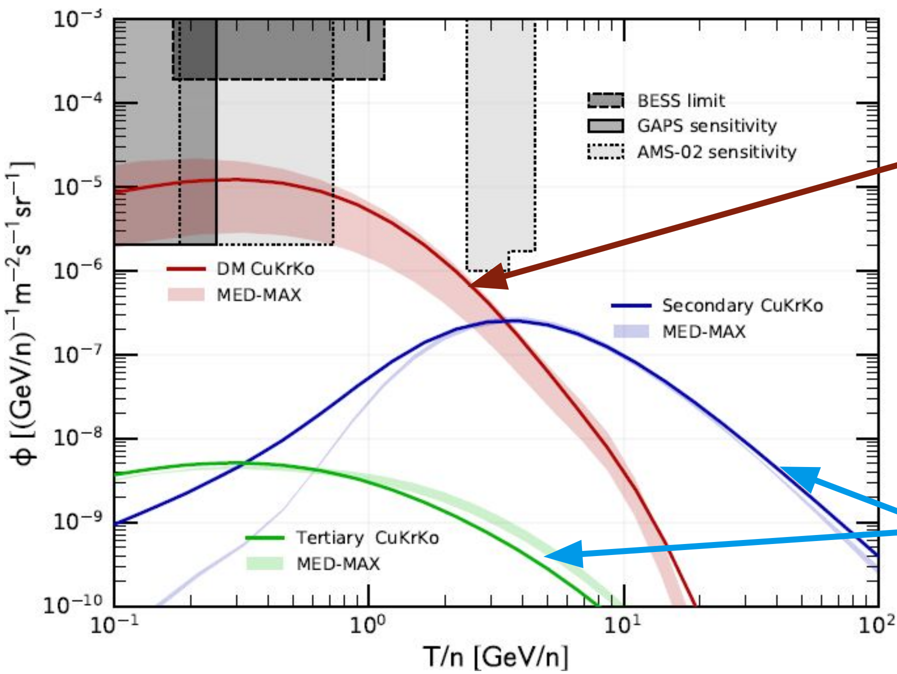
Status of the GAPS simulation and analysis development

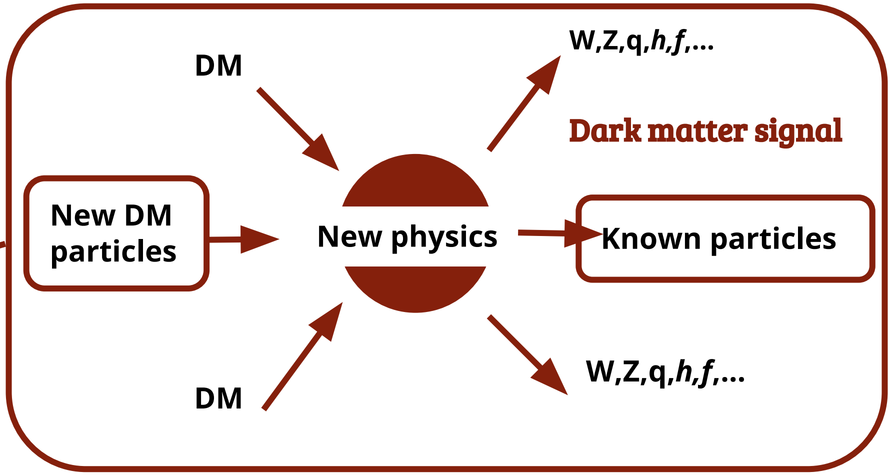
Achim Stoessl for the GAPS collaboration
dbar19, Los Angeles
Thursday, 03/28/2019

Anti deuterons as probes for DM

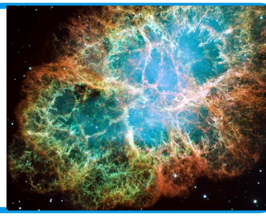
Anti deuteron fluxes



Korsmeier et al,, 2017 arXiv:1711.08465,



Cosmic ray interaction with interstellar medium



assumption: cosmic-rays from dark matter annihilation follow different kinematics than conventional production

➤ peak/bump/shoulder on top of conventional spectrum

➤ GAPS sensitive energies ~20 MeV - 230 MeV/n

Anti-deuteron search channel benefits from extremely low conventional production!

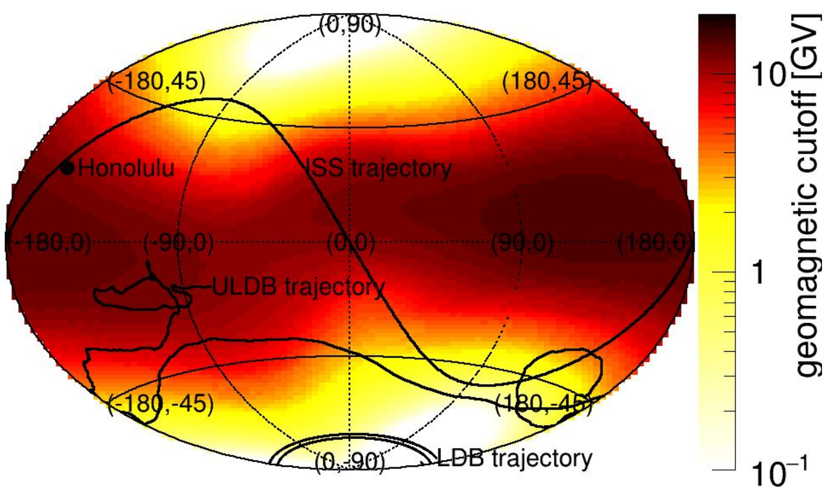
How to measure a $\bar{d}$ flux?

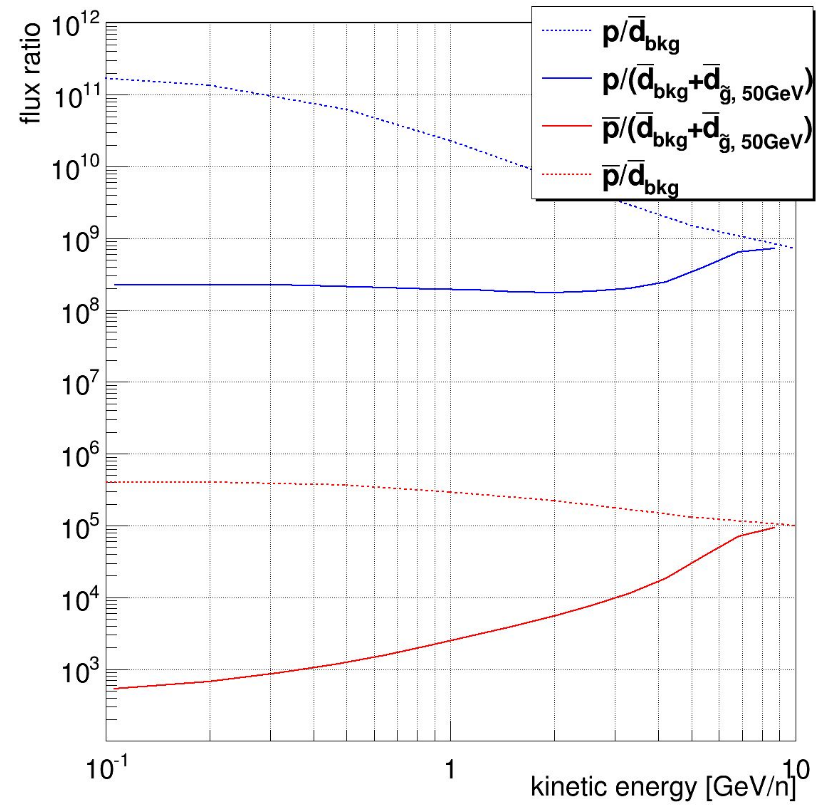
Long duration flight planned from McMurdo Station, Antarctica

