Production of ultra-slow antiproton beams

Hiroyuki A. Torii
Institute of Physics, University of Tokyo

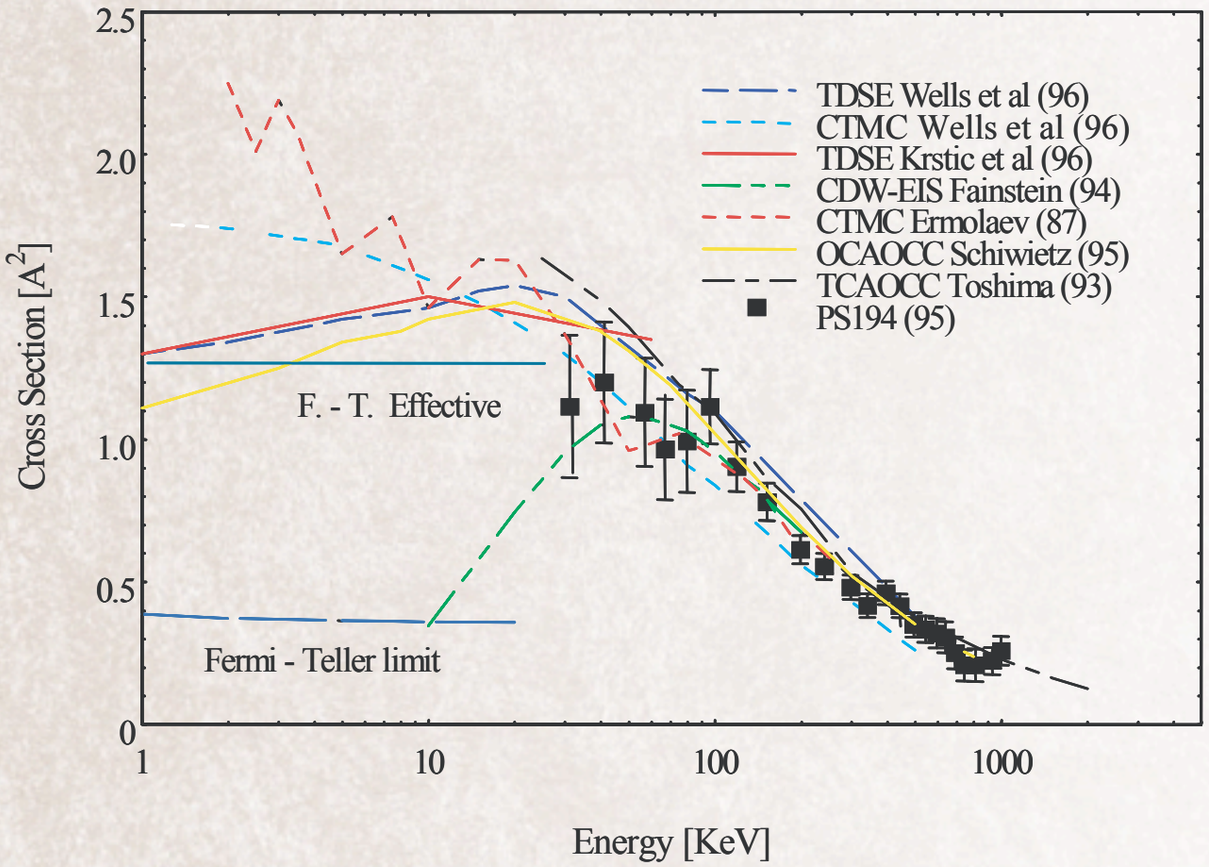
MUSASHI-Trap group
N. Kuroda, M. Shibata, Y. Nagata, D. Barna, M. Hori, J. Eades,
A.Mohri, K. Komaki and Y. Yamazaki
University of Tokyo, RIKEN, KFKI (Budapest), CERN
ASACUSA Collaboration

Production of ultra-slow antiproton beams

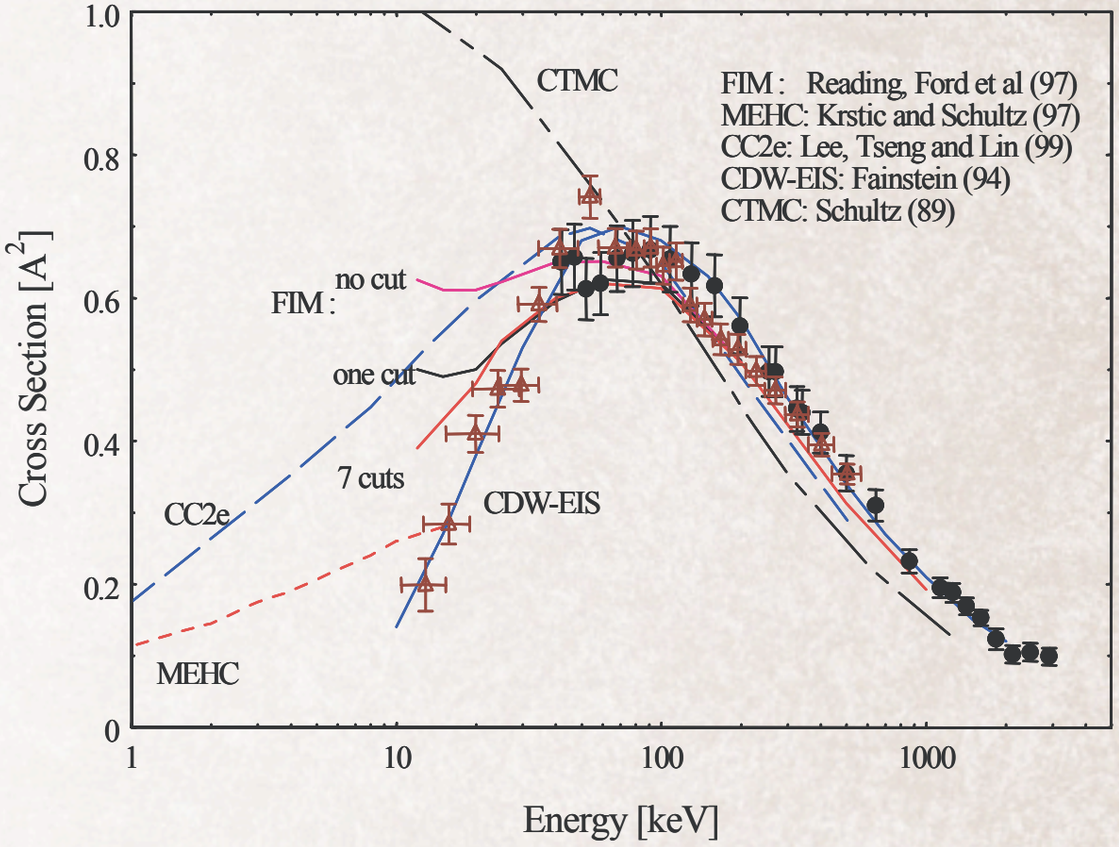
- Why low-energy antiprotons
- Cooling scheme
- Trapping
- Extraction & beam transport
- Near-future plans

Low-energy Antiproton
— as a probe of atomic processes

ionization cross section for atomic $\bar{p}$ – D



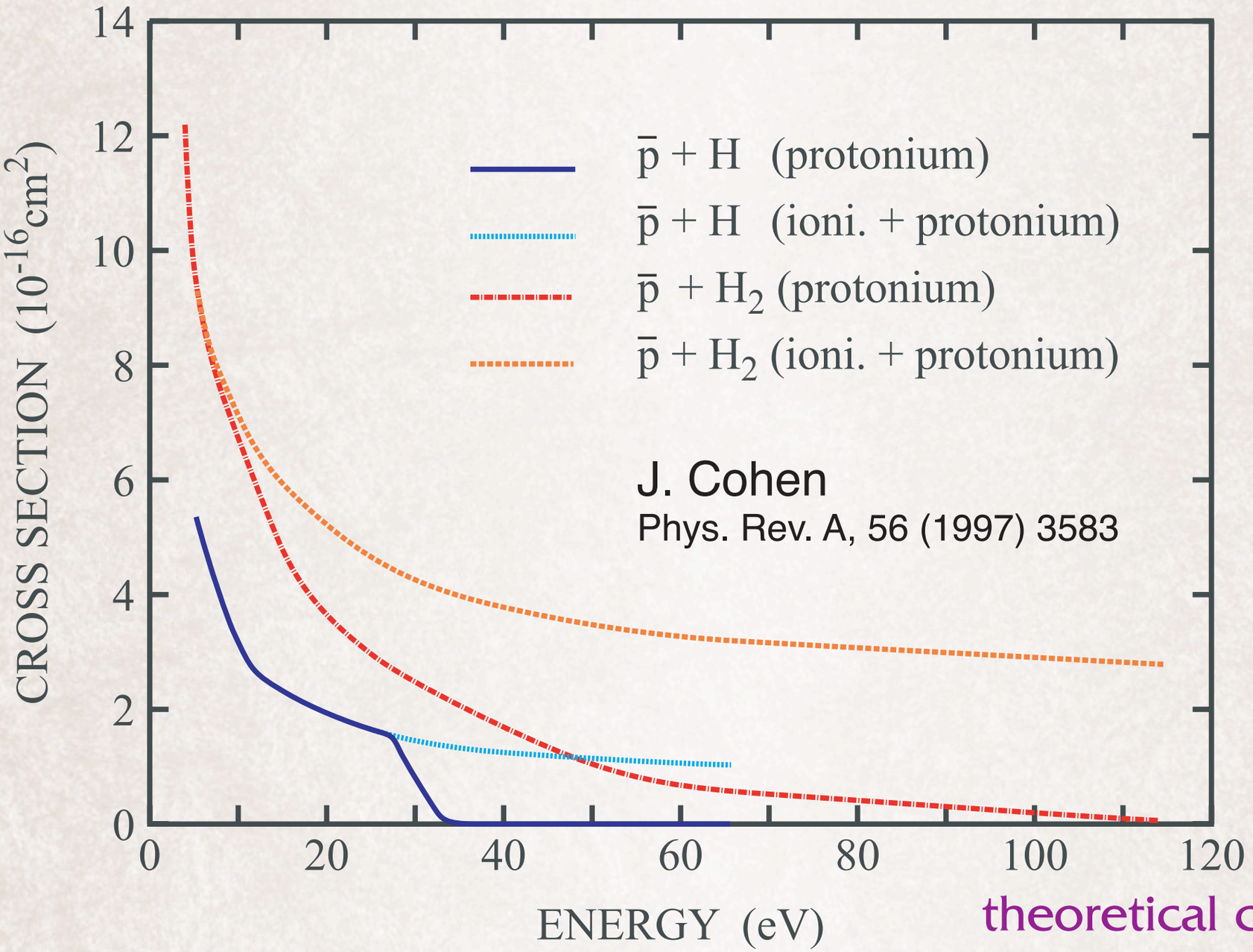
single ionization cross sect. for $\bar{p}$ – He



ionization : 1–1000 keV

theoretical calculations widely vary

capture + ioniz. cross. sect. for $\bar{p}$ + H / H_2



theoretical calculations

atomic formation : 1–100 eV

ASACUSA

Atomic Spectroscopy
And Collisions
Using Slow Antiprotons

MUSASHI

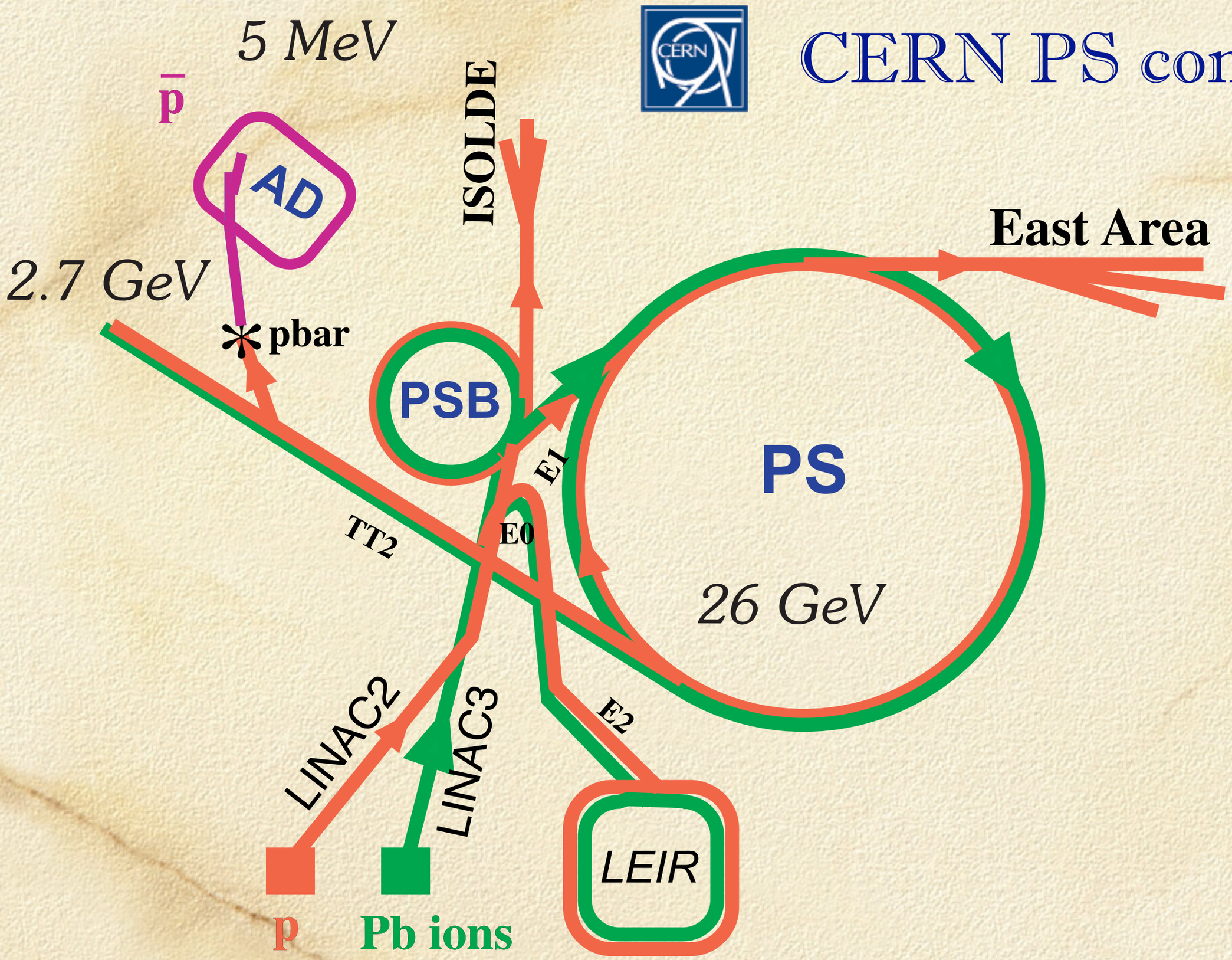
Monoenergetic UltraSlow
Antiproton Source
for High-precision
Investigations

