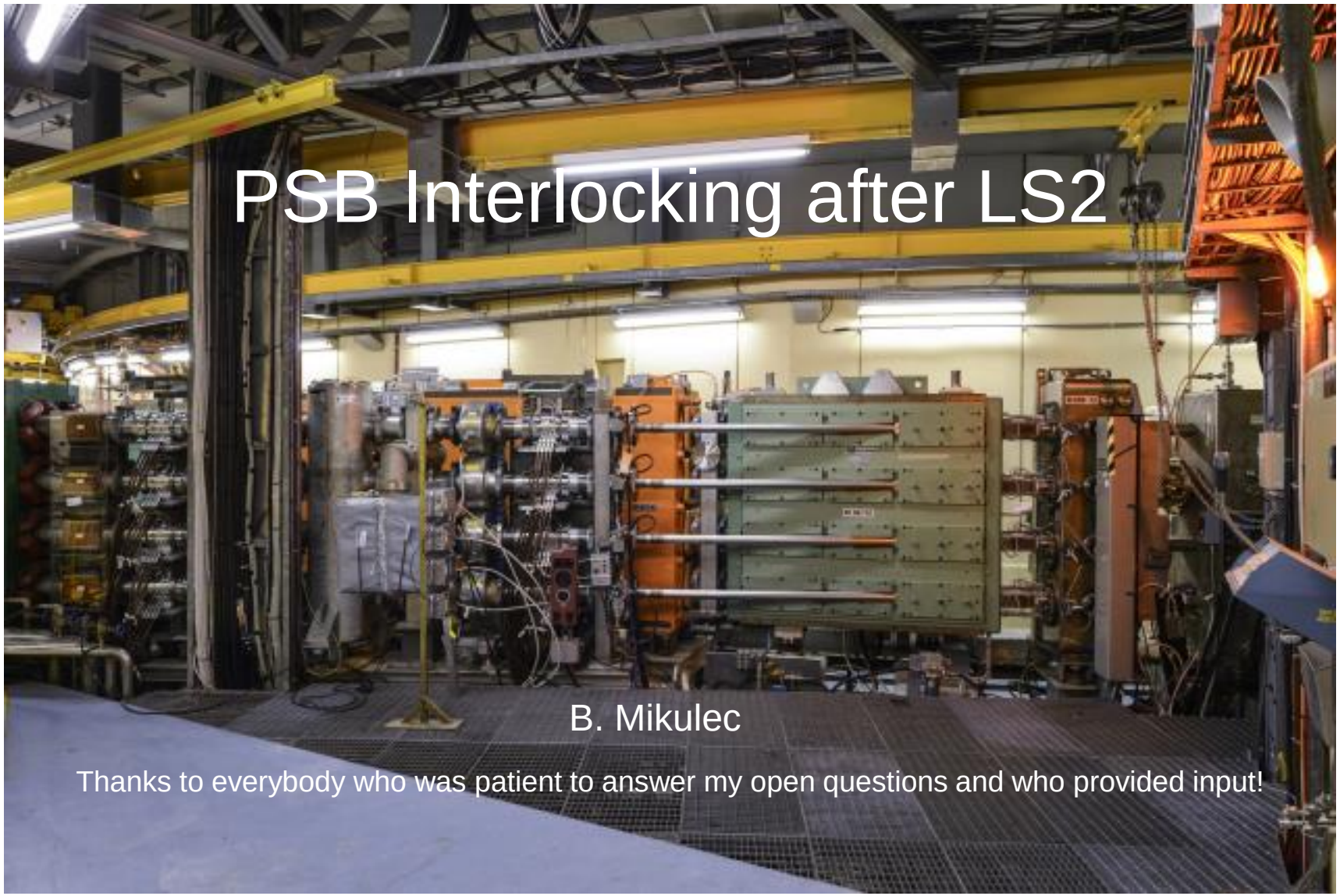

PSB Interlocking after LS2

B. Mikulec

Thanks to everybody who was patient to answer my open questions and who provided input!

