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HiLumi
HL-LHC PROJECT

LHC Availability Dependencies and Lessons Learnt from LHC Run 2

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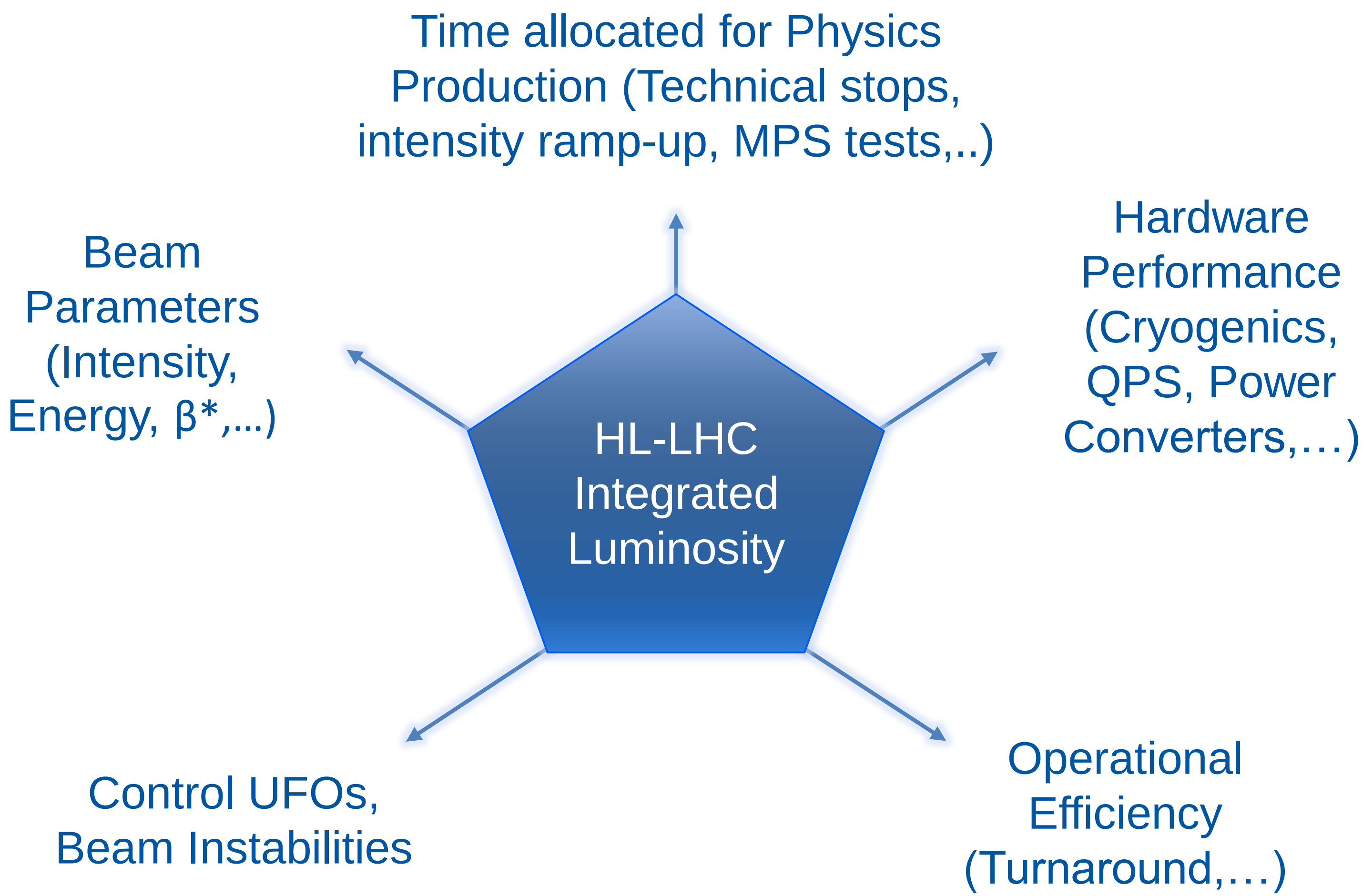
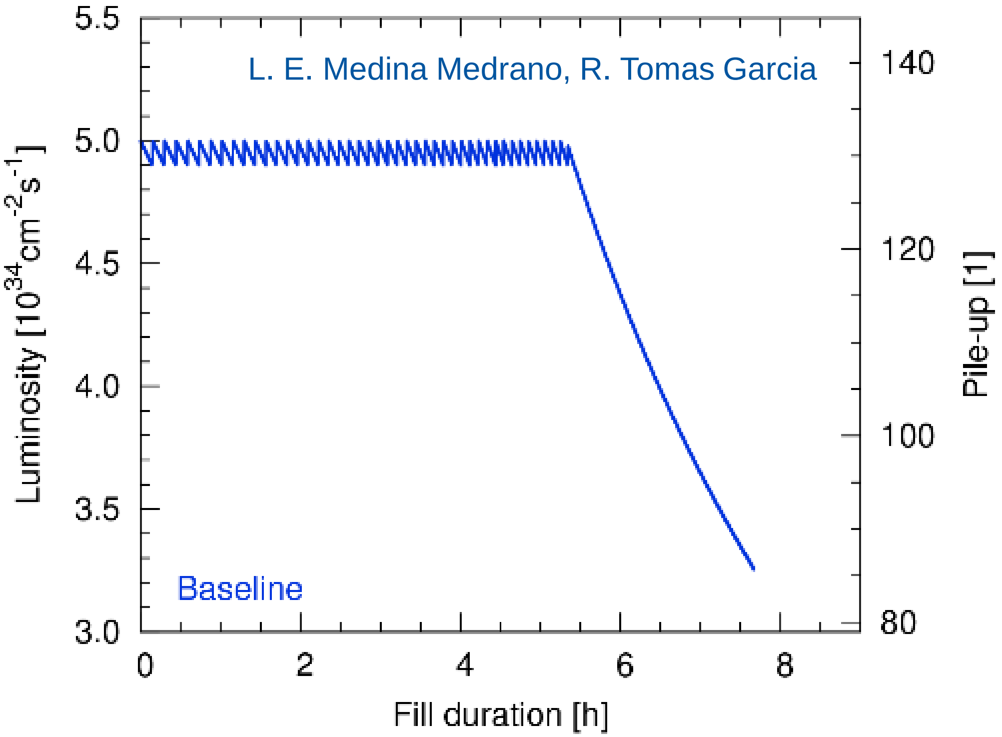
Outline