High latitude ➤ low geomagnetic cut-off

Input from Simulation needed to model Exotic atom X-rays & hadronic interactions

Rare event search: Rejection power of 10^4 for antiprotons and 10^{10} for protons required





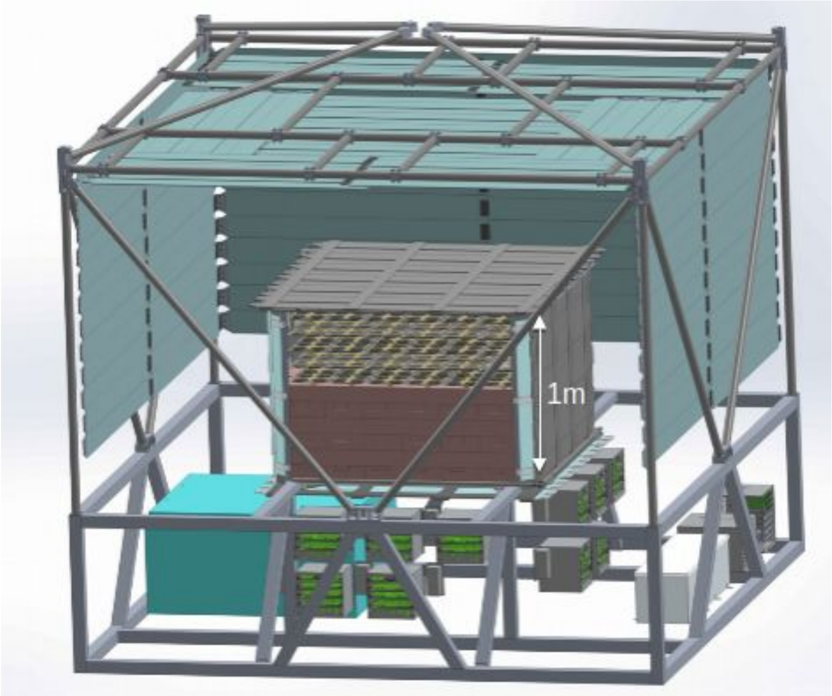
particle/anti-deuteron flux ratios

GAPS - experimental setup

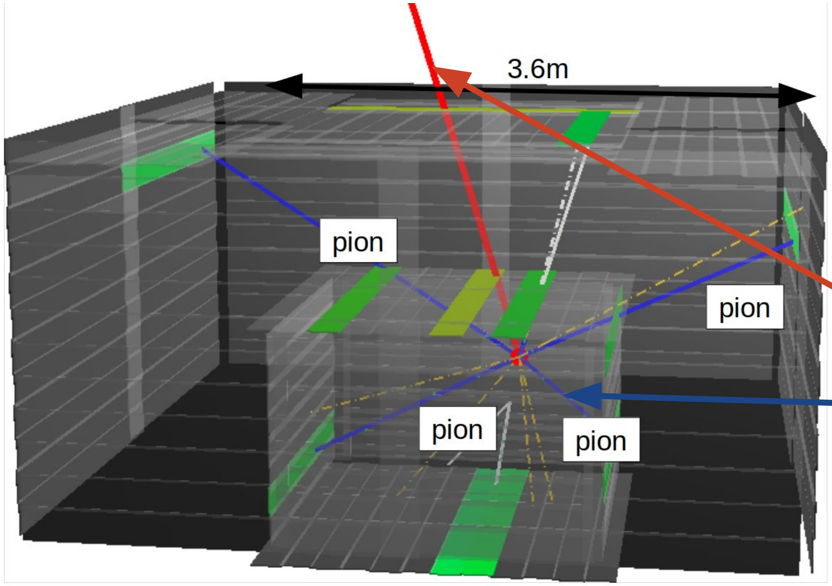
Balloon-borne experiment with Si(LI) tracker and time-of-flight system

Total acceptancance ~25m^2
(trigger on 1 cube + 1 umbrella hit)

➤ See S. Quinn's talk



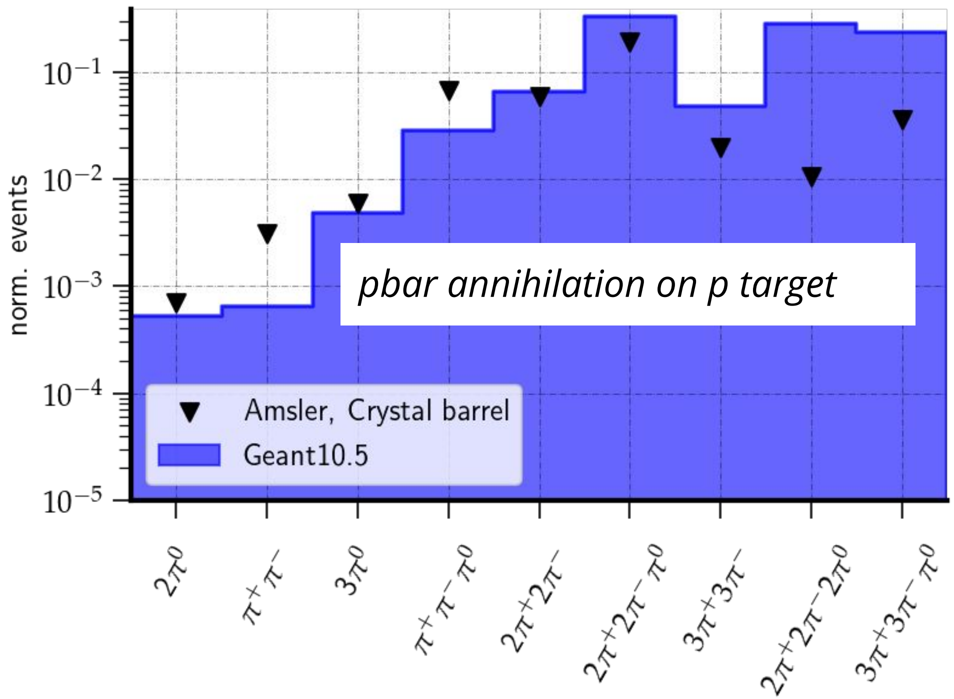
GAPS detector assembly



Red: antideuteron primary
Blue: secondary pions from annihilation star
Dashed: leptons

