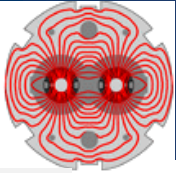
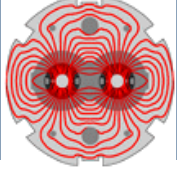


## Feedback from operations LHC & injectors

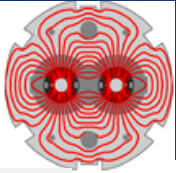
J. Wenninger, V.Kain, B. Mikulec



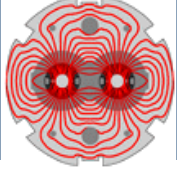
# At the beginning



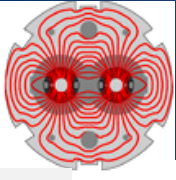
- ❑ Since its first installation at the SPS (2003 - 2004), the BIS hardware initially designed for the LHC has conquered a large part of the CERN accelerator chain.
  - R. Giachino and J. Wenninger convinced B. Puccio and R. Schmidt in 2001(?) that with modest modifications the LHC BIS design could also be used in pulsed machines.
- ❑ After the 2005 CERN accelerator complex shutdown, the complex restarted in 2006 in the new CCC (874). The SPS had the first operational BIS installations and became a testbed for pulsed machine interlock systems.
- ❑ Large BIS systems are currently installed at the SPS and at the LHC for rings and for transfers.
  - SPS and LHC rings,
  - SPS transfers for CNGS/AWAKE, HiRadMat, LHC B1 and LHC B2,
  - Growing systems in LINAC4/PSB.



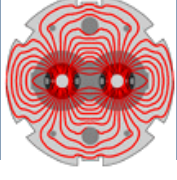
# General comments



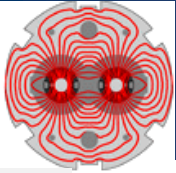
- ❑ The current BIS hardware is very reliable and provides a wealth of information on signals and state to diagnose interlocks.
  - The history buffers are invaluable.
  - The addition of key timing events like extraction in the history buffers is essential for proper diagnostics.
- ❑ Operation of the BIS hardware and integration into OP tools like the sequencer and PM (LHC) are very good.
  - The only recurrent tricky issue concerns re-arming of BICs after power cycles in the SPS complex.
    - Since contrary to the LHC case re-arming is not needed in regular operation, re-arming is often forgotten.
    - In the SPS 'dis-armed' BICs are rather tricky to diagnose for the typical shifter.



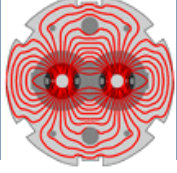
# Operation vs equipment expert



- ❑ It is common that the data provided by our equipment, mainly through FESA interfaces, can be grouped into information relevant (mainly) for equipment experts and into information for operation (users).
  - The boundary is sometimes diffuse.
- ❑ Applications for operation and equipment expert do not always overlap, and operation may require a different view on the same data in order to survive.
- ❑ The first BIS application, useable for operation during test phases, proved to be **inadequate** for operation of a **pulsed** machine. Initially CNGS beam extraction monitoring was a nightmare.
  - Analysis of transients (level of milliseconds),
  - Overview of past cycles with summary of events,
  - ...



# Dynamic !



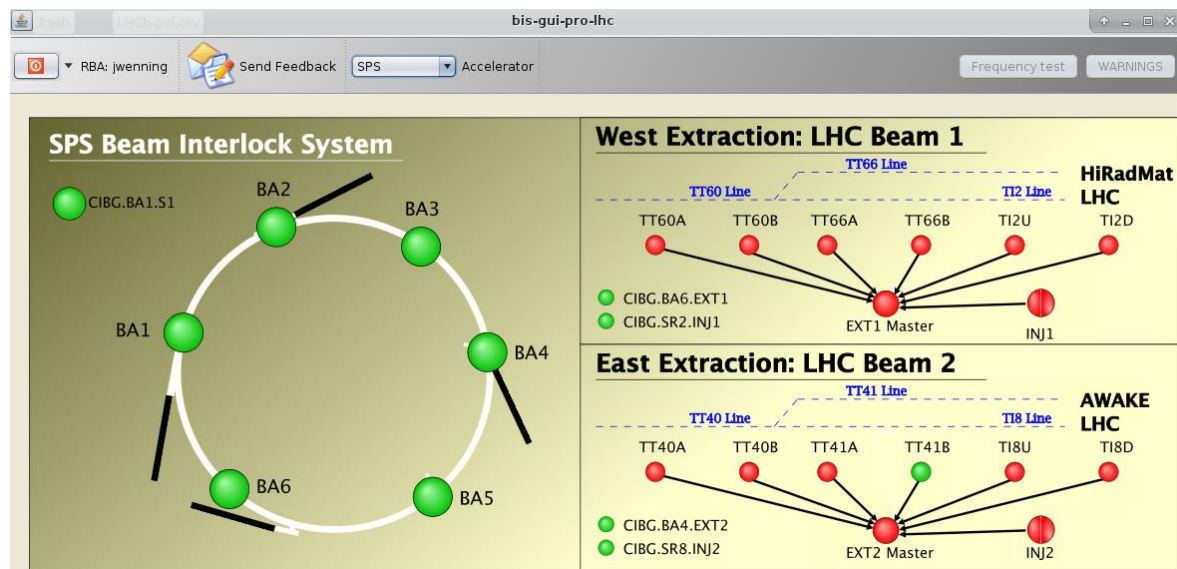
- A 2007 BIC history buffer during a test phase.
  - Read this for a few hours...

