Feasibility Check / How to test

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**

livered from Mainz to Sheffield in 2001
agnetized spin box
ousing a glass vessel
elaxation time ~ 50 hours (reproducibly ?)

Feasibility check experiment

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

(Polarization: P_i, Intensity: I_i) — **NMR**

(Polarization: P_f, Intensity: I_f

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

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

Theoretical / Simulation evaluation

Equipments	Status	Cost	Date	Comments	Contact
Polarized ^{3}He atoms	Cell for transfer design / LKB, Paris/Mainz		Ssp	m.e. optical pumping	Prof. Tastevan
Polarized ^{3}He atoms	Shimizu Target at RCNP			Spin exchange	
ECR Ionizer	Exists : HIPIS			2.45GHz	
Connection to ECR	Need drawings etc… around ECR			Magnet for Holding field	
Polarimeter for atoms	NMR				
Polarimeter for ions	Beam course / When ?				
Readout/DAQ/Control	Should be prepared				
Feasibility test 1	Depolarization		2003 end	BPAC / Possible schedule to install 3He cell etc..	
Feasibility test 2	Ion collection efficiency with 4He/6Li		2003 end	BPAC / What should be prepared ?	

Critical Field to keep polarization

Hyper Fine Interaction

$$H' = aI \cdot J - g_J \mu_B J \cdot B - g_I \mu_I I \cdot B$$

$$a = \frac{\mu_0}{4\pi}\frac{16\pi}{3}\mu_B \frac{u_I}{I}|\psi(0)|^2 = \frac{\mu_0}{4\pi} 4 g_I \mu_B \mu_I \frac{1}{J(J+1)(2L+1)} \frac{Z^3}{a_\mu{}^3 n^3}$$

$$h\nu = E(F = I + J) - E(F = I - J) = a$$

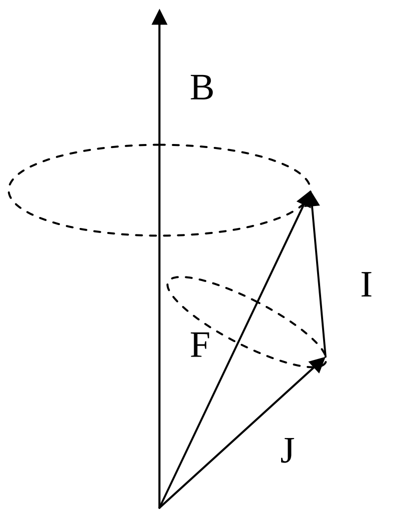
Critical field to keep polarization :

$$Bc = \frac{h\nu}{g_J u_B - g_I u_I} \approx \frac{a}{2u_B} \propto Z^3$$

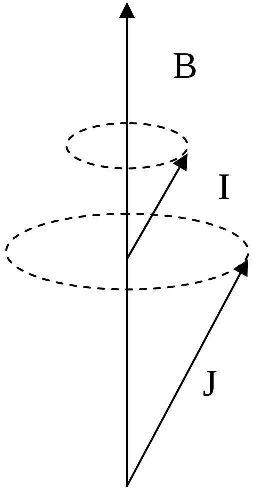
	ν (MHz)	B_c (Gauss)
^1H	1422.6	508.2
$^3He^+$	8669.4	3097.1
$^6Li^{2+}$	8479.2	3029.1

