Silicon direct annihilation antimatter detectors

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on behalf of the CERN AEgIS collaboration

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Outline

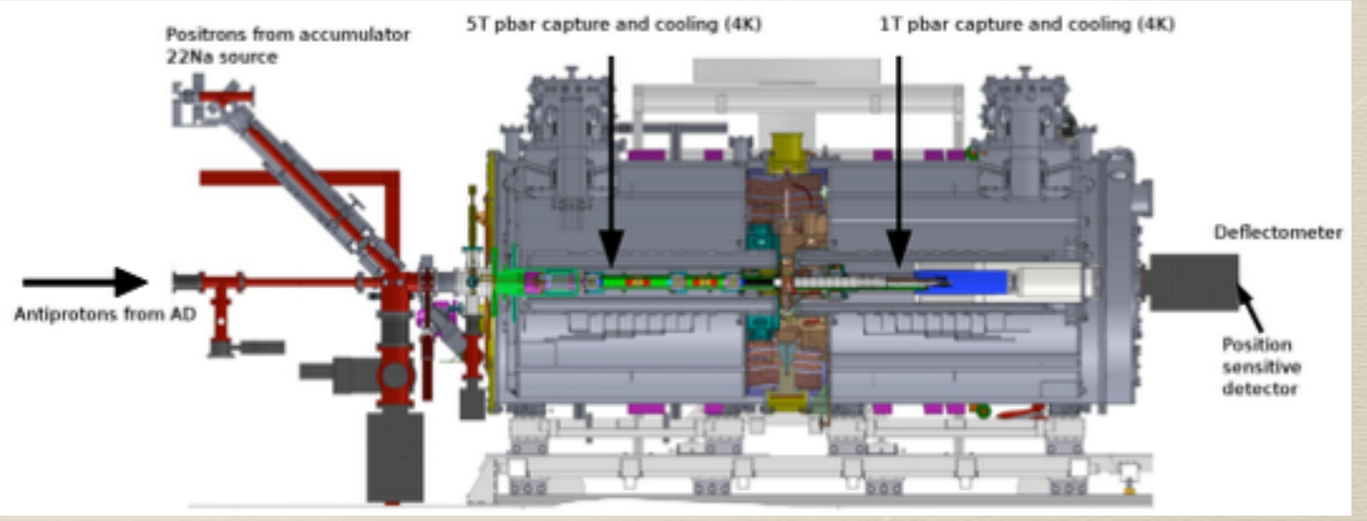
* Applications of silicon annihilation detectors
* AD - DEM Beamline and our new extraction line
* The Timepix3 as a direct annihilation detector
* Test beam results - thin / thick detectors
* Time topology of the antiproton bunch in the Timepix3
* Efficiency simulations
* Conclusions

A E $\bar{g}$ I S collaboration

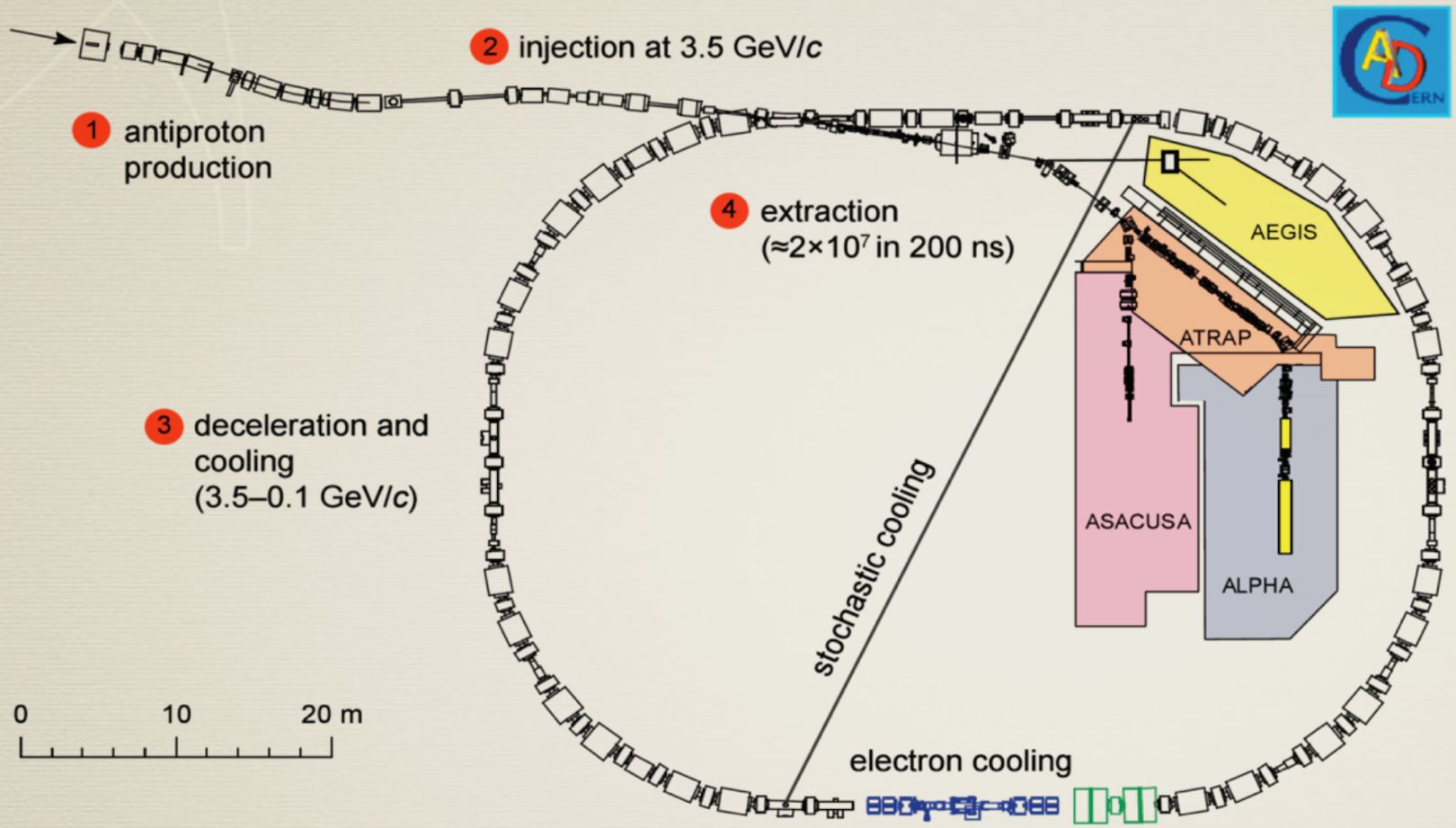
- Stefan Meyer Institute
- CERN
- Czech Technical University
- ETH Zurich
- University of Genova
- University of Milano
- University of Padova
- University of Pavia
- Institute of Nuclear Research of the Russian Academy of Science
- Max-Planck Institute Heidelbert
- Politecnico di Milano
- University College London
- University of Bergen
- University of Bern
- University of Brescia
- Heidelberg University
- University of Lyon 1
- University of Oslo
- University of Paris Sud
- University of Trento
- INFN sections of: Genova, Milano, Padova, Pavia, Trento

