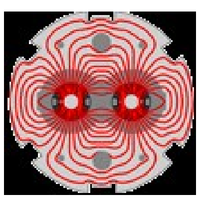
[Prelim] IR Layout of Crab Cavities

Rama Calaga, HL-LHC PLC Meeting, Jan 2013

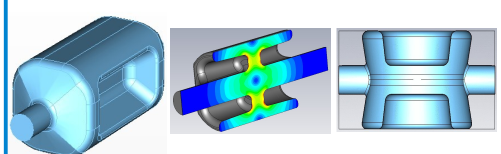
(Material derived from Crab Cavity Meetings)

LHC Constraints



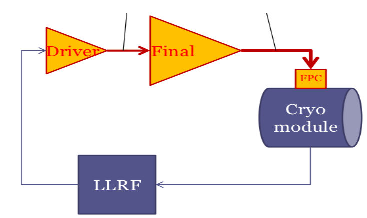
Beam requirements, Optics & Aperture, Space constraints, Cryogenics, Infrastructure, Integration & Safety

Cavity & Enclosure



Freq.,Temp, RF inputs & outputs, He-vessel & Tuner, Shielding, Instrumentation

Cryomodule/RF System

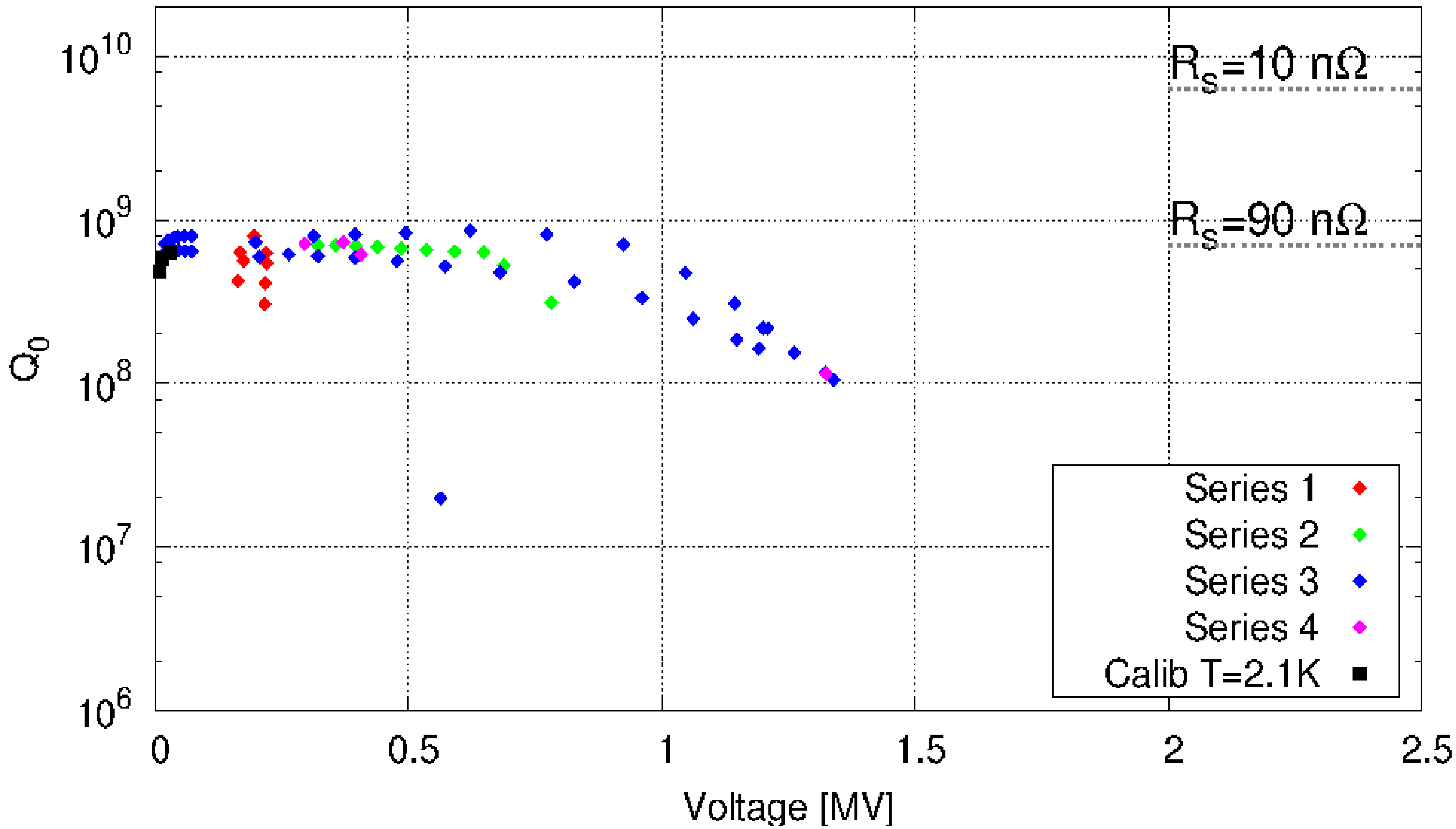


Vacuum vessel & layout,
Cryogenic interfaces
RF interfaces (power etc.)
Transmission lines
Controls & Feedback

1^{st} Vertical Test (SM18)

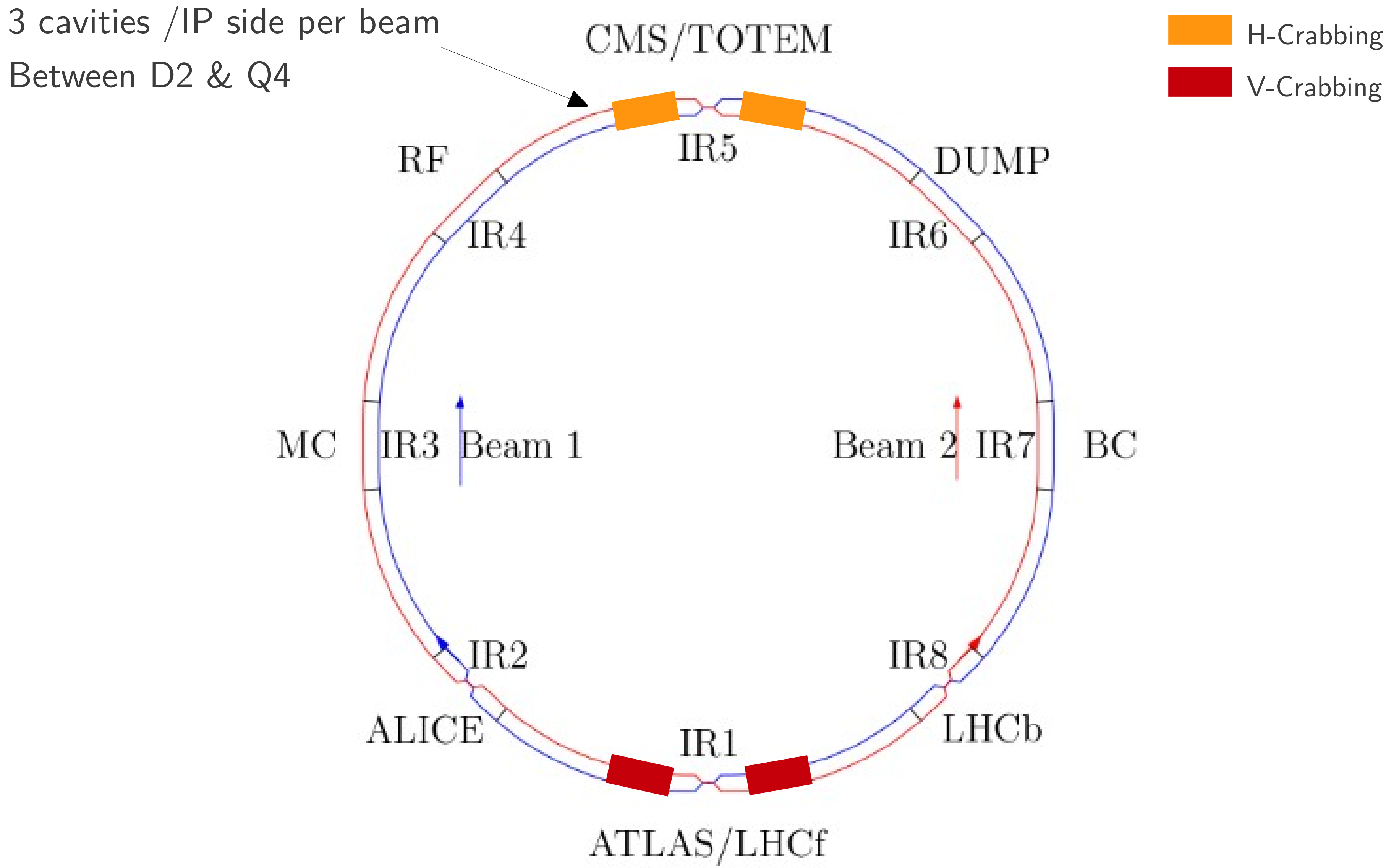
Nov 2012

A vacuum leak & time prevented us from testing to nominal gradients



Cavity will undergo full surface treatment in Feb → Improved performance

Baseline Crab Scheme



Some Basic Parameters

Voltage = 3.3 MV/cavity (3 cavities /module)

Frequency = 400 MHz

R/Q ~300-900 Ω, Qext = 5×10^5 - 1×10^6

RF power source = 40-80 kW ($<$ 15 kW nominal)

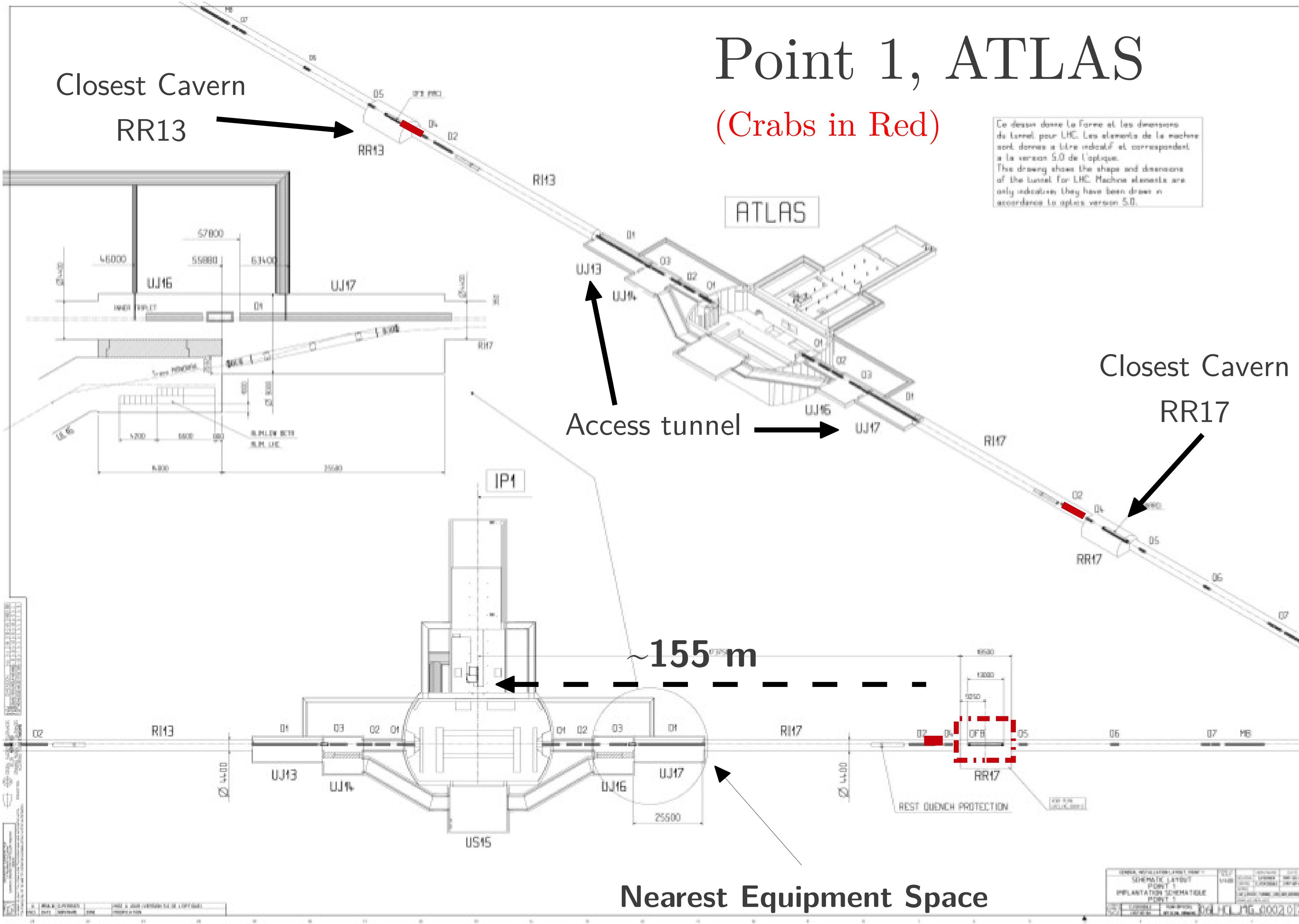
Cavity tuning/detuning $\sim \pm$ 1.5kHz (or multiples of it)

Beam current $\sim$ 1.1 A

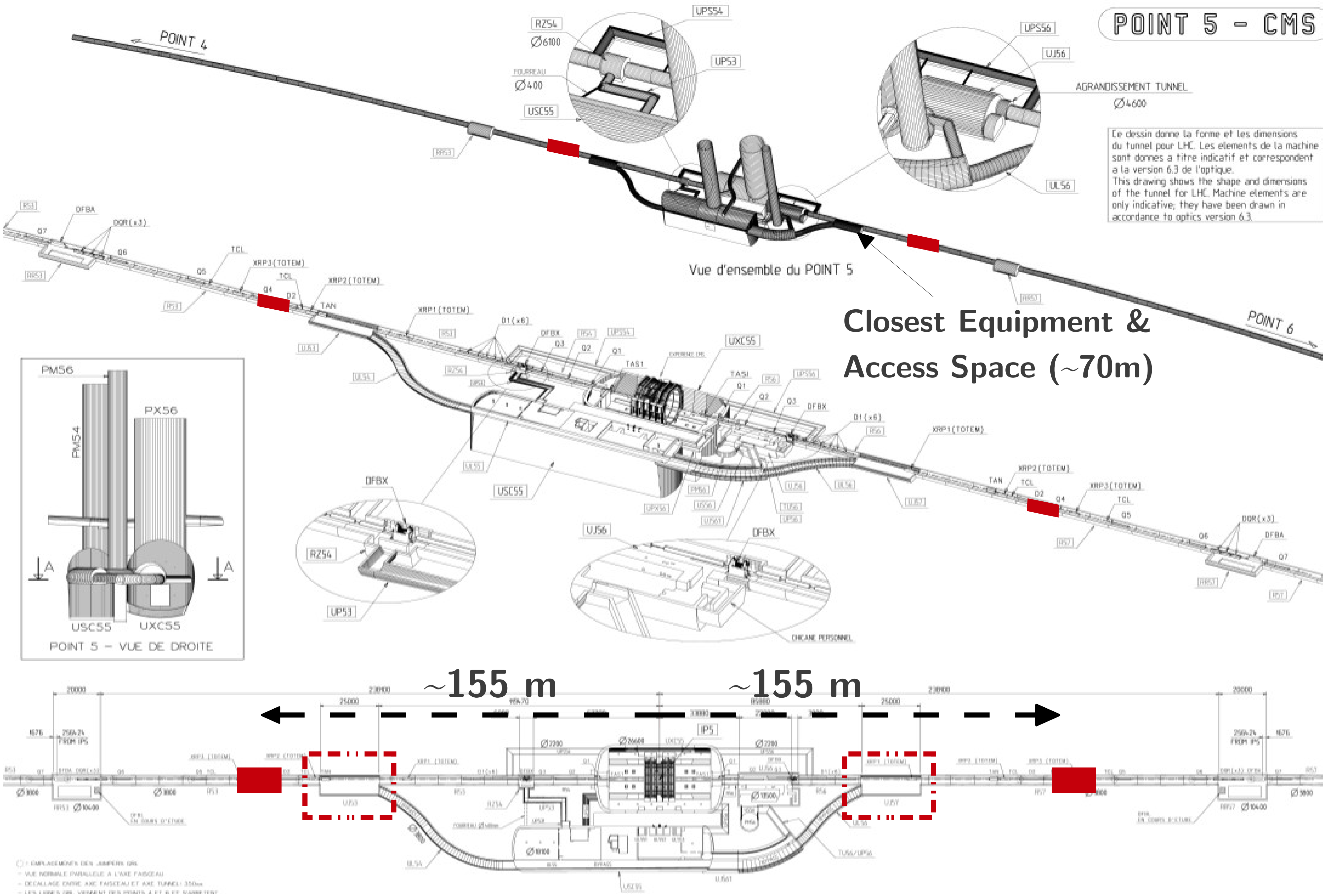
Functional specification document for Crab Cavities by end of Jan2013

