MACHINE PROTECTION CONSIDERATIONS TO LINAC4 BIS COMMISSIONING

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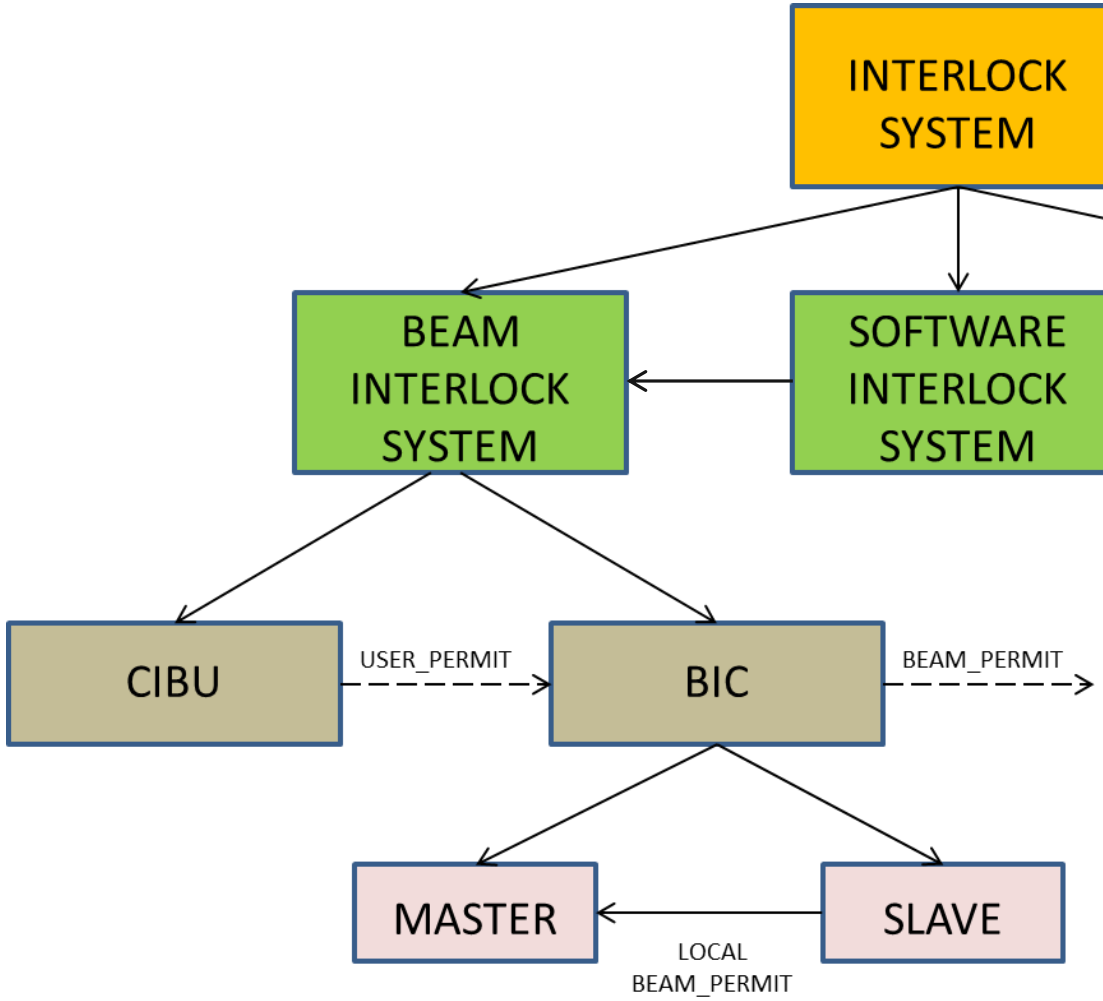
LINAC4 PARAMETERS

