# Input Mode Matching of LCGT

2012/1/5, Yoichi Aso

## Baseline layout: bLCGT

- Negative g-factor (R1 = 1.68km, R2 = 1.87km)
- Sapphire Test Masses (n = 1.754)
- Vacuum chambers are installed so that the mirrors are centered for the bLCGT layout

## Several possibilities for iLCGT

### Test Mass

(A) New TM from CSIRO (ROCs are the same as bLCGT)
(B) iLIGO Mirror (R1 = Flat, R2 = 7.2 km)

### Optimize Folding Part

Tweak the distance between PR2 and PR3 to optimize the mode matching between the PRC and the arm cavities. Do the same for SRC.
(a) Yes, (b) No

### Geometric layout correction method

How the mirrors are moved to compensate for the change of the ITM position

(1) Move PR3, Rotate PR2 and BS
(2) Laterally move ITMs

# Detailed notes on the iLCGT layout (You can skip this slide)

## About the folding part optimization

- A good mode matching between the PRC/SRC and the arm cavities is necessary to do power- or signal-recycling. If we want to do the Silica RSE, this is crucial. (See Appendix A)
- On the other hand, for FPMI or DRMI, this mode matching is not that important. What we care is the mode matching of the input beam to the arm cavities, or DRMI.
- Folding part optimization involves moving the PRC/SRC mirrors. We want to avoid this if possible.

## About the geometric layout correction

- The bLCGT ITMs have a finite wedge angle on the AR side. In order for the incident beam to hit the HR surface at right angle, the beam must hit the AR from slightly non-normal angle.
- Because of this, when the ITMs are put 26.6m further from the BS in iLCGT, the beam will not hit the center of the ITMs.
- We have to correct this by either moving the ITMs laterally (option 2) or by tweaking the PRC mirrors to correct the incident beam angle and position (option 1). (See Appendix B)
- Option 2 is simple because we do not have to move the PRC mirrors between iLCGT and bLCGT.
- However, option 2 requires that the arm cavity beam axis be shifted laterally by 7cm. This means that the beam does not go through optical windows on the GVs separating the central part and the arm pipes. It is not good for initial alignment. Therefore, the GVs have to be displaced for iLCGT, which is possible according to Saito-san.

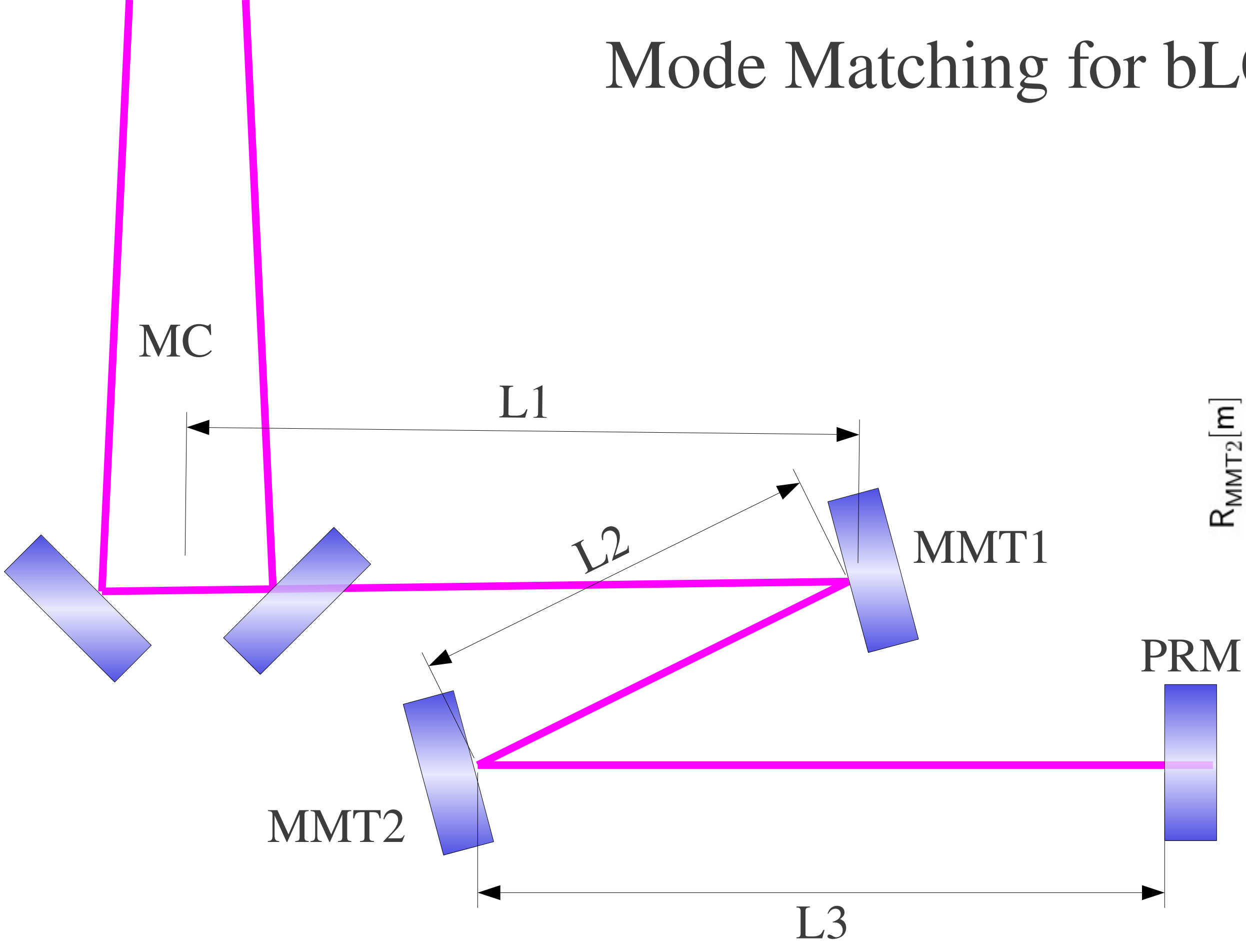
# Default iLCGT: iLCGT-Aa2

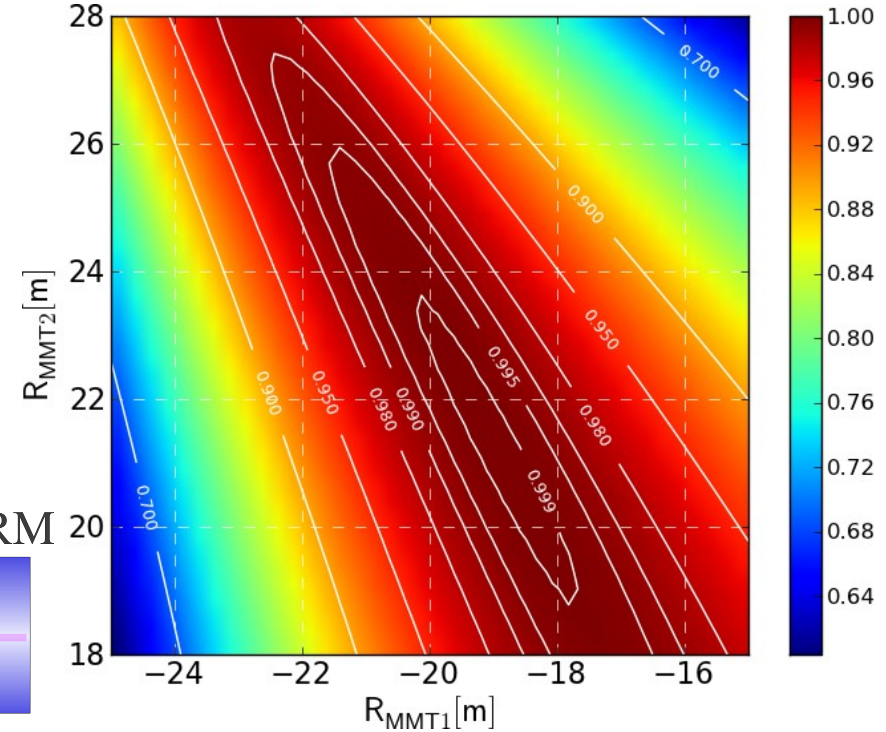
- CSIRO Mirrors
- Optimize the Folding Part
- Laterally move ITMs

I will also consider:

iLCGT-Aa1 (CSIRO, Optimize Folding, Move PR3)
iLCGT-Ab1 (CSIRO, No Folding Optimization, Move PR3)
iLCGT-Aa2 (CSIRO, Optimize Folding, Laterally move ITMs)
iLCGT-Ab2 (CSIRO, No Folding Optimization, Laterally move ITMs)
iLCGT-Ba1 (iLIGO, Optimize Folding, Move PR3)
iLCGT-Bb1 (iLIGO, No Folding Optimization, Laterally move ITMs)
iLCGT-Ba2 (iLIGO, Optimize Folding, Move PR3)
iLCGT-Bb2 (iLIGO, No Folding Optimization, Laterally move ITMs)

# Mode Matching for bLCGT




L1, L2 and L3 are given. Optimized $R_{MMT1}$ and $R_{MMT2}$.