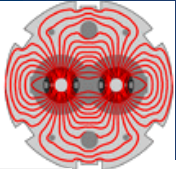
HISTORY BUFFER - slave BIC for TT40 ( 2 of 2)			
FILTER...		<input checked="" type="checkbox"/> USE SNAPSHOT	
A/B	TIME	DELTA	DESCRIPTION
❗❗	12:45:41 (411939)	540	BLM TT40 (B): TRUE -> FALSE
❗❗	12:45:41 (411939)	540	BLM TT40 (A): TRUE -> FALSE
❗❗	12:45:41 (379585)	508	BLM TT40 (B): FALSE -> TRUE
❗❗	12:45:41 (379585)	508	BLM TT40 (A): FALSE -> TRUE
❗❗	12:45:41 (319962)	448	BCT (B): FALSE -> TRUE
❗❗	12:45:41 (319962)	448	BCT (A): FALSE -> TRUE
❗❗	12:45:40 (870986)	10799	TIM record found (80161)
❗❗	12:45:35 (639240)	5568	Screens TT40 (B): FALSE -> TRUE
❗❗	12:45:35 (639240)	5568	Screens TT40 (A): FALSE -> TRUE
❗❗	12:45:34 (395478)	4324	Screens TT40 (B): TRUE -> FALSE
❗❗	12:45:34 (395478)	4324	Screens TT40 (A): TRUE -> FALSE
❗❗	12:45:30 (70998)	6000	TIM record found (80160)
❗❗	12:45:29 (301794)	5230	BCT (B): TRUE -> FALSE
❗❗	12:45:29 (301794)	5230	BCT (A): TRUE -> FALSE
❗❗	12:45:24 (611882)	540	BLM TT40 (B): TRUE -> FALSE
❗❗	12:45:24 (611882)	540	BLM TT40 (A): TRUE -> FALSE
❗❗	12:45:24 (579536)	508	BLM TT40 (B): FALSE -> TRUE
❗❗	12:45:24 (579536)	508	BLM TT40 (A): FALSE -> TRUE
❗❗	12:45:24 (519963)	448	BCT (B): FALSE -> TRUE
❗❗	12:45:24 (519963)	448	BCT (A): FALSE -> TRUE
❗❗	12:45:24 (70998)	10800	TIM record found (80159)
❗❗	12:45:13 (270995)	6000	TIM record found (80158)
❗❗	12:45:12 (502137)	5231	BCT (B): TRUE -> FALSE
❗❗	12:45:12 (502137)	5231	BCT (A): TRUE -> FALSE
❗❗	12:45:07 (811927)	540	BLM TT40 (B): TRUE -> FALSE
❗❗	12:45:07 (811927)	540	BLM TT40 (A): TRUE -> FALSE
❗❗	12:45:07 (779583)	508	BLM TT40 (B): FALSE -> TRUE
❗❗	12:45:07 (779583)	508	BLM TT40 (A): FALSE -> TRUE
❗❗	12:45:07 (719978)	448	BCT (B): FALSE -> TRUE
❗❗	12:45:07 (719978)	448	BCT (A): FALSE -> TRUE
❗❗	12:45:07 (270995)	10800	TIM record found (80157)
❗❗	12:44:58 (89110)	1618	Screens TT40 (B): FALSE -> TRUE
❗❗	12:44:58 (89110)	1618	Screens TT40 (A): FALSE -> TRUE
❗❗	12:44:56 (470993)	6000	TIM record found (80156)
❗❗	12:44:55 (702078)	5231	BCT (B): TRUE -> FALSE
❗❗	12:44:55 (702078)	5231	BCT (A): TRUE -> FALSE
❗❗	12:44:54 (169885)	3698	Screens TT40 (B): TRUE -> FALSE
❗❗	12:44:54 (169885)	3698	Screens TT40 (A): TRUE -> FALSE
❗❗	12:44:51 (12045)	541	BLM TT40 (B): TRUE -> FALSE
❗❗	12:44:51 (12045)	541	BLM TT40 (A): TRUE -> FALSE

# OP view on interlocks

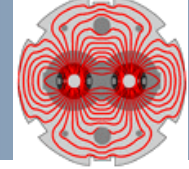
- ❑ In operation the approach to a BIS system is **global** and **top-down** rather than bottom-up.
- ❑ OP wants to know:
  - Is there an interlock on the extraction/ring/... ?
  - If yes, what are all channels across all associated BICs that are false?
    - This must be analysed at the relevant time of the cycle.
    - Also for tricky OR logics (SPS extraction, LINAC4).
  - What masks are set across all associated BICs?
    - How can I mask all channels of a category (BLMs, PCs, collimators..).
  - Are there any interlocks ‘protected by mask+SBF’?
  - ....

- ❑ The standard BIS application does not answer those questions without opening many windows...





# OP application



- ❑ After the first (difficult) experience with CNSG at SPS, OP developed a simple application with a **global view** on all BIC units involved in a ring loop (→dump kicker) or in an extraction (→extr. kicker) as opposed to the expert view on single devices.
  - *Temporary* OP application, still backbone for BIS monitoring @ SPS and LHC.

