Antideuterons

Quy Nhon, Vietnam
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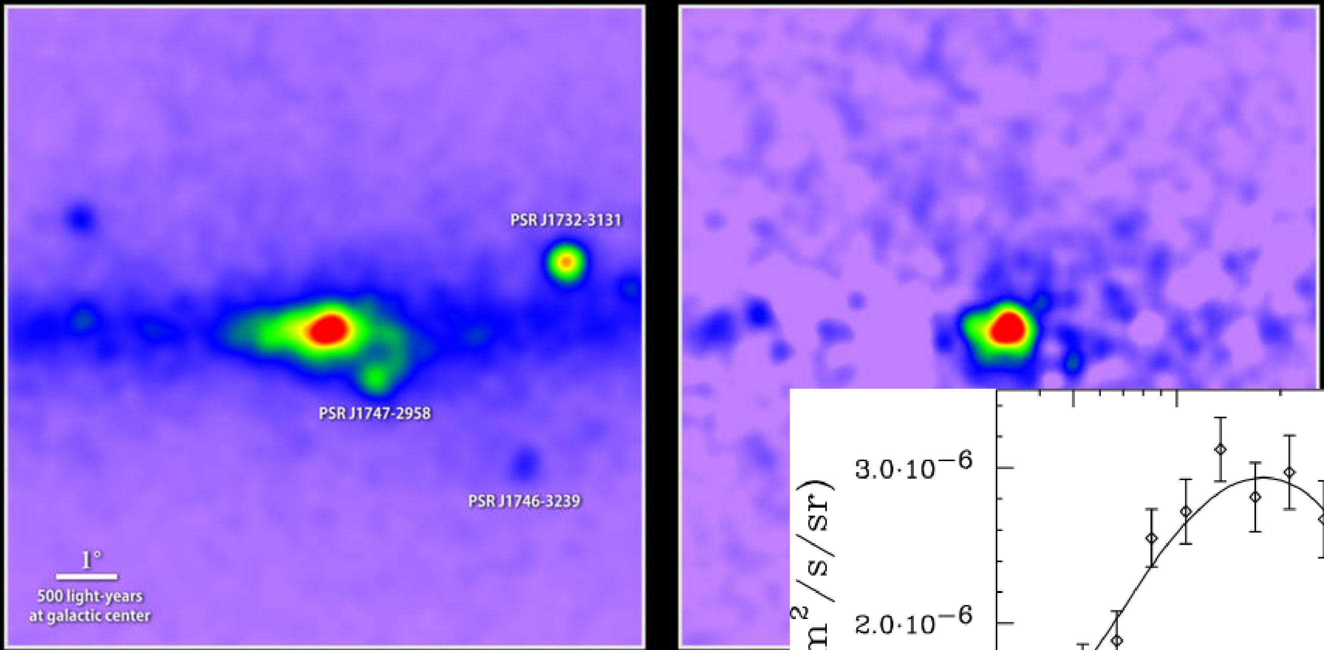
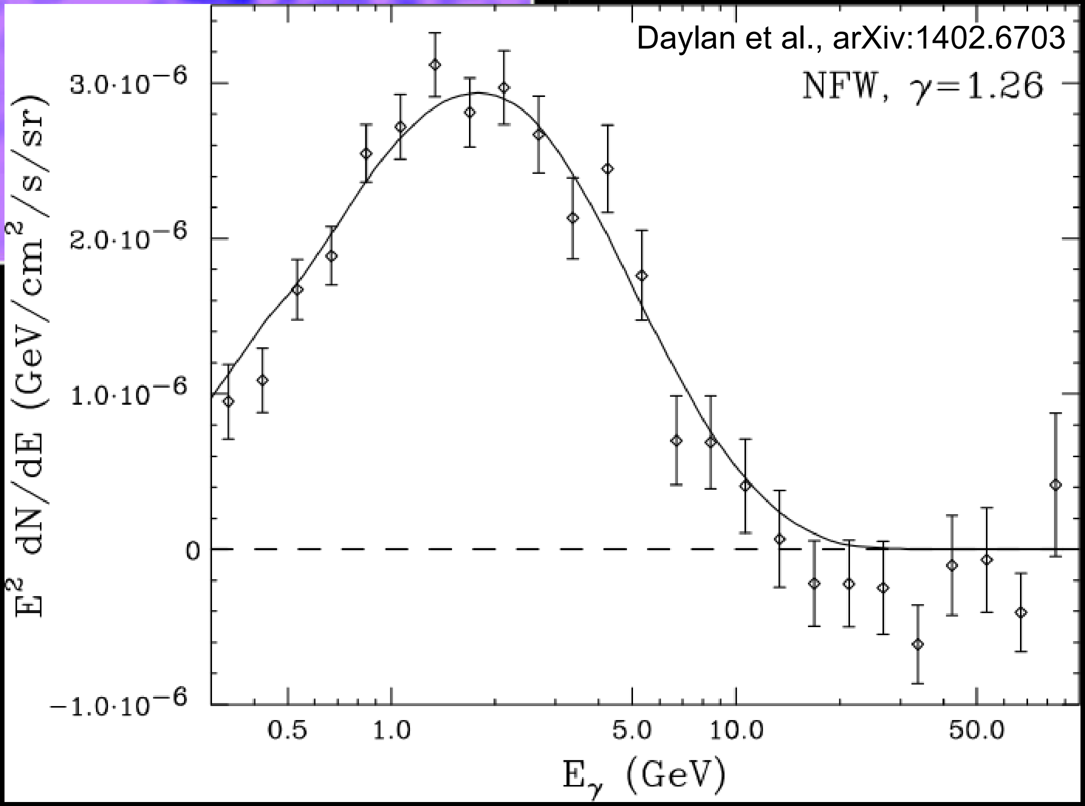
Diffuse Galactic γ-ray excess?

Uncovering a gamma-ray excess at the galactic center



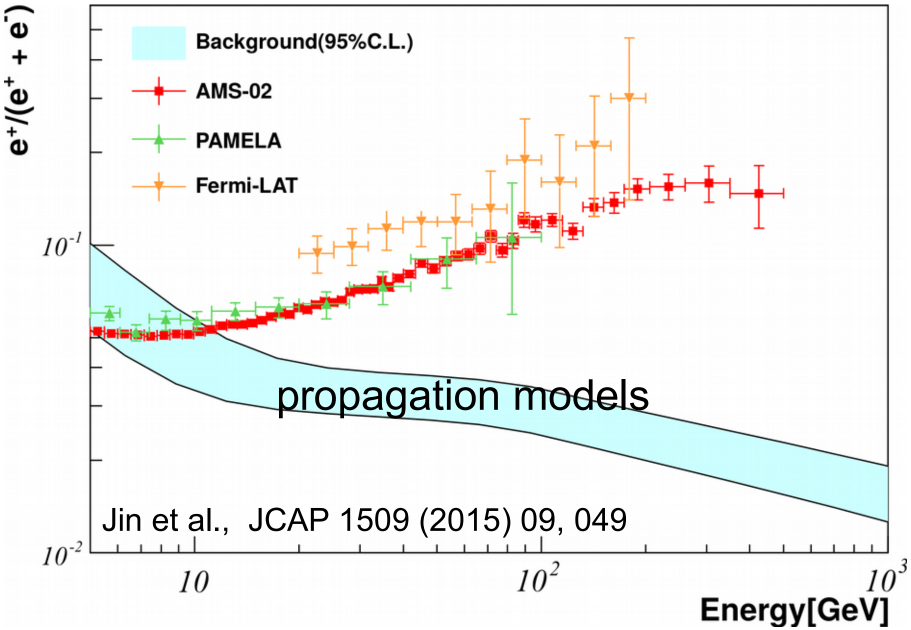
Unprocessed map of 1.0 to 3.16 GeV gamma rays

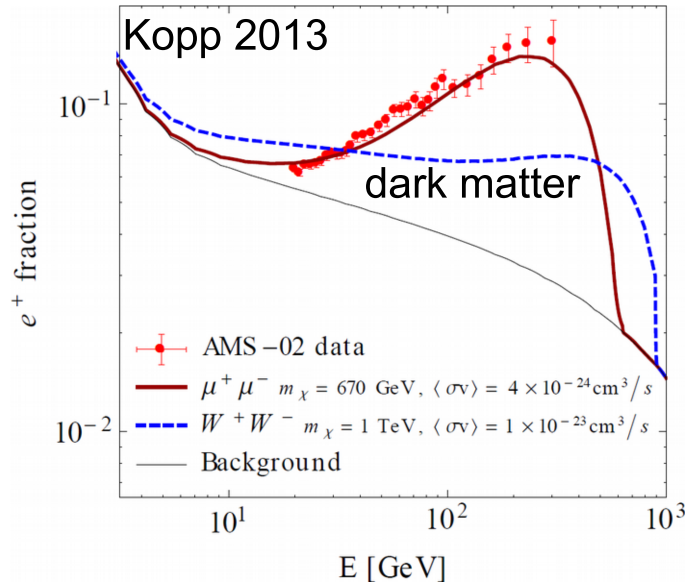


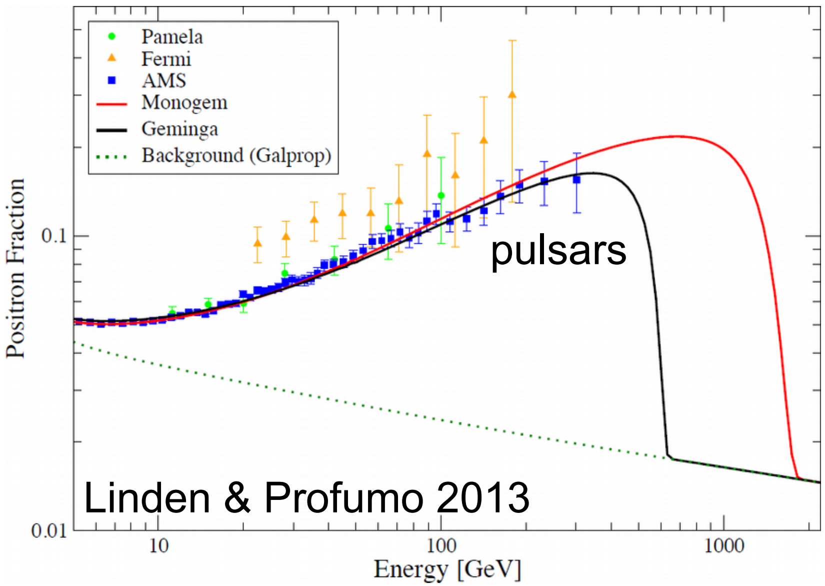
- gamma-ray excess at the galactic center → ~30GeV dark matter particle?
- unresolved millisecond pulsars?
- from pion production in molecular clouds
- tension with dwarf galaxies
- understanding of astrophysical background is a big challenge

Dark matter signal in positrons?

