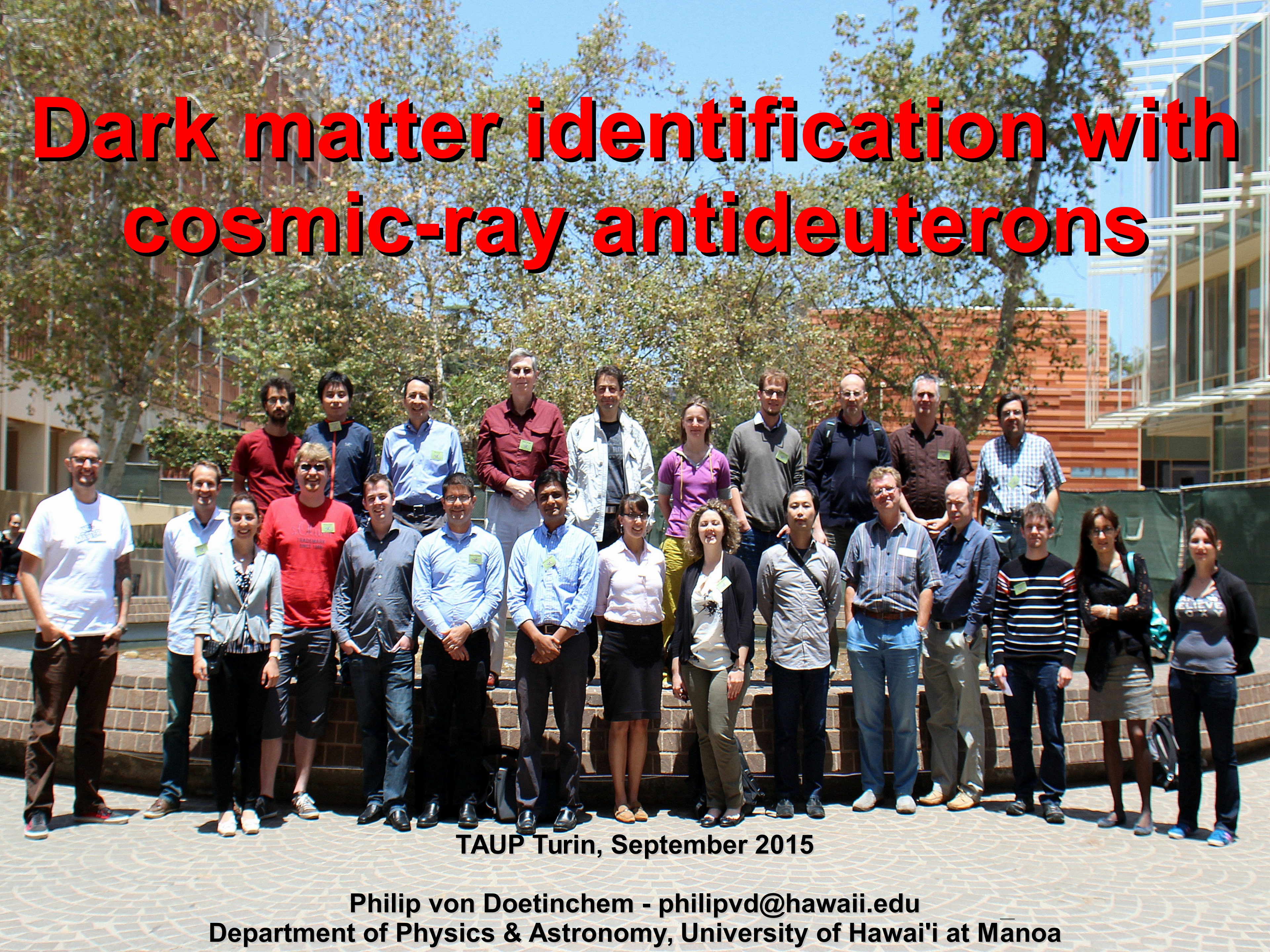
Dark matter identification with cosmic-ray antideuterons



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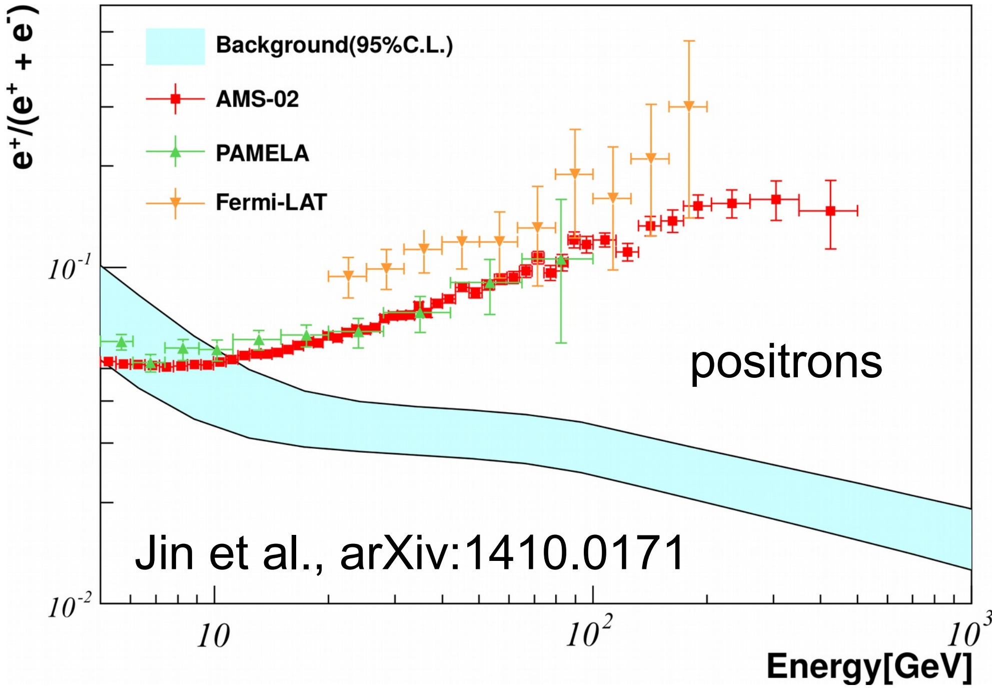
Philip von Doetinchem - philipvd@hawaii.edu
Department of Physics & Astronomy, University of Hawai'i at Mānoa