Point 1, ATLAS

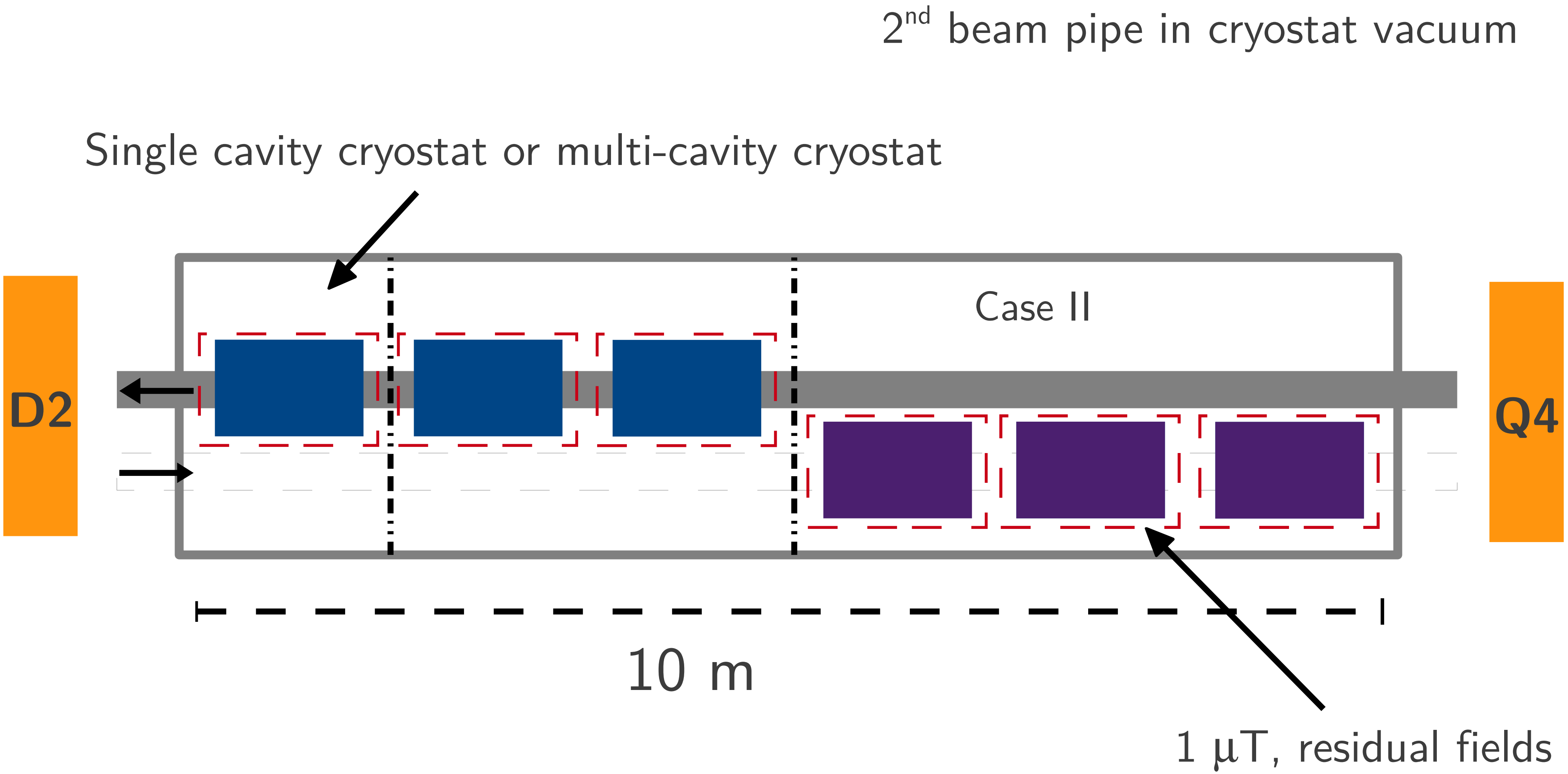
(Crabs in Red)



Point 5, CMS


POINT 5 - CMS
POINT 4
POINT 6
RZ54
Ø6100
UPS54
UPS3
FOURREAU
Ø400
USC55
UPS56
UJ56
AGRANDISSEMENT TUNNEL
Ø4600
UL56
Ce dessin donne la forme et les dimensions du tunnel pour LHC. Les elements de la machine sont donnes a titre indicatif et correspondent a la version 6.3 de l'optique.
This drawing shows the shape and dimensions of the tunnel for LHC. Machine elements are only indicative; they have been drawn in accordance to optics version 6.3.
Vue d'ensemble du POINT 5
Closest Equipment &
Access Space (~70m)
UXC55
PM56
PX56
PM54
USC55
UXC55
POINT 5 - VUE DE DROITE
DFBX
RZ54
UP53
UJ56
DFBX
CHICANE PERSONNEL
~155 m
~155 m
IP5

