16th International Toki Conference, December 5-8, 2006

Sensitivity study for the optimization of the viewing chord arrangement of the ITER poloidal polarimeter

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Acknowledgements
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Introduction

<Objectives>

·Plasma stability analyses
·Transport analyses
·Control and optimization of high performance operating mode

Measuring of the toroidal current profile (q profile)

Requirements for current profile measurements in ITER

spatial resolution	q(r) : a/20
temporal resolution	q(r):10 ms, r(q=1.5, 2)/a:10 ms, (q_{min})/a : 1 s

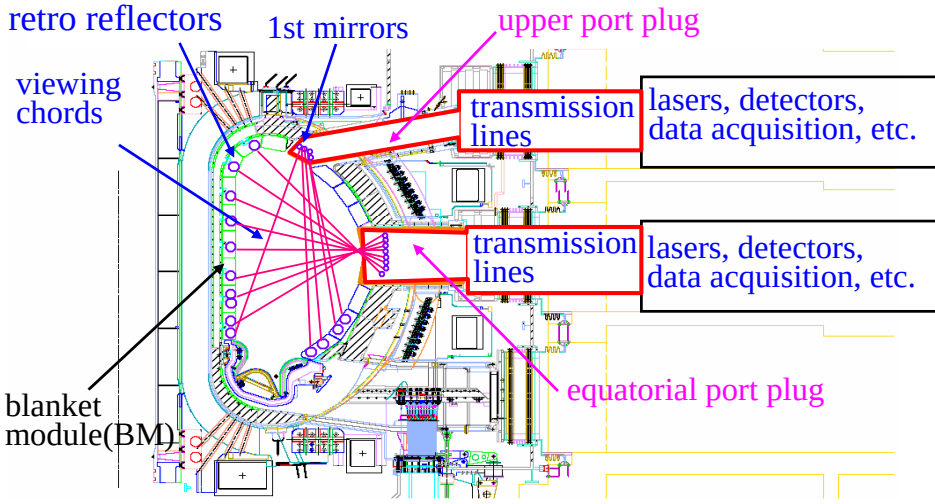
Diagnostic methods
Combination of
- *poloidal polarimeter* (core)
- MSE (peripheral)
- magnetic probes

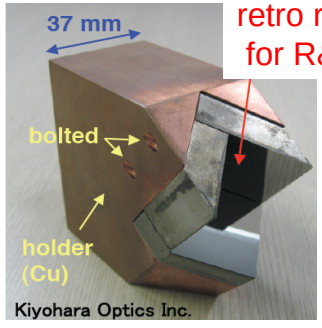
<Outline of the system>

-The far-infrared laser beams (λ~118μm) are launched from equatorial port and the upper port

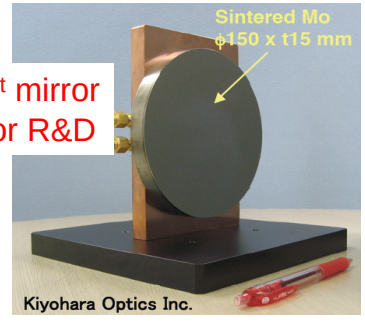
-The laser beams are reflected back along the same path by retroreflectors

-The Faraday rotation is induced by B_θ inside the plasma





retro reflector for R&D



1st mirror for R&D

<Optimization of the viewing chord geometry>

<Engineering constrains>

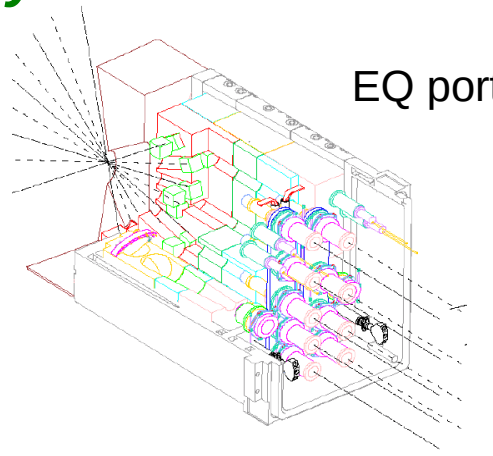
Number of chord is restricted by the geometric capacity of the port plugs[1]

→ EQ port : 9 chords, UP port : 6 chords

There is a possibility to be more reduced.

- shutters of 1st mirrors
- the beam steering function (if inside the port plug)

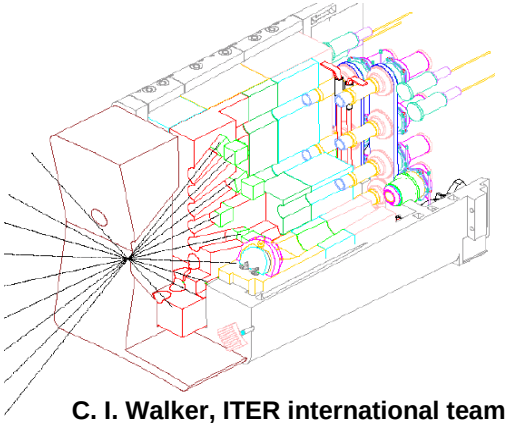
[1] A.J.H. Donné et al., Rev. Sci. Instrum, **75**, 4694 (2004).



