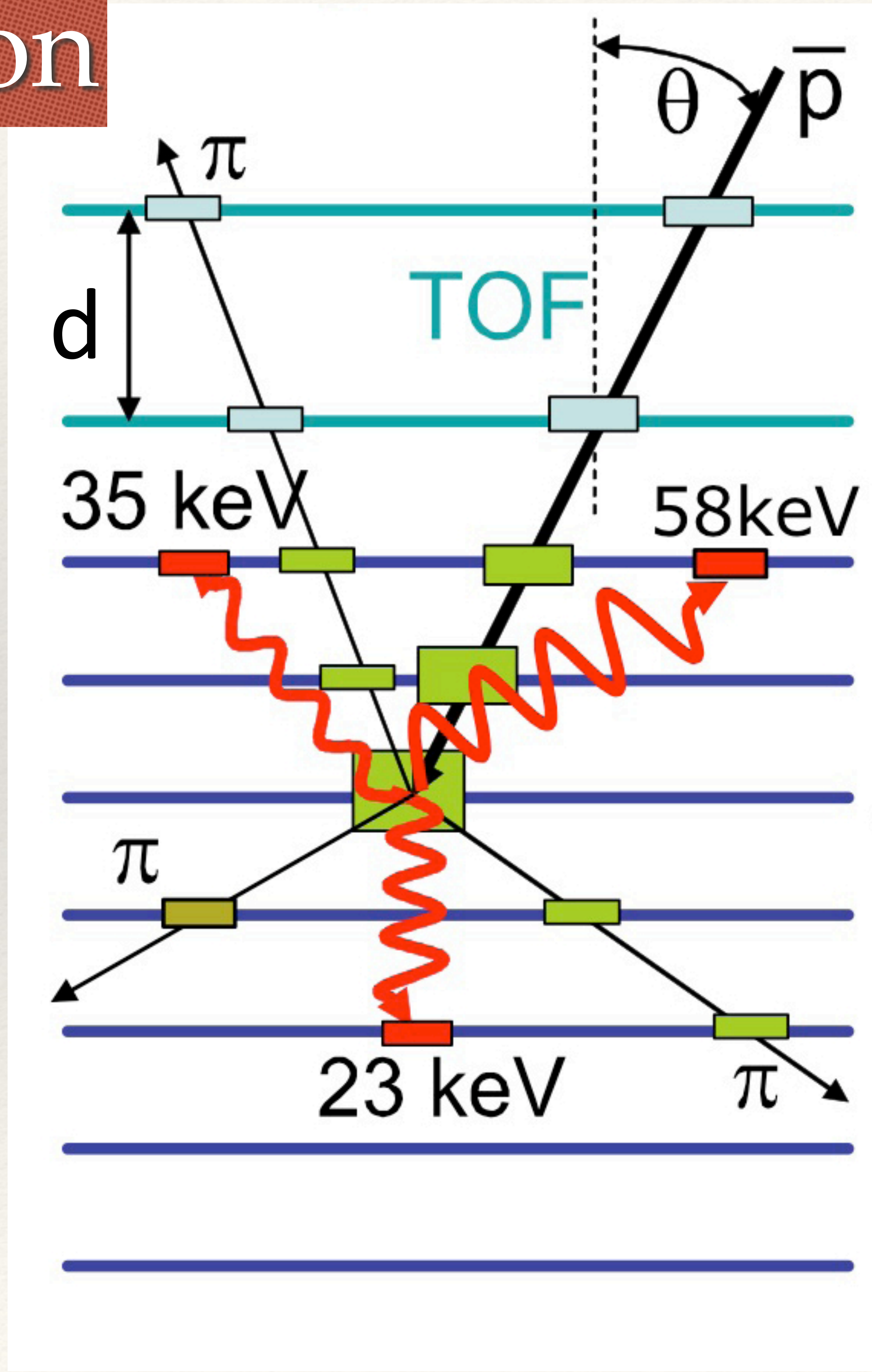




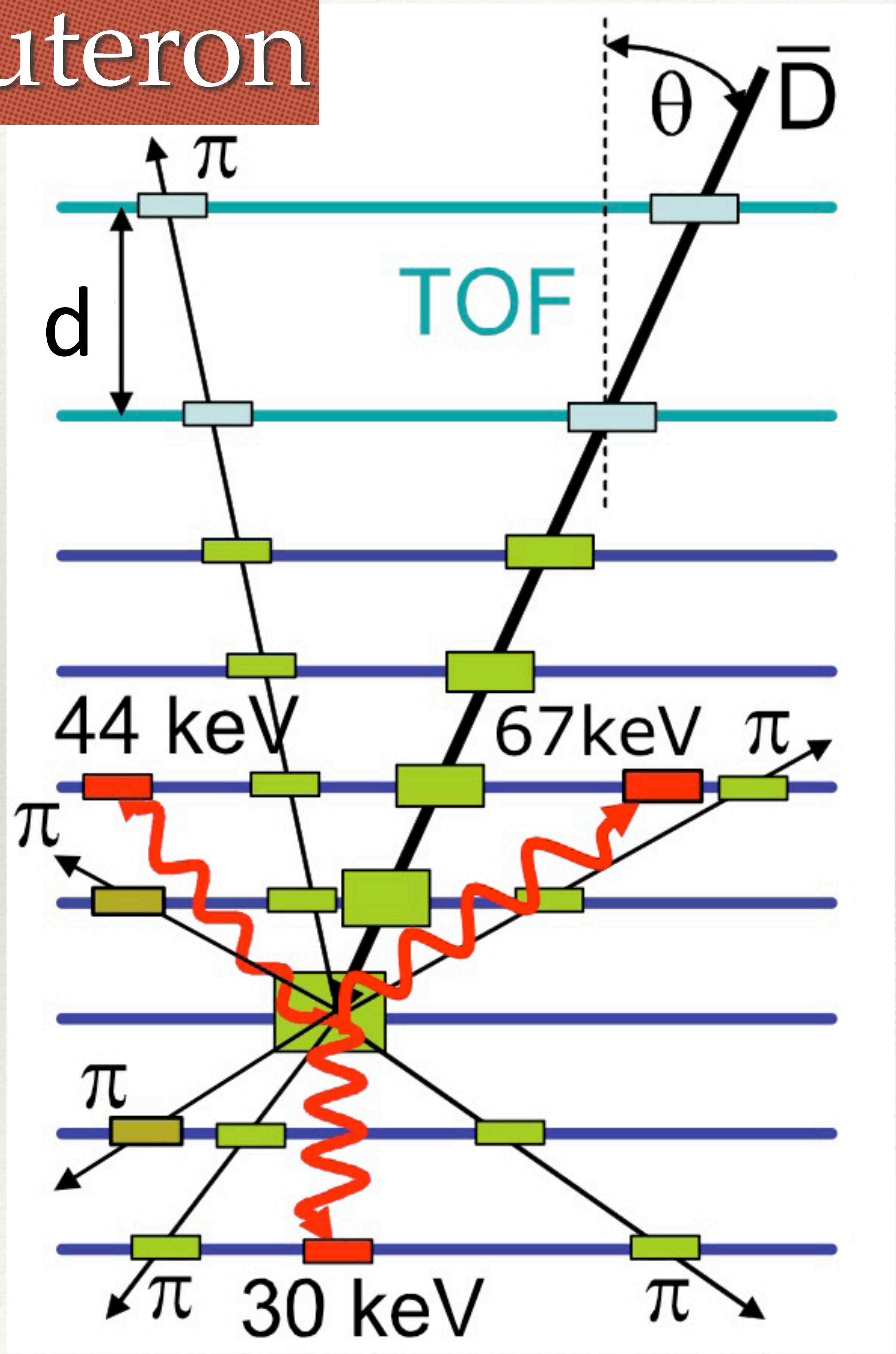


Putting It All Together

antiproton



antideuteron

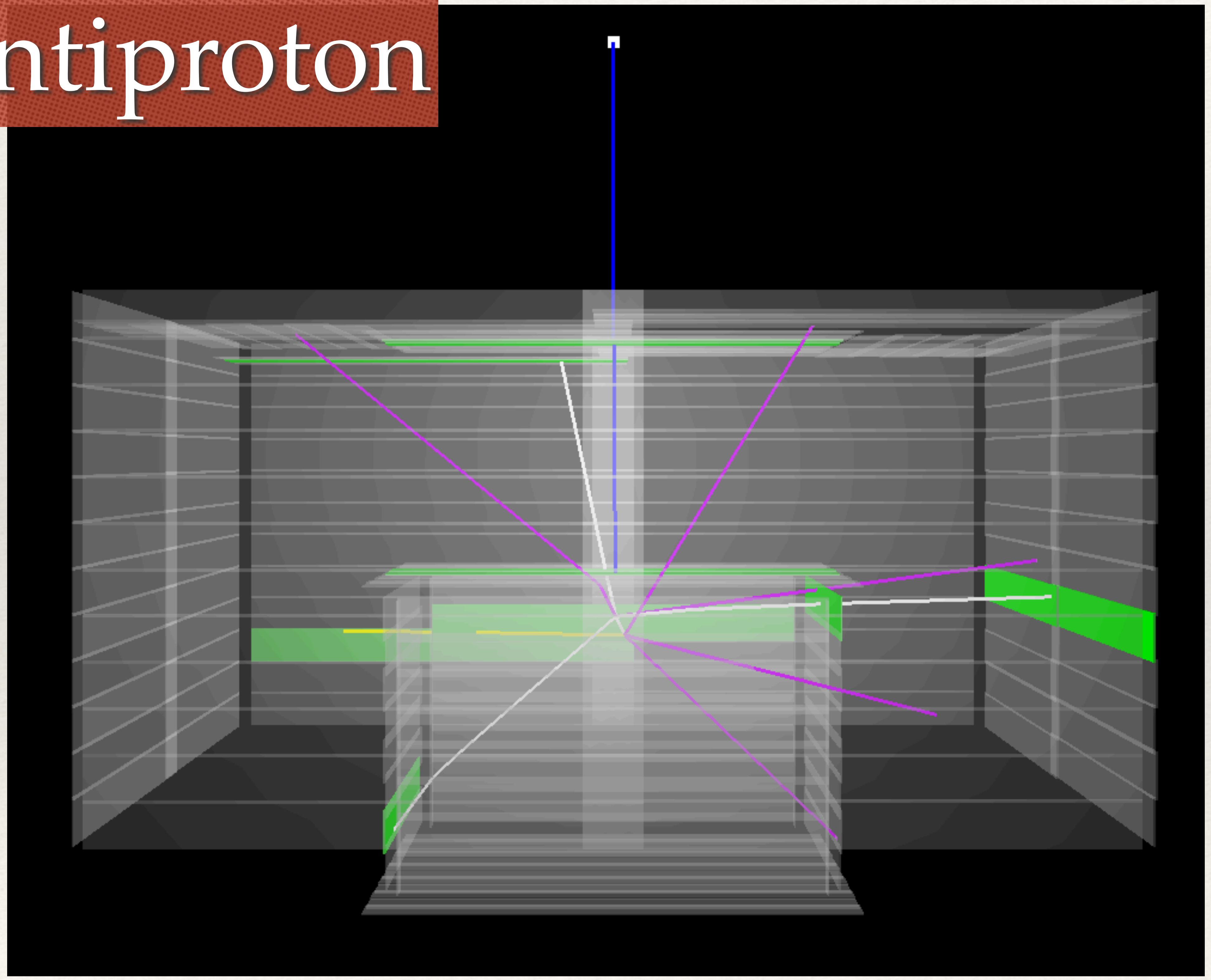


Aramaki+15

(It works in simulations too …)

60 MeV $\bar{p}$
4 pions produced

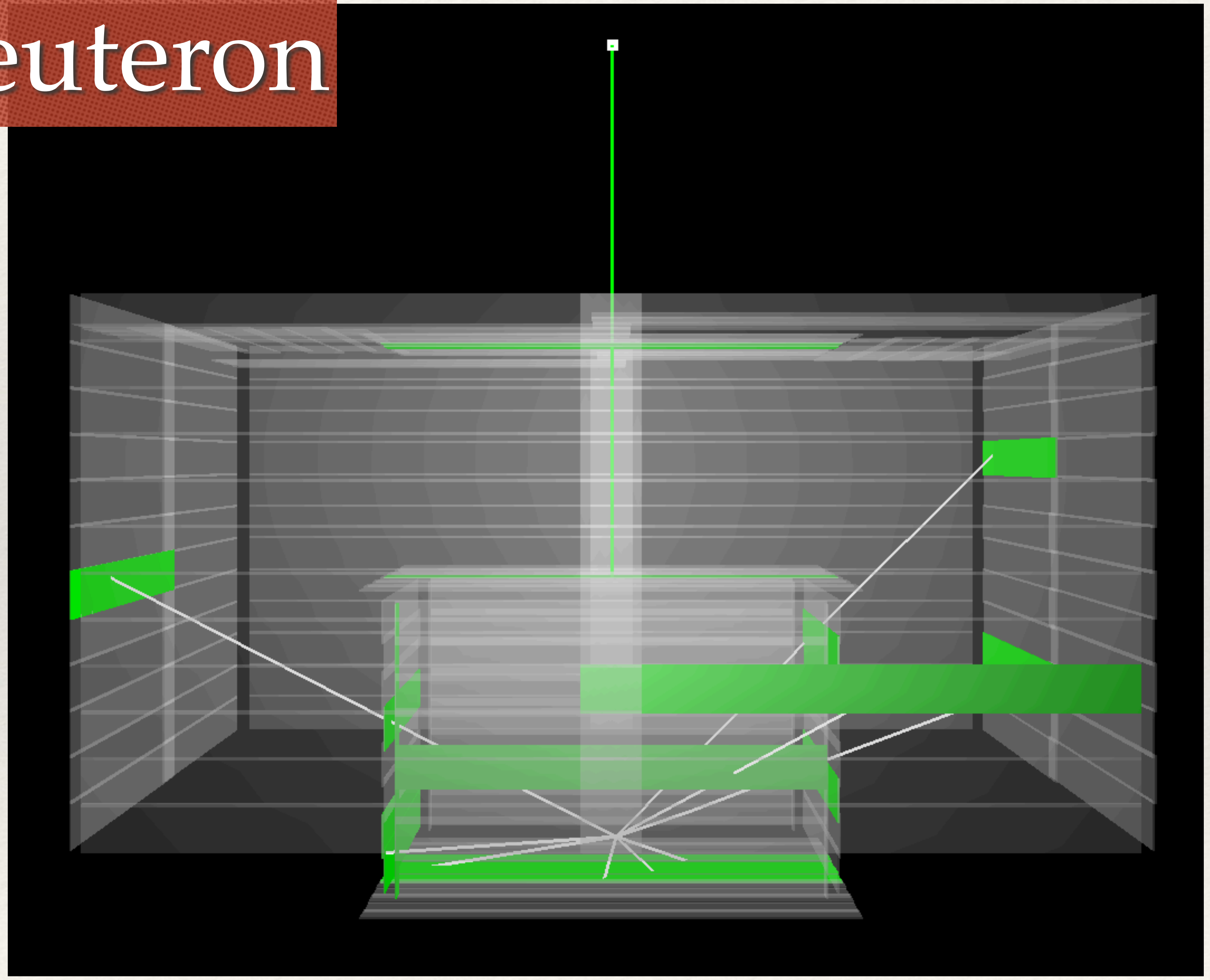
antiproton



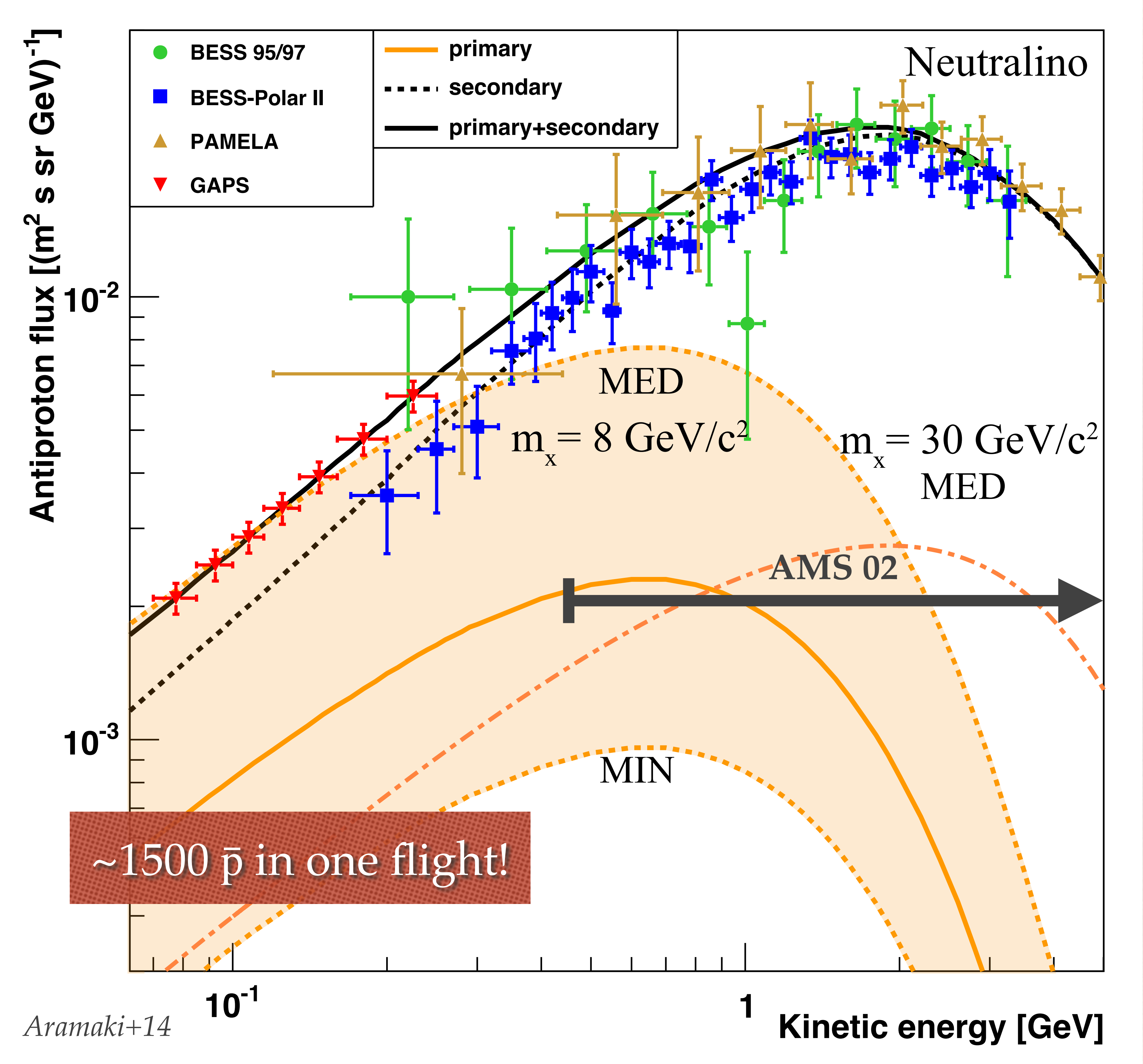
blue = $\bar{p}$
green = $\bar{d}$
white = pion
yellow = electron
purple = other