Time allocated for Physics Production (Technical stops, intensity ramp-up, MPS tests,..)
Hardware Performance (Cryogenics, QPS, Power Converters,…)
Operational Efficiency (Turnaround,…)
Control UFOs, Beam Instabilities
Beam Parameters (Intensity, Energy, β*,...)
HL-LHC Integrated Luminosity

Integrated Luminosity for HL-LHC



- Target: 3000 fb^{-1} over HL-LHC lifetime
  - 250 fb^{-1} per year
  - 160 days of p-p physics
  - 1.56 fb^{-1} per day
- Levelling: 5*10^{34} [cm^{-2}s^{-1}]

Simple calculation:

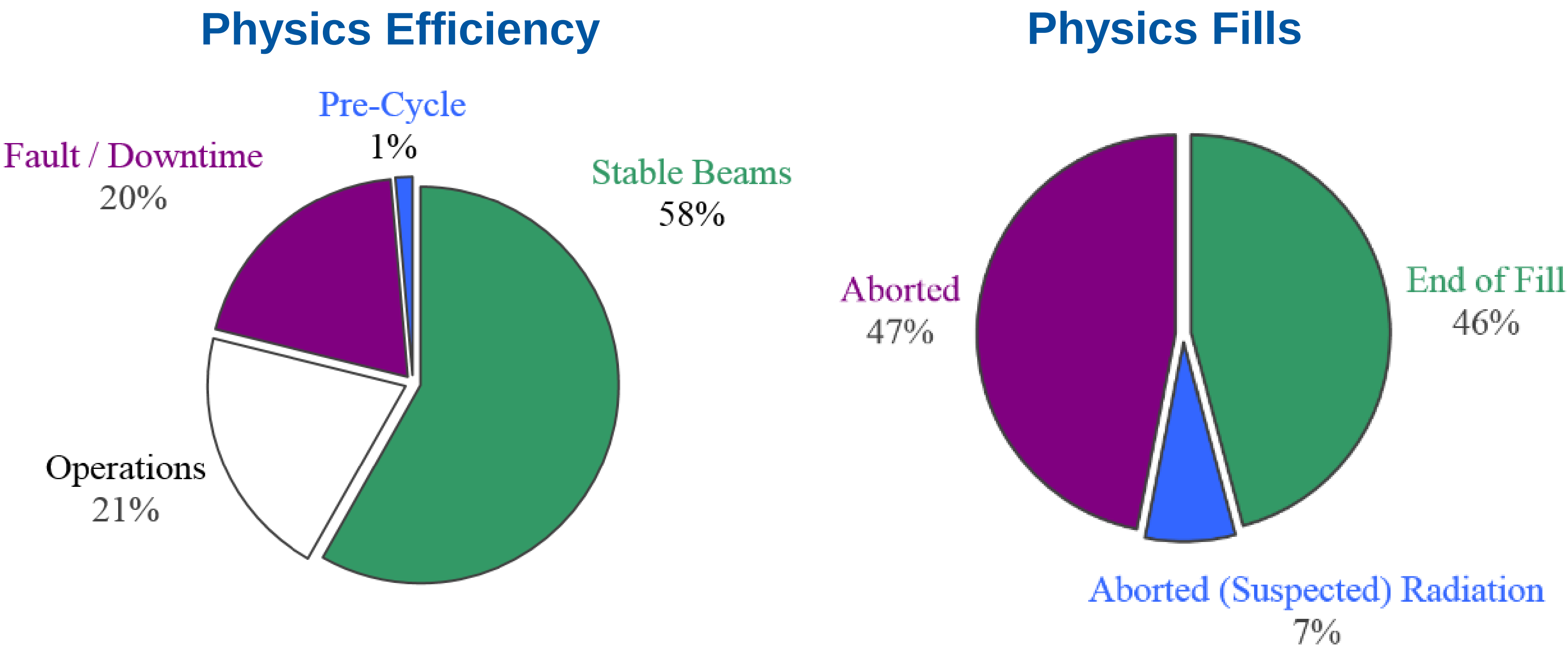
- A fill of 12 h HL-LHC would produce ~ 1.5 fb^{-1}
- Requirement for HL-LHC physics efficiency is ~ 50 %
- The physics efficiency depends on the achieved machine availability

Availability for HL-LHC

- Starting point: 2016 LHC availability
  - Rate of premature dumps
  - System Downtimes
  - Turnaround time
  - Availability of the injector chain

