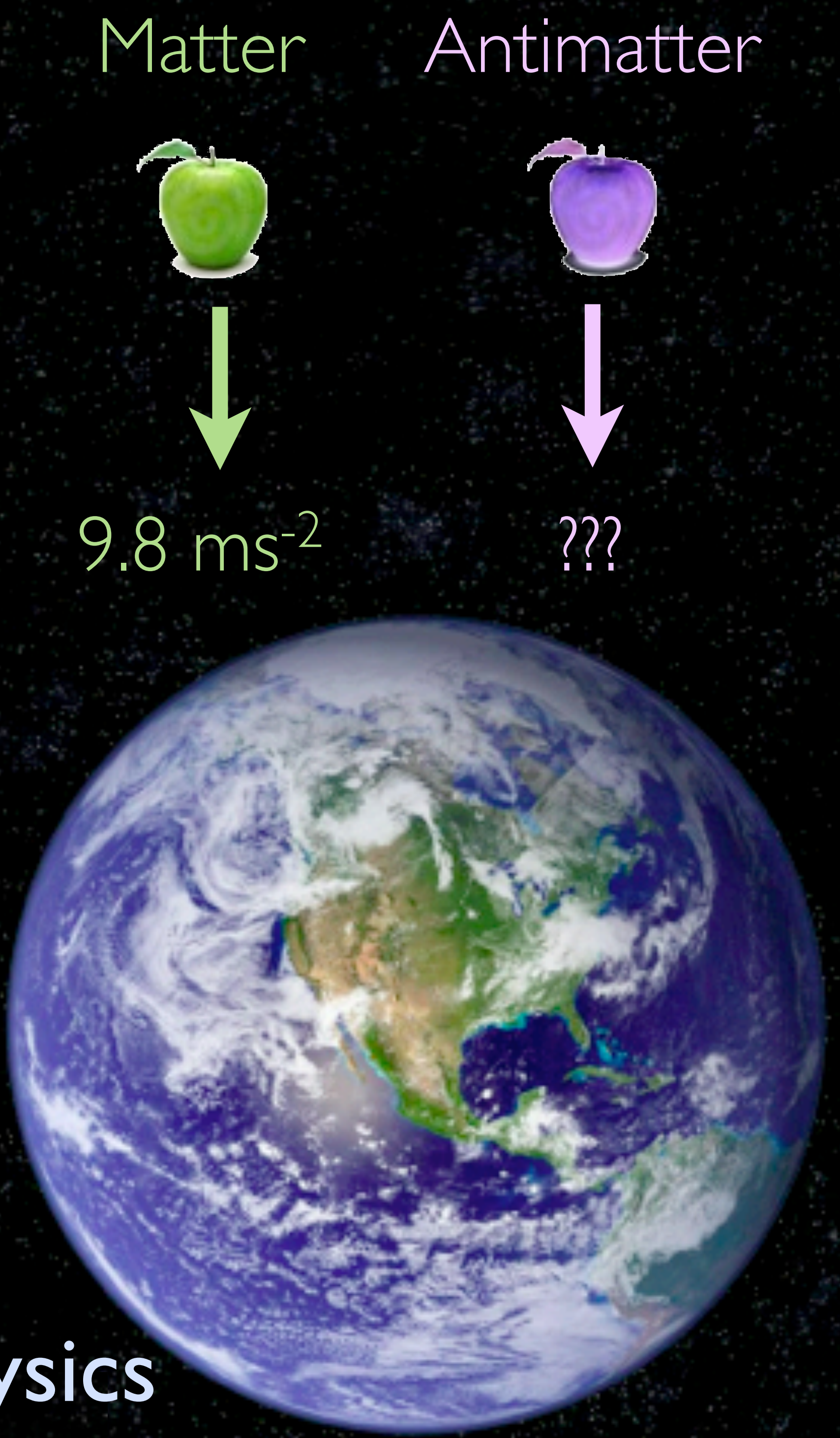
Measuring the gravitational free-fall of antihydrogen



James Storey
on behalf of the AEgIS collaboration.

Albert Einstein Center for Fundamental Physics
Laboratory for High Energy Physics (LHEP)
University of Bern

Talk outline

1. The AEgIS experiment & very brief status.
2. How many antihydrogen atoms do we need for $\Delta g/g=1\%$?
3. How can we measure the Hbar annihilation vertex with micron level resolution?
   - Emulsion detectors.
   - Measurements with antiprotons.
4. Free-fall detector design.
   - Simulated performance.
   - Flux requirement for $\Delta g/g=1\%$.

AEgIS collaboration

CERN, Switzerland

INFN Genova, Italy
INFN Bologna, Italy

Kirchhoff Institute of Physics, Heidelberg, Germany

Max-Planck-Insitut für Kernphysik Heidelberg, Germany

INFN, Università degli Studi and Politecnico Milano, Italy

INFN Pavia-Brescia, Italy

INR Moscow, Russia

Université Claude Bernard, Lyon, France

University of Oslo and University of Bergen, Norway

Czech Technical University, Prague, Czech Republic

INFN Padova-Trento, Italy

ETH Zurich, Switzerland

Laboratoire Aimé Cotton, Orsay, France

University College, London, United Kingdom

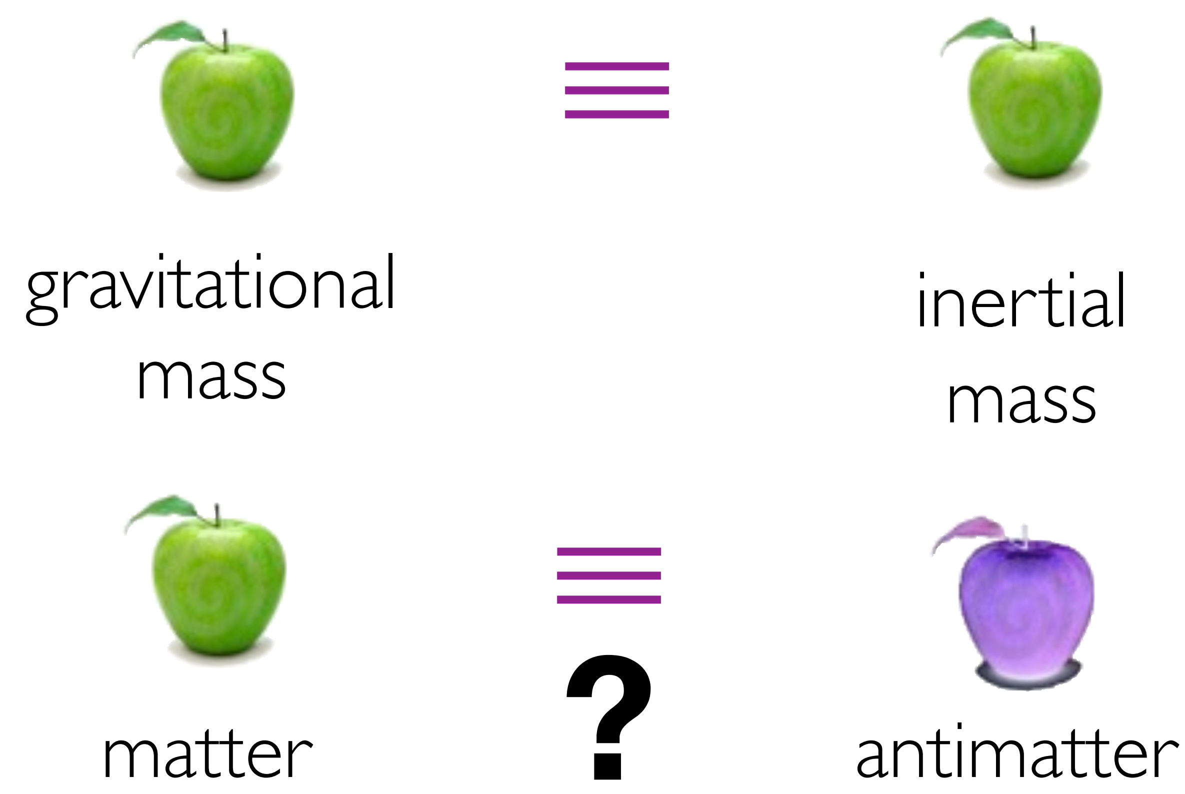
Stefan Meyer Institut, Vienna, Austria

University of Bern, Switzerland

Why study the gravitational interaction between antimatter and matter?

Principal of equivalence between gravitational and inertial mass is a foundation of General Relativity.

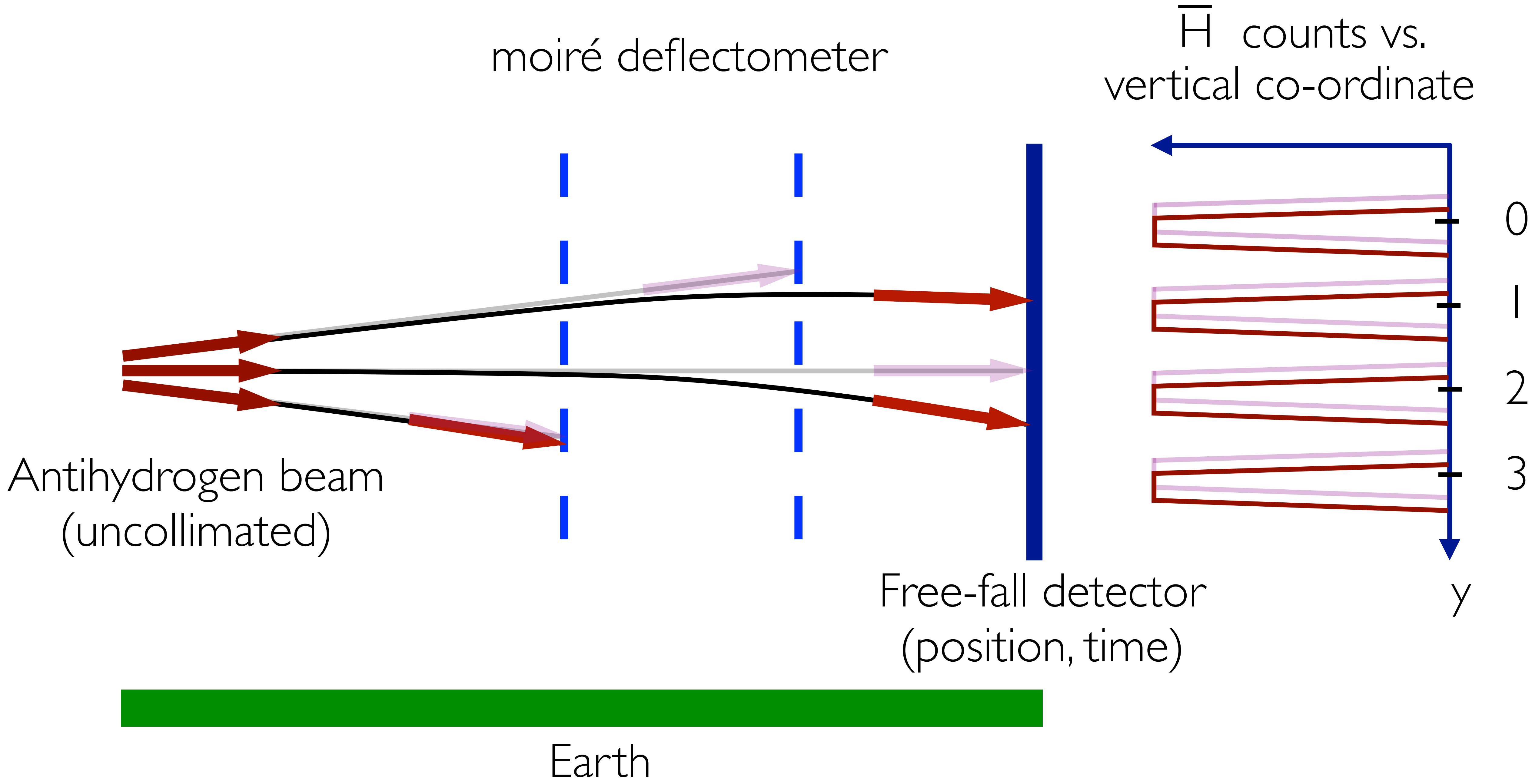
General relativity: classical theory that makes no distinction between matter and antimatter.



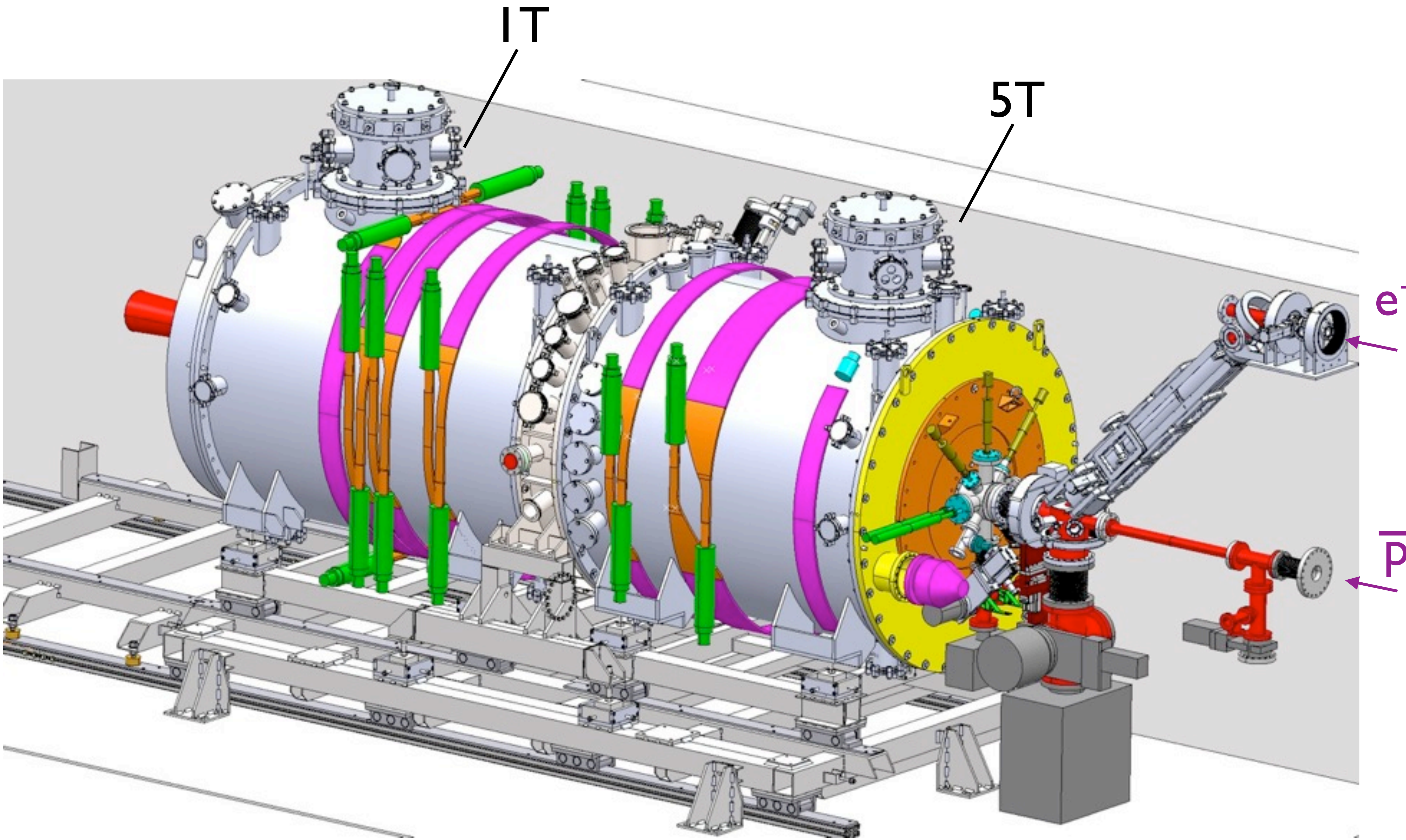
Universality of Free-Fall tested to 1 part in 10^{12}, but only with matter based experiments.

