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CERN MPP Workshop 2019

LINAC4 experience and open points

D. Nisbet

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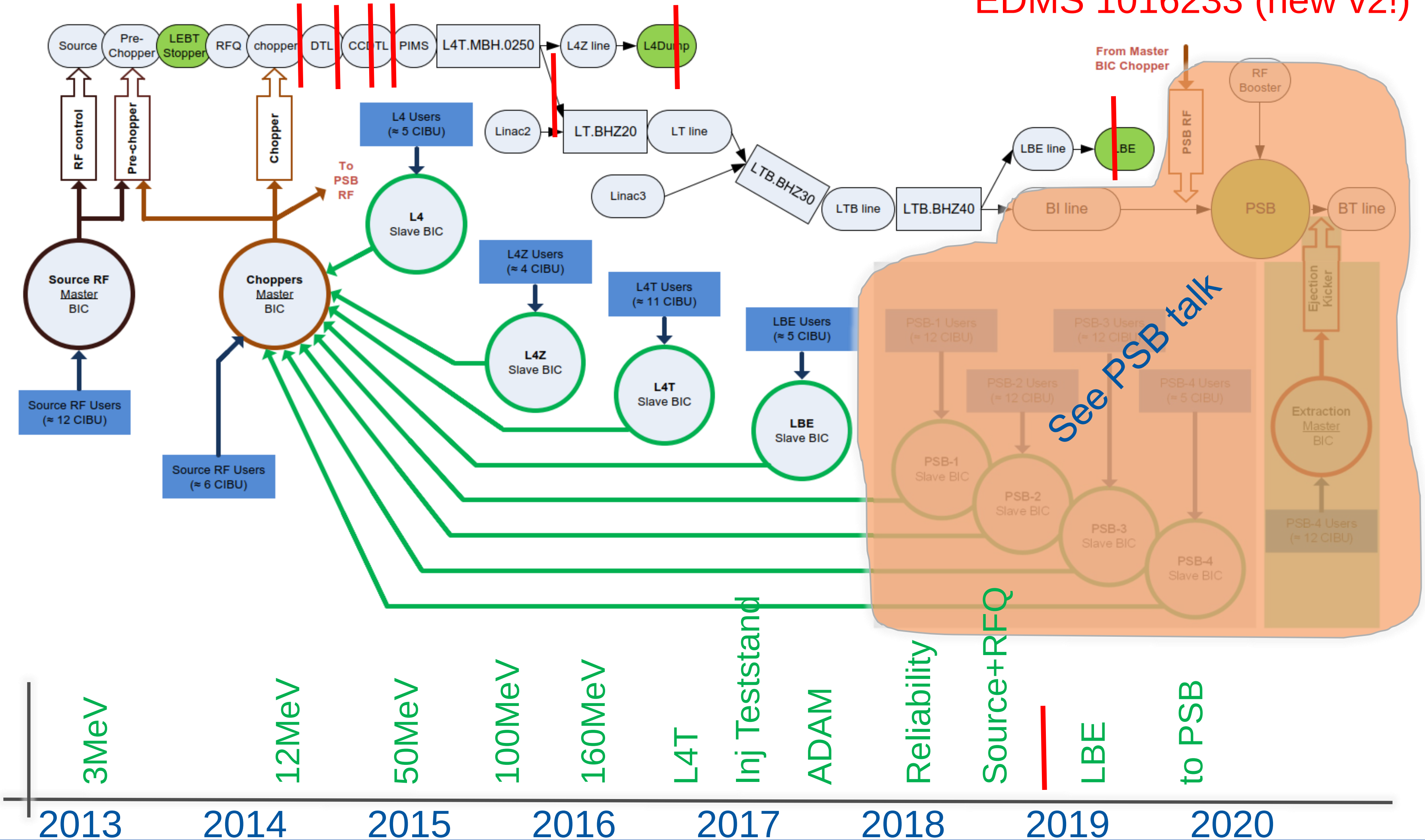
Introduction

- LINAC4 Machine Protection architecture
- LINAC4 Review
- Incidents and lessons learnt
- Machine Protection Status and Settings
- Incoming

