Exploring a New Anti-Deuteron Detection Signature in Cosmic Rays Using Plastic Scintillators

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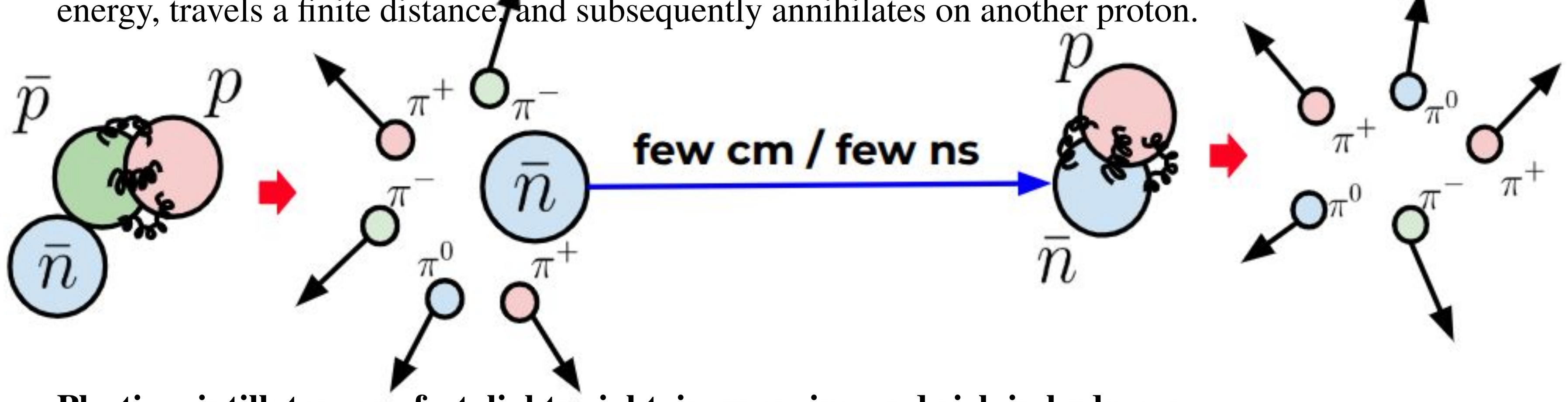
a new signature for antideuterons in hydrogen-rich target

The search for low-energy antideuterons in cosmic rays provides one of the most sensitive channels to **probe dark matter annihilation** and to test the possible presence of primordial antimatter in our Galaxy. The extremely low expected fluxes motivates the investigation of novel signatures that could enhance the sensitivity to antideuterons complementing existing approaches.

In a hydrogen-rich target, the annihilation of an antideuteron can proceed in two steps: one antinucleon annihilates promptly on a proton, while the surviving antinucleon retains kinetic energy, travels a finite distance, and subsequently annihilates on another proton.



Plastic scintillators are fast, lightweight, inexpensive, and rich in hydrogen.

In a detector geometry based on stacked and segmented layers, the displaced annihilation vertices can be identified through their spatial separation and precise timing.

Preliminary Geant4 simulations indicate that a stopped antideuterons in plastic scintillator produces a single full annihilation in about 30% of events, while in the remaining **~70% a partial annihilation** occurs and a recoiling antinucleon is emitted.