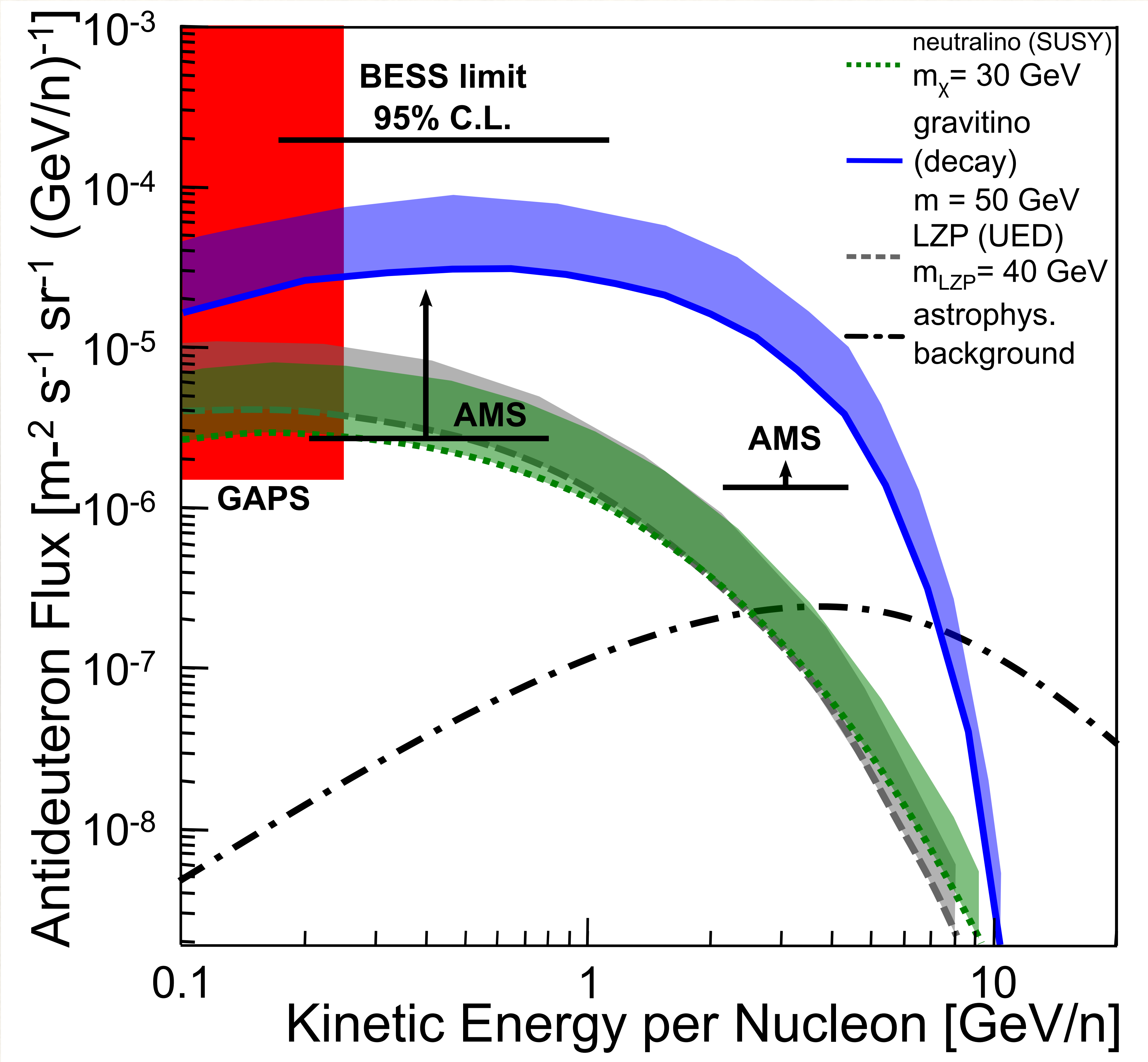
120 MeV $\bar{d}$
10 pions produced

antideuteron



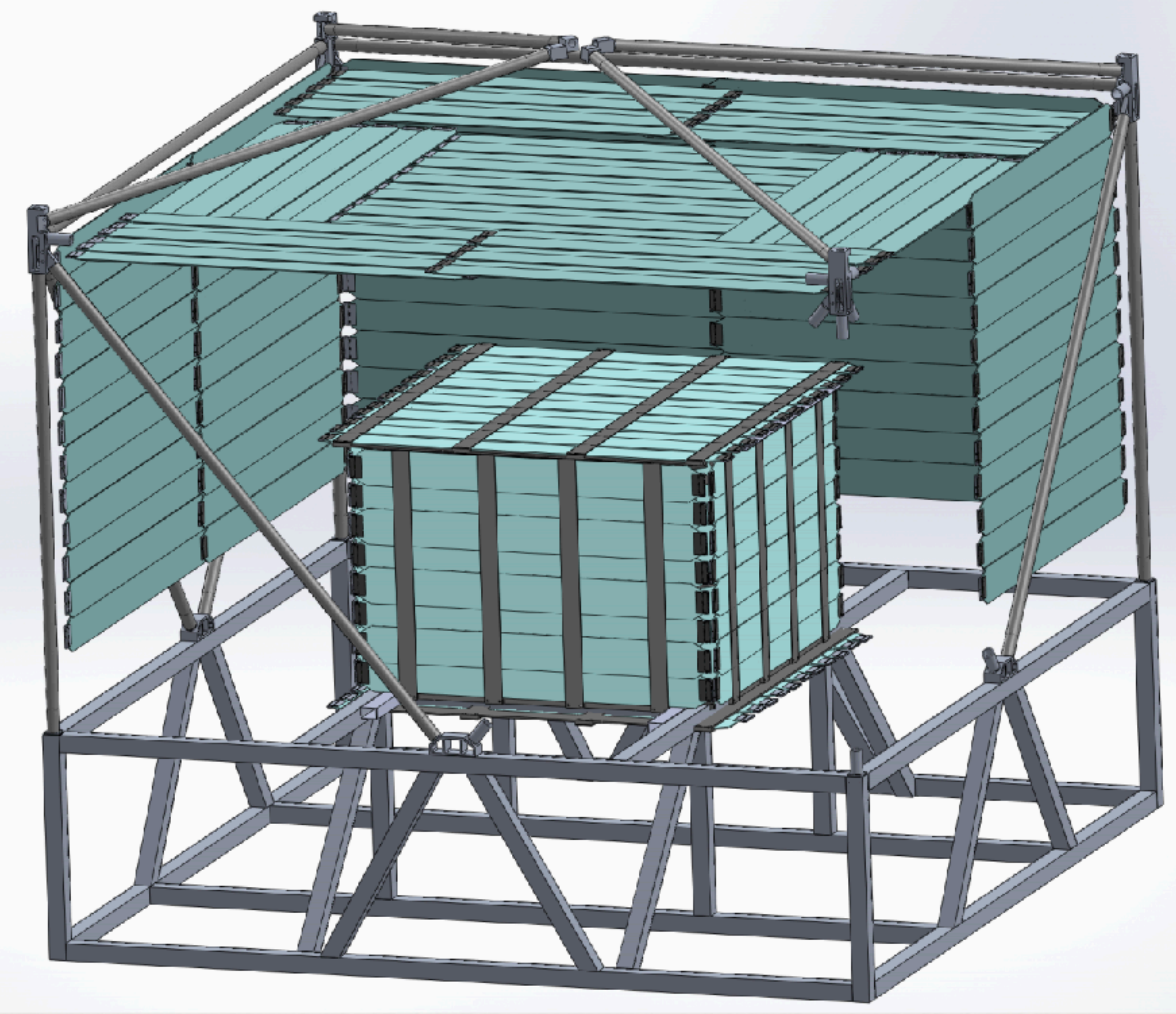
Predicted Sensitivity

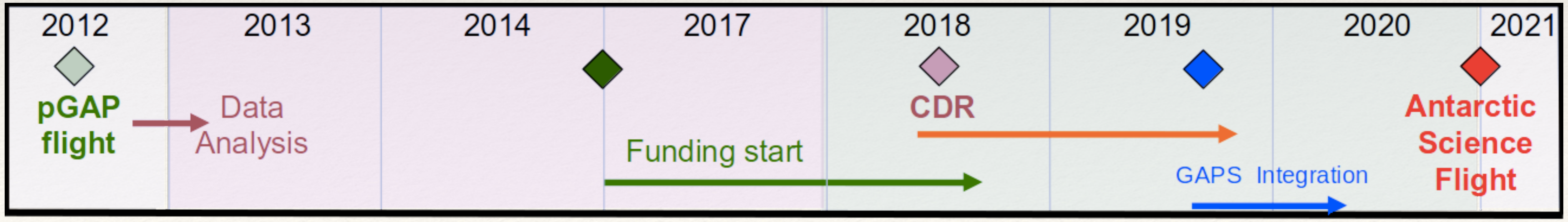




Status Update

- NASA funding started 2017.
- Strong and welcome involvement from INFN joining GAPS.
- First flight austral summer 2020-21.
- Now the fun begins:
  - 1350 silicon detectors.
  - ~200 ToF paddles (~400 ends to read out).
  - Trigger & readout electronics.
  - Cooling.
  - Mechanical design.
  - …

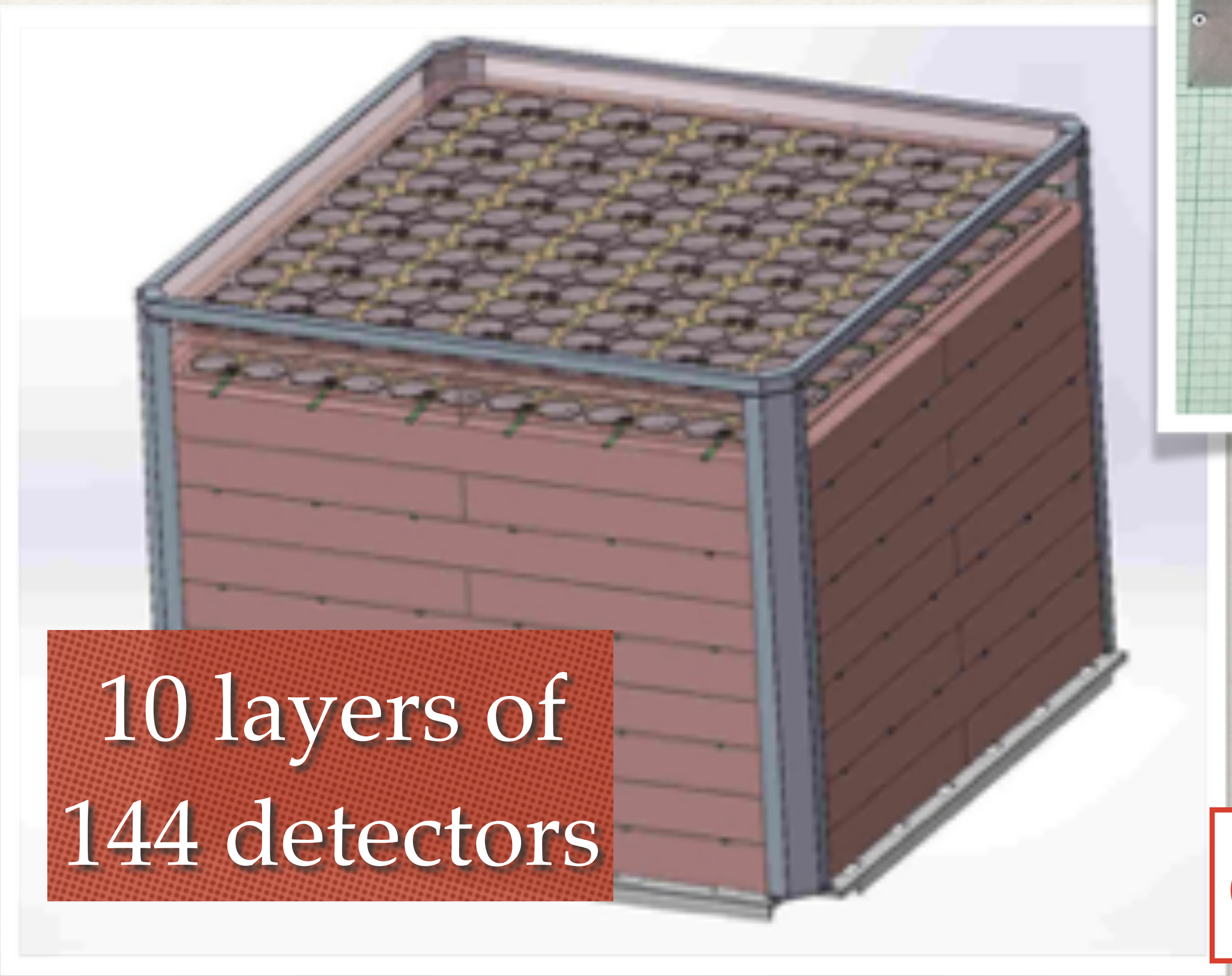




Si(Li) Detectors

- Process developed in partnership with Shimadzu Corp. (Japan).
- Readout ASIC designed by INFN

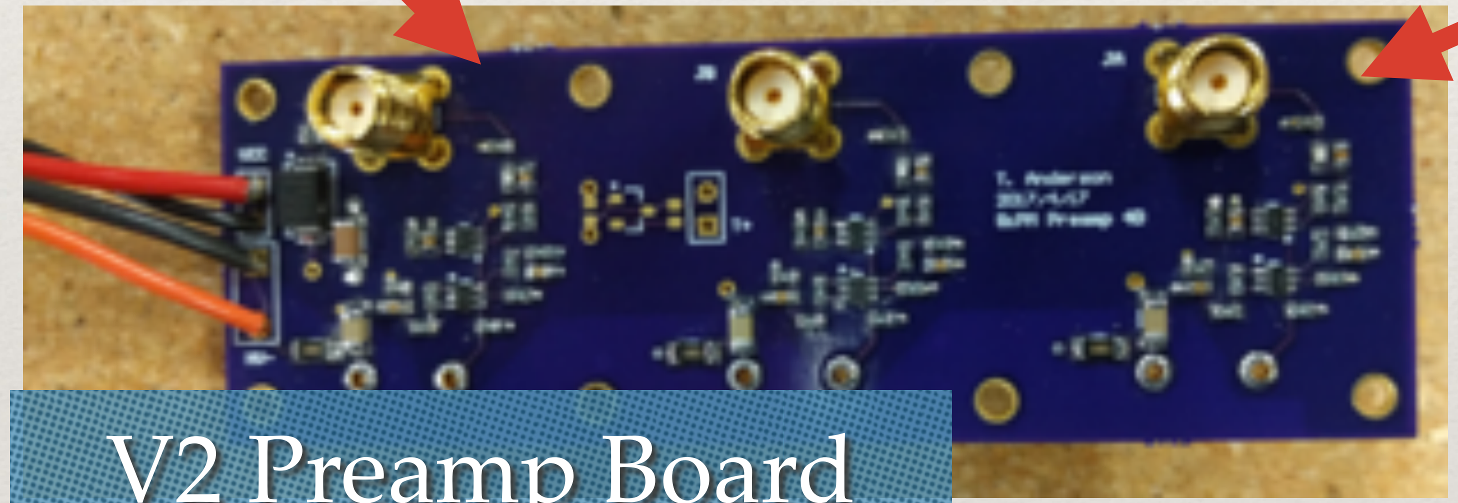
	High Gain	Low Gain
Timing Resolution	100 ns	
Energy Resolution	4 keV	10%
Energy Range	20 - 80 keV	0.1 - 100 MeV
Operating Temperature	< -40 °C	
Leakage Current	< 10 nA	



Perez et al. accepted to NIM A (2018)

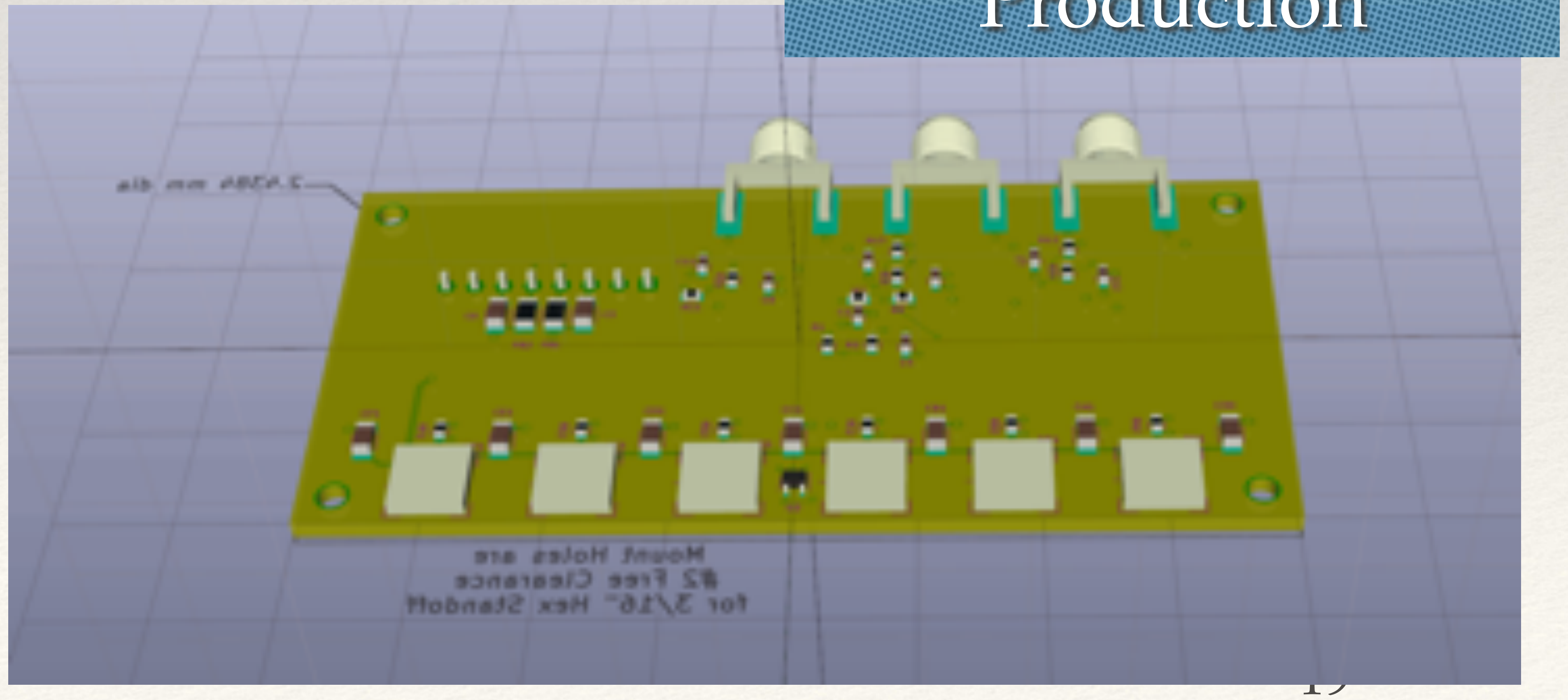
Time of Flight (ToF)

1.8m Test Paddle

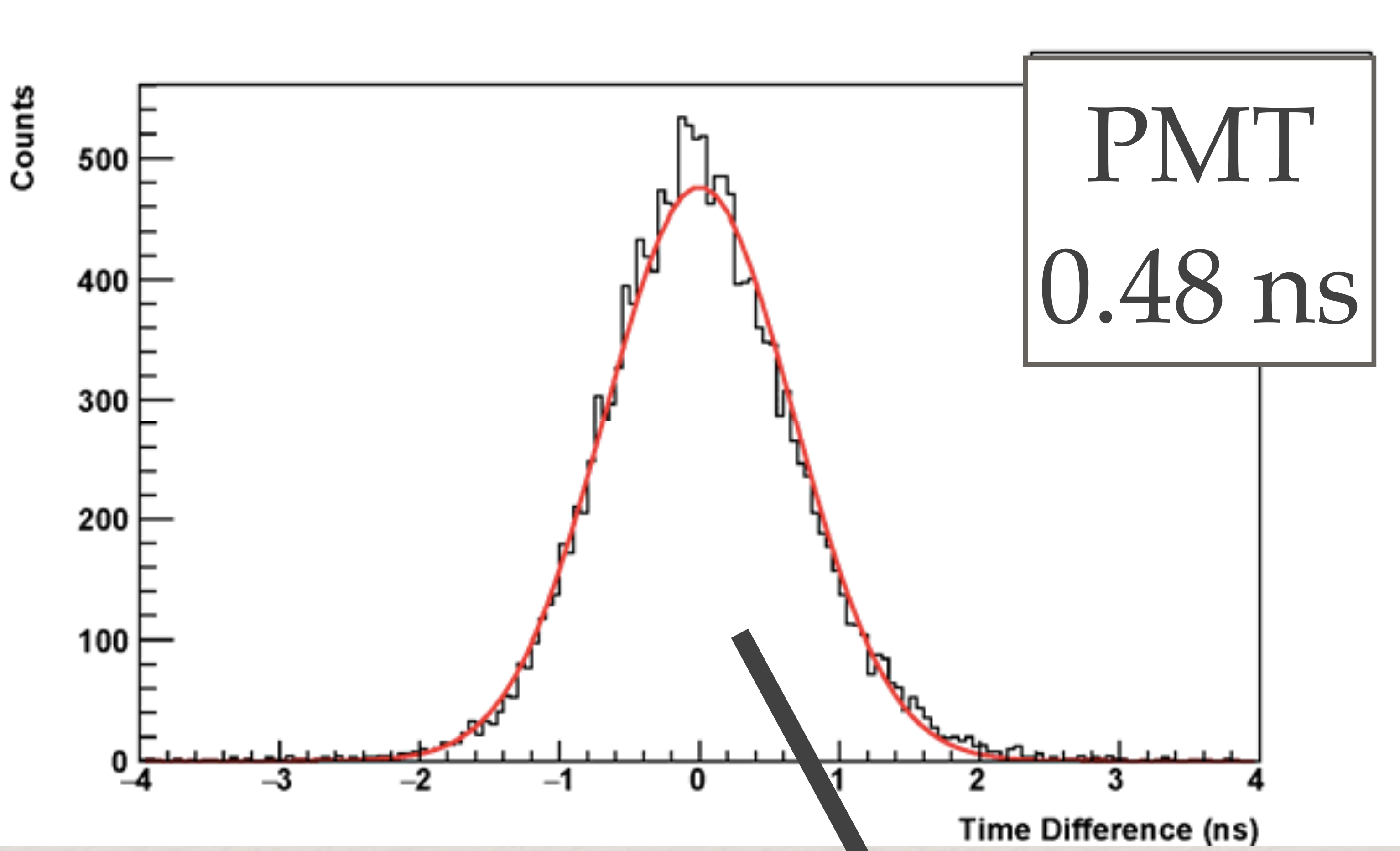


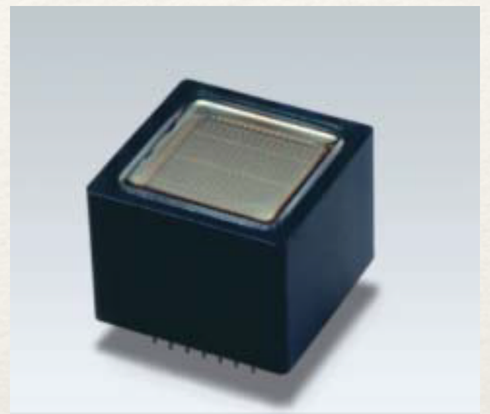
V2 Preamp Board

V3 Board in Production



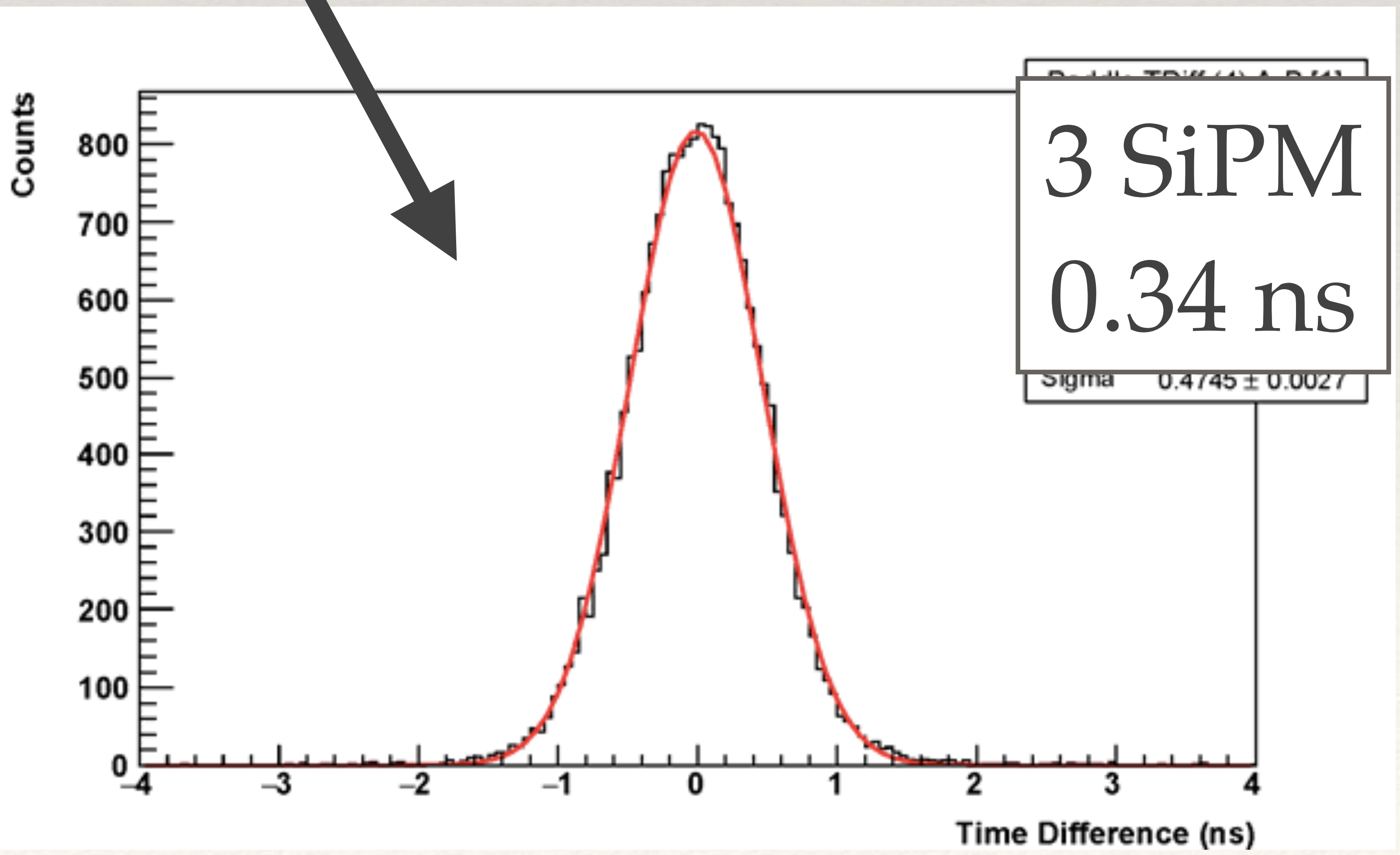
Timing Resolution = $(T_A - T_B)/\sqrt{2}$



