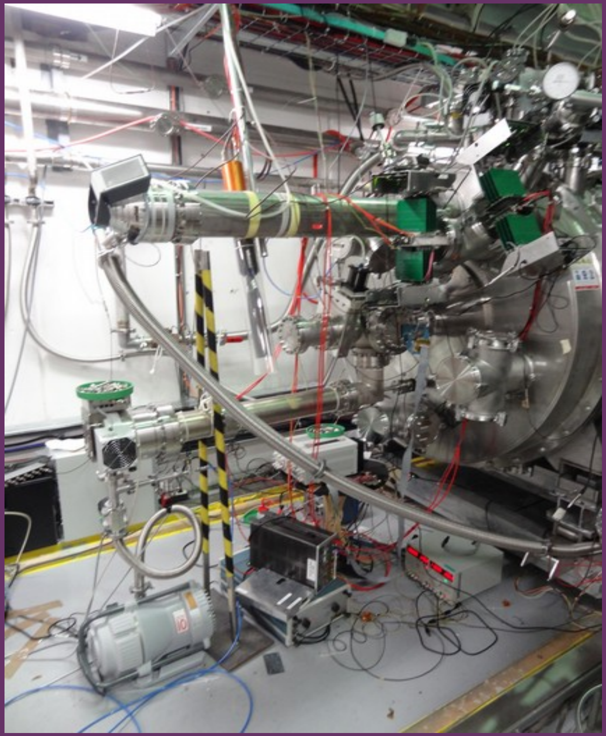

Detection of antiproton annihilation with silicon detectors of different geometry

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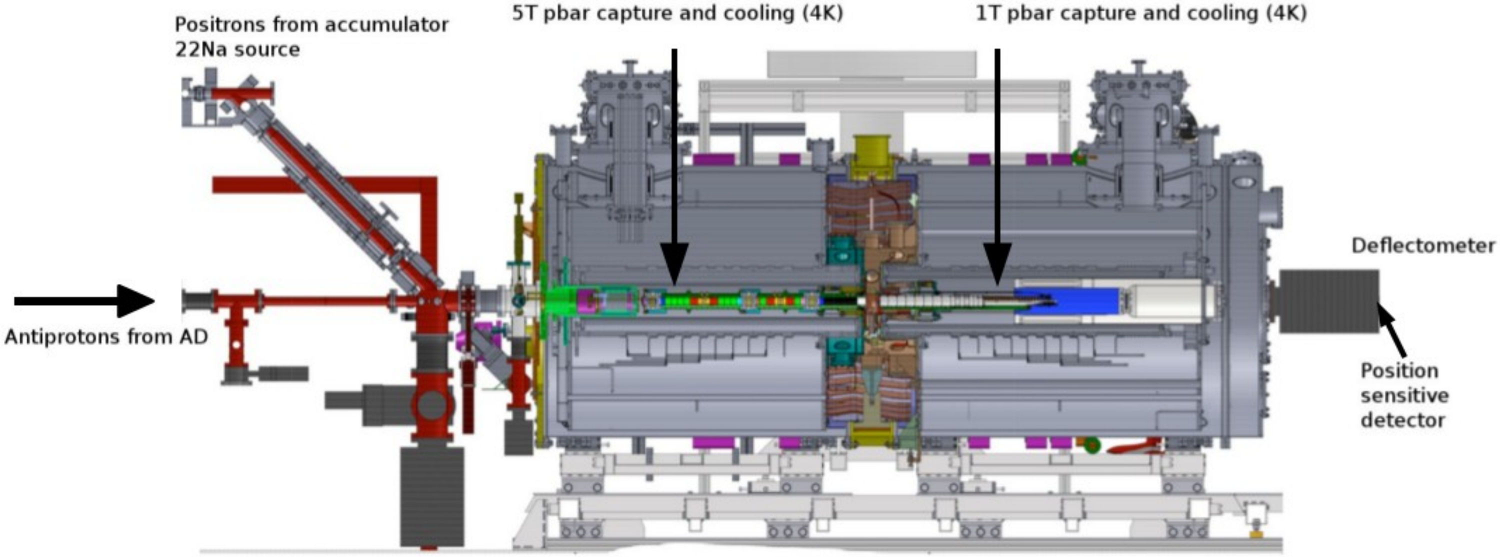
On behalf of the AegIS collaboration with Cinzia Da Via, Clara Nellist (3D)

Hiroshima, HSTD 9, 2013

Outline

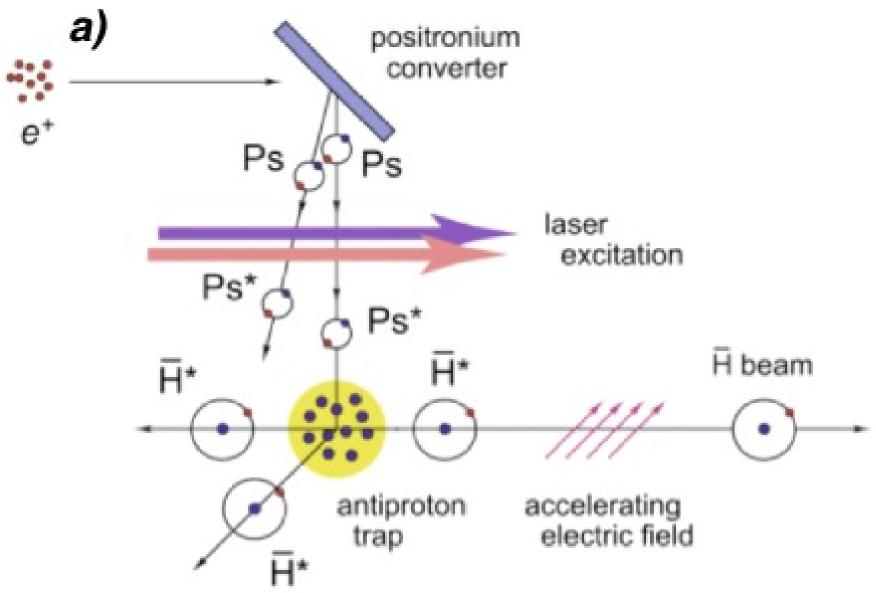
- A silicon antihydrogen detector for the AEgIS experiment
  - The AEgIS experiment
  - Working principle of AEgIS
  - Aim and requirements for the silicon sensor
- Test beams:
  - Previous results: the MIMOTERA detector
  - Miniature strip sensors, Alibava readout
  - CNM 3D detector with FE-I4 readout
- Results
- Conclusions and further developments

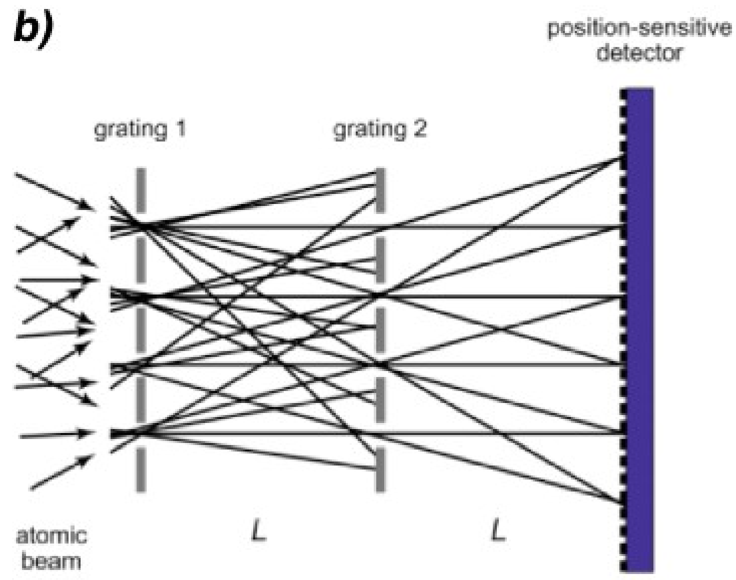
AEgIS – Section view of the main apparatus.



