A compact Cherenkov detector for measurement of the high energy antideuteron flux in cosmic rays

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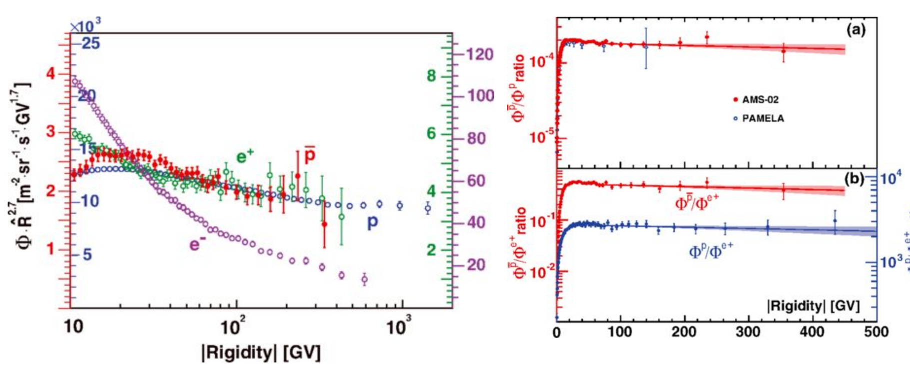
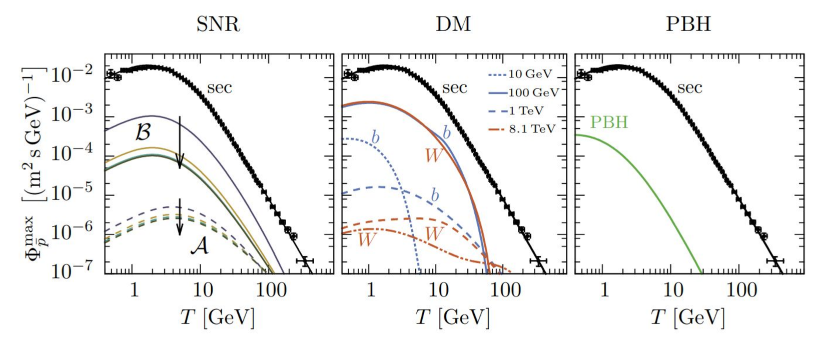
Antibaryons in cosmic rays

- In the standard Big Bang scenario, the relic abundance of antibaryons in our universe should be suppressed by a factor of 10^{-22} with respect to the baryons.
- Antiprotons can however be produced in our Galaxy due to the **secondary interaction** of cosmic rays with the the interstellar medium.
- The first evidence of galactic antiprotons was reported in 1979, and many more observations came after that.
- The antiproton data in cosmic rays measured to this day are all in agreement with the expectation from secondary production .



Measurement of the proton flux compared to the antiproton flux, electron flux and positron flux as measured from the Alpha Magnetic Spectrometer (AMS) [1]

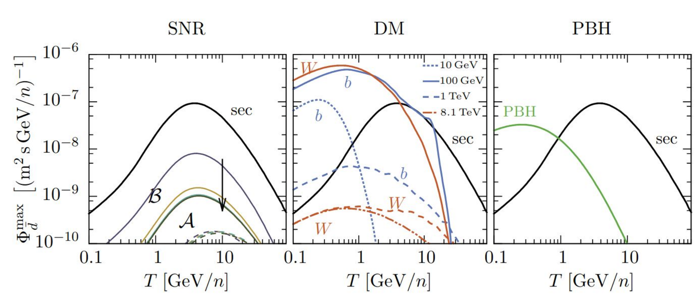
- Antiprotons and heavier antinuclei could be also produced from the so called **primary interaction**, like **supernova remnants (SNR)** or more exotic sources like **primordial black hole evaporation (PBH)** or **dark matter annihilation (DM).**
- This latter components are more relevant in the low momentum part of the spectrum, but in the case of antiprotons, they are submerged by the background from secondary production.



Maximum contribution to the antiproton flux allowed by current MS-02 data for the secondary contribution and expected contribution from SNRs, DM annihilation and PBH evaporation calculated by [2].