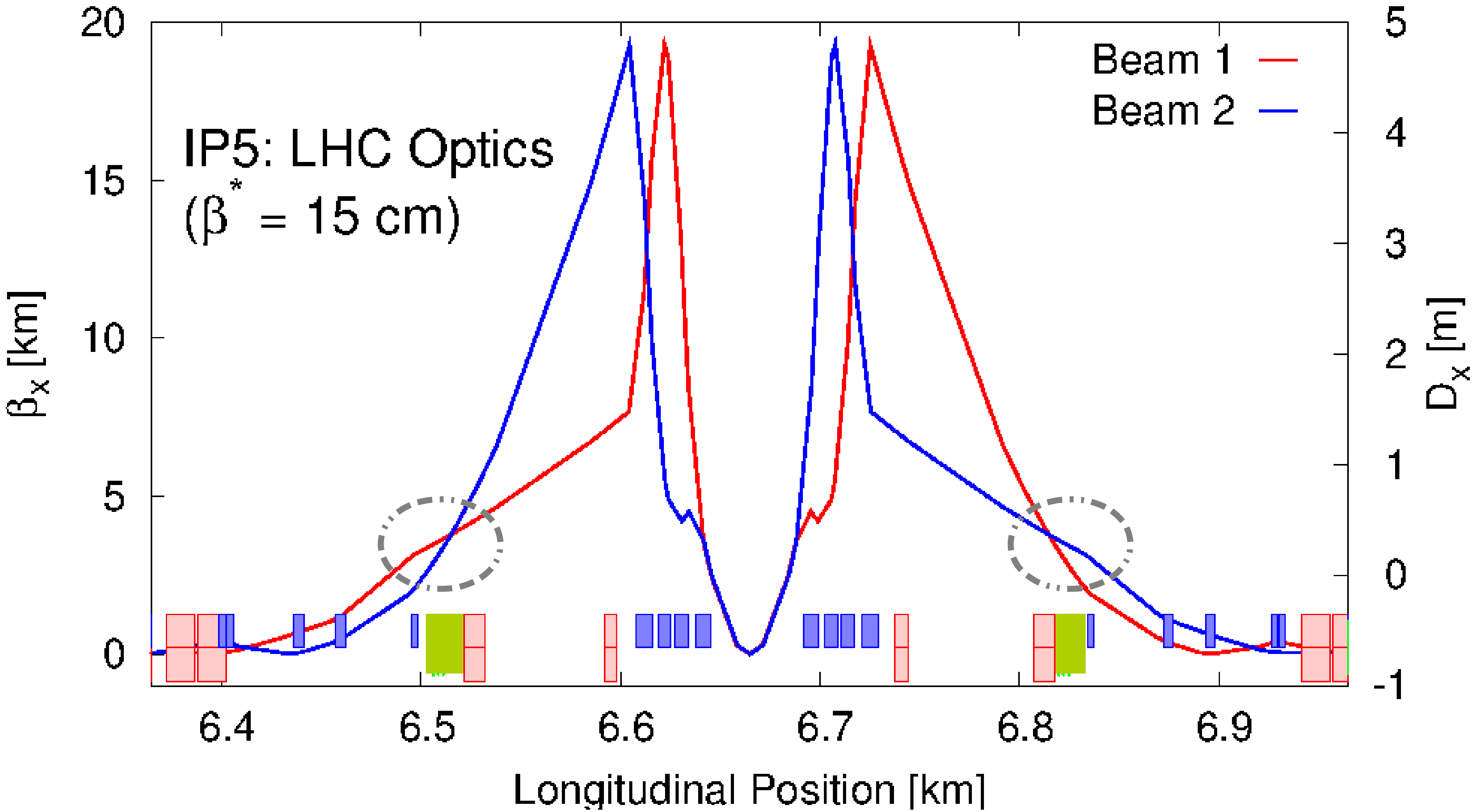
Example Module Layout



Multi-cavity cryostat → each cavity will only have common cryostat vacuum

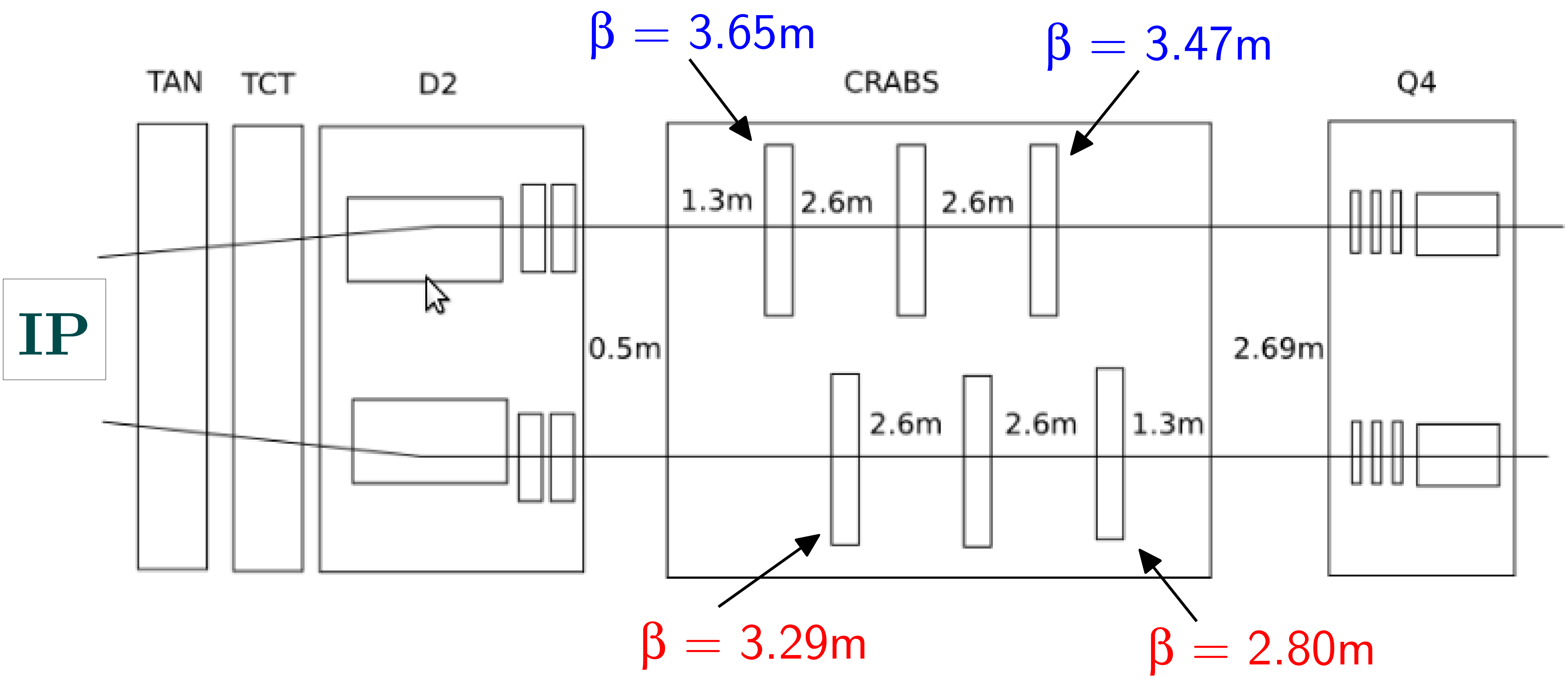
ATS Optics, IP5

Asymmetric β-slope left/right across cavities



Optics Layout Proposal

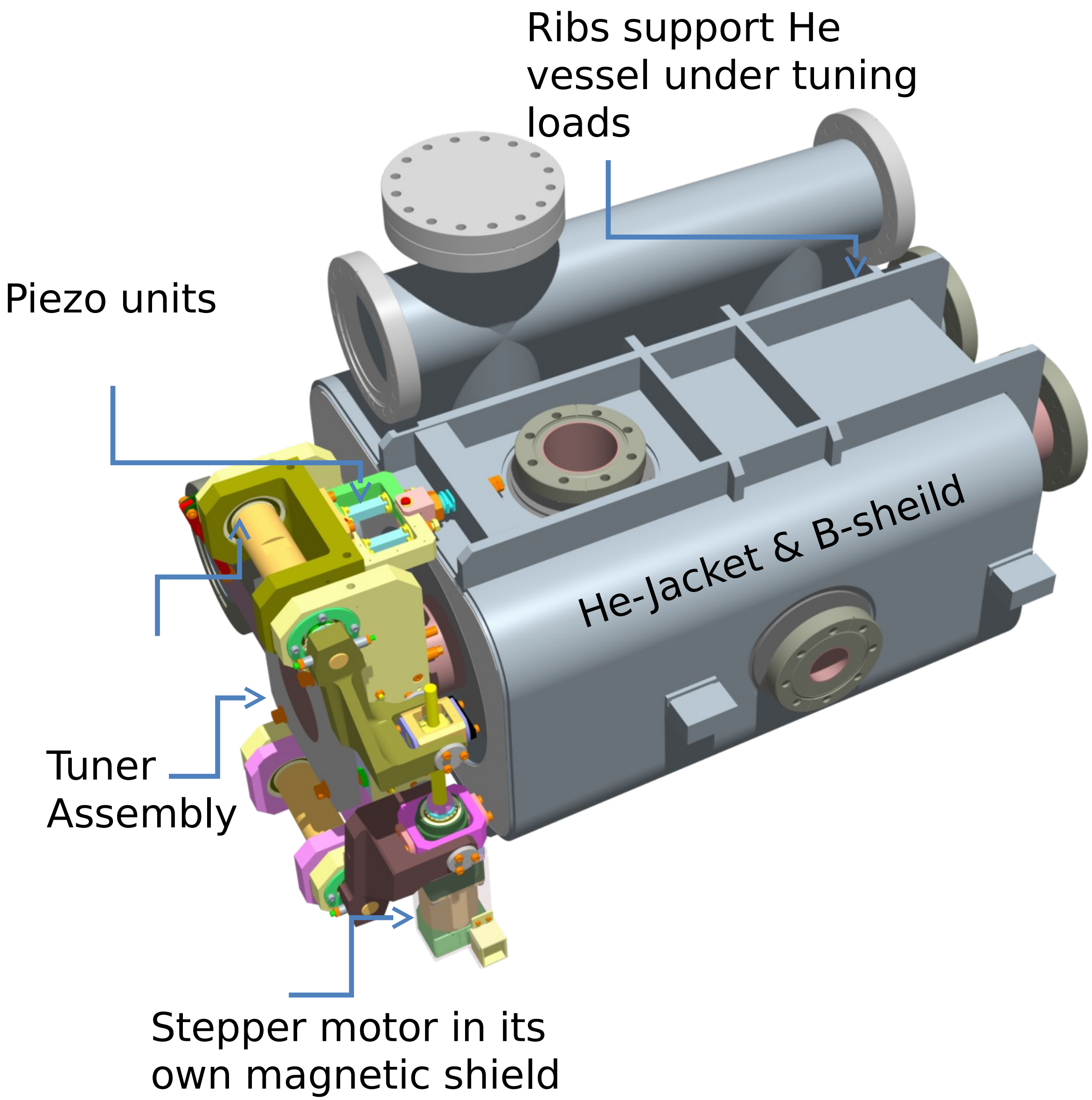
R. de Maria et al.
LHC-CC11



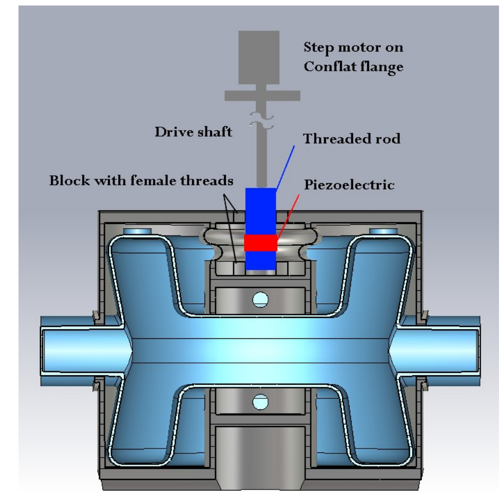
Approx 1.5 MV (½ cavity) imbalance between B1/B2

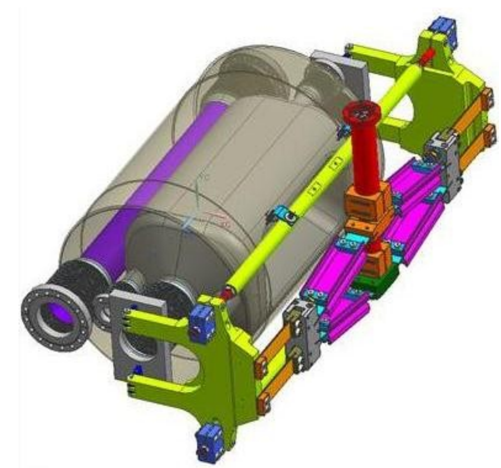
(Staggering efficient ? technical complication for common cryostat ?)

Present Design Status (3 Cavities)

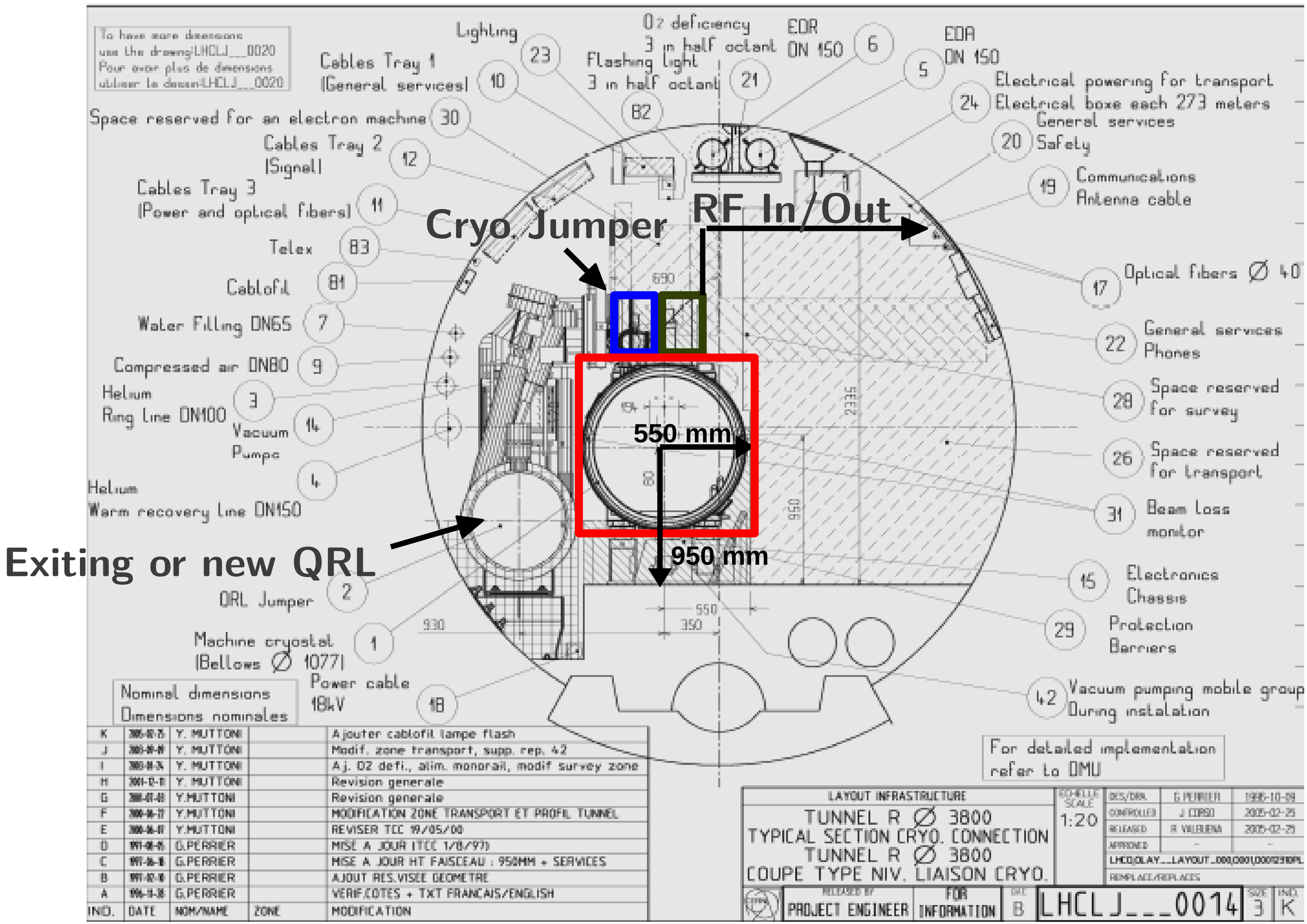


Tuner transverse plane





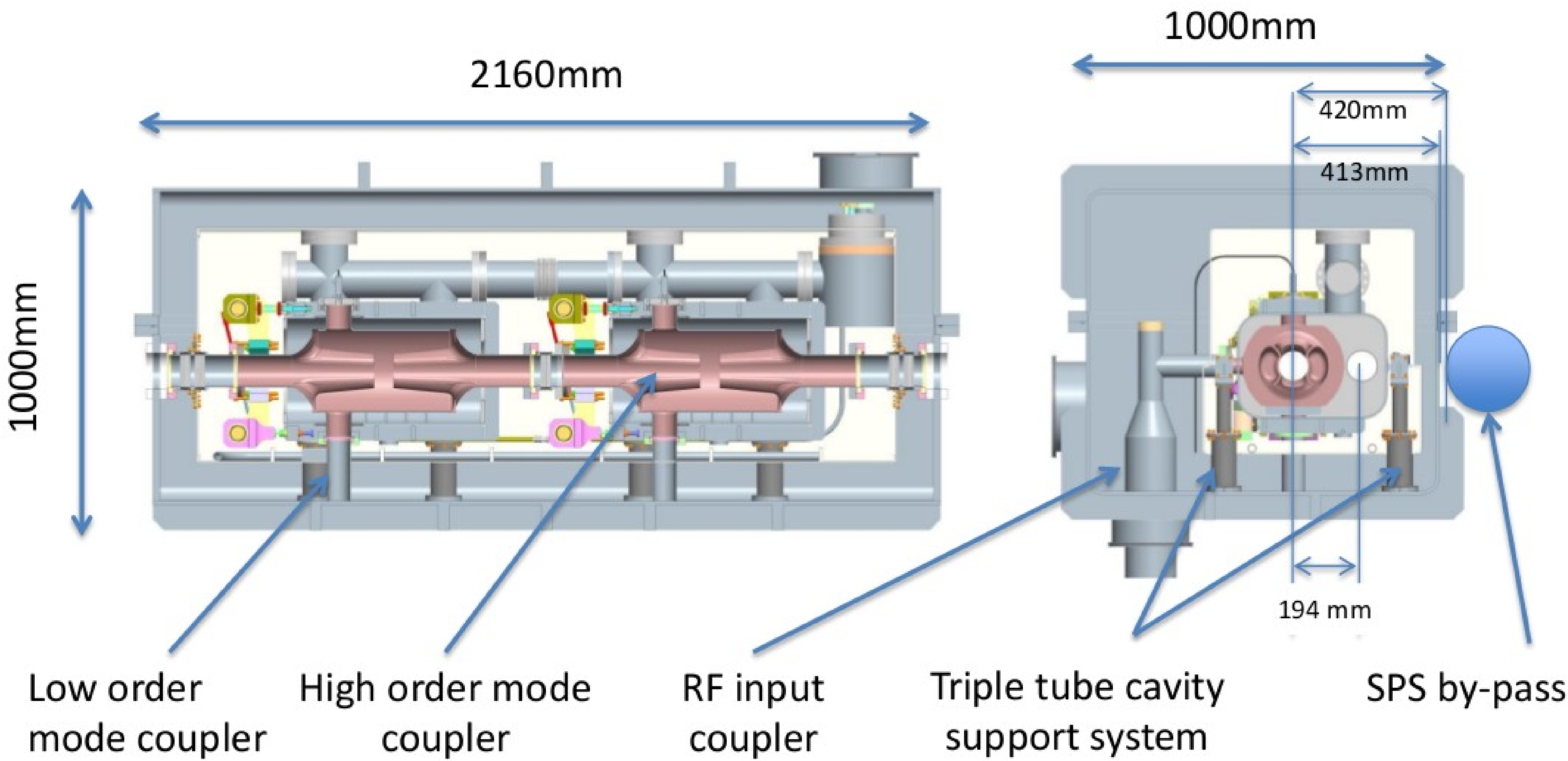
Tunnel Cross Section



Cryostat Cross Section (SPS)

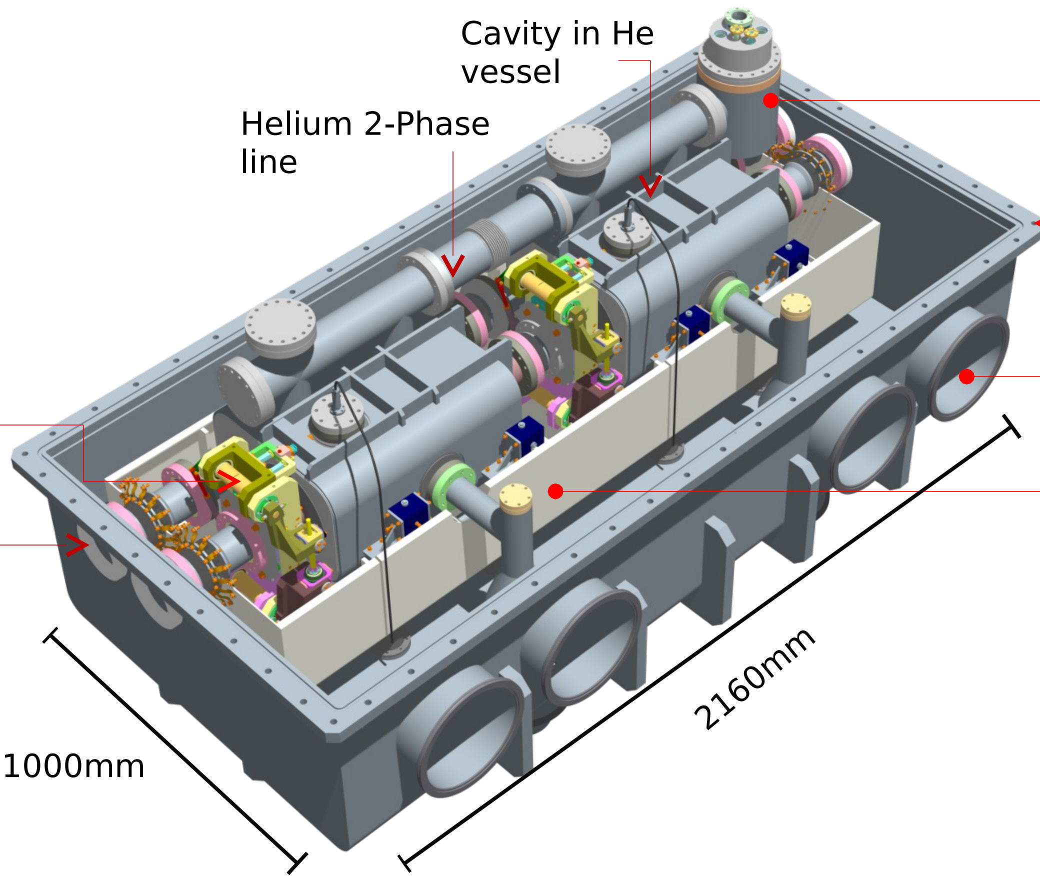
S. Pattalwar, T. Jones
(4Rod Cavity)

LHC 3-cavity/beam (~3.3m) layout could look similar



2 Cavity Cryostat Proposal (SPS)

S. Pattalwar, T. Jones
(4Rod Cavity)



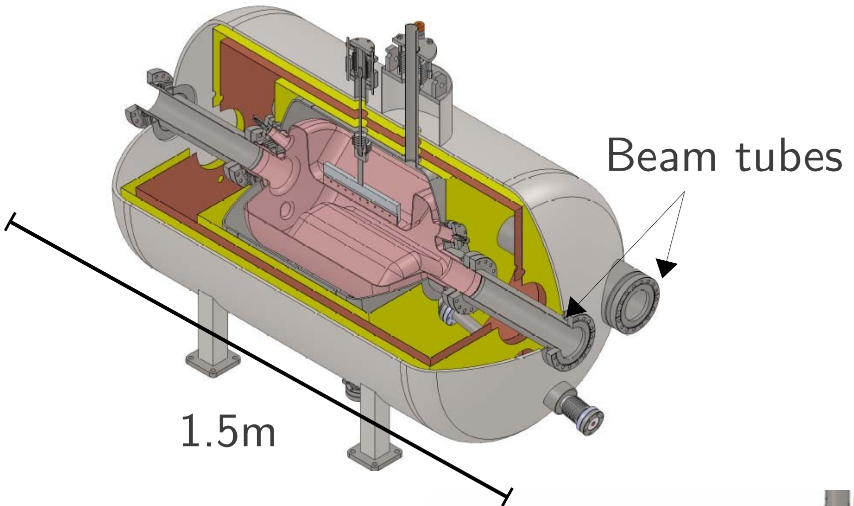
Simplified cryostat for easy assembly/access/maintenance