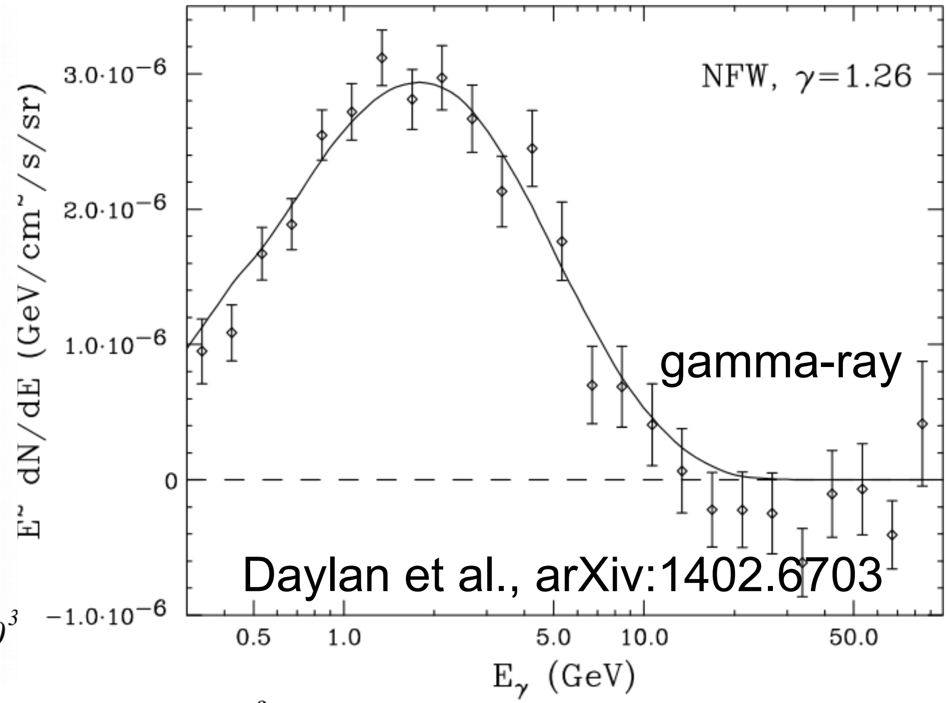
Review of the theoretical and experimental status of dark matter identification with cosmic-ray antideuterons

under review at Physics Reports: arXiv:1505.07785

T. Aramaki[a,b], S. Boggs[c], S. Bufalino[d], L. Dal[e], P. von Doetinchem[f,*], F. Donato[d,g], N. Fornengo[d,g], H. Fuke[h], M. Grefe[i], C. Hailey[a], B. Hamilton[j], A. Ibarra[k], J. Mitchell[l], I. Mognet[m], R.A. Ong[m], R. Pereira[f], K. Perez[n], A. Putze[o,p], A. Raklev[e], P. Salati[o], M. Sasaki[l], G. Tarle[q], A. Urbano[r], A. Vittino[d,g], S. Wild[k], W. Xue[s], K. Yoshimura[t]

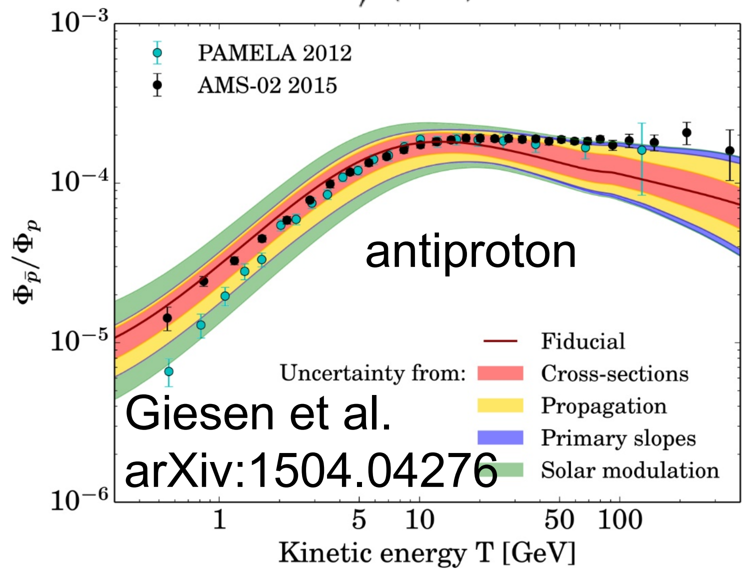
Dark matter signal in cosmic rays?



