Reflections of Low Energy Antiprotons on Foils

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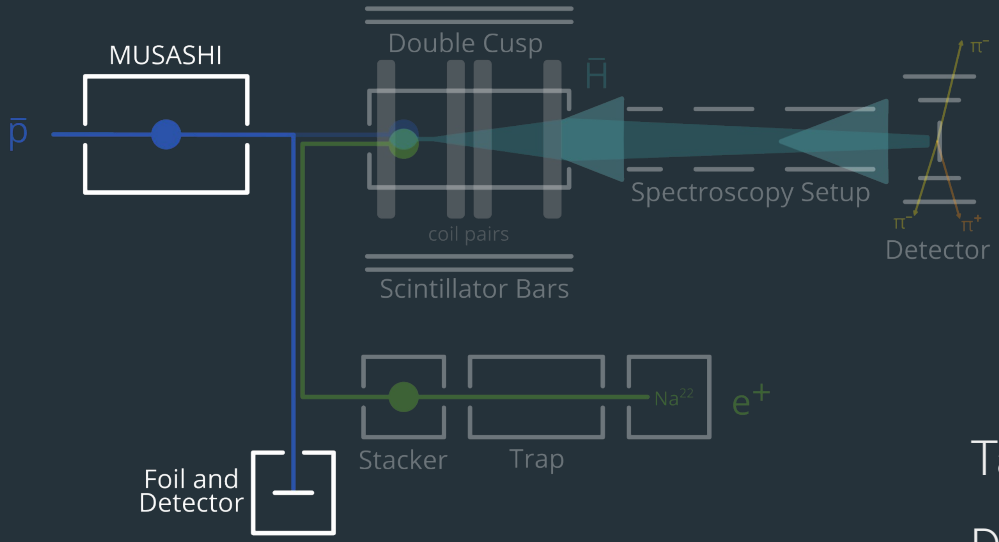
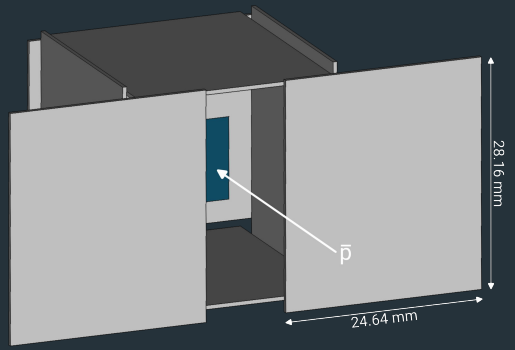
CERN

1. Motivation
2. Antiproton Reflection
3. Experimental Setup
4. Simulations
5. Conclusion

Antiproton Annihilation Study



Permanent electrostatic beamline for slow extraction in ASACUSA



Target foil surrounded by detectors

Detector ready by end of summer

- Reconstruct annihilations
- Measure scattering antiprotons

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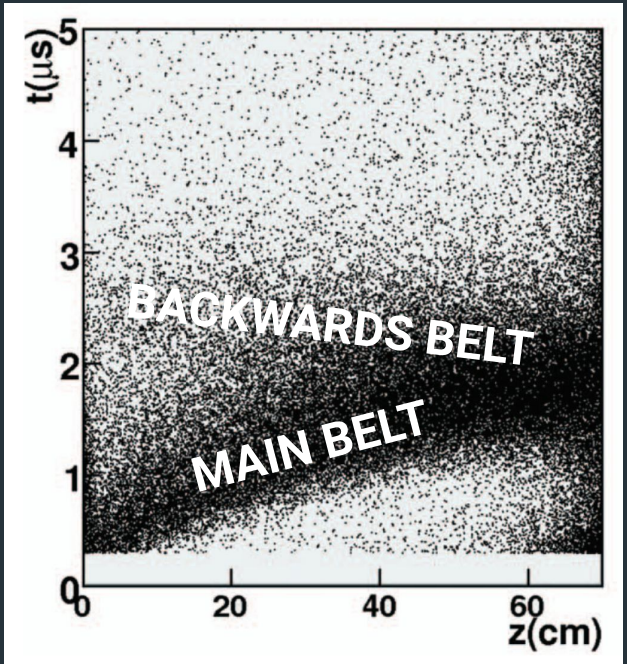
Previous Reflection Measurements



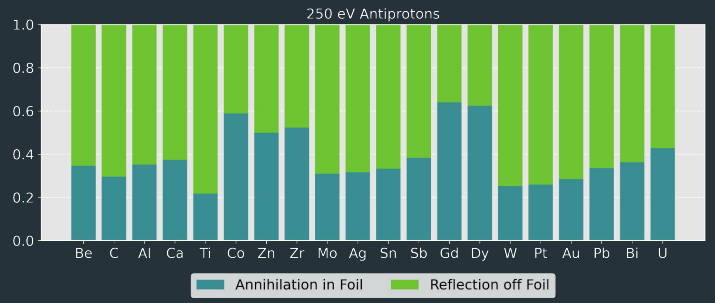
Bianconi et. al. Phys Rev A 78 (2008)
Experimental evidence of antiproton reflection by a solid surface

"The experimental evidence refers to **antiprotons that are reflected with energy approximately a few keV, by a wall of solid aluminum**. At these energies, the simulation of the reflection process shows that it is dominated by multiple Rutherford-type "large angle" scattering, where "large" means some tens of degree. According to our simulation, the reflected fraction should increase at decreasing energy, possibly reaching 50% at 500 eV."

