Beam Studies at CRYRING for FLAIR

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COOL07

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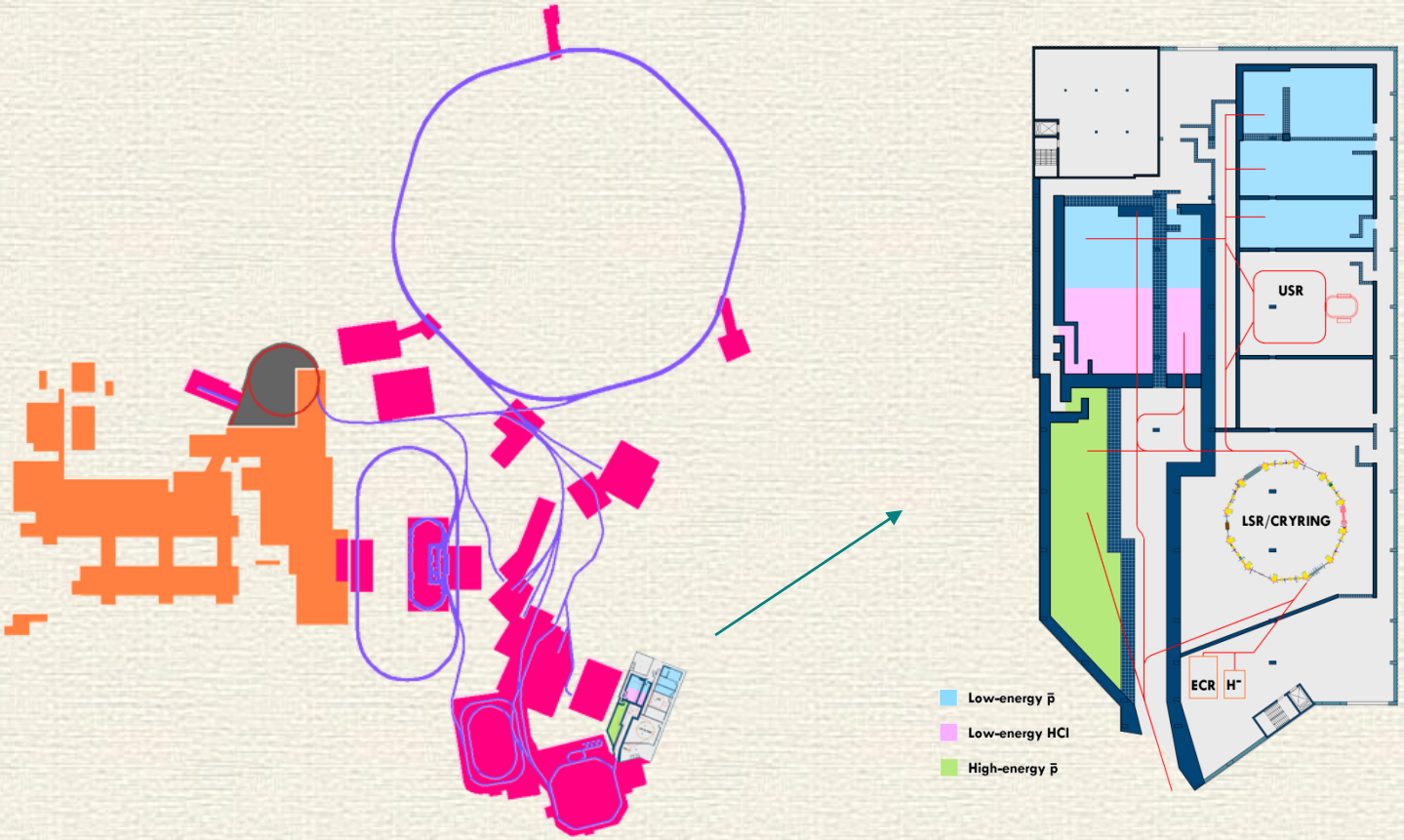
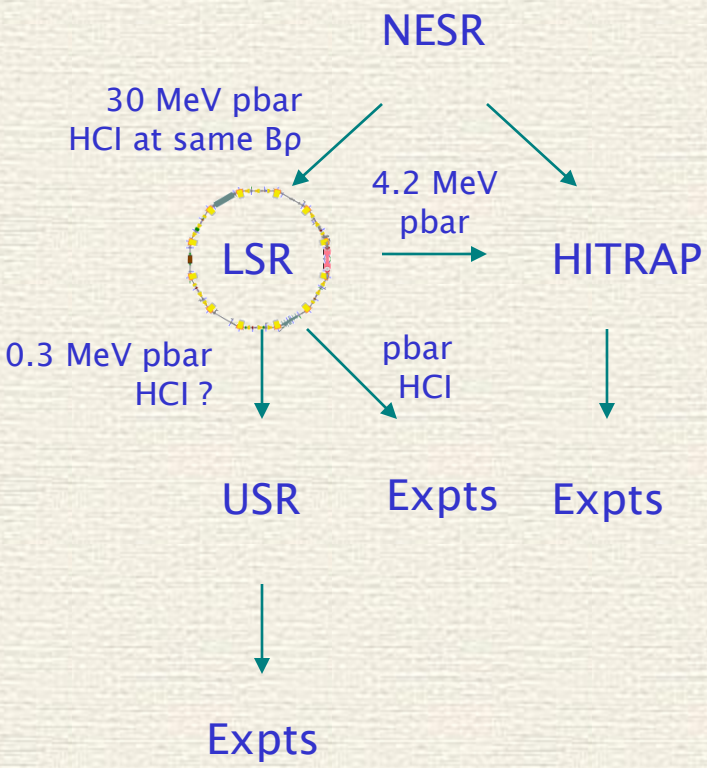
FLAIR