Outline

- PSB post-LS2 interlock design
  - Design principle
  - BIS, SIS, WIC, EC
- The four rings of the PSB
  - Available flexibility
  - Open issues
- Special considerations
  - BT.BHZ10 switching magnet
  - POPS-B / MPS switching
- Fault diagnostics, masking of interlocks, settings management
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Pre-LS2 PSB Interlock Situation

- Pre-LS2: interlock based on External Conditions, timing and SIS
  - External Conditions (EC): served as **HW interlock**, but also **to optimize beam availability** (usually spare cycles programmed and useful e.g. during periods when ISOLDE was not continuously requesting beam)
    - Main EC, e.g. MPS, extraction septum/bumpers, recombination kickers, beam stoppers, ring vacuum valves, PSB inhibit…
    - Destination-dependent EC: ISOLDE, GPS, HRS, PS, Bdump
    - Linac2 test and MDs
  - Tailclipper: reducing the Linac2 pulse length with the 'tailclipper' timing
    - e.g. for zero turns in one or several rings, PS BLMs, as possible SIS action etc.
  - SIS: when the above could not be used, e.g. for
    - PS stray field compensation (injection trajectory), average current or pulse current limitation for ISOLDE targets or EAST/TOF cycles
- Should remember that the PSB has no internal dump and no fast kicker magnet to the external dump → once the beam is in the machine, either cut RF (spread out losses in rings) or extract…

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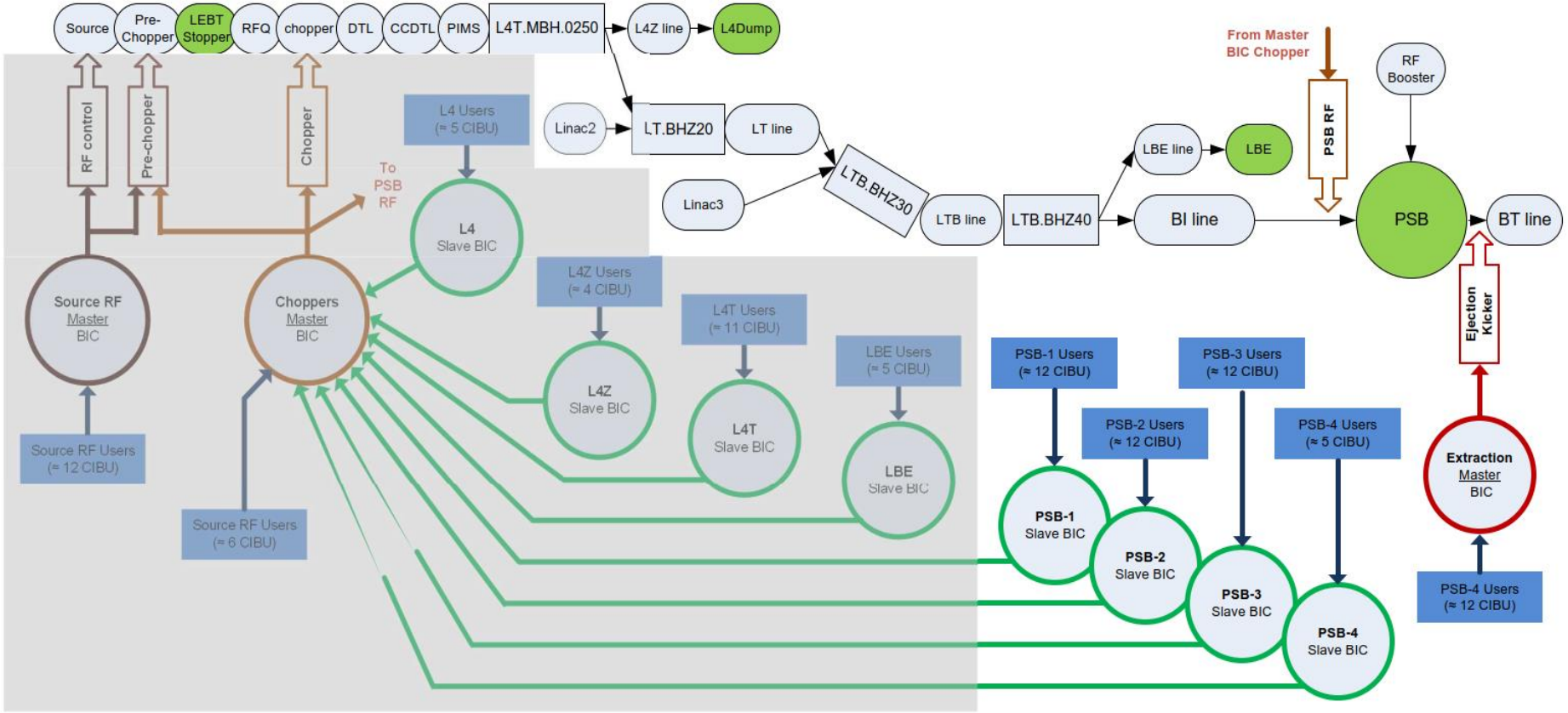
Post-LS2 Design Considerations