3-cavity LHC system would be a natural extension

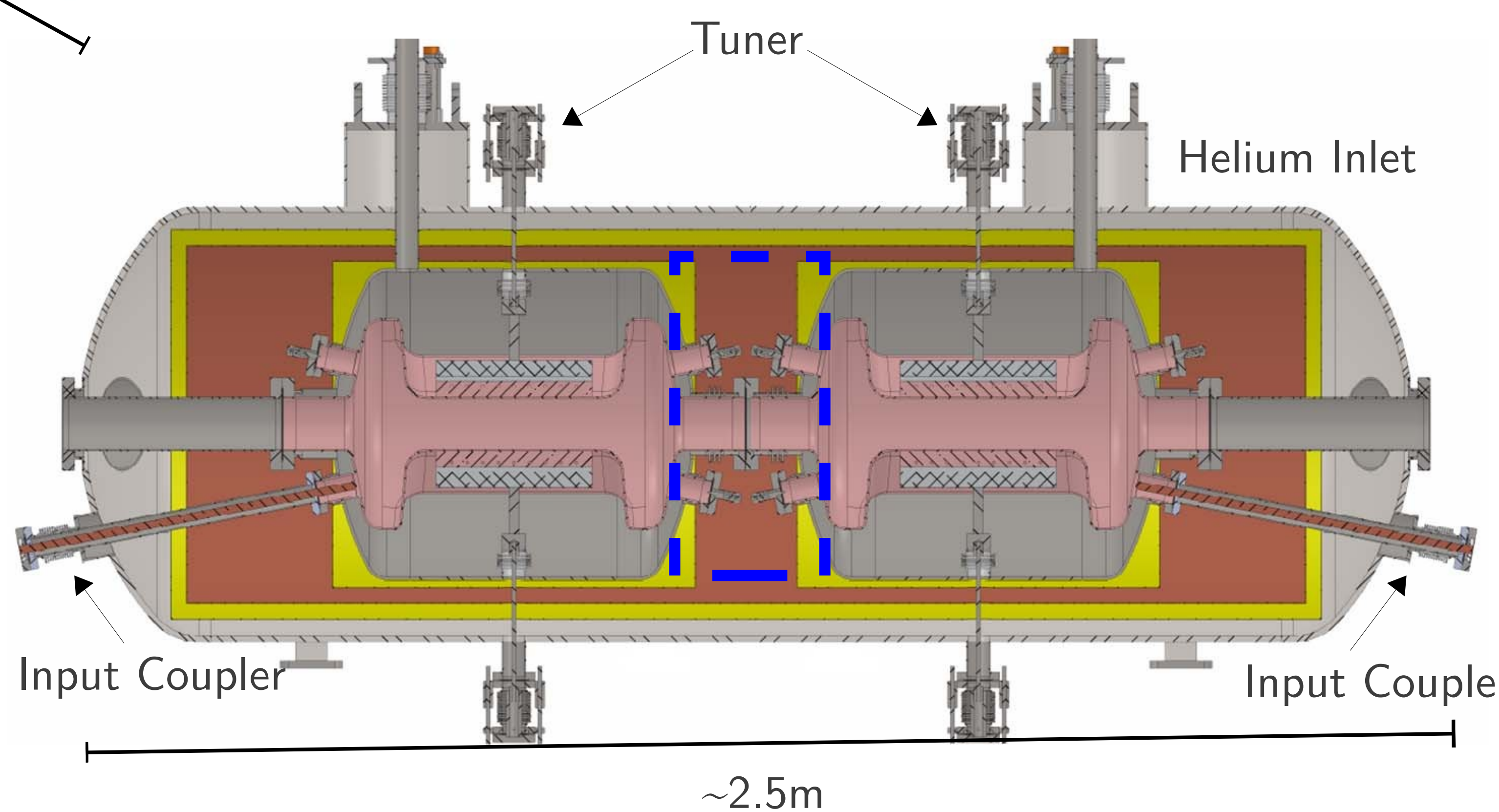
Comment: Staggered configuration may make 2K cryo piping complex

One/Two Cavity Cryostat Proposal

Niowave Inc.
(RF Dipole Cavity)



Even single-cavity cryostat could fit
(drawback: Several warm-cold transitions)



Heat Load, 1st Estimates (2K)

	/Cavity	/IP (12 Cav)
Static [W]	**0.6**	**7.2**
Radiation	0.2	2.4
Support	0.1	1.2
Couplers	0.1	1.2
Tuner	0.1	1.2
Instrumentation	0.1	1.2
Dynamic	**3.9**	**54.8**
Cavities	2.5	30
Couplers	0.2	2.4
HOM Couplers	0.2	2.4
Beam	1.0	20

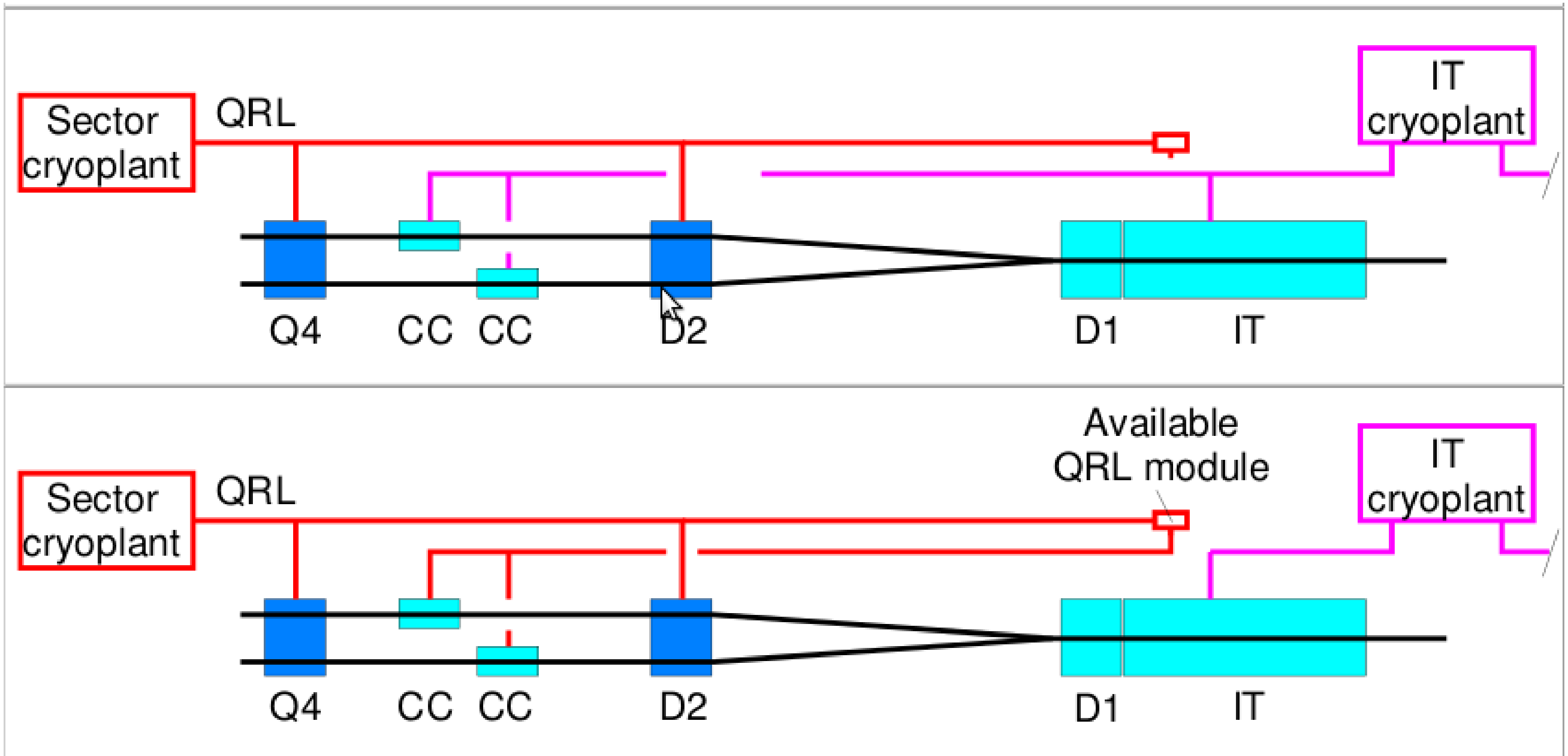
Derived from K. Brodzinski
(at Crab Engineering Meeting)

With safety margin 1.5
→ 100 watts/IP

Heat loads @4K/80K
to be detailed from
cryomodule design

Cryogenic Layout

L. Tavian, HiLumi Frascati

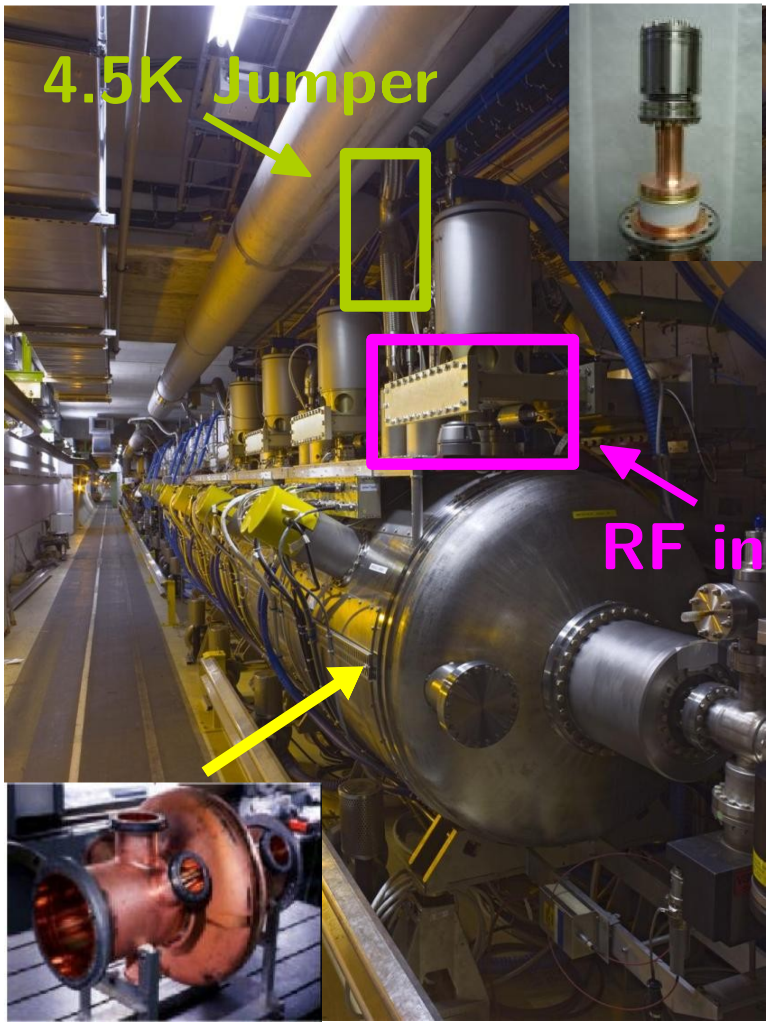


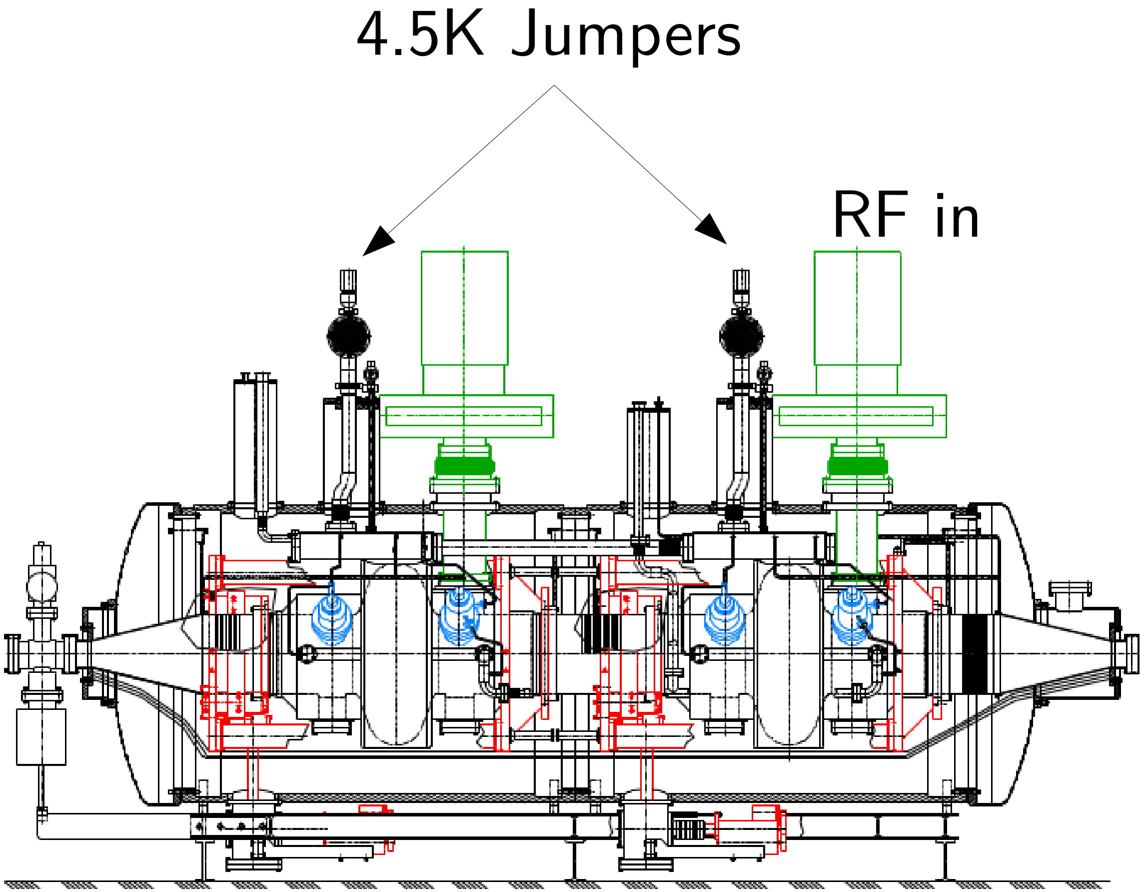
In both scenarios, service module close to crab location could be envisioned

- Jumpers to feed to cryomodule (# depending on the # cav/cryomodule)

Cryogenic controls in the experimental cavern (~155m)