20 - 30 % of the 1-10 keV antiprotons were reflected

Motivation

Initial simulations of the annihilation experiment showed that according to Geant4 a large amount of 250 eV antiprotons should reflect from the foil
Fluka does not include antiproton scattering below 1 keV energies



Antiproton scattering has not been studied at sub-keV energies

- Ratio of annihilating to scattering antiprotons unknown
- Numerous processes play a role at these energies
- No reliable theory or simulation available

Nordlund et. al. Phys Rev A 106 (2022)
Bianconi et. al. Phys Rev A 78 (2008)

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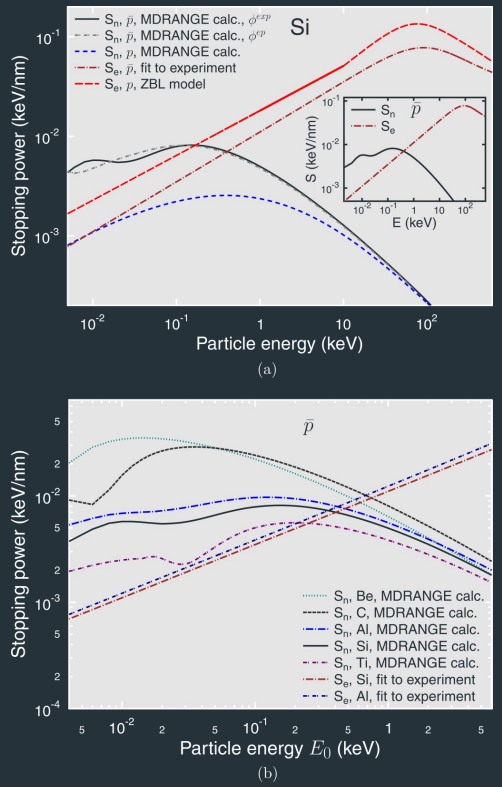
Reflection Process

Energies above keV:

- Consecutive Rutherford scattering at angles 10° - 40°
- Electronic stopping power is dominant

Energies below keV:

- Contributions from multi-electron and molecular effects
- Large angle collisions become more likely
- Nuclear stopping power becomes more relevant



Nordlund et. al. Phys Rev A 106 (2022)
Bianconi et. al. Phys Rev A 78 (2008)

Nordlund et. al. Phys Rev A 96 (2017)

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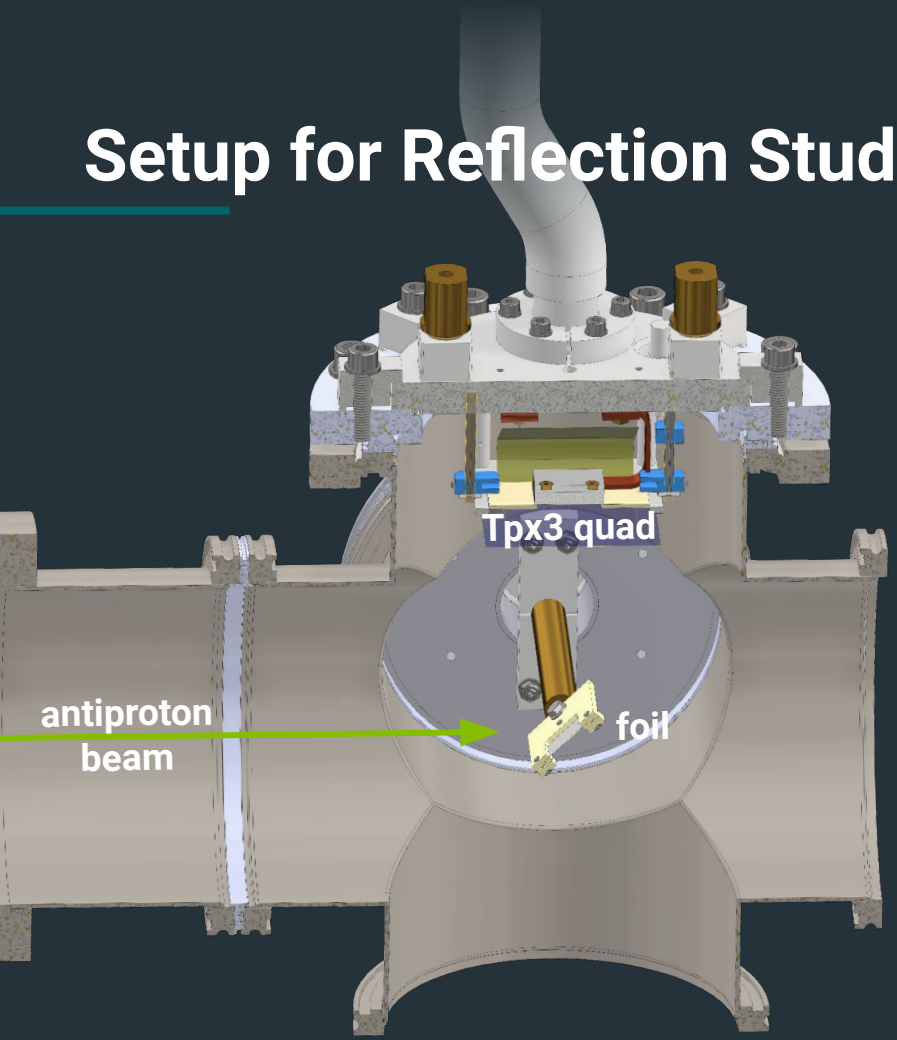
Setup for Reflection Study



Modified setup from annihilation study:

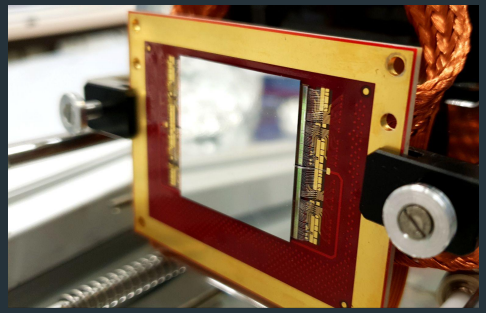
- Different foils mounted on a rotatable manipulator
- Timepix3 quad