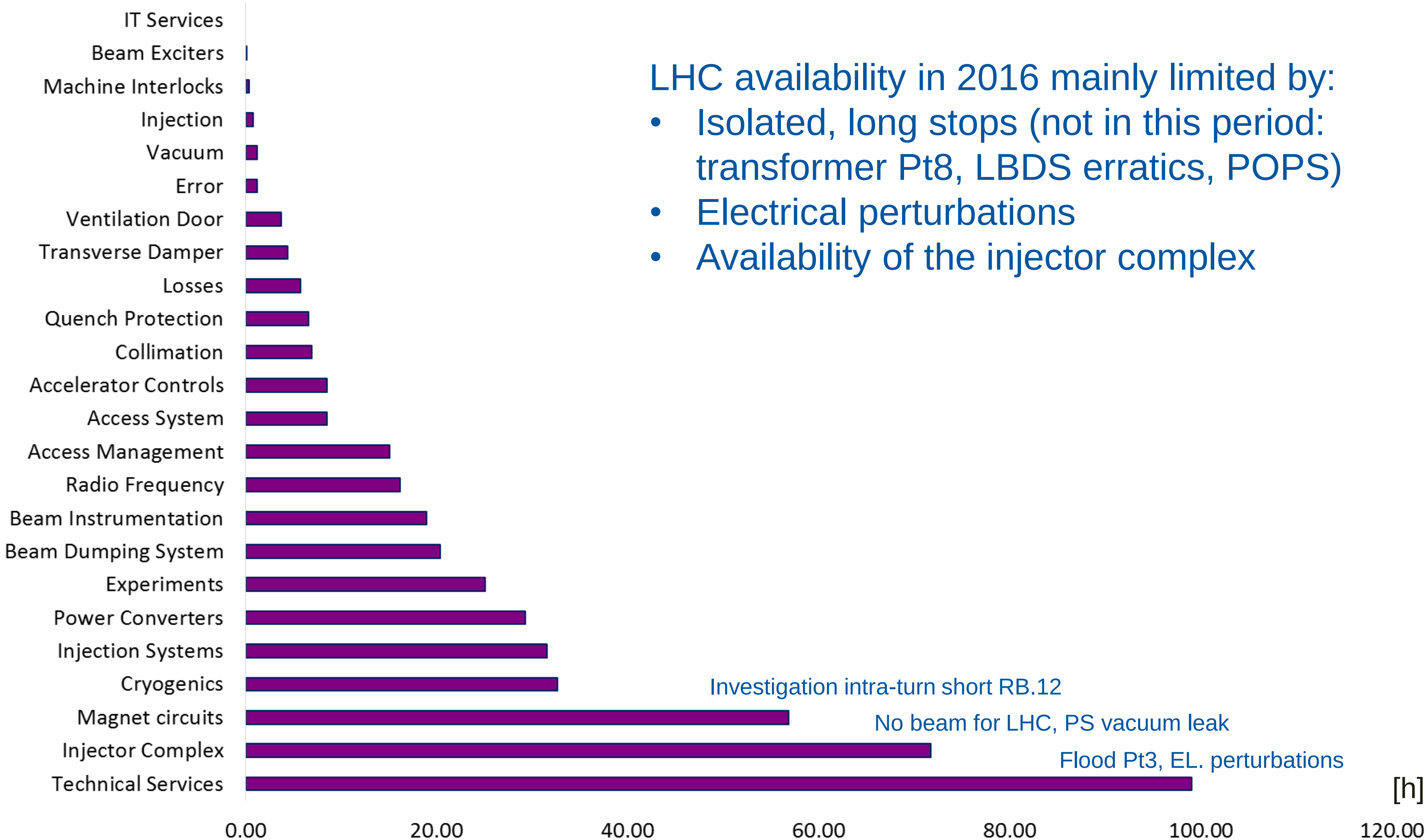
- In addition, for HL-LHC, account for:
  - Operation at 7 TeV
  - Introduction of ***new*** systems and technologies (uncertainty !), potentially leading to:
    - Increased number of premature dumps = increased sensitivity to turnaround time and availability of the injector complex
    - Increased downtime
  - Effect of different beam parameters
  - Ageing of accelerator equipment

2016 Statistics for period TS1 to TS2



- The period from TS1 to TS2 in 2016 is chosen as a reference for the reproducibility of operating conditions – ideal conditions
- 96 fills to Stable beams for a total of 1112 h