SPS/LHC BIS Monitor V9.1.4

File BIC Details MKE & BETS LTIM & Prepulse Inits & Resets Help

**LHCB1** RBA: lhcop Timing LHCION4 >> SPS\_DUMP # 3

Extraction Overview MKE6 Status BIC Overview Active Intlks Masks

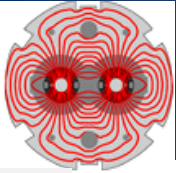
Extraction Status LHCB1

Time	User	Ring BCT	Extr BCT	BETS	Extr BIS
18:06:36	LHCION4	5	0		
18:05:48	LHCION4	5	0		
18:05:00	LHCION4	6	0		
18:04:12	LHCION4	7	0		
18:03:24	LHCION4	3	0		
18:02:36	LHCION4	6	0		
18:01:48	LHCION4	5	0		
18:01:00	LHCION4	5	0		
18:00:12	LHCION4	7	0		
17:59:24	LHCION4	6	0		
17:58:36	LHCION4	4	0		
17:57:48	LHCION4	5	0		
17:57:00	LHCION4	5	0		
17:56:12	LHCION4	6	0		
17:55:24	LHCION4	6	0		

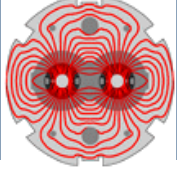
Open Scope Display

Interlock Channel List

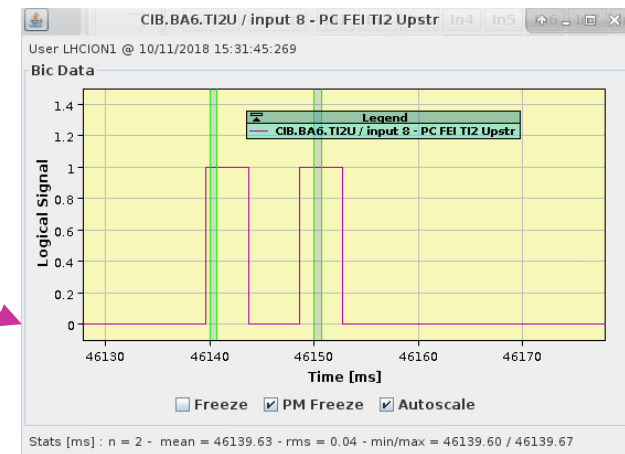
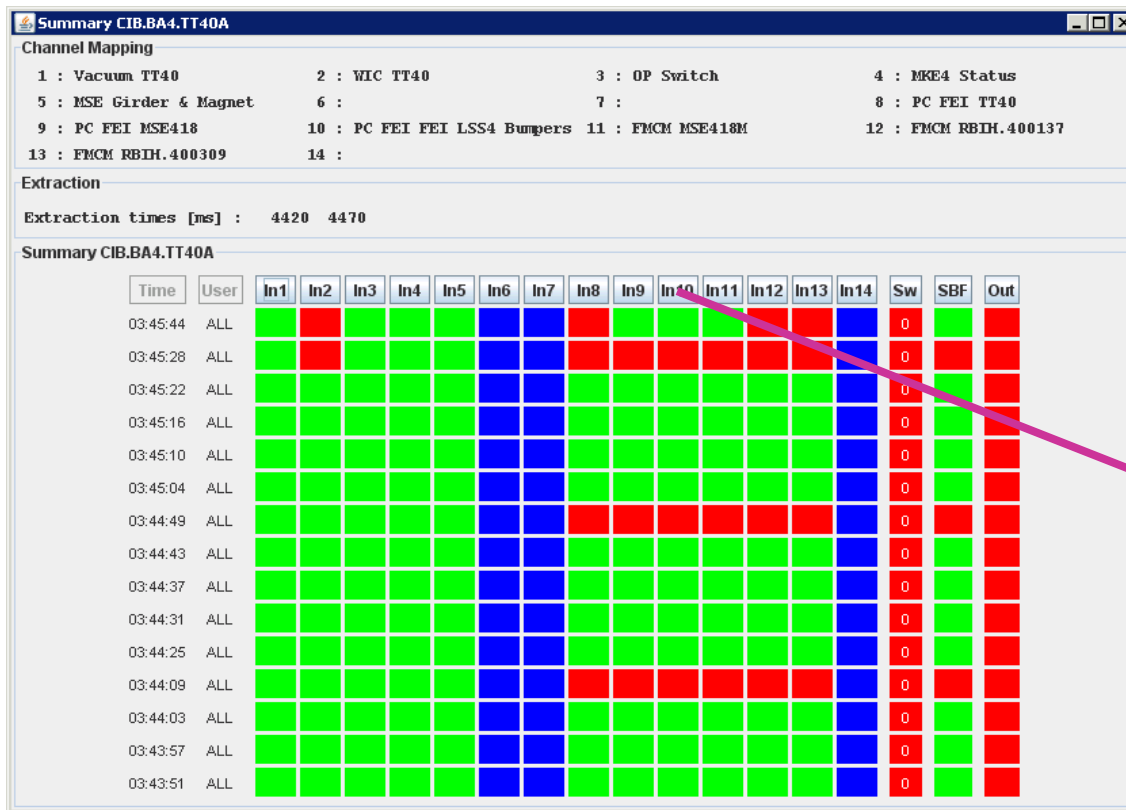
- CIB.SR2.TI2D In 2 : ALICE Inj. Inhibit
- CIB.SR2.TI2D : SIS INJ1\_SW\_PERMIT
- CIB.SR2.INJ1.1 In 1 : INJ1-2
- CIB.SR2.INJ1.1 In 3 : Op Switch
- CIB.SR2.INJ1.1 In 4 : MKE6 Status



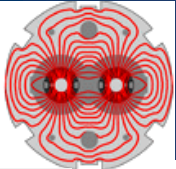
# Cycle history



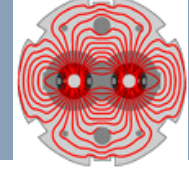
- Traces over many cycles for all inputs of a given BIC.
  - With optional filters on the user names and timing information.
  - Graphical display with indication of critical decision window(s).