ECR ion source
2.45 GHz ~ 875 Gauss
10 HGz ~ 3571 Gauss

Weak magnetic field

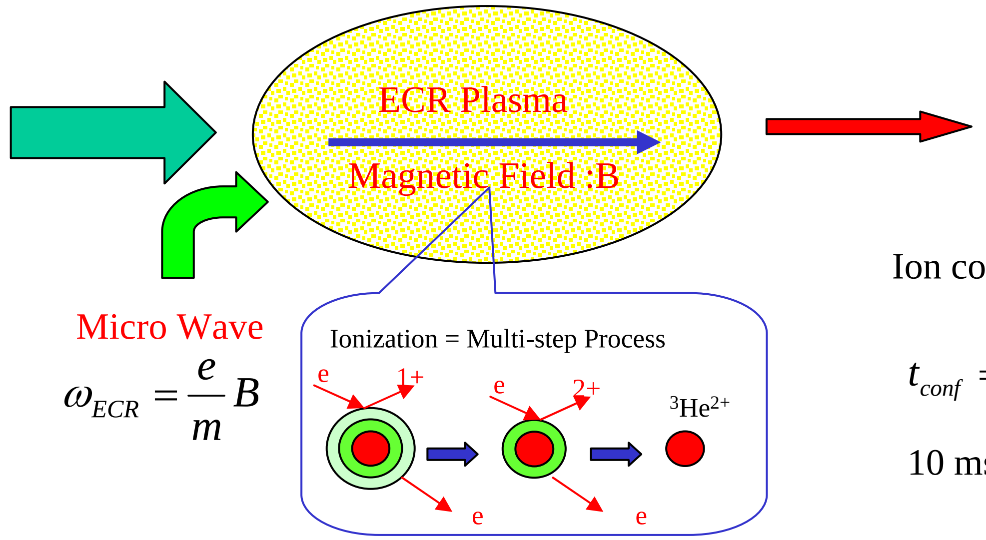


Strong magnetic field



Depolarization Mechanism

Polarized 3He atoms



Polarized $3He^{++}$ Ions

Ion confinement time : t_{conf}

$$t_{conf} = 10^{-2}\left(\frac{f_{ECR}}{10}\right)^{1.5} \text{(sec)}$$

10 msec at 10 GHz (ANL)

1. Ionization process / Electron Capture and FI/HFI
   - (1) $3He \rightarrow 3He^{+} + e^{-}$: depolarization with HFI
   - (2) $3He^{+} \rightarrow 3He^{++} + e^{-}$: no depolarization
   - (3) $3He^{++} + e^{-} \rightarrow 3He^{+}$: depolarization with HFI
   - (4) $3He^{++} + e^{-} \rightarrow 3He^{+*} \rightarrow 3He^{+} + h\nu$: depolarization due to HF (LS coupling)

2. Spin Flip due to Electron Spin Resonance (ESR) and HFI
   - (1) $3He^{+} + \mu$ wave → ESR transition ~ electron spin flip ~ HFI : only ECR resonance zone

Electron Cyclotron Resonance :

$$\omega_{ECR} = \frac{e}{m}B$$

Electron Spin Resonance :

$$\omega_{ESR} = \frac{g_s}{2}\frac{e}{m}B = \frac{e}{m}B = \omega_{ECR}$$

3. Others

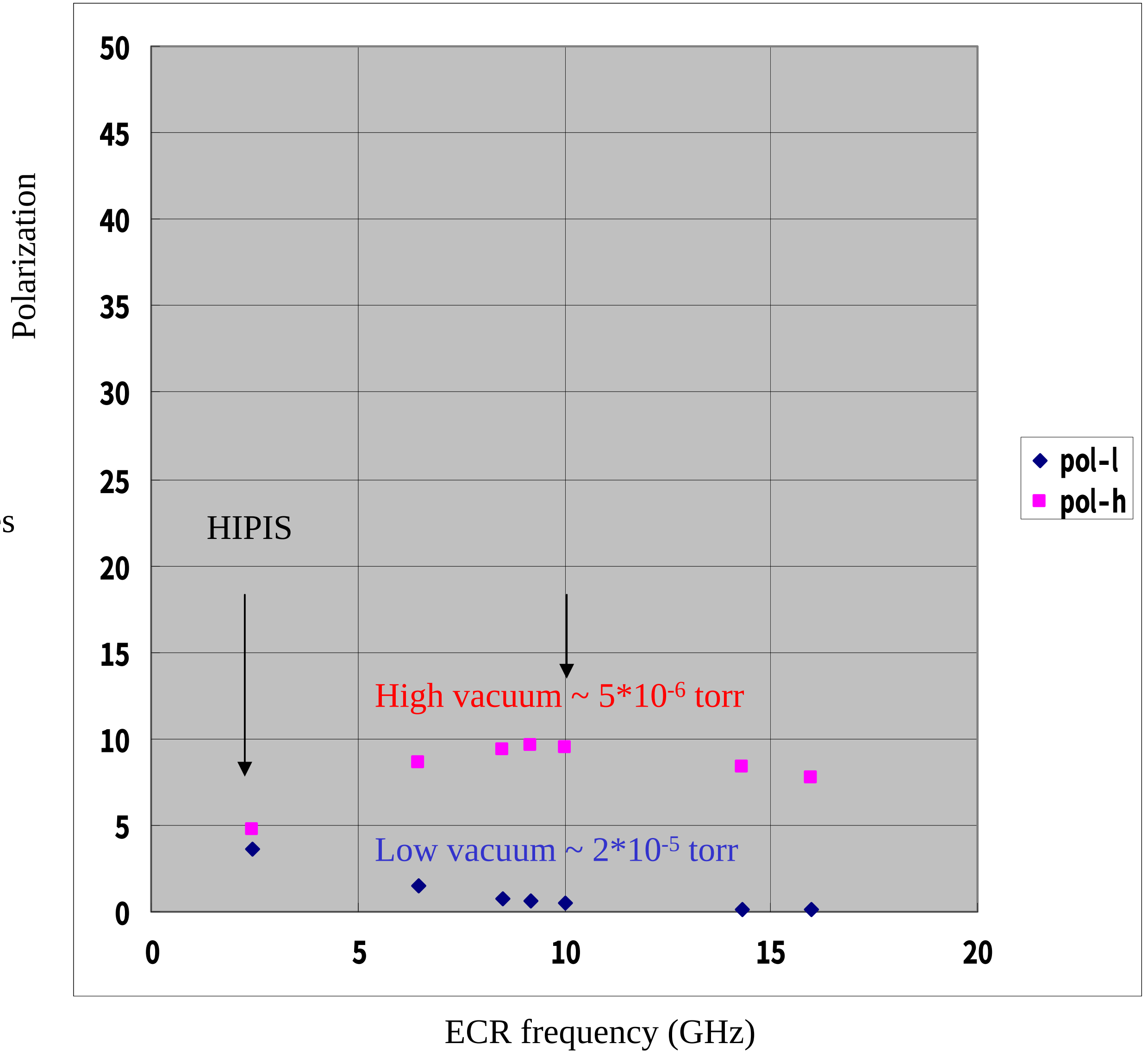
Results on depolarization (1) : full effects

