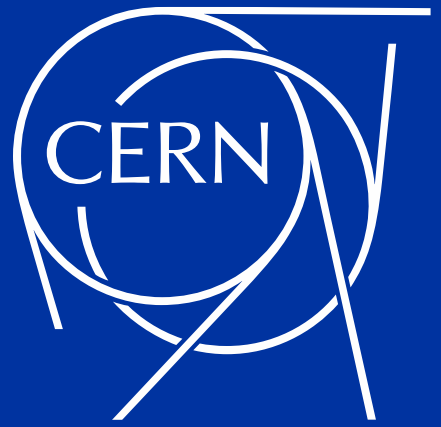

ABT Equipment: Operational Insights and Future Perspective

M. Barnes, W. Bartmann, C. Boucly, C. Bracco, J. Borburgh, P. Burkel, M. Diaz, L. Ducimetière, Y. Dutheil, **G. Favia,** L. Feliciano, L. Fernandez, T. Kramer, V. Namora, N. Magnin, F. Pelloux, V. Senaj, D. Standen, T. Stadlbauer, P. Trubacova, F. Velotti, N. Voumard, C. Zannini

Outline

1. **Operational insights**
   - 2024 ABT equipment operation
   - 2024 operational experience:
     - KFA71
     - KFA14
     - MKP-L
     - MKI
2. **Looking forward**
     - MKP-S
     - MKDH
     - AC dipole
3. **Conclusions**

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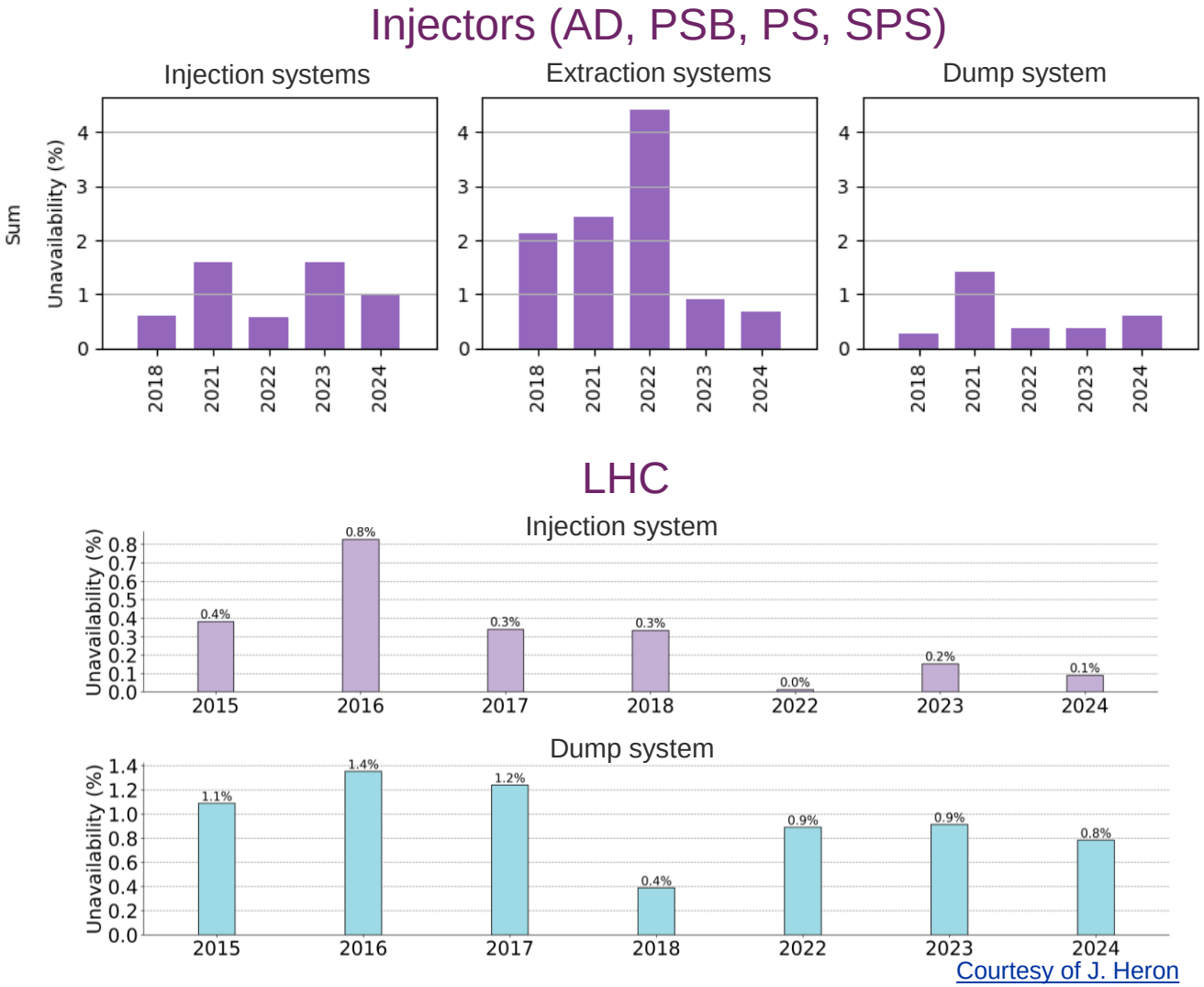
2024 performance in a glance



