MACHINE PROTECTION CONSIDERATIONS TO LINAC4 BIS COMMISSIONING

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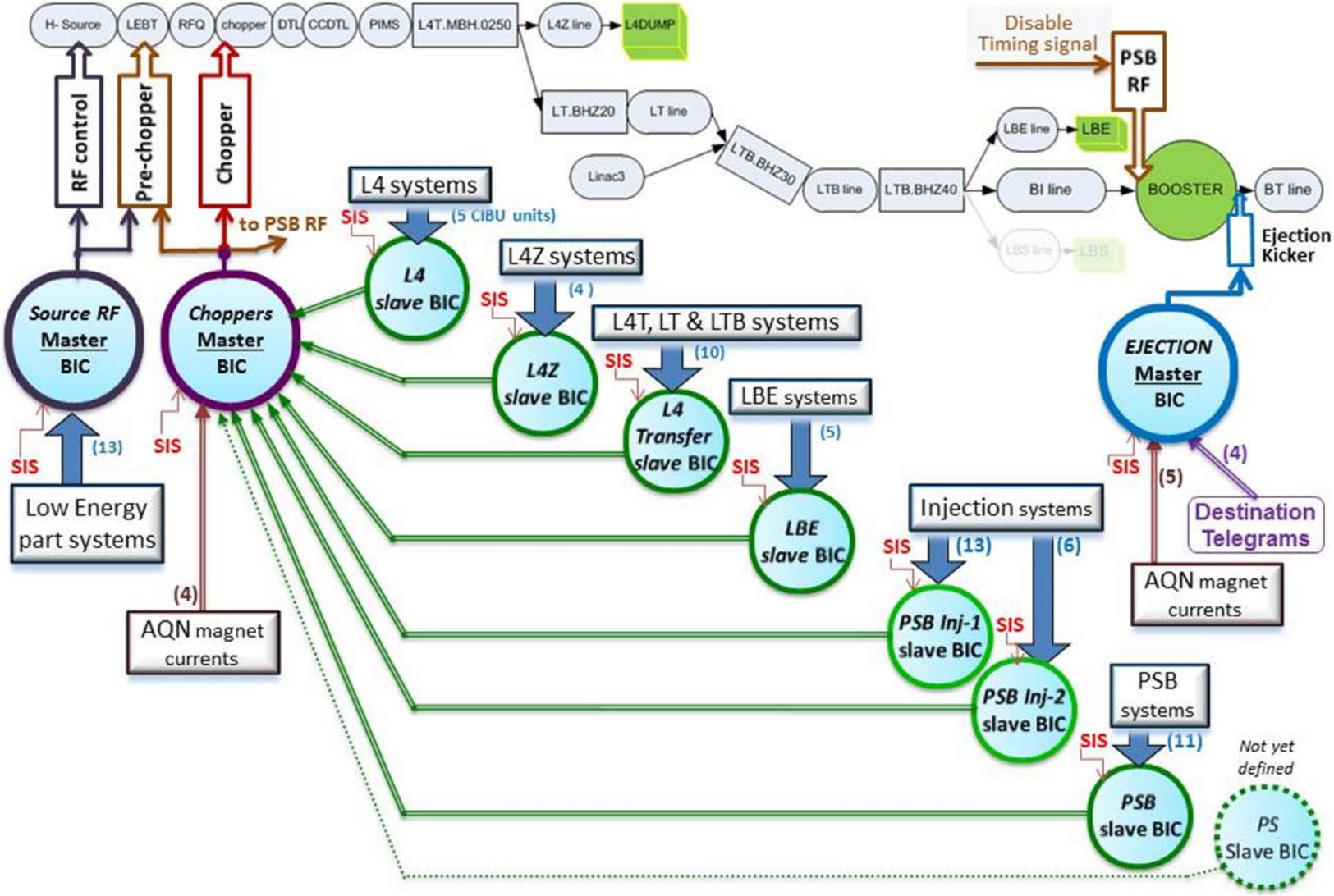
4/4/2014