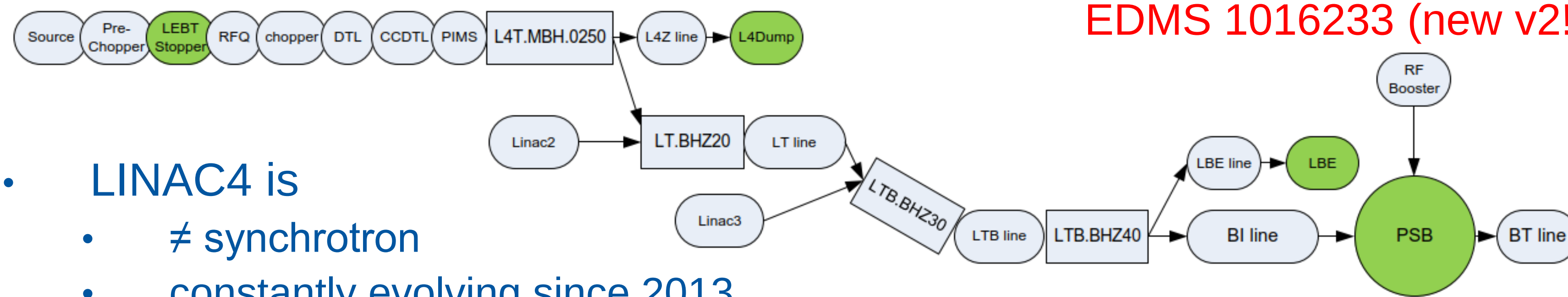
LINAC4 Machine Protection architecture

EDMS 1016233 (new v2!)



LINAC4 commissioning experience

EDMS 1016233 (new v2!)



- LINAC4 is
  - ≠ synchrotron
  - constantly evolving since 2013
  - lengthy commissioning phase
  - rigid protection environment → flexible settings
  - special machine phases
    - 3MeV and 12MeV testbench, injection chicane teststand, medical experiment, source+RFQ tests

- = challenging machine protection environment

LINAC4 Reviews

- Context
  - Two recent reviews with a focus on performance and availability
- Review June 2018 https://indico.cern.ch/event/735286/timetable/
  - Significant progress – no show stoppers
  - Still many issues, functionality, operability: “beam quality a major worry”
- Review January 2019 https://indico.cern.ch/event/778856/timetable
  - “the autumn 2018 run solved many issues and improved beam quality”
  - Achieving steady 25mA; however now need 600us pulse length;
  - Stability requires progress on autopilot and source continuous caesiation
  - Further studies required on transmission through RFQ
  - Significant progress with RF controls, still need work on feedforward
  - Issues with steerers around 0A (cf transactional behaviour)
  - Instrumentation development for wire grids and laser emittance measurement
  - Longitudinal painting…

Naturally leads to…

The 12 Top Ingredients of the LBE Line Run

- LBE Commissioning of TLs and LBE
- LBE Validation of controls and timing changes
- LBE New applications
- LBE RF system optimised for 600 µs long pulses
- LBE New motor controllers for WS; BSM2; new Semgrids
- LBE Power supply changes (HW + SW + 600 µs FT)
- LBE LLRF: evaluation of new feedback and feedforward algorithms
- LBE Debuncher commissioning w/o and with beam loading
- LBE Twiss parameter matching and dispersion
- LBE Optimisation of transmission, minimisation of losses
- LBE Energy ramping
- LBE Longitudinal painting

15

"from Open Days to Christmas 2019"

