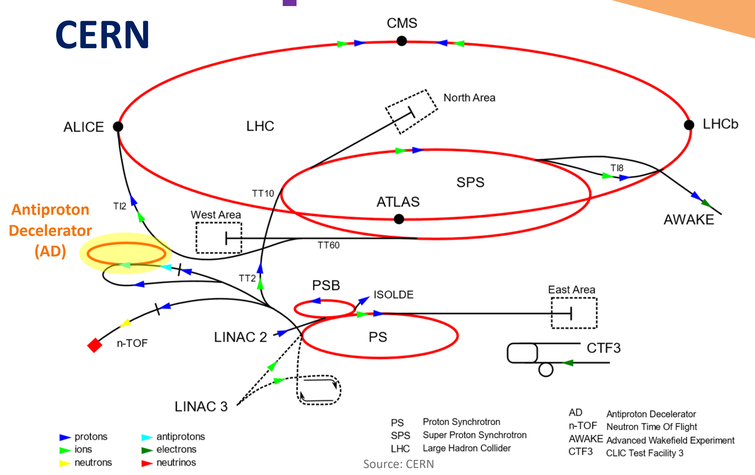
Optimization of Antiproton Capture and Delivery for Antihydrogen Creation

S. Fabbri, W. Bertsche

University of Manchester, Dept. of Physics, Manchester, England

1 Abstract

At the ALPHA Experiment at CERN, thin foils of material are used to slow down and trap antiprotons in a Penning trap, where they can be used for antihydrogen creation and measurements. Historically, over 99% of antiprotons are lost during the capture process as a result of the 5.3 MeV initial kinetic energy of the beam delivered by the Antiproton Decelerator. This places a limit early on in the achievable number of antihydrogen. ELENA is a new storage ring coming online which will lower this initial kinetic energy of the beam to 100 keV, requiring experiments to update their infrastructure. We present Monte Carlo and particle tracking simulation results for the optimization of the new degrading foil material, thickness, and location in the ALPHA catching Penning trap. From these results, we expect an upper capture efficiency of approximately 50 %.

