SPS crab cavity test stand –
Results of interlock test and readiness for taking beam

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MPP 18th May 2018

Outline

Test stand layout
MD phasing
Generalities on interlocks architecture
Machine and equipment protection
- BIS
- RF

Timescales
Conclusions

MPP and Doc on crab interlocks for SPS

9 Dec 2016: Foreseen interlocks for the operation of crab cavities in SPS
29 Sep 2017: Final plan for interlocking of crab cavities in SPS

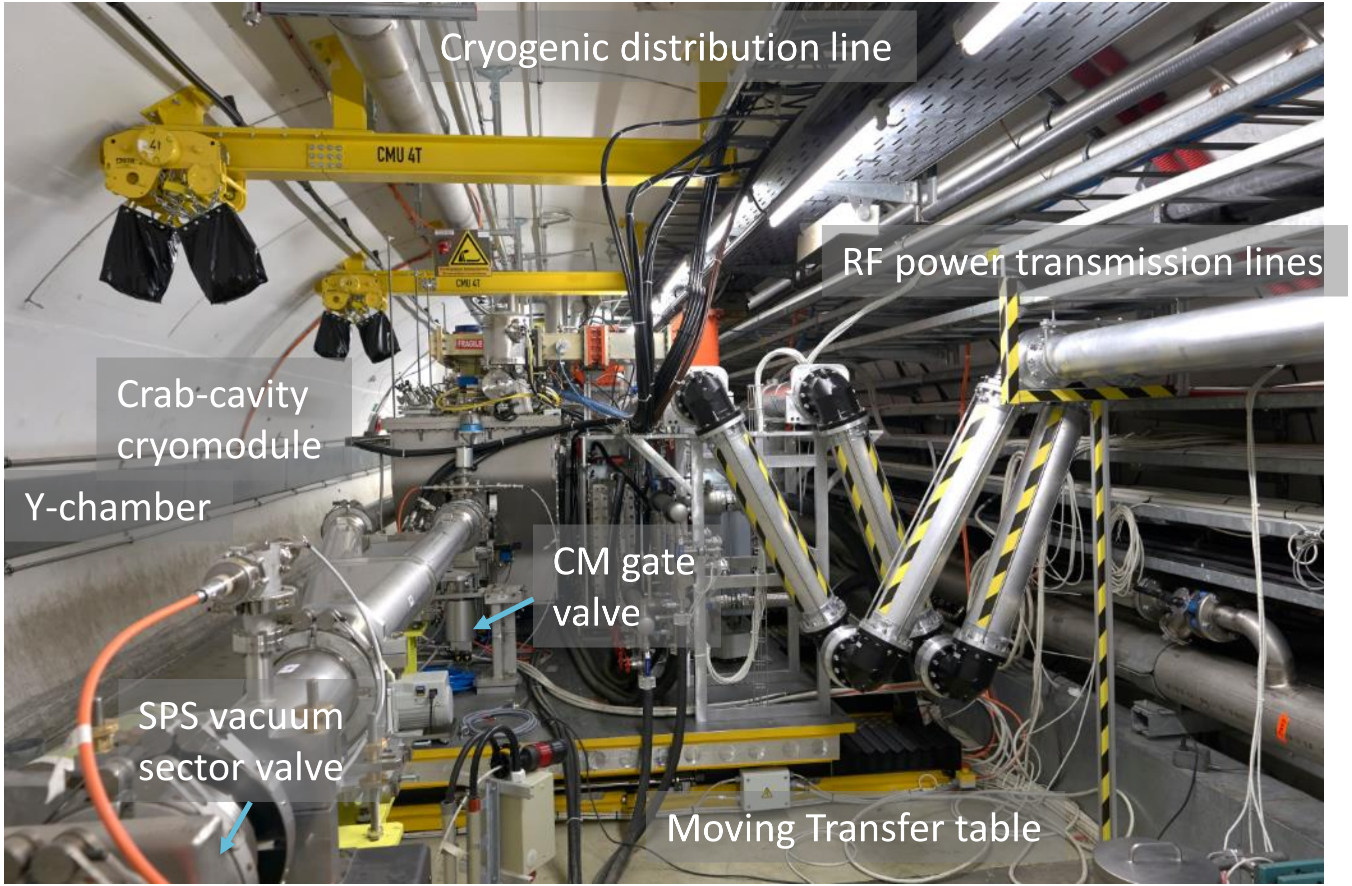
EDMS 1843638: Interlocks for the HL-LHC Crab-cavity test stand in SPS, L.Arnaudon, G.Vandoni