ncludes depolarization due to :
1. Ionization / capture process
2. Spin flip with ESR and HFI

Occurred any place in ECR plasma

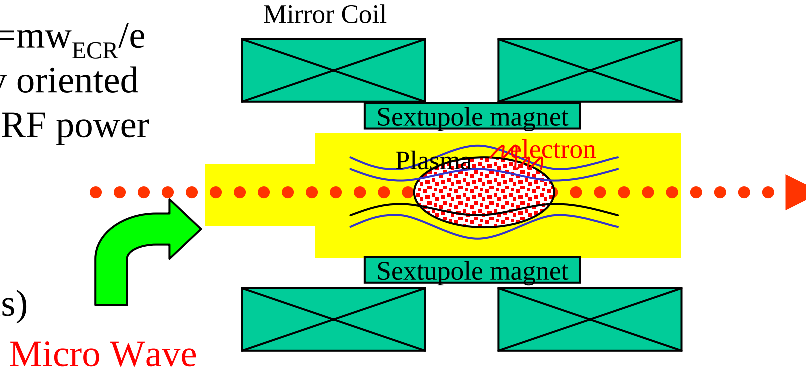
Can be seen
1. High ECR frequency
   ~ confinement time ~ long
   ~ ionization process : many times
2. Low vacuum
   ~ electron capture
   ~ low polarization
3. Others

Polarized 3He atoms ~ polarization : 50 %

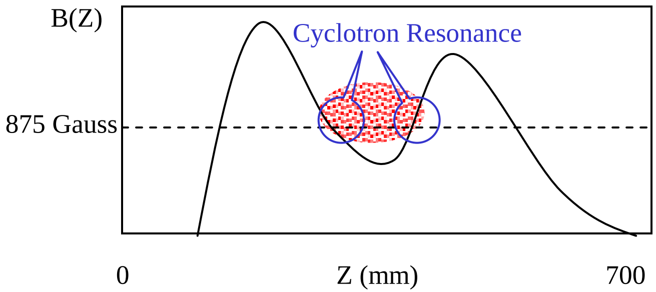


What should be considered carefully

1. Spin flip due to ESR
   (1) ESR ~ only at ECR resonance field region ~ at $B=B_0=mw_{ECR}/e$
   (2) RF magnetic field : B_1 due to micro wave ~ randomly oriented
   (3) $B_1^{max} = (2u_0 s/c)^{1/2}$: s~ pointing vector for microwave RF power
   (4) B1 ~ very small
   (5) One Larmor precession of the electron in B1 :
   $(\gamma_J B_1)^{-1}$ ~ μ sec
   (6) Time to pass Resonance zone (10 um / 10^5 cm/s ~ 1 ns)
   (7) Too short to flip the spin of electron
   (8) Can be neglected



$$\omega_{ECR} = \frac{e}{m} B$$



2. Confinement time ~ Depolarization in Ionization Process
3. Polarized He gas transfer from ECR Loss Cone ~ confinement time
4. Others