Courtesy of J. Heron

- **Very reliable operation** with **> 99% availability,** both for injectors and LHC equipment
- Reached ultimate LIU beam intensities in the LHC injectors, without **any limitation from ABT equipment**
- No major HW change, **but continuous effort on improving operation**, relying on experience and enhancing AI and automation

PSB / KFA14

- Four magnet modules per ring, to extract beams from the PSB. The connection boxes, PFL and TX lines are filled with SF6 gas

- On March 29th a **SF6 leak** developed in Ring3 generator, originated by an electrical breakdown in the SF6 feedthrough insulation of the dump switch
  - Likely air bubbles generated during previous oil filling
  - 12 kg out of 100 kg SF6 lost
  - > 11 hours blocking time

Dump switch

Broken feedthrough

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Broken feedthrough

PE HV Low Attenuation Cable

Actions:

- Improved KFA14 SF6 fault prevention to be implemented:
  - Check status of all generators to identify early signs of deterioration
  - Refine switch maintenance and oil filling procedures
- Improved feedthrough design under study
- Replace SF6 cables: R&D campaign ongoing to find alternatives
- Established safety procedure to ensure safe interventions performed on still operational equipment

PS / KFA71-79

- 12 magnet modules: nine located section 71 and three in section 79 used for the fast extraction of all PS beams

- **> 164 hrs downtime in 2021** → Consolidation of generator modules and control systems started during YETS21/22
  - 6 out of 12 modules already upgraded, full renovation expected to be completed by LS3 (2027)
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  - Fault originated from TDR discs assembly operations

KFA71 nominal and distorted pulses

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Actions:

- New documented discs validation and assembly procedures
- EPA anomaly detection and forecasting
- Established safety procedure to ensure safe interventions performed on operational equipment

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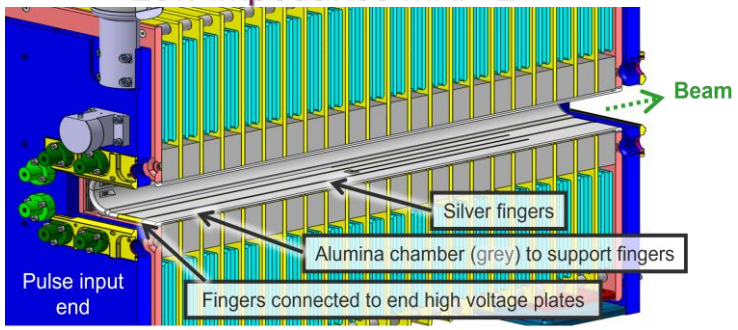
SPS / MKP-L

- System designed to inject LHC beams in the SPS together with the MKP-S
- MKP-L was identified as a limitation for the HL beam intensity reach:
  - In 2016 high voltage weaknesses were addressed by limiting the operational voltage (36.8kV vs 49 kV nominal), increasing MKP-S voltage and introducing transfer line steering
  - New low impedance MKP-L installed during YETS 22/23:
    - Significantly lower beam induced heating and fast beam conditioning
    - Kept reduced voltage as no available low-impedance spare
    - Reached LIU intensities in 2024