- Aim of AEgIS is the determination of the gravitational acceleration of antihydrogen in Earth's gravitational field.

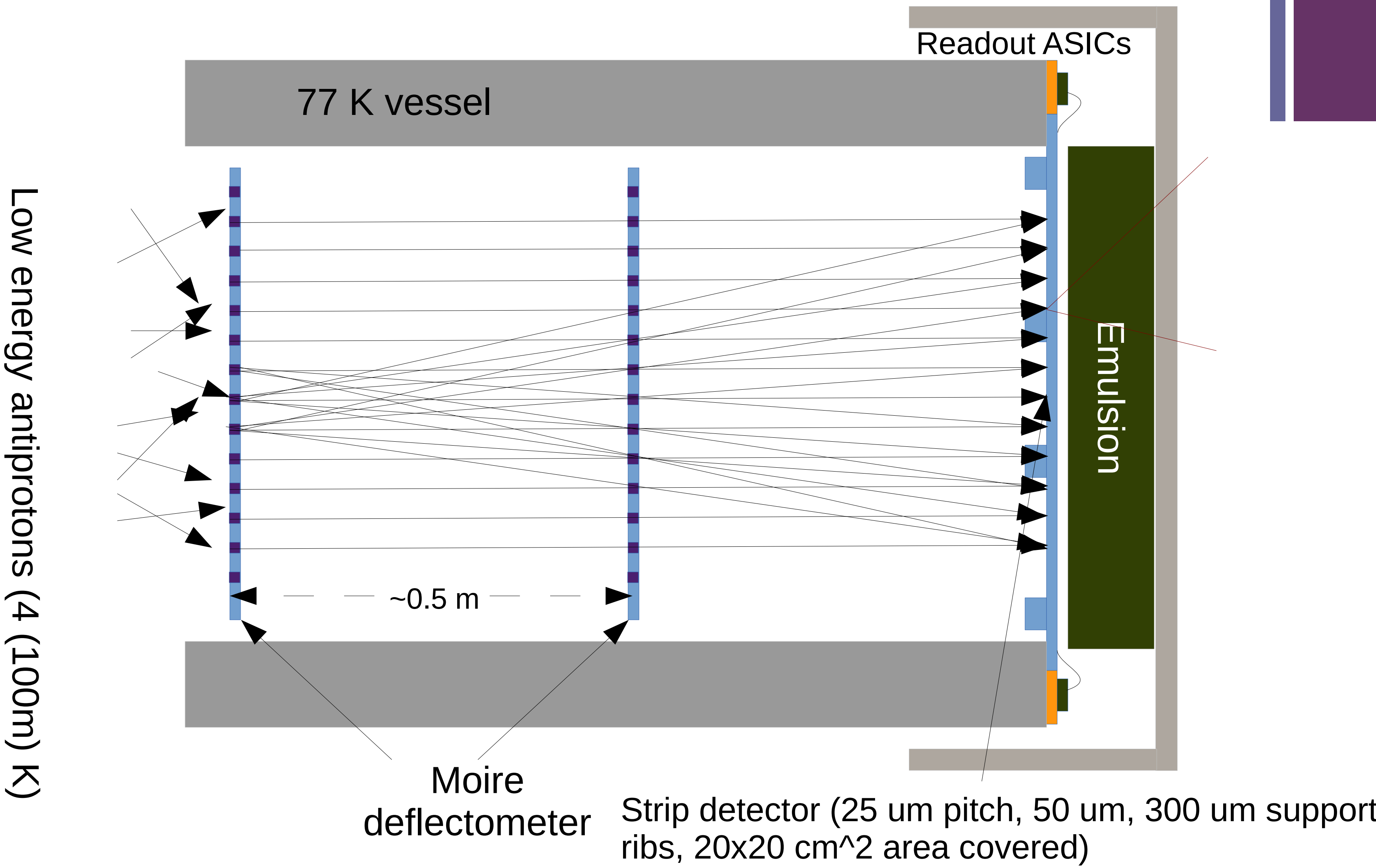
Producing and detecting the antihydrogen



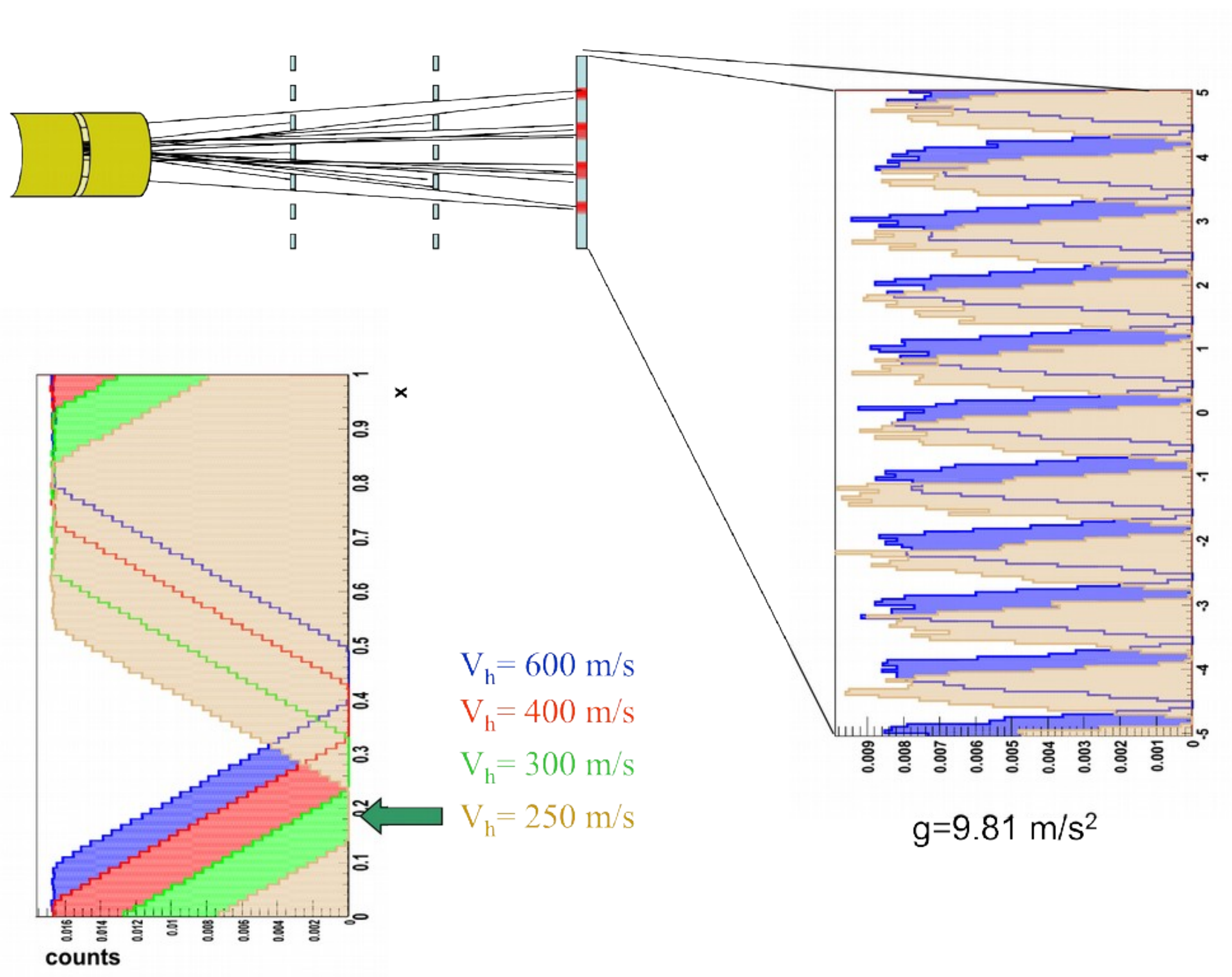


- Thermal motion of antihydrogen (though cold, to 4K and eventually to 100 mK) also has a random transversal component.
- Path selection is made by means of a Moire deflectometer, a TOF measurement is required to know the longitudinal component.