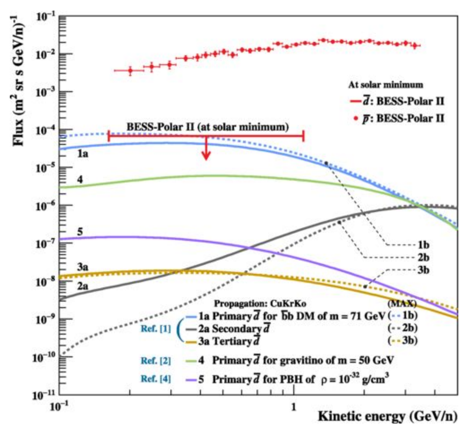
Antideuterons: a low energy fruit

- For **antideuterons** the energy threshold for the secondary production is much higher than the one for the proton (17 proton mass vs 7 porton mass).
- Thus, the lower energy region is basically background free, making antideuterons a **golden chanel for the discovery of exotic process**.

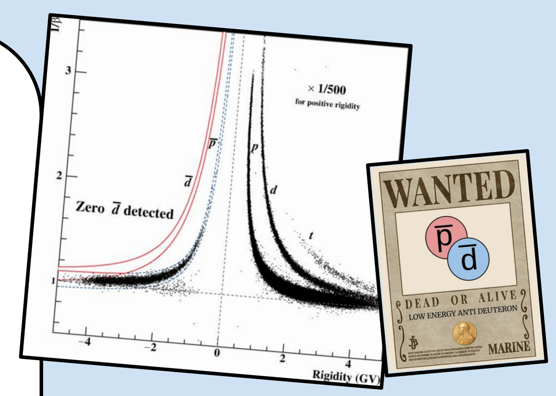


Maximal antideuteron flux at Earth from secondary interaction alongside contribution from SNRsrS, DM annihilation and PBH evaporation calculated by [2]

Still, **no antideuterons has been detected so far**, with the BESS-Polar II collaboration providing the current best limit on the antideuteron flux in the **0.163 to 1.1 GeV/n** region.

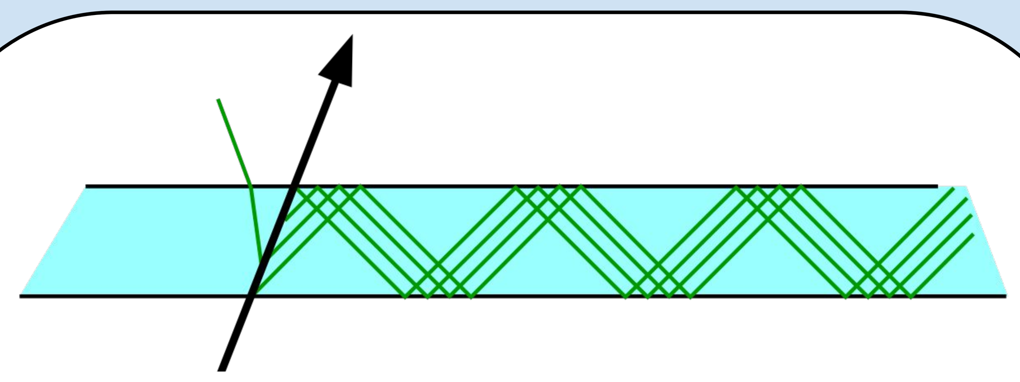


The upper limit on the $\bar{d}$ flux at the 95% C.L. resulting from BESS-Polar II at solar minimum in 2007–2008, compared with the possible solar-minimum $\bar{d}$ flux curves derived from theoretical calculations [3].