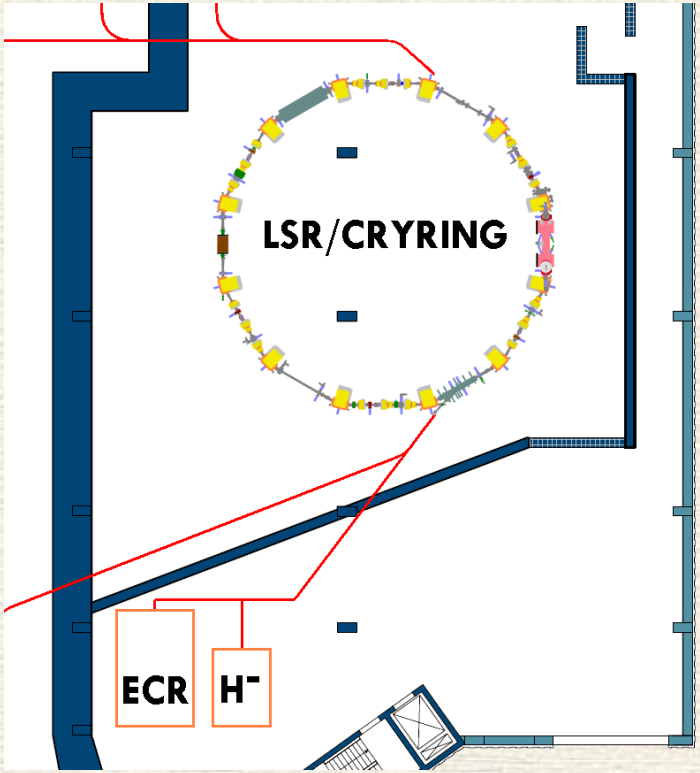
Facility for Low-energy Antiproton and Ion Research: LSR, USR, HITRAP, Expts