AEgIS: Test the Universality of Free-Fall with antimatter by measuring the Earth's gravitational acceleration on a beam of antihydrogen.

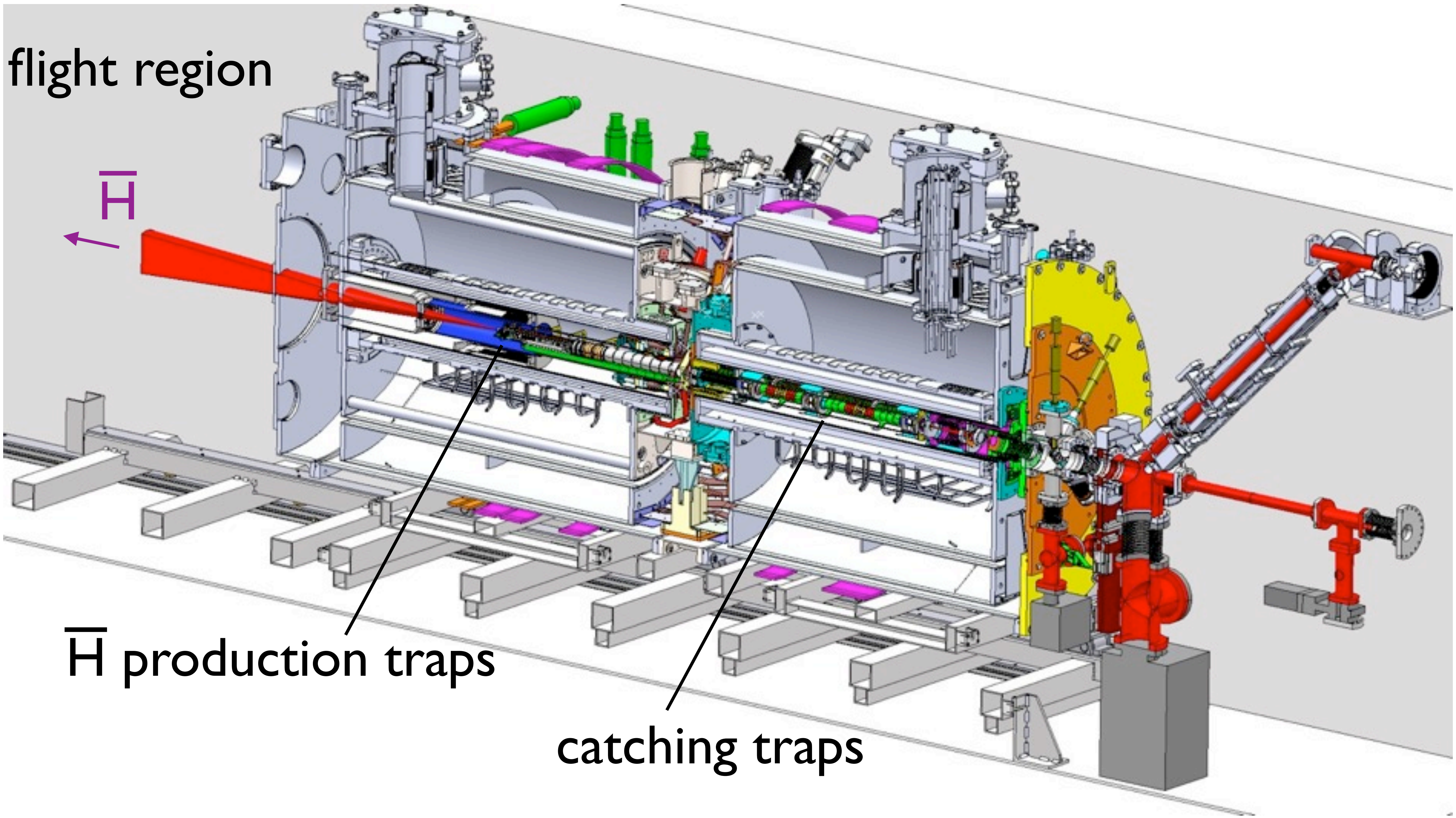
Principle of the experiment



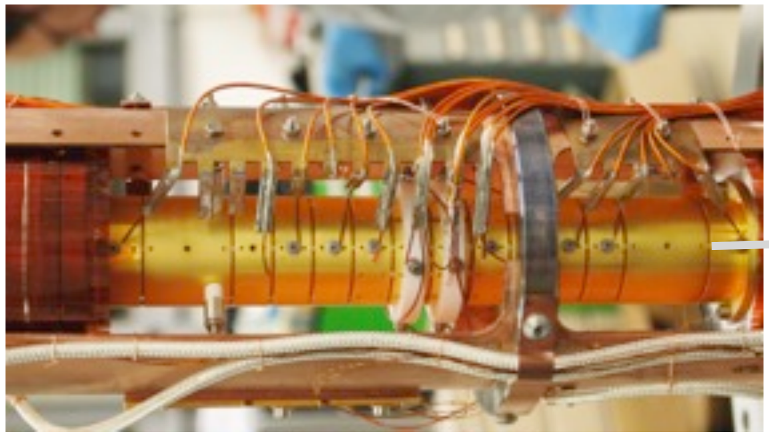
The AEgIS apparatus



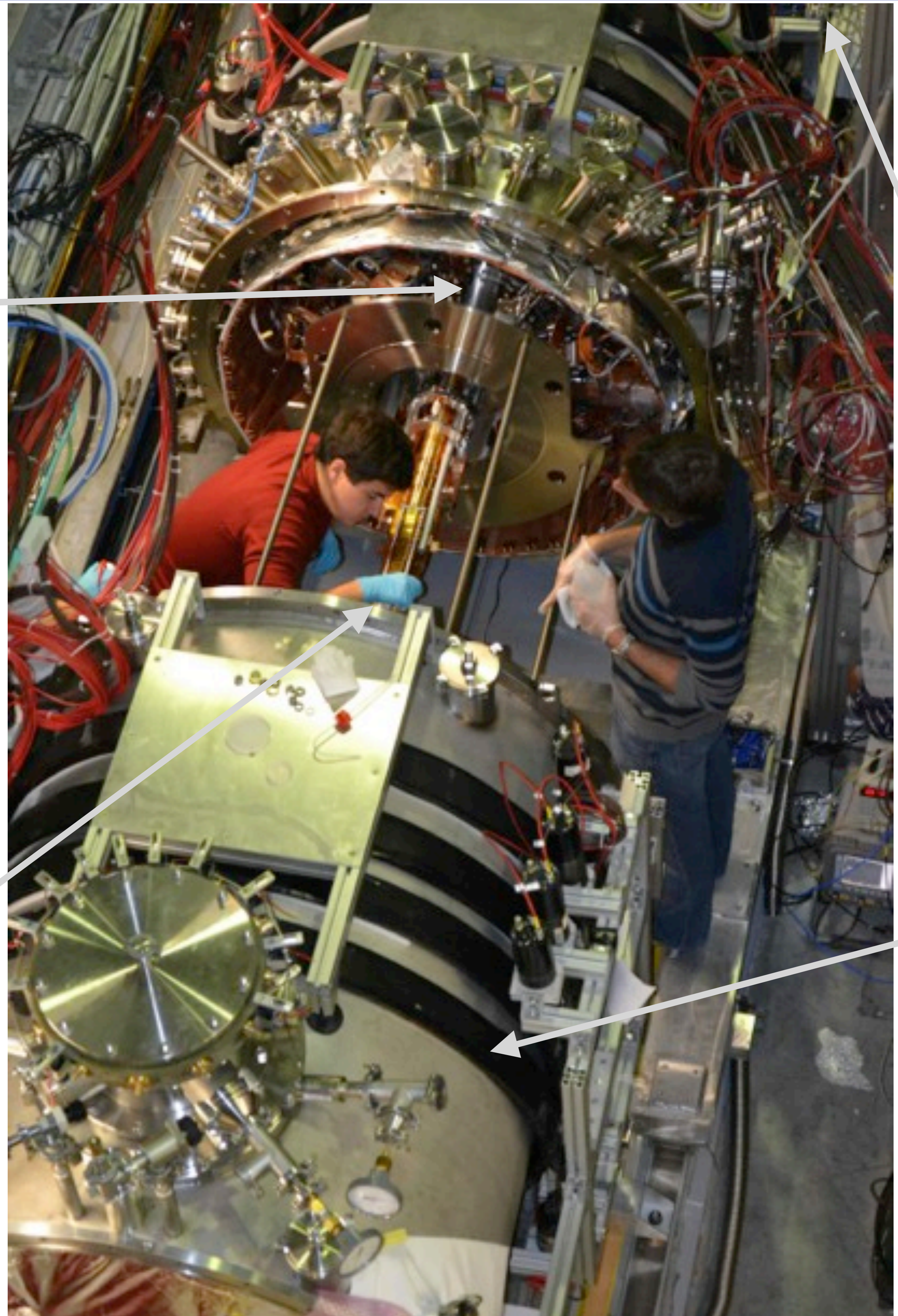
The AEgIS apparatus

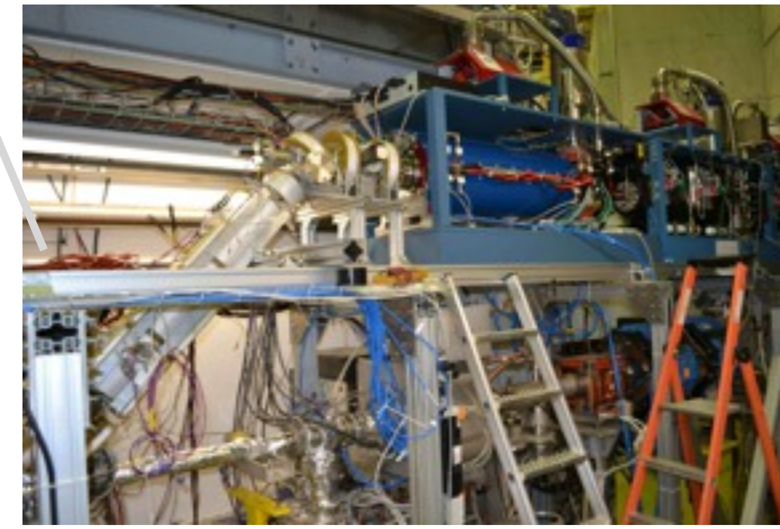


Current status

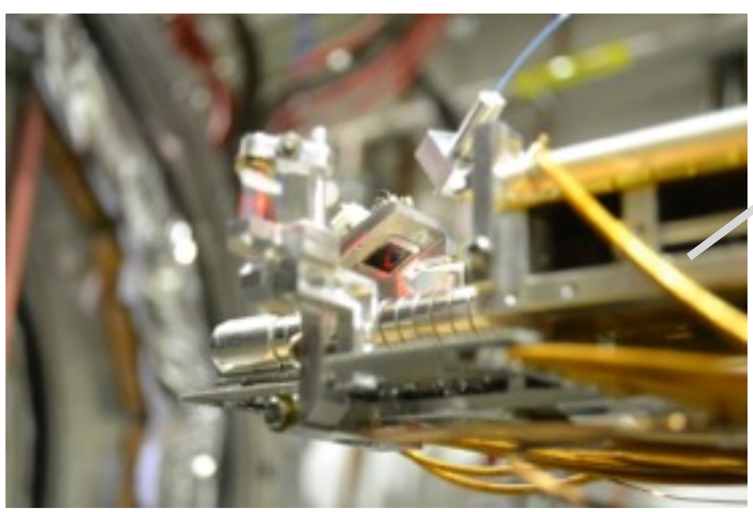


catching traps

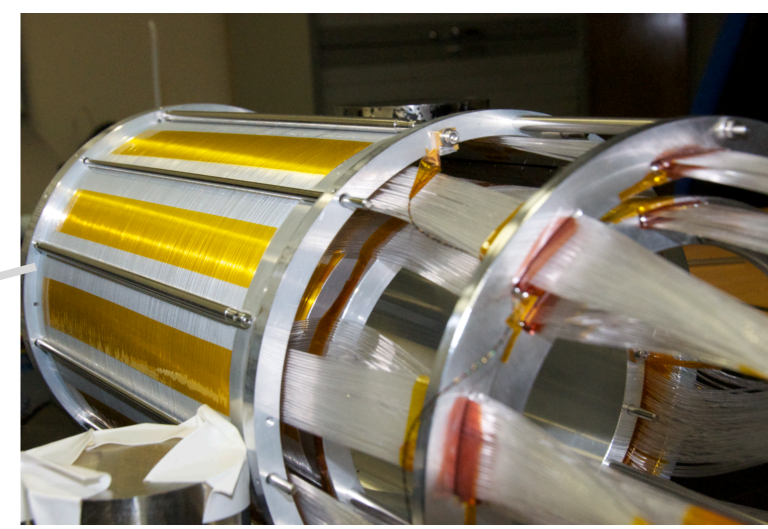




positron accumulator & transfer line

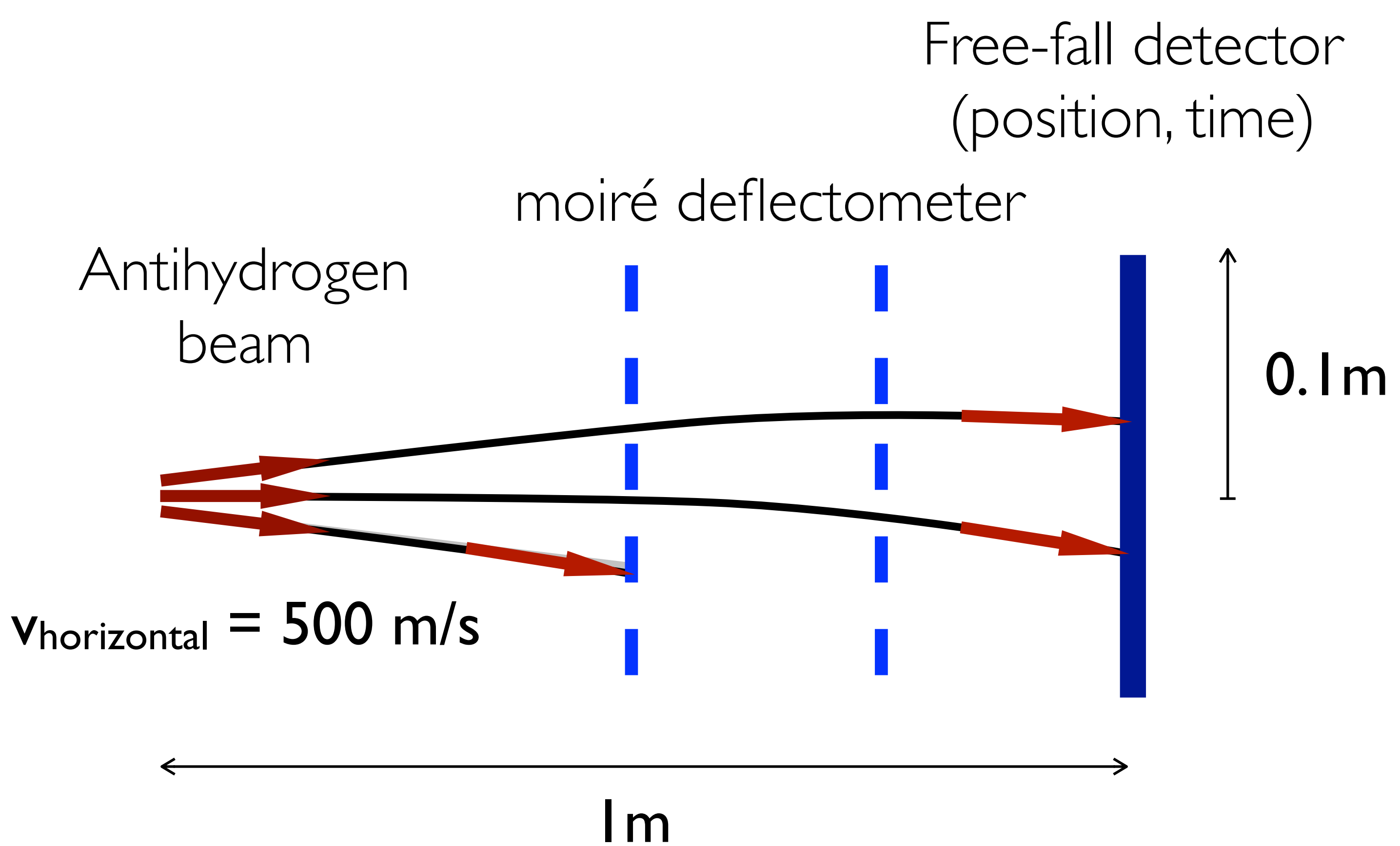


Ps production target, fiber for laser excitation, & antihydrogen production traps



antihydrogen detector

Experimental challenges



For all Hbar to reach free-fall detector:

Solid angle → $v_{radial} \leqq$ 100mK

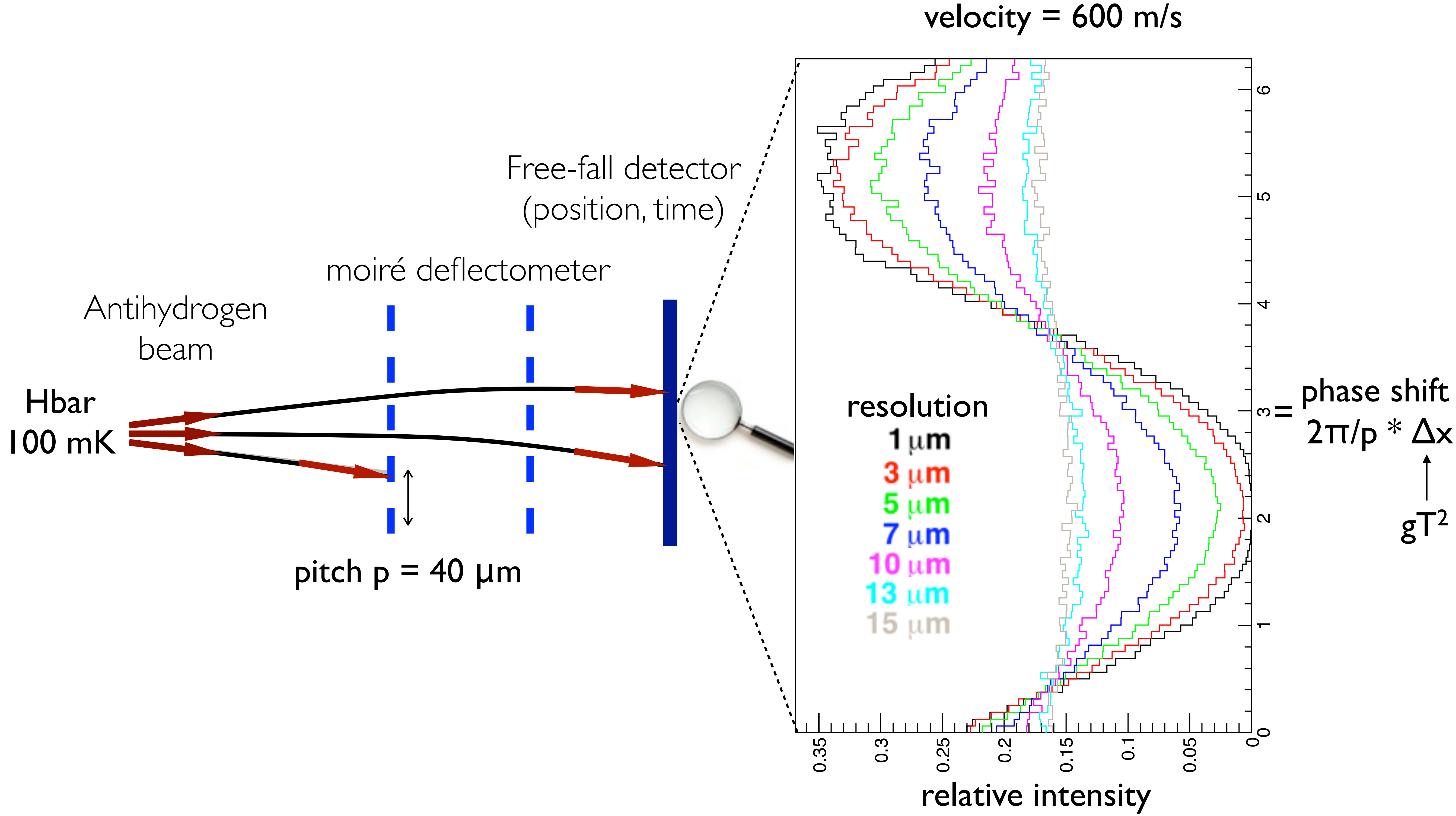
Experimental approaches:

1. Produce cold antihydrogen (resistive, evaporative, laser cooling).
2. Produce more antihydrogen (Ps production, enhance Ps overlap).

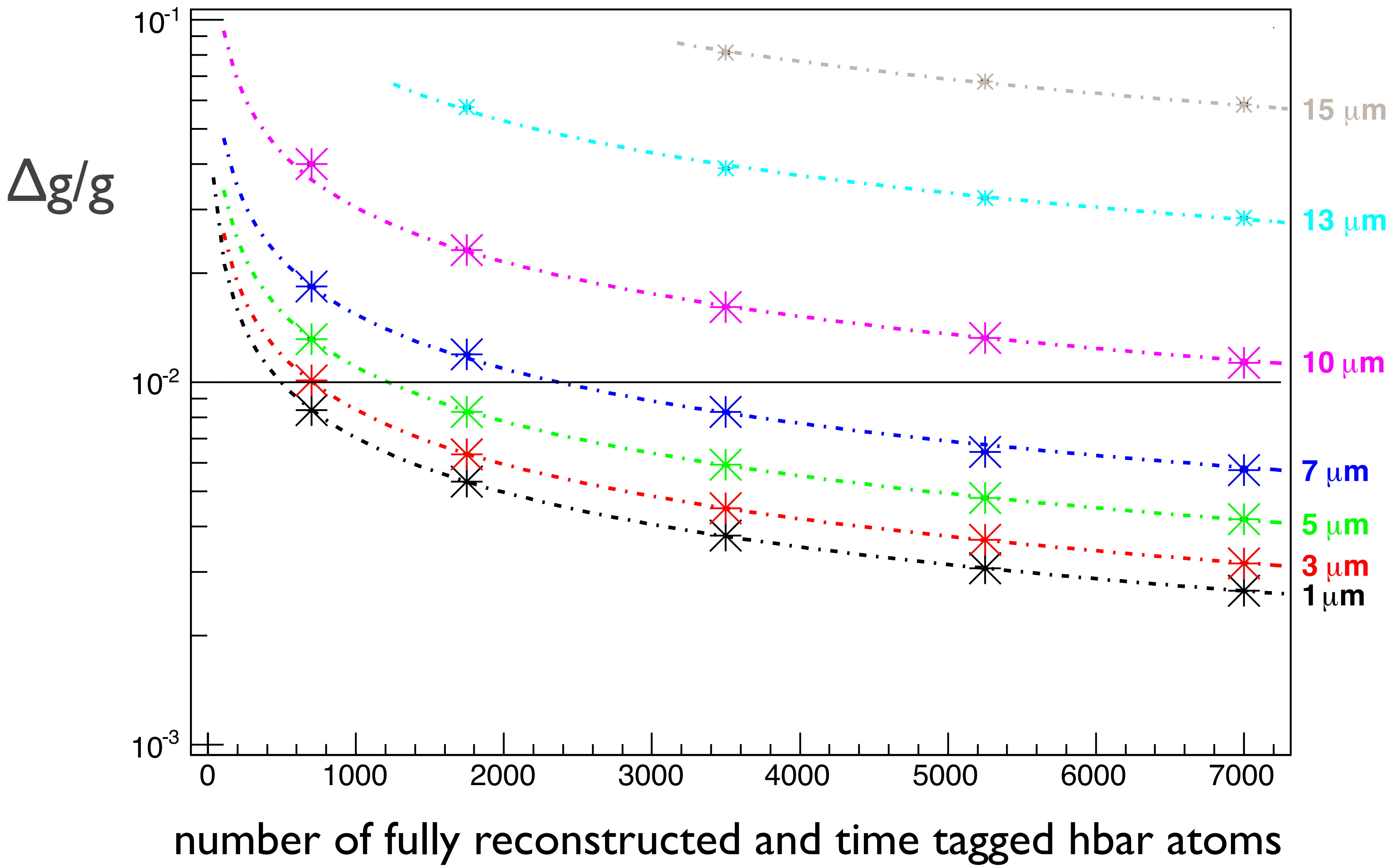
and/or

3. Minimise the number of antihydrogen atoms that need to be detected on the free-fall detector for a $\Delta g/g$ = 1% measurement.

How much flux(*) do we need?
$\Delta g/g$ dependancy on vertex position resolution



How much flux(*) do we need?
Δg/g dependancy on vertex position resolution



Higher resolution → fewer Hbar atoms required for the measurement.

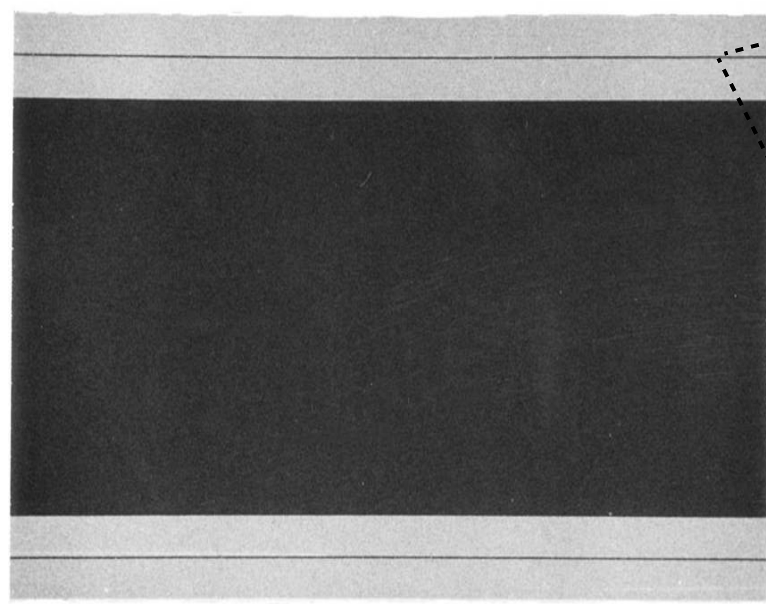
What tracking detector technology has the highest position and angular resolution?

Nuclear emulsion based detectors (*)

emulsion layer
(44 microns)

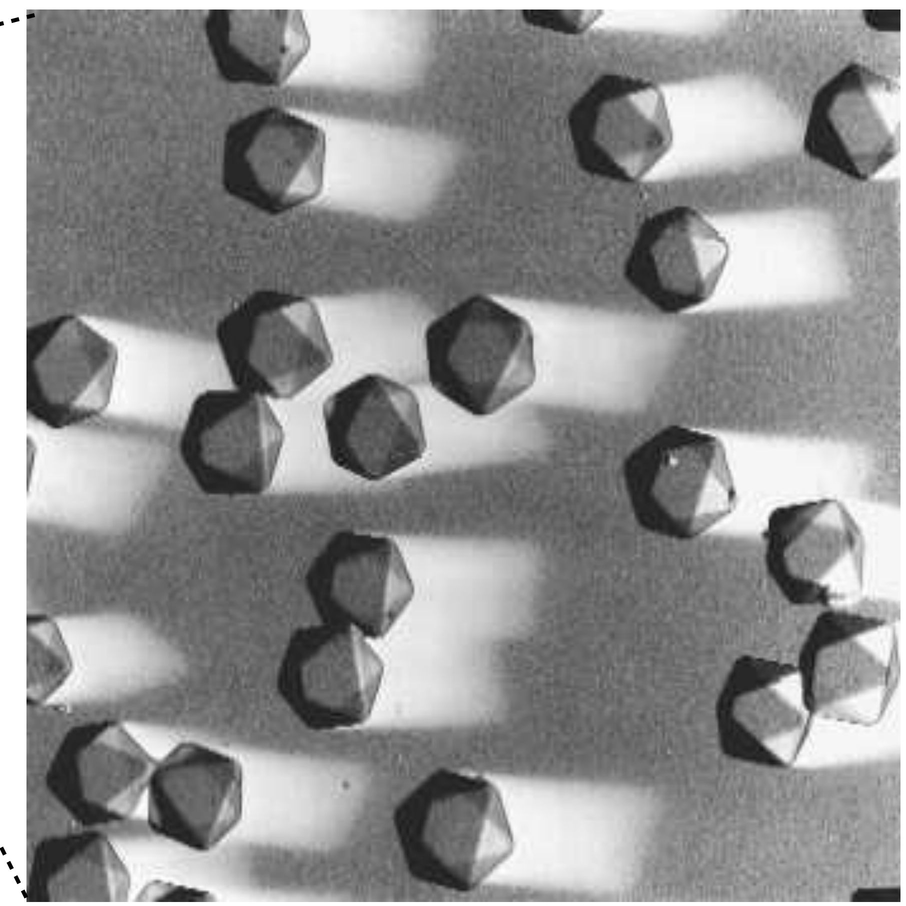
base layer
(200 microns)

emulsion layer
(44 microns)



