Interferometer session 15-26.11.2021:

- Compare timing reference for Interferometer and TS
  → there might be an offset of 100 us in the Fig. 3 of 2018 paper!
  → check relative timing… by recording the 10Hz signal, then PD in front of the tube?
  → (move TS triggering down to 200 us by shifting both flash lamp (10 Hz) and Q-switch triggers)

1. Antenna performance and comparison:
   1. Braided Cu antennas radial scan for **p = 8 Pa Ar, P = 9 kW, B = 350 A** ("TS reference")
      → compare to TS data from Oct. 2021
   2. Helical antennas radial scan (TS reference) + **p = 8 Pa Ar, P = 9 kW, B = 400 A** ("IPP reference")
      → compare to IPP data from 2018
   3. Solid ring antennas radial scan (TS reference)
2. Axial uniformity scan (~~using "most efficient" antenna~~ using available antenna: solid ring)
   1. 4 measurements per position (L,R,L+R,L+R+3) to re-build the respective contributions of each antenna and determination of excitation/dissipation localization.
   2. radial scans at leftmost, center, rightmost axial position
3. Axial uniformity scan (~~using "most efficient" antenna~~ using half-helical antenna)
   1. 4 measurements per position (L,R,L+R,L+R+3) to re-build the respective contributions of each antenna and determination of excitation/dissipation localization.
   2. radial scans at leftmost, center, rightmost axial position
4. (if differences in antennas and time allows) Include directional couplers in the line for refined matching and cross check

- Mon 15.11.2021
  - braided Cu ring antennas are mounted
  - **TS reference measurement**: profile at p=8Pa, Prf=9kW/ant, I=350A
  - high-power measurements (single point) at z=z_center at p=8Pa, Prf=9.5kW/ant and Prf=10.0kW/ant, I=350A and I=400A
  - change to half-helical antennas
- Tue 16.11.2021
  - try to run system as-is with half-helicals → lots of arcing at antenna #3 (pump side)
  - disassembly and check of ant. #3, re-assembly without changes
  - find optimal phase shift between ant. #2 and #3 → optim. phase 208 deg rel. to phi3(master)
  - extremely bad rf system performance, no significant improvement by matching
  - new grounding connections: Brewster windows, pressure gauges, pumping bellow, gas feeding line (to table or Cu base plate)
  - re-do phase shift (#2-#3) resulting in different optimum → optim. phase 147 deg rel. to phi3(master)
  - find optimal phase shift between ant. #1 and #2 → optim. phase 20 deg rel. to phi3(master)
  - increase rf power up to 6 kW/antenna with "optimized" phases (0/147/20) without arcing, but poor matching (and no improvements)
- Wed 17.11.2021
  - optimization of rf system (noise) → CO_2 laser power line re-routing
  - phase scans diff. combinations of antennas
    1. optimum phase shifts independent of rf power (thus plasma density) → rf stray field, not helicon field
    2. phase shifts 1-2 (220 deg), 2-3 (125 deg) and 1-3 (310 deg) incompatible → 2D map is needed for 3-antenna operation
- Thu 18.11.2021
  - 2D scan of phases (30 deg step width) + 10 deg scan around "sweet spot"
  - perform matching at optimum phase shifts
  - increase rf power to maximum achievable value → 6 kW per antenna achieved, arcing at higher powers
  - try to minimize rf noise on detectors (change cable routing, use fiber for CO_2 laser TTL) + piezo signal → **piezo stage failed**
  - install manual translation stage for IF reference arm
- Fri 19.11.2021
  - assess IF operation with manual calibration stage → annoying but works
  - radial scan with half-helicals at p=8Pa, Prf=6kW/ant, I=350A → beautiful profile (!), low density (3.2e20)
  - change to solid ring antennas
  - had to open matchbox #3 to fix rf line connection to capacitor; checked and re-tightened some coil cooling water connections after small leak

- Mon 22.11.2021
  - solid Cu ring antennas are mounted
  - **TS reference measurement**: profile at p=8Pa, Prf=9kW/ant, I=350A
  - “axial scan” by displacing the ring antennas with fixed inter-antenna distance at p=8Pa, Prf=8kW/ant, I=350A
  - change to half-helical antennas
  - planning for intra-coil rf shielding (fixed Cu half-shells do not fit the CERN set-up!)
- Tue 23.11.2021
  - mount rf shield inside coils for improved grounding and reduction of rf stray field
- Wed 24.11.2021
  - test operation with new rf shielding inside magnetic field coils → no big difference.
  - test of different matchbox grounding schemes (template: HGW set-up, MBs grounded via rf lines only)
  - measurement of rf voltages at antennas (directly at MB out).
    → full grounding: clean rf, up to **3 kV absolute** voltage → best for environment, worst for high-power operation
    → no grounding: **rf pollution**, up to 2 kV absolute voltage → best for high-power operation, worst for environment
    → grounding back only: clean rf, up to **2.6 kV absolute** voltage → best for environment, high-power operation…?
- Thu 25.11.2021
  - removed inner screen
  - measure antenna voltages w/ different grounding connections of MBs → final solution: keep mesh at back + dedicated grounding strips from MB screws
  - replace Kapton under antenna #2 (slowly dissolving with constant arcing) → ant#2 disassembled/reassembled
  - after restart: antenna voltages up to 3.7 kV absolute
  - antenna voltage under different (geometry/etc) changes → no change of voltage
  - try different phase setting (arbitrary: 30 / 270 deg) → voltage decreased (2.6 kV at q’n’d best matching)
- Fri 26.11.2021
  - 2d phase scan, done, trial of 3 different settings and measurement of antenna voltage, same range as yesterday, focus on phi1 = 180deg, phi2 = 210 deg with lower voltage (2.7 kV, as yesterday) and lower reflected power (about 3% at 2kW) and kept this for the axial scan.
  - axial density scan, limited to 5kW/antenna due to arcing threshold around 6-7kW -> about 10% uniformity between ant3 and 2 with 2.5-3x10^20 m-3 local density, assuming same parabolic profile btw antennas.