→ Boudaud



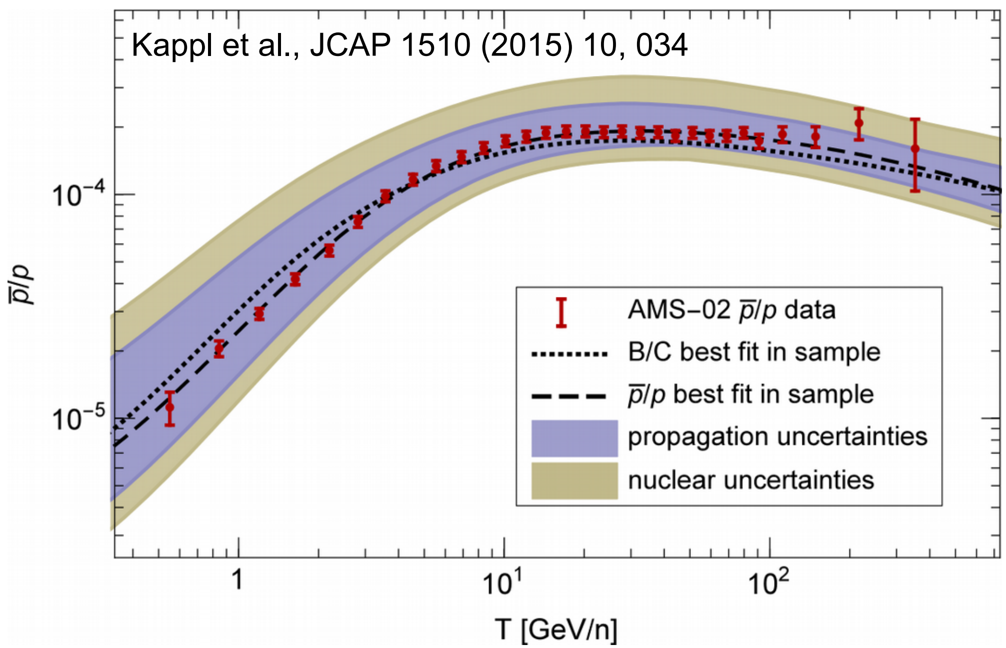


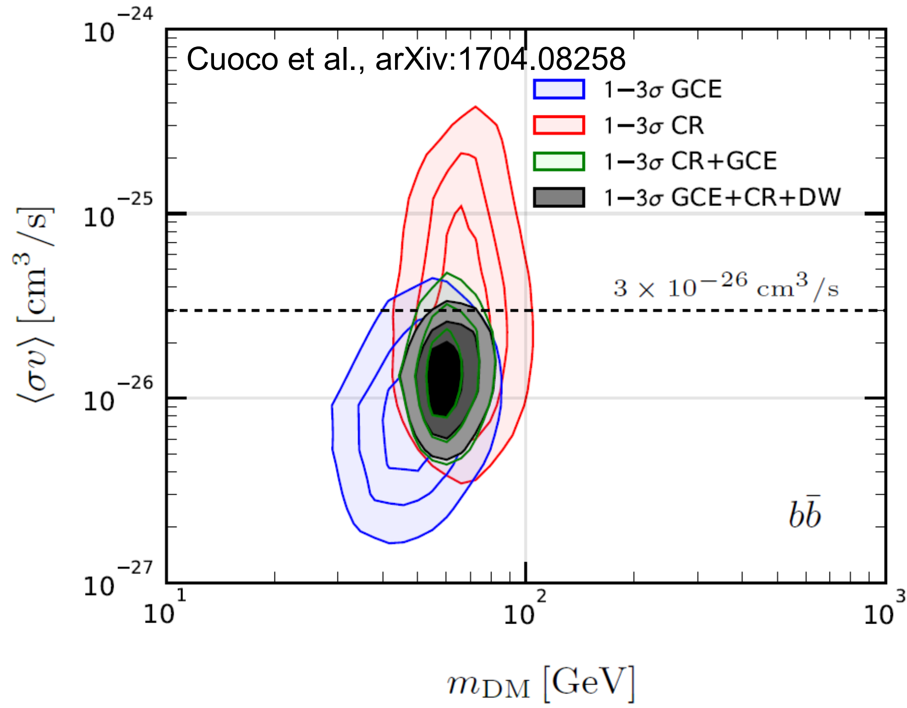


- dark matter models are severely constrained:
  - large cross sections
  - leptophilic?
- explained by nearby pulsars producing electrons and positrons?
  - anisotropy should be smaller than AMS-02 limit, but still measurable with ACTs
- different acceleration mechanisms
- important to see how the positron fraction continues

Antiprotons

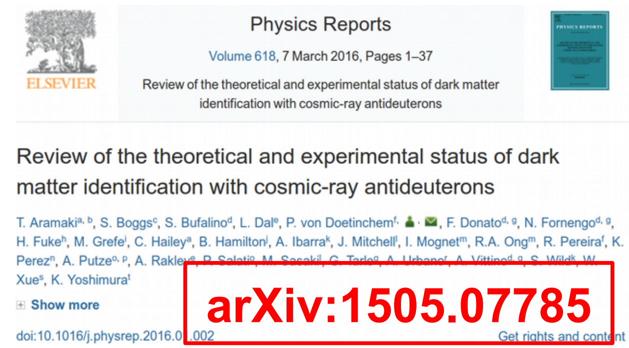
→ Winkler





- latest AMS-02 antiproton results are also very actively interpreted
- discussion is inconclusive if an additional component is needed or not
- better constraints on cosmic-ray propagation and astrophysical production are needed

Status of cosmic-ray antideuterons



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Review of the theoretical and experimental status of dark matter identification with cosmic-ray antideuterons

Review of the theoretical and experimental status of dark matter identification with cosmic-ray antideuterons

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doi:10.1016/j.physrep.2016.01.002

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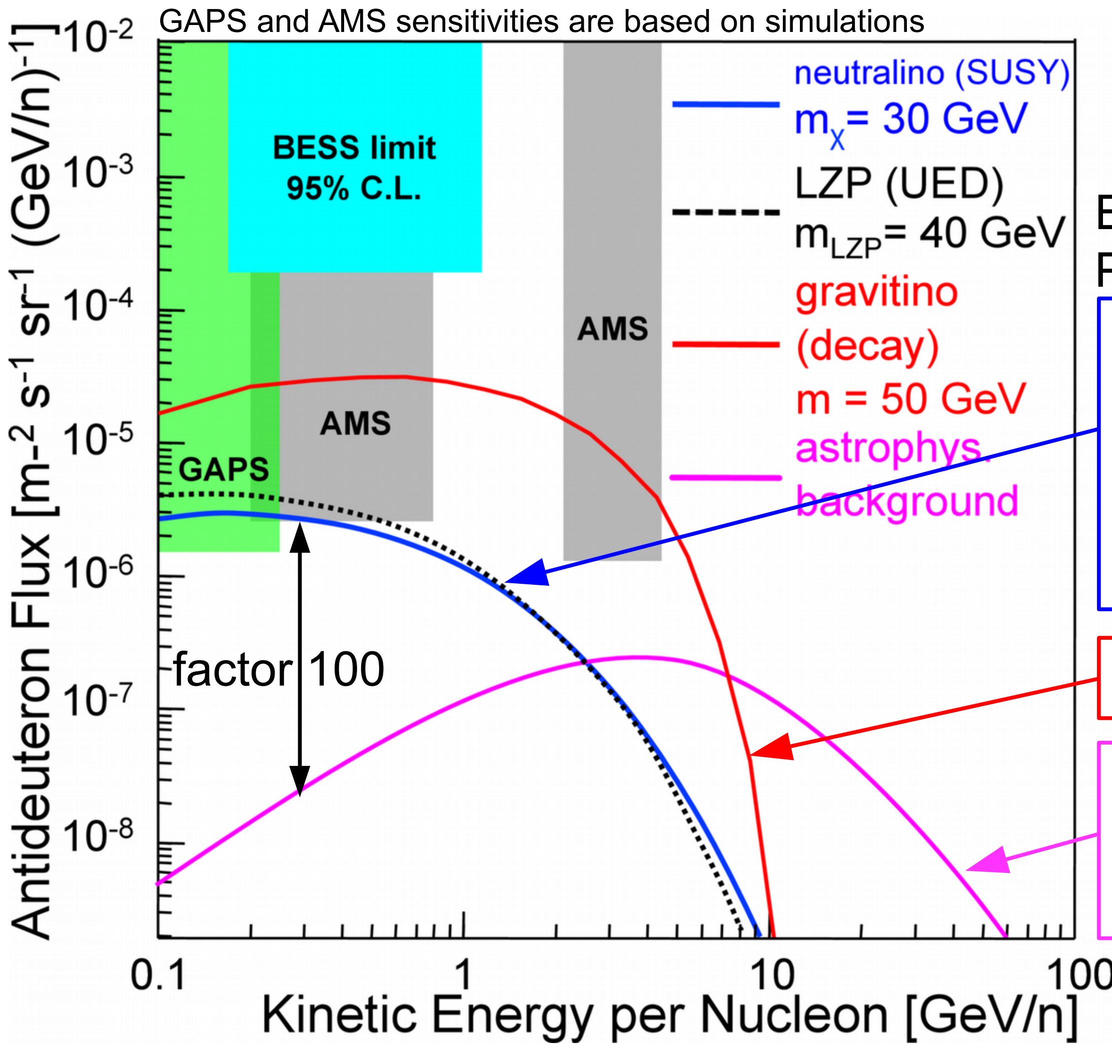


Examples for beyond-standard-model Physics (compatible with $\bar{p}$):

Neutralino:
SUSY lightest supersymmetric particle, decay into $b\bar{b}$, compatible with signal from Galactic Center measured by Fermi