- With **Linac4** new options to cut the beam → decided to deploy an integrated Linac4 and PSB BIS design for post-LS2, still maintaining:
- EC: mainly for **user requests / inhibits**, equipment affecting **individual rings / destinations** or certain equipment in the extraction lines (see later…)
  - Still needed due to PSB individual rings (BIS action always means cutting the entire Linac4 pulse…) and to maximize proton delivery
- Tailclipper: will be maintained, but different action → advance pre-chopper and chopper timings to remove the beam at low energy
- SIS: similar to pre-LS2, additional equipment survey (mainly in extraction lines) or e.g. degradation of stripping efficiency in ppm
- WIC: will cover now full machine with transfer lines* (before LS2 only PSB rings); input into BIS

* Remark: the BTY line (transfer line to ISOLDE) will be added after LS2.

PSB BIS Layout

https://edms.cern.ch/document/1016233/



- **4 slave BICs**; action → cut Linac4 beam with pre-chopper & chopper and disable PSB RF
- **1 extraction master BIC**; action → disable PSB extraction kickers

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The PSB and it's 4 Rings…

- In 2017 an analysis was done based on some past experience with **'degraded' (<4 ring) operation** and a downtime analysis of individual ring equipment https://edms.cern.ch/document/1715266/
  - Operation with <4 rings can be attractive for certain physics users, also production of standard LHC25 beam with 3+3 instead of 4+2 rings
- Decision to modify the BIS architecture to allow for degraded mode mainly for the following cases:
  - Failure of the stripping foil holder (intervention time including cool-down and pump-down times up to 20h)
  - Degraded vacuum in the new PSB injection section (leak or time for intervention/pump-down)
- Procedure for OP:
  1. Set the number of turns to zero in affected ring and force it to zero (min/max) in the controls DB (~1h intervention by BE-CO)
  2. Person with appropriate RBAC role can then mask the corresponding BIC input

BIS PSB Injection (+ Rings) Layout

- Allows operation with <4 rings for limited failure modes
  - Stripping foil system status, injection painting kickers and chicane bumpers and SF vacuum valves → protection through procedure and BLMs at valve location
- Other ring-dependent failure modes will cut beam for all rings (e.g. RF, distributor, extraction bumpers + septa…)

Ch.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	OUT
Interlock Users	SIS	BI WD	PSB Injection WD	H^0/H^- Current Monitor	Distributor	BLMs in BI line & in PSB Injection	BI.SMV	*Not used*	BI1.KSW	BI1.BSW	Injection Foil Status #1	SF Vacuum Valves#1	*Not used*	*Not used*	*Not used*	PSB_1 OK Slavve BIC Beam_Permit
	1	1	1	1	1	1	1	x	1	1	1	1	x	x	x	1

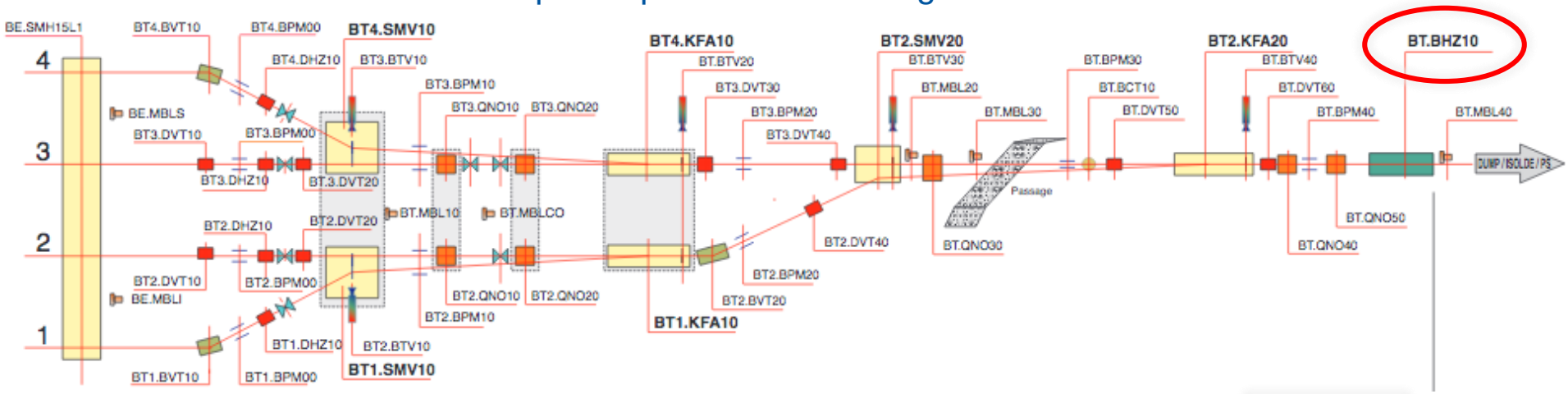
Ch.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	OUT
Interlock Users	SIS	H^0/H^- Dumps OK	Head & Tail Dump OK	WIC BI line	WIC PSB Mains	WIC PSB Aux#1	WIC PSB Aux#2	WIC PSB Aux#3	BI2.KSW	BI2.BSW	Injection Foil Status #2	SF Vacuum Valves#2	*Not used*	*Not used*	*Not used*	PSB_2 OK Slavve BIC Beam_Permit
	1	1	1	1	1	1	1	1	1	1	1	1	x	x	x	1

