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Requirements for IMC Mirror Placement

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Scope

- Set the requirement for placement errors for input mode cleaner (IMC) mirrors.

- References:
  - J. Opt. 13 055504 (2011)
    (triangular cavity eigenmode paper by Kawazoe)
  - JGW-T1402481 (calculation by T. Saito)

  - JGW-D1402507 (IOO 3D drawing)
  - JGW-T1402486 (layout around IFI)

Conclusion

- MCi placement error should be
  yaw < 0.5 deg, pitch < 1 deg, disp < 1 mm, roll < 4 deg
- MCo placement error should be
  yaw < 0.5 deg, pitch < 1 deg, disp < 1 mm, roll < 6 deg
- MCe placement error should be
  yaw < 0.5 deg, pitch < 1 deg, disp < 1 cm, roll < 30 deg

- Angular requirements are from actuation range (alignment should be done within ~0.1 mrad to get the beam resonating in the cavity).
- Displacement requirements are from beam displacements at succeeding mirrors/viewports.

Requirement 1

- The beam should hit the IMC mirrors.

Definitions

- α/β for yaw/pitch misalignment
- γ for longitudinal displacement
  (there are 3 DOFs for longitudinal displacements, but DOF which affect most is considered)

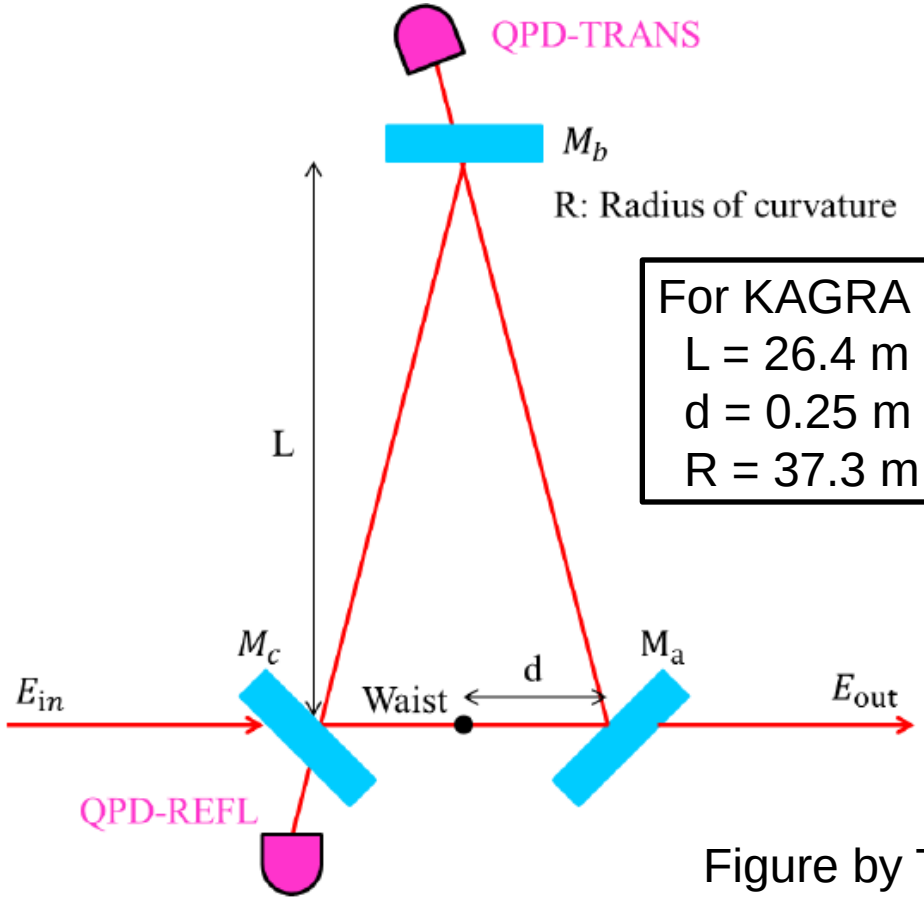


Fig.1 Input Mode Cleaner

For KAGRA IMC,
L = 26.4 m
d = 0.25 m
R = 37.3 m

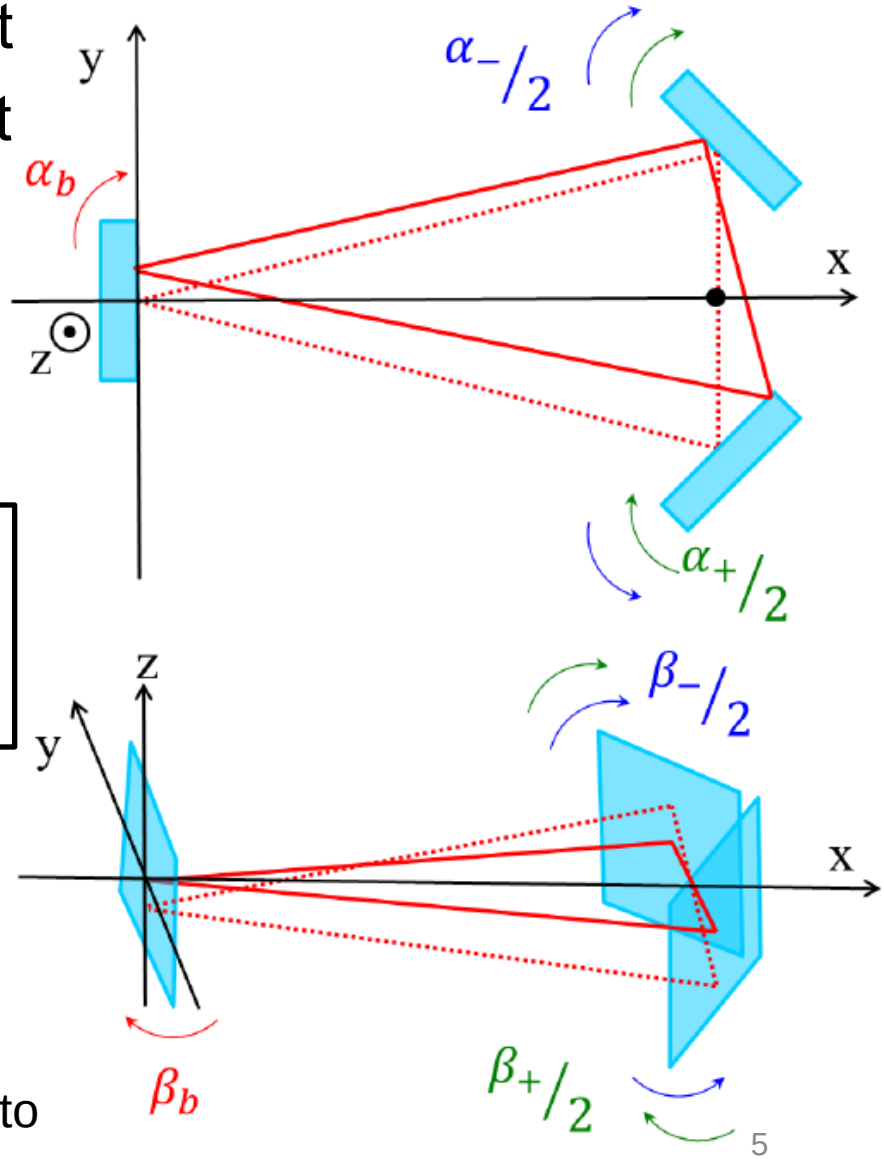


Fig.4.1 ミスアラインメント時の共振器軸の変化

Figure by T. Saito
JGW-T1402481

Miscentering from Misalignments

- all values are in m/rad
- αb < 0.5 mrad
  α- < 1.5 mrad
  α+ < 50 mrad
  βb < 1.5 mrad
  β- < 250 mrad
  β+ < 1.5 mrad

	Δr_{c} (MCi)	Δr_{a} (MCo)	Δr_{b} (MCe)
α_{b}	$\frac{\sqrt{2}Rd}{R-L-d} = 1.24$	$\frac{\sqrt{2}Rd}{R-L-d} = 1.24$	$-\frac{R(L+d)}{R-L-d} = -93.3$
α_{-}	$\sqrt{2(L^2+d^2)} = 37.3$	$-\sqrt{2(L^2+d^2)} = -37.3$	0
α_{+}	$-\frac{\sqrt{2}(R-L)d}{R-L-d} = -0.362$	$-\frac{\sqrt{2}(R-L)d}{R-L-d} = -0.362$	$\frac{Rd}{R-L-d} = 0.876$
β_{b}	$-R = -37.3$	$-R = -37.3$	$-R = -37.3$
β_{-}	$\frac{d}{\sqrt{2}} = 0.177$	$-\frac{d}{\sqrt{2}} = -0.177$	0
β_{+}	$\frac{R-L}{\sqrt{2}} = 7.71$	$\frac{R-L}{\sqrt{2}} = 7.71$	$\frac{R}{\sqrt{2}} = 26.38$