250 eV antiproton beam
(possibly also 500 eV)

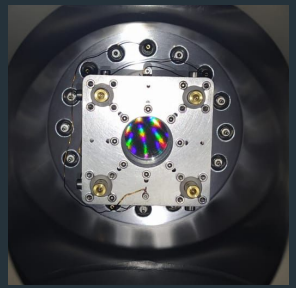
~ 25,000 antiprotons/extraction

Equipment

Detectors

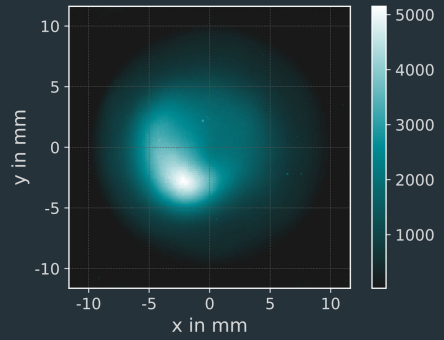


- Timepix3 quad
  - Hybrid pixel detector readout chip
  - 512 x 512 pixels with 55 µm pitch
  - Time of arrival + time over threshold
- 8 plastic scintillators with SiPMs
  - Used as counters
  - Movable, can be placed anywhere around experiment chamber
- MCP with camera
  - Currently used to visualize the beam spot and estimate # antiprotons

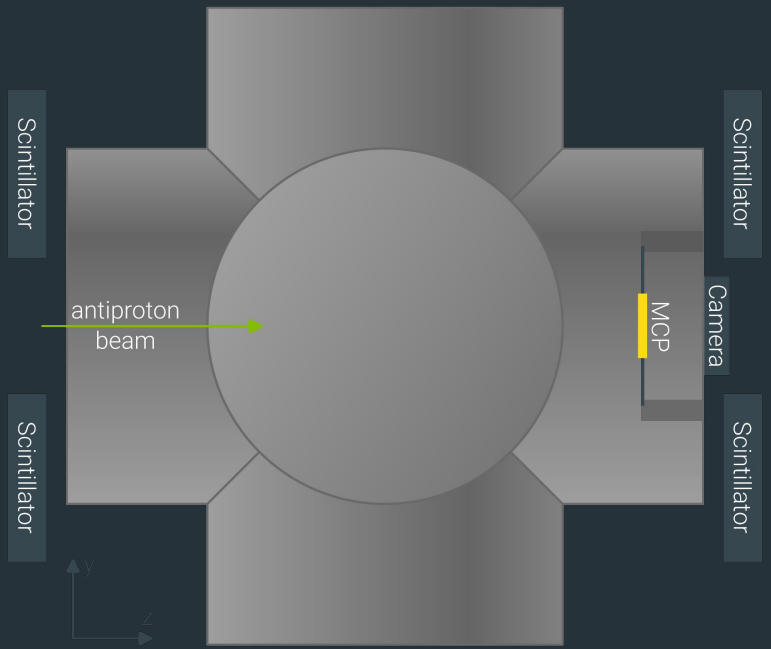


Foils

- $_{13}$Al 8 µm
- $_{22}$Ti 5 µm
- $_{29}$Cu 10 µm
- $_{40}$Zr 10 µm
- $_{79}$Au 12.5 µm



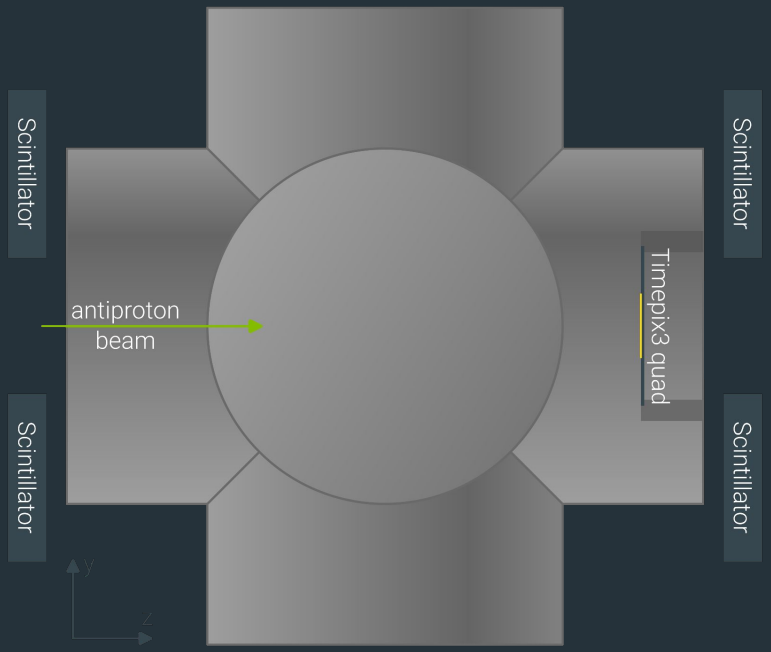
How many antiprotons are in one extraction?



Normalise the number of scattering antiprotons:

Step 1 Cross-calibrate the counts on scintillators and antiprotons on the MCP

How many antiprotons are in one extraction?