2016 Downtime Distribution (TS1-TS2)



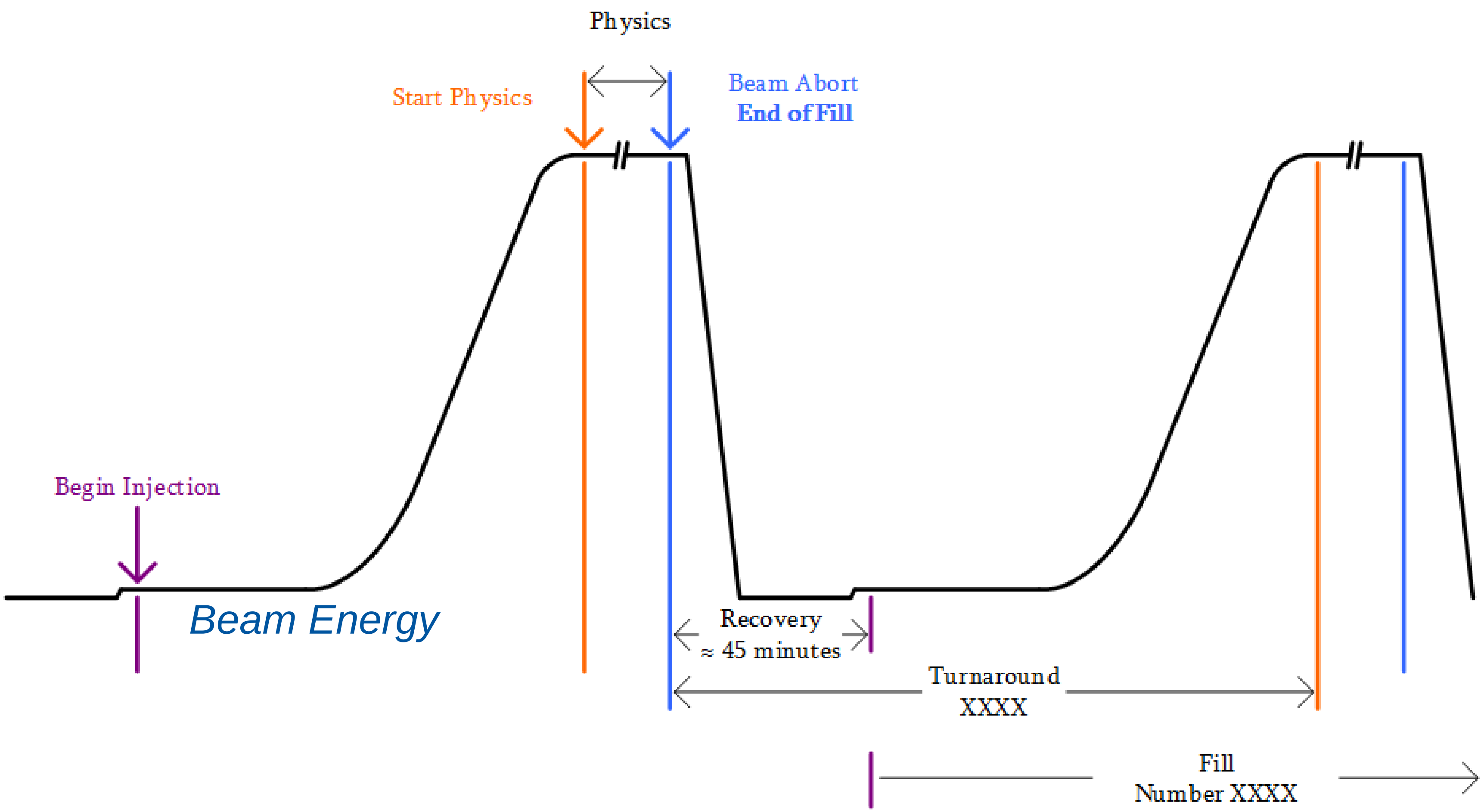
LHC availability in 2016 mainly limited by:

- Isolated, long stops (not in this period: transformer Pt8, LBDS erratics, POPS)
- Electrical perturbations
- Availability of the injector complex