SEM cross sectional view of standard film by FUJI film

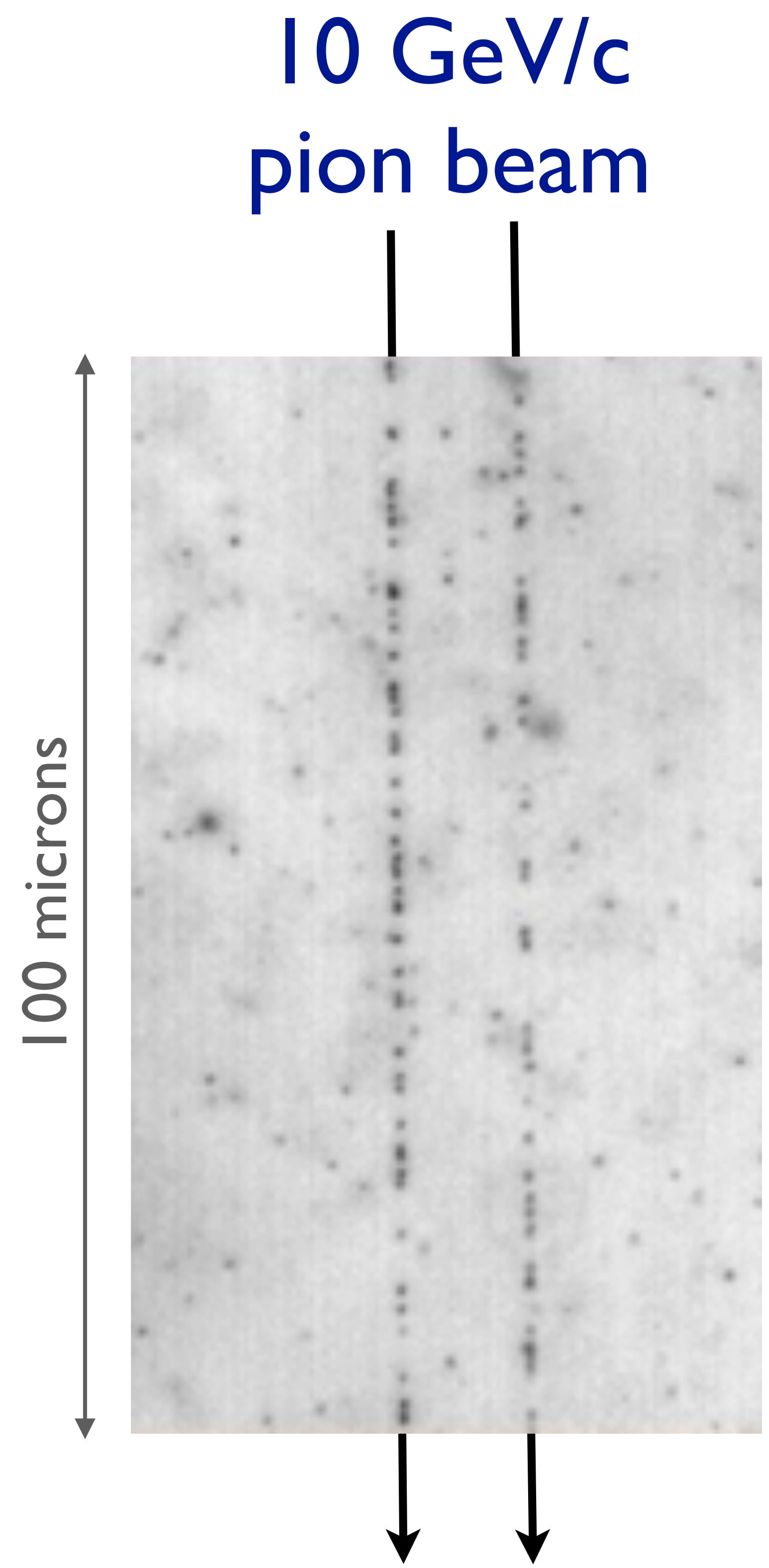
0.2 microns



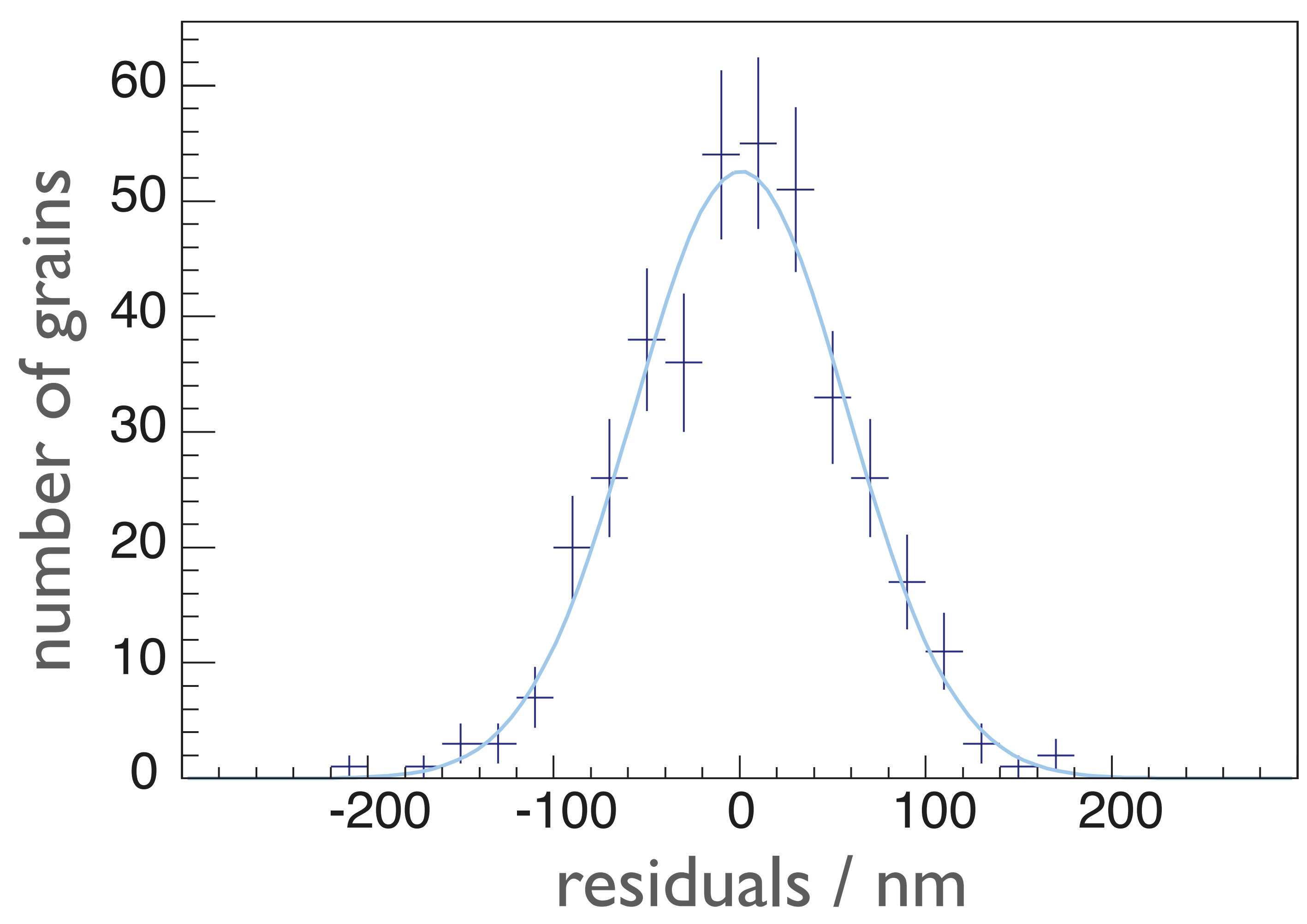
AgBr crystal suspended in a gelatine matrix.

(*) Integrating detector, no timing information.

Emulsion detectors: Intrinsic resolution

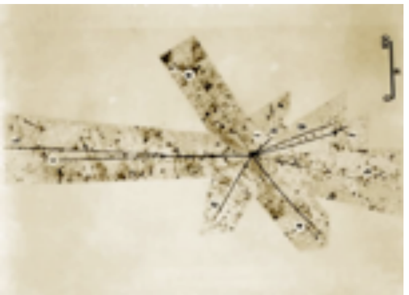


56nm intrinsic resolution



Emulsion detectors: Current state-of-the-art

Long history of use in particle physics e.g. discovery of the antiproton.



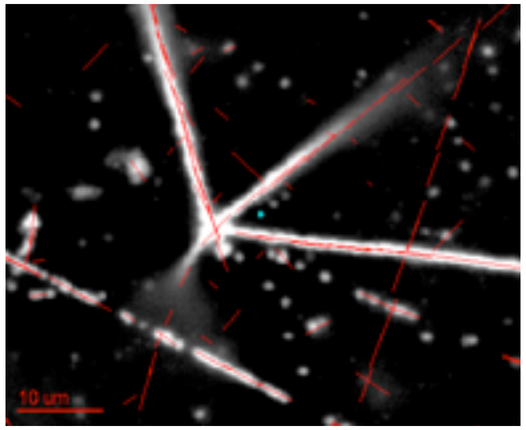
1st observed annihilation star (Bevatron)

100cm^2 emulsion film → 10^{14} channels of AgBr crystal detectors, each with a detection efficiency of 16% for a MIP.

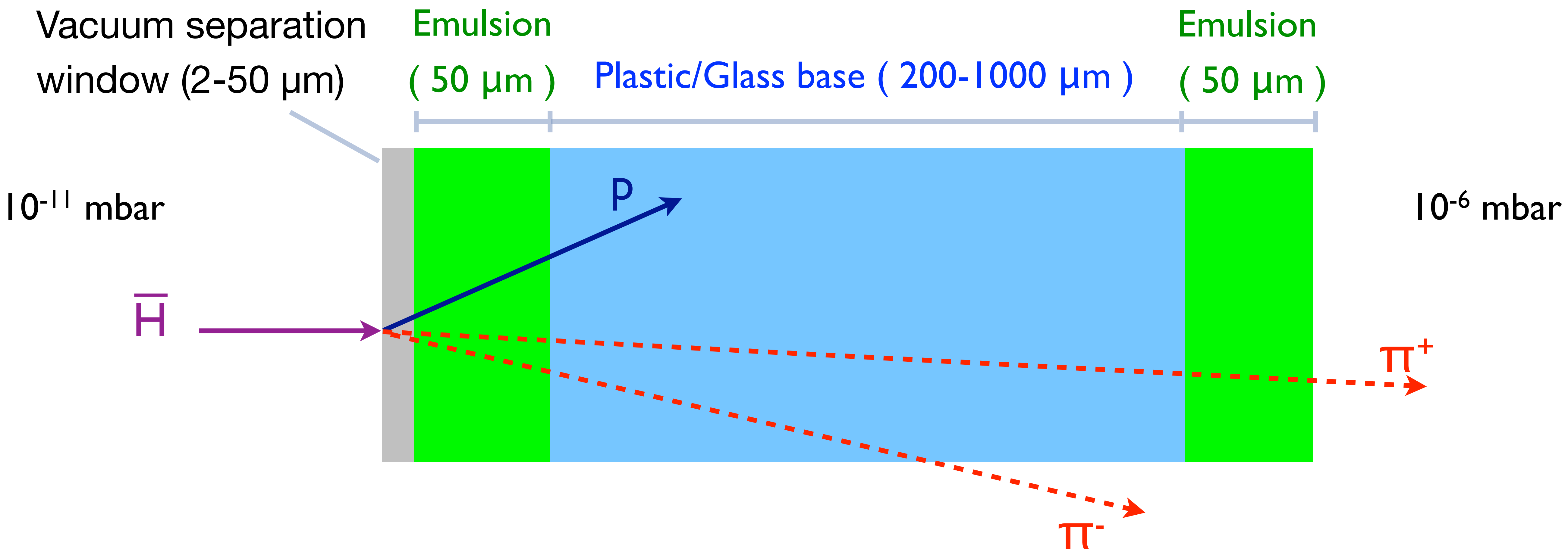
Automated scanning (Univ. Nagoya) → 20 cm^2/hour (European Scanning System at Bern)

Graphical Processor Unit (GPU) based track reconstruction algorithms (Bern)

AEgIS raw image data → 1 TB/hour

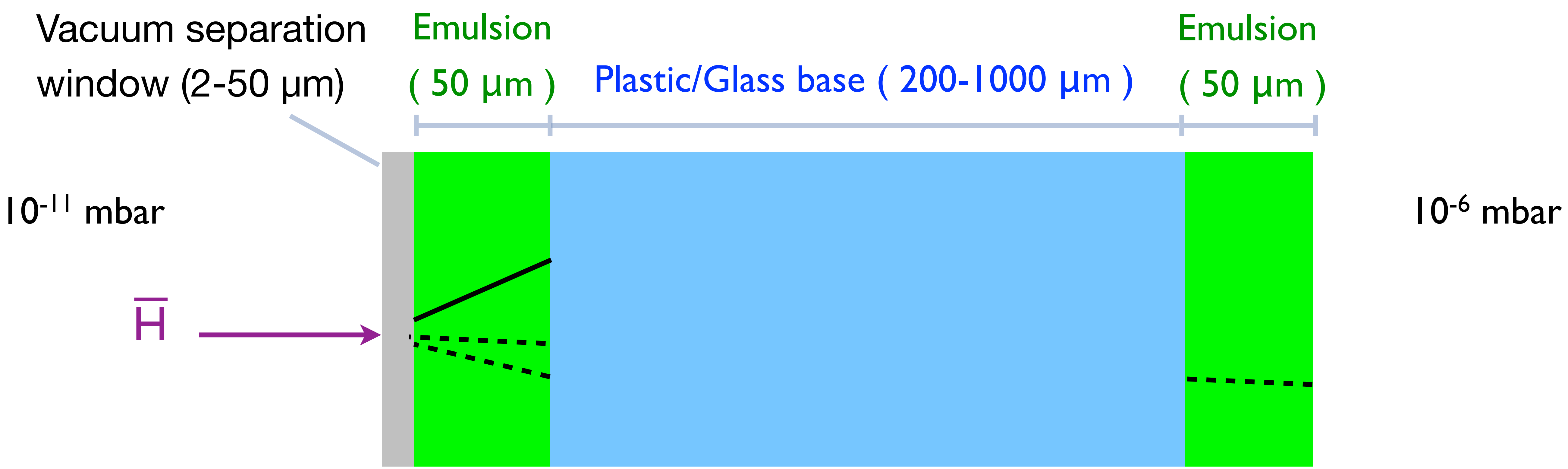


Emulsion based free-fall detector: How will it work?



$\bar{H}$ annihilation produces (in 2π): 2 pions + 1 proton or 1 pion + 2 protons.

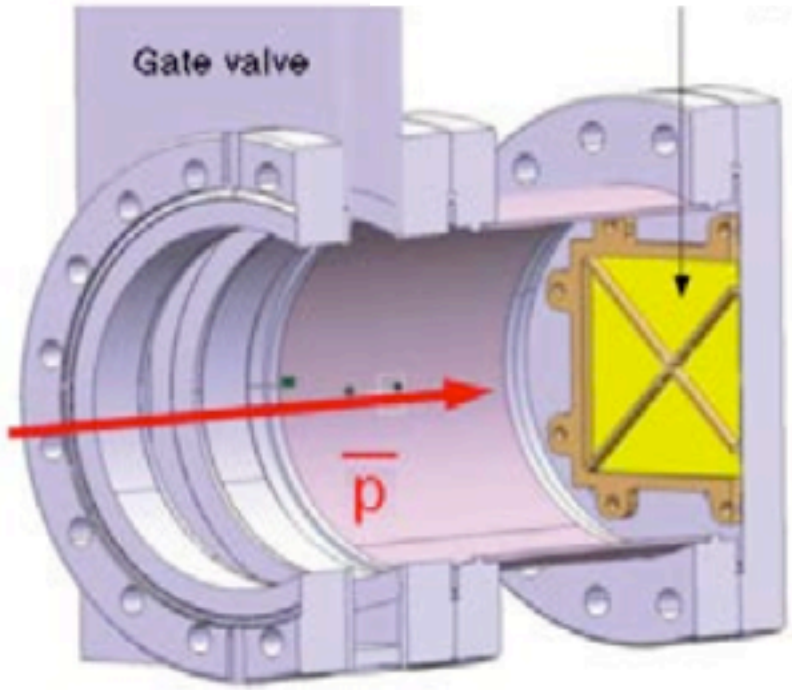
Emulsion based free-fall detector: How will it work?