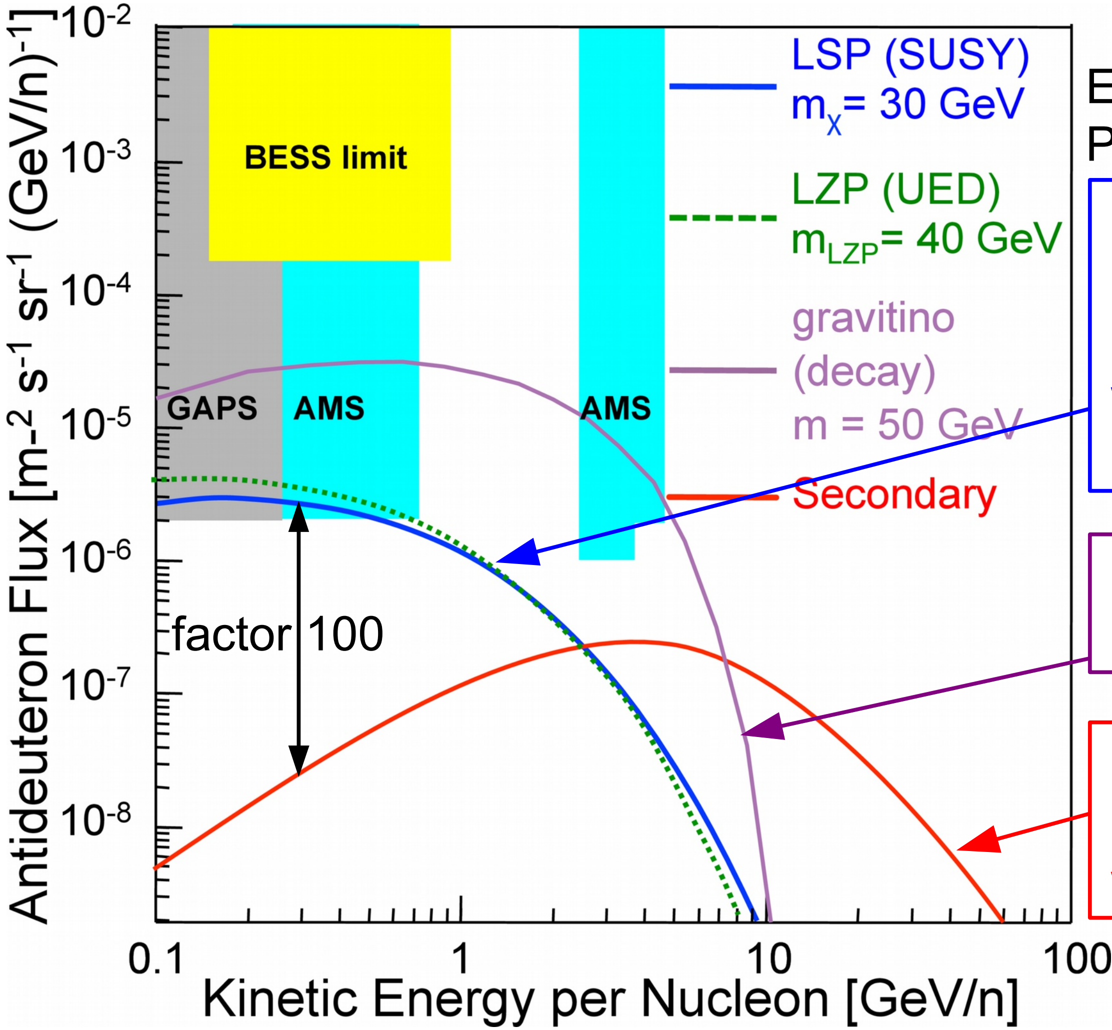


- unexplained features in positrons
- proposed theories:
  - astrophysical origin → pulsars
  - SNR acceleration
  - **dark matter self-annihilation**
- gamma-ray excess at the galactic center → 30GeV dark matter particle?

- **No (?) excess for antiprotons → inconclusive**



Status of cosmic ray antideuterons



Examples for beyond-standard-model Physics:

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

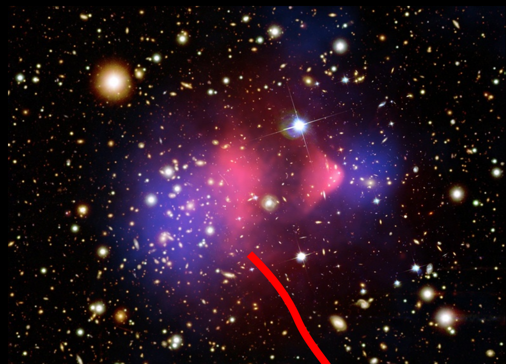
late decays of unstable gravitinos
→ Timur Delahaye

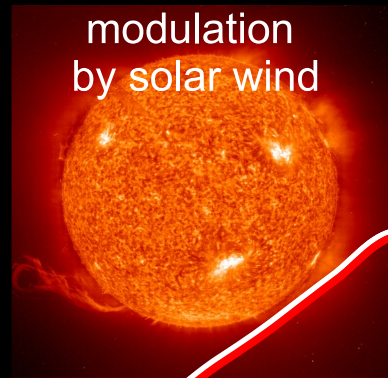
astrophysical background:
collisions of protons and antiprotons with interstellar medium

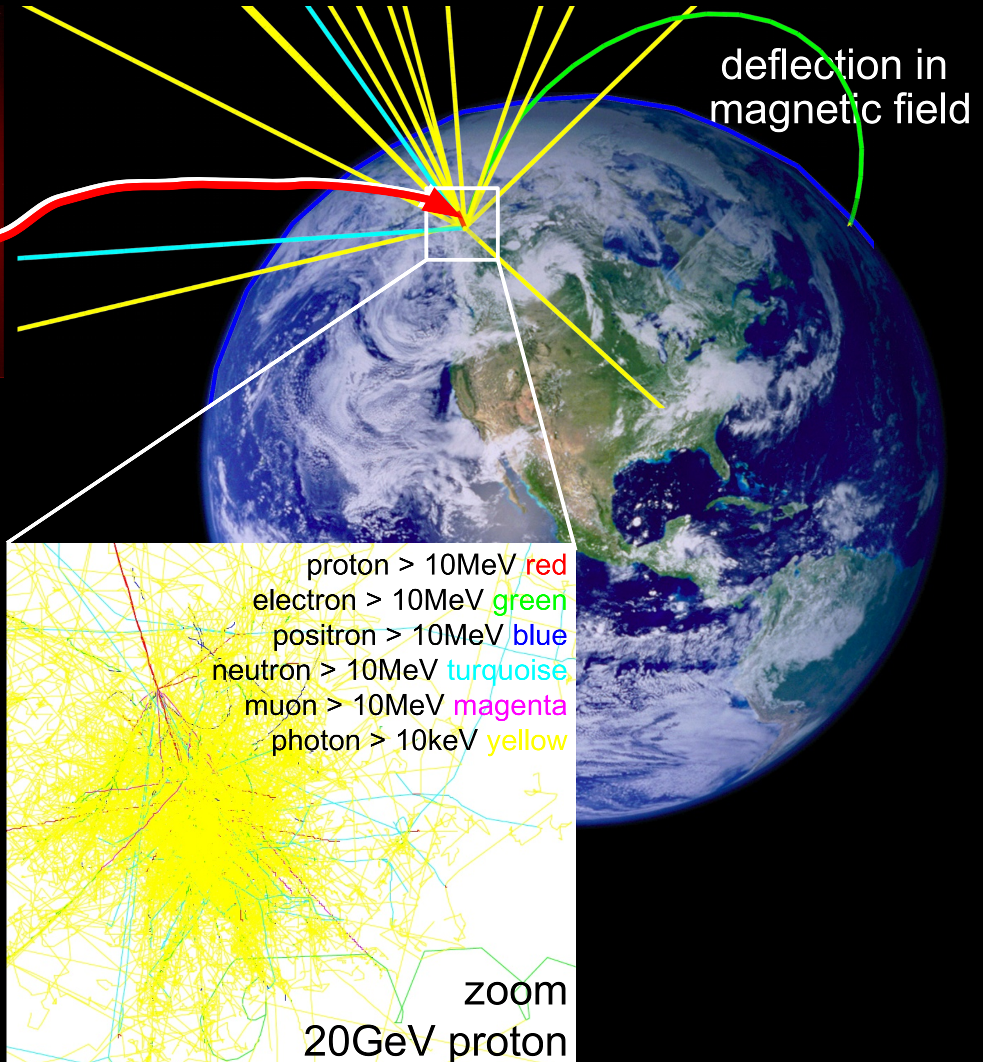
+ models with heavy dark matter

Antideuterons are the most important unexplored indirect detection technique!