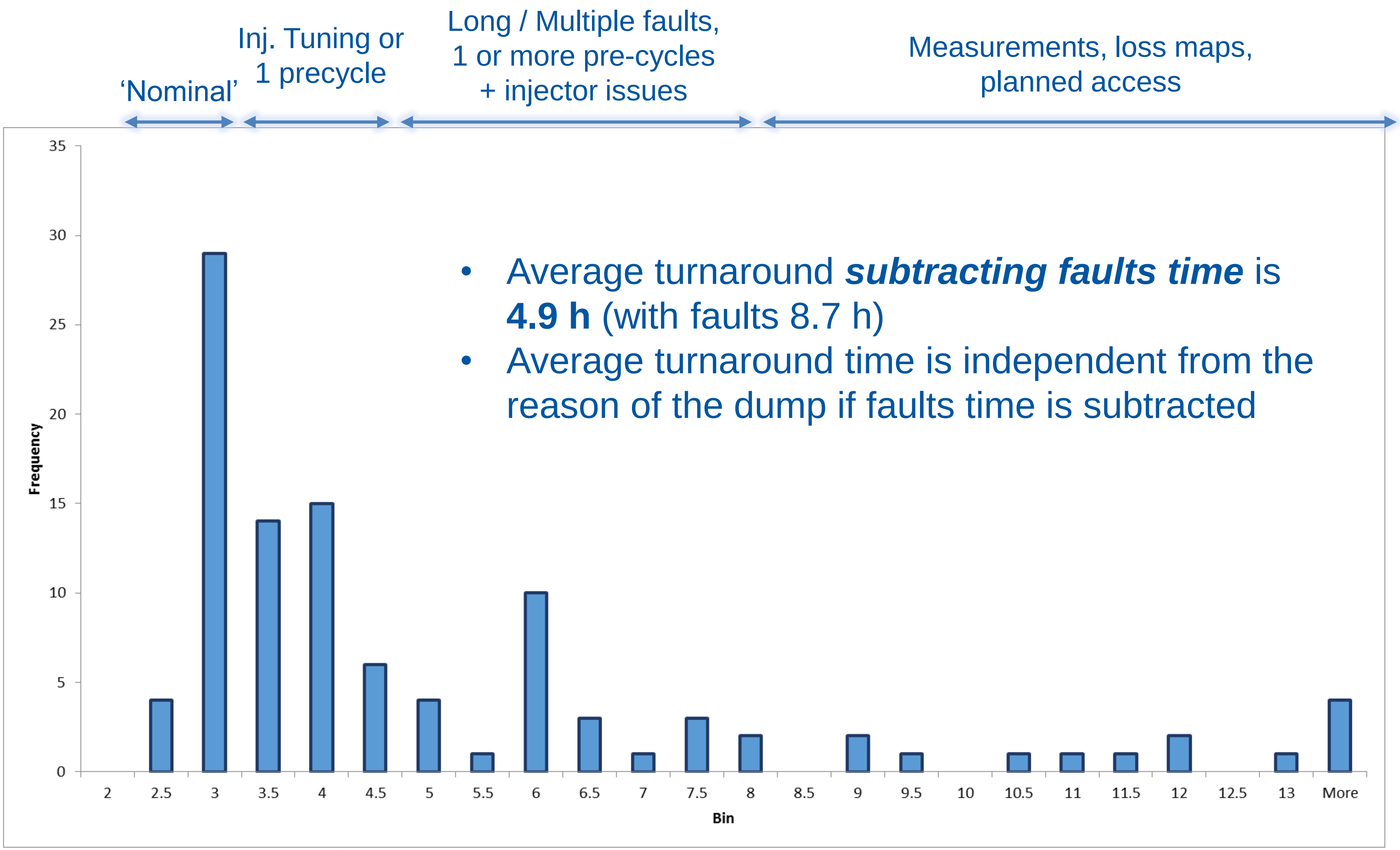
Extrapolation to HL-LHC

- **Operation at 7 TeV + higher beam brightness**:
  - UFOs:
    - UFO rate: release mechanism not understood, scaling with intensity unknown
    - Lower quench levels (30 %) → Potentially 3x more quenches due to UFOs (3 quenches in 2015 *and* 2016, low statistics)
    - BLM thresholds are already tolerating few quenches
  - Impact of R2E: target 0.1 SEUs dumps / fb-1 (order of 25-30 per year)
  - Possibly increased failure rate of LBDS due to running at higher voltage
  - No major impact expected on:
    - Quench recovery times and failure rate of power converters
    - Availability of the injector chain: new elements, but mostly established technology (exception: H^- stripping foil)
- **New systems**:
  - Quench behaviour of Nb_3Sn magnets, reliability of HTS links
  - Reliability of crab cavities (failure rate, failure modes and effects)
  - New cryogenic configuration (Pt. 1-5, 4)

Definition of Turnaround Time

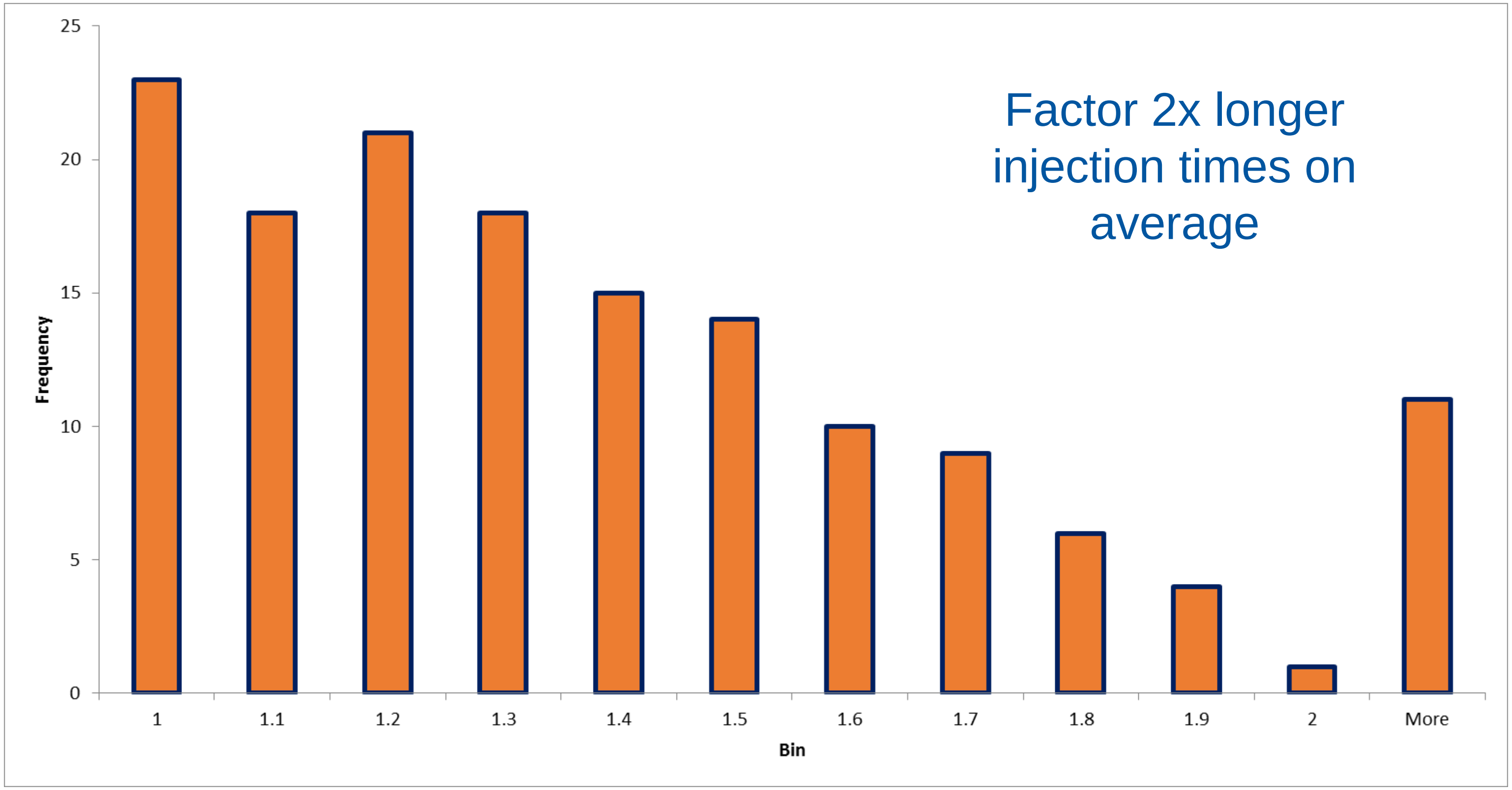


Turnaround Distribution (2016 TS1–TS2)



