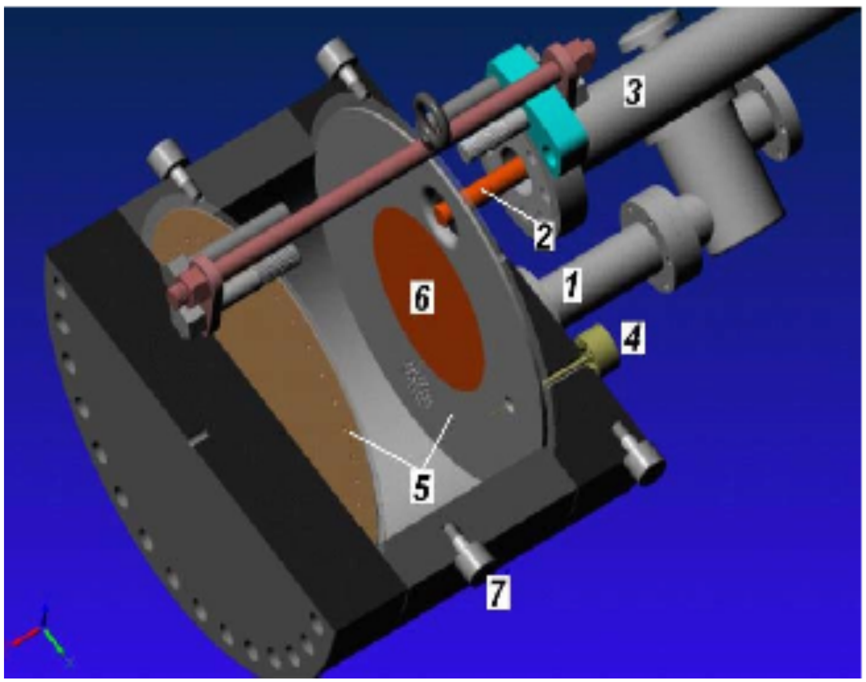
Beryllium tests with the All Seasons Cavity (ASC)

A joint effort between Muons, Inc, Los Alamos National Lab, & Fermilab

- Following slides represent information collected from:
  - Gregory Kazakevich, Mike Neubauer, Al Dudas, Jim Nipper, Rol Johnson (Muons, Inc.)
- Further details can be found in the backup slides

Quick introduction to the cavity

- The ASC largely funded by LANL, built by Muons, Inc., and resides/conditioned at FNAL.
- Designed to run with vacuum, pressure, and modular enough to test variety of material options .



The All Seasons Cavity:
1.vacuum port
2.Antenna
3.RF coax feeder
4.Probe
5.Test plate holder
6.Test plate to study material property at high gradients
7.roller

RF properties of the cavity

- Computed f_0=812.69 MHz; Computed $Q_0=2.703 \times 10^4$
- Measured f_0=810.16 MHz; Measured $Q_0=3.0 \times 10^4$

Parameters of the cavity vs. gradient of the RF field

Gradient, MV/m	Stored Energy, J	Wall loss power, MW	Feeder voltage, kV	*Average wall loss power, W
20	4.715	0.754	8.68	133.0
25	7.367	1.178	10.85	207.8
30	10.61	1.697	13.03	299.2
35	14.44	2.309	15.2	407.3
40	18.86	3.016	17.37	532.0

***Average wall loss power for pulse duration of 20 μs at the repetition rate of 15 Hz and considering reflected power**

Cavity sealing surfaces

- Key elements of the cavity:
  - Cylindrical body (SS 316 with copper plating (25-37µm)
  - Two test plate holders that allow a variety of inserts to be tested (Be etc)
  - Silver plated SS 316 bolts used to assemble end plates to cylindrical body
- Cavity designed for both vacuum and pressure operation
  - A lot of effort in surface prep for vacuum

Old technology

New technology

Current Status of ASC

- Completed first round of conditioning:
  - 16.3 MV/m
  - Vacuum seal in coupler broke (epoxy coupler-originally designed for pressure)
- Rebuilt coupler without epoxy, this time we have a dielectric window and will run SF6 on upstream side.
- Cavity assembled and leak checked 06/03/11
- Currently pumping down (in Linac gallery) – vacuum currently ~$1.6x10^{-7}$
- Hope to start conditioning again soon

Current Status of ASC cont.