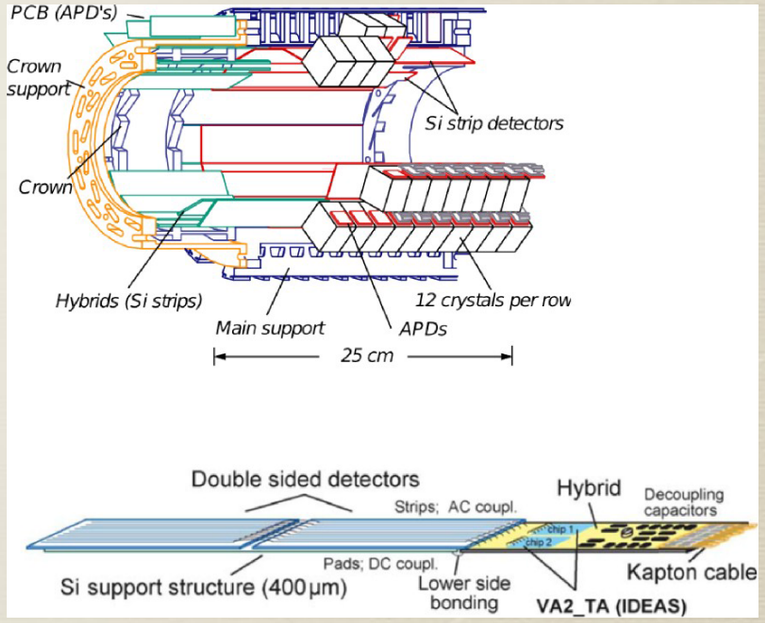
Silicon as a direct annihilation detector

* 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)



CERN AD - Antiproton Decelerator

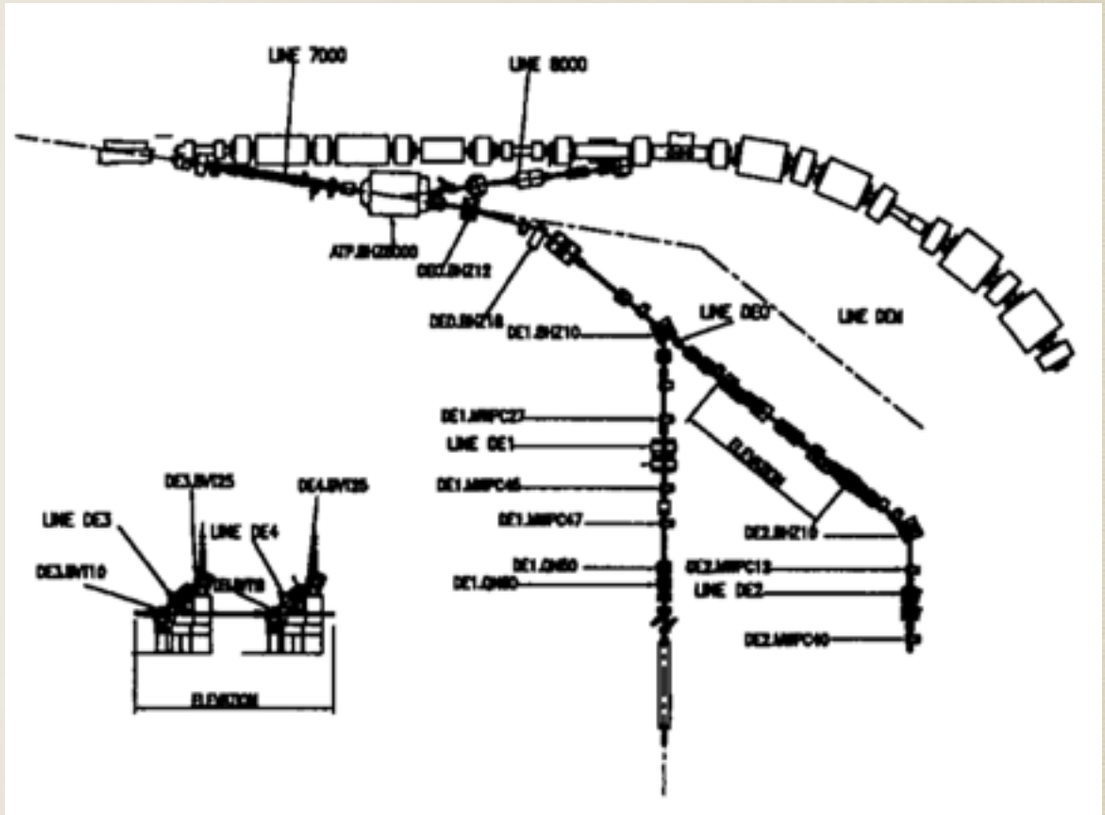




- Slowing down antiprotons to ~ 5 MeV to allow trapping by antimatter experiments
- Several examples of silicon trackers already operated for indirect antihydrogen detection

Our test facility at CERN/AD -DEM beamline

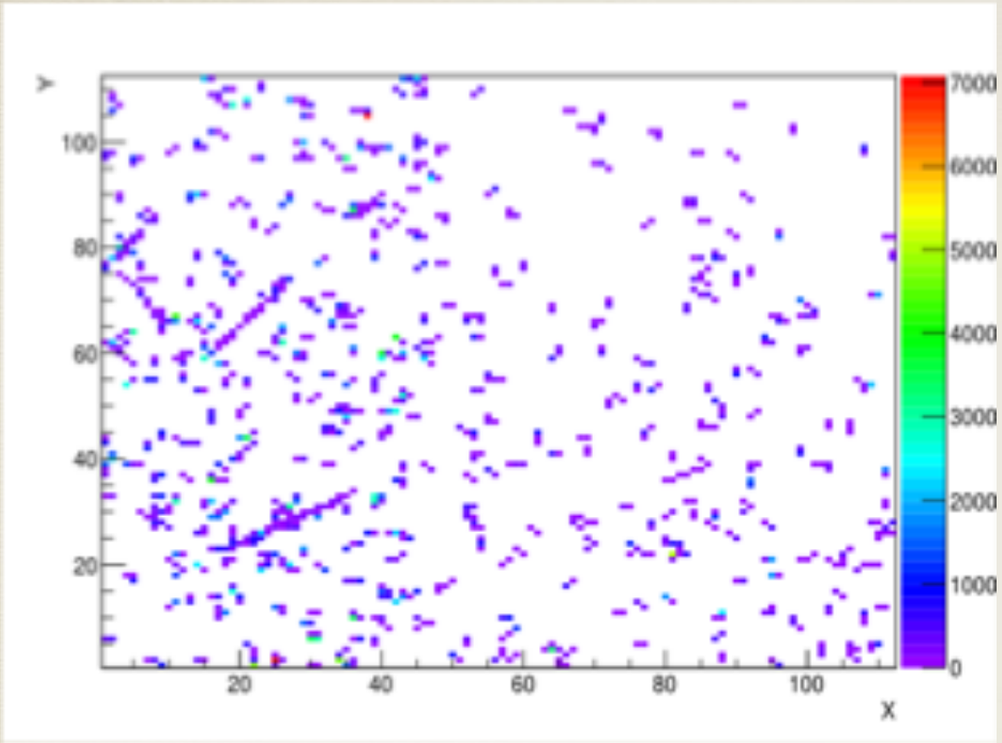
* 5 MeV antiproton energy from AD (decelerated from ~ 3.5 GeV after 24 GeV proton / iridium target collision)
* Hosting the AEgIS experiment
* Secondary beamline can be deflected to vacuum separation foil for further measurements (used by the ACE collaboration in the past)
* 3e7 Antiprotons delivered per AD cycle (100 s).