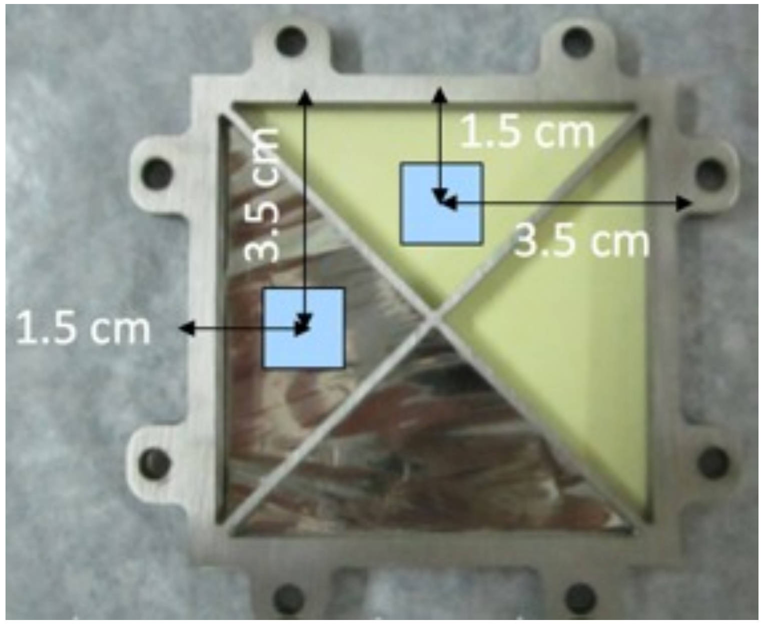


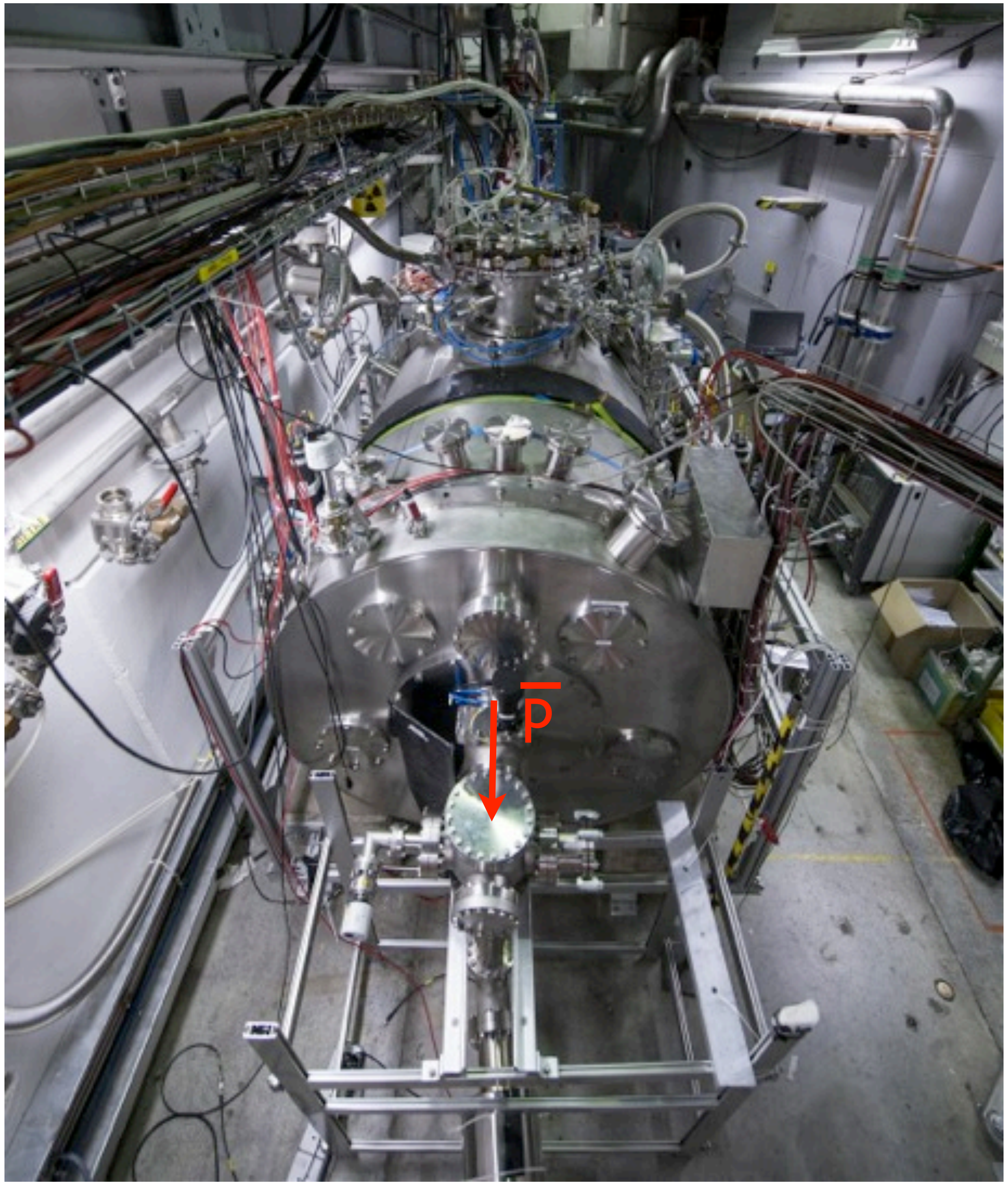
Grain density → dE/dx → proton / pion separation.

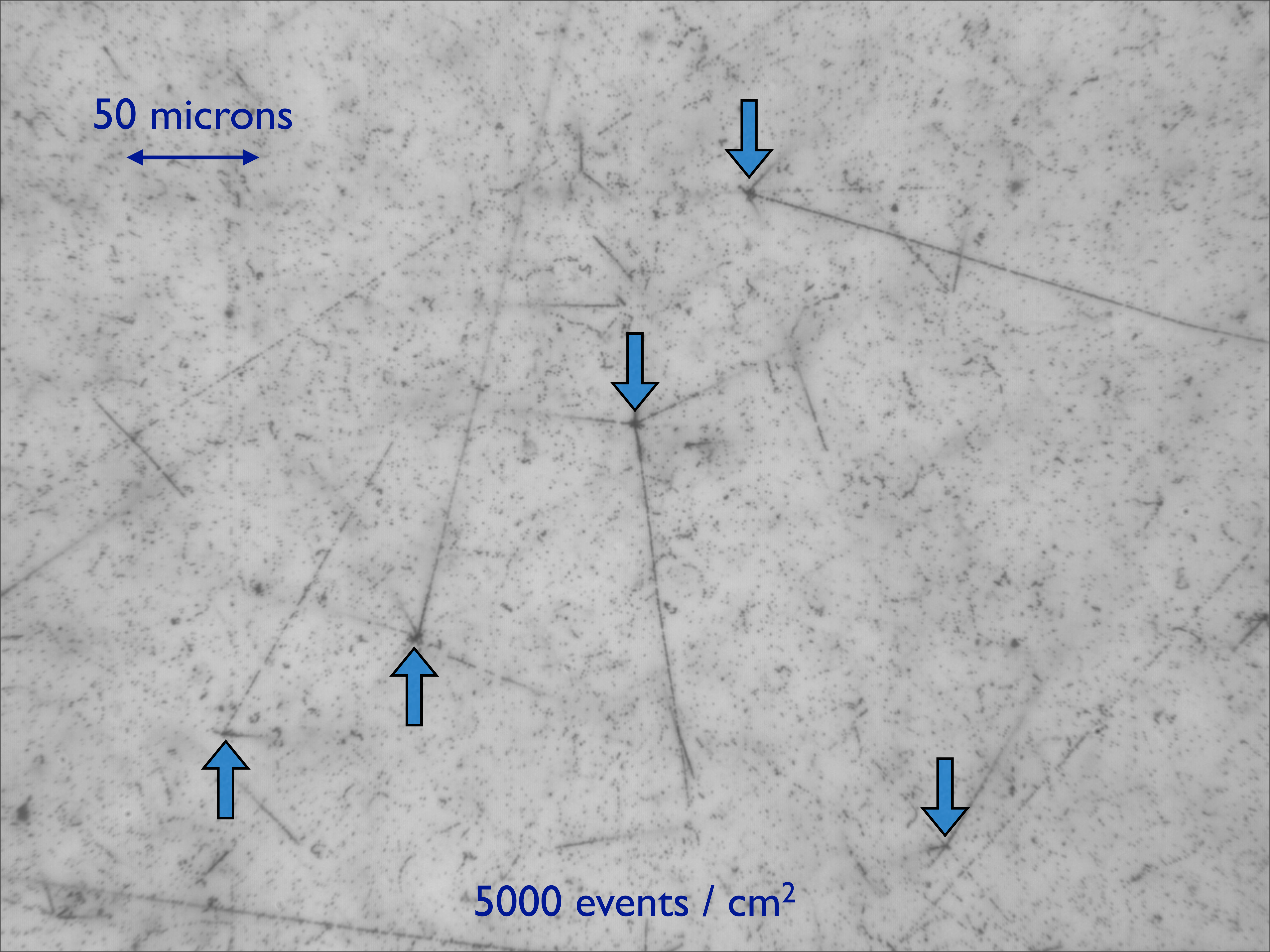
Measurements with antiprotons during the 2012 AD run: Experimental setup

emulsion films (yellow)