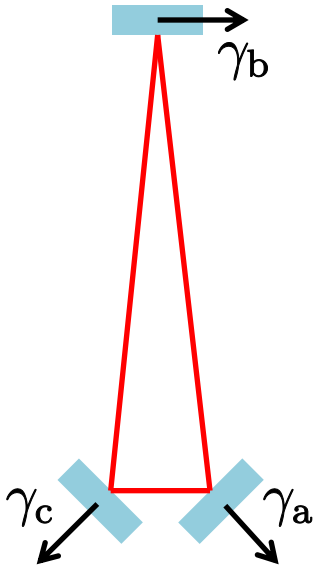
Note that miscentering is defined by $\Delta r = \sqrt{(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2}$, where Δx, Δy, Δz are the displacements defined in J. Opt. 13 055504 (2011) .

Miscentering from Displacements

- all values are in m/m
- γc < 2 cm
  γa < 2 cm
  γb < 2 cm

	Δr_c (MCi)	Δr_a (MCo)	Δr_b (MCe)
γ_c	0	1	$\frac{R}{\sqrt{2}(R-L-d)} = 2.48$
γ_a	1	0	$-\frac{R}{\sqrt{2}(R-L-d)} = -2.48$
γ_b	$\frac{\sqrt{2}d}{R-L-d} = 0.03$	$\frac{\sqrt{2}d}{R-L-d} = 0.03$	$\frac{L+d}{R-L-d} = 2.50$

- γ in vertical direction with respect to the mirror surface is considered for MCi and MCo
- γ in horizontal direction in the plane of the mirror surface is considered for MCe (note that MCe displacement in vertical direction creates larger beam displacement at MCi and MCo by √2 m/m)



