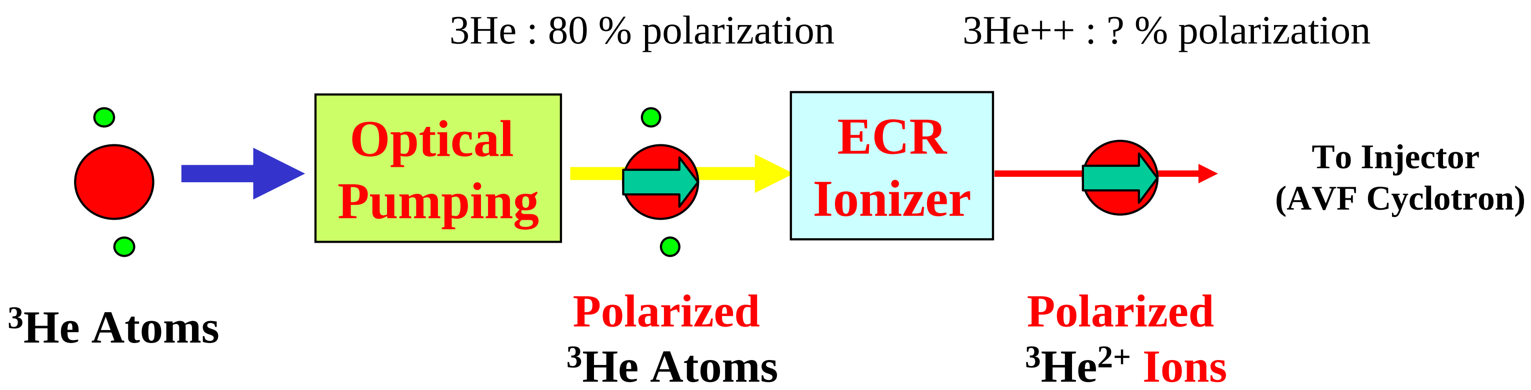
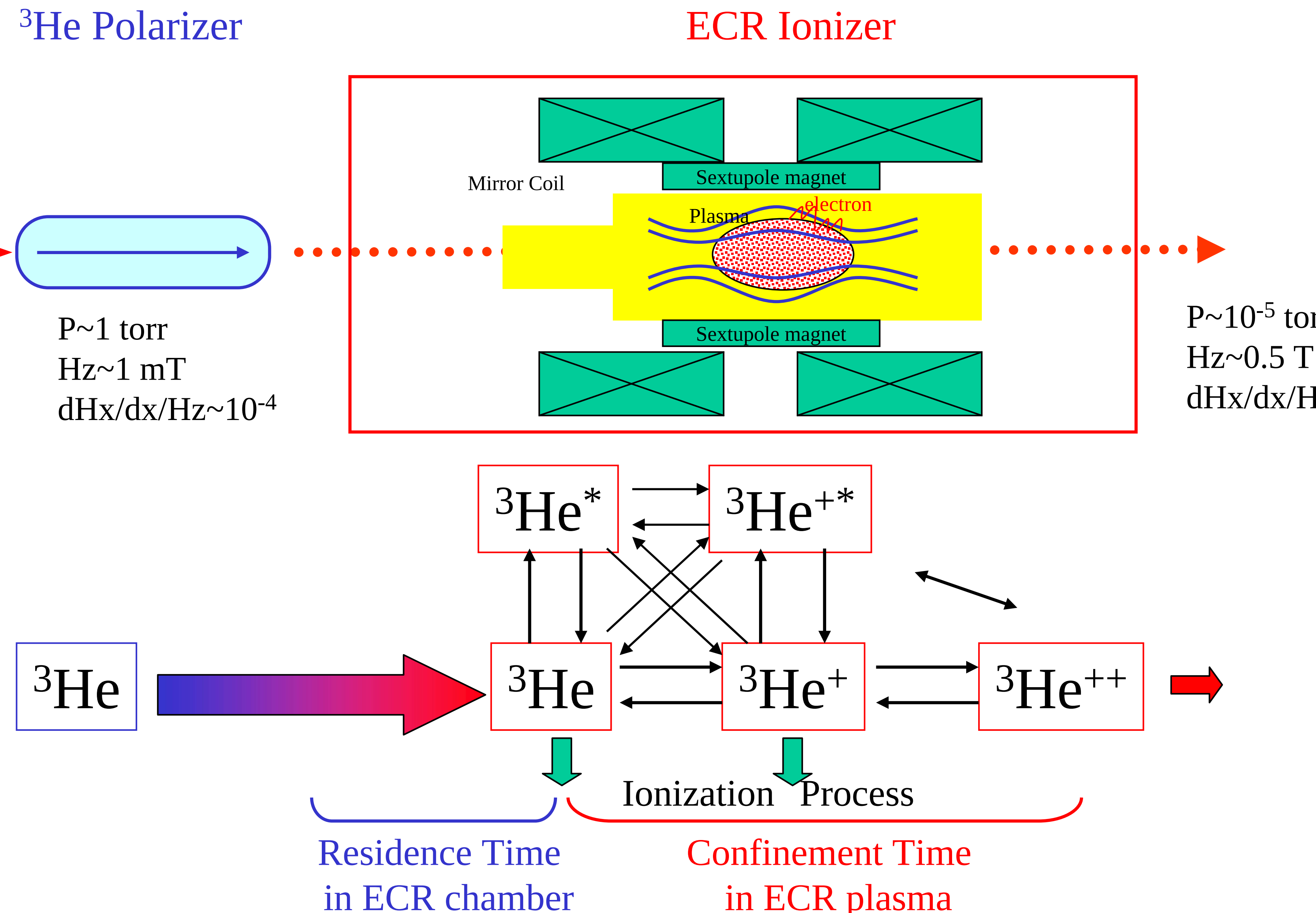
Yasuhiro Sakemi : 2003-October-20



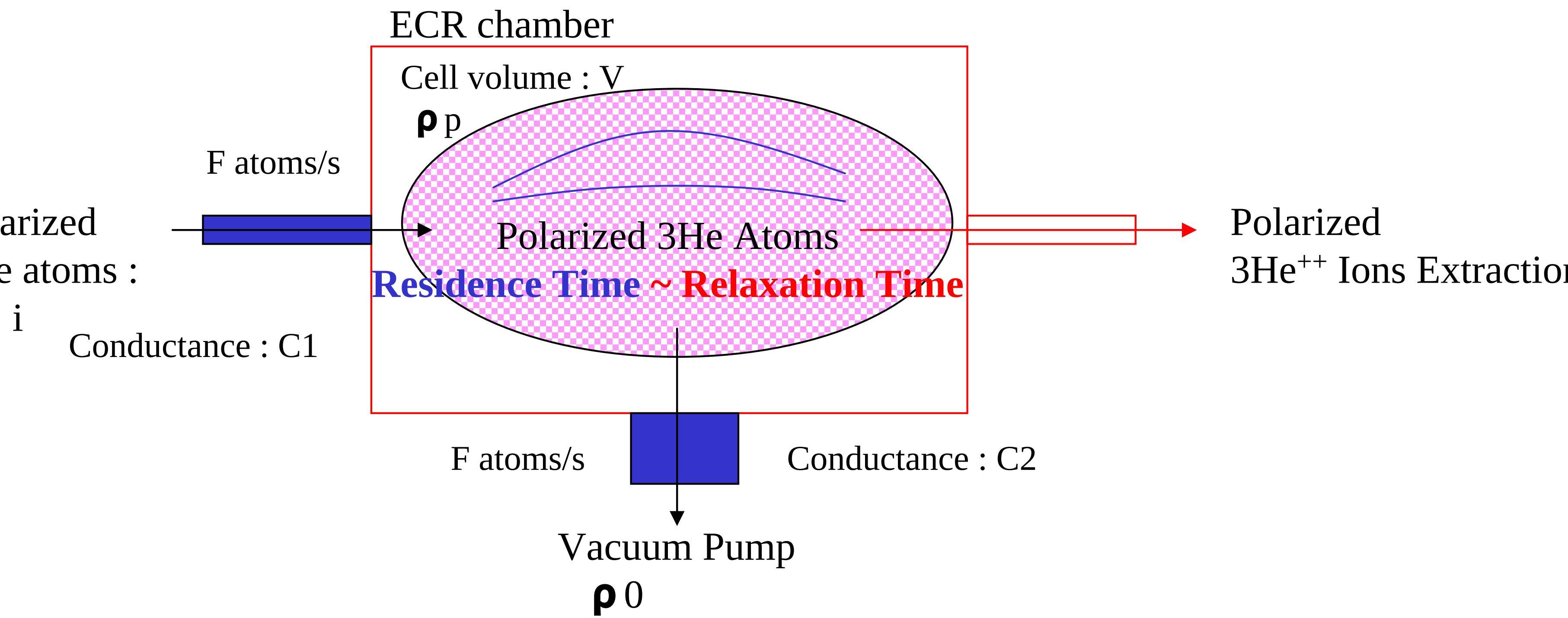
1. ^3He polarizer + ECR ionizer

2. $^3He^+$ Ion Polarizer + Ionizer (alternative design)

Depolarization in ECR Ionizer



Depolarization 1 : Depolarization due to inhomogeneous magnetic field



nce Time : t_r ~ depend on ECR chamber size, vacuum system, pressure, conductance, flow rate …

$$= \frac{\rho_p V}{F}$$

$$= C_1(\rho_i - \rho_p) = \rho_p C_2$$

$$t_r = \frac{V}{C_2} = \frac{V}{\frac{2}{3}\pi \frac{a^3 v}{L}}$$

ECR chamber size : 13 Φ, 42 cm , a= 1Φ, L=50 cm

Residence Time ~ 100 ms order, but depend on ECR chamber spec.