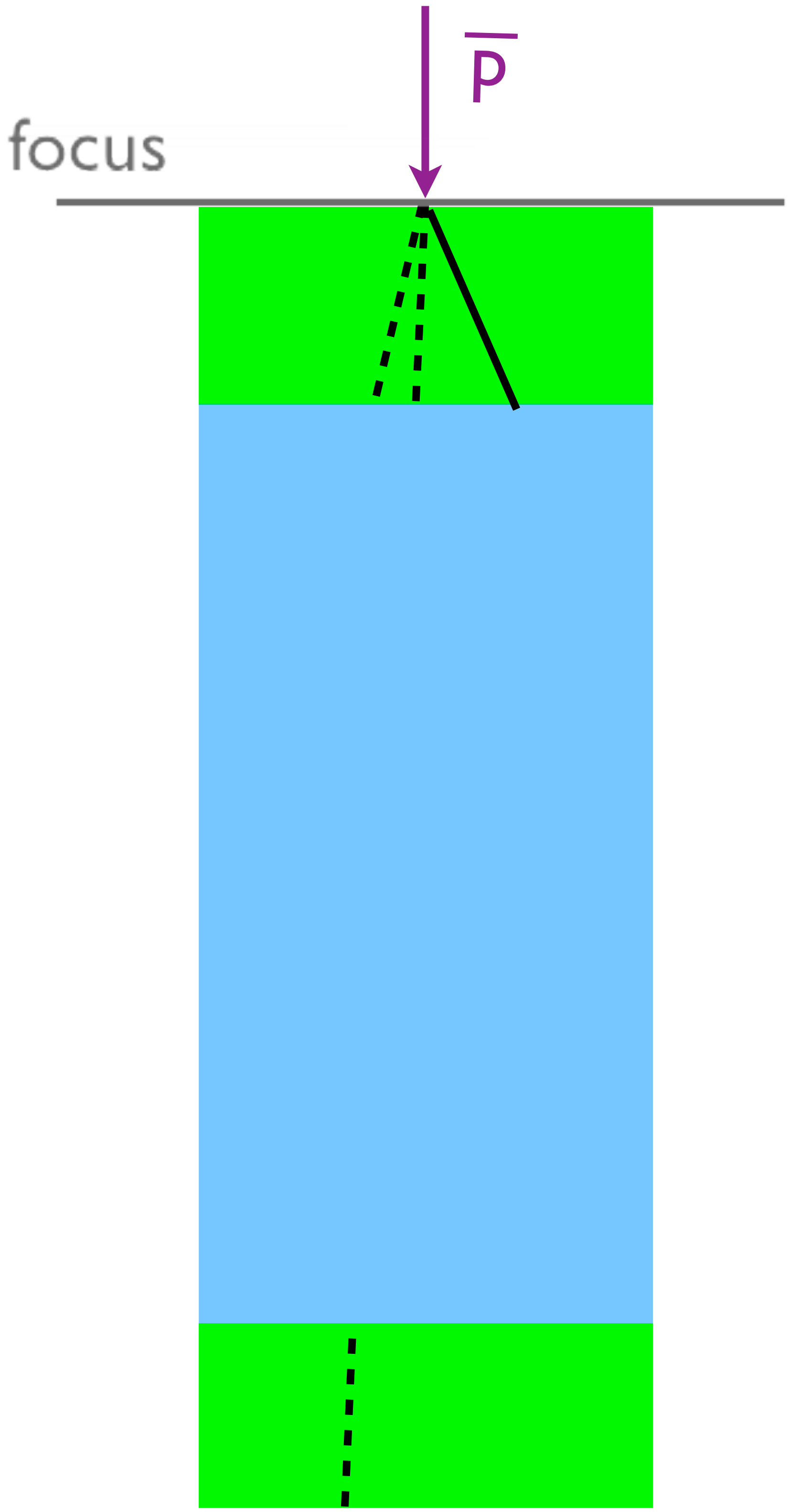




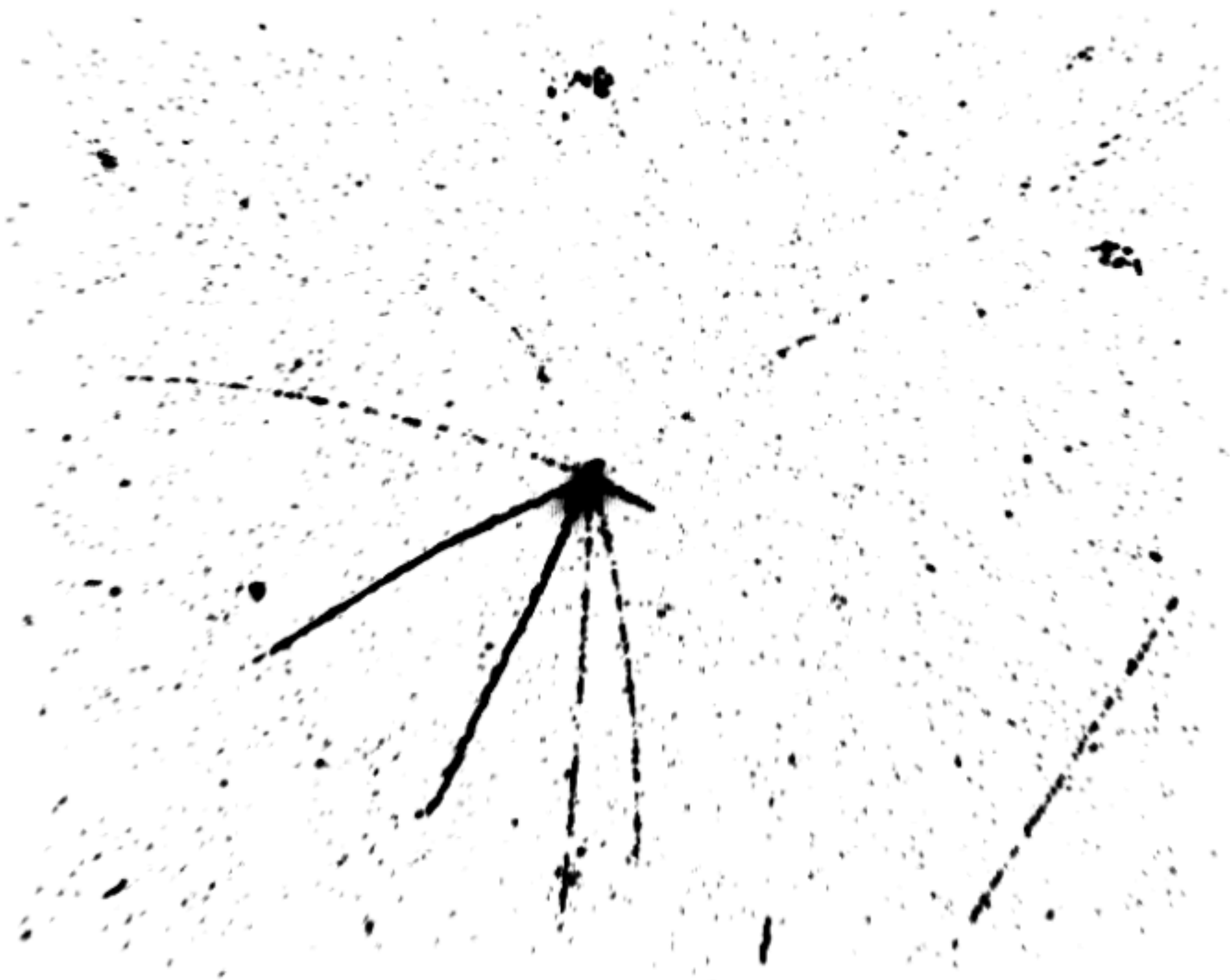



50 microns
5000 events / cm2

Topographic readout of the emulsion by optical scan

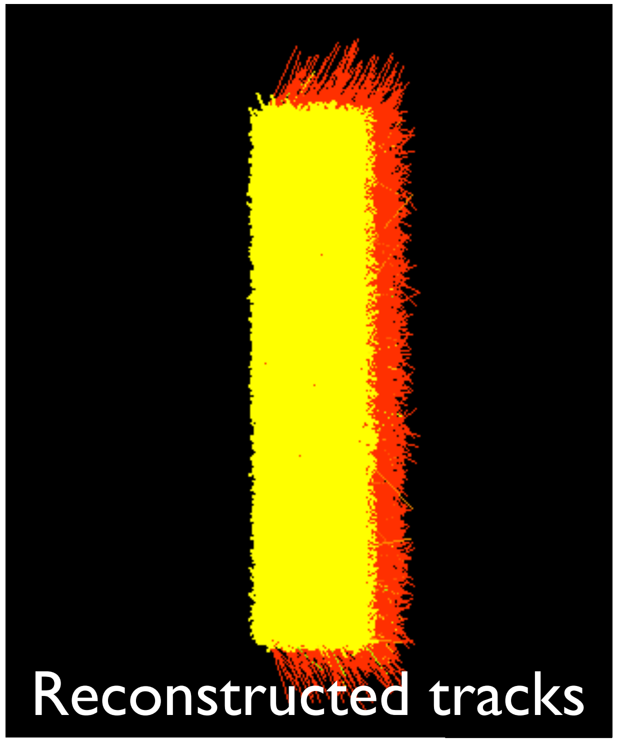


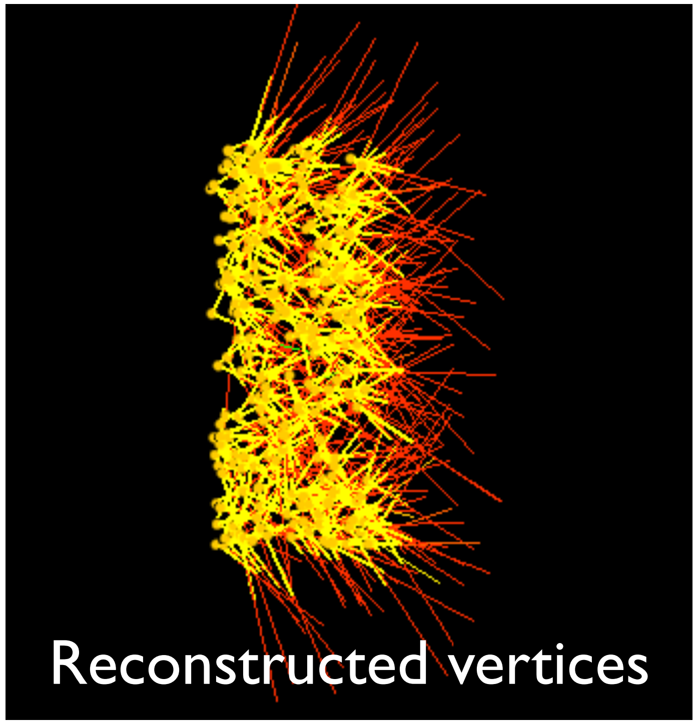
Antiproton annihilation in a bare emulsion



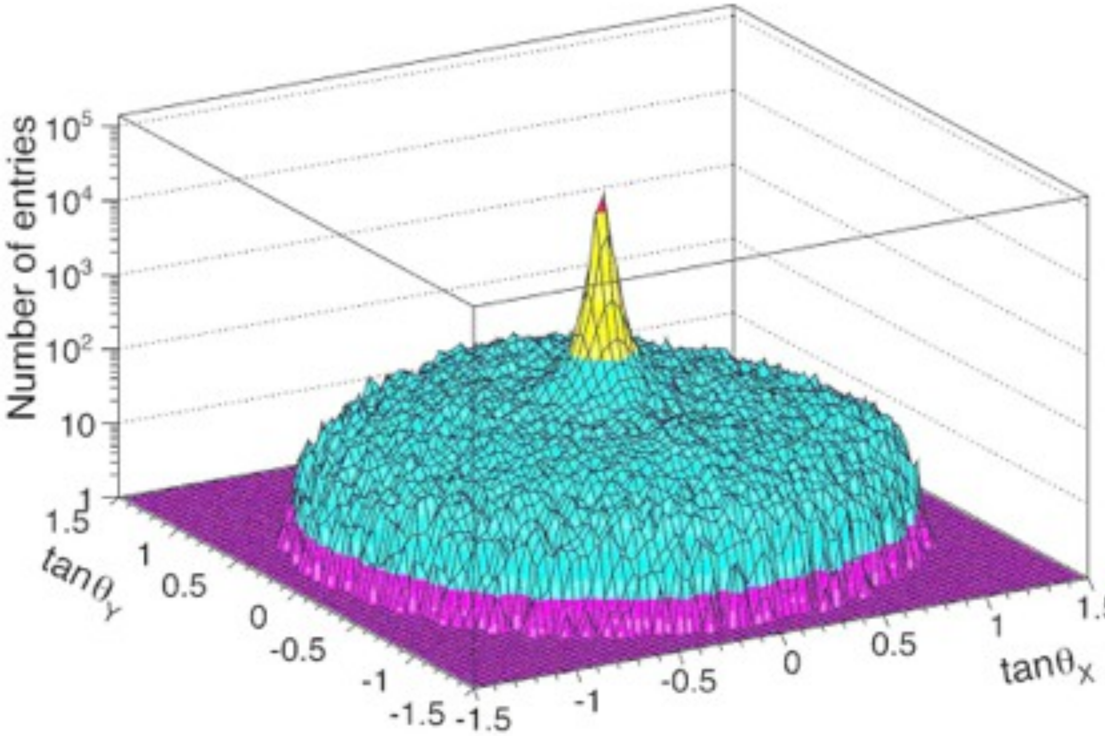
150 μm x 120 μm x 50 μm

Reconstructed tracks and annihilation vertices

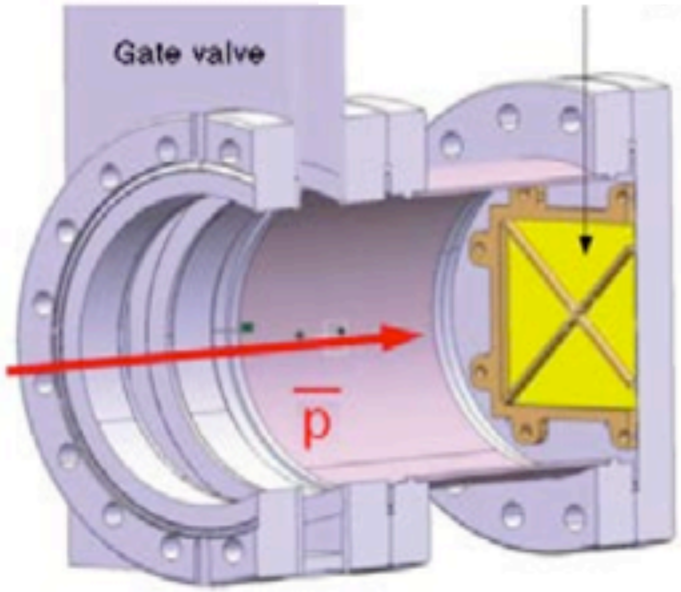




Angular distribution of reconstructed tracks



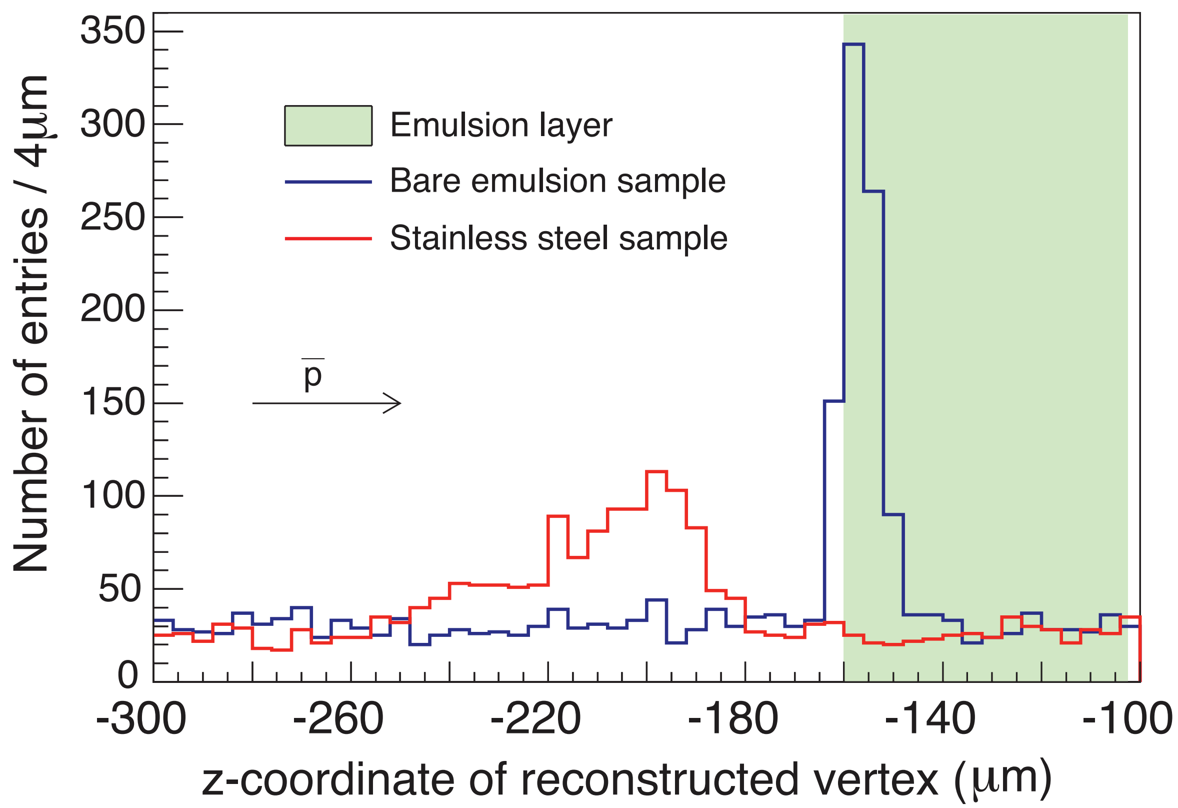
emulsion films (yellow)

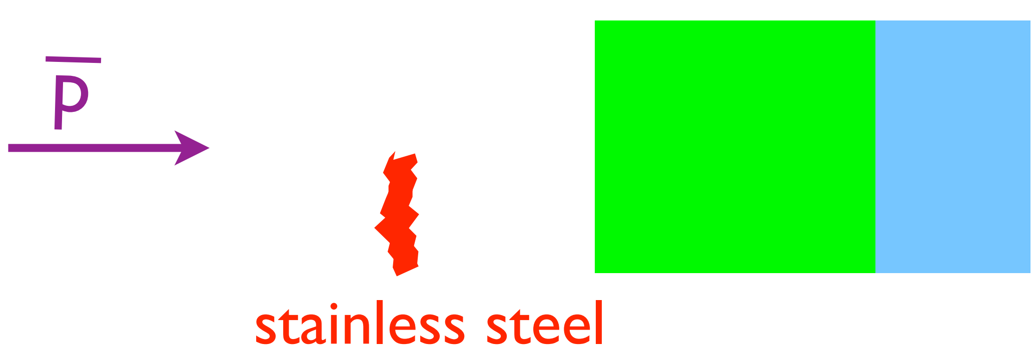


track perpendicular to emulsion surface = 0°

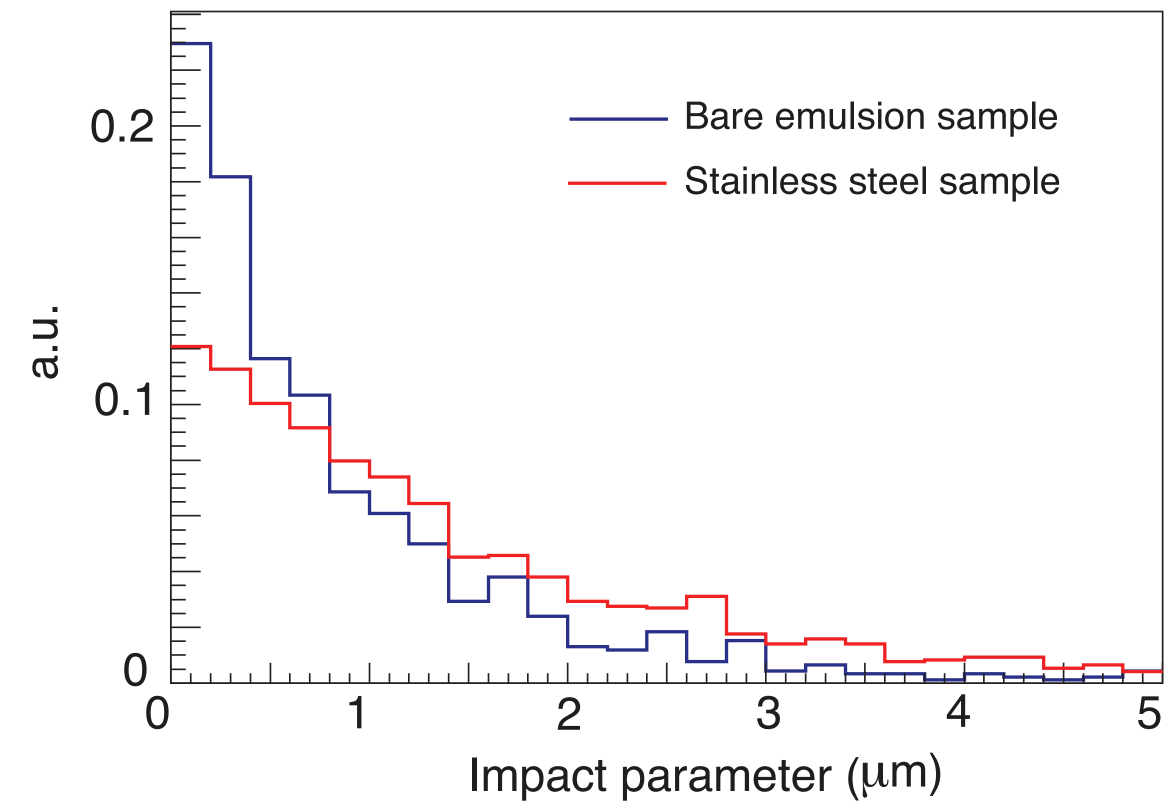
Antiproton annihilation vertex resolution