- Average turnaround ***subtracting faults time*** is **4.9 h** (with faults 8.7 h)
- Average turnaround time is independent from the reason of the dump if faults time is subtracted

Injection Time Distribution (2016)



- Average: 1.37 h   Theoretical minimum: 0.6 h

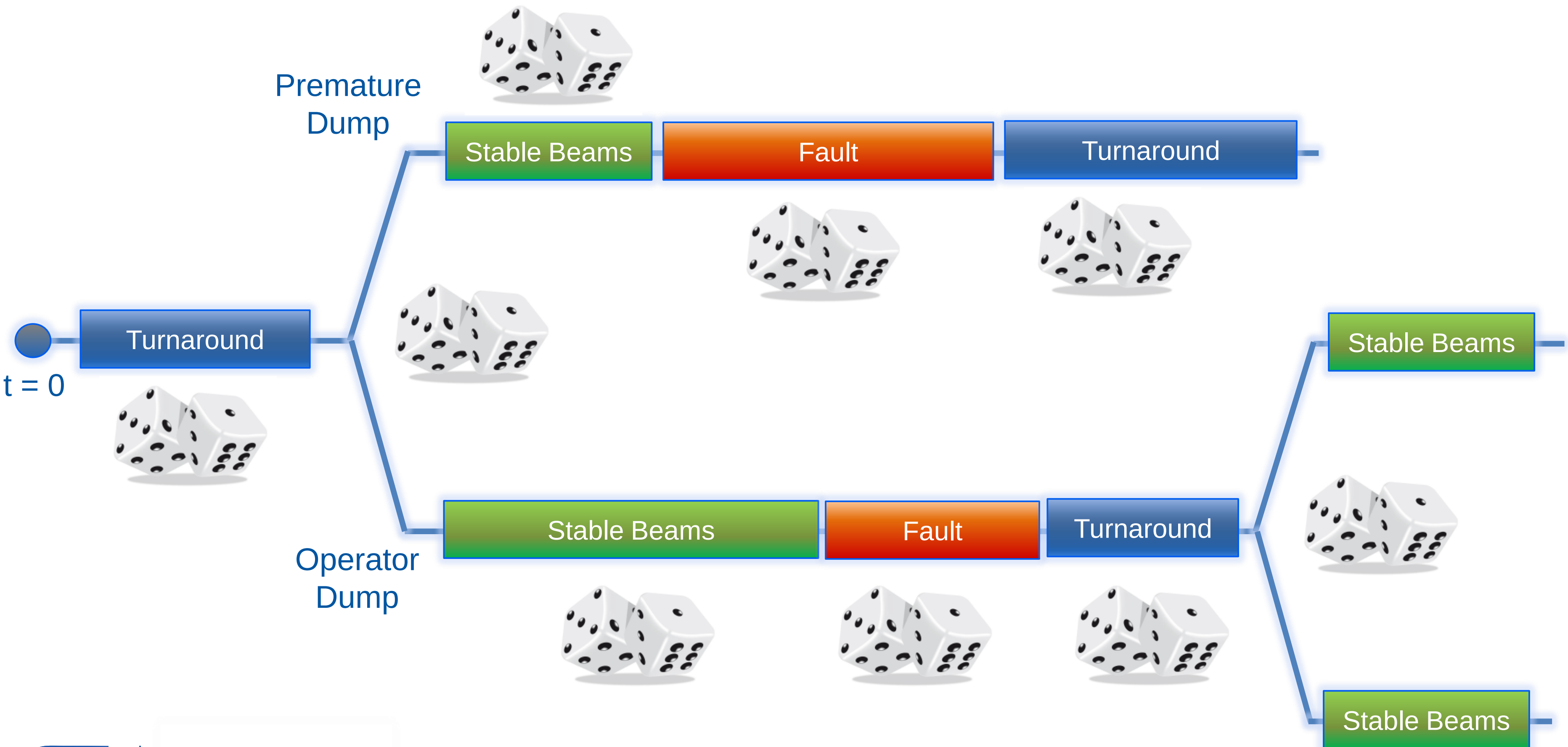
2016 Figures - Extrapolation to HL-LHC

- **Turnaround Time**
  - Increased time for energy ramps (small impact)
  - Still consider inefficiency of factor 2 time spent at injection (with 288 b / injection):
    - Faster: Increased experience and optimisation
    - Slower: Additional complexity in handling high brightness beams
  - ***Overall similar average turnaround: 4.9 h***
- **Fraction of premature dumps**: 50 %
- **Average Downtime** following premature dumps: 5.6 h