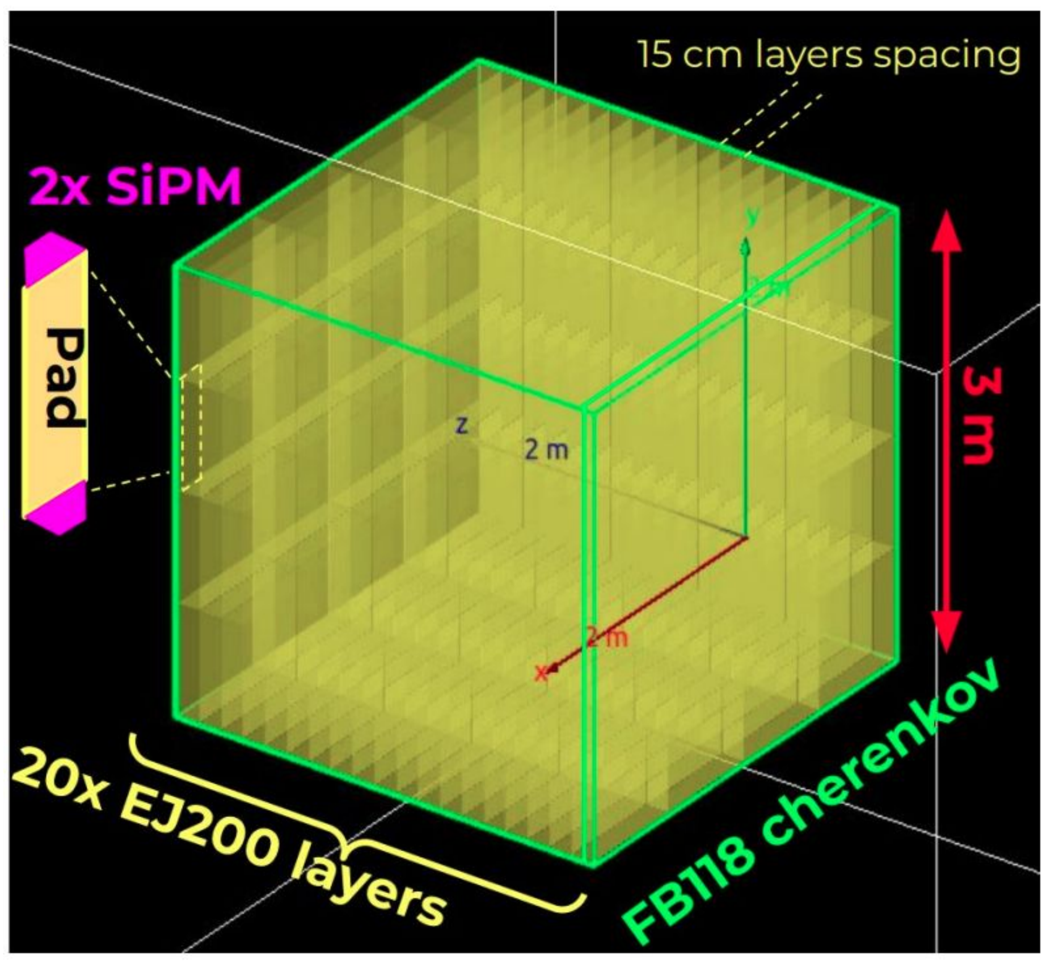
The antinucleon emission after the first, partial, annihilation is roughly evenly split between antineutron and antiproton, both subsequently annihilate, producing a nearby "pion-star".

For antideuteron annihilating at rest in a plastic medium, the median separation between the two annihilation vertices is **3.5 cm for antineutron emission and 1.5 mm for antiproton emission**, values consistent with recoil energies of order 10 MeV, measured using antiproton on deuterium.

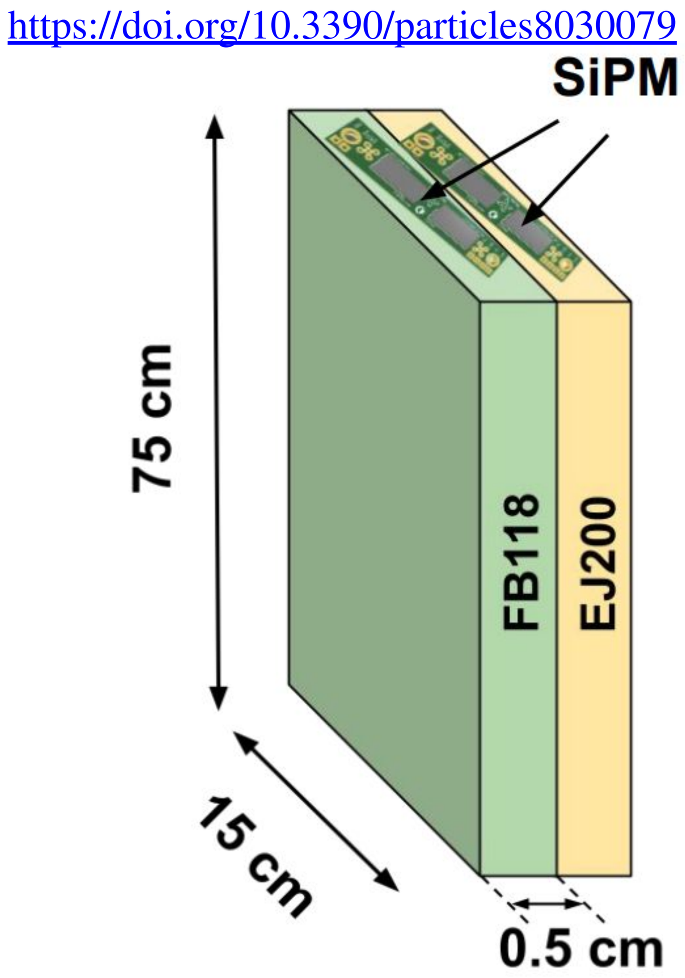
This "PlastiCAMI" signature also applies to antihelium and other complex antinuclei.