vertex resolution perpendicular to emulsion surface





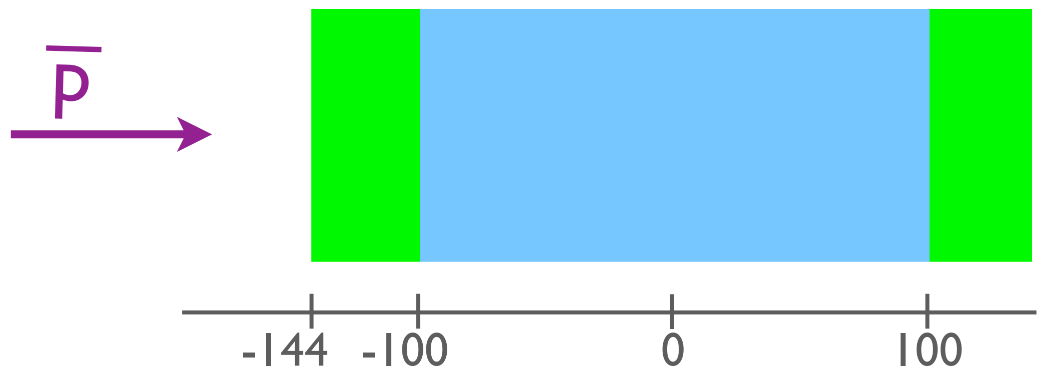
vertex resolution

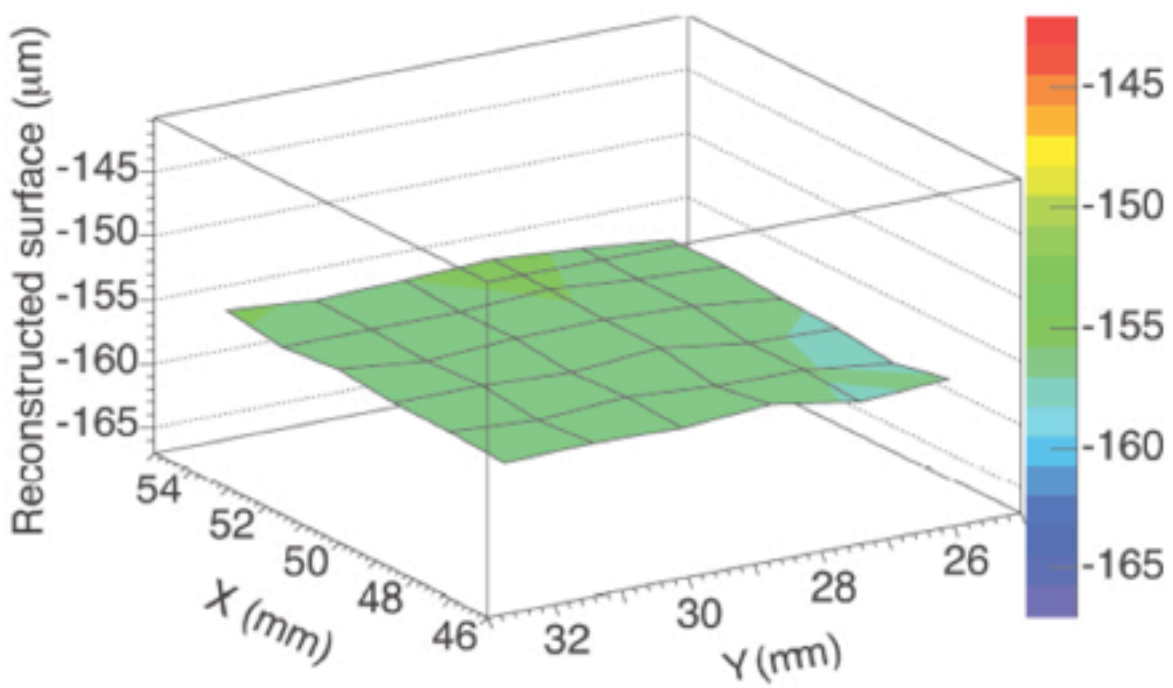


r.m.s. resolution ≃ 1 μm on the vertical position of the annihilation vertex

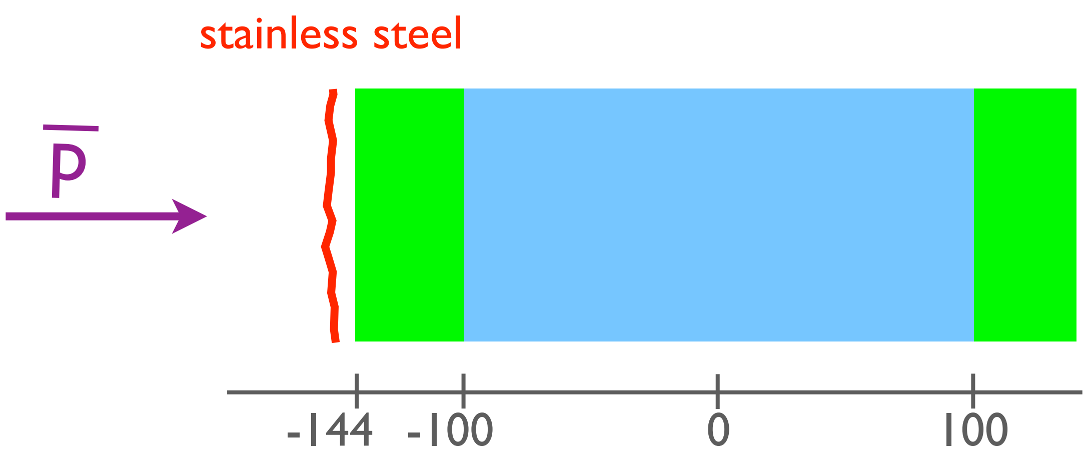
Topography of bare emulsion & stainless steel foil