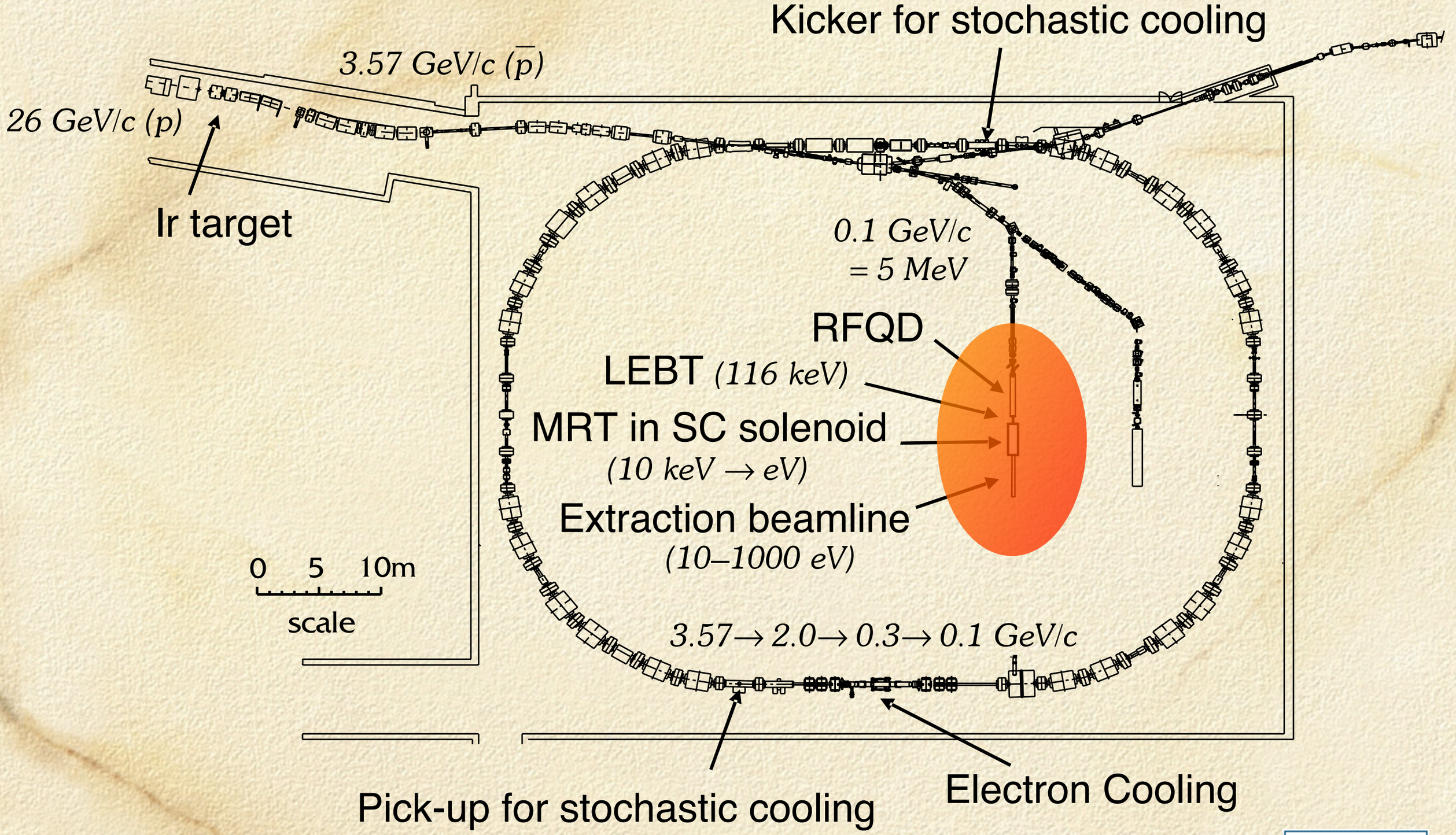
武蔵

浅草

Asakusa, Tokyo

CERN PS complex





CERN AD ring
Antiproton Decelerator

Cooling scheme

5.3 MeV antiproton from AD

↓ RFQD (Radio-Frequency Quadrupole Decelerator)