Low impedance MKP-L



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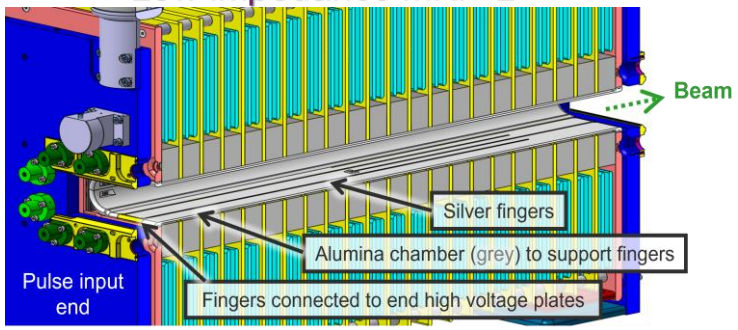

- During 2024 run the **operating voltage has been increased up to 43 kV**:
  - Planned tests on old module to understand HV weakness
  - Spare assembly ongoing, validation tests will follow → ready in 2025
  - Expected loss reduction and lighter beam commissioning with full voltage at zero bump

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- Significant beam induced heating in Post-LS1 design magnets
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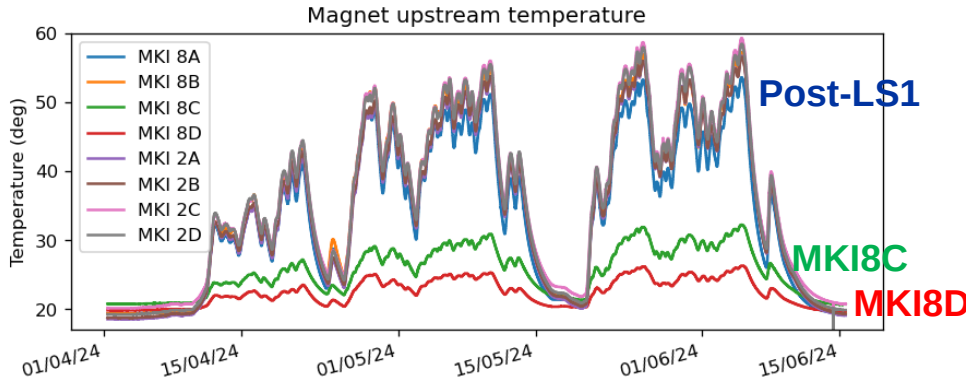
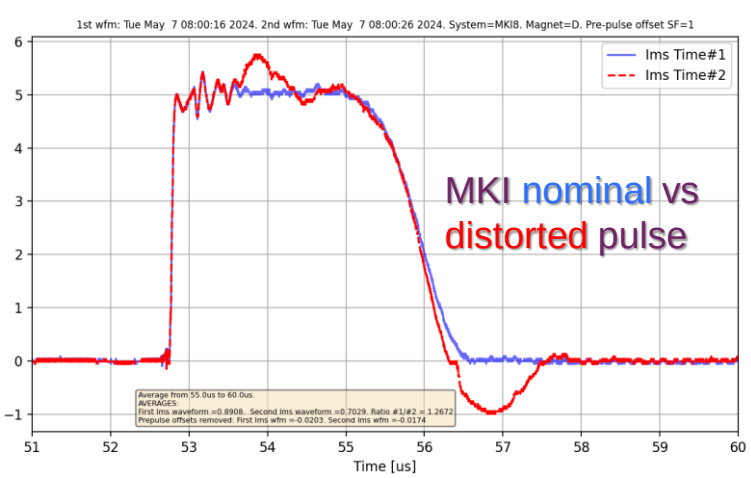


- Two MKI Cool magnets already installed in Pt8
  - Temperature rise, near ferrite yoke, is only 30% of Post-LS1 MKIs
  - Rapid beam conditioning
  - HV Sparks or discharges occurring on screen conductors:
    - **emittance growth and some beam dumps** triggered by BLM losses and BPM