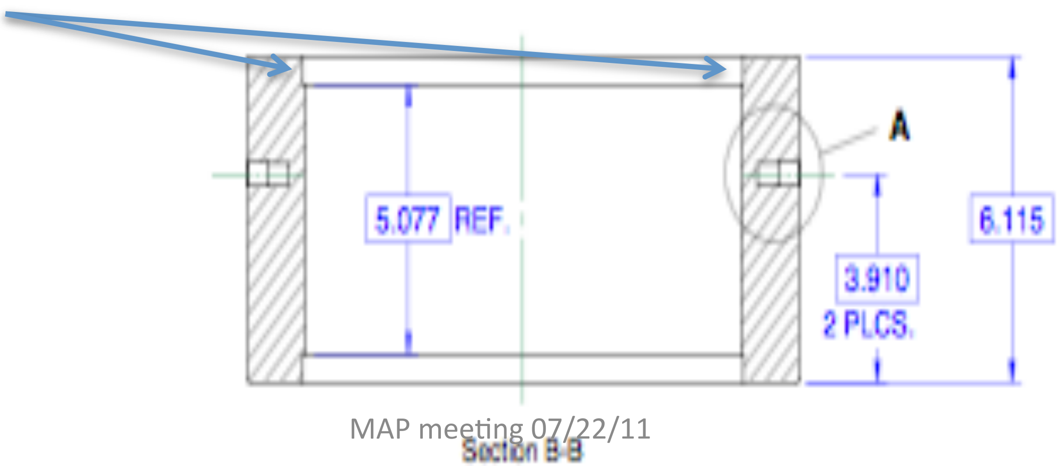
- Goal is ~25 MV/m this time
- Once this is done-- wait our turn to run in the magnet.
- In parallel with next round of conditioning:
  - we are re-evaluating what we need to have ready in order to run in the magnet (vacuum adapter etc).
  - Preparing for Be test plate testing

Moving toward testing Be end plates

- Currently working out details of mounting options (trying to make sure we optimize the electrical and rf properties when inserts are added to the cavity).
- Option 1:
  - Be covers the entire inner diameter of cavity ends.
  - Need to study flexing etc
- Option 2 (in backup slides):
  - Smaller diameter Be insert
  - Probably more involved machining/mounting
  - Ends up being closer to a button test
- Will focus on option 1

Option 1: Be covers full Inner Diameter of cavity

- If Be disc covers the full ID of the cavity
  - we need to thin (or remake) existing test plate to make room for/incorporate Be disc, then refinish surfaces to make sure vacuum surfaces are still good.
  - Make sure Be is thick enough to avoid flexed membrane type situation (need to model this)/or have different configuration.
  - Make sure there is a good connection between Be disc and the lip in the cavity body that it will sit in.



Distortion of Be disk clamped at the circumference

- From simple calculation (see backup slides for details):
  - Found that the deflection of the Be disk ~0.697 mm per 1 K.
  - This results in a frequency shift of ~4.37 MHz
    - Note: this is for very thin disk and we clearly expect to do much much better than this.
- Need to ANSYS calculations with total power dissipation with appropriate density profile center to edge and the heat conduction of SS to fully understand this (more detail in backup slides).
  - Need some time to do this.

Another test plate construction possibility

- Currently talking with Brush-Wellman Electrofusion
  - They can diffusion bond Be plate to copper or other materials
  - 12-13 week lead time on delivery (part machined to fit the cavity)
  - No cost estimate yet
- Need to understand what is best material to bond to

Possibilities of materials to bond to

- We would like to match the thermal expansion of the Be so unwanted stresses do not build up that may delaminate the Be from the backing plate.
  - We do not know what sheer stresses the diffusion bonding can withstand.
- Elkonite with a thermal coefficient of expansion (TCE) matching Be would be preferred (Elkonite is a copper and tungsten matrix “alloy”)
  - Elkonite “1W3” TCE=11.7
  - Be TCE=11.3

Effect of flat end walls

- End walls (the existing test plates) have fake iris structure.
- If we use flat Be disks we change freq and Q of cavity
  - Computed f_0=812.69 MHz -> ~790 MHz
    - (measured f_0 = 810.16 MHz)
  - Q->23170/27030=86% of original
- Need to remake cavity with smaller inner diameter to re-tune cavity (more details in backups)