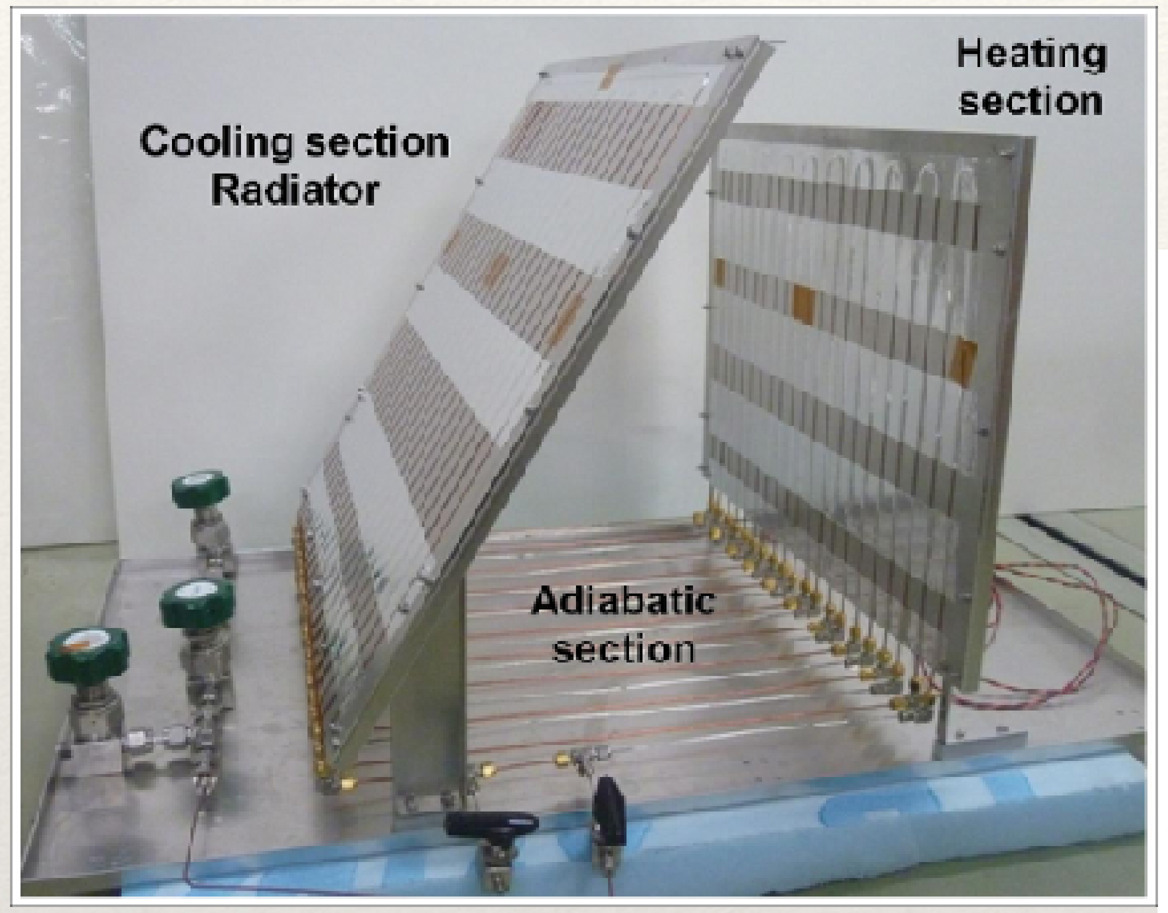


Hamamatsu R7600-200

Hamamatsu S13360-6050CS (LCT5-6050)

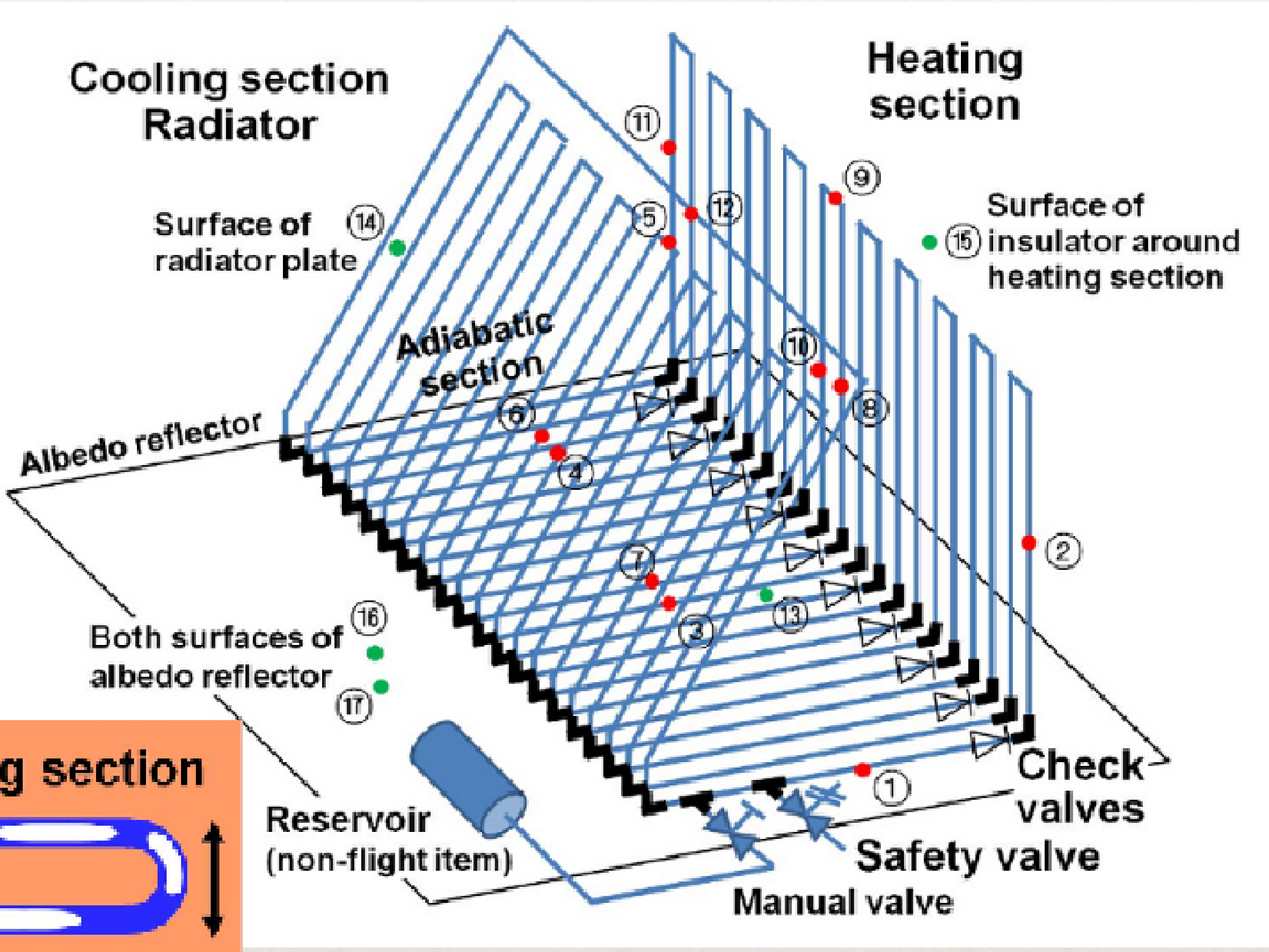


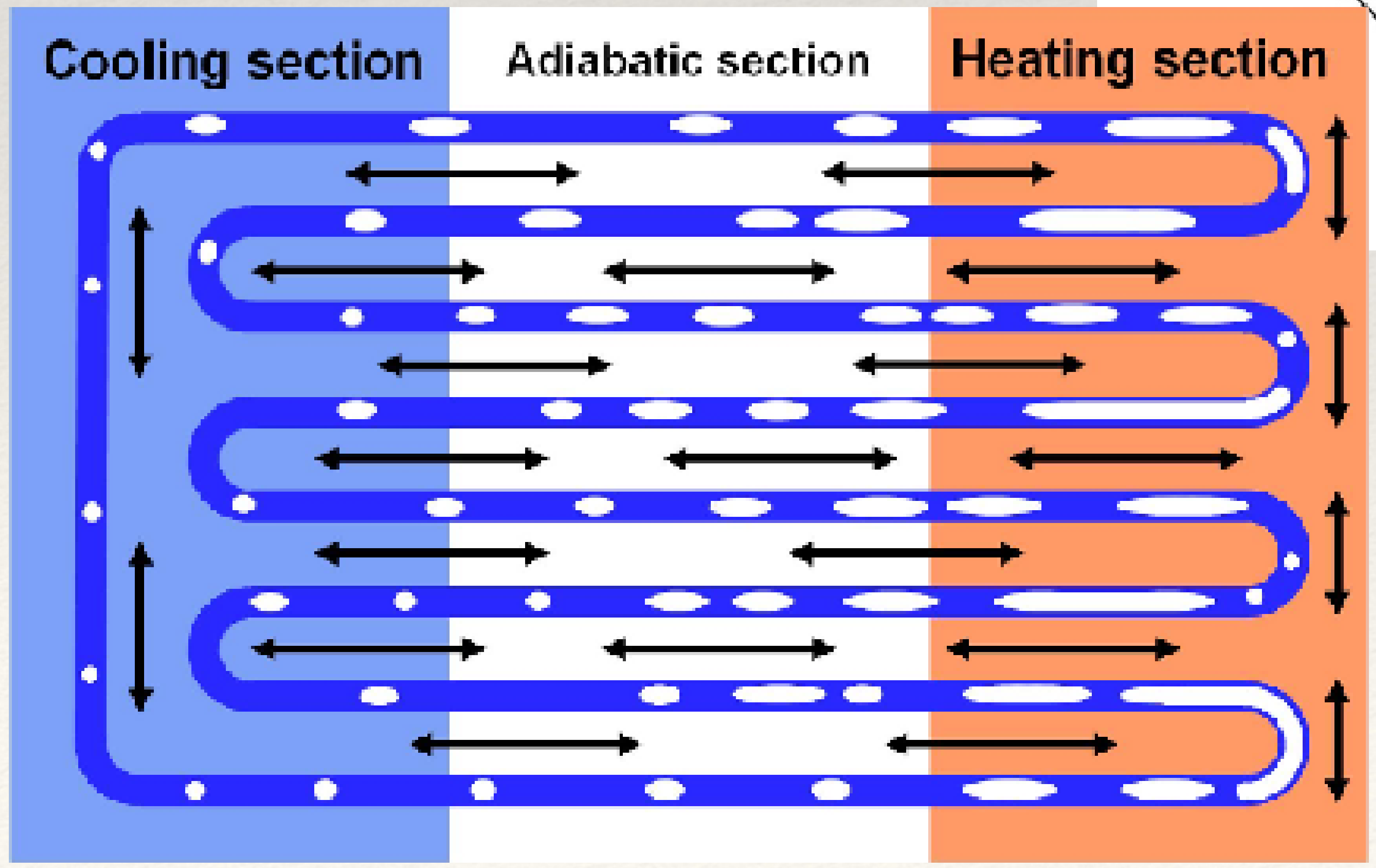
Cooling & Mechanical

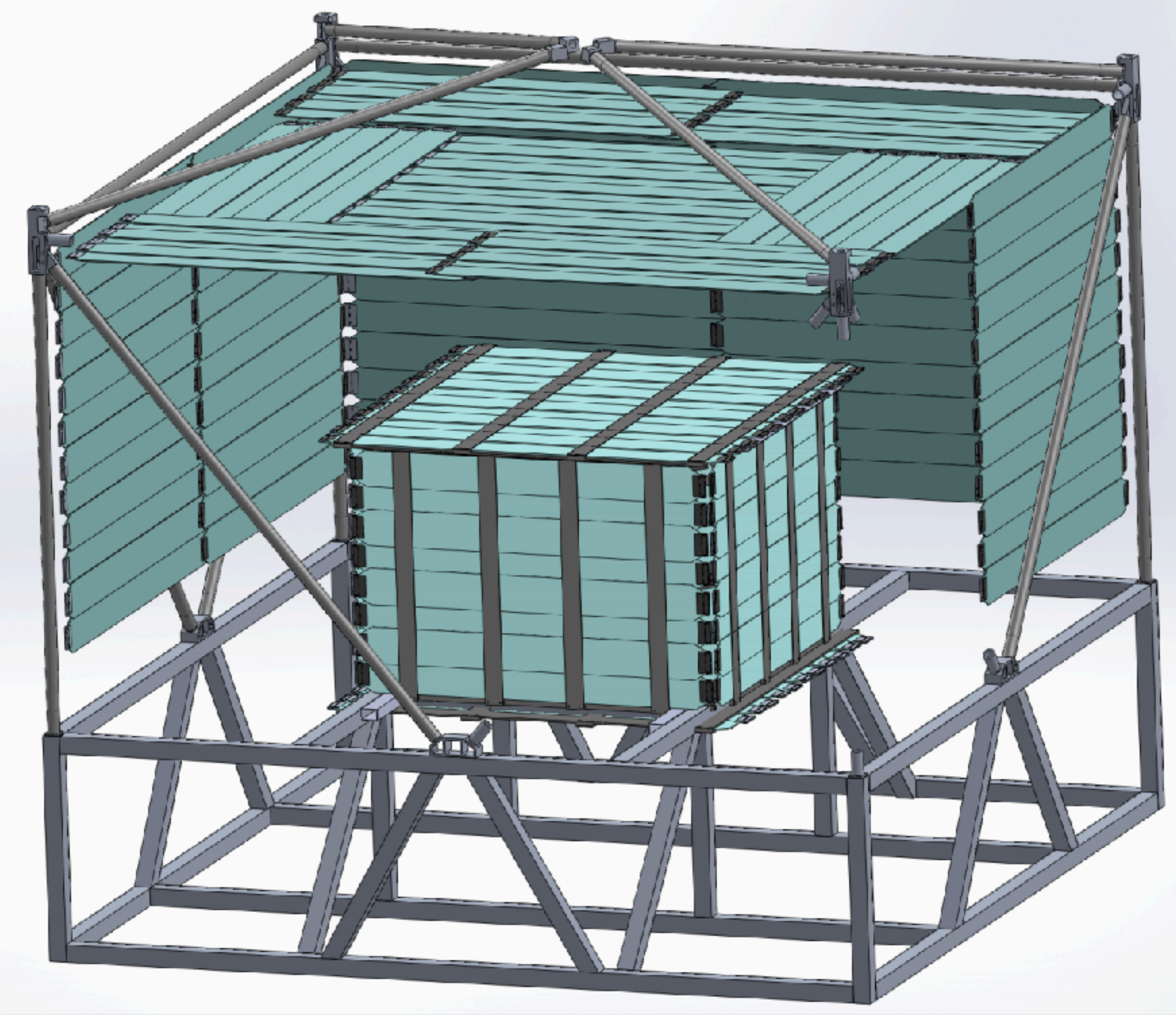


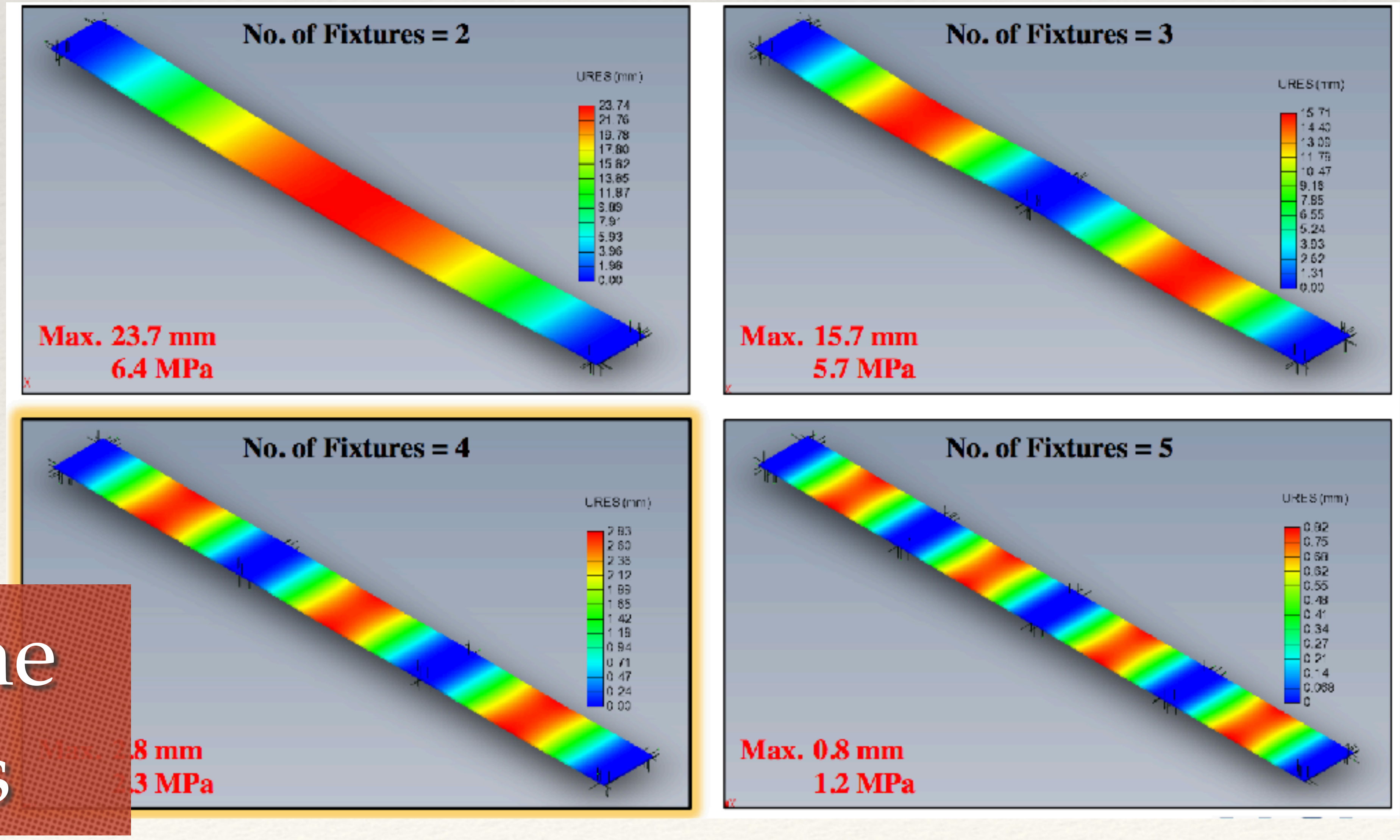
Fuke et al. JAI 6(2) 2017

Oscillating Heat Pipe Cooling System









Carbon Fiber Frame and ToF Supports

Antinucleons provide a complementary channel for indirect dark matter searches.

