LHC Integration of a Crab Cavity

(A first update)

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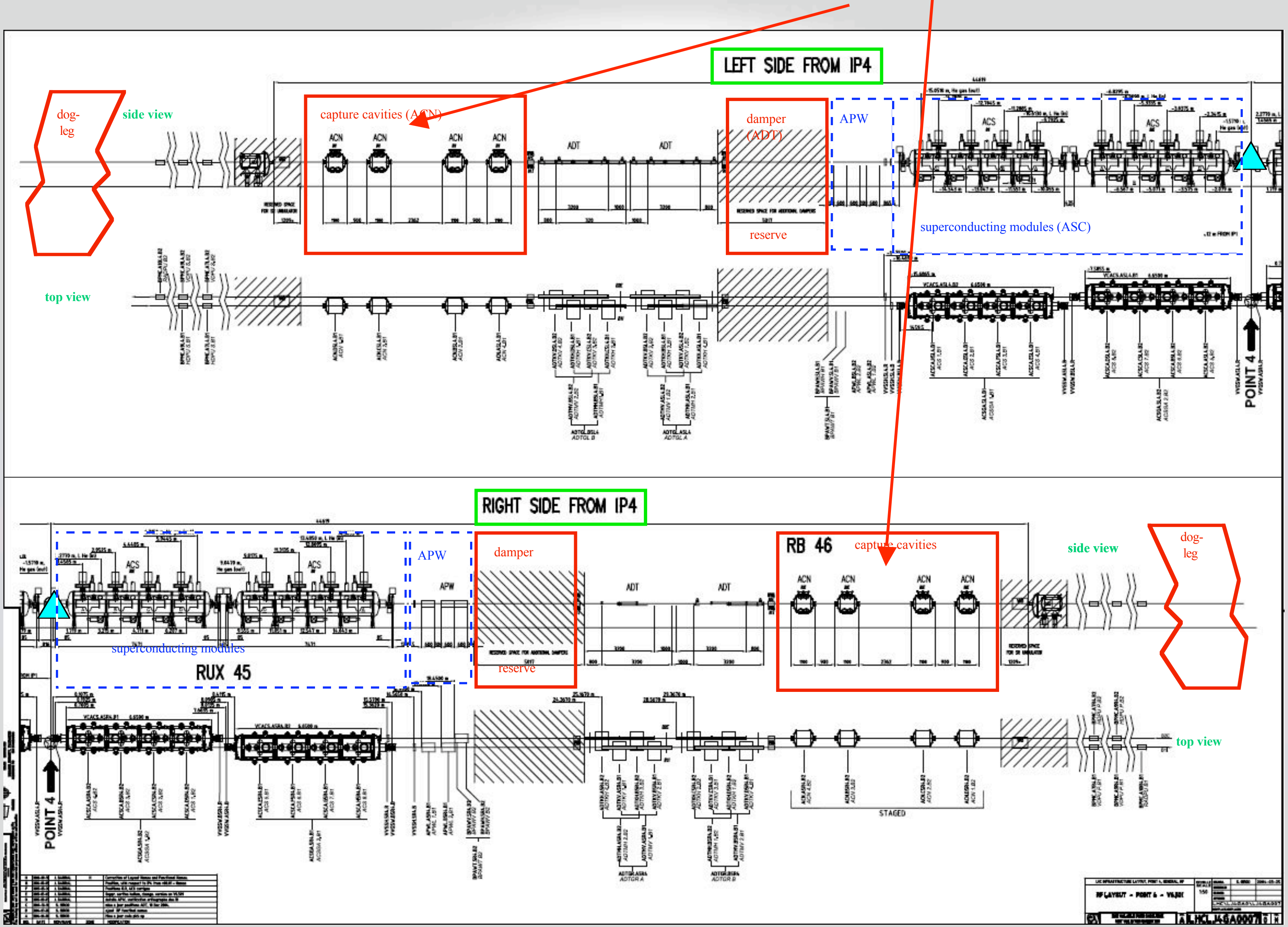