Approved! R.Calaga, K.Cornelis, T.Otto, D.Wollman, 13/3/2018

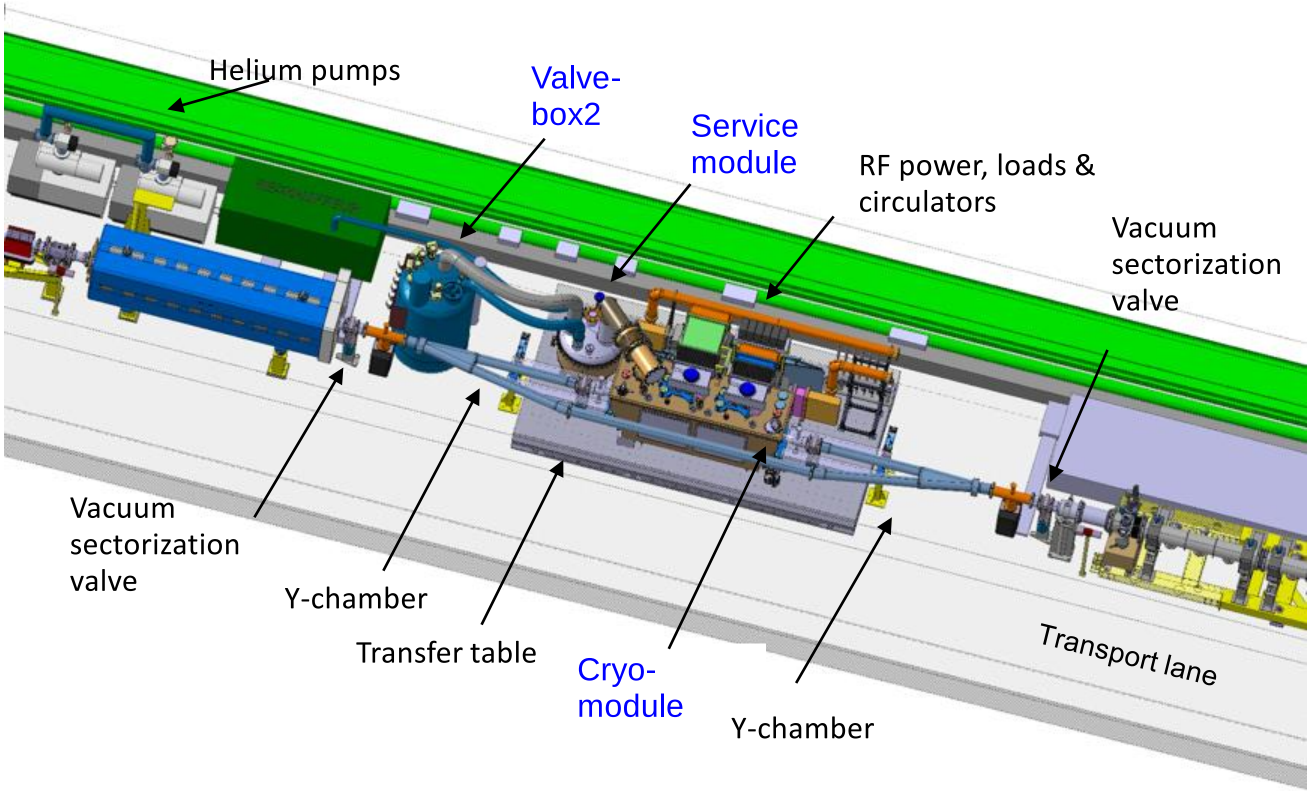
EDMS 1921540: DSO tests report, released 8 May 2018

Electron lens review 2016, indico: R.Calaga, RF Overview of crab Cavities for HL-LHC and potential failure modes

Test stand architecture – tunnel



System architecture – Crab-cavity test stand



Overview of the MD phases

The MDs were split into 4 main categories (for 2018):

1. RF-beam commissioning (2x10h)
2. Transparency (1-2x10h)

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3. Performance (1-2x10h)
4. High intensity (2x10h)

low intensity,
1 to 12 bunches, 2 10^{10}

MPP review

high intensity,
1 bunch to 4 x 72 trains

Before going to high intensities, a **special MPP** will be held to **assess the cavity performance** concerning protection issues.