LINAC4 BIS: BEAM INTERLOCK CONTROLLERS



BIS Linac4 & PSB layout

LINAC4 BIS: GENERAL CONSIDERATIONS

- Same implementation as LHC BIS (except differential links)
  - ✓ LHC BIS: SIL3
  - ✓ Very good experience from the past
  - ✓ Linac4 only requires SIL1/SIL2 (also from the user side)
- Reaction time within the same Linac4 pulse (few tens of us)

- SIS: complementary role wrt to the BIS protection

- BIS Commissioning:
  - ✓ Try to reproduce realistic operation since the beginning
  - ✓ Try to avoid HW modifications in the following steps
  - ✓ Allow for flexible operation

SAFETY INTEGRITY LEVEL (SIL)

Safety Integrity Level (SIL) is defined as a relative level of risk-reduction provided by a safety function, or to specify a target level of risk reduction.

Frequency	per year	Consequence			
		Catastrophic	Major	Moderate	Low
Frequent	1	SIL4	SIL3	SIL3	SIL2
Probable	0.1	SIL3	SIL3	SIL3	SIL2
Occasional	0.01	SIL3	SIL3	SIL2	SIL1
Remote	0.001	SIL3	SIL2	SIL2	SIL1
Improbable	0.0001	SIL3	SIL2	SIL1	SIL1
Not Credible	0.00001	SIL2	SIL1	SIL1	SIL1
Cost [MCHF]		> 50	1-50	0.1-1	0-0.1
Down-time [days]		> 180	20-180	3-20	0-3

- 3 weeks downtime is at the boundary between Moderate/Major!

LINAC4 BIS: COMMISSIONING STEPS

The BIS commissioning will match the 5 phases of the Linac4 commissioning [1]:

- Up to the DTL:
  - ✓ 3 MeV with 2 destinations (inline to 3 MeV dump and to diagnostic line + dump)
  - ✓ 12 MeV with 2 destinations (inline to Commissioning dump and to diagnostic line + dump)
- Downstream the DTL:
  - ✓ 50 MeV with 1 destination (inline to Commissioning dump)
  - ✓ 100 MeV with 1 destination (inline to Commissioning dump)
  - ✓ 160 MeV with 1 destination (inline to L4Z and main Linac4 dump)

BIS COMMISSIONING: 3 MeV

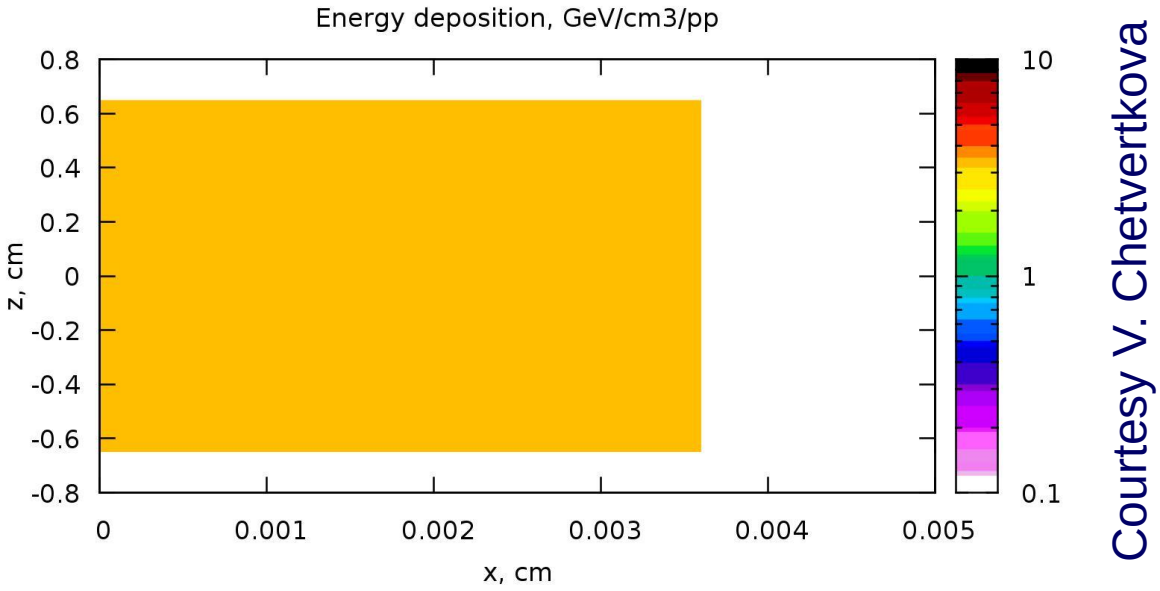
- The 3 MeV commissioning phase included the Linac4 elements up to end of the chopper line + diagnostic line:
  - ✓ Only one BIC was deployed (MASTER BIC SOURCE RF)

- For the start of the commissioning, not all the inputs of the BIS were available. The **criticality** of the different inputs was defined for the different commissioning steps.