Relaxation Time in inhomogeneous magnetic field

navior of relaxation time : T_1 ~ depend on the ratio of diffusion time : τ_d and precession time : τ_l

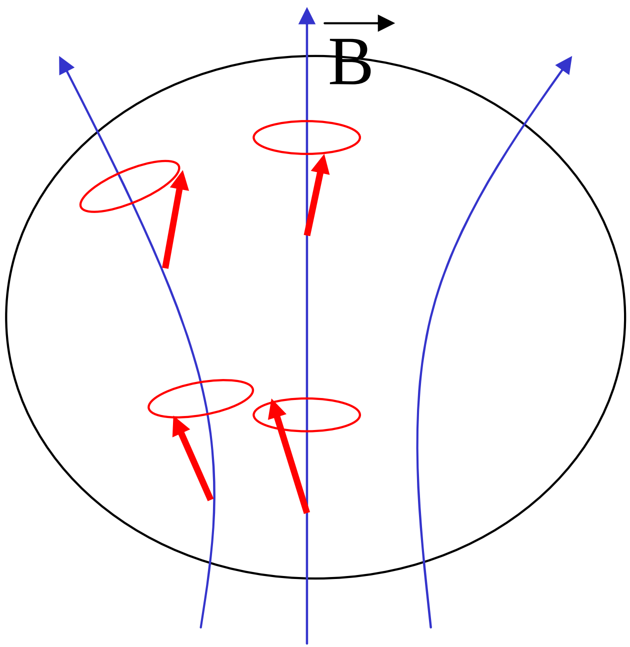
$$\frac{\tau_d}{\tau_l} = \frac{\frac{R^2}{D}}{\Omega_0^{-1}} = \frac{\frac{R^2}{v\lambda/3}}{\gamma H_0^{-1}} = \frac{3R^2\gamma}{v}\frac{H_0}{\lambda}$$

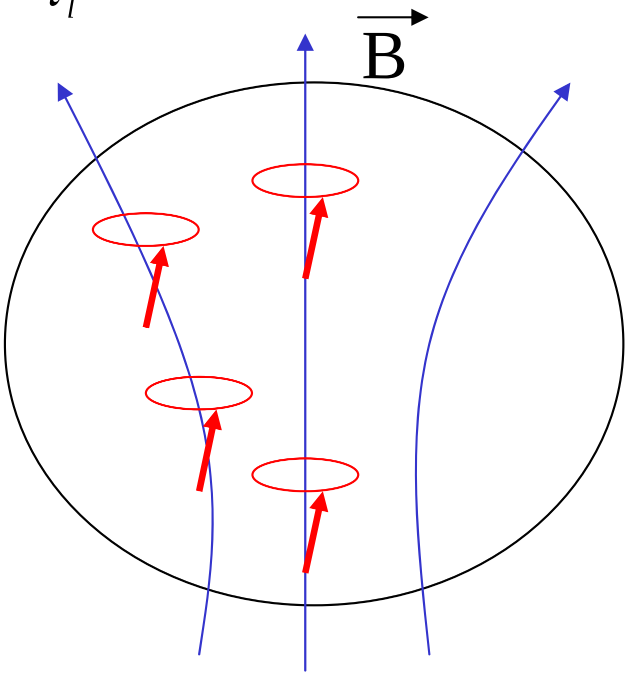
Relaxation time : T_1 depend on field gradient

$$- >> 1$$

$$\frac{1}{T_1} = D\frac{\left|\vec{\nabla}H_x\right|^2 + \left|\vec{\nabla}H_y\right|^2}{H_0^2}\frac{\tau_c}{1+\Omega_0^2\tau_c^2}$$

$$\frac{\tau_d}{\tau_l} << 1$$





CR chamber : dH_x/dx ~ 0.1-0.3 T/cm , H_0~0.5 T : field gradient ~ 20 – 30 m^{-1} : T_1 ~ 100 ms

mping cell@HERMES : dH_x/dx ~ 0.001 mT/cm, H_0~1 mT : field gradient ~ 0.1 m^{-1} : T_1 ~ 300 s

ECR chamber design

Depolarization due to relaxation ~ should be careful

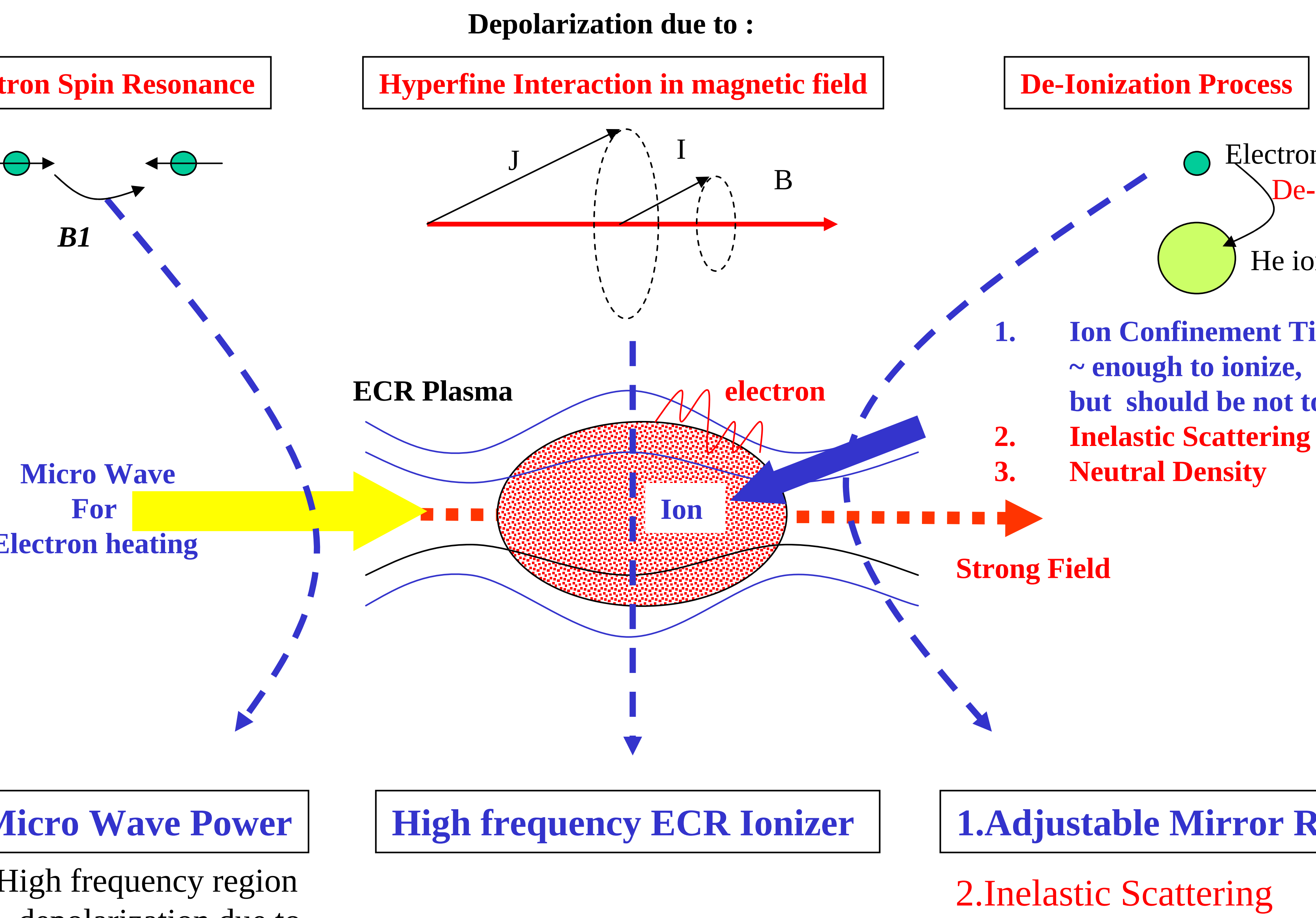
ECR design :