~ 100 keV antiproton

↓ thin degrader foils

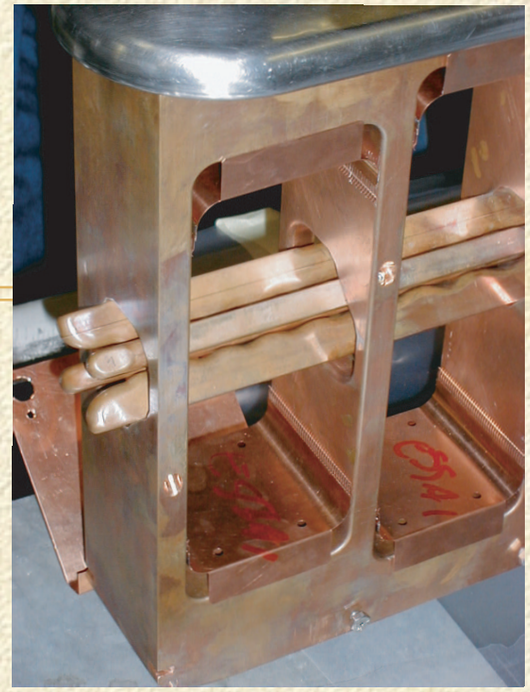
< 10 keV antiproton

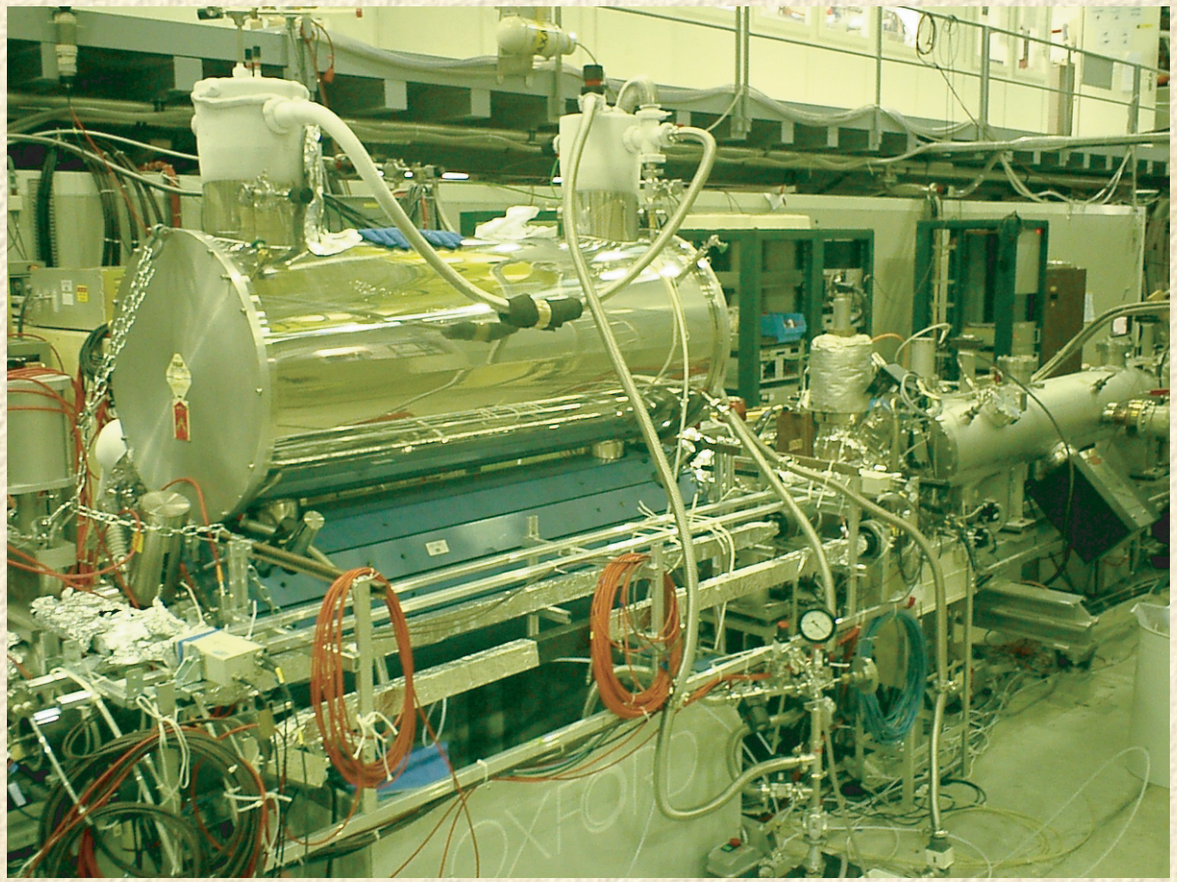
↓ MRT (Trap) electron cooling

sub-eV antiproton

↓ beamline

extraction of 10–1000 eV antiproton beam





100GeV

Proton beam from PS : 27GeV

10GeV

Threshold of antiproton production
Produced antiprotons at AD : 3.5GeV

1GeV

100MeV

10MeV

AD beam : 5.3MeV

1MeV

100keV

AD+RFQ :120-60keV

10keV

1keV

Extracted antiprotons
: 1000-10eV

100eV

10eV

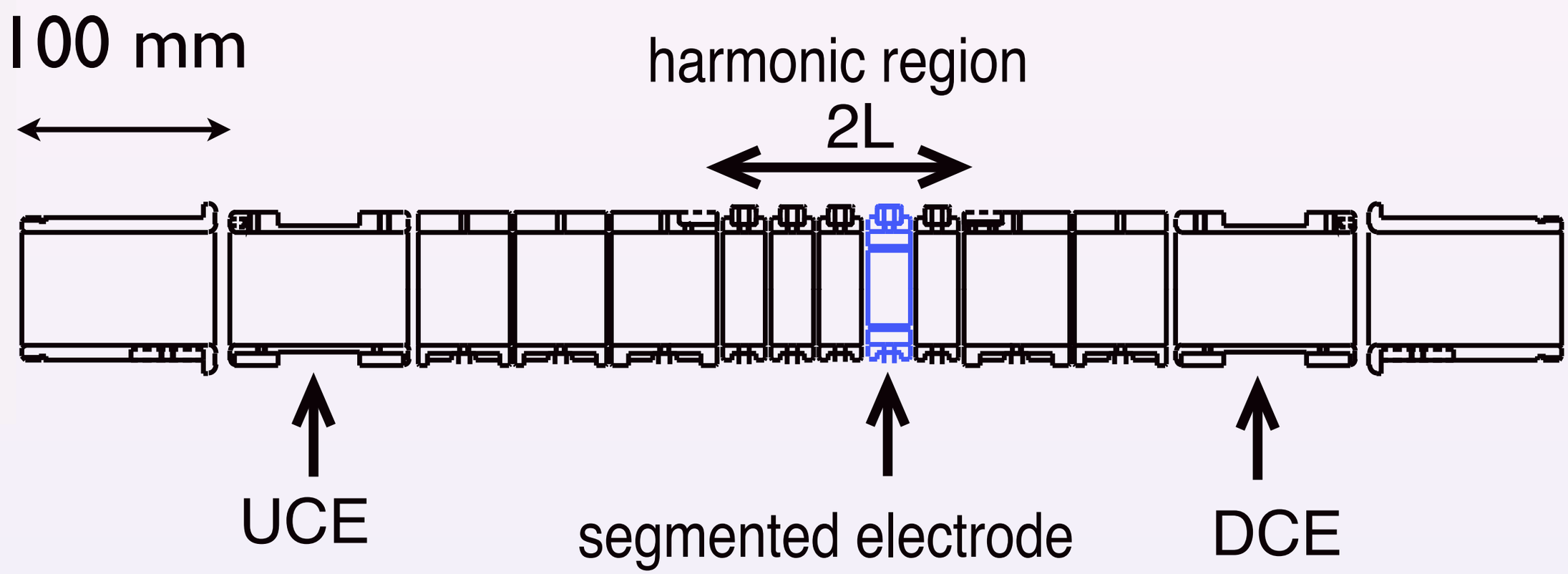
AD+RFQ+Trap
: < 100eV

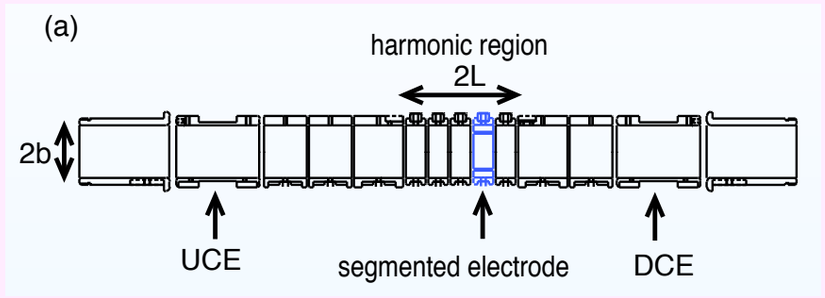
1eV

electron cooling : < 1 eV

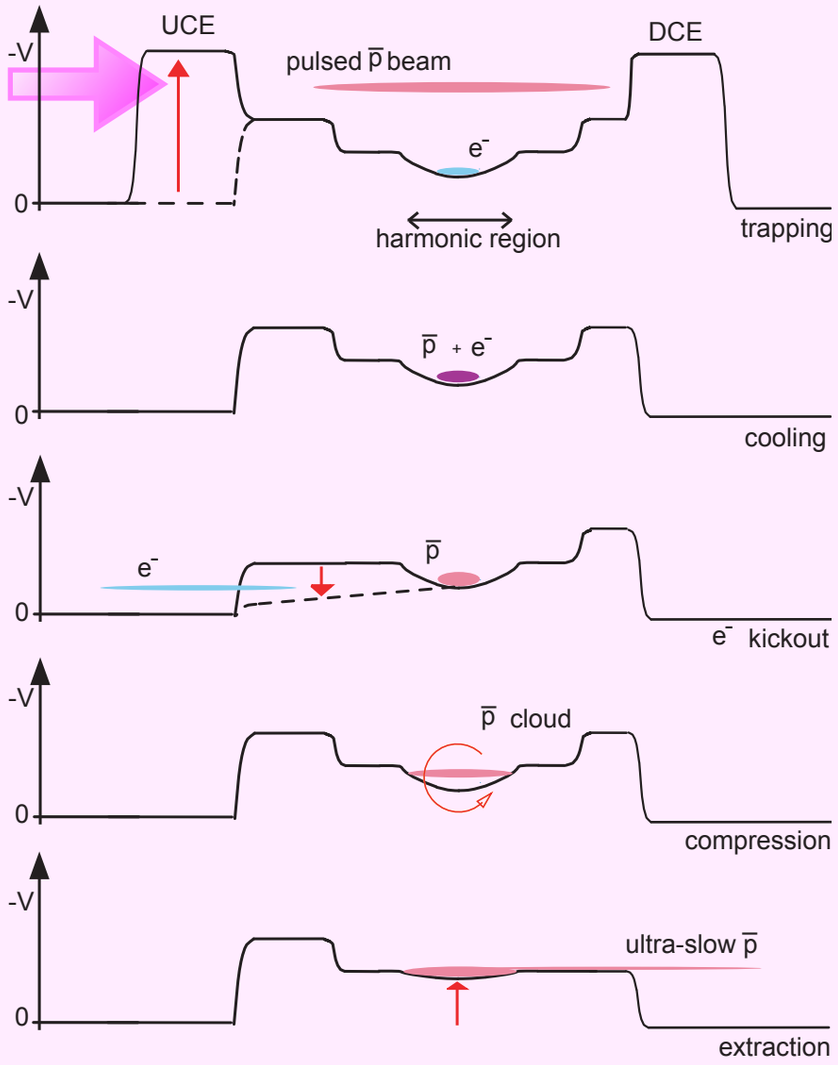
Cooling of 10^{-11} in energy !

MRT (Multi-Ring electrode Trap) installed in 2.5 T magnetic field

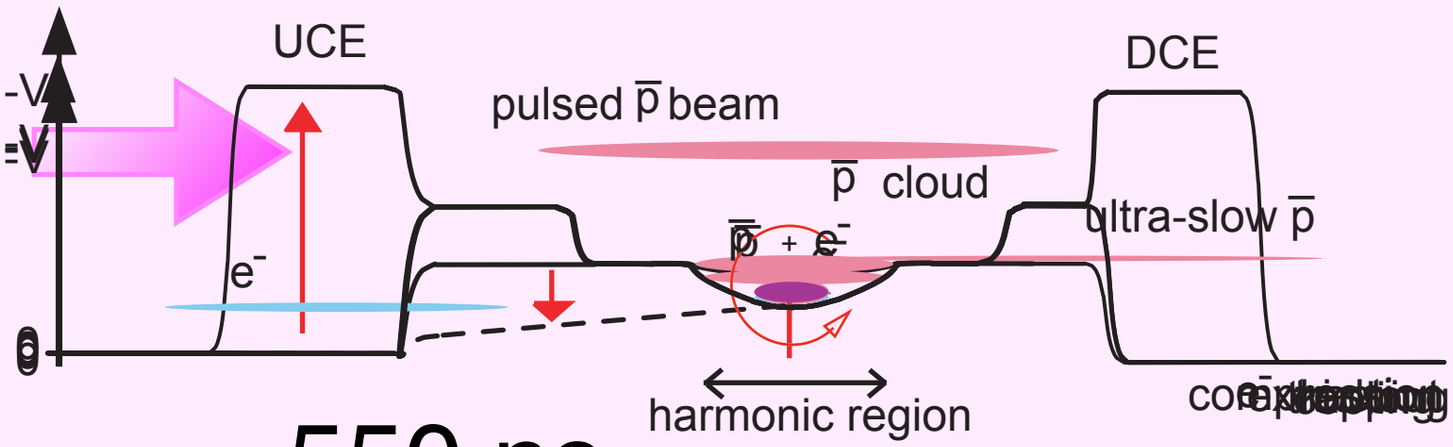




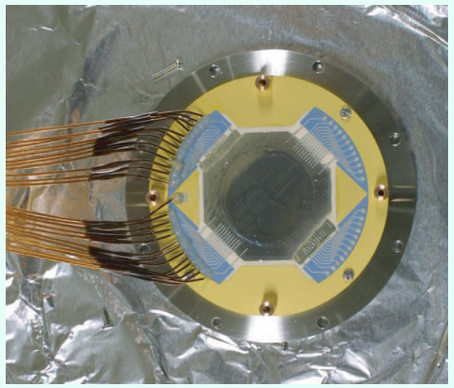
CE Cooling

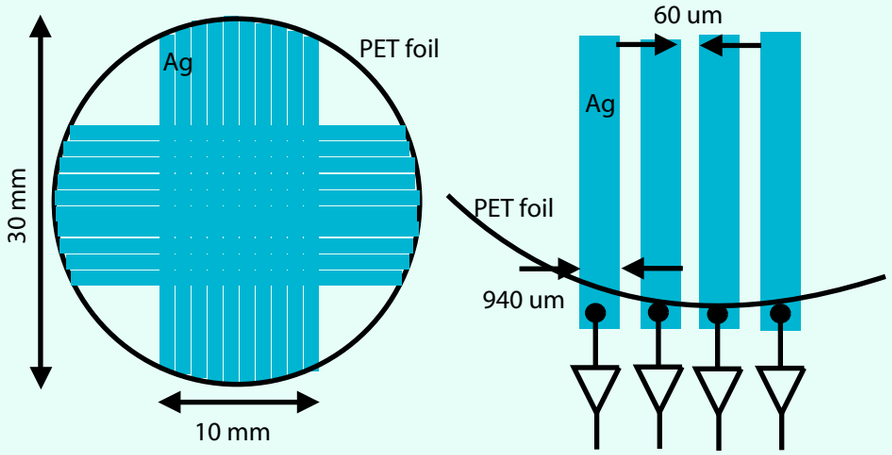


ca. 500 ns



550 ns



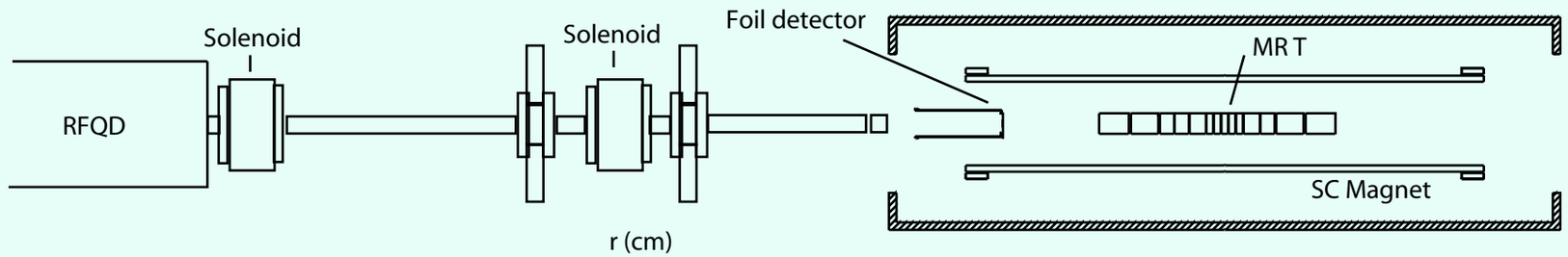


foil detector ($\bar{p}$ beam profile monitor)