Uncertainties

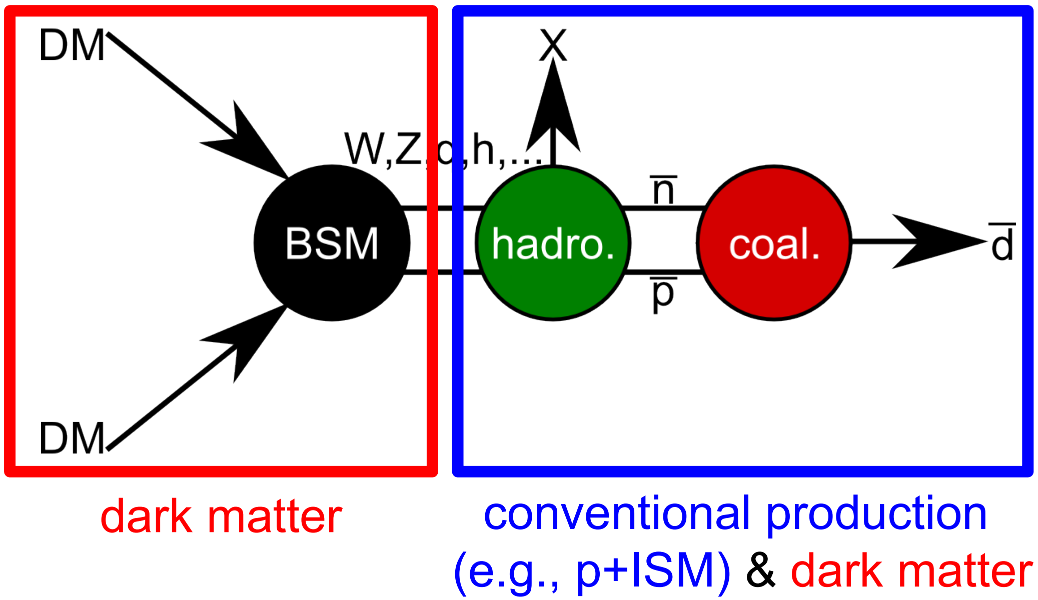


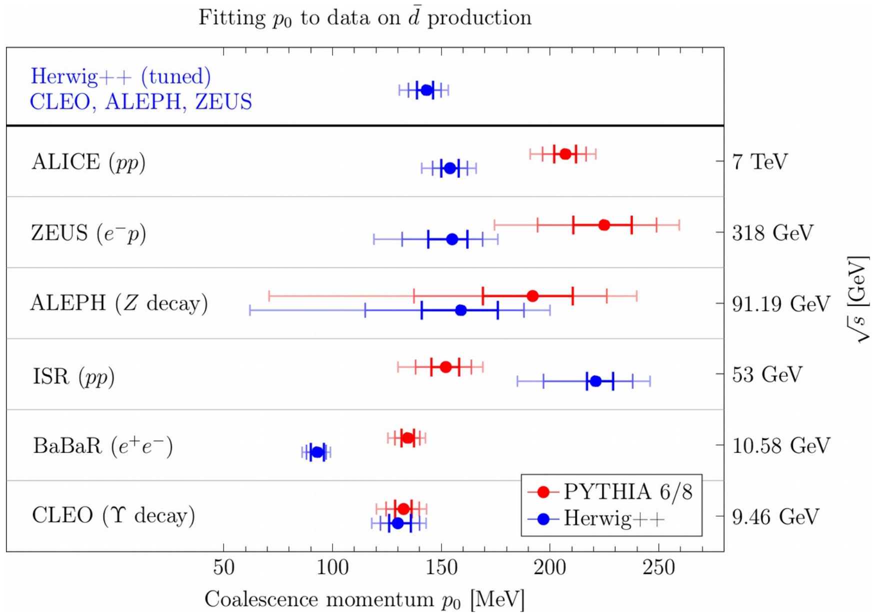




- Dark matter annihilation or decay
- Dark matter clumping
- **Antideuteron production**
- **Galactic propagation**
- Solar modulation
- **Geomagnetic deflection**
- Atmospheric interactions
- Interactions in detector

Antideuteron formation



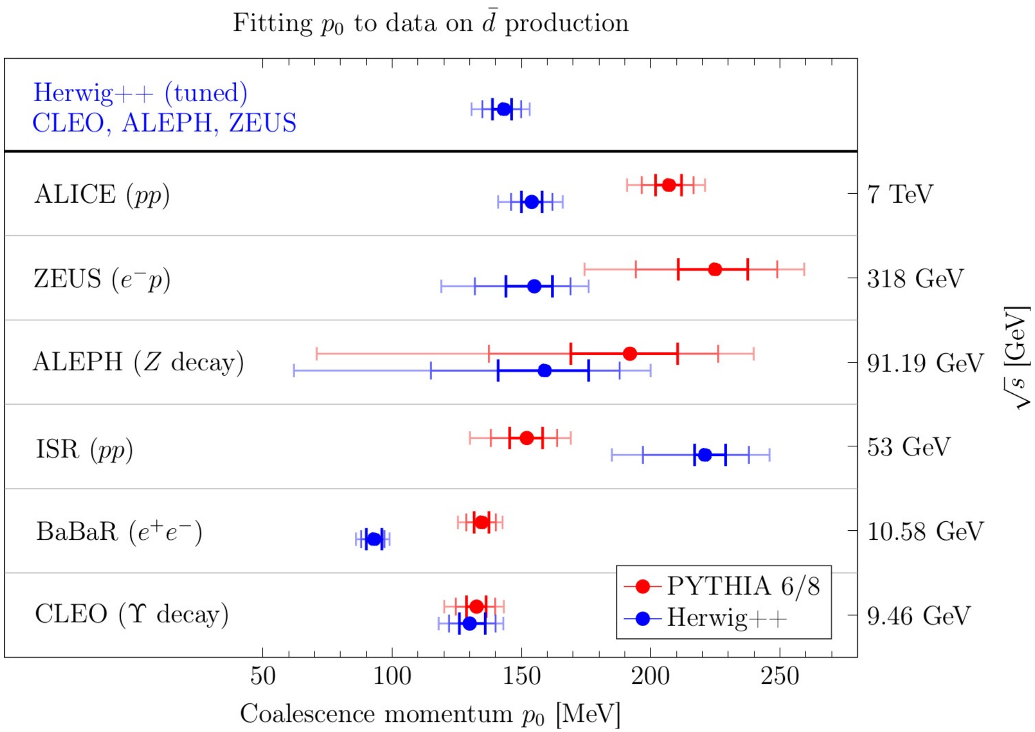


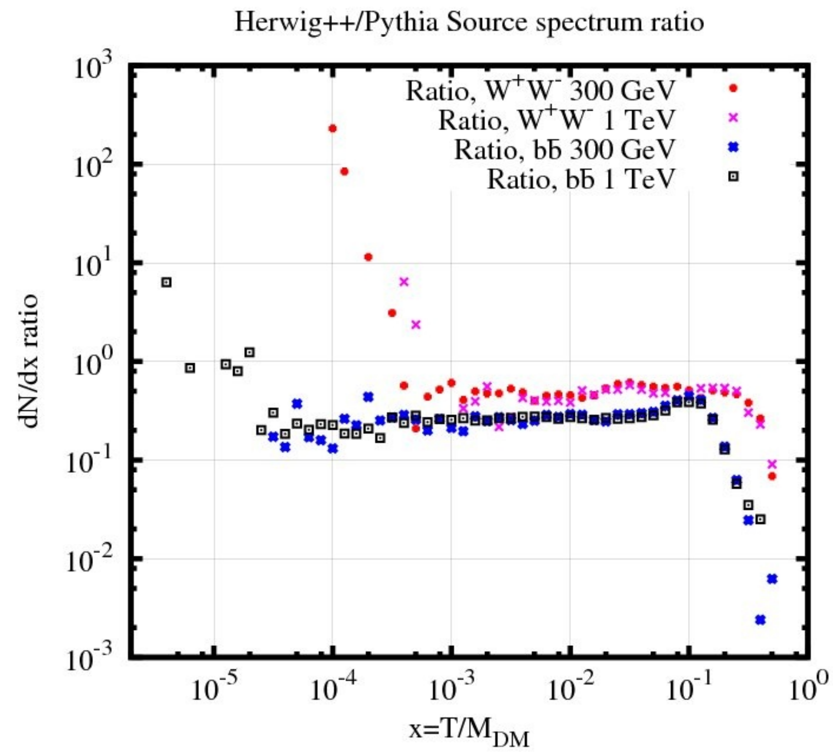
- antideuterons can be formed by an antiproton-antineutron pair if relative momentum is small (coalescence momentum p_0)