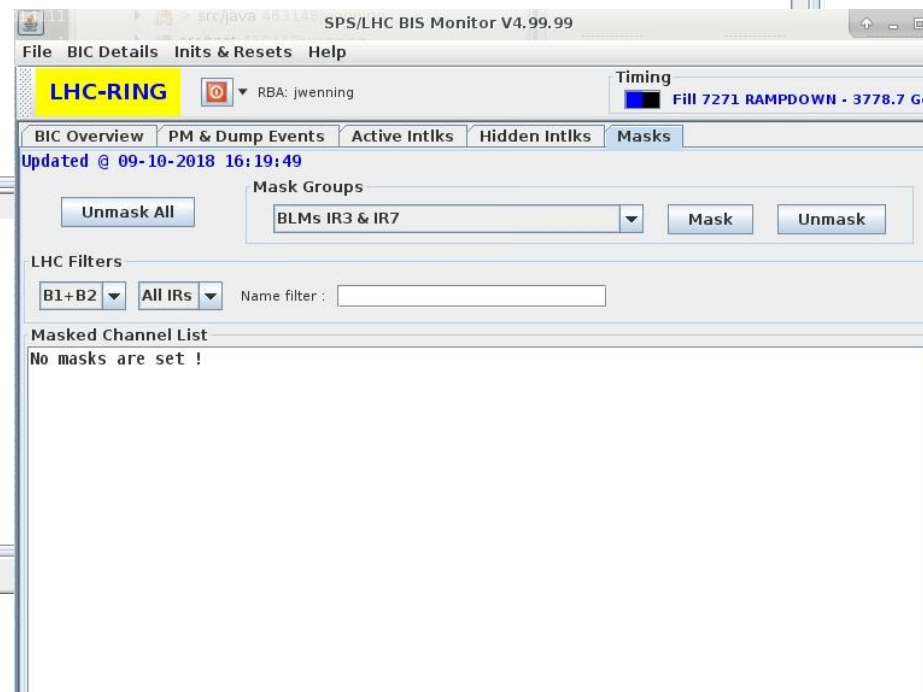
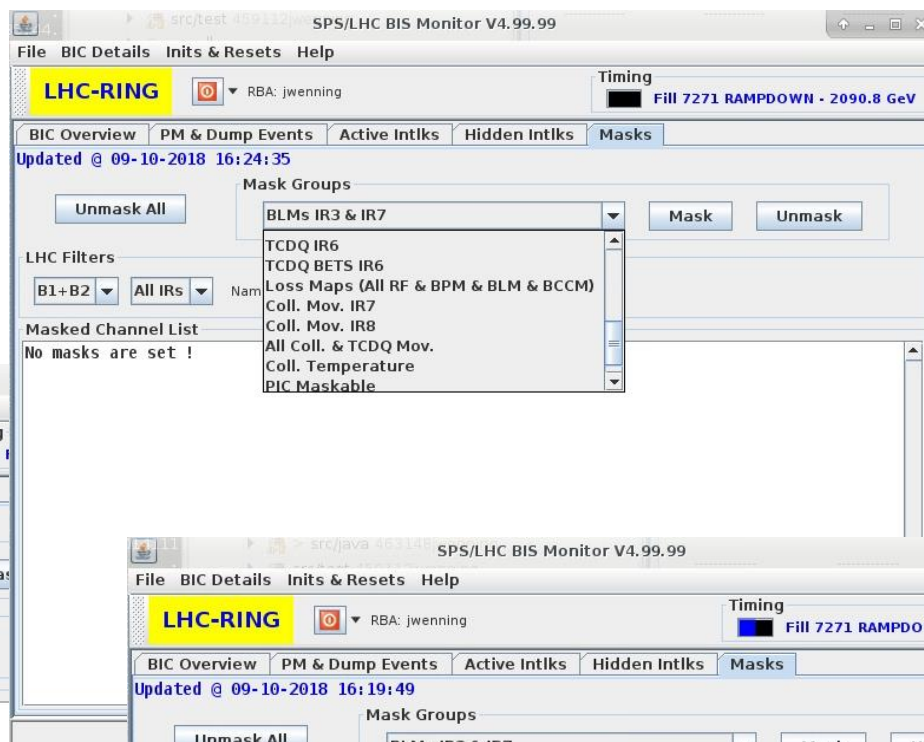
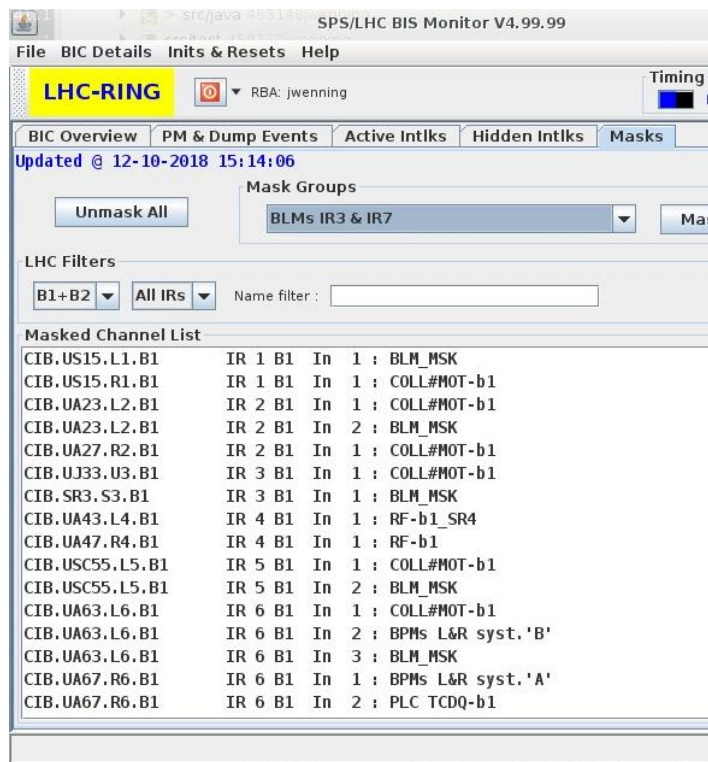