Well reconstructable antideuteron
4 pion event, with well reconstructable tracks

Hadronic annihilation products

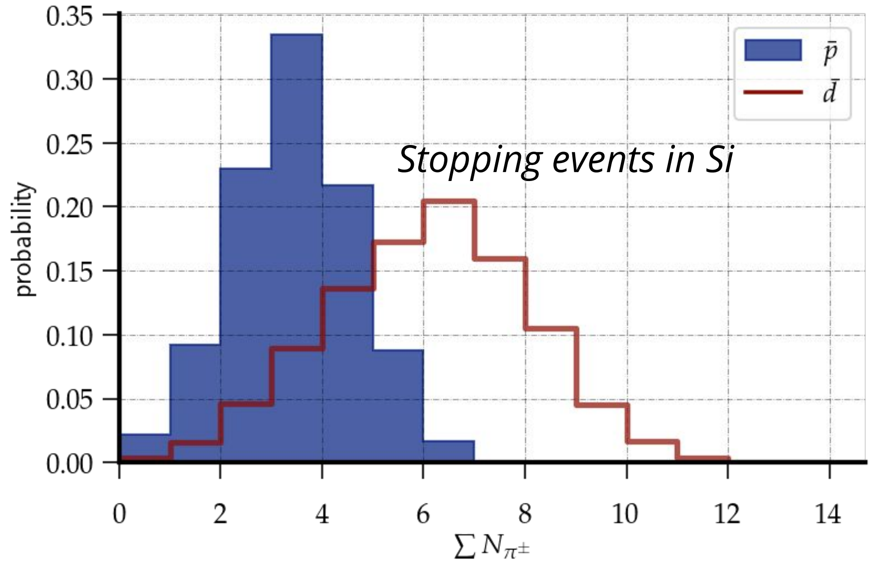


Studying final states of annihilation with Geant4 - validation with pbar data at rest

➢ close collaboration with Geant4 developers

Some fixes already included in Geant10.5

Some channels already in good agreement, others need more work, integrated distributions look as expected

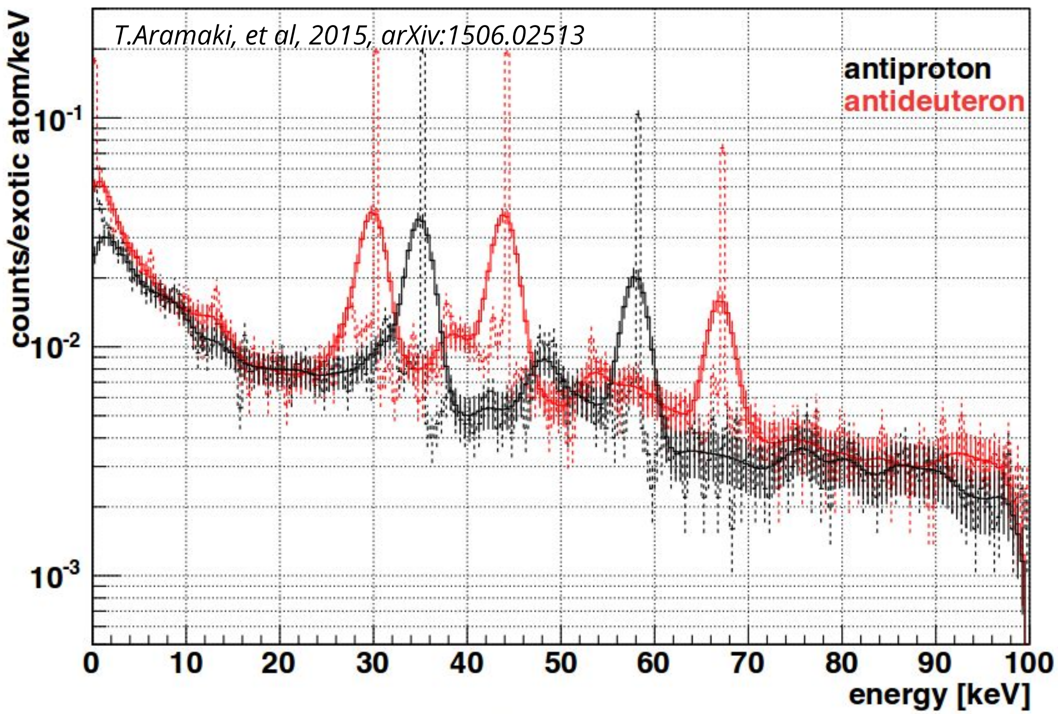


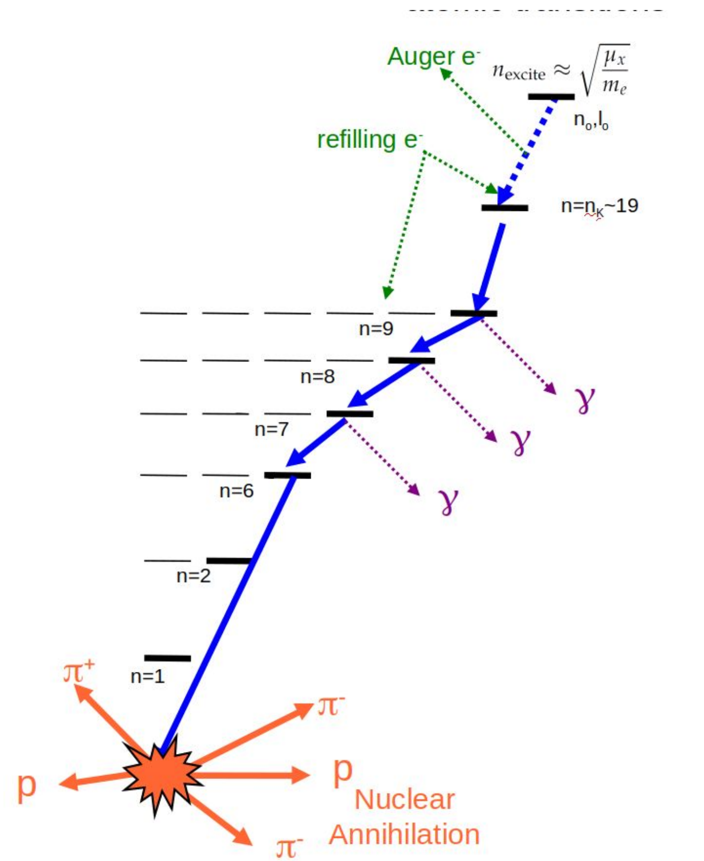
Total number of charged pions independent of individual channel, Si-pbar/Si-dbar interactions at rest.

Larger nuclei expected to produce more pions.

Simulation of hadronic annihilation processes under control! ✓

Characteristic X-rays





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

At rest annihilation: Nucleus can capture anti-nucleus, similar to muonic atom

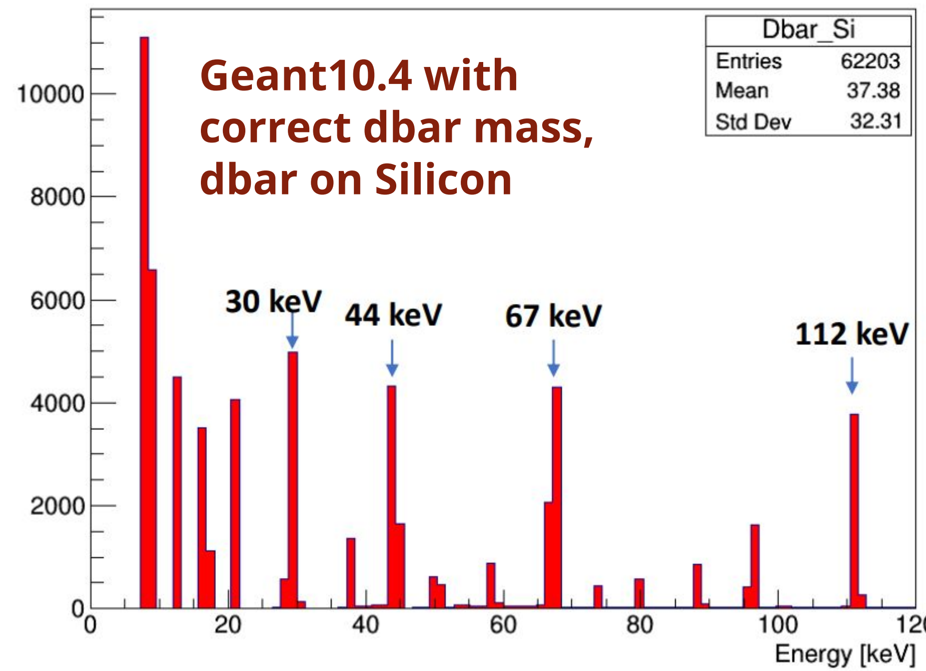
Characteristic cascade of X-rays

Characteristic X-rays

Ongoing efforts to implement predicted X-ray spectrum from exotic atoms in Geant4