Ch.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	OUT
Interlock Users	SIS	PSB RF Global	BLMs in PSB extraction & transfer lines	POPS-B Status	BE.BSW Status	BE.SMH15L1	BI + BR + BT Vacuum Valves	WIC BE + BT lines	BI3.KSW	BI3.BSW	Injection Foil Status #3	SF Vacuum Valves#3	*Not used*	*Not used*	*Not used*	PSB_3 OK Slavve BIC Beam_Permit
	1	1	1	1	1	1	1	1	1	1	1	1	x	x	x	1

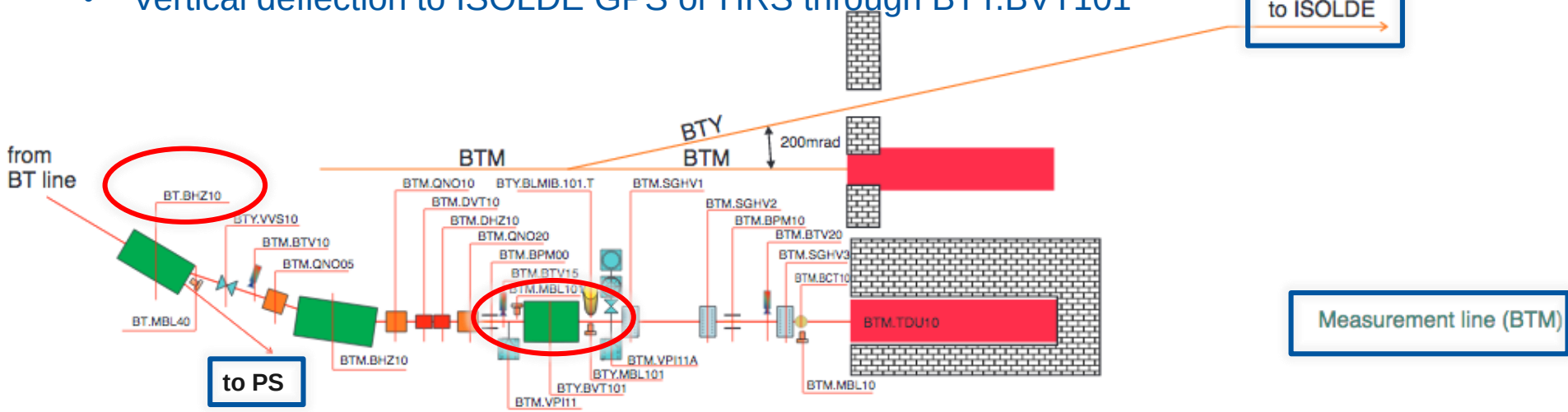
Ch.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	OUT
Interlock Users	SIS	BLM IC Ring 1 & 2	BLM IC Ring 3 & 4	BLM FIC Ring 1 & 2	BLM FIC Ring 2 & 3	*Not used*	*Not used*	*Not used*	BI4.KSW	BI4.BSW	Injection Foil Status #4	SF Vacuum Valves#4	*Not used*	*Not used*	*Not used*	PSB_4 OK Slavve BIC Beam_Permit
	1	1	1	1	1	X	X	X	1	1	1	1	x	x	x	1