The Moire deflectometer and the Hybrid detector



How we measure gbar?

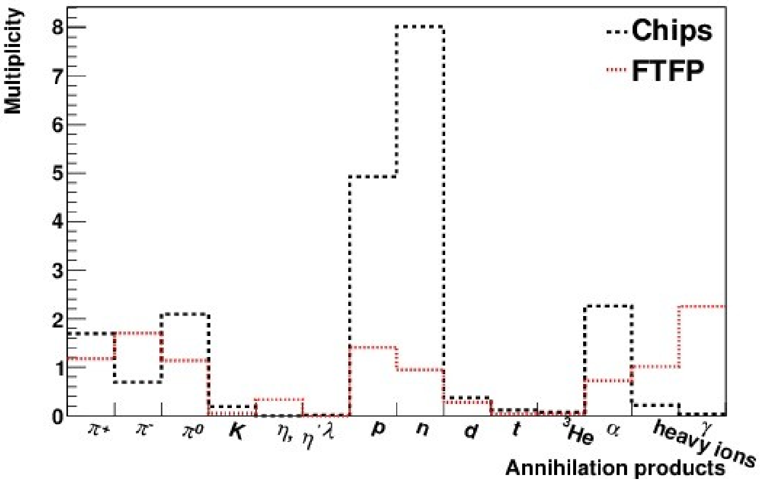


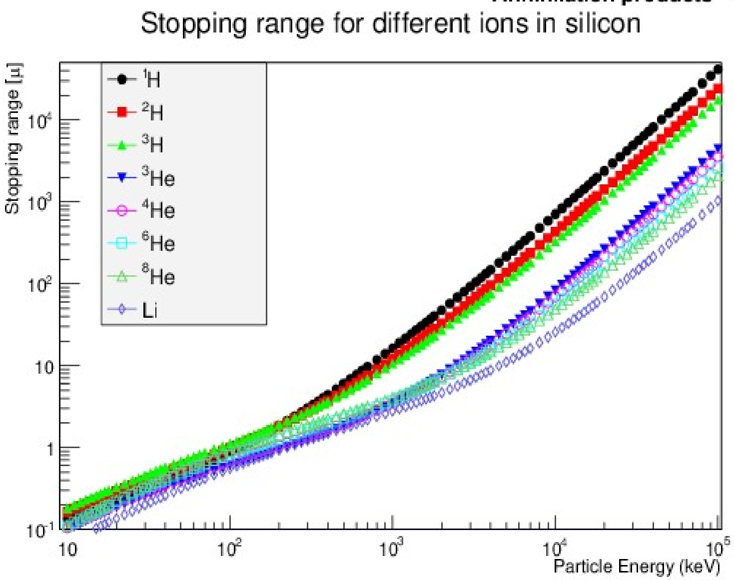
- Shift of the fringes wrt horizontal path proportional to gbar on antihydrogen
- High resolution required (better than 5 um for measuring a 20 um deflection of the pattern) to achieve 1% precision on gbar at expected statistics
- Main source of error from multiple scattering of annihilation products.

+ Aims of the AEgIS silicon detector

- Observation of direct annihilation on a silicon strip detector
- Online beam quality check
- High efficiency (90%) in the detection of antihydrogen
- Measurement of the annihilation position of the antihydrogen with a single hit resolution better than 25 um, providing a seach seed for the downstream emulsion detector.
- Precision measurement of the TOF of single antiprotons

Annihilations in silicon



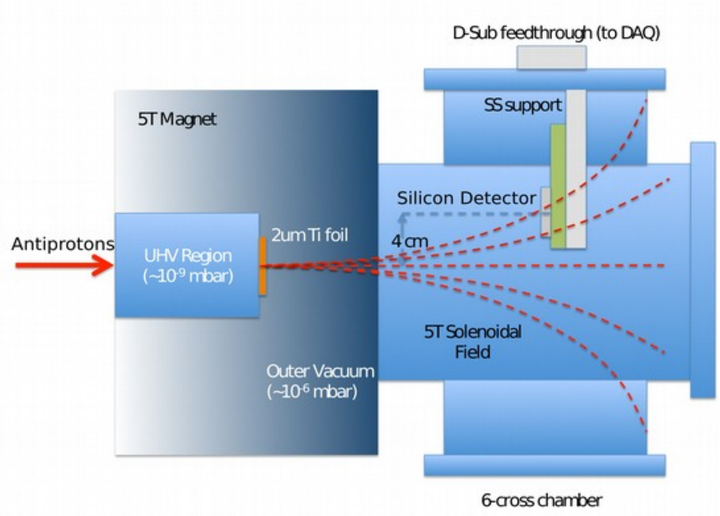


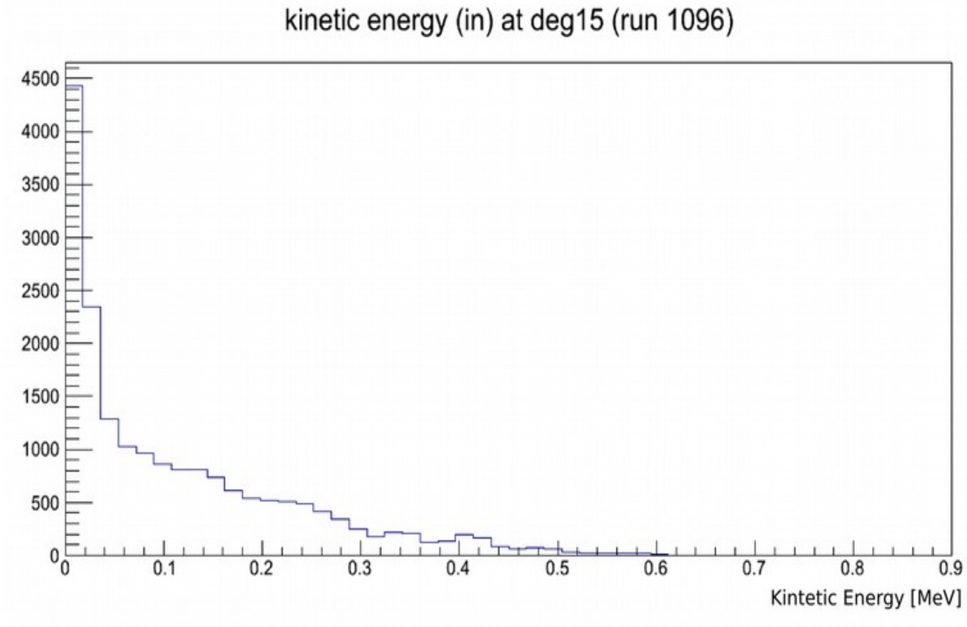
- Annihilation of antiprotons with a nucleon produces mainly pi-mesons
- If the annihilation happens within a nucleus of a heavier element, pions may interact and cause nuclear fragmentation
- Detection of annihilation is made through the detection of charged annihilation products (pi-mesons, protons, heavy nuclear fragments)
- Total kinetic energy of products emitted in annihilations up to ~1,880 MeV

+ Test beam

Aim:
Understand the signature of annihilation events in silicon in different kinds of silicon sensors.