a possible design for the "PlastiCAMI" detector

Segmented EJ200 plastic scint. calorimeter/tracker



External Cherenkov veto FB118 $\eta = 1.5$
https://doi.org/10.3390/particles8030079

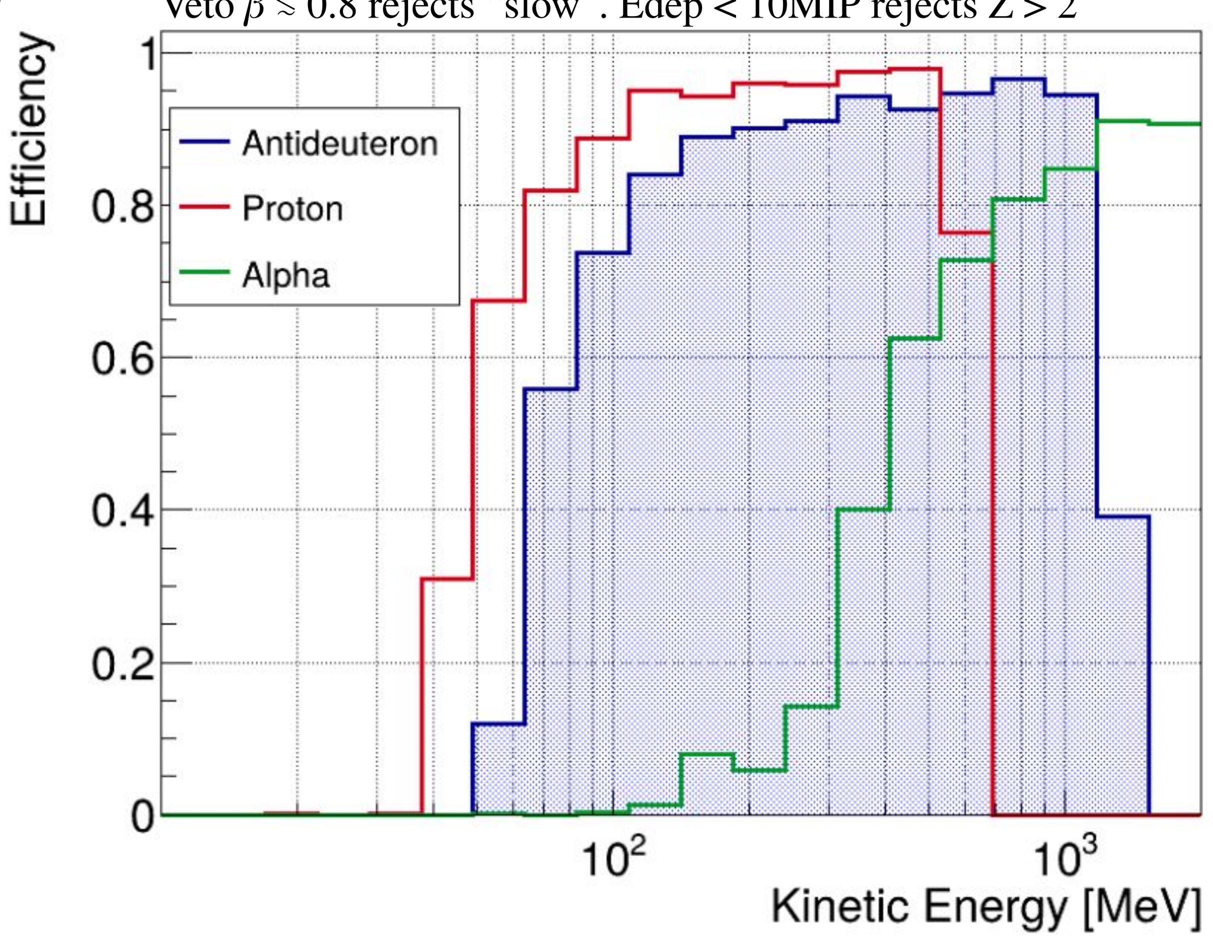


"Plastic Calorimeter for AntiMatter Identification": 2400 EJ200 + 480 FB118 (5760 SiPM channels)