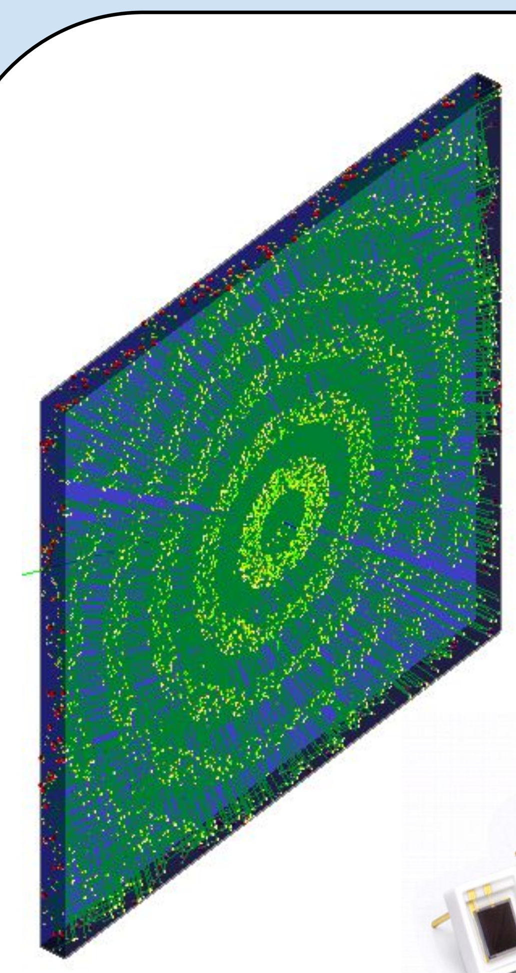


But what about higher energy?

To explore the higher momentum region and constrain the current models for ordinary production, we propose a compact ring imaging Cherenkov detector able to separate antiprotons e antideuterons in the 5 to 10 GeV/c momentum range.

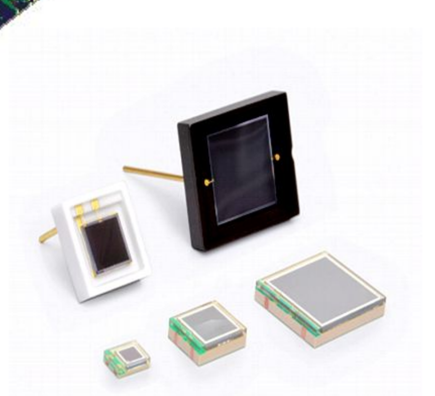


- Internal reflection inside a Cherenkov radiator has been used in the past in the **Dirc from BaBar** and now in the **TOP from Belle II** as an effective way to perform ring imaging PID in a compact and modular fashion.
- The design of such detectors was pushed by the necessity of fitting them inside a quite tight gap in the barrel of collider experiments.
- Our detector needs also to be **lightweight** since is meant to be mounted on balloons and with really **low passive materia**l, in order to suppress the background noise.

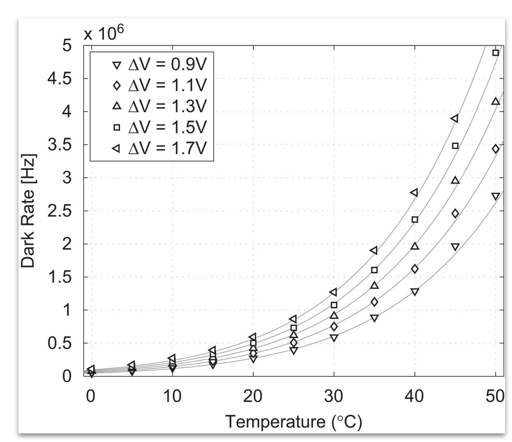


The design of our detector is quite simple and consist in instrumenting a rectangular plate of fused silica of dimension (500mm x 500mm x 18mm).

- The plate serves two purposes:
  - A Cherenkov radiator (with refractive index around 1.5) for the incoming particle.
  - A light guide via internal reflection for the photons emitted.
- The lateral faces of the crystal would be instrumented with an array of Silicon Photo Multiplier (SiPM) able to detect single photon with timing resolution of around 100 ps.



The MPPC S1336 series, that would provide good quantum efficiency and satisfying position resolution



For astroparticle applications the dark counts can be mitigated with a narrow signal window, but additional cooling should be considered for collider applications.

- We developed a preliminary simulation with GEANT4 with different pixel granularity
- The results are promising, and we see good discrimination power at 5 GeV/c momentum instrumenting the faces with 2mm x 2mm SIPMs.