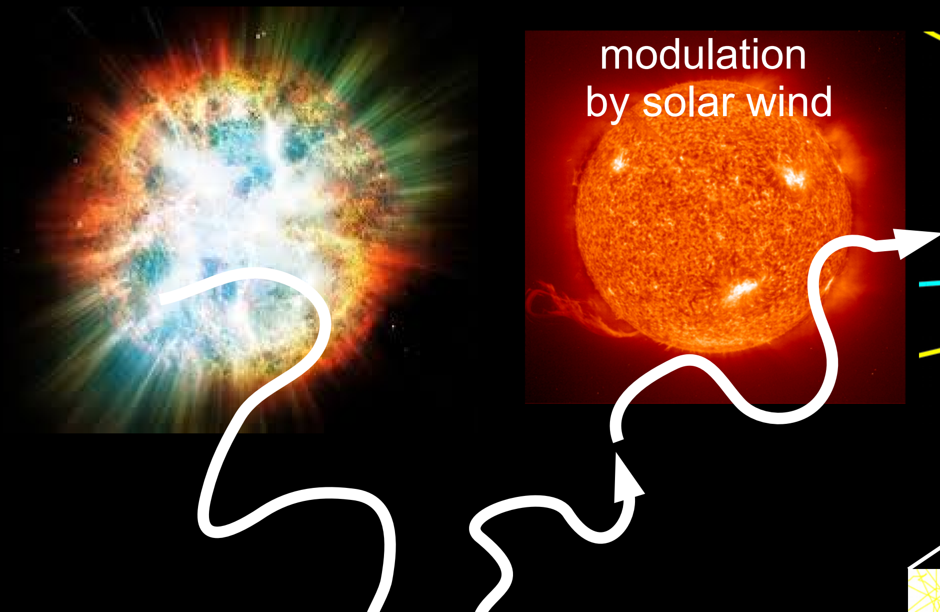
late decays of unstable gravitinos

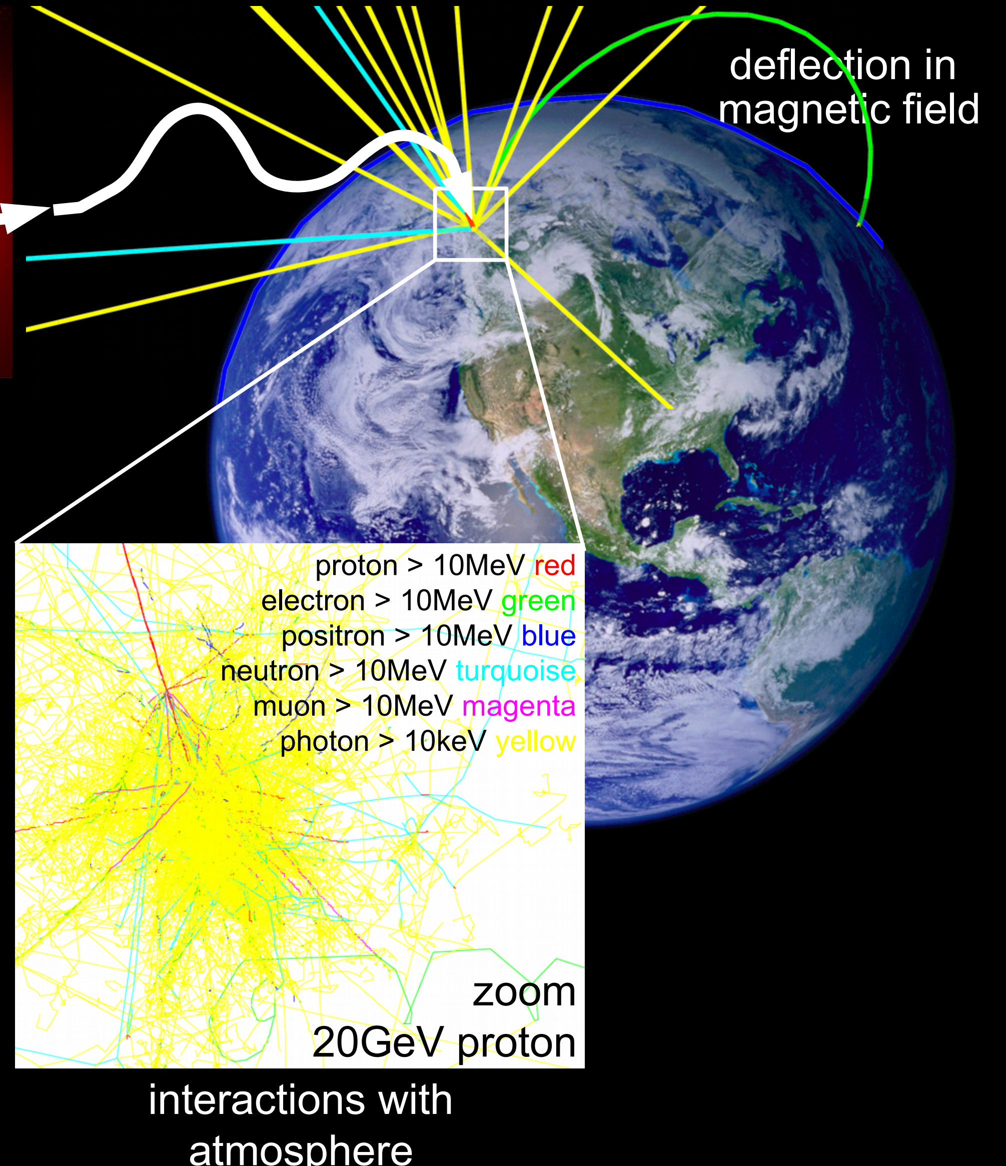
astrophysical background:
collisions of protons and antiprotons with interstellar medium

+ models with heavy dark matter

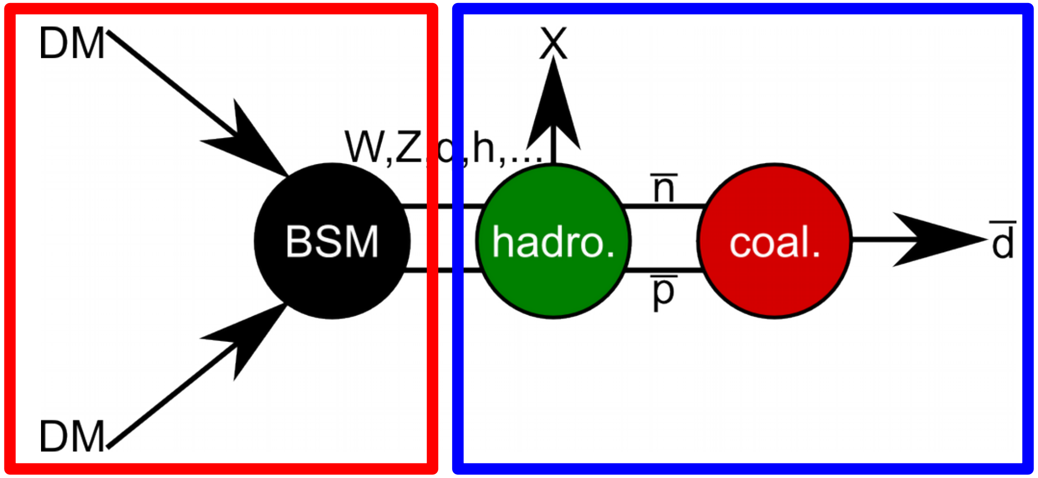
Antideuterons are the most important unexplored indirect detection technique!

Uncertainties



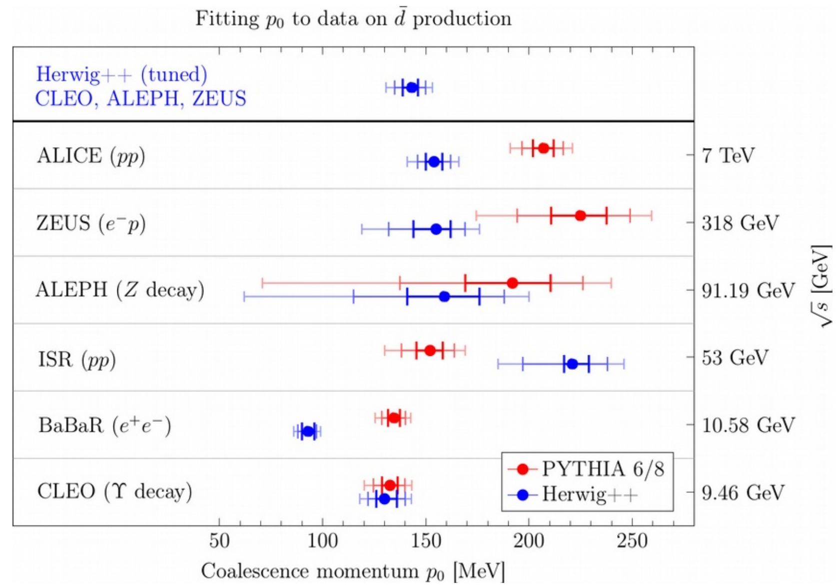


- dark matter annihilation or decay
- dark matter clumping
- **antideuteron production**
- Galactic propagation
- solar modulation
- **geomagnetic deflection**
- atmospheric interactions
- interactions in detector



dark matter

conventional production (e.g., p+ISM) & dark matter



- $\bar{d}$ can be formed by an $\bar{p}$-$\bar{n}$ pair if coalescence momentum p_0 is small

$$\frac{\mathrm{d}N_{\bar{d}}}{\mathrm{d}T_{\bar{d}}} = \frac{p_0^3}{6} \frac{m_{\bar{d}}}{m_{\bar{n}} m_{\bar{p}}} \frac{1}{\sqrt{T_{\bar{d}}^2 + 2 m_{\bar{d}} T_{\bar{d}}}} \frac{\mathrm{d}N_{\bar{n}}}{\mathrm{d}T_{\bar{n}}} \frac{\mathrm{d}N_{\bar{p}}}{\mathrm{d}T_{\bar{p}}}$$

- **important differences for different experiments and MC generators exist → more data needed**

Issues of the coalescence model

- phase space for ion production depends on the available energy in the formation interaction

- coalescence is highly sensitive to two-particle correlations between the participating (anti)nucleons → no a-priori reason to expect two-particle correlations from one generator to be more reliable than from another

- spatial separation → antinucleons originating from weakly decaying particles with macroscopic decay lengths are produced too far from the primary interaction vertex

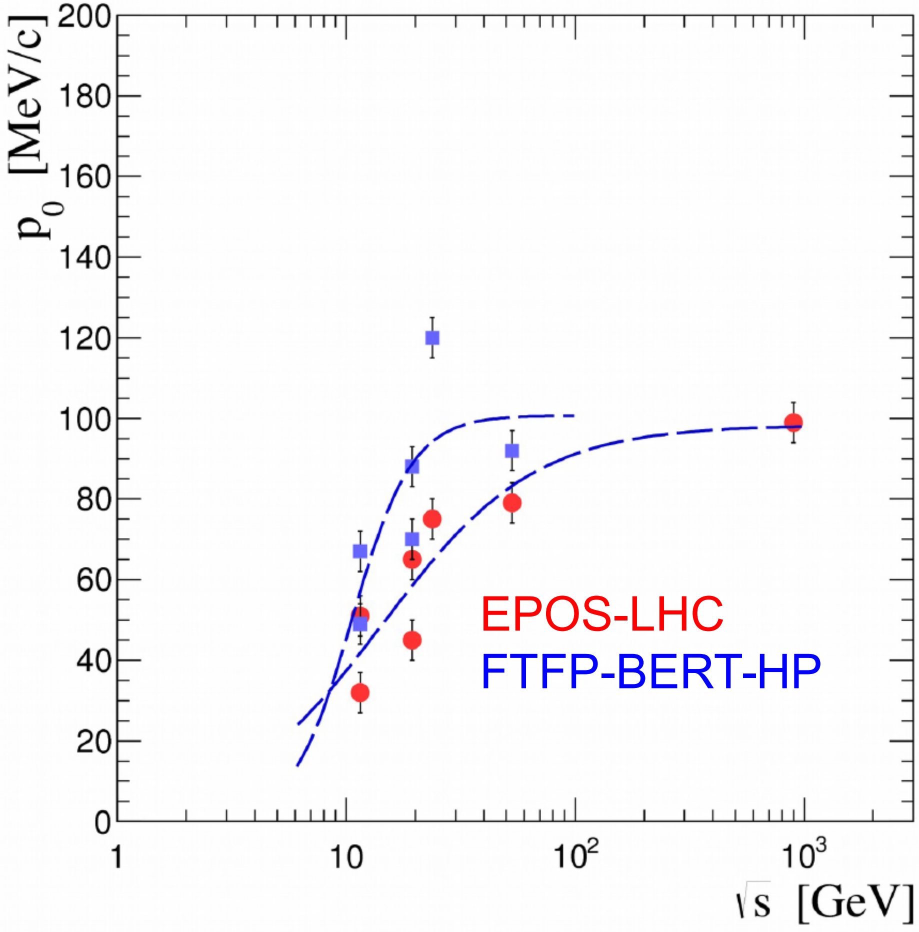
- generators not really tuned for antiparticle production
→ tune with antiproton, deuteron, and antideuteron data
→ test antiproton spectra first, antineutron data are hard to come by