L1=7.5m, L2=4.5m, L3=4.7m

$R_{MMT1}$ = -21.579m, $R_{MMT2}$ = 23.968m

This is the start point. We won't change the ROCs of the MMT mirrors.
We will move MMT1 and MMT2 to adjust the mode matching.

# iLCGT Input Mode Matching

- From the next slide, iLCGT mode matching is shown for many cases.
- For each case, the bLCGT layout is transformed with the following procedure

1. Start from the bLCGT layout
2. Change the TMs to the silica mirrors: (A) CSIRO Mirrors, (B) iLIGO TMs.
3. Move ITMs by 26.6m
4. Do either of the followings to hit the center of ITMs with right angle:
   (1) Rotate PR2 and BS, move PR3 and adjust the ITM wedge angle.
   (2) Move the ITMs laterally and adjust the ITM wedge angle.
5. Do either of the followings:
   (a) Adjust the distance between PR2 and PR3 to match the eigen-modes of the PRC and the arm cavities.
   (b) Do nothing.

## Eigen-modes of the main interferometer

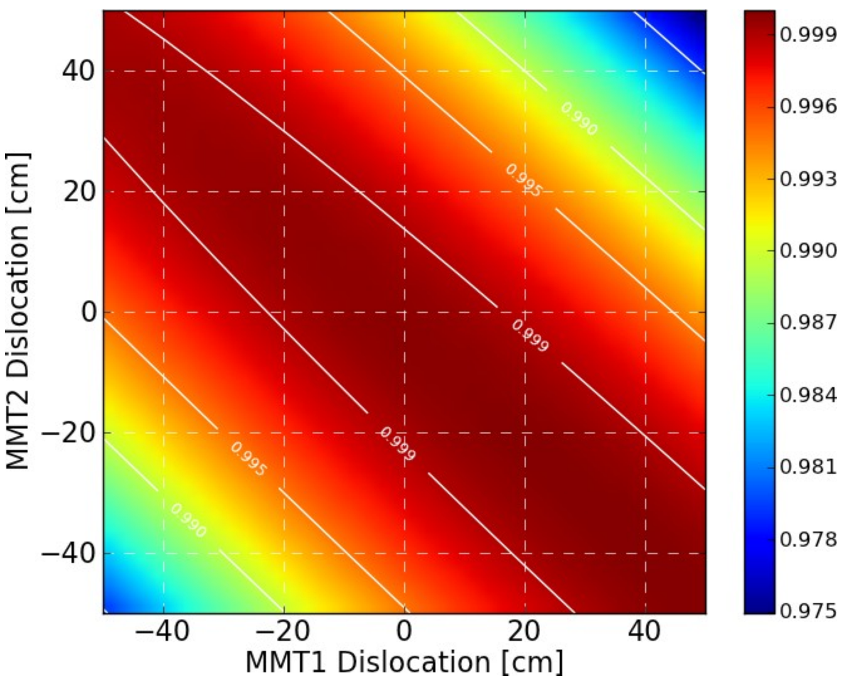
After the layout is adjusted, the eigen-mode of the arm cavity is propagated to the PRM to obtain the beam parameter, q0, at the AR surface of the PRM. q0 is calculated also for the case without PRM (just propagating the beam on the PRM HR surface by the thickness of PRM). Additionally, the eigen-mode of the DRMI is calculated and translated into the beam parameter at the AR surface of the PRM.

## Mode matching with the beam from the input MMT

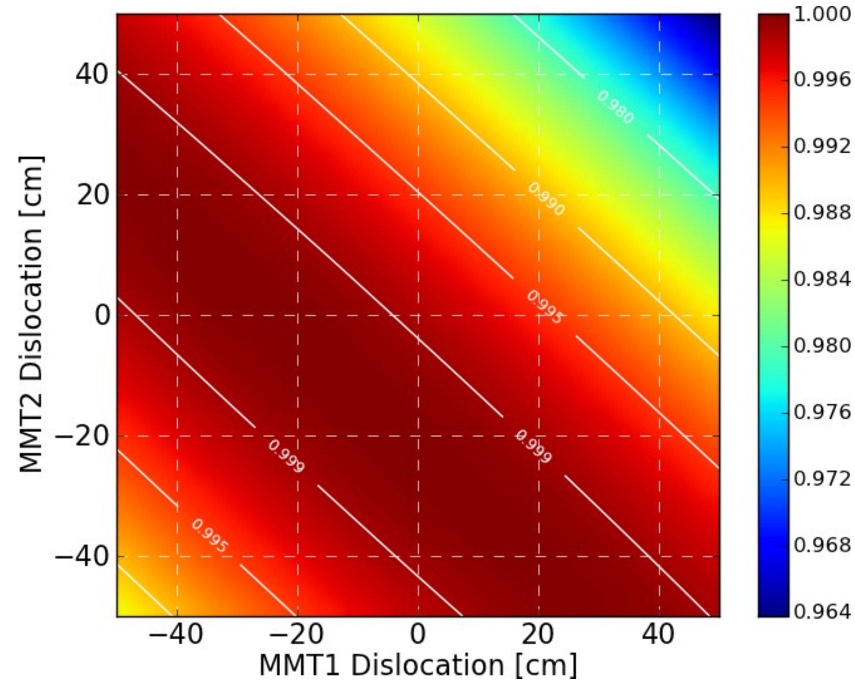
The beam coming out of the input MMT is propagated to the AR surface of the PRM. The beam parameter is compared with the ones calculated above to get the mode matching. This is repeated by sweeping the positions of the MMT mirrors to see if the mode matching can be recovered by moving those mirrors.