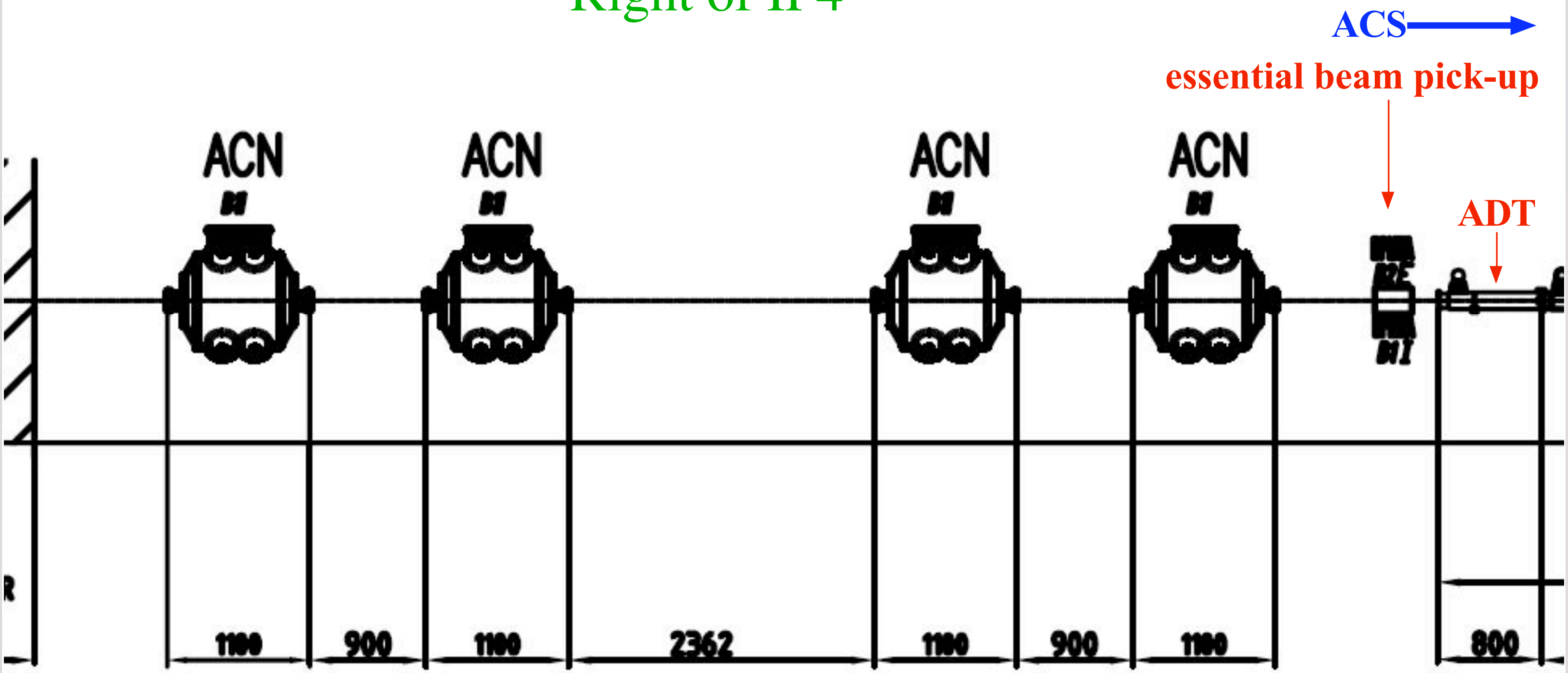
- ‘Consensus’ at the BNL WS
- Cavity/Cryostat requirements
- External requirements
- Conclusions