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

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

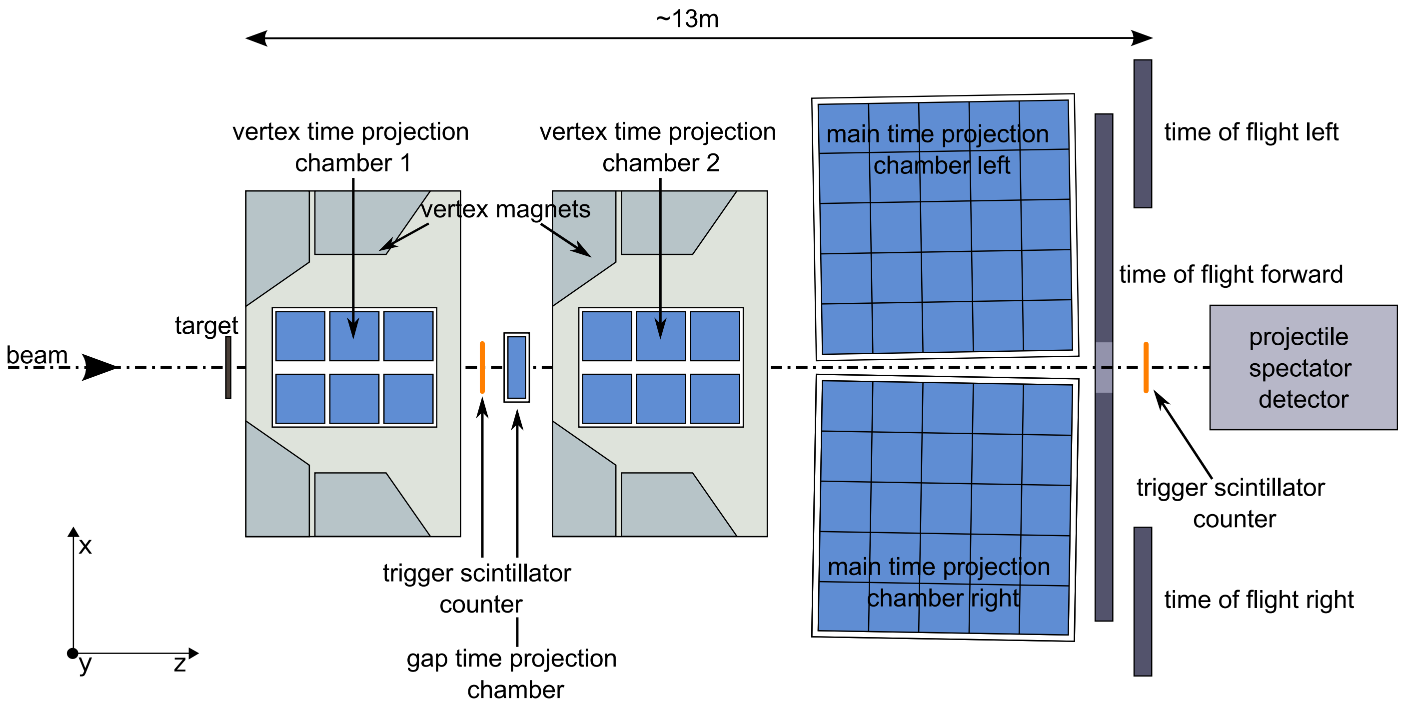
Coalescence uncertainty





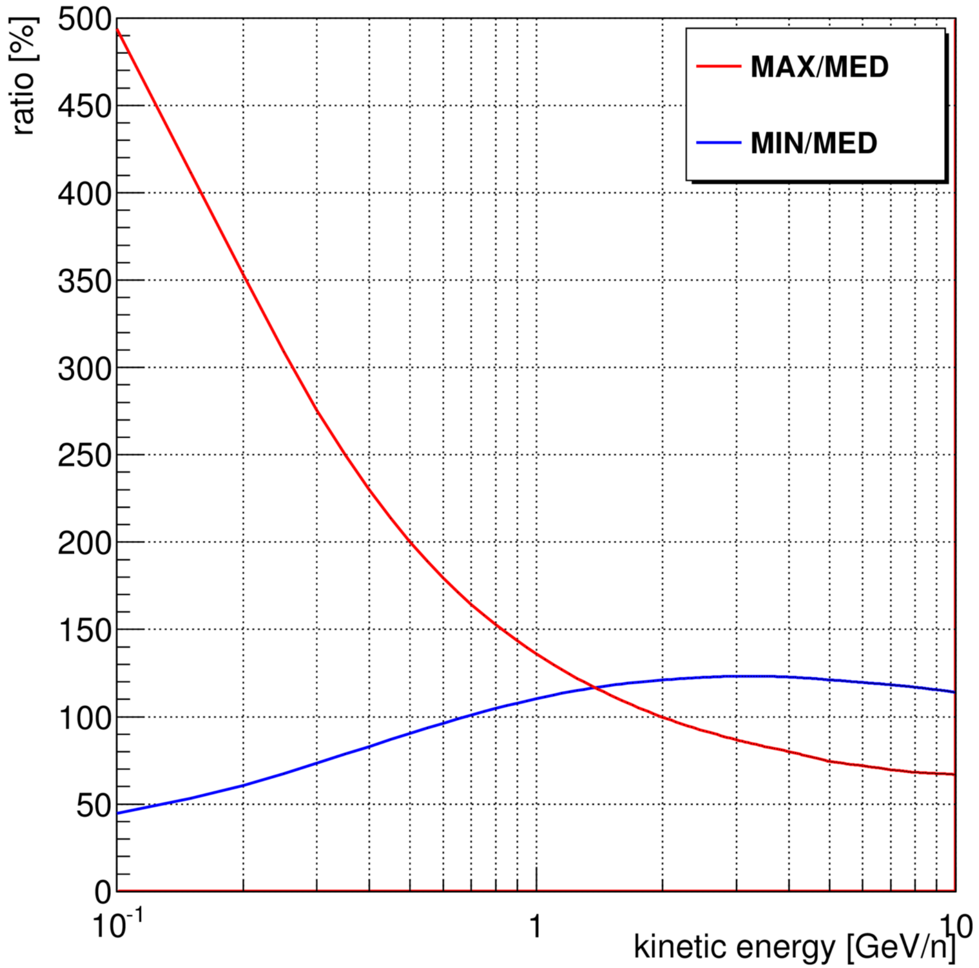
- improvement during the last years using tools like Pythia and Herwig for hadronization:
  - produce antiprotons and antineutrons
  - respect jet structure
  - antiproton and antineutron have to be close in space and momentum space