LHC Prototype Example

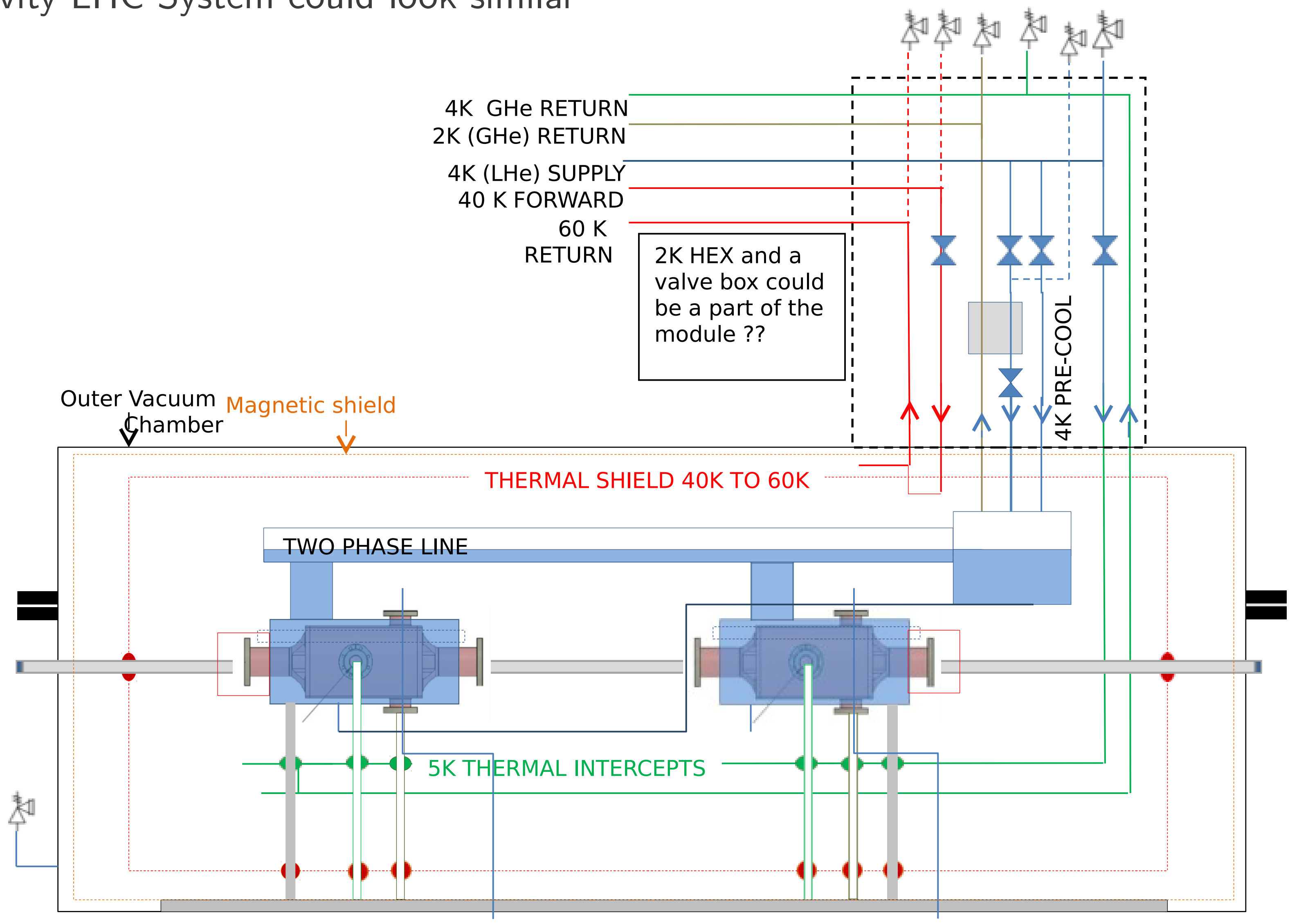




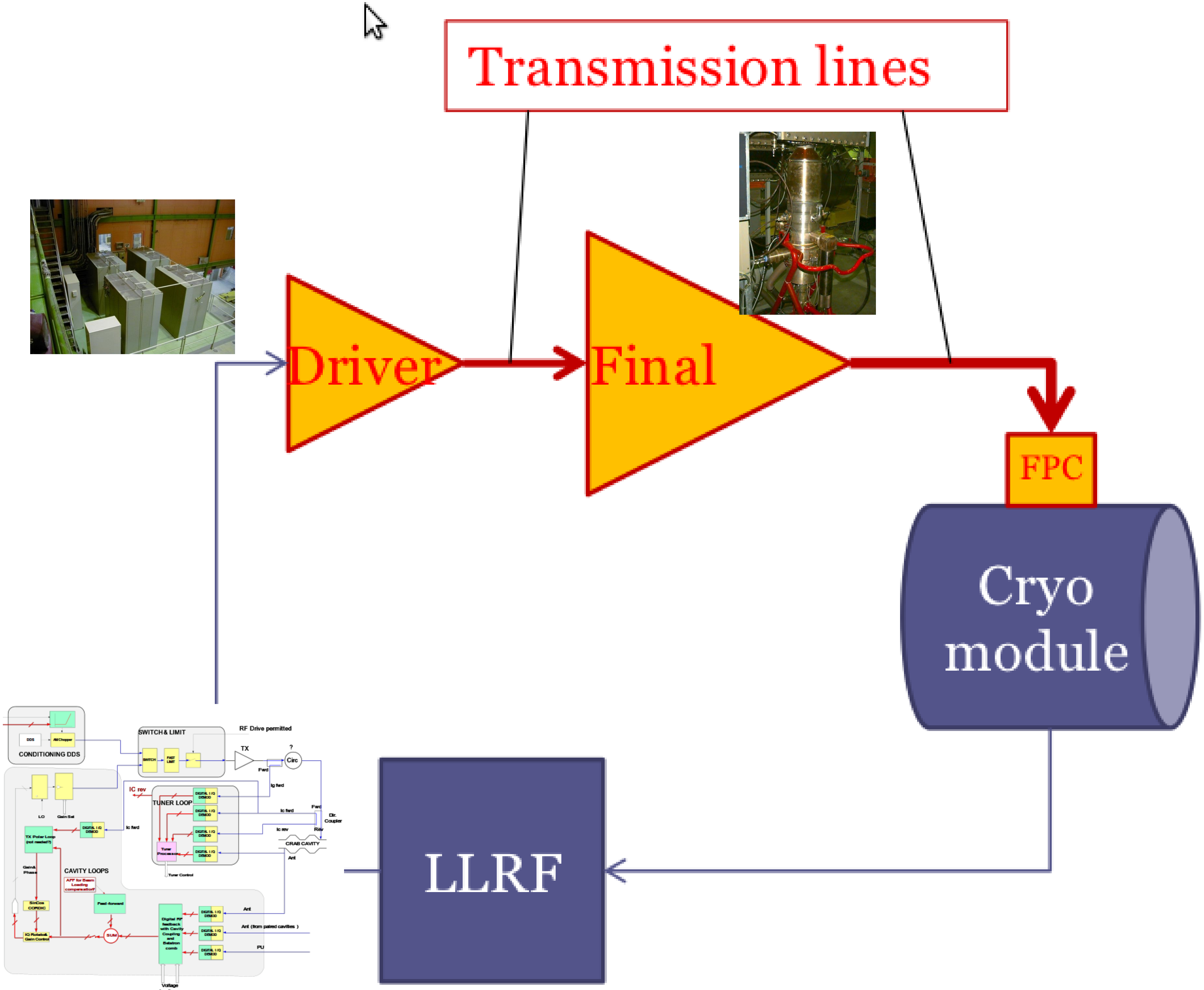
Cryo Layout Proposal (SPS)

S. Pattalwar, T. Jones
(4Rod Cavity)

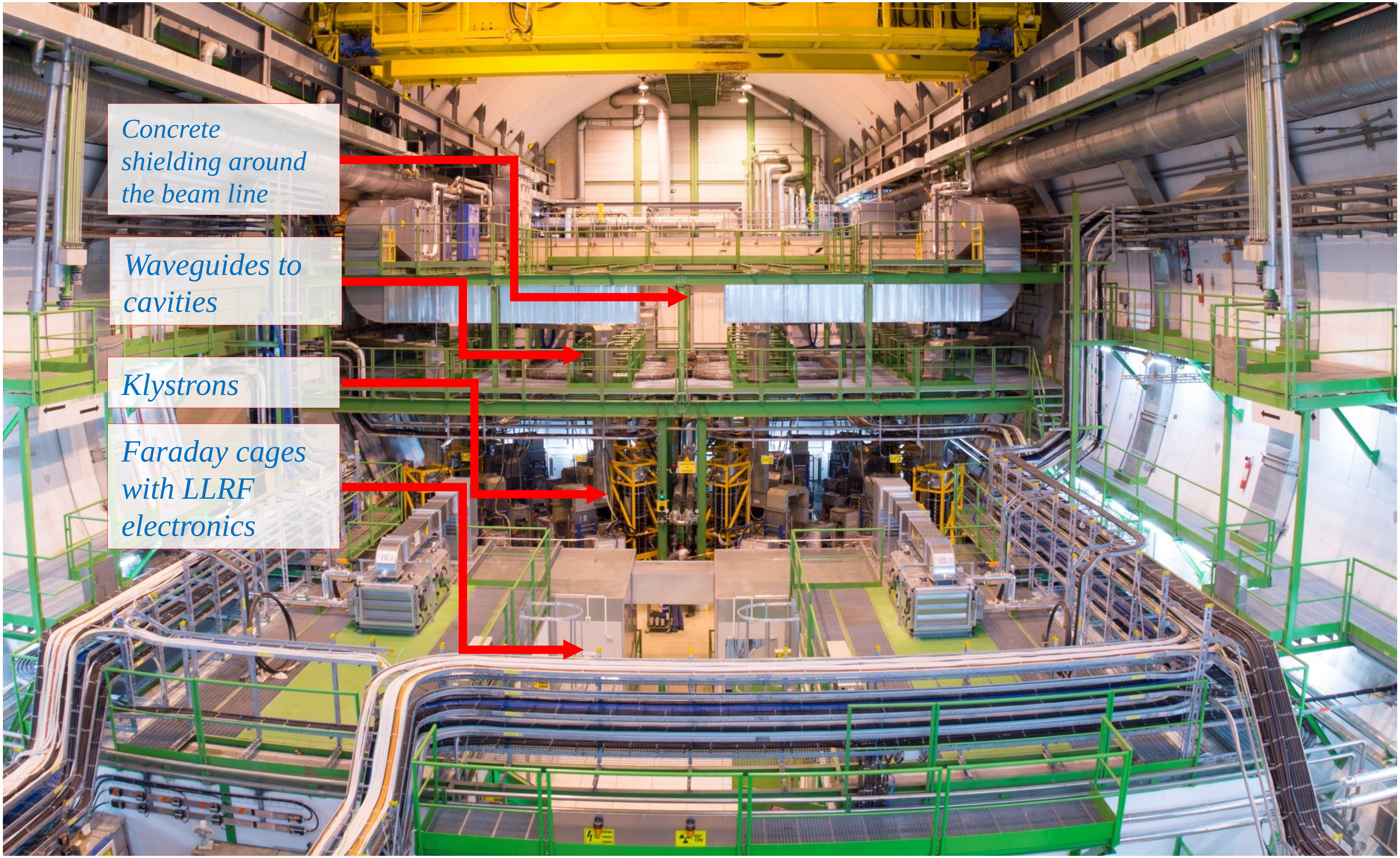
3-Cavity LHC System could look similar



RF Layout


Transmission lines
Driver
Final
FPC
Cryo module
LLRF
CONDITIONING DDS
SWITCH & LIMIT
RF Drive permitted
TX
Circ
IC rev
TUNER LOOP
CAVITY LOOPS
CRAB CAVITY

LHC-RF in UX45

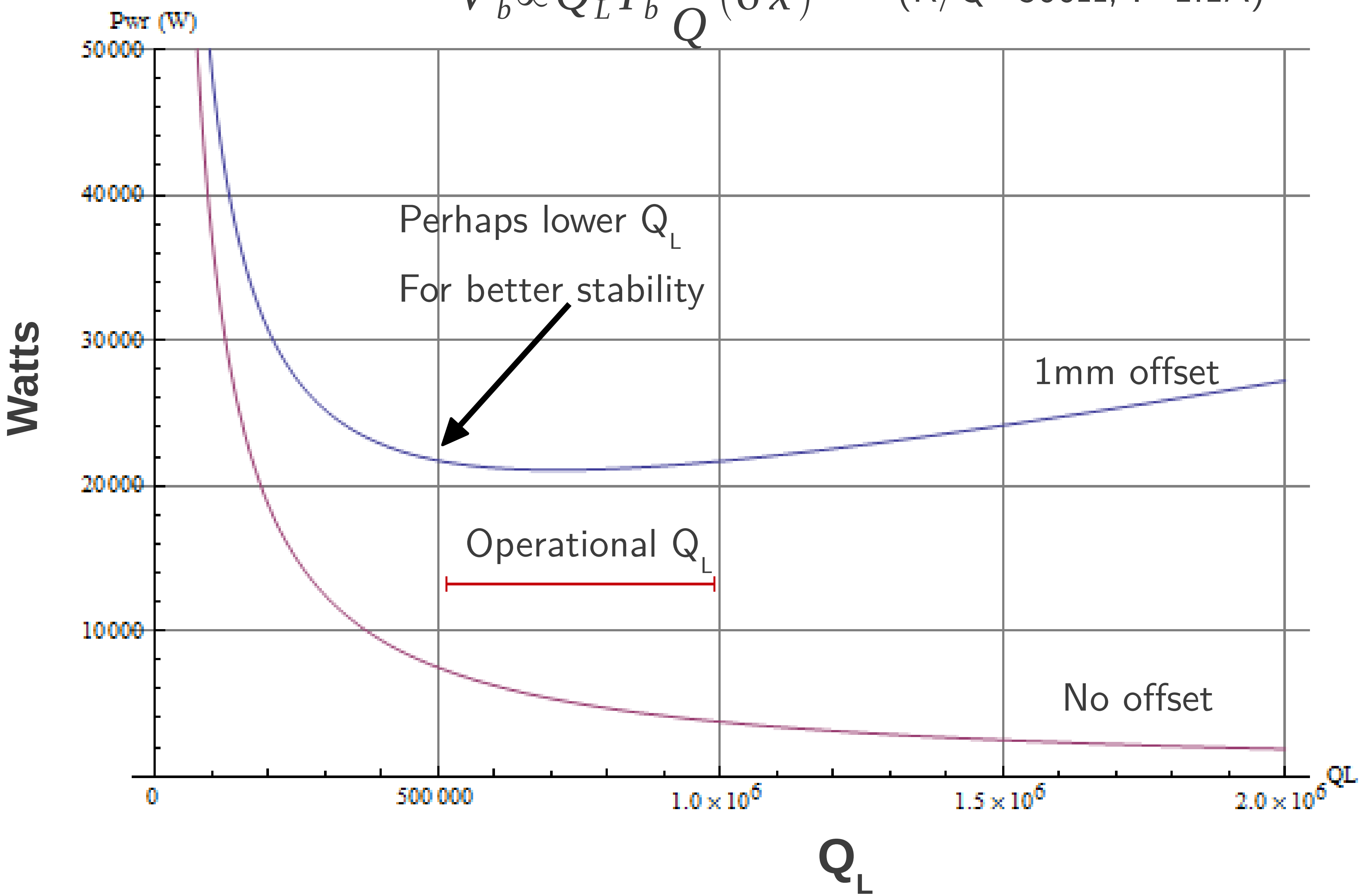


Power system likely more compact for crab cavities

Crab RF Power

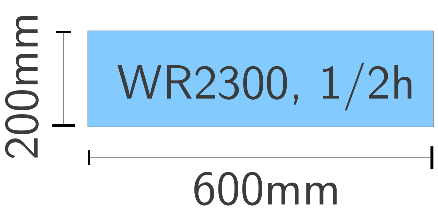
$$V_b \propto Q_L I_b \frac{R}{Q} (\delta x)$$