Will perform **failure studies in parallel** during the MDs, as the beam parameters vary.

Progressive increase in energy + intensity || failure scenarios:

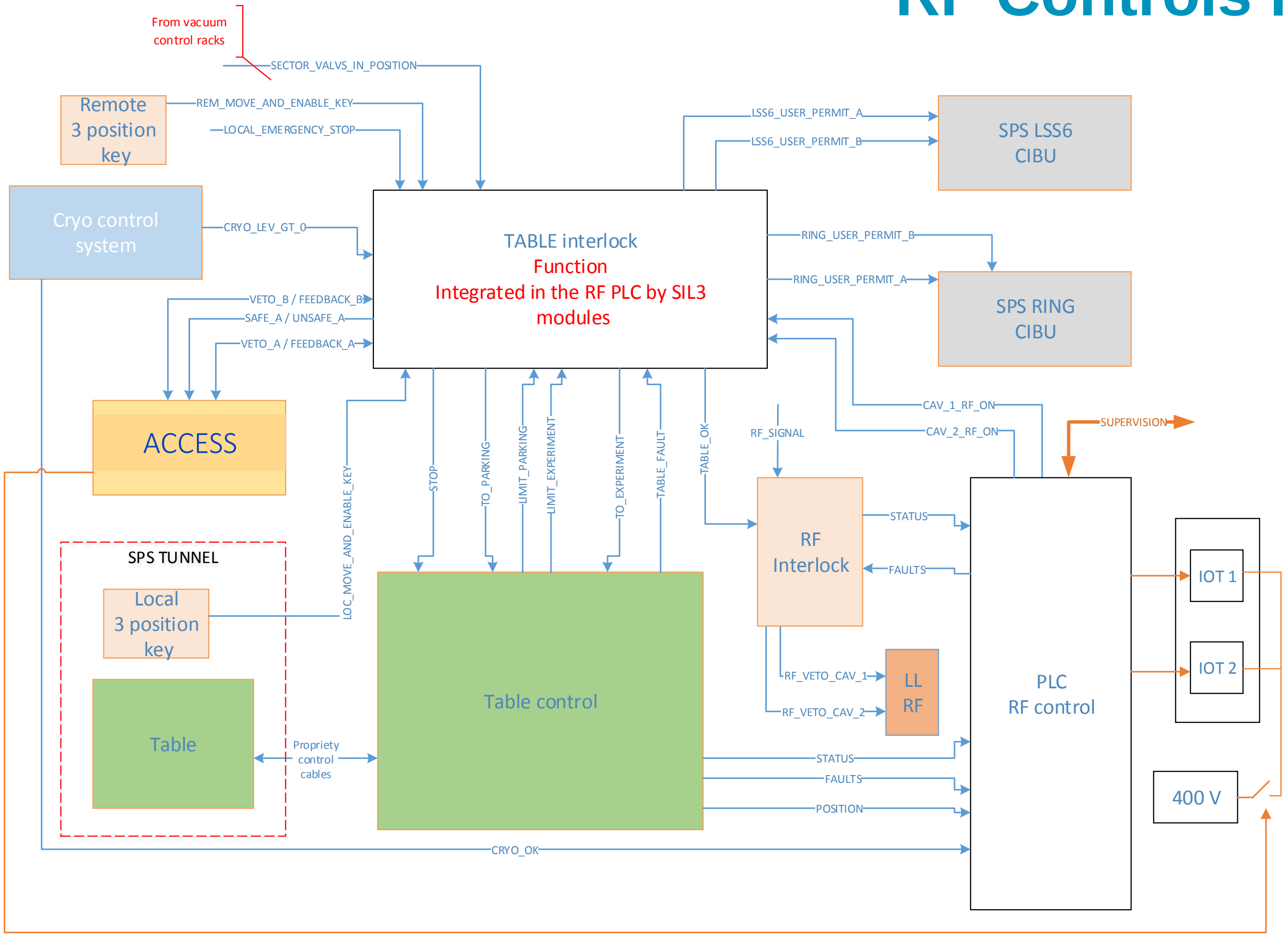
flexible interlocking as we learn to know the system.