• Global Option •Location: P4 at (staged) ACN location

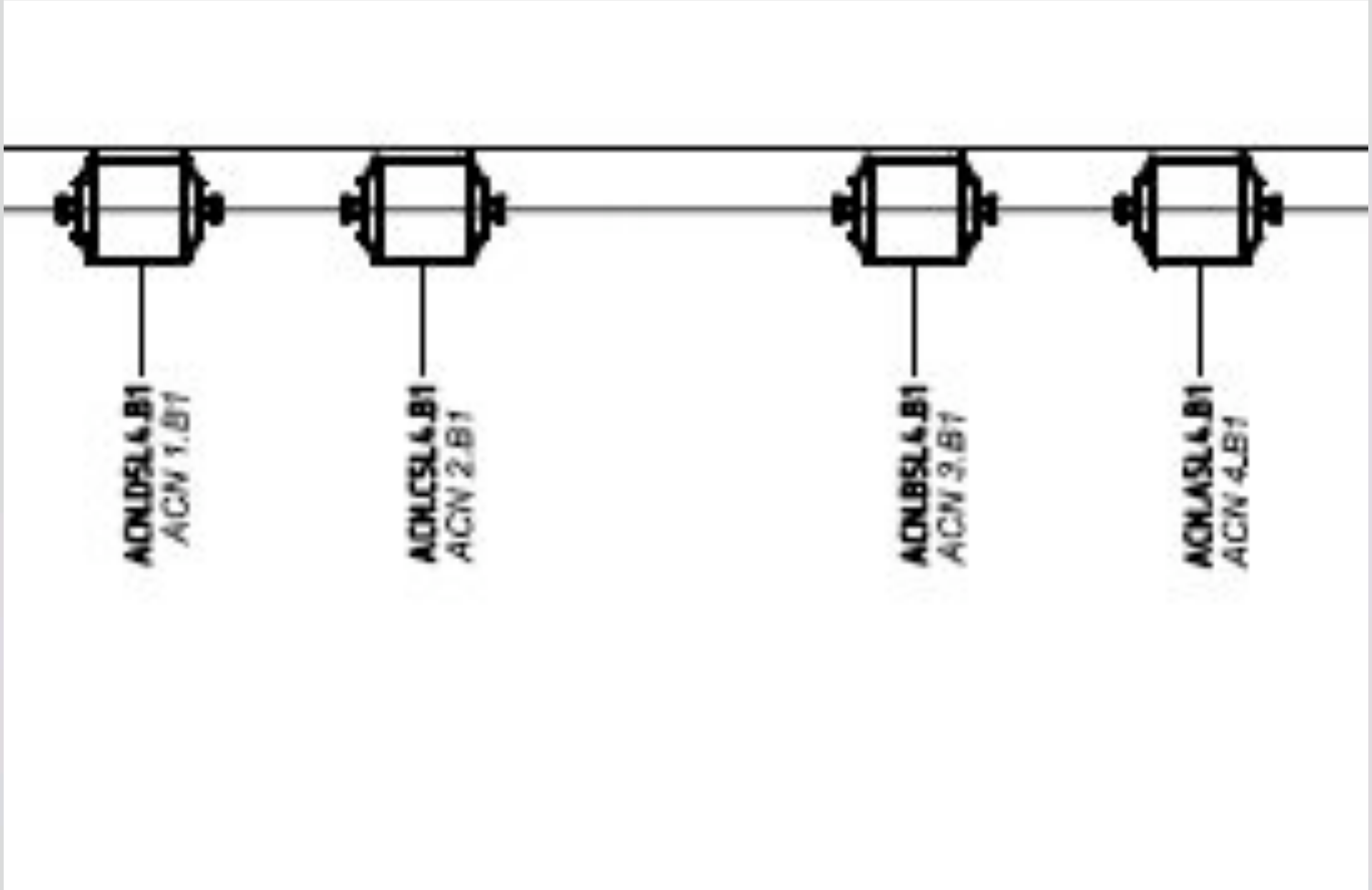


Right of IP4



When ACN are needed: <u>Crab Cavity has to make room</u>

(?? for higher intensity, at least 1 year forewarning)

