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荷電粒子トラップ中の水素負イオン・陽子雲の状態とその制御

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ASACUSA
Trap group

（１）ASACUSA トラップ

（設計思想・性能）

（２）回転電場による

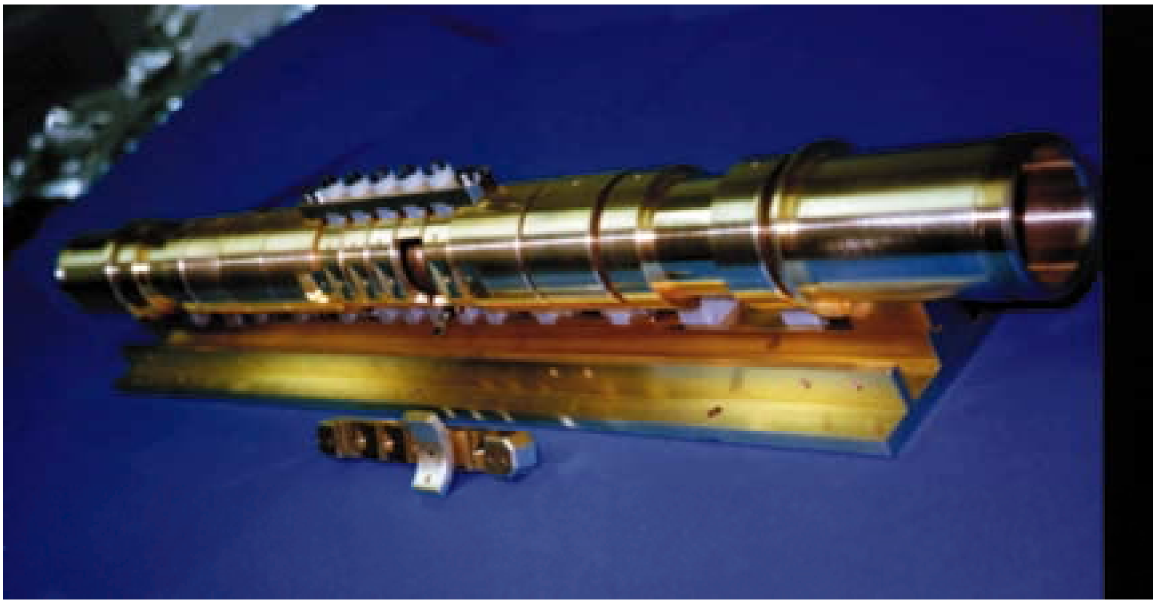
電子プラズマの制御

（３）H^-イオンの閉じ込めと電子冷却

（４）回転電場による陽子雲の制御

（５）まとめ、今後の実験計画

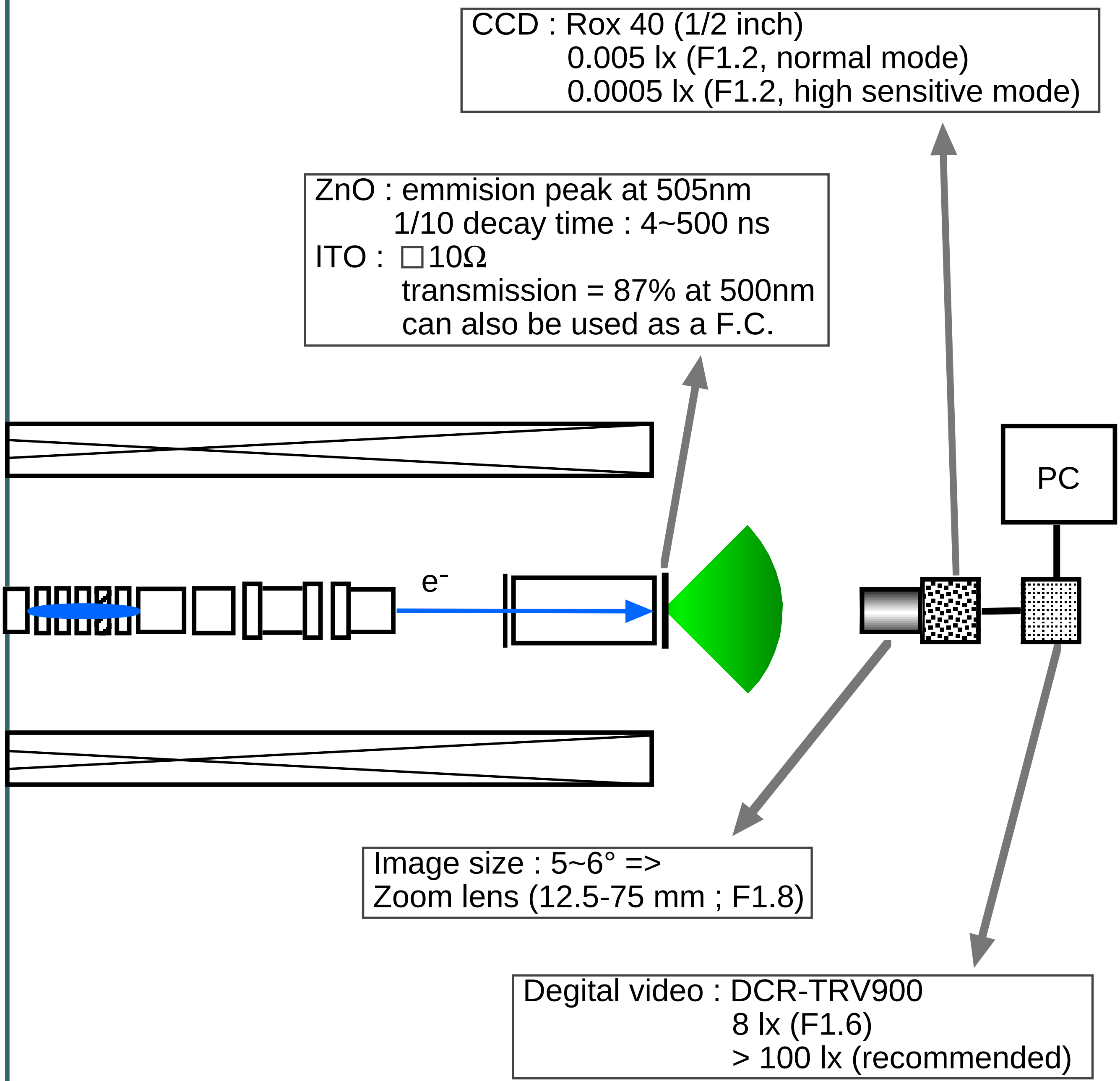
ASACUSA トラップデザイン



Requirements	solutions
* Stable storage and cooling of $10^{6\sim8}$ antiprotons * Monitoring of plastma modes	# Penning type trap # Harmonic potential well # 10µm precision # Gold plating
* Pulse length of 50keV antiprotons from the RFQ = 300ns	# Trap length = 50cm (Harmonic region = 10cm)
* Vacuum in the magnet bore ~ 10^{-12} Torr or better	# Oxygen free copper # AlN (high thermal conductivity)
* Injection from RFQ * Extraction of stored antiprotons * $n_e + n_{\bar{p}} < 6.6 \times 10^{10}$ (Brillouin limit of $\bar{p}$)	# Cylindrical electrodes # Central harmonic potential region ~ 10cm
* Control of plasma shape and density by rotational RF field	# One segmented electrode
* System control from outside the area	# LabView + GPIB + CAMAC