EQ port

<Physics understandings>

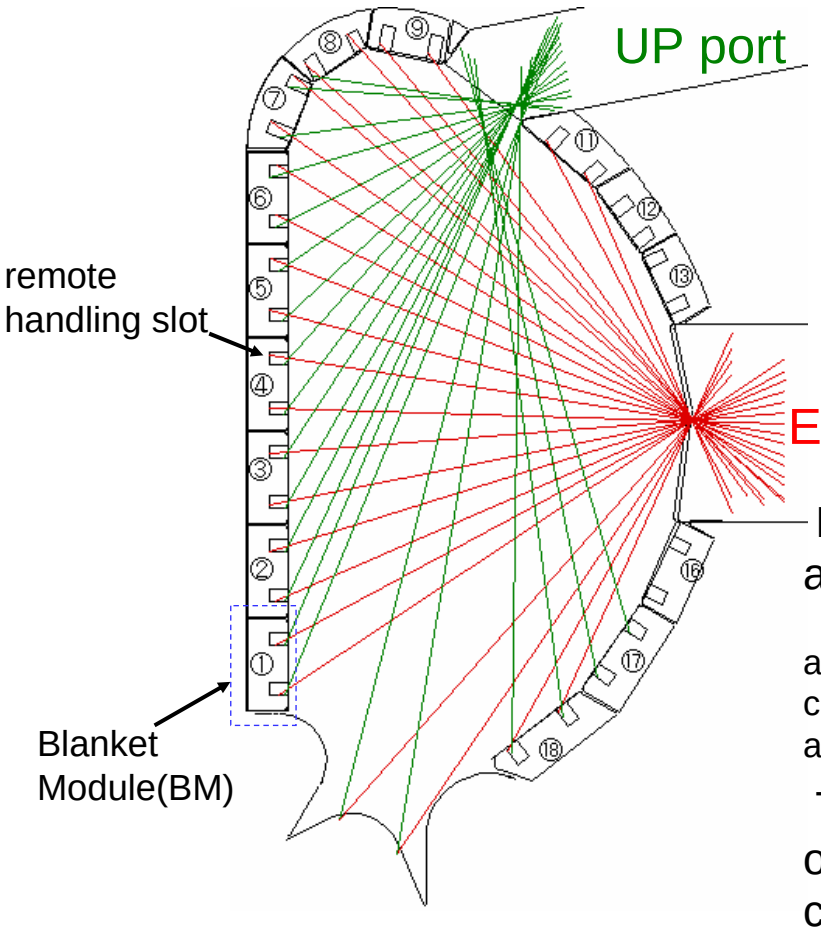
- The identification of the toroidal current profiles at ITER design scenarios and the change of the profile around the scenarios with the required resolution
- The detection of the advanced physical phenomena like
  - current hole
  - ELM (edge peaked current)
  - disruption



C. I. Walker, ITER international team

Purpose of the sensitivity study

<All candidates of viewing chords>



All candidates of viewing chords, which are based on
- -the remote handling slots in BMs (assumed as the positions of retroreflectors in this study)
- -possible 1st mirror positions

⇩

45 chords are picked up

It is very difficult to evaluate the reconstruction accuracy for all chord arrangement patterns.

(There are 10^6 patterns per one current profile even if apertures are fixed. If 3appertures patterns, 1000 toroidal current profiles, 0.1sec per one reconstruction then 13 years are needed)

Therefore we should restrict the combinations of chord arrangement patterns and toroidal current profiles based on the result of the sensitivity study.

<Method to optimize viewing chord geometry>

Sensitivity Study

- the understanding the sensitive viewing lines' positions to the change of the toroidal current profile around the estimated MHD equilibrium
- the physical mechanisms of the sensitivities should be also understood

restriction

toroidal current profiles

chord arrangement patterns

Equilibrium Reconstruction

the evaluation of the quantitative accuracy of the toroidal current profiles using a MHD equilibrium reconstruction method based on the knowledge given by the first step

<Calculation method>

Grad-Shafranov eq.

$$J_{tor} = \frac{-1}{\mu_0}\left(\frac{\partial}{\partial R}\frac{1}{R}\frac{\partial \psi}{\partial R} + \frac{\partial^2 \psi}{r \partial z^2}\right)$$

$$\left(= R\frac{dp}{d\psi} + \frac{\mu_0 f}{R}\frac{df}{d\psi}\right)$$

$\psi(r,z)$ ⇄ $B_r = \frac{-1}{r}\frac{\partial \psi}{\partial z}, B_z = \frac{\partial \psi}{\partial r}$

Faraday rotation angle

$$F = \frac{e^3 \lambda^2}{8\pi^2 \varepsilon_0 m_e^2 c^3}\int n_e B_{\parallel} dl$$

($_{\parallel}$ shows 'parallel to the viewing line')

- Cotton-Mouton ellipticity from poloidal polarimeter

$$CM = \frac{e^4 \lambda^3}{16\pi^3 \varepsilon_0 m_e^3 c}\int n_e B_{\perp}^2 dl$$

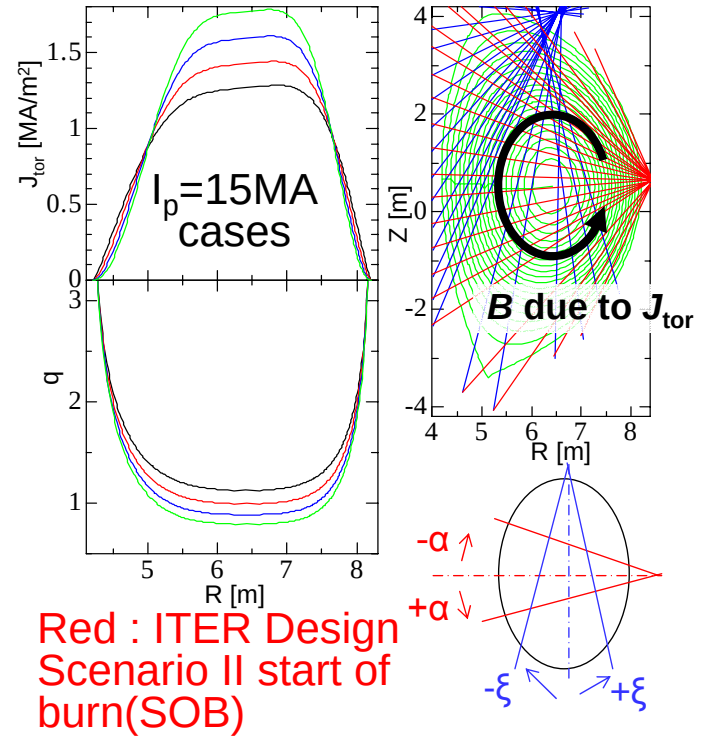
- Thomson Scattering
- Toroidal interferometer/polarimeter