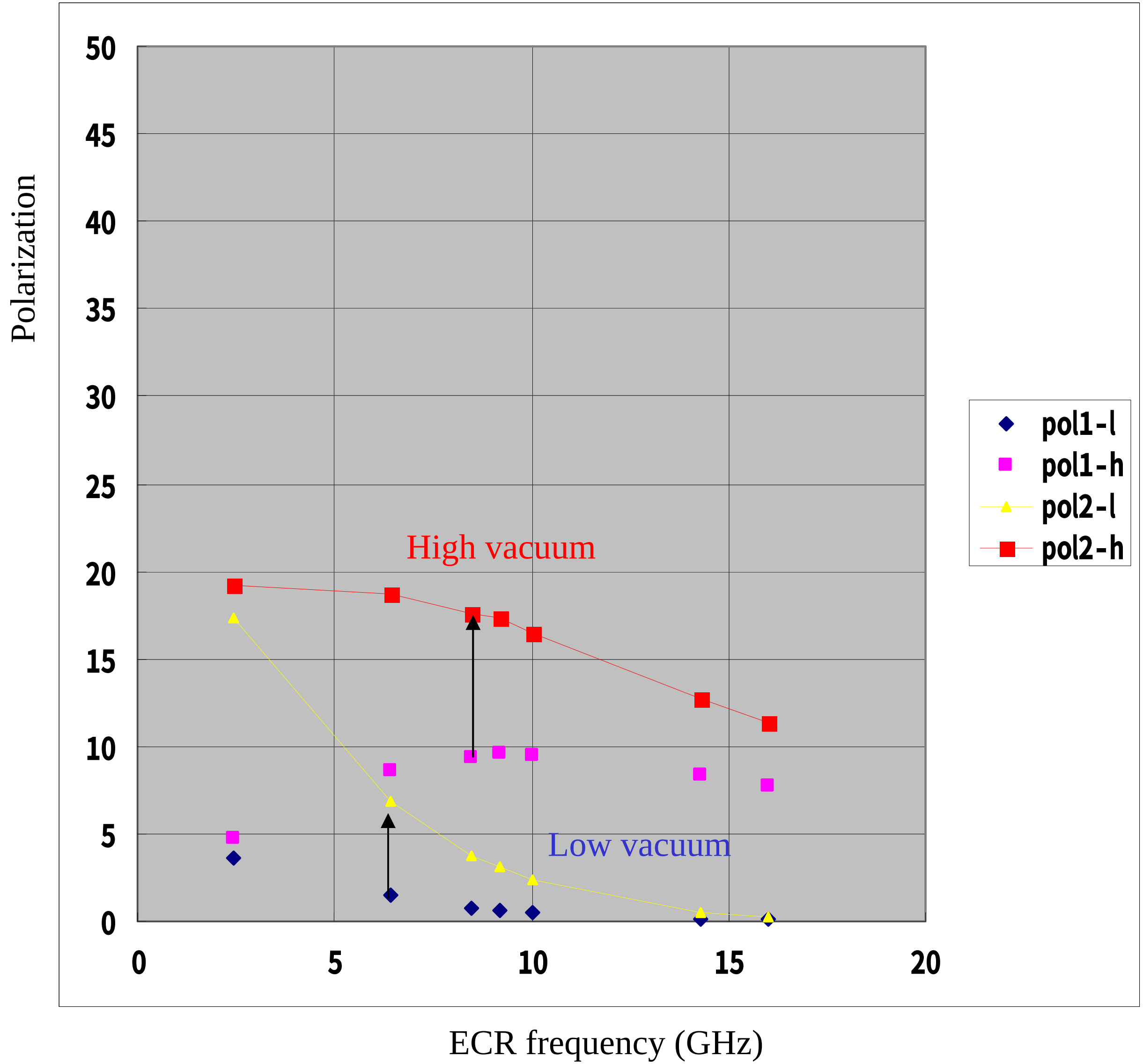
Results on depolarization (2)