Beryllium safety at FNAL

- People assembling cavity will need Be training.
- Lab needs to be notified when we bring it on site
- They would like (but not clear it is essential) a surface contamination report before bringing it to the lab
  - We will need to make sure it is clean since it will be in vacuum
  - If it comes directly from Brush Wellman this is easy, if we re-machine it we will have to do it ourselves
- May need to think about filtering vacuum exhaust
- Main question comes when we are finished– will need a procedure for opening it up (in case of damaged surface)
  - Not a big deal, been done before
- Mainly just need to make sure we are trained and keep in touch with Raymond Lewis (he is already familiar with the cavity)

Be summary/to-do list

(all items can be done in parallel with current copper conditioning work)

- Need ANSYS calculation to understand distortion of disk
- Determine best backing material in the case of a bonded disk
- Quotes for Be in the context of both options (simple disk and bonded disk)
- Lead time on materials ~8-13 weeks depending on configuration
- Talking with AD ES&H folks, does not look like a big deal.

Backups

Electrical and thermal properties of the ASC cavity materials

Material	Be	Oxygen free copper	Stainless steel 316
Electrical resistivity, Ω·m	$36 \cdot 10^{-9}$	$15.9 \cdot 10^{-9}$	$7.5 \cdot 10^{-7}$
Thermal conductivity, W/m·K	200	401	14.6
Thermal expansion, m/m·K	$11.3 \cdot 10^{-6}$	$17 \cdot 10^{-6}$	$16.5 \cdot 10^{-6}$
Specific heat, J/kg·K	~1740		465
Density, kg/m^3	1849		7960

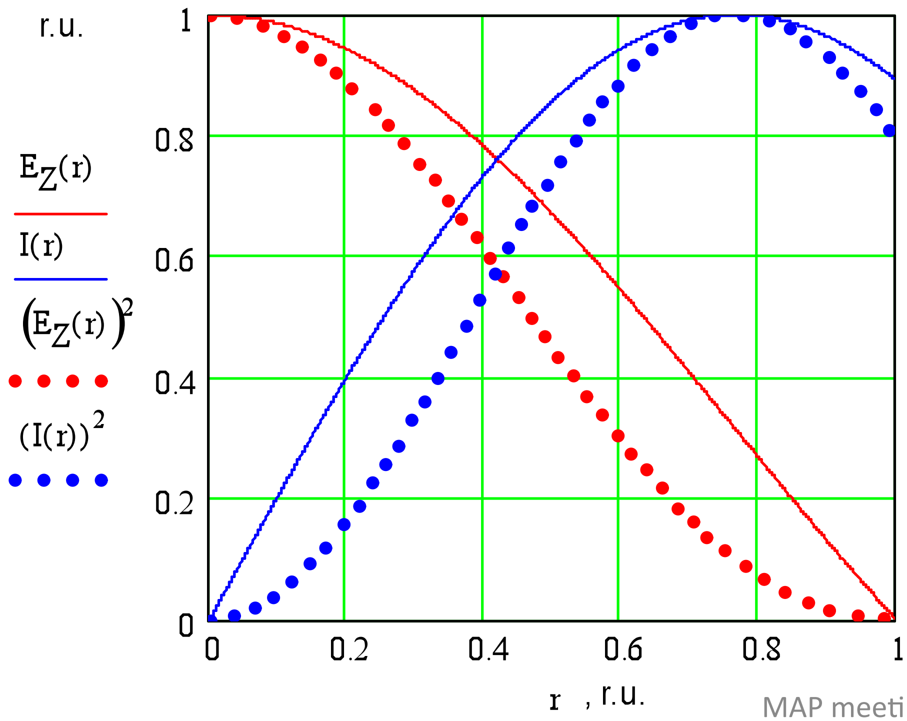
Consideration of dynamics of heating shows that temperature of Be insert should be higher than that for SS part in location where the Be inset is clamped. It means that the radial forces will act on the Be inset during permanent process of heating causing bend of the insert as a membrane clamped on the circular boundary under compressing forces.

Some estimations for 4-seasons cavity

G. Kazakevich, Muons, Inc.

7/22/2011

I. **Distribution of the electric field of E_{010} mode in the cylindrical cavity is described as: $E_Z(r) \sim J_0(\chi_{01} r)$, while for magnetic field distribution is: $H_\phi(r) \sim J_1(\chi_{01} r)$ Radial distribution of currents coincides with distribution of $H_\phi(r)$.**
Radial distributions of the electric field an currents is shown in following figure.



