Machine Plans through HL-LHC Goals & Status

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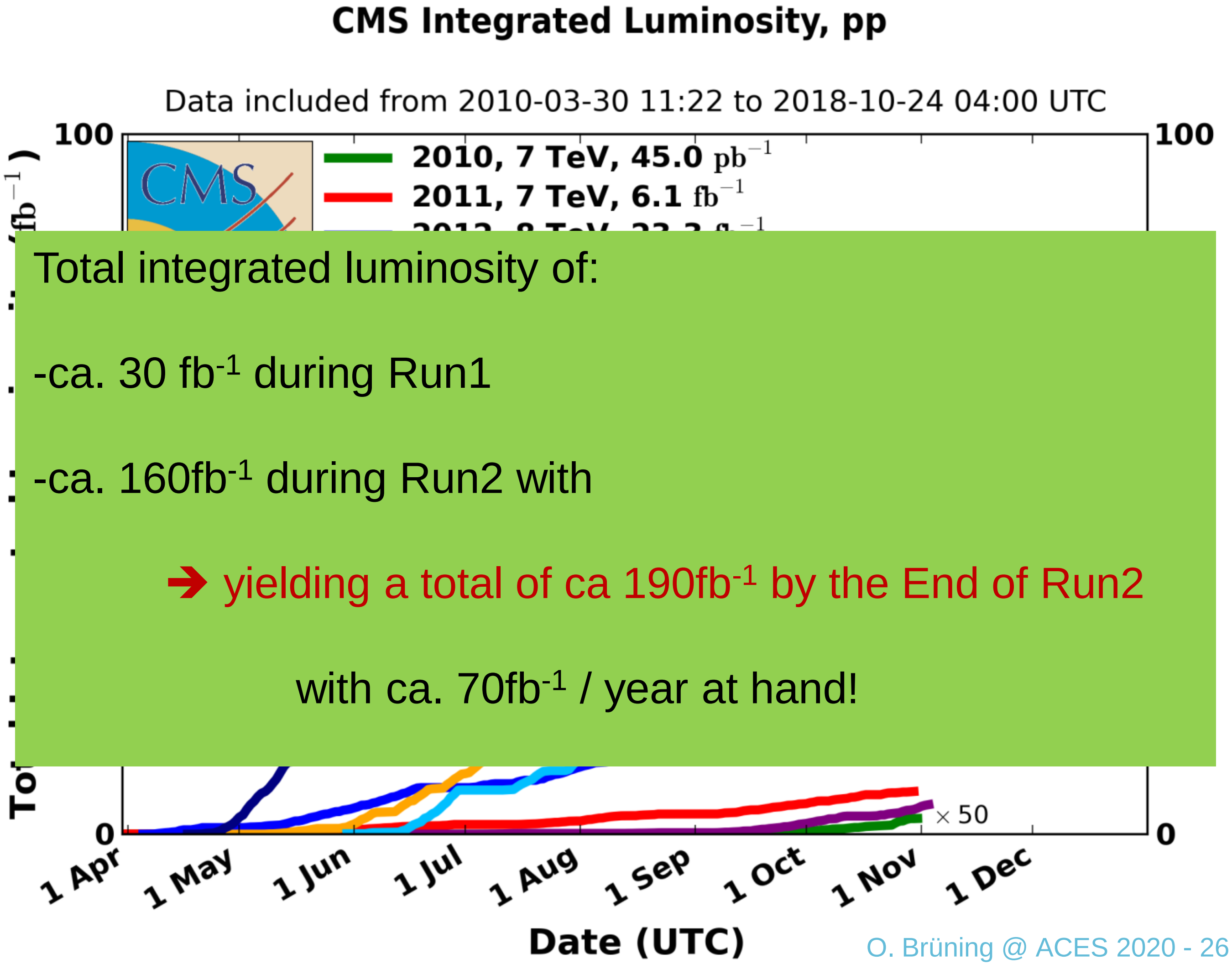
With input from G. Arduini; M. Lamont; L. Rossi; R. Tomas

ACES Meeting, 26 May 2020



Total integrated luminosity of:

-ca. 30 fb^{-1} during Run1

-ca. 160fb^{-1} during Run2 with

➔ yielding a total of ca 190fb^{-1} by the End of Run2

with ca. 70fb^{-1} / year at hand!