Previously: all exotic atoms were treated as muonic atoms

- ➢ First step - implement correct mass ✓
- ➢ Second step - adjust the yields (ongoing)



X-ray simulation (almost) under control! ✓

Event reconstruction

Reconstruction methods under active development, multiple methods available for track fitting and vertex finding

In general multi-step process:

➢ First try to reconstruct primary Track

➢ Iteratively add hits and find the interaction Vertex

➢ Quality parameters available to assess reconstruction quality

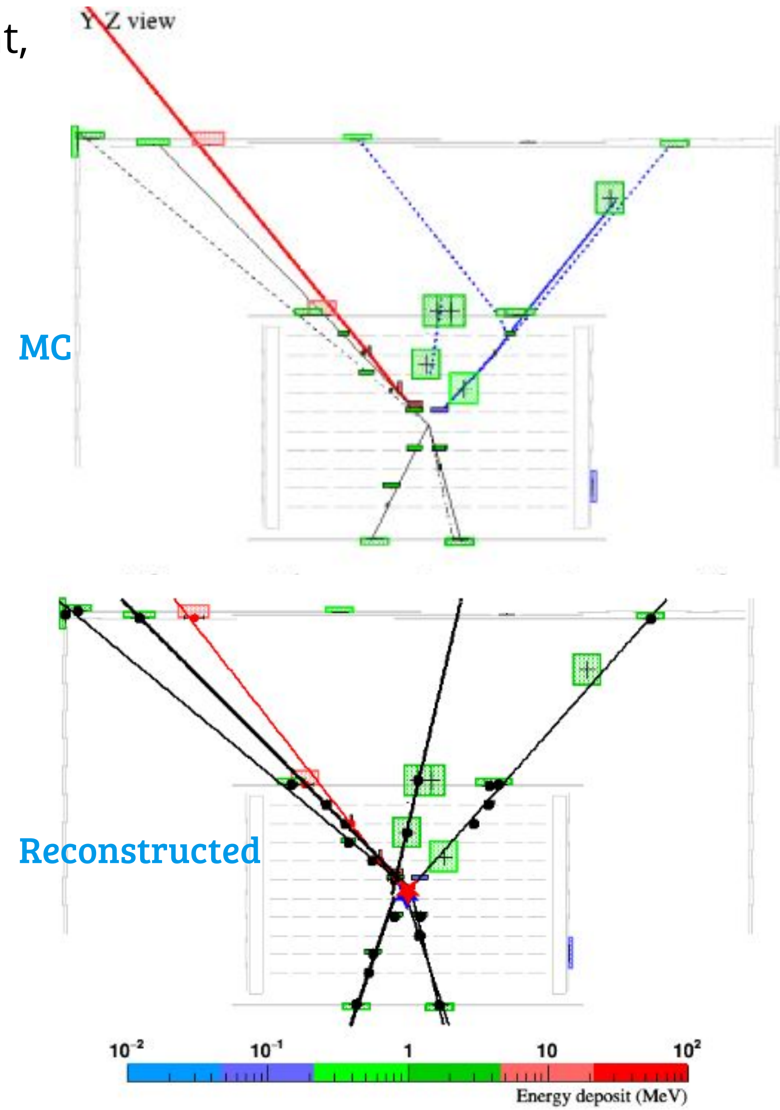
<u>Example Event</u>

Dbar Event with beta = 0.35

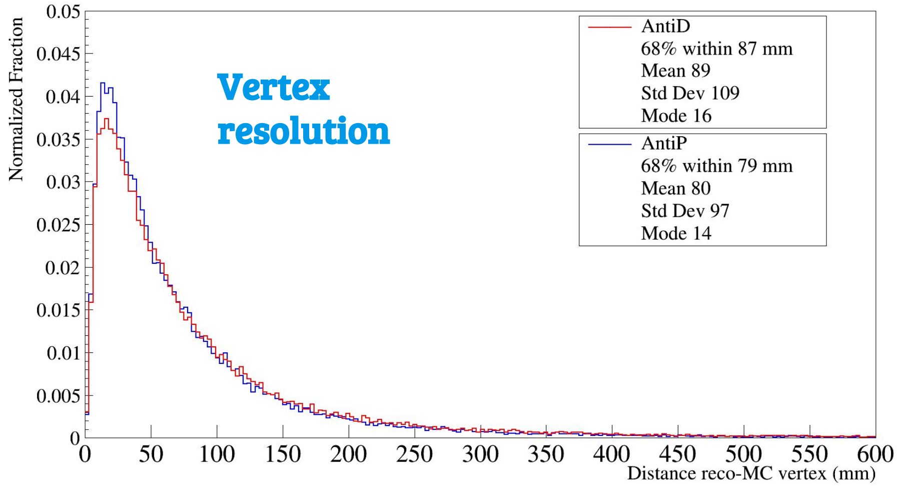
Emulating digitization by smearing the true Mc values with Gaussians with expected resolution

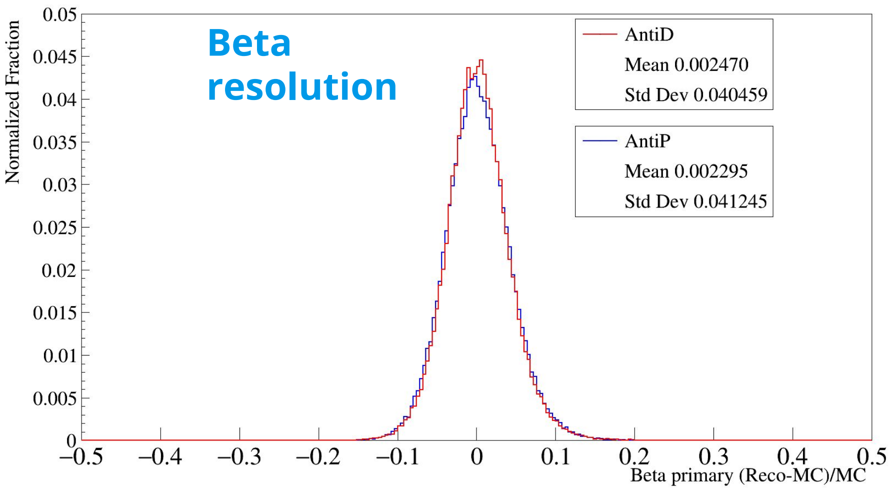
➢ Use smeared values for reconstruction

Reconstruct primary mainly with TOF information, reconstruction in tracker utilizes Hough transform methods.