← **sensitivity study**

← MHD equilibrium reconstruction

Sensitivity Study <normal shear>

Result of Equilibrium Code "TOSCA"[2]



Red : ITER Design Scenario II start of burn(SOB)

B_t=5.3T, β_p=0.65(fix), LCFS:fix, n_e:fix
I_p=11, 13 and 15MA

[2] H. Fujieda et al., JAERI-M 08-256, (JAERI, 1996).

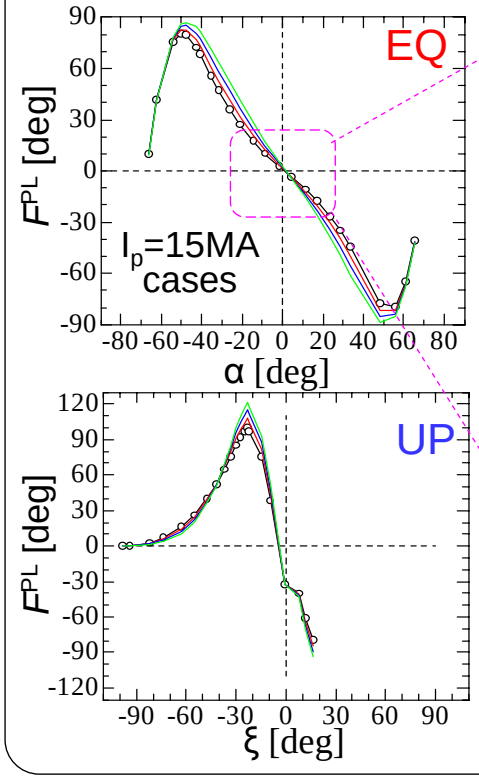
Calculation of the Faraday rotation angle

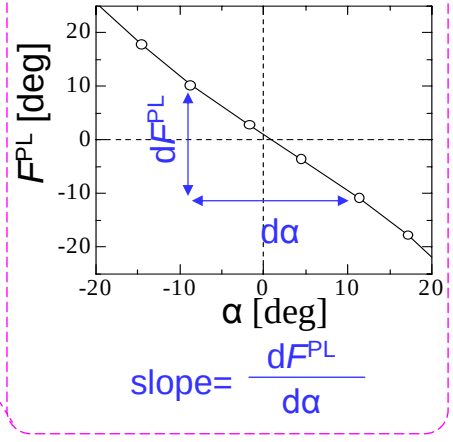
B^{EXT} effect is removed

$$F \propto \int n_e B_{||} dl = \int n_e B_{||}^{EXT} dl + \int n_e B_{||}^{PL} dl$$

$$B_{||} = B_{||}^{EXT} + B_{||}^{PL}$$

shown as "F^{PL}"

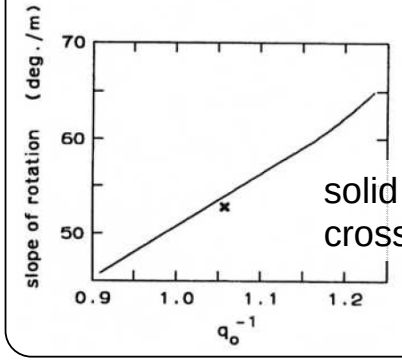




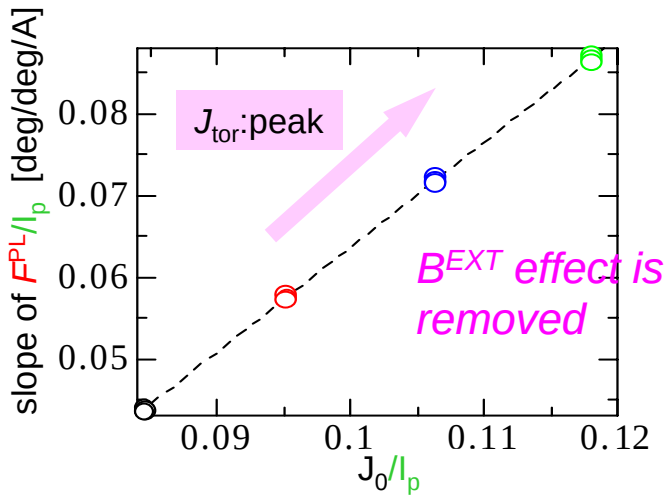
The definition of "slope"

<The previous works[3][4]>

The slope of the Faraday rotation depends stronger on the value of q_0 than on the toroidal current profile.



solid line: I_p scan, profile fix
cross mark: profile change



- Slope and q_0 include B^{EXT} effect
- Does this relation have the enough information of the J_{tor}? (not only B^{EXT} effect?)

*It can be said **with good reliability** that the central viewing chords of the EQ port are sensitive to the J_0.*

[3]A.J.H. Donné et al., in *Diagnostics for Experimental Thermonuclear Fusion Reactors* ***2***, edited by P. E. Stott et al. (Plenum, New York, 1998) p.203.
[4]C. Nieswand, in same as above, p.213.