LHC Beam Energy

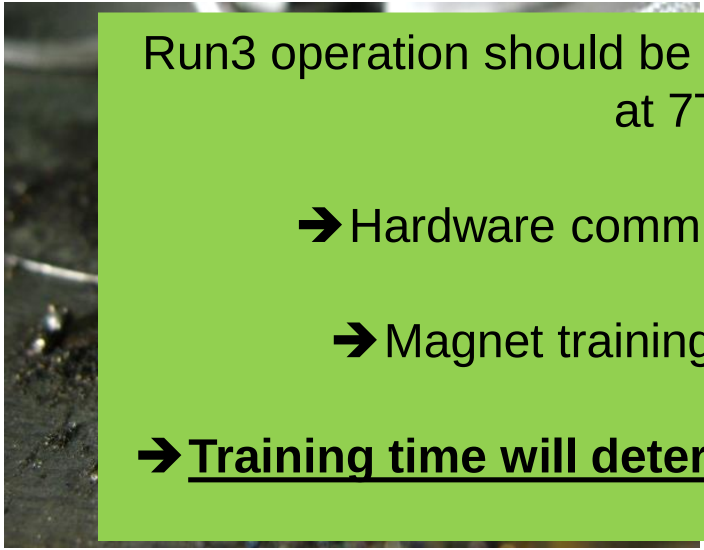
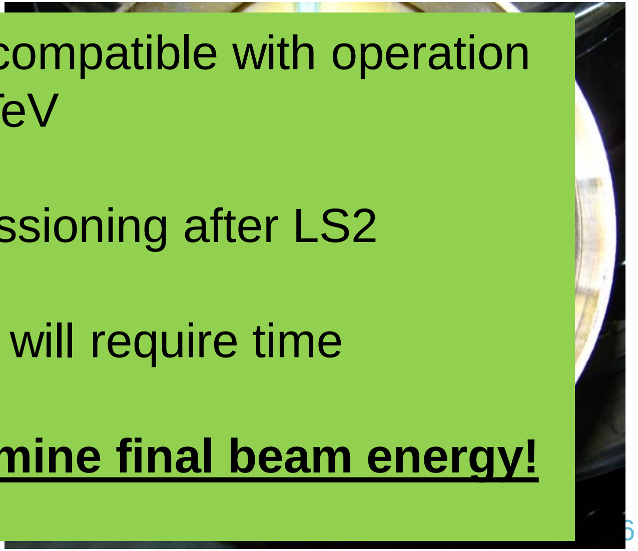
Unforeseen Obstacles:

Short in the magnet diode box following a training quench:

Risk Assessment:

➔ Systematic cleaning and insulation of the diode box

➔ Decision for Intervention during LS2 and to stay at 6.5TeV for Run2

Run3 operation should be compatible with operation at 7TeV

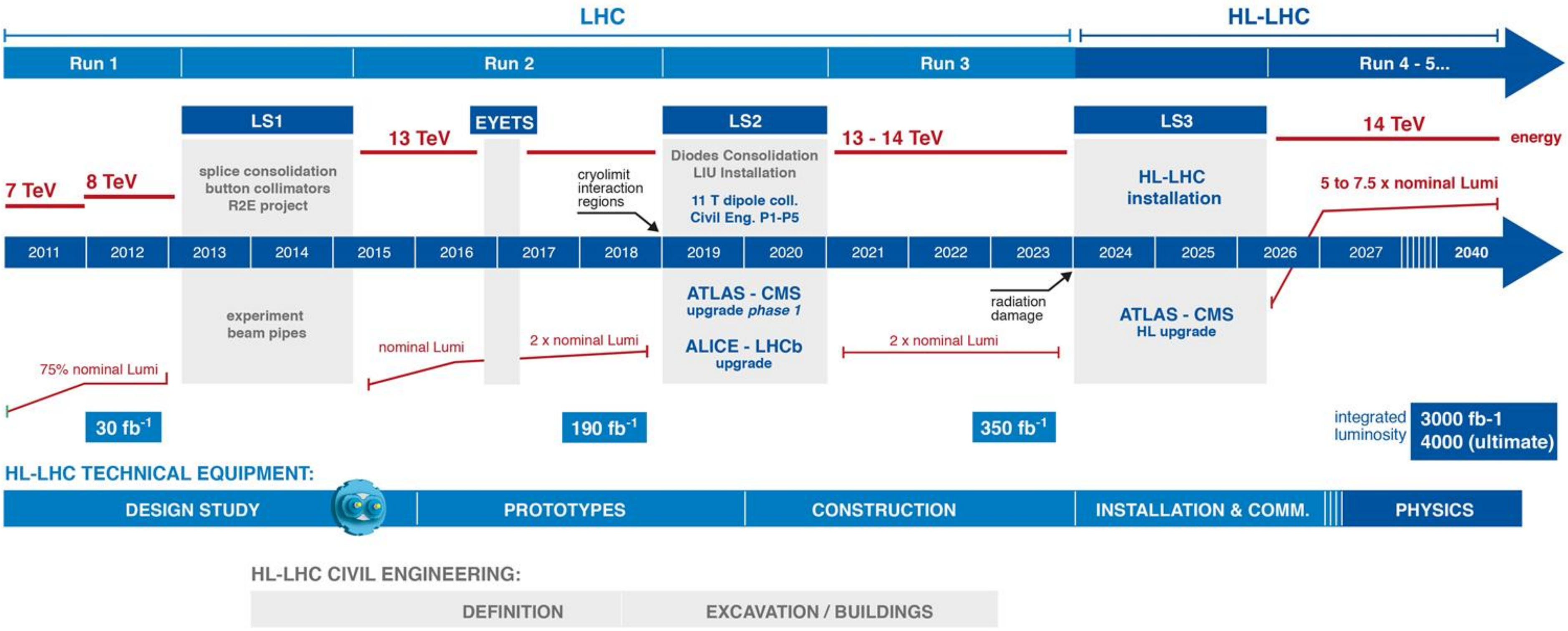
➔ Hardware commissioning after LS2

➔ Magnet training will require time

➔ **Training time will determine final beam energy!**

LHC / HL-LHC Plan

Before November 2019 retreat



Total integrated luminosity:

➔ 70fb^{-1} / year with 3+ years of operation could give 210fb^{-1} during Run3

➔ LHC reach between 350fb^{-1} and 400fb^{-1}

➔ Luminosity goal for Run3 will be revised in June 2020

Beam Energy during Run3:

➔ all hardware will be trained towards 7TeV; Decide on the final beam energy after the magnet training at the end of the extended LS2!

➔ Training time versus time for physics in 2021

LS2 extended by 2 months (+2?); 2 EYETS ?; LS3 starts now in 2025
Final length of LS2 and long EYETS 2022-23 to be decided in due course
However HL-LHC keeps the construction schedule unchanged to keep the momentum!
➔ Covid-19 impact still to be fully evaluated [Run3 start and HL-LHC production]!

Technical bottleneck:
Radiation damage to triplet magnets at 300 fb^{-1}

ore
ion
Gy

➔ New schedule gives a potential performance reach of 400fb^{-1}, which implies 33% more radiation

➔ Over 35MGy @ Q2 and 45MGy @ Cold Bore!!

➔ Risk versus performance reach!

Risk mitigation: change of crossing plane and variation of crossing angle

➔ Replace the triplet with a new system that is more radiation hard for HL-LHC!!!

3X3
MGy

HiLumi HL-LHC PROJECT

Goal of High Luminosity LHC (HL-LHC):

The main objective of HiLumi LHC Design Study is to determine a hardware configuration and a set of beam parameters that will allow the LHC to reach the following targets:

Prepare machine for operation beyond 2025 and up to late **2030ies early 2040ies**

Devise beam parameters and operation scenarios for:

enabling at total integrated luminosity of **3000 fb^{-1}**

implying an integrated luminosity of **250 fb^{-1} per year**,

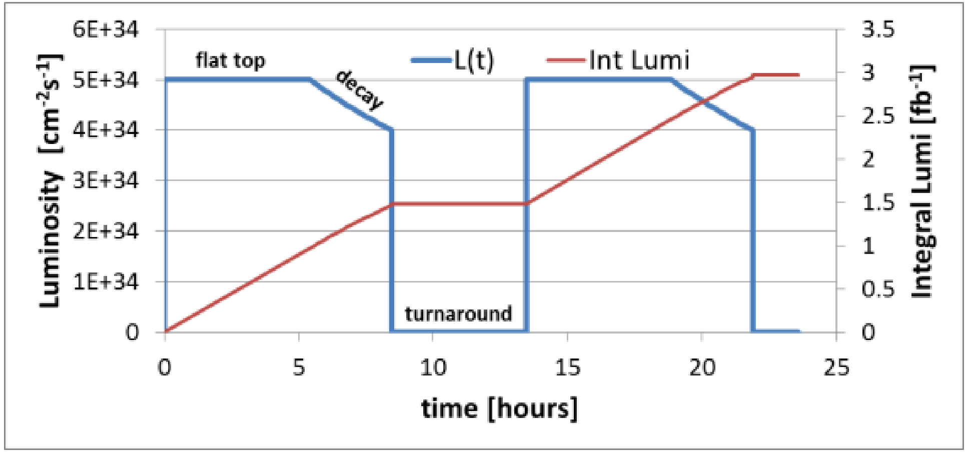
design oper. for μ δ **140** (➔ peak luminosity **5 10^{34} cm^{-2} s^{-1}**)

'ultimate' ➔ μ δ **200** (➔ peak luminosity **7.5 10^{34} cm^{-2} s^{-1}**)

➔ Operation with levelled luminosity; high Efficiency and New Technologies!