2 foils × 90 μm thickness
50 nm Ag evaporative-plated

10^{-9} Torr

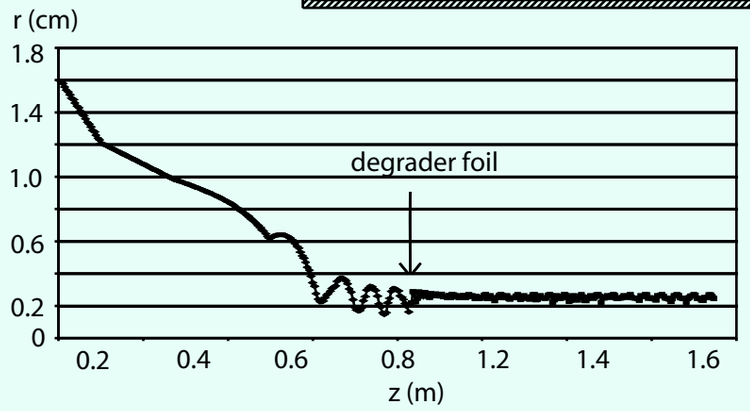
10^{-12} Torr



110 keV

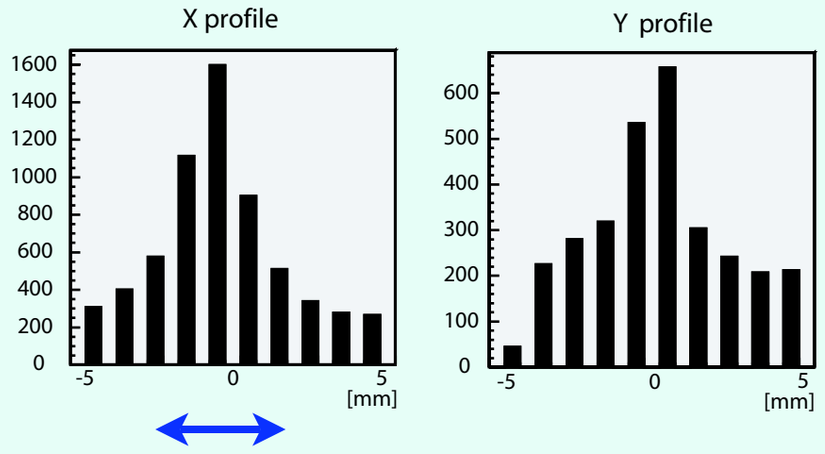
Antiproton Injection

$\bar{p}$ beam focused to
3 – 4 mm Ø FWHM

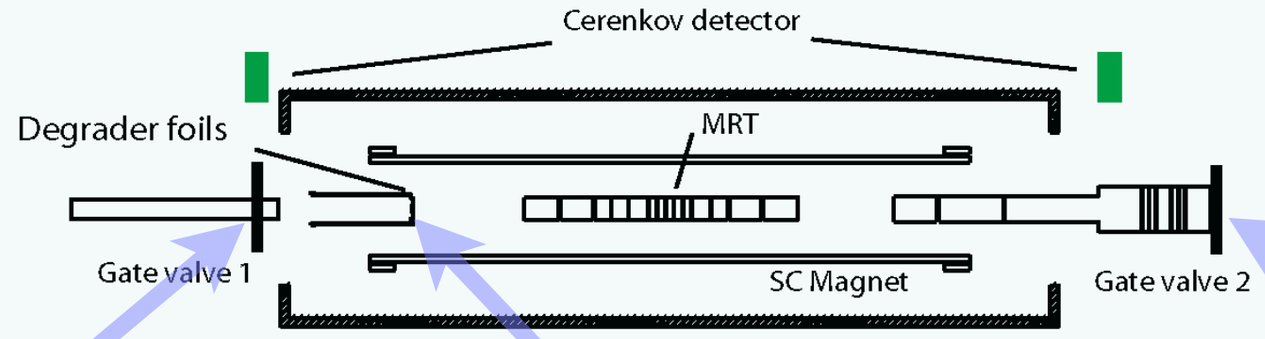


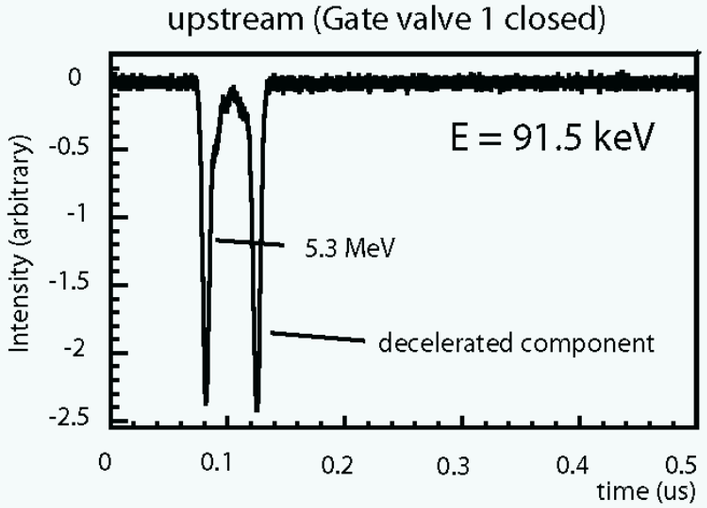
< 10 keV

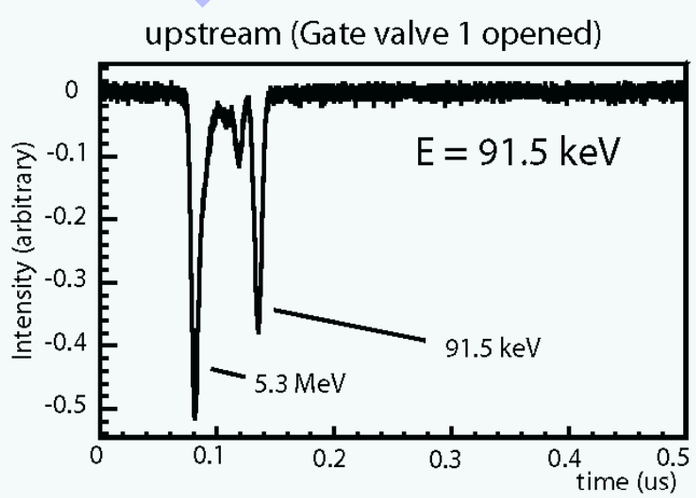
2.5 Tesla

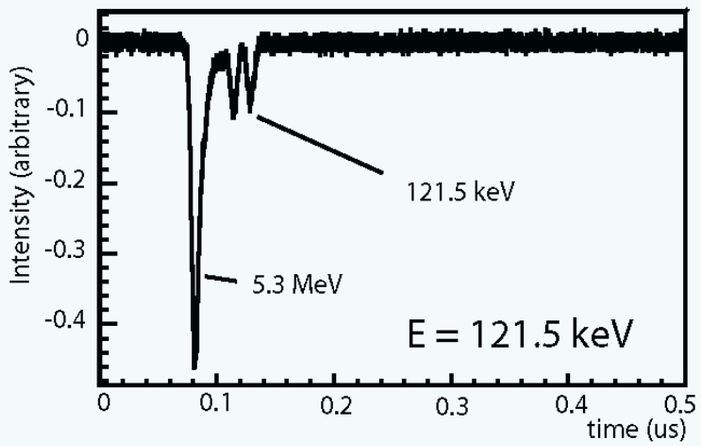


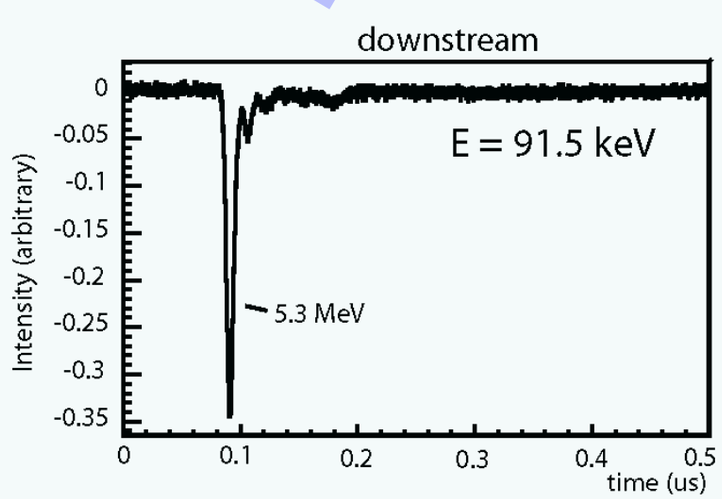
Antiproton Injection : Čerenkov detectors

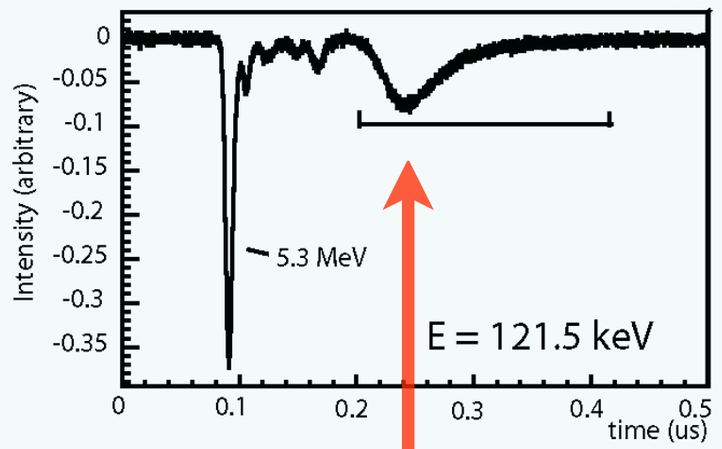










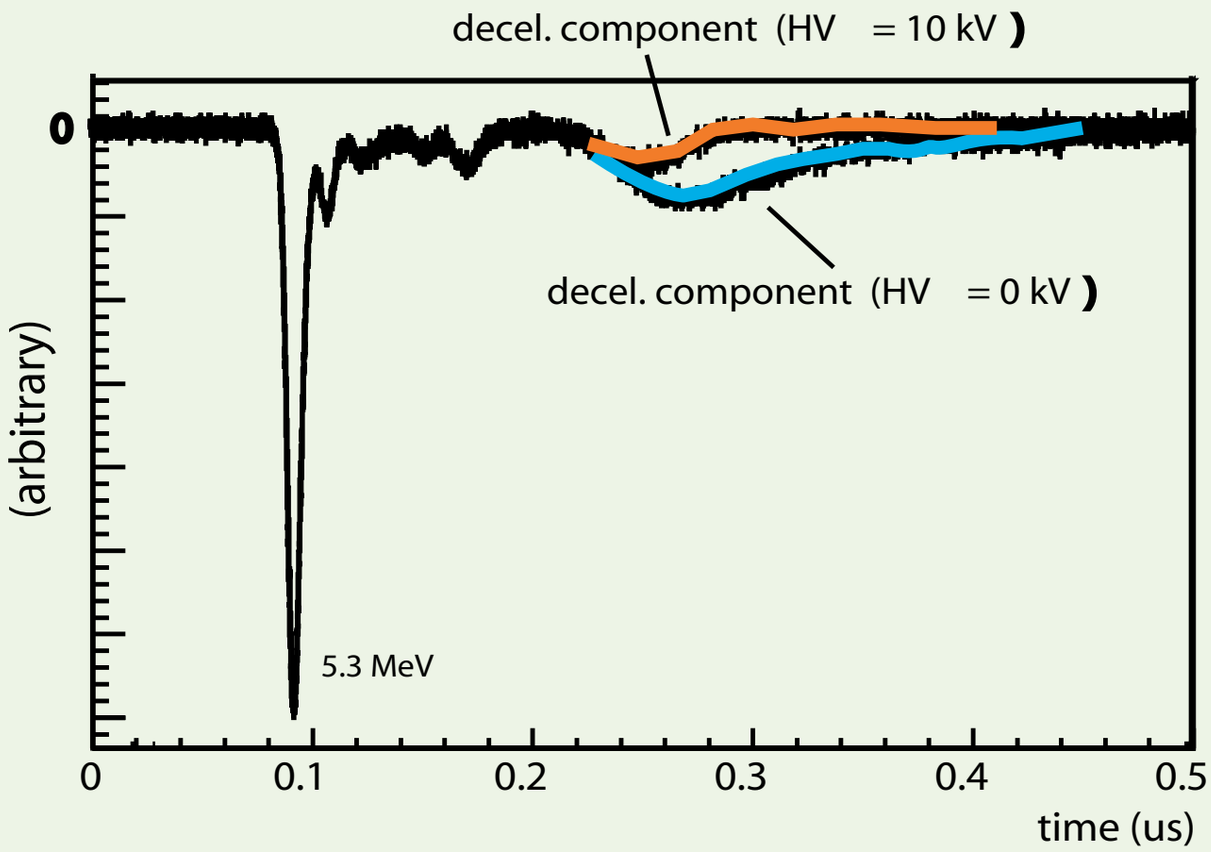


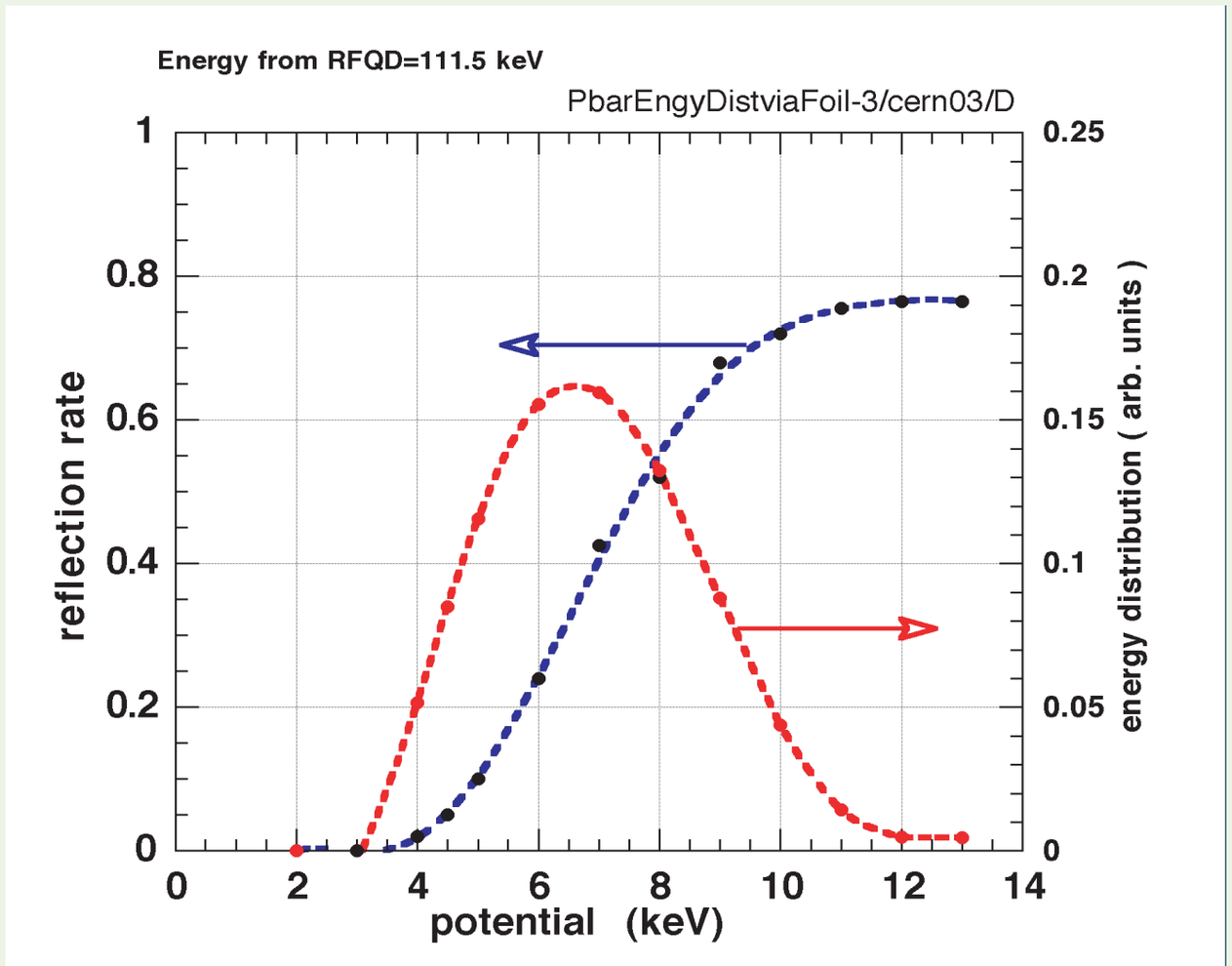
TOF

decelerated

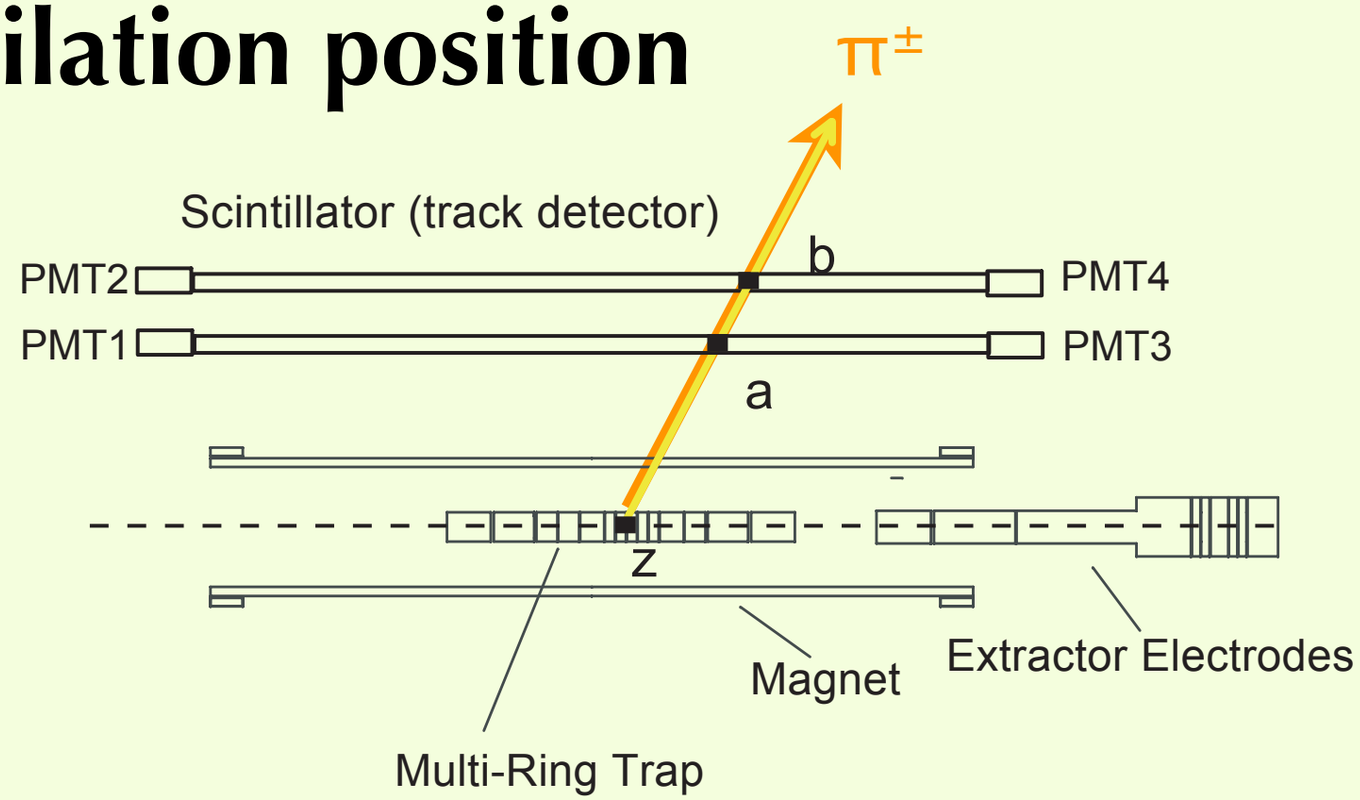
5.3 MeV component

decelerated $\bar{p}$


decel. component (HV = 10 kV)
decel. component (HV = 0 kV)
0
(arbitrary)
5.3 MeV
0
0.1
0.2
0.3
0.4
0.5
time (us)