Sensitivity Study <finite beta effect>

Bt=5.3T, I_p=15MA, LCFS:fix

β_p=0.05 (β_N=0.2)

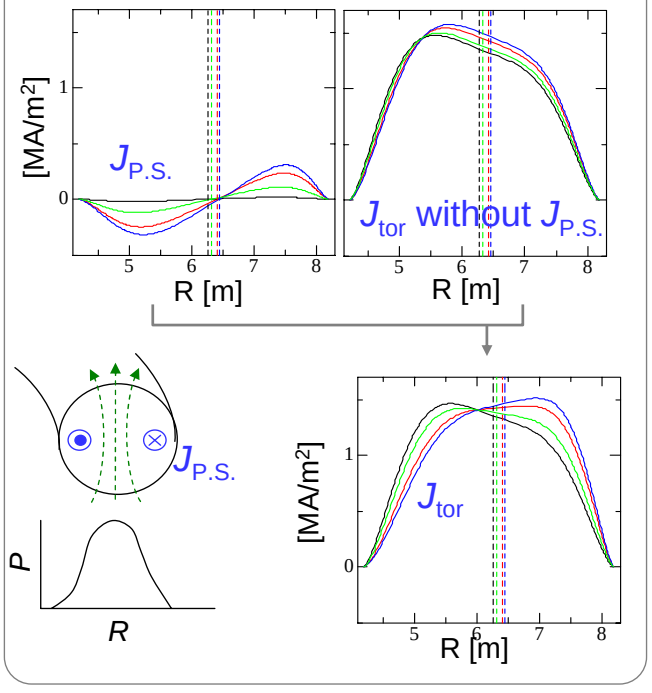
β_p=0.3 (β_N=0.8)

β_p=0.65 (β_N=1.8), Design Scenario II (SOB)

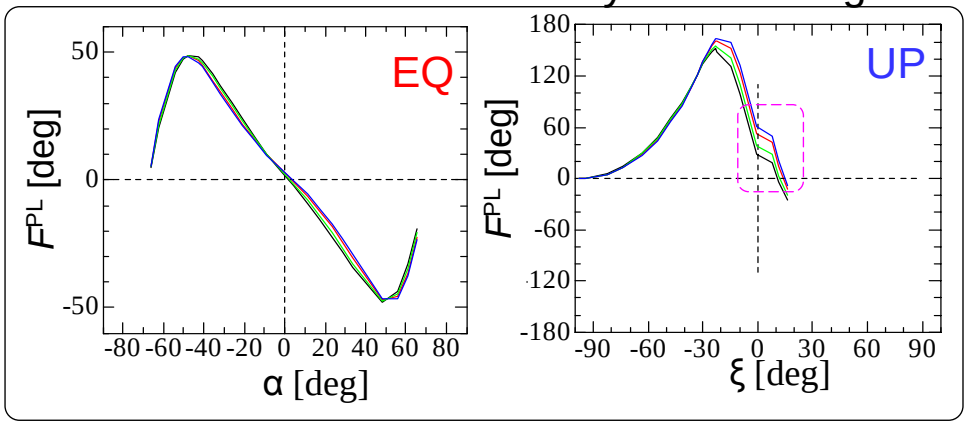
β_p=0.85 (β_N=2.3)

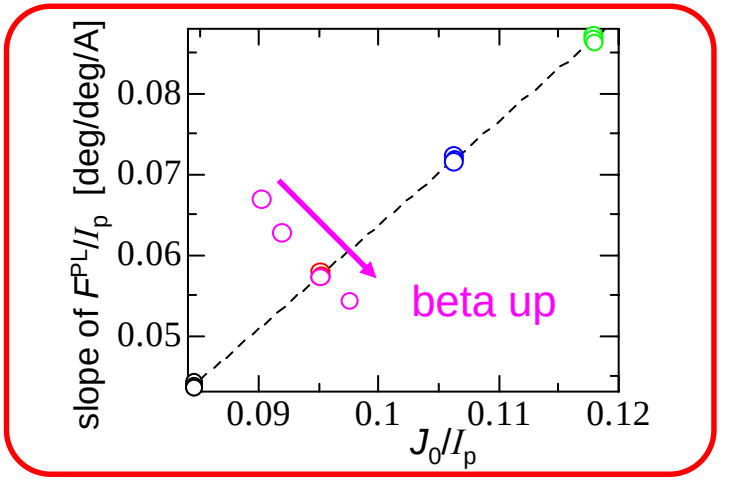
Result of "TOSCA"

$$J_{PS} \sim \frac{1}{B\,\iota}\frac{\partial\left(p_{para}+p_{perp}\right)}{\partial r}\cos\theta$$