Luminosity optimization:

- Luminosity Levelling at the luminosity frontier:
  Design for highest possible virtual luminosity, but keep the luminosity artificially lower during operation!!
  This helps to cope with the total number of events per time interval and the event pileup in the detector!



HL-LHC Virtual Luminosity:
Ca. 17 $10^{34}cm^{-2}s^{-1}$

➔ ca. 3 times the operational levelled value

- Lifetime proportional to total particles: $\tau_{eff} = \frac{N_{tot}}{n_{IP} \cdot \sigma_{tot} \cdot L_{leveled}}$

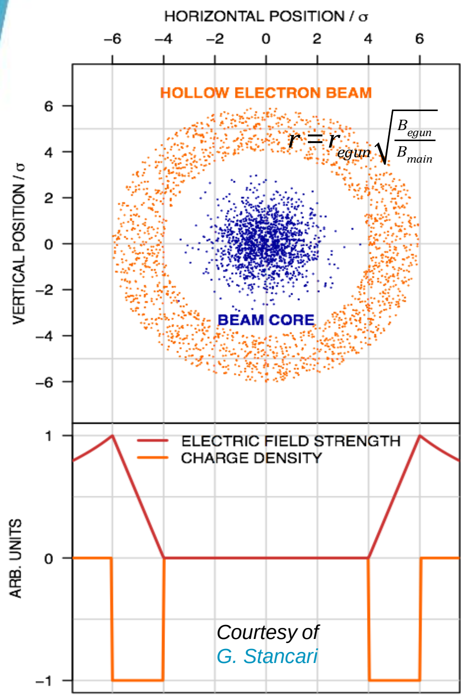
➔ **maximize proton intensity & machine efficiency!**

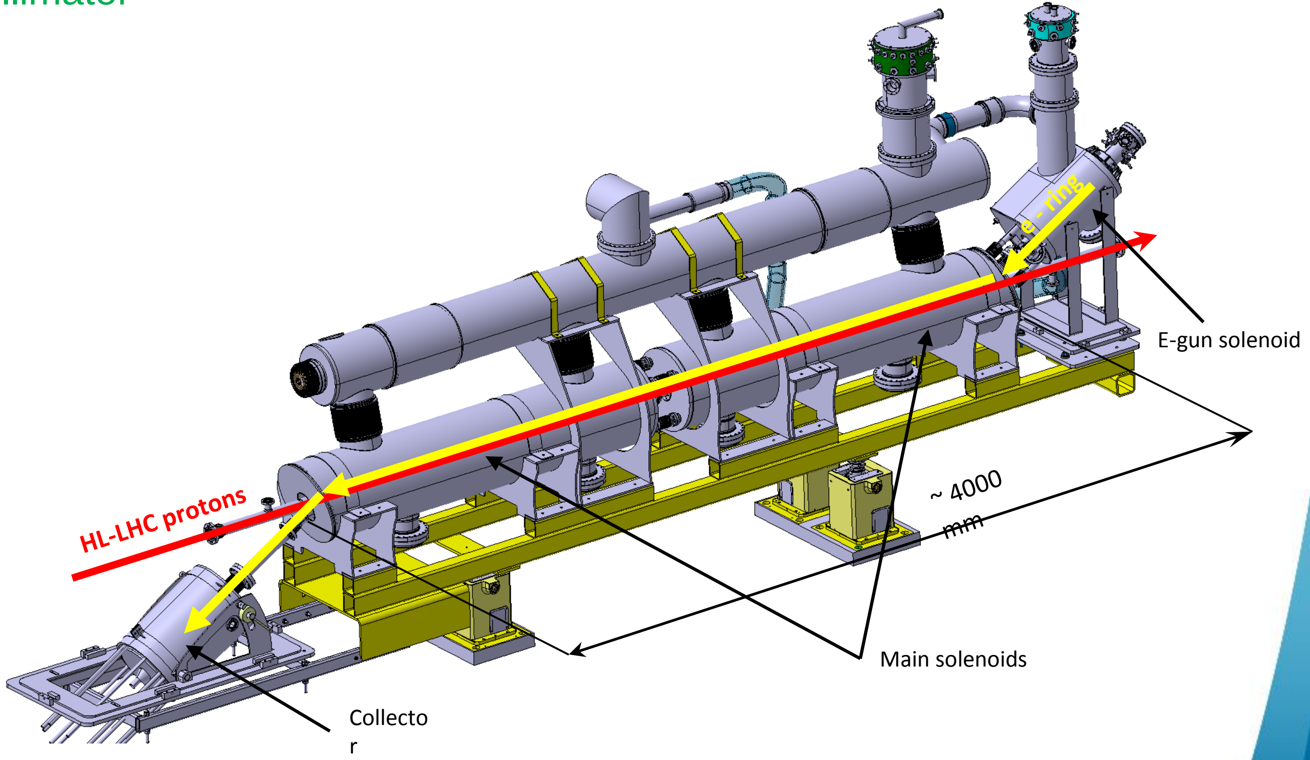
➔ > 30MJ of beam power in beam halo > 3.5σ