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

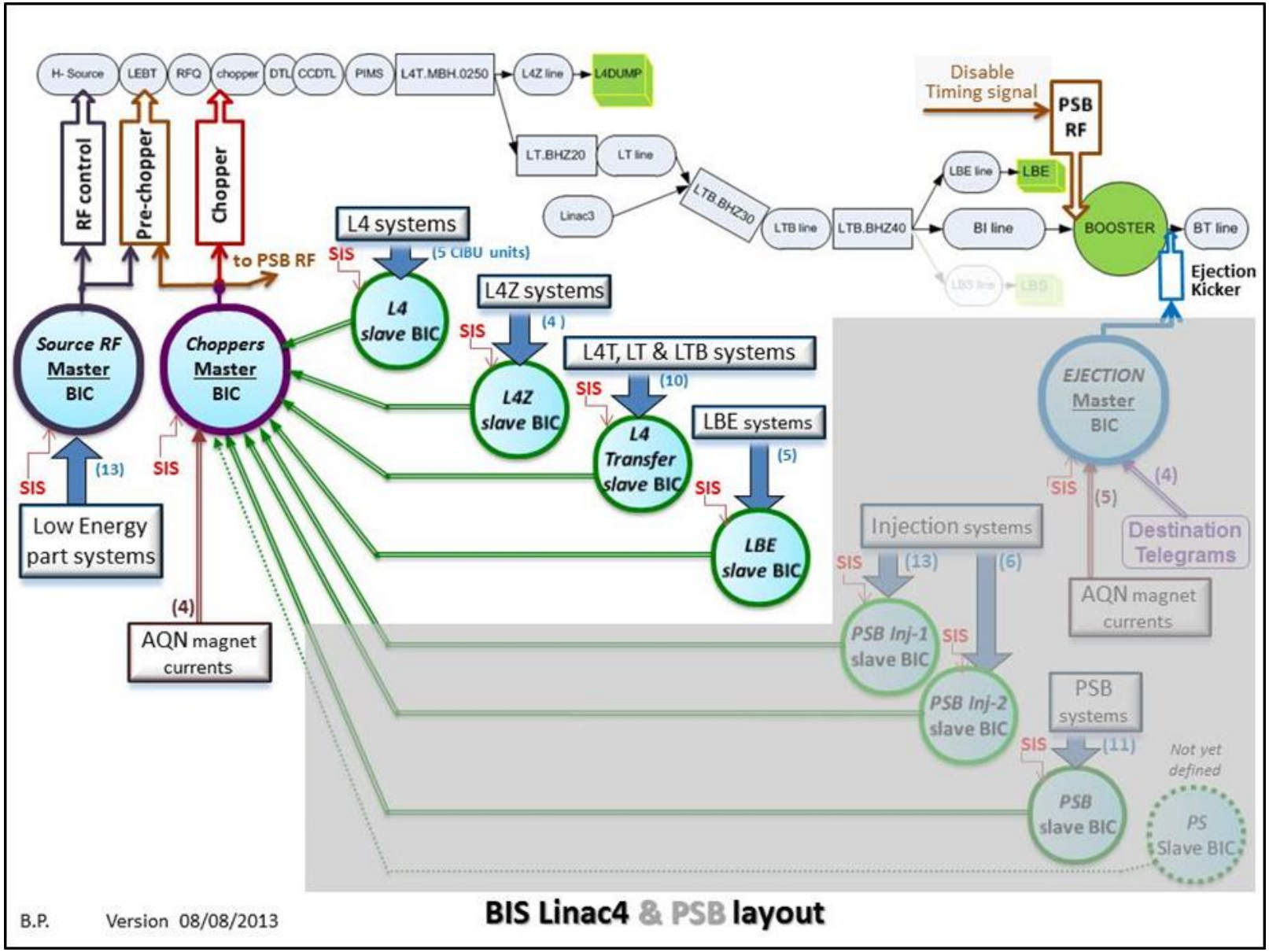
→ 12 mA during commissioning At 3 MeV

LINAC4 INTERLOCK SYSTEM



- **BIS**: fast reaction times or minimization of machine activation needed
- **SIS**: monitor slow-changing parameters or for complex logic implementation
- **EC**: Optimization (Users requests,…)

LINAC4 BIS


H- Source
LEBT
RFQ
chopper
DTL
CCDTL
PIMS
L4T.MBH.0250
L4Z line
L4DUMP
LT.BHZ20
LT line
Linac3
LTB.BHZ30
LTB line
LTB.BHZ40
BI line
BOOSTER
BT line
Ejection Kicker
Disable Timing signal
PSB RF
LBE line
LBE
RF control
Pre-chopper
Chopper
to PSB RF
L4 systems
(5 CIBU units)
L4Z systems
(4)
L4T, LT & LTB systems
(10)
LBE systems
(5)
SIS
L4 slave BIC
L4Z slave BIC
L4 Transfer slave BIC
LBE slave BIC
Source RF Master BIC
Choppers Master BIC
(13)
Low Energy part systems
(4)
AQN magnet currents
EJECTION Master BIC
(5)
(4)
Destination Telegrams
AQN magnet currents
Injection systems
(13)
(6)
PSB Inj-1 slave BIC
PSB Inj-2 slave BIC
PSB systems
(11)
PSB slave BIC
Not yet defined
PS Slave BIC
B.P.
Version 08/08/2013
BIS Linac4 & PSB layout