Calculation of the Faraday rotation angle

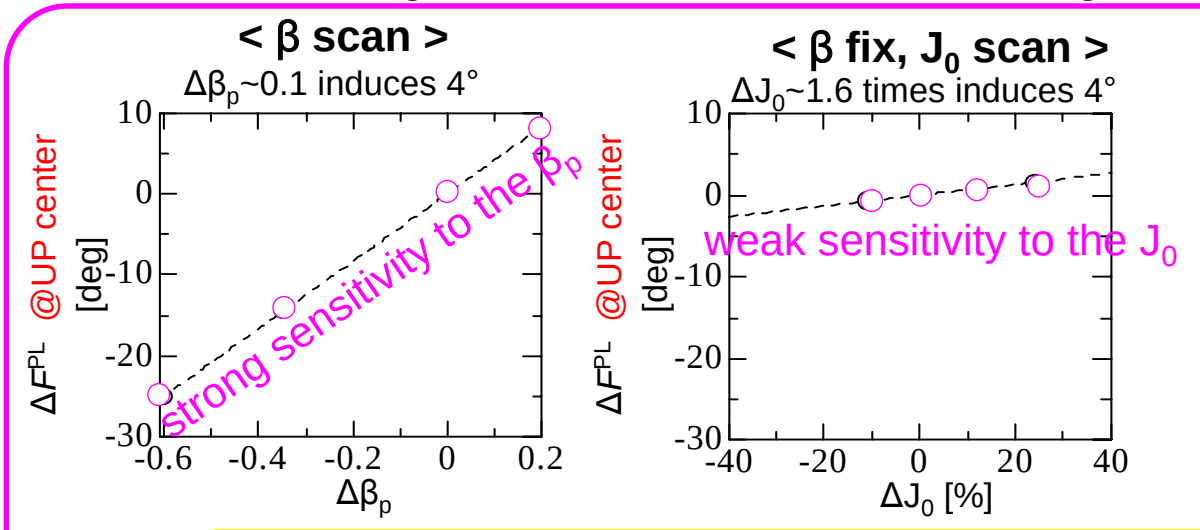




EQ central chords can not distinguish the change of J_0 and the change of β.

The P.S. current $\propto \partial(p_{para}+p_{perp})/\partial r$ [5]
the measurement of $\partial(p_{para}+p_{perp})/\partial r$ is difficult

The detection of the magnetic field due to P.S. current using UP central chord



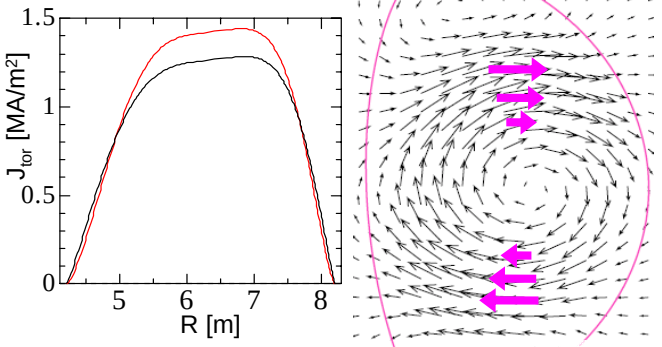
UP central chord is useful to detect the beta effect

[5] T. Yamaguchi et al., Nucl. Fusion, **45**, L33 (2005).

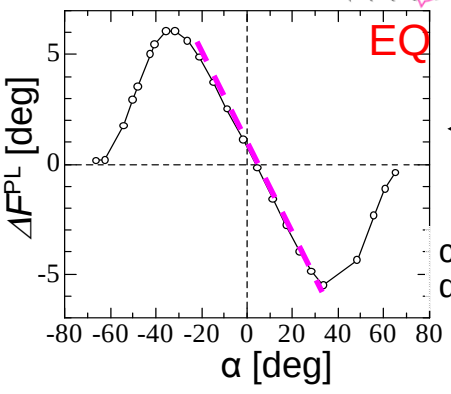
Sensitivity Study <negative shear>

the toroidal current profile can be changed in the negative magnetic shear plasma even if J_0 does not change.

<normal shear>

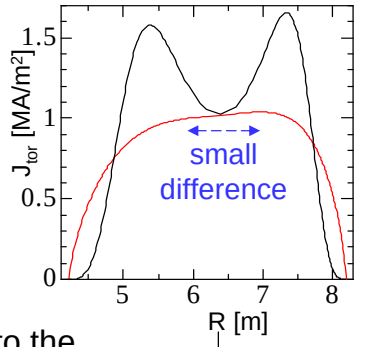


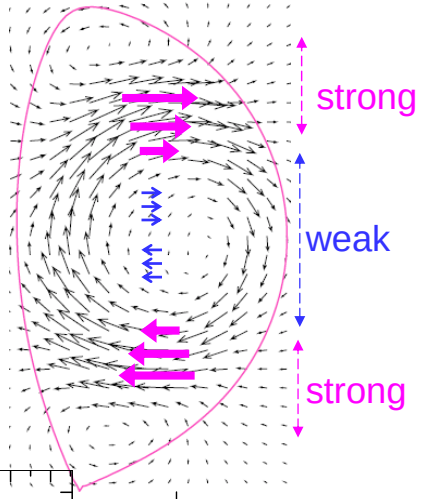
the magnetic field due to the difference between the red and the black

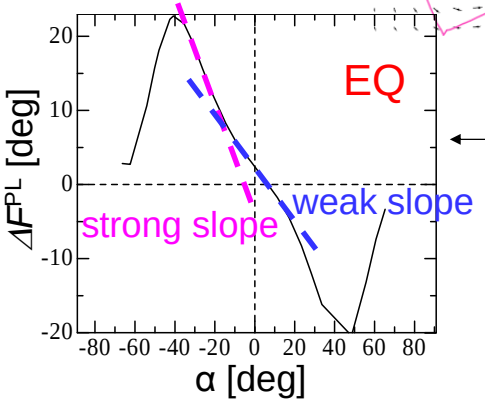


calculated F^{PL} from the difference of magnetic field

<negative shear>

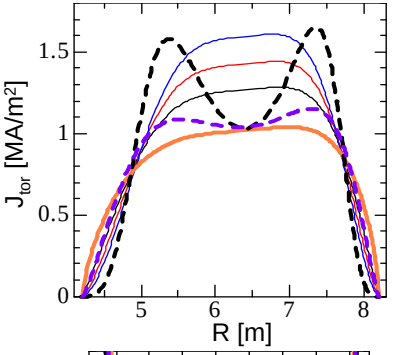


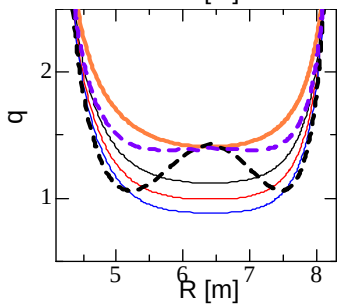




Result of “TOSCA”