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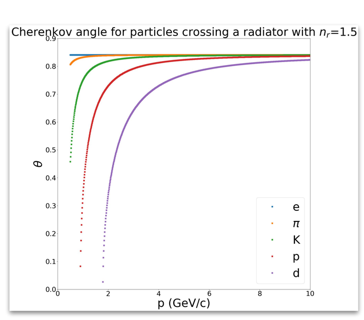
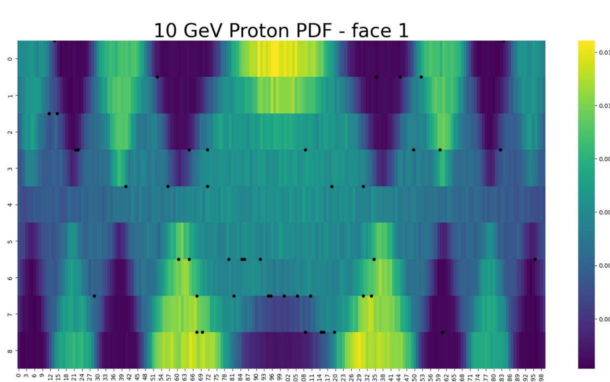
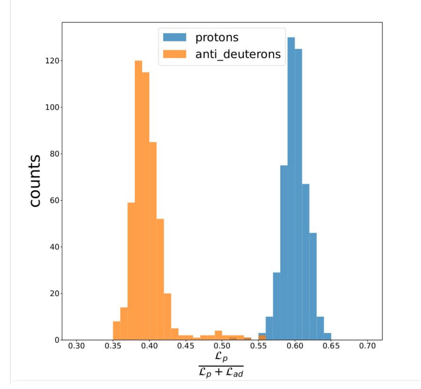
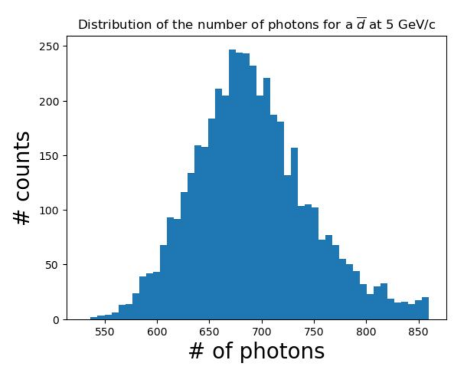
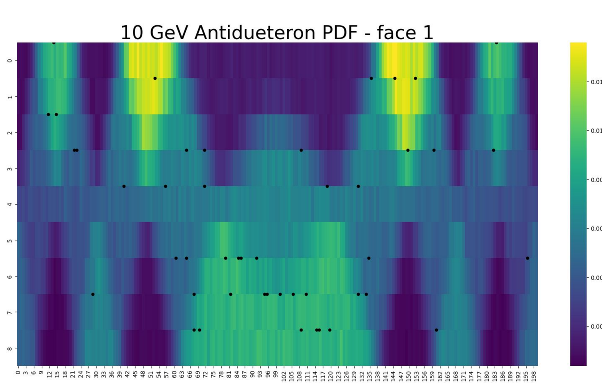
- To improve the performance we plan to use also the timing information from the SIPM.

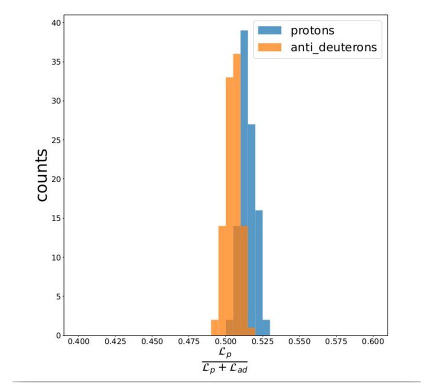












Our design is not limited to the astrophysics, but could also be implemented as a **module for a segmented detector** in the forward direction for collider experiments.

The simulation will be compared with a partially instrumented prototype exposed to cosmic muons, so stay tuned for more!

References

1) Antiproton Flux, Antiproton-to-Proton Flux Ratio, and Properties of Elementary Particle Fluxes in Primary Cosmic Rays Measured with the Alpha Magnetic Spectrometer on the International Space Station, (Phys. Rev. Lett. 117, 091103).
2) Antideuterons in cosmic rays: sources and discovery potential (Johannes Herms *et al* JCAP02(2017)018).
3) Search for Antideuterons of Cosmic Origin Using the BESS-Polar II Magnetic-Rigidity Spectrometer, (Phys. Rev. Lett. 132, 131001).

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