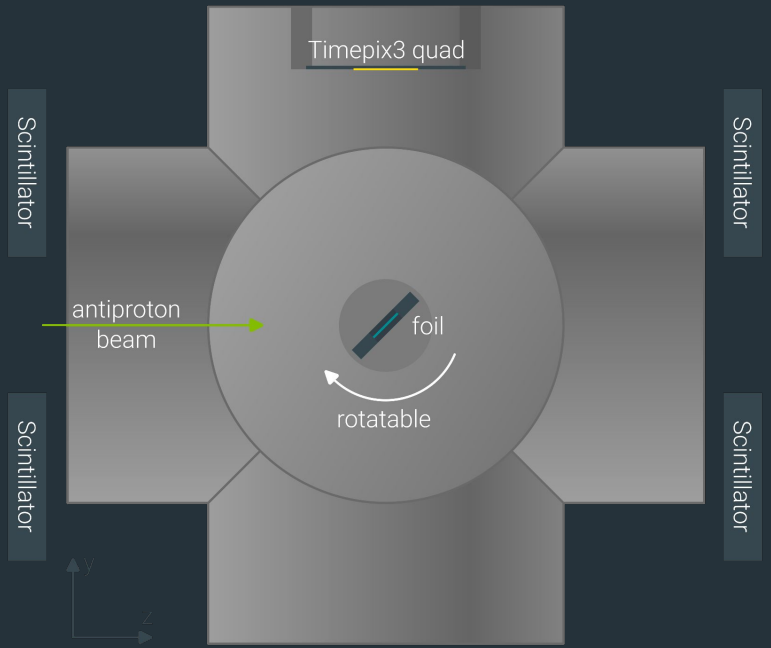


Normalise the number of scattering antiprotons:

Step 1 Cross-calibrate the counts on scintillators and antiprotons on the MCP

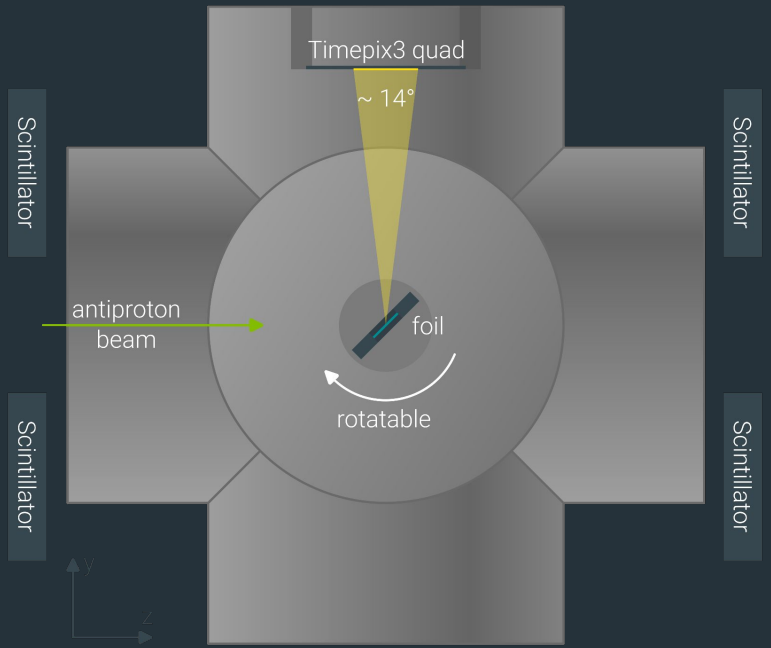
Step 2 Confirm the total number of antiprotons on the Tpx3 by first placing it directly in the beam and assess the shot-to-shot consistency of the beam

Methods



- Obtain antiproton number from calibrated scintillators
- Count the scattered antiprotons on the Timepix
- Vary the angle of the foil
- Vary extraction energy

Methods



- Obtain antiproton number from calibrated scintillators
- Count the scattering antiprotons on the Timepix
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- Vary extraction energy

Angle covered by the detector is very small

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Simulation

Estimation of the detected number of antiprotons on Tpx3
with respect to the number of incoming pbars
Percentage of reflected antiprotons

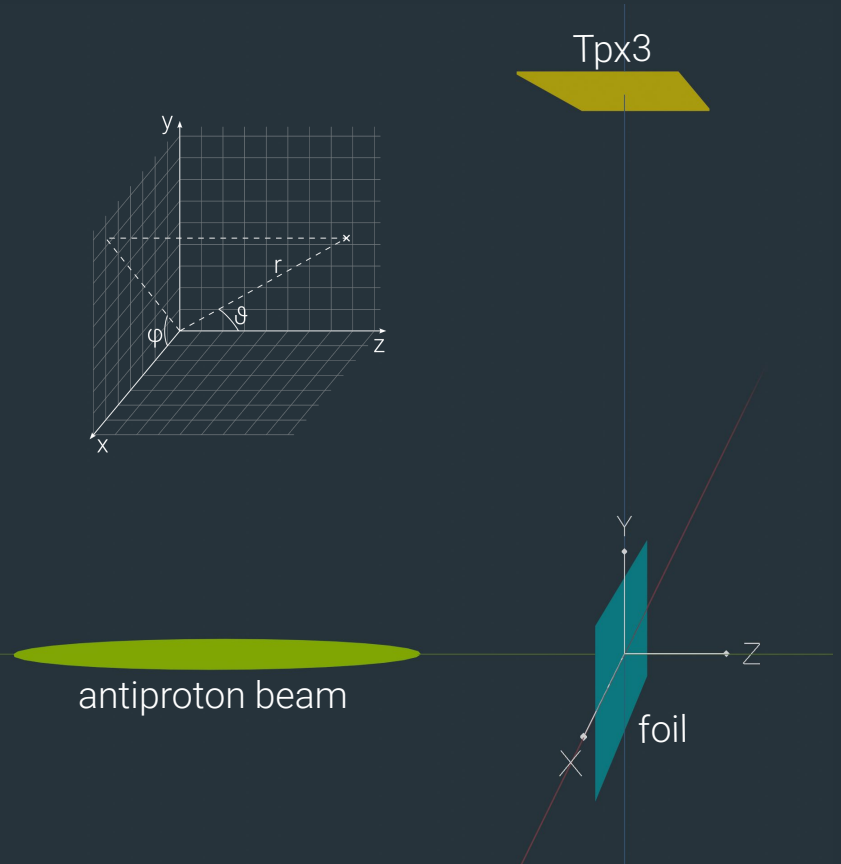
- Antiproton beam onto 12.5 μm Au foil
- Geant4 FTFP BERT physics list
  - EM physics option EMZ: “most precise at lower energies”
    Multiple Coulomb scattering is performed by the WentzelVI model and Coulomb scattering by the eCoulombScattering model
  - EM physics Single Scattering:
    Multiple scattering is not used, only elastic scattering process
- Tpx and dummy detector cube around it