Hollow Electron Lens:

Halo depletion by Diffusion enhancement of Halo particles:

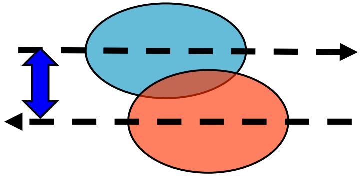
An indestructible collimator



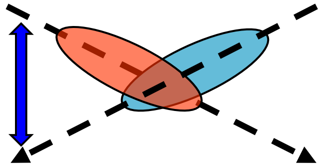


Luminosity Levelling

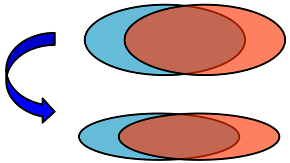
- In the LHC we have essentially 3 different levelling options
- Each levelling technique has its advantages and drawbacks



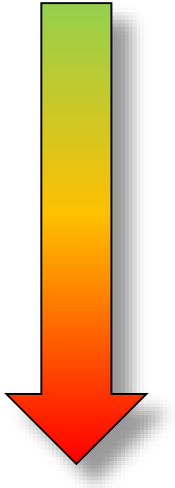
Levelling by beam offset / separation



Levelling by crossing angle

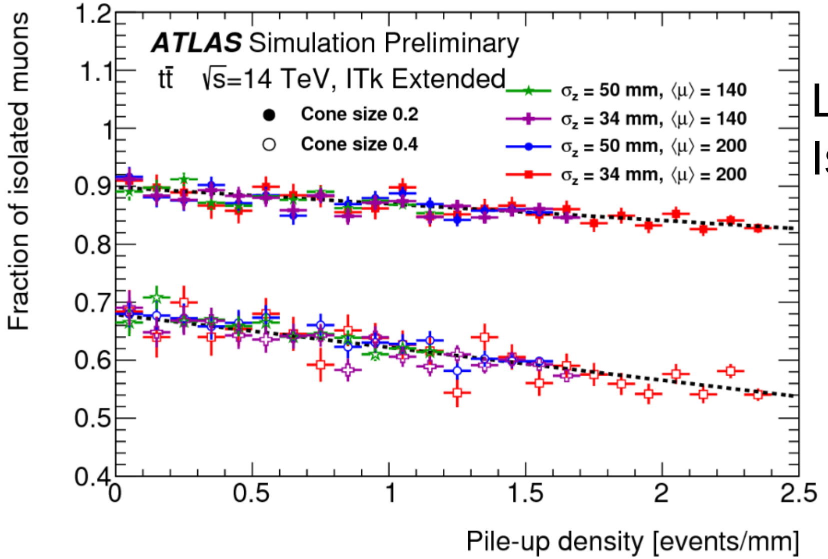


Levelling by β^* (= beam size at IP)