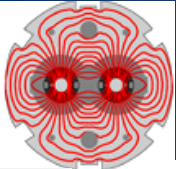


# Masks

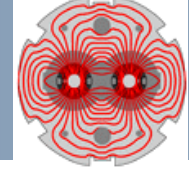


Overview on all masks,  
(un)masking by logical groups





# Interlocks



List of active and of 'hidden interlocks' (protected by a mask)

SPS/LHC BIS Monitor V4.99.99

File BIC Details Inits & Resets Help

**LHC-RING** RBA: jwenning Timing Fill 7271 RAMPDOWN - 4105.2 GeV

BIC Overview PM & Dump Events **Active Intlks** Hidden Intlks Masks

☐ Display in separate Window

Updated @ 09-10-2018 16:18:56

Interlocked Channel List

CIB.US15.L1.B1	In 4 : BLM_UNM
CIB.US15.L1.B1	In 11 : BLM_MSK
CIB.US15.R1.B1	In 8 : COLL#MOT-b1
CIB.UA23.L2.B1	In 4 : BLM_UNM
CIB.UA23.L2.B1	In 8 : COLL#MOT-b1
CIB.UA23.L2.B1	In 11 : BLM_MSK
CIB.UA27.R2.B1	In 3 : MKI2
CIB.UJ33.U3.B1	In 8 : COLL#MOT-b1
CIB.SR3.S3.B1	In 4 : BLM_UNM
CIB.SR3.S3.B1	In 11 : BLM_MSK
CIB.UA43.L4.B1	In 4 : BLM_UNM
CIB.UA43.L4.B1	In 11 : BLM_MSK
CIB.UA47.R4.B1	In 8 : RF-b1
CIB.USC55.L5.B1	In 4 : BLM_UNM
CIB.USC55.L5.B1	In 8 : COLL#MOT-b1
CIB.USC55.L5.B1	In 11 : BLM_MSK

SPS/LHC BIS Monitor V4.99.99

File BIC Details Inits & Resets Help

**LHC-RING** RBA: jwenning Timing Fill 7284 ADJUST - 449.9 GeV

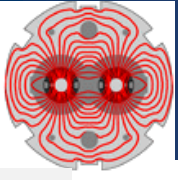
BIC Overview PM & Dump Events **Active Intlks** **Hidden Intlks** Masks

☐ Display in separate Window

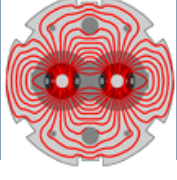
Updated @ 12-10-2018 15:14:39

Hidden (by mask) Interlocked Channel List

CIB.US15.R1.B1	In 8 : COLL#MOT-b1
CIB.USC55.L5.B1	In 8 : COLL#MOT-b1
CIB.UA83.L8.B1	In 8 : COLL#MOT-b1
CIB.US15.R1.B2	In 8 : COLL#MOT-b2
CIB.UA27.R2.B2	In 8 : COLL#MOT-b2
CIB.USC55.L5.B2	In 8 : COLL#MOT-b2



# Summary



- ❑ BIS systems are very reliable and essential for safe operation.
- ❑ Diagnostics provided through the FESA interface is adequate.
  - Insertion of key timing events into the history buffer is very important.
- ❑ OP software – quick development of temporary SW, used since > 10 y – used at SPS and LHC essential for operation thanks to global system approach.
  - Essential to maintain this SW (please no dramatic FESA design changes in LS2) or replace by new design.
  - Extend / reuse for LINAC4 !