Comparing Physics Lists + Energies

	FTFP_BERT EMZ 250 eV	FTFP_BERT SS 250 eV	FTFP_BERT EMZ 500 eV	FTFP_BERT EMZ 1000 eV
Foil Angle	Scattering	Scattering	Scattering	Scattering
90 °	75.51 %	75.0 %	63.81 %	71.21 %
75 °	75.94 %	76.2 %	63.97 %	71.68 %
60 °	77.52 %	74.4 %	65.80 %	72.59 %
45 °	80.42 %	80.7 %	69.80 %	73.41 %
30 °	83.64 %	82.2 %	74.58 %	75.34 %

Similar results for models at 250 eV
Higher energies show inconsistencies

Scattering angles

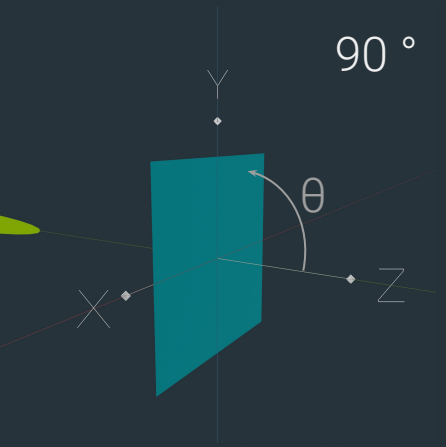


Converting (x, y, z) coordinates of the antiproton's first hit in the Tpx/Dummy to spherical coordinates (r, θ, φ)

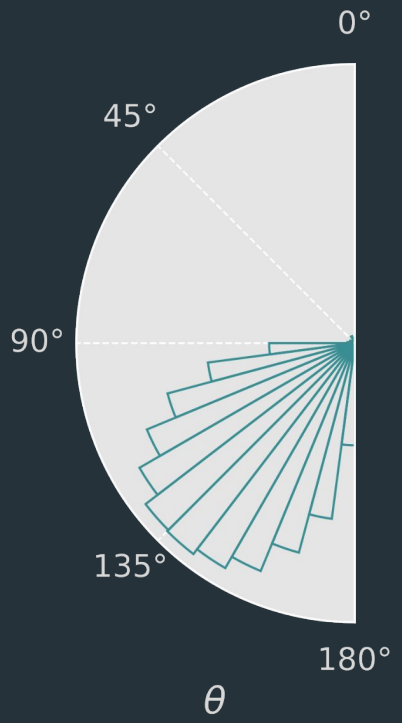
Polar angle θ is also the scattering angle
→ 90 ° would mean directly onto the Tpx

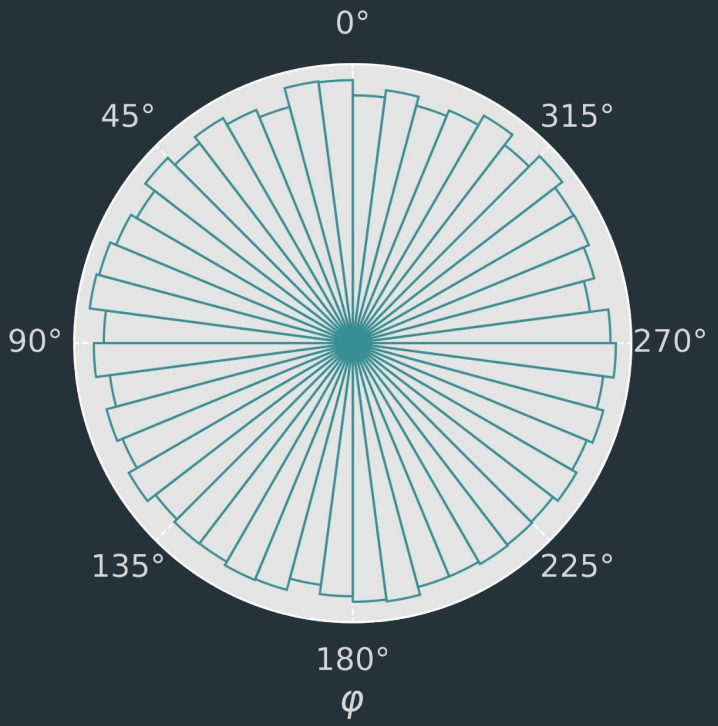
Does tilting the foil change the outcome?