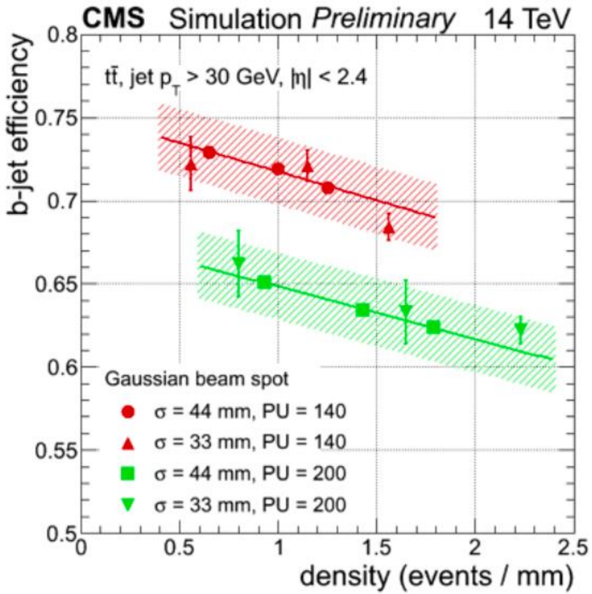
Pileup Density

Experimental Data Quality WG



Lepton Isolation

B-tag efficiency

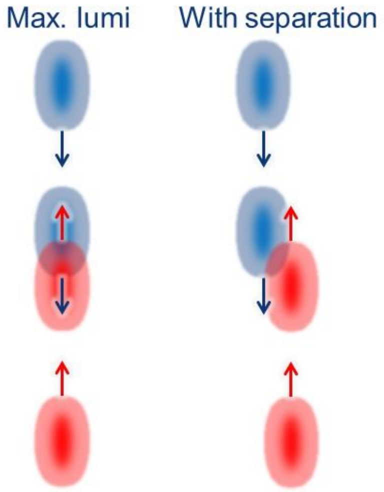


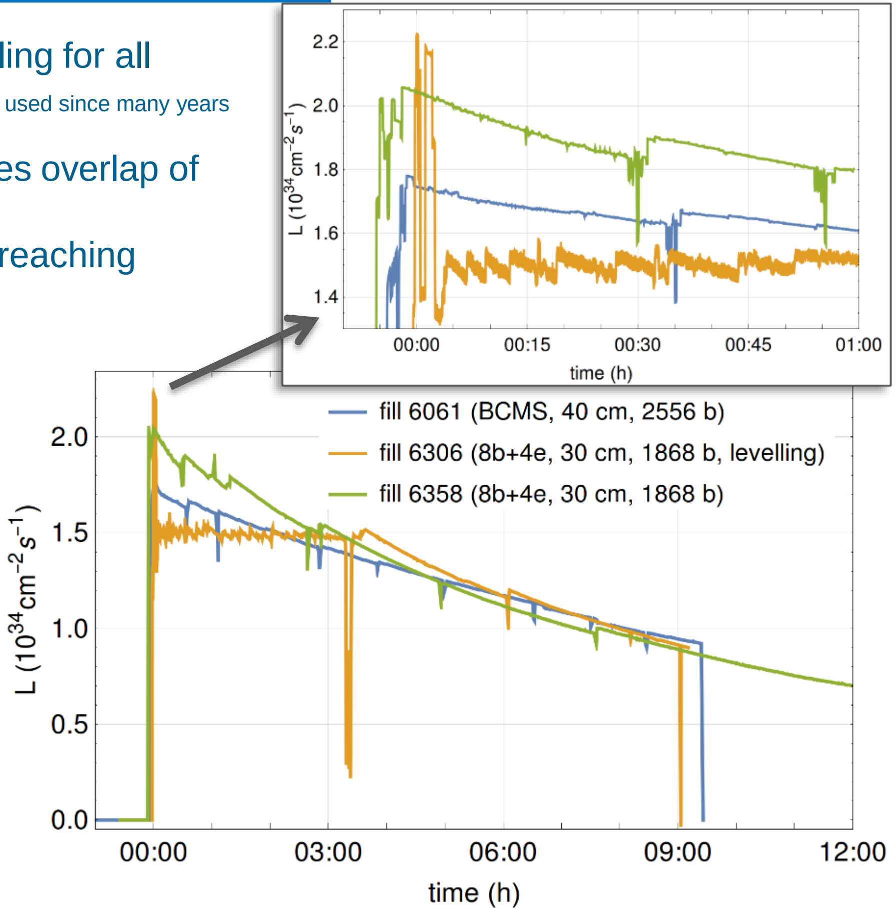
Pile-up density deteriorates signals in a linear fashion

➔ Effective density is the average

LHC 2017 : separation levelling

- Introduced separation levelling for all experiments (Separation levelling is used since many years for ALICE and LHCb)
- Dynamic orbit bump changes overlap of colliding bunches
- Initial spike before leveling reaching $2.2\times10^{34}\ cm^{-2}s^{-1}$