Lee Carver, SPS-CC MD Planning Overview, SPS Test Day #2

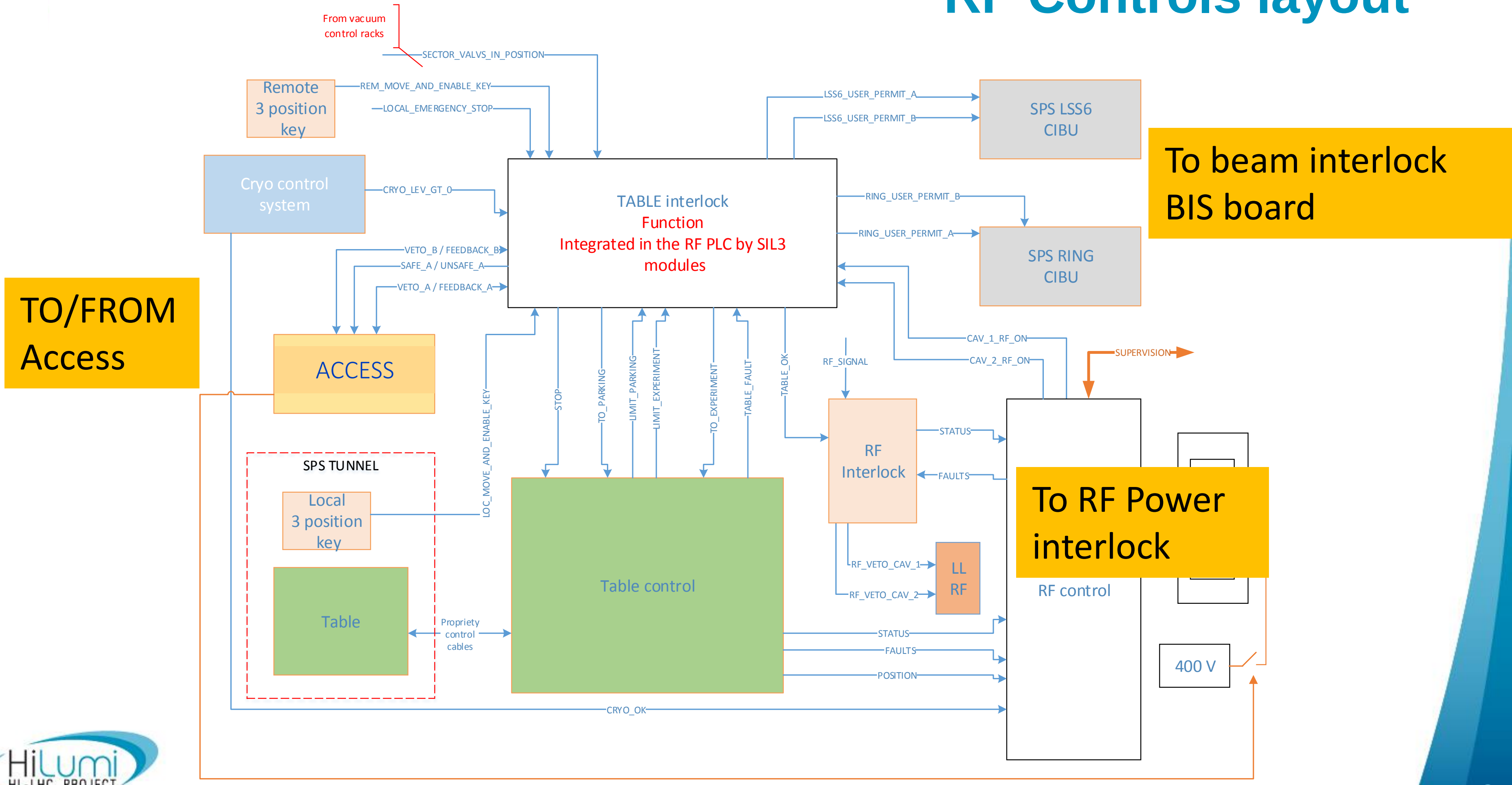
Interlock types

type	why	what
Personnel safety	Radiation (X-rays) ODH and cryo hazard mechanical hazard	Access versus RF Power to cavities Table movement
Machine protection	Aperture Protection SPS and crabs	Beam & extraction versus table position, movement, vacuum sector valves SIS
Equipment protection	Protection SPS and crabs	RF Power versus Vacuum, cryogenics. Beam versus HOM power