PSB Extraction, Recombination + Transfer

- Recombination with help of septa and kicker magnets + bends/correctors



- Vertical deflection to ISOLDE GPS or HRS through BTY.BVT101



The PSB Extraction BIC and Open Issues

Ch.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	OUT	
Interlock Users	SIS	Destination PSB Dump	Destination ISOGPS	Destination ISOHRS	Destination PS	AQN BT.BHZ10 BDUMP/ISOLDE	AQN BT.BHZ10 PS	BTM.BHZ10 PSB Dump & ISO GPS & ISO HRS	AQN BTY.BVT101 ISOLDE	AQN BTY.BHZ301 GPS	AQN BTY.BHZ301 HRS	WIC BTM	WIC BTP	WIC BTY	PS Dump	PSB Extraction Master Beam_Permit	
Matrix Equation	1	1	0	0	0	1	0	1	0	x	x	1	x	x	x	1	Beam to Dump
	1	0	1	0	0	1	0	1	1	1	0	1	x	1	x	1	Beam to GPS
	1	0	0	1	0	1	0	1	1	0	1	1	x	1	x	1	Beam to HRS
	1	0	0	0	1	0	1	x	x	x	x	x	1	x	1	1	Beam to PS

- The 4 PSB destinations are provided by timing receiver cards
- Only bending magnets and WIC connected (+ PS dump)
- No distinction between the 4 PSB rings
- Action: do not pulse PSB extraction kickers → loose beam in rings
  - Acquisition of power converter currents within the interlock window only once beam is already in the PSB → cannot be safely dumped
  - ➢ Reproduce BIC matrix with SIS and remove beam permit (latched) of Choppers master BIC for the corresponding destination

PSB Extraction Interlocks with EC

- Affecting individual rings (extraction/recombination kickers/septa)

BT2.KFA20	EC.12	Recombination kicker ring 2
BT1.KFA10	EC17	Recombination ring 1
BT4.KFA10	EC.13	Recombination ring 4
BE1.KFA	EC.18	Ejection ring 1
BE2.KFA	EC.19	Ejection ring 2
BE3.KFA	EC.20	Ejection ring 3
BE4.KFA	EC.21	Ejection ring 4

BT1.SMV10	IF False THEN Inhibit Ring 1
BT4.SMV10	IF False THEN Inhibit Ring 4
BT2.SMV20	IF False THEN Inhibit Ring 2 & 1
BT1.BVT10	IF False THEN Inhibit Ring 1
BT4.BVT10	IF False THEN Inhibit Ring 4
BT2.BVT20	IF False THEN Inhibit Ring 2 &1

- Destination-dependent equipment in extraction (sometimes only for proton delivery optimisation; for other cases it would have required adding another BIC, CIBUs etc. → budget considerations at the time; in addition the destination inputs always block several channels…); BIS not 'destination-aware'

BTY.BVT101	EC.6	Isolde line bending vertical
BTY.VV	EC.5	Isolde vacuum
BTY.WDOG	EC.9	Watch dog Isolde line
BTY.STP	EC.24	Beam stopper 103
R.GPS	EC.7	Isolde GPS beam request
R.HRS	EC8	Isolde HRS beam request
R.GPS_OS	EC.125	One shot GPS request
R.GPS	EC.7	Isolde GPS beam request
R.HRS_OS	EC.126	One shot HRS request
R.HRS	EC8	Isolde HRS beam request

I_B.ISOLDE	EC.111	Isolde inhibit
BTP.VV	EC.4	Vacuum Booster to PS line
BTP.STP	EC.23	Beam stopper btp
BTM.VV	EC.15	Vacuum PSB to ML
BT.BHZ10_PS	EC.10	BT.BHZ10: Stop extraction to PS on failure
BT.BHZ10_BTM	IF False THEN Spare	

To be added: quadrupoles in BTP line (dest. PS) and quadrupoles in BTY line (dest. ISOLDE)