Antideuterons and NA61/SHINE



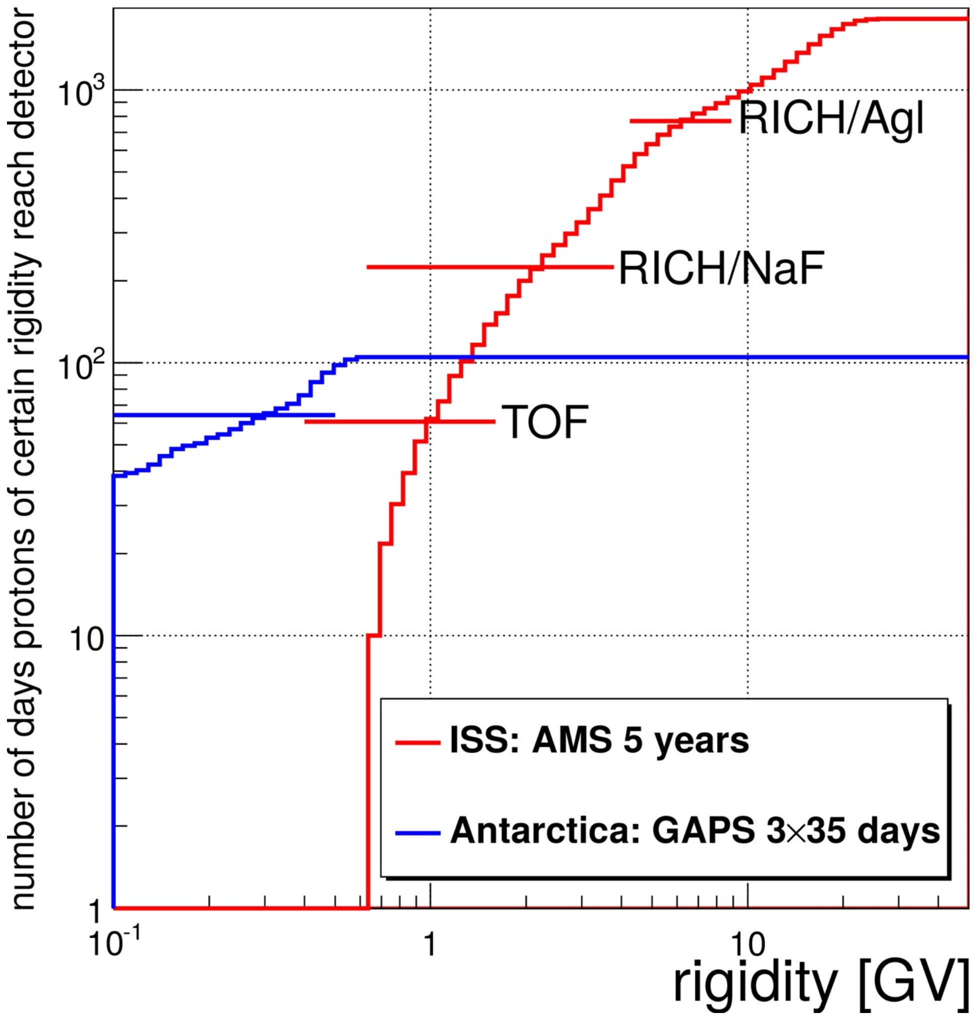
- Fixed target experiment: main motivation is QCD phase transition, but NA61 also has “customers“ from the UHECR and neutrino community
- Cosmic-ray production happens between 40 and 400 GeV
  → SPS energies from 9 to 400 GeV are ideal
- proton-proton interactions with incident momentum between 13 and 158 GeV/c were already recorded in 2011
- 350GeV *p*-*p* run this fall → now

Propagation uncertainty



- Propagation is a large uncertainty source for low-energy antideuterons: **halo size for diffusion calculation is poorly constrained**
- More data on different cosmic nuclei are needed (and hope that they do not need more complicated modeling for interpretation!)