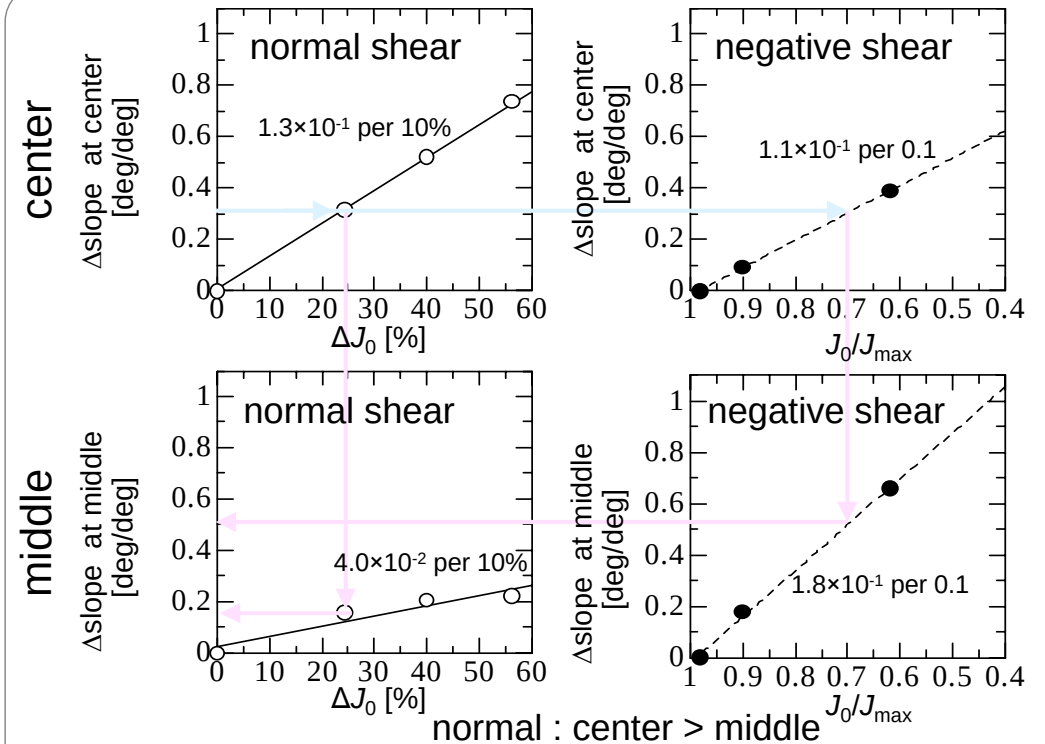
B_t=5.3T, β_p=0.65(fix),
LCFS:fix, I_p=15MA





solid lines : normal shear
broken lines : negative shear

Calculation of the Faraday rotation angle



normal : center > middle
negative : center < middle

If the central slope is same, however the middle slope is different.

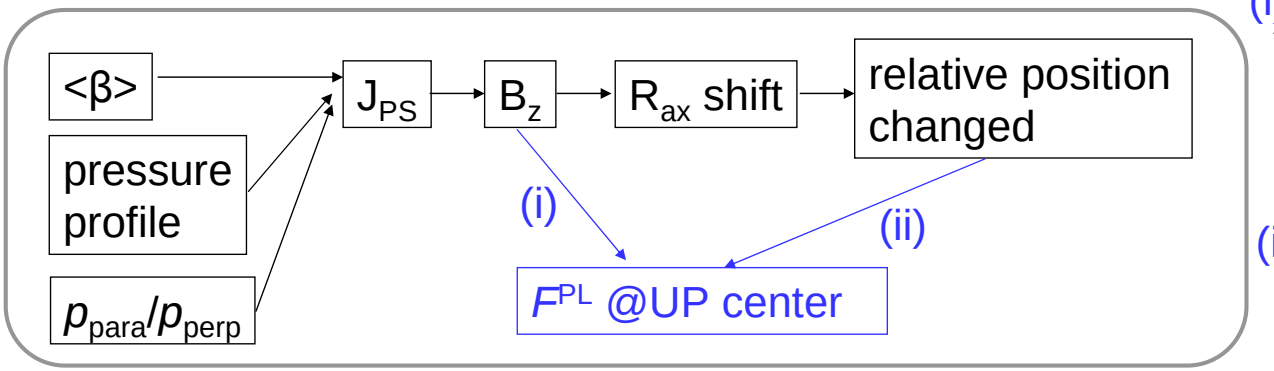
the combination of the central chords and the middle chords are useful to identify the toroidal current profile in the negative magnetic shear