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

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

LINAC4 BIS: COMMISSIONING STEPS

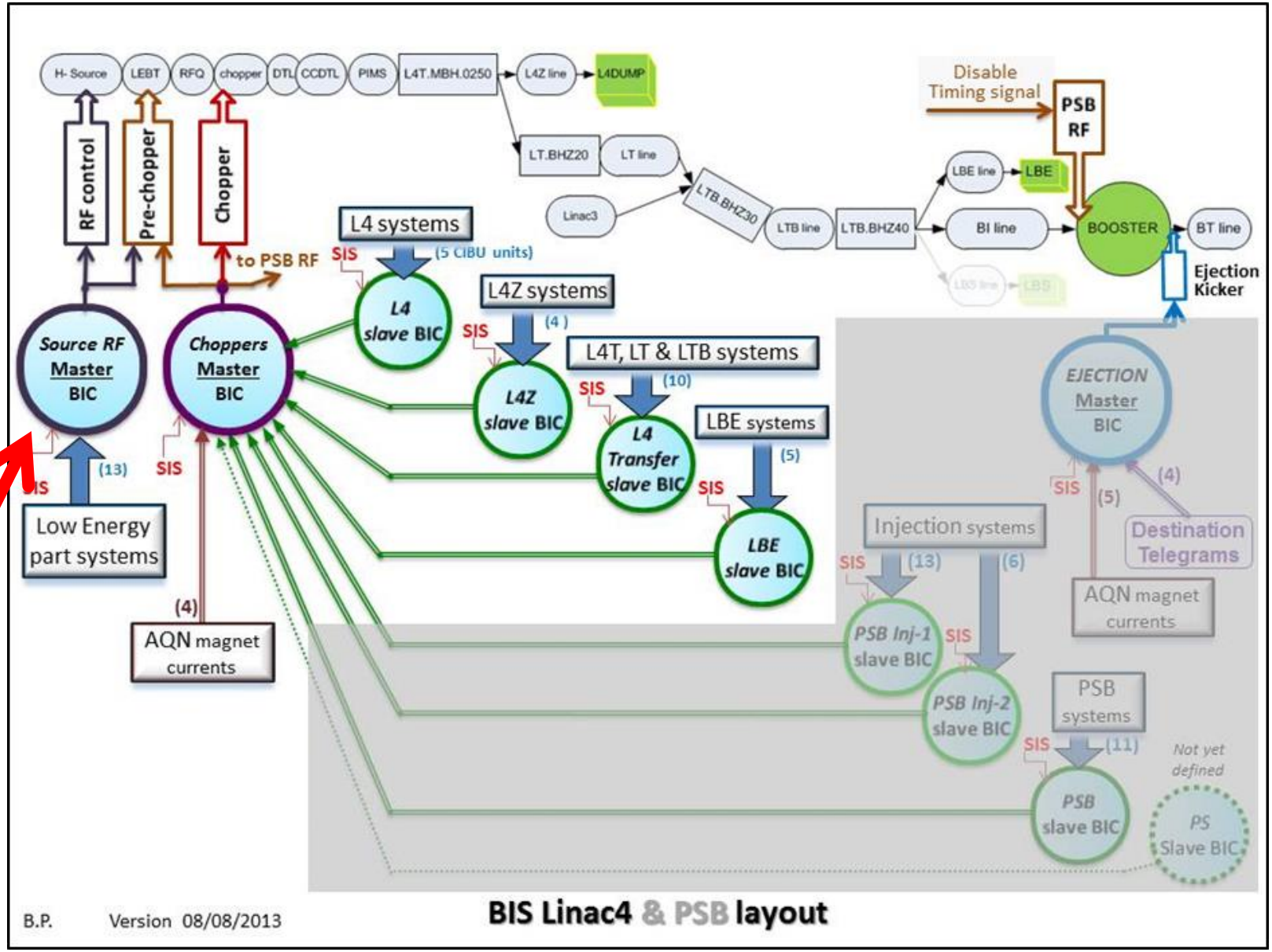
The BIS commissioning will match the 5 phases of the Linac4 commissioning [1]:

- 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 includes the Linac4 elements up to end of the chopper line + diagnostic line:
  - ✓ Only one BIC will be deployed (MASTER BIC SOURCE RF)
- For the start of the commissioning, not all the inputs of the BIS will be available. A criticality of the different inputs has been defined for the different commissioning steps.
- Machine Protection Considerations:
  - ✓ No damage to equipment due to beam losses
  - ✓ Damage potential beyond the BIS action (see next slide)
  - ✓ No activation below 10 MeV [2]
  - ✓ Some inputs required to gain experience in view of the next steps
  - ✓ Safe states:
    - ➢ RF Source pulsing + Beam-stoppers IN
    - ➢ Source RF deactivated (following the BIS action)

LINAC4 BIS: 3 MeV



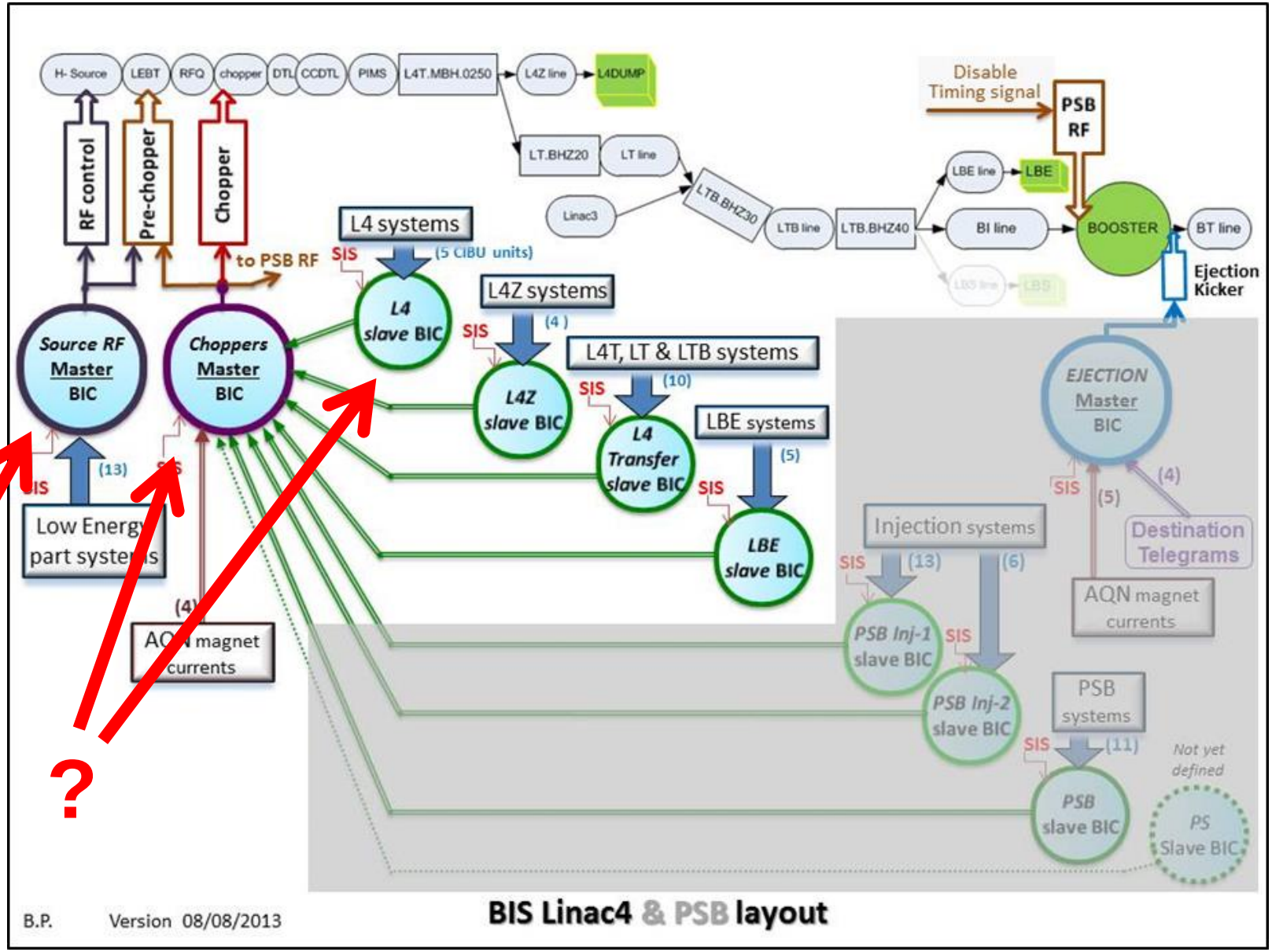
BIS COMMISSIONING: 3 MeV [1]