- Machine Protection Considerations:
  - ✓ Damage to equipment possible at Low-Energy
  - ✓ No activation below 10 MeV [2]

DAMAGE POTENTIAL AT 3 MeV

- Beam impact on a 200 um thick stainless steel bellow (aperture bottle neck)
- a 3 MeV proton beam is stopped at ~ 35 um in stainless steel
- Rectangular (uniform) beam distribution (13 mm x 1mm)
- Total energy deposition is ~12kJ/cm3/pulse
- Depositing 12 kJ in stainless steel will increase the temperature to ~2800K in case of head-on impact (melting point is ~1800 K)



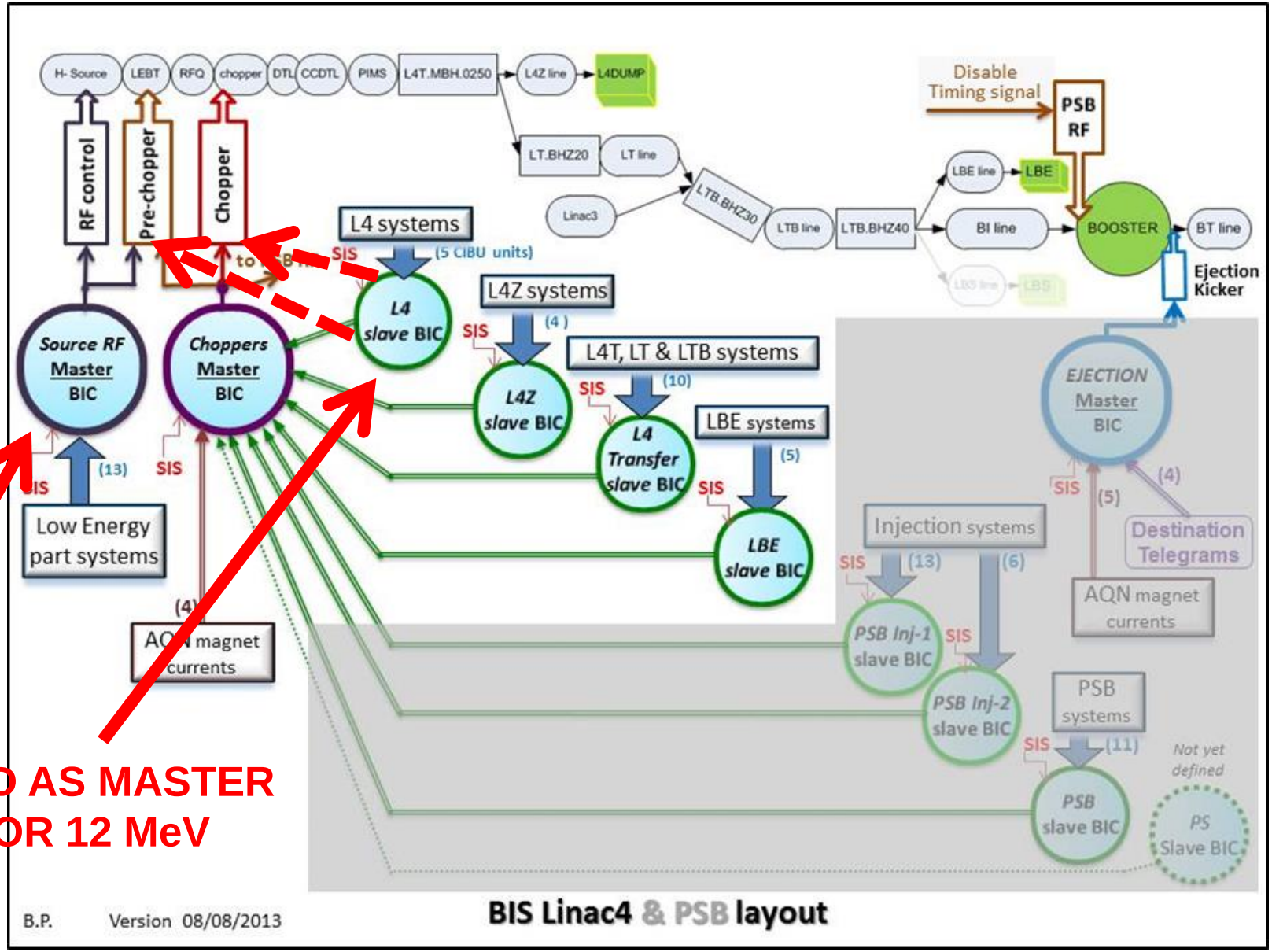
BIS COMMISSIONING: 12 MeV

- The 3 MeV commissioning phase includes the Linac4 elements up to first DTL tank + diagnostic line:
  - ✓ MASTER BIC SOURCE RF was already deployed in the 3 MeV phase
  - ✓ Slave BIC Linac4 used as 'temporary master' (connected to pre-chopper and chopper)

- The criticality of the different inputs was updated for the Master Source RF and defined for the slave BIC Linac4

- Machine Protection Considerations:
  - ✓ Damage to equipment possible energy at Low-Energy
  - ✓ Risk of activation above 10 MeV [2]

LINAC4 BIS: 12 MeV



USED AS MASTER FOR 12 MeV

MASTER SOURCE RF: 12 MeV

Ch.	0	1	2	3	4	5	6	7	8	9	10	11	12	(13)