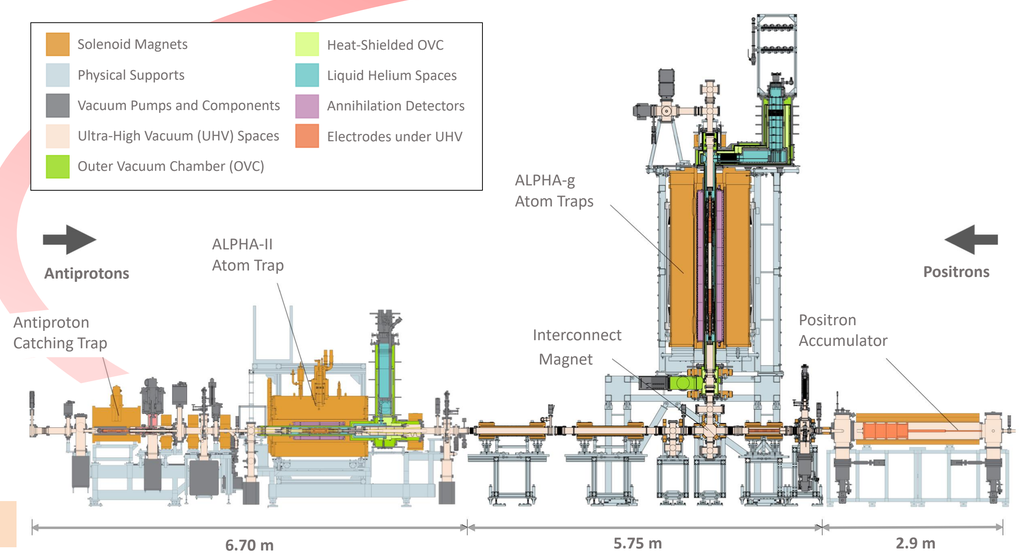


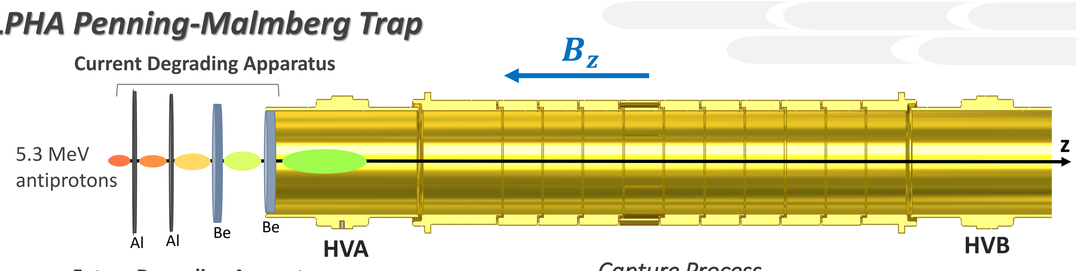
2 Introduction

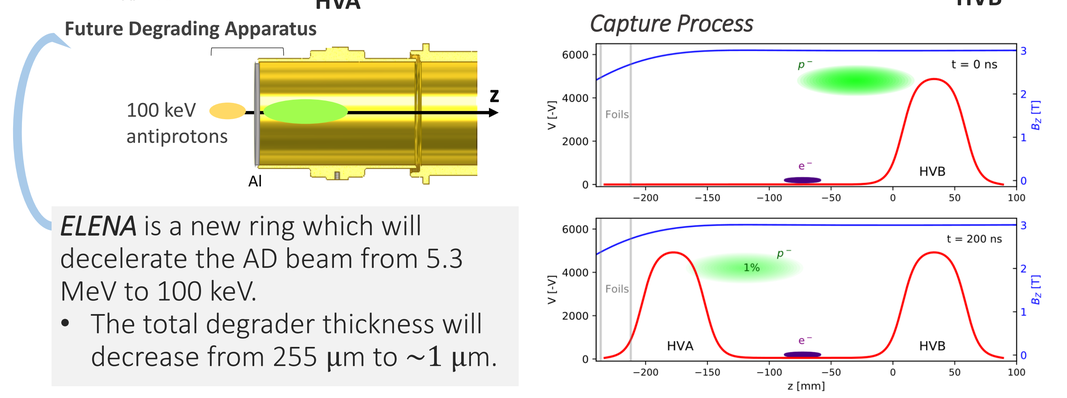
The *ALPHA Experiment* at CERN studies the antihydrogen spectrum and gravitational interaction [1].

Antiprotons are captured and prepared in ALPHA's Catching Penning Trap.

Once the antiprotons are cold and dense, they are extracted to the Atom Trap for $\bar{H}$ formation.







ELENA is a new ring which will decelerate the AD beam from 5.3 MeV to 100 keV.

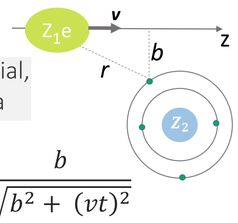
- The total degrader thickness will decrease from 255 μm to ~1 μm.

3 New degrader material and thickness

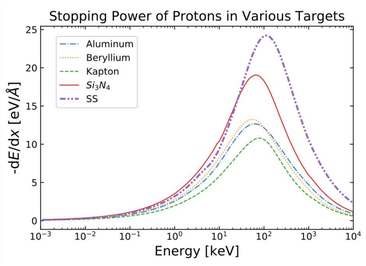
Theory:

As ions pass through a material, they lose energy primarily via the Coulomb force:

$$\mathbf{F}_y = \frac{1}{4\pi\epsilon_0}\frac{Z_1 e^2}{b^2+(vt)^2}\frac{b}{\sqrt{b^2+(vt)^2}}$$



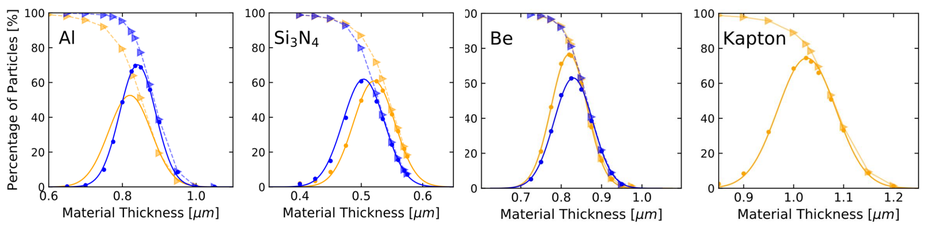
The *stopping power*, $-dE/dx$, of a material directly describes the energy loss of penetrating ions →



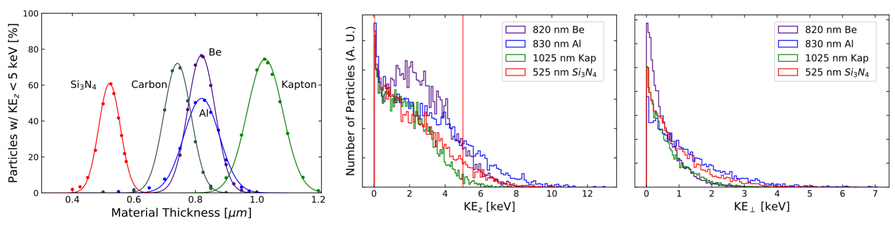
Simulations: 10^4, 100 keV protons simulated in the Monte Carlo codes SRIM and Geant4.