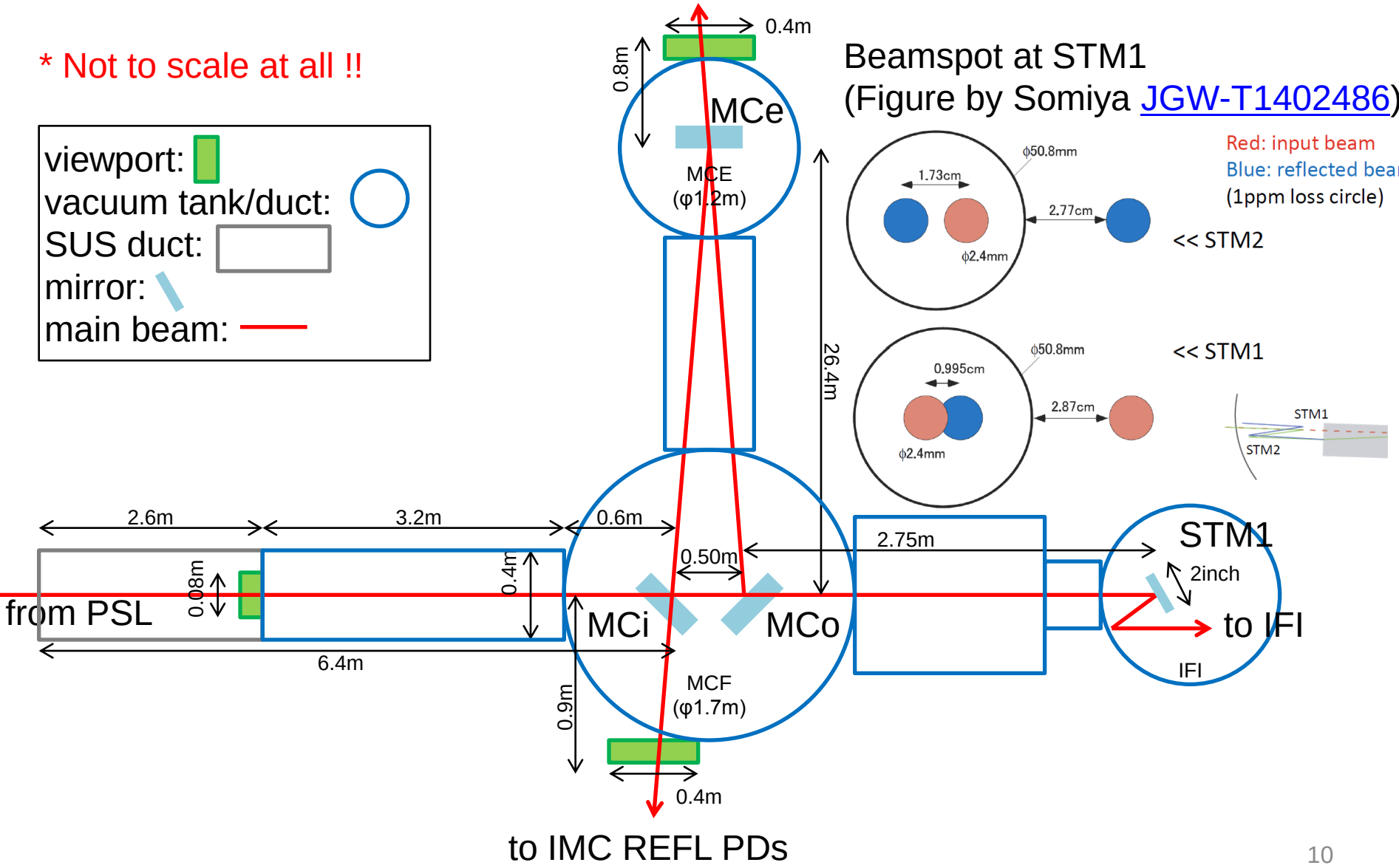
Summary 1

- If we set the requirement for the beam miscentering to be 5 cm (c.f. mirror diameter = 10 cm);
- MCi placement error should be
  yaw < 0.7 mrad, pitch < 0.7 mrad, disp < 2 cm
- MCo placement error should be
  yaw < 0.7 mrad, pitch < 0.7 mrad, disp < 2 cm
- MCe placement error should be
  yaw < 0.5 mrad, pitch < 0.7 mrad, disp < 3.5 cm
  (c.f. 1 mrad = 0.06 deg)
- It seems impossible to meet the angular requirements only by placing the optics. Fine adjustment should be done with picomotors on IMC suspensions.
  → angular requirement should be set from actuation range
- The displacement requirements seem to be too easy from other point of view.

Requirement 2

- IMC transmitted beams should hit the succeeding optics.
- IMC incident beam path and oplev beam paths should be clear.

IMC layout


to IMC TRANS PDs
* Not to scale at all !!
viewport:
vacuum tank/duct:
SUS duct:
mirror:
main beam:
0.4m
0.8m
MCe
MCE
(φ1.2m)
26.4m
Beamspot at STM1
(Figure by Somiya JGW-T1402486)
Red: input beam
Blue: reflected beam
(1ppm loss circle)
ϕ50.8mm
1.73cm
2.77cm
ϕ2.4mm
<< STM2
ϕ50.8mm
0.995cm
2.87cm
ϕ2.4mm
<< STM1
STM1
STM2
2.6m
3.2m
0.6m
0.50m
2.75m
STM1
2inch
0.08m
0.4m
from PSL
MCi
MCo
to IFI
IFI
6.4m
MCF
(φ1.7m)
0.9m
0.4m
to IMC REFL PDs

Beam Displacements

- Assumption: All the mirrors are aligned so that the beam hits the mirror at the center, even if they are misplaced
- all values are in m/m

	Laser Inj.	IMC REFL	IMC TRANS	STM1
γ_c	8.6	1.0	0	5.5
γ_a	7.6	0	0.03	6.5
γ_b	0	0.03	1.0	0

- beam displacements at each viewport and STM1 from γ is shown in the table

Summary 2

- If we set the requirement for the beam displacement at STM1 and viewports to be less than 1 cm;
- MCi placement error should be
  disp < 1 mm
- MCo placement error should be
  disp < 1 mm
- MCe placement error should be
  disp < 1 cm