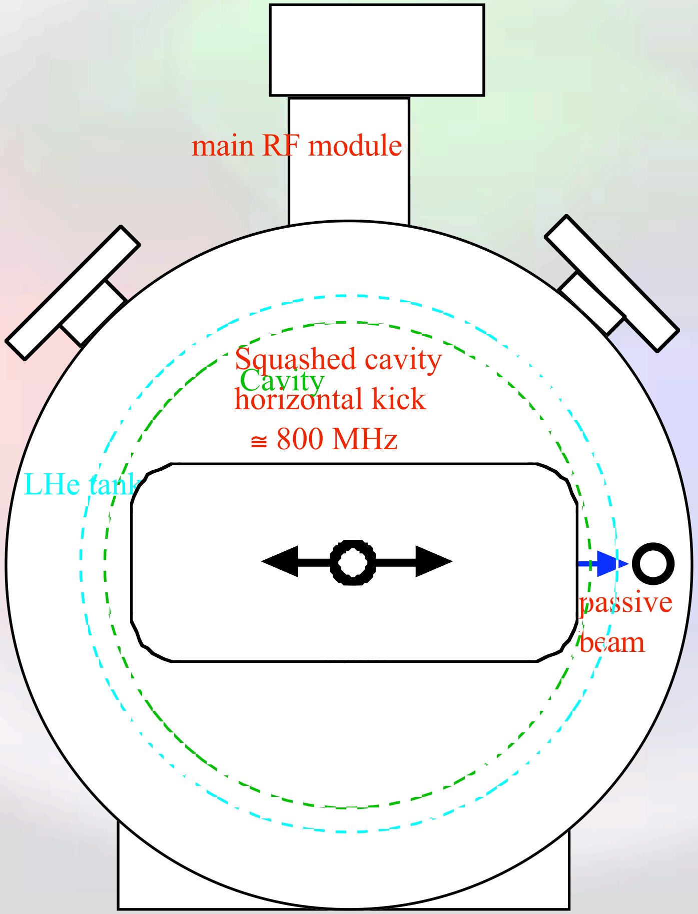


(Top view)

- Transverse Space: **800 MHz l* OK**

- LHC **standard** beam-beam distance: **20 cm**

around P4: **special 42 cm** (for main RF!), not easy (dog-leg)



(*) 800 MHz **will NOT do** for the real thing:too crooked bunches

A) The presence of the crab test cavity should by no means reduce the obtainable integrated LHC luminosity

-> no limit of dynamic aperture (cavity/tube opening, required changes of (magnetic) optics, ….)

-> no limitation of obtainable beam current (impedance, …)

-> CC system should not cause machine stops due to e.g. vacuum problems, unjustified beam dump interlocks …

-> In case of insurmountable problems, cavity should become ‘immediately invisible’ for the beam

(even with RF and/or cryo (?) down)

B) Hardware, controls, ancillaries… should be prepared thoroughly that the operation is worthwhile. The installation (and possible removal) should be swift.

Should not present a safety risk to personnel and material

- Cavity/Cryostat

• **Legal considerations**:
CERN hast its own safety standards:
about {Most severe | Swiss , French/EU standards }
(present DG -> == EU (rubber ?))

• **Electric Power**:
– European 400/230 V 50 Hz, plugs **Swiss standard**
(also on French site and in all tunnels)
– UPS (uninterrupted) ‘low’ power emergency connections to be negotiated in advance (CERN/TS)
– ‘on board’ electrical installations (ion pump, …) have to match CERN rules

• **Fire and radiation considerations**:

– External cables/connectors/.. have to match CERN rules
(e.g. no PVC, Teflon, .. : risk of HCl or HF acids)

– Exceptions for **cold internal** RF cables: Teflon only reasonable material
(not ad hoc, negotiable: Fritz Caspers did it for 'us')

– External 'plastic parts': suffic. radiation resistant and see above

• **Steel for 'cold objects close to cavity'** (He tank, tubing, ..):

316 LN (international norm ?)

– sufficient strength at LHe temperatures (not brittle as 'Titanic')

– no recrystallization forming 'magnetic islands'
(would lower cavity Q-value by frozen flux)

• **Vacuum flanges**:
– CERN standard for beam line UHV: ® Conflat (in 316 LN)

• **Bake-out**:
– All warm volumes connected to the beam-vacuum have to be bakeable to T= ???
– internal cables, gauges, superinsulation, .. have to resist
(compromise to be defined)

– possibly heaters for internal parts

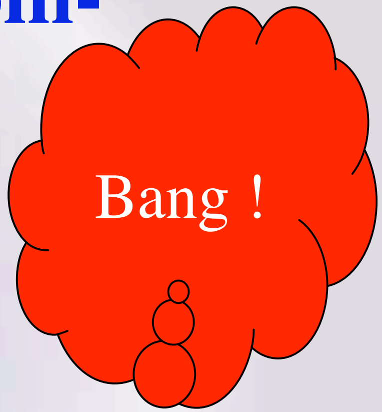
• **Safety (Personnel & Hardware)**

Any tank full of LHe is a sort of bomb !!

The evaporated liquid, warmed to room-temperature, would produce about

700 bar

Cryostat bursts long before



Cryostat equipped with safety device(s):

– Rupture disk: large passage to let He escape into tunnel

– small - self-closing - valve for small (accident.) overpressure

- Passage for GHe flow (when disk breaks) has to be large enough to keep pressure sufficiently low

-Also vacuum tank needs spring loaded "toilet lid valve" in case of rupture of interior vessels

Blown out GHe dangerous for people close bye:

'Burning' of exposed skin, bronchiae and lungs

(may be lethal)

—> for main RF system constraint:

before any work on/close to cavities

empty liquid He

(nuisance, but … safety first)

• **LHe and vacuum tank**:

Pressure simulations for cryogenic T (LHe tank), warm tests

Pressure simulations/tests T (vacuum tank)

(to be considered: if LHe tank ruptures … ?)