Interlock Element	SIS	Source Internal	Source HV	Pre-chopper	Source Beam Stoppers Out/Moving	Source Beam Stoppers In	Chopper	L4 Low-Energy Watchdog	L4 Low-Energy Vacuum Valves	L4L. ChopperQuads	RFQ	CCC Operator Veto	L4 Operator Veto	Commissioning Dumps status

- Source HV and Internal not ready for 12 MeV (Source HV in SIS as for 3 MeV, masking for start-up tbd; Source Internal forced to 'true' following discussion with source experts)
- Chopper: ***mandatory***
- L4 Low-Energy Watchdog: ***mandatory*** (this measures an average current; how to set a threshold for operation at this stage?)
- Commissioning Dump status: will be connected

‘SLAVE’ BIC LINAC4: 12 MeV

Ch.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Interlock Element	**SIS**	**External Conditions (full pulse)**	**L4 Vacuum Valves + (L4T.VVGS.0101)**	**BLMs L4+L4Z**	*not used (L4 RF)*	**WIC L4**	*not used*	*not used*	**L4 RF**	*not used*	*not used*	*not used*	*not used*	*not used*	*not used*

- EC only needed for operation + no BLMs will be present at this stage
- RF: only first tank of DTL is present (temporarily to maskable input #8)
- WIC: only the surveillance of the magnets temperatures will be available (survey the status of the power converters via the SIS?)
- WIC: some magnets in the LEBT so far without protection