Roughly one assumes that the electric field mainly located at 0<r<0.5, while the magnetic field is mainly located at 0.5<r<1. This gives estimate for the cavity effective inductance:

$$L_{eff} \sim \frac{\mu_0}{2\pi} L \ln \frac{r_{max}}{r_{min}} \quad \sim 1.8 \cdot 10^{-8} \text{ H}$$

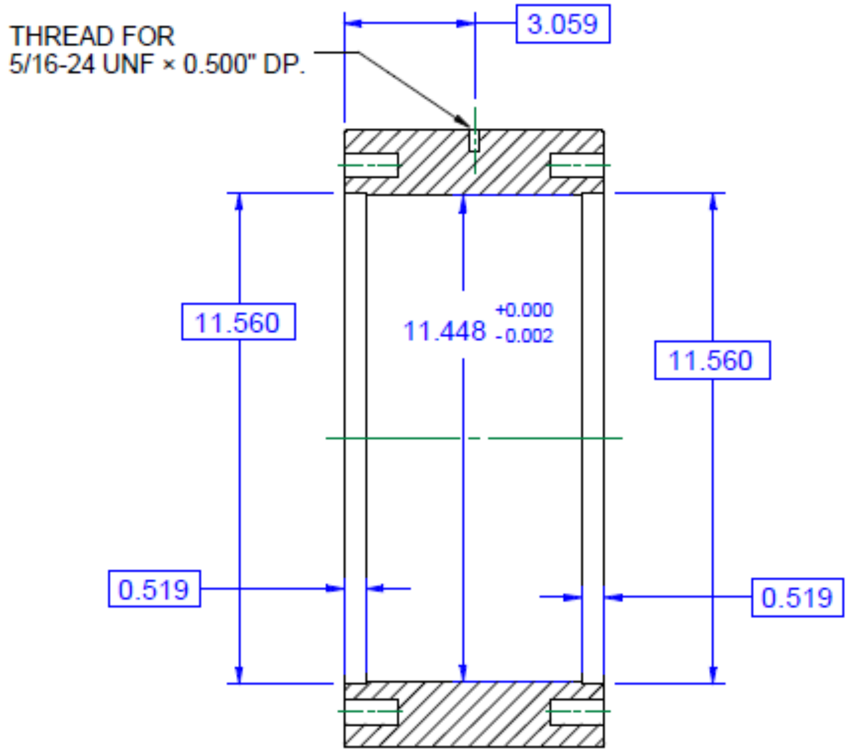
Here: r_{max}=1, r_{min}=0.5, L=0.13 m

By dots are shown space distributions of the electric and magnetic energy in the cavity

Since $Q = \omega \frac{L_{eff}}{R}$, for measured $Q \approx 3 \cdot 10^4$, the cavity impedance, $R \sim 3 \cdot 10^{-3}\ \Omega$

Using $P_{loss} = \frac{RI^2}{2}$ one gets total current through the cavity: $I = \sqrt{\frac{2P_{loss}}{R}}$.

For accelerating field gradient of 25 MV/m, $P_{loss} \sim 1.2$ *MW*; that gives: $I \sim 30$ *kA*.



From design follows that contact surface is at most of ≈ 14 cm², that gives the current density through the contact at least of 20 A/mm², which is very high.

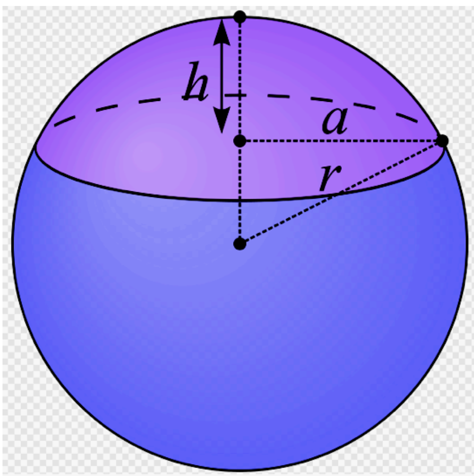
II. **Using flat covers in the cavity will decrease operating frequency to ≈ 789.2 MHz.**

The frequency is out of the operation range of the klystron (805±5 MHz).

To tune the cavity one needs to make the cylindrical part with smaller internal diameter, which has to be 11.2205".