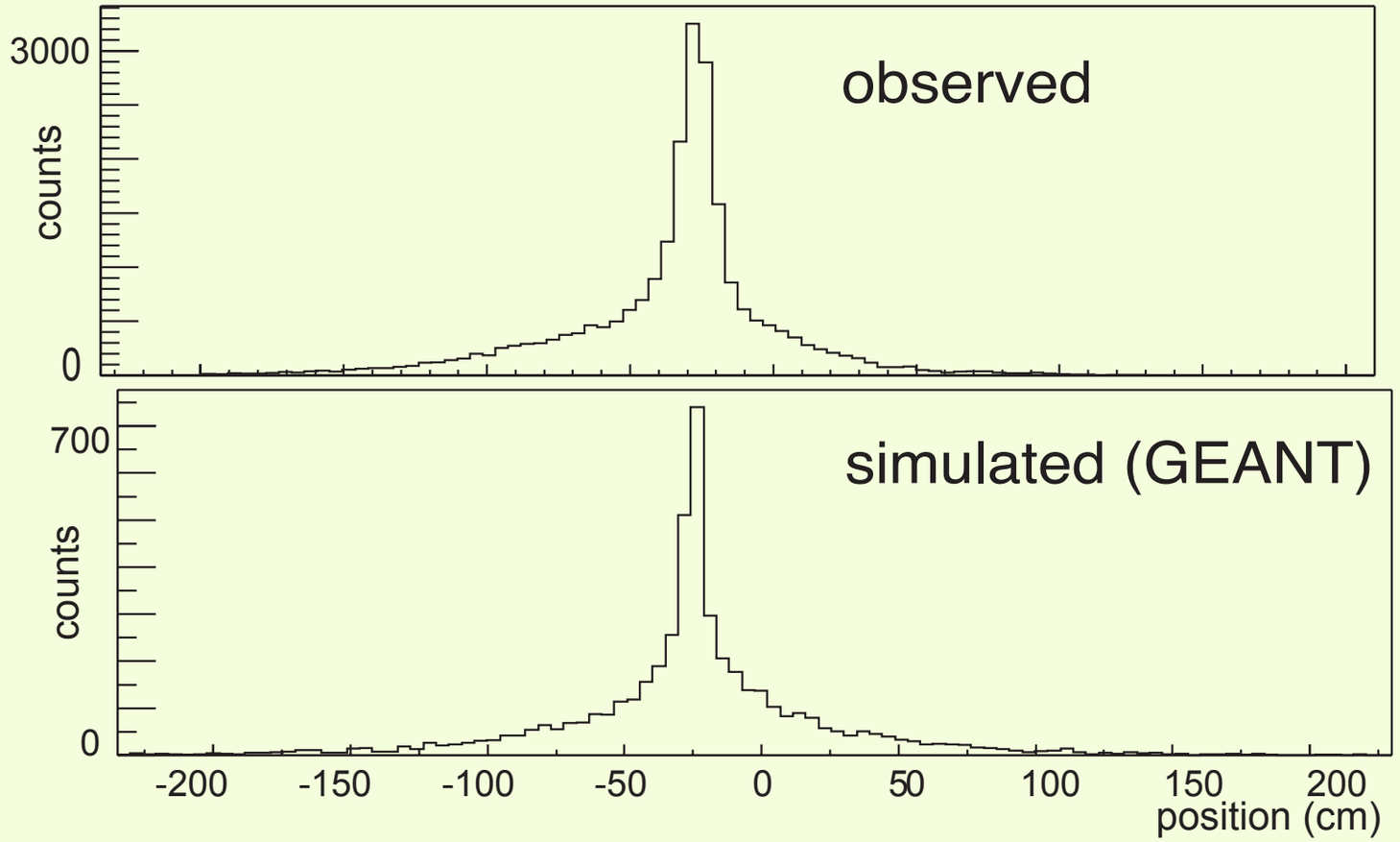

Energy from RFQD=111.5 keV
PbarEngyDistviaFoil-3/cern03/D
reflection rate
energy distribution (arb. units)
potential (keV)
1
0.8
0.6
0.4
0.2
0
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
12
14