M. Giovannozzi et al./Nuclear Physics A655 (1999) 339c–344c

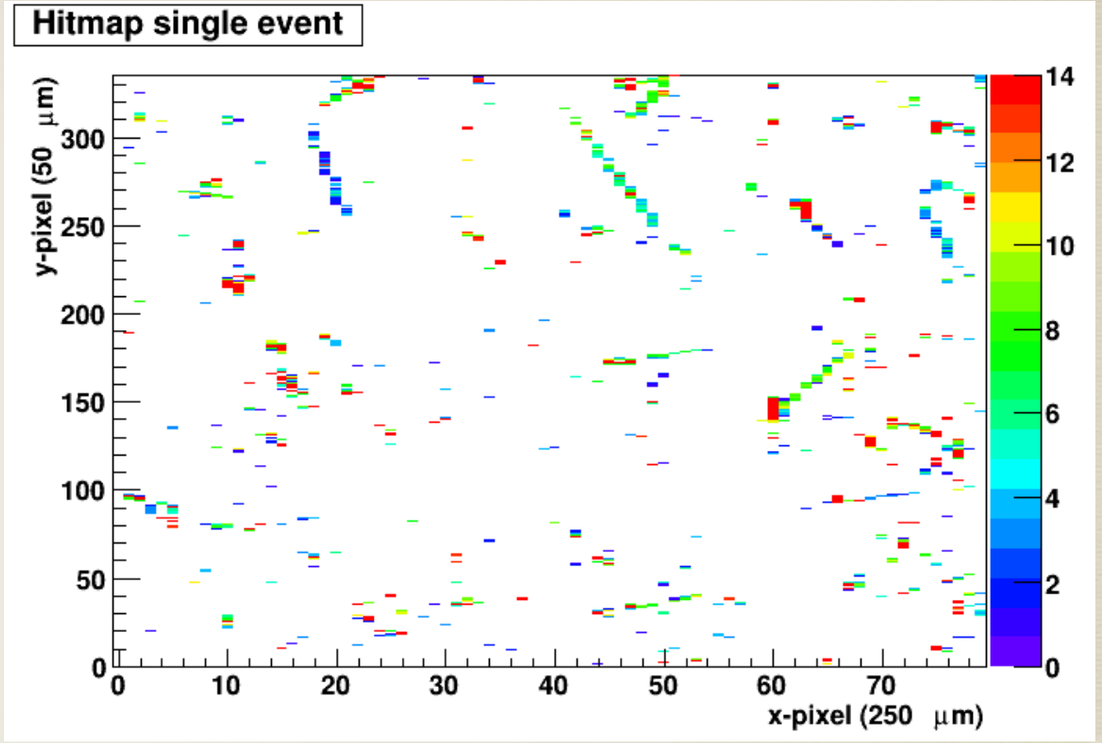
Previous tests with direct annihilation on silicon detectors

Mimotera (14 um monolithic)