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

- Source HV: not present at the beginning, will be monitored via SIS (sparking can cause damage to the electrodes)
- Source RF: sparking due to an oscillating user permit (not latched)
- Cooling of the slit of the diagnostics line: monitored via SIS
- Commissioning dump status: temporarily as input of the Source RF BIC
- Bending magnet to the diagnostic line: monitored via SIS

LINAC4 BIS: 12 MeV



NEXT STEPS OVERVIEW: 12 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**	x	x	**1**
	1	**1**	**1**	x	**0**	**1**	x	x	x	x	x	x	x	x	x	**1**

- Source HV and Chopper: ***mandatory***
- Possibly 2 other BICs need to be added at this stage (Master Choppers and Slave Linac4)

NEXT STEPS OVERVIEW: 12 MeV

Ch.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	OUT
Interlock Element	**SIS**	**Linac4 OK**	**AQN L4T.MBH_DUMP**	**L4Z OK**	**AQN L4T.MBH_LT**	**Linac4 Transfer OK**	**AQN LTB.BHZ40_LBE**	**LBE OK**	**AQN LTB.BHZ40_PSB**	**PSB Injection OK**	**PSB OK**	Destination PS	**PS OK**	*Not used*	*Not used*	**Choppers Beam_Permit**
	1	**1**	**1**	**1**	**0**	x	x	x	x	x	x	x	x	x	x	**1**
	1	**1**	**0**	x	**1**	**1**	**1**	**1**	**0**	x	x	x	x	x	x	**1**
	1	**1**	**0**	x	**1**	**1**	**0**	x	**1**	**1**	**1**	x	x	x	x	**1**
	1	**1**	**0**	x	**1**	**1**	**0**	x	**1**	**1**	**1**	**1**	**1**	x	x	**1**

Beam to Dump

Beam to LBE

Beam to PSB

Beam to PS

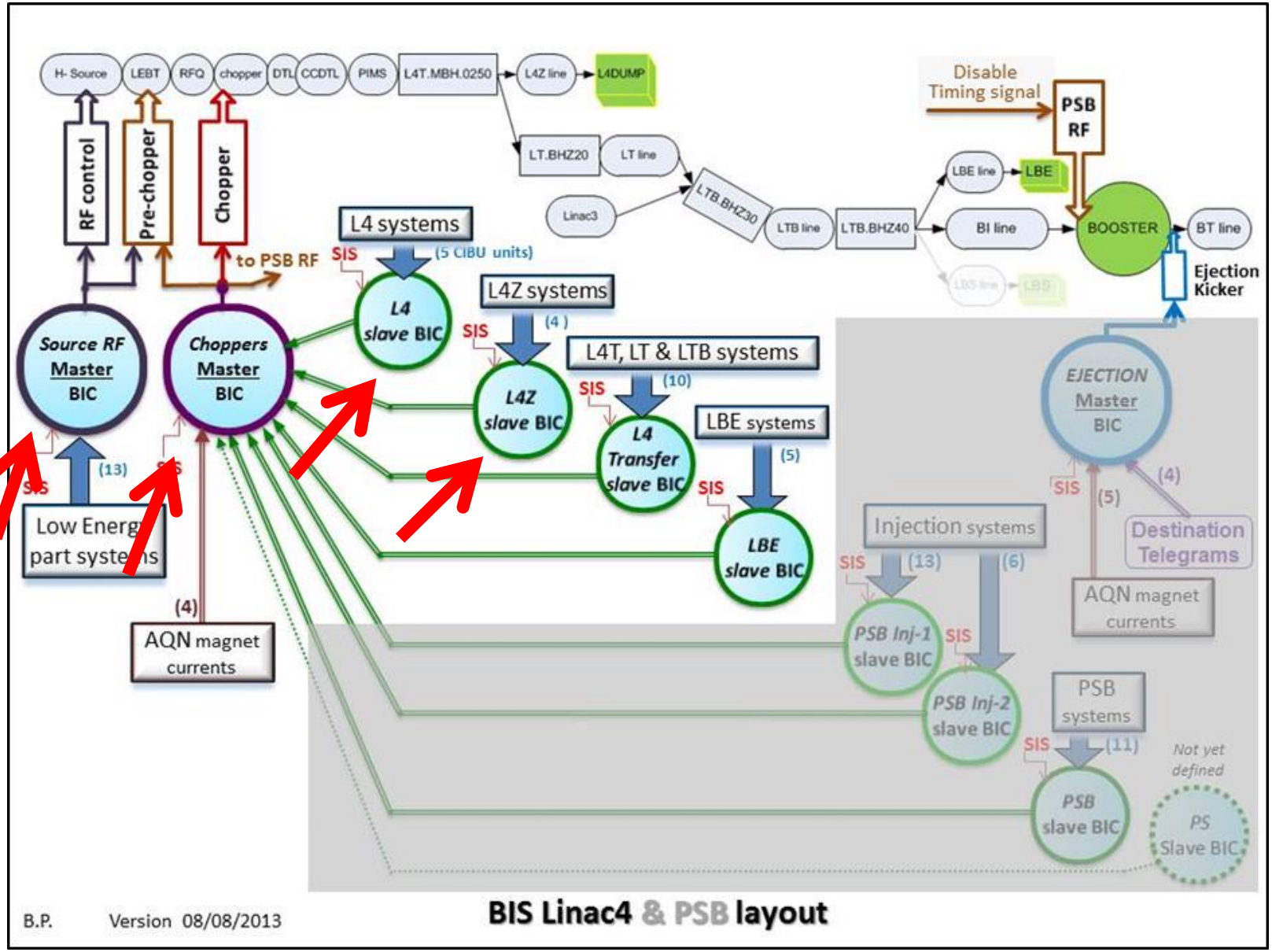
Master BIC Choppers: mainly handles destinations, only the input from the Slave BIC Linac4 should be considered