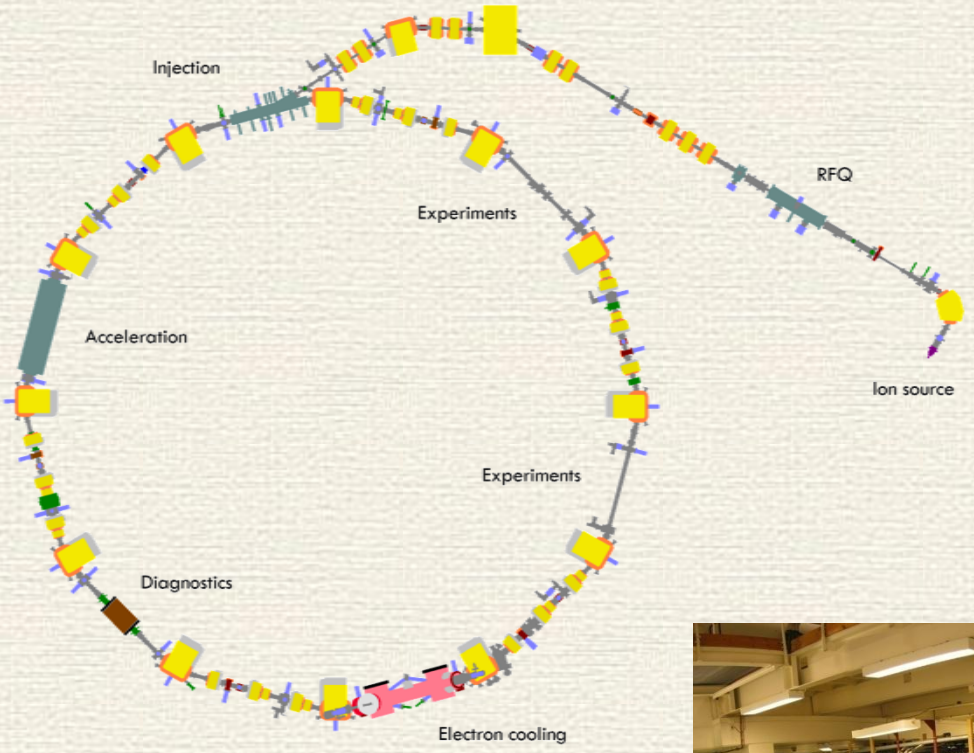
LSR

Facility for Low-energy Antiproton and Ion Research: LSR, USR, HITRAP, Expts





CRYRING



Rigidity 1.44 Tm

Circumference 52 m

Proton energy 0.2–96 MeV

First stored beam 1991

First user experiment 1992

“Close-down decision” 2003

Ions stored in CRYRING

Singly charged positive atomic ions: H^+, D^+, $^3He^+$, $^4He^+$, $^7Li^+$, $^9Be^+$, $^{11}B^+$, $^{12}C^+$, $^{14}N^+$, $^{16}O^+$, $^{40}Ar^+$, $^{40}Ca^+$, $^{45}Sc^+$, $^{48}Ti^+$, $^{56}Fe^+$, $^{83}Kr^+$, $^{84}Kr^+$, $^{86}Kr^+$, $^{88}Sr^+$, $^{129}Xe^+$, $^{131}Xe^+$, $^{132}Xe^+$, $^{138}Ba^+$, $^{139}La^+$, $^{142}Nd^+$, $^{151}Eu^+$, $^{197}Au^+$, $^{208}Pb^+$

Multiply charged positive atomic ions: $^4He^{2+}$, $^{11}B^{2+}$, $^{12}C^{2+}$, $^{12}C^{3+}$, $^{12}C^{4+}$, $^{12}C^{6+}$, $^{14}N^{2+}$, $^{14}N^{3+}$, $^{14}N^{4+}$, $^{14}N^{7+}$, $^{16}O^{2+}$, $^{16}O^{3+}$, $^{16}O^{4+}$, $^{16}O^{5+}$, $^{16}O^{8+}$, $^{19}F^{6+}$, $^{19}F^{9+}$, $^{20}Ne^{2+}$, $^{20}Ne^{5+}$, $^{20}Ne^{6+}$, $^{20}Ne^{7+}$, $^{20}Ne^{10+}$, $^{28}Si^{3+}$, $^{28}Si^{11+}$, $^{28}Si^{14+}$, $^{36}Ar^{9+}$, $^{36}Ar^{10+}$, $^{36}Ar^{12+}$, $^{36}Ar^{13+}$, $^{40}Ar^{9+}$, $^{40}Ar^{11+}$, $^{40}Ar^{13+}$, $^{40}Ar^{15+}$, $^{48}Ti^{11+}$, $^{58}Ni^{17+}$, $^{58}Ni^{18+}$, $^{84}Kr^{33+}$, $^{126}Xe^{36+}$, $^{129}Xe^{36+}$, $^{129}Xe^{37+}$, $^{136}Xe^{39+}$, $^{136}Xe^{44+}$, $^{207}Pb^{53+}$, $^{208}Pb^{53+}$, $^{208}Pb^{54+}$, $^{208}Pb^{55+}$