Relaxation time : T_1 > Residence time : T_r

Depolarization due to relaxation can be solved by :

1. Field gradient ~ small : Mirror field , Multipole field
2. Chamber size, Conductance, Vacuum system : optimize
3. Others …

Depolarization 2 : Depolarization in the ionization process



Obtained Polarization

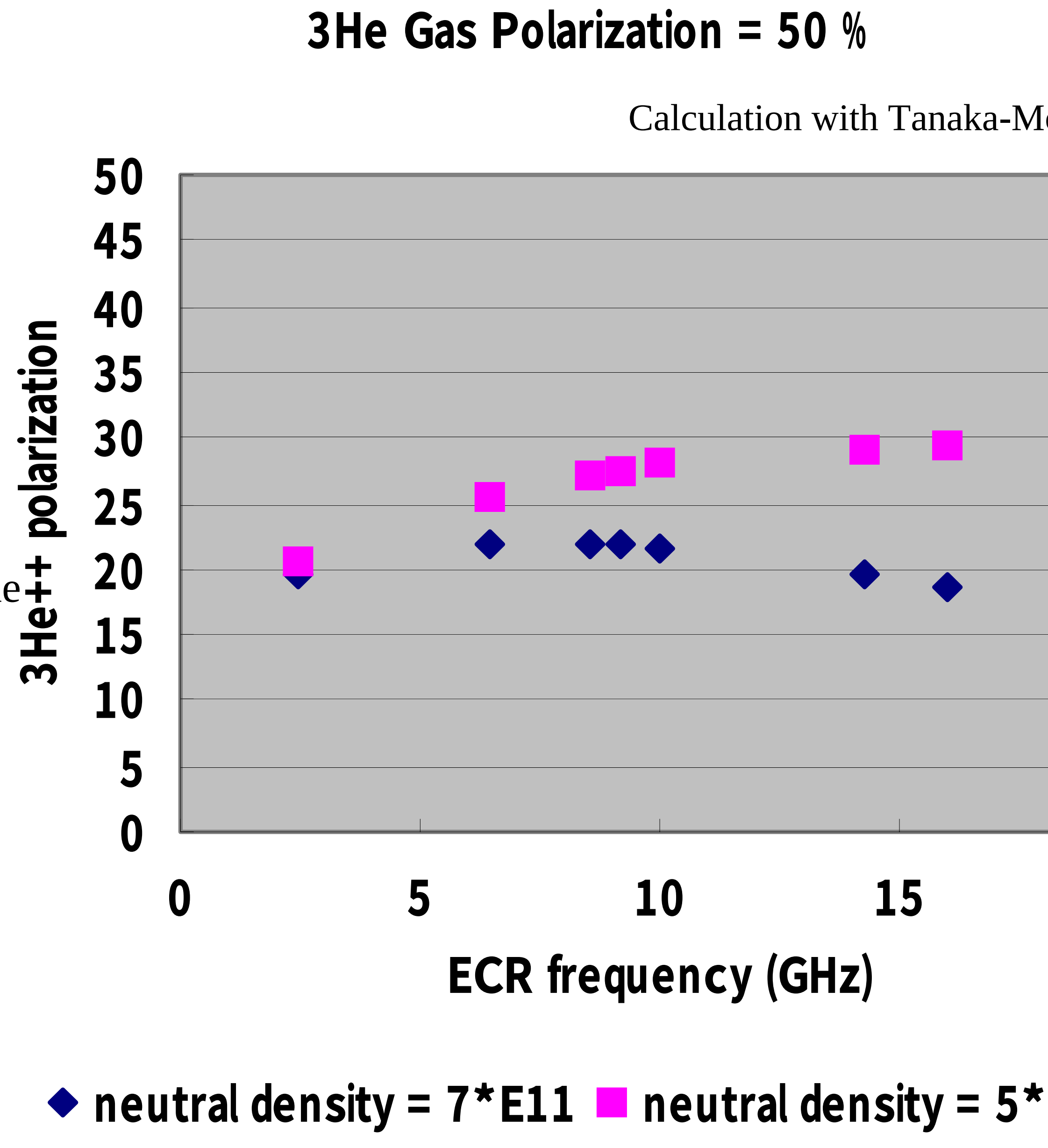
rization ~ 30 % will be achieved with
rized ^{3}He gas : 50 % input

Confinement Time : 1.5 msec input

olarization due to ionization, de-
ation effects : included

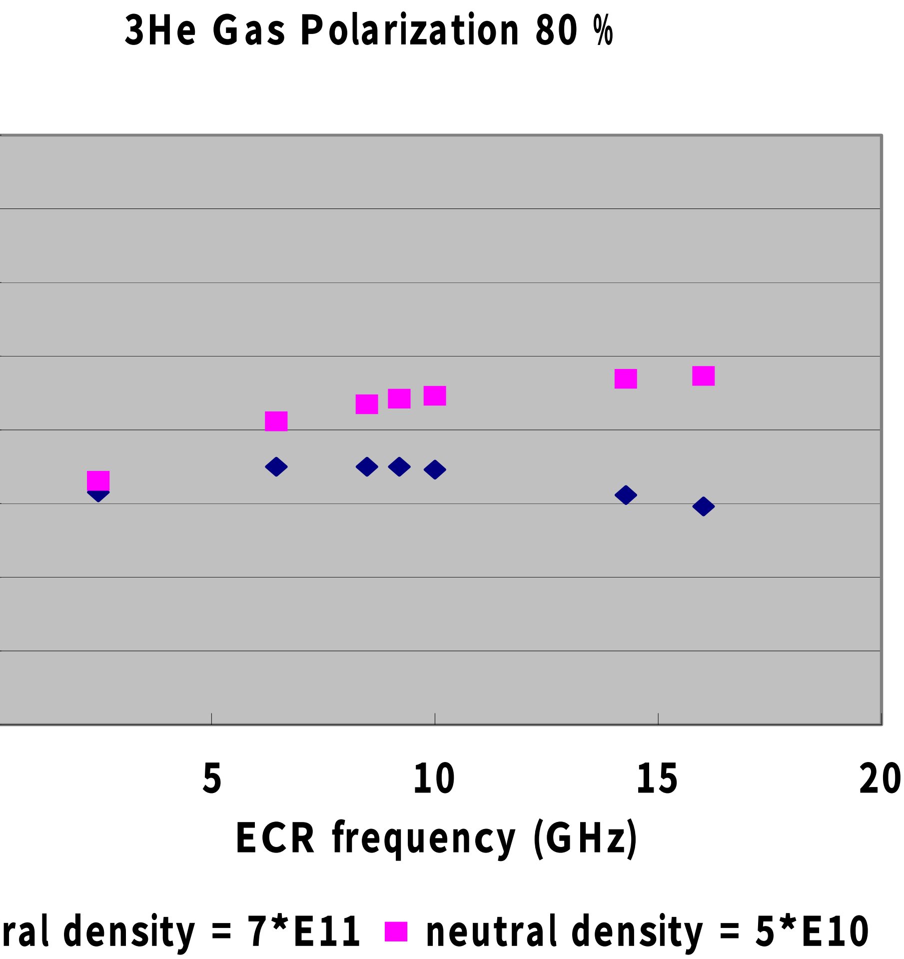
olarization due to ESR effects ~ not
ded for the reason described later slide