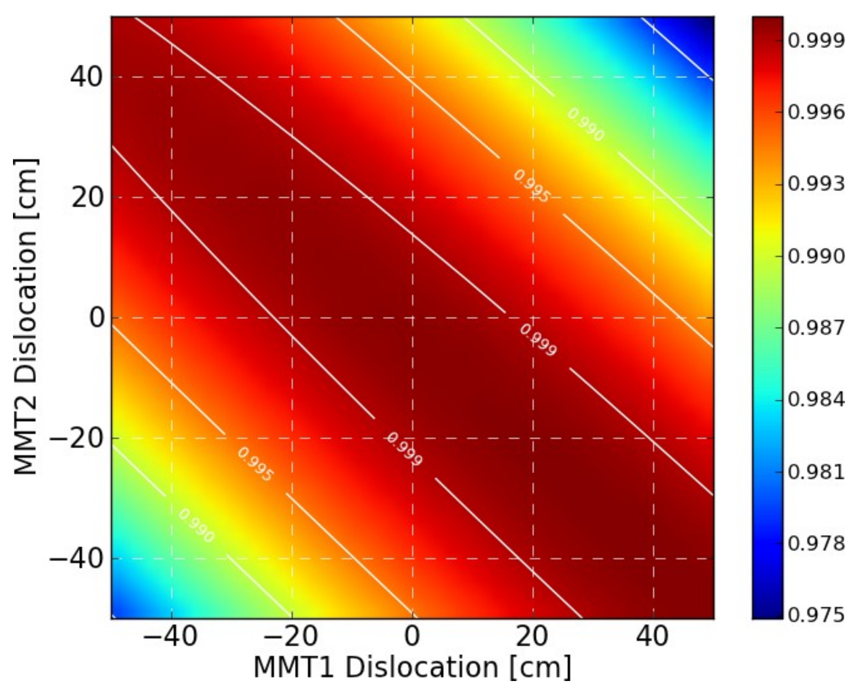
# iLCGT-Aa1

## With PRM



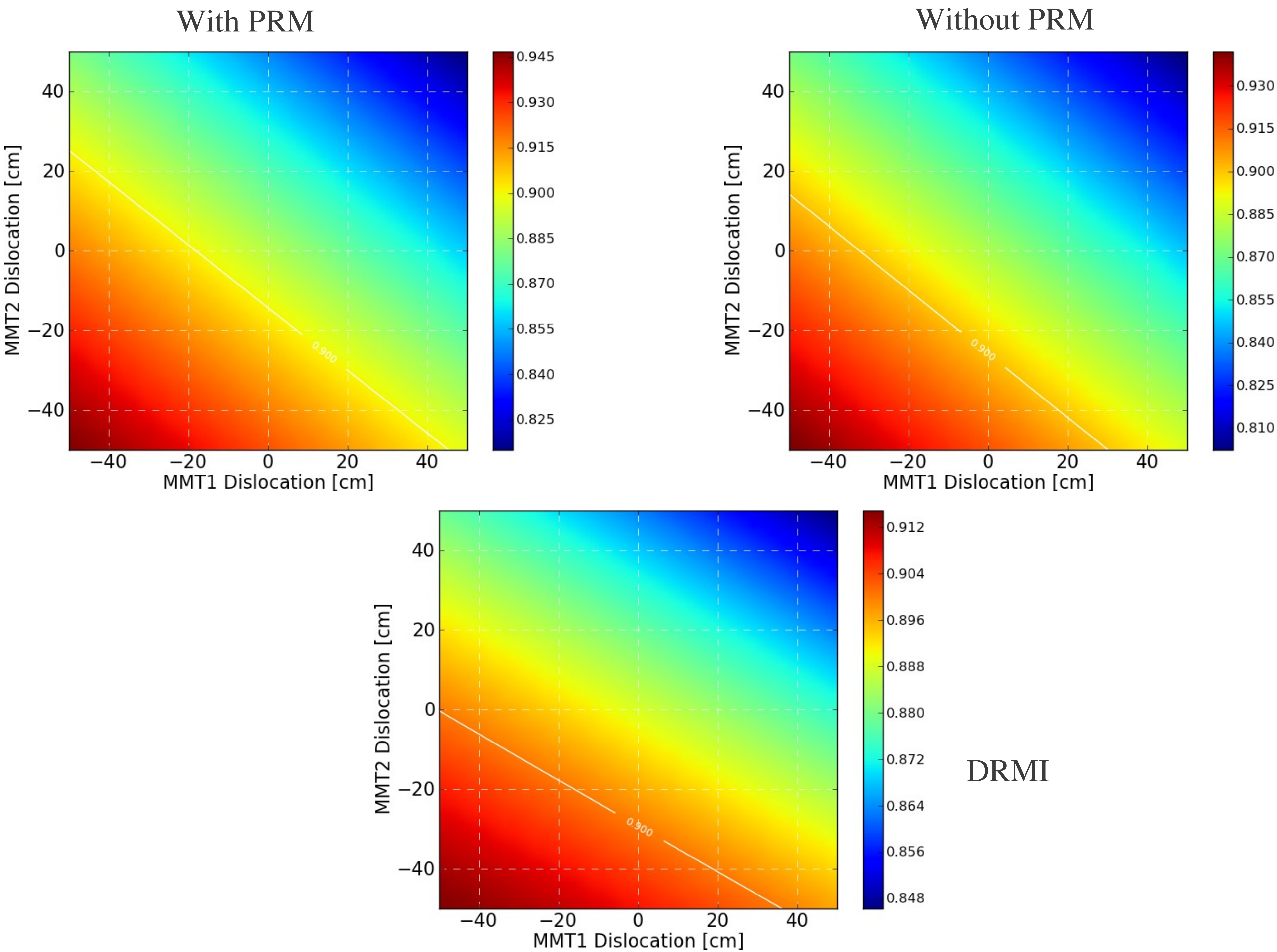

## Without PRM



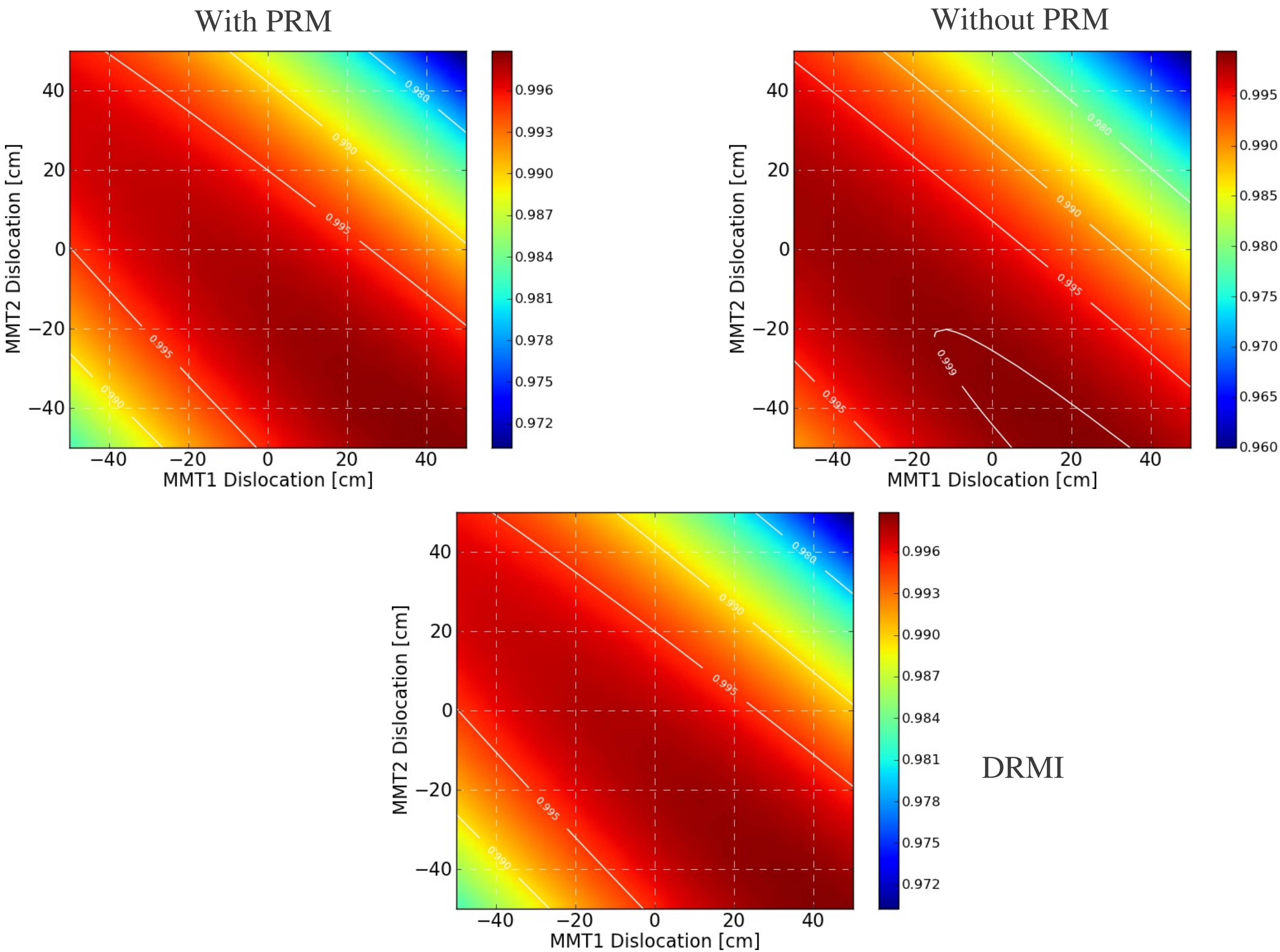




## DRMI

# iLCGT-Ab1

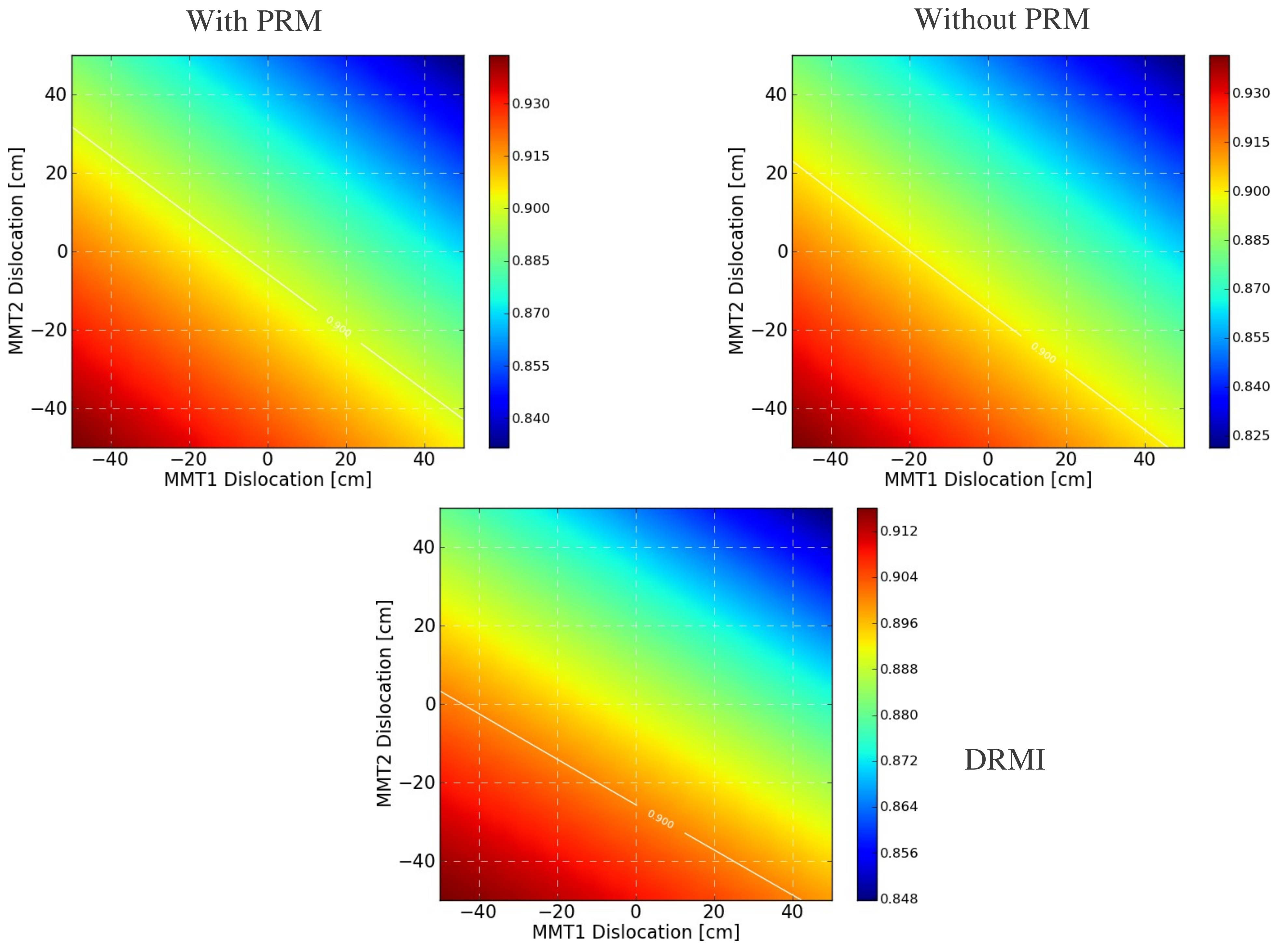

With PRM
Without PRM
DRMI
MMT1 Dislocation [cm]
MMT2 Dislocation [cm]
−40
−20
0
20
40
0.900
0.945
0.930
0.915
0.885
0.870
0.855
0.840
0.825
0.810
0.912
0.904
0.896
0.888
