Mode Matching to in-air cavity

MMT = Mode matching telescope
MML = Mode matching lens

Initial plan

- [x] Beam scan after SM2 -> Which is now a 50-50 BS for s-polarization light
- [x] Calculate the waist size necessary for the cavity
- [x] Measure lengths for approximate (waist position) cavity location
- [x] Insert parameters into JAMMT
- [x] Install MMT
- [x] Take another scan somewhere after the telescope to verify the solution
- [ ] Do best to match JAMMT to on-table situation
- [ ] Install cavity
- [ ] Calculate, Measure and Install all that is necessary for REFL PD
- [ ] Fine-tune cavity

10-23-2019

- Set up 2 Lens MMT after SM2
  - f_MML1 = 57.4 mm
  - f_MML2 = 171.9 mm
  - **Note:** there should probably be a standardized procedure to make sure the center of the lenses will be at the same location within the holders
- We set up the MMT and steering mirrors but are having issues with the rough waist position
- The only way to know how well the mode matching solution agrees with the JAMMT solution is to measure the lengths from all the optics after SM2 and scan the beam from after the last steering mirror

10-24-2019

- [x] Measure the lengths between installed optics after SM2
  - SM2 to MML1 : 4 and 20/32 inches (.1174 [m])
  - MML1 to MML2: 10 and 16/32 inches (.2667 [m])
  - MML2 to SM3*: 6 inches
  - SM3* to SM4*: 2 and 15/32 inches
  - SM4* to SM5*: 19 inches

    - Total distance between SM2 and SM5*: 1.08 meters
- [x] Beam scan from SM5*
    - Results:

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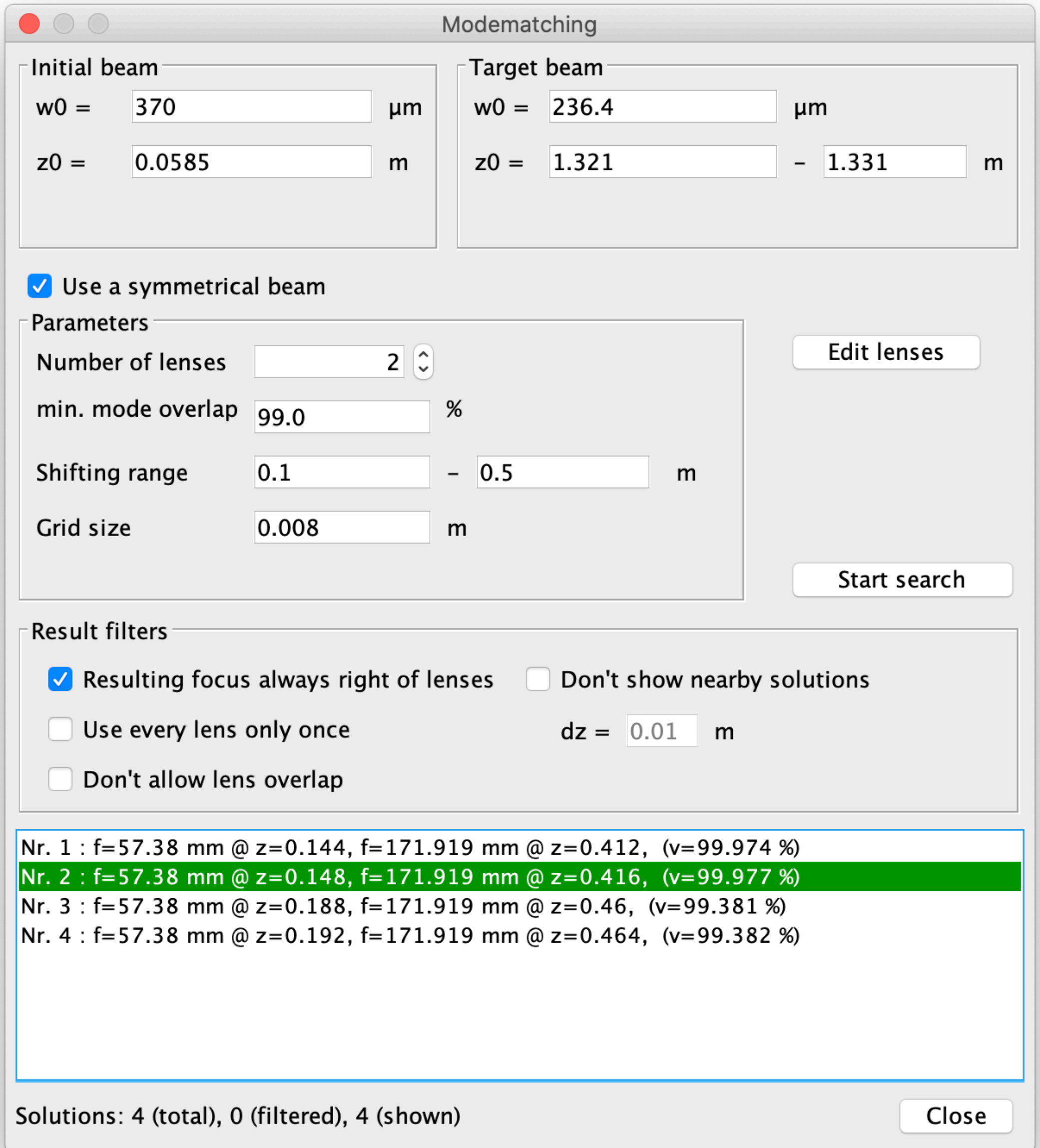
    - Report two sets of measurements between the two scans:
        - Between u and v and minor and major respectively:
            - U (x) vs minor:
                - Waist position difference: 7 mm
                - Waist size difference: 20 um
            - V (y) vs major:
                - Waist position difference: .8 mm
            - Waist size difference: 1 um
    - JAMMT solution was set so that the beam waist is to be approximately 1.330 (1.325-1.335) meters away from SM2
    - The measured x-waist position: 1.08 [m] + .338 [m] = 1.418 [m]
    - Discrepancy of .008 [m] = 3.46 inches
- [ ] Write log entry on which part of DataRay Software we should be measuring (consult with WinCamD manual) **[DRAFTED]**
    - Summary of what we want to measure:
        - Standard gaussian beam diameter / radius measurements (Where the intensity drops off 1/(e^2))
            - DataRay by default sets this for Clip[a]
            - To set the u-axis as the x-axis and the v-axis to the y-axis, set the cursors to zero degrees
- [x] Consult JAMMT solution again
    - How well reality reflects the model
        - [x] Double check solution with proper lenses