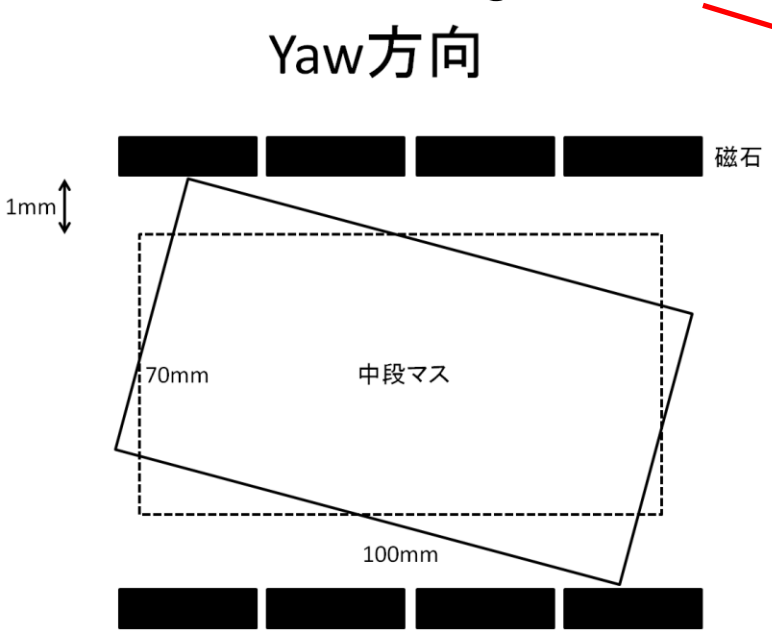
- Oplev beams won't be blocked if mirrors are placed within the requirements above.

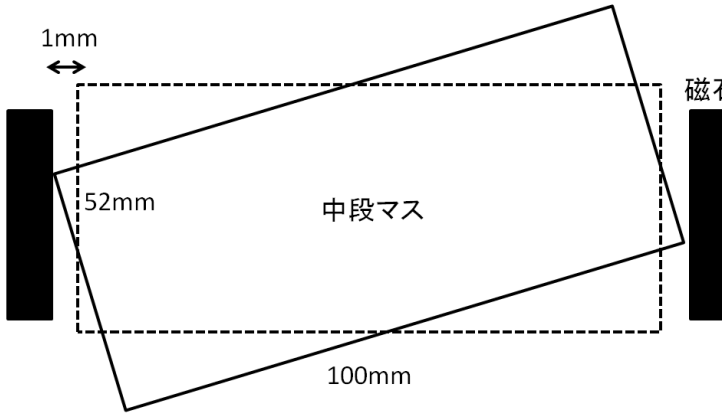
Requirement 3

- Alignments of IMC mirrors should be able to be fine adjusted with picomotors.
- So, placement error should be smaller than the picomotor actuation range.

IMC Angular Actuation Range

- Actuation range is limited by the gap (~1 mm) between the middle stage mass and damping magnets





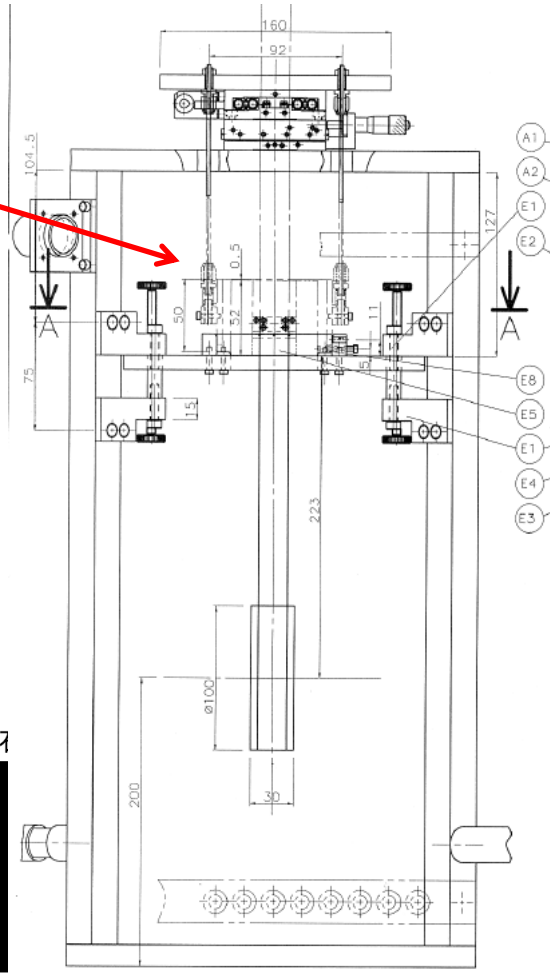


Figure by T. Saito

Summary 3

- Angular actuation range of IMC mirrors are ~1 deg in yaw, ~2 deg in pitch.