Slave BIC Linac4:

- EC: only needed for operation
- Only few BLMs included, redundant action wrt the WD
- RF: only first tank of DTL is present
- WIC (tbd): depends on the installation of the magnets and power converters

Ch.	0	1	2	3	4	5	6	…	14	OUT
Interlock Element	**SIS**	**External Conditions (full pulse)**	**L4 Vacuum Valves + L4T.VVGS.0101**	**BLMs L4+L4Z**	**L4 RF**	**WIC L4**	*not used*	*not used*	*not used*	**Linac4 OK**
	1	**1**	**1**	**1**	**1**	**1**	x	x	x	**1**

LINAC4 BIS: 50 MeV



NEXT STEPS OVERVIEW: 50 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**	*Not used*	*Not used*	**H^- Source Beam_Permit**
	1	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	x	x	**1**
	1	**1**	**1**	x	**0**	**1**	x	x	x	x	x	x	x	x	x	**1**

- Watchdog, Vacuum Valves: ***mandatory***
- Dumps risk analysis: fire risk in the dump from 30 MeV
- Chopper Line Quads: ***recommended***
- Master Choppers, Slave Linac4: ***mandatory***

NEXT STEPS OVERVIEW: 50 MeV

Ch.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	OUT
Interlock Element	**SIS**	**Linac4 OK**	**AQN L4T.MBH_DUMP**	**L4Z OK**	**AQN L4T.MBH_LT**	**Linac4 Transfer OK**	**AQN LTB.BHZ40_LBE**	**LBE OK**	**AQN LTB.BHZ40_PSB**	**PSB Injection OK**	**PSB OK**	Destination PS	**PS OK**	*Not used*	*Not used*	**Choppers Beam_Permit**
	1	**1**	**1**	**1**	**0**	x	x	x	x	x	x	x	x	x	x	**1**
	1	**1**	**0**	x	**1**	**1**	**1**	**1**	**0**	x	x	x	x	x	x	**1**
	1	**1**	**0**	x	**1**	**1**	**0**	x	**1**	**1**	**1**	x	x	x	x	**1**
	1	**1**	**0**	x	**1**	**1**	**0**	x	**1**	**1**	**1**	**1**	**1**	x	x	**1**

Master BIC Choppers: mainly handles destinations, the input from the Slave BICs Linac4 and L4Z should be considered

Slave BIC Linac4:

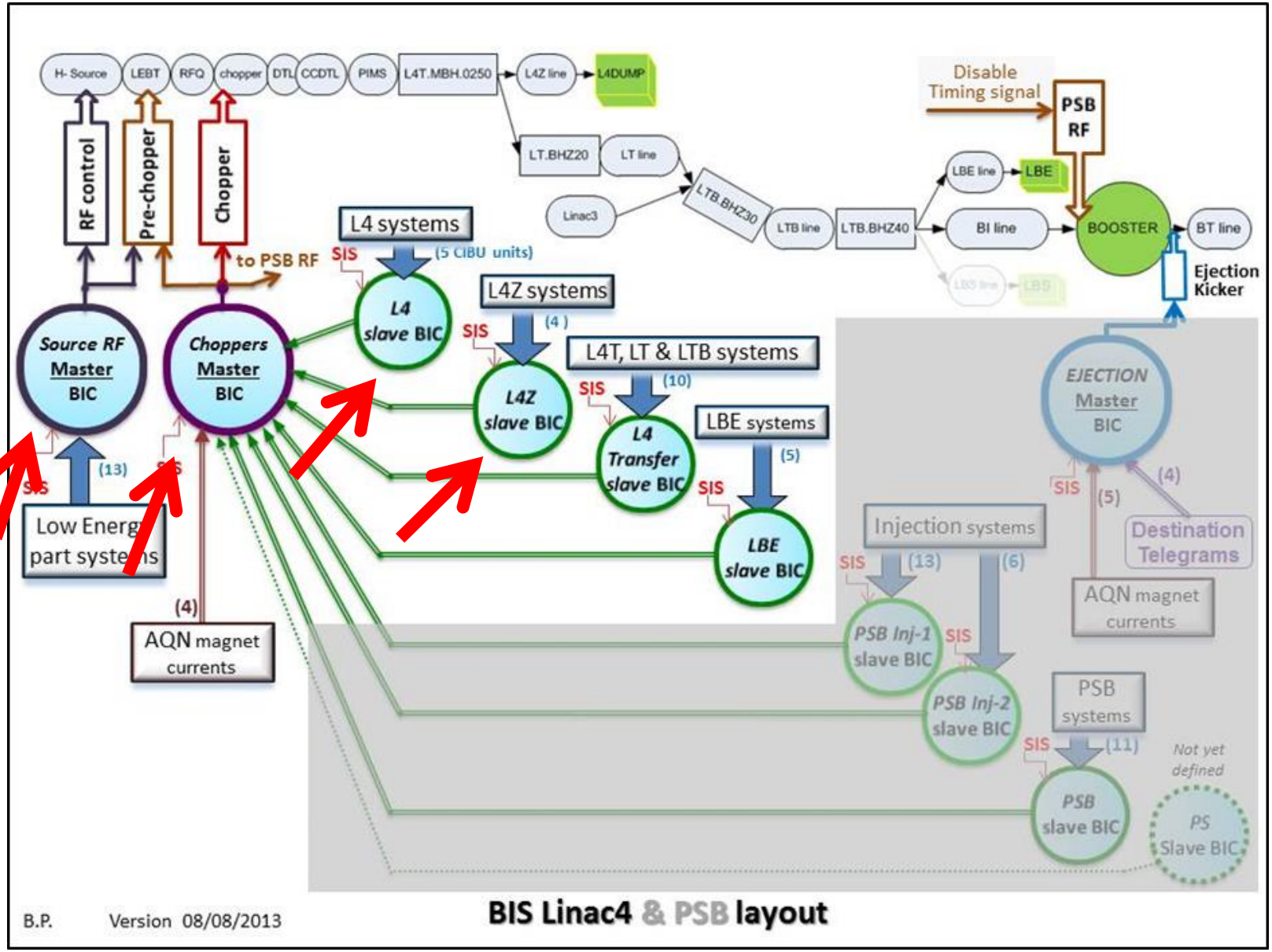
- RF: ***mandatory***
- Vacuum Valves: mandatory to prevent fire risks in the dump

Slave BIC L4Z:

- Tbd when to transfer the temporary user permit from the Master Source RF to the L4Z slave

Ch.	0	1	2	3	4	5	6	…	14	OUT
Interlock Element	**SIS**	**External Conditions (full pulse)**	**L4 Vacuum Valves + L4T.VVGS.0101**	**BLMs L4+L4Z**	**L4 RF**	**WIC L4**	*not used*	*not used*	*not used*	**Linac4 OK**
	1	**1**	**1**	**1**	**1**	**1**	x	x	x	**1**

LINAC4 BIS: 100-160 MeV



NEXT STEPS OVERVIEW: 100/160 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**	*Not used*	*Not used*	**H^- Source Beam_Permit**
	1	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	x	x	**1**
	1	**1**	**1**	x	**0**	**1**	x	x	x	x	x	x	x	x	x	**1**

- Watchdog, Vacuum Valves: ***mandatory***
- Dumps risk analysis: fire risk in the dump from 30 MeV
- Chopper Line Quads: ***mandatory***
- Master Choppers, Slave Linac4, Slave L4Z: ***mandatory***

NEXT STEPS OVERVIEW: 100/160 MeV

Ch.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	OUT
Interlock Element	**SIS**	**Linac4 OK**	**AQN L4T.MBH_DUMP**	**L4Z OK**	**AQN L4T.MBH_LT**	**Linac4 Transfer OK**	**AQN LTB.BHZ40_LBE**	**LBE OK**	**AQN LTB.BHZ40_PSB**	**PSB Injection OK**	**PSB OK**	Destination PS	**PS OK**	*Not used*	*Not used*	**Choppers Beam_Permit**
	1	**1**	**1**	**1**	**0**	x	x	x	x	x	x	x	x	x	x	**1**
	1	**1**	**0**	x	**1**	**1**	**1**	**1**	**0**	x	x	x	x	x	x	**1**
	1	**1**	**0**	x	**1**	**1**	**0**	x	**1**	**1**	**1**	x	x	x	x	**1**
	1	**1**	**0**	x	**1**	**1**	**0**	x	**1**	**1**	**1**	**1**	**1**	x	x	**1**

Master BIC Choppers: mainly handles destinations, the input from the Slave BICs Linac4 and L4Z should be considered

Slave BIC Linac4 and L4Z:

- BLMs: ***mandatory***
- WIC: ***mandatory***
- L4Z WD: ***mandatory***

Ch.	0	1	2	3	4	5	6	…	14	OUT
Interlock Element	**SIS**	**External Conditions (full pulse)**	**L4 Vacuum Valves + L4T.VVGS.0101**	**BLMs L4+L4Z**	**L4 RF**	**WIC L4**	*not used*	*not used*	*not used*	**Linac4 OK**
	1	**1**	**1**	**1**	**1**	**1**	x	x	x	**1**

Ch.	0	1		3	4	…	14	OUT
Interlock Element	**SIS**	**L4Z Dump OK**	**L4Z Dump WD**	**L4Z Vacuum Valve**	*not used*	…	*not used*	**L4Z OK**
	1	**1**	**1**	**1**	x	x	x	**1**

BIS COMMISSIONING: CONCLUSIONS

- The Linac4 BIS uses the same approach adopted for the LHC
- Some modifications needed due to the different topology and to the multiple destinations
- Fast reaction time: beam chopped within the same pulse
- No damage to equipment is expected in the first commissioning stage (following a missed BIS action)
- 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 (FLUKA)
- Activation will need to be considered for the commissioning steps after 3 MeV
- Is an access system foreseen during commissioning?
- Test mode implementation on the user CIBUs: also beyond the LHC systems?