Singly charged postive molecular ions: H_2^+, HD^+, H_3^+, D_2^+, H_2D^+, $^3HeH^+$, $^3HeD^+$, $^4HeH^+$, D_3^+, He_2^+, LiH_2^+, D_5^+, BH_2^+, CH_2^+, NH_2^+, OH^+, CH_5^+, NH_4^+, H_2O^+, H_3O^+, HF^+, ND_3H^+, CD_5^+, ND_4^+, D_3O^+, C_2H^+, CN^+, $C_2H_2^+$, HCN^+, $C_2H_3^+$, $HCNH^+$, $C_2H_4^+$, CO^+, N_2^+, $^{13}CO^+$, N_2H^+, $C_2H_5^+$, NO^+, $D^{13}CO^+$, CH_3O^+, CF^+, O_2^+, $CH_3NH_3^+$, CH_3OH^+, $CH_3OH_2^+$, H_2S^+, CD_3O^+, PD_2^+, $N_2H_7^+$, $D_2{}^{32}S^+$, $CD_3OH_2^+$, CD_3OD^+, $H_5O_2^+$, $D_2{}^{34}S^+$, $D_3{}^{32}S^+$, $CD_3OD_2^+$, $^{13}CD_3OD_2^+$, $D_3{}^{34}S^+$, $C_3H_4^+$, $D_5O_2^+$, CH_3CNH^+, $C_3D_3^+$, $N_2D_7^+$, N_3^+, $C_3H_7^+$, NaD_2O^+, CO_2^+, HCS^+, $C_2H_5O^+$, DN_2O^+, $C_2H_5OH^+$, CO_2D^+, CD_3CDO^+, $NO^+{\cdot}H_2O$, O_3^+, $CD_3OCD_2^+$, $C_3D_7^+$, CF_2^+, $NO^+{\cdot}D_2O$, DC_3N^+, $CD_3OCD_3^+$, $N_3H_{10}^+$, DC_3ND^+, $CD_3ODCD_3^+$, $H_7O_3^+$, COS^+, $N_2O_2^+$, $CH_3OCOH_2^+$, $D_7O_3^+$, $N_3D_{10}^+$, $C_4D_9^+$, $S^{18}O_2^+$, ArN_2^+, $H_9O_4^+$, $CD_3COHNHCH_3^+$, $CD_3CONHDCH_3^+$, $C_6D_6^+$, $PO^{37}Cl^+$, $H_{11}O_5^+$, $C_2S_2H_6^+$, $C_2S_2H_7^+$, $H_{13}O_6^+$, $PO^{35}Cl_2^+$

Multiply charged positive molecular ions: N_2^{2+}

Negative atomic ions: H^-, Li^-, F^-, SI^-, S^-, Cl^-, Se^-, Te^-

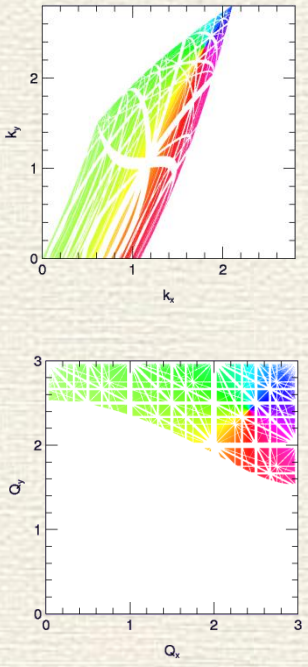
Negative molecular ions: CN^-, C_4^-, Si_2^-, Cl_2^-