Space-time resolution of a single hit on the scintillator bars ≃ 10 cm × 5 cm × 0.15 cm × 0.3 ns
Only "slow" particles ($\beta \lesssim 0.8$) can trigger EJ200 without releasing a veto signal in FB118 ($\eta = 1.5$)

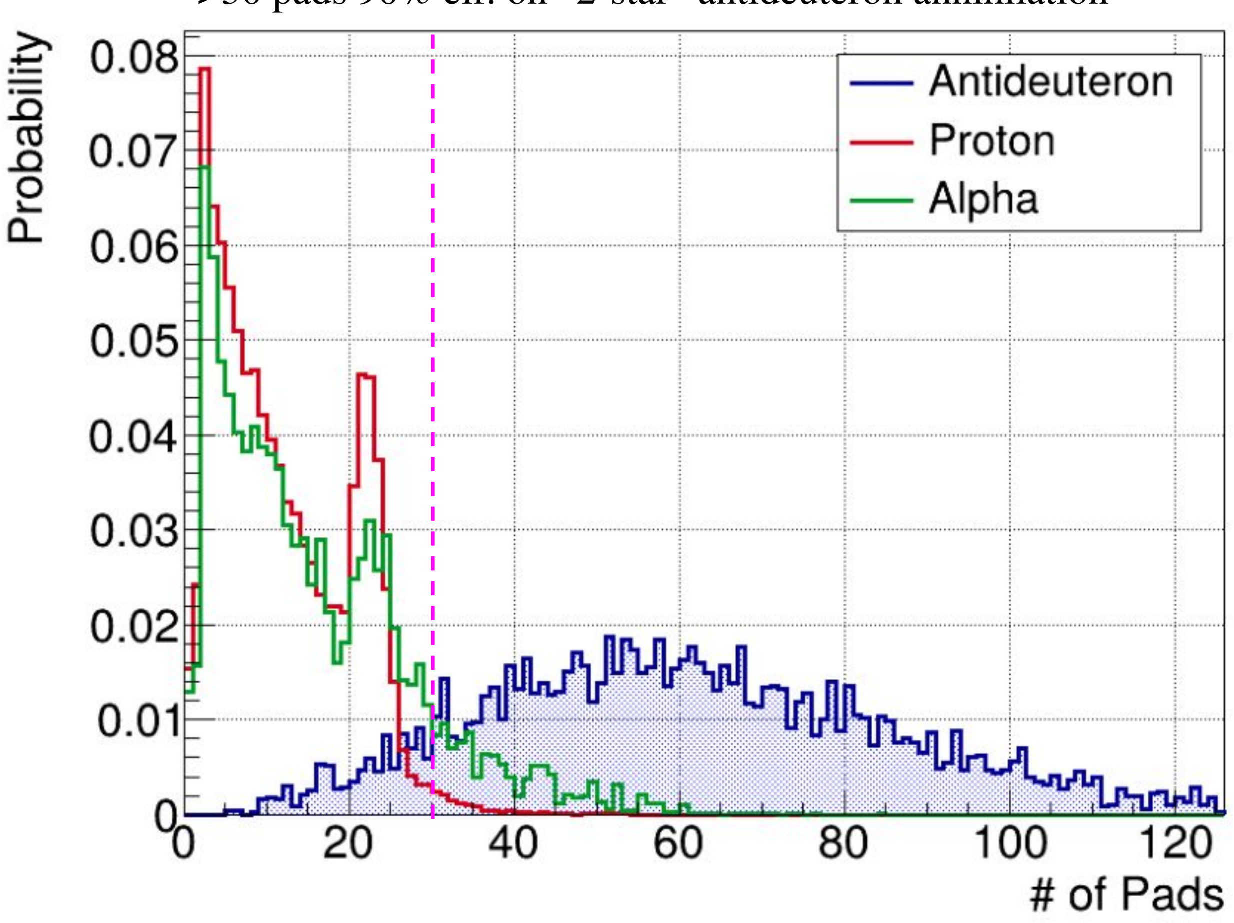
Antarctic 30d long-duration balloon, air grammage ~4g/cm^2, geomagn.cut.eff. ~75% at 0.2GeV/n
Total Mass: 2.5Ton (1.6Ton of EJ200+FB118) Total power: 1.5kW