…so much to do, so little time…

Incidents and lessons learnt

#	Incident (year)	Energy, Down Time	Cause
1	Hole in bellows (2013)	3MeV, 4d	Misalignment and unusual beam setting found, aperture restriction in bellows https://indico.cern.ch/event/404834/contributions/962491/attachments/810974/1111460/20150709_LINAC4_BIS_50MeV.pdf
2	Destroyed laser emittance meter diamond detector (2014)	12MeV, degraded data	By-Pass of the BIS on both pre-chopper and chopper → full beam on diamond https://indico.cern.ch/event/404834/contributions/962491/attachments/810974/1111460/20150709_LINAC4_BIS_50MeV.pdf (slide 7-8)
3	SEM grid damaged (2017)	160MeV, degraded data	Either wrong operational limits defined or SIS failed or low energy beam on grids (no logging active) https://indico.cern.ch/event/735286/contributions/3032795/attachments/1674525/2688200/TL4O_Reiew_26Jun18_BI_FR.pptx
4	Damaged foil in teststand (2018)	< 160MeV, one foil damaged	RF Cavity Tuning (from DTL to PIMS) caused showers on foil (when in OUT position) https://indico.cern.ch/event/735286/contributions/3032795/attachments/1674525/2688200/TL4O_Reiew_26Jun18_BI_FR.pptx (slide 7)
5	BTV screen broken (2018)	160MeV, no BTV for foils	Equivalent of 4 PSB rings on screen (designed for 1 ring) https://indico.cern.ch/event/778856/contributions/3253865/attachments/1786900/2909722/TL4O_Reiew_29Jan19_BI_FR.pptx (slides 14-16)
6	Hole in bellows (2019)	3MeV, 2hr	Over-focusing and steering of the beam onto bellow before the dump, caused by an anomalous setting during automated parameter search to improve chopping efficiency

Incidents and lessons learnt

#	Incident (year)	Energy	Lesson learnt
1	Hole in bellows (2013)	3MeV	Bellows are weak point (reinforce, remove aperture restriction); simulate abnormal settings; check machine alignment;
2	Destroyed laser emittance meter diamond detector (2014)	12MeV	Follow procedure for BIS masking;
5	SEM grid damaged (2017)	160MeV	Need to implement logging during commissioning phases! Reviewing thermomechanical simulations to set operational limits; New design in pipeline;
3	Damaged foil in teststand (2018)	160MeV	Unique for teststand. Empty foil in first frame. Extra care when setting up with high intensity. Implement BLM monitoring?
4	BTV screen broken (2018)	160MeV	BTV movement and presence included in SIS.
6	Hole in bellows (2019)	3MeV	Experienced supervision required when making special tests; Worth exploring further protection options…

- Observations
  - Care needed – even at low energy!
  - All incidents during special (MD-like) measurements

Machine Protection Settings Status

- All installed systems for L4T running are in an (almost) definitive state with the exception of the settings for the following equipment:

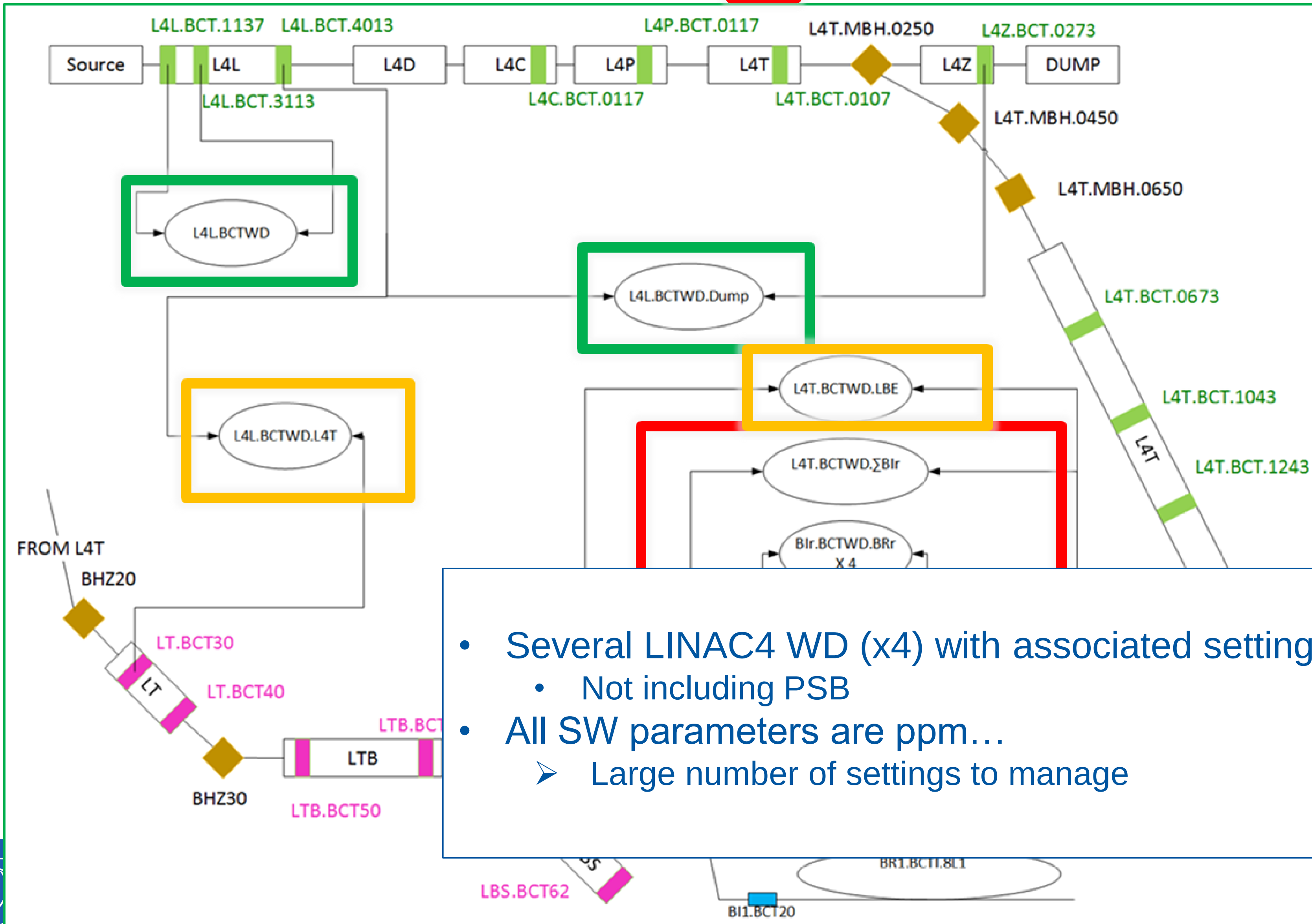
- Power converters
  - Flexibility demanded for setting up and investigations
  - For LBE run the analog fixed thresholds (expert setting) will be changed to remote digital thresholds (OP setting)

- BCT Watchdog and BLM
  - Both have similar strategy with a ppm software threshold
  - Non-ppm hardware threshold
  - Operator settings for WD; no settings yet for BLMs…

- SIS

BCT–Watch Dog

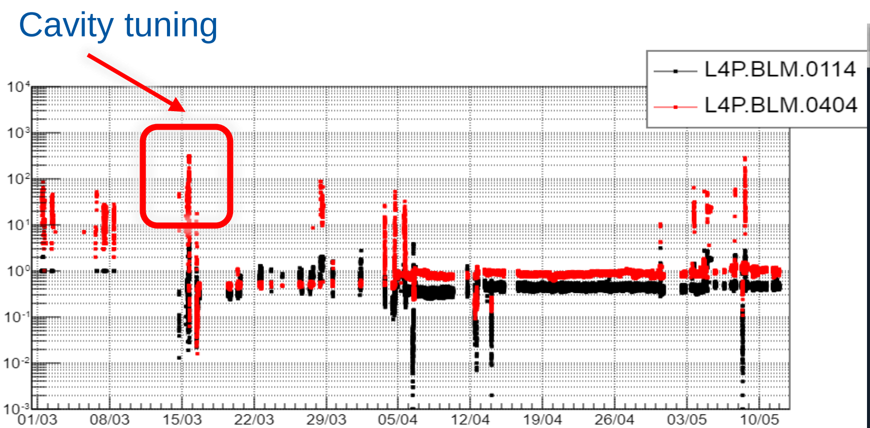
- L4L-L4L, L4Z-L4L Operational 2018
- L4T - L4L, LBE-L4T : LBE Run
- BR_X – L4T, Sum(BR_X-L4T) : L4 Connection