rs …

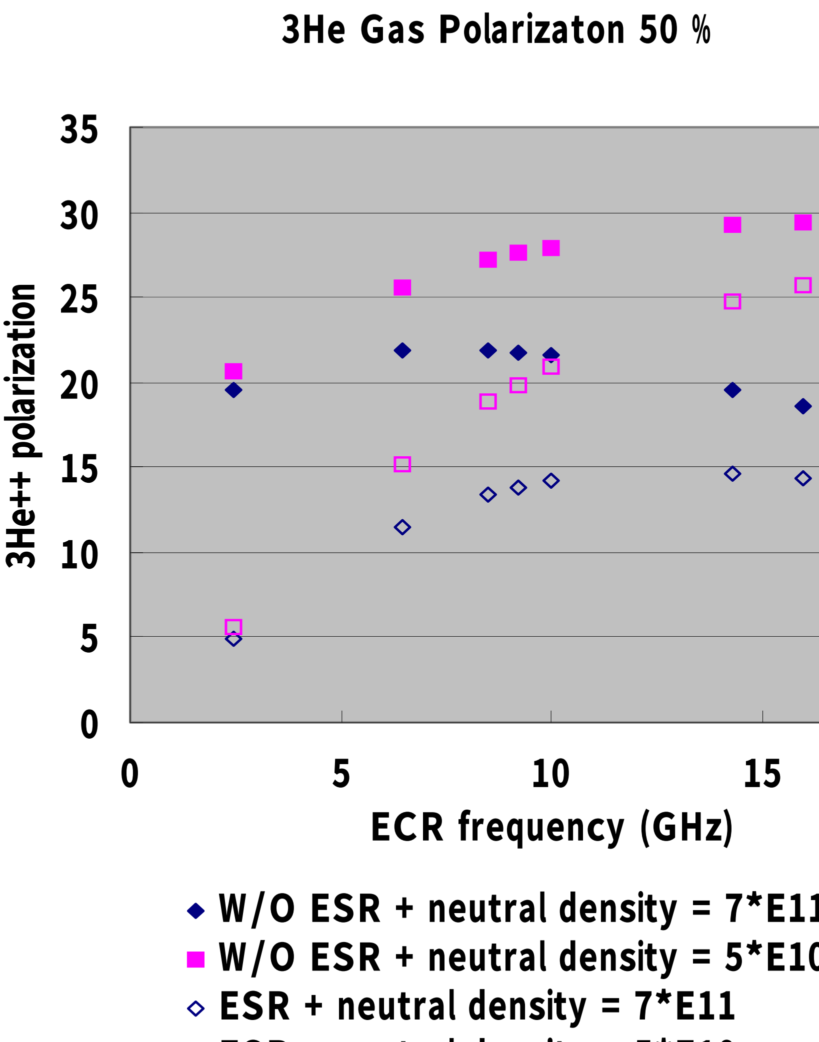


Additional Information

we apply nice Mainz ^{3}He polarizer,
gh polarized ^{3}He gas : 80 % is obtained !
on Confinement Time =1.5 msec)



ESR effects ~ what should be checked:
Can be neglected or should be included ?
(Ion Confinement Time = 1.5 msec)



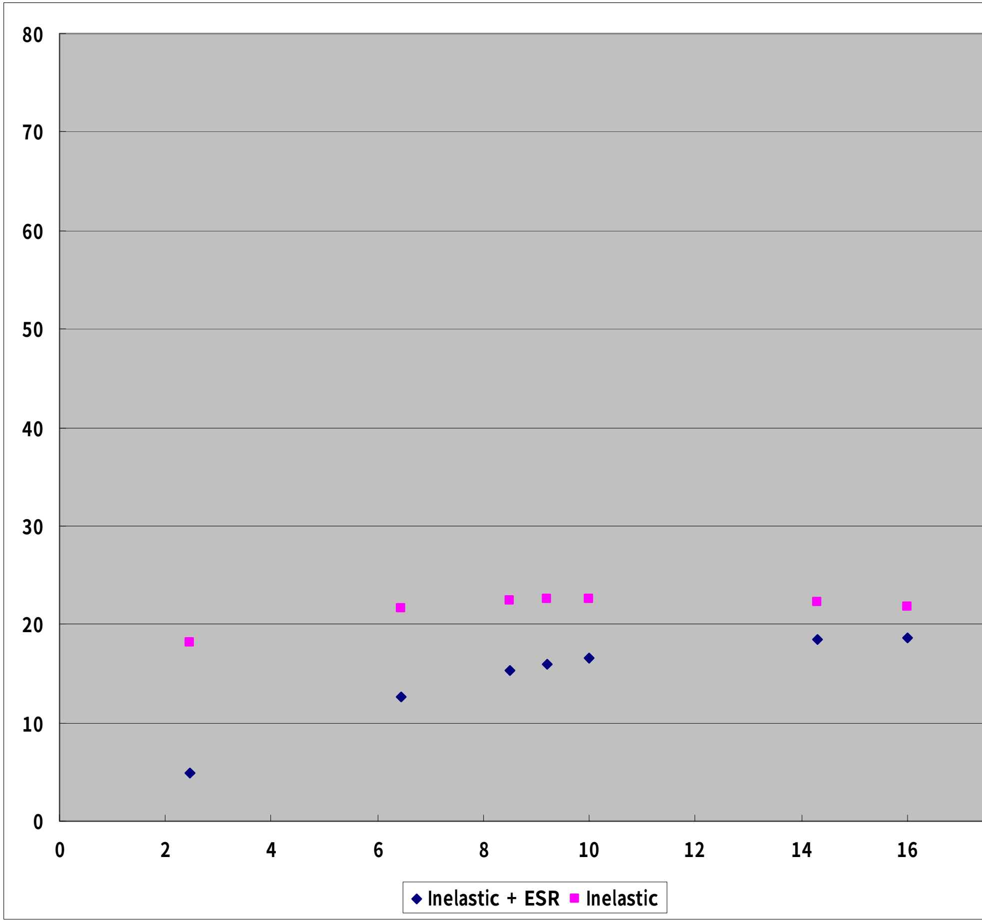
Polarization including all effects (inelastic scattering)

ion rate (3He+ ⇒ 3He++)
2.3 × 10^{-9} cm^3/s

c scattering rate (3He+⇒3He+*)
2.5 × 10^{-8} cm^3/s

s polarization ~ 80%
c scattering included

He++ ~ 25% polarization
epolarization due to
elastic scattering ~ dominant
SR effects ~ small effect
high frequency region
thers..



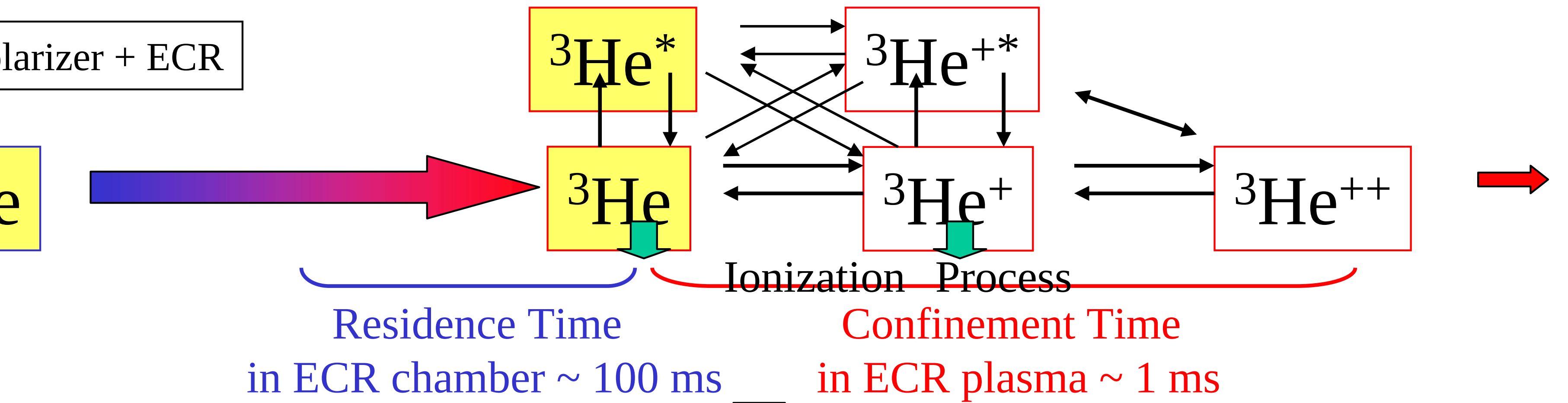
Conclusion at present

epolarization due de-ionization process (inelastic scattering) ~ dominant process
eutral density in ECR chamber ~ large effect to depolarization
epolarization due to ESR effects ~ at high frequency region, other effects large
elaxation time ~ Residence time : should be careful in the design of ECR ionizer
CR ionizer ~ modify to dedicate for the 2 electrons stripping / Not highly charged ions
irror Ratio , Micro-Wave power adjustment
xpected polarization : 20 % ~ 30 % @ 80 % 3He atoms polarization at present
xperimental depolarization study ~ necessary

r feasibility study
onizer is Good or Bad for polarized ion source ~ should be concluded soon…

should be checked further :
acuum (Neutral Density) in ECR chamber
e-ionization process ~ depolarization process
equired polarization and intensity for Physics goal