Event reconstruction





Vertex reconstructed for annihilation events within 8 cm

Velocity reconstruction uses TOF timestamps

TOF timing resolution ~400ps

Velocity reconstruction within 4% for primary track, resolution incorporates TOF timing resolution (~400ps) and spatial resolution due to extension of the TOF paddles.

➤ **accurate velocity reconstruction is crucial for identification analysis**

Reconstruction under control! ✓
(will get included in analysis soon)

Event discrimination

Discirimination categories

particle/antiparticle discrimination

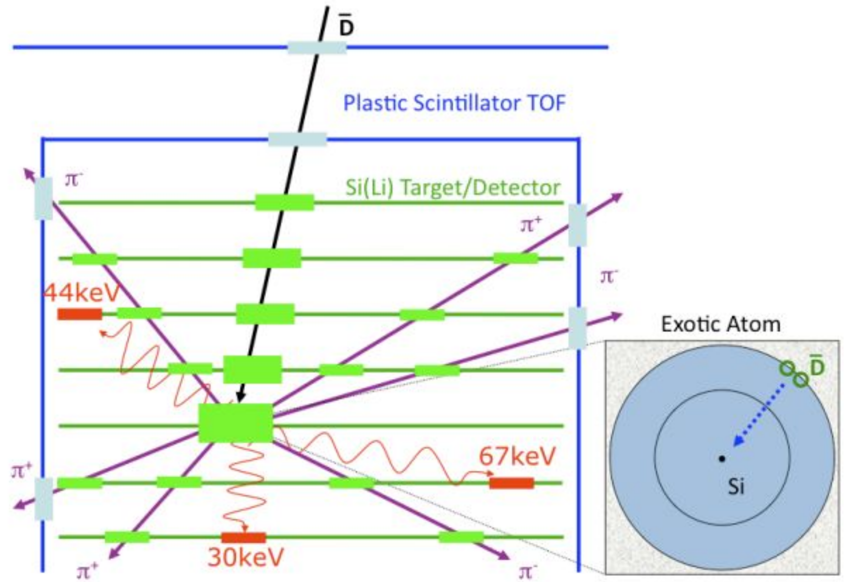
Interaction characteristics

- number of tracks from vertex
- total hits
- characteristic X-rays
- energy deposition within sphere around vertex

charge/mass discrimination

Primary track characteristics:

- penetration depth
- column density
- total energy deposition on primary track



T.Aramaki, et al, 2015, arXiv:1506.02513

Track characteristics depend strongly on beta
➤ investigate every variable in dependence of beta

Suppression of proton events

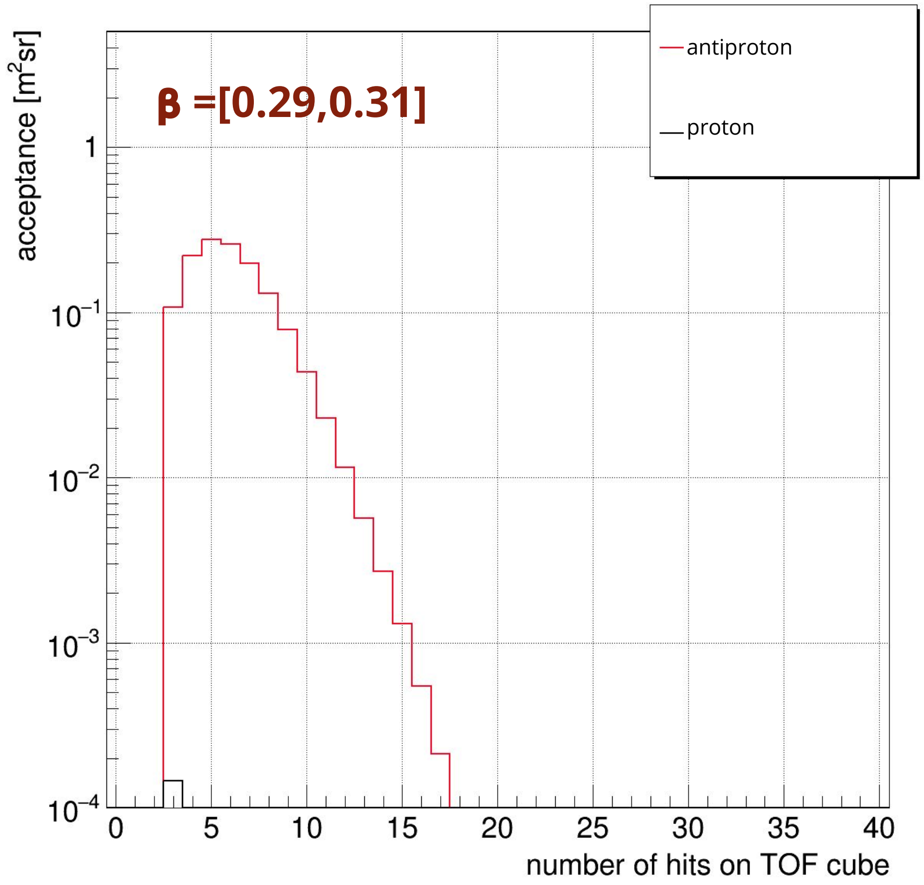
Utilize above discussed particle/antiparticle discriminators

➢ Searching for annihilation stars vs clean tracks

Number of hits on inner TOF correlates very good with number of tracks from interaction vertex

➢ Excellent discrimination, as shown in antiprotons (signal) vs protons (background)