With a low astrophysical background they have exciting potential for a clean signal.

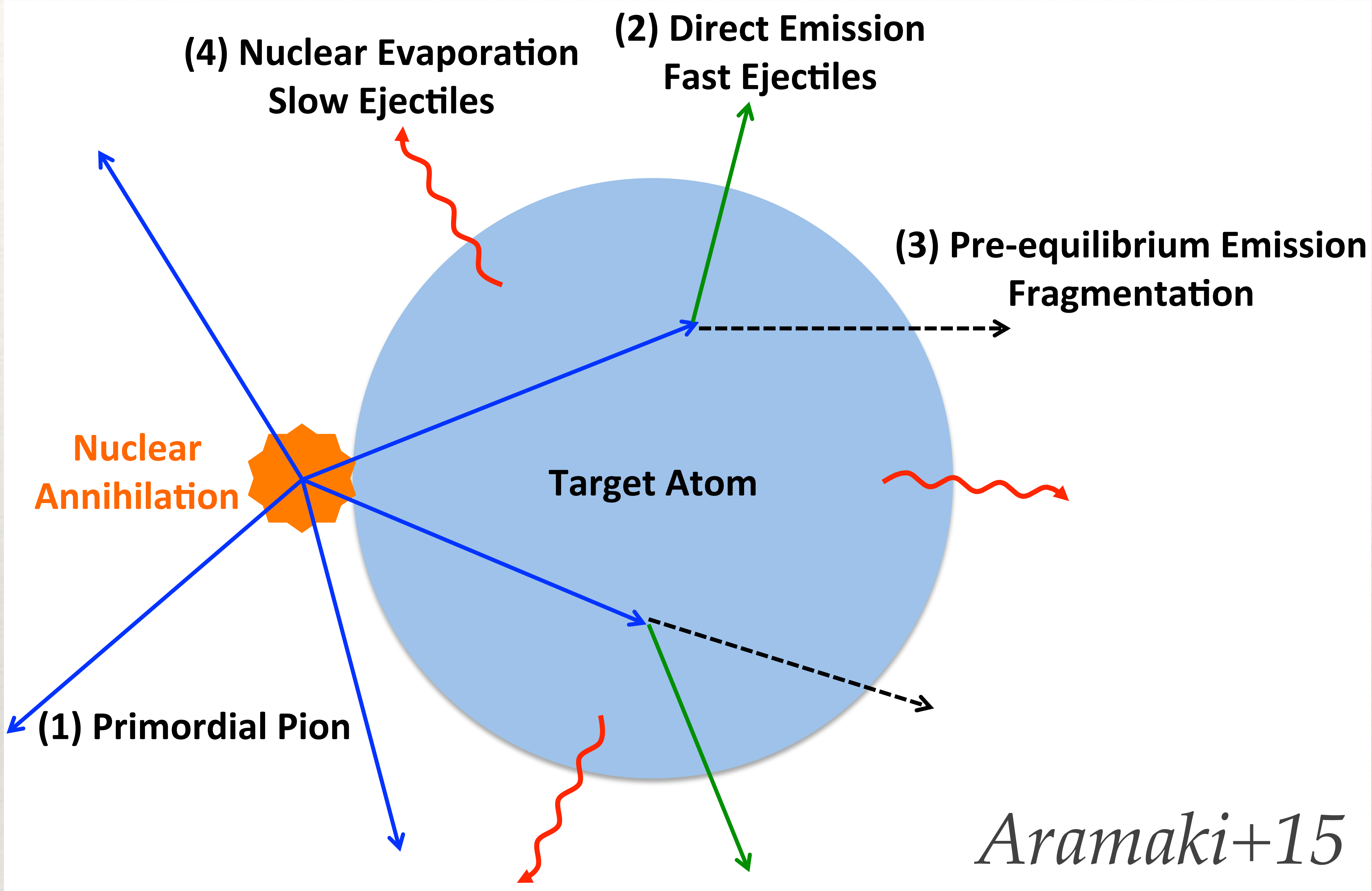
GAPS will search for low energy antinucleons and provide the best measurement to date of low energy $\bar{p}$.

The exotic atom technique increases signal purity over rigidity searches.

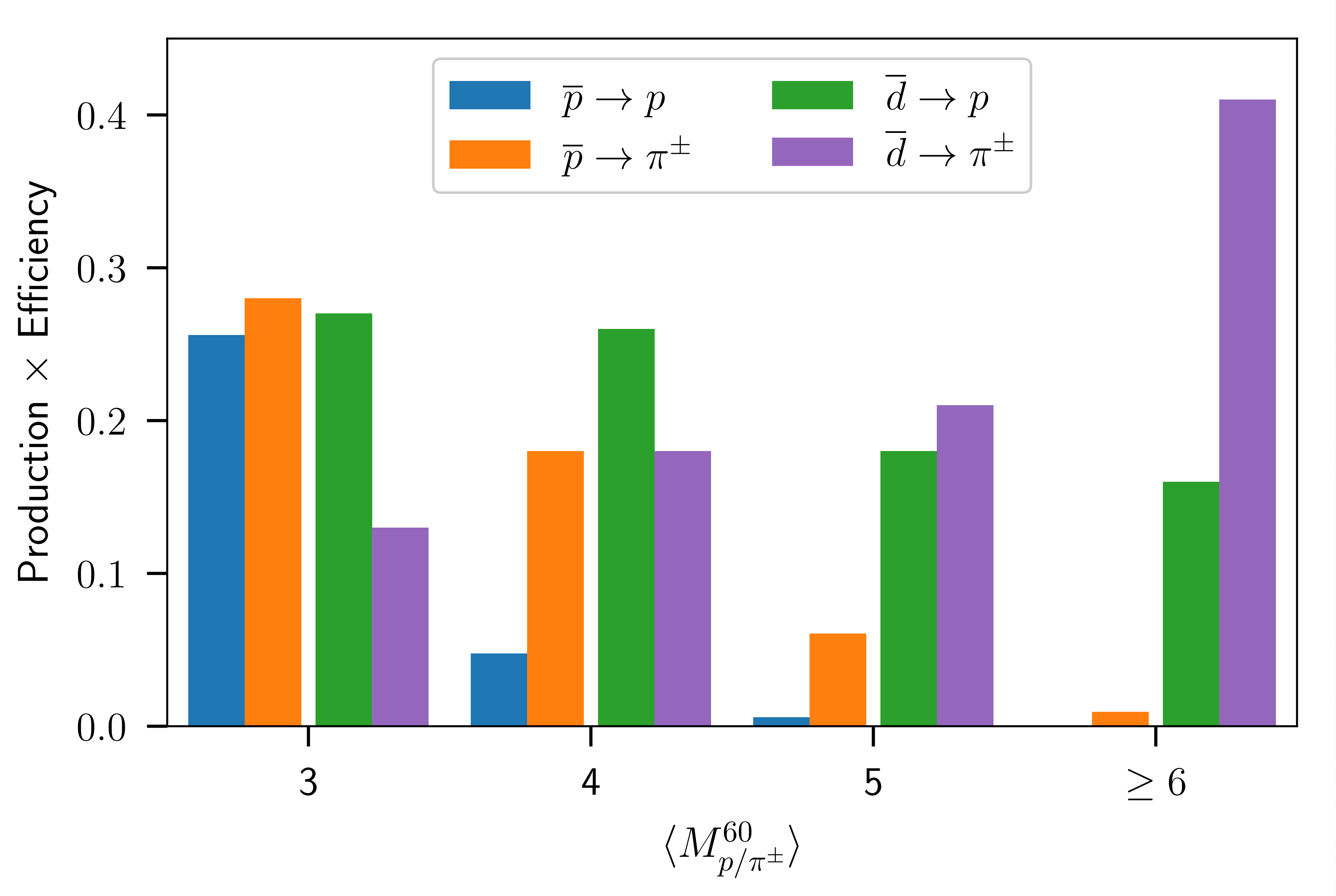
Scheduled to fly in the austral summer of 2020-21 significant progress has been made.

Backup

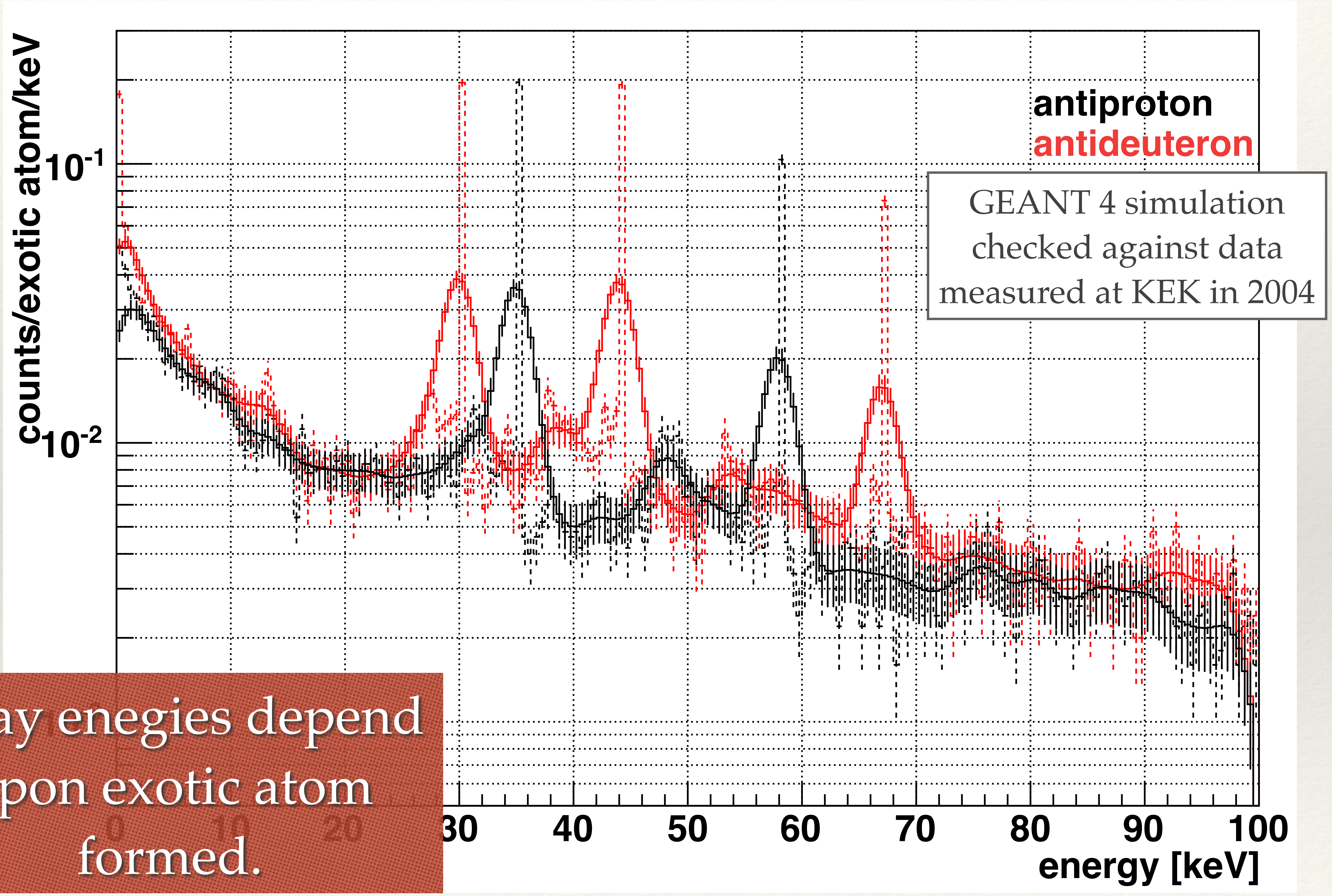
Pion Production



Number of π/p depend upon nucleon annihilating



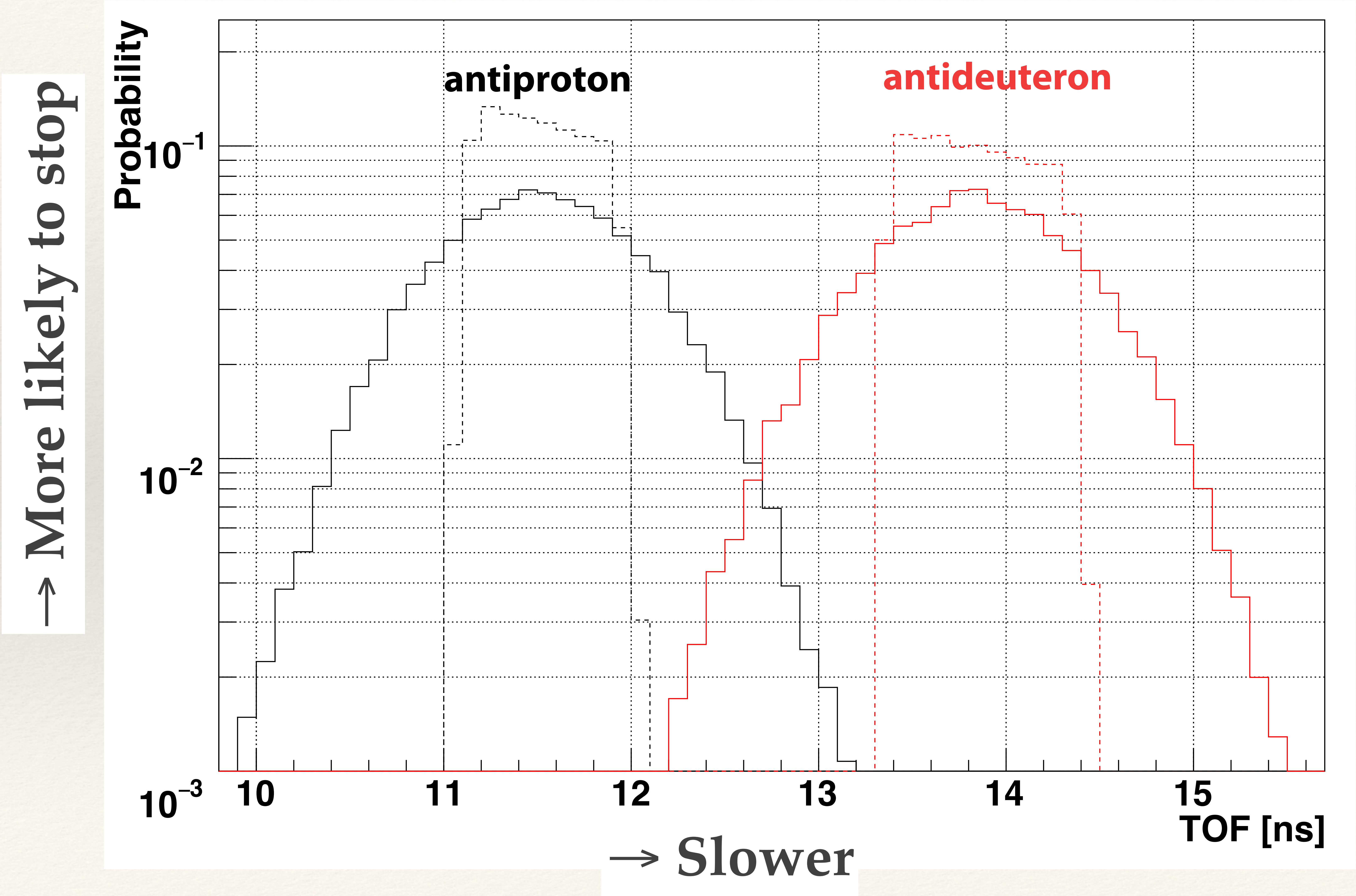
X-Rays



X-ray enegies depend upon exotic atom formed.

Aramaki+13

dE/dX


antiproton
antideuteron
Probability
10^{-1}
10^{-2}
10^{-3}
10
11
12
13
14
15
TOF [ns]
→ More likely to stop
→ Slower

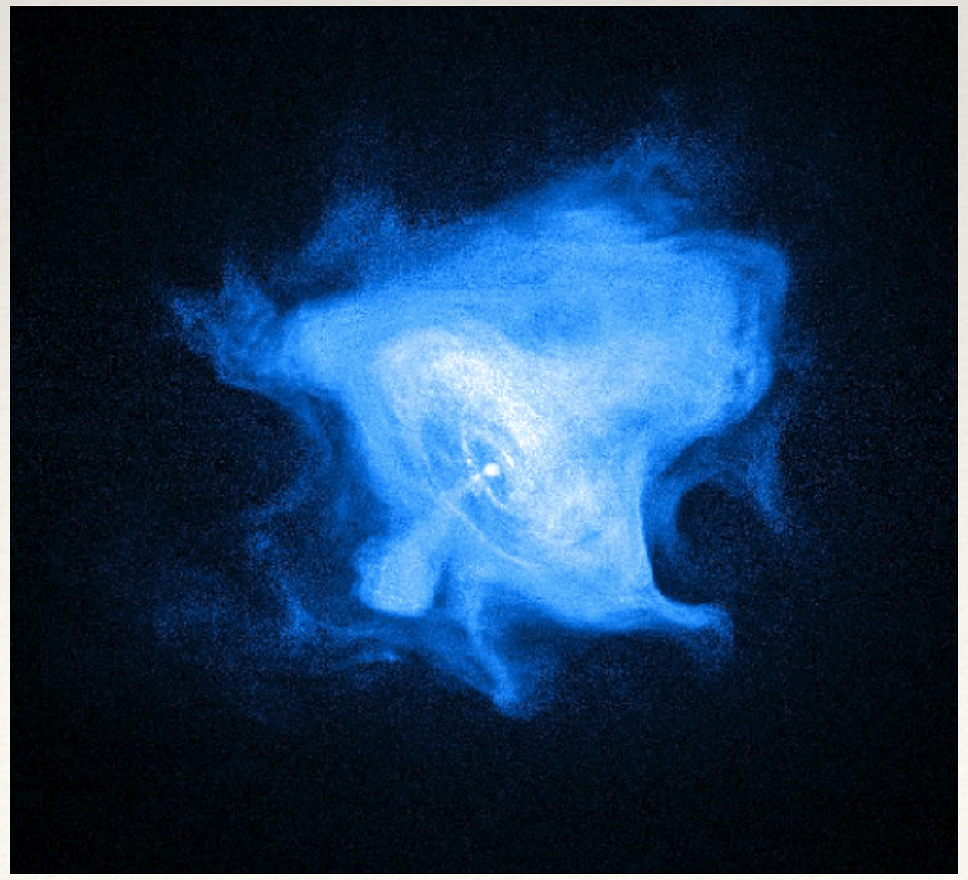
Cosmic Rays - Primary Sources

Protons

Primarily in supernova remnants.

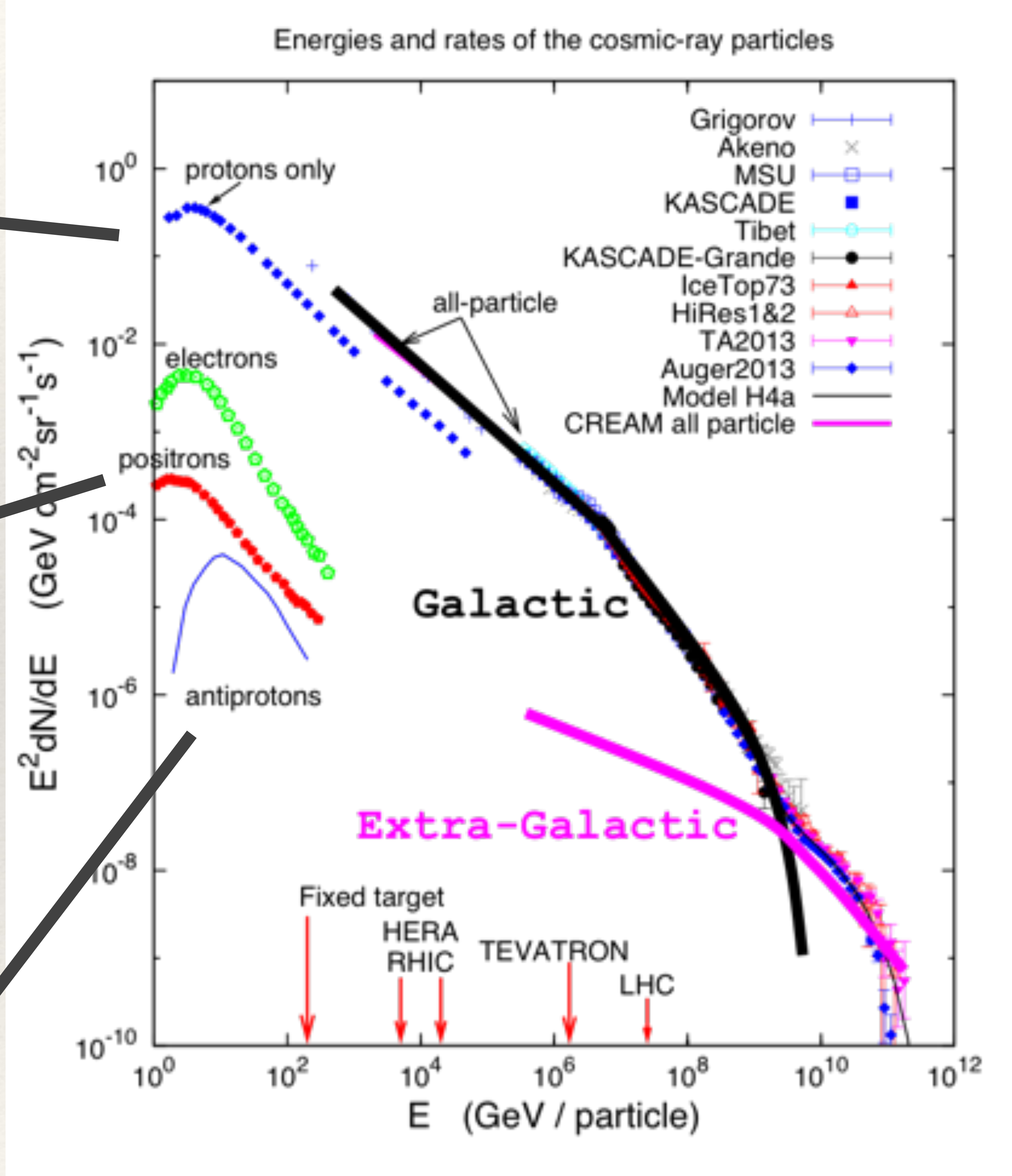
Leptons

Primarily in pulsars, their nebulae & binaries.