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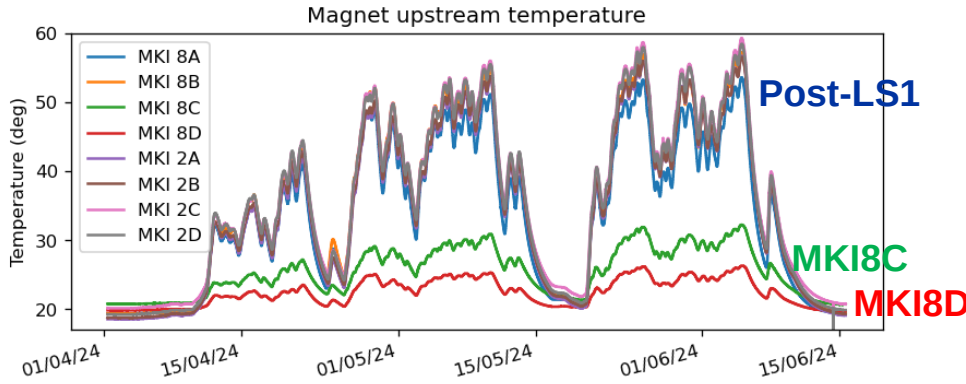

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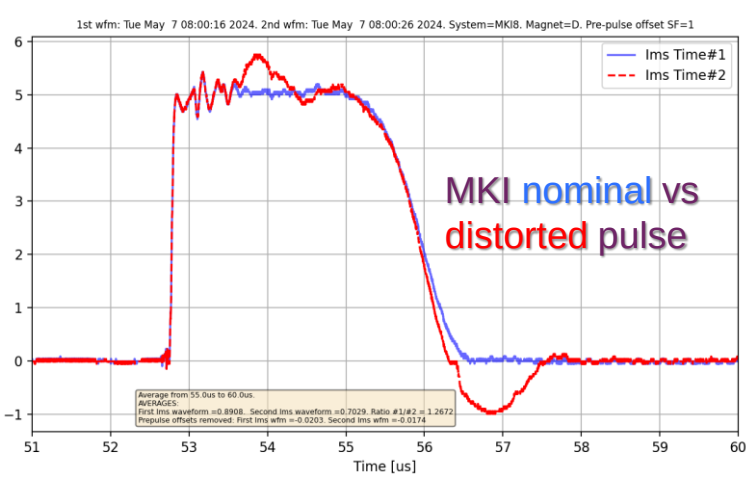

Actions:

- Improved conditioning of magnets following a beam dump
  - ✓ Event frequency has drastically reduced, with events almost disappearing in MKI8C
- HV tests on coated samples to rule out issues related to coating charge-up or deterioration

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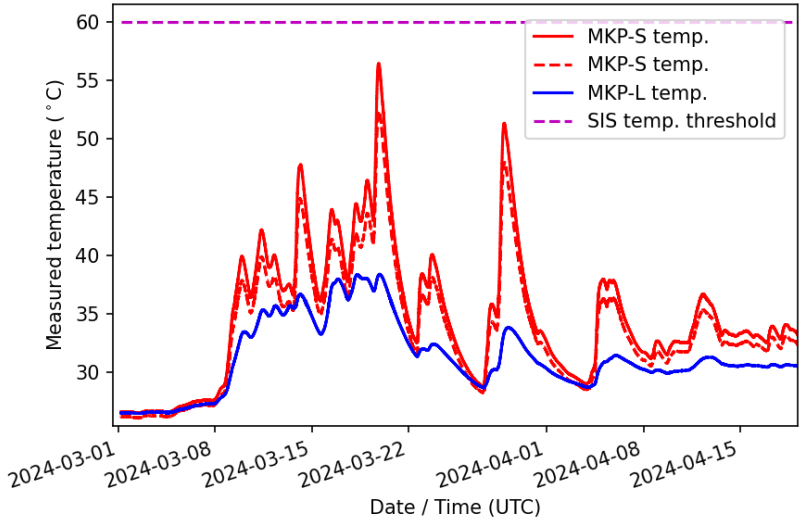

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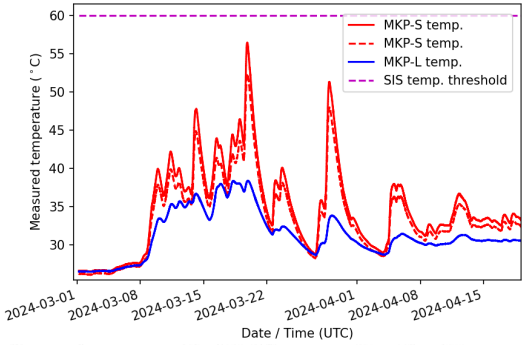