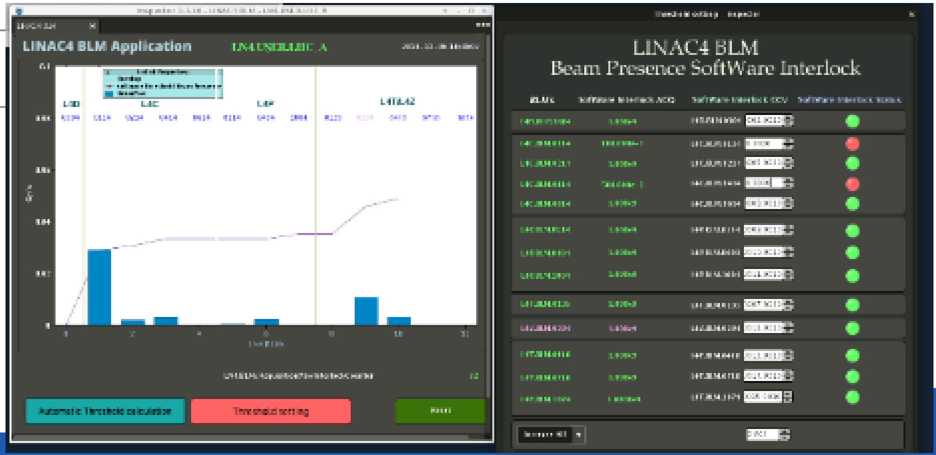


- Several LINAC4 WD (x4) with associated settings
  - Not including PSB
- All SW parameters are ppm…
  - ➢ Large number of settings to manage

BLM system status

- The electronics (HW and SW) have been upgraded several times to match OP needs
  - Important change was adding a timing reconfiguration to synchronise with Beam Presence.
- The connectivity with the BIS is ready - “only” settings required
  - New OP application will be used to empirically acquire settings for LBE run
  - The SW Thresholds functionality was verified with beam in 2018
  - The HW Thresholds functionality only verified in the lab. Still needs DB (InCA) for storing the thresholds and the ‘drive’ to electronics functions.





SIS and External Conditions

- External Condition:
  - [INCOMING] Change beam destination to L4Z if beam stopper L4T.TDISA.0740 is IN

- SIS:
  - [DONE] Shorten the Linac4 pulse length to the equivalent of one ring injection for: wire scanners, Semgrids, BTV screen
  - [DONE] Cut the beam when the BTV screen is moving

  - [INCOMING] Automatic entry in the elogbook + LASER and a sound alarm after a certain number of shots without beam
  - [INCOMING] Limit the average power sent to the LBE dump to allow access to PSB during LBE line run (use BCT acquisition and define a threshold in average current over a certain time)
  - [INCOMING] For 'continuous' caesiation, monitor the temperature of the caesium oven and close the vacuum valve if too high

Machine Protection Settings

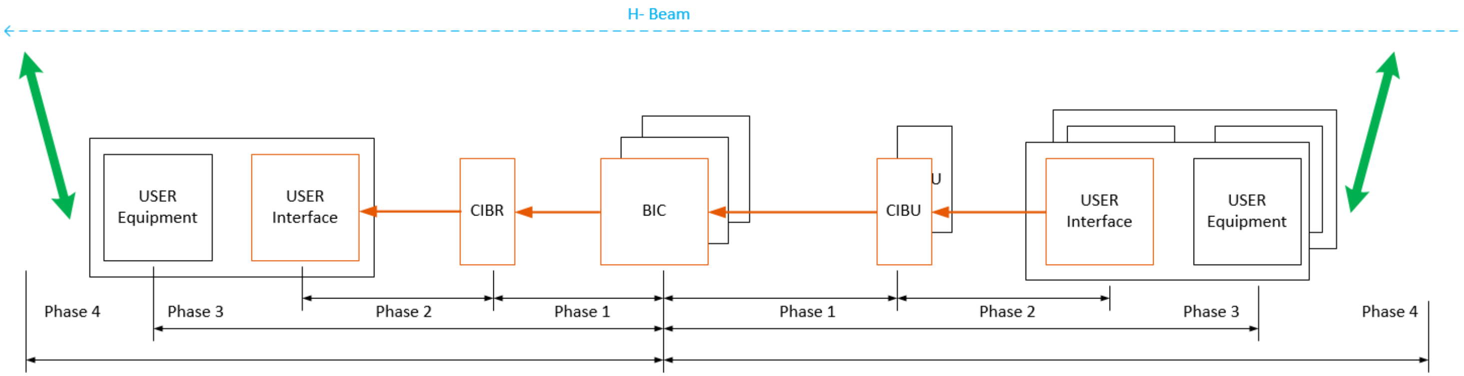
- A recurring theme throughout the extended commissioning phase is settings flexibility
  - Necessary for machine studies and performance improvement
  - However evidently creates an operational risk
- Several important machine protection settings are assured by experienced supervision and operation
  - the same supervisors are often probing the performance boundaries
- How to ensure settings are correct and reverted to nominal?
  - Technical solution: consider deploying Machine Critical Settings
  - Human solution: roles and rules to be respected
- The MPP has a clear mandate for the LHC
  - In the LIU era a proactive “Injectors MPP” and “Injectors Threshold WG” would provide a good framework for injector machine protection.
  - LINAC4 experience shows this is most useful during the commissioning phase