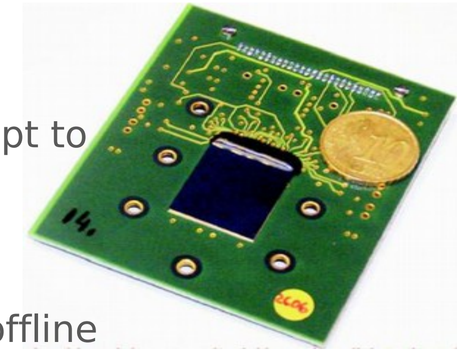
- Spill composed by 10^7 antiprotons
- Spill spacing ~ 100 keV
- Antiproton energy spectrum slowed down to ~ 100 keV by means of Aluminum degraders
- Annihilations expected within ~ 15 um from detector surface
- Detector mounted in vacuum chamber, vacuum level 10^-7 mbar
- Tests took place during 5 days in december 2012

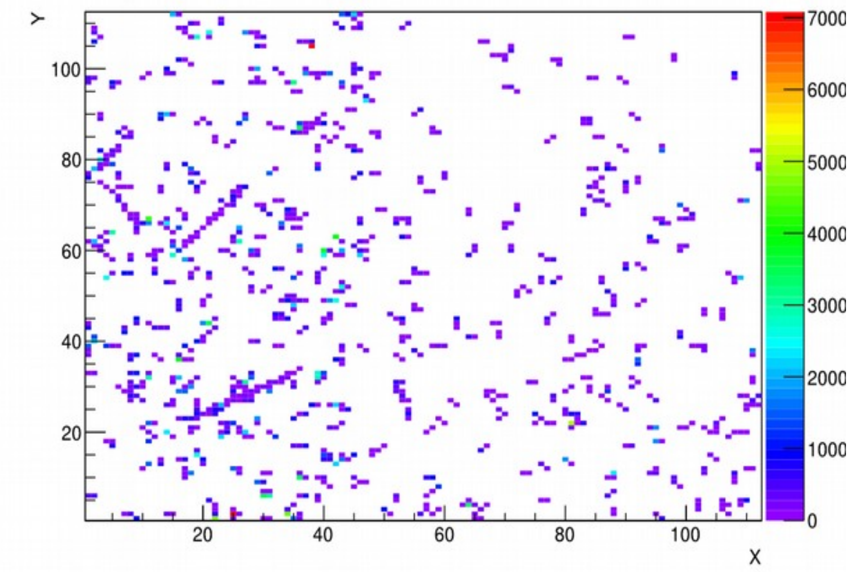




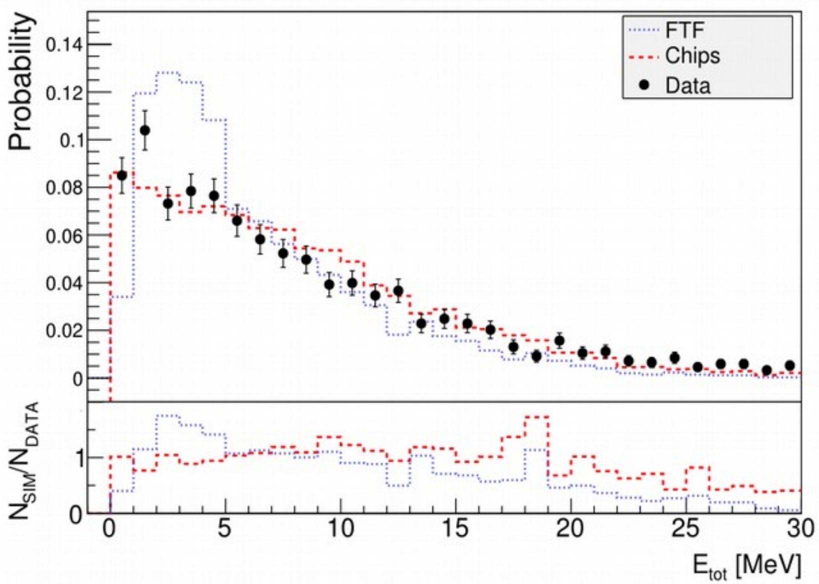
Previous results

- Previous test-beam (May, 2012) using the Mimotera (Monolithic diffusion pixel) – First ever (successful) attempt to measure antiproton annihilation directly on silicon!
- 14 um thickness, pixel size 153x153 um
- 2.5 MHz total analog readout without zero suppression (offline cut of noise events)



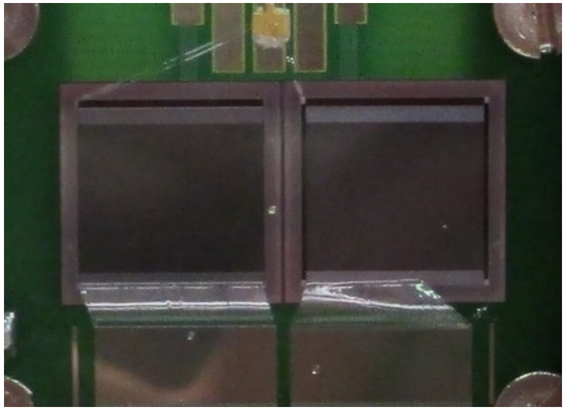


Sample frame of an annihilation event after noise and background suppression.



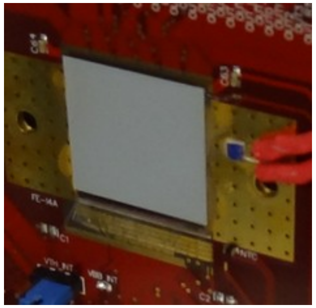
Cluster energy spectrum with Geant4 comparison.