Scattering angles simulated with FTFP_BERT at 250 eV



0.28 % on Tpx3
~ 70/25000





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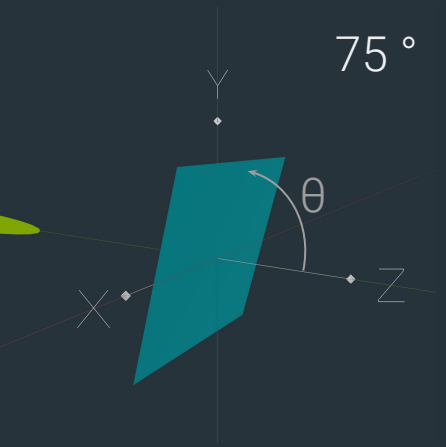
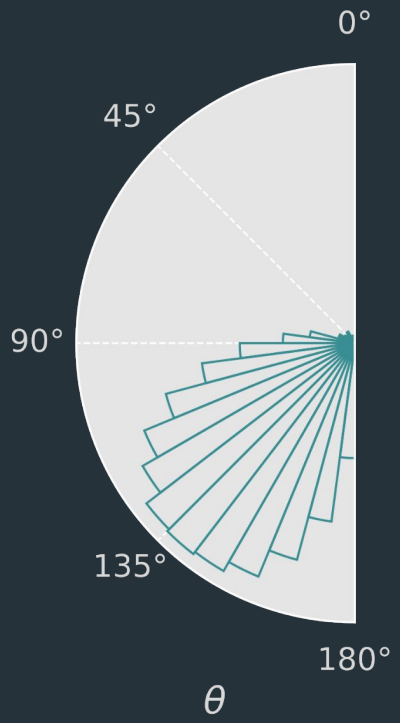
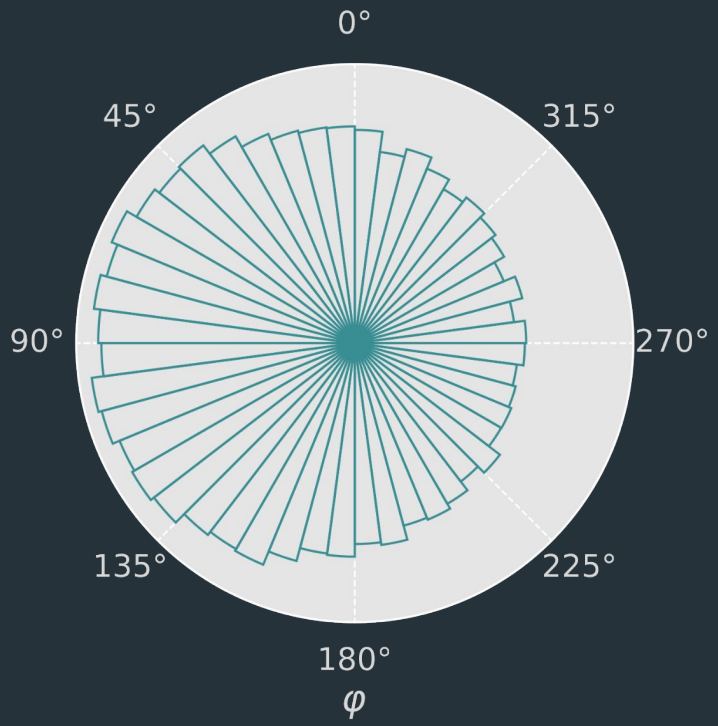


0.38 % on Tpx3
~ 95/25000





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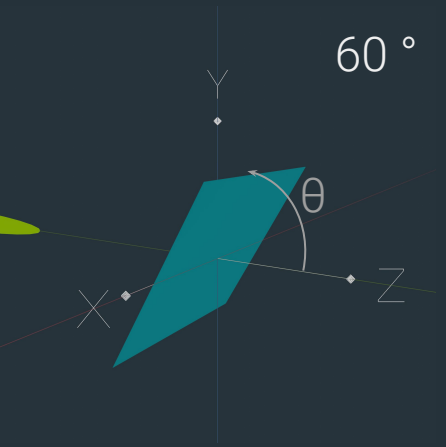
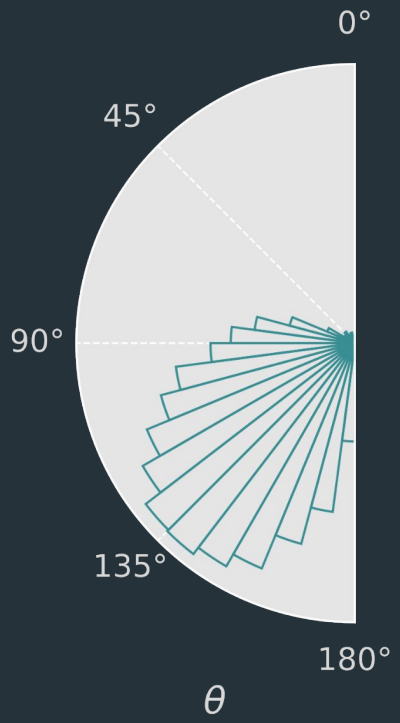
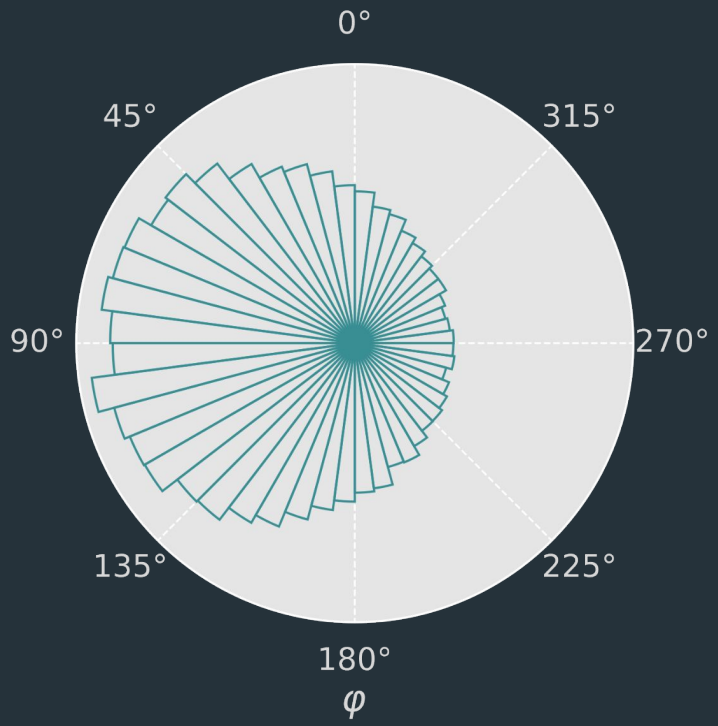
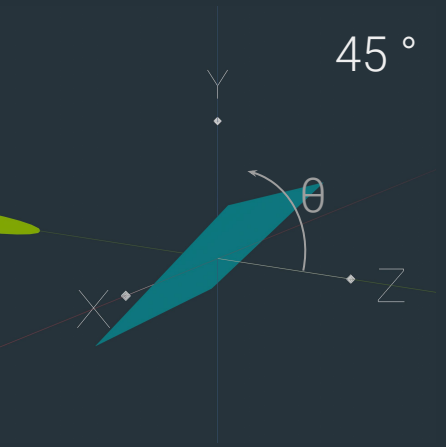