THE COMMISSIONING STEPS OF THE L4 BIS

https://edms.cern.ch/file/1310007/0.2/L4-CIB-ES-0005-00-20.pdf

CERN
CH-1211 Geneva 23
Switzerland

EDMS NO.	REV.	VALIDITY
1310007	0.2	DRAFT

REFERENCE
L4-CIB-ES-0005

the Linac4 project

Date: 2014-04-03

Engineering Specification

THE COMMISSIONING STEPS OF THE LINAC4 BEAM INTERLOCK SYSTEM

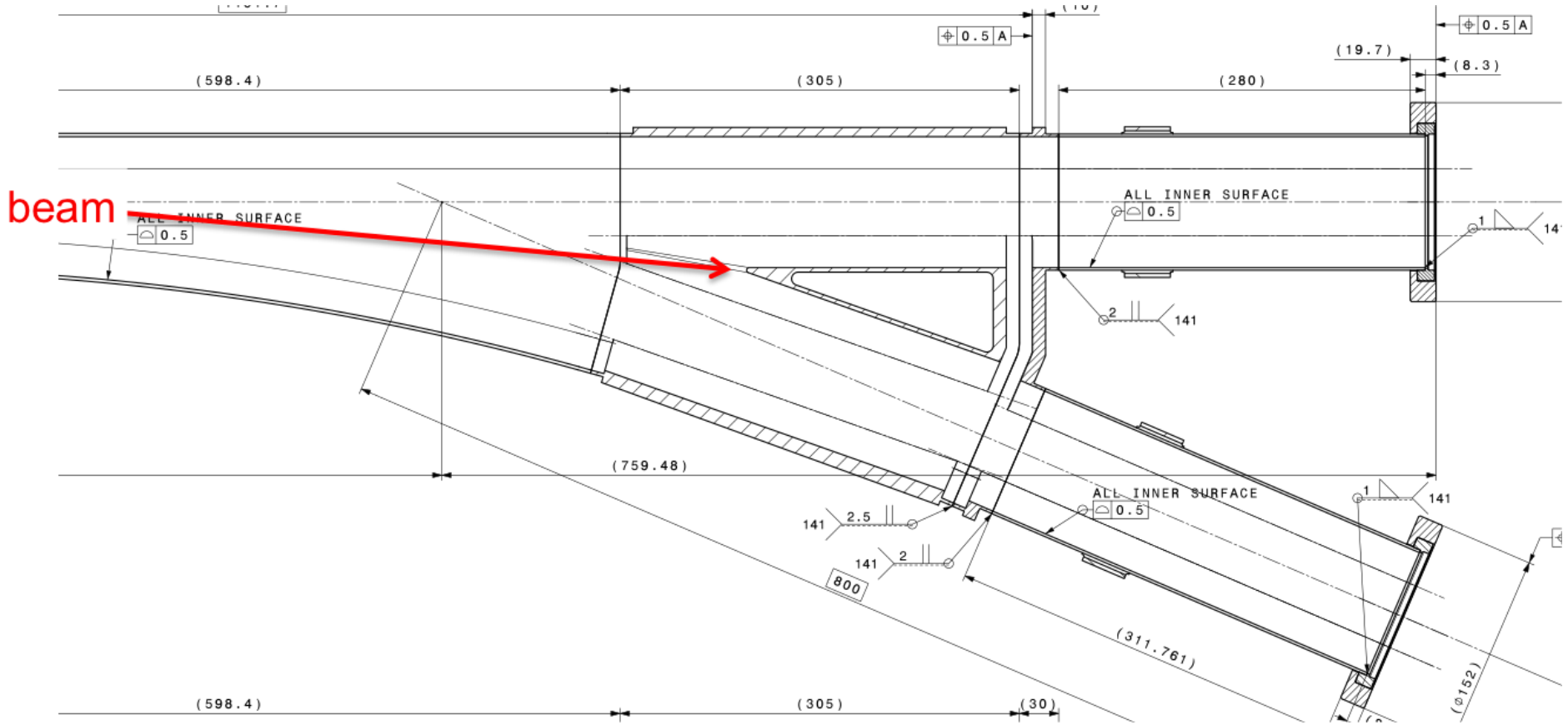
ABSTRACT:

The Beam Interlock System for Linac4 and its transfer lines to the PSB will be deployed in accordance with the global Linac4 schedule which includes five commission phases: 3MeV, 12MeV, 50MeV, 100MeV and 160MeV.

This document describes the steps to deploy the different Beam Interlock Controllers and to identify the connected systems which will be required for each phase of the commissioning.