0.880
0.872
0.864
0.856
0.848

# iLCGT-Aa2



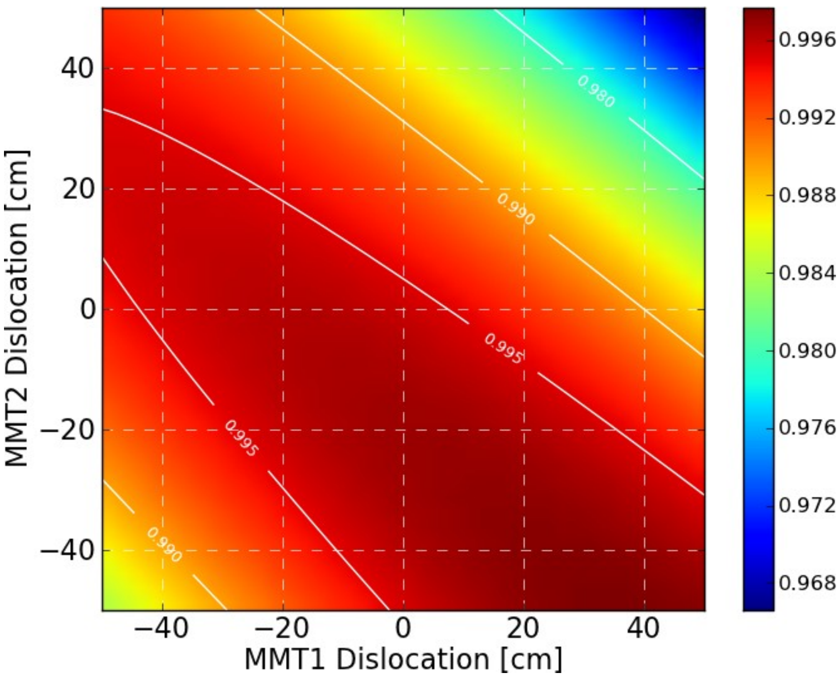
With PRM
Without PRM
DRMI
MMT1 Dislocation [cm]
MMT2 Dislocation [cm]
0.980
0.990
0.995
0.999

# iLCGT-Ab2

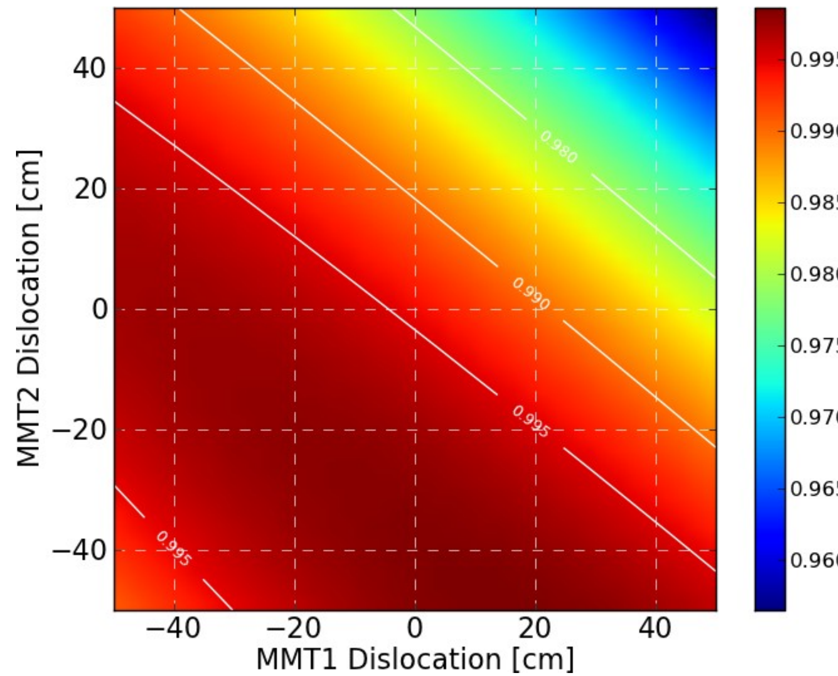

With PRM
Without PRM
DRMI
MMT1 Dislocation [cm]
MMT2 Dislocation [cm]
0.900
0.930
0.915
0.885
0.870
0.855
0.840
0.825
0.912
0.904
0.896
0.888
0.880
0.872
0.864
0.856
0.848