Internal weldings/brazings have to be low-T guaranteed

‘warm’ He outlets should have metal seals and possibly be heated (regulator); avoid forming of ice blocks

Recommendation:

Keep LHe volume in module as low as possible

- **Compatibility requirements**:

LHe and GHe taps should be identical to main RF ones

(accepting ‘standard’ flexible cryo lines)

He level and pressure gauge(s) should be as main RF ones

Temperature gauges should be standard (CERNOX |[*])

(no A/B resistors nor Pt100 !)

(easier integration into cryo control system

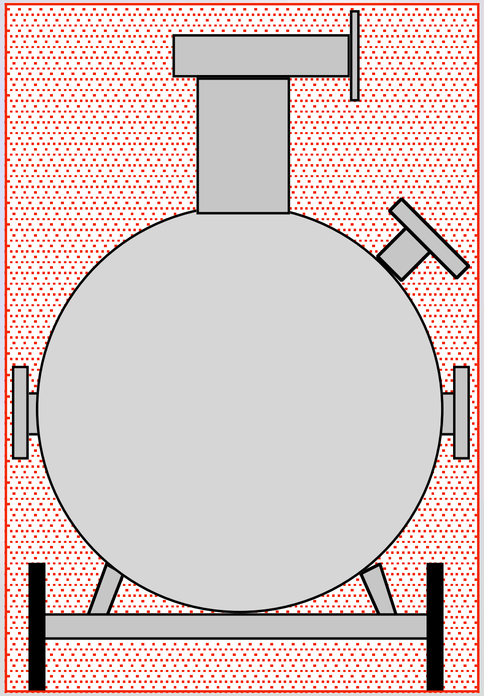
(*) similarity with CERN accidental:

made by LakeShore company, Ohio, USA

• **Transport**

Crab Cavity Cryostat is shorter and has less weight than main RF module —> no problem to lower down in shaft

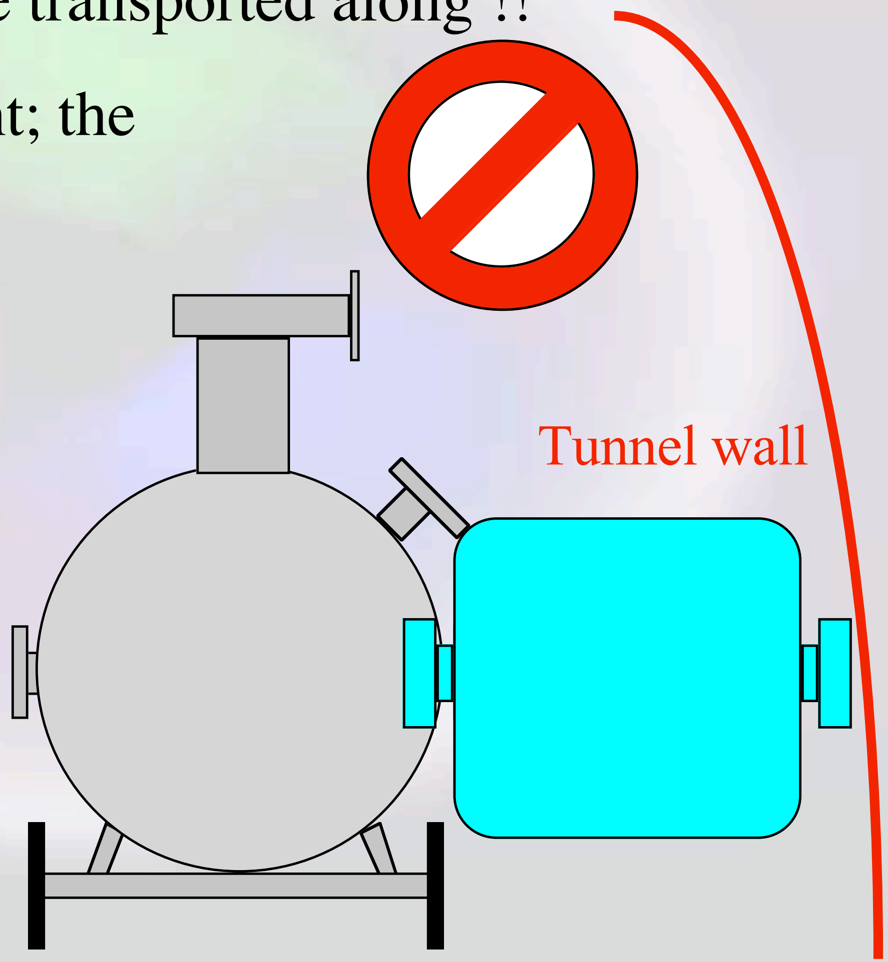
{ But anchor-points and solid support (with wheels ?) must be previously agreed on with LHC transport team }