蛍光膜とCCDカメラによるプラズマ像の観測

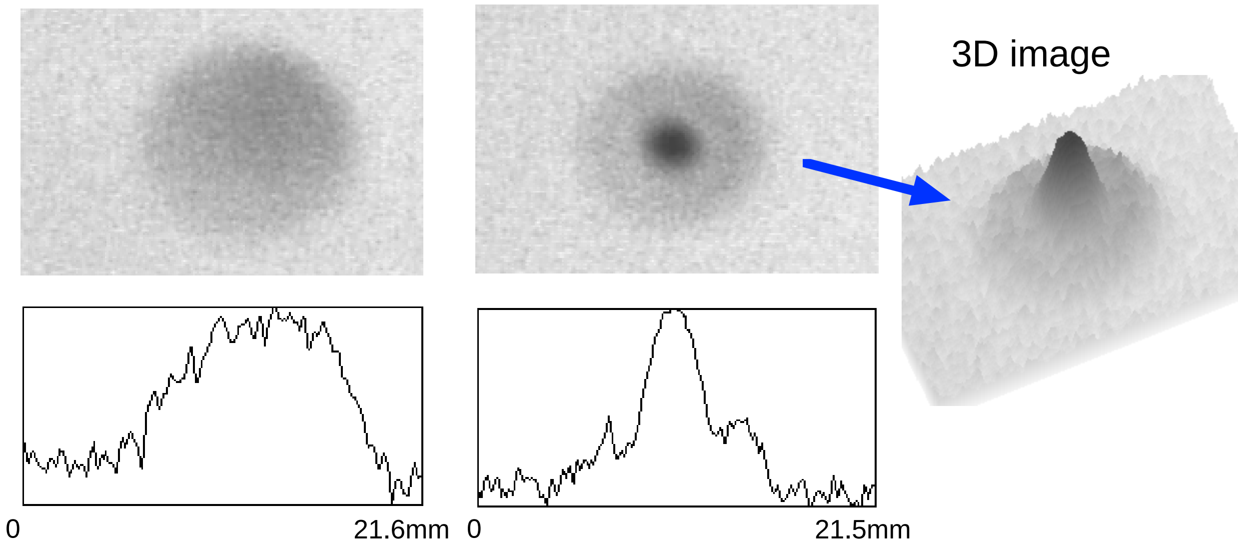
* ZnO (light emitter)
* ITO (tranparent ; electrically conductive)
* CCD (image monitoring)



回転電場による電子プラズマの制御

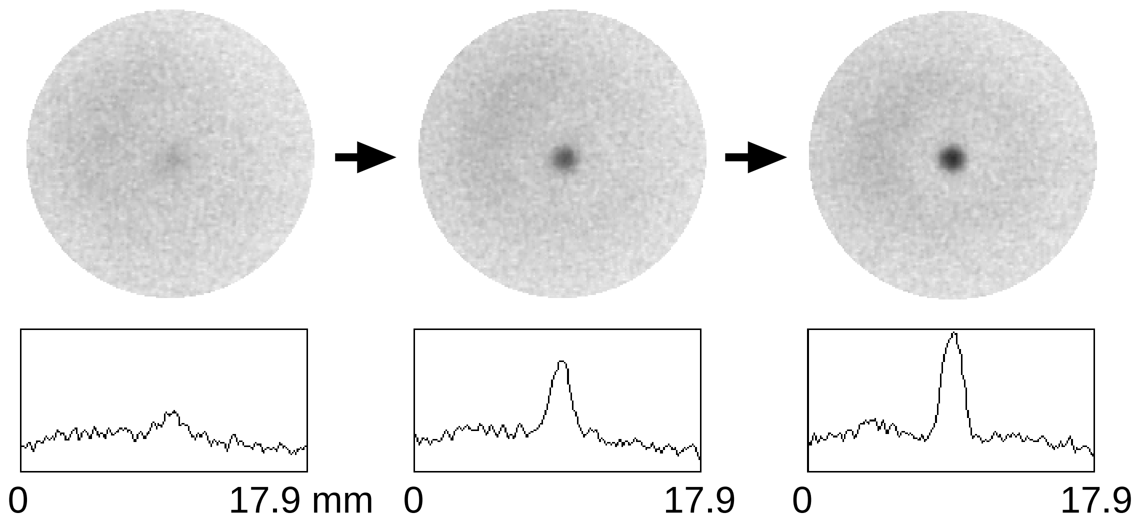
number of electrons ～ 1.1 x 10^8, 1inch off axis
pressure outside the cryogenic region ～ 3.5 x 10^{-9} Torr
rotating field : 60 sec wait after the injection of electrons
voltage swept from 500kHz to 3MHz, 1.0V in 15sec