PSB SIS

- A not yet exhaustive list of SIS-based interlocks (or other…) for the PSB:
  - PS stray field compensation at PSB injection
  - Survey of H^0/H^- monitor (ppm threshold) for stripping efficiency degradation
  - Set number of turns to 0 in the corresponding ring if one of the stripping foil vacuum valves is closed (additional security when the BIC input is masked as explained earlier)
  - Survey of power converters that are not covered by WIC (e.g. shavers)
  - Survey of extraction and recombination elements (ring-specific)
  - Reproduce Extraction BIC and cut the beam at the low energy
  - Survey status of BTP quads (inhibit BTP destination) and BTY quads (inhibit ISOLDE destination) → input for EC
  - ISOLDE SIS interlocks (ppp and pps, max. average current to targets)
  - Limit intensity for TOF/EAST cycles
  - Elogbook and/or LASER notifications in case of masked interlocks

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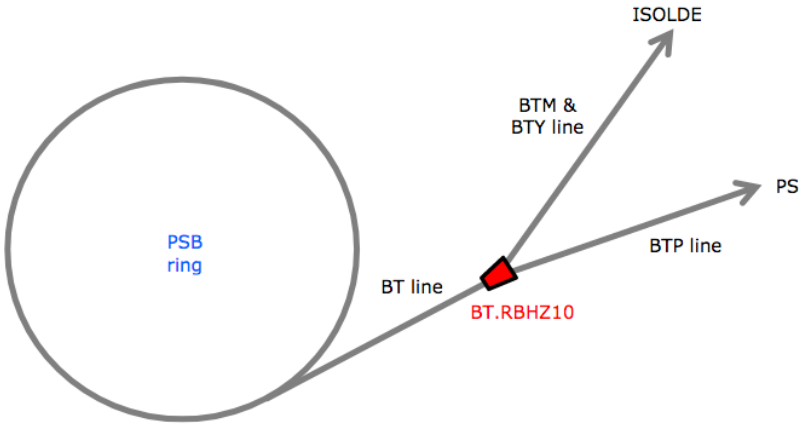
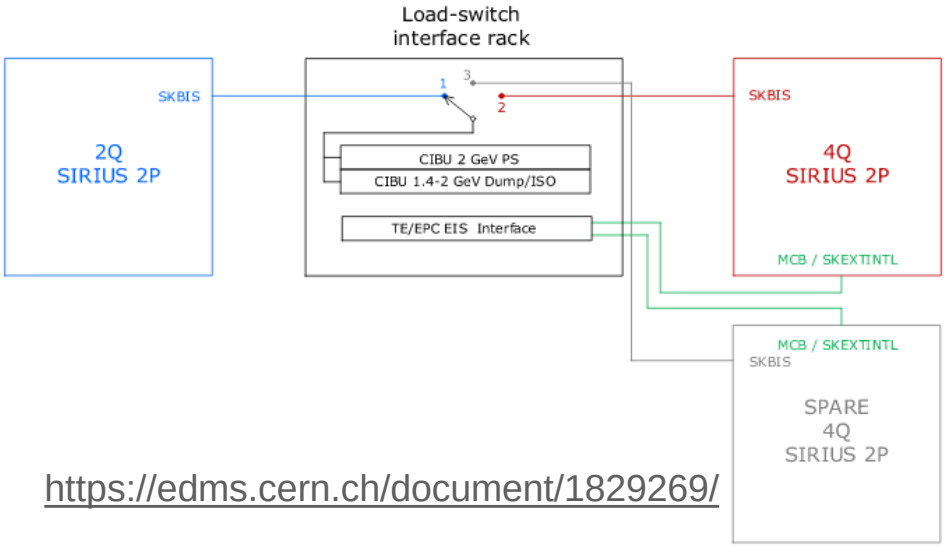
The Special Case of BT.BHZ10

- **Switching magnet between PS and BDUMP/ISOLDE**
  - Normal operation: bipolar current for the different destinations
  - If PS is in access mode: EIS applies VETO → BT.BHZ10 must only provide a negative current
- Before LS2, only one power supply was available (+ it's spare), and the operators had to manually switch off / reset / switch to unipolar mode / restart in case of a PS access



The Special Case of BT.BHZ10 after LS2

- During LS2, 3 power supplies will be installed for BT.BHZ10, one 2-quadrant and one 4-quadrant SIRIUS 2P (+ a 4Q spare)
  - Normal operation: 4Q supply in use
  - VETO from PS access system: the main circuit breakers of the power supplies will trip and a switch will start moving towards the 2Q supply when the current is zero and both power supplies are off → operators can restart the 2Q supply



https://edms.cern.ch/document/1829269/

- 4 CIBUs installed in load-switch interface rack
  - 2 for destination PS and 2 for destination BDUMP/ISOLDE (small and larger current window, respectively)
  - User_inputs 6+5 of PSB extraction BIC
- The CIBUs are always connected to the currently operational BT.BHZ10 power supply