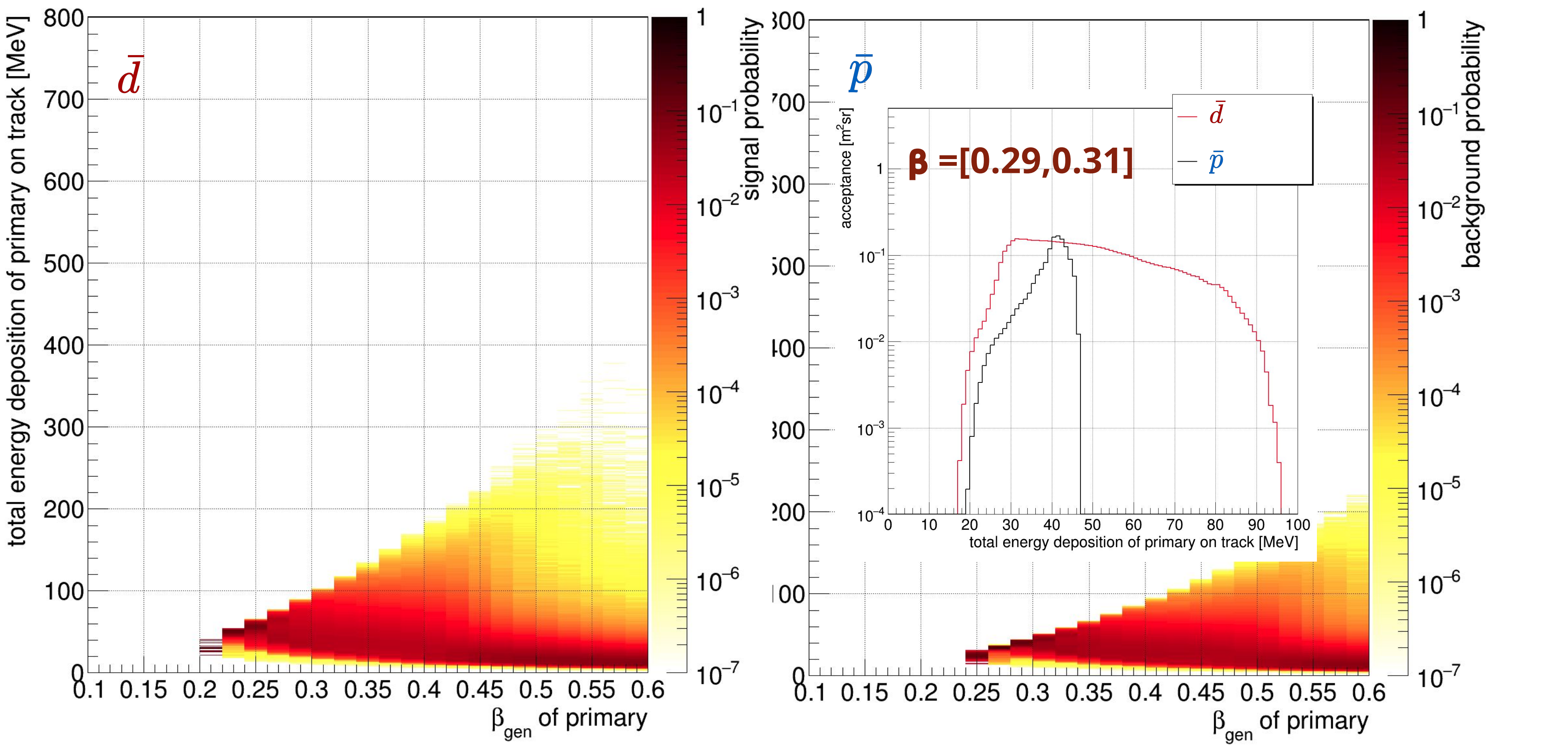
Cutoff at 4 hits due to trigger



Proton background can be suppressed effectively even without any reconstruction

$\bar{p}$ **remain dominant background for** $\bar{d}$ **search**

Energy deposition on primary track

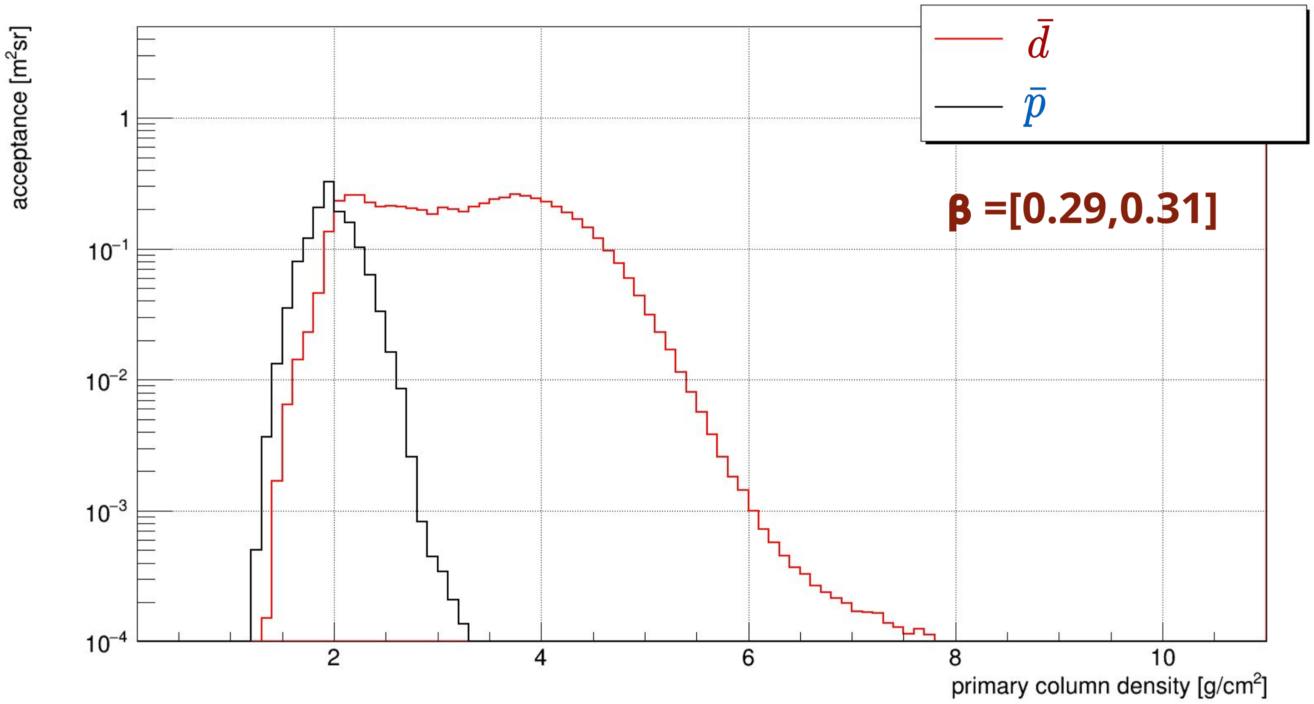


Energy deposition (dE/dx) on primary track - one of the most powerful variables

Can be verified with proton/deuteron with high statistics

Antiprotons expose kinematic cut-off

Primary column density



Integrated column density of material that the primary particle traversed before stopping

Antideuteron requires more material at same beta to get stopped

Can be calibrated with p/d with high precision

Multivariate analysis

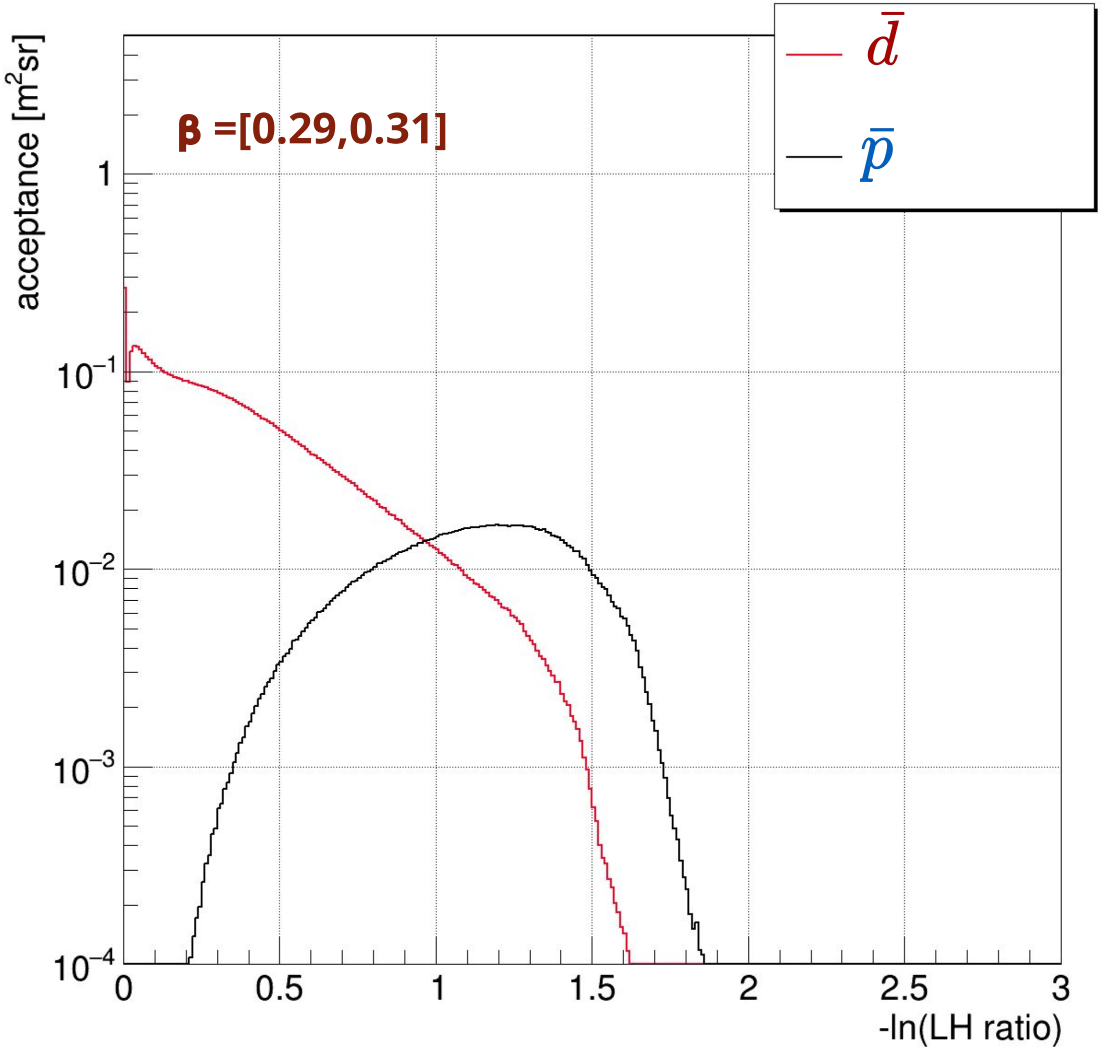
Multiply the pdfs and interpret a s likelihood