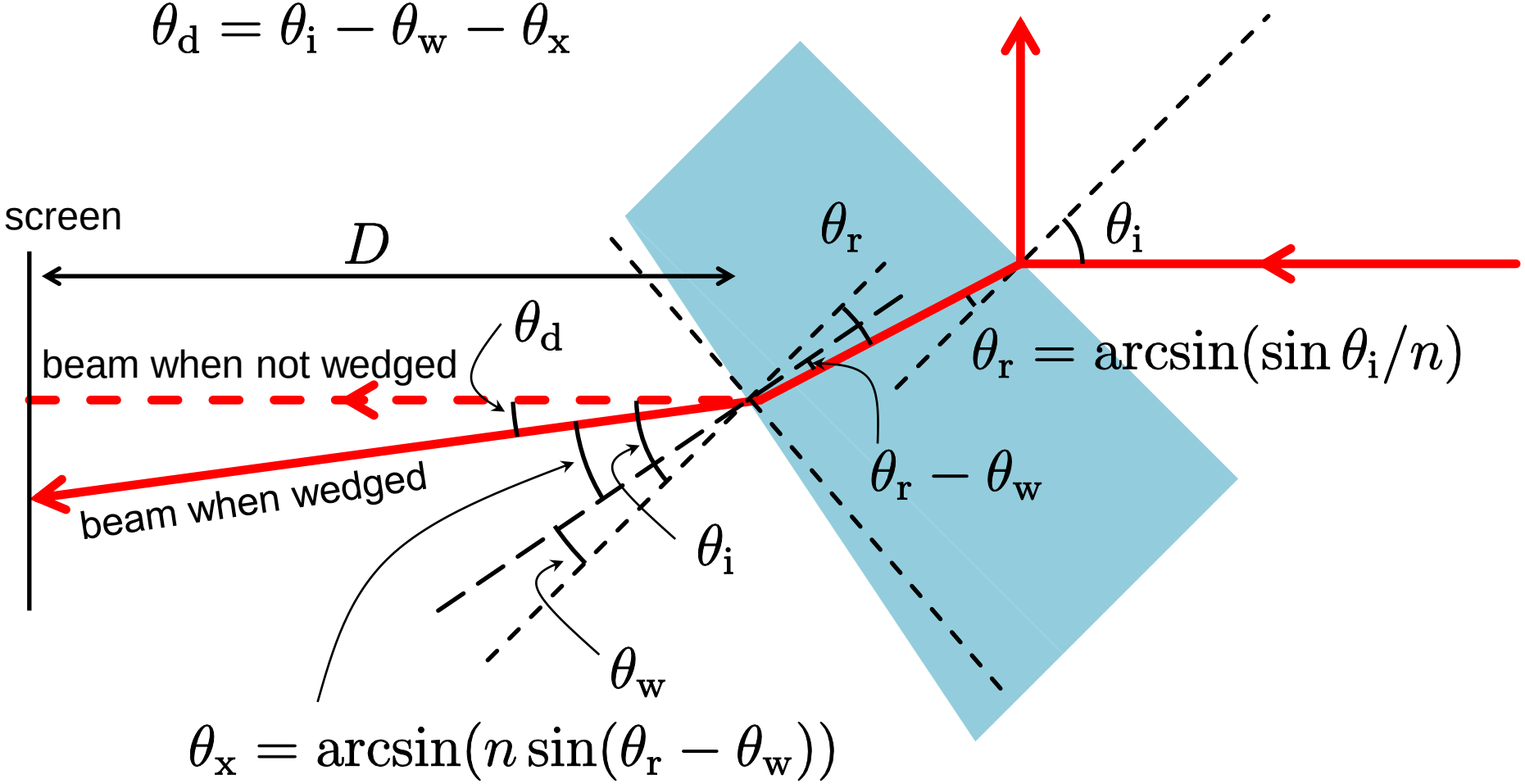
Requirement for Roll

- IMC transmitted beams is displaced when IMC mirrors are rotated in roll because of wedge