Antiprotons

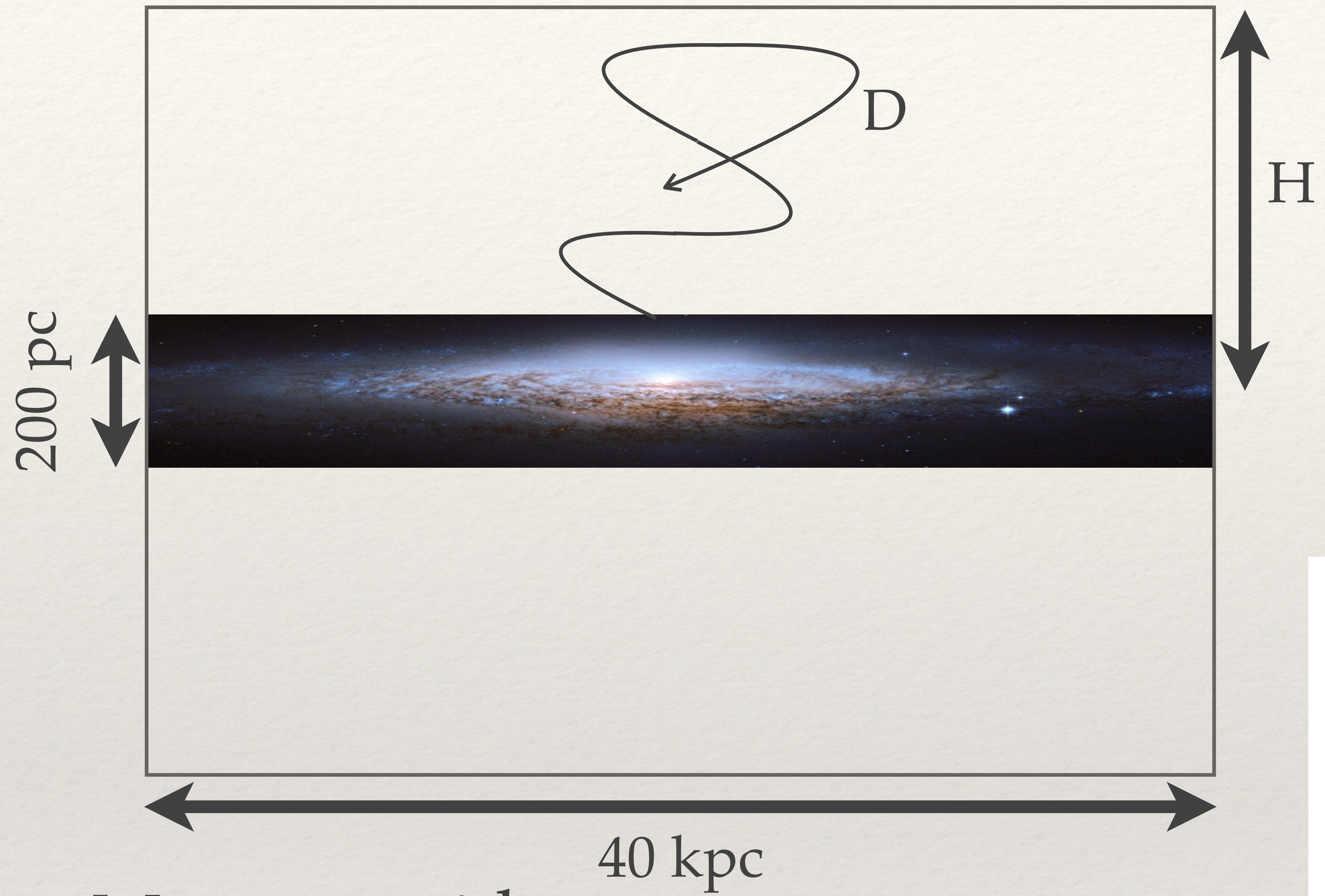
??



Probably not a lot

+ Dark Matter???

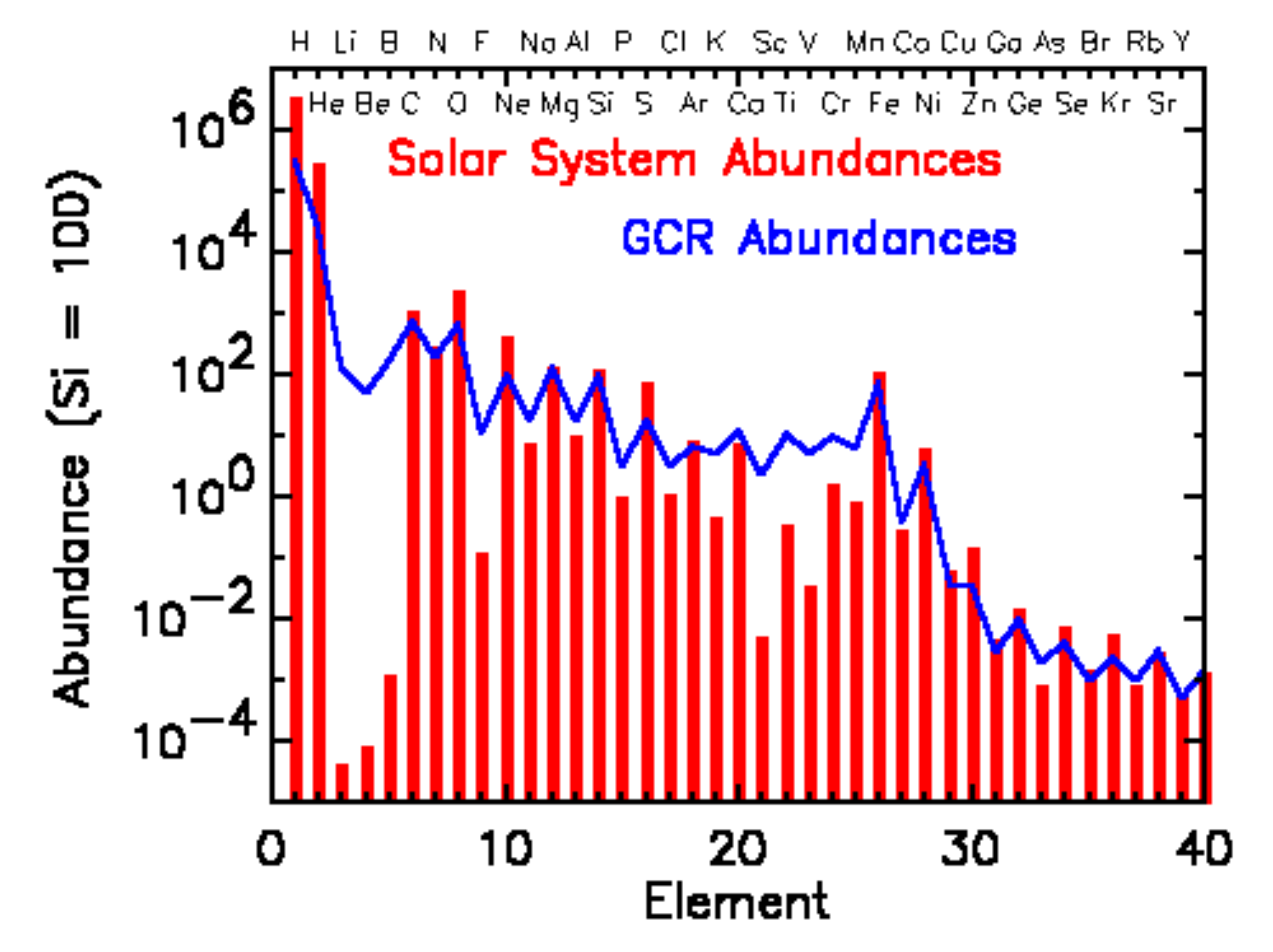
Cosmic Rays - Propagation



Leaky Box Model → need size of box and diffusion coefficient

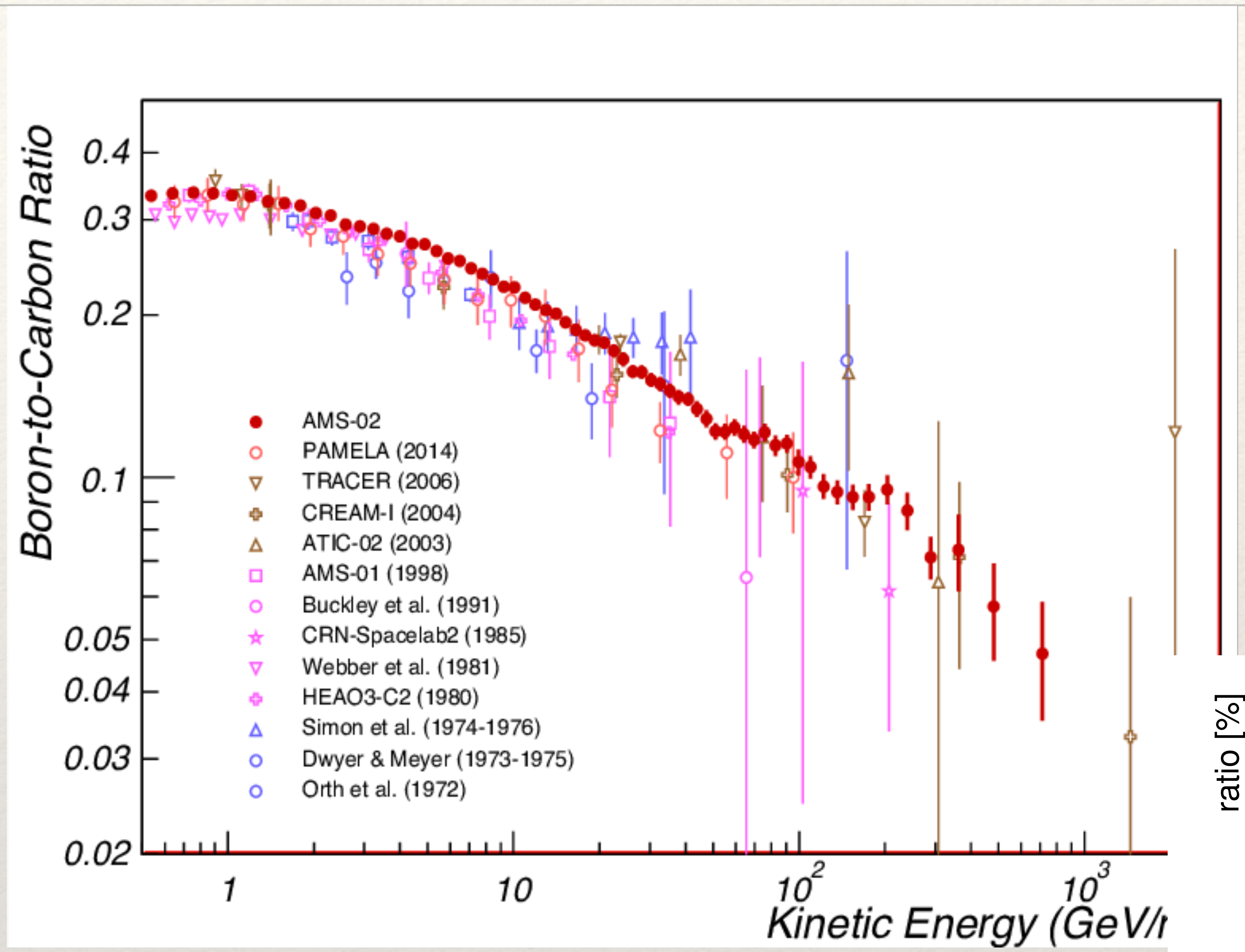
Measure with e.g.:

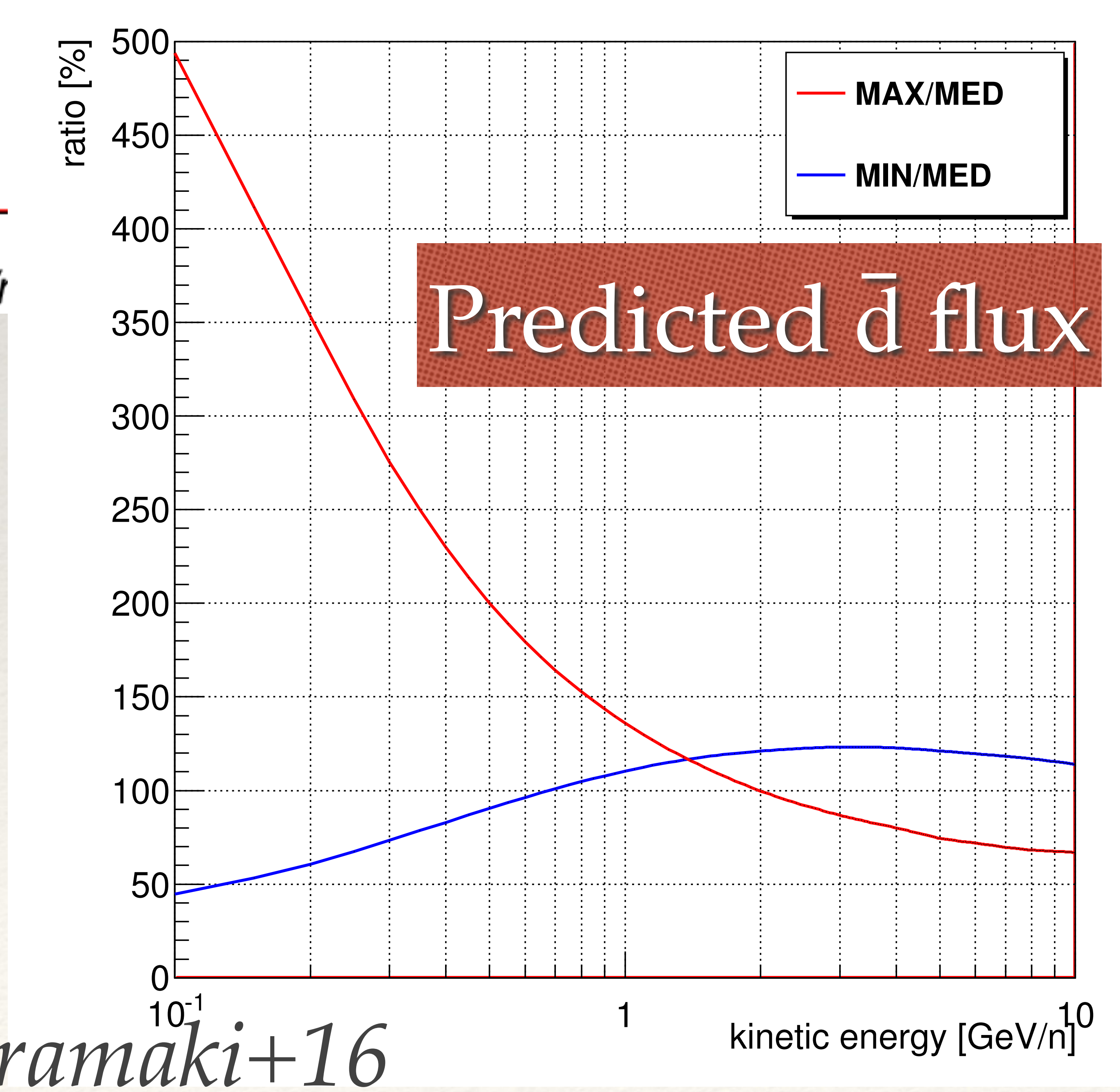
- Boron-to-Carbon ratio,
- Radioactive isotopes,
- Diffuse radio & γ-rays



Diffusion Coefficient

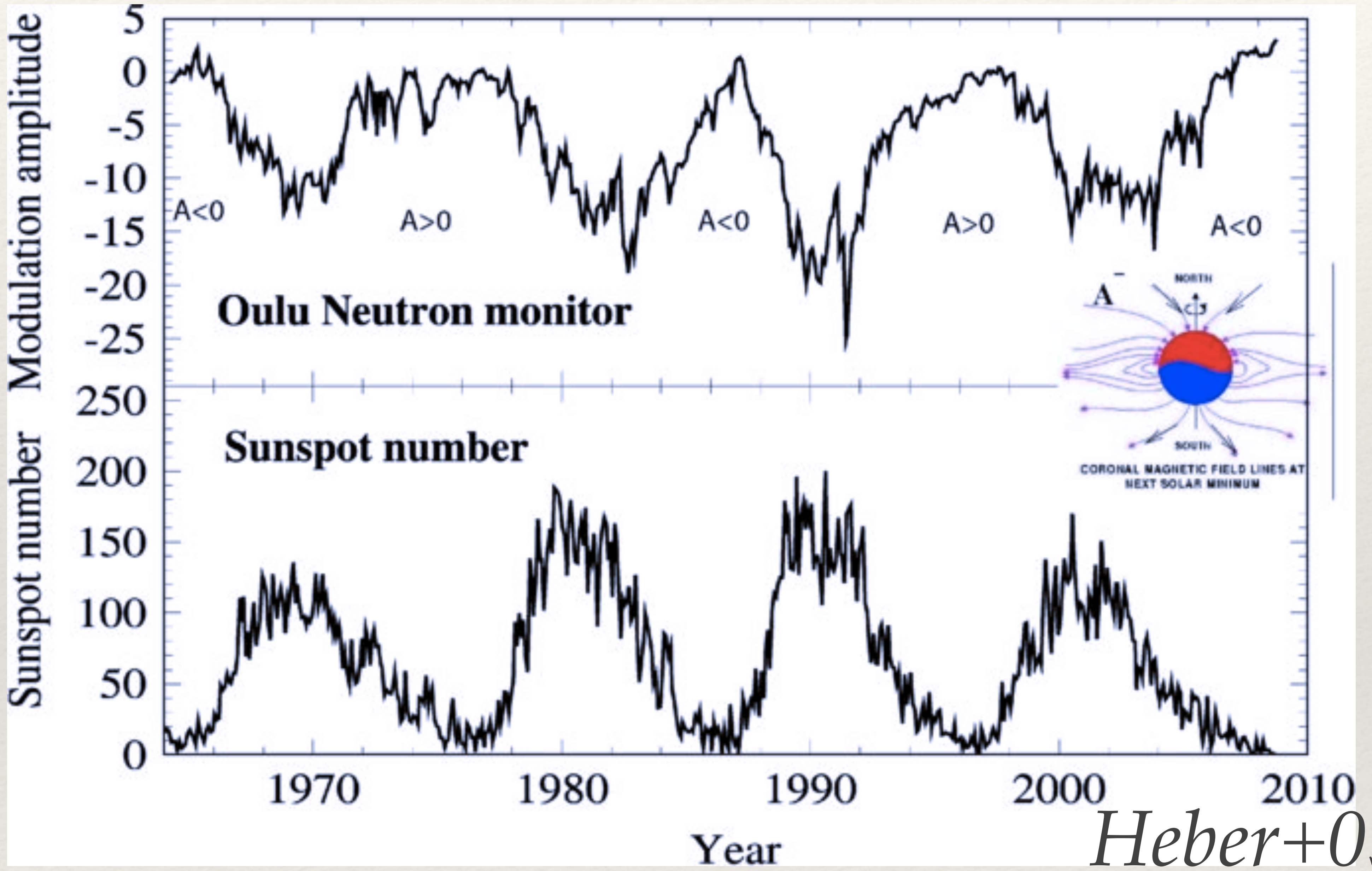
- Principle constraint comes from boron-to-carbon ratio ($\propto H^2/D$).
- H has a strong impact upon relative strength of dark matter signal.
- Typically 3 bounding cases of H, D considered: MIN (H = 1 kpc), MED (4 kpc), MAX (15 kpc).
  - MIN is now largely excluded using positron data.