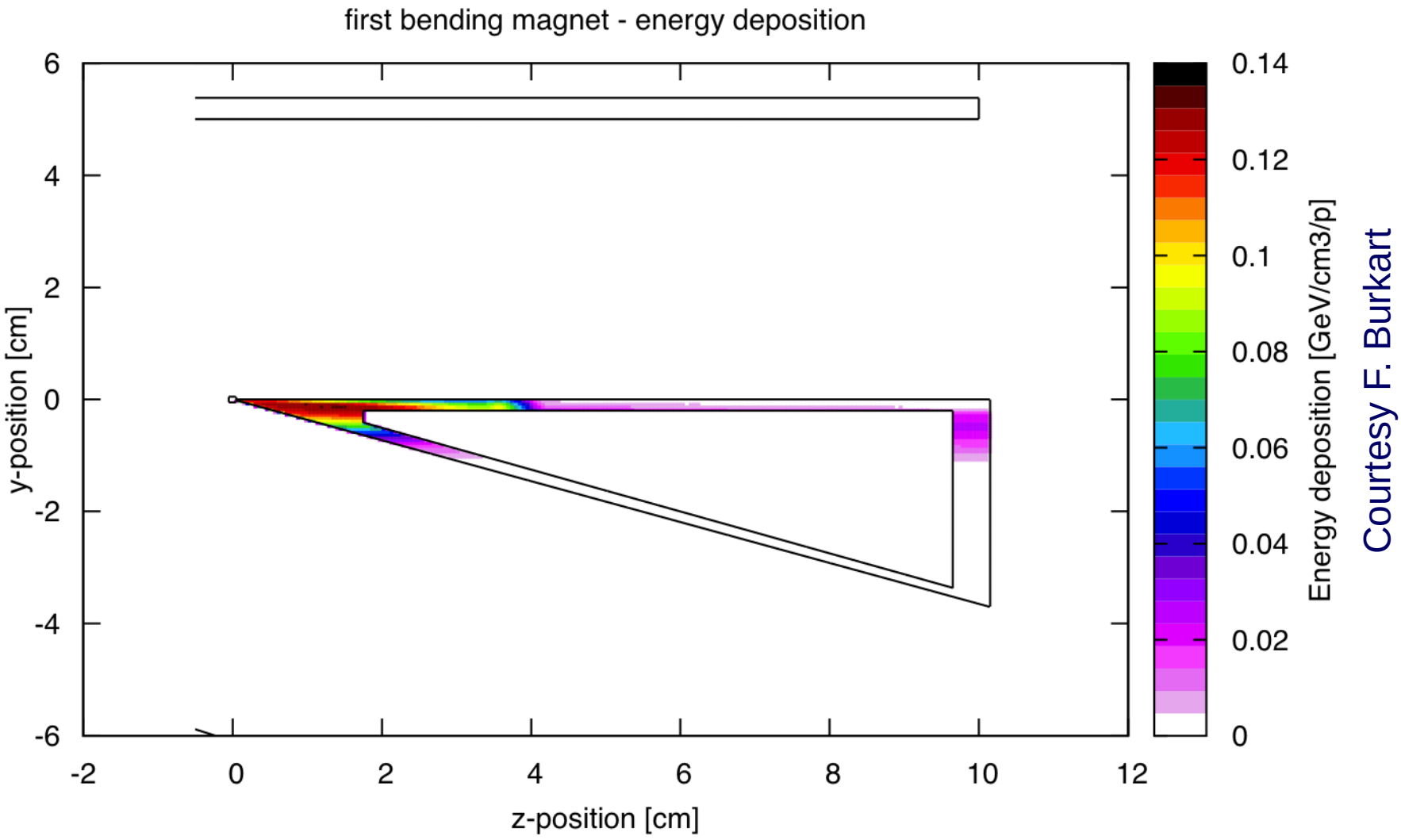
DAMAGE SIMULATIONS – WORST CASE

- Simulation of 1 full pulse impacting on the beam pipe at the end of the Linac (400 us, 160 MeV)



Courtesy F. Burkart

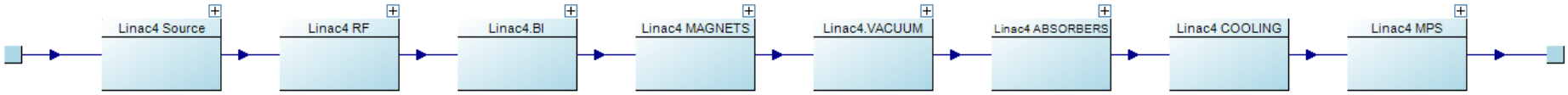
DAMAGE SIMULATIONS



Courtesy F. Burkart

- No harm will be caused to the Stainless Steel beam pipe in this scenario

LINAC4 AVAILABILITY MODEL



FAILURE MODES:

- Failure pdf
- MTBF
- Maintenance strategy
- Repair Time
- Resources needed

SPARES:

- Spare Type
- # Spares
- Storage cost
- Logistic Delay
- …

LABOR:

- Personnel
- # Experts
- Call out cost
- Logistic Delay
- …

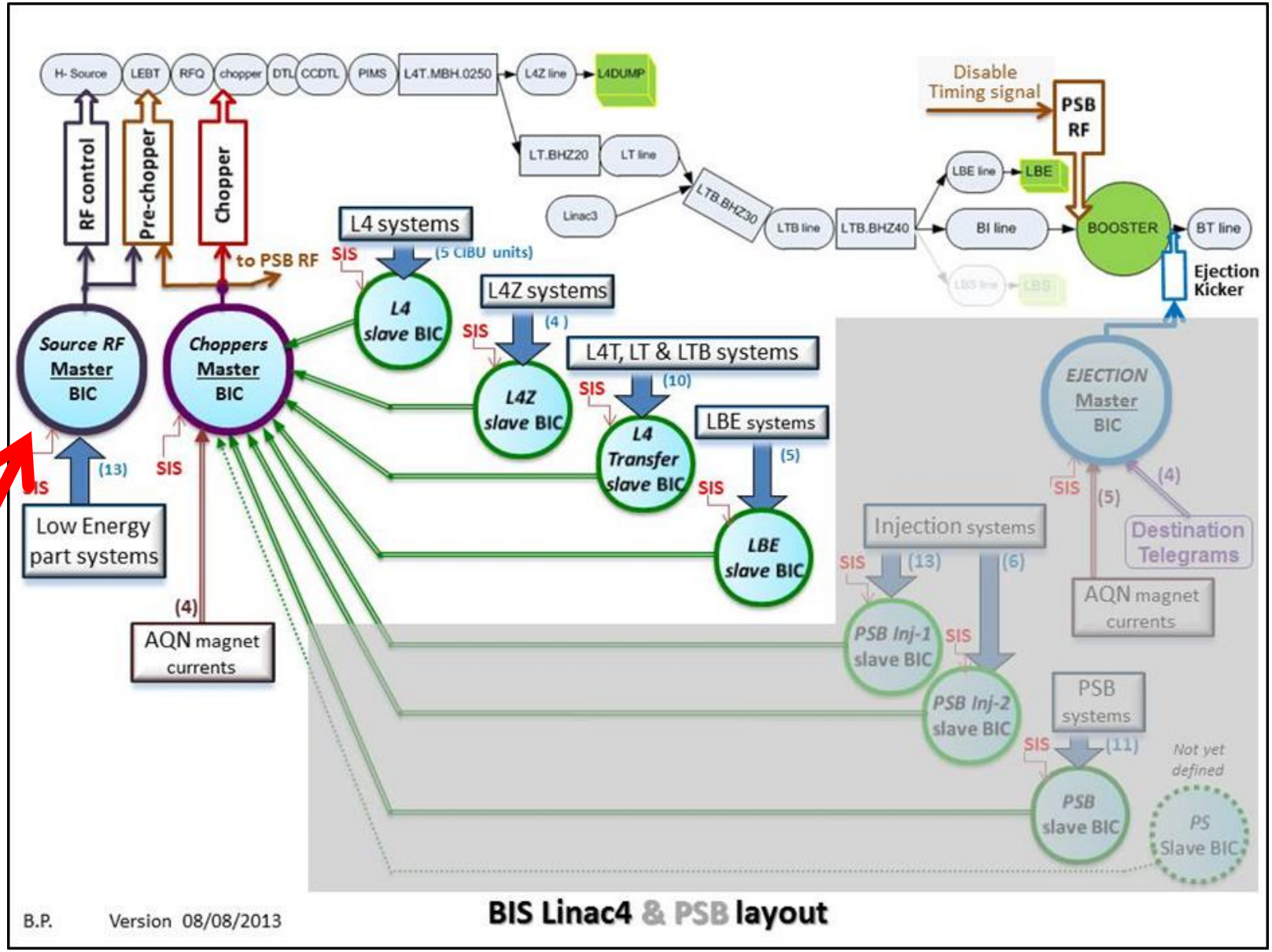
BIS COMMISSIONING: CONCLUSIONS

- Reliability requirements on electronic components must be met also on the user side; re-commissioning after each change implemented is necessary
- Damage to equipment is possible even at Low-Energy, leading to significant downtime
- A good balance between the required flexibility for commissioning and protection needs to be found
- Damage simulations for the beam pipe (F. Burkart) at 160 MeV show that no harm will be caused to the Stainless Steel beam pipe even in case of full beam impact (1 pulse, FLUKA)
- At 12 MeV activation of equipment starts to be an issue