Incoming – Source interlocking

- Request from ABP and OP to move BIS actuating system from Source_RF to Source_HV
- Discussed during 1st LINAC4 review (June 2018) (https://indico.cern.ch/event/735286/timetable/#12-power-converters-and-interl)
  - Concluded that any change should be synchronised with eventual source update to magnetron
  - However since this review the magnetron solution is not actively considered, thus for the moment continue interlocking with Source RF
  - Mitigated by manual intervention to close beam-stopper if LINAC beam is inhibited
  - Observe that the Beam Stopper must be operational… a (low probability) fault in this system will induce a long recovery time
- Monitor situation and consider implementation post-LS2
  - Affected teams principally EPC (Source_HV) and MPE (BIS)

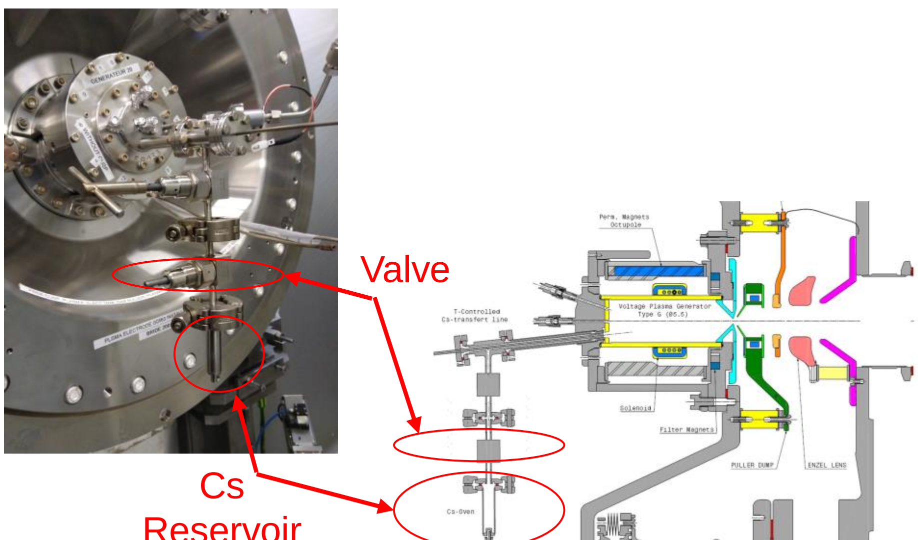
Incoming – Restart and Machine Protection