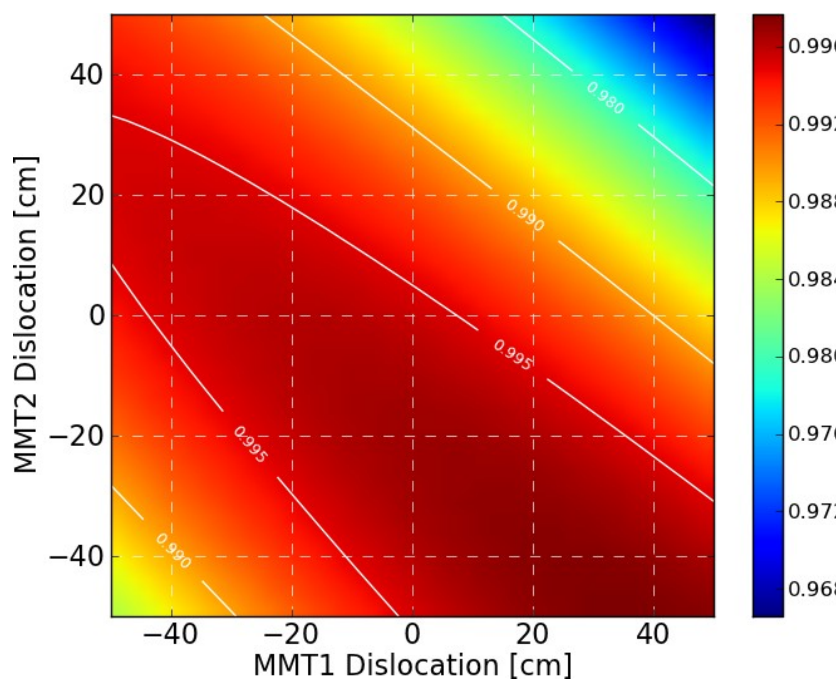
# iLCGT-Ba1

With PRM




Without PRM

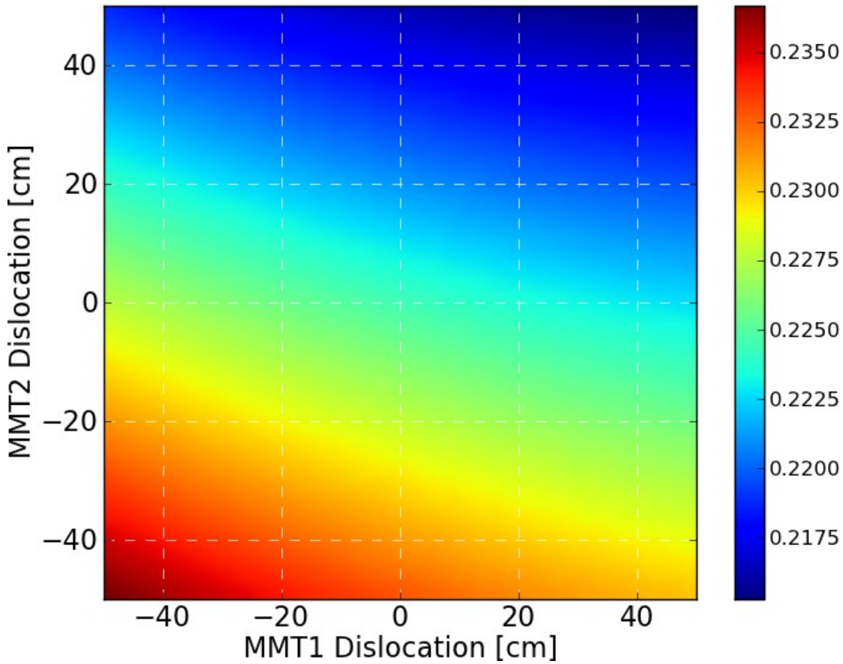


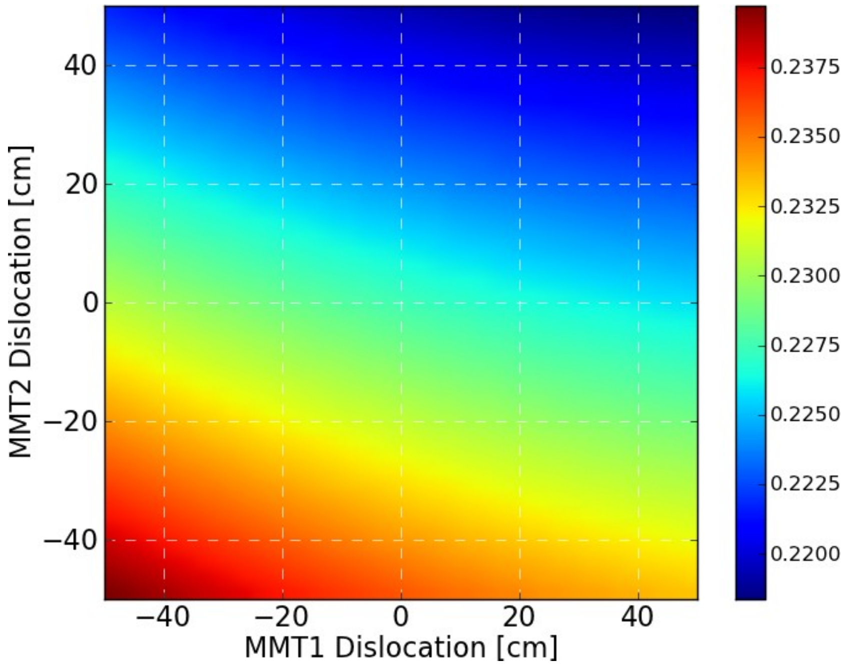

DRMI

# iLCGT-Bb1

With PRM



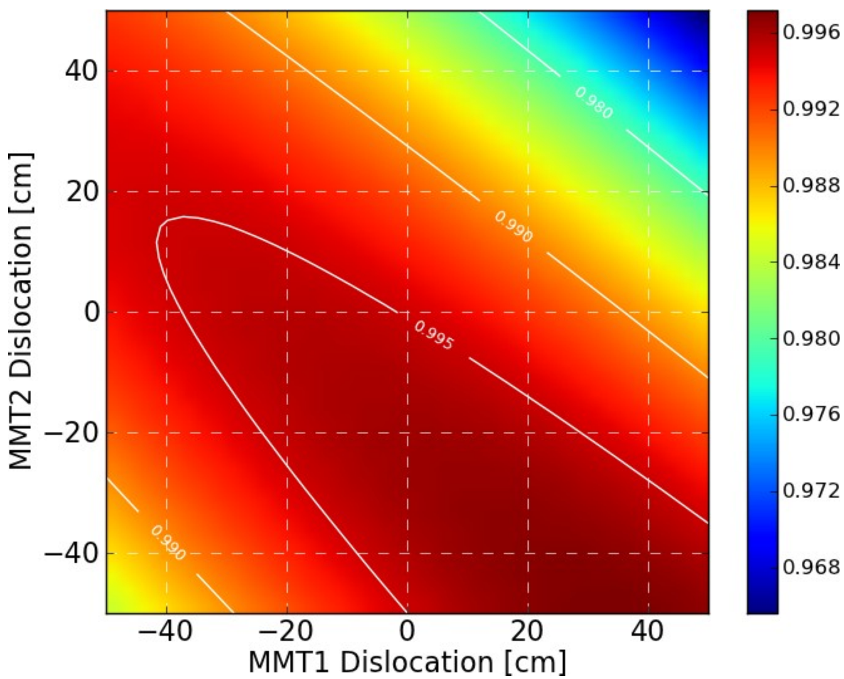

Without PRM



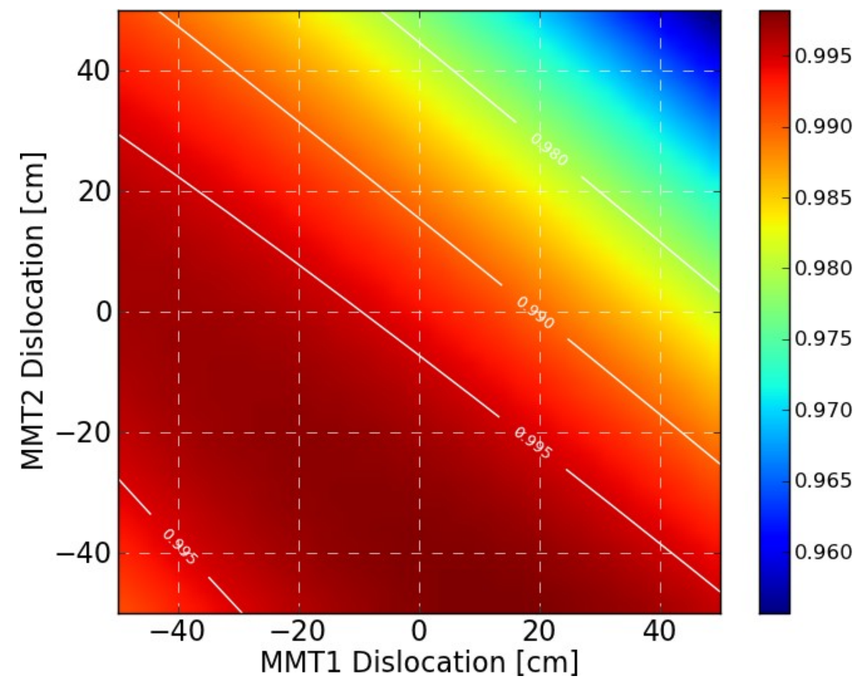

## DRMI Cavity is Unstable

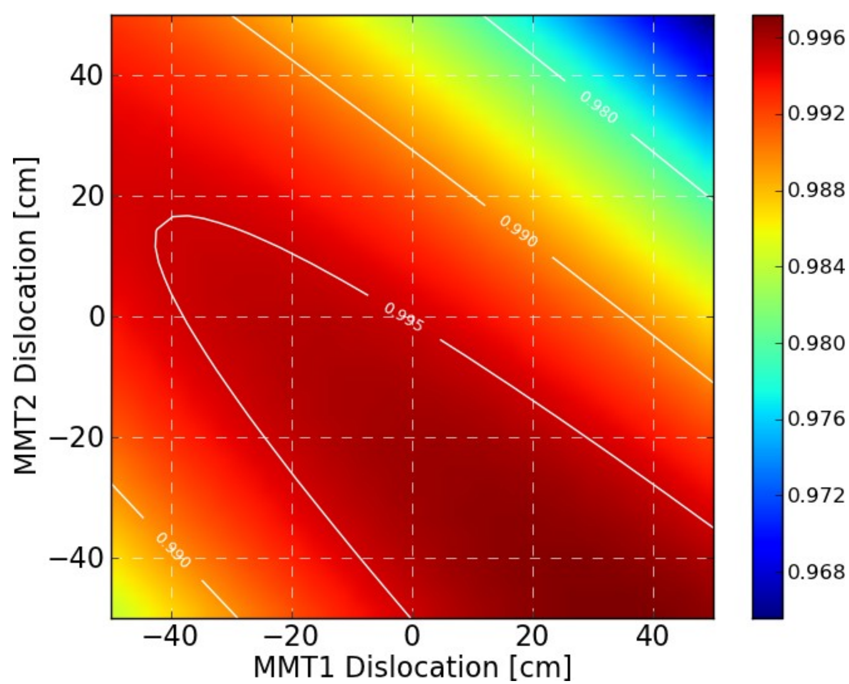
# iLCGT-Ba2

With PRM



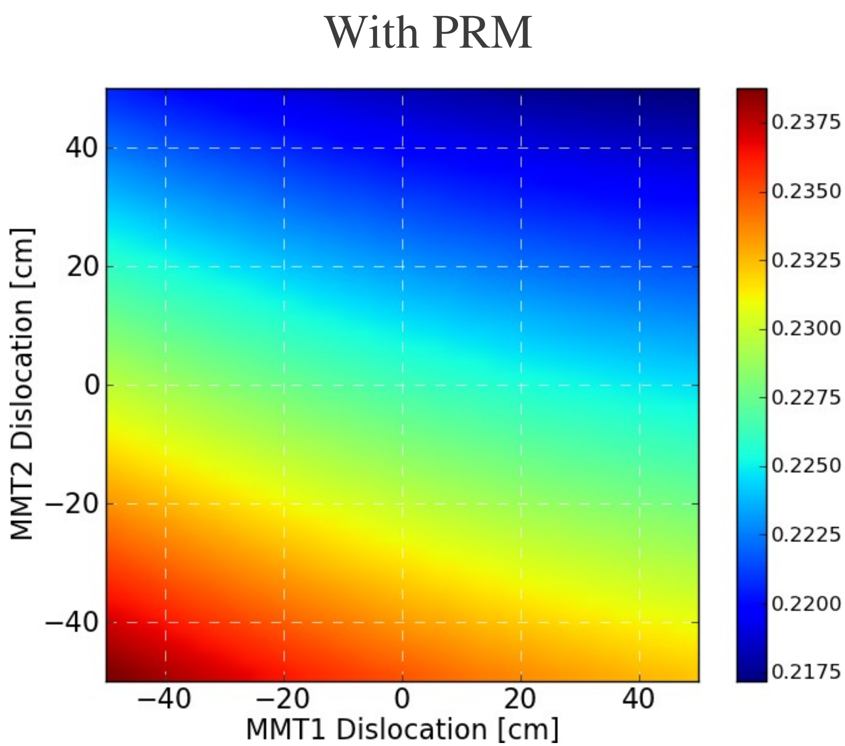

Without PRM

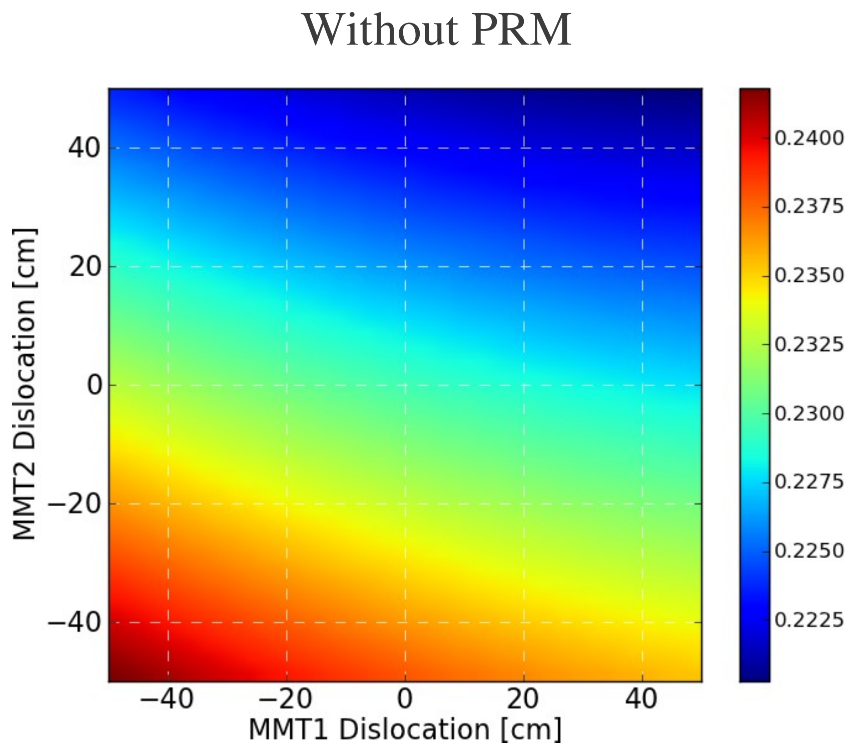



DRMI

# iLCGT-Bb2




# DRMI Cavity is Unstable

# Conclusion

- The input mode matching is good (more than 85%) even without the folding part optimization (b cases) for CSIRO mirrors.
- For iLIGO TMs, the folding part optimization is inevitable.
- Absence of PRM does not degrade the mode matching so much.
- If silica RSE is not necessary (DRMI test is sufficient), iLCGT-Ab2 is probably best, as it provides reasonable mode matching rates for FPMI and DRMI, plus no adjustment of auxiliary mirror positions is necessary.
- For silica RSE, better mode matching between the RCs and the arm cavities is necessary. In this case, iLCGT-Aa2 is best.
- If CSIRO mirrors are not available, we should employ iLCGT-Ba2.