Alternative (Ideal) method of Polarized ^{3}He Ion Source



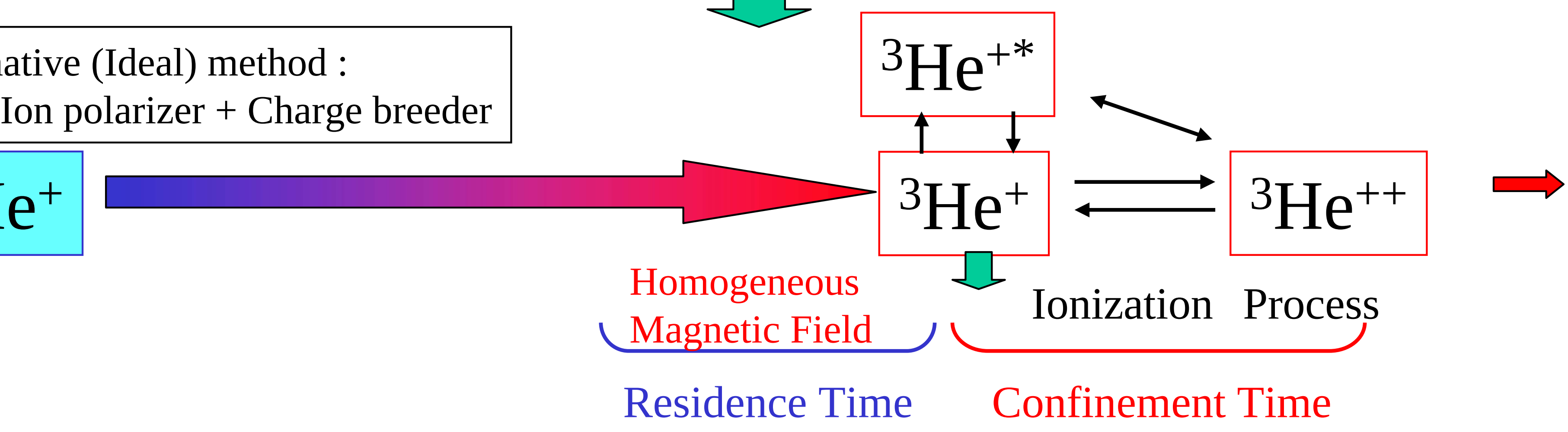
Depolarization due to

1. Ionization process
2. ESR (u-wave)
3. Relaxation

⇒ 3He+ polarize + 1 electron strip in ionizer

⇒ decrease the strip electron number

⇒ homogeneous magnetic field



$^3He^+$ Ion Polarizer + Ionizer

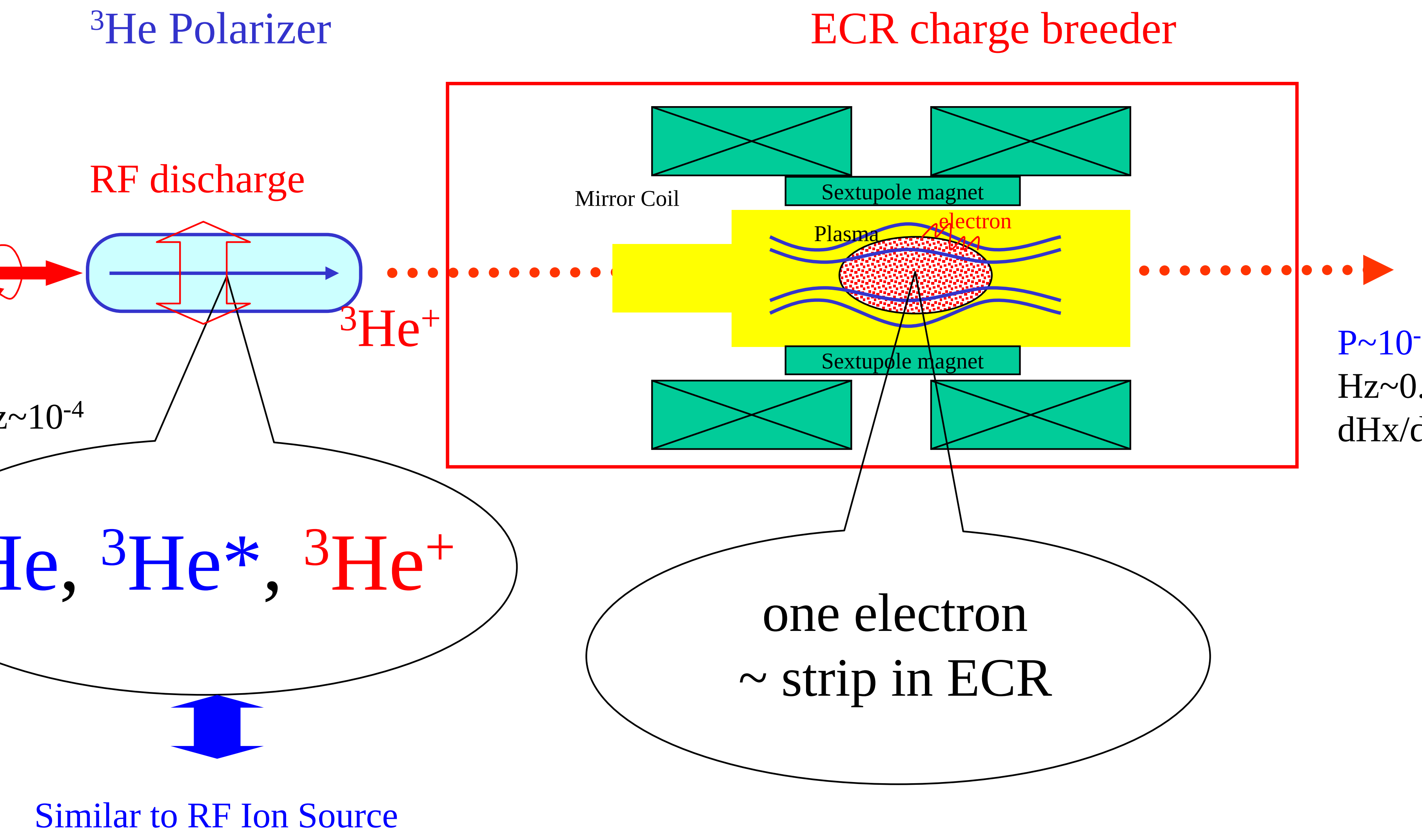
- Meta-Stability Exchange
- Spin Exchange
- Electron Pumping
- Others …