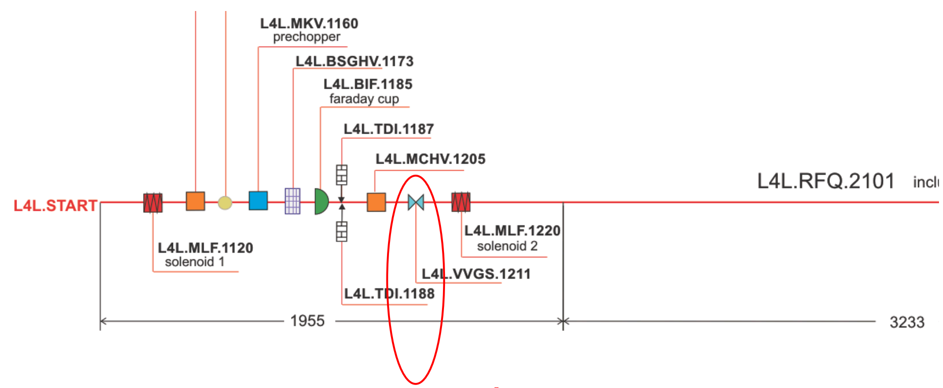
- Main phases
  - Phase 1: BIS connectivity (MPE)
  - Phase 2: BIS user connectivity (MPE + equip groups)
  - Phase 3: non-beam functionality (OP)
  - Phase 4: beam functionality (OP)
- Commission LBE
  - 1 BIC + 10 new users
- Commission PSB connection
  - For LINAC4, add PSB BICs x4 and PSB destination to 52 existing users
  - Then need to commission the other 45 PSB users…



Incoming – source caesiation

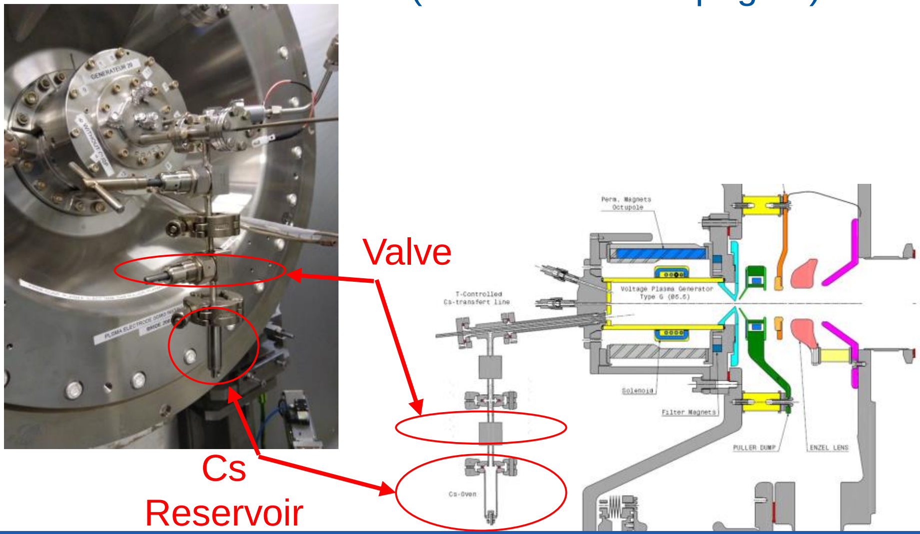
- **Current method of periodic caesiation.**
  - RFQ is protected with the sector valve closed during the process.
    - Once per month, process takes approximately 4-5 hours.
    - High temperature (typ. 140-170°C) to deliver relatively high quantity of caesium (5 mg).
    - Disadvantage is that source electron to ion ratio evolves over time as the caesium is consumed and required very regular tuning.