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

BIS COMMISSIONING: 3 MeV

- **SIS:** ***mandatory*** from the first commission phase, as it is foreseen that some signals will be included in it.
- **Source Internal:** this signal monitors the combined status of the relevant parameters of the RF source. If a failure occurs, the beam production must be stopped in order to avoid damage of the source. This interlock is considered ***mandatory*** for commissioning at 3 MeV.
- **Source HV:** if a failure occurs at the source high voltage, the beam cannot be properly accelerated to the LEBT and therefore the beam production must be stopped in order to avoid losses further downstream in the Linac. Its presence is ***recommended***, but is not critical for machine protection at 3 MeV.
- **Pre-chopper:** if the Pre-chopper is not working, the nominal pulse length cannot be set (see operational paragraph) and the redundant action upon a BIS request cannot be provided. Since this signal accounts for the overall status of the pre-chopper, including cooling conditions, power supply, etc., its presence is ***mandatory*** during commissioning at 3 MeV.

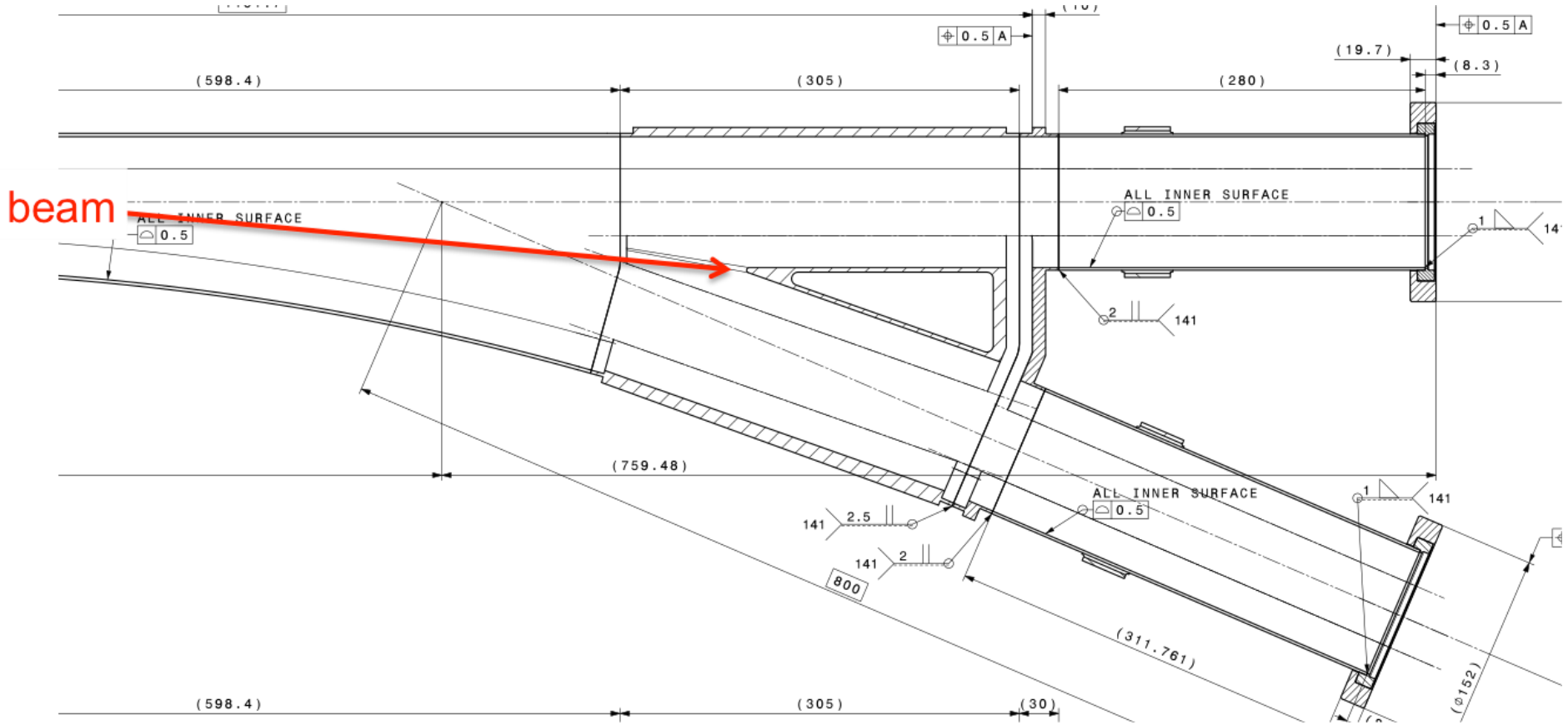
BIS COMMISSIONING: 3 MeV

- **L4 Beam-stoppers** (out/moving/in): the beam-stopper is originally designed for personnel safety; for the commissioning phase, this device is an alternative solution to stop the beam at low energy and keep the RF Source pulsing to guarantee source current stability. Given these considerations, it is ***mandatory*** to have the interlocks on the beam-stopper from the first commissioning stage.
- **Chopper:** if the Chopper is not working, the nominal beam structure cannot be set (see operational paragraph). At this stage this doesn't entail machine protection issues, as losses would only be observed at injection into the PSB. Since this signal provides the overall status of the chopper, including cooling conditions, power supply, etc., its presence is ***recommended*** during commissioning, especially in view of the next steps.
- **L4 Low-Energy Watchdog:** the measurement of the relative beam transmission is essential to estimate the amount and location of beam losses and, in view of the next steps, possible activation of equipment. No damage is expected to equipment in case of losses, therefore its presence is ***recommended***.
- **L4 Low-Energy Vacuum Valves:** the interlock is activated following a vacuum valve closure to prevent the beam impacting on the valves. Its presence is ***recommended*** during commissioning, but not critical for Machine Protection at 3 MeV.