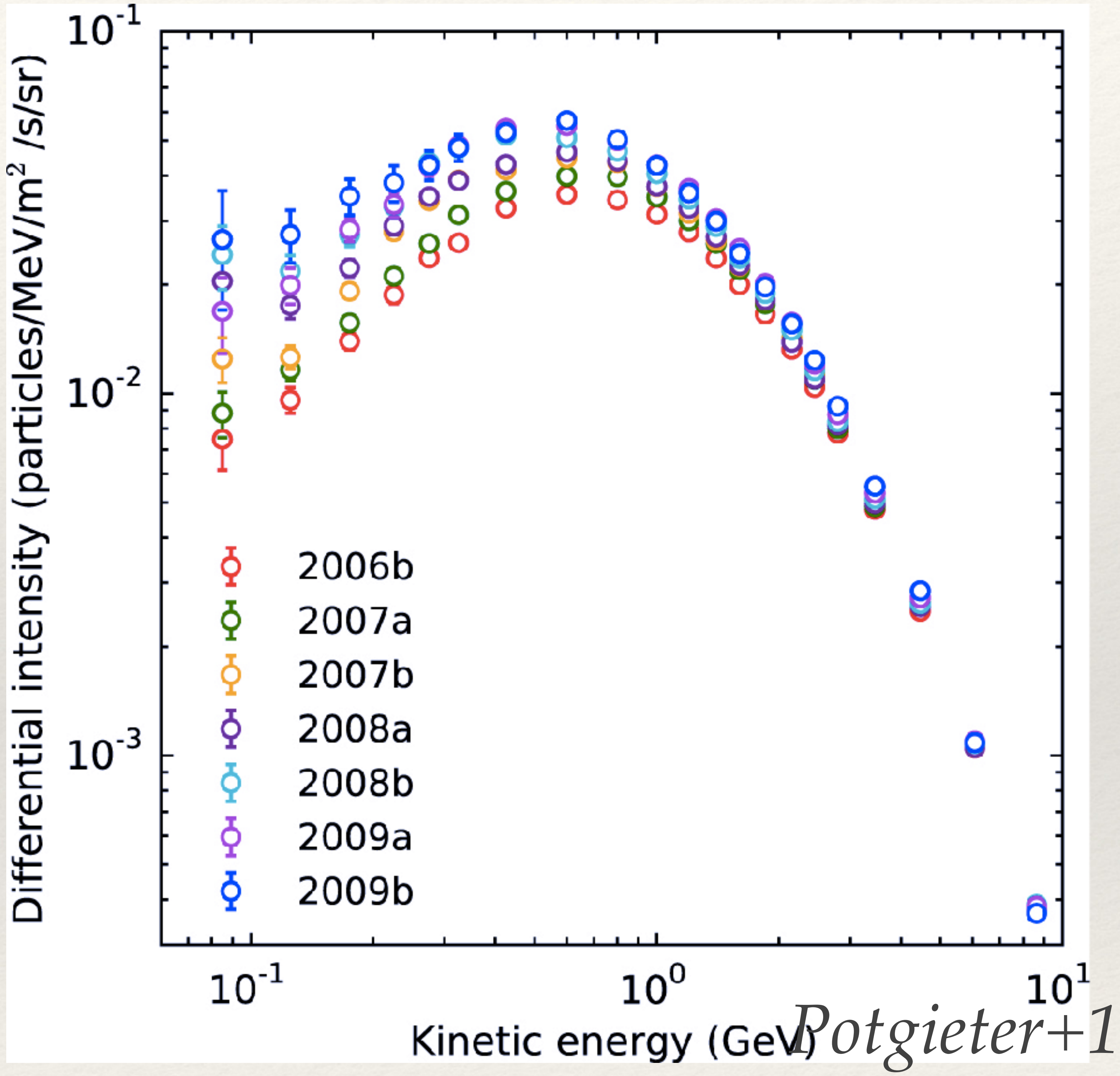


Aramaki+16

Solar Modulation

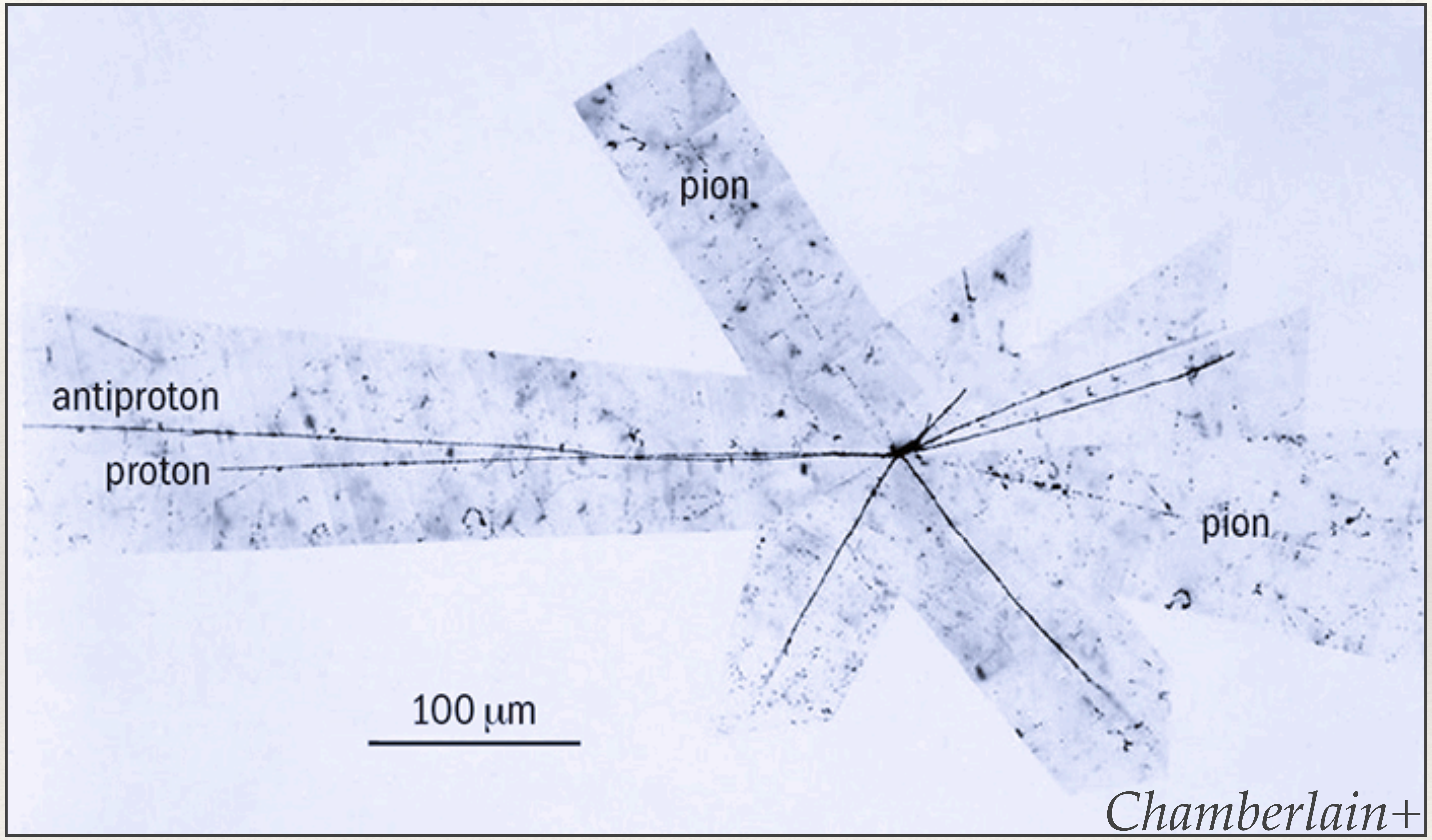


Heber+09



Potgieter+15

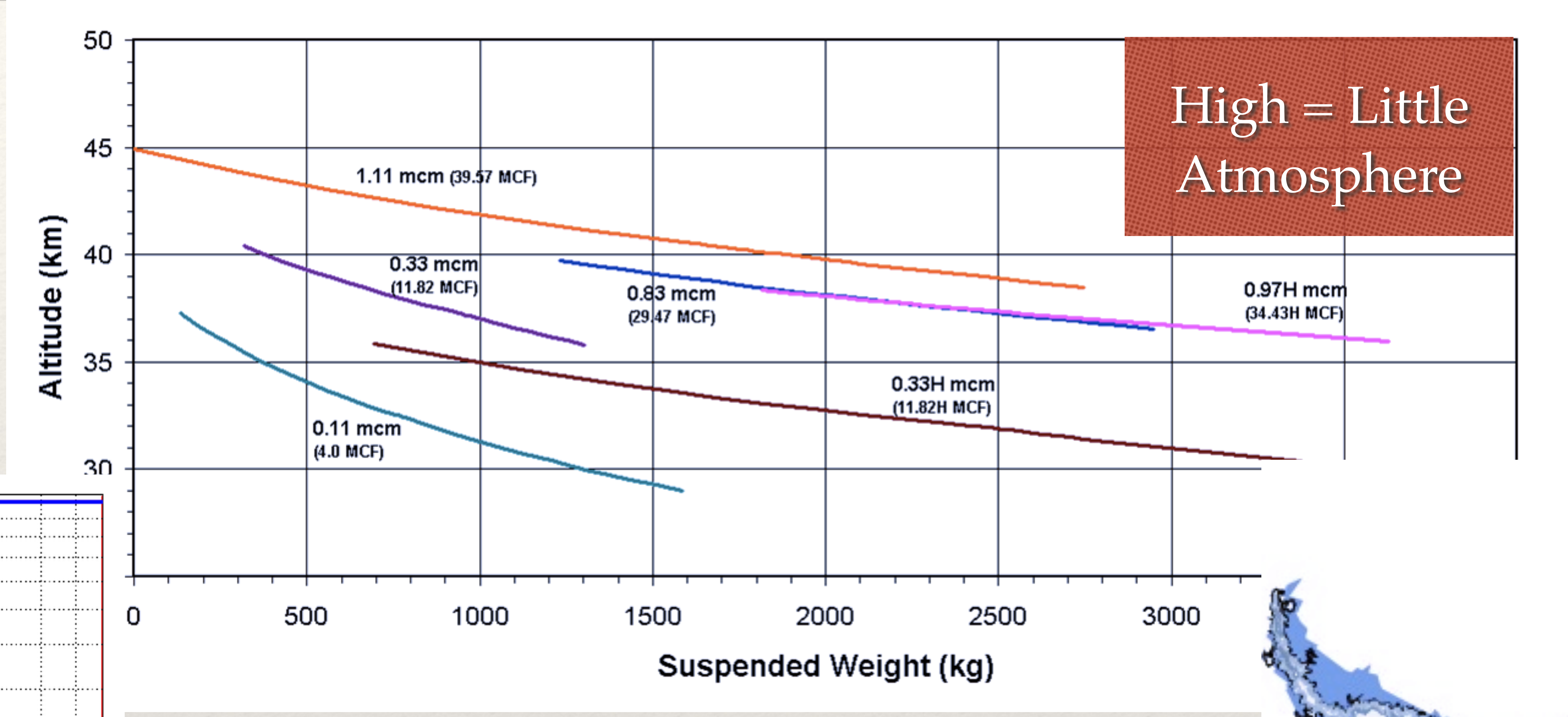
Cosmic Rays - Secondary Production



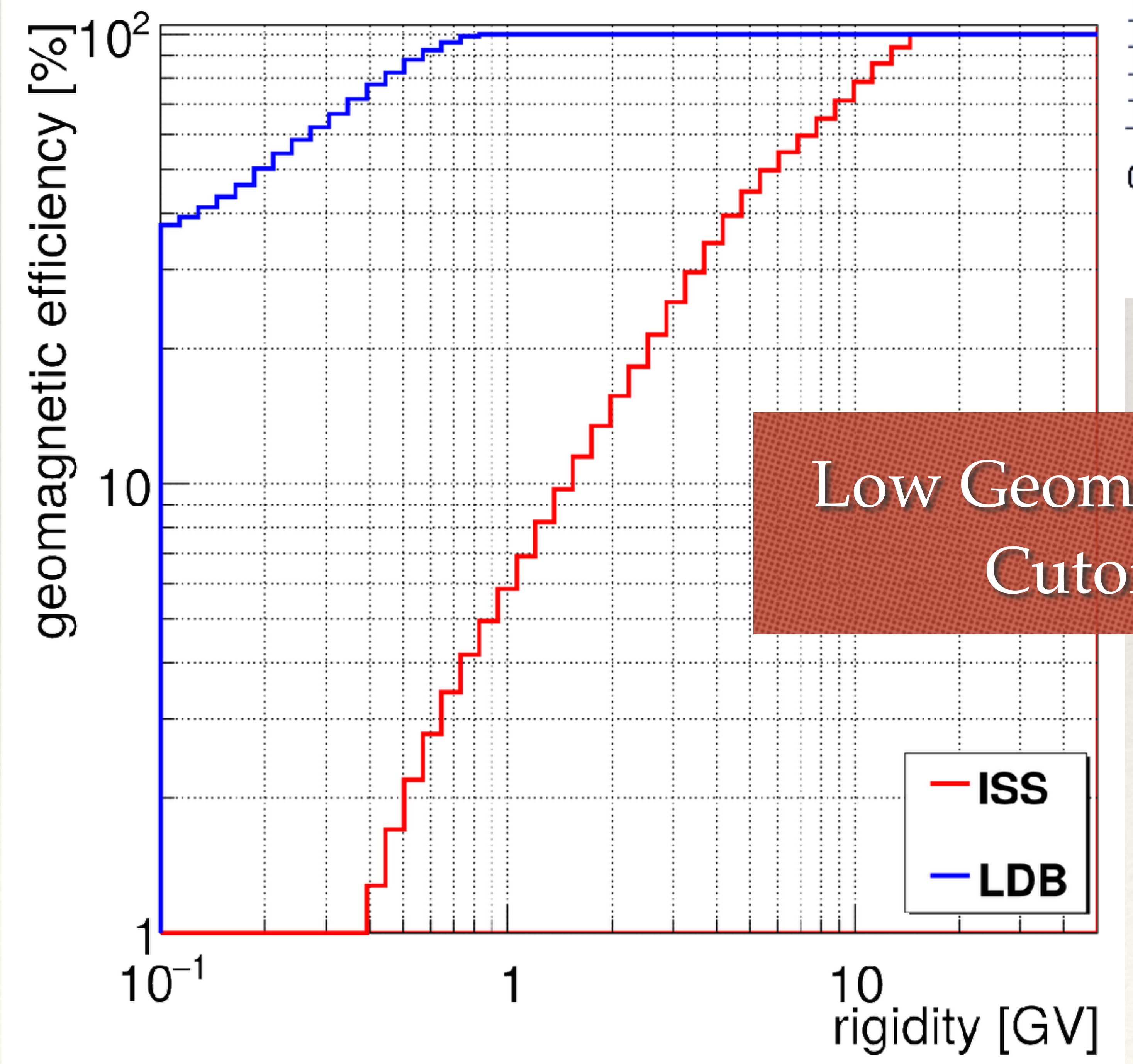
Chamberlain+ 56

$$p + p \rightarrow \bar{p} + p + p + p \text{ (+ stuff)}$$

Why Antarctic Balloon?