POPS-B / MPS Switching

- **POPS-B** will be the new PSB main power supply and replace the old **MPS** after LS2
  - Nevertheless maintain MPS to be used in case of POPS-B breakdown
    - Different magnetic cycles; old MPS can only provide 1.4 GeV cycles (no 2 GeV operation)
    - Different powering layout and configuration of trim power supplies (with POPS-B separate powering of inner and outer PSB rings etc.)
    - Different interlocking → procedure will be prepared in case of a swap
- POPS-B interlocks:
  - BIC user_input (PSB-3 BIC)
  - EC (software-based)
- MPS interlocks:
  - EC (hardware)

POPS-B / MPS Switching Procedure for Interlock

- OP propose to have a common EC for either POPS-B and MPS
  - ‘Soft’ is only checking POPS-B, ‘hard’ only the MPS status
  - *Other option: 2 EC (hard for MPS and soft for POPS-B) and possibility of masking one*
- Changes in case of switchover from POPS-B to MPS:
  1. MPE to add a ‘bouchon’ instead of the POPS-B BIC user_input for PSB-3 BIC
  2. EC: OP needs to switch from ‘soft’ condition (will be BAD during a POPS-B failure) to ‘hard’ condition in the Sequence Manager GUI

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Fault Diagnostics

- For BIS:
  - BIS GUIs provided by TE-MPE
  - For better ppm diagnostics plan to use Joerg's BIS Monitor application
    - Experience from Linac4 that a debugging of the BIS interlocks at 1.2s cycle repetition is otherwise practically unfeasible; also the OP application might require some adaptation from the SPS to Linac4/PSB
- For WIC:
  - WIC GUIs provided by TE-MPE well adapted to OP needs
- For EC:
  - EC tab of Sequence Manager GUI (BE-CO)
  - In the new LIC Central Timing online information on used (destination-dependent) and bad conditions
- For SIS:
  - Sometimes SIS fault diagnostics is not straight-forward → hope for some improvements along the SIS upgrade

Masking of Interlocks

- Masking of BIS and SIS interlocks will happen more frequently during the beam commissioning phase (need certain flexibility) compared to standard operation
- Procedures will be written for more complex masks, e.g. for beam without stripping foil (H^0/H^- monitor calibration etc.) or for stripping foil vacuum valves
- Regular reminders (elogbook/LASER) for OP team (SIS)
- For interlock masking we still need to define and create the corresponding RBAC roles

Settings Management

- Deducing from Linac4 experience this is **a challenge**
- Will have to define most interlock thresholds etc. during beam commissioning when there is a lot of pressure and not yet stable operation
  - Contrary to the SPS and LHC we will soon have to face tens of operational cycles with ppm settings and in total several hundreds of cycles at the end of the year including MD cycles
  - List of critical settings still to be compiled
    - Examples: power converter acquisition windows, BLM and watchdog thresholds, H^0/H^- monitor thresholds…
- Would be useful to discuss with OP and MPE colleagues what could be the best method for the PSB

Conclusions

- With Linac4 connection in LS2 the BIS will cover most of the hardware interlocks for the PSB with the aim to cut the beam at lowest possible energy (still keeping the Linac4 source pulsing…)
- Nevertheless a mixed design including External Conditions, tailclipper and SIS to allow for the required flexibility, including optimisation of proton delivery to the numerous physics users
- Minimising machine activation is another desired ‘side-effect’ of the interlock system
- Only very few cases where we require fail-safeness; the challenge for the PSB lies more in maintaining operational flexibility and adapted interlock settings with hundreds of cycles covering 4 orders of magnitude of intensity

Summary

- Specific PSB issues:
  - 4 rings (beam distribution at injection and beam recombination at extraction) being served by one Linac4 pulse
  - No internal dump or fast kickers separating the different destinations
  - Complication: no BIS per destination at extraction
- 'Rapid' cycling poses issues for interlock monitoring in ppm
- Will need to work on procedures for masking, settings management, definition of machine critical settings etc.
  - The PSB OP team still needs to gain experience with the new interlock system
- A regular discussion/consultancy forum with TE-MPE and a core BE-OP team with a special eye on settings management / improvements for the injectors would be very useful!

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