0.43 % on Tpx3
~ 107/25000

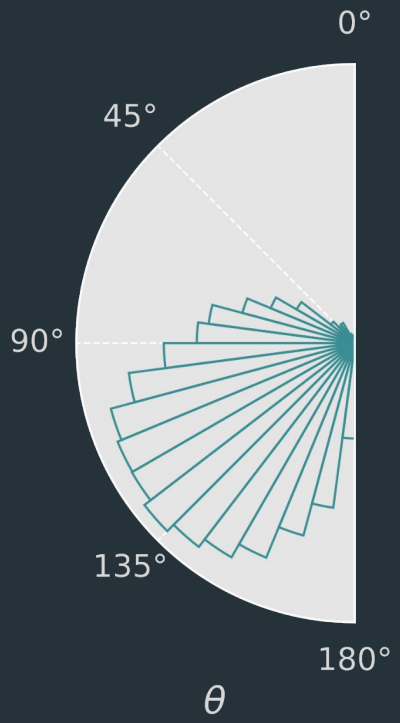


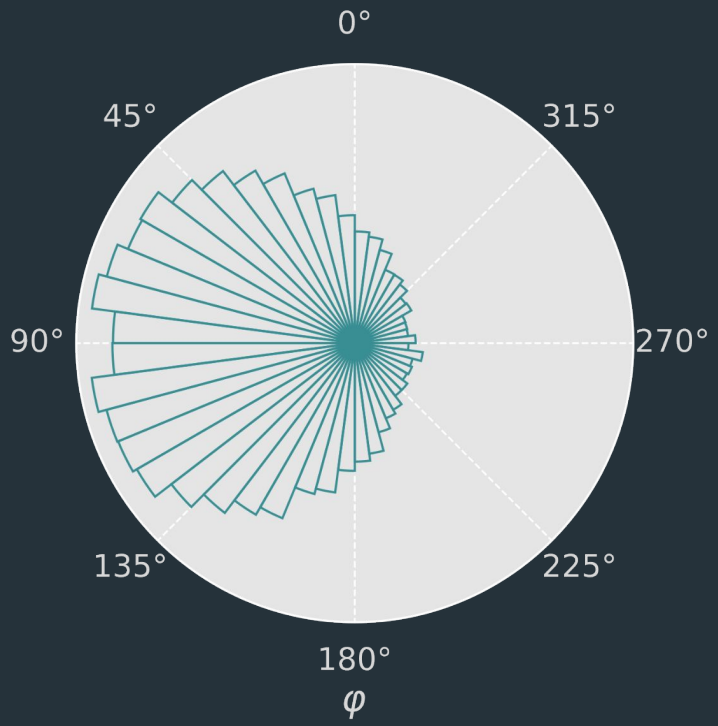


Scattering angles simulated with FTFP_BERT at 250 eV

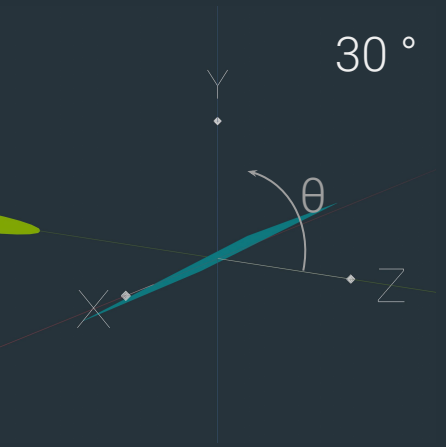


0.61 % on Tpx3
~ 151/25000

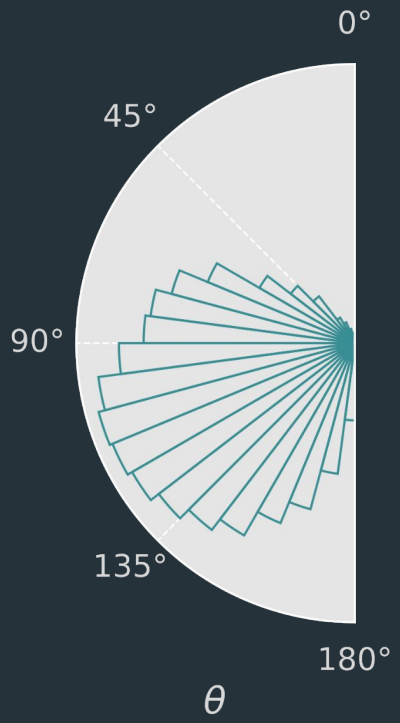


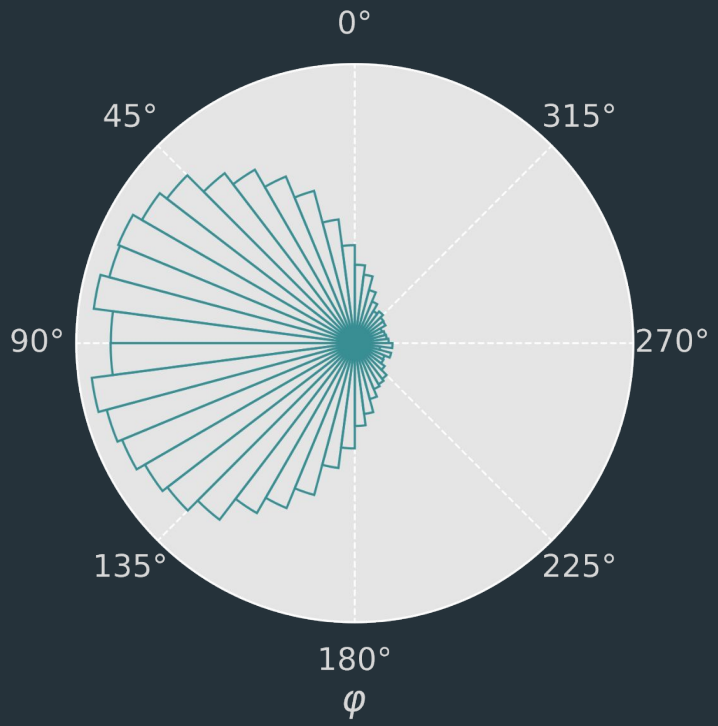


Scattering angles simulated with FTFP_BERT at 250 eV



0.73 % on Tpx3
~ 182/25000





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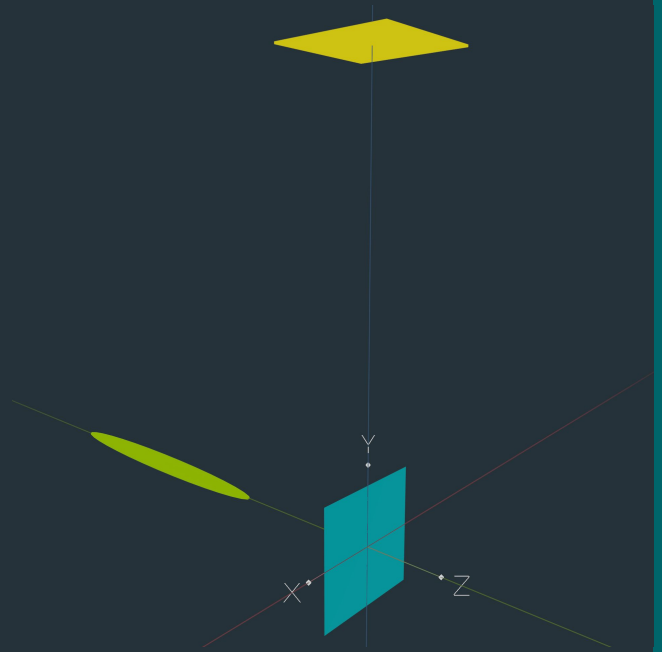
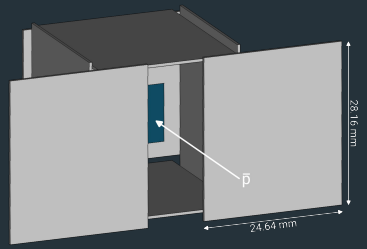
Summary & Conclusions

- At sub-keV energies there is no complete model
- Second experiment for pbar reflection
  - Foil angle dependence
  - Precise energies (250 eV / 500 eV)