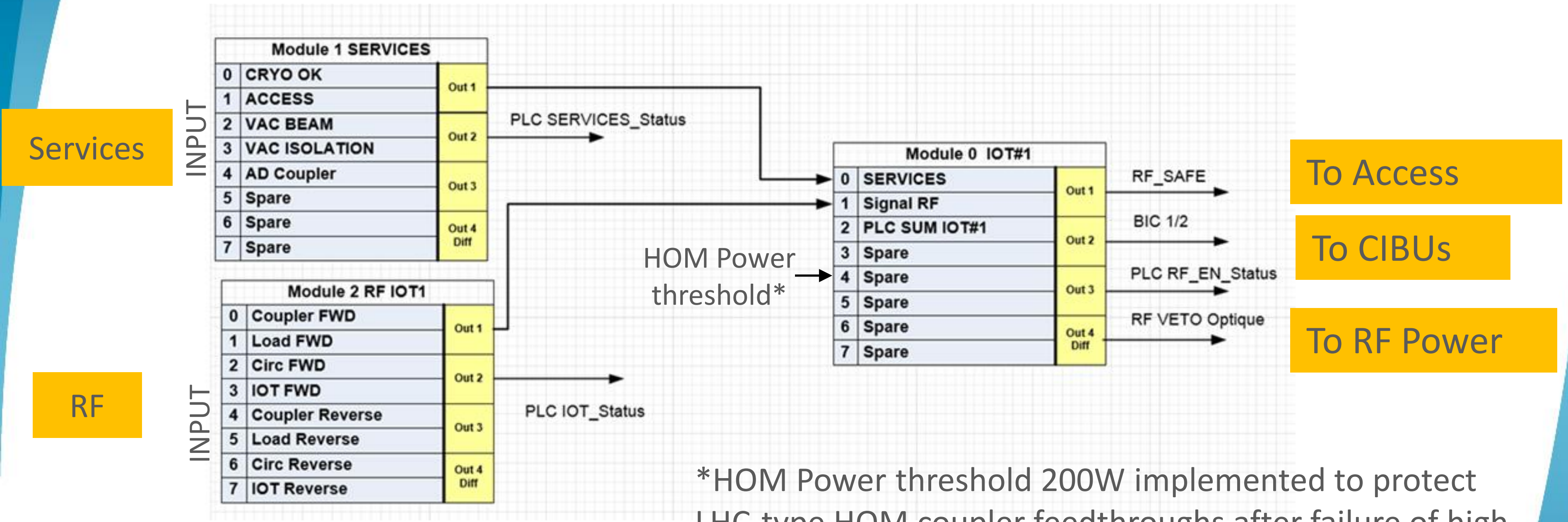
RF Controls layout



RF Controls layout



IOT Interlock modules



Same for IOT2

*HOM Power threshold 200W implemented to protect LHC-type HOM coupler feedthroughs after failure of high power new design HOM FT's during dressed cavity tests

From crab test stand via CIBU- BIS board entries

SIS Permit: Table OUT/IN

VVS CIBU

SPS RING CC CIBU

BLM CIBU

BIS SPS RING – BA6

SPS EXTR1 CC CIBU

BIS EXTR1 – BA6

- **1 new entry, unmaskable, from CC**
- VVS exception for V1/V3
- Software permit, maskable, with Table position
- CC BLM individual threshold setting, in BLM sector’s CIBU

- **1 new entry, unmaskable, from CC**

SPS Ring and Extr CC CIBUs (unmaskable)

*HOM Power threshold 200W implemented to protect LHC-type HOM coupler feedthroughs after failure of high power new design HOM FT's during dressed cavity tests

	Table OUT	Table IN	Table undefined / error / moving	HOM Power < 200 W	RF PLC status OK	RF parameters set	VVSB_61731 open	VVSB_61757 open	VVSB_61736 open	VVSB_61752 open	BLM one sector< threshold
Beam enabled											
EXTR enabled											
Beam enabled											
Beam NOT enabled											
EXTR NOT enabled											