Expected trigger rate and event topology reconstruction

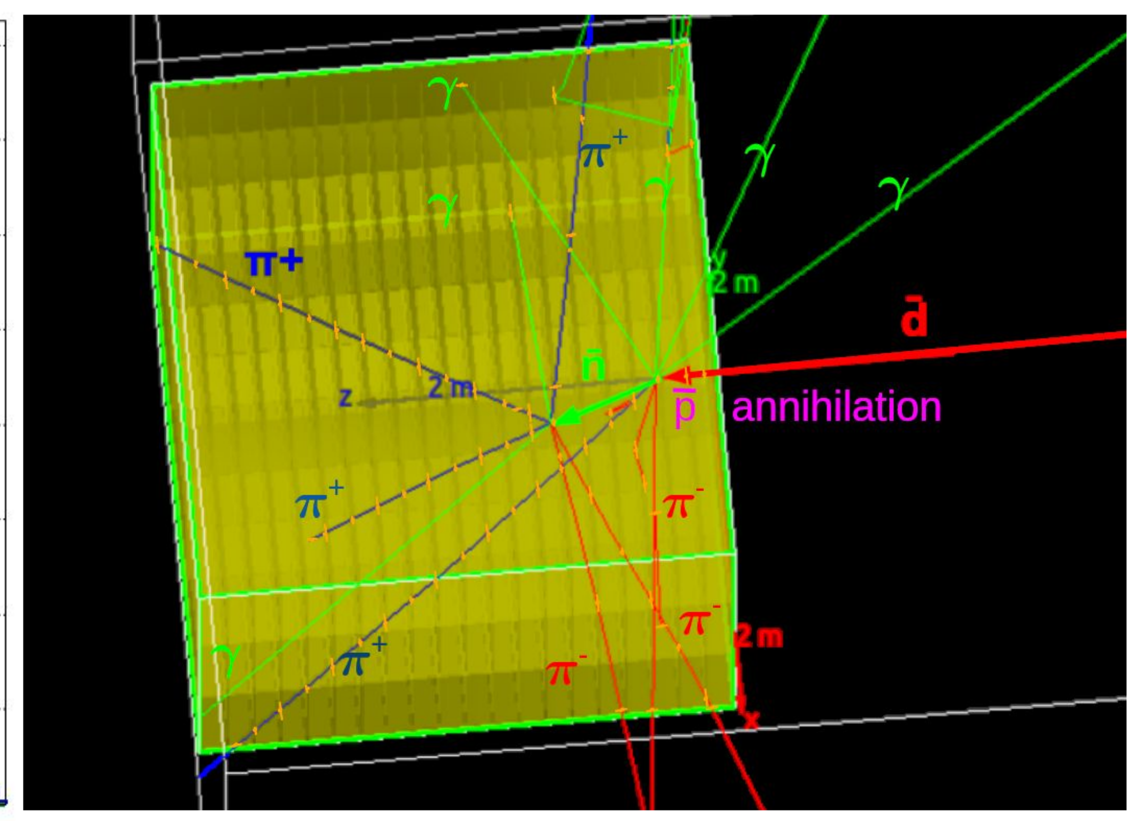
Trigger Level-1: (external layer + veto) open 50ns gate
Veto $\beta \lesssim 0.8$ rejects "slow". Edep < 10MIP rejects Z > 2



Trigger Level-2: number of fired pads (Edep>0.3 MIP)
>30 pads 90% eff. on "2-star" antideuteron annihilation