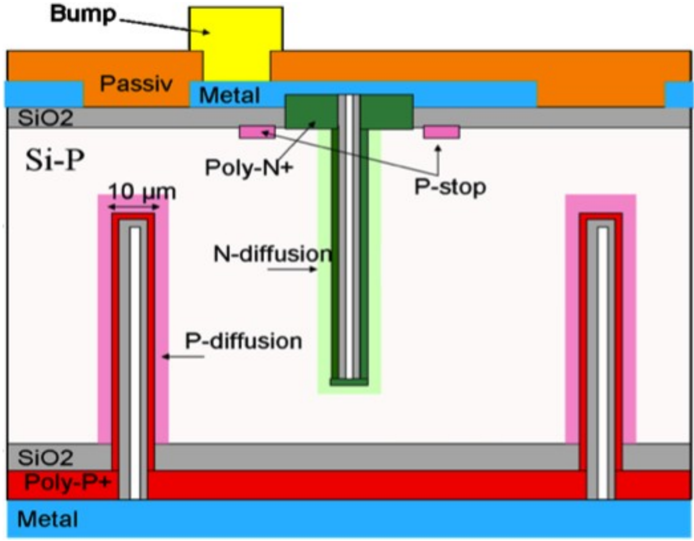
+ Tested sensors



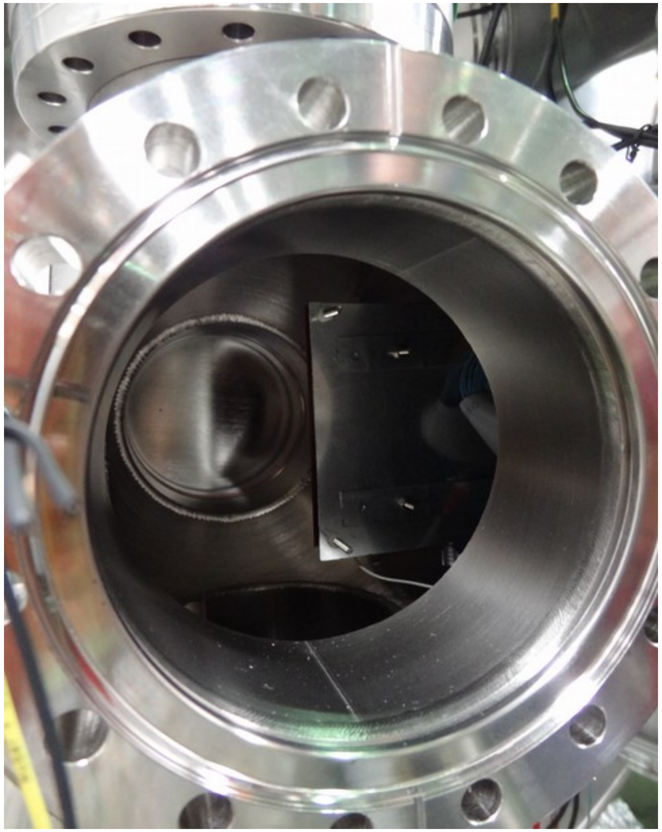
- Two silicon strip sensors:
  - Sensor 1: 300 um thickness, 80 um pitch, 128 strips, 1 cm strip length.
  - Sensor 2: 300 um thickness, 50 um pitch, 128 consecutive strips connected, 1 cm strip length
- Sensors, realized on MCz silicon, were provided courtesy of HIP.
- Sensors' depletion voltage ~ 120 V.

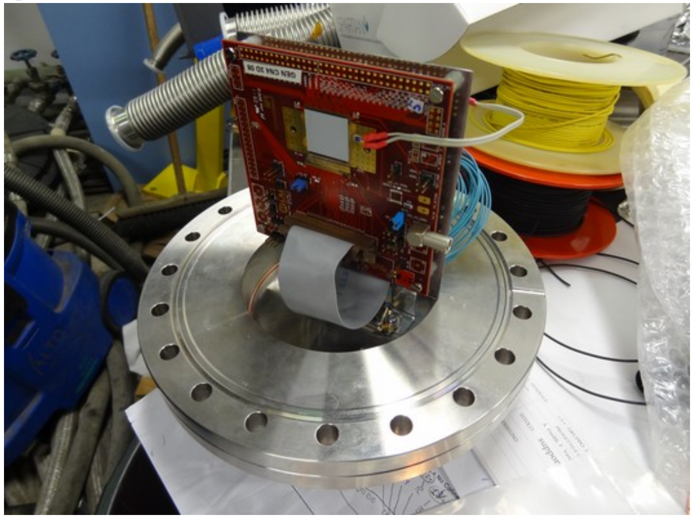
- CNM 3D sensor, developed for the IBL:
- 230 µm thickness, electrode diameter of 10 µm
- Bias voltage down to -30 V
- Pixel dimensions: 50 µm x 250 µm, 80(col) x 336 (rows) = 26880 cells.
- 2cm x 2cm
- 2um passive material on surface (stopping slower particles)