THANK YOU FOR YOUR ATTENTION

[1] “THE COMMISSIONING STEPS OF THE LINAC4 BEAM INTERLOCK SYSTEM”, EDMS number 1310007
[2] F. P. Della Torre, M. Silari, “Predictions of induced radioactivity and residual dose rates in Linac4”, EDMS 1304119 (2013)
[3] https://espace.cern.ch/linac4-and-machine-protection/SitePages/Home.aspx

LINAC4 BIS: 3 MeV



BIS COMMISSIONING: 3 MeV

Ch.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	OUT
Interlock Element	**SIS**	**Source Internal**	**Source HV**	**Pre-chopper**	**Source Beam Stoppers Out/Moving**	**Source Beam Stoppers In**	**Chopper**	**L4 Low-Energy Watchdog**	**L4 Low-Energy Vacuum Valves**	**AQN L4L.QUADS**	**RFQ**	**CCC Operator Veto**	**L4 Operator Veto**	**Commissioning Dump status**	*Not used*	**H^- Source Beam_Permit**
	1	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	x	**1**
	1	**1**	**1**	x	**0**	**1**	x	x	x	x	x	x	x	x	x	**1**

REQUIRED
RECOMMENDED
NOT NEEDED

ENDORSED BY MPP (13-9-2013)

- Source HV: not present at the beginning, was monitored via SIS
- Source RF: sparking due to an oscillating user permit (not latched)
- Cooling of the slit of the diagnostics line: was monitored via SIS
- Commissioning dump status: temporarily connected as input of the Source RF BIC (not available at 3 MeV)
- Bending magnet to the diagnostic line: was monitored via SIS

BIS 3 MeV: DEPLOYED CONFIGURATION

0	1	2	3	4	5	6	7	8	9	10	11	12
SIS	**Source Internal**	**Source HV**	**Pre-chopper**	**Source Beam Stoppers Out/Moving**	**Source Beam Stoppers In**	**Chopper**	**L4 Low-Energy Watchdog**	**L4 Low-Energy Vacuum Valves**	**L4L.QUADS4Chopper**	**RFQ**	**Commissioning Dump status**	**L4 Operator Veto**
1	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
1	**1**	**1**	x	**0**	**1**	x	x	x	x	x	x	x
Temporary conditions to provide the User_Permit (see paragraph 2.2.3)	Set permanently TRUE by the User_System	Forced to TRUE by TE-MPE	Normal conditions to provide the User_Permit	Temporary conditions to provide the User_Permit (as only the 1st Beam Stopper will be taken into account)		Forced to TRUE by TE-MPE	Normal conditions to provide the User_Permit	Normal conditions to provide the User_Permit	Normal conditions to provide the User_Permit	Normal conditions to provide the User_Permit	Forced to TRUE by TE-MPE	Normal conditions to provide the User_Permit

REQUIRED
RECOMMENDED
NOT NEEDED

LINAC4 PARAMETERS

LINAC 4 PARAMETERS	
Ion species	H-
Output energy	160 MeV
Bunch frequency	352.2 MHz
Max. rep.-rate	2 Hz
Beam pulse length	400 us
Max. beam duty cycle	0.08%
Chopper beam-on factor	62%
Chopping scheme	222/133 full/empty buckets
Source current	80mA
RFQ output current	70mA
Linac current	40mA
Average current	0.032mA
Beam power	5.1kW
No. particles per pulse	10^14
No. particles per bunch	1.14*10^9
Source transverse emittance	0.2 pi mm*mrad
Linac transverse emittance	0.4 pi mm*mrad

→ 12 mA during commissioning At 3 MeV