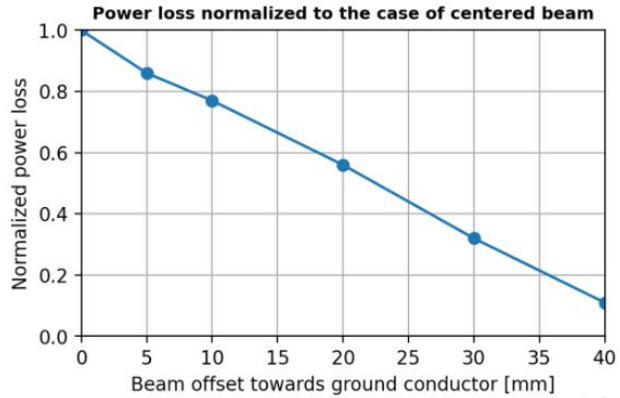

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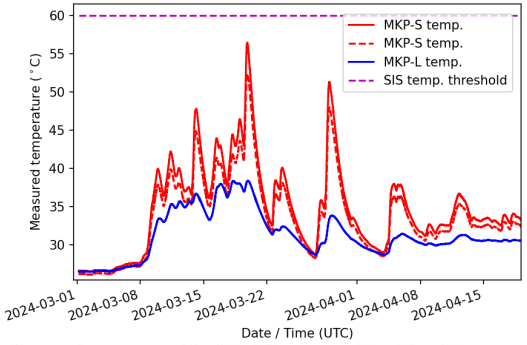
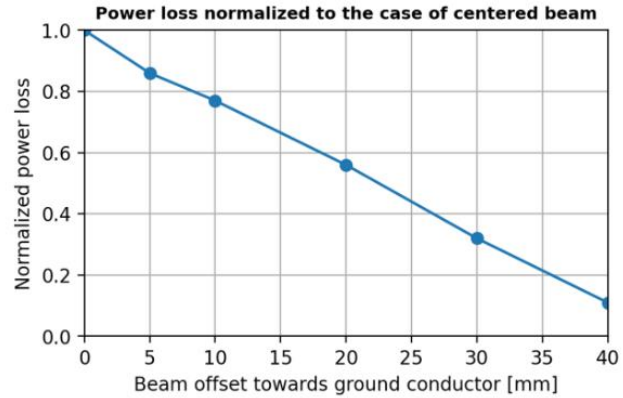
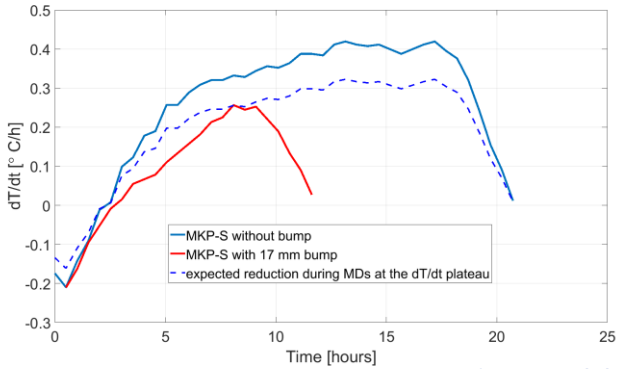
  - 17mm bump used
  - Required 10h stable beam conditions ($\frac{dT}{dt}$=0.4℃/h)
  - Bump only possible at flat bottom energy, due to limited SPS corrector strength
  - Complementary magnet re-alignment needed