Wedge and Transmitted Beam

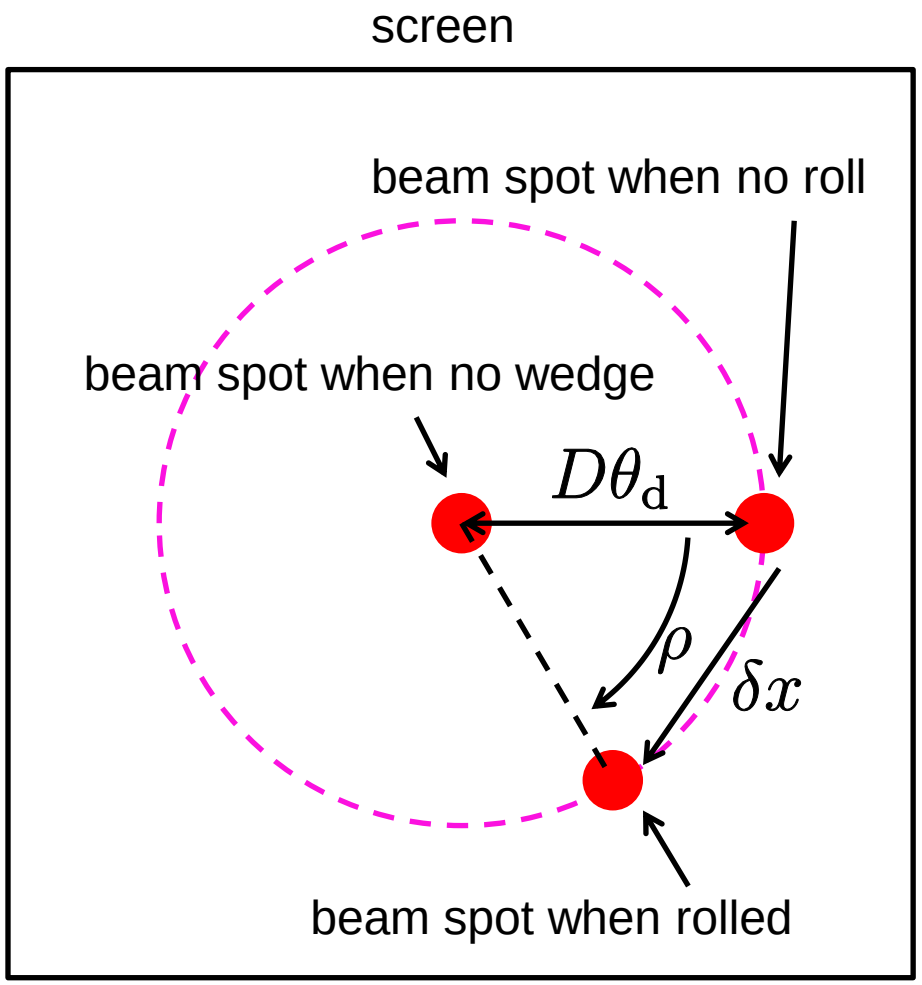
- the wedg angle: θ_w
- angle between incident beam and transmitted beam

$$\theta_d = \theta_i - \theta_w - \theta_x$$



Beam Displacement vs Roll

- beamspot on the screen in the previous slide rotates as the mirror rotates
- when mirror roll is ρ, beam displacement is
  $\delta x = D\theta_{\mathrm{d}}\rho$
- for IMC mirrors,
  $n = 1.45 \quad \theta_{\mathrm{w}} = 2.5\,\mathrm{deg}$
  $\theta_{\mathrm{i}} = 44.7\,\mathrm{deg}$ for MCi/o
  $\theta_{\mathrm{i}} = 0.5\,\mathrm{deg}$ for MCe
- so,
  $\theta_{\mathrm{d}} = 0.032\,\mathrm{rad}$ for MCi/o
  $\theta_{\mathrm{d}} = 0.020\,\mathrm{rad}$ for MCe



Summary for Roll

- If we set the requirement for the beam displacement at STM1 and viewports to be less than 1 cm;
- MCi roll error should be
  roll < 4 deg
- MCo roll error should be
  roll < 6 deg
- MCe roll error should be
  roll < 30 deg