Learnings – physics aspects

1. Antenna comparisons:
   - Rings (braided or solid) antenna at max power (9kW) limited to 3 (TS) to 4 (IF) x10^20 m-3 → thus rings antennas not currently best candidate for high density operation
   - Half helical antennas, reach up to 3x10^20 m-3 at 5 to 6 kW (IF), although not equaling the performances of Greifswald (about 5x10^20 m-3 at 5kW/antenna), where they also could reach AWAKE nominal density → remain best candidate for high density once technical issues (arcing threshold at 6-7 kW) are solved.

   → Good basis to choose the half helical antenna as a baseline for the high density operation of the cell.

2. Radial density profile:
   - Rings antennas show a wide/flat profile, that is also visually observable, and that goes into the direction of a mainly inductively coupled plasma behavior.
   - Half helical antennas profile identical to what has been observed in Greifswald, with strong blue-core visual aspect, larger gradient at the edges, thus less inductive coupling and more helicon wave heating.

   → Confirm the choice of #1 above.

3. Axial density distribution (by moving antennas around the IF port):
   - Both antennas show density variations of 10 to 15% total, relative variations slightly smaller. But different shapes.
   - Ring antenna shows a deep in the center (and one side as well)
   - Half helical antenna shows a more peaked profile, as one would expect from what has already been done with axial density profile with one antenna.

   → First measurement of the axial density done, not necessarily great, but still not too bad in the current setup configuration (moving the antennas, B-field uniformity, limited power, matching, etc…), will maybe be different at higher density for the half helical antenna case.

Learnings – technical aspects

1. High voltage on the antennas (half helical case, not measured with rings antennas) resulting in arcing:
   - Up to 3.7 kV on the antennas, can be changed within limited range with matching and phases shifts and can also be changed by the grounding scheme of the matchboxes (full mesh on both sides, highest voltage, mesh on one side only, smaller, no mesh, RF cables only lowest voltage a the expense of large RF noise)
   - After all trials to match Greifswald conditions, one of the remaining difference is the RF cable length that may have an impact on this voltage (standing waves effects - reflections), that are 2x longer at CERN (about 8 m for the longest)

   → This is the main limitation of the system to achieve high power without arcing.

   → Need to investigate further and understand how to control this (simulations of the Rf circuit, test with shorter/longer cables with the ones of Greifswald), etc.

2. Matching/Phase shift:
   - 1D phase shift scan worked for ring antennas (as started last July), 2D phase shift mapping is a good tool for the half helical antennas (with the 3 antennas we have now) to approach an optimum of matching of the system running the 3 antennas at the same time.

   → Defined method for matching the system.

3. Grounding, cable routing and RF noise:
   - RF can damage the piezo actuator (was replaced then by manual actuation, need to purchase new ones)
   - RF can stop the tubomolecular pump, need to insert in-vacuum RF shielding, and possibly rings to end the cell?
   - Re-routing of laser power cable, coaxial cables of the IF detectors, replacement of the laser control signal coaxial cable by an optical link, etc.

   → As usual, to be optimized in order to limit the noise on the instrumentation and diagnostics.

To do list:

- Antenna voltage, RF issues/understanding:
  - Get RF cables from Greifswald to evaluate impact of cable length (standing wave, etc.) on antenna voltage, with simulations and tests, find optimal length and extrapolate to tunnel conditions (are 30 m +/-) possible, etc.
  - Measure voltage at different location in a non-intrusive manner afap
  - Possible simulations for electrical scheme, matching, etc., with CERN, EPFL, and/or external consulting Solayl?
  - Discuss RF with Steffen Dobert -> effect of cable length, shielding, ground schemes, how to lower the antenna potential, etc.
  - Trial of EPFL resonant antennas x3 bird cages for 50 mm diameter quartz tube → launch calculation and fabrication
  - “Flexible”RF cable in btw type-N and 7/8’’ + connectors -> viable for our voltages/power conditions?

- General lab improvements:
  - Coils spacer, especially for edge coils and/or new SS316 angle pieces to replace the Al ones.
  - Extra coils from Olaf? And the ones at CERN mounted in parallel? Adapt the manifolds accordingly.
  - Manifolds/hoses and fittings renewal?
  - 2^{nd} emergency switch outside (control rack side)
  - 2 HV probes measurements -> find 2^{nd} hook
  - 2 current probes (open loop, 60A max.) + HV isolation!

- Diagnostics:
  - Buy new piezo actuator + 1 spare (quotation received, 10 weeks lead time)
  - potential new diagnostics option: µ-wave cut-off measurement (MPP, O. Reimann → contacted and interested) → meeting?

Side stories:

- 17 mm inner diameter quartz tube (available)? And what would be the influence of the tube diameter on plasma characteristics?