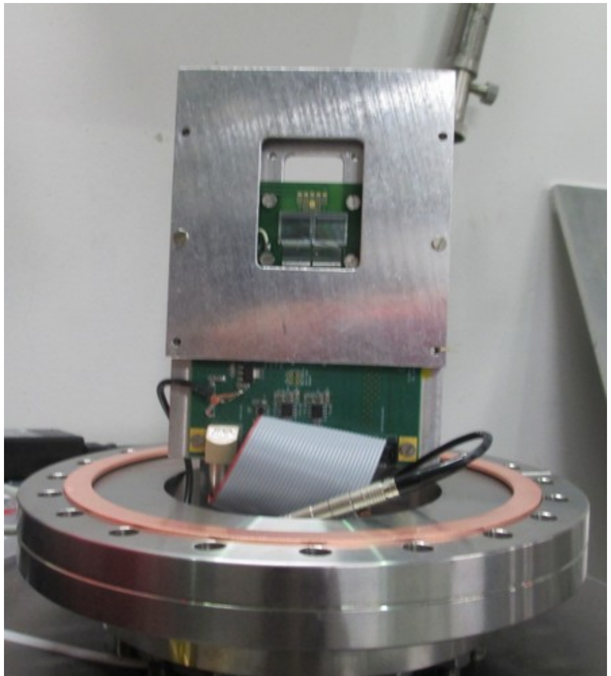




+ Detector mounting and measurements

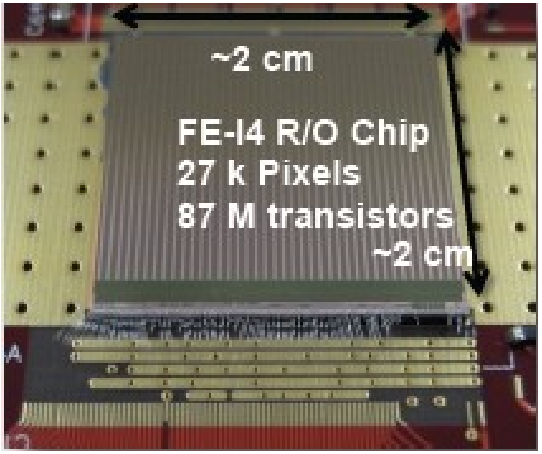


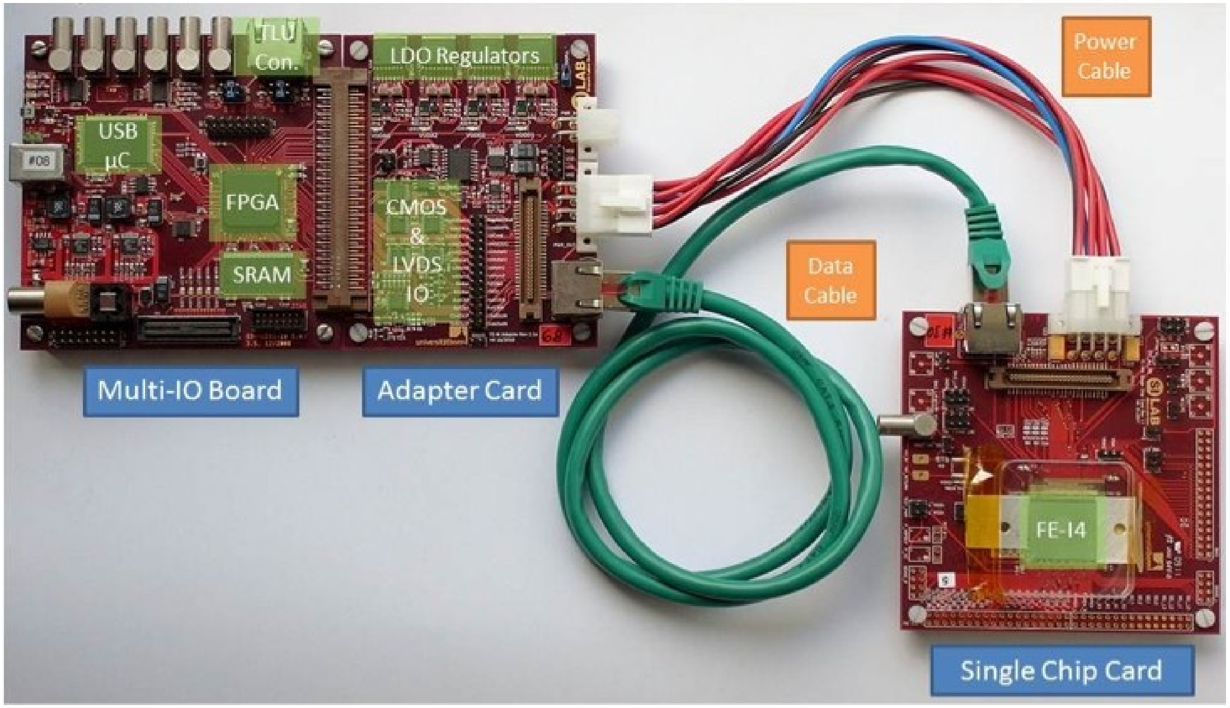




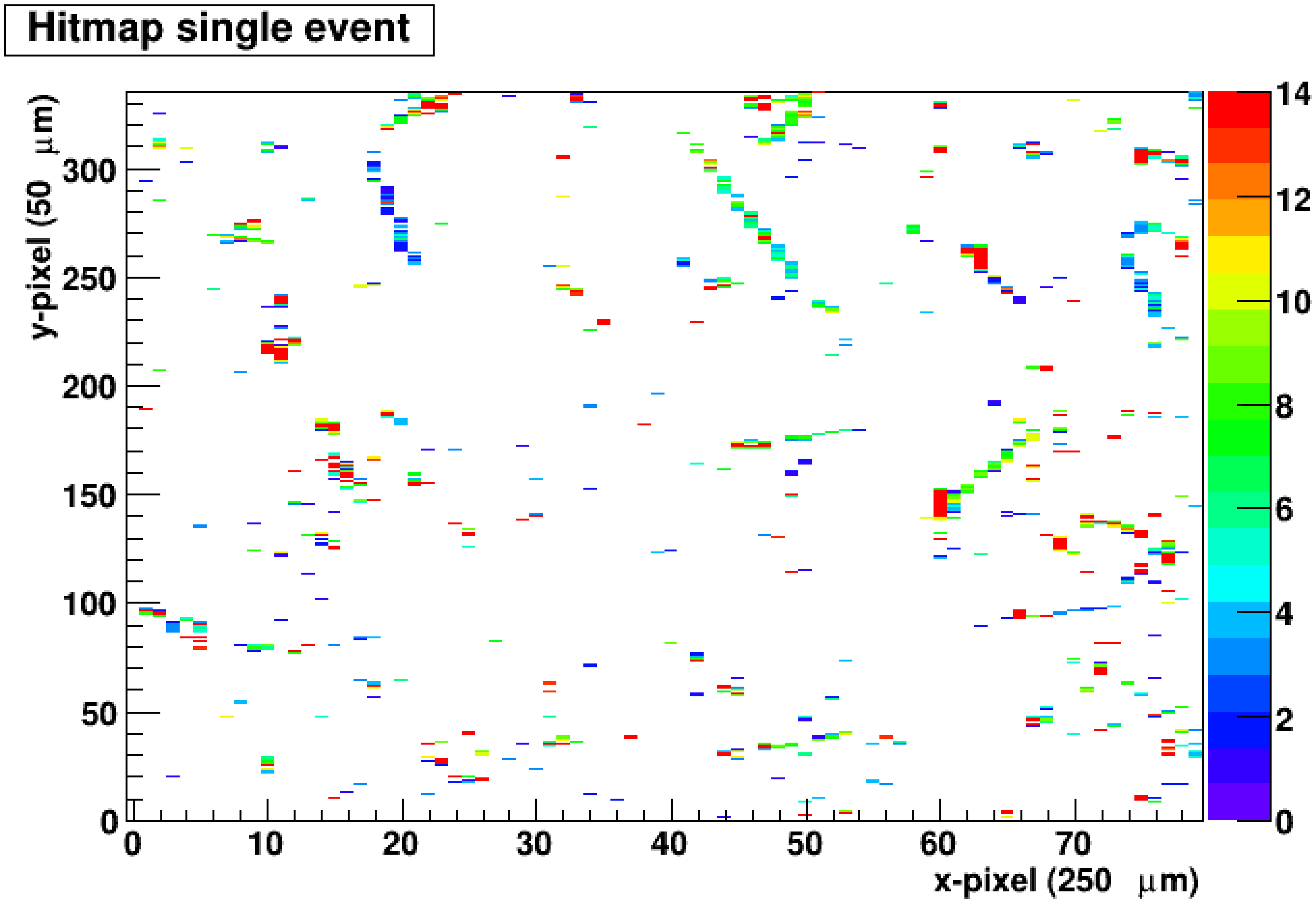
3D detector: readout system

- Multipurpose I/O board with USB interface
- Adapter card
- Single chip card (sensor front end) with FE-I4 readout: (50x250 um cells)
- Zero-suppressed redout



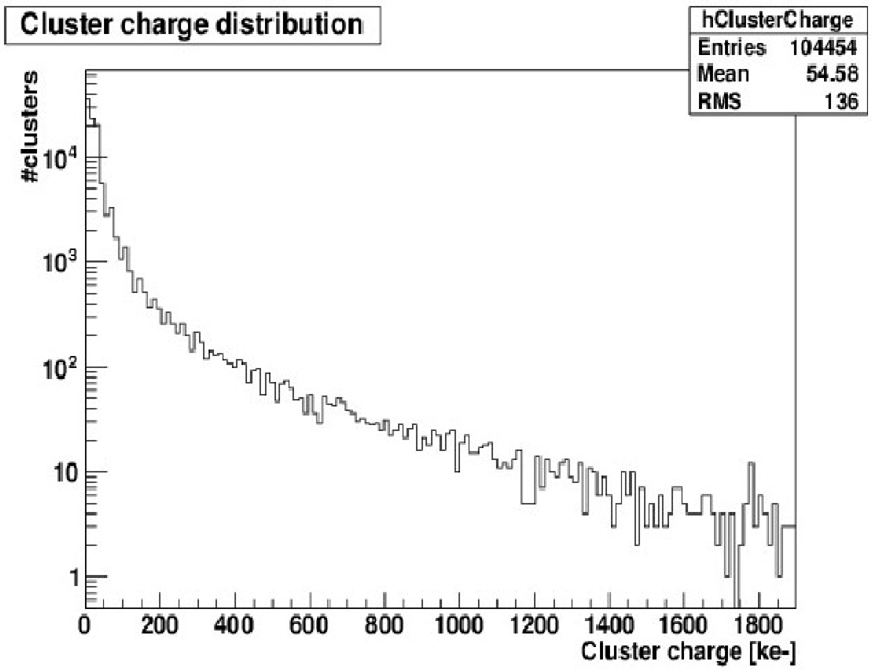


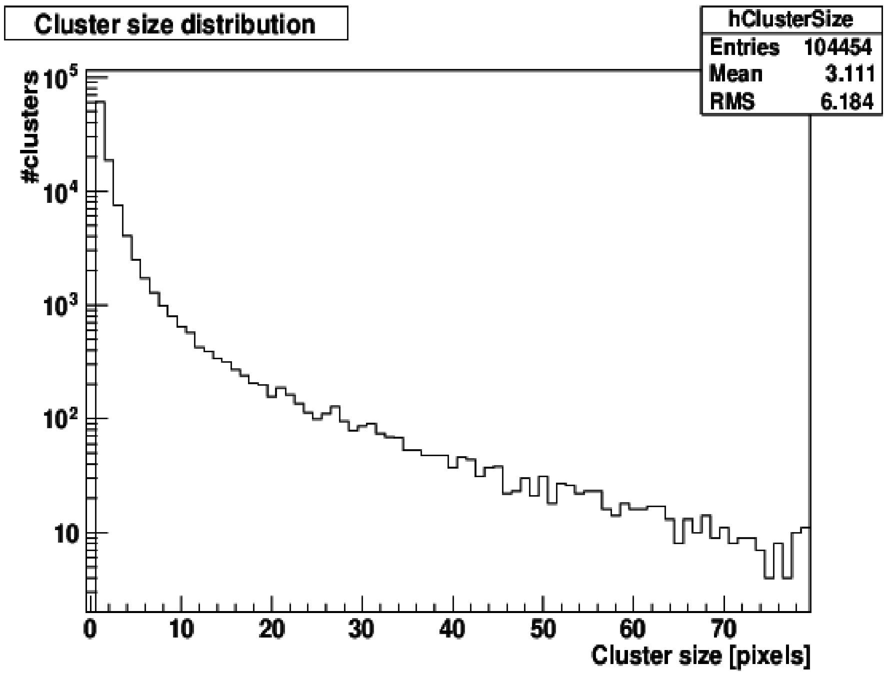
3D: annihilation event



- Saturation of a few pixel (high energetic fragment at annihilation point)
- Long tracks recorded with different energy deposits (pions – blue tracks, protons, green to turquoise tracks)