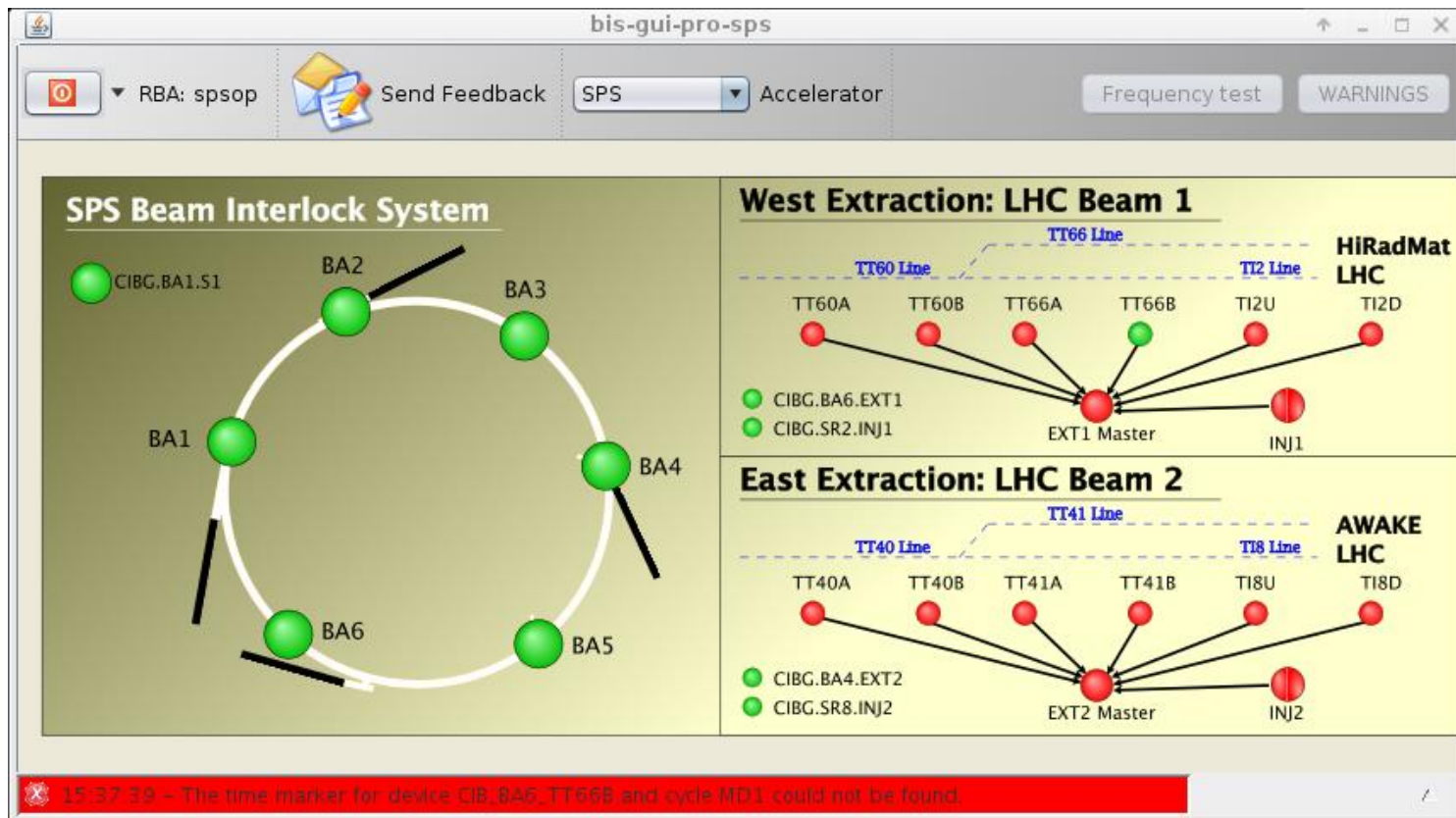
# **INTERLOCKING SLOW EXTRACTION**

# Interlocking slow extraction for BDF/SHiP and NA

- ❑ Slow extraction – intensity extracted over 1000s of turns
  - No extraction kicker involved
  - The machine tune is put on resonance and beam driven unstable in a controlled manner. All quadrupoles, sextupoles and other equipment around the ring involved.
- ❑ If an interlock comes from the client of the slow extracted beam, cannot just inhibit extraction equipment
  - The beam would continue to spill out and crash into the extraction equipment.
  - **Need to trigger the SPS beam dump kickers** → slow extraction/TT2xx equipment/NA equipment directly connected to Ring Beam Interlock System
- ❑ **But should not interlock all other beams, if slow extraction equipment stays in fault.**