doi:10.1088/1748-0221/9/06/P06020

3D on FE-I4

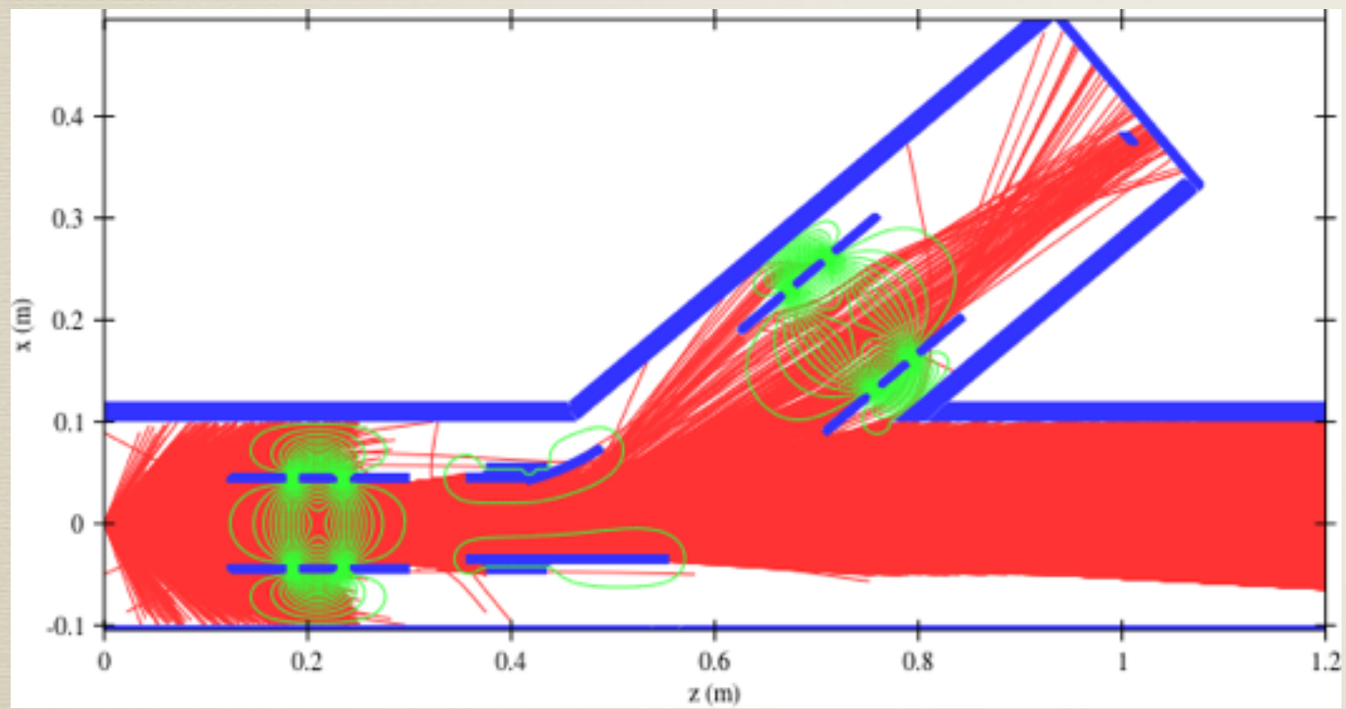


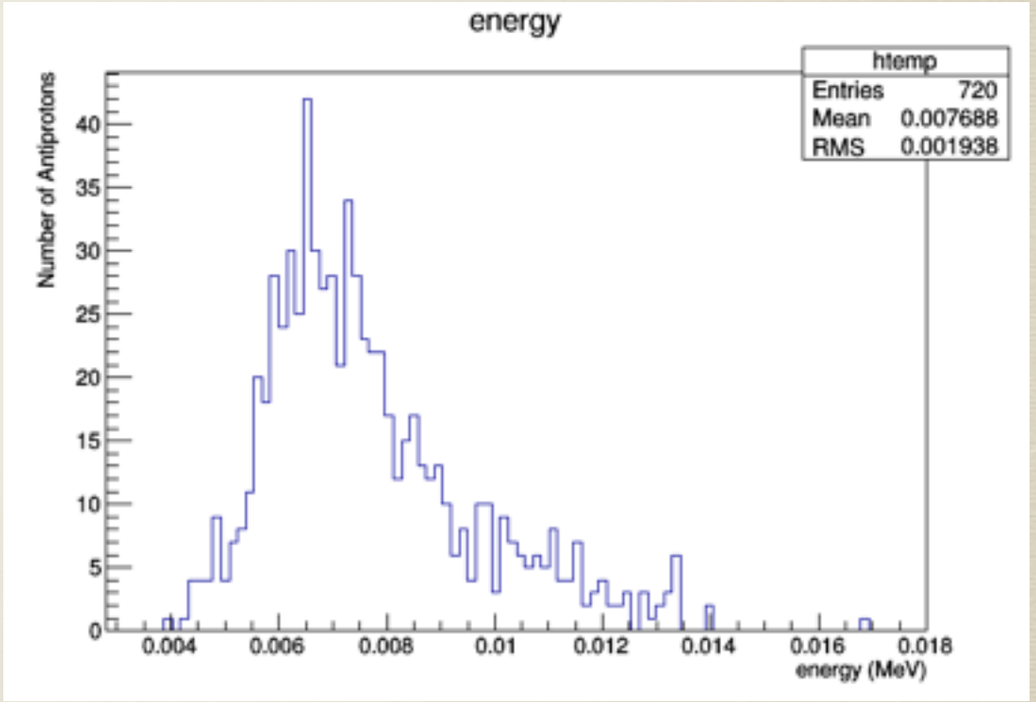
doi:10.1088/1748-0221/9/06/P06020

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

Extraction chamber

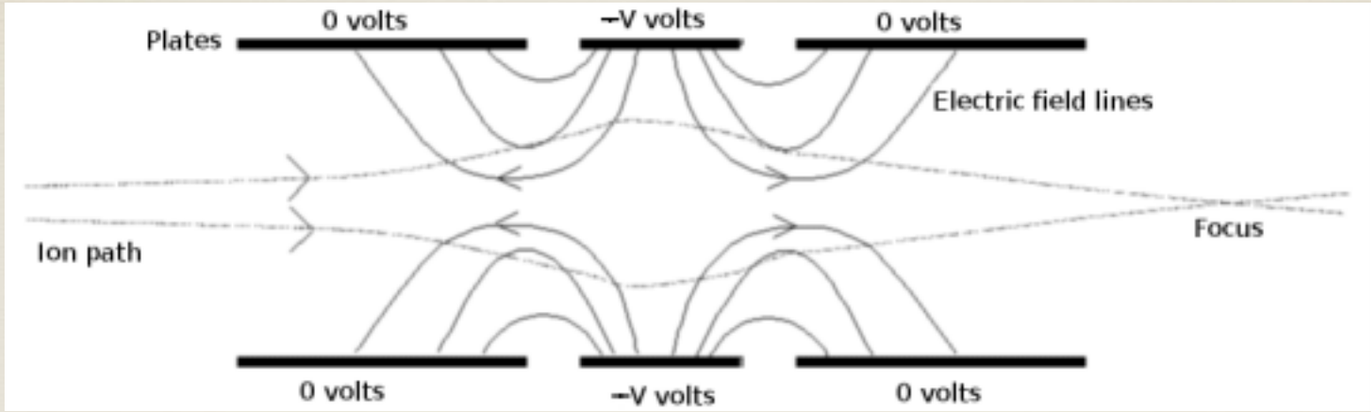
* 5 MeV antiprotons moderated with Al foils to 0-100 keV energy
* Delivery of low (tunable) energy antiprotons, 0-16 keV
* Fully electrostatic optics: 2 Einzel lenses + Electrostatic deflector
* Beam optics simulation with IBSimu

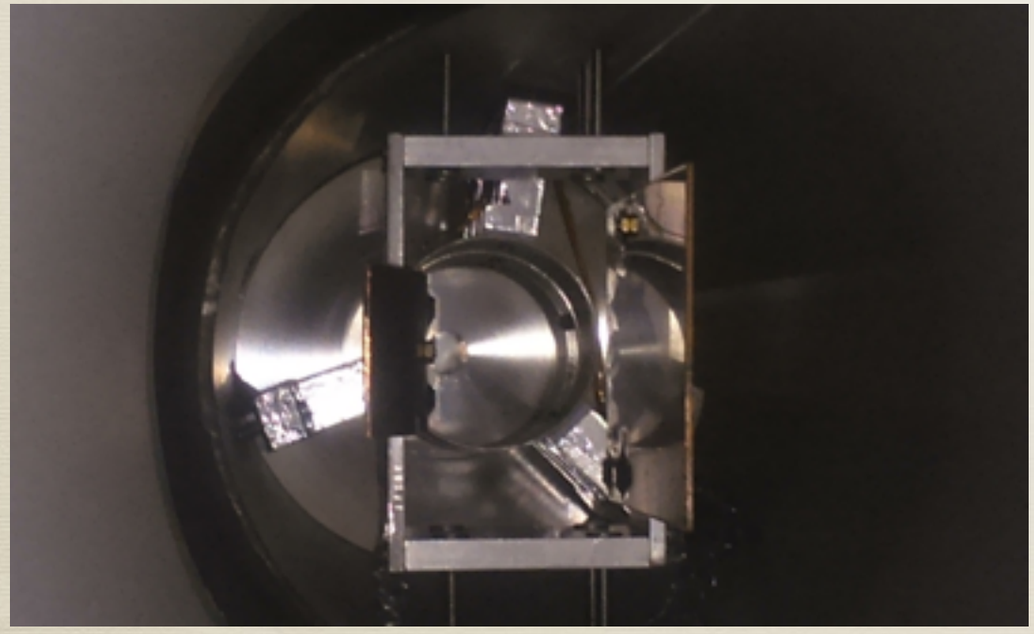




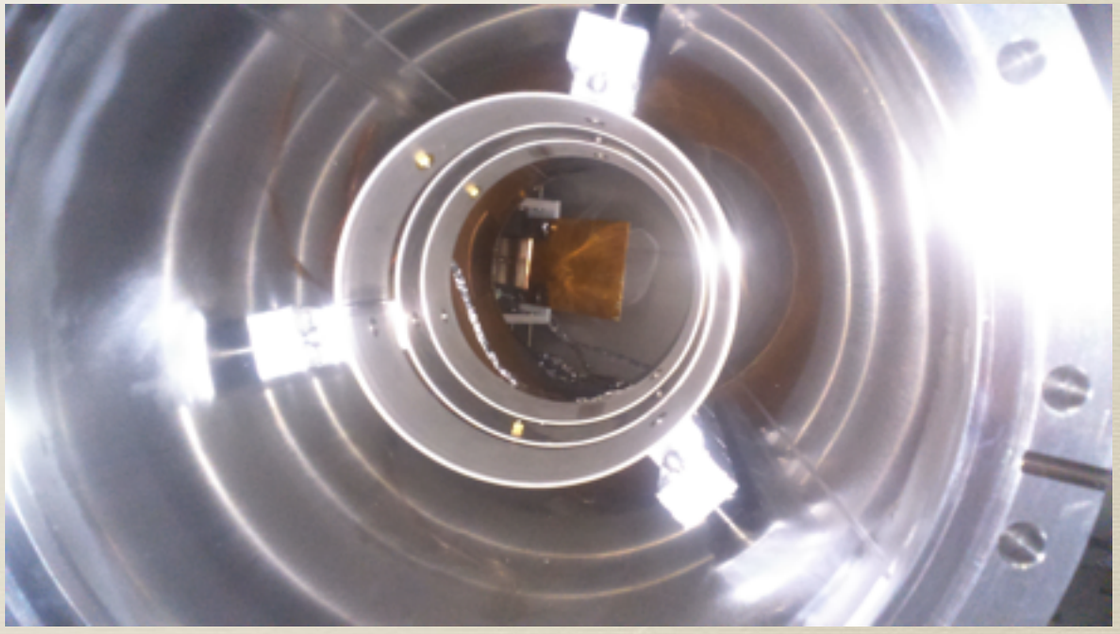
* Motivations
  * Control annihilation depth (Energy)
  * Avoid detector saturation