Transverse dimensions of cryostat **with all non-dismountable ancillaries** (as main coupler) must pass along the **whole** transport path in the LHC ring (Active transport requirement)

The crab cavity, once installed, has to respect the ‘transport zone’ so that other equipment (dipoles, main RF modules, ….) can be transported along !!

(Passive transport requirement; the LHC tunnel cross-section is not enormous !!)



- **Alignment**

Assume that cavity in cryostat or whole cryostat

can be adjusted transversely

—> longit. voltage zero @ beam; remote control preferred

Cavity position at cold (!!: differential contraction of rods) carried onto 'fiducial marks' on the outside of cryostat

(active alignment)

'Standard space' above cavity has to be left free for

alignment of other equipment (=surveyor's working area);

agree with surveyor team (passive alignment)

- RF

• Parts of 'High Power RF' (cables, insulation) and most of 'Low Level RF' (semi conductors) equipment are

Radiation Sensitive

and nuclear activation contradicts 'hands on' setting / repair

• Cavities may create strong γ-ray activity by field emission (especially during processing)

—> No RF equipment in the LHC tunnel

Hide it 'around the corner'

—> Need shielded 'alveolus', parallel gallery, …. ?

– C.C. represents an impedance in a ‘low impedance LHC’

– Mechanical cavity vibration make field shake

(e.g. pumps, from LHe, ‘whistle’ by GHe, …)

– Ponderomotive (electro-acoustic) auto-oscillations occur (LEP2)

Need fast RF vector feedback:
Distance (around all corners !) cavity - RF system ≤ 100 m

Distance ‘cavity - RF equipment’ OK at P4:

Foreseen for ACN anyway

RF reference signal:

present at P4 (main RF !)

High voltage & high power supply:

AC transformer (on ground level ? HV-cable …)

High voltage bunker ? (800 MHz klystron / IOT: a few 10 kV)

‘steal a few kW from a neighbor’ ?

RF transmitter:

800 MHz klystron / IOT: For SPS 800 MHz (!) 4th harmonic Landau System needs new transmitters (old ones dying of old age):

In principal can use 'a spare' that would fit nearly perfectly

(probably slight 'overkill' but OK for a test set-up)

Low level RF control:

Equivalent fast RF vector feedback exists for 400 MHz:

– adapt filters, LO, …. to 800 MHz???

– new card to be developed based on 400 MHz experience ???

Phase stability/locking to be higher than for main RF ??????

Tuner control:

‘half-detuning|*’ for 400 MHz, not necessary but does not harm neither here. Adapt existing main RF tuner card ?

(change filters, LO, …)

The ‘high power’ tuner drive is a stepper motor for the main RF ..

Interlock chain:

Has to be thought over, very similar to main RF, details ?

New design or adaptation ?

|* cavity resonance is kept half-way between optimum value without beam loading and with ‘on train’ current beam-loading; minimizes peak RF power for ‘gapped’ beam

- Cryogenics: “the big hammer”

LHe of T≤1.9 K LHe exists ‘everywhere’ **BUT:**

– was never considered to tap to other ‘objects’ (than the LHC magnets). Is it possible ?? Timescale (warm up) ?

(A leak might empty whole circuit !!!)

– when magnet(s) quench, pressure rises up to 20 bar

—> cavity will be crushed = destroyed: special system

– 1.9K LHe is not boiling but ‘re-pressurized’ to ≈1 bar

(norm. sc. cavities use evaporation cooling)

REMINDER: An 800 MHz system is not good for the ‘real thing’ !! For f≤ 500 MHz 4.5 K would do !!