Geant4 (blue) and SRIM (orange) simulation results for the total percentage of particles:

- Transmitted through the foil (dashed curves with triangles)
- Transmitted through with $KE_z < 5$ keV (solid curves with dots) **which can be trapped.**

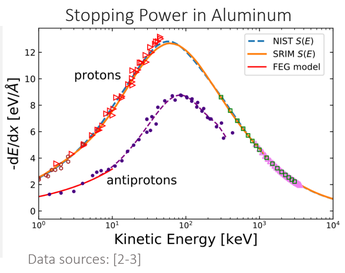


Left: SRIM results for the total percentage of particles which can be trapped for all materials.
Right: SRIM simulation results for the longitudinal and perpendicular energy spreads at the optimal thickness of all materials considered.



Adapting for antiprotons

- Below ~2 MeV, negative particles experience smaller stopping power due to Barkas Effect [ref].
- Antiprotons penetrate 73.3 % more Al than protons.
- 0.83 μm for protons = 1.44 μm for antiprotons



Data sources: [2-3]

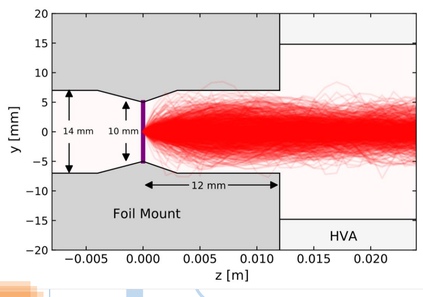
Conclusions

- Foil will be ~1.5 μm thick, thus **monolithic**.
- Beryllium & Kapton are optimal materials.
- Taking Engineering/manufacturing constraints into account: **Aluminum is the best choice.**
- **Al foil of ~1438 nm** will transmit 50-70% of antiprotons w/ $KE_z < 5\ keV$.

Radial Clipping

Particles diverging out of the foil can cyclotron orbit into the mount.

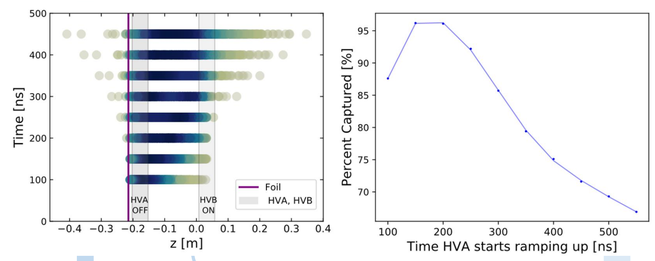
- A mount ID of 14 mm equates to **3.5% of particles lost.**



Longitudinal Clipping

Not all of the beam will fit between HVA and HVB. Scanning over the time HVA is turned on, a maximum in the number of trapped particles can be found:

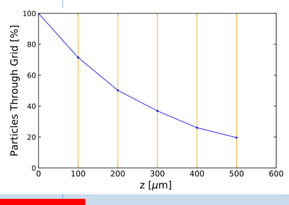
- The optimal ramp up time is 200 ns, with **3.8% of trappable particles lost.**

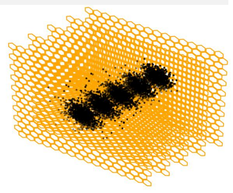


500 μm Silicon Support Grid

80% Si clear aperture honeycomb grid used for supporting degrader.

- Over 500 μm distance, **80% of particles lost.**

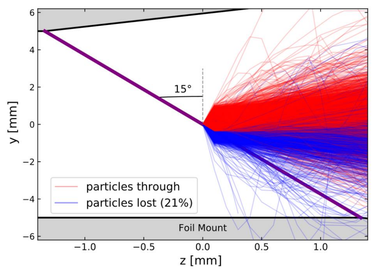




Rotated Foil

Rotating a 1.5 μm foil by 15° tunes the thickness experienced by the beam by 50 nm:

→ **20% lost.**



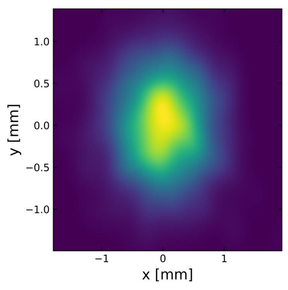
4 Particle loss after the foil

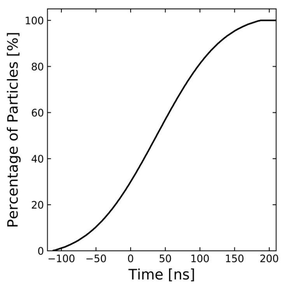
Particle Tracking in GPT

- Zero space charge and initial divergence.