- This assumes a beam size of 231.345 [um] at 1.331 [m]
- Can actually perform a bit better with MML1 at 1.488 [m] which will shift your beam to 1.346 [m] away
- Also suggests that if I am about a .8 mm off with the placement of MML1 then:
  - The beam position shifts by about .015 [m]
  - The beam size shifts by about 236.153 [um]
- If we assume that this change is linear, then we can say that the final waist position shift and size shift (respectively) for a change in length between the two MMLs are: .01875 [m]/[mm] (or .74

[in] / [mm]) and 6 [um]/[mm]

- [x] Shift lenses to measured positions
    - With the measured positions we estimate that the waist size is 236.702 [um] and is 1.313 [m] away from SM3*
    - A secondary scan today revealed that the beam waist should be at 1.418
    - This amounts to a discrepancy of .105 [m]

- [ ] Tackle discrepancy between JAMMT solution and solution on the table
    - Currently are not including error bars on our length measurements
        - [ ] Re-measure lengths and add error bars
    - Currently have not created a standardized procedure for centering the lens in the holder.
        - [x] Re-install lenses that are approximately set (MAY NOT BE NECESSARY IF WAIST SIZE IS GOOD ENOUGH. CALCULATE % MM GIVEN SCAN MEASUREMENT [Power overlap])
    - Is astigmatism problematic?
        - Possibly (can include astigmatism in power overlap integral to see how bad mode matching might be)
- [x] Calculate mode overlap percentage
    - [x] Symmetric beams
    - [x] Asymmetric beams

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Assuming Asymmetry

$$E_{inp}(z=z_{cav}) = A_{inp,x}A_{inp,y}\, e^{\left(-\frac{x^2}{w_{inp,x}^2}-\frac{y^2}{w_{inp,y}^2}\right)}$$

$$E_{cav}(z=z_{min}) = A_{cav}\, e^{-\left(\frac{r^2}{w_0^2}\right)}$$

$$\frac{\left|\int \cancel{A_{cav}A_{inp,x}A_{inp,y}}\, e^{\left(-\frac{x^2}{w_{inp,x}^2}-\frac{y^2}{w_{inp,y}^2}-\frac{x^2}{w_{cav}^2}-\frac{y^2}{w_{cav}^2}\right)}\, dA\right|^2}{\int \cancel{A_{inp,x}A_{inp,y}}\left(e^{-2\left(\frac{x^2}{w_{inp,x}^2}+\frac{y^2}{w_{inp,y}^2}\right)}\right) dA \cdot \int \cancel{A_{cav}^2}\, e^{-\frac{2r^2}{w_{cav}^2}}\, dA}$$

$$\frac{w_{cav}^2 - w_{inp,x}^2}{(w_{inp,x}w_{cav})^2}$$

$$\frac{\iint e^{-x^2\left(\frac{1}{w_{inp,x}^2}-\frac{1}{w_{cav}^2}\right)-y^2\left(\frac{1}{w_{inp,y}^2}-\frac{1}{w_{cav}^2}\right)}\, dx\,dy}{\iint e^{-2\left(\frac{x^2}{w_{inp,x}^2}+\frac{y^2}{w_{inp,y}^2}\right)} \cdot \int e^{-\frac{2(x^2+y^2)}{w_{cav}^2}}\, dx\,dy}$$

$$= \frac{\left(\sqrt{\pi\frac{w_{inp,x}^2 w_{cav}^2}{w_{cav}^2-w_{inp,x}^2}}\cdot\sqrt{\pi\frac{w_{inp,y}^2 w_{cav}^2}{w_{cav}^2-w_{inp,y}^2}}\right)^2}{\sqrt{\pi\frac{w_{inp,x}^2}{2}}\cdot\sqrt{\pi\frac{w_{inp,y}^2}{2}}\cdot\left(\sqrt{\pi\frac{w_{cav}^2}{2}}\right)^2}$$

$$\frac{4}{\sqrt{(w_{cav}^2-w_{inp,x}^2)(w_{cav}^2-w_{inp,y}^2)}} \cdot \frac{\left(\sqrt{w_{inp,x}^2 w_{inp,y}^2 \cdot w_{cav}^4}\right)^2}{\sqrt{w_{inp,x}\, w_{inp,y} \cdot w_{cav}}}$$

$$\frac{w_{inp,x}^{\cancel{2}}\, w_{inp,y}^{\cancel{2}} \cdot w_{cav}^{\cancel{4}\,2}}{\cancel{w_{inp,x}}\,\cancel{w_{inp,y}} \cdot \cancel{w_{cav}^2}}$$

$$\eta = \frac{4\left(w_{inp,x}\, w_{inp,y}\,(w_{cav}^2)\right)}{\left(\sqrt{(w_{cav}^2-w_{inp,x}^2)(w_{cav}^2-w_{inp,y}^2)}\right)^2}$$