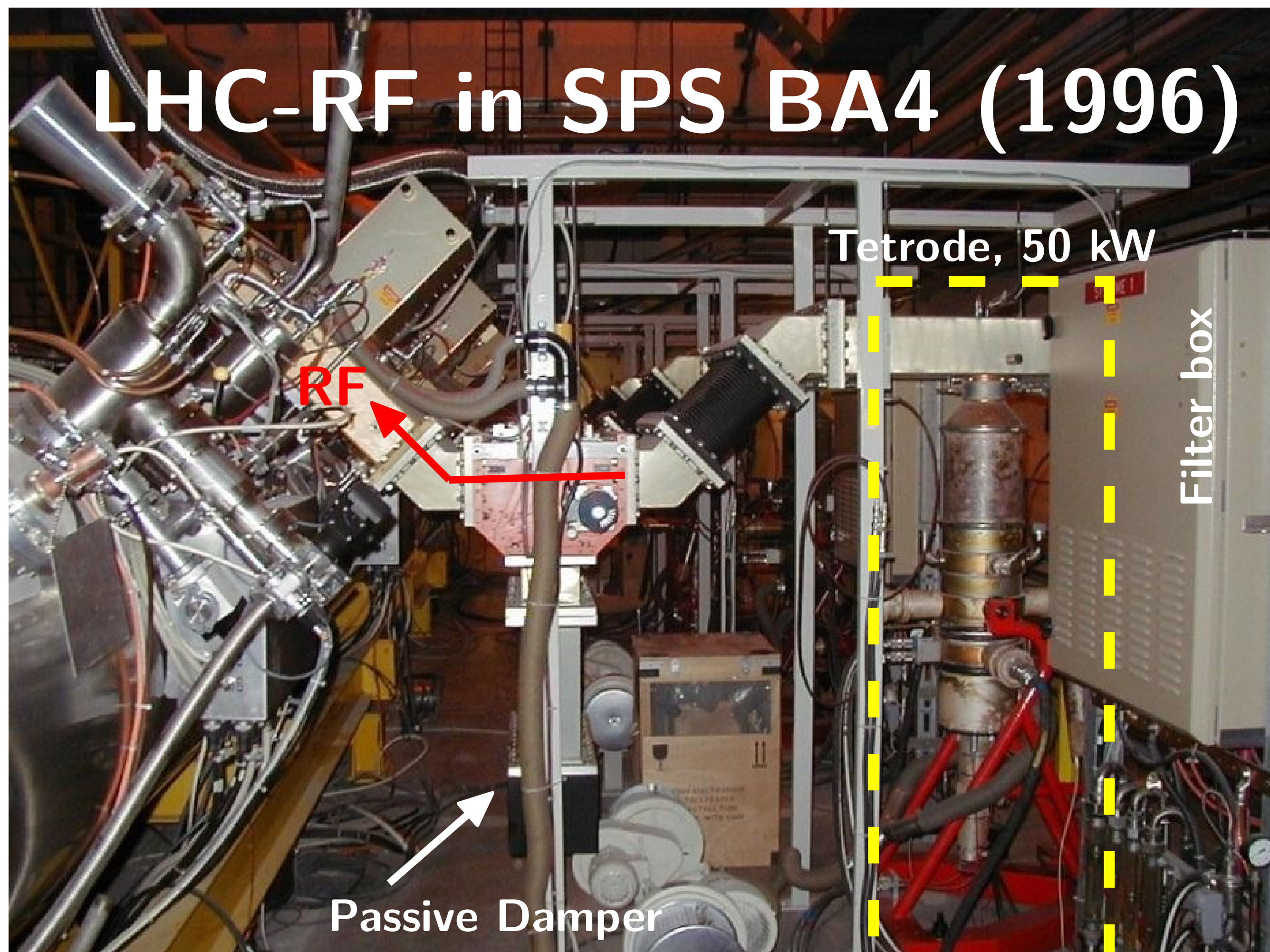
(R/Q=300Ω, I=1.1A)



RF Power/Cavity

- Input power 40-80kW Tetrode at 400 MHz
  - Prototypes exist for SPS (40kW), newer amplifier for LHC (? m^2)
  - Short transmission line preferred → Amplifiers in the closest gallery
  - Circulator & passive damping (perhaps both for safety)





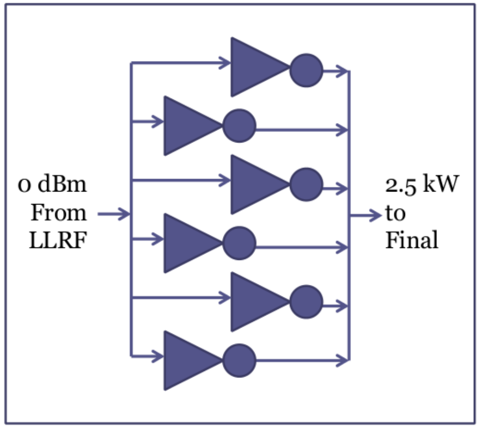
RF Driver & Peripherals

E. Montesinos

- Driver and other inputs either in a shield gallery or surface
  - New 500W SSA driver is ordered (SM18 tests)
  - HV power supply and related controls on the surface bldg.
  - Other peripherals: Grid PS, demineralized water for cooling, controls

- Main Constraint: Driver close to LLRF & LLRF close to cavity ($<1\mu s$ total loop delay)

Driver: 2.5kW (6x500W)



Drivers option with 6 x 500 W SSA

HV Power Supply (SPS Tetrodes)

Water for cooling amplifiers

LLRF/Cavity

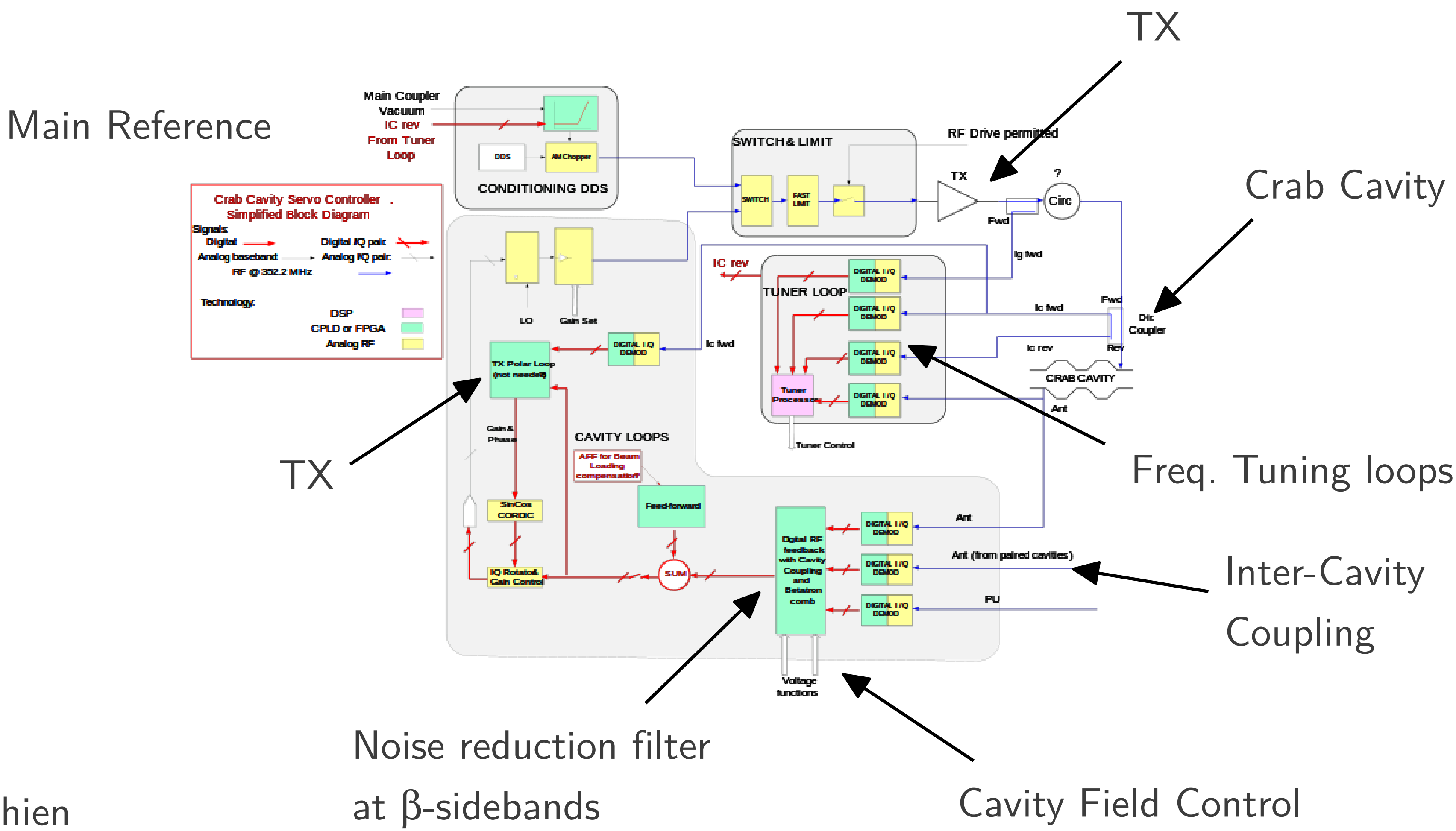
P. Baudrenghien

RF Feedback Loop for noise and beam loading control

TX Polar Loop to reduce the TX noise and stabilize its gain/phase shift

Tuner Loop detune or retune cavity during inj/ramp/physics.

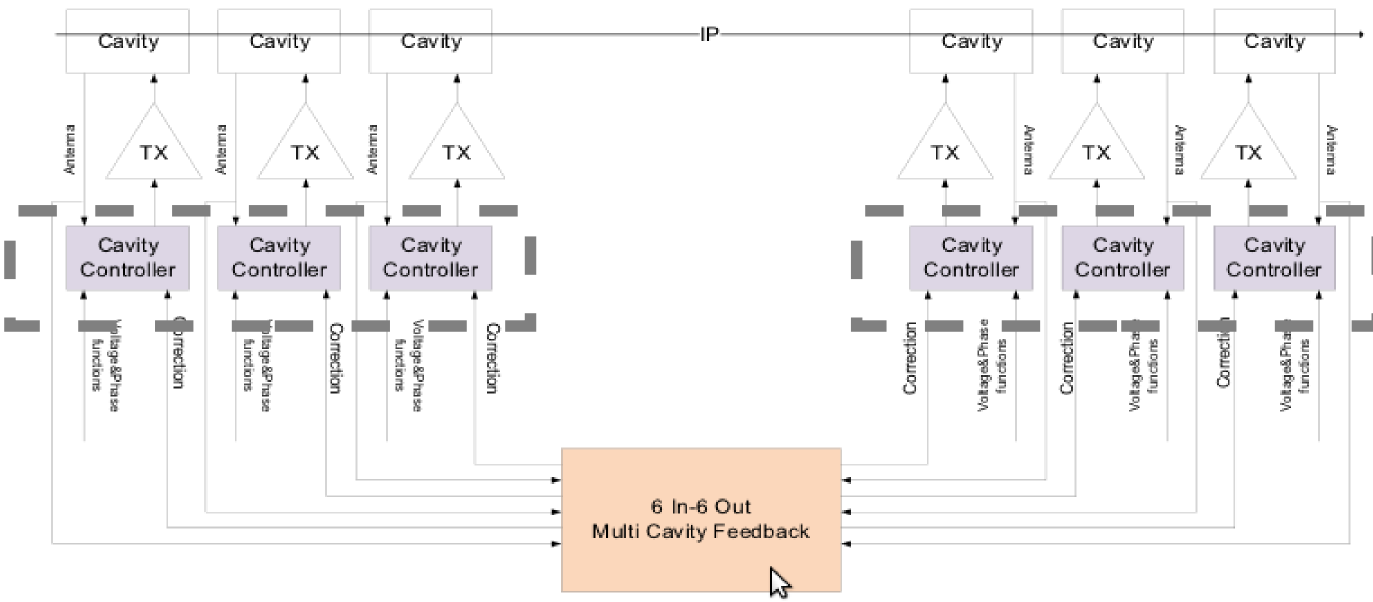
Field Set Point for precise control of the cavity field.



P. Baudrenghien

RF Control Layout

P. Baudrenghien (Frascati Meeting)



Shielded Racks or Faraday Cage

Cavity Controller — Strong RF feedback (< 1 μs loop delay) regulating the individual cavities

6 In-6 Out Multi Cavity Feedback — Global feedback regulating the relative crabbing-uncrabbing actions. Sligthly larger loop delay (< 5 μs loop delay?)

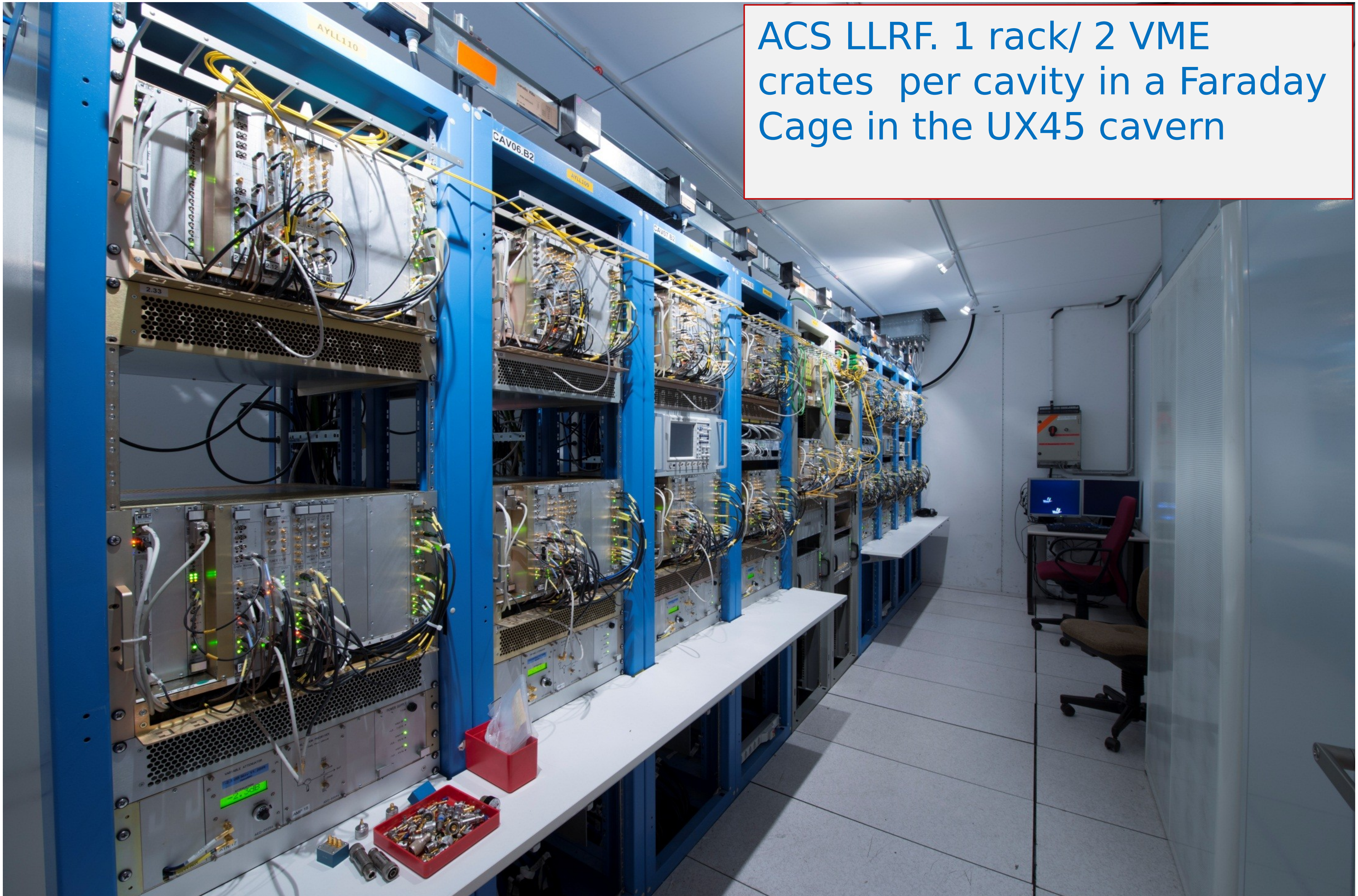
6+1 Racks/IP side (one/per cavity, close to cavity)