- formation probability in the per-event simulation coalescence approach is taken to be exactly 100%, e.g., spin is not considered

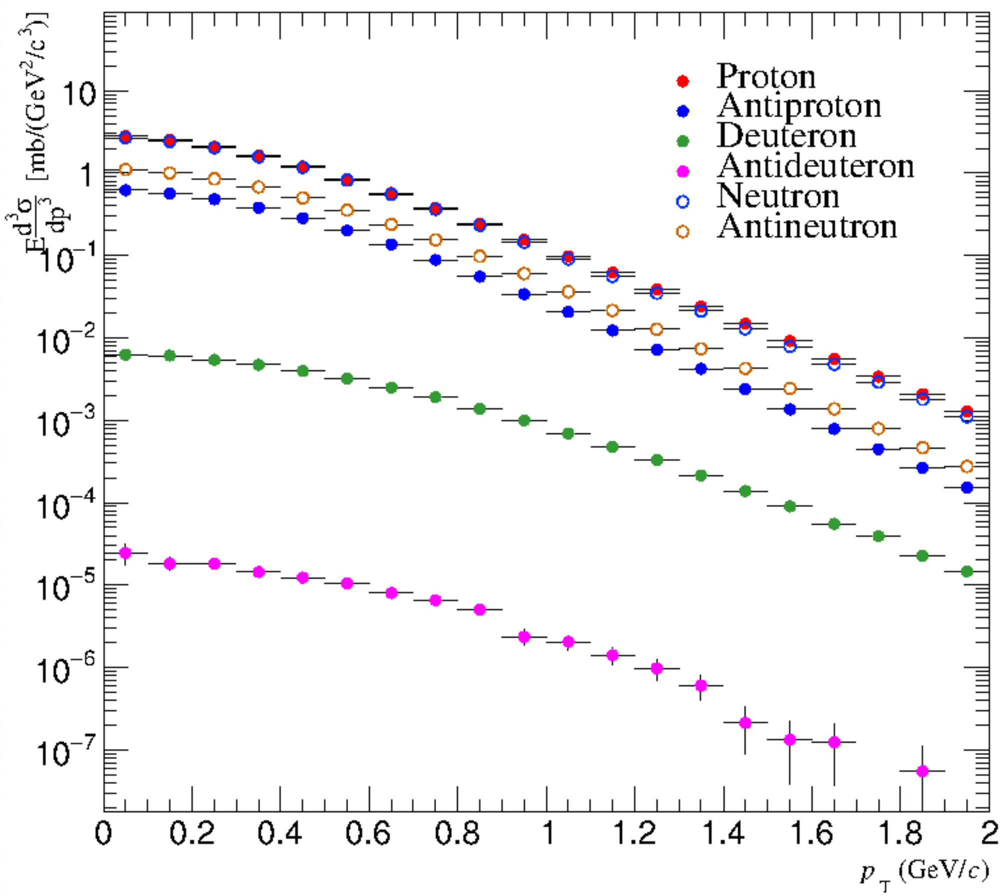
- I do not know any hadronic generator that includes coalescence
→ construct "afterburner""

Modified antideuteron coalescence

Credit: Gomez, Menchaca from UNAM



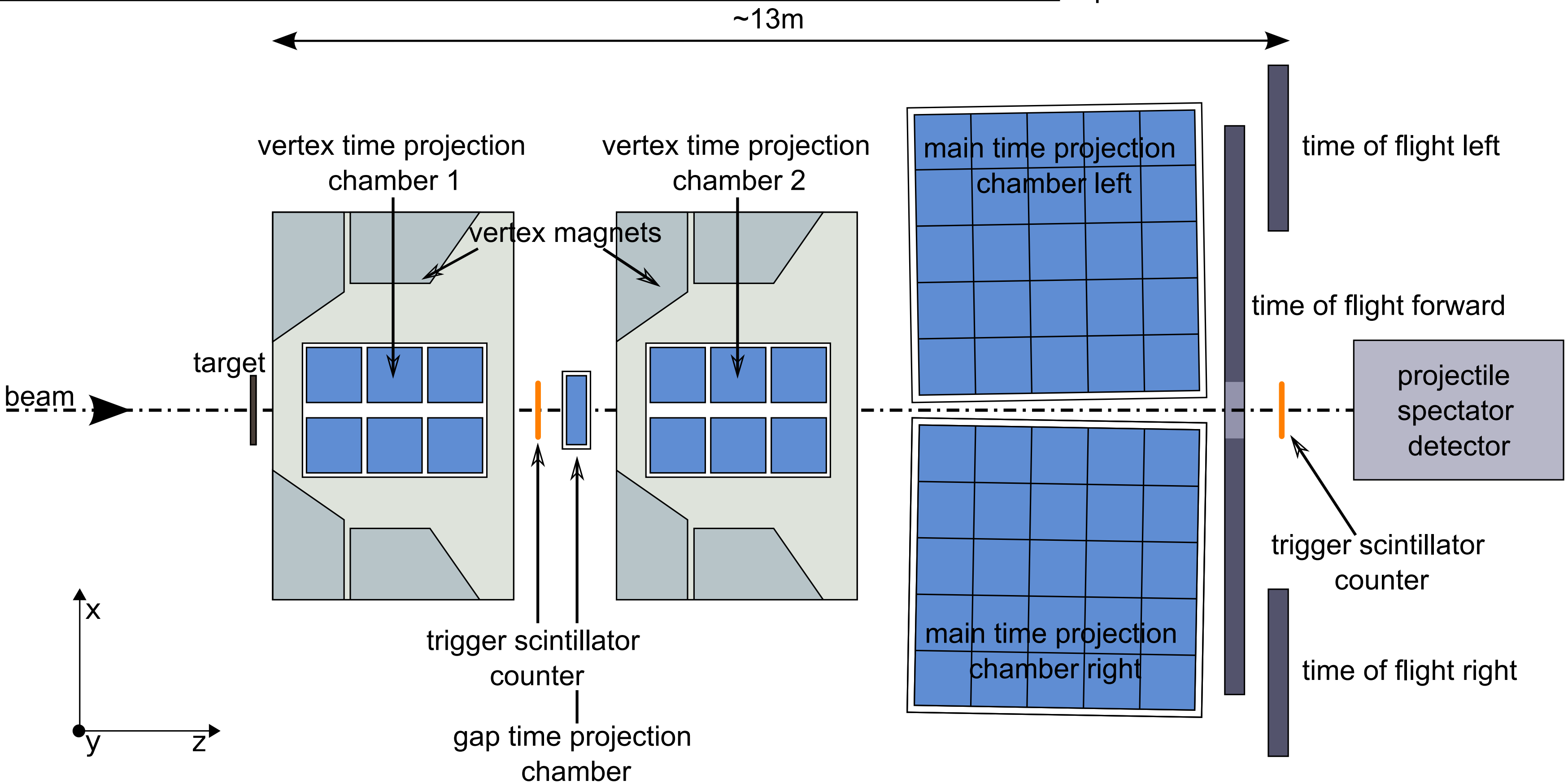
p+p at 158 GeV/c with EPOS-LHC, |y| < 0.5



- coalescence afterburner added to EPOS-LHC, Geant4
- more data needed to constrain (anti)deuteron coalescence model

NA61/SHINE at CERN

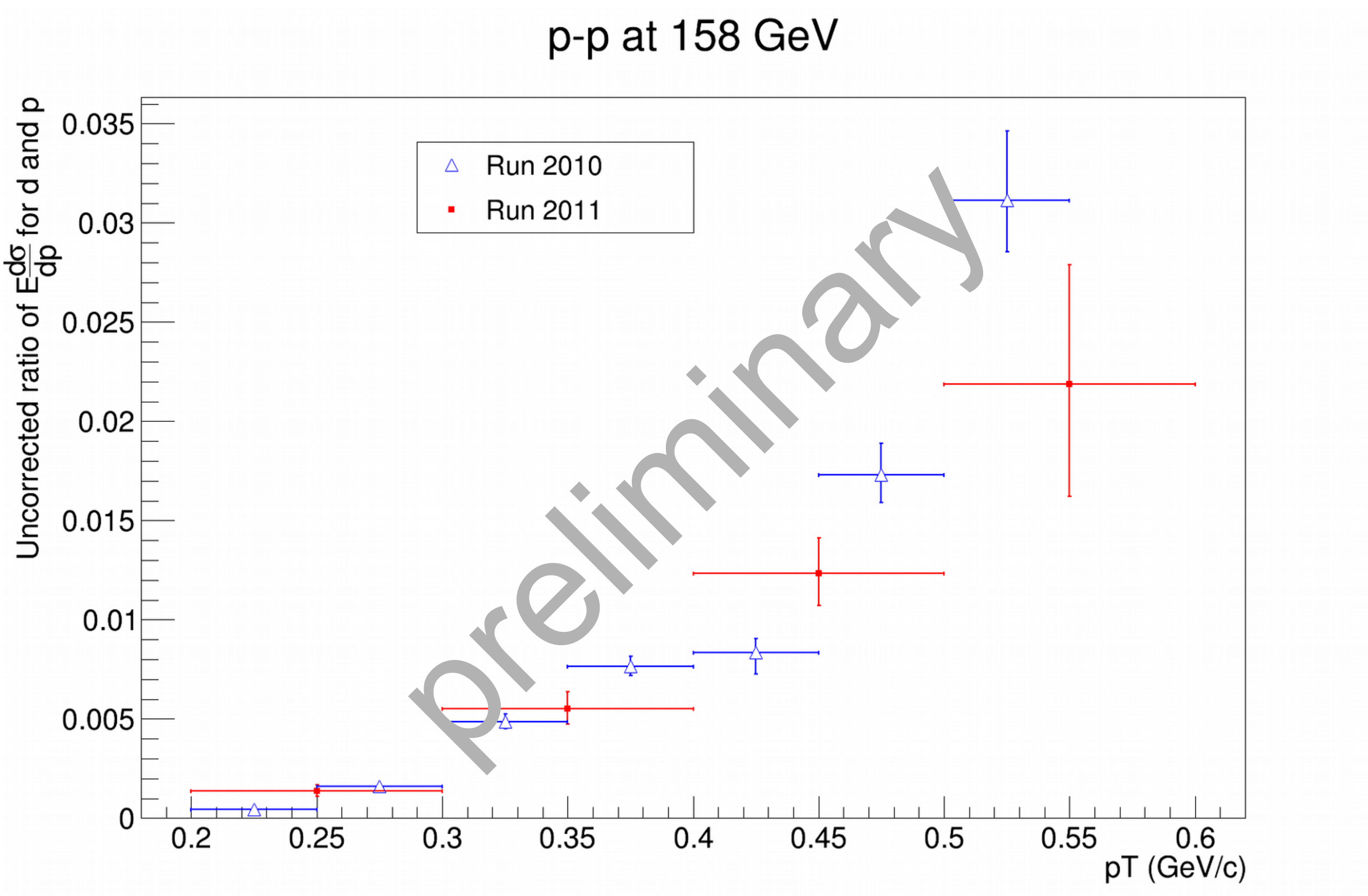
SPS **H**eavy **I**on and **N**eutrino **E**xperiment
pre-decessor: NA49