III. *Bend of Be membrane clamped over the circumference*

One considers Be membrane with diameter of *2a = 11.560”* that is 293.62 mm clamped over the circumference. One assumes the temperature difference, ΔT, between the membrane body and clamping parts is in K.



The curved surface area of the spherical cap, A, is:

$$A_{curv} = \pi\left(a^2 + h^2\right)$$

The area is equal to one resulted from thermo expansion of the Be disc overheated by ΔT:

$$A_{\Delta T} = \pi\left(a + \Delta a\right)^2$$

where *Δa = a·k·ΔT*; k = 11.3·10^{-6} m/m·K is the thermo expansion coefficient for Be. The equations results in:

$$h \cong a\sqrt{2k \cdot \Delta T}$$

For our cavity this gives the bend height of 0.697 mm for 1 K. That will shift the cavity frequency in the range of 4.37 MHz

Impact of Changing the top and bottom plates to Be

Mike and Al

Change in Cavity Frequency and Q

- Computed f_0=812.69 MHz; Computed $Q_0=2.703x10^4$
- Measured f_0=810.16 MHz; Measured $Q_0=3.0x10^4$
- With flat walls, now a pillbox cavity Be top and bottom plate
  – 11.448 in =>f0= ~790 MHz computed for -13 MHz
  – Q->23170/27030=86% of original

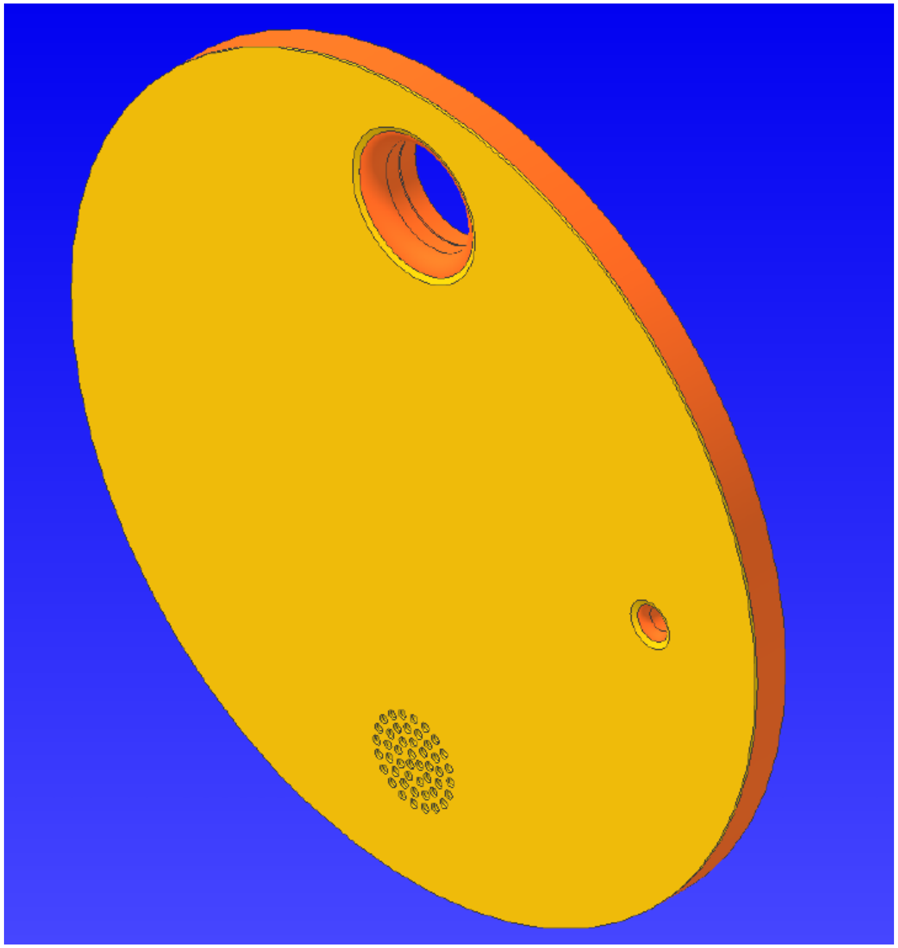
Losses at 25 MV/m

- With copper, 207.8 watts (Grigory's number) are dissipated at 25 MV/m including rise time effects for a 20 μs pulse.
  - 54% of the losses are on the top and bottom walls (assuming a pillbox)
- We Be on the top and bottom there is about a 25% increase in total losses (ignoring rise time effects)
  - 63% of the losses are on the top and bottom wall
  - 207.8*1.25*.63/2=81 watts on each Be plate@ 25 MV/m

What thickness Be plate will distort?