witout rotating field　　　　with rotating field

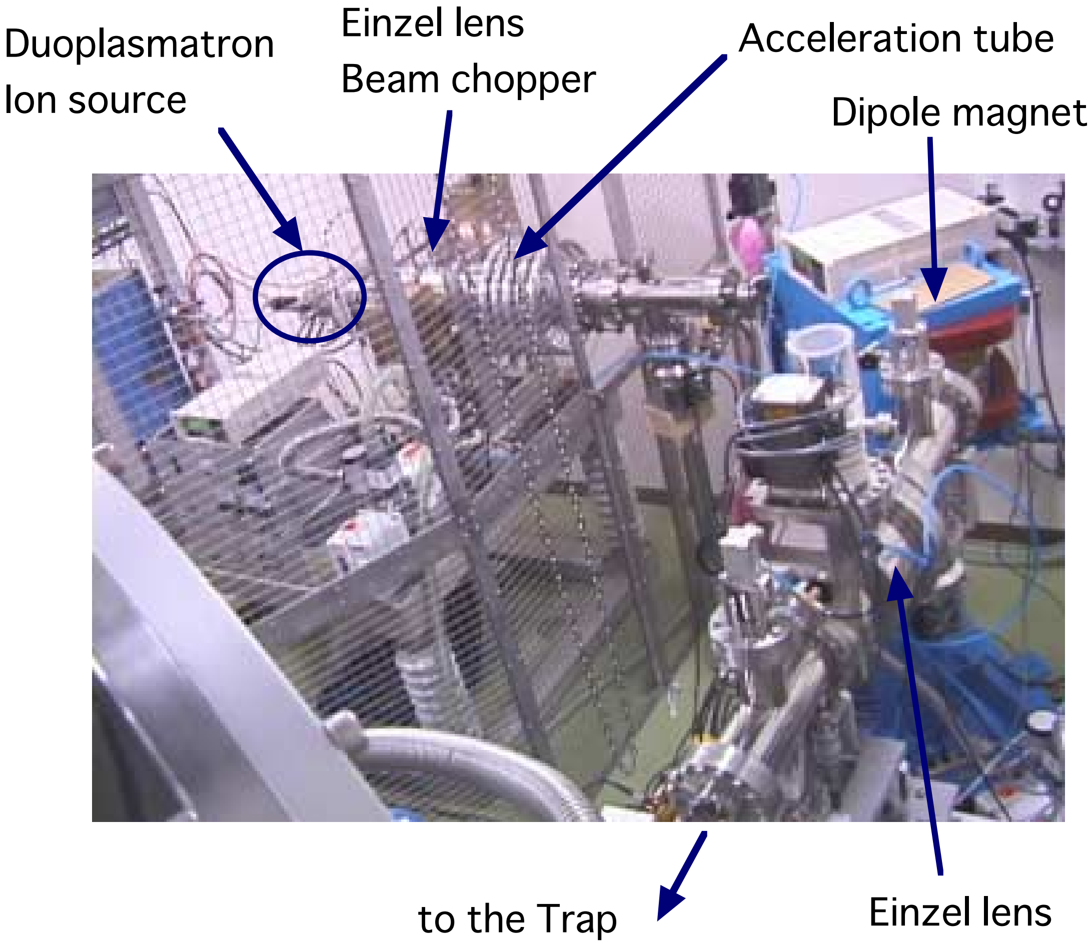


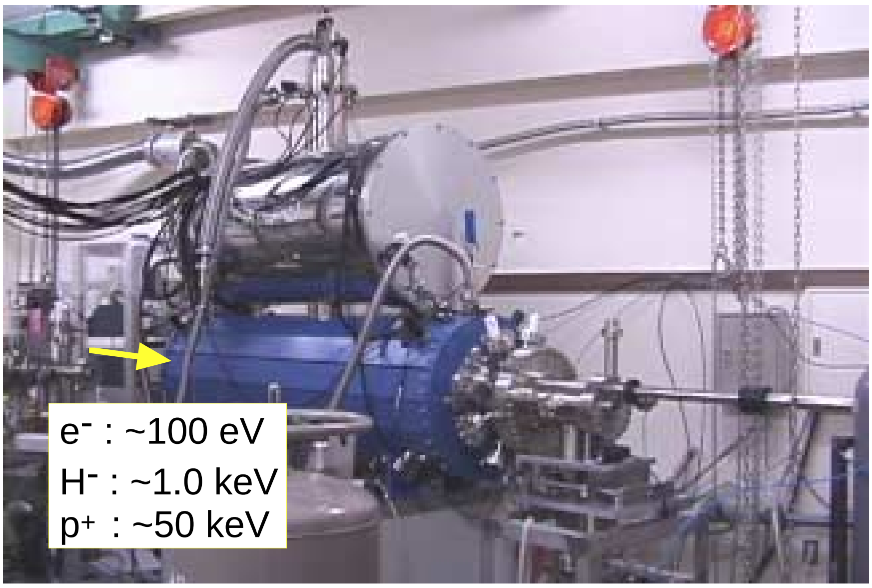
number of electrons ～ 1.3 x 10^8, 2inch off axis
pressure outside the cryogenic region ～ 1.6 x 10^{-9} Torr
rotating field : 60 sec wait after the injection of electrons
120 sec rotating field at 2MHz, 0.5V

30 sec　　　　60 sec　　　　120 sec



陽子・水素負イオンビームライン





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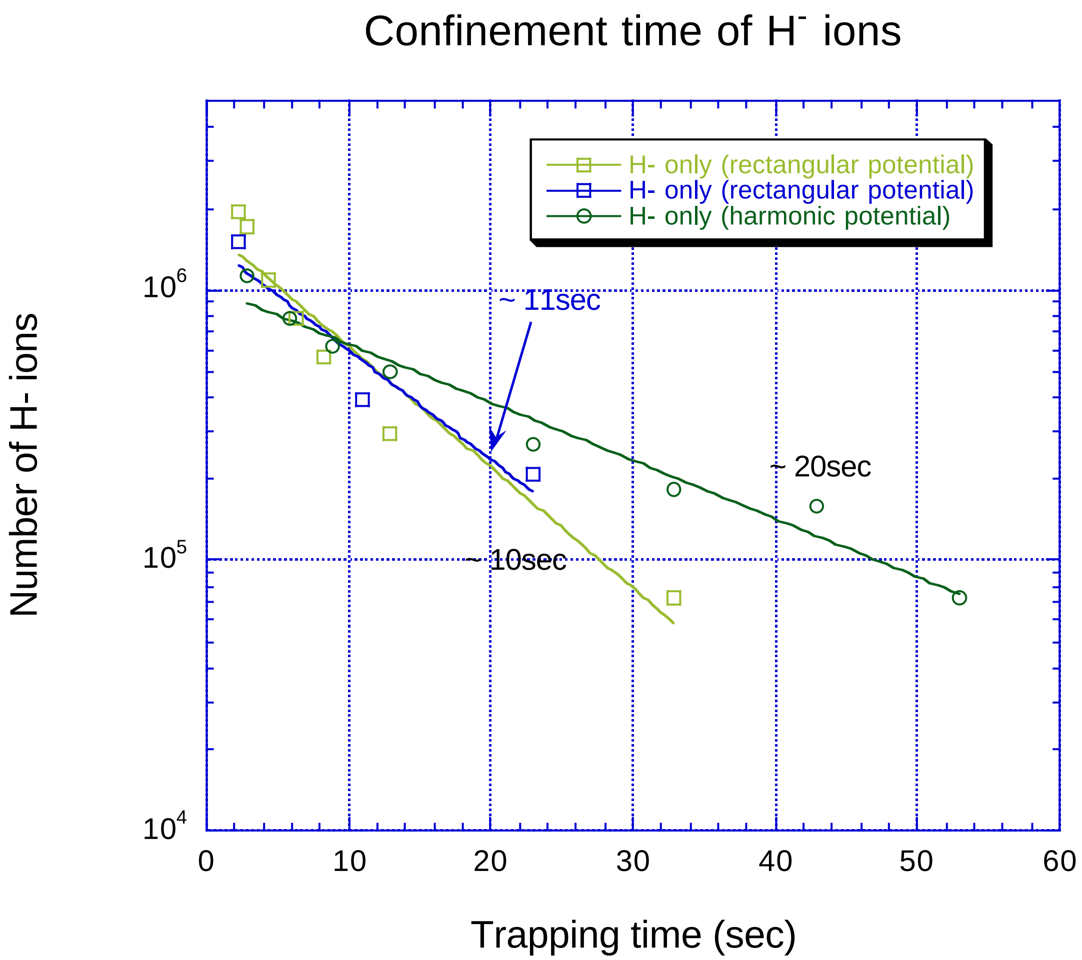
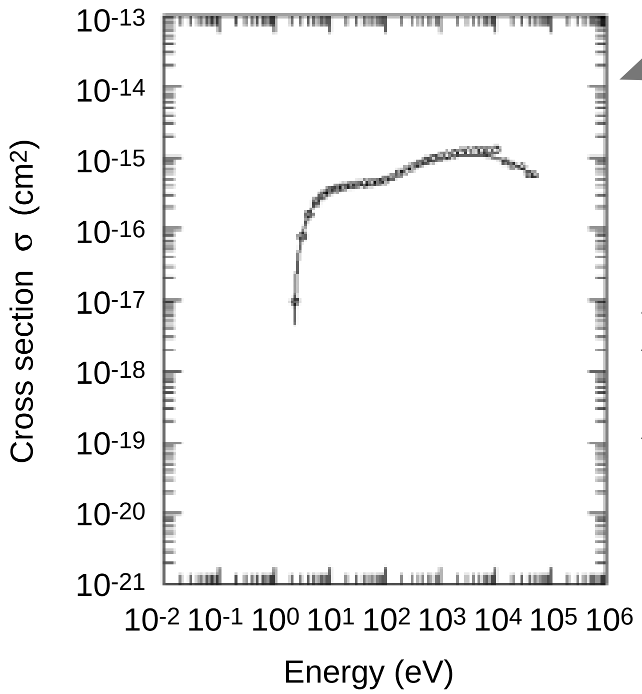
H^- イオンの閉じ込め