Is this 4.5 K sufficient in CW mode at 800 MHz ???

To be studied !!!

There is a supply of 4.5 K boiling LHe (to cool special magnets), but enough reserve cryo power: special magnets, main RF, … ??

main RF system uses such a 'facility' (boosted cryo power) but

– when magnet(s) quench, pressure may rise up to 20 bar

—> cavity will be crushed = destroyed

special safety system as for main RF….

best option at 4.5 K: hook to main RF system

As for main RF

‘magnet-quench pressure protection’ required

New lines (cut metal in cryo-installation) for

- Liquid He inlet (flex. + fix cryogenic line = € $ ¥
- Gas He outlet (flex. + fix cryogenic line = € $ ¥

} coax

- warm gas recovery (cooldown, counter current cooling)

Regulation, connection to cryo-control:

- He tank pressure
- LHe level (has to cover cavity)

} interlinked

- Some reference temperatures (cooldown, warm up and interlocks)

- Vacuum

Two vacuua:

- beam / cavity : 2 RF compensated metal seal valves on ends
  - During operation:

    * no beam rest-gas collisions

    * avoid cryo-pumping of ‘junk’ drifting into cavity –>

      destroys cavity surface (RF losses !)
  - Before start cooldown: get ‘good’ vacuum –>

    avoid cryo-pumping of rest gas ($< 10^{-7}$ mBar)

(Mobile) pump after installation, before cooldown and permanent ‘ion sputter pump’ or ..

—> electric supply

- insulation vacuum:
  avoid LHe to boil away in receiving heat from condensing
  atmospheric gasses (N_2,O_2, CO_2..) touching He tank
  (avoid direct infra-red radiation:
  'dark' cryostat, superinsulation)

Once cooldown started, gasses in insul. vac, are cryo-pumped (except He !)

A cryostat allowing opening of 'ports' to exchange defect parts without cutting metal is probably not 'perfectly tight'

Permanent pumping unit..

2 beam valves (RF compensated)

have to be operated (open/close):

—> compressed air

Mobile (or permanent) pump stand:

—> electric supply (3 phase, 400V), interlocks

Ion sputter pump:

—> HV power supply, interlocks

in radiation protected area (@ RF equipment)

- Cooling and Ventilation

'H'OM damping in KEK design C.C. uses

resistive tiles to 'unload' coupled power as heat:

—> need water cooling at cavity of some kW

If air cooling (direct or by heat exchangers) envisaged:

Air cooling much less efficient;

—> check with TS dep. for air cooling capacity in the cavity sector

RF high power transmitter, circulator and RF load need

water cooling of corresponding capacity @ shielded area

—> check with TS dep. if available or can 'easily' be installed

- Controls

- In contrast to LEP: with beam there is NO ACCESS to areas as shaft bottoms, klystron gallery, ….
- To get access is a long business (wait decay of fast lived radio-nuclei, tunnel air ventilation, … and other people want to have beam (to find the Higgs or show it is not there)

——> Wherever feasible: use remote control € $ ¥

* Need space in protected area for 'semiconductors' (CPUs …)

* connection to LHC control system (bus, server, …)

* radiation-hard 'servos' on cryostat/cavity

(today any stupid washing machine has at least one CPU in it !!)

• Psychology: Be invisible if problems arise

• When cavity is not cooled, RF down (due to **any problem**) ,

a safe procedure **still allowing coasts** should exist:

——> higher probability to be accepted in the ring by

lumi-hungry Higgs-hunters !!

Can main impedance sufficiently be ‘reduced’ by detuning ?

• Coast a high current LHC beam through or running RF into

a “s.c.” cavity not in s.c. state (bad cooling, warmed up, …):

May heat cavity and ancillaries (thermally well insulated !)

possibly to destruction of super insulation, cables,..

-—> Need interlock to “RF off (and beam dump ?)”

then *manual* ‘retreat into safe state with beam’

• Conclusion(s)

- In the medium time range (having reasonable lumi, beam current ≤ nominal) there is a good chance for a

not permanently installed TEST CRAB CAVIY

in the area around P4: at (staged) ACN (or ADT-reserve..)

– The additional hardware installation is manageable

but not for free (cryo-lines, RF high-power equipment, controls)

– Apparent 'details' have to be settled with concerned LHC groups / persons even before starting construction of C.C.

(i.e. before signing any contract)

Thank you

for listening!