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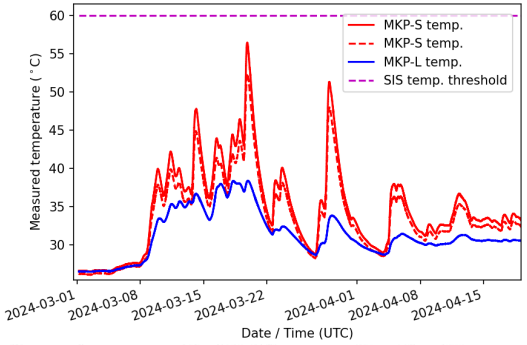
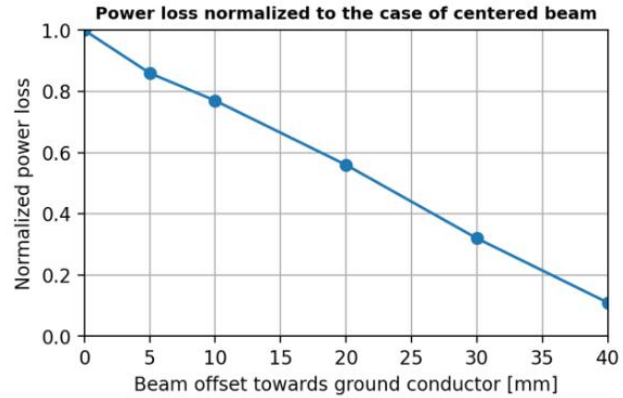
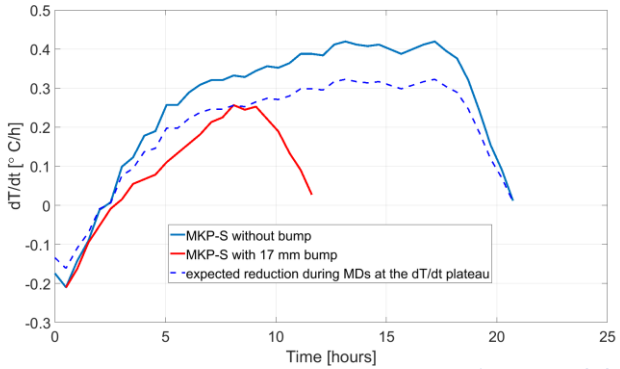
- Only 5mm re-alignment possible without venting the sector:
  - Aperture studies still pending
  - Investigate possibility of realignment during LS3
  - Dedicated scrubbing of both MKP and newly installed MKDH







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SPS / MKDH limitations and performance improvement studies

- Three dump kicker magnets used for sweeping SPS particles on TIDVG
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  - Long beam conditioning and vacuum interlocks limiting LIU beam intensity reach
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    - ~7 weeks, including ~10days of beam conditioning (assuming 50% availability)

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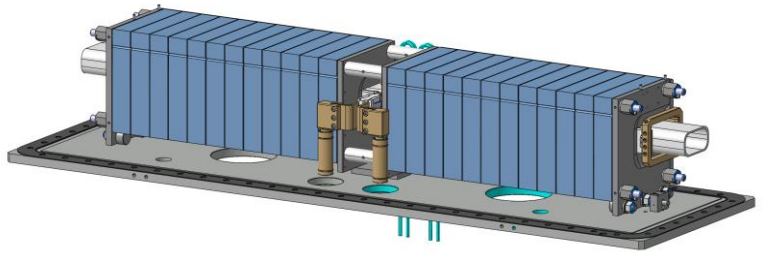

- **A mitigation strategy is being examined:**
  - Installation of a coated chamber to improve vacuum performance:
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  - Replace weaker magnets with lower-eddy current ones:
    - They can be operated at lower voltage → improvement of HV and vacuum performance as well as relaxed vacuum interlock

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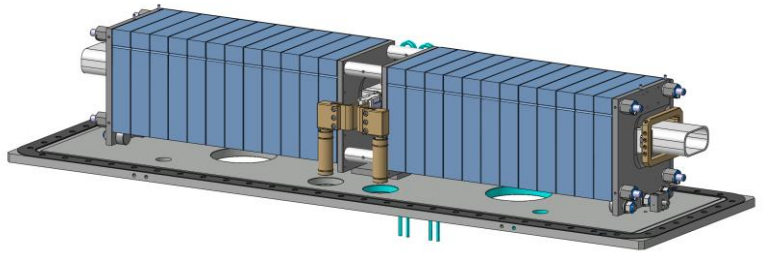

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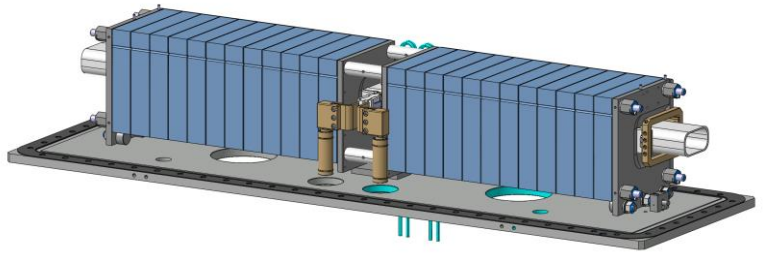