Geomagnetic cutoff



- Simulations with IGRF geomagnetic field and Tsyganenko 2001 magnetosphere

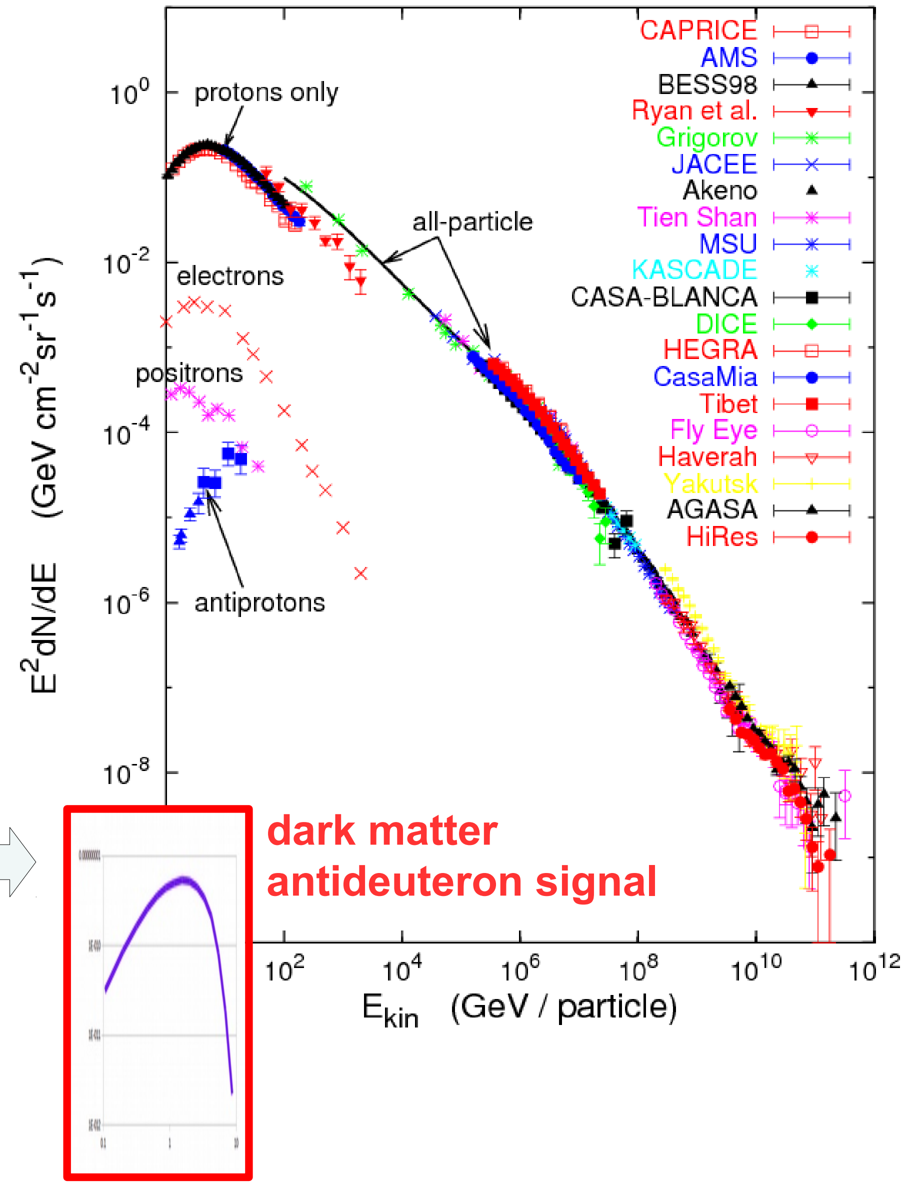
Identification challenge

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

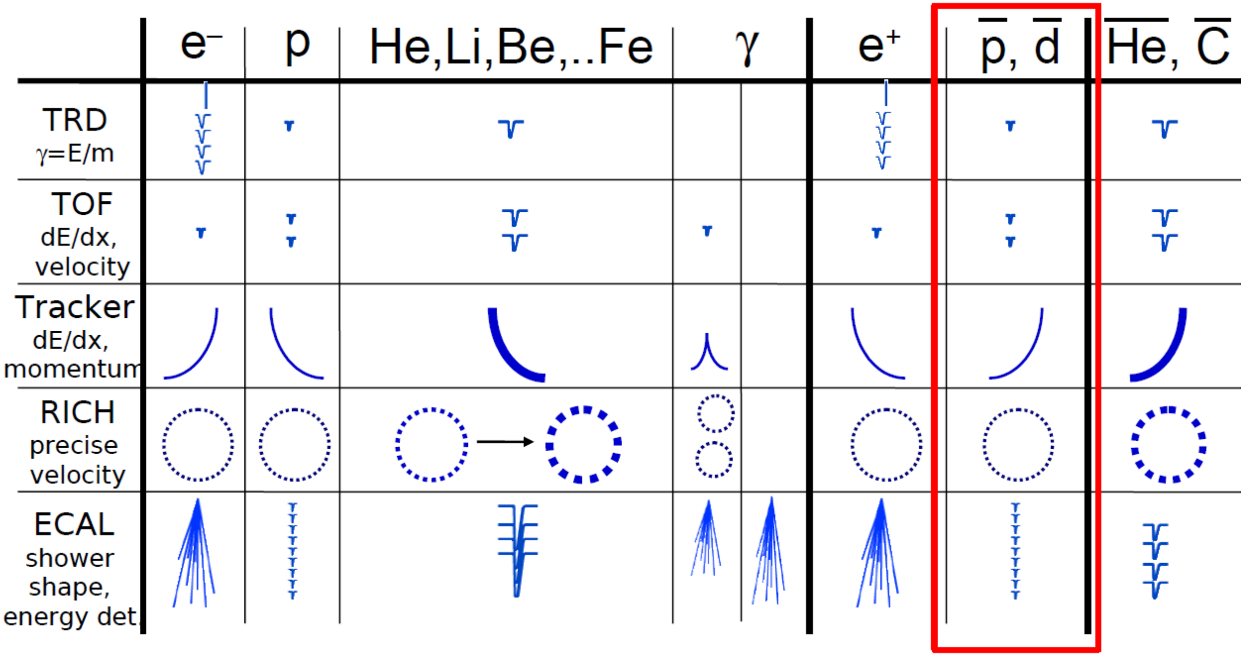
Antideuteron measurement with balloon and space experiments require:

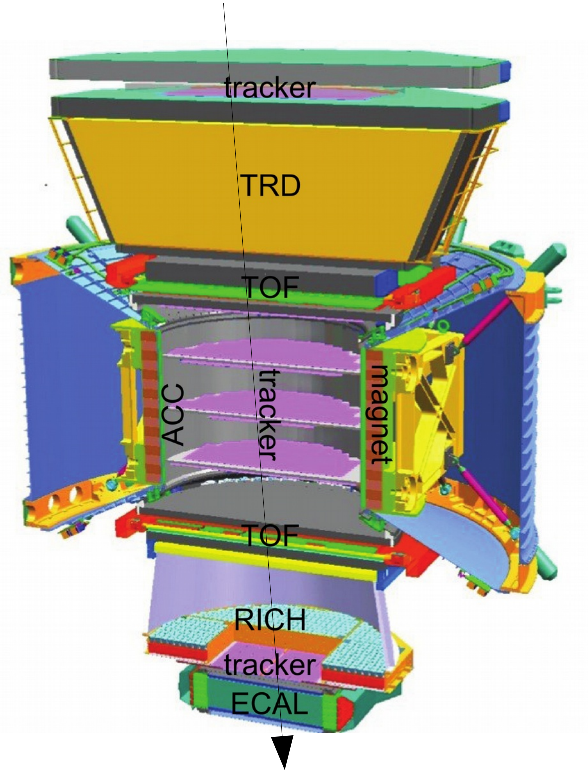
- **strong background suppression**
- **long flight time and large acceptance**



dark matter antideuteron signal

AMS-02 antideuteron analysis





- **Operating on the ISS since 2011**
- **antideuteron identification:**
  - –lower velocities: **T**ime **O**f **F**light scintillator system
  - –higher velocities: **R**ing **I**mage **Ch**erenkov detector