BIS COMMISSIONING: 3 MeV

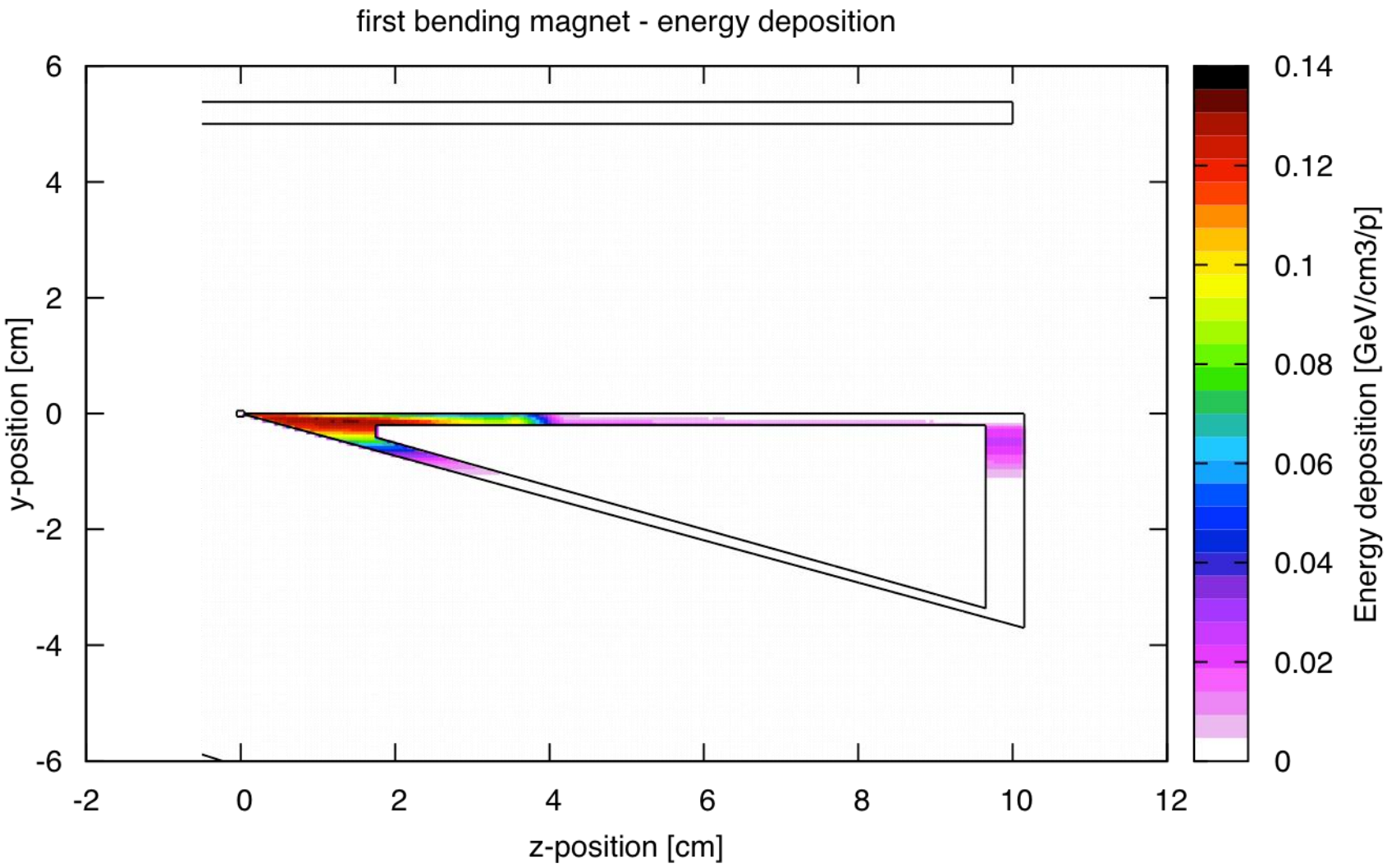
- **L4L.QUADS4Chopper**: these 3 quadrupoles ensure that the correct deflection is applied to the beam in case the chopper is ON. Simulations show that in case of a failure of e.g. L4L.MQD3610 (no deflection applied) about 5% of the beam is not intercepted by the chopper dump in the MEBT. This would result in 4.8 W lost in the commissioning dump (2.4 J/pulse) at nominal intensity. Its presence is ***not required*** during commissioning at 3 MeV.
- **RFQ:** this signal monitors the overall status of the RFQ and related powering and cooling, its presence is ***mandatory*** during commissioning.
- **CCC Operator Veto / L4 Operator Veto:** a manual switch to trigger the interlock system actions allows for flexible operation, but is ***not required*** for machine protection.
- **Commissioning dump status:** an additional hardware interlock is ***recommended*** to monitor the commissioning dump status, as the dedicated L4Z BIC will not be deployed in the 3 MeV phase of the commissioning.

DAMAGE SIMULATIONS



Courtesy F. Burkart

DAMAGE SIMULATIONS



Courtesy F. Burkart