$$\mathcal{L}^{\bar{p}/\bar{d}} = \sqrt[n]{\prod_{i}^{n} P_i^{\bar{p}/\bar{d}}}$$

$P_{i:}$: individual pdfs

Calculate classifier as likelihood to be deuteron over the number of all events

$$L = \frac{\mathcal{L}^{\bar{d}}}{\mathcal{L}^{\bar{d}} + \mathcal{L}^{\bar{p}}}$$



Identification acceptance

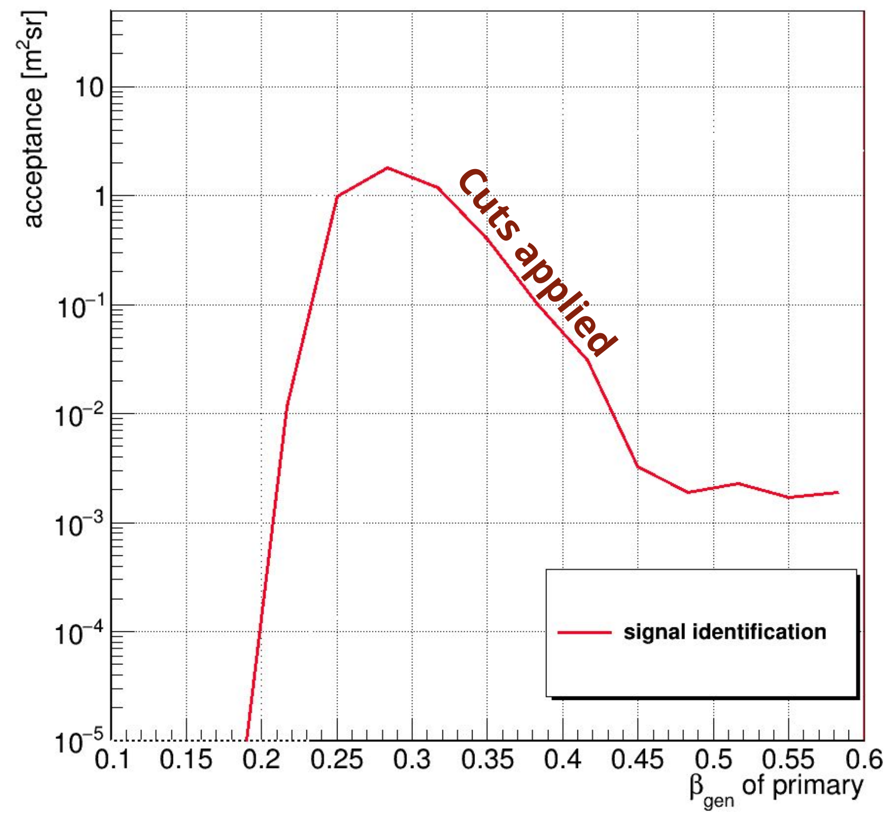
Identification exploits the fact that antideuterons “turn on“ earlier for most of the variables

Acceptance ratio of 10^5 antideuteron/antiproton required in each bin

Transition between stopping events and in-flight annihilation (deep inelastic scattering) is happening at about beta=0.4

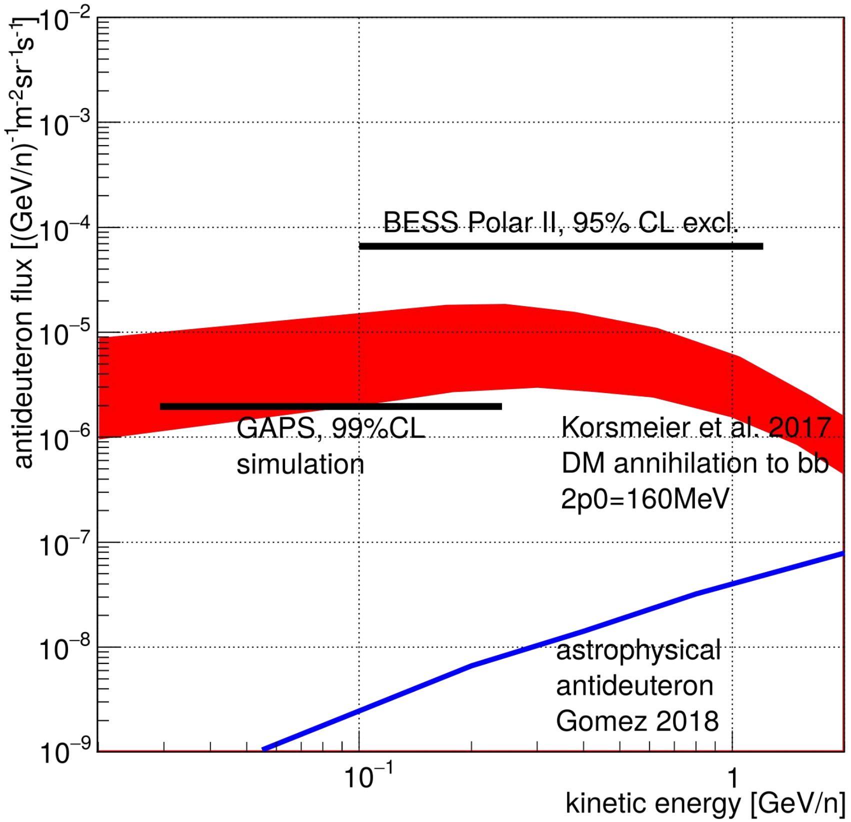
Ongoing:
Identification based on stopping position in the tracker
➤ This can increase identification power significantly by mitigating geometric effects