- multi-purpose, fixed-target experiment at the CERN SPS (NA61/SHINE facility paper: JINST 9 (2014) P06005)
    - precise measurements of properties of produced particles: q, m, p
- cosmic-ray antideuteron production happens between 40 and 400GeV
    - SPS energies from 9 to 400GeV are ideal
- data under discussion from the NA61/SHINE strong interactions program:
    - p+LH data taken at 13, 20, 31, 40, 80,158GeV/c + 400GeV/c (2016)

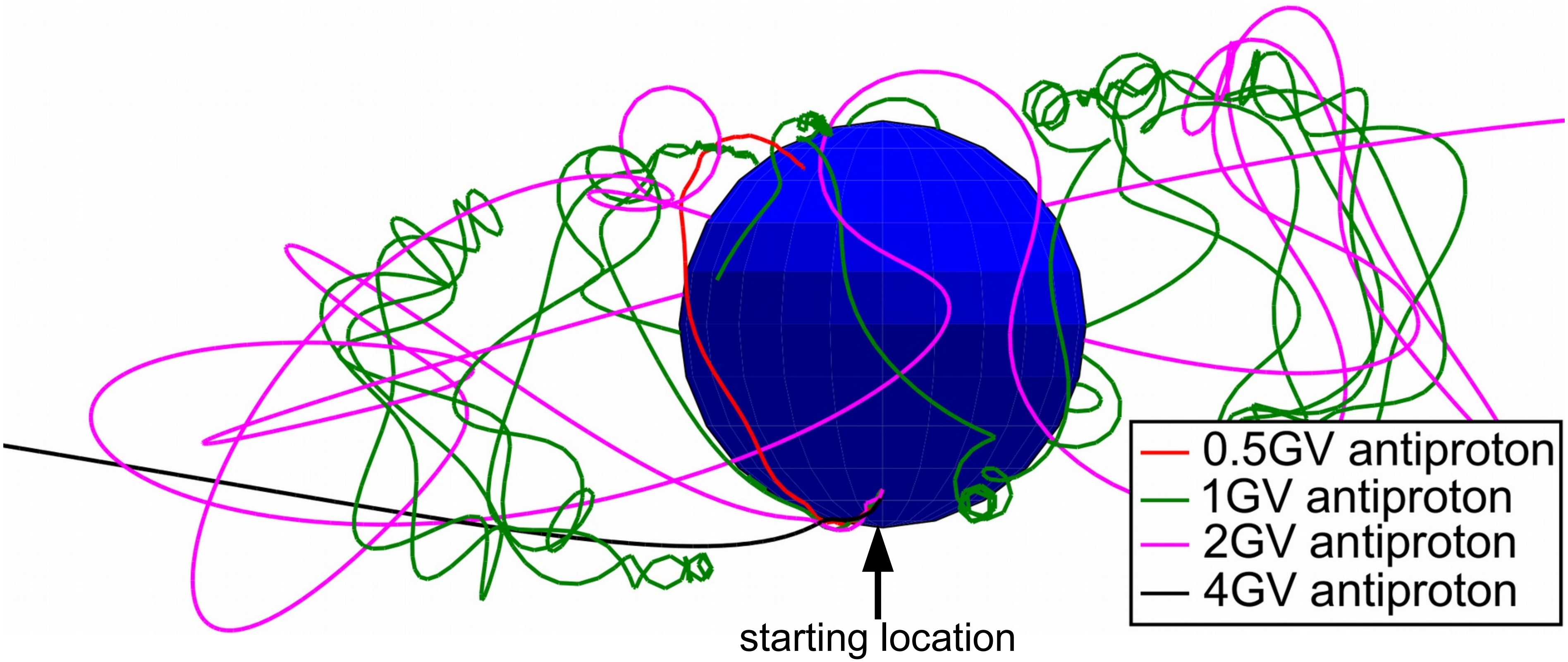
- high momentum resolution: $\sigma(p)/p^2 \approx 10^{-4}(\mathrm{GeV}/c)^{-1}$ (at full B=9Tm)
- ToF walls resolution:
    - ToF-L/R: $\sigma(t) \approx 60$ps
    - ToF-F: $\sigma(t) \approx 120$ ps
- Good particle identification:
    - $\sigma(dE/dx)/\langle dE/dx \rangle \approx 0.04$
    - $\sigma(minv) \approx 5$ MeV
- high detector efficiency: > 95%
- event rate: 70Hz

d/p ratio



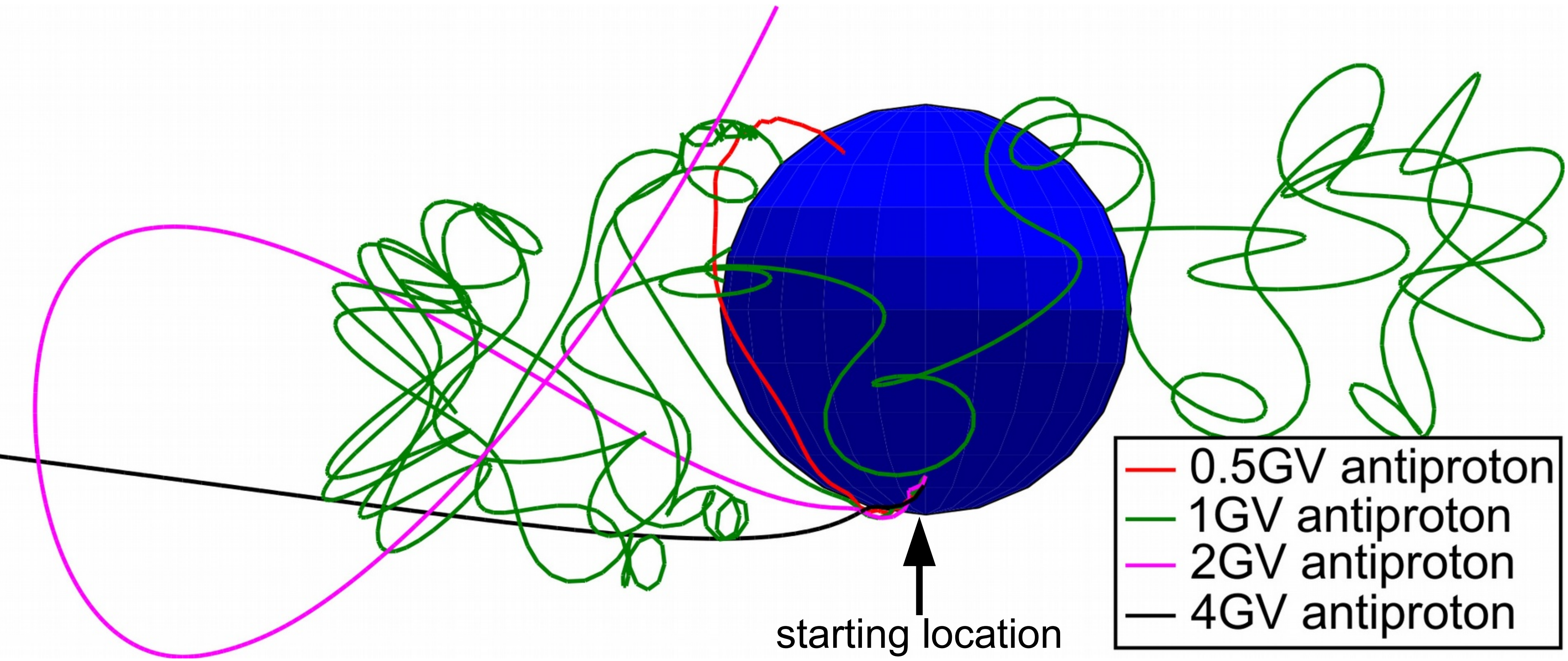
p-p at 158 GeV
Run 2010
Run 2011
preliminary
Uncorrected ratio of $E\frac{d\sigma}{dp}$ for d and p
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
pT (GeV/c)

Geomagnetic cutoff – 5/19/11



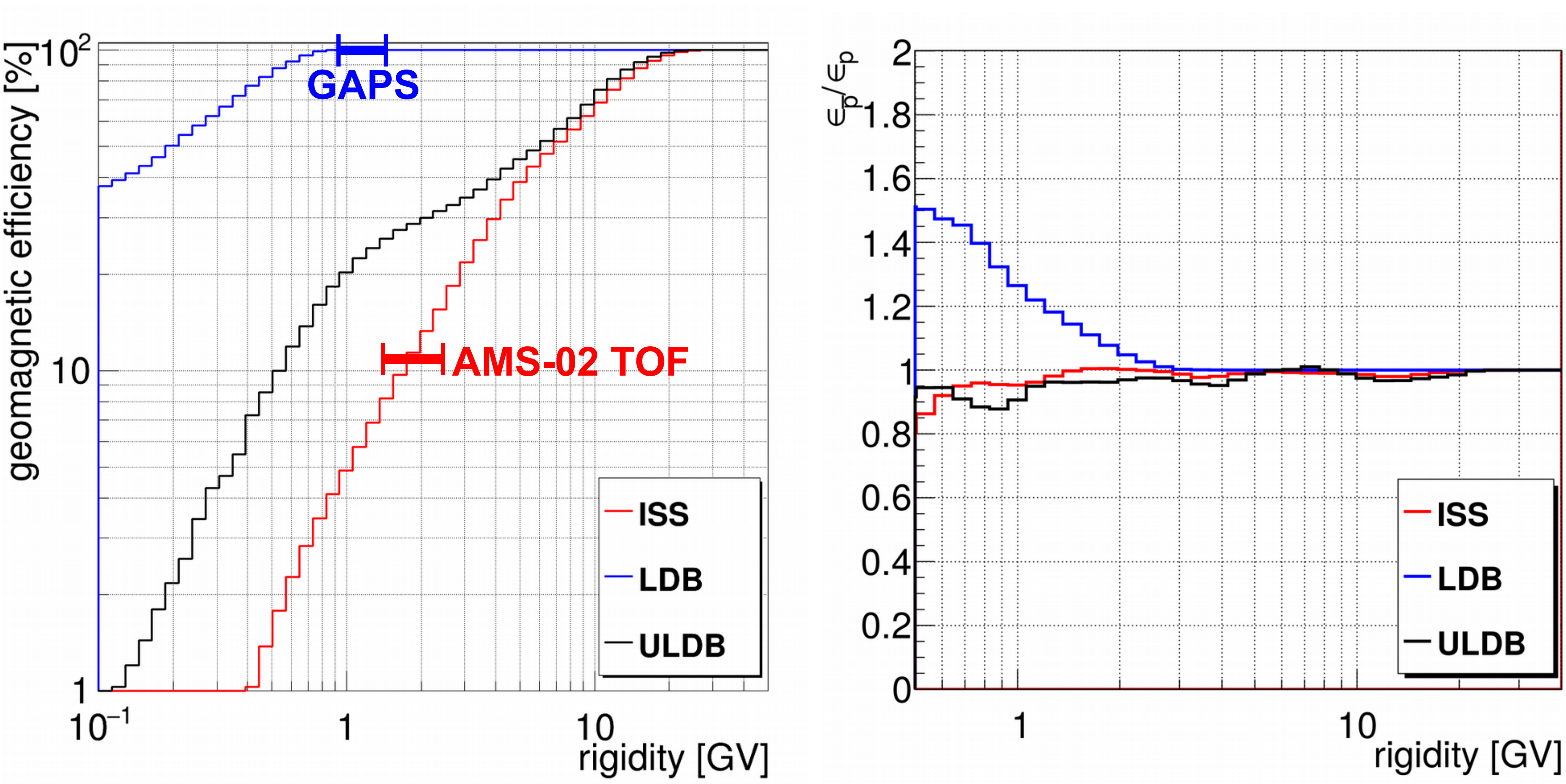
- reverse computation of antiproton trajectories starting at the same location with different rigidities