BIS – Conformity and Functional Tests

BIS conformity reports

TE/MPE/EP - Beam Interlock System (BIS) Commissioning Report for BIC User Permit System			
Date :	Thu 08 Mar 2018	MI Member Name(s) :	RSEC

General User Informations

BIC Name	CIB.BA6.S6		Input	5	Beam B1
CIBU/CIBF ID#	354	CIBUS	Rack	RA4726	
User System Name	Crab Cavity RING		Group	BE-RF	

TE/MPE/EP - Beam Interlock System (BIS) Commissioning Report for BIC User Permit System			
Date :	Thu 08 Mar 2018	MI Member Name(s) :	RSEC

General User Informations

BIC Name	CIB.BA6.TT60A		Input	7	Beam B1
CIBU/CIBF ID#	355	CIBUS	Rack	RA4726	
User System Name	Crab Cavity LSS6		Group	BE-RF	

BIS functional tests with time stamping

TE/MPE is looking into the time-stamping during table movement tests 2/5

Proposal to go through the procedure with timestamps at the beginning of the MD

RF Power Interlocks

All tested or being tested during present commissioning and RF conditioning, off beam

	Access Safe	Vacuum FPCs (beam)	Vacuum - beam	Vacuum - insulation	Cryo OK	Arc detectors	Coupler FRW	Load FWD	Circulator FWD	IOT FWD	Coupler REV	Load REV	Circulator REV	IOT REV
RF Power OK														

3.5 10^{-7}mbar

4.0 10^{-7}mbar

Monitored but not used for interlocking, they may be used for LHC.

RF Power Interlocks - timescales

	Reaction time
Arc detection	< 1 μs
Reflected RF power (or any RF Power parameter)	< 1 μs
Vacuum FPC	< 0.1 to 5 ms
SIS	≈ 1s

Interlock non-conformity

Table position to Vacuum valves opening is now via software	Cable to be pulled for hardware interlock
Vacuum to cryogenics is now via software	Cable to be pulled for hardware interlock
Interlocks Engineering Specification defines only Safety and Machine Protection interlocks, not the equipment mutual protection	Modify the Interlocks Engineering Specification to include all equipment protection interlocks

Conclusion

- Functional test of BIS with timestamps could be repeated for completeness at MD start
- SIS (maskable BIS entry) only includes the table position: it is evolutive

Phases 1-2: READY (after functional BIS test)

Stopping point: MPP review in June

Phases 3-4: Evolution of the interlocking scheme via RF parameter set interlocking RF and SIS

Back-up slides

Potential Failure Modes

- Cavity stored energy is 10-12 J

- Some "slow" failure
  - RF arcing, $\tau_F \sim 1$ ms
  - Power supply trips ($50 - 300\ Hz$): $\tau_F \sim$ few ms
  - Mechanical changes: $\tau_F \sim 100$'s ms

- Fast Failures (10's $\mu s - ms$)
  - Cavity quench, RF breakdown, Sudden discharge
  - Fast orbit changes, external forces

- LHC Collimation, maximum allowed (old numbers)
  - Slow: 0.1% of beam/second for 10s
  - Transient: 5×10^{-5} in 1 ms
  - Fast: Up to 1 MJ in 200 ns into $0.2\ \mathrm{mm}^2$