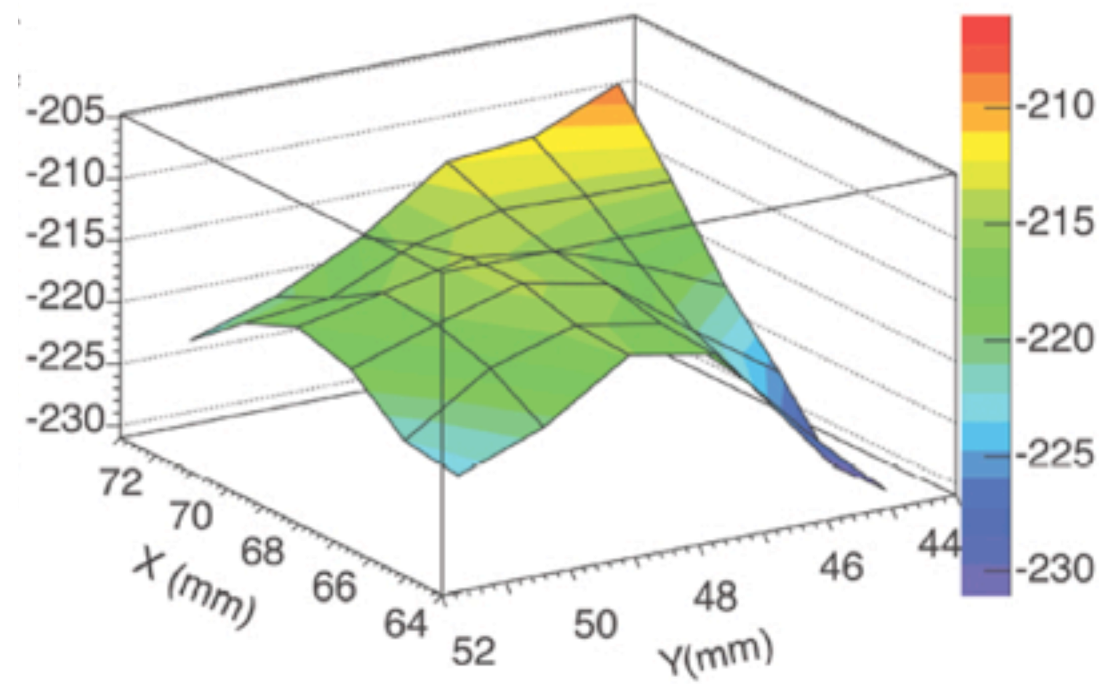
Bare emulsion



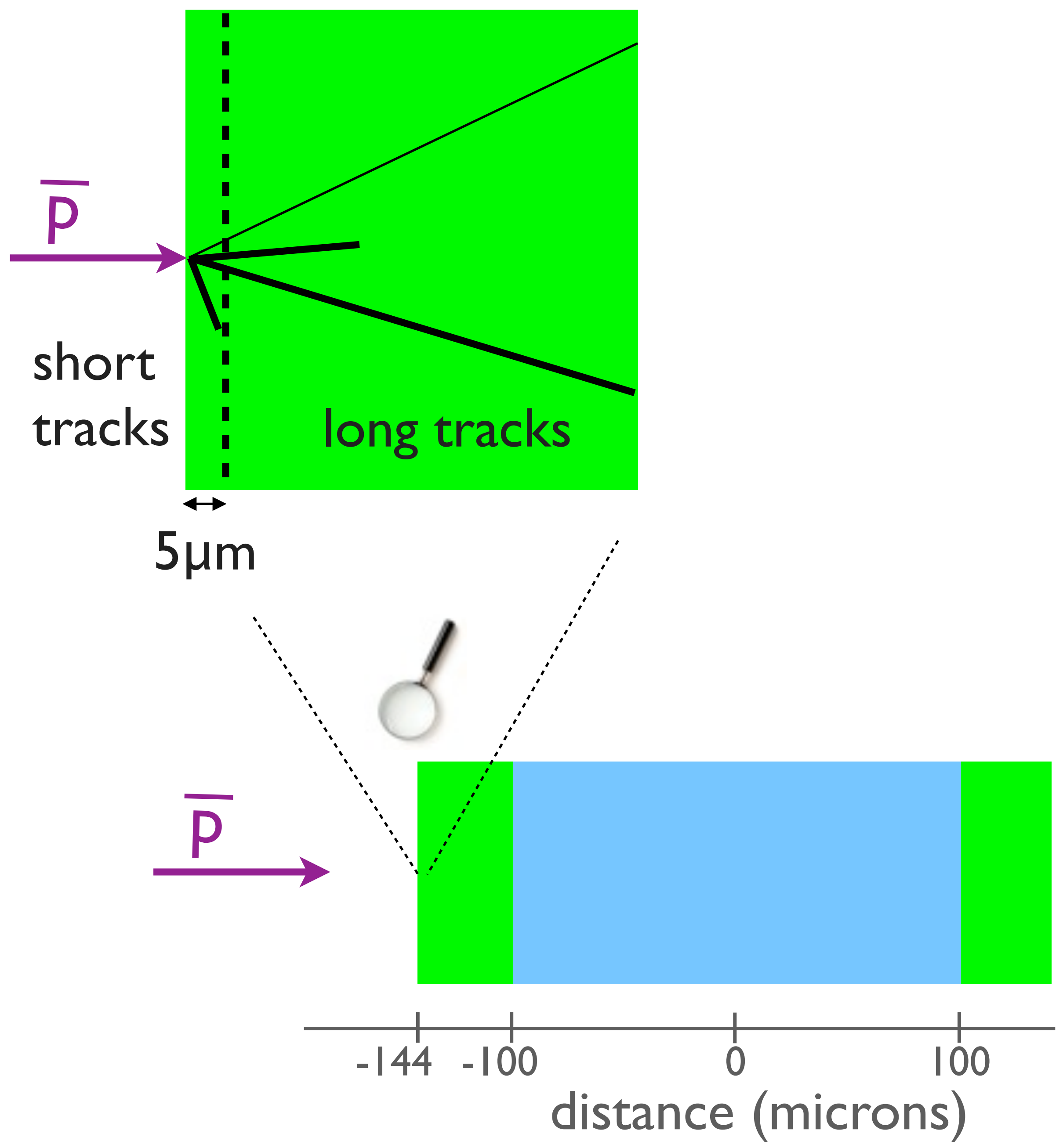


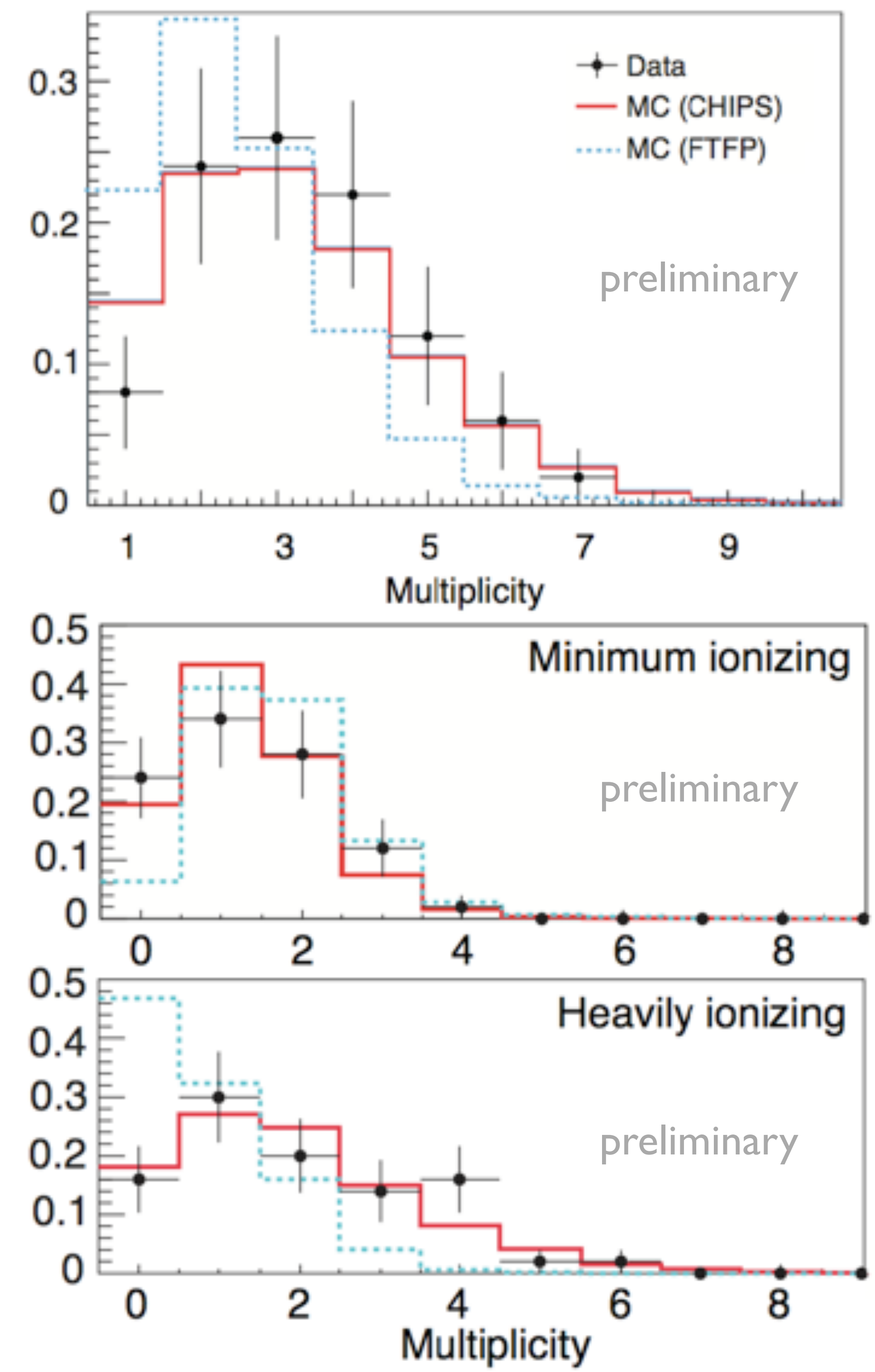
Emulsion covered with stainless steel foil



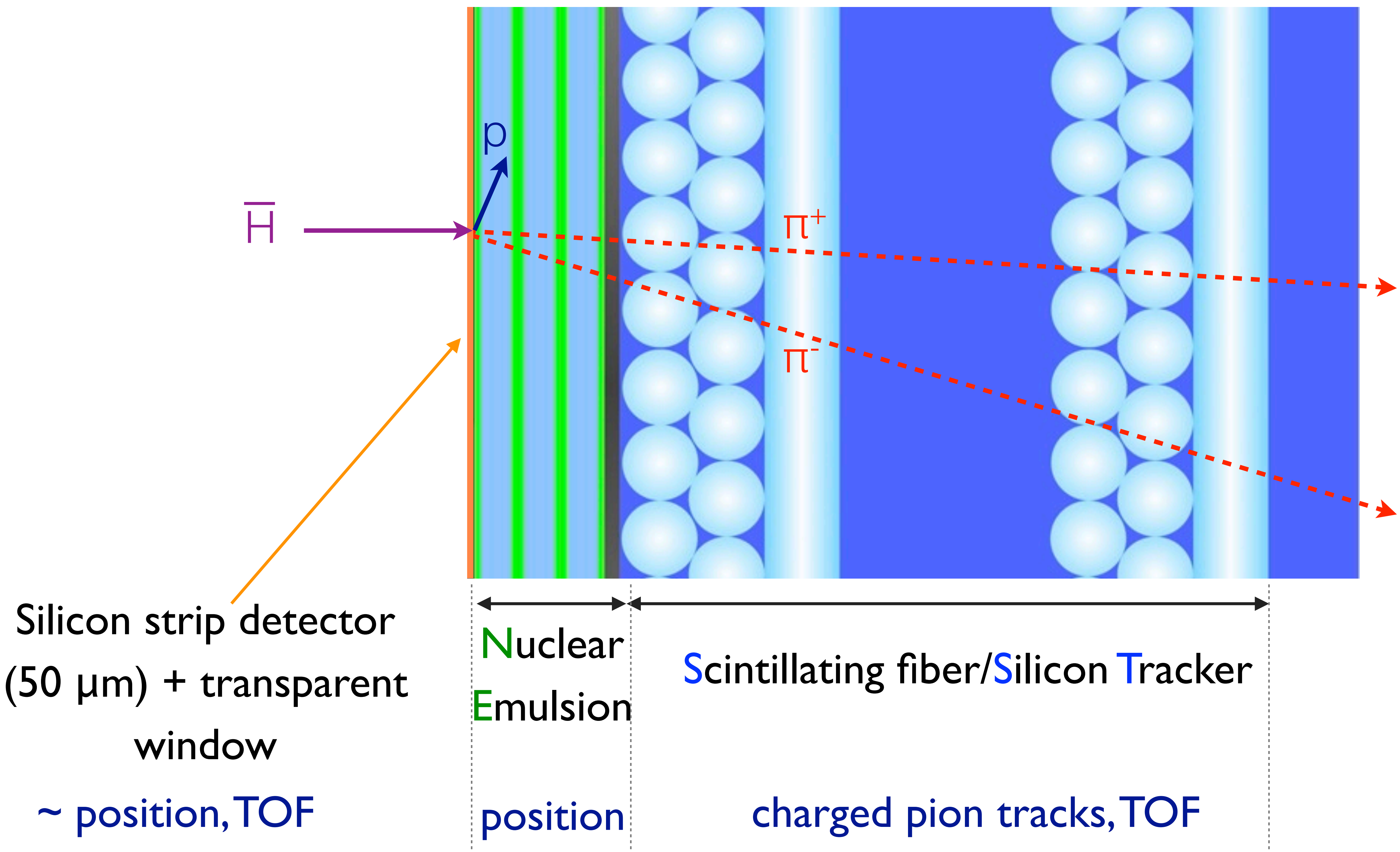


Multiplicity of annihilations in emulsion detector: Data / Monte Carlo comparison

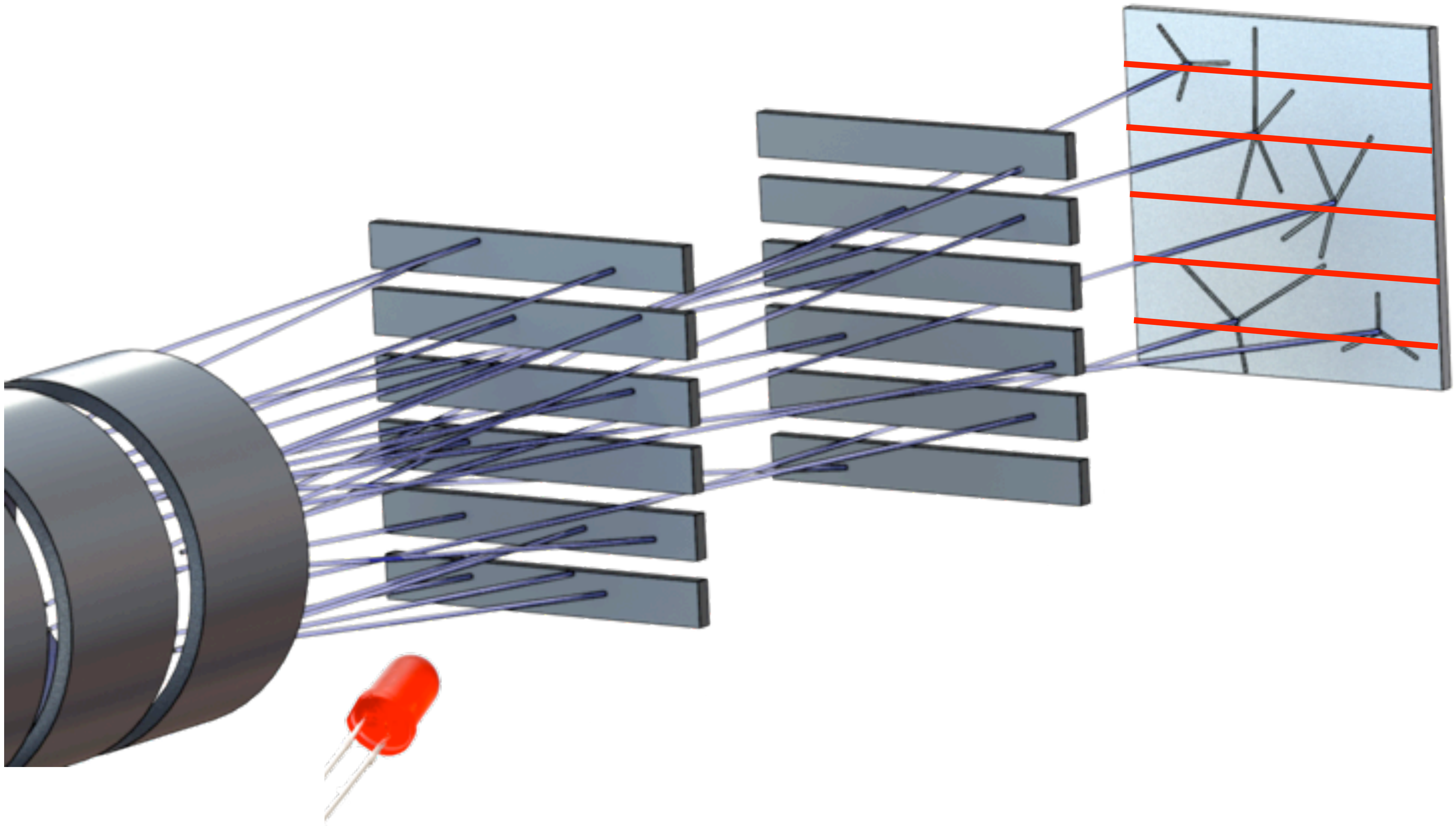




Hybrid detector concept: **N**uclear **E**mulsion + **S**cintillating-fiber/**S**ilicon **T**racker (**NEST**)



Alignment between moiré gratings and emulsion detector



Absolute reference can be "stamped" directly on emulsion surface.

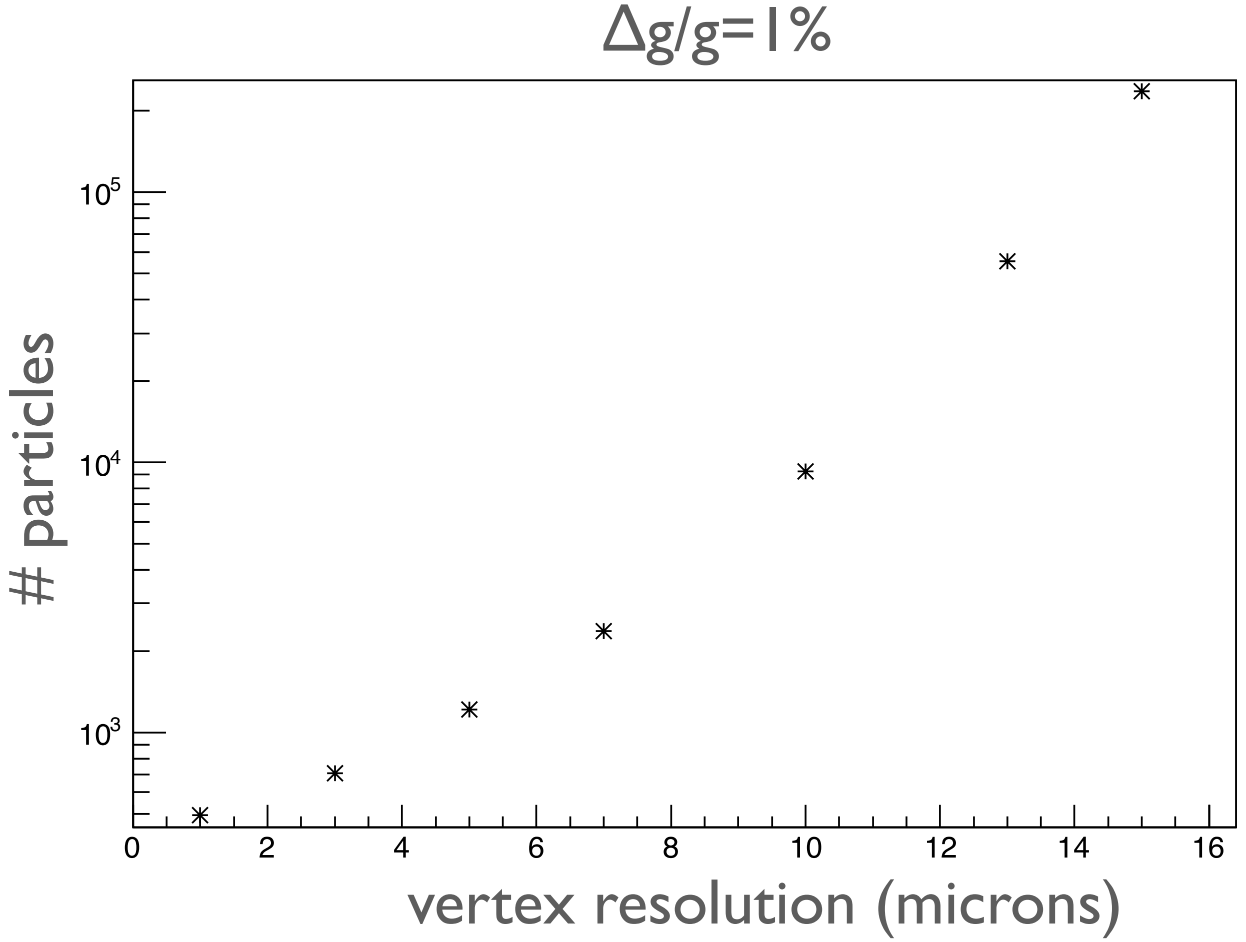
Simulated performance

Annihilation position resolution = 1-2 μm

Efficiency (require 2 tracks traversing emulsion) = 50%

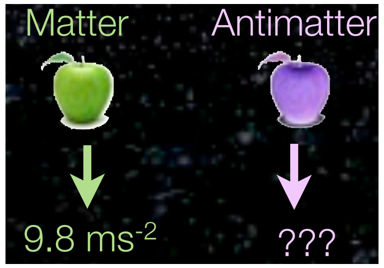
With a 2um position resolution how many antihydrogen atoms do we need for $\Delta g/g = 1\%$?

~600 fully reconstructed and time tagged Hbar annihilations



Implication: can afford to relax other (challenging) requirements e.g. Hbar temperature.

Conclusions



- Micron precision reconstruction of the Hbar annihilation vertex allows for a measurement of $\Delta g/g = 1\%$ with ~600 Hbar atoms.

- Emulsion detectors have been used to reconstruct the vertex of antiproton annihilations with an r.m.s resolution ≃ 1 µm.

- Simulations of a hybrid free-fall detector based on emulsion and silicon strip technologies demonstrate vertex reconstruction with micron level resolution.

Thanks
for
listening!