+ 3D cluster analysis



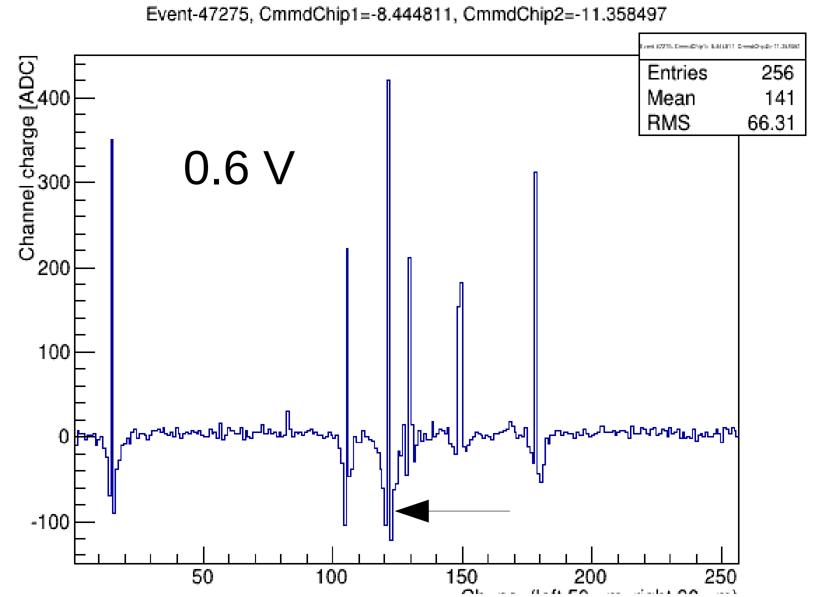


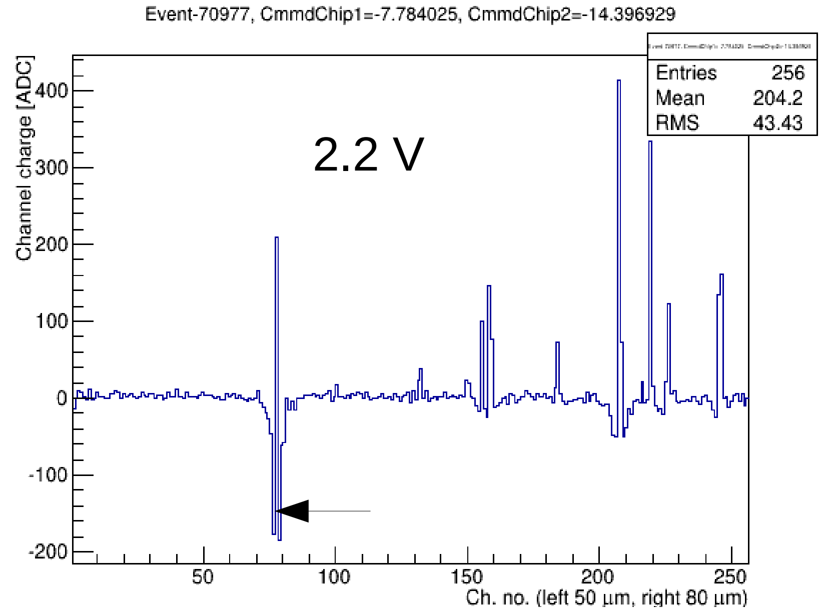
- Wide spread of cluster size (long in-plane pion tracks)
- Cluster energy in excess of 10 MeV.

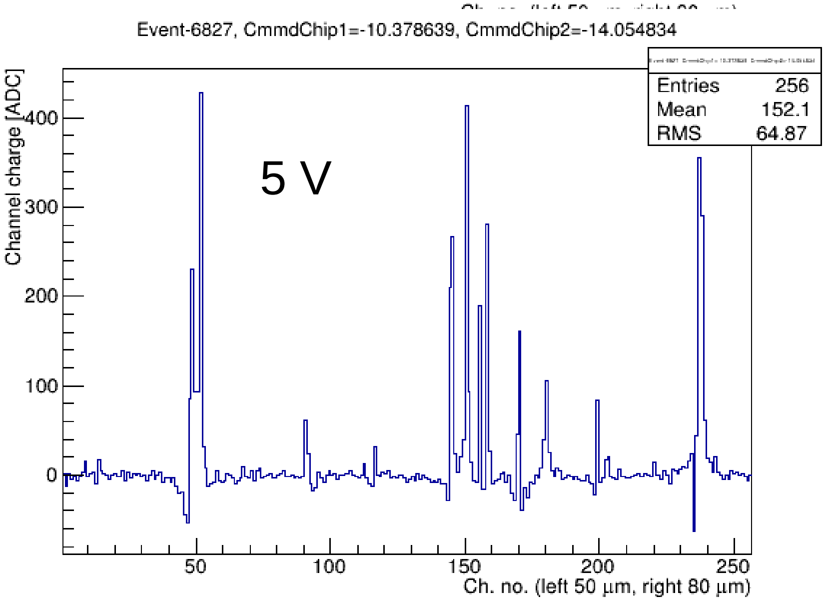
+ Strip detector: readout system

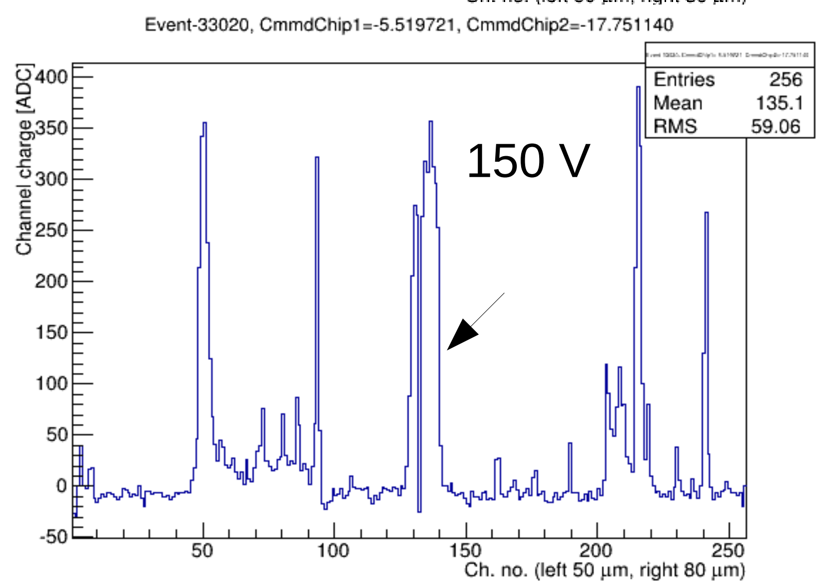
- The tests were performed using the Alibava test system, provided courtesy of RD50 collaboration.
- USB readout making use of two Beetle chips (LHCb Velo) with 25 ns shaping, 128 channels each
- Triggering was done on AegIS silicon beam condition monitor scanning manually through different latencies
- Given Alibava DAQ incompatibility with slow triggers, a 30 Hz trigger was continuously running (pedestals), 'OR'ed with the trigger from the Antiproton Decelerator.

