Silicon direct annihilation
antimatter detectors

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on behalf of the CERN AEgIS collaboration

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Outline

- Applications of silicon annihilation detectors
- AD - DEM Beamline and our new extraction line
- The Timepix3 as a direct annihilation detector
- Test beam results - thin / thick detectors
- Time topology of the antiproton bunch in the Timepix3
- Efficiency simulations
- Conclusions
Silicon as a direct annihilation detector

* In this configuration, silicon serves both as an annihilation and detection medium.
* Detection of antiprotons / anti hydrogen annihilation positions to micron-scale resolution
* Uses:
  * Measurement of antiproton/antihydrogen displacement by external forces
  * Absorption / scattering experiments
* Requirements
  * Good detection efficiency
  * Good tagging efficiency
* e.g. AEgIS (measuring gravitational acceleration on antimatter)
- Slowing down antiprotons to ~5 MeV to allow trapping by antimatter experiments.
- Several examples of silicon trackers already operated for indirect antihydrogen detection.
Our test facility at CERN/AD - DEM beamline

* 5 MeV antiproton energy from AD (decelerated from ~ 3.5 GeV after 24 GeV proton / iridium target collision)

* Hosting the AEgIS experiment

* Secondary beamline can be deflected to vacuum separation foil for further measurements (used by the ACE collaboration in the past)

* $3 \times 10^7$ Antiprotons delivered per AD cycle (100 s).

M. Giovannozzi et al./Nuclear Physics A655 (1999) 339c-344c
Previous tests with direct annihilation on silicon detectors

Mimotera (14 um monolithic)

3D on FE-I4

- Antiprotons with ~ 100 keV energy pre-moderated by main AEgIS apparatus
- Position resolution at ~ pixel pitch level
Extraction chamber

* 5 MeV antiprotons moderated with Al foils to 0-100 keV energy
* Delivery of low (tunable) energy antiprotons, 0-16 keV
* Fully electrostatic optics: 2 Einzel lenses + Electrostatic deflector
* Beam optics simulation with IBSimu

* Motivations
  * Control annihilation depth (Energy)
  * Avoid detector saturation
Electrostatic beam optics

1st Einzel Lens + Electrostatic Deflector

2nd Einzel Lens
Annihilation topology in silicon

The antiproton annihilates with a nucleon in the silicon atom, producing mesons (pions and K).

Mesons interact with remaining (unstable) nucleus and cause its fragmentation.

Variety of charged nuclear fragments of different energies to be detected.
Timepix3

* Detector and readout provided courtesy of the CERN Medipix group
* General purpose hybrid pixel detector (wide dynamic range)
* Extremely good time resolution (1.2 ns on TOA)
* Concurrent TOA and TOT capabilities
* High density pixel matrix (55 um)
* 5 Gbit/s data rate through Spidr readout (VHDCI connector)

Sensors employed (to date)

* 1 x 300 um, p-on-n, depletion @ ~ 50 V
* 1 x 680 um, p-on-n, depletion @ ~200 V
Tests with low energy antiprotons (E=8 keV) - ID through Heavy Fragments - 300 um sensor

**Pros**: Easiest Signature to detect. Typical star shape and lots of energy deposited

**Cons**: Ions are produced less frequently and resolution is limited by track width and multiple scattering
Tests with low energy antiprotons (E=8 keV)
- ID through pion tracks -
680 um sensor
Tests with low energy antiprotons ($E=8$ keV)
- ID through pion tracks -

Tracks length in excess of several mm are observed for many annihilation events.
Background (fast gaussian, pions and fast fragments from beam annihilations on chamber walls and moderators) is extinguished before the arrival of late antiprotons.
Efficiencies vs Thickness

* High resolution vertex fitting requires long pion tracks to be detected in the bulk => Thicker detector

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<th>Thickness</th>
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<tr>
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<td>43%</td>
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Geant 4 simulated detector efficiencies (events w/at least 2 pion tracks of at least 1 mm)

* A proposal has been submitted to manufacture detectors up to 2 mm thickness
Conclusions

- We developed a beam line capable of extracting antiprotons with low energy. While still under optimization, it will allow in the near future fragmentation studies and further detector characterisation.

- Timepix3 has optimal features for antiproton tagging
  - High TOA resolution, allowing discriminating events and overlapping tracks and annihilation depth as well as kinetic energy
  - High spatial resolution, potentially allowing good annihilation position reconstruction

- Thicker detectors allow for longer tracks, with increased accuracy on track parameters. Further research is underway and a funding proposal has been submitted (together with HIP).