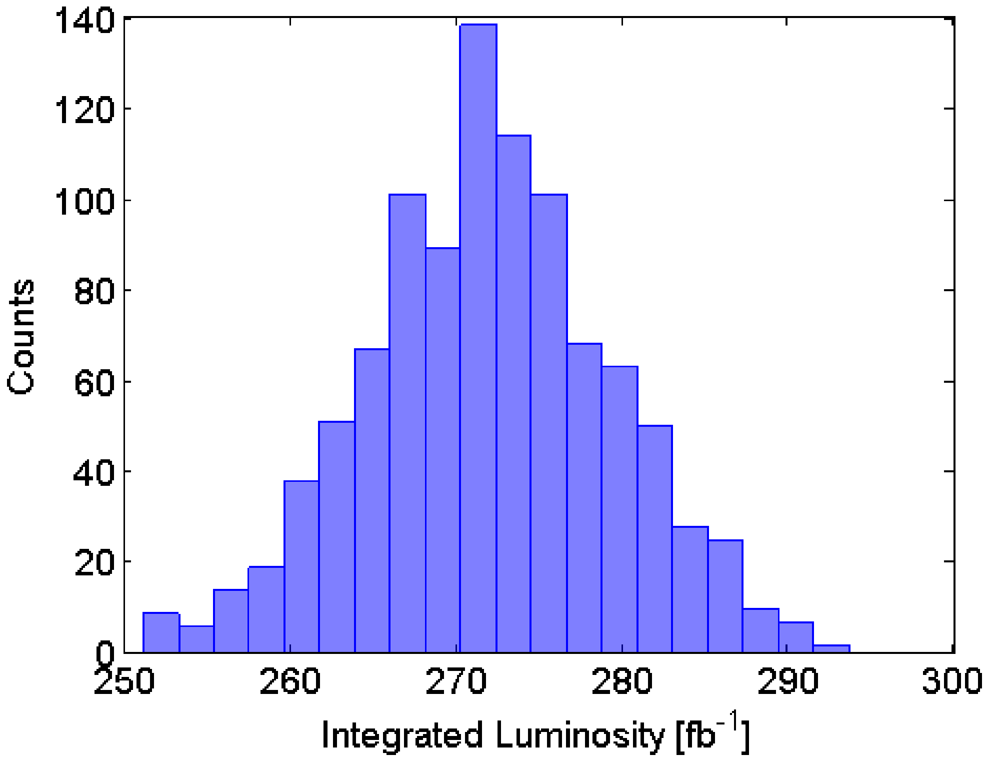
Optimal Fill Length 9.2 h

HL-LHC Luminosity Predictions

- A Monte Carlo model was developed to describe integrated luminosity production as a function of LHC availability



HL-LHC Availability and Luminosity Predictions – based on 2016 figures



Assumptions (from WP2):

- Lumi Levelling Time: ~5 h
- Lumi Lifetime (exp) after levelling: ~5 h

2016 fault and turnaround distributions

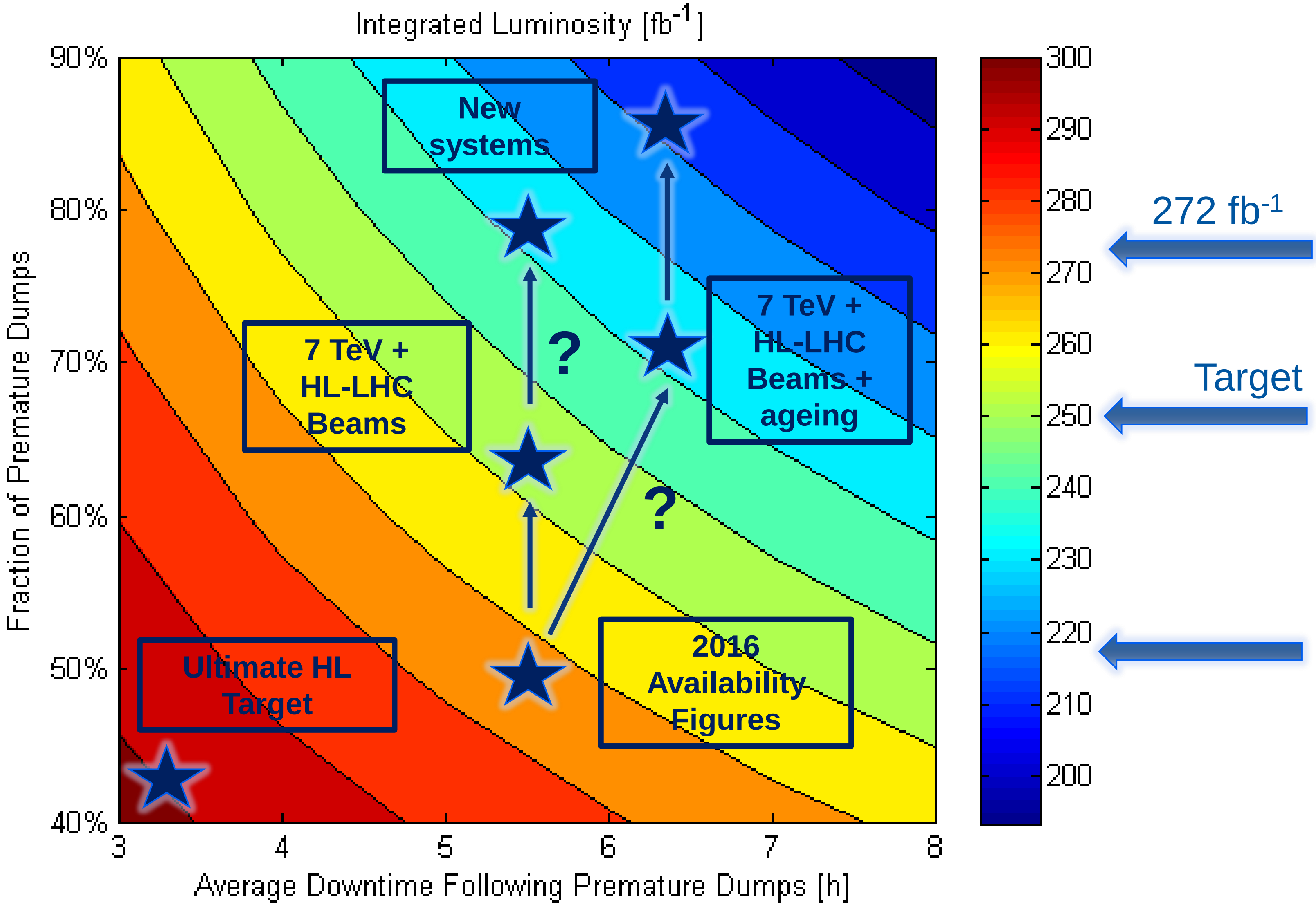
Model Output (160 days operation):