Remove ESR effects
Include ionization process

Recover polarization thanks to
ESR effects neglect

High ECR frequency
~ long confinement time
~ dominant process = ionization

Polarized 3He atoms ~ polarization : 50 %



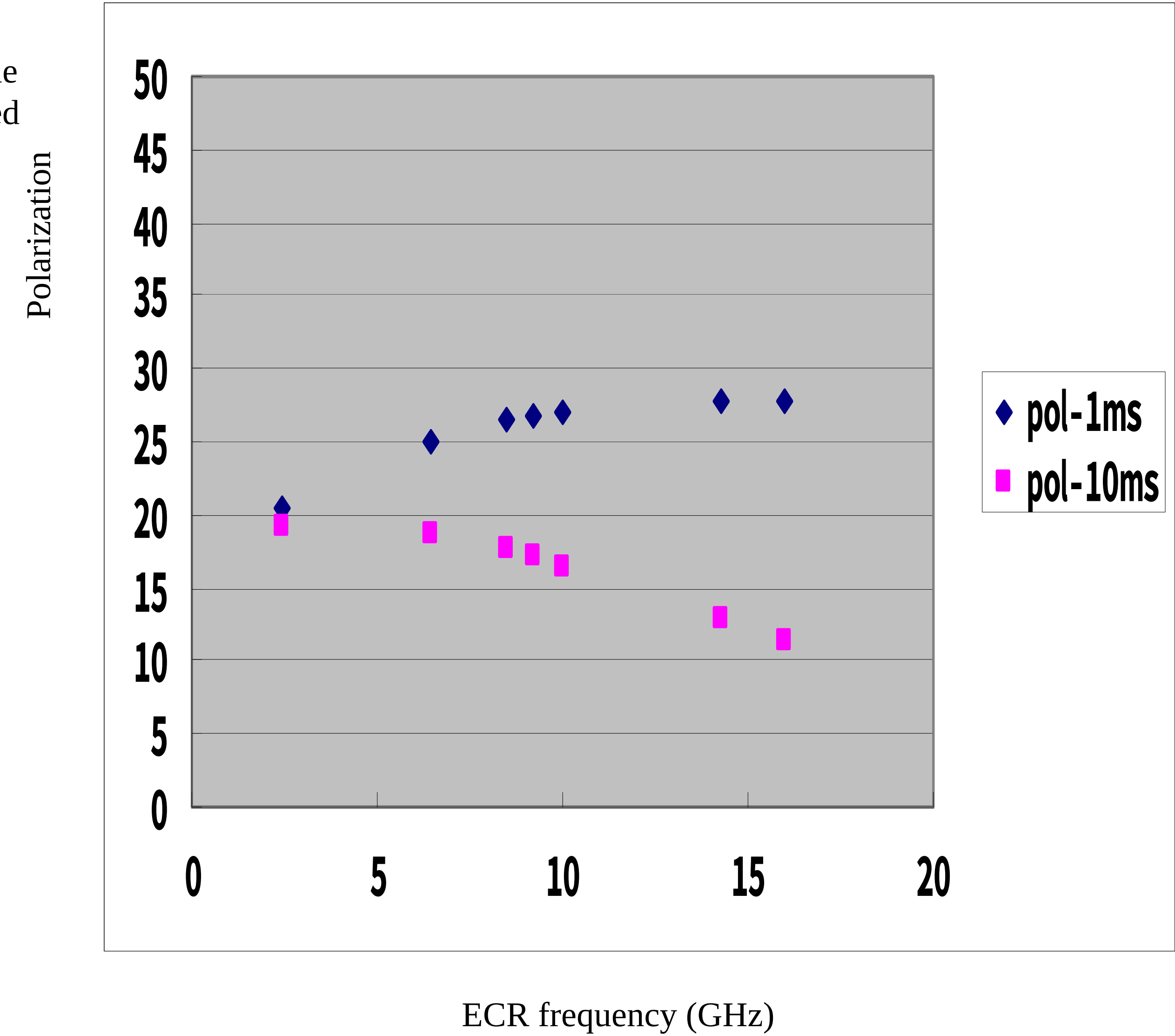
Results on depolarization (3)