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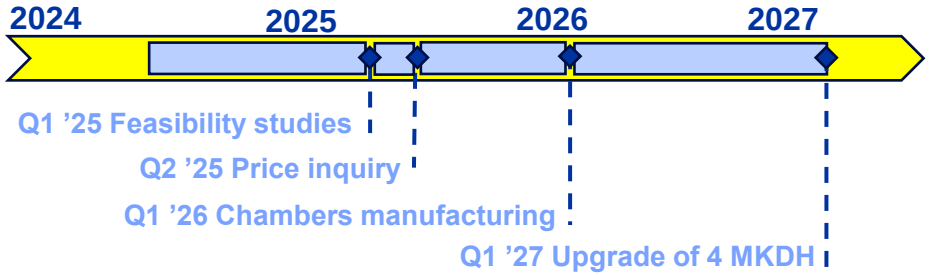
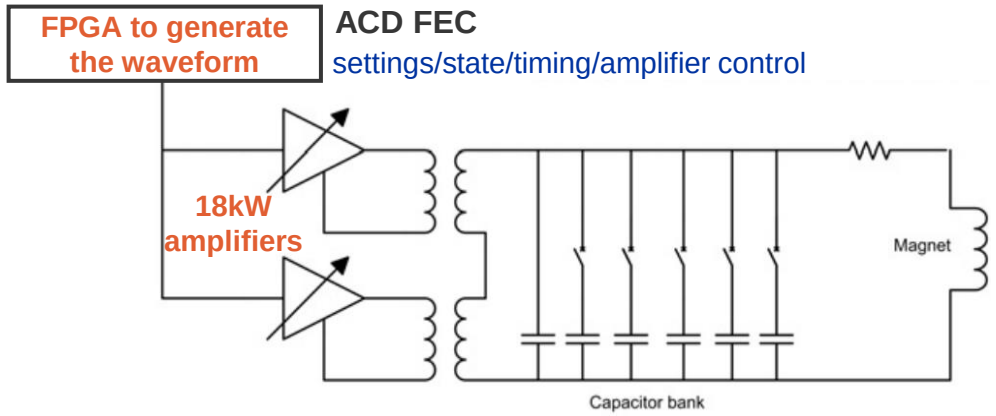


LHC / MKQA spare strategy

- MKQA is used for measuring beam dynamics parameters (‘A’ or ‘Q’ mode) and overcome spin resonances (‘ACdipole mode’)

- From 2024 operational experience:
  - **FPGA failing several times**, temporarily fixed:
    - Not blocking OP
    - 20 years old cards → **need replacement!**
  - **Amplifiers failing** due to aging**:**
    - All four spares were used, running out of spare during reparation
    - Amplifiers out of production and reparation possible depending on component availability

Simplified schematics of AC dipole configuration



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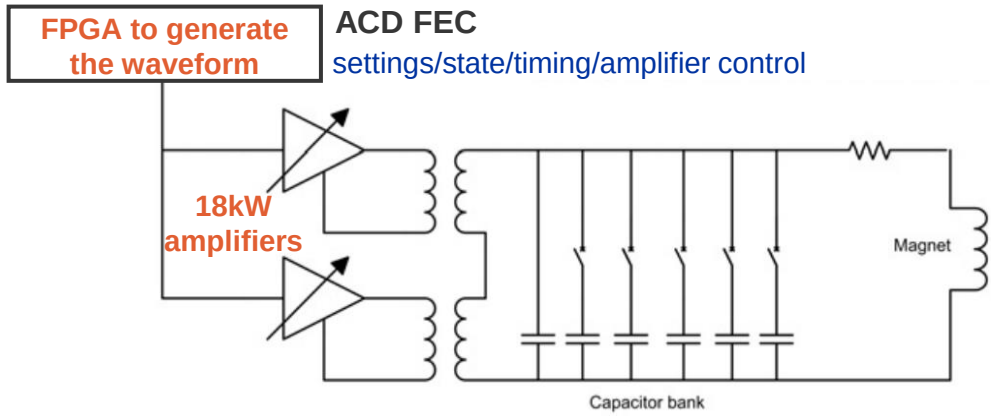

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AC dipole FEC and power amplifiers

Actions:

- New FPGA design already tested, validated and ready for installation (YETS24/25)
- Amplifier replacement strategy under definition (no equivalent solution available):
  - Contact with industries ongoing to find possible technical solutions
  - In house development or outsourcing?
  - Consolidation planned for LS3