Tracking of annihilation position

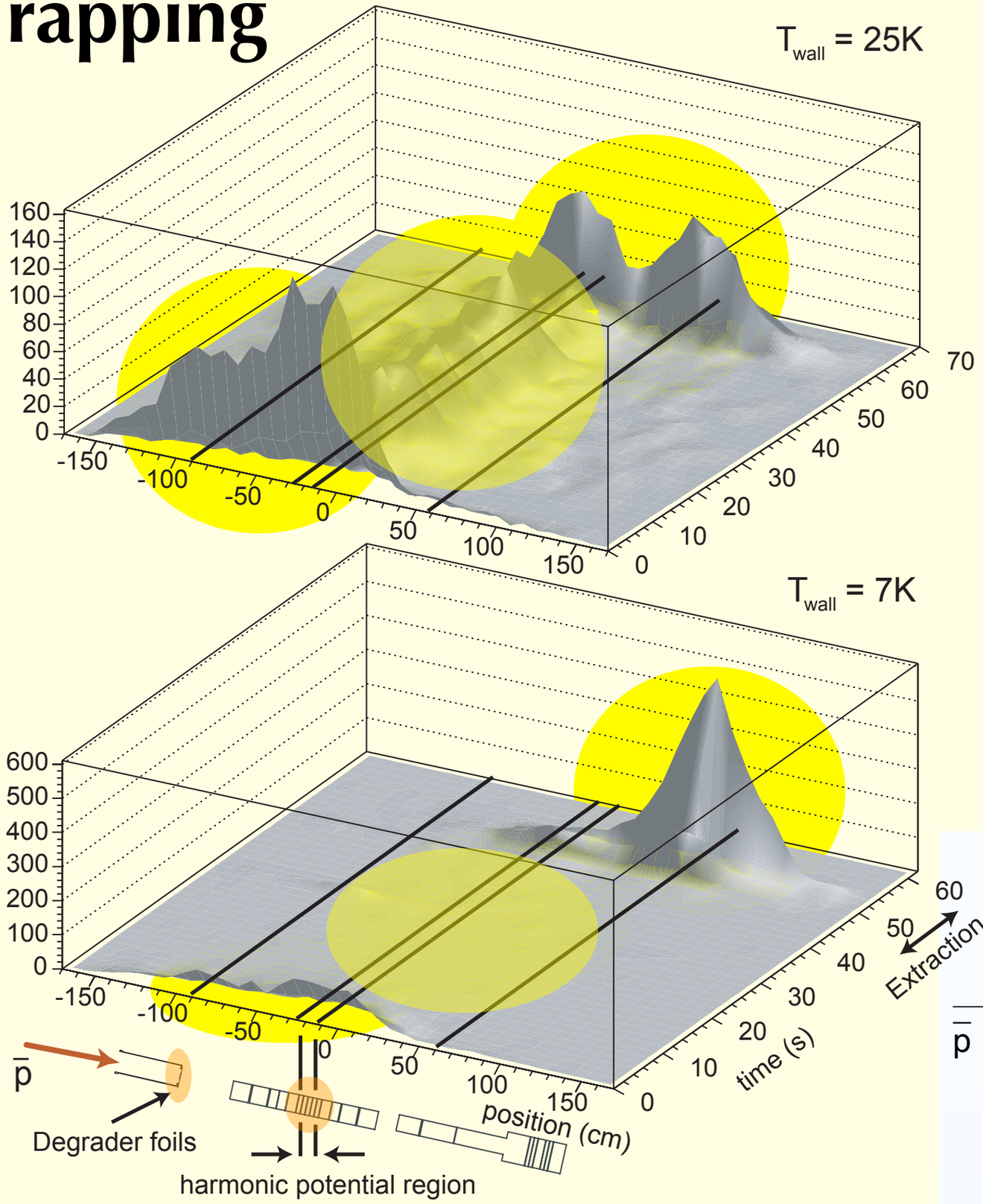


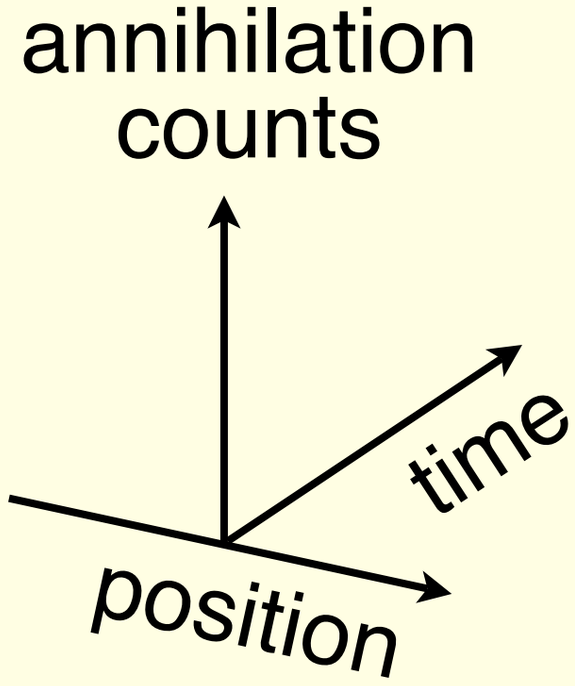
$\Delta z \sim 20$ cm

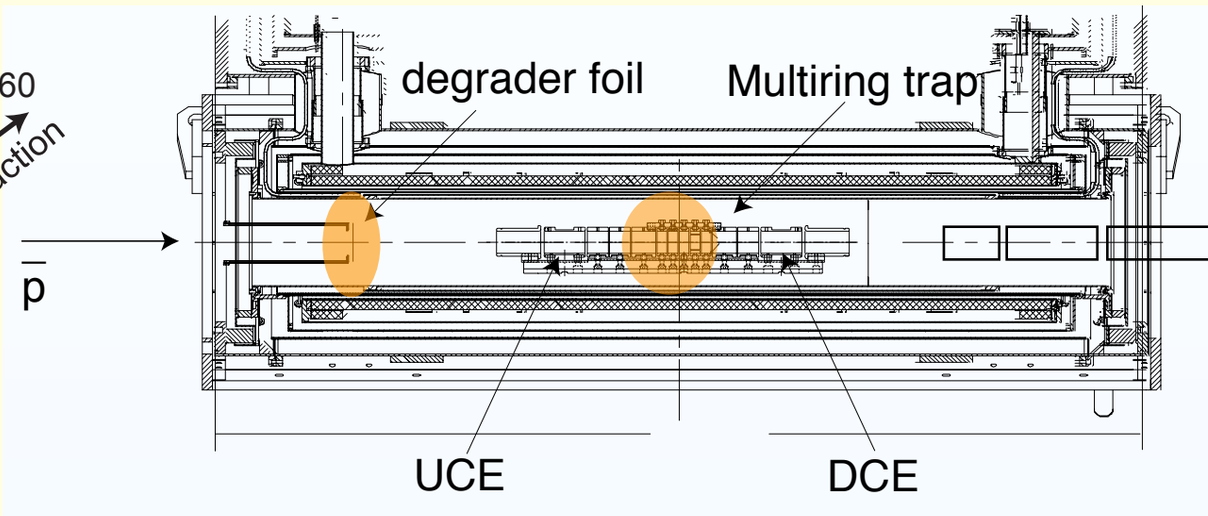
$\varepsilon \sim 4\%$



Trapping



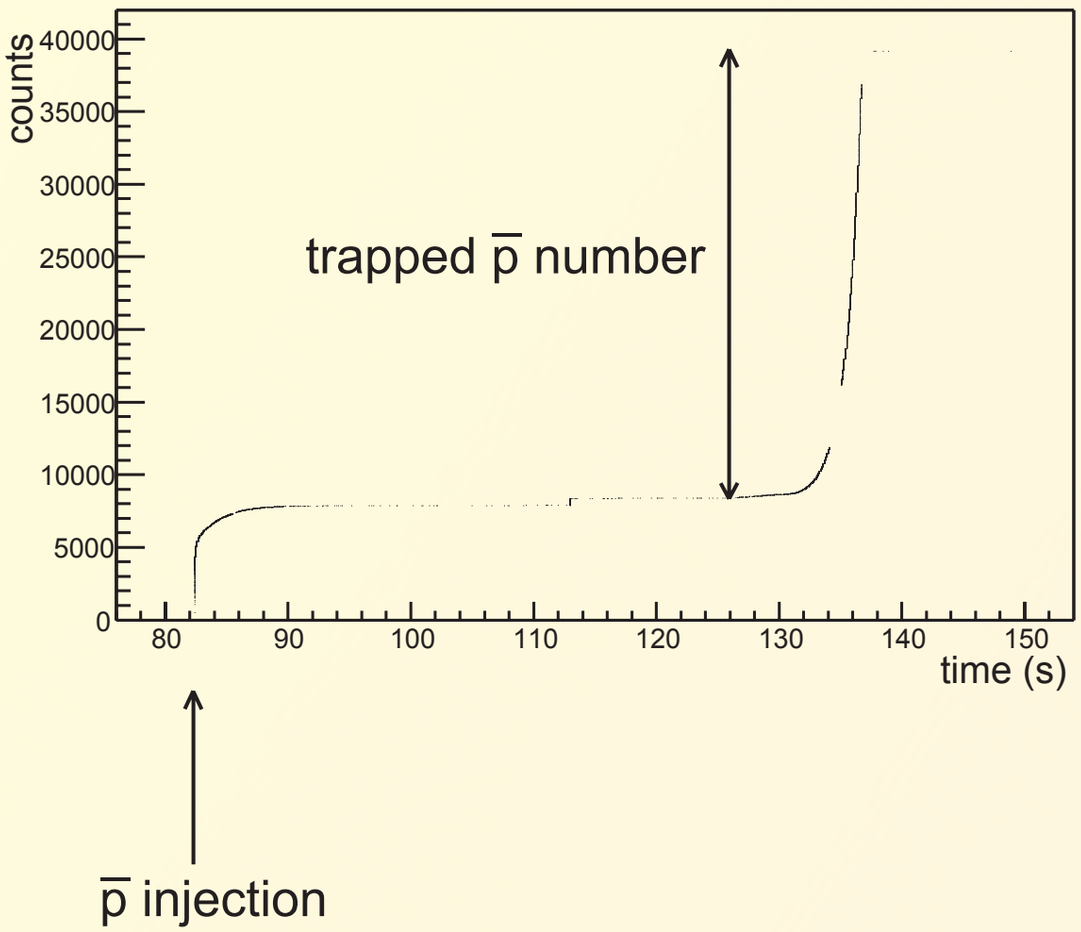


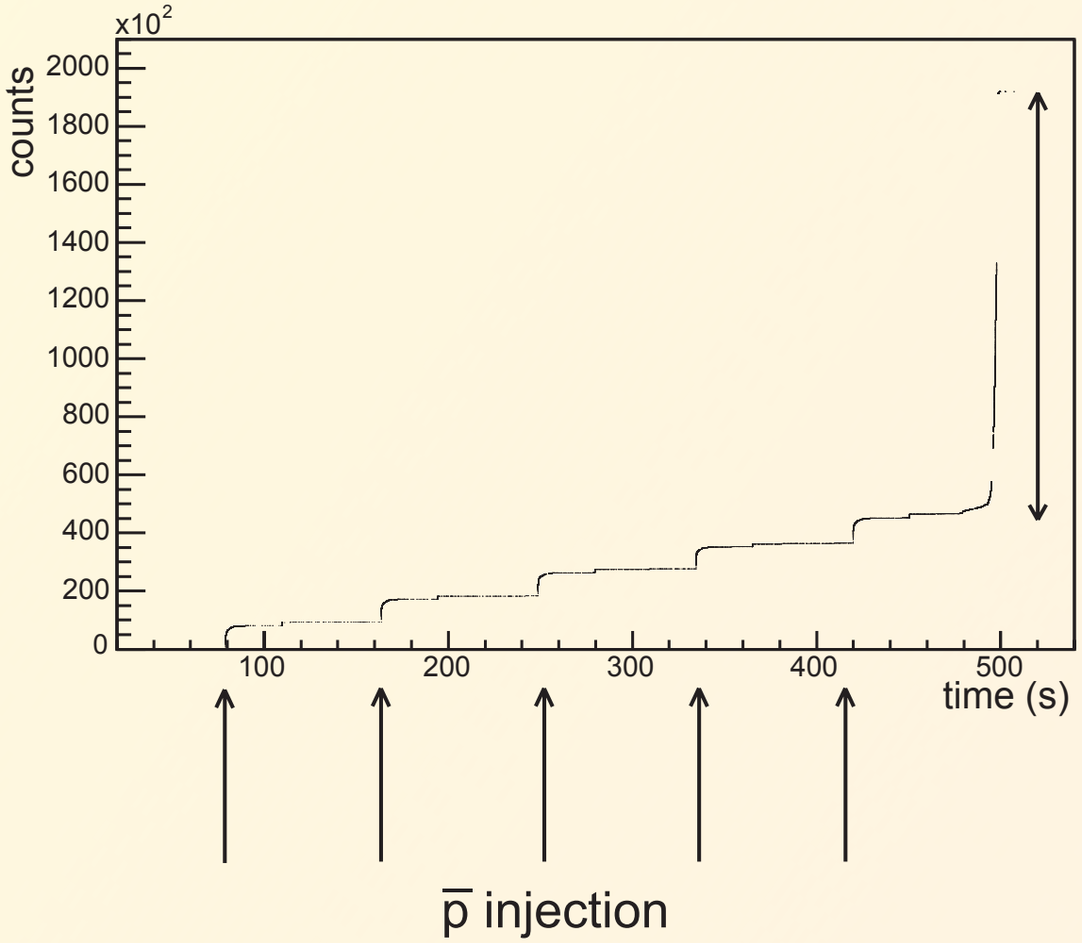


Degrader foils / Center of MRT / Extraction Electrode

Trapping and Accumulation of Antiprotons

cumulative count of $\bar{p}$ annihilation v.s. elapsed time



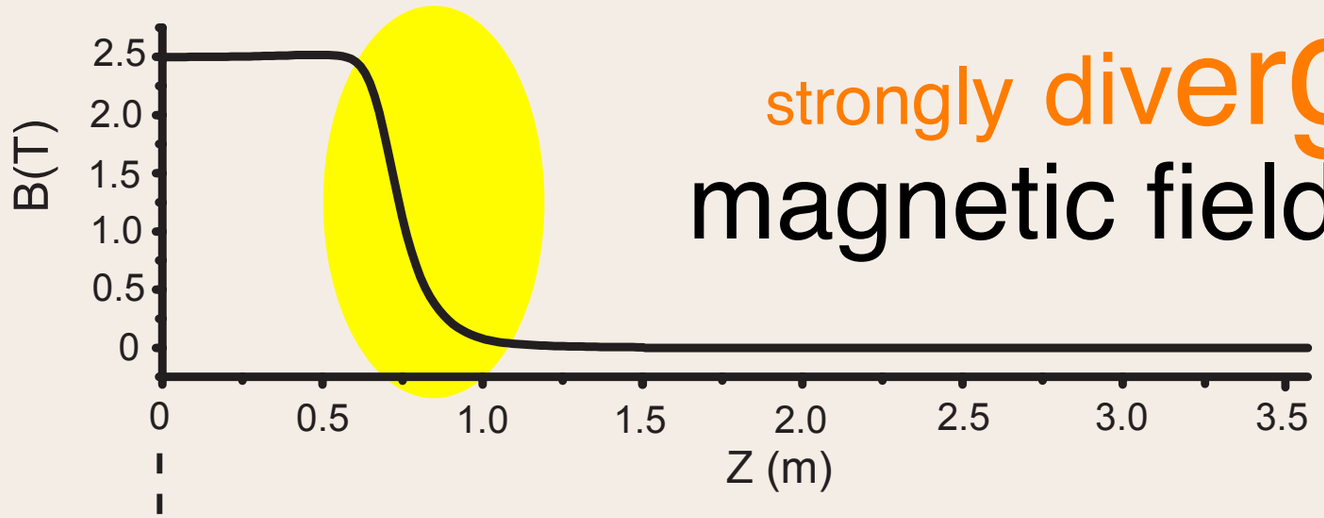


1.2 Million $\bar{p}$'s trapped per AD shot of 20 Million

Stacking of several AD shots 4.8 Million for 5 shots