Cross section for a process

$H^- + H_2 \rightarrow H + H_2 + e^-$

Tabata T. and Shirai T.,

Atomic Data and

Nuclear Data Tables 76 ('2000)

* cross section : $\sigma \sim 10^{-15}$ cm^2 at 100eV

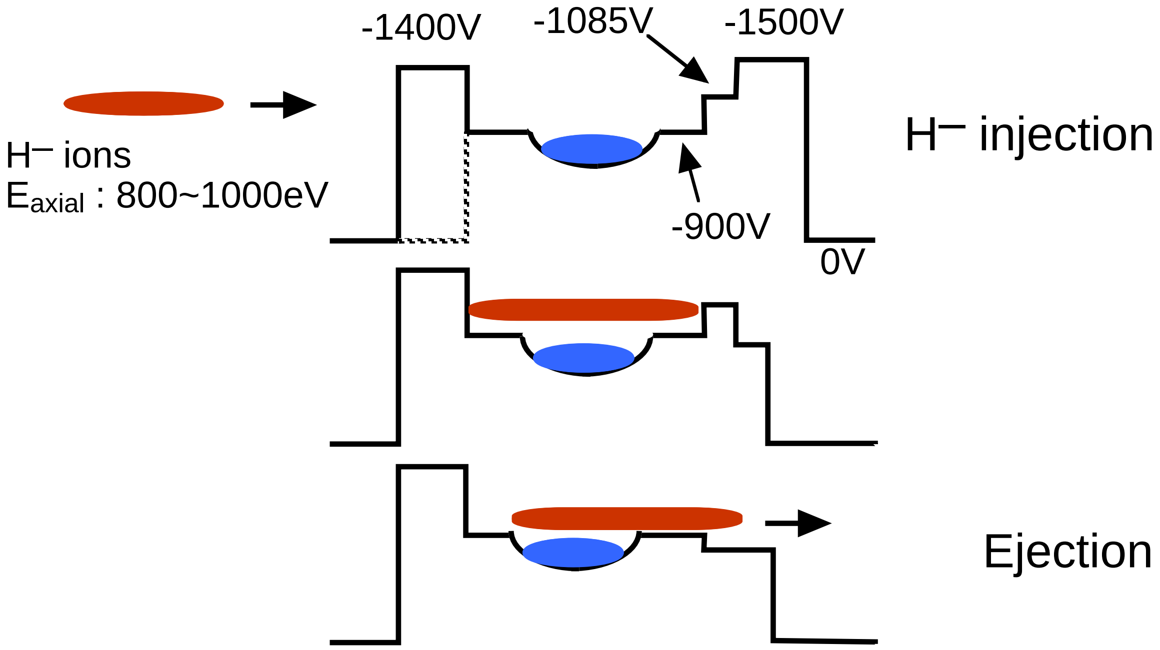
* density of residual hydrogen

: $n \sim 10^6$ cm^{-3} at 10K, 10^{-12} Torr

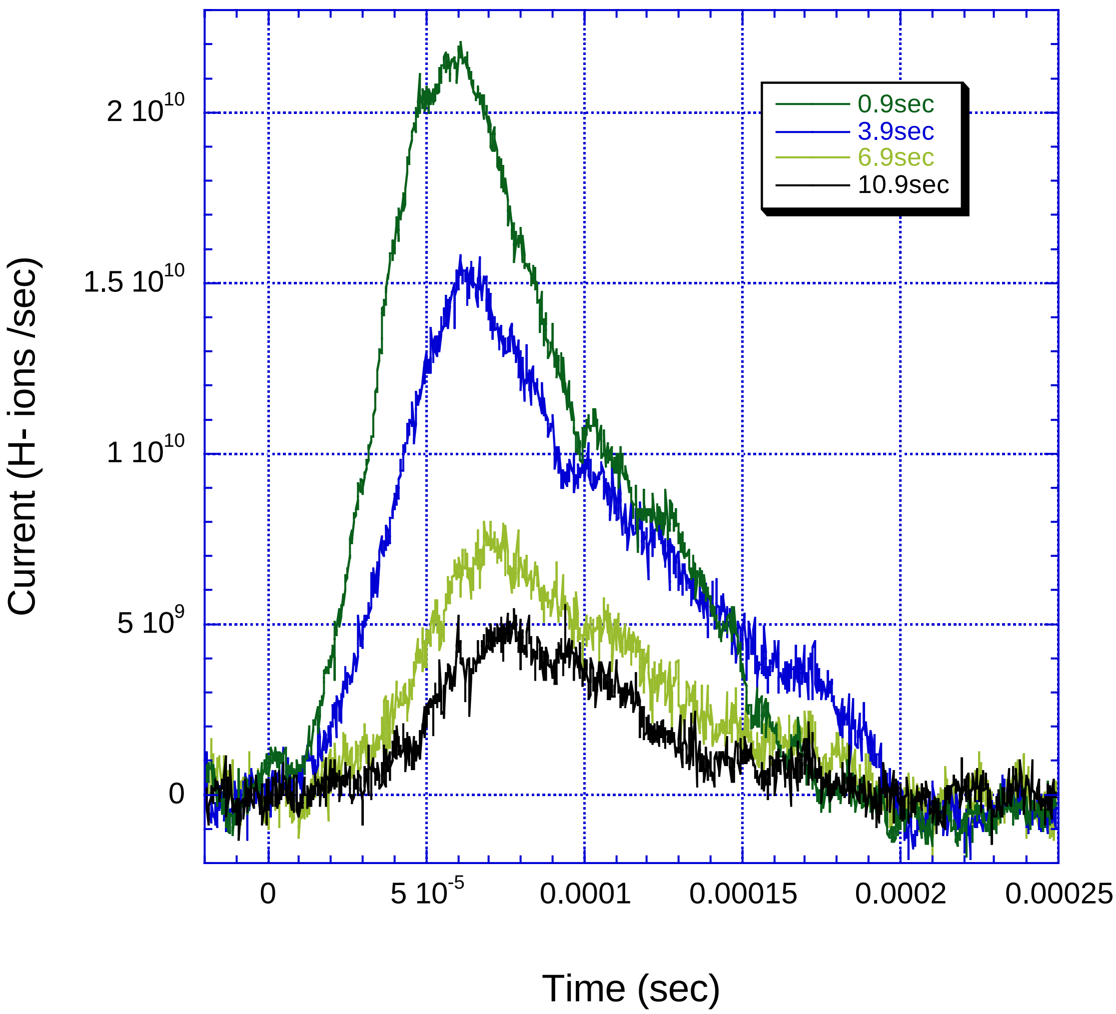
* velocity of H^- ions : $v \sim 2 \times 10^7$ cm s^{-1} at 100eV