Electrostatic beam optics



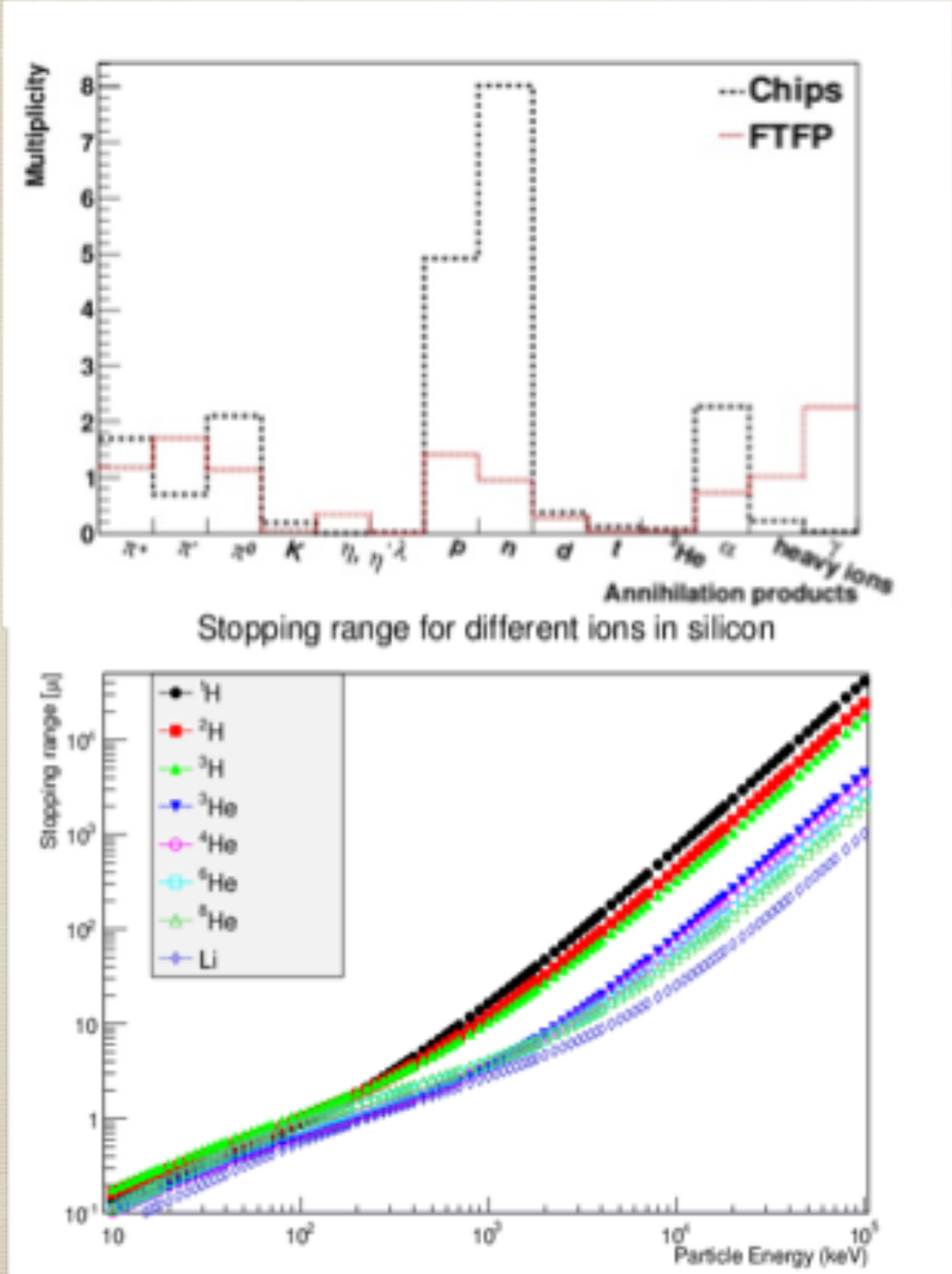


1st Einzel Lens + Electrostatic Deflector



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.