Geomagnetic cutoff – 3/7/12



- reverse computation of antiproton trajectories starting at the same location with different rigidities
- change in magnetic environment changes the trajectories drastically
  → changes geomagnetic cutoff values

Cutoff comparison of different trajectories



- average geomagnetic cutoff efficiency depends on flight location (LDB = antarctic trajectory, ULDB = COSI flight from Wanaka, New Zealand)
- antiprotons less suppressed for Antarctic trajectory

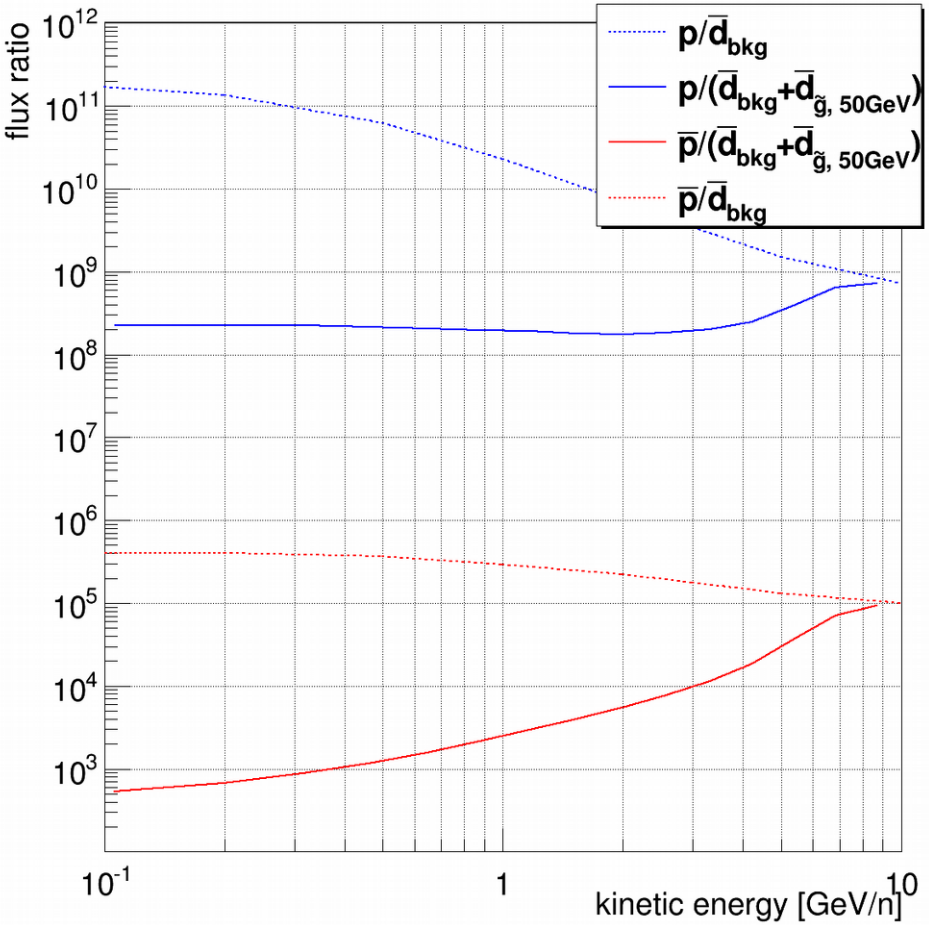
Identification challenge

Required rejections for antideuteron detection:

- **protons**: > 10^8 - 10^{10}
- **He-4**: > 10^7 - 10^9
- **electrons**: > 10^6 - 10^8
- **positrons**: > 10^5 - 10^7
- **antiprotons**: > 10^4 - 10^6

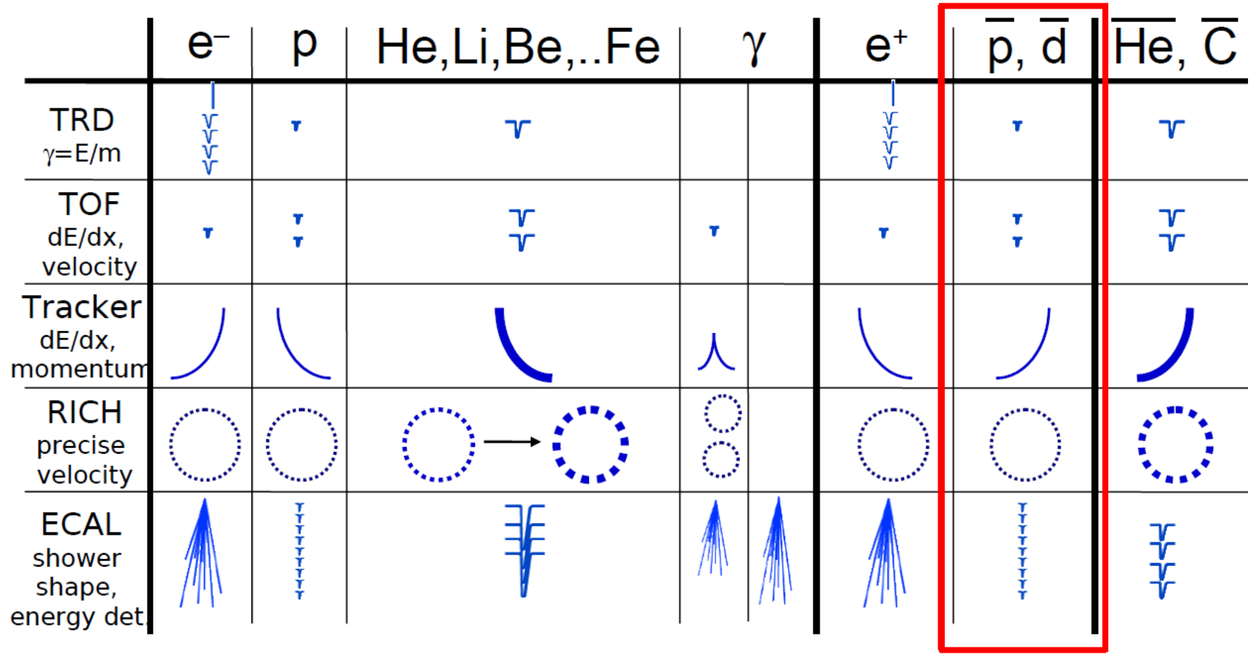
Antideuteron measurement with balloon and space experiments require:

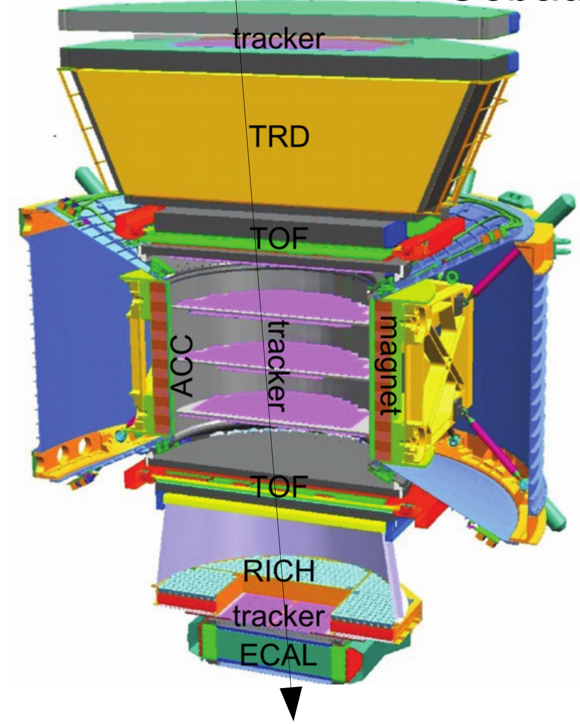
- **strong background suppression**
- **long flight time and large acceptance**



AMS-02 antideuteron analysis

→ Gebauer





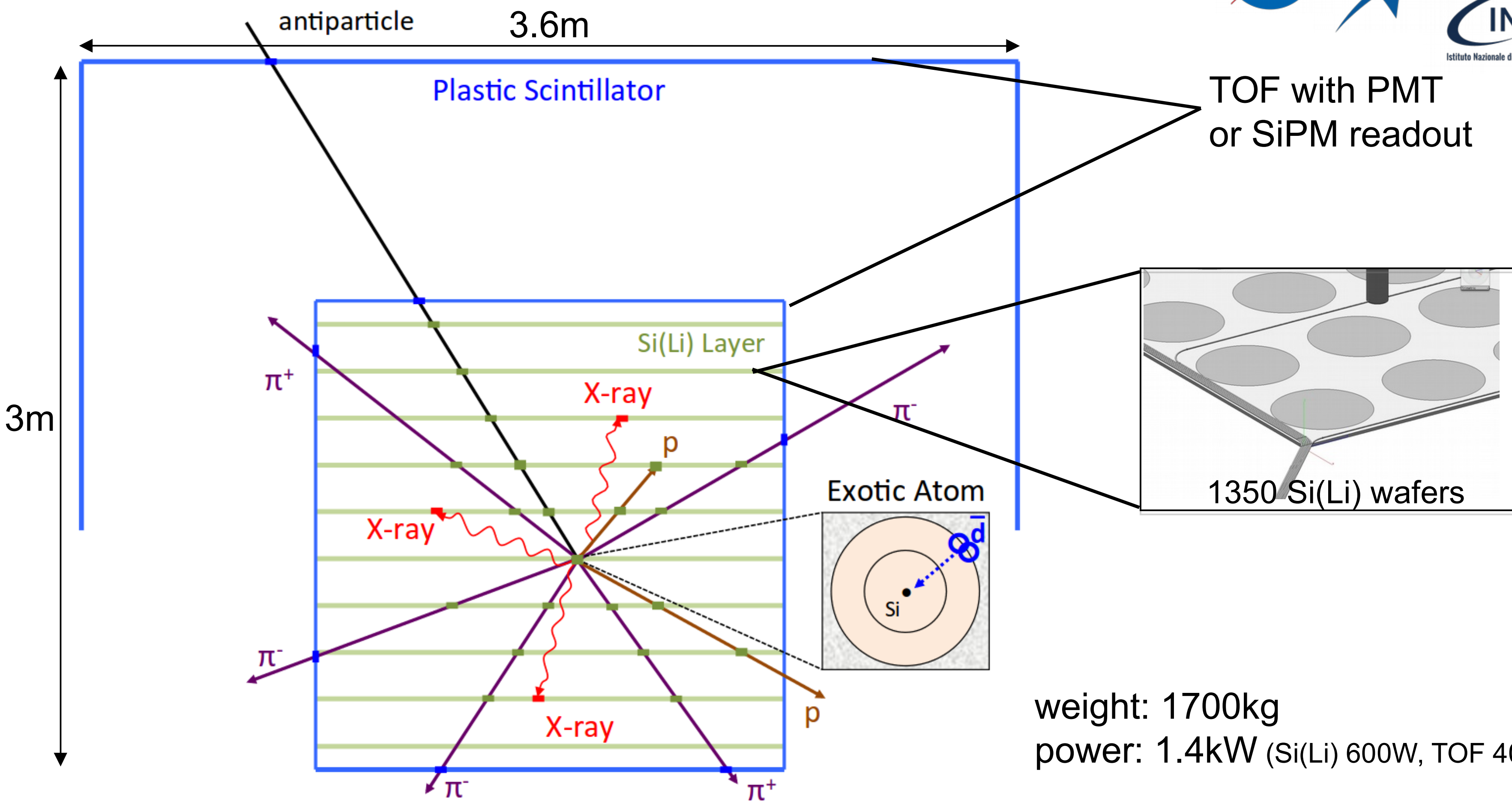
- **antideuteron identification:**
  - momentum measured in the form of rigidity
  - charge from TOF, TRD, tracker
  - lower velocities: **T**ime **O**f **F**light scintillator system
  - higher velocities: **R**ing **I**mage **Ch**erenkov detector