→ lifetime of H^- ions ~ 50sec

H^- イオンの閉じ込め　2

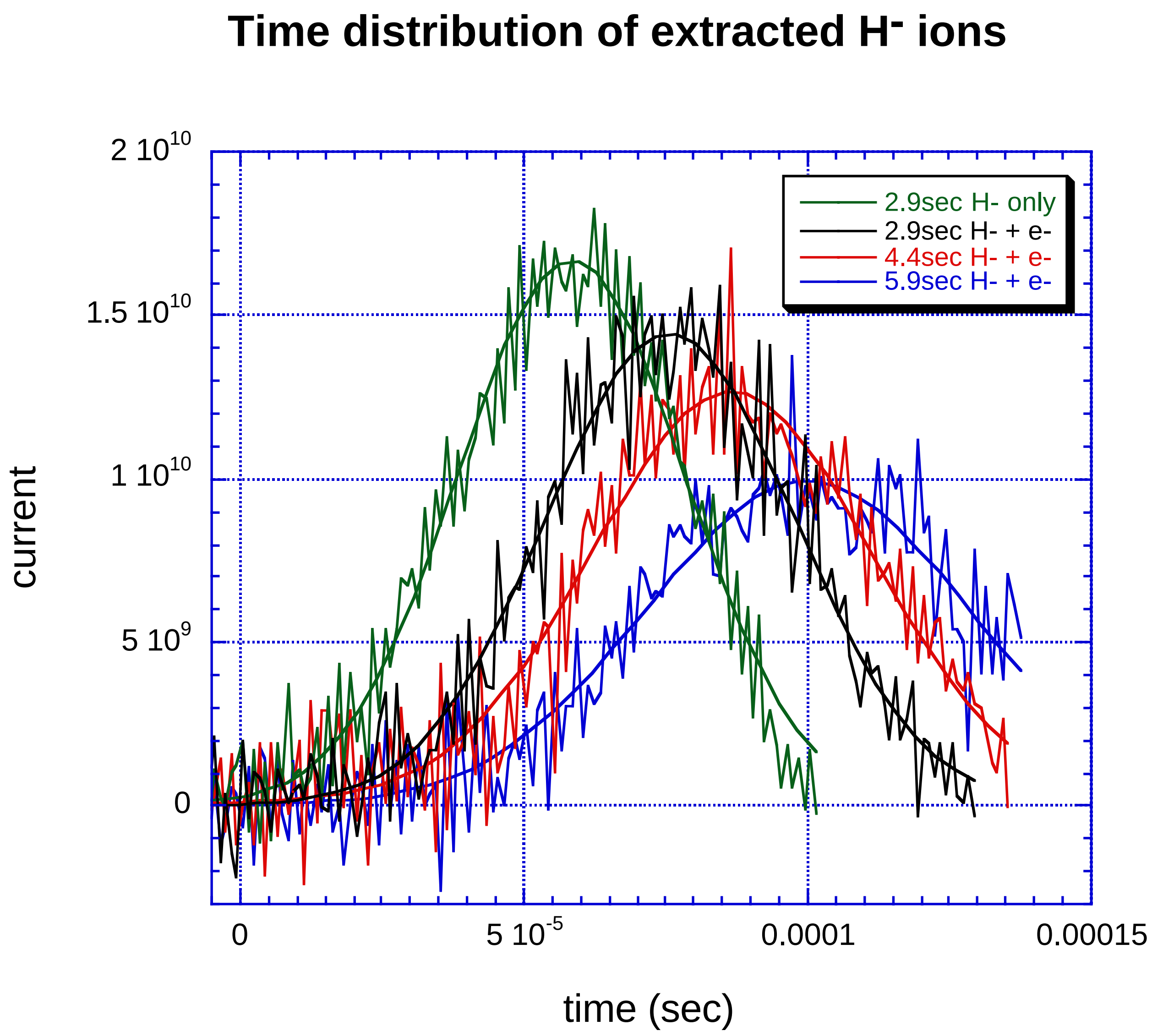


Extracted H- ions (only H- ions are trapped)



H^- イオンの電子冷却 1

$H^- \sim 2 \times 10^6$ for H^- only, 2.9 sec trapping
$e^- \sim 1.5 \times 10^8$, loaded 70 sec before H^- injection



H^- イオンの電子冷却 2 （電子プラズマの温度）

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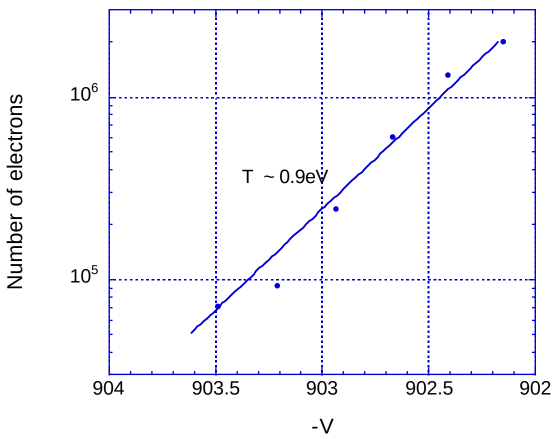
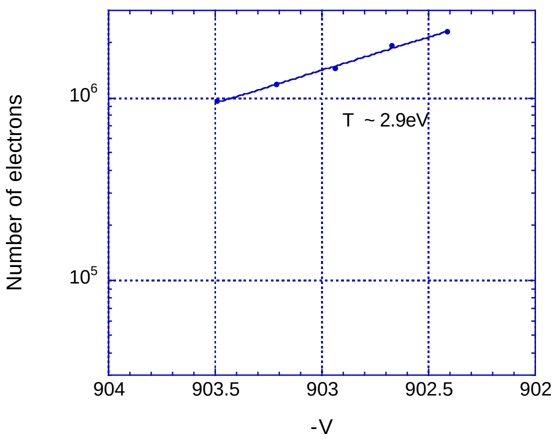
measured	culculateded

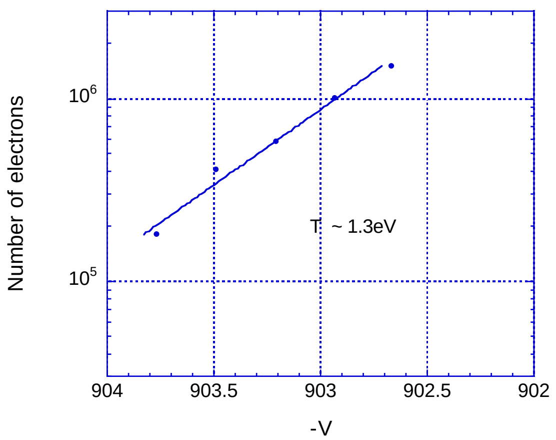
e^- only (before H^- injection)



H^- + 2.9 sec trapping



H^- + 5.9 sec trapping



$$\frac{dT_{H^-}}{dt} = \upsilon_{H^-e}(T_e - T_{H^-})$$

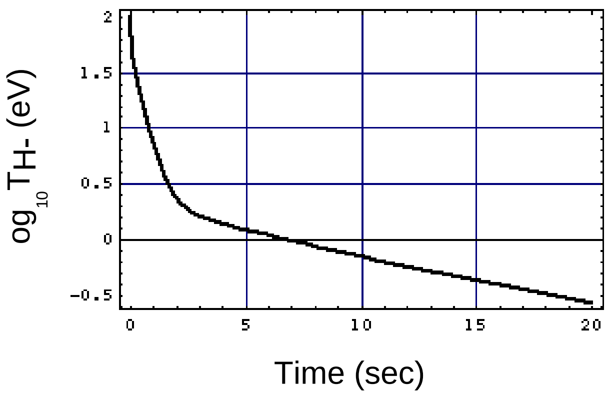
$$\frac{dT_e}{dt} = \upsilon_{eH^-}(T_{H^-} - T_e) - T_e A$$