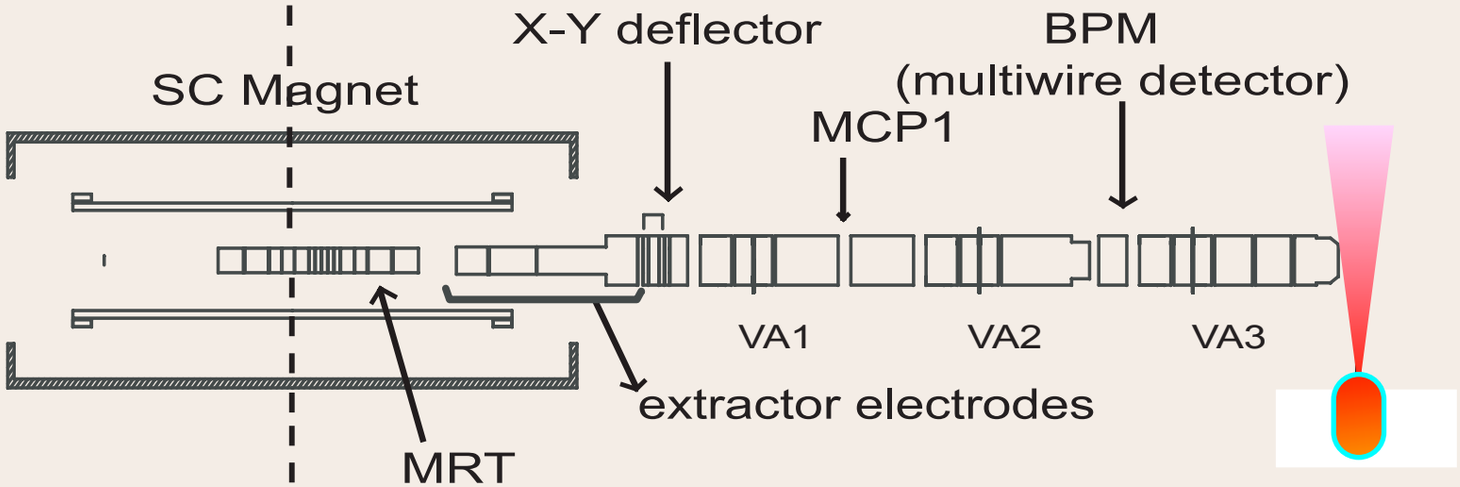
track detector

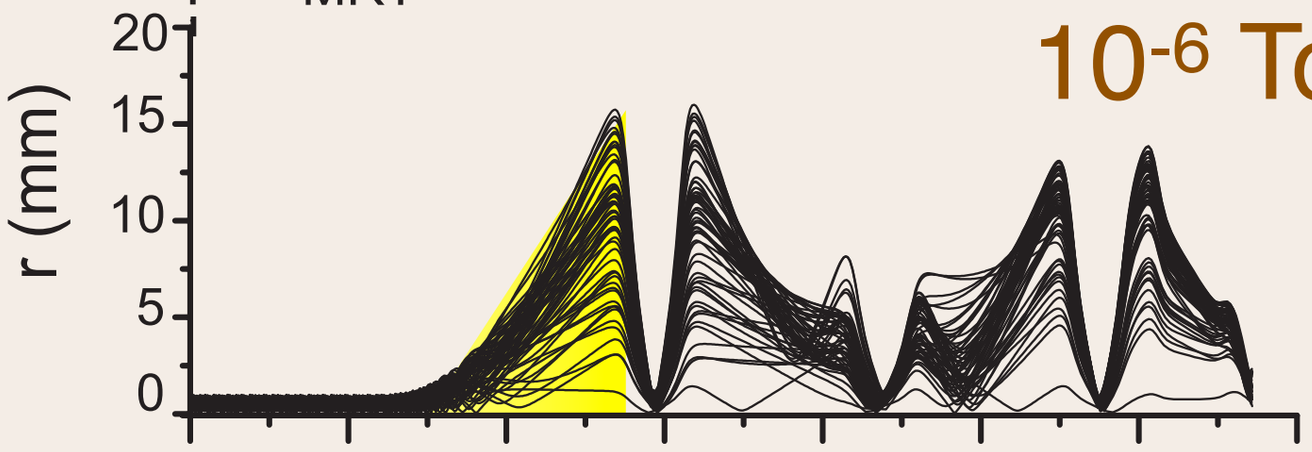
beamline



strongly diverging magnetic field

Extraction beamline



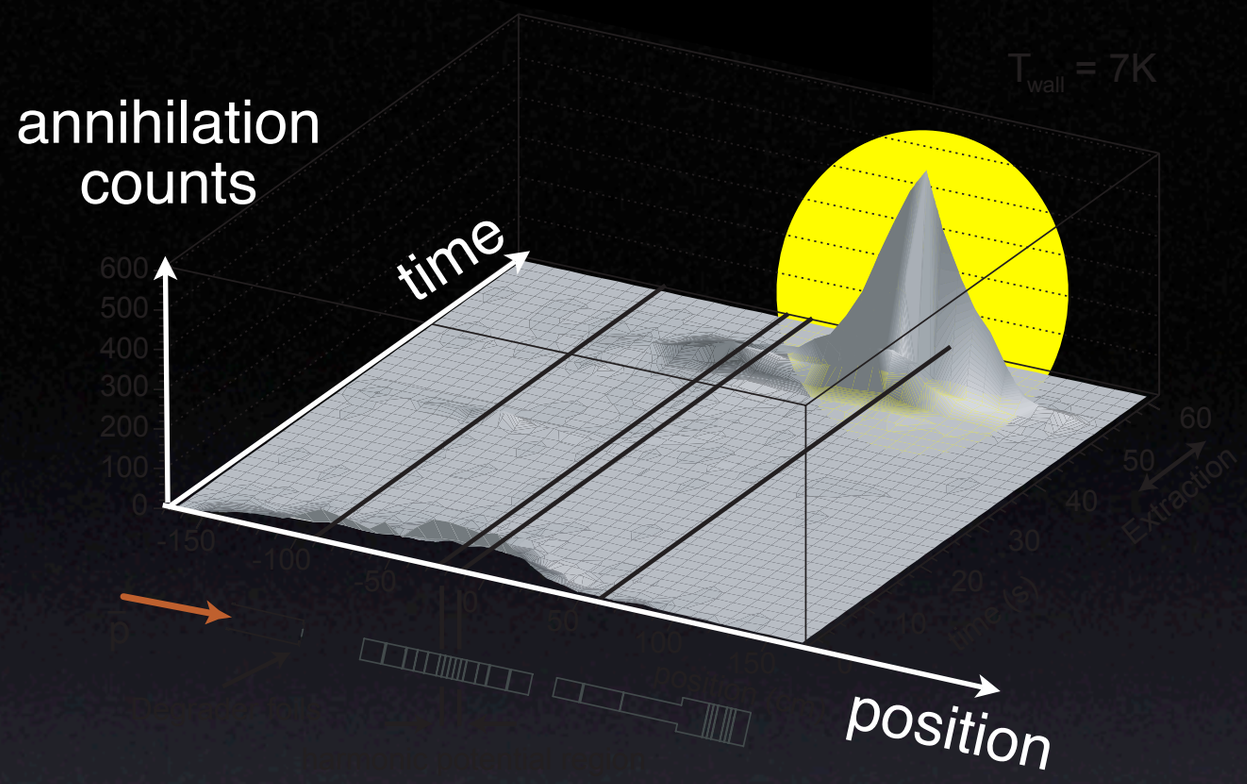


10^{-6} Torr

10^{-12} Torr

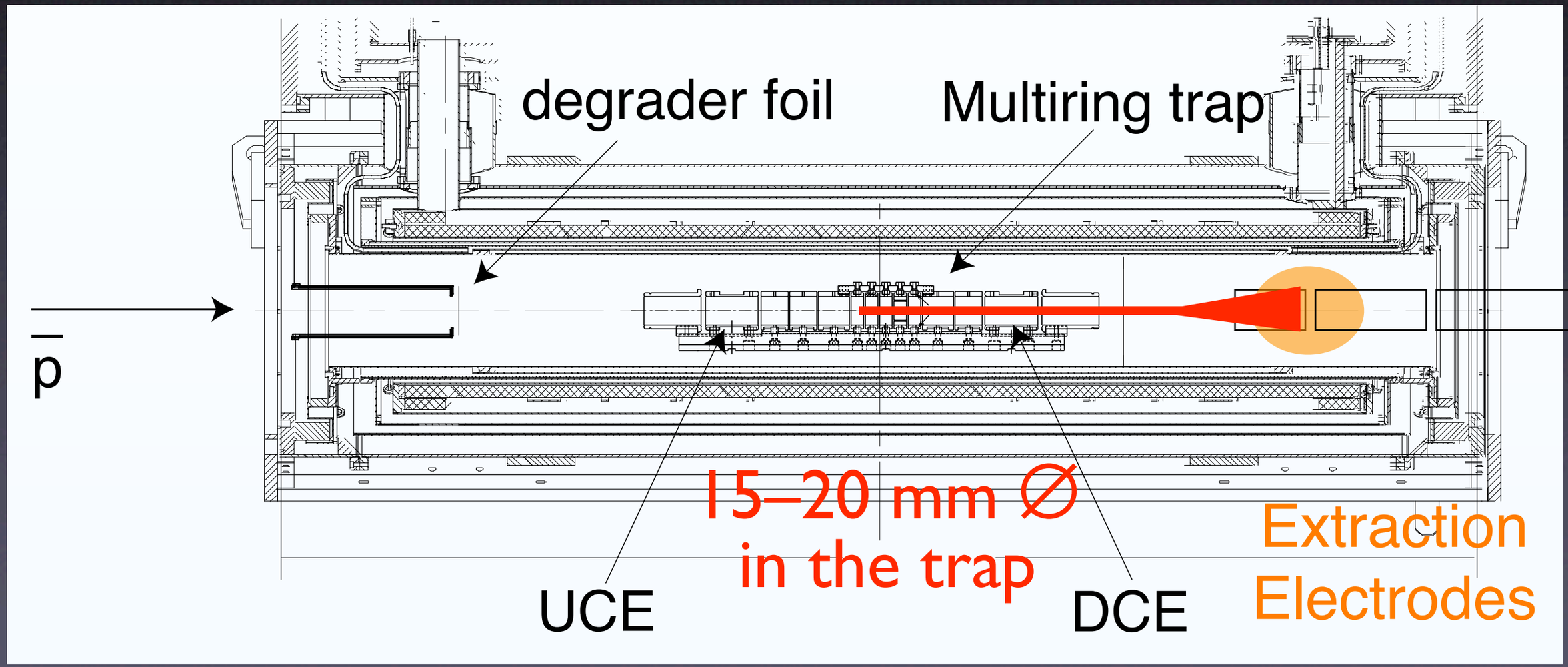
2 mm Ø

differential pumping



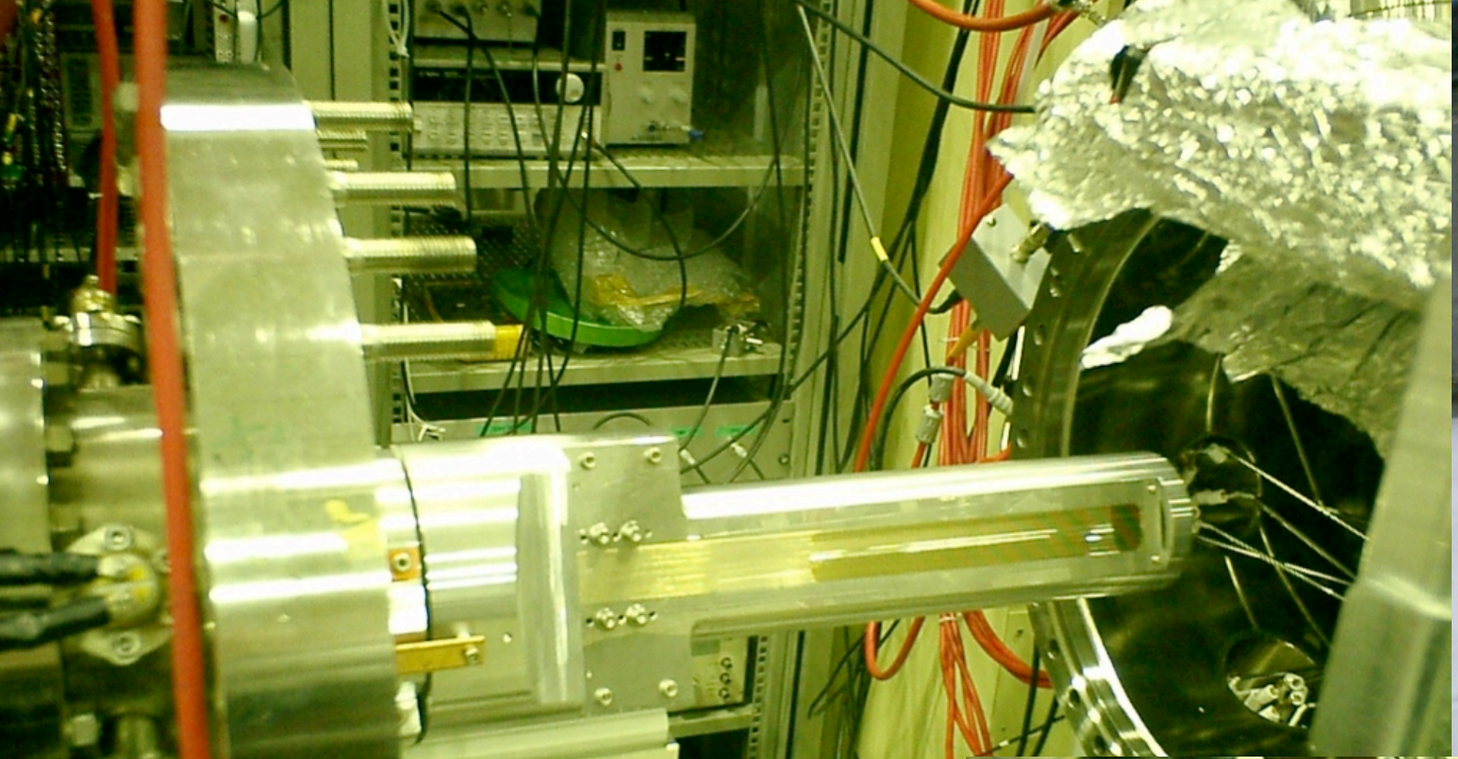
Problem in extraction

Most of antiprotons annihilated against an Extraction Electrode !

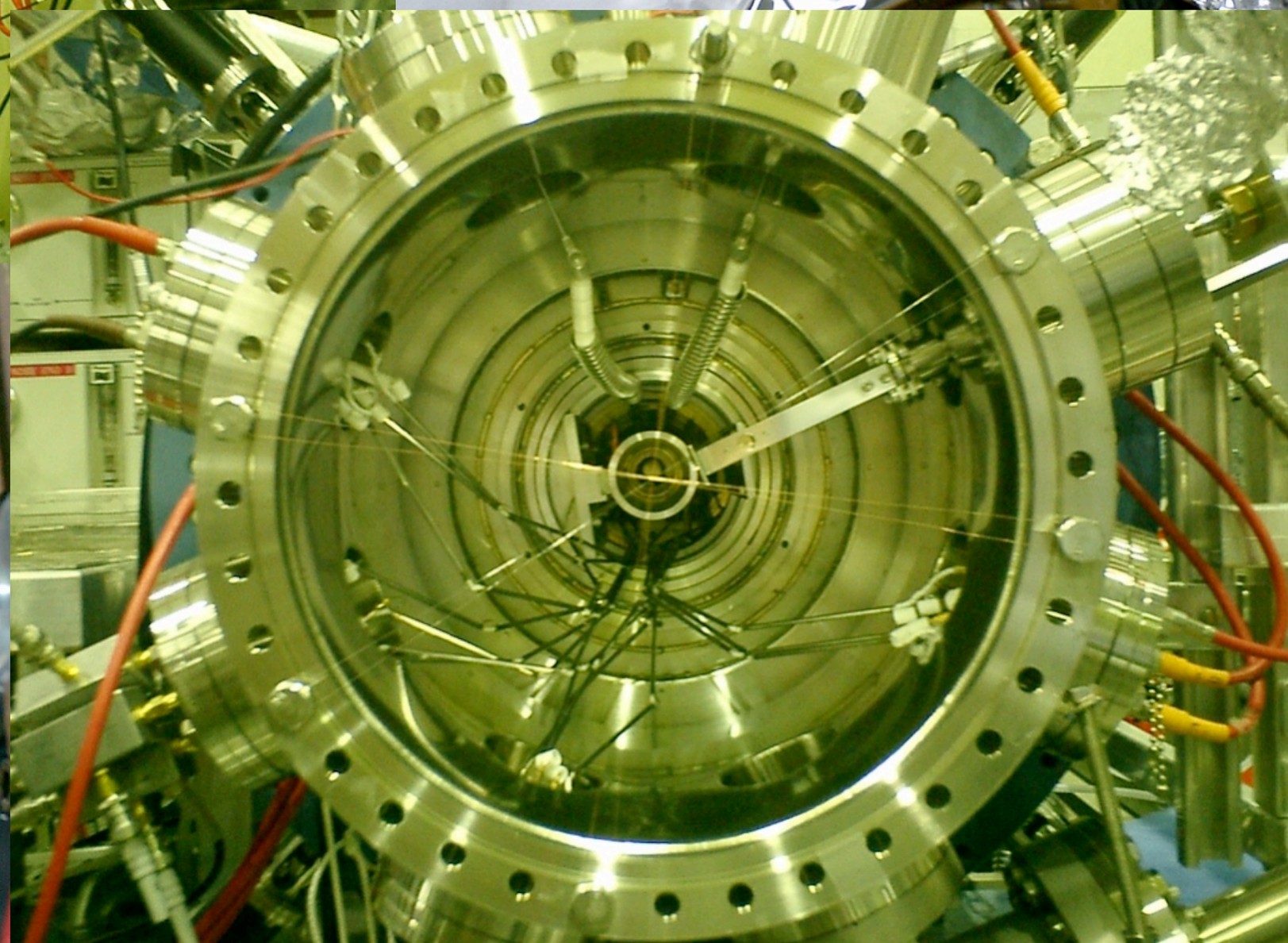


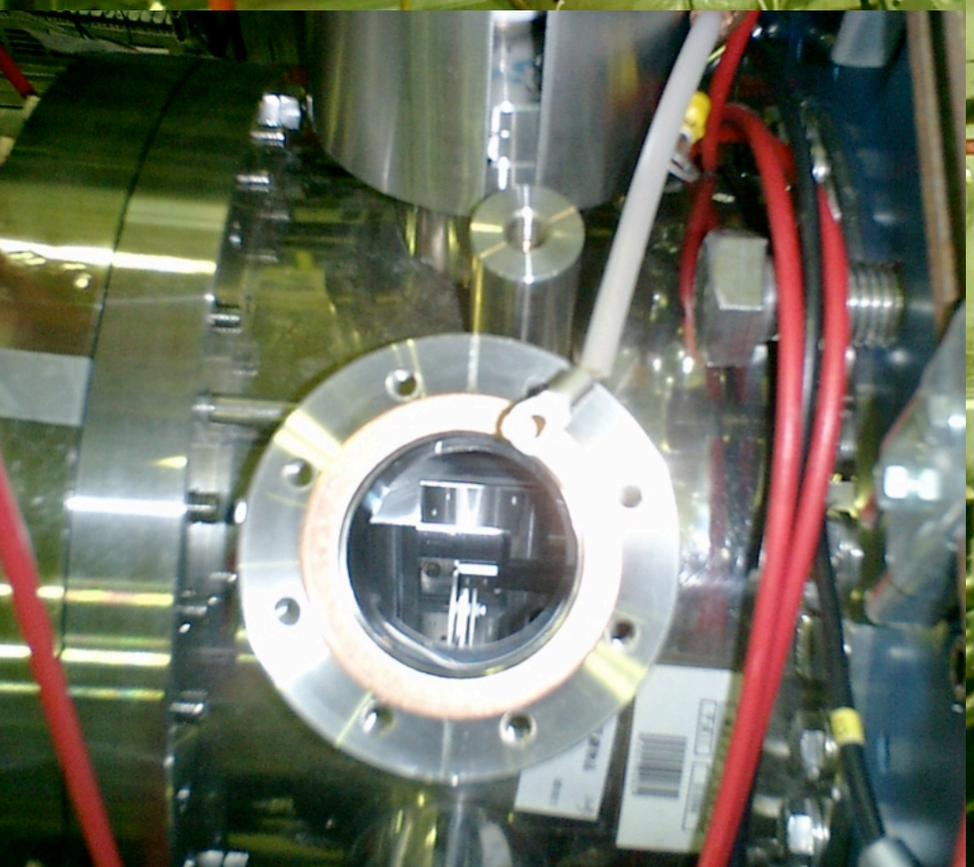
Keys for efficient extraction

- Bore alignment
- on-axis electron injection (10^8 electrons)