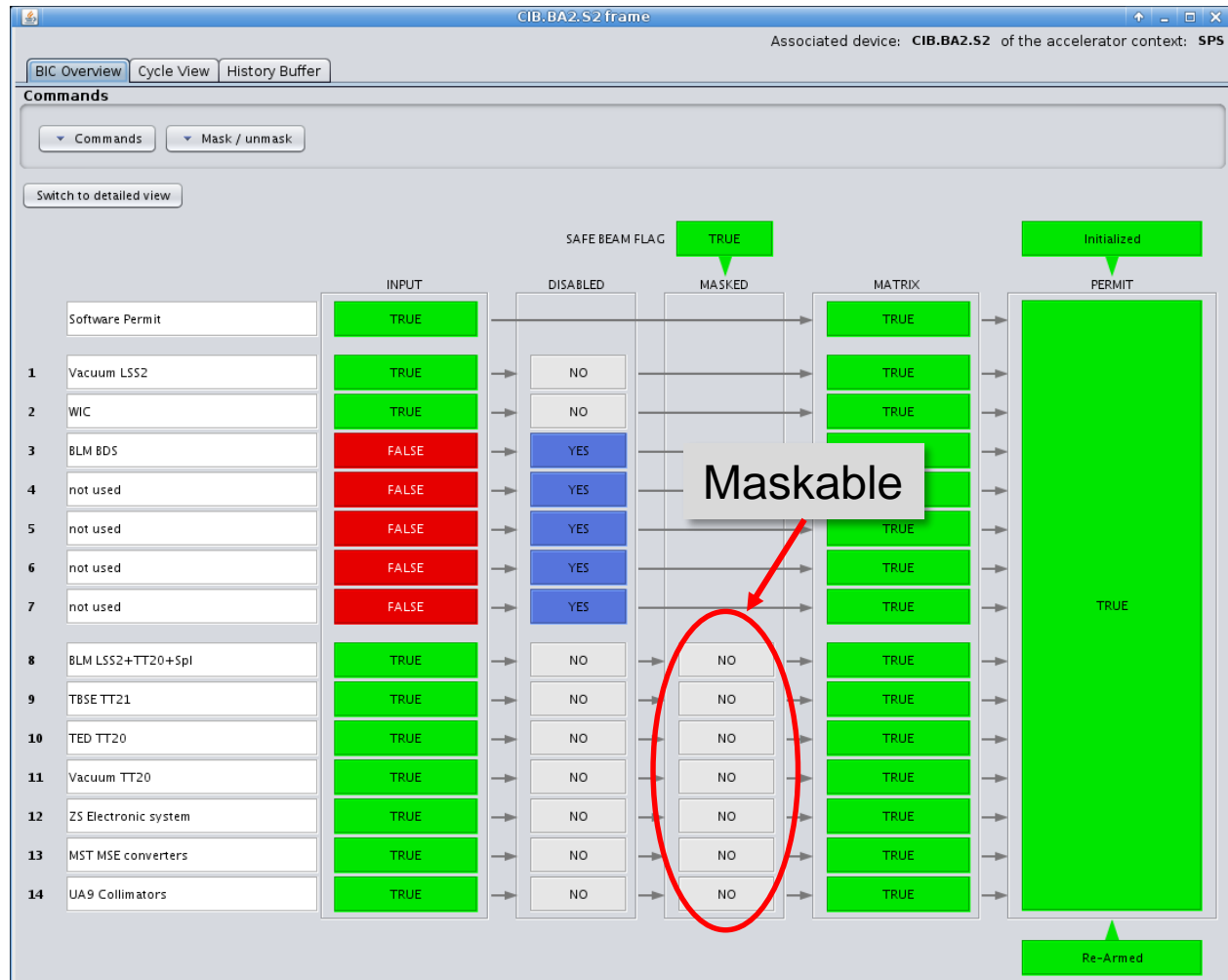
# Current interlocking

- ❑ Only a few elements interlocked for slow extraction. Few elements from the North Area with fast interlock: BLMs up to splitter
  - Status of targets etc is only checked before slow extraction starts with software interlocks and not during spill



# Current interlocking

## ❑ BA2 Ring Beam Interlock Controller





# Need a new idea (1)

- ❑ Possible solution: work with "timing destinations"
  - Would need destination “North Area”, “SHiP” (BDF)

OPER.LIC - Video Display for machine SPS

↑

-

□

×

Machine Mode

Telegram

Events

TimeStamps

Infos

Tgm Layout

History

USER	SFTPRO2	PARTY	PROTON	DEST	FTARGET	MMODE	CYCLE	NUSER	MD5
DDEST	FTARGET	BPNM	4	BPNCY	4	DURN	9	CYCLE	1
SCNUM	10	CYTAG	769	SCTAG	22113	BEAMID	42117	INJ_ENG	14
FTOP_ENG	400	NCYTAG	17418	NDURN	6	NBINJ	2		
SPCON									
COMLN	EDF_COMP				NLSQ_CTL				
		HRM_BB1							
MISC_A							NORMAL		
			COUPLED						
MISC									
LHCSEQR									
	LSR_NOM	LSR_ID2	LSR_ID1	LSR_ID0		LSR_PROT			
LHCSEQE									
SFTPRO2	MD5	SFTION4	MD2						

Freeze

16:21:54 - Registering RDA3 Subscription Filter JMX Interface

7

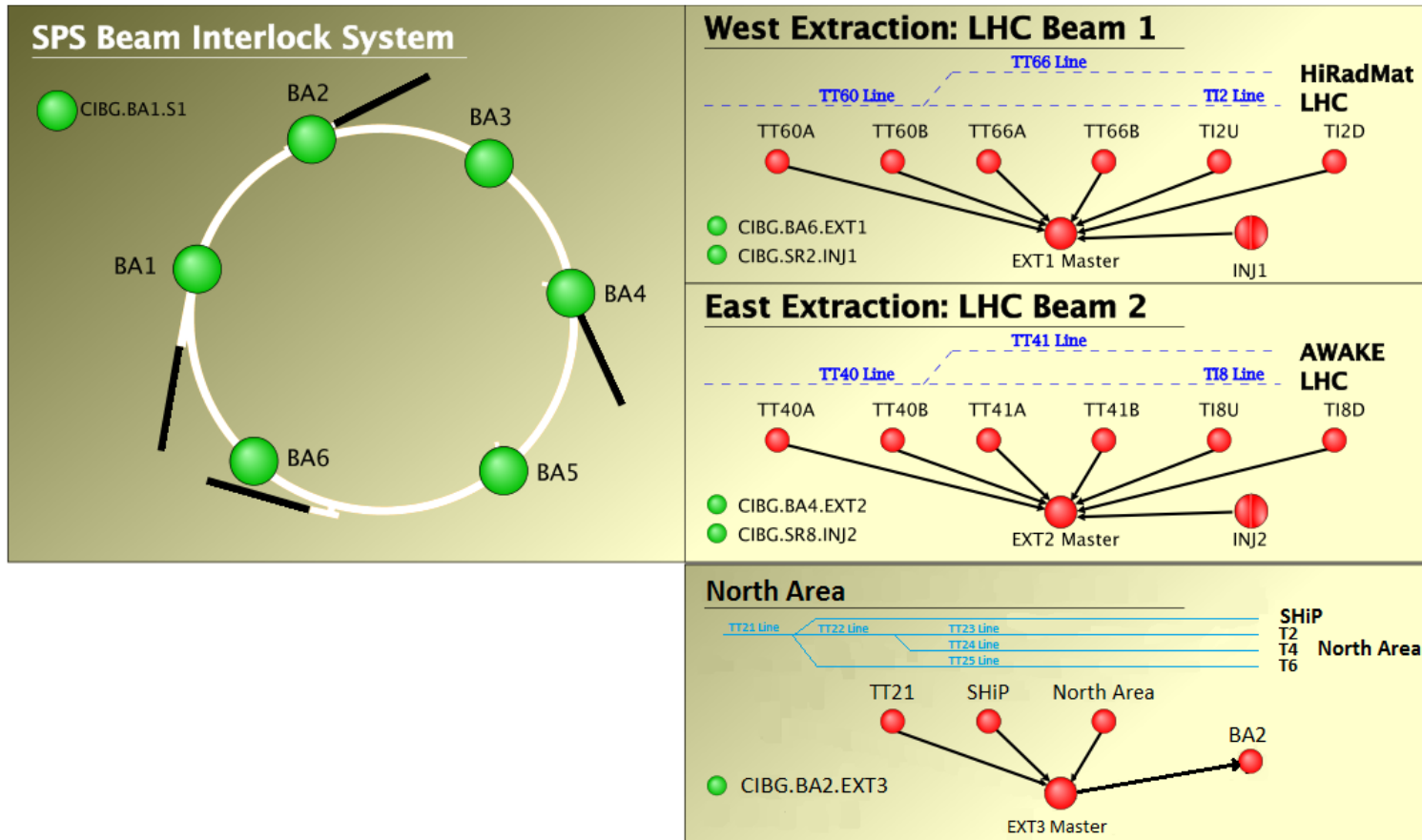
- ❑ Condition interlocking with flags generated by the “Safe Machine Parameter” (SMP) system like for the multi-purpose extraction regions LSS4/6