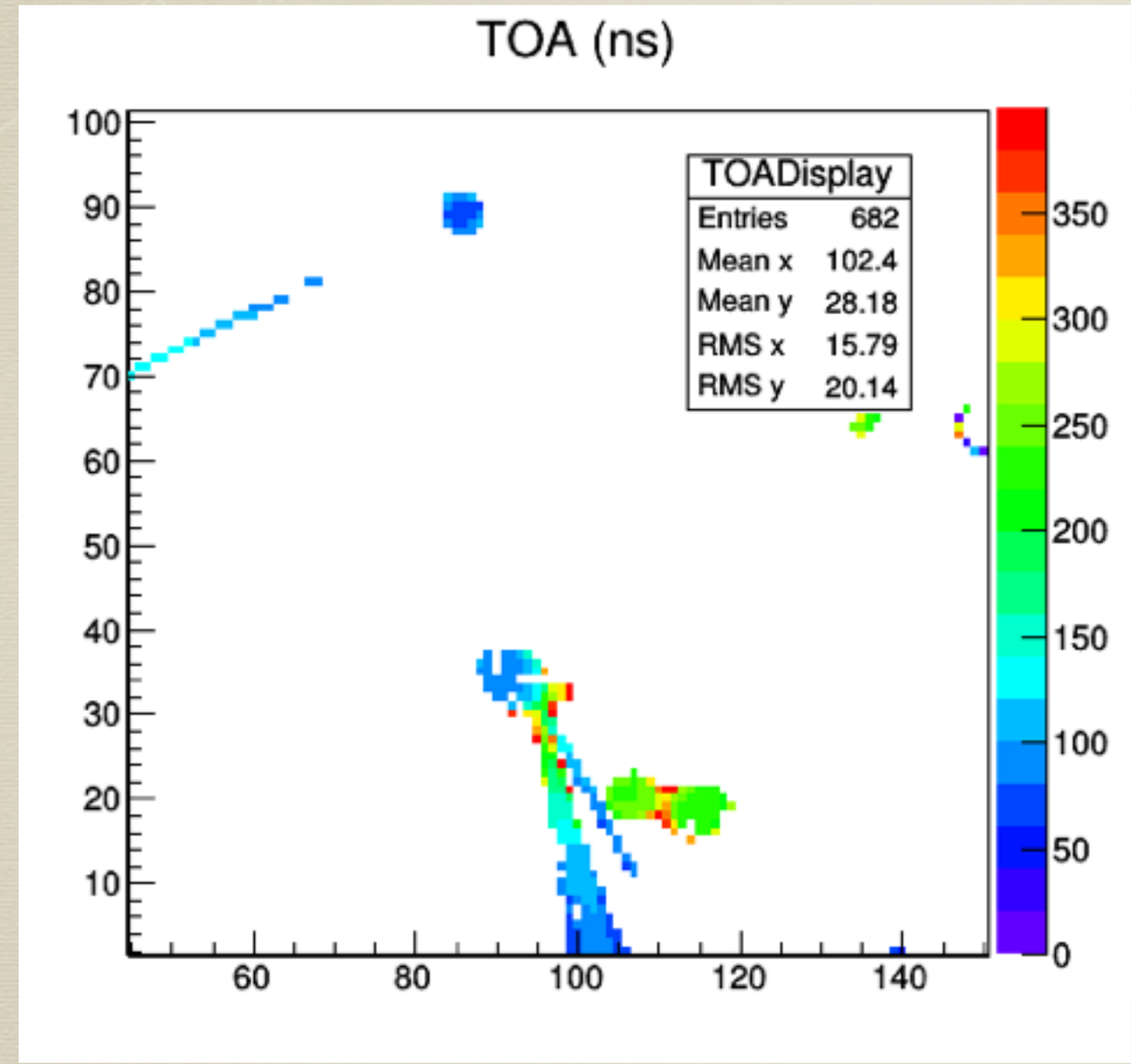
Timepix3

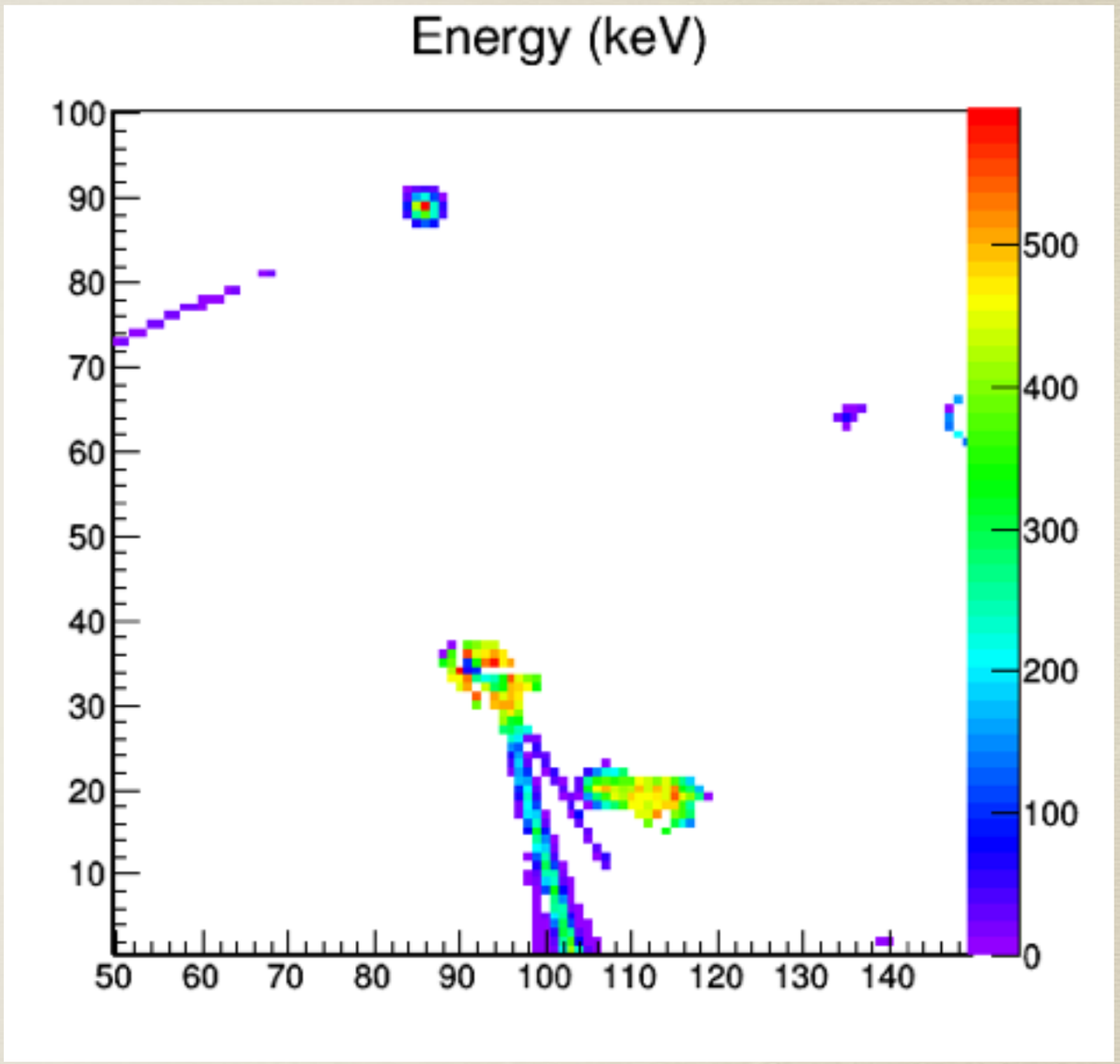
* Detector and readout provided courtesy of the CERN Medipix group
* General purpose hybrid pixel detector (wide dynamic range)
* Extremely good time resolution (1.2 ns on TOA)
* Concurrent TOA and TOT capabilities
* High density pixel matrix (55 um)
* 5 Gbit/s data rate through Spidr readout (VHDCI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

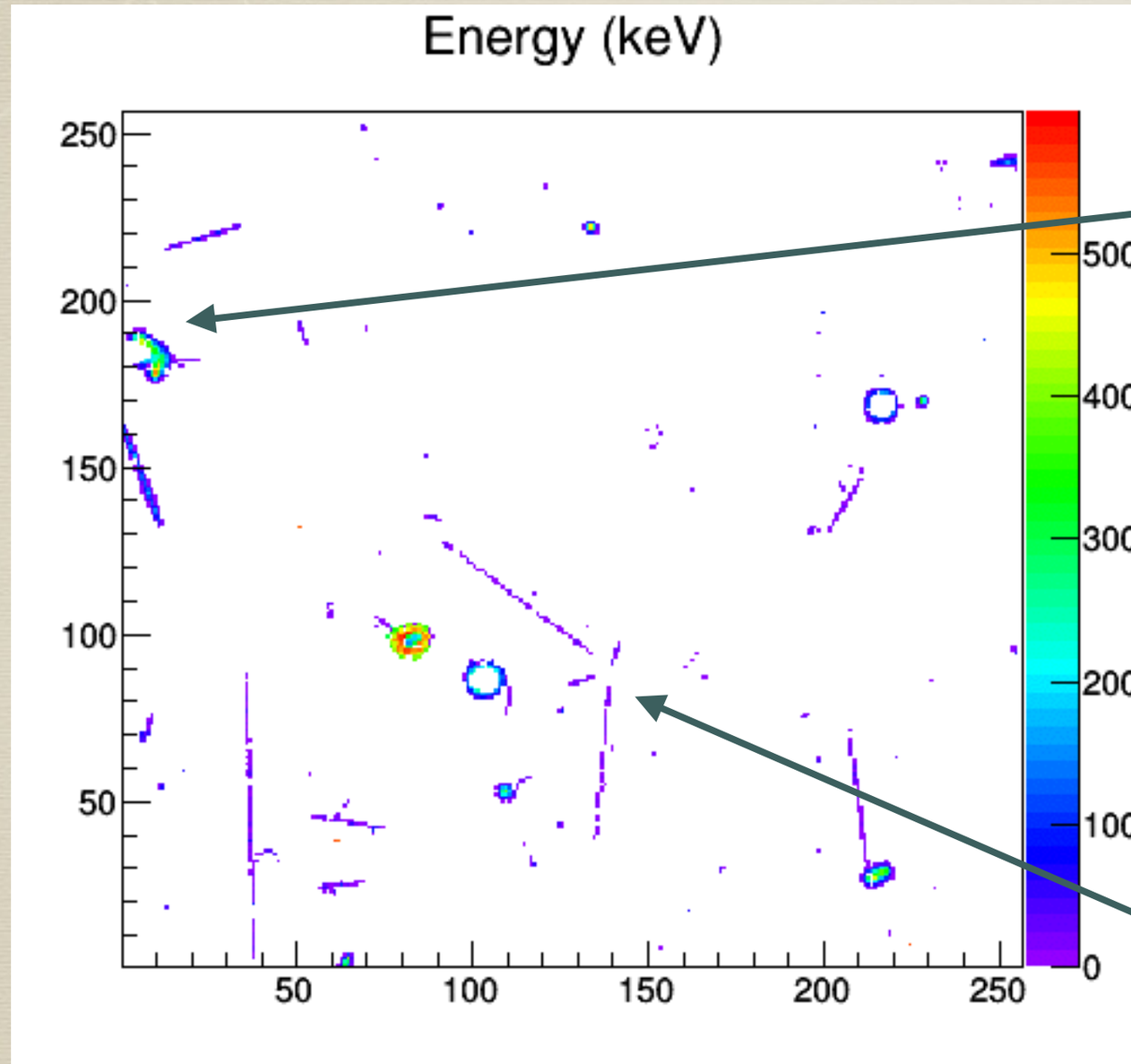
Tests with low energy antiprotons (E=8 keV)
- ID through Heavy Fragments -
300 um sensor