- Availability: 75 %
- Stable Beams Efficiency: 45 %
- Integrated Luminosity: 272 fb^{-1}

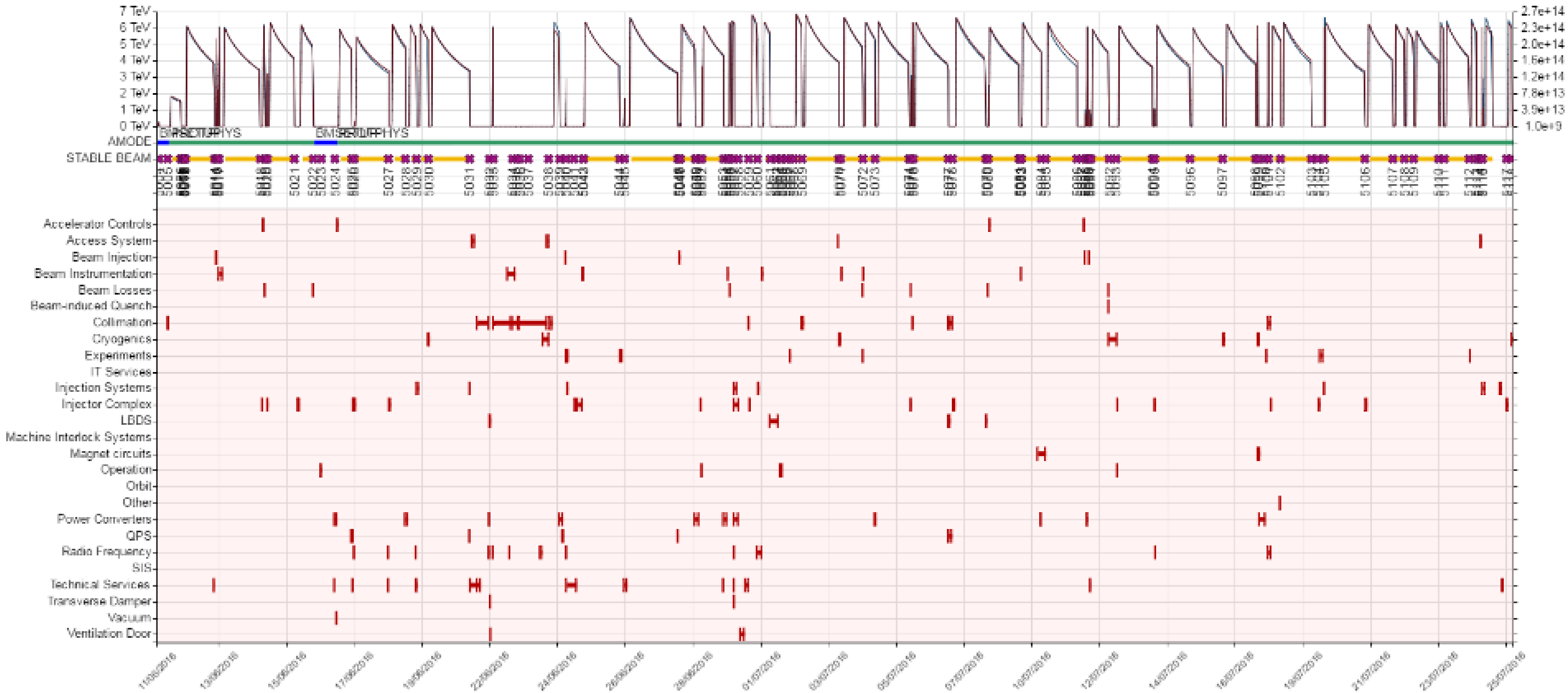
For the same equipment availability, the stable beams efficiency is lower for HL-LHC due to shorter fills: **45 % compared to 58 %**
→ higher sensitivity to turnaround time and injectors' availability

Sensitivity Analysis

M. Valette, "Crab cavities: failures and availability studies" on 15/11



Fault Tracking Activities towards HL-LHC



- Important: tracking faults, their dependencies and impact on operation
- Exploitation of **Accelerator Fault Tracker** (AFT)
- The IEFC endorsed the implementation of AFT in the injectors in 2017

Outlook

- Assess availability of **new HL-LHC systems**
  - Identify weaknesses during the design phase
  - Schedule dedicated tests and reliability runs (e.g. Linac4)
- Identify **availability bottlenecks** of the present LHC and injectors
  - Prioritize consolidations based on impact on availability
  - Monitor failure trends to anticipate systems' "end-of-life" (ageing)
- Optimize time allocated for **physics production**
  - Schedule 2016: 233 days (excluding ions)
  - 10 % HW commissioning (24 days), 14 % Beam recommissioning (33 days), 9 % MDs (20 days), **67 % p-p Physics (156 days)**
  - 3 technical stops + 1 Christmas shutdown
  - Balance, need to keep the machine 'safe': if you break it downtime rockets up

Conclusions

- Excellent LHC availability in 2016 (effectiveness of LS1 + YETS mitigations, increased experience with the machine, not pushing intensity limits)

- Extrapolation to HL-LHC has to account for
  - Increased energy and higher beam brightness
  - Impact of new systems and failure modes: important to carry out availability studies and reliability runs
  - Ageing of equipment

- Based on 2016 TS1-TS2 availability figures, the yearly HL-LHC target (250 fb^{-1}) is in reach

- Optimization of accelerator schedules to increase the number of days for physics production can have a very significant effect

- Exploit potential of AFT tool for availability tracking of individual systems to aim for improvement

Thanks a lot for your attention!

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