electron gun





Keys for efficient extraction

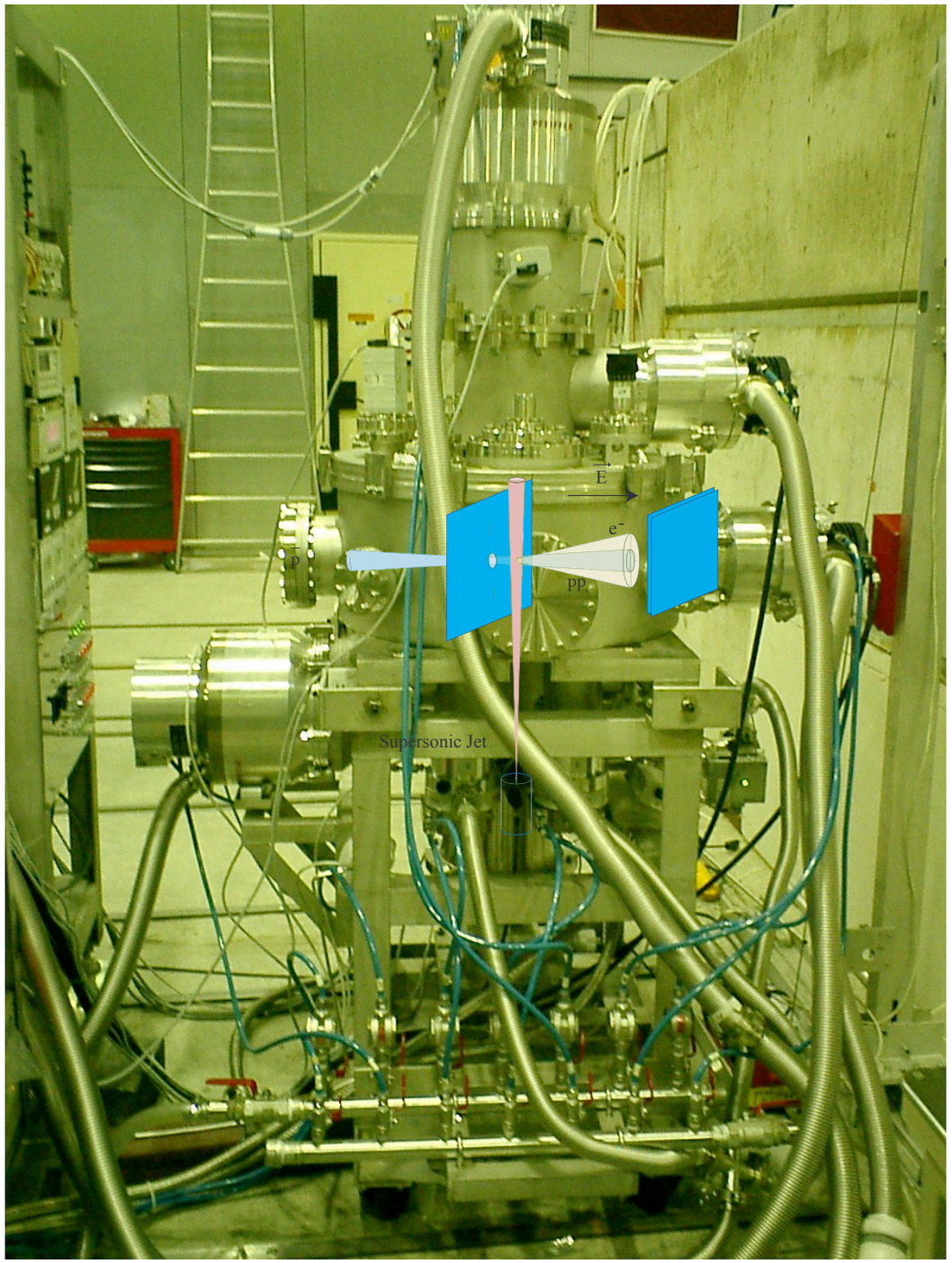
Bore alignment

on-axis electron injection (10^8 electrons)

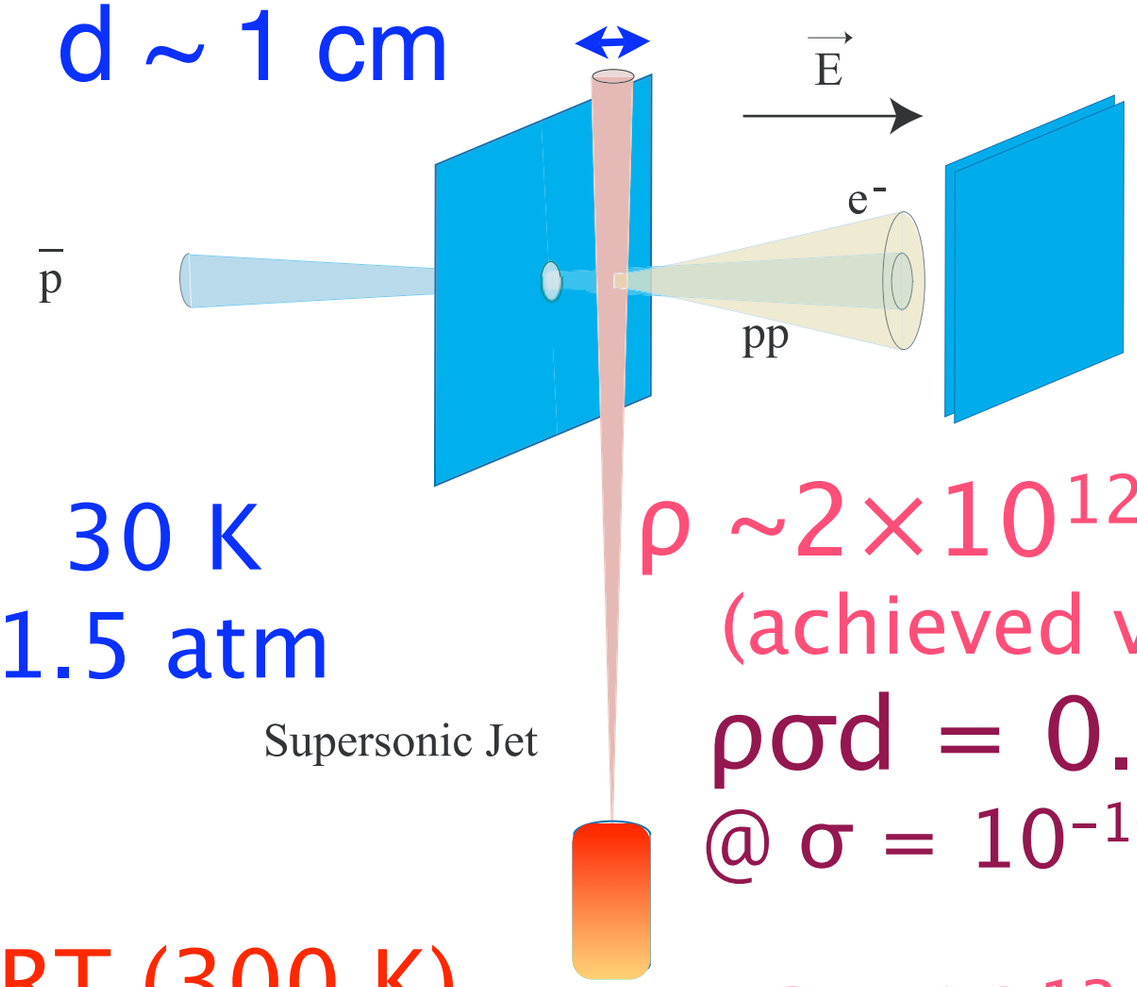
- radial size of antiproton cloud

- beam tuning: focusing $\bar{p}$ beam into the trap
- decompression of electron plasma
- electron ejection
- radial compression by rorating **E** field

Gas-jet target



d ~ 1 cm



30 K
1.5 atm

$\rho \sim 2\times10^{12}$ cm^{-3}
(achieved value)
$\rho\sigma d = 0.05\%$
@ $\sigma = 10^{-16}$ cm^2

RT (300 K)
23 atm

$\rho \sim 3\times10^{13}$ cm^{-3}
(design value)
$\rho\sigma d = 0.3\%$
@ $\sigma = 10^{-16}$ cm^2

10^5 $\bar{p}$ ⇒ 10^2 $\bar{p}$–atoms

Gas-jet : talk by V.L. Varentsov

Summary

- We have decelerated 5-MeV $\bar{p}$ and cooled them to sub-eV energies.
- Confinement of 1.2 Million $\bar{p}$'s per AD shot.
- Diagnosis and control of electron plasma and antiproton cloud.
- Slow extraction of antiprotons as a monoenergetic beam at 250 eV.
- Single-collision experiment to study capture and formation process of antiprotonic atoms.

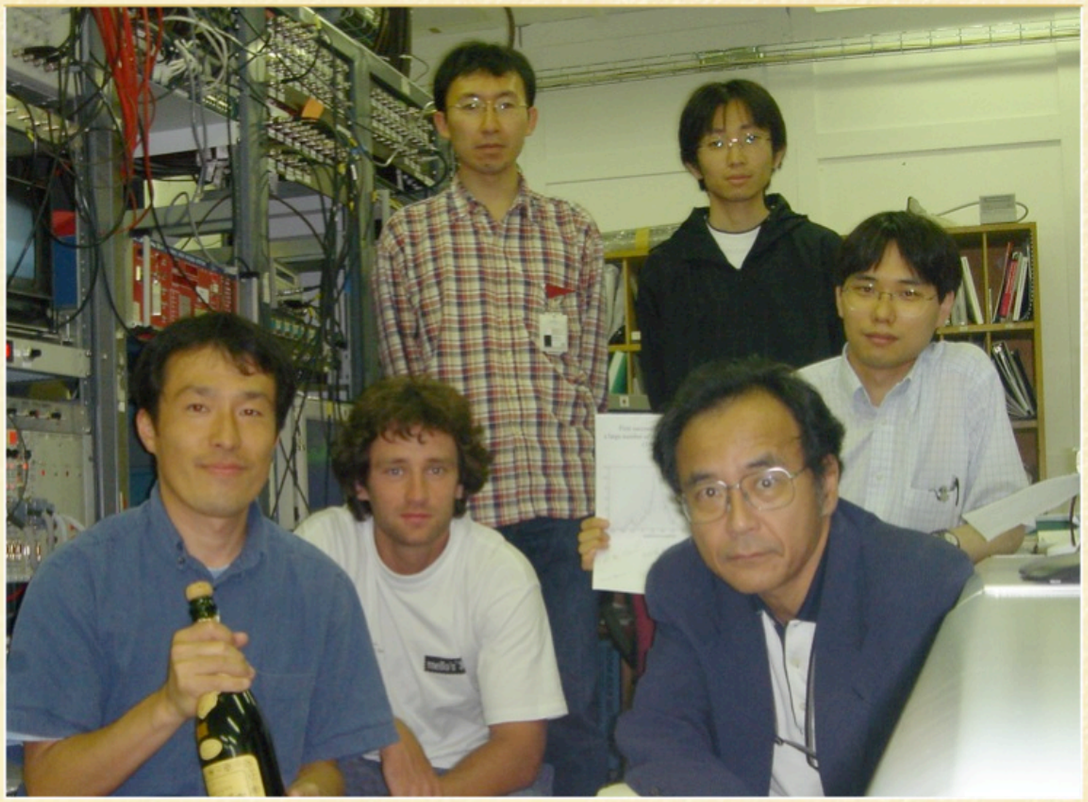
Related talks

N. Kuroda: Control of plasmas for production of ultraslow antiproton beams

V. L. Varentsov: ASACUSA gas-jet target: present status and future development

Cheers!

Félicitations !



Present members: N. Kuroda, M. Shibata, Y. Nagata, H.A. Torii, M. Hori,
D. Barna, A. Mohri, K. Komaki, Y. Yamazaki
Ex-members: K. Yoshiki Franzén, Zhigang Wang, T. Ichioka, H. Higaki,
N. Oshima, T.M. Kojima
Special thanks to: Y. Odashima, W. Pirkl, CERN cryolab, CERN PS & AD staff