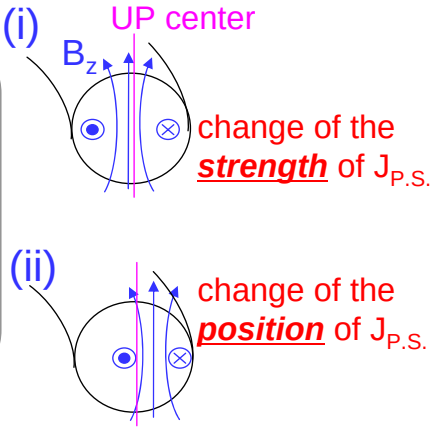
Discussion

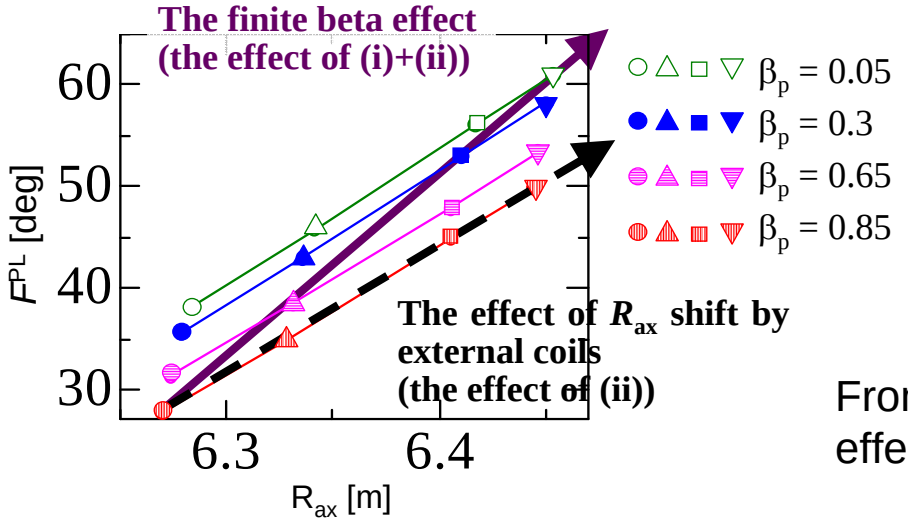
Two possibilities as the mechanism of the strong sensitivity of the finite beta effect,

(i) B_z affects directly the central viewing chord in the UP port

(ii) the relative position between the viewing chord and the magnetic axis is changed by the R_{ax} shift.

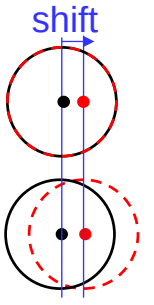






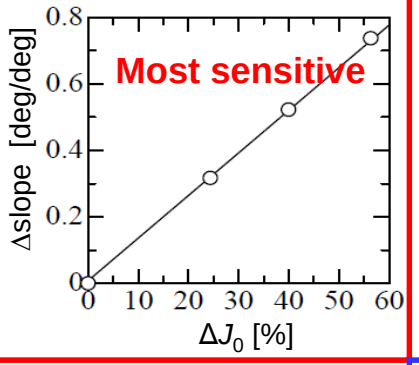
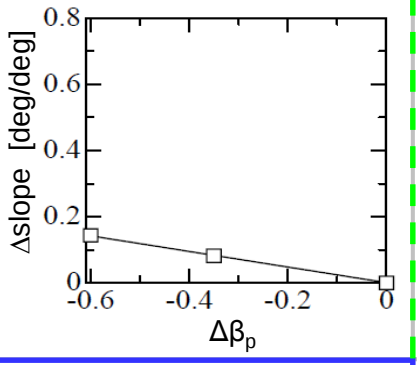
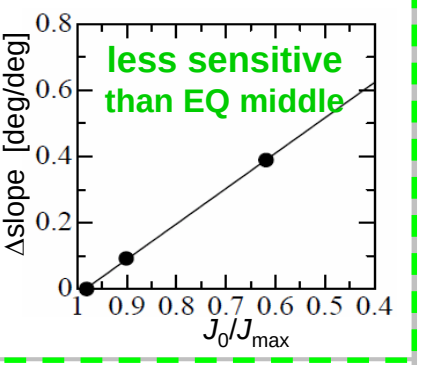
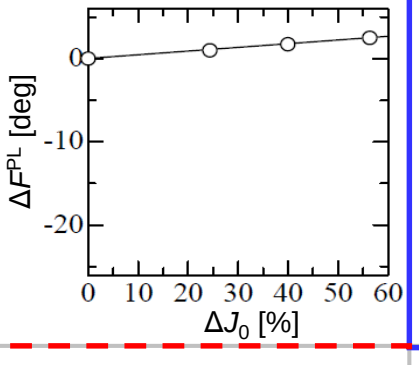
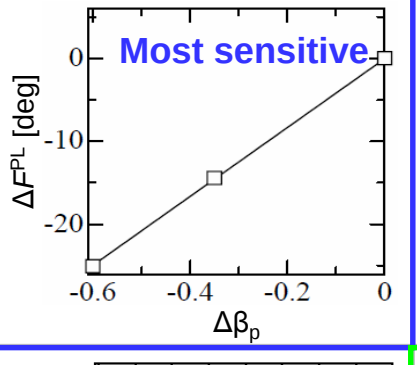
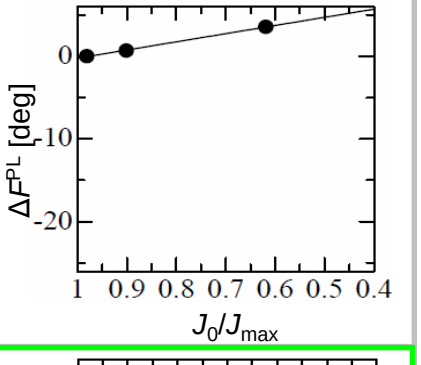
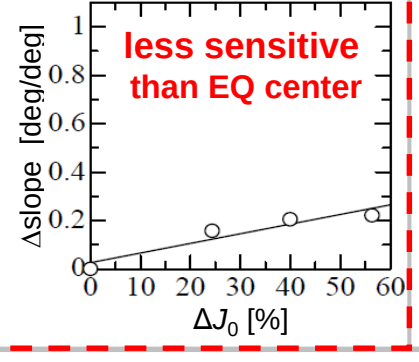
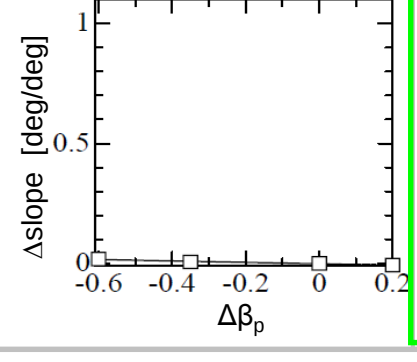
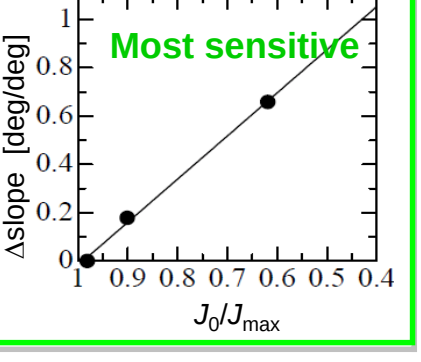
It is rough estimation because

- ΔR_{ax} is different with ΔR_0 when the beta value increases
- ΔR_{ax} and ΔR_0 are almost same when external coil current change



From this analysis, it is thought that the effect of (ii) is much larger than one of (i).