- Need to make ANSYS calculations with 81 watts total dissipation with the appropriate density profile center to edge and heat conduction to stainless steel
  - Need some time to do this.
- Too many variables to make a guesstimate.
- We may find that the Be distortion with 81 watts is acceptable for a .125 thick plate
  - We just don't know at this point.

Possible Construction Details-Bonded



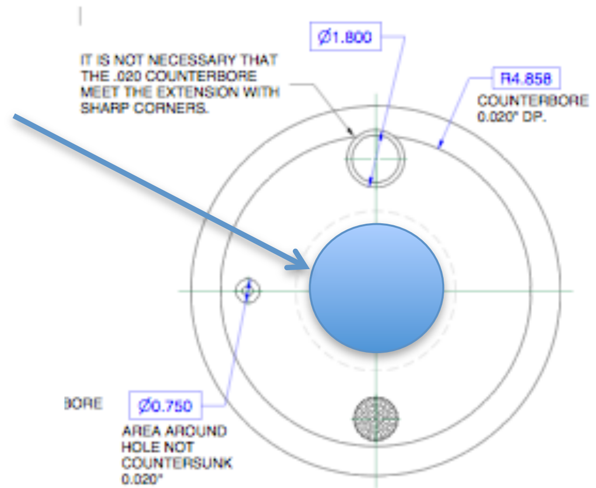
- Al has begun discussions with Brush-Wellman Electrofusion
- They can diffusion bond the Be to a backing plate of copper or other materials
- About 12-13 weeks delivery for a part machined to fit into the cavity
- We do not have an estimate for total $
- We do not know the best material to bond to.

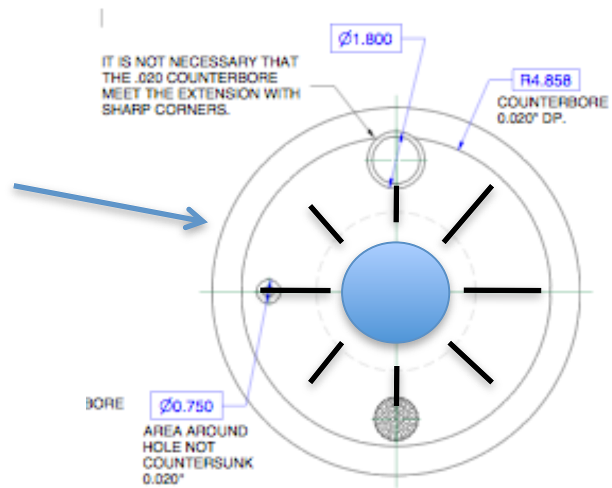
Possibilities of materials to bond to

- We would like to match the thermal expansion of the Be so unwanted stresses do not build up that may delaminate the Be from the backing plate.
  – We do not know what sheer stresses the diffusion bonding can withstand.
- Elkonite with a thermal coefficient of expansion (TCE) matching Be would be preferred (Elkonite is a copper and tungsten matrix “alloy”)
  – Elkonite “1W3” TCE=11.7
  – Be TCE=11.3