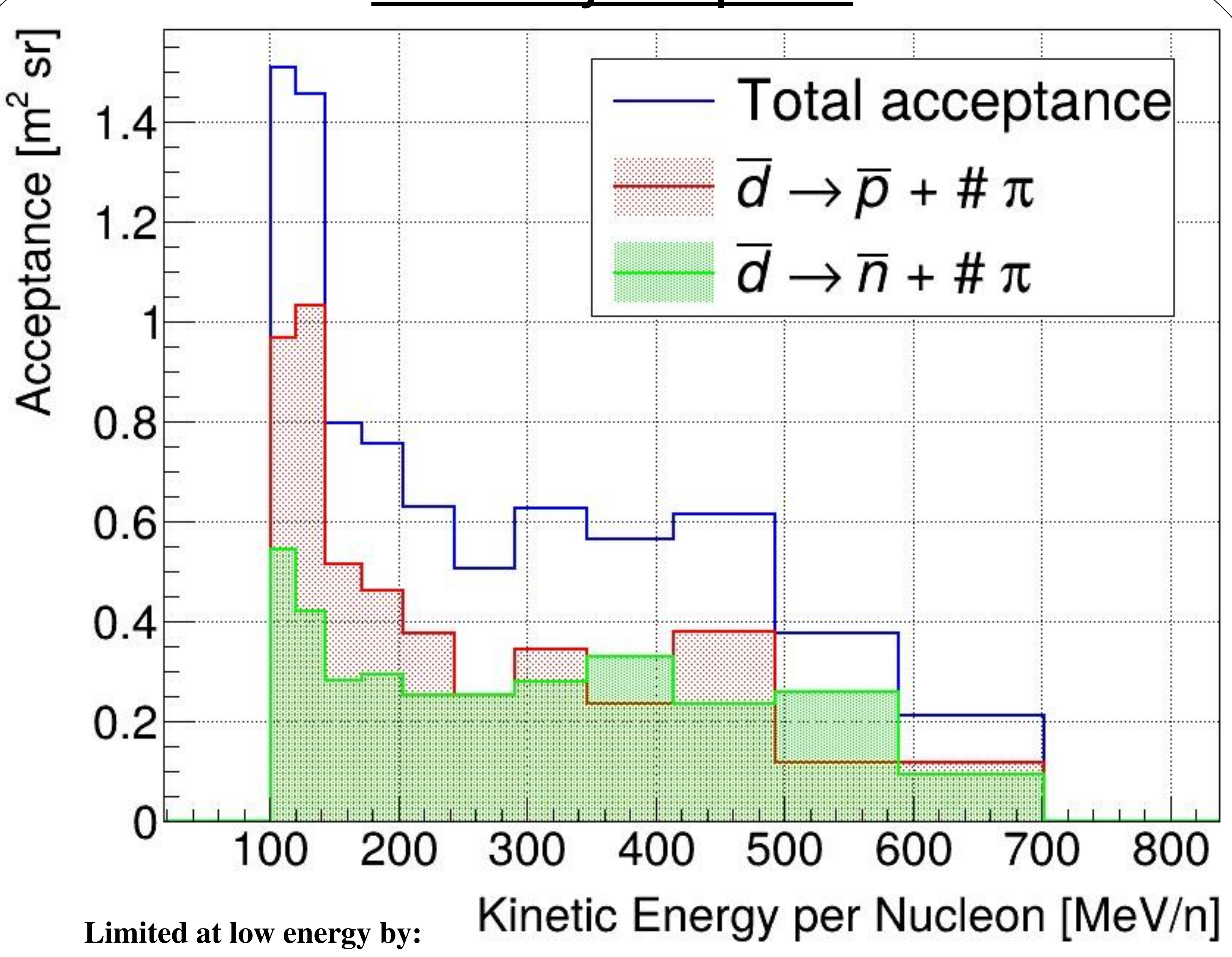
Offline analysis: double annihilation vertex reconstruction



Considering the natural flux of protons and helium, the expected Level-1 trigger rate is about ~50kHz, dominated by protons.
This ensures that within the 50ns gate the dead time and event pile-up remain negligible.
Taking into account the Level-2 trigger, the expected PlastiCAMI acquisition rate is ~1kHz.