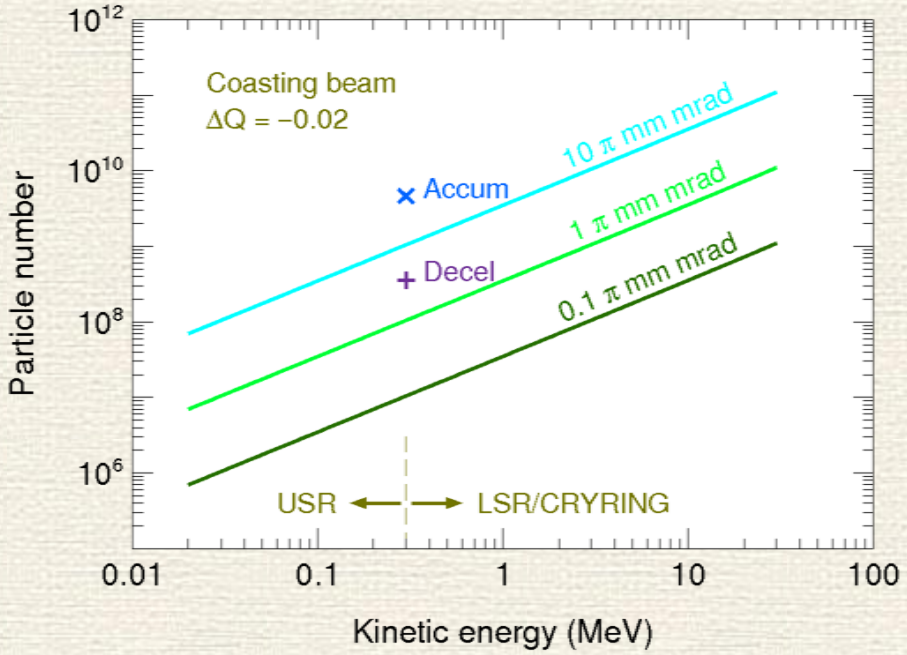
Range of energies per nucleon: 38 eV/u – 92 MeV/u

Range of total energies: 5 keV – 1.4 GeV

Space-charge limit

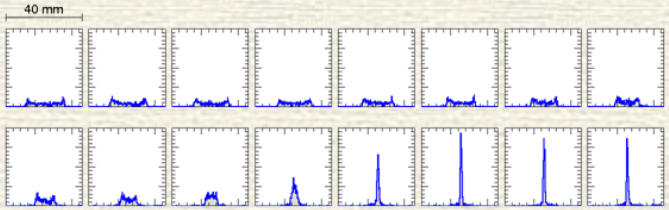
Space-charge induced tune shift $\Delta Q = -\frac{Nr_0}{4\varepsilon\beta^2\gamma^3}$ limits beam intensity



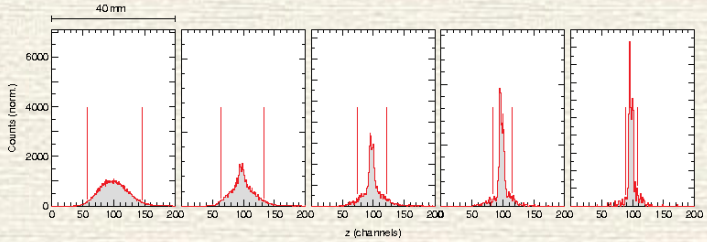


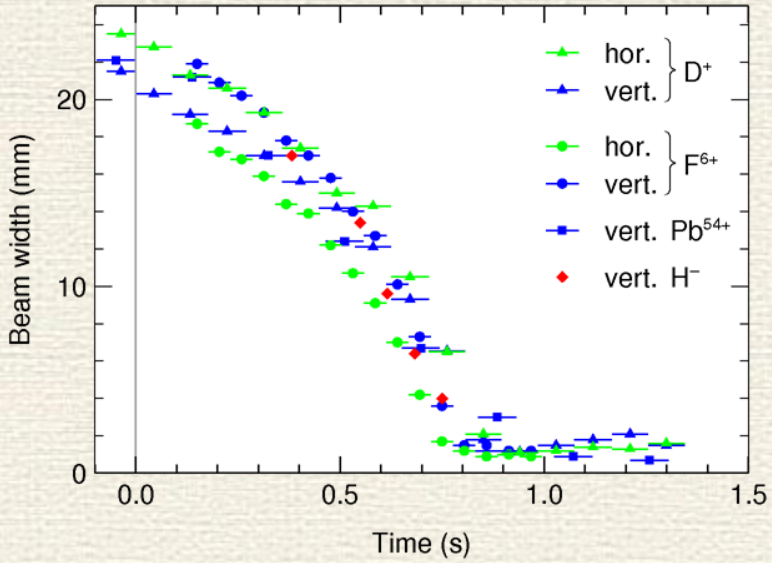
Transverse cooling of H^-

Cooling of hollow beam (EPAC 2000)