Summary

	J_0 scan	β_p scan	J_0/J_{max} scan
EQ center			
UP center			
EQ middle			

Summary

- It was shown with a good reliability that central viewing chords of the EQ port are sensitive to J_0 by removing the effect of external coils.
- The central viewing chord of the UP port is sensitive to the finite beta effect, moreover not sensitive to J_0 and J_0/J_{max}.
- The combination of the central and the middle viewing chords of the EQ port, is useful to distinguish the change of J_0 and J_0/J_{max}.

<The central slope of the EQ port>

The smaller interval of two viewing chords is better to detect the local toroidal current information near the plasma center. But the amplitudes of the signals and the amplitudes of the difference between signals are smaller.

<The middle slope of the EQ port>

They should be selected near the point of largest change of the slope of F^{PL}. The smaller interval is also better to distinguish the change of J_0 and J_0/J_{max} although the amplitude of the difference is smaller.

Future Plan

-It is necessary to evaluate the amplitudes of the signals based on small I_p, low n_e and the broad toroidal current profiles.

-The considerations of detailed positions of viewing chords in the other operation scenario and the advanced physical phenomena.

-The optimization of the viewing chord arrangement using the MHD equilibrium reconstruction.

The new reconstruction method of the toroidal current profile

From the previous work*

The result using Function parameterization (FP) method
- UP port channels do not bring a significant improvement in recovery accuracy.
- The additional EQ port channels (8ch → 15ch) do not bring a significant improvement.
- "The large regression model" for FP method masks the improvement?

⇩

The comparison with alternative approach is necessary
- Alternative statistical method (artificial neural network)
- Interpretative method (like EFIT, CLISTE, etc.)

* P.J.Mc Carthy, private communication

Interpretative method

The reconstruction method based on the "toroidal current representation" function has been developed [6].
- It is regarded as one of interpretative method although it does not assume Grad-Shafranov equation. (Maxwell eq. and toroidal symmetry are assumed.)
- The poloidal polarimeter data has not been used (magnetic diagnostics only).
- The following constrainer, which is introduced from $J \times B = \nabla p$, has been used.

$$\mu_0 \frac{r^3}{B_r}\left\{B_r \frac{\partial}{\partial r}\left(\frac{j}{r}\right) + B_z \frac{\partial}{\partial z}\left(\frac{j}{r}\right)\right\} = -\frac{\partial}{\partial \varphi}\left(r B_t^2\right)$$

[6] K. Kurihara et. al., Fusion Eng. Des. **72**, 527 (2005)

Our proportional

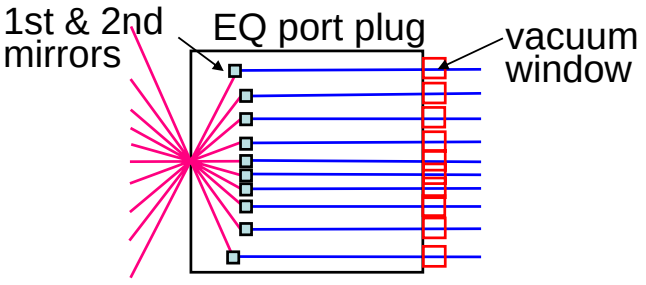
The poloidal polarimeter data is used instead of the assumption of $J \times B = \nabla p$
→ accurate reconstruction is expected on the conditions where $J \times B = \nabla p$ does not stand up, for example, the highly anisotropic pressure plasma and the temporal behavior like the disruption

Optical arrangement through port plug: other concept[7]

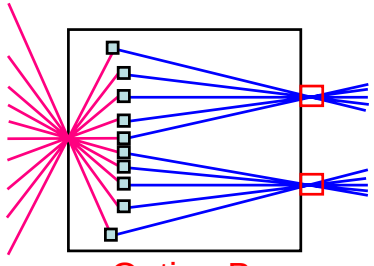
Proposal of alternative arrangements in EQ port plug

Several transmission lines have a common vacuum window
-- relaxed space limitation at back plate
-- reduced risk of vacuum leakage
-- reduced cost
-- complicate drawing

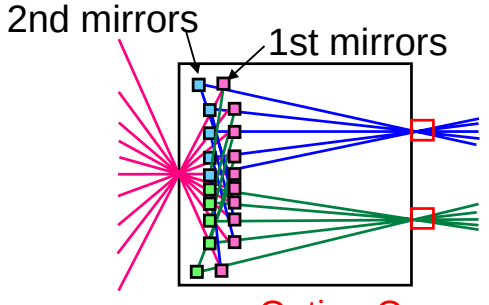
Assessment needed



Option A
(present concept)



Option B
(reduced number of vacuum windows)



Option C
(option B plus reduced size of 1st & 2nd mirrors)

[7] Y. Kawano et. al., 23rd Annual meeting of Japan Society of Plasma Science and Nuclear Fusion Research, 29aC04P (2006)