1. ECR charge breeder
2. EBIS ~ pulse beam, low intens
3. Acceleration and Strip with foi
4. Others …

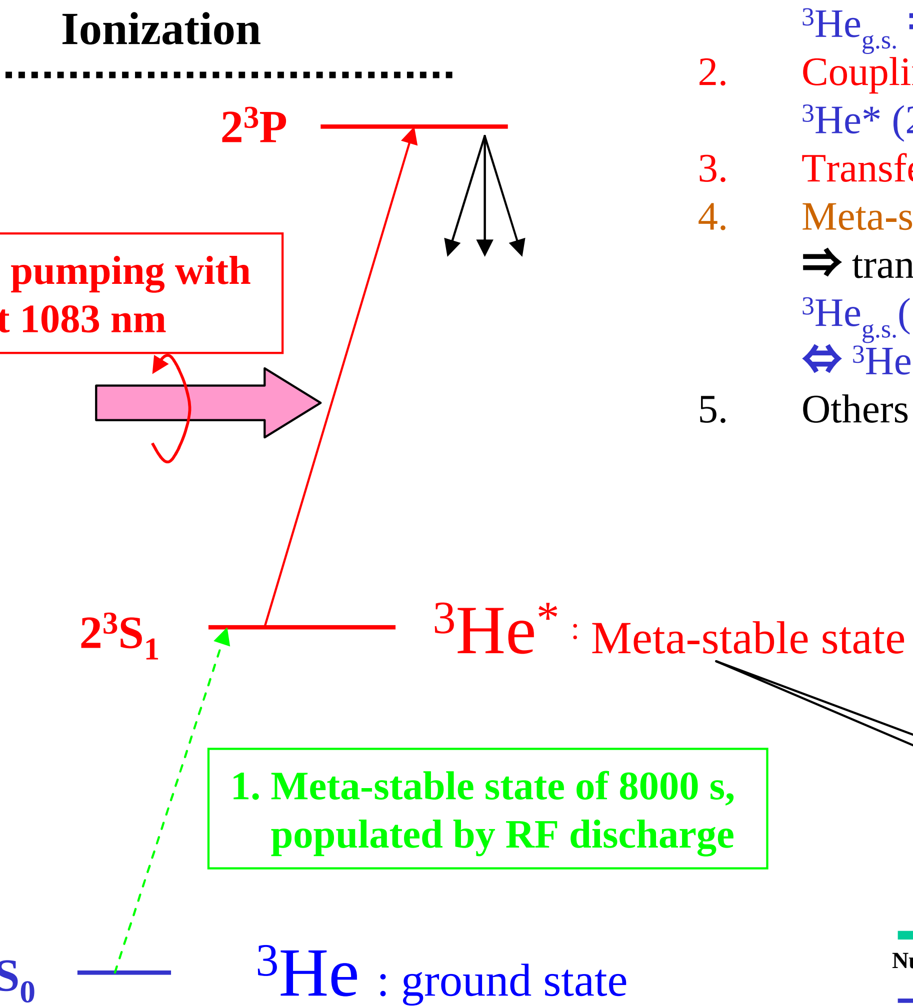
3He⁺ ion polarizer + ECR charge breeder

Based on the work at Rice Univ. ~ Phys. Rev. Lett. 20 (1968) 738

3He+ ion beam ~ Polarization : 5 %, Intensity : 4 uA

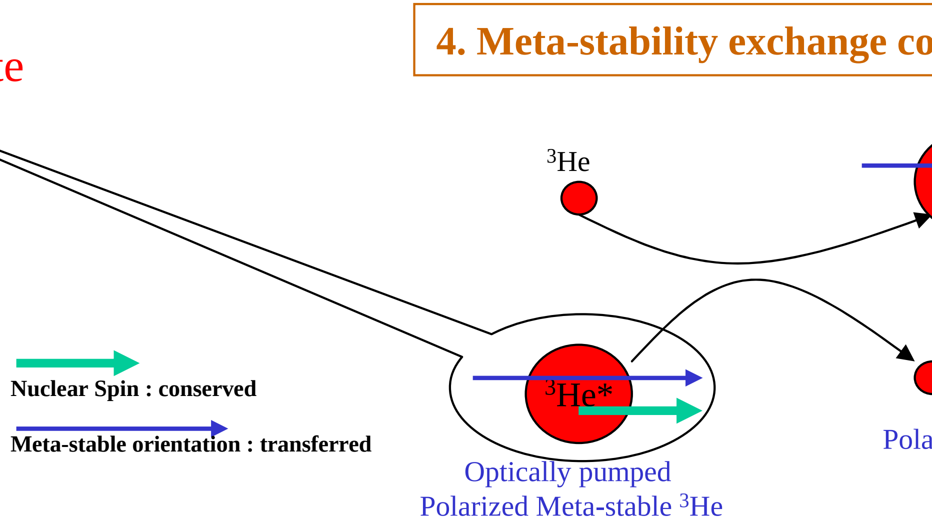


^{3}He polarization with direct optical pumping



Polarization production process :

1. Produce meta-stable ^{3}He atoms with RF discharge
   $^3He_{g.s.} \Rightarrow {}^3He\ (2^3S_1)$
2. Coupling to the radiation field with optical pumping
   $^3He^*\ (2^3S_1) \Leftrightarrow {}^3He\ (2^3P_0)$ ~ atom polarization
3. Transfer of polarization to the nucleus with hyperfine coupling
4. Meta-stability exchange collisions
   $\Rightarrow$ transfer of nuclear polarization to the ground state
   $^3He_{g.s.}(1^1S_0\ , m_F=-1/2) + {}^3He^*(2^3S_1\ , m'_F)$
   $\Leftrightarrow {}^3He^*(2^3S_1, m'_F-1) + {}^3He_{g.s.}(1^1S_0\ , m_F=1/2)$
5. Others



3He+ Ion Production in pumping cell

Pumping Cell

^3He, $^3He^*$, $^3He^+$

1 Torr

	3He(glound state)	3He*(meta-stable)	3He+(ion)
nsity cm^{-3}	10^{16}	10^{10}	? (Production rate = 10^{13} /s)
hange time	1 s	10^{-6} s	10^{-6} s

Ionization

$$^3He + e^- \rightarrow {}^3He^+ + 2e^- \qquad \frac{d\,^3He^+}{dt} \approx 9\times10^{-10} N_{He} n_e (> 24.5$$

ative Ionization

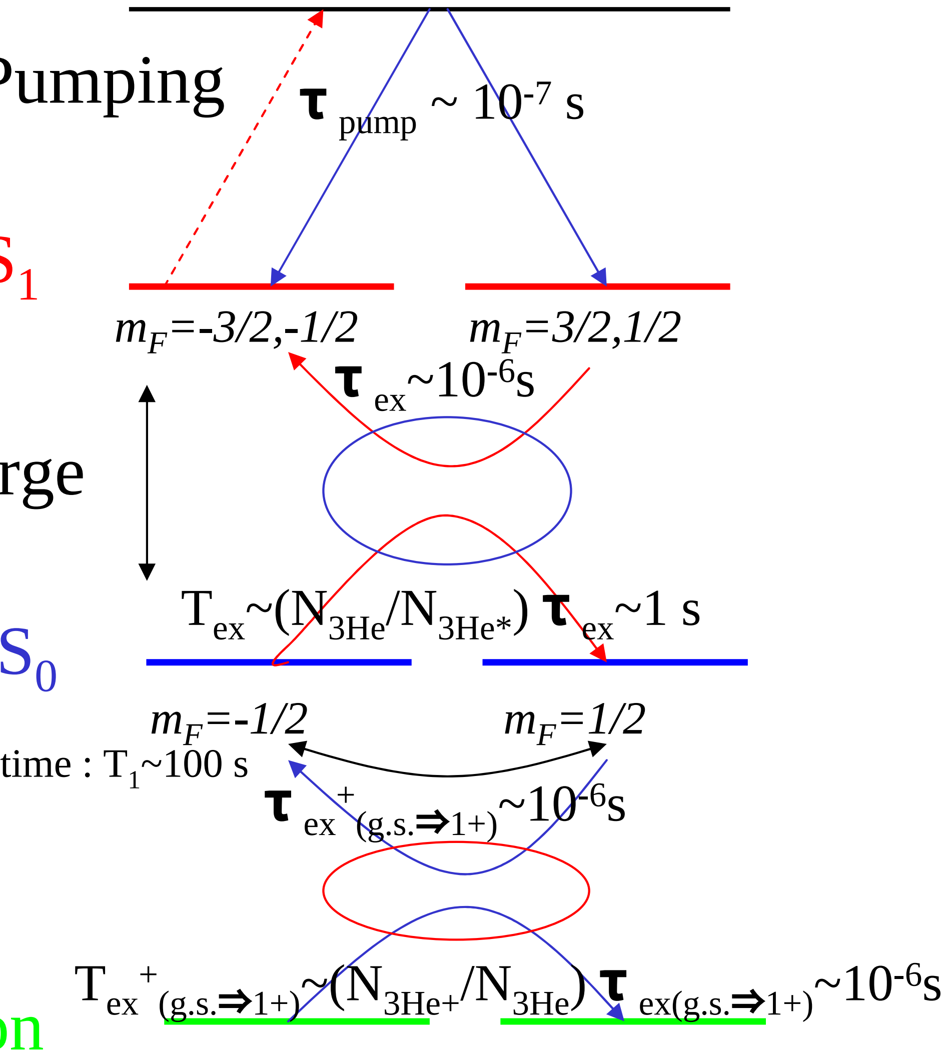
σ ~ 10^{-18}

$$^3He^* + e^- \rightarrow {}^3He^+ + 2e^- \qquad \frac{d\,^3He^+}{dt} \approx 3.2\times10^3 n_e (> 4.7eV)$$

stable collisions

$$^3He^* + {}^3He^* \rightarrow {}^3He^+ + {}^3He + e^- \qquad \frac{d\,^3He^+}{dt} \approx \sigma\times v\times(N_M)^2 \approx 1.3\times$$

Meta-stable collision cross section : **σ** ~ 10^{-14} cm^2 : large



Meta-stability exchange collisi

$\sigma \sim 7 \times 10^{-16}\ cm^2$

$${}^3\vec{He}^{*} + {}^3He \rightarrow {}^3\vec{He} + {}^3$$

Electron transfer reaction ~ larg

$\sigma \sim 10^{-15}\ cm^2$

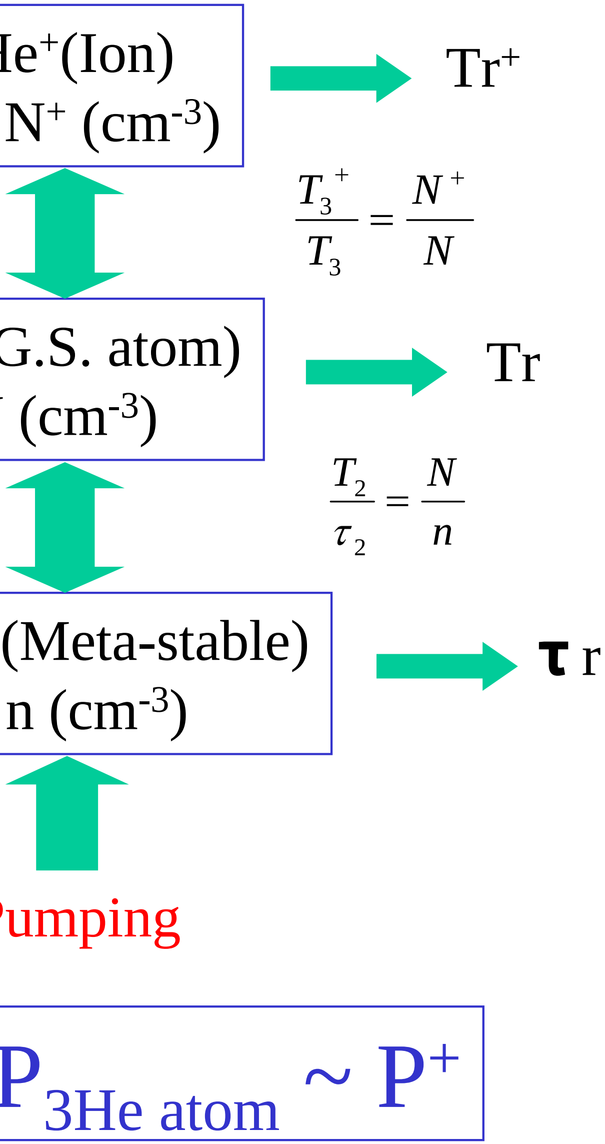
$${}^3\vec{He} + {}^3He^{+} \rightarrow {}^3\vec{He}^{+} +$$

$$\tau_{ex(g.s.\rightarrow 1+)} \sim 1 \big/ \sigma \rho_{{}^3He} v \sim 10$$

Hierarchy of time constants :