H^-, 3 MeV, 300 ms/frame
10 → 0.25 π mm mrad





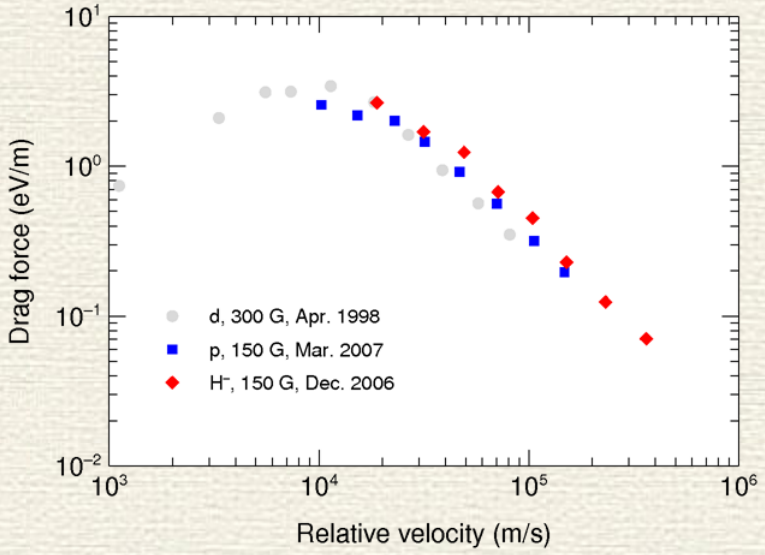
Normalized to 1.7×10^{13} m^{-3} (100 mA at 4.2 MeV/u for D, F and Pb)

Adjusted horizontally to reach minimum width simultaneously

Scaled by factor $q^{1.7}/A$

Longitudinal cooling of p and H^-

Preliminary measurements, compared with data from ECOOL'99



3 MeV p and H^-, 14 mA electron current

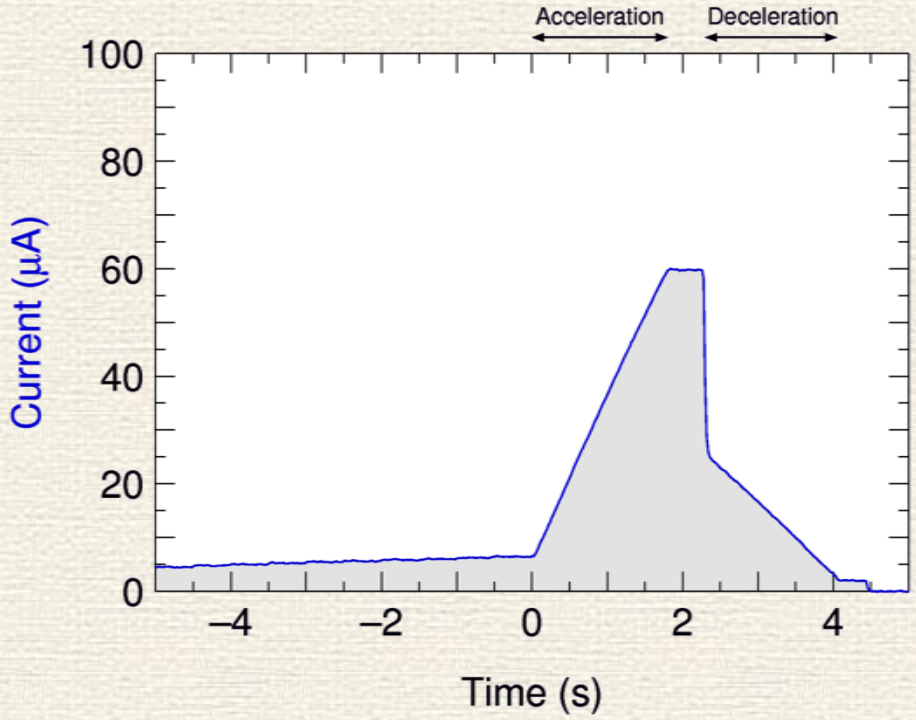
1.5 T / 150 G magnetic field (only)

Normalized to 1×10^{14} m^{-3} and $q^2/A = 1$

Systematic errors 50% ? Stronger cooling of H^- than p not conclusive

Deceleration of protons (1)

Injection at 300 keV → Acceleration to 30 MeV →
Storage at 30 MeV (bunched) → Deceleration to 300 keV