$$m = R \cdot Z \sqrt{\frac{1}{\beta^2} - 1}$$

- **self-calibrated analysis:**
  - calibrate antideuteron analysis with deuterons and antiprotons (simulations and data)
  - **analysis is ongoing**

The GAPS experiment

Columbia U, UCSD
UCLA, U Hawaii,
MIT

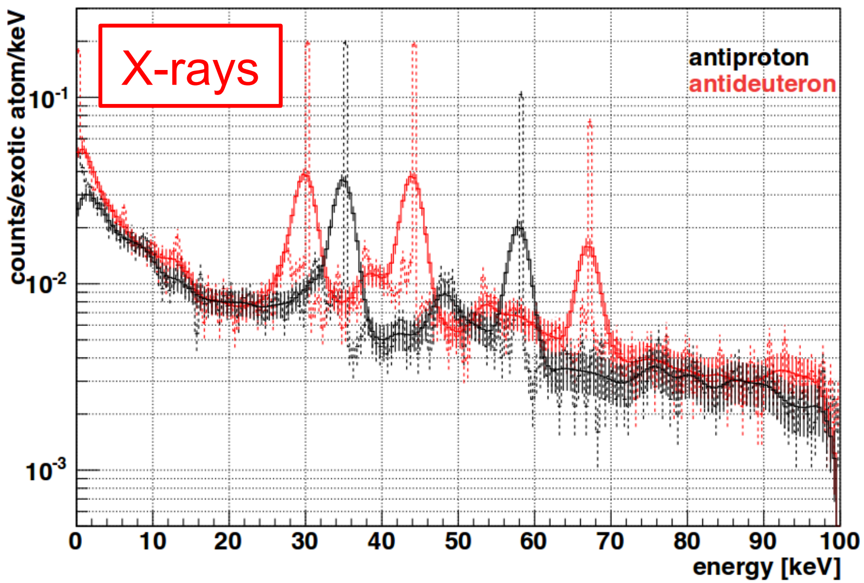


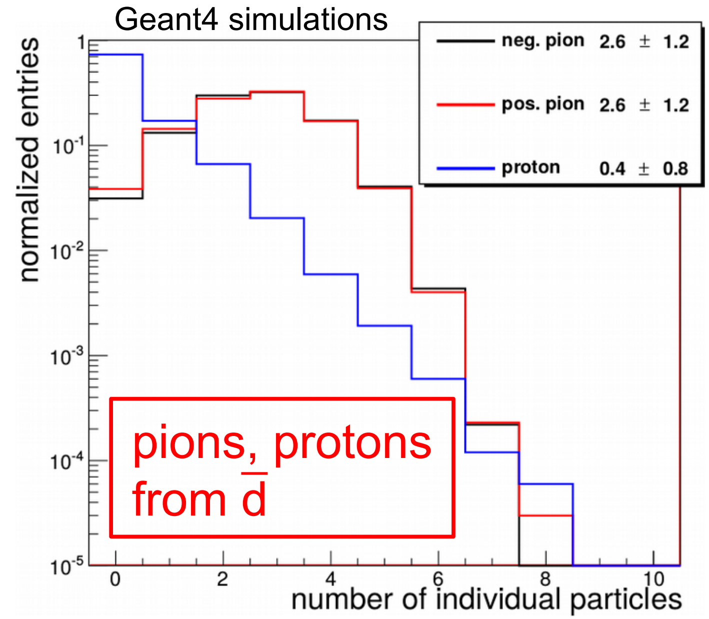
weight: 1700kg
power: 1.4kW (Si(Li) 600W, TOF 400W)

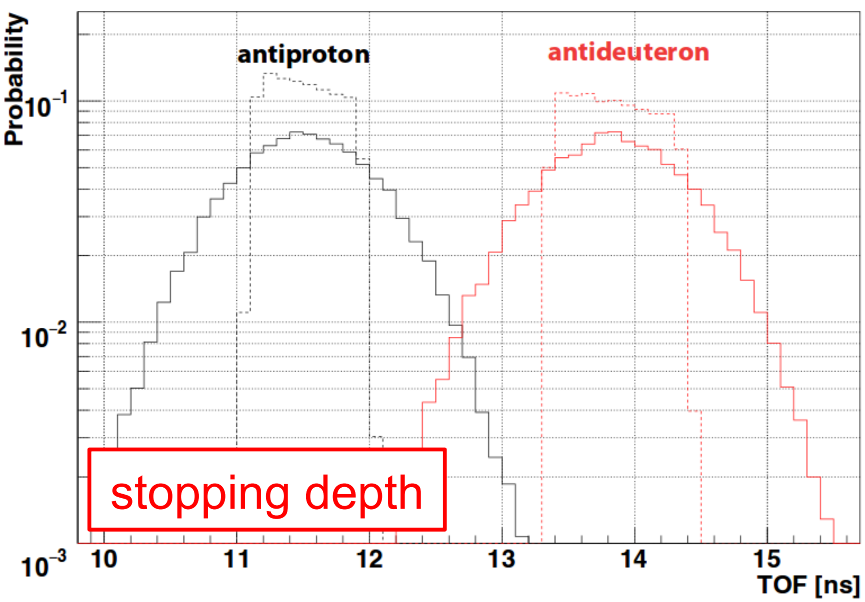
- the **G**eneral **A**nti**P**article **S**pectrometer is specifically designed for low-energy antideuterons and antiprotons
- Long Duration Balloon flights from Antarctica
- identification by stopping and creation of exotic atoms tested in KEK testbeam measurements: Astropart. Phys. 49, 52 (2013)
- **GAPS has been approved by NASA & JAXA → first flight 2020**

GAPS sensitivity

Aramaki et al., Astropart. Phys. 74, 6 (2016)



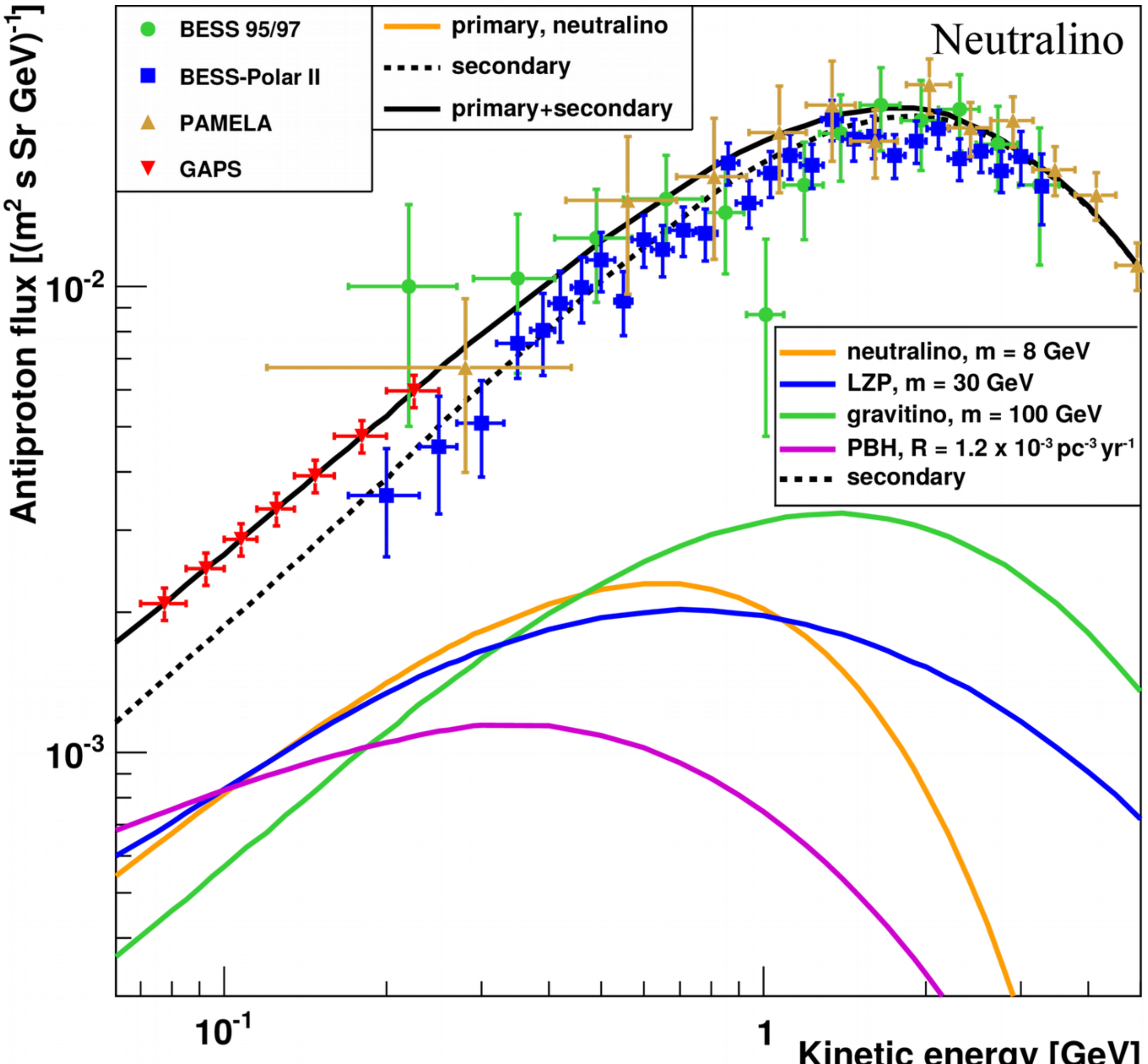




Background rejection:

- stopping protons don't have enough energy to produce pions and cannot form exotic atoms (pos. charge)
- deexcitation X-rays have characteristic energies
- number of annihilation pions and protons
- stopping depth in detector

GAPS low-energy antiproton

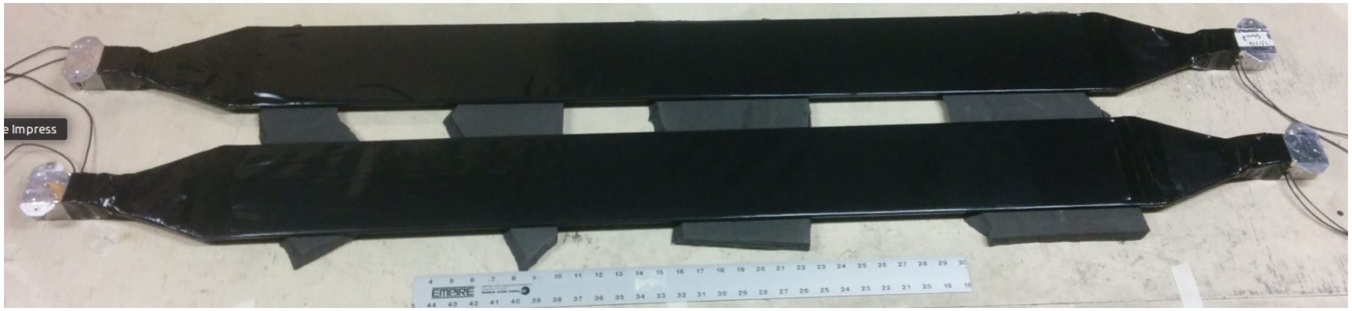


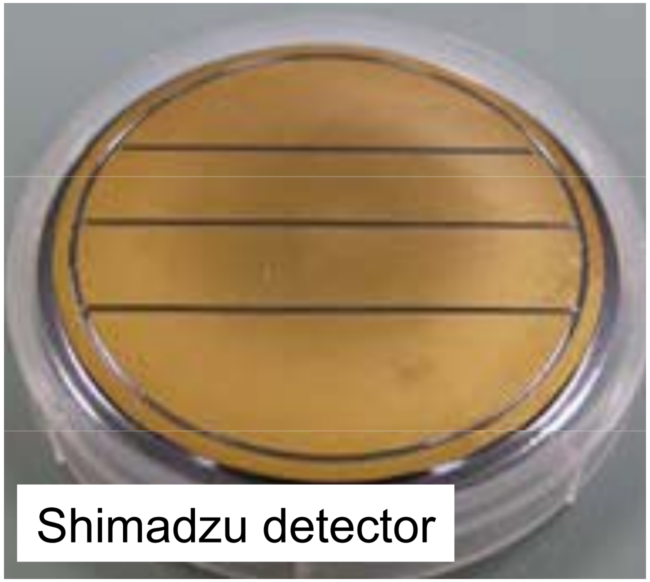
Predicted primary antiproton fluxes from:

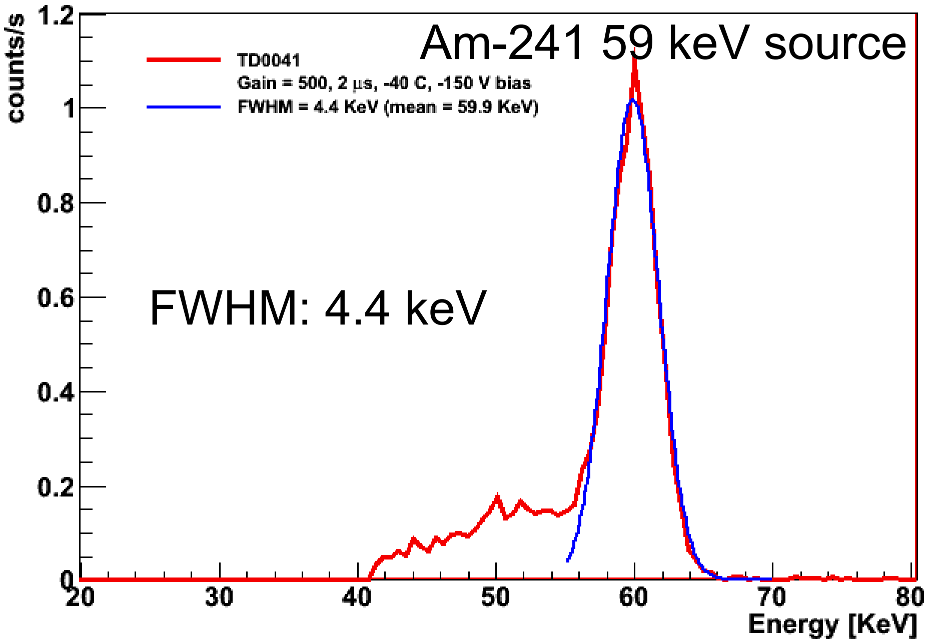
- Neutralinos
- LZP
- Gravitinos
- primordial black holesPBHs, along with neutralino signals

as seen by 1 GAPS LDB flight

Detector production





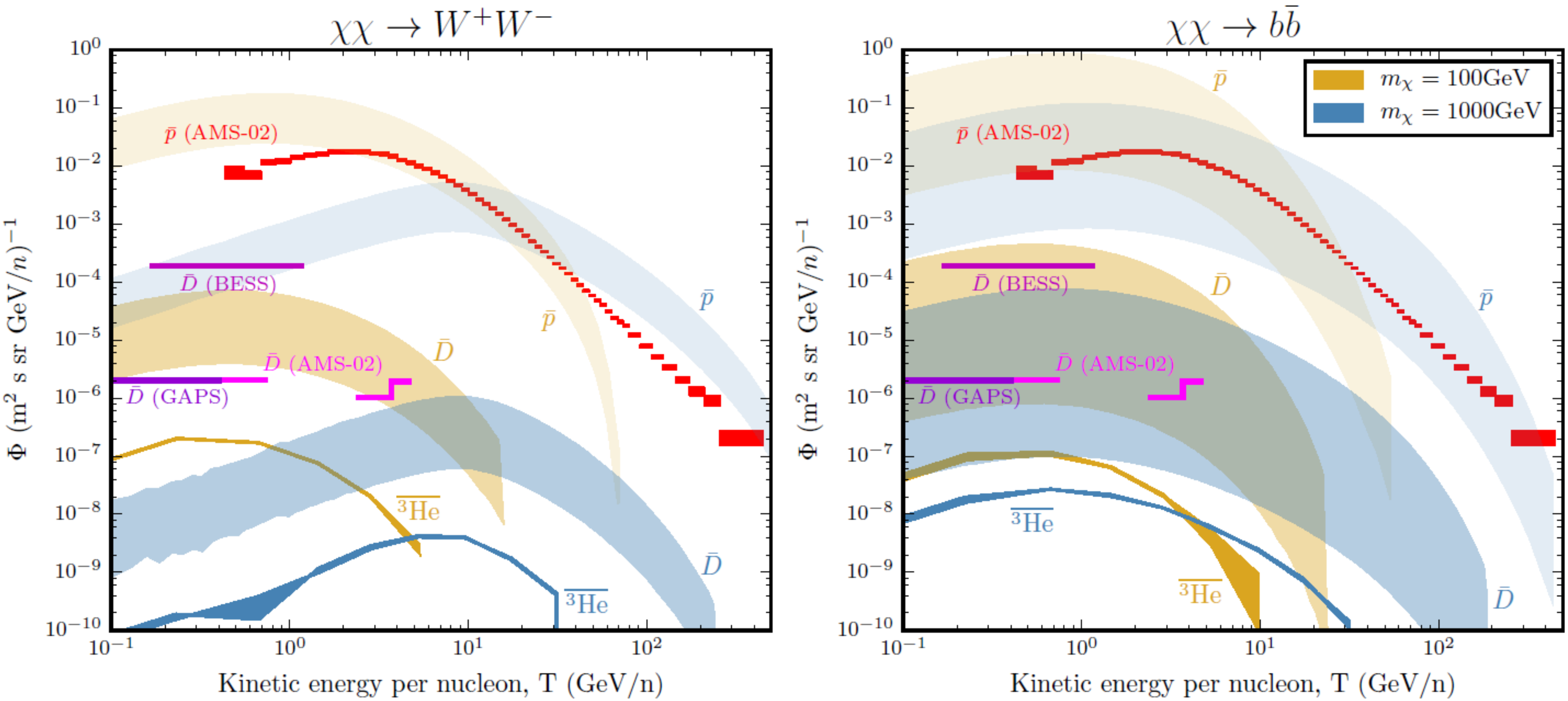


- GAPS will use ~1350 4” Si(Li) detectors, 2.5mm thick
- fabrication scheme developed at Columbia U, produced by private company Shimadzu, Japan
- confirmed performance with cosmic rays (MIPs) and Am-241 source (X-rays)

- TOF testing and development ongoing → decision between PMTs and SiPms

Next up: antihelium?

Coogan, Profumo, arXiv:1705.09664



- AMS-02 announced antihelium candidates
- needs more data over the next years to make a statistically sound statement
- has important implications for antiprotons and antideuterons
  → all three channels have to be explained at the same time
  → nuclear formation is a key issue

Postdoc openings for GAPS

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Astroparticle Physics

Hawaii U. - Postdoc

Field of Interest: astro-ph, hep-ex
Experiment: GAPS
Deadline: 2017-07-31
Region: North America

http://inspirehep.net/record/1495582

Job description:
Duties and Responsibilities:
The successful candidate will participate in the balloon-borne cosmic-ray antideuteron experiment GAPS. Cosmic-ray antideuterons are an important new probe for indirect dark matter identification. Detailed design and construction of the payload will start in 2017 and the first flight from Antarctica is planned for the end of 2020. The Hawaii group is mainly involved in the simulation tools and analysis software development as well as the calibration and qualification of lithium-drifted-silicon detectors.

Minimum Qualifications:
Applicants must hold a doctoral degree, preferentially in (astro)particle physics. Extensive experience with simulation tools (Geant4) and data analysis (ROOT) as well as hands-on lab experience with solid-state particle physics detectors is expected.

To Apply:
Send application (cover letter, curriculum vitae, list of publications, and contact information for at least two references) to philipvd@hawaii.edu. Please specify in the subject of the email: Postdoctoral fellow for the GAPS experiment.

Other Conditions:
The initial term of this position is for one year. Renewal subject to satisfactory performance.

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Contact: Philip von Doetinchem
Email: philipvd@hawaii.edu
More Information: http://www.phys.hawaii.edu/~philipvd/
Letters of Reference should be sent to: philipvd@hawaii.edu

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Date added: 2016-11-03

Position also open at UCLA:
http://inspirehep.net/record/1505690

Conclusion & Outlook

- antideuteron searches are experimentally challenging
  → **multiple experiments for cross-checks are important**

- AMS-02 and GAPS have very different event signatures **AND** very different backgrounds
  → **very good for independent confirmation**

- measurements with NA61/SHINE will improve understanding of antideuteron production and modeling

- measurement of antideuterons is a promising way for indirect dark matter search