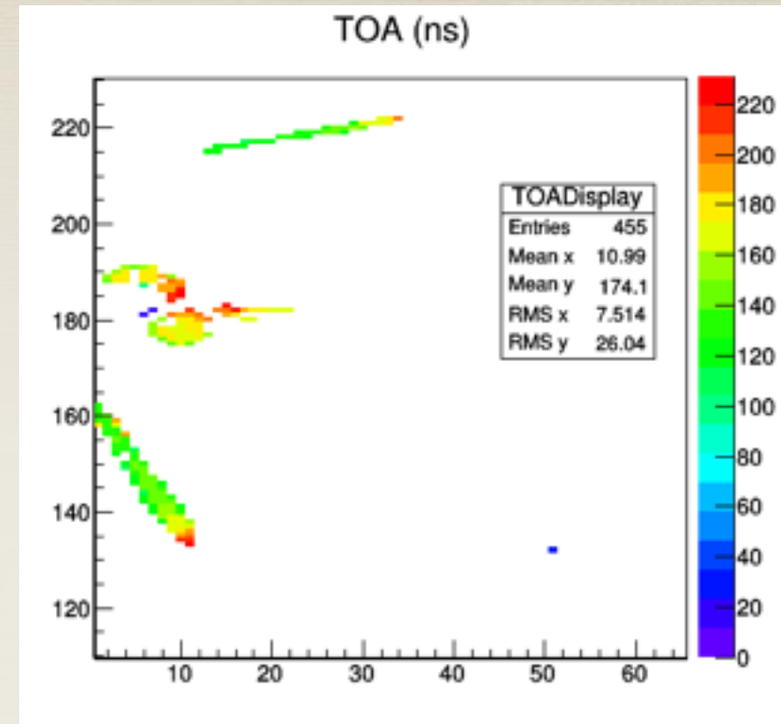




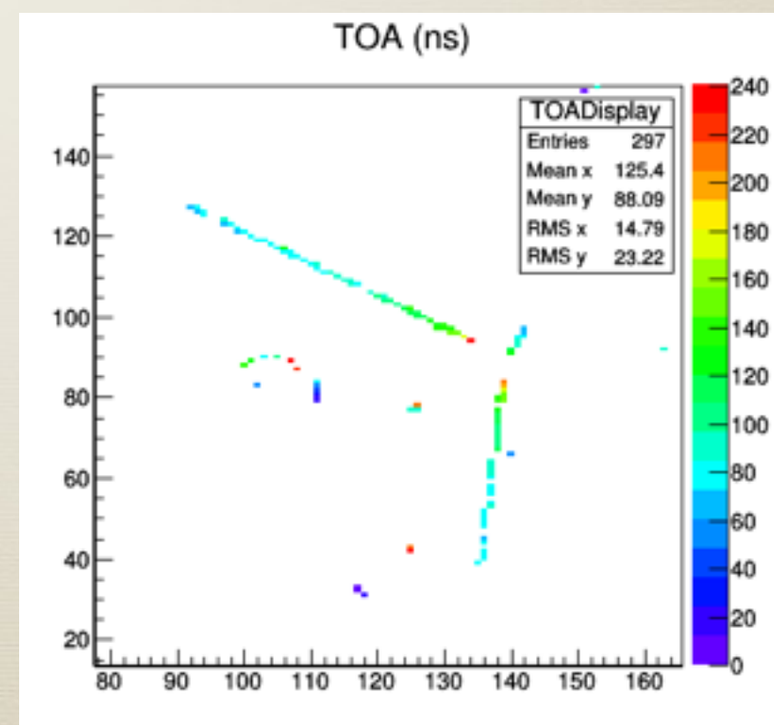
Pros: Easiest Signature to detect. Typical star shape and lots of energy deposited
Cons: Ions are produced less frequently and resolution is limited by track width and multiple scattering

Tests with low energy antiprotons (E=8 keV)
- ID through pion tracks -
680 um sensor