1 HOM rack/IP side (close to the cavity) + loads

4 central racks (experimental cavern) + 1 service

LHC Example

ACS LLRF. 1 rack/ 2 VME crates per cavity in a Faraday Cage in the UX45 cavern

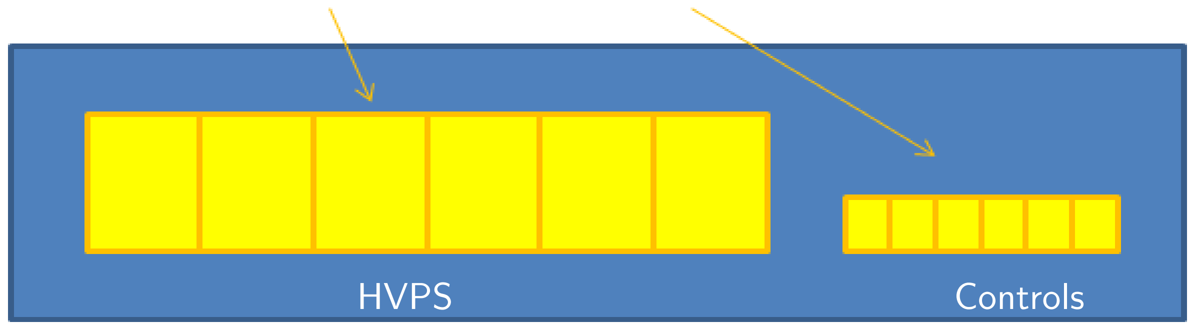


Space Required (6 x RF Power+LLRF)

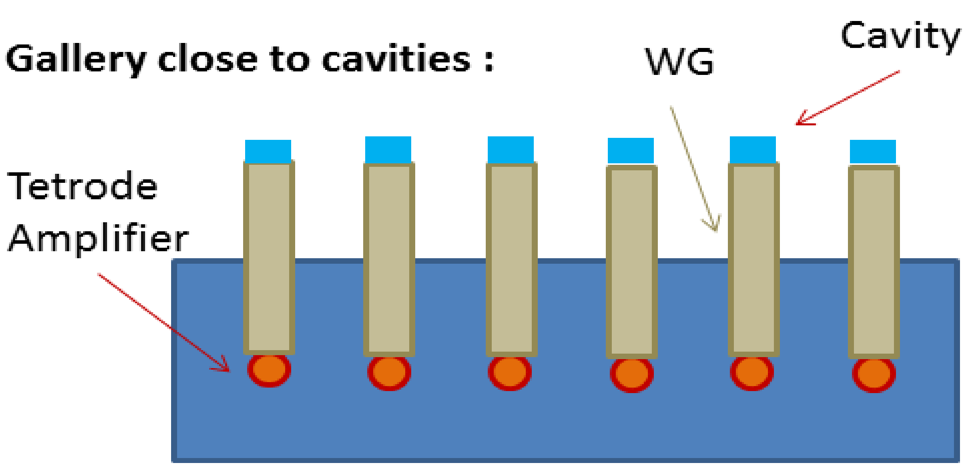
E. Montesinos

6 x 40 kW power transmitters / IP side

Surface building : 6 x (individual HVPS + power controls): 4.0 x 16 m

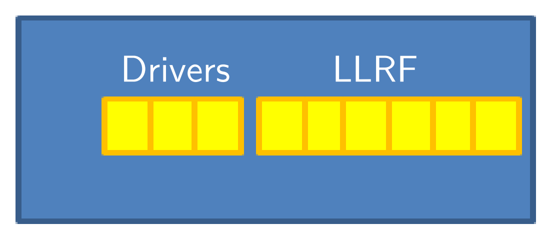


Gallery close to cavities :



6 x tetrodes amplifiers : 3.0 x 10.0 m

Shielded Gallery close to cavities :



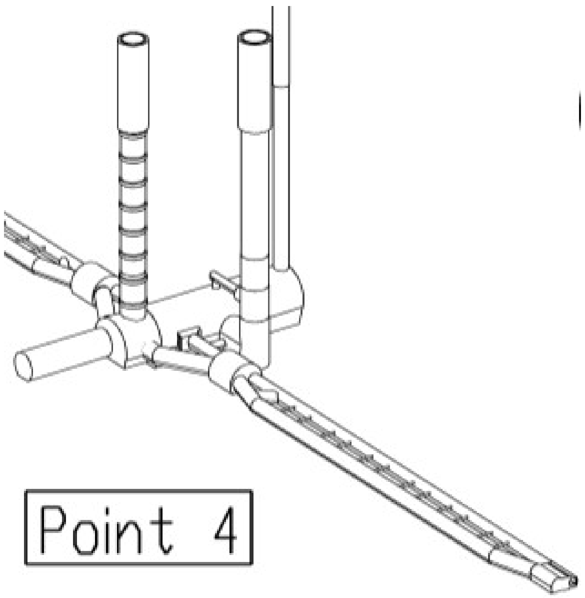
6 x SSA Drivers : 3.0 x 4.0 m
6+1 LLRF Racks: 3.0 x 8 m
Total: 3.0 x 12 m

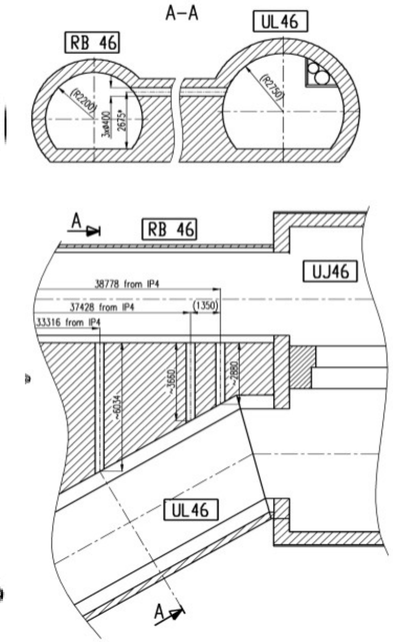
Summary Table

Cryomodule	Tunnel	<10m/IP side	6 cavities /IP side
Cryo Jumpers	Tunnel	Integrated with QRL	6jumpers /IP side
RF Amplifiers	Crab Cavern1	3m x 10m	6 Tetrodes
Circulators & Loads	Crab Cavern1	-	6 /IP side
Drivers & Controls	Crab Cavern2	3m x 4m	6 racks /IP side
LLRF Racks	Crab Cavern2	1.5m x 9m	6+1 racks /IP side
LLRF Central Rack	Exp. Cavern	1.5m x 6m	4+1 racks /IP side
Slow Controls	Exp. Cavern	2m x 4m	2 Racks
Remote Alignment	Exp. Cavern	-	-
HV Supply	Surface Bldg.	4m x 16m	6 Tetrodes/IP side

Crab Cavern: Nearest shielded location to the crab cavities ($< 1\mu s$ round-trip (including tetrode-circulator-driver-cable group delay, LLRF latency: 700ns)
Therefore only~40m cabling distance max to the cavity!

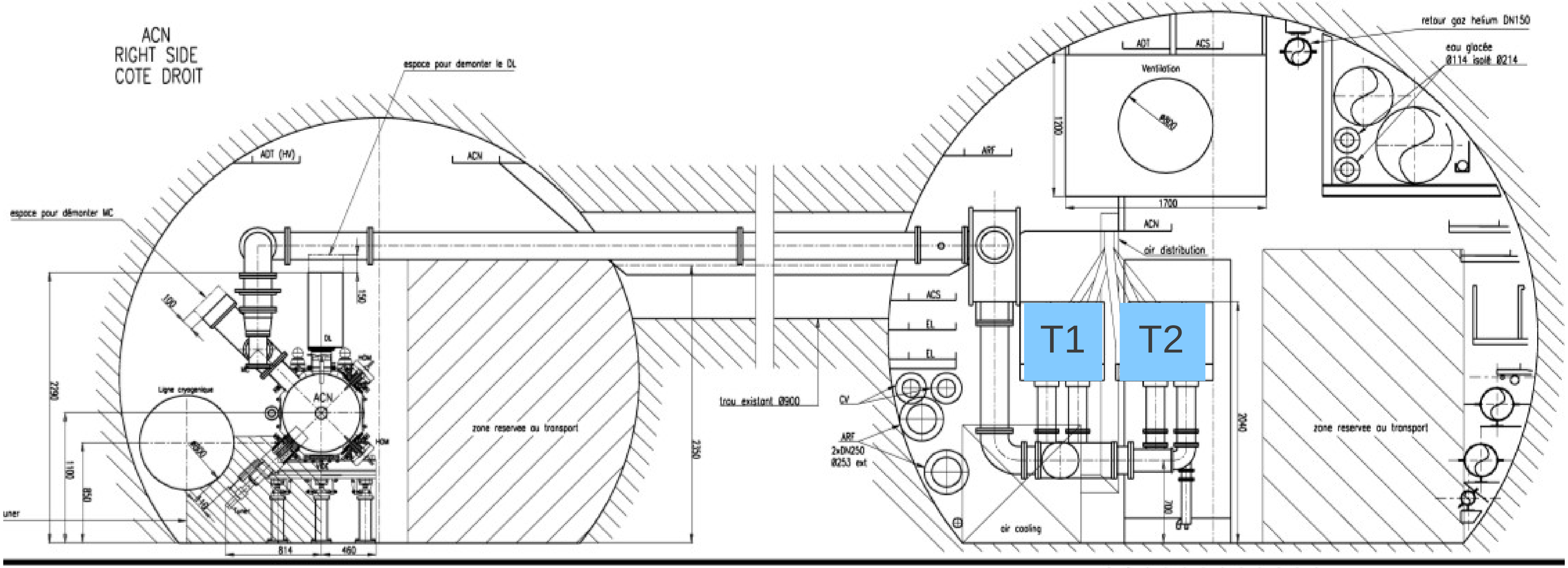
Service Gallery similar to P4 ideal



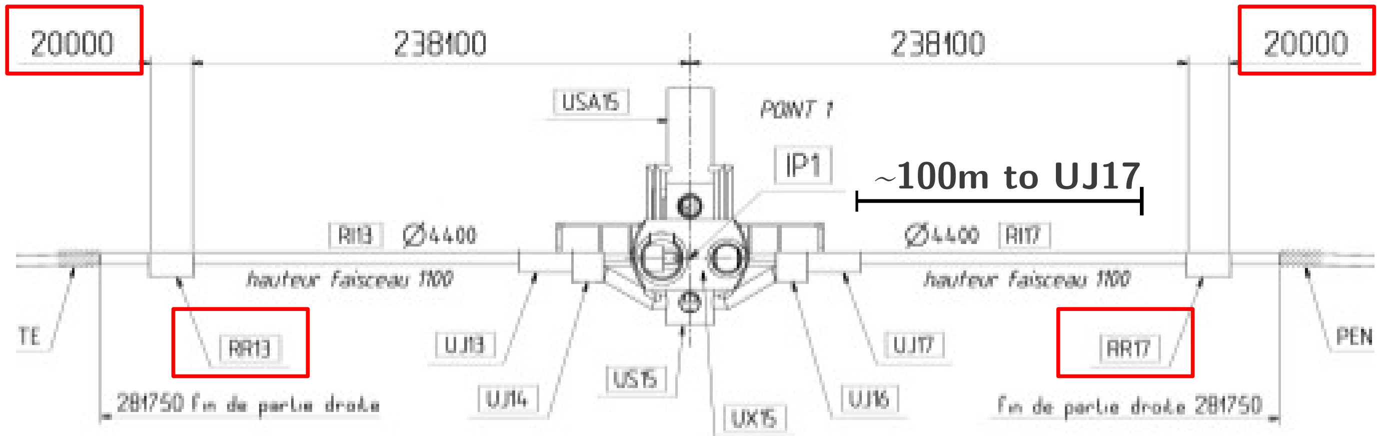


Capture cavity layout (not installed)

LLRF close to Amplifier (small loop delay)



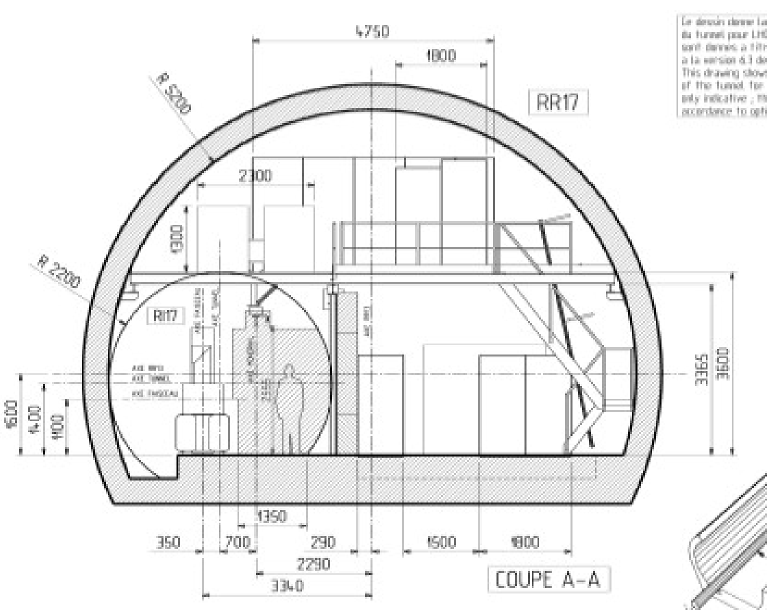
Point 1, RR17/RR13

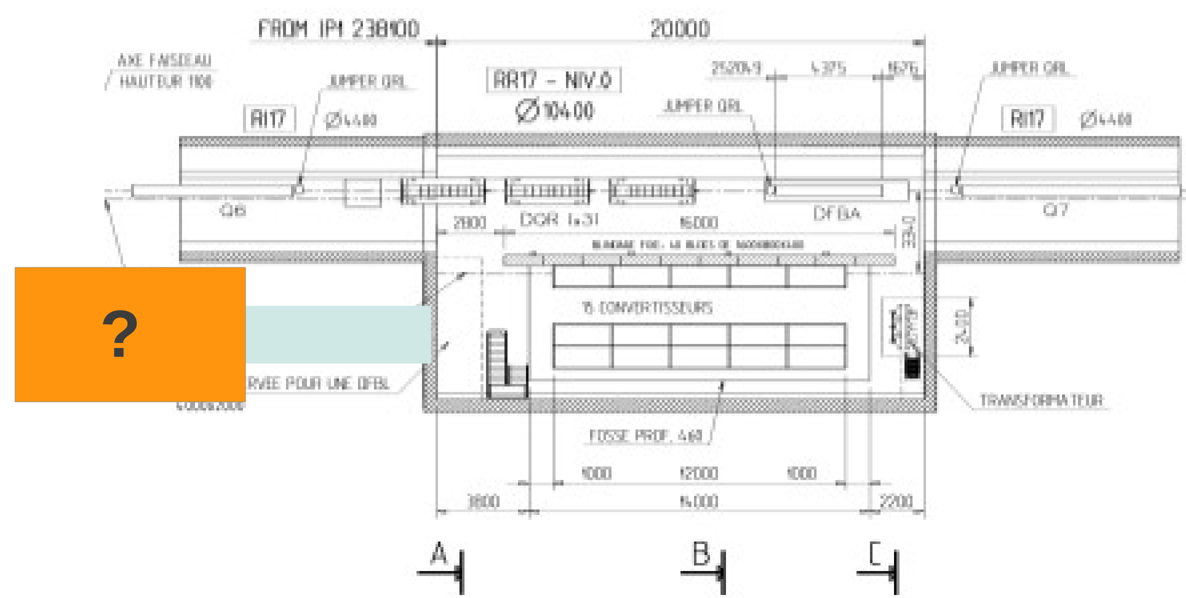


Can we have space here ?