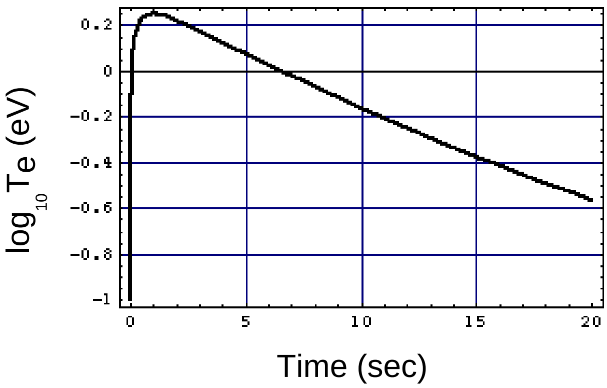
$$A = \frac{8}{B\,[T]}$$

Magnetic field : 1T

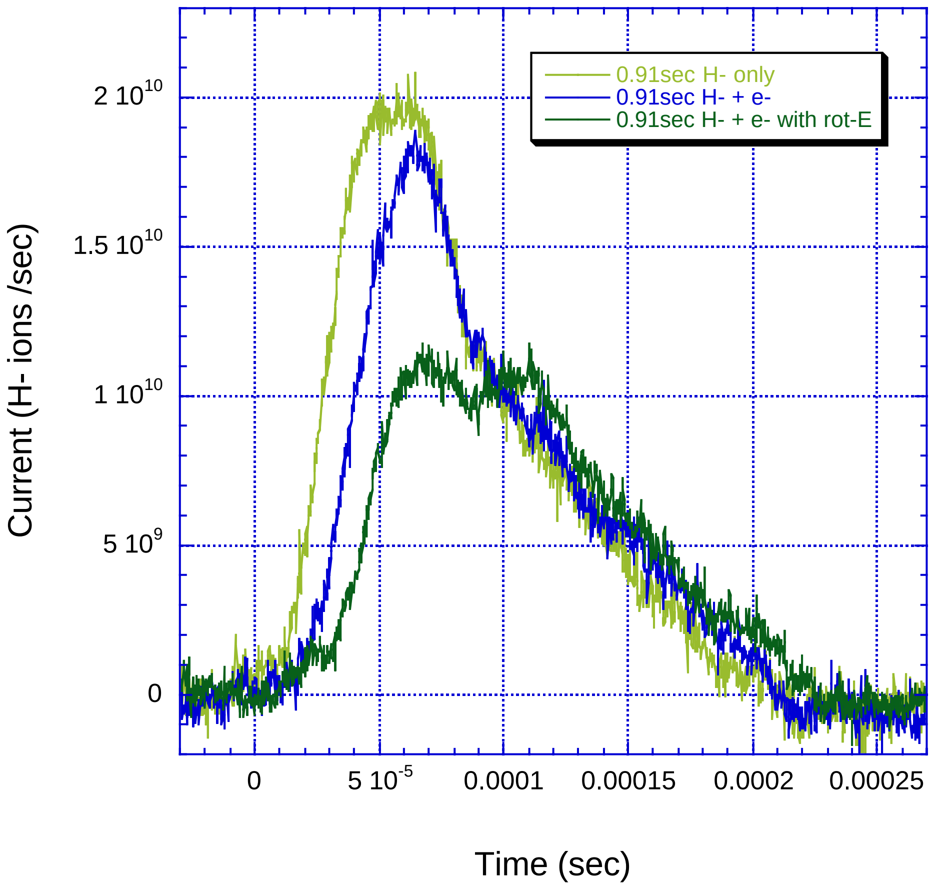
$n_{H^-} = 1\text{x}10^6\ /\text{cm}^3$, $n_e = 5\text{x}10^7\ /\text{cm}^3$

$T_{H^-}(0) = 100$ eV, $T_e(0) = 0.1$ eV





H⁻ イオンの電子冷却 3



0.9sec cooling

$H^- \sim 2 \times 10^6$

$e^- \sim 9 \times 10^7$

no rot-E :

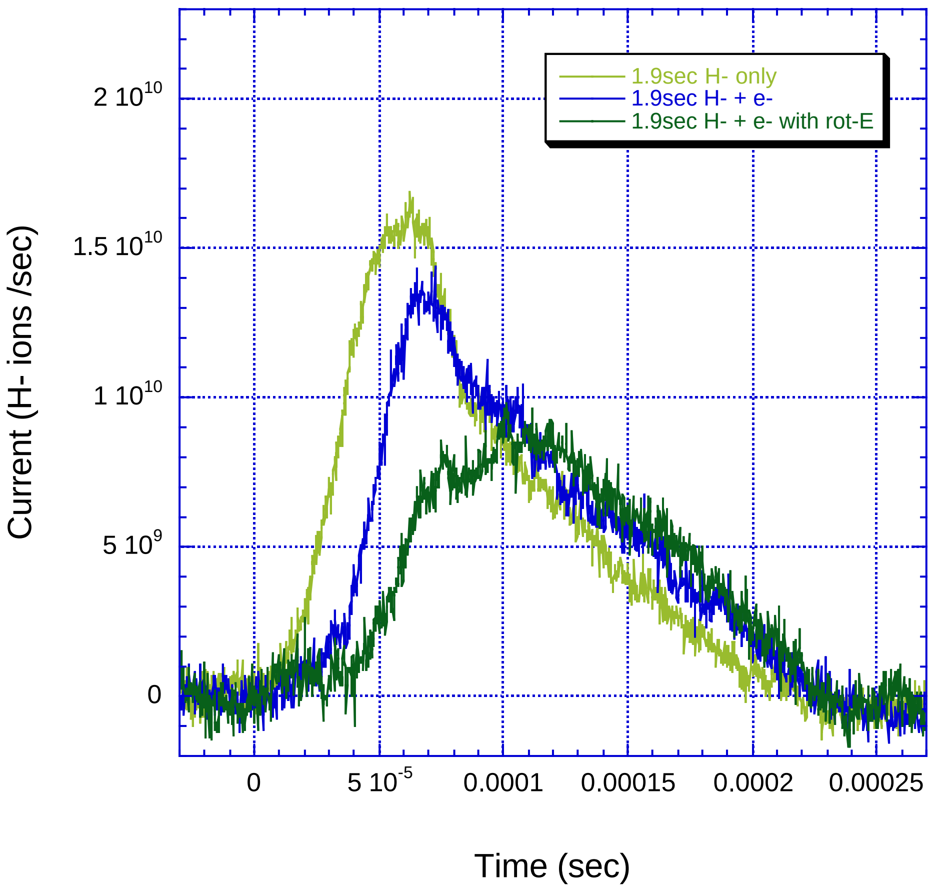
(1) e- loaded 70sec before H^- injection

with rot-E :

(1) 60sec wait

(2) 120sec rotating field at 2MHz, 0.5V

(3) 30 sec wait before H^- injection



1.9sec cooling

$H^- \sim 2 \times 10^6$

$e^- \sim 9 \times 10^7$

no rot-E :