Transmission

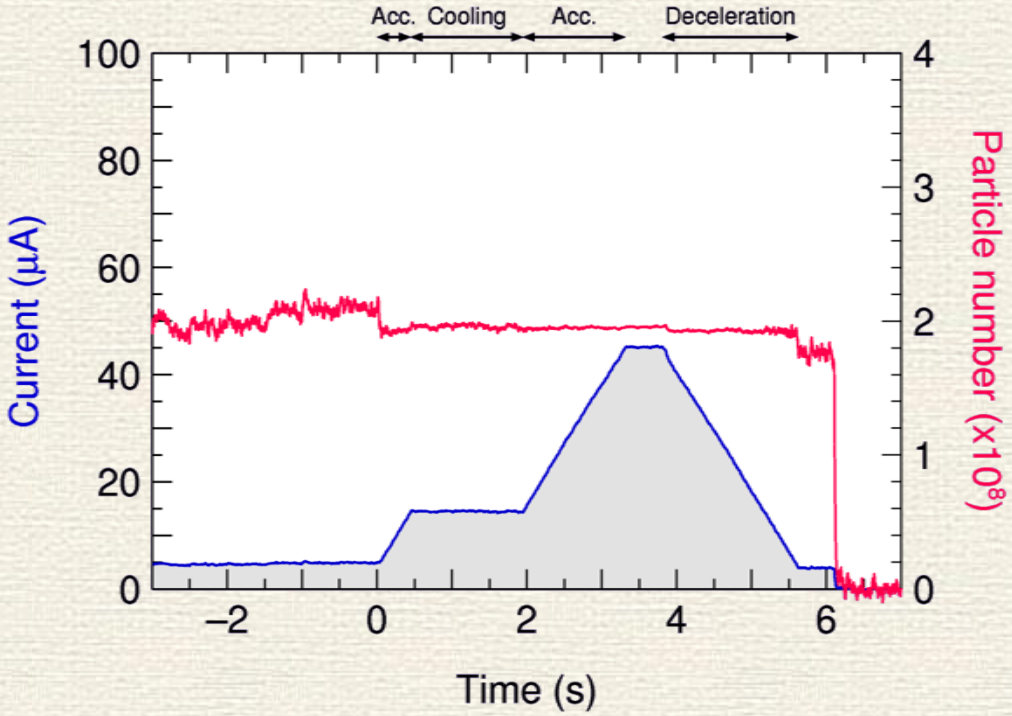
Acceleration 93%
Start deceleration 42%
Deceleration ramp 75%

Total 0.93×0.42×0.75=30%

Deceleration 0.42×0.75=91%

Deceleration of protons (2)

Injection at 300 keV → Acceleration to 3 MeV → Cooling →
Acceleration to 30 MeV → Storage at 30 MeV (bunched) →
Deceleration to 300 keV



Transmission

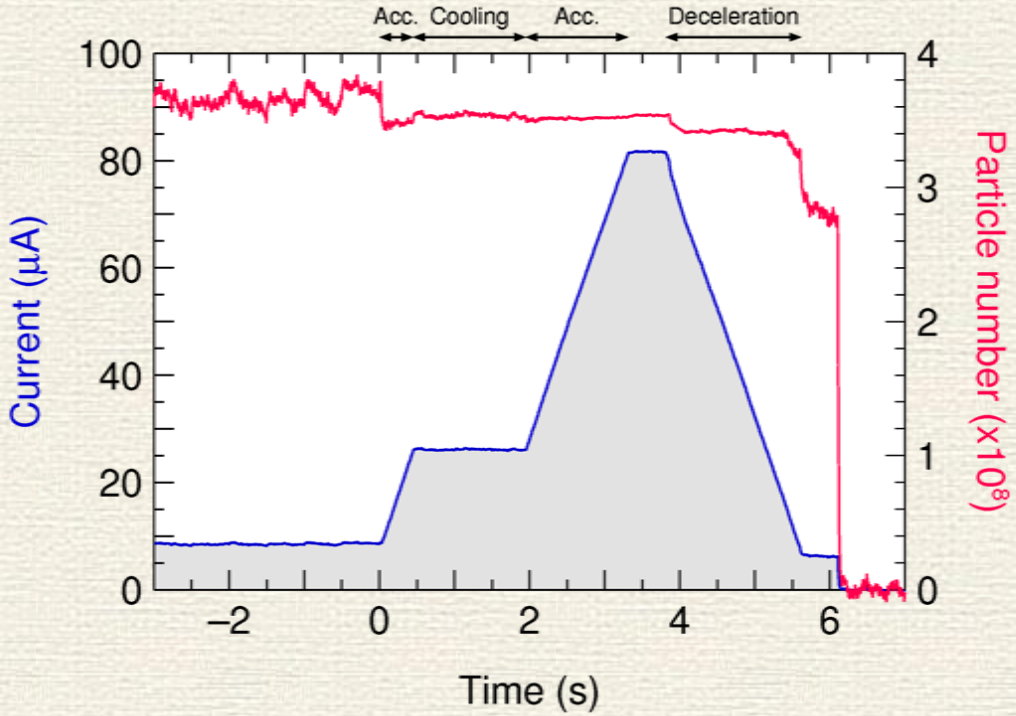
Acceleration 93%
Start deceleration 99%
Deceleration ramp 92%