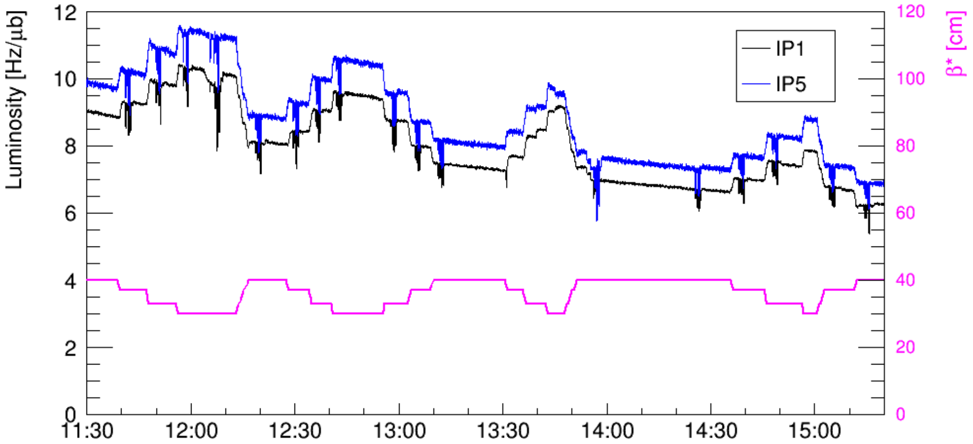




MDs on β* levelling

Levelling luminosity by β* should be the main levelling technique for HL-LHC

β* levelling in **LHC**: already used in 2018 operation



Luminosity evolution during β levelling, moving back and forth between 30 cm and 40 cm. The beams remained head-on* ***within ~ 2 μm*** *!*

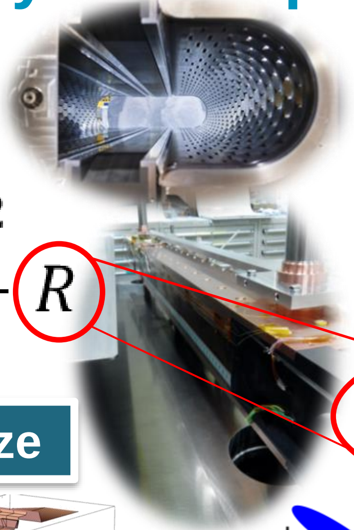
Luminosity: which parameters count for LHC?

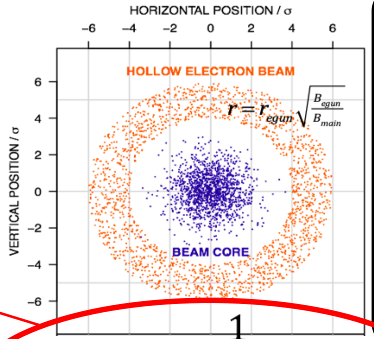
Beam current

$$L = \gamma \frac{f_{rev}\, n_b\, N_b^{2}}{4\pi \varepsilon_n \beta^*} R$$

energy

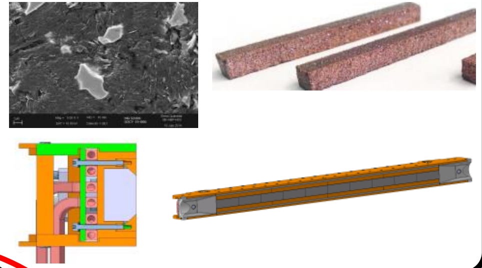
Beam size

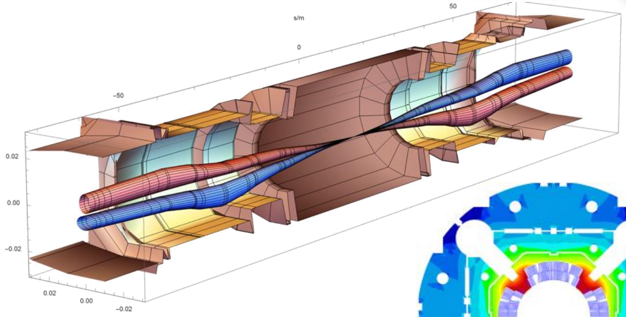


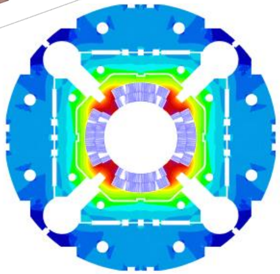


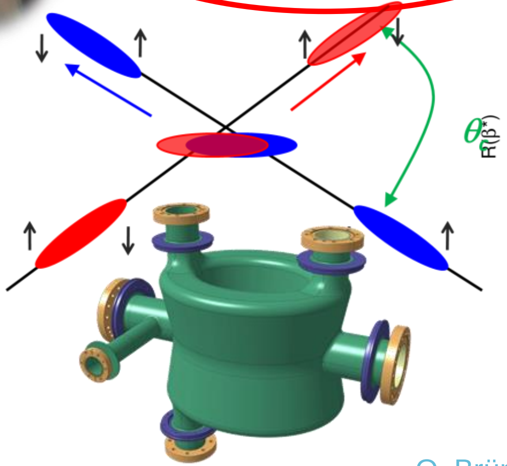
$$R = \frac{1}{\sqrt{1 + \left(\frac{\theta_c \sigma_s}{2\varepsilon_n \beta^*}\gamma\right)^2}}$$