Conclusion

- Achieved excellent ABT operational performance, with less than 1% unavailability across both injectors and the LHC
- Successfully managed significant incidents involving KFA71 and KFA14 through prompt expert intervention, alongside ongoing efforts to enhance fault detection and prevention measures
- Conducted interventions during operation shadowing to minimize blocking time. Safety procedures have been established
- Confirmed performance improvements in the recently upgraded MKP-L and MKI systems, with room for further enhancement
- Identified potential limitations in the MKP-S and MKDH systems; upgrade strategies are currently being explored for LS3
- Addressed AC dipole spare limitations, with final consolidation foreseen during LS3

Spare Slides

SMH16 eddy current septum installation

Scope:

- Present system based on direct drive topology, with limited lifetime (magnet exchange every 2yrs)
- Present power converter (SY/EPC) at the end of its life. Regular wrong pulses

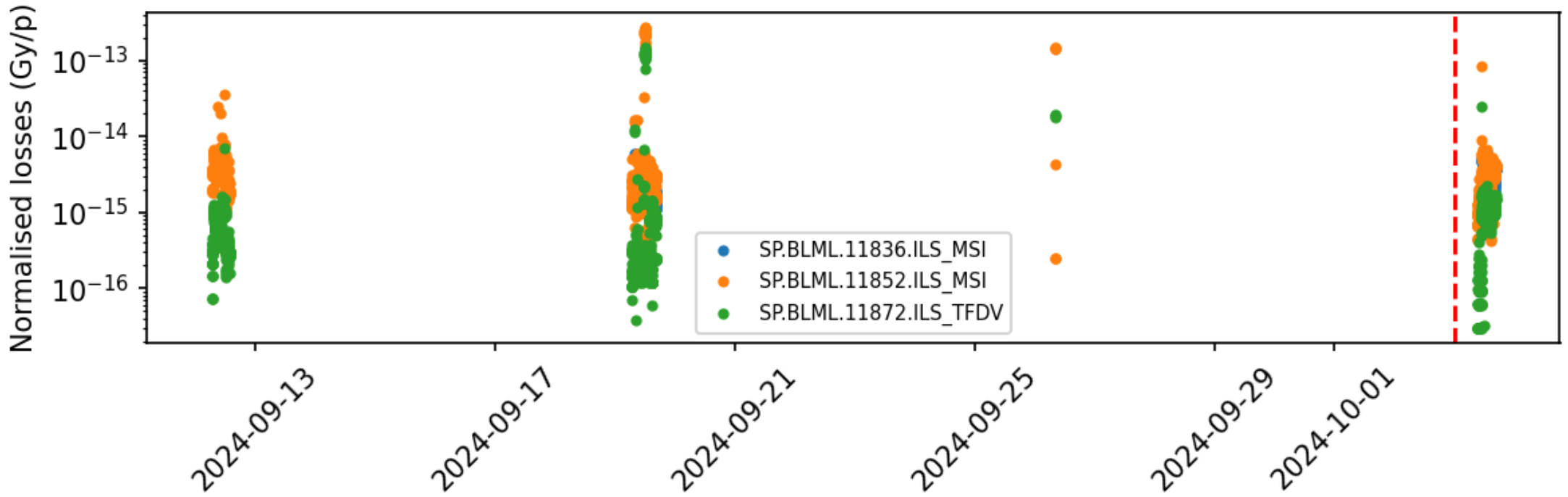
Consolidation strategy:

- Novel eddy current topology, under vacuum, with expected longer lifetime
- New power generator design (SY/ABT)
- Planning foresaw installation during YETS 24/25

Current status:

- 2 generators: 1 in lab 867 under test, 1 in blg 151 ready for pulsing with dummy load
- Reliability run not yet completed, generator requiring still minor adjustment to be within specs. Timing and control systems being finalized
- Installation of SMH16CF during YETS 25/26 has been proposed:
  - 1 yr of life left for present SMH16DD, exchange is needed
  - The nToF run would need to be concluded earlier to enable immediate intervention after end of run (in compliance with RP constraints)
  - Cabling and generator installation done in YETS 24/25 already

MKP-L losses at 43kV



- Increased aperture due to the reduced bump
- Insufficient data points available to draw a conclusion
- A dedicated measurement campaign is required to better evaluate impact

MKDH impedance measurements