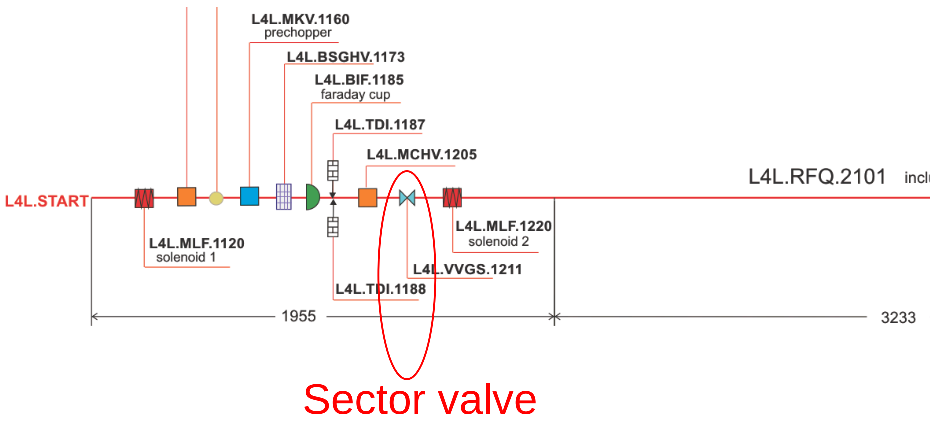




Incoming – source caesiation

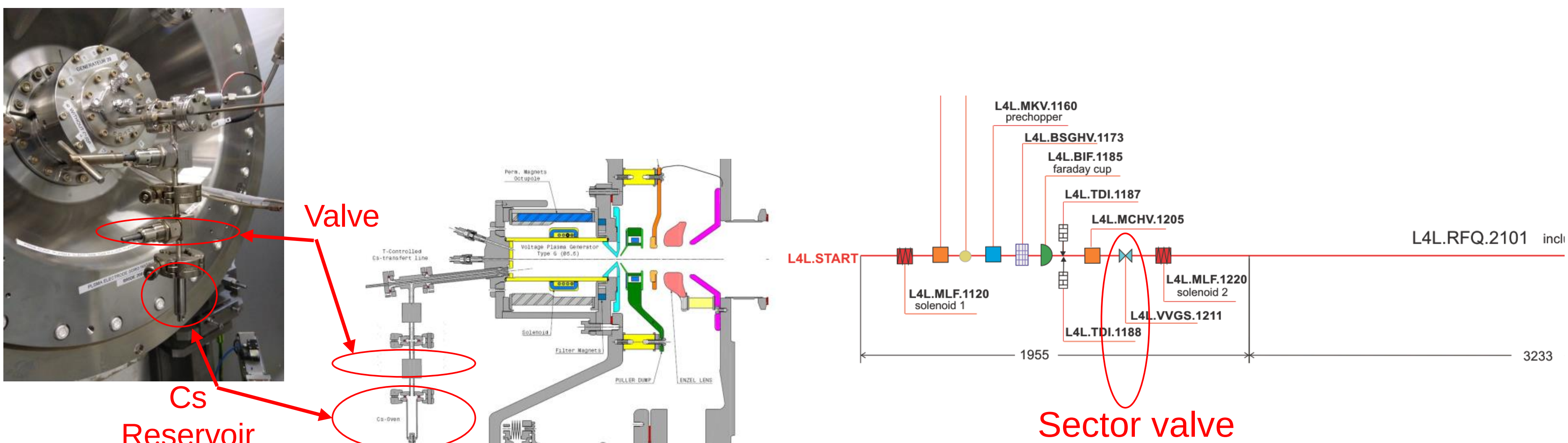
- **Proposed new method of continuous caesiation.**
  - RFQ sector valve is always open, protection against Cs-overflow achieved by keeping temperature at or below nominal.
    - Low temperature (possibly 60-100°C) where delivery of caesium matches consumption.
    - Similar caesiation methods used at other labs: J-PARC (hourly high temp. micro caesiation) and BNL (constant caesiation @100 °C).
    - Advantage with a cusp free plasma generator is that the source remains stable over time (e/H < 1); tested in 2018 in Linac4.
    - Further study of this mode of operation was recommended by L4 source review of Nov. 2018 (EDMS 2048831 page 5).





Incoming – source caesiation

- **Proposed new method of continuous caesiation.**
  - RFQ sector valve is always open so caesium reservoir must be kept at a low operation temperature that is deemed safe (temperature still to be determined)
  - PLC control of heaters and Cs valve to prevent high temperature with sector valve open
  - Review machine protection aspects during Summer 2019
  - Objective is to use this method for the LBE run (starting September 2019)



Conclusion

- LINAC4 is extensively exploiting the LHC BIS components
  - Usual compromise between machine flexibility and machine protection during the long performance exploration phase
  - Machine protection strongly dependent on supervision expertise
  - The need for deployment phases and commissioning scenarios should be carefully considered when designing new BIS implementations
- The few incidents that have occurred suggest some improvements are possible particularly with a decision making protocol
  - More formality required when deviating from ‘standard’ operating envelope? Clarify roles and procedures?
  - Consider a rigorous approach to machine protection settings, such as defining Machine Critical Settings (WD, PC, BLM, …)
- Incoming
  - Moving to full exploitation of LINAC4 (LBE run then PSB connection)
  - Review the machine protection aspects of continuous source caesiation

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