What about radiation shielding

(May not be compatible with LLRF, not hermetic)

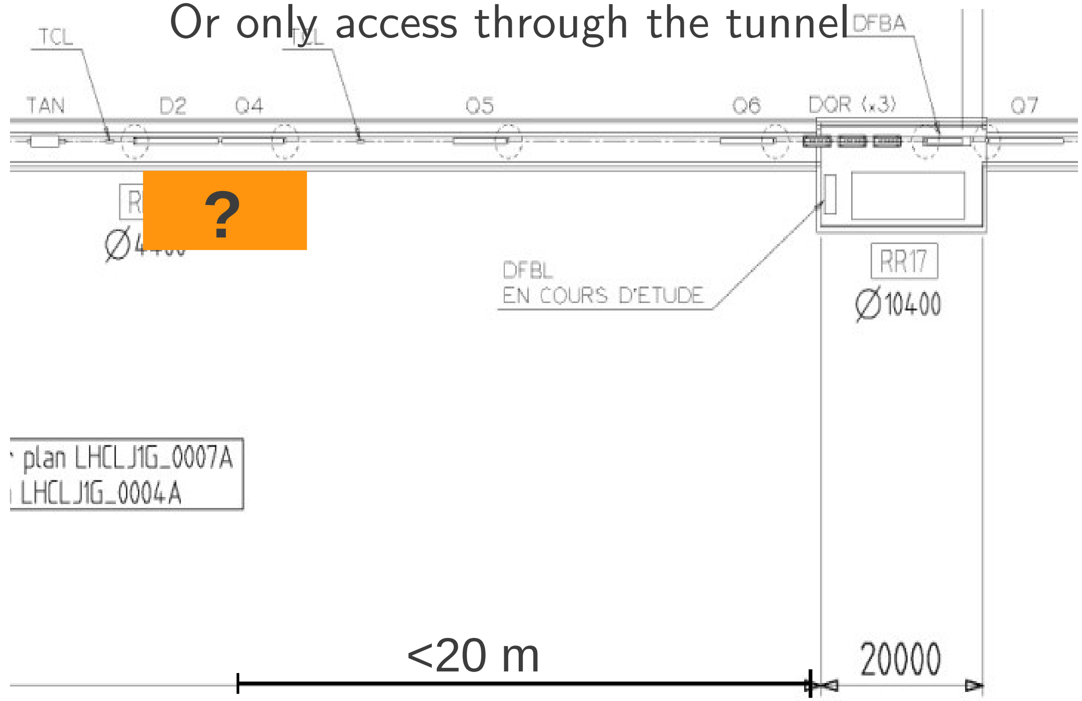




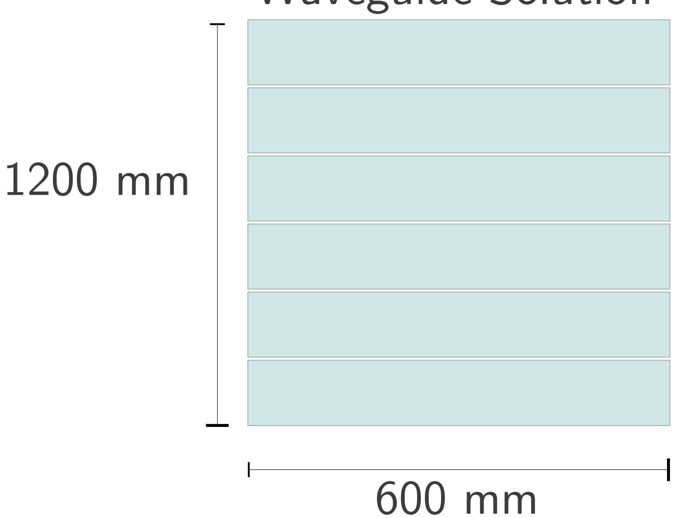
Point 1, RR17

Access line ?

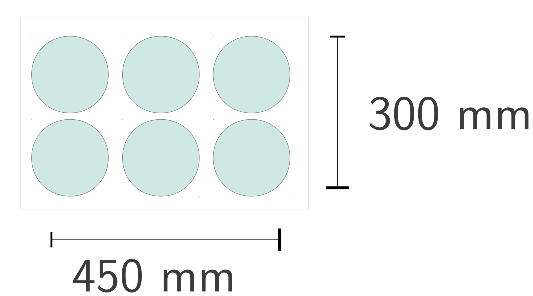
Or only access through the tunnel



Waveguide-Solution



Coaxial-Solution

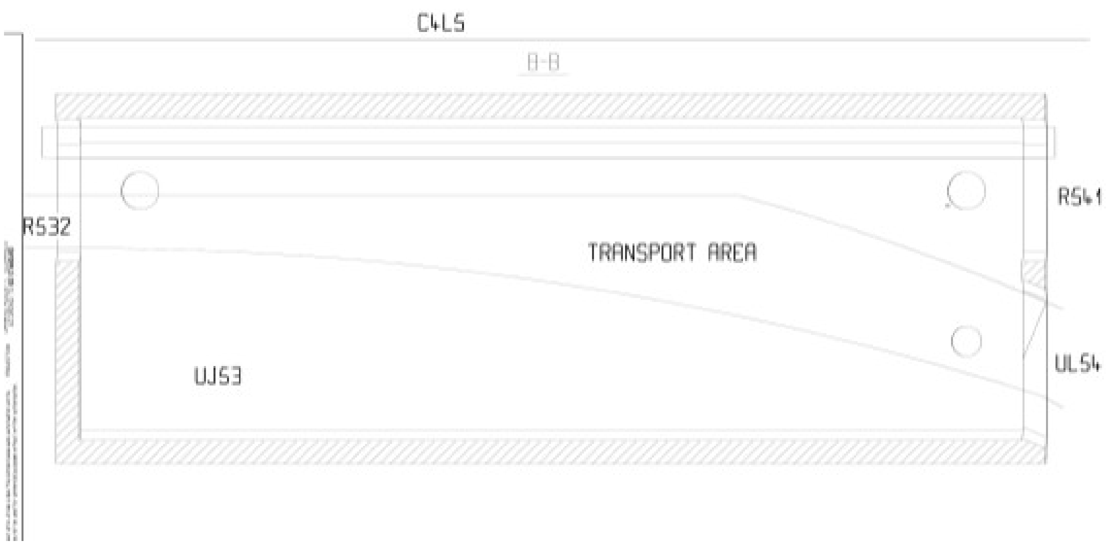


Point 5, UJ53/57

Nearest equipment space 100m(~0.4µs)

Round trip loop delay (still acceptable)

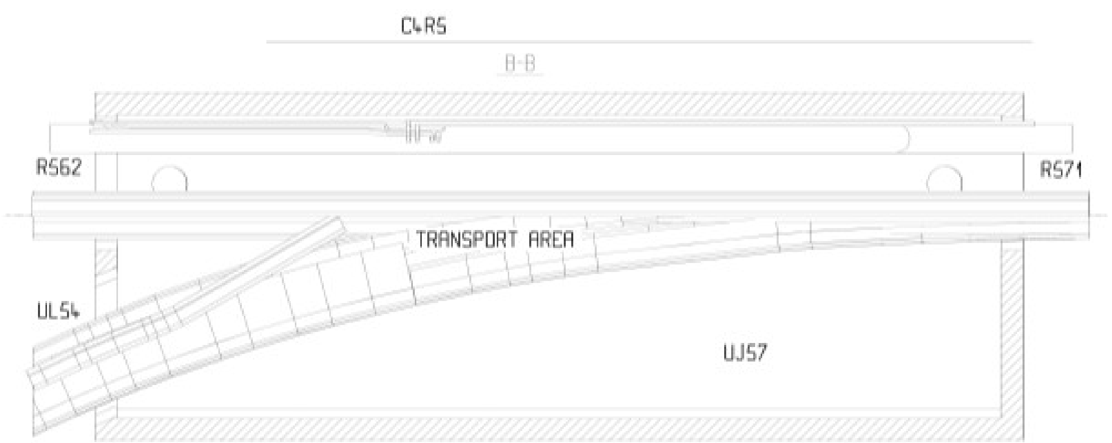
Can we have space here ?



But 6-Waveguides maybe complicated!

Better solution → similar to P4 or P1

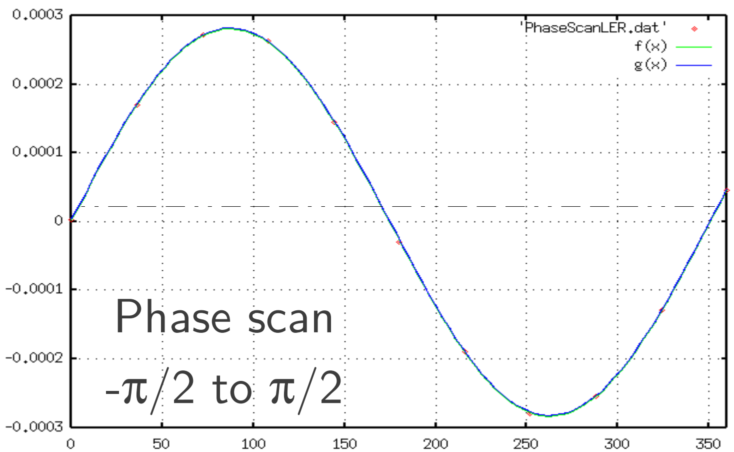
What is the expected radiation dose ?

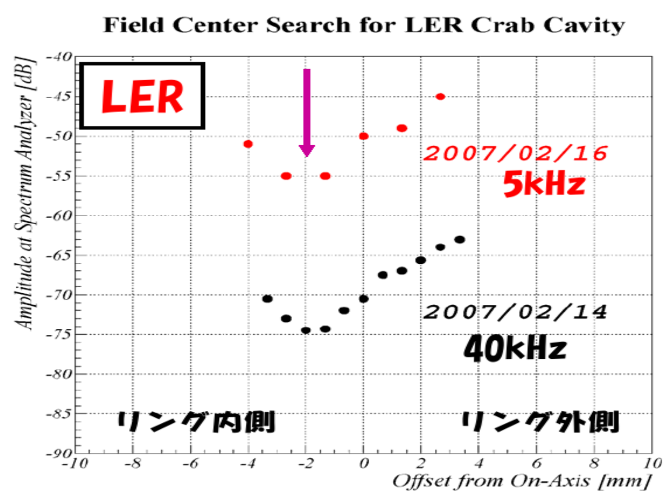


Instrumentation Needs

Crabbing effect cannot be seen outside the IR region with left/right compensation.
Luminosity & RF are best diagnostics inside the IR

Precise closed orbit measurement for RF phase & beam centering using amplitude (KEKB example, see below)





Input Power vs. beam offset

Headtail monitor & streak camera → Present location & number of devices to be studied w.r.t to the crab cavity phase-adv.

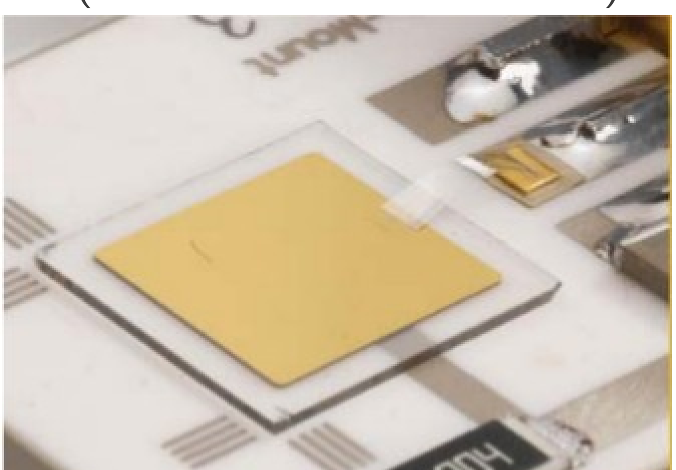
Instrumentation Needs

Halo monitoring & fast beam loss monitors $\rightarrow$ machine protection
(option for faster integration times/diamond loss monitors)

Wire scanners/BSRT for emittance measurements

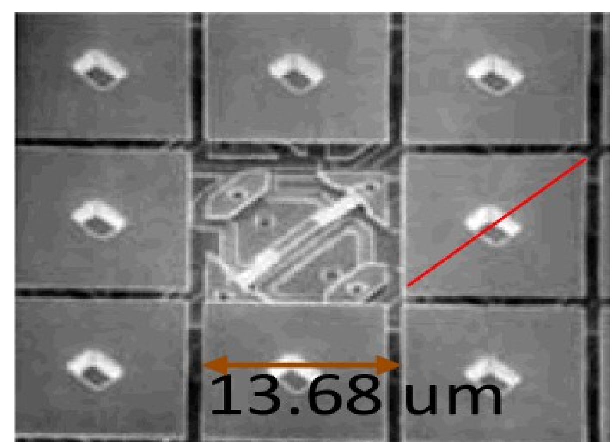
Other fancy devices (?)

CVD Diamond Detectors
(Fast Beam Loss Monitors)



B. Dehning, CERN

Digital Micro-Mirrors
(Beam Halo-Monitoring)



A. Fischer, SLAC

Summary Thoughts

- Cavity & cryomodule equipment seem compatible with the present constraints
  - Longitudinal 10m/6-cavities and Transversely 1m in diameter

- Cryogenics and associated equipment is being worked out
  - A service module close to cavities on the QRL is preferred
  - No crab specific issues so far identified from the layout yet

- RF power, drivers & controls have to be in a shielded area + close to the cavities
  - A "Point4 like" layout with a parallel access cavern would be ideal
  - Alternative solutions to be studied

Additional Items (To be addressed by RF)

- Operation w/o one TX (or cavity) out of 6 ? Impedance tolerable ?
  - Else → Passive damping system necessary & lower Q_L

- Maximum allowable beam offset: 1mm for the full energy cycle ? Power

A1: β-functions

Beam 1

Name	Location	β_x	β_y	D_x	α_x	α_y
	[km]	[m]	[m]	[m]	[m]	[m]
ACFA.L5B1	6505.87	3469.54	2915.04	0.097	-17.22	-46.69
ACFB.L5B1	6508.47	3559.66	3162.88	0.097	-17.44	-48.63
ACFC.L5B1	6511.07	3650.94	3420.84	0.097	-17.67	-50.58
ACFC.R5B1	6819.37	3290.97	3604.89	-0.097	49.61	17.56
ACFB.R5B1	6821.97	3038.07	3514.18	-0.097	47.66	17.33
ACFA.R5B1	6824.57	2795.28	3424.63	-0.097	45.72	17.11
ACFA.L1B1	19835.46	3469.54	2915.04	0.097	-17.22	-46.69
ACFB.L1B1	19838.06	3559.66	3162.88	0.097	-17.44	-48.63
ACFC.L1B1	19840.66	3650.94	3420.84	0.097	-17.67	-50.58
ACFC.R1B1	20148.96	3290.97	3604.89	-0.097	49.61	17.56
ACFB.R1B1	20151.56	3038.07	3514.18	-0.097	47.66	17.33
ACFA.R1B1	20154.16	2795.28	3424.63	-0.097	45.72	17.10

Beam 2

Name	Location	β_x	β_y	D_x	α_x	α_y
	[km]	[m]	[m]	[m]	[m]	[m]
ACFA.L5B2	6504.87	2795.28	3424.63	-0.097	-45.72	-17.11
ACFB.L5B2	6507.47	3038.07	3514.18	-0.097	-47.66	-17.33
ACFC.L5B2	6510.07	3290.97	3604.89	-0.097	-49.61	-17.56
ACFC.R5B2	6818.37	3650.94	3420.84	0.097	17.67	50.58
ACFB.R5B2	6820.97	3559.66	3162.88	0.097	17.44	48.63
ACFA.R5B2	6823.57	3469.54	2915.04	0.097	17.22	46.70
ACFA.L1B2	19834.16	2795.28	3424.63	-0.097	-45.72	-17.12
ACFB.L1B2	19836.76	3038.07	3514.18	-0.097	-47.66	-17.33
ACFC.L1B2	19839.36	3290.97	3604.89	-0.097	-49.61	-17.56
ACFC.R1B2	20147.66	3650.94	3420.84	0.097	17.67	50.58
ACFB.R1B2	20150.26	3559.66	3162.88	0.097	17.44	48..63
ACFA.R1B2	20152.86	3469.54	2915.04	0.097	17.22	46.68