Polarized 3He atoms ~ polarization : 50 %

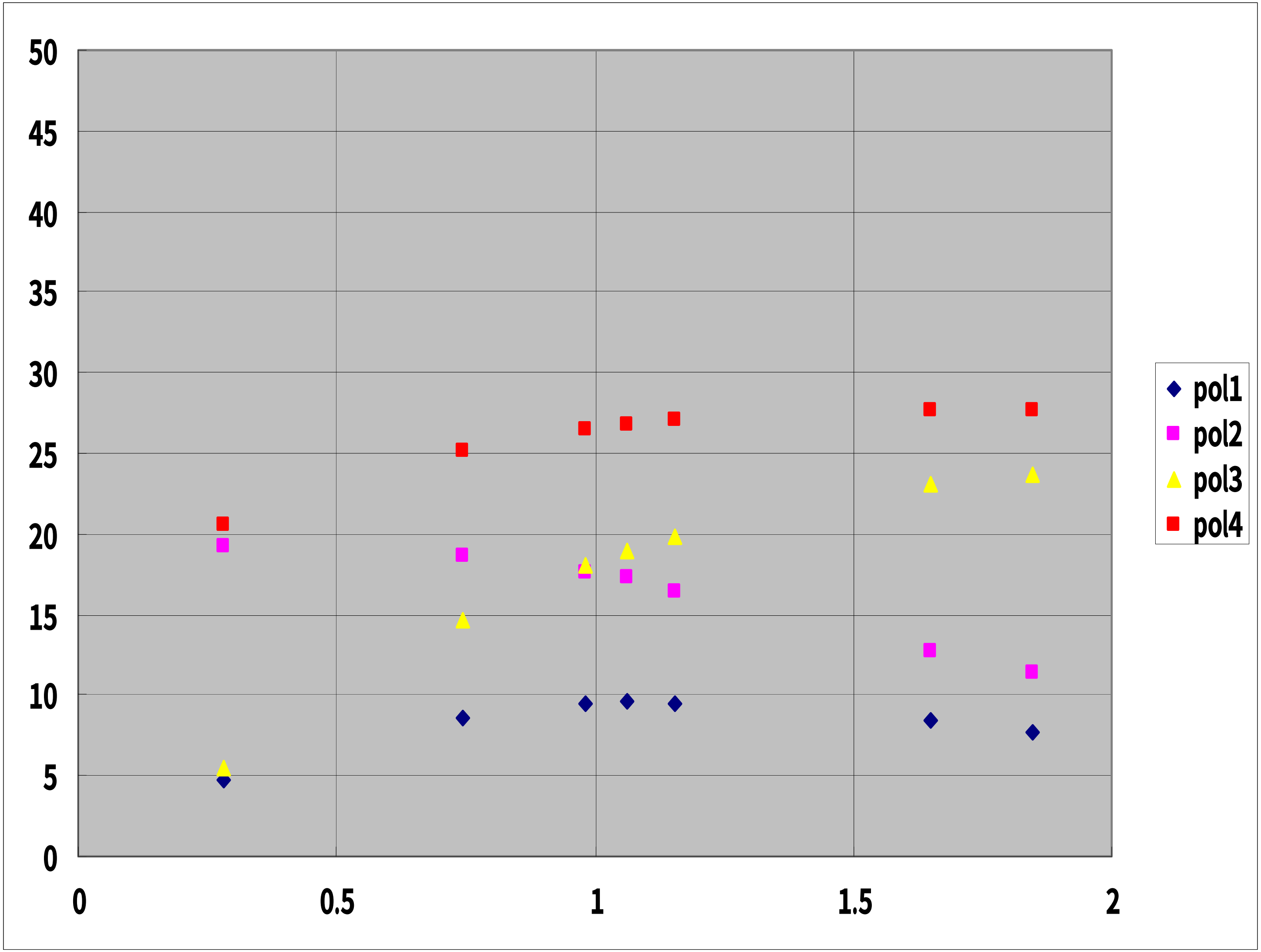
omparison
Confinement time ~ 1 msec : blue
Confinement time ~ 10 msec : red

Without ESR effects
High vacuum

ossible to realize high polarization
ith reduction of confinement time
y the adjustment of mirror ratio of
CR ionizer …



Results (3)



What should be done Next

1. Understand the Depolarization mechanism
   (1) Consider / evaluate each depolarization process carefully
   (2) Polarization estimation obtained by existing ECR (HIPIS)

2. Idea to Overcome the depolarization
   (1) Straightforward ~ high polarization 3He atom + short confinement time = high polarization + low intensity
   (2) Nice Idea ….. ~ should be considered …

3. Preparation to measure the depolarization / feasibility test