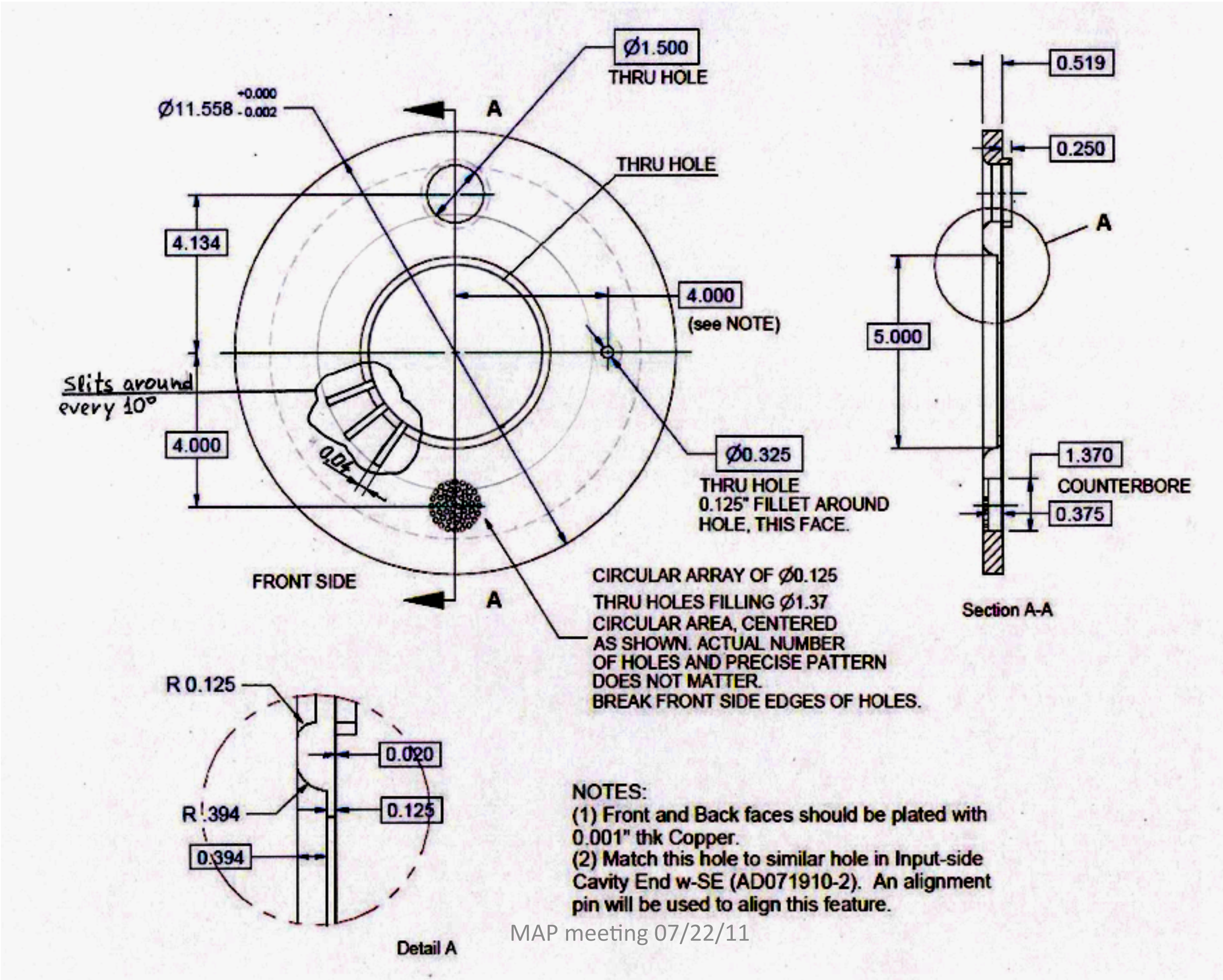
Option 2: small center disc only

- ~6" Be plate mounted in center of test plate
  - Will not effect vacuum
  - Will need to ensure good electrical contact and flushness with test plate.
  - Cold fit Be and finish test plate+Be to make sure everything is flush.
  - All vacuum surfaces etc should be same as current setup
  - Could also consider cutting radial slots into test plate to make a collet then cold fit Be, spring of the test plate will provide good electrical connection
    - In this case make test plate from phosphor-bronze





More detailed look at the collet-style test plate. The material for the test plates is a phosphor bronze.



Cost Estimates (Brush Wellman)

- Note, these probably not be the final dimensions (final dimensions will depend on mounting choice and FEA)

ITEM	DESCRIPTION	QTY	EACH	TOTAL
10	PF-60® Beryllium Sheet Disc 3.175 (±0.127mm) Thick x 152.4mm (±0.127mm) Diameter	2	$ 1,371.00	$ 2,742.00
20	PF-60® Beryllium Sheet Disc 1mm (±0.0762mm) Thick x 292.1mm (±0.127mm) Diameter	2	$ 2,725.00	$ 5,450.00

- Materion-Electrofusion to provide all labor and materials to fabricate parts per description
- Material: PF-60® beryllium, 99.0% Be assay minimum by specification

- Nominal lead time <u>8 weeks</u>
  - cannot expedite due to size
  - Following up to make sure they can deliver Be sheet with required configuration
- Non-Be machine estimates will be done once mounting technique is finalized