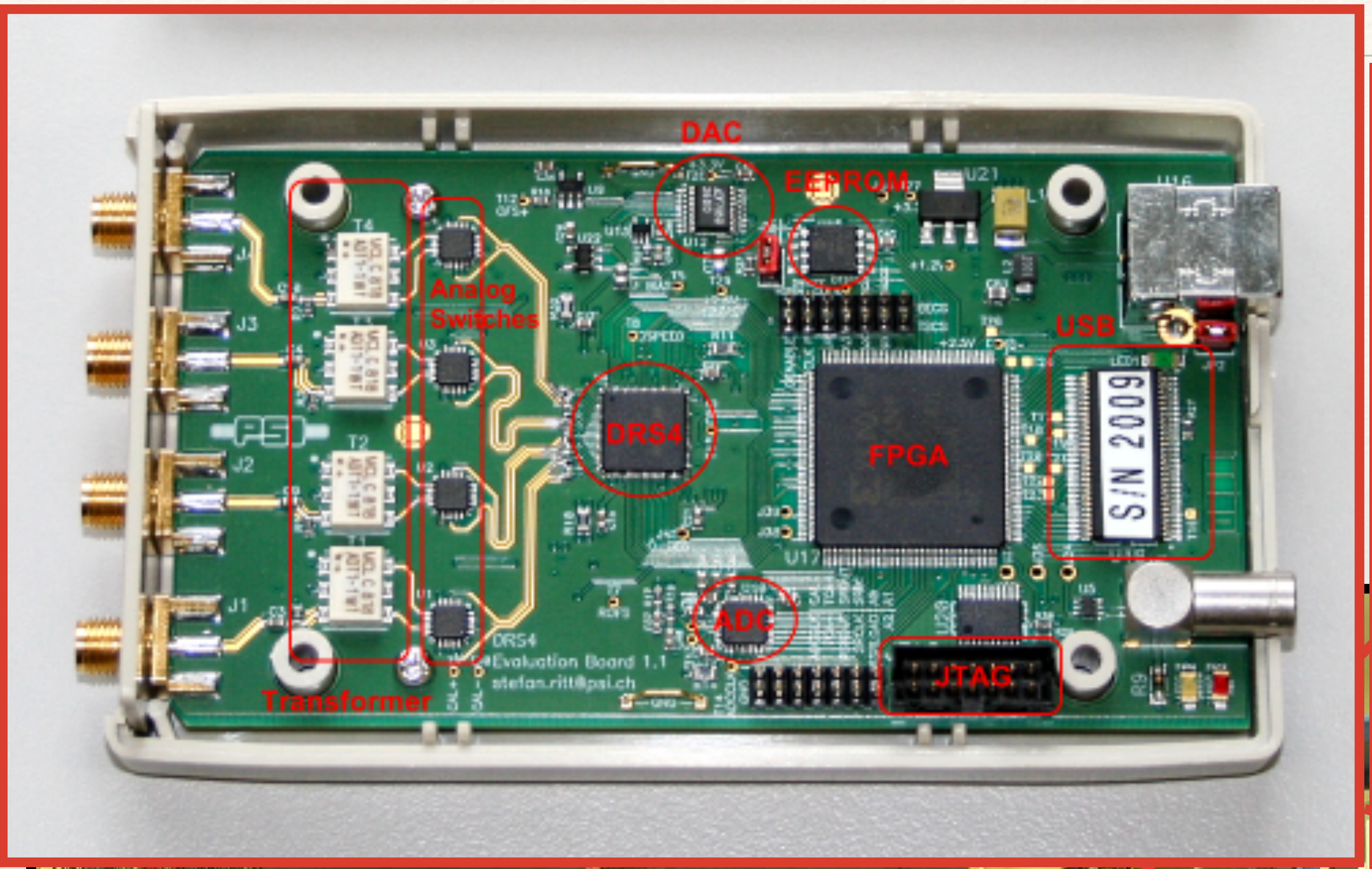
High = Little Atmosphere

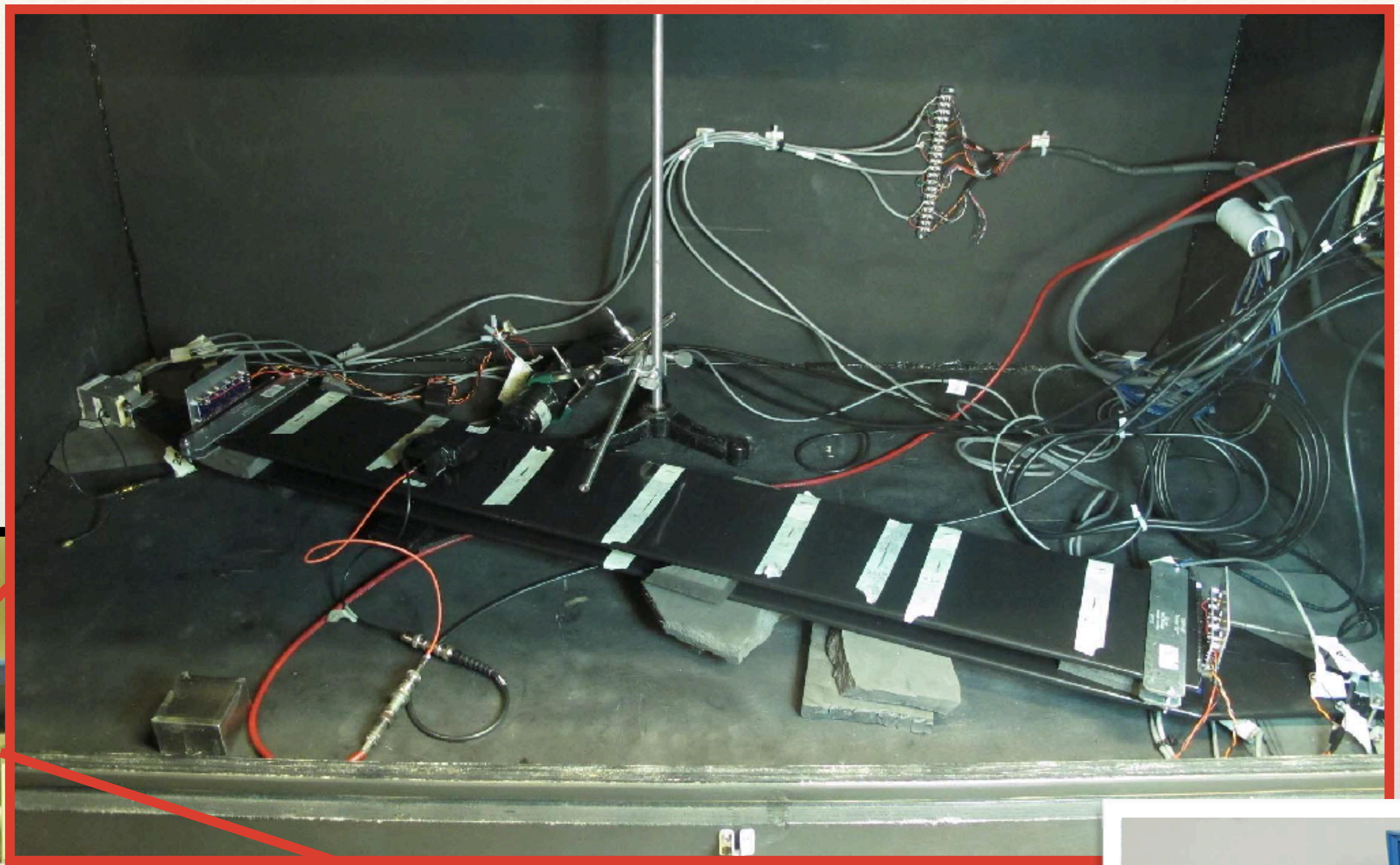


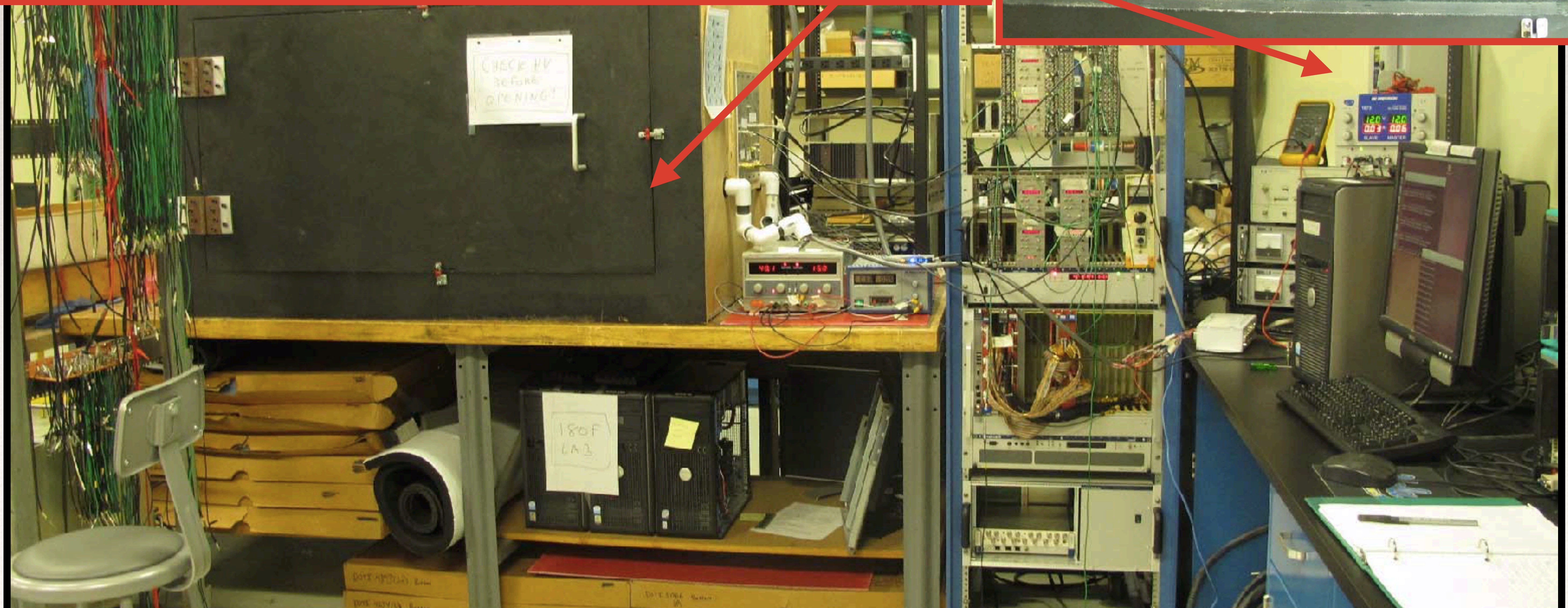
Low Geomagnetic Cutoff

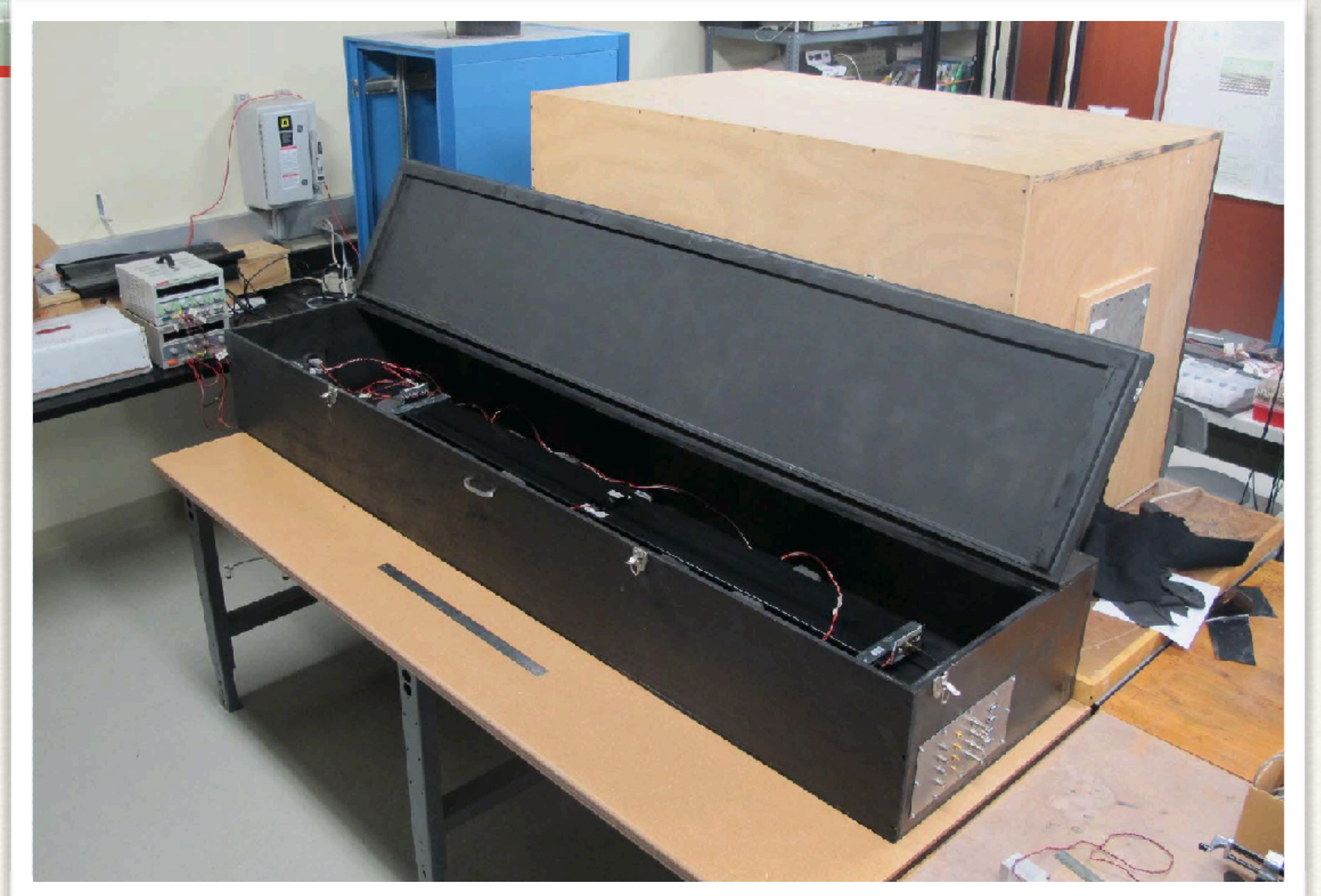
Long Flight Over Land

ToF

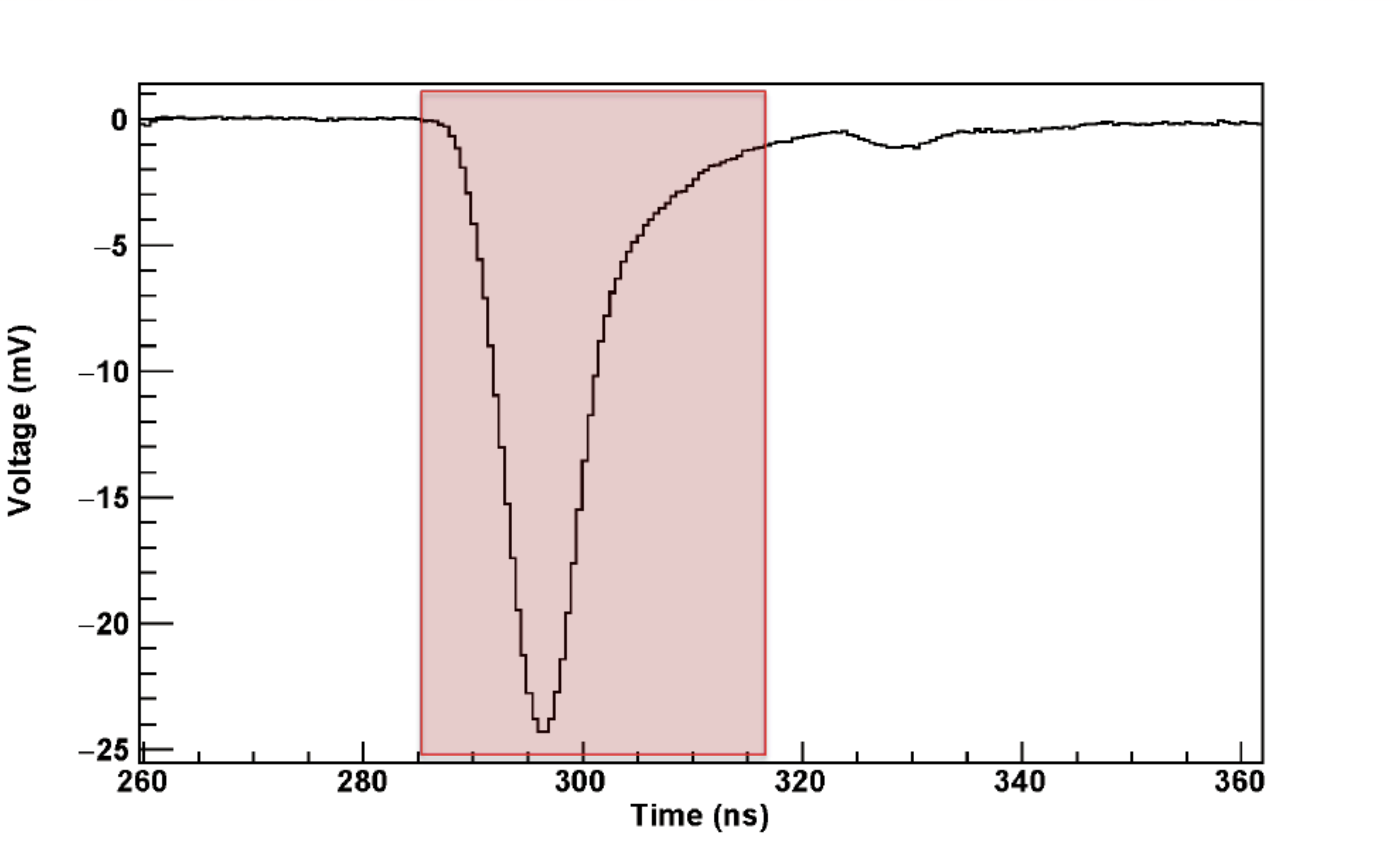

DAC
EEPROM
Analog Switches
DRS4
FPGA
USB
S/N 2009
ADC
JTAG
Transformer
DRS4 Evaluation Board 1.1
stefan.ritt@psi.ch

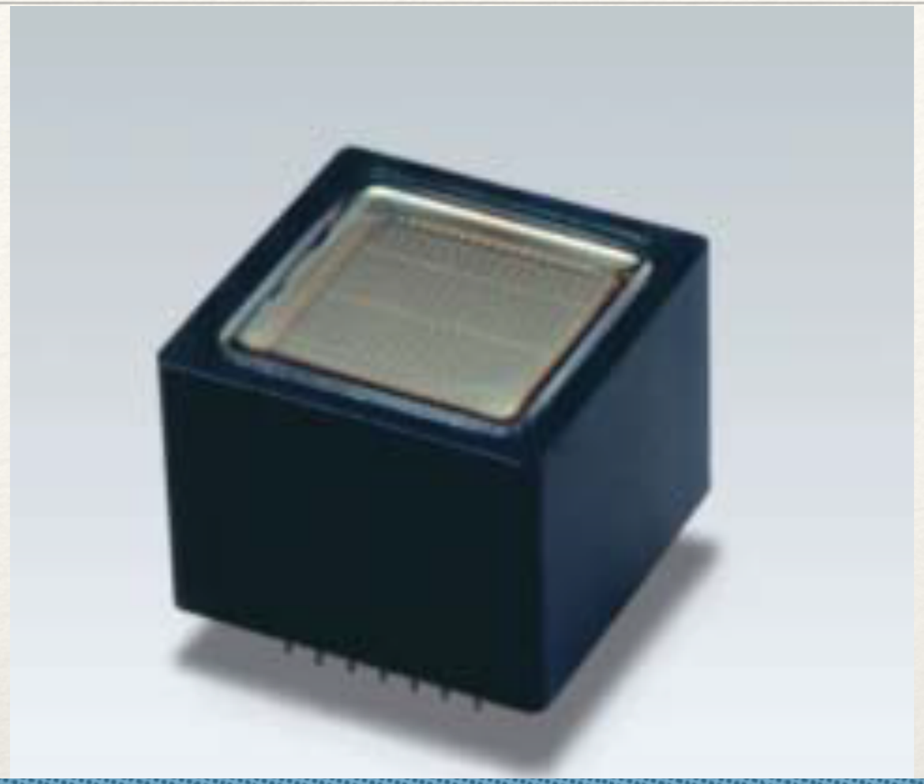






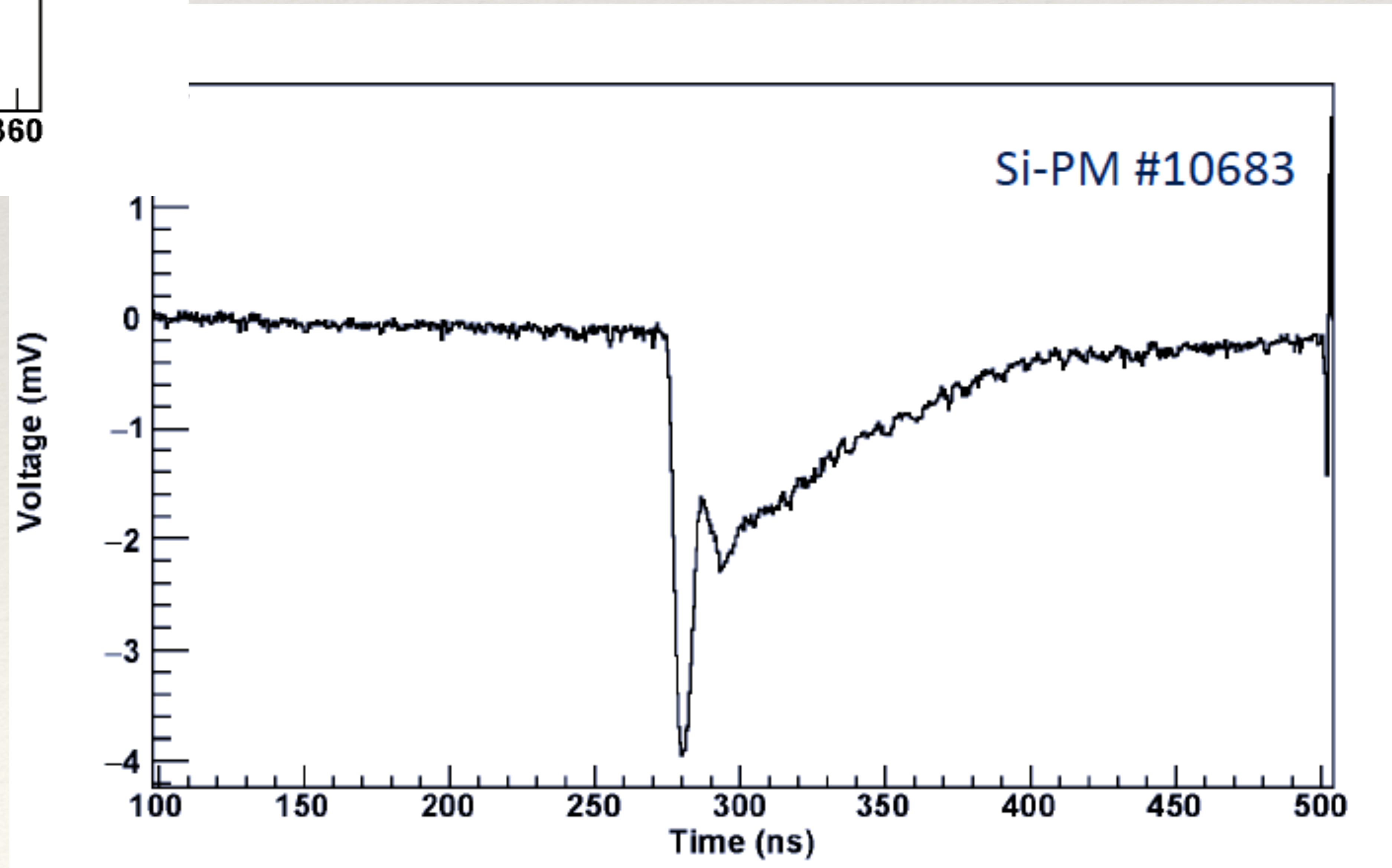
PMT or SiPM?



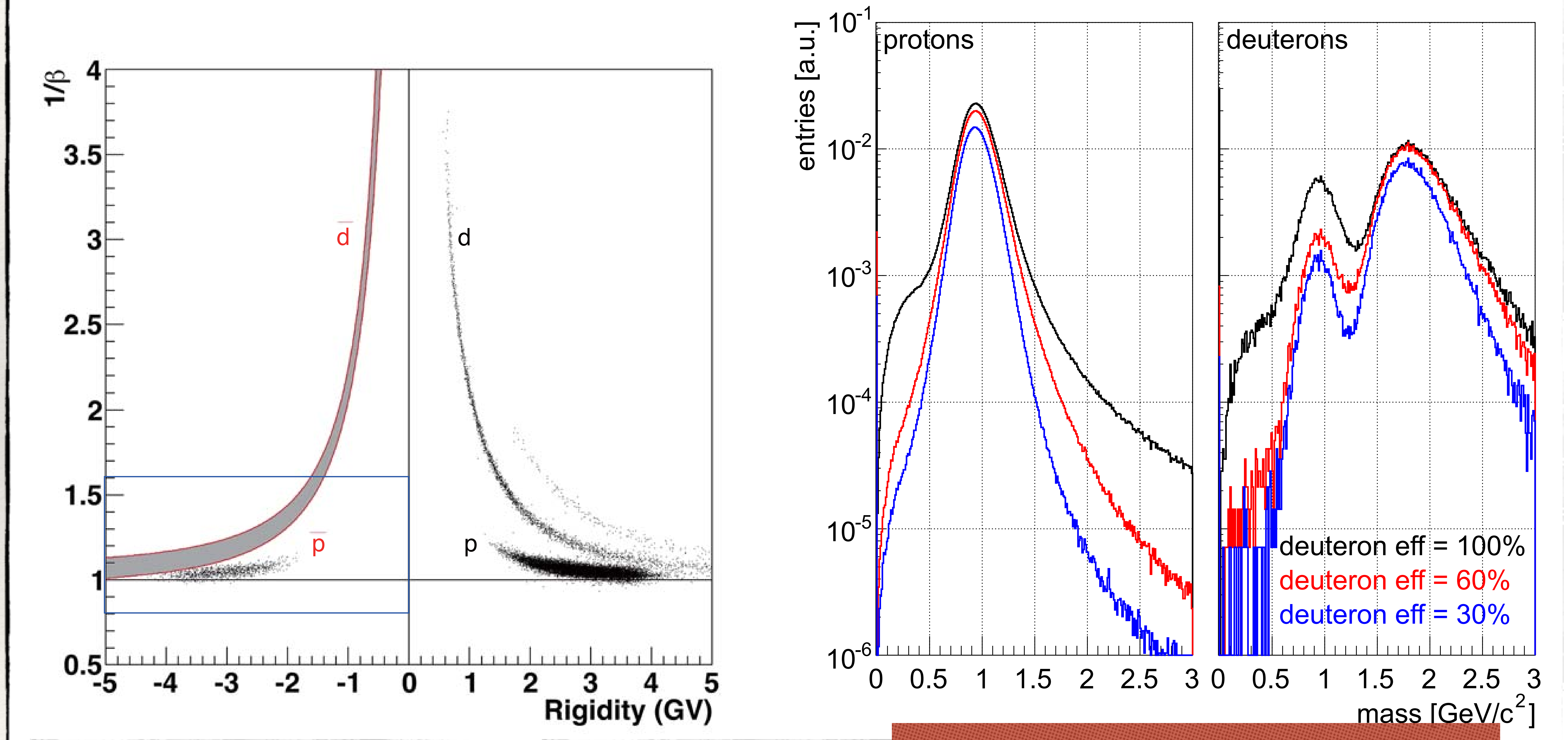


Hamamatsu R7600−200

Hamamatsu S13360−6050CS (LCT5−6050)