$\tau_{pump} << \tau_{ex} << T_{ex} << T1 >> \tau_{ex}^{+} \sim$

Polarization of 3He+ ions



$$
\begin{cases}
\dfrac{dP^{+}}{dt} = \dfrac{P - P^{+}}{T_3^{+}} - \dfrac{P^{+}}{T_r^{+}} \\[2ex]
\dfrac{dP}{dt} = \dfrac{P^{*} - P}{T_2} - \dfrac{P}{T_r} + \dfrac{P^{+} - P}{T_3} \\[2ex]
\dfrac{dP^{*}}{dt} = \dfrac{1 - P^{*}}{\tau_P} - \dfrac{P^{*}}{\tau_r} + \dfrac{P - P^{*}}{\tau_2}
\end{cases}
$$

$$
\begin{cases}
P^{+} = \dfrac{T_r^{+}}{T_r^{+} + T_3^{+}} P \\[2ex]
P = \dfrac{1}{1 + \dfrac{T_2}{T_r} + \dfrac{T_2}{T_3} \dfrac{T_3^{+}}{T_r^{+} + T_3^{+}}} P^{*} \\[2ex]
P^{*} = [1 + \dfrac{\tau_p}{\tau_r} + \dfrac{\tau_p}{\tau_2}(1 - 1 + \dfrac{T_2}{T_r} + \dfrac{T_2}{T_3} \dfrac{T_3^{+}}{T_r^{+} + T_3^{+}})]^{-1}
\end{cases}
$$

Pumping — Degradation of polarization

Pumping term >> Degradation term ⇒

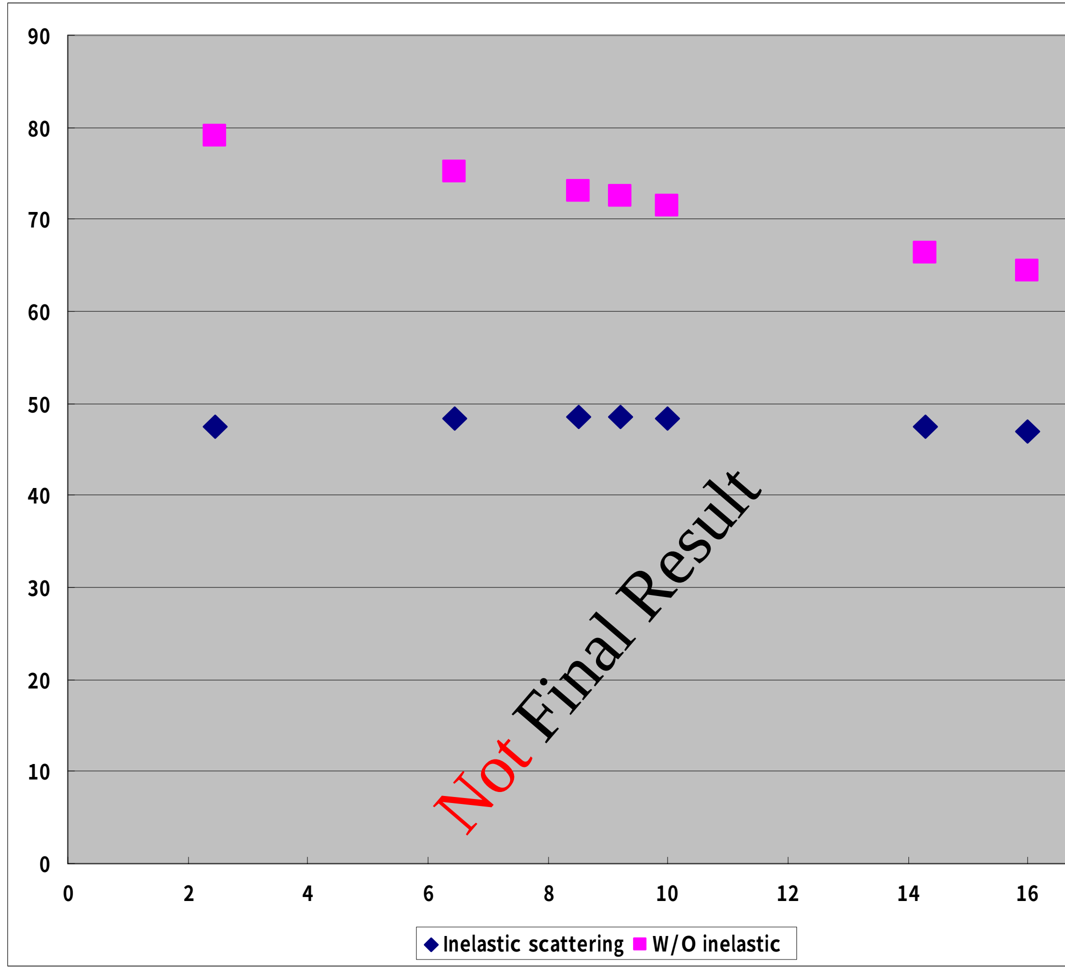
1. $T_2/T_r << 1$ ~ experimentally OK
2. $T_2/T_3 <<1$ or $Tr^{+}/T3^{+} >>1$

⇒ relaxation time : Tr+ >> T3+

Expected Polarization of extracted 3He++ ion beam

n polarization ~ 80 %
onization process

ly rough estimation !!
e++ ~ 50 % polarization
polarization due to
lastic scattering ~ large contribution
tailed MC study ~ necessary
polarization mechanism
- to inelastic scattering
ners