+ Sample frames at different Vbias





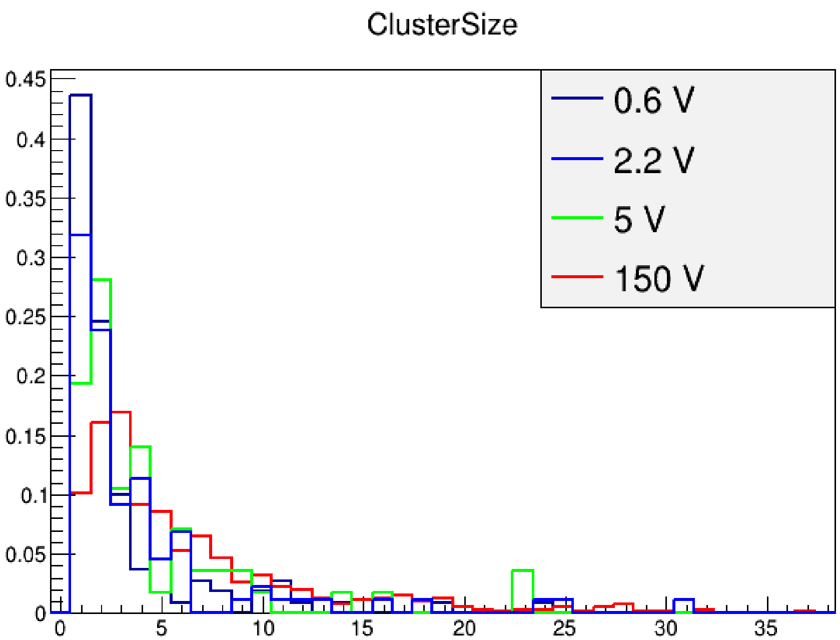




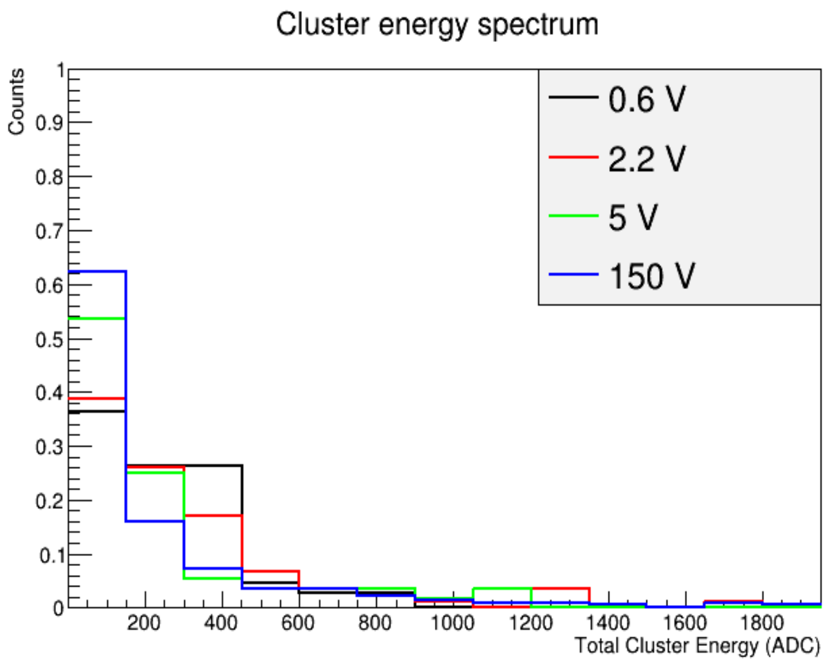
Varying Vbias to “virtually” test different detector thicknesses

Strip: cluster analysis

- Selection on the frames with lower occupancy (<40%)
- Clusters defined at > 5 noise RMS conglomerates of strips (no seeding algorithm possible here)



Decrease in the active volume corresponds to a lower sensitivity to long-travelling (low-ionizing particles): Improved position resolution.



Decreased sensitivity to long-travelling products (low ionizing) affects the distribution at lower voltages.

+
Strips: considerations on the active volume / thickness of the detector

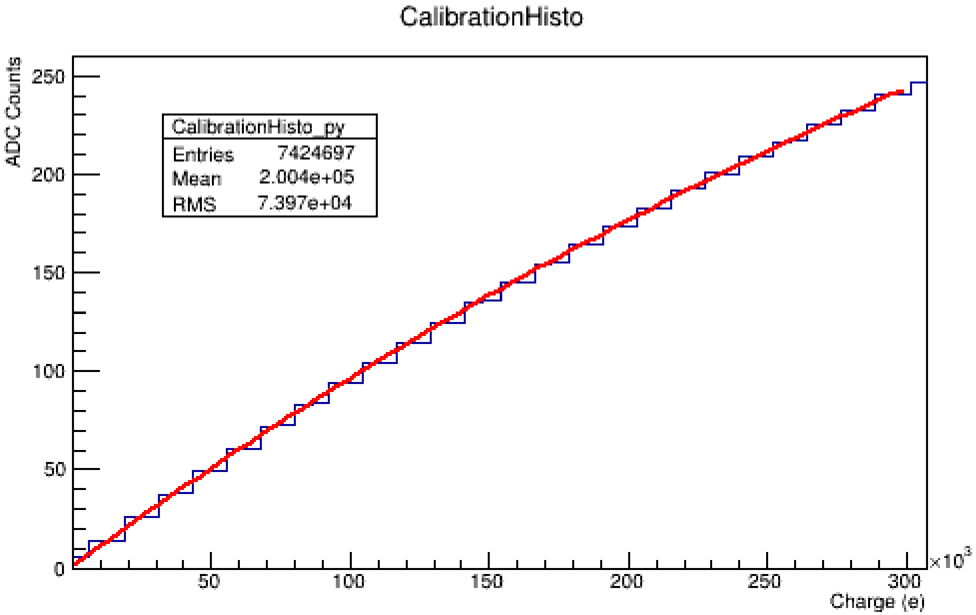
- Events at low applied bias voltage (20 to 50 um depletion) are very localized (max 2 strips in 70% of the events)
- Low voltage brings to consistent undershoots in the strip neighboring the event: increase in the interstrip capacitance
- Higher voltages (full detector depletion) result in extension of the active volume: annihilation products with long range can extend considerably the cluster (even to millimeters), negatively affecting the detector resolution.

Conclusions and developments

- Cluster composition (heterogeneity) doesn't allow the reconstruction of the annihilation position by standard centre of mass methods in the strip detector.
- Primary source of resolution is the position of short-travelling products (heavy fragments) which can be identified by large and localized energy release
- Resolution down to foreseen strip pitch width for the final detector
- Resolution on the fringes should be achieved in the final detector to 25 um / sqrt(12)~ 8 um.
- The requirement of having a thin detector (avoid multiple scattering of products) is compatible with having the highest possible resolution achievable with the sensor technology.

+ Backups

Alibava calibration curve up to 300 ke:



$$ADC = a \cdot \left[1 - \exp\left(-b \cdot charge\right)\right]$$

A=5.89e2, B=1.77e-6