## Need new idea (2)

- ❑ Extraction sextupoles and extraction bumpers only pulse if destination set to NA or SHiP
  - Needs modification of power converters
  
- ❑ → without correct destination no slow extraction
  
  
  
  
  
  
  
  
  
- ❑ (Still investigating how to have flexibility to use extraction sextupoles with LHC destination in case they are needed for resonance compensation for ions)
  - Could include particle type in power converter check
  - Currently not foreseen to use extraction sextupoles with LHC beams

# New SPS Beam Interlock System with proper interlocking for slow extraction



S. Cettour-Cave

EXT3 master is connected to Ring BIS

# Preliminary: BIC overview EXT3 Master

S. Cettour-Cave



Simplified MASTER BIC equation:

(! SHiP destination **AND** ! NA destination) **OR** [TT21 **AND** ((SHiP destination **AND** SHiP interlocks) **OR** (NA destination **AND** NA interlocks))]

# Preliminary: BIC overview TT21

S. Cettour-Cave

		Safe beam Flag ->	False or true		Initialized
<b>BIC Overview TT21</b>			↓		↓
	Input	Disabled	Masked	Matrix	Permit
Software permit	False or true			False or true	False or true
FEI TT21 line	False or true	Yes or No		False or true	
FEI extraction sextupole	False or true	Yes or No		False or true	
FEI Bumper extraction	False or true	Yes or No		False or true	
FEI MST	False or true	Yes or No		False or true	
FEI MSE	False or true	Yes or No		False or true	
Girder position ZS, MST, MSE	False or true	Yes or No		False or true	
Cristal position	False or true	Yes or No		False or true	
FMCM MBE2103	False or true	Yes or No	Yes or No	False or true	
ZS Voltage	False or true	Yes or No	Yes or No	False or true	
	False or true	Yes or No	Yes or No	False or true	
	False or true	Yes or No	Yes or No	False or true	
	False or true	Yes or No	Yes or No	False or true	
	False or true	Yes or No	Yes or No	False or true	
	False or true	Yes or No	Yes or No	False or true	
					↑
					Rearmed

# Preliminary: BIC overview SHiP

S. Cettour-Cave

		Safe beam Flag ->	False or true		Initialized
<b>BIC Overview SHiP</b>			↓		↓
	Input		Masked		Permit
Software permit	False or true			False or true	False
FEI SHiP line	False or true	Yes or No		False or true	
FEI splitter 1	False or true	Yes or No		False or true	
Polarity splitter 1	False or true	Yes or No		False or true	
FMCM splitter	False or true	Yes or No		False or true	
Muon shield	False or true	Yes or No		False or true	
Sweeper	False or true	Yes or No		False or true	
	False or true	Yes or No		False or true	
	False or true	Yes or No	Yes or No	False or true	
	False or true	Yes or No	Yes or No	False or true	
	False or true	Yes or No	Yes or No	False or true	
	False or true	Yes or No	Yes or No	False or true	
	False or true	Yes or No	Yes or No	False or true	
	False or true	Yes or No	Yes or No	False or true	
	False or true	Yes or No	Yes or No	False or true	
					↑
					Rearmed

# Preliminary: BIC overview North area

S. Cettour-Cave

		Safe beam Flag ->	False or true		Initialized
<b>BIC Overview North area</b>			↓		↓
	Input		Masked		Permit
Software permit	False or true			False or true	F a l s e  o r  t r u e
FEI TT22, TT23, TT24, TT25 line	False or true	Yes or No		False or true	
FEI splitter 1	False or true	Yes or No		False or true	
Polarity splitter 1	False or true	Yes or No		False or true	
FMCM splitter	False or true	Yes or No		False or true	
	False or true	Yes or No		False or true	
	False or true	Yes or No		False or true	
	False or true	Yes or No		False or true	
	False or true	Yes or No	Yes or No	False or true	
	False or true	Yes or No	Yes or No	False or true	
	False or true	Yes or No	Yes or No	False or true	
	False or true	Yes or No	Yes or No	False or true	
	False or true	Yes or No	Yes or No	False or true	
					↑
					Re-Armed

# Next steps

- ❑ Finalize equations and verify technical feasibility
- ❑ Power converter interlocking (e.g. sweepers, splitters,...):
  - Need upgraded settings check before applying functions on hardware
    - Cannot have threshold functions!
  - New FGCs will provide regulation interlocking
  - Feasibility of FMCMs to be checked with “Constant Optics Slow Extraction” (COSE) type of extraction
    - Functions are not constant during extraction flattop
    - FMCMs are probably excluded
- ❑ Include Machine Protection Group to provide functional specifications for
  - Discussions on technical implementation
  - SMP
  - Beam interlock controllers