- Fiducial volume cut: removed vertex 15cm near the walls
- Minimum vertex space separation >15cm & >2ns time delay
- Antideuteron Mass reconstruction: energy depositions of the incoming primary track matched with the ToF information
- preliminary Vertex reconstruction efficiency: 50%

Preliminary Acceptance



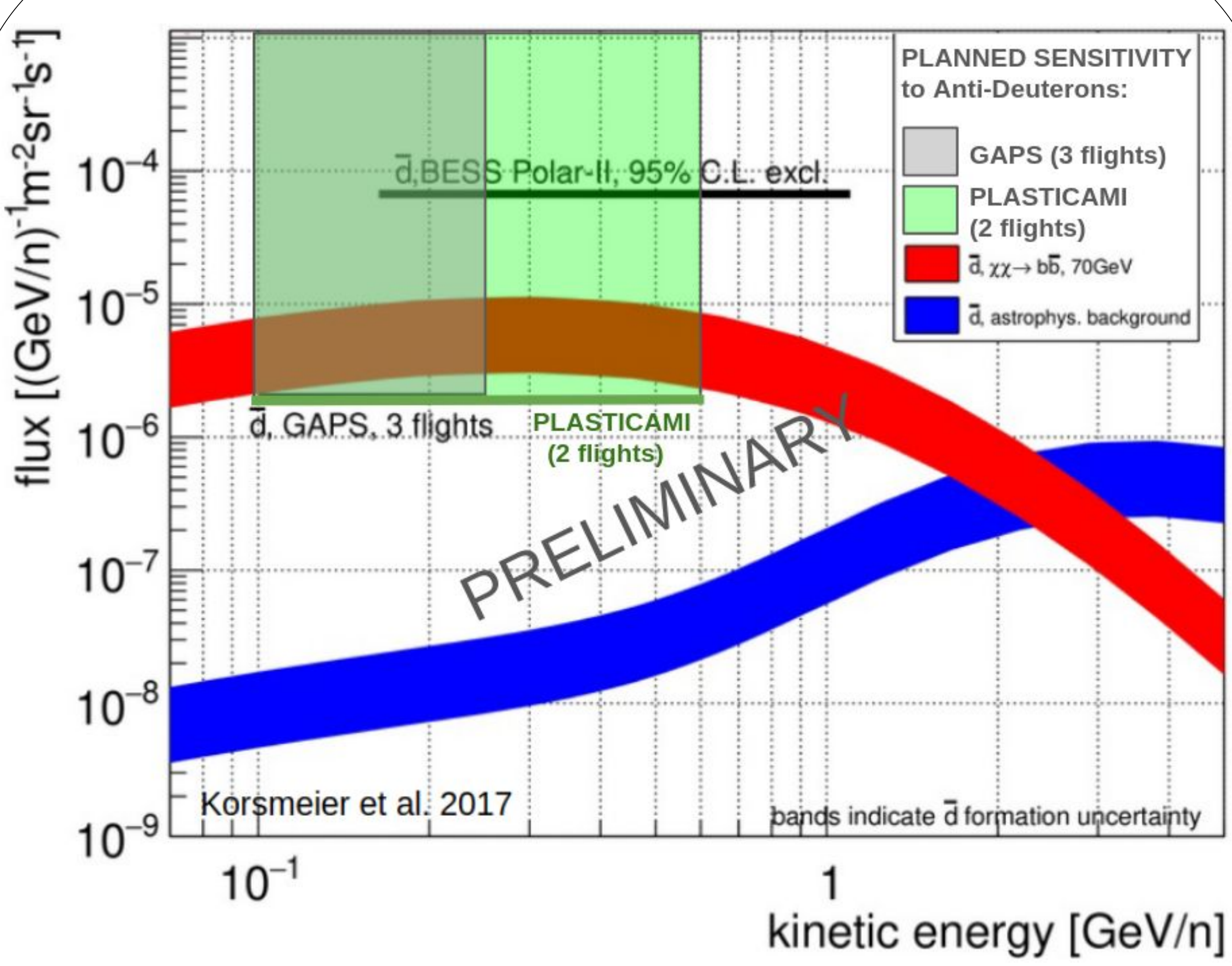
Limited at low energy by:

- (unavoidable) geomagnetic cutoff + air-grammage
- (necessary) housing structure + wrapping material + FB118 veto material
- (trigger rate mitigation & analysis required) Edep<10MIP & Fiducial volume cut

Limited at large energy by:

- (total detector mass) antideuterons are stopped by 22x0.5xcm plastic layers < 11g/cm^2
- (trigger rate mitigation) Cherenkov veto $\beta \lesssim 0.8$

Preliminary sensitivity



Considering two Antarctic balloon flights (70 days exposure) and assuming no candidates: preliminary sensitivity ≃ 2×10^{-6} (m^{2}sr s GeV/n)$^{-1}$ in the 100–600 MeV/n interval

Approach complementary to GAPS and AMS-02

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