(1) e- loaded 70sec before H^- injection

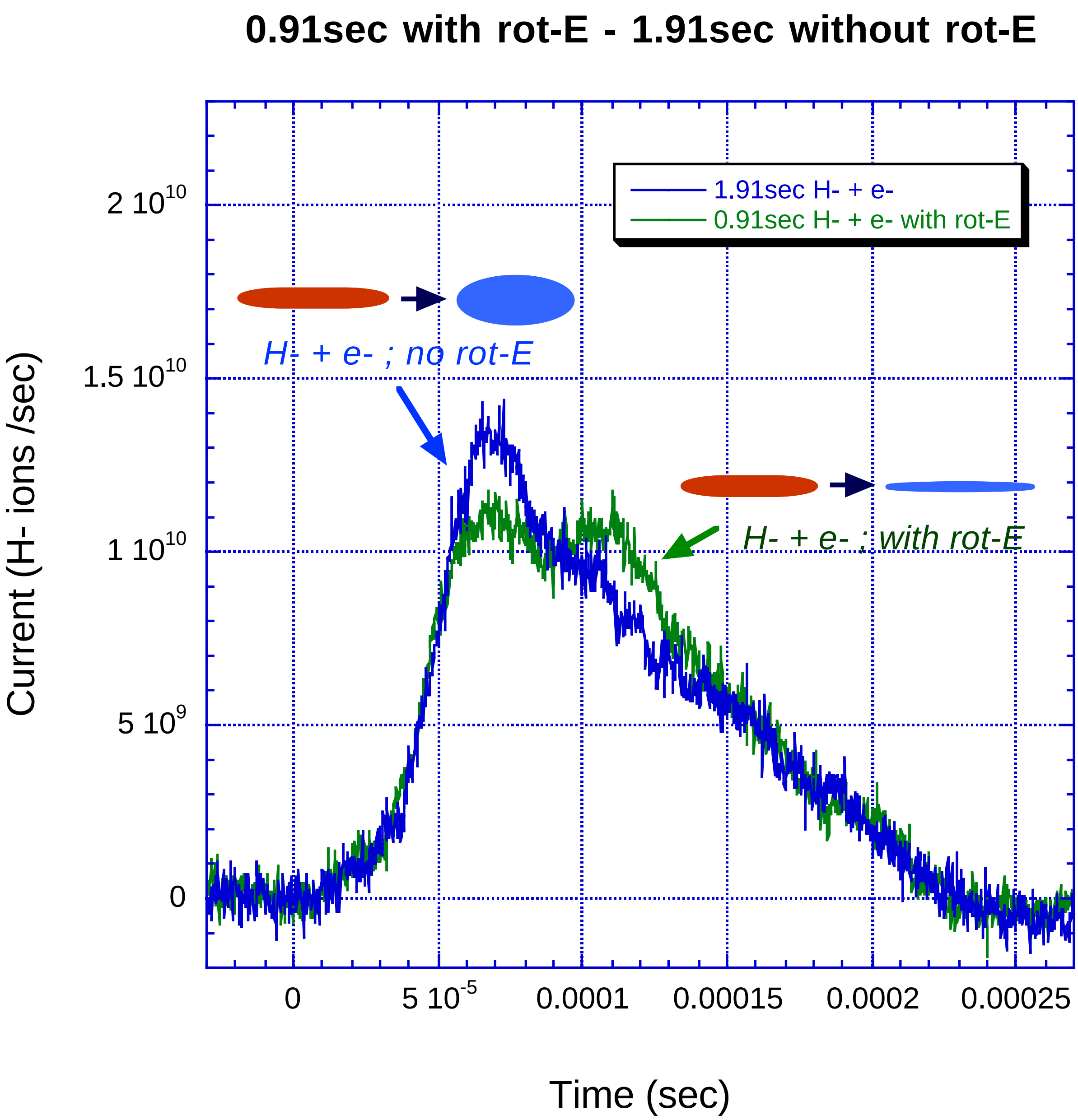
with rot-E :

(1) 60sec wait

(2) 120sec rotating field at 2MHz, 0.5V

(3) 30 sec wait before H^- injection

H^- イオンの電子冷却に対する回転電場の効果



H^- ～ 2×10^6

e^- ～ 9×10^7

no rot-E : electrons loaded 70 sec before H^- injection

with rot-E : 60 sec wait

120 sec rotating field at 2MHz, 0.5V

30 sec wait before H^- injection

(2,0) modes による温度モニターの可能性

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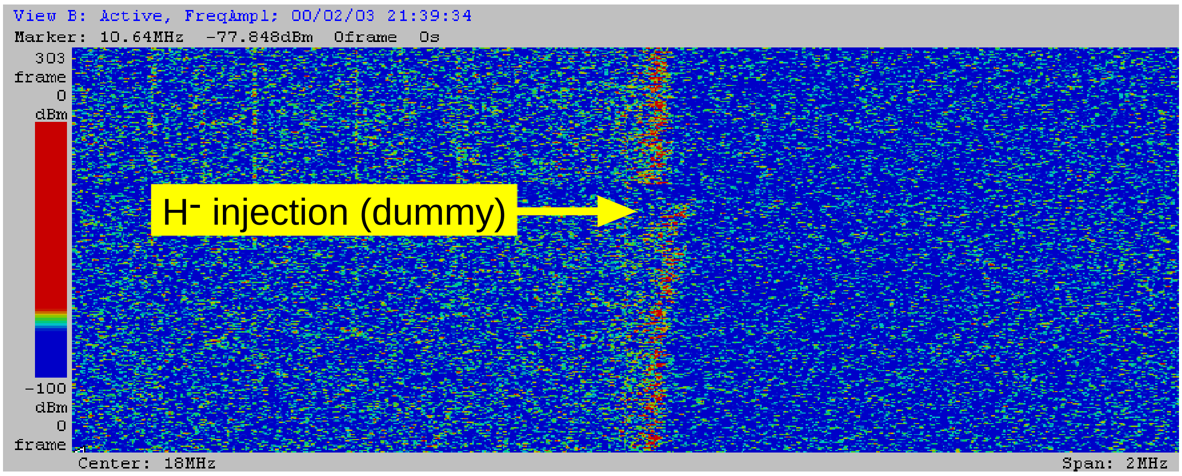
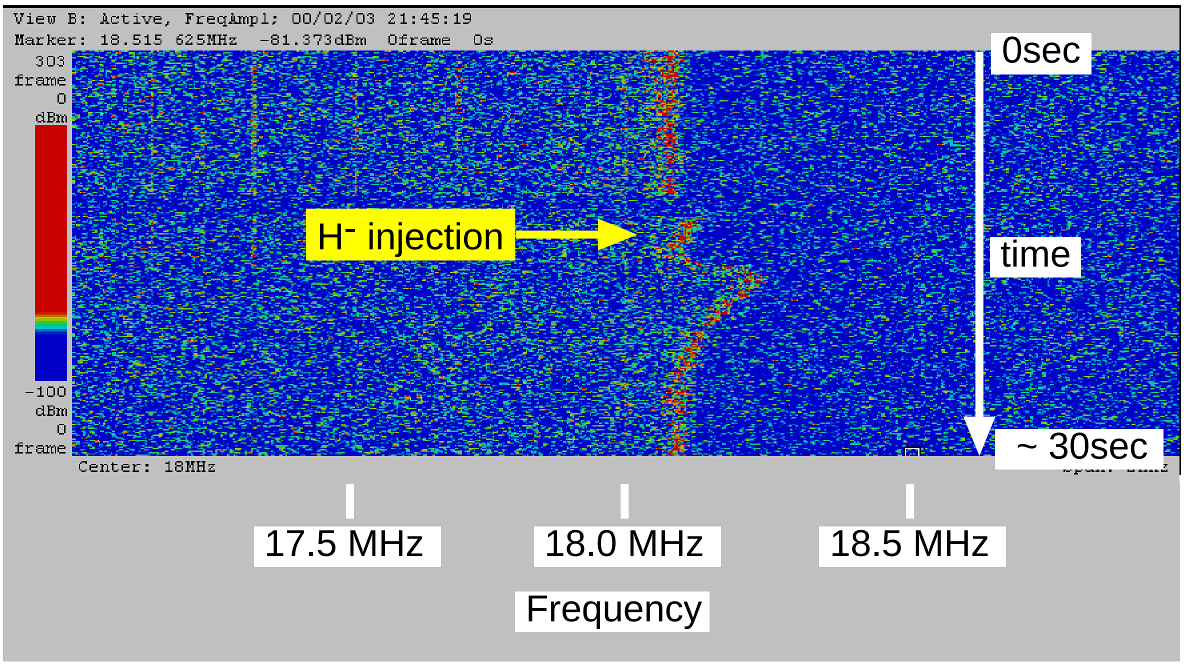
(2,0) mode ; no H⁻