  - Tpx3 quad covers 83° < θ < 97°

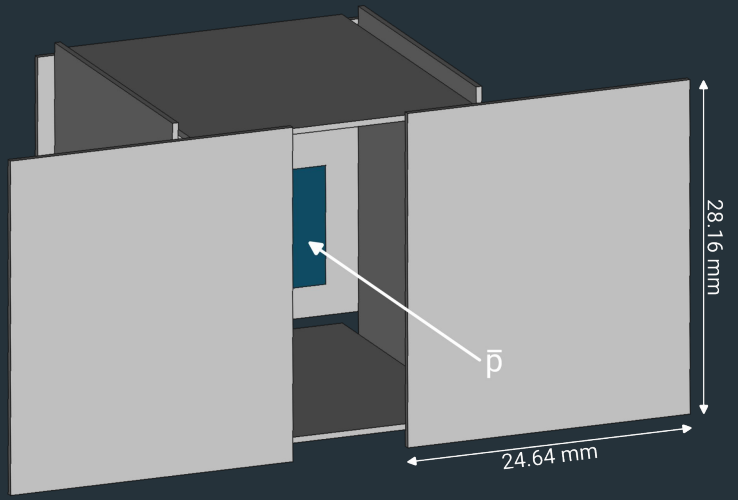
- More reflection measurements during annihilation study
  - Large solid angle coverage
  - Annihilation vertices can be reconstructed if on the foil or on the detector
  - Foil has fixed angle
  - Tpx4 cube covers 0° < θ < 139°

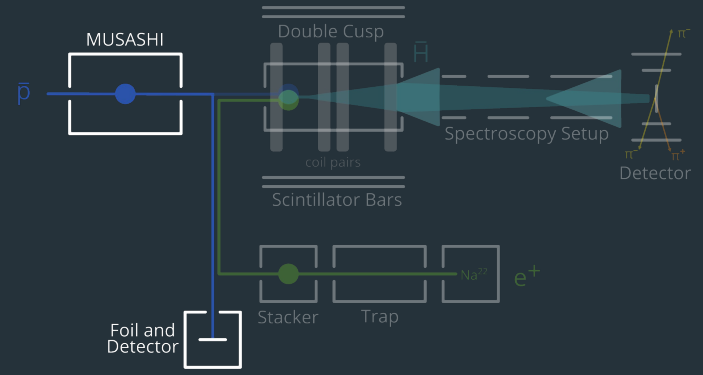




Thank you

Antiproton Annihilation Study





Target foil surrounded by detectors

7 x 500 µm Si sensors coupled to Timepix4 ASICs:

- 2 sensors placed such that a beam of ~ 10 mm diameter can enter
- 5 sensors cover the other planes of the cube-like geometry

Detector ready by end of summer

- Reconstruct annihilations
- Measure scattering antiprotons