# Appendix A

Procedure for optimizing the folding part of the recycling cavities.

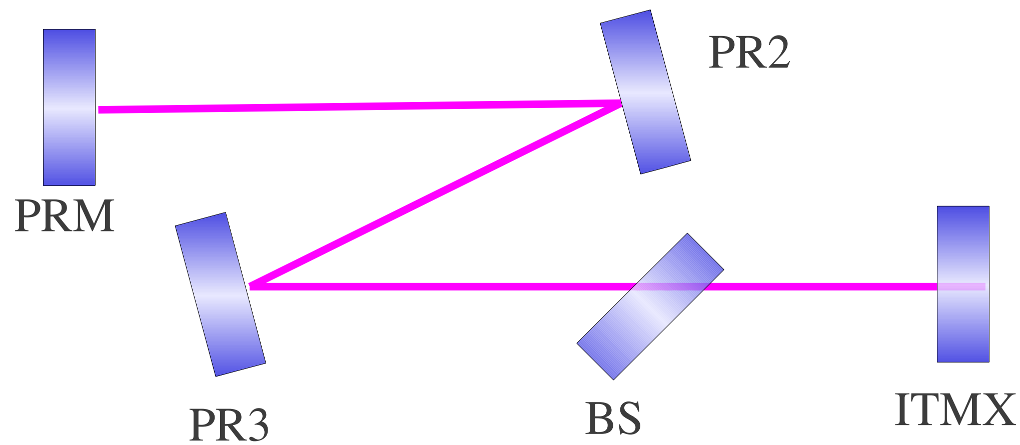
# 1st. step: Optimize the ROCs of PR3 and PR2 for bLCGT

Method

- Propagate a beam matching the arm cavity mode from ITMX to PRM
- Repeat this with different combinations of PR3 and PR2 ROCs.
- PRM ROC is set to the ROC of the beam hitting PRM.
- Do the same for SRC

Target

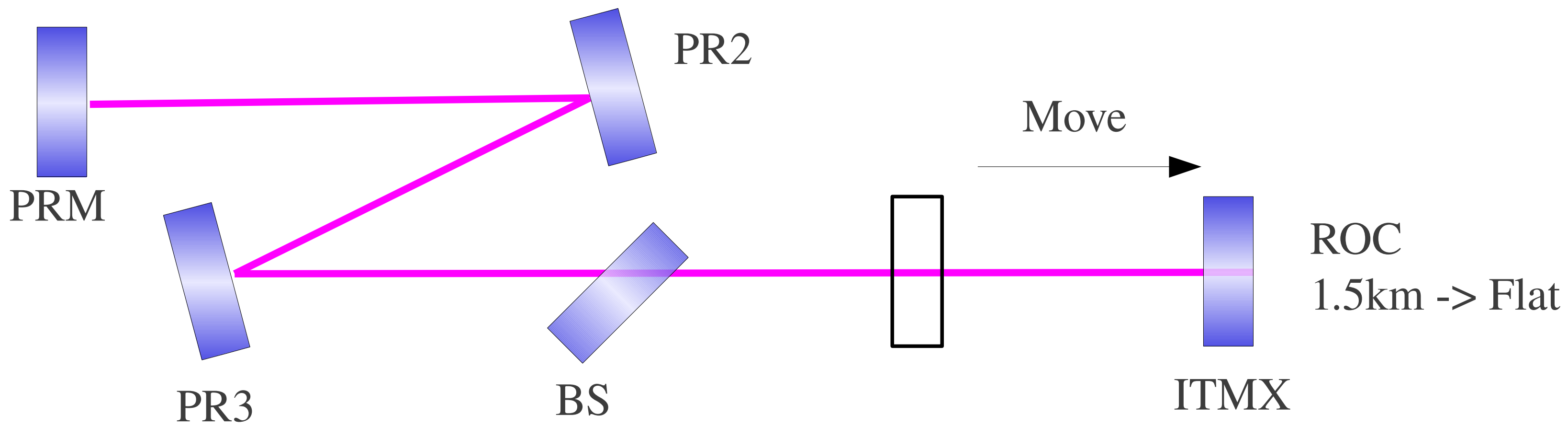
- Gouy phase change from ITMX to PRM is 20 deg.
- Beam spot sizes on PR2 and PRM are equal




PRC/SRC parameters after the optimization

| PRM ROC | PR2 ROC | PR3 ROC | PRM Spot Size | PR2 Spot Size | PR3 Spot Size |
|---|---|---|---|---|---|
| 303.96m | -2.763m | 24.574m | 4.03mm | 4.03mm | 36.48mm |
| **SRM ROC** | **SR2 ROC** | **SR3 ROC** | **SRM Spot Size** | **SR2 Spot Size** | **SR3 Spot Size** |
| 303.96m | -2.776m | 24.584m | 4.03mm | 4.03mm | 36.33mm |

# 2nd step: Move and Change ITMs

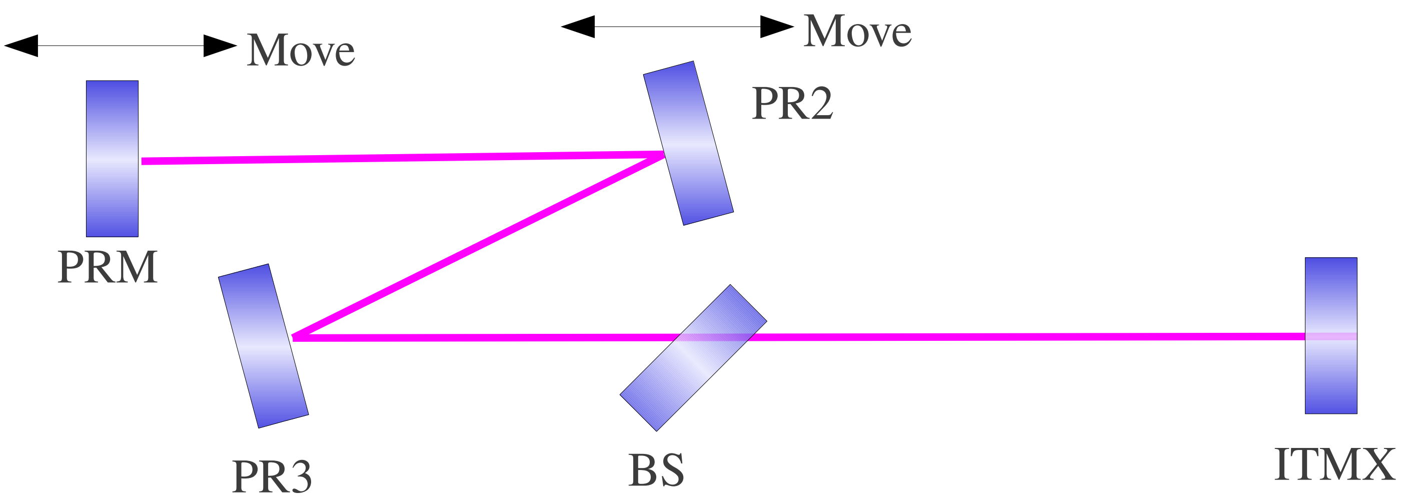



Need to tweak the positions and orientations of PR2, PR3 and BS to make the beam normal incidence to ITMs

## Test: Is this PRC stable ?

- Calculate the round trip (PRM -> ITM -> PRM) ABCD matrix
- See if $-1 < (A+D)/2 < 1$ is satisfied ===> No ! $(A+D)/2 = -1.85$
- We cannot use this configuration.