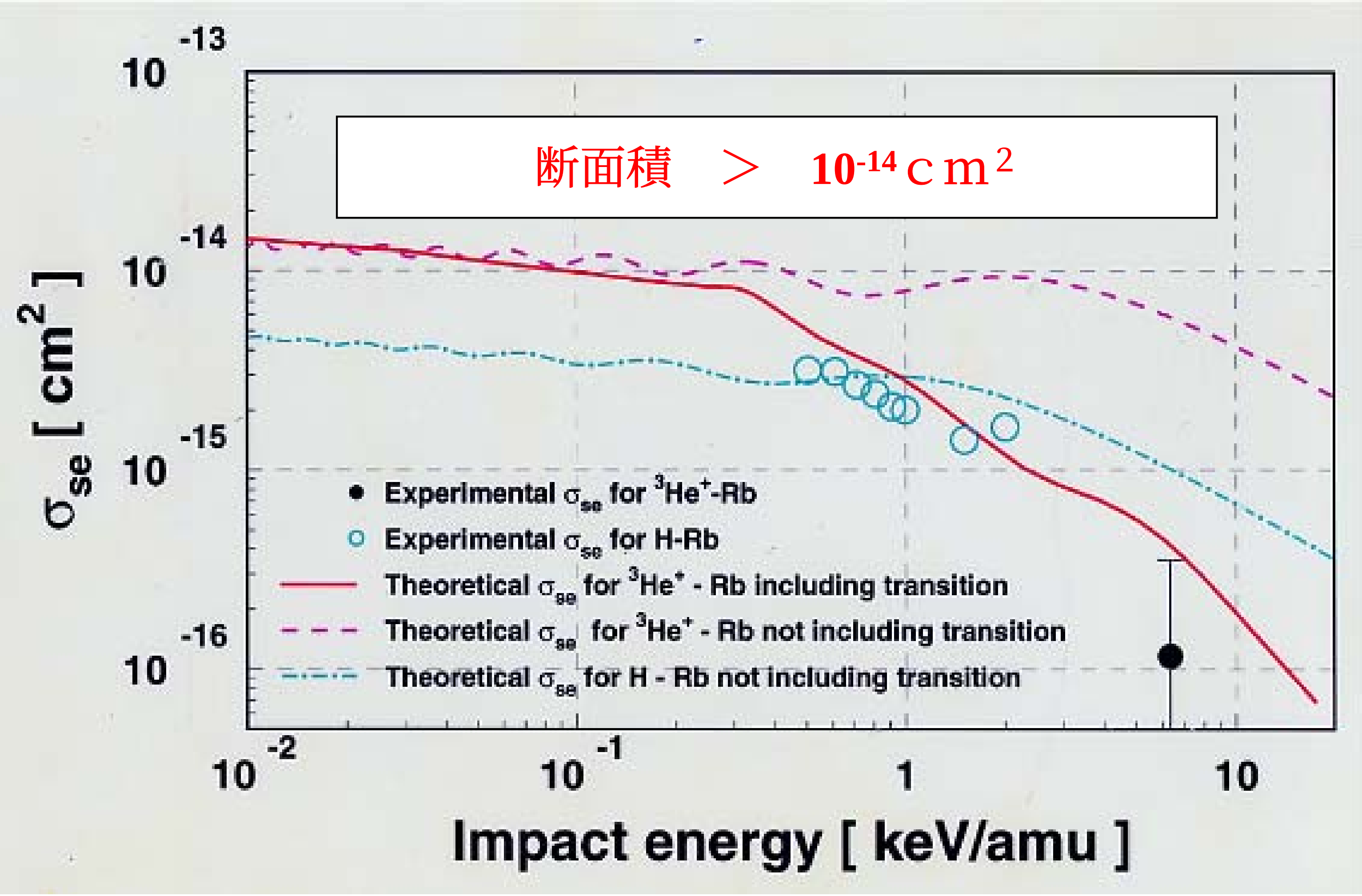


What should be checked

1. Polarization of 3He+ ion in the pumping cell
2. Relaxation time of polarized 3He+ ions in the pumping cell
3. Density of 3He+ ions in the cell
4. Depolarization of 3He+ ions in ECR charge breeder
5. Beam intensity

スピン交換型偏極^{3}Heイオン源

$$^3He^+ + \overrightarrow{Rb} \Rightarrow \overrightarrow{^3He^+} + Rb$$

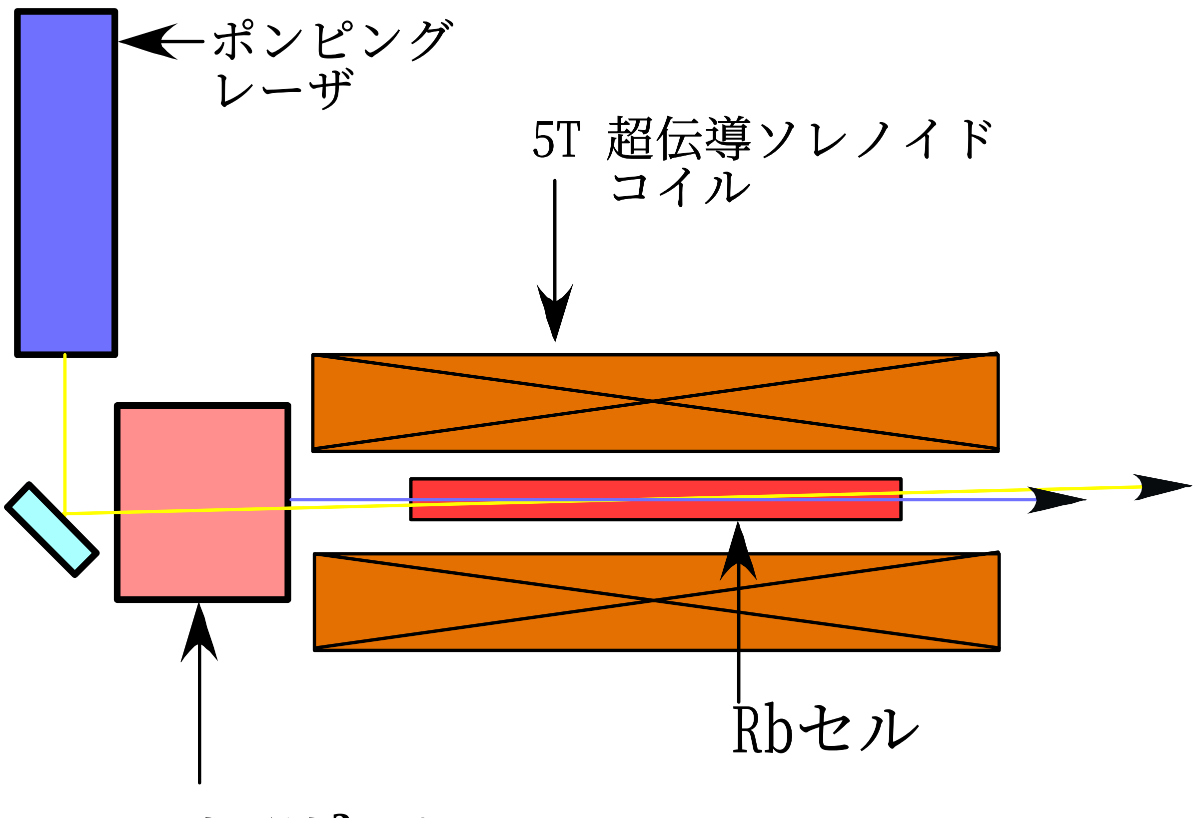


：１）大電流　　I($^3He^+$) ～１mA以上

２）$^3He^+$核偏極度　８０％以上

３)　$^6Li^+$偏極にも用いられる。

（スピン交換断面積は$^3He^+$より大きい？）



Estimated Polarization and Intensity at present

	SEPIS	ECR with 3He	3He+ + Charge breeder	3He+ + Ideal Ionizer (acceleration/foil)	I
olarization	--	80 %	80 %	80 %	
polarization	80 %	--	80 % Should be checked	80 % Should be checked	
Intensity	100 uA	--	4 uA@Rice Univ. Should be estimated	4 uA@Rice Univ. Should be estimated	
+ polarization		20 % ~ 30 %	~ 50 % (?)	80 %	
+ Intensity		1~100 uA ?	?	?	
ruction Time					

Summary

ity study ~ continue
Carlo simulation for feasibility study and design work
of 3He polarizer + dedicated Ionizer

nental feasibility check : Unknown number
onfinement Time in ECR : 6Li development ~ RIKEN experiment ~ 2003
epolarization due to ECR ionizer : detailed plan ~ until next meeting ~ 2004
nization efficiency ~ μ wave power : RCNP ~ 2003/2004
SR effects ~ μ wave power : HIPIS@RCNP ~ 2003/2004
larization of 3He+ ions : discussion with ENS/Mainz group

ck everything into LOI/TDR

e
PAC on Nov-10 ~ Polarized 6Li ion source , depolarization study of 3He
03 – 2004 ~ feasibility check, design work
PAC in 2004 ~ LOI , judgment which method is best for polarized 3He ion source
dget in 2004 ~ 科研費等、外部資金
onstruction ~ start in 2004 or 2005 if P-PAC, budget ~ approved
me line ~ 2006

Experimental Feasibility Check

What should be checked experimentally and with simulation (if possible)

1. **Depolarization in the ionizer** : **inject polarized 3He gas supplied by (1) Polarized Target at RCNP or (2) LKB, Paris**
2. **Ionization efficiency** : **inject 4He gas / detect 2+ ions**
3. **Detailed study of ionization mechanism**

Mainz to Sheffield in 2001
box
vessel
~ 50 hours (reproducibly ?)

Feasibility check experiment

Polarized ^{3}He atoms → **ECR ionizer : Ionization ~ complicated multi-step** → **Polarized $^3He^{2+}$ ion** → **Polarimet**

NMR
(Polarization: P_i, Intensity: I_i)

(Polarization: P_f, In

$$P_f = F_P(P_i, Spec(ECR), Others\ ...) = \varepsilon(P) \times P_i$$

$$I_f = F_I(I_i, Sprc(ECR), Others\ ...) = \varepsilon(I) \times I_i$$

Theoretical / Simulation evaluation

Present Status of Polarized Nuclear Beam

Polarized 3He ion source ~ feasibility study : still continued, in progress
(1) Independent feasibility study (Sakemi / Prof. Tanaka)
(2) Prof. Tanaka ~ publication NIM ~ discuss the difficulty of this method
(3) Still no consensus in the collaboration
(4) Nice idea for high polarization ~ needed ! ~ alternative method

Polarized 6Li ion source (Dr.Tamii) ~ feasibility check : in progress / almost completed
(1) Detailed study ~ reported in the previous meeting , 6Li polarization ~ 70~80 %
(2) Physics ~ workshop on 0- states in Aug.
(3) LOI writing ~ in progress / PPAC on 10-Nov / Budget
(4) Construction in part ~ will be started after the discussion at P-PAC

Others