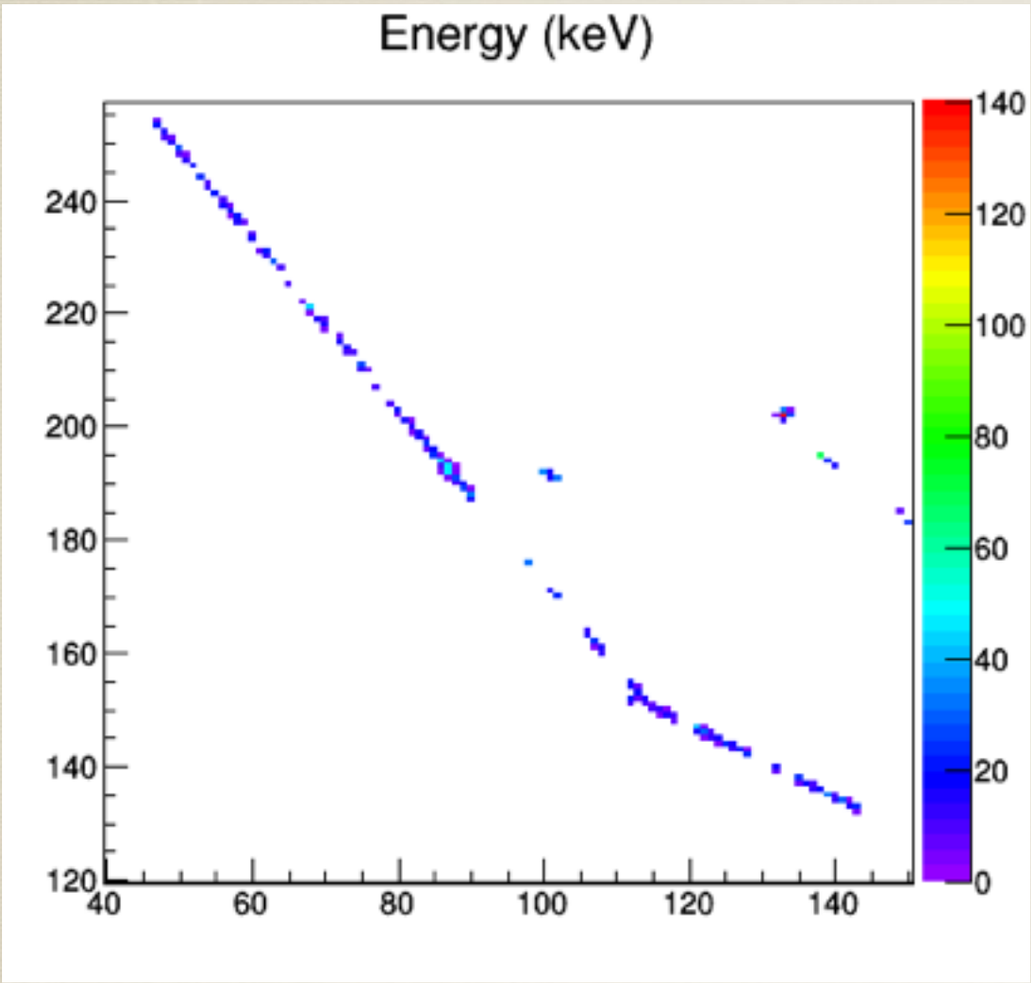


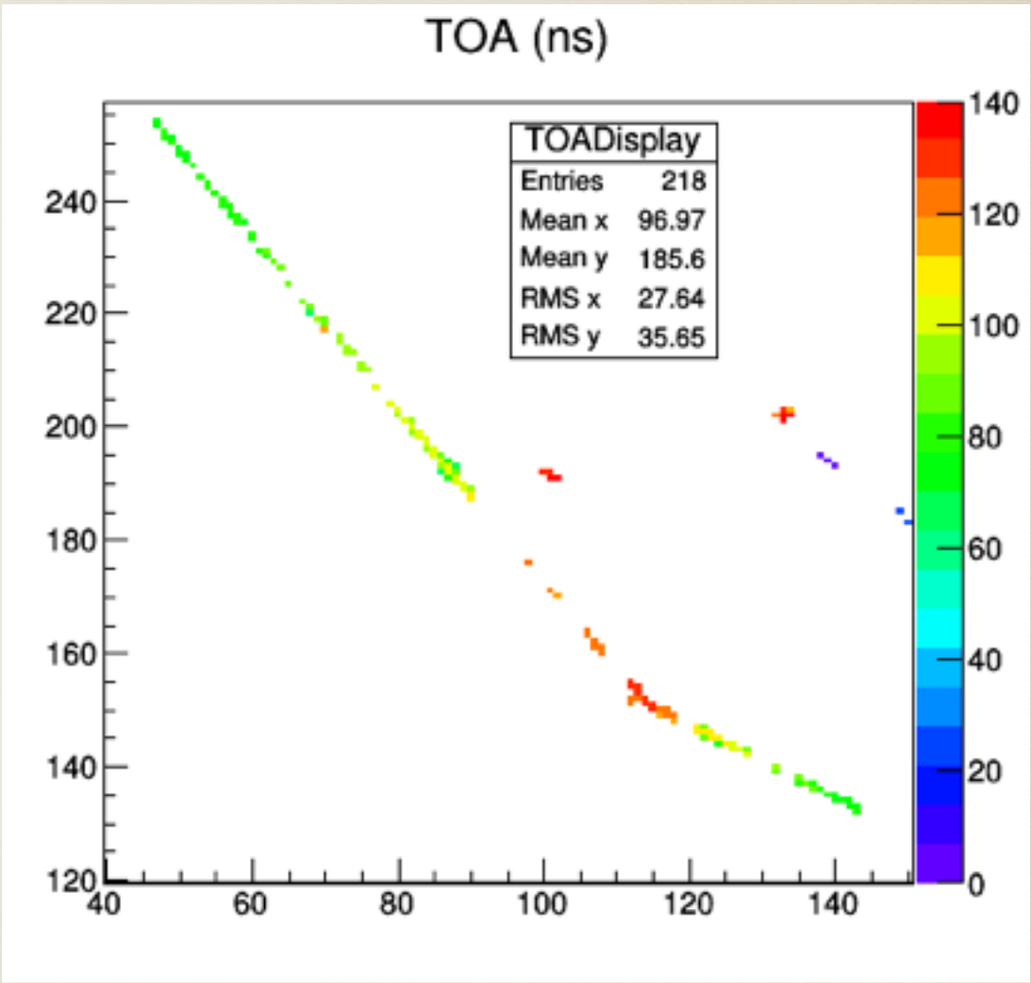
Annihilation on PCB



Surface annihilation

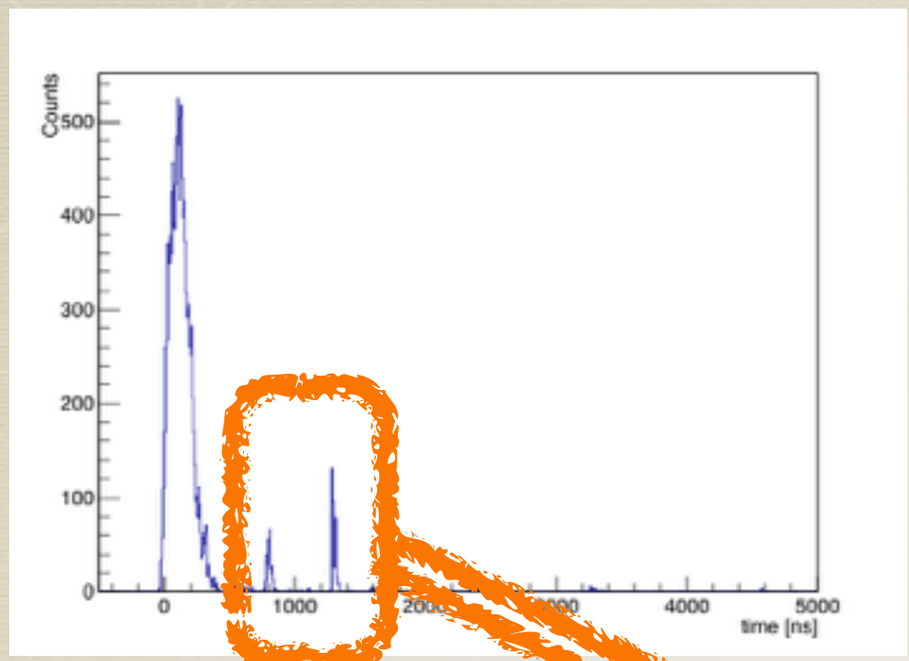
Tests with low energy antiprotons (E=8 keV)
- ID through pion tracks -



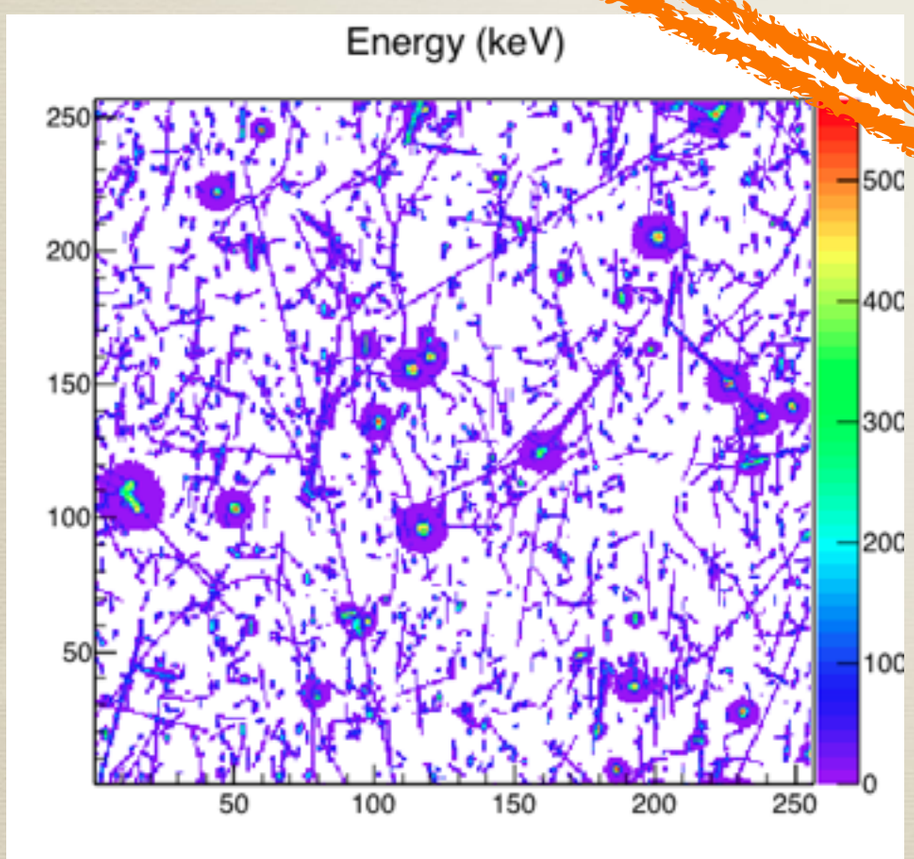


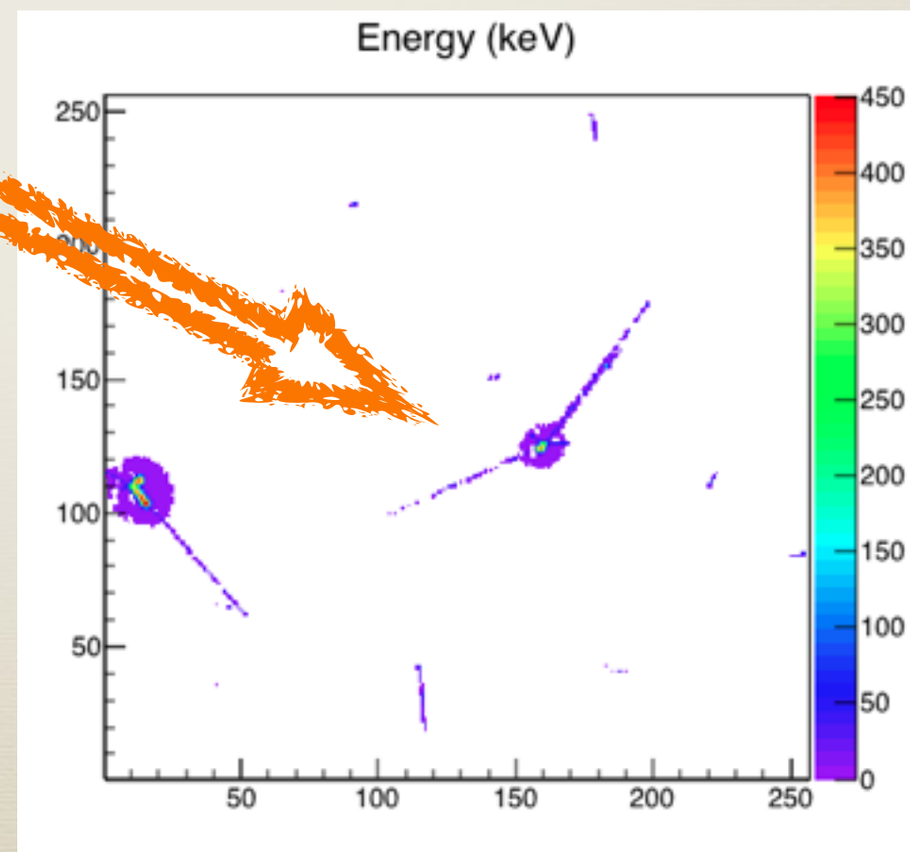
Tracks length in eccess of several mm are observed for many annihilation events.

Time topology



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

Thickness	Efficiency
300	10%
600	24%
900	33%
1200	40%
1500	43%
1800	45%

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).