# 3rd step: Tweak the distance between PR2 and PR3



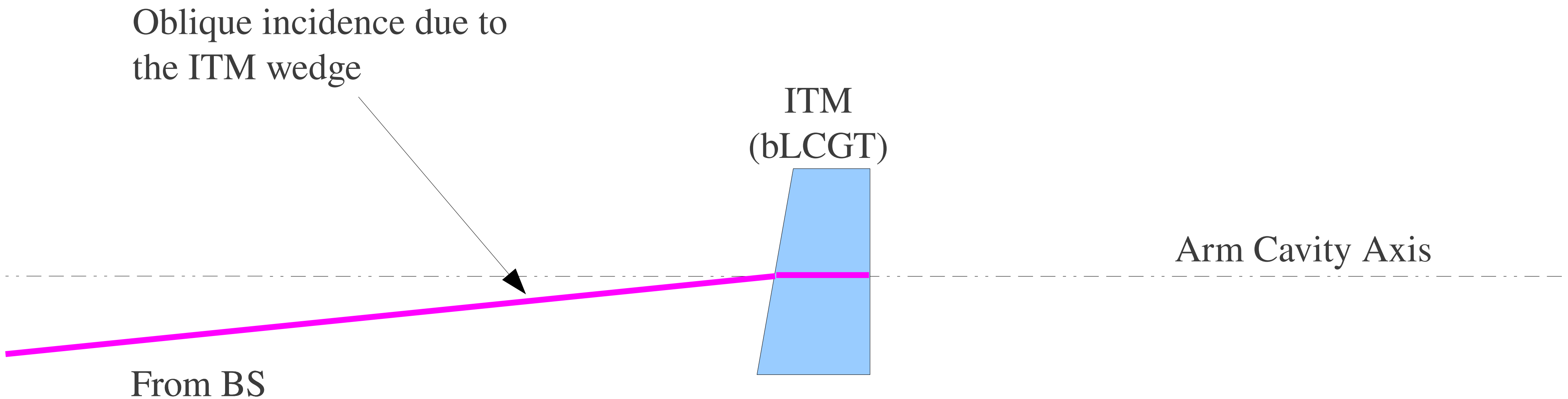

- Keep the PRC length unchanged
- Find the optimal displacement to match the eigen mode of PRC with the arms
- By moving PR2 by 17cm and PRM by 34cm, the two modes match very well

Mode matching between the input beam from MMT and the PRC eigen mode = 99.8%
Mode matching between the PRC eigen mode and the arm cavity eigen mode = 99.99%

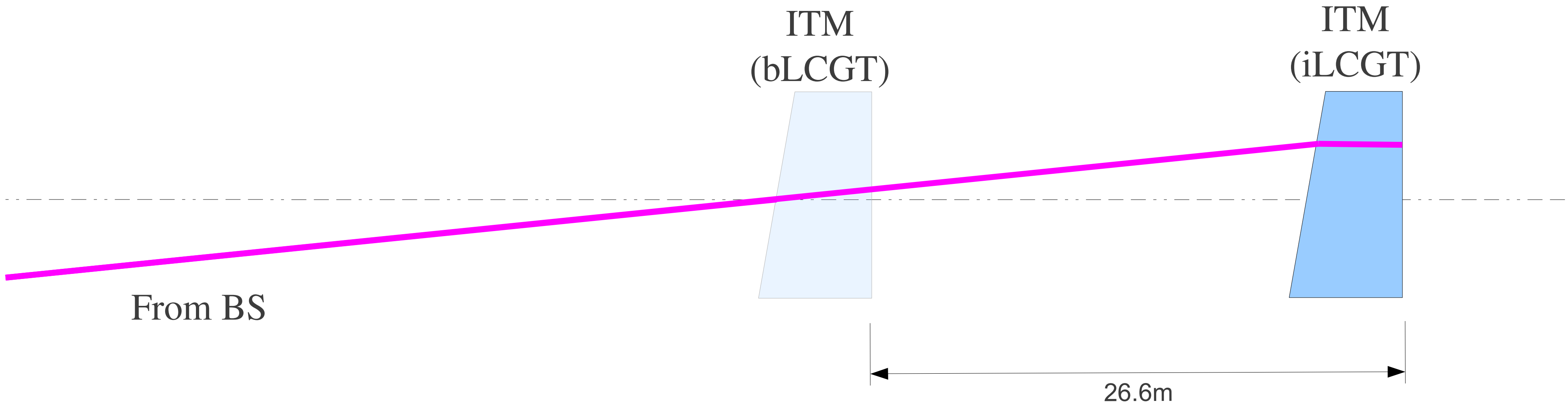
(Using the same mirrors and the same MMT, optimized for bLCGT)

# Appendix B

## Geometric layout correction for iLCGT

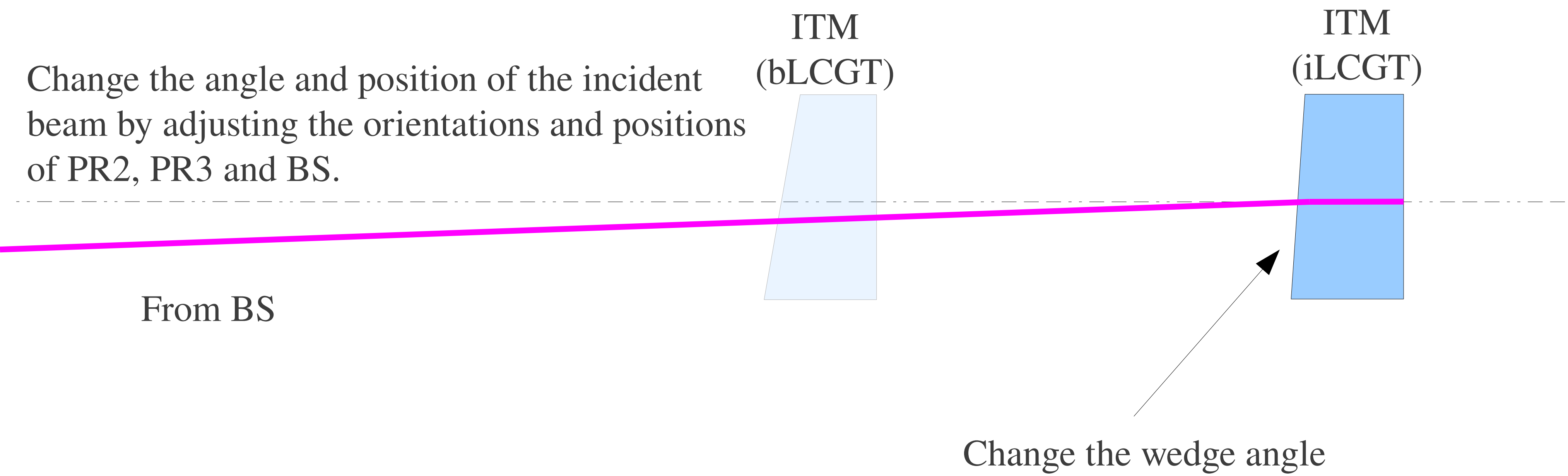

Oblique incidence due to
the ITM wedge
ITM
(bLCGT)
Arm Cavity Axis
From BS

The beam does not hit the center of the ITM if we just move it by 26.6m



# Adjustment Method 1

- Move BS and PR3
- Maximum shift ~ 2cm
- Also adjust SRC



# Adjustment Method 2

- Laterally move ITM
- Do not touch other mirrors
- The beam does not go through the optical window on the GV