GPT Input Beam:

- Energy distributions from SRIM.
- Initial spatial and temporal distributions from ELENA beam parameters:





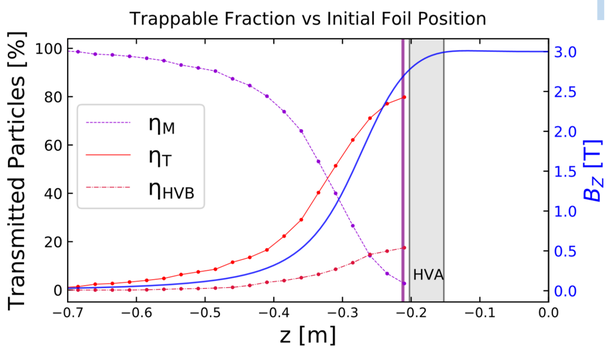
Magnetic Mirror Effect

As transmitted particles travel into the increasing magnetic field, B_z, they can turn around:

- η_M = % of particles which mirror.
- η_{HVB} = % of particles which escape through HVB.
- η_T = % of particles which are trappable (do not mirror and reflect off of HVB).

Conclusion: Place foil as close as possible to HVA.

- In this location, of this particles which could be trapped, **0.5% are lost** to mirroring.



5 Construction

Features

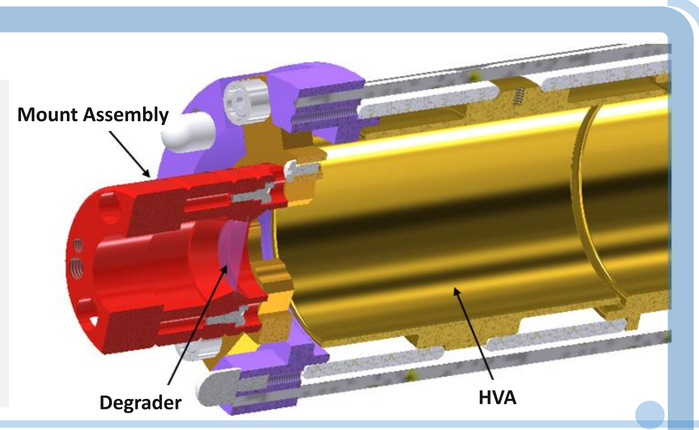
- Reinsert-able foil mount.
- Foil is gold sputtered and acts as Faraday Cup.

Pressure differentials on foil

- Special fluid flow restriction chambers.
- Bypass chamber.

Vacuum – achieve current 10^{-15} *torr*

- 3 to 4 new vacuum pumps.
- New cryocooler.



6 Conclusion and Ongoing Work

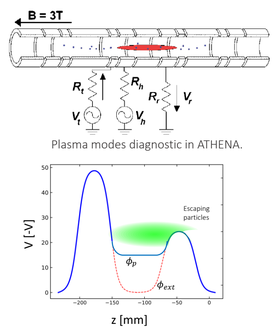
Conclusion: 0.9 – 1.5 μm aluminum foil will allow for catching up to ~50% of the beam.

Antiproton Plasma Manipulation

- New plasma manipulation techniques for large numbered antiproton plasmas.
- New diagnostics to non-destructively characterize trapped antiproton plasma: temperature, density, size, and number.

Antiproton Delivery

- Novel tailored beam extraction on a spheroidal antiproton plasma
- Zero magnetic field antiproton source.



7 References

[1] Amole, C., et al. "The ALPHA antihydrogen trapping apparatus." *Nucl. Inst. and Meth.* 735 (2014): 319-340.
[2] Møller, Søren Pape, et al. "Antiproton stopping at low energies: confirmation of velocity-proportional stopping power." *Phys. Rev. Lett.* 88.19 (2002): 193201.
[3] Moro, Marcos Vinicius, et al. "Traceable stopping cross sections of Al and Mo elemental targets for 0.9–3.6-MeV protons." *Phys. Rev. A* 93.2 (2016): 022704.