A plasma of 1x10⁸ electrons.

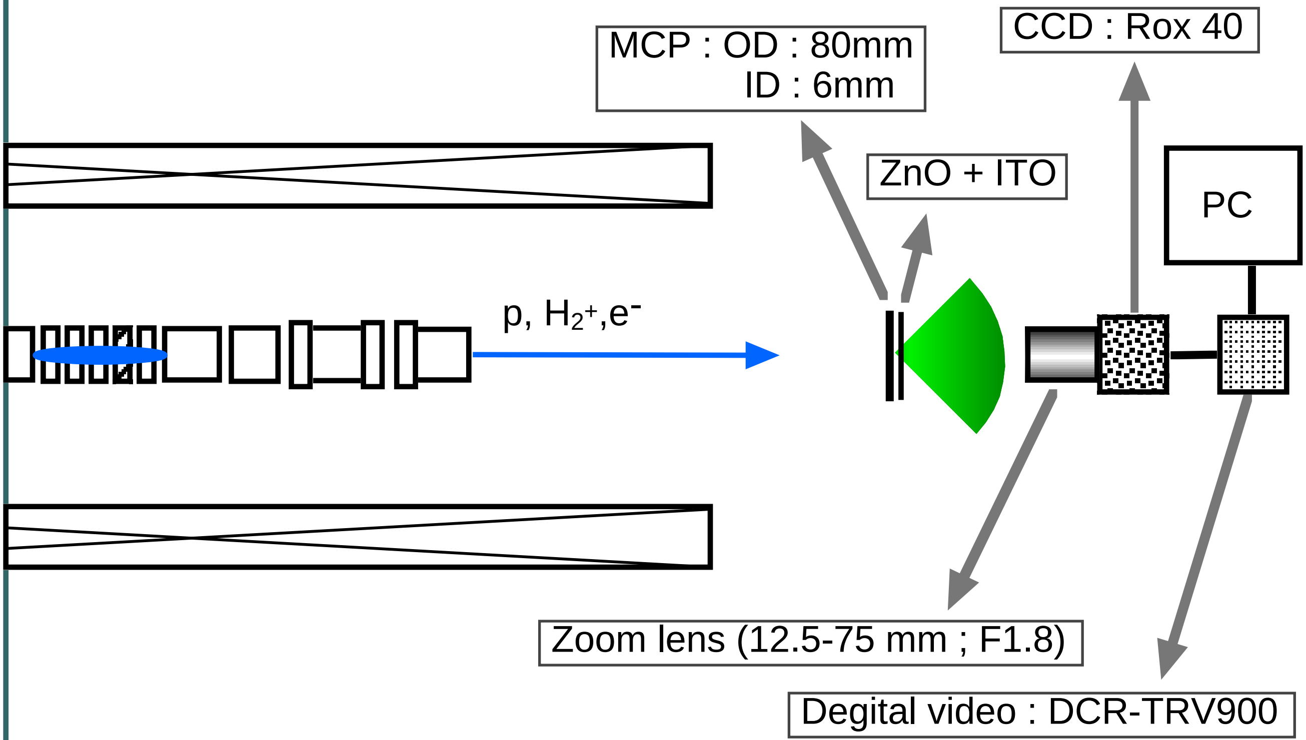


(2,0) mode ; with H⁻

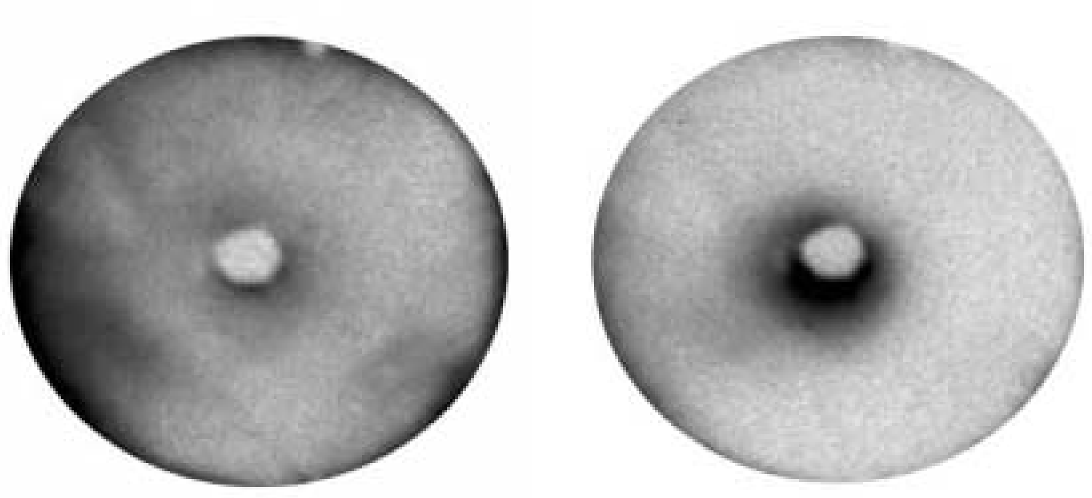
5x10⁷ H⁻ ions injected into a plasma of 1x10⁸ electrons.



回転電場による陽子雲の制御



witout rotating field | with rotating field



number of protons 〜 1.3 x 10^6
trapping time : 300sec

H^{2+} kicked out
number of protons 〜 1.3 x 10^6
rotating field : 200sec at 250kHz, 1.6V

まとめと今後の実験計画

(1) 超低速反陽子ビームの生成のための
ASACUSA trapping system の開発

- Multi-ring harmonic trap
  (harmonic region ~ 10cm : 大容量)
  $10^{6\sim8}$ 個の反陽子の電子冷却
  プラズマの状態のモニターと制御

(2) 回転電場による電子プラズマの制御

- ø < 2mm

(3) 水素負イオンの電子冷却

- (2,0) mode が温度計として使える可能性あり

(4) 回転電場による陽子プラズマの制御

- パラメーターが見つかりつつある

↓

(a) 10~50keV 陽子の捕獲と電子冷却
(b) プラズマの形状を整形した後の、ビームとしての引き出し（パルス幅 1μsec - DC）
(c) プラズマの状態の非破壊測定法の整備