Total 0.93×0.99×0.92=85%

Deceleration 0.99×0.92=91%

Deceleration of protons (2)

Injection at 300 keV → Acceleration to 3 MeV → Cooling →
Acceleration to 30 MeV → Storage at 30 MeV (bunched) →
Deceleration to 300 keV



Transmission

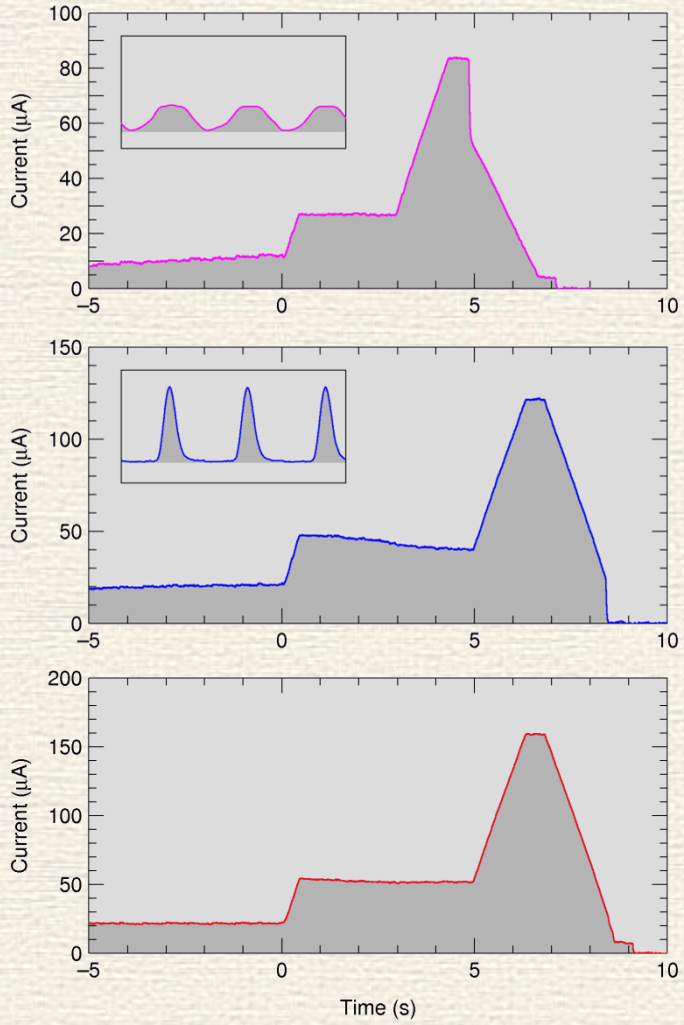
Acceleration 95%
Start deceleration 97%
Deceleration ramp 84%

Total 0.95×0.97×0.84=77%

Deceleration 0.97×0.84=81%

Deceleration of protons (3)

Why cooling at 3 MeV?



No cooling at 3 MeV
Long bunches
Loss at start of decleration

Cooling at 3 MeV
Short bunches
No loss at start of decleration,

Poorely adjusted functions at cooling and end of deceleration

Cooling at 3 MeV

Better adjusted functions but no oscilloscope picture saved

Moderate transverse displacements did not cause losses

Acknowledgements

This work was performed together with:

Anders Källberg

Ansgar Simonsson

The CRYRING staff