Use reconstructed quantities



Stopping acceptance vs velocity

$\bar{d}$ - Sensitivity



Kinetic energy range:
20-230MeV/n (top of atmosphere)

Korsmeier et al. flux extrapolated below 100 MeV

Antiproton background evaluated with GALPROP

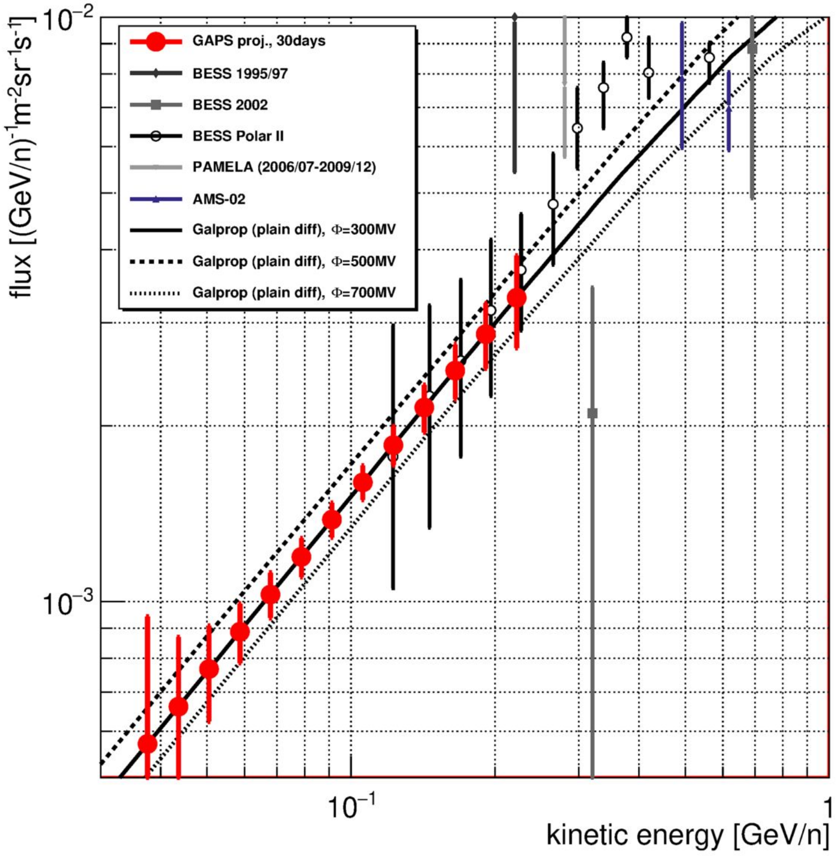
For 30d flight [shown]:
1 dbar is above 3 sigma discovery threshold

Sensitivity: ~$6 \cdot 10^{-6}$(GeV/n m^{2}sr s)$^{-1}$

For 3x30d flight [shown]:
1 dbar is above 3 sigma discovery threshold

Sensitivity: ~$2 \cdot 10^{-6}$(GeV/n m^{2}sr s)$^{-1}$

Measuring the $\bar{p}$-spectrum



Identification technique can be validated using much more abundant protons, deuterons, and antiprotons

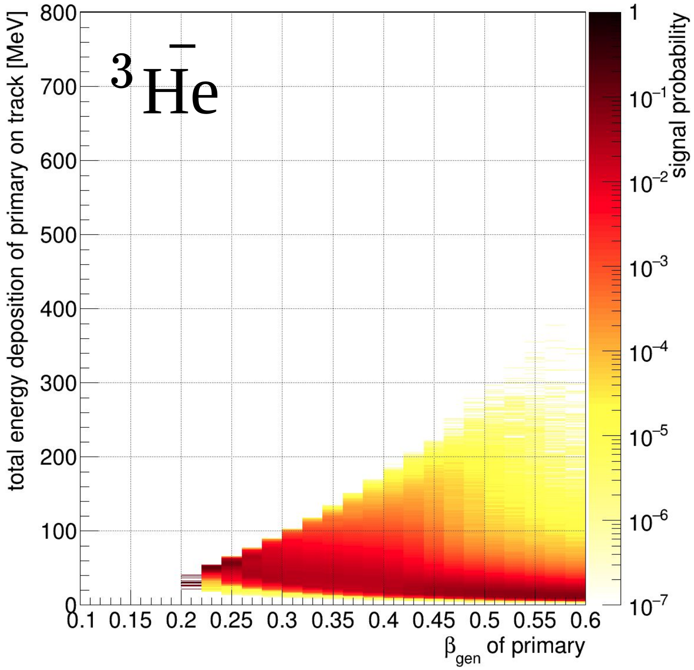
Antiproton search with same technique - protons as singular background.

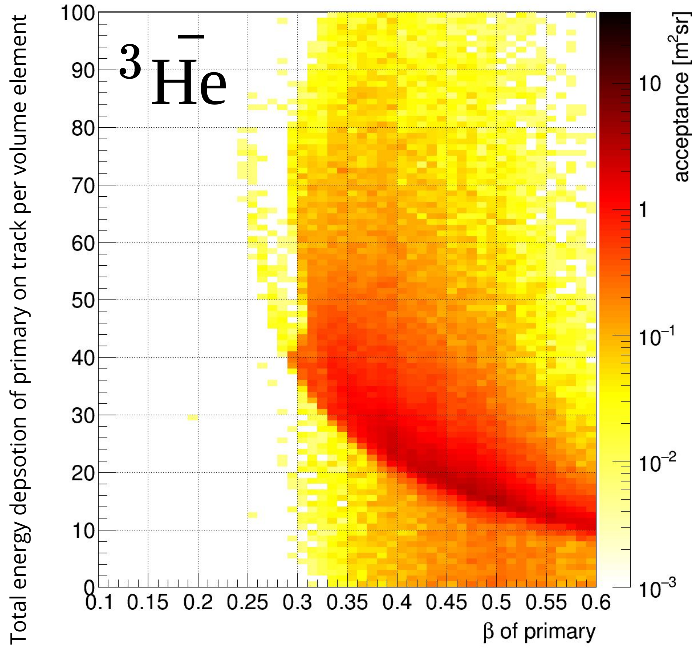
GAPS will detect ~1400 antiprotons per 30 day flight (order of magnitude more than BESS Polar II)

Antiprotons are essential to:

- Validate the identification technique
- Compare with other experiments
- Estimate antideuteron background
- Antiprotons are sensitive to various DM models: Neutralinos, LZP Gravitinos, primordial black holes

$^3\overline{\mathrm{He}}$ capabilities





$^3\overline{\mathrm{He}}$ "Hot topic" - AMS-02 reports on candidates [*see talk by Alberto Oliva*], however $\bar{d}$ missing yet (as predicted by coalescence models)

$^3\overline{\mathrm{He}}$ identification similar to $\bar{d}$ identification, with $\bar{d}$, & $\bar{p}$ as dominant background

Challenge for GAPS:
High individual energy deposition in the tracker (up to 100 MeV) - high dynamic range required (X-Rays in keV regime!) - GAPS ASIC can do it.

Summary

Most simulation challenges under control ✓

Working reconstruction ✓

Variables for discrimination of antideuteron/antiproton provide large enough rejection power ✓

Prospect of very competitive antideuteron limit

High statistics, low energy antiproton measurement expected

Exploring He3 capabilities

Thank you!