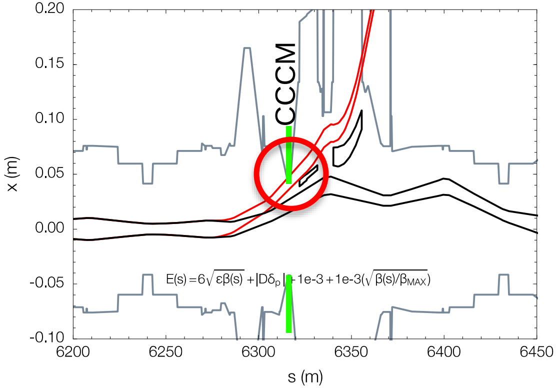
R.Calaga,
Electron Lens review 2016

Truth Table for Transfer Table

		PLC COMMANDS				INPUTS FROM														
						TABLE CONTROL					LOCAL		ACCESS		VACUUM	CRYO	TUNNEL			
OUTPUTS TO		TO PARKING	TO EXP	SERVICE	LIFE	park	exp	moving	fault	life	EM Switch	key lock	VETO A	VETO B	Valves closed	He Level OK to move	EM Switch	TO Park	TO Exp	stop
TABLE CONTROL	TO PARK	1	0	0	1	0	x	0	0	1	0	1	1	1	1	x	0	x	x	x
		1	0	0	1	0	x	0	0	1	0	1	1	1	1	x	0	x	x	x
		1	0	0	1	0	x	0	0	1	0	0	x	x	1	1	0	1	x	x
		1	0	0	1	0	x	0	0	1	0	0	x	x	1	1	0	x	1	x
	TO EXP	0	1	0	1	x	0	0	0	1	0	1	1	1	1	x	0	x	x	0
		0	1	0	1	x	0	0	0	1	0	1	1	1	1	x	0	x	x	0
		0	1	0	1	x	0	0	0	1	0	0	0	0	1	1	0	1	x	x
		0	1	0	1	x	0	0	0	1	0	0	0	0	1	1	0	1	x	x
	STOP	0	0	0	1	x	x	x	x	0	x	x	x	x	x	x	x	x	x	x
		0	0	0	1	x	x	x	x	1	1	x	x	x	x	x	x	x	x	x
		0	0	0	1	x	x	x	x	1	x	x	x	x	x	x	1	x	x	x
	SERVICE PERMIT	0	0	1	1	x	x	x	x	1	0	x	x	x	1	1	0	x	x	x
	LIFE	x	x	x	1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
PLC	TABLE OK	x	x	x	1	x	x	0	0	1	0	1	x	x	0	0	0	x	x	1
PASS	FB	x	x	x	1	x	x	x	x	x	x	x	1	x	x	x	x	x	x	x
	FB	x	x	x	1	x	x	x	x	x	x	x	x	1	x	x	x	x	x	x
	SAFE	x	x	x	1	1	0	0	0	1	x	x	x	x	1	1	x	x	x	x
		x	x	x	1	0	1	0	0	1	x	x	x	x	1	1	x	x	x	x
CIBU	LSS6-PERMIT A	x	x	x	1	1	0	0	0	1	0	x	0	0	0	0	0	x	x	x
	LSS6-PERMIT B	x	x	x	1	1	0	0	0	1	0	x	0	0	0	0	0	x	x	x
	RING-PERMIT A	x	x	x	1	1	1	0	0	1	0	x	0	0	0	0	0	x	x	x
	RING-PERMIT B	x	x	x	1	1	1	0	0	1	0	x	0	0	0	0	0	x	x	x

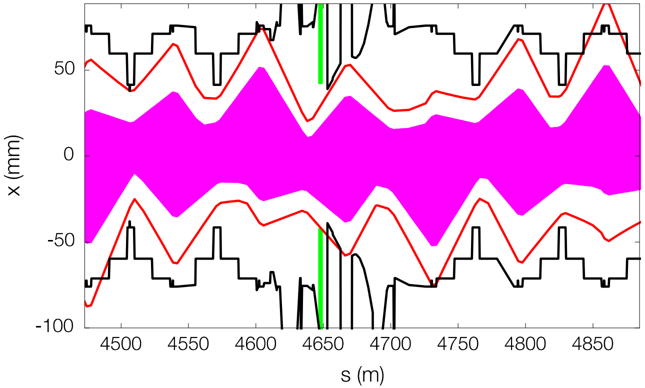
Aperture and crab cavities

LHC beam extraction in LSS6



CCCM aperture

NA slow extraction in LSS6



Fast extraction to LHC
Crab-cavity in beam does **not** yield **enough aperture** for extracted beam

Slow extraction of fixed target beam
at 400GeV, incl. extraction bump
purple : raw beam envelope
red: beam envelope + tolerance

Crab cavity in beam gives sufficient aperture for slow extraction to NA
No bumper dipole interlock (opp. to Coldex)

H.Bartosik @
SPS Test Day, I
https://indico.cern.ch/event/463435/

HiLumi HL-LHC PROJECT