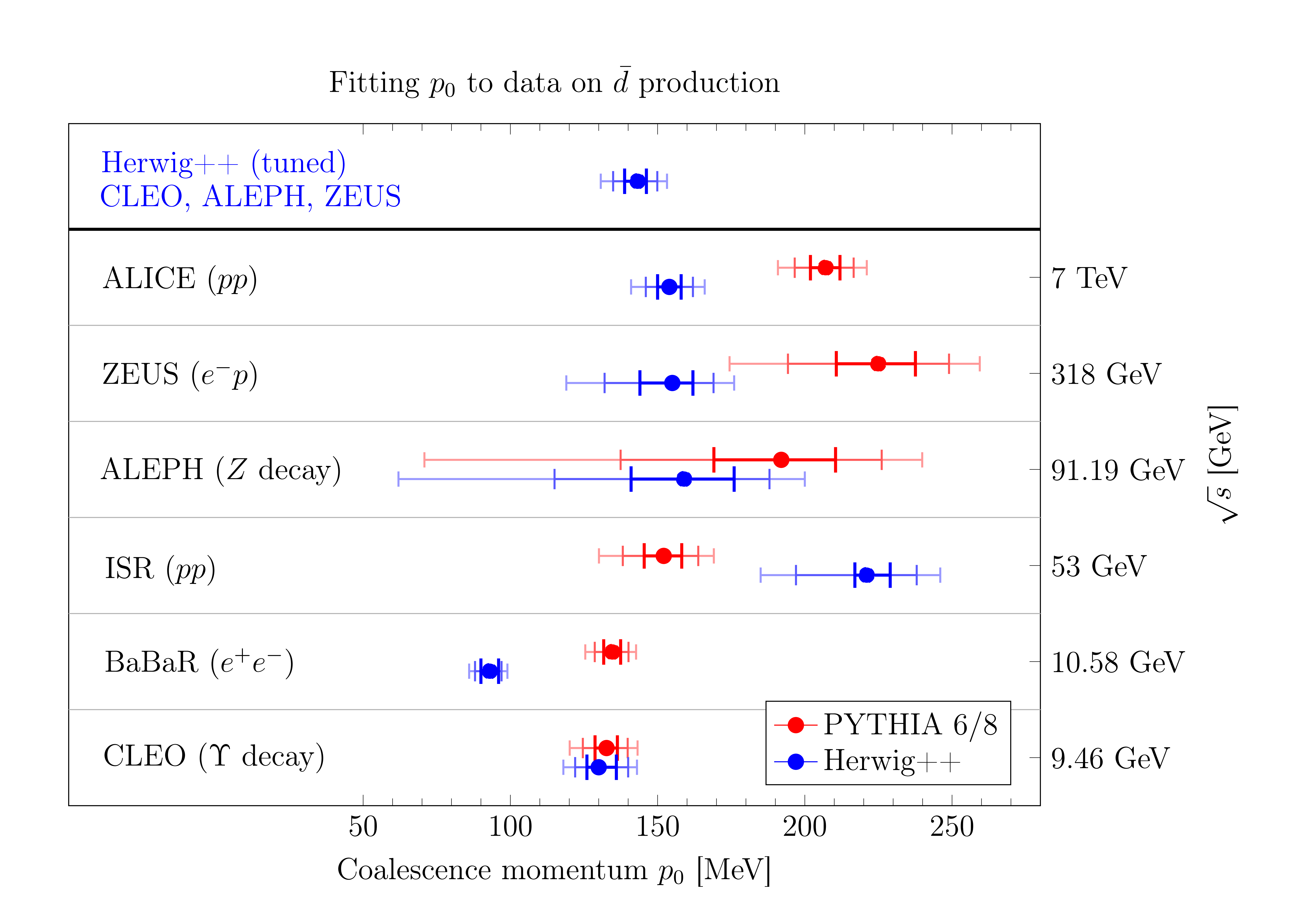
Low Energy Antinucleons



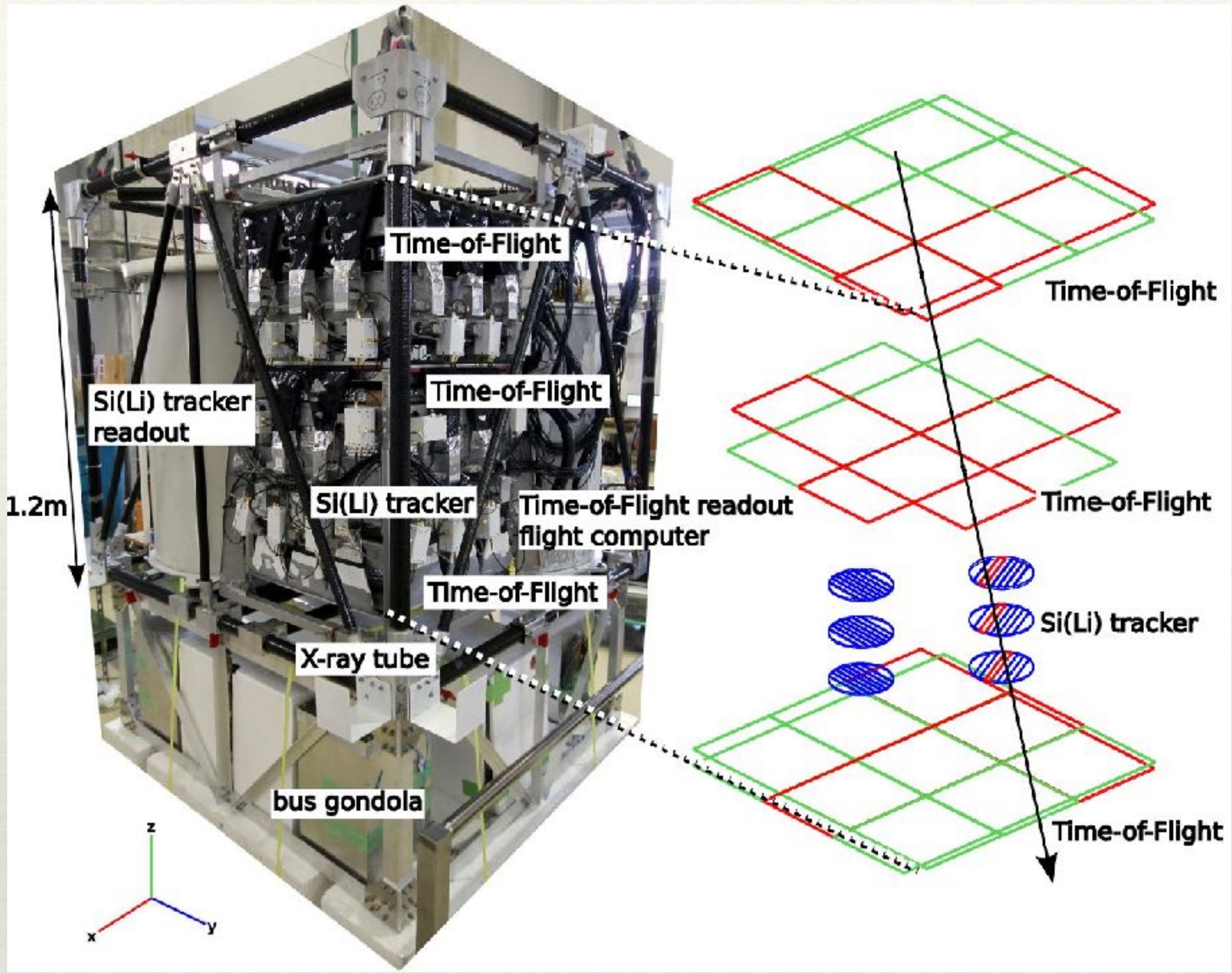
Rigidity ∝ gyro radius

Contamination from other species

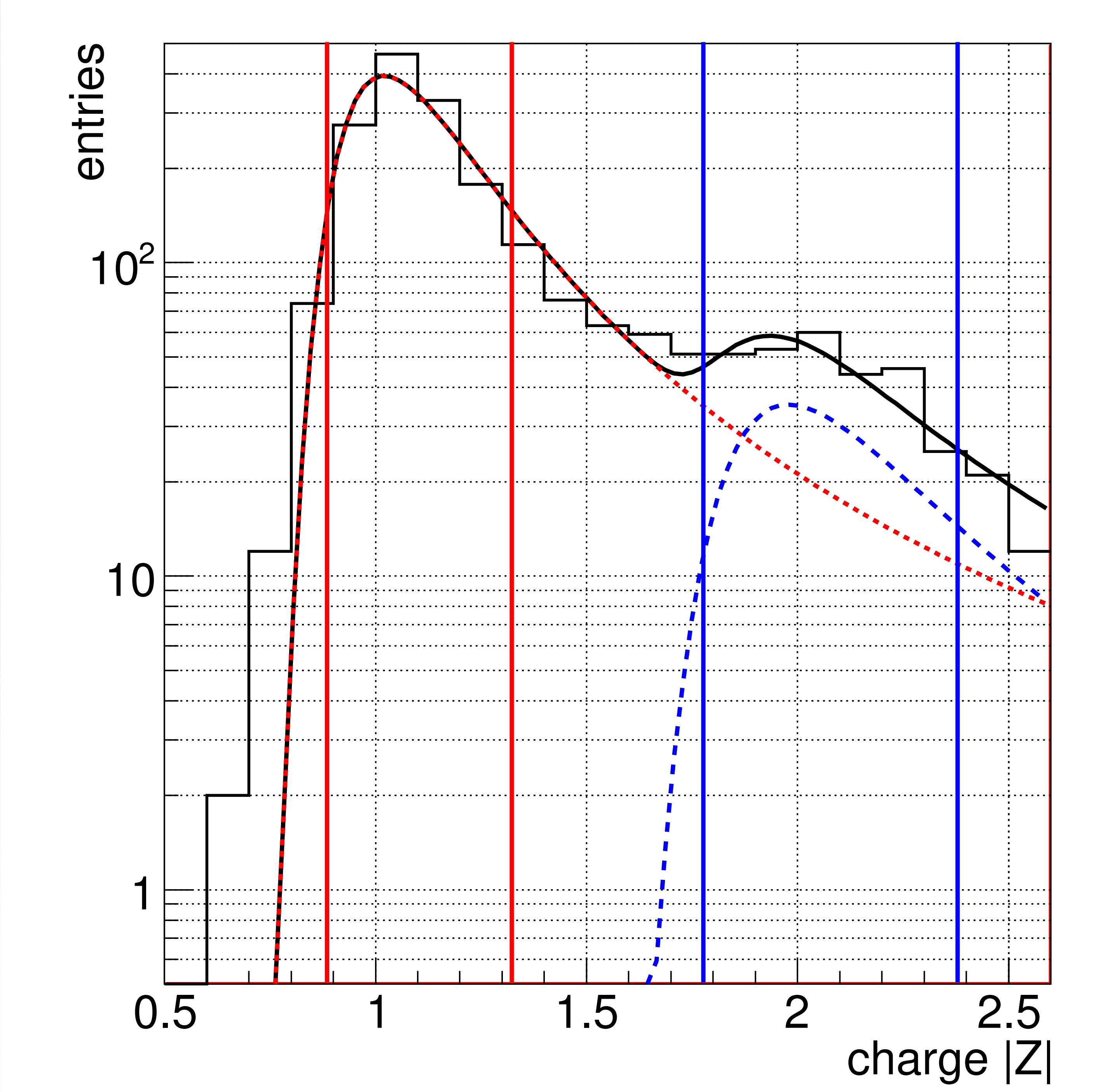
Coalescence Momentum



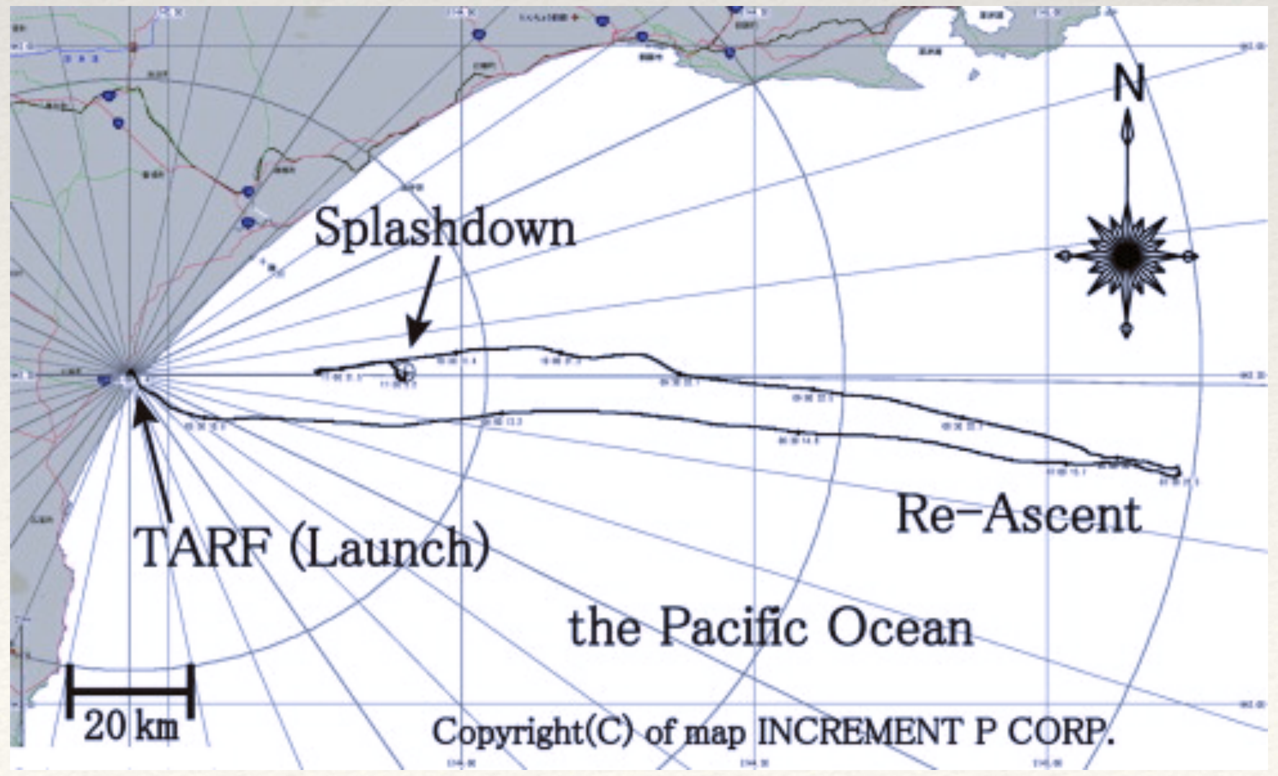
pGAPS (2012)



Time-of-Flight
Si(Li) tracker readout
Time-of-Flight
1.2m
Si(Li) tracker
Time-of-Flight readout flight computer
Time-of-Flight
X-ray tube
bus gondola
Time-of-Flight
Time-of-Flight
Si(Li) tracker
Time-of-Flight

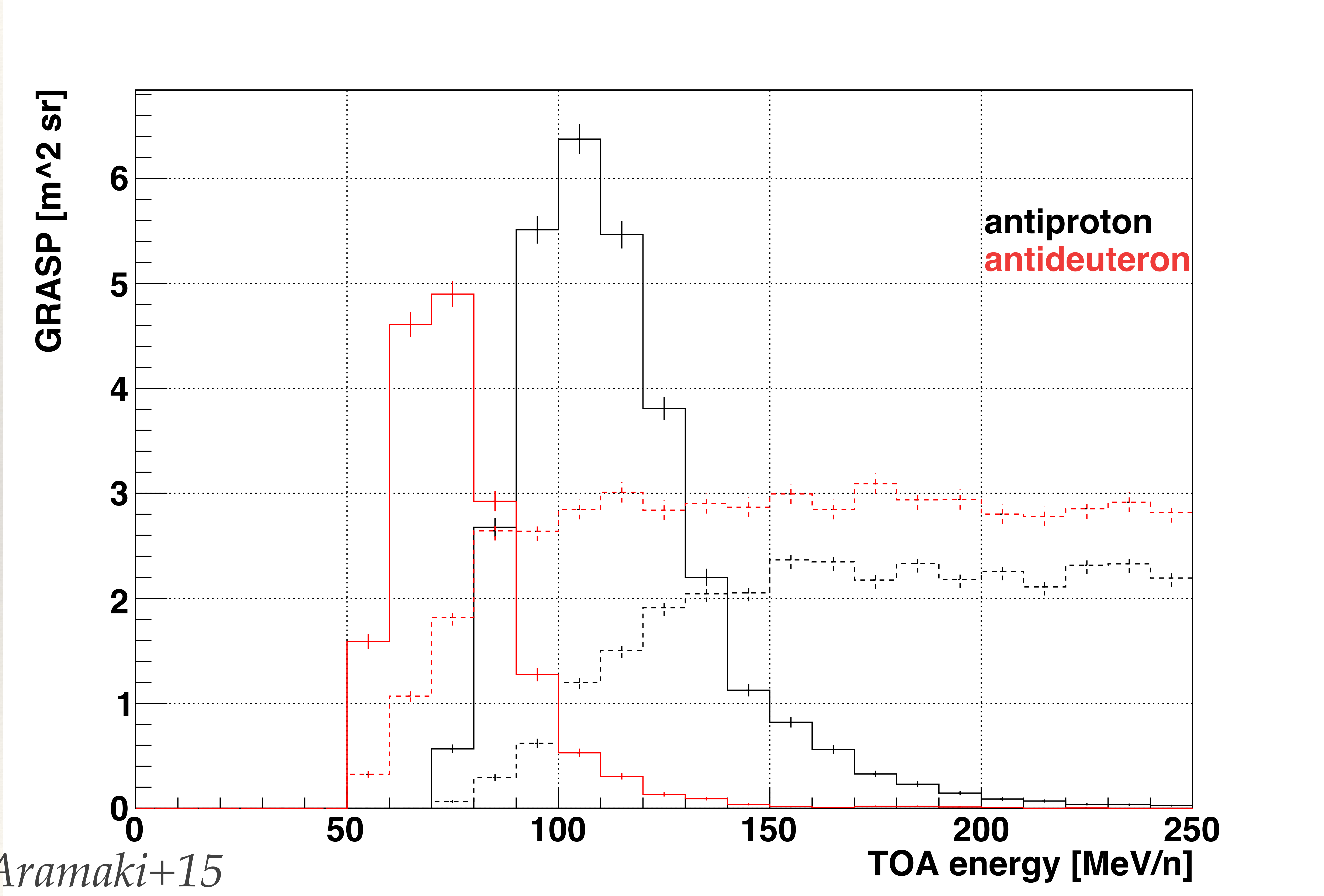


entries
10^2
10
1
0.5
1
1.5
2
2.5
charge |Z|



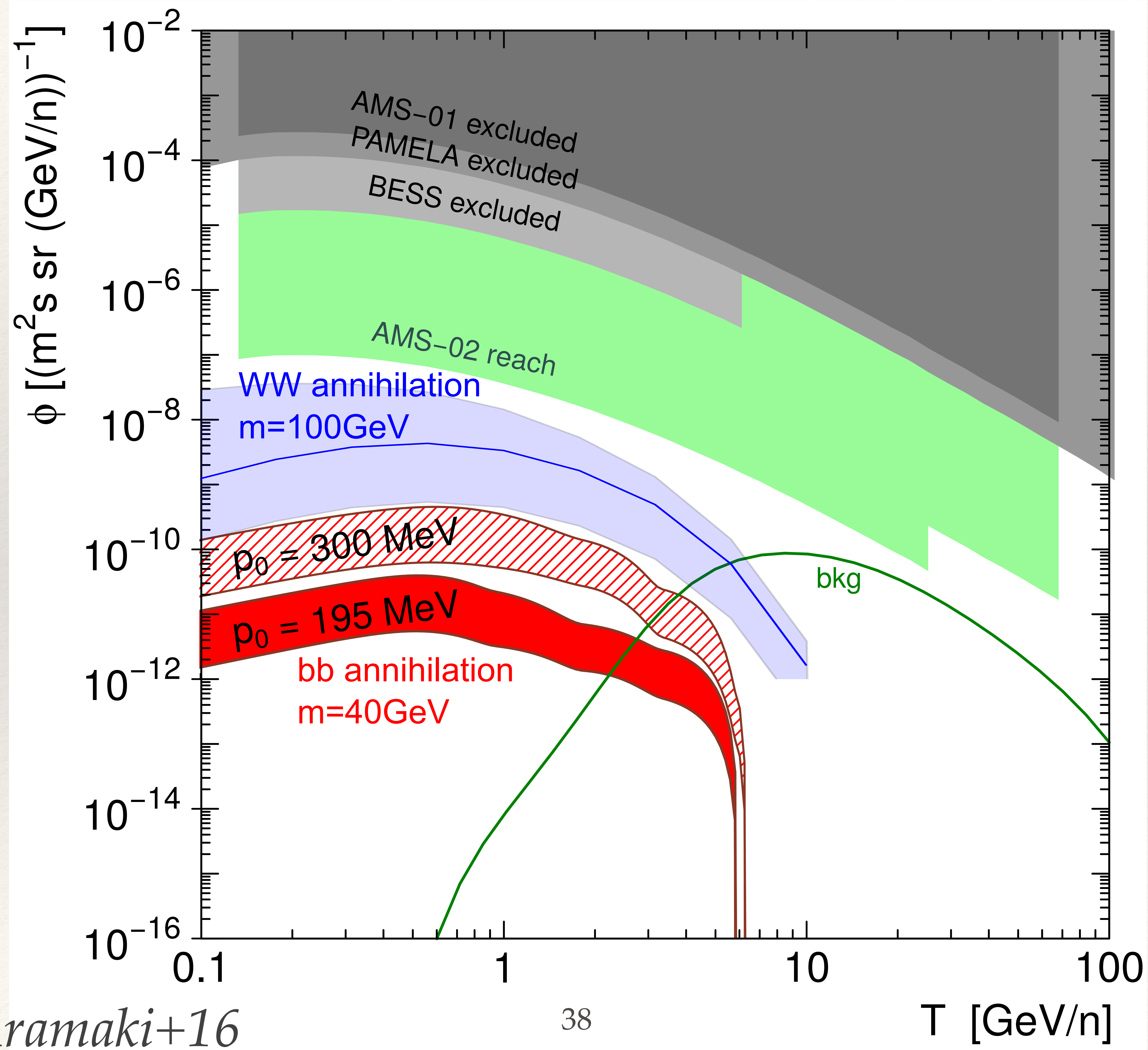
N
Splashdown
TARF (Launch)
Re-Ascent
the Pacific Ocean
20 km
Copyright(C) of map INCREMENT P CORP.

Grasp



Aramaki+15

anti-^{3}He Sensitivity?



Aramaki+16

Primordial Black Holes