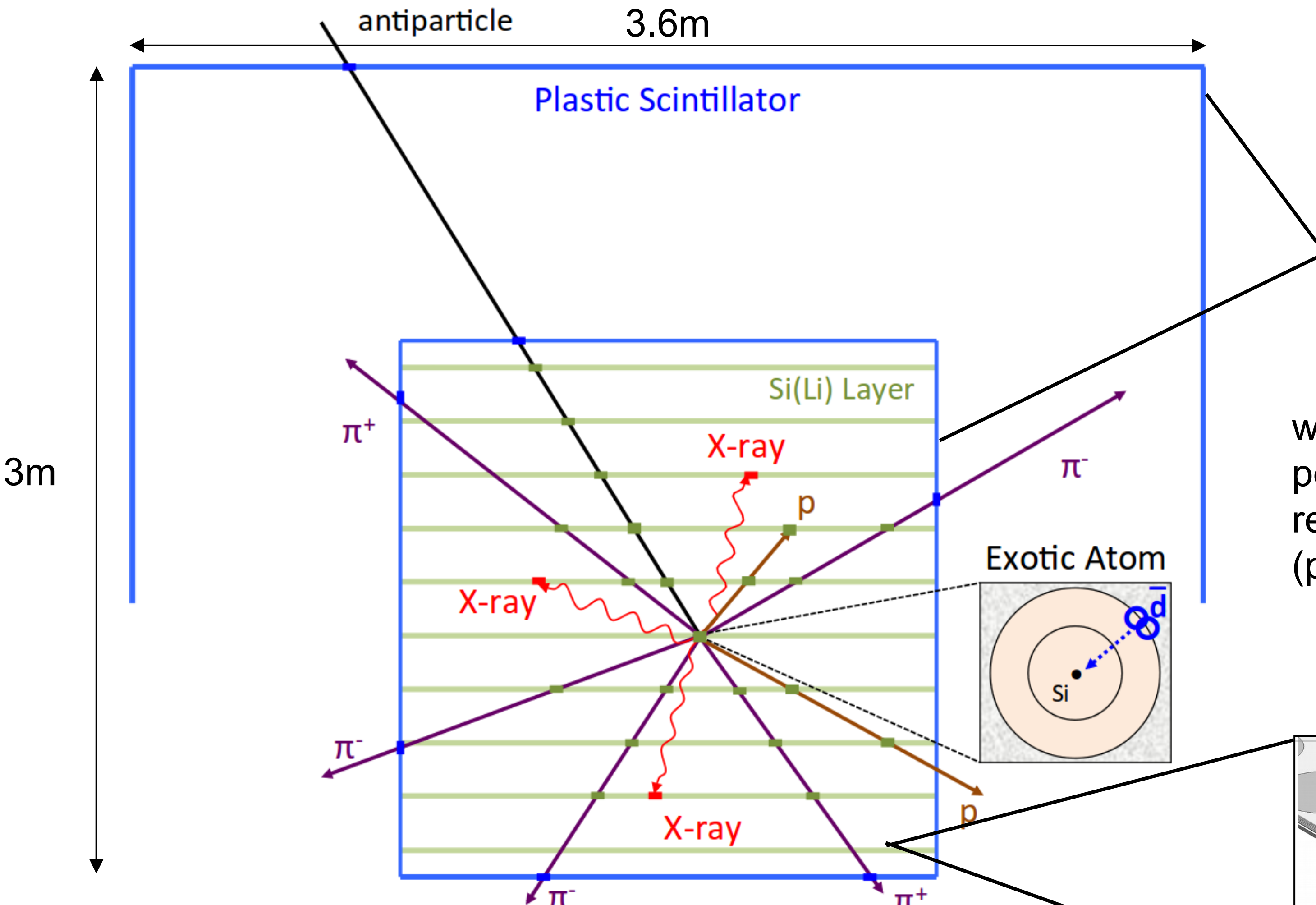
$$m = R \cdot Z \sqrt{\frac{1}{\beta^2} - 1}$$

- **self-calibrated analysis:**
  - –calibrate antideuteron analysis with deuterons and antiprotons (simulations and data)
  - –geomagnetic cut-off and solar effects: study much more abundant low-energy protons, antiprotons, and deuterons for calibration

Analysis ongoing!

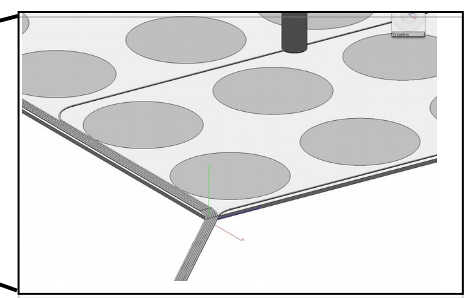
The GAPS experiment

Columbia U, UC Berkeley
UCLA, U Hawaii,
Haverford



plastic scintillators
with PMT readout

weight: 1700kg
power: 1.4kW
readout: ~100mW/ch
(preamp: ~15mW/ch)

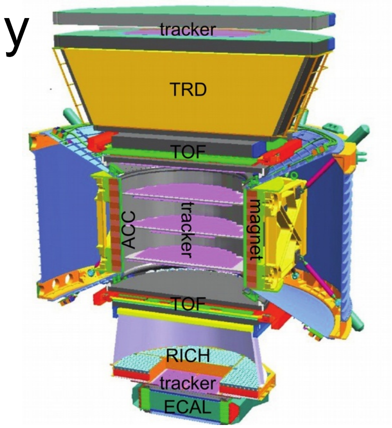


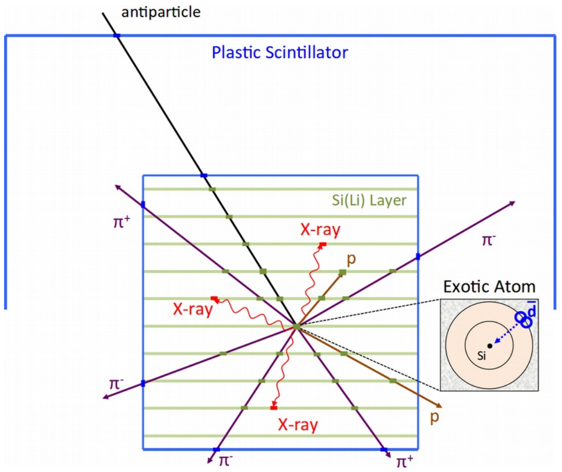
~1400 Si(Li) wafers

- the **G**eneral **A**nti**P**article **S**pectrometer is especially designed for **low-energy antideuterons and antiprotons**
- identification by stopping and creation of an exotic atom [KEK testbeam measurements → Astropart. Phys. 49, 52 (2013)]
- **all prototyping is done**
- LDB flights from Antarctica proposed

Complementarity

- antideuteron search is experimentally challenging
  → multiple experiments for cross-checks are very important





- AMS-02 and GAPS have very different event signatures AND very different backgrounds
  → very good for independent confirmation
  (see also direct dark matter searches with different approaches)

- two indepenent flight trajectories → different geomagnetic cut-off locations
  - ISS is at a maximum of ±52deg
  - GAPS would fly at ~-80deg

- **low-energy antiproton flux measurement will be the most important cross-check between AMS-02 and GAPS**

Conclusion

- measurement of antideuterons is a promising way for indirect dark matter search
- AMS on the ISS is currently the best instrument for the study of antideuterons
- future GAPS is specifically designed for low-energetic antideuterons
- more exchange between theory and experiments:
  We started a bigger community effort last year!