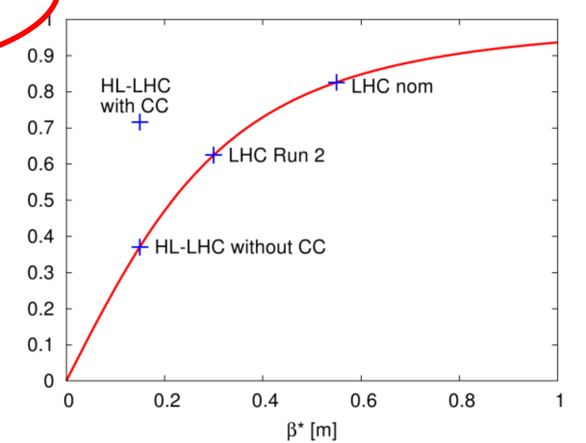
Low-impedance, high robustness secondary collimators







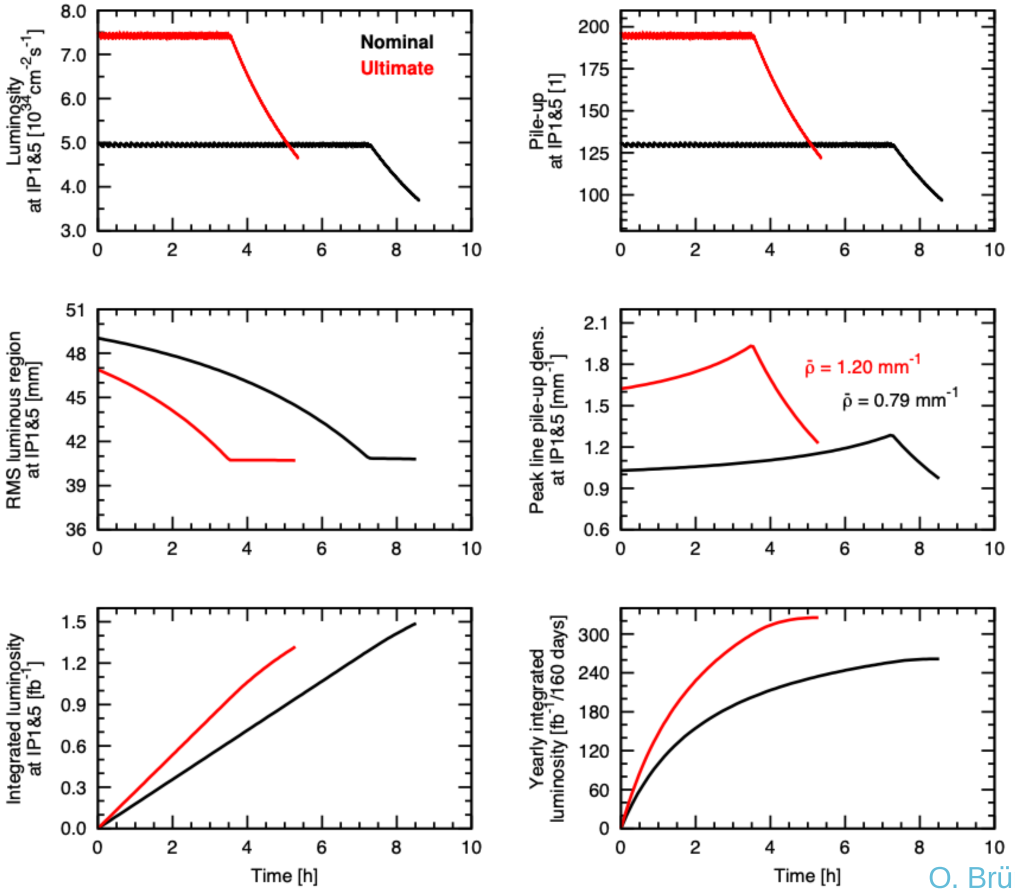




Baseline Parameters and Goals

- Baseline: 250fb^{-1}/year to reach 3000fb^{-1}
  - Levelled luminosity of 5 10^{34}cm^{-2}s^{-1}; levelling via β^*
  - Pileup of ca 140
  - **Machine efficiency of 50% !!!**
- Ultimate: 320fb^{-1}/year to reach 4000fb^{-1}
  - Levelled luminosity of 7.5 10^{34}cm^{-2}s^{-1}; levelling via β^*
  - Pileup of ca 200
  - Machine efficiency of 50%; no engineering margins left!
- Ultimate beam energy: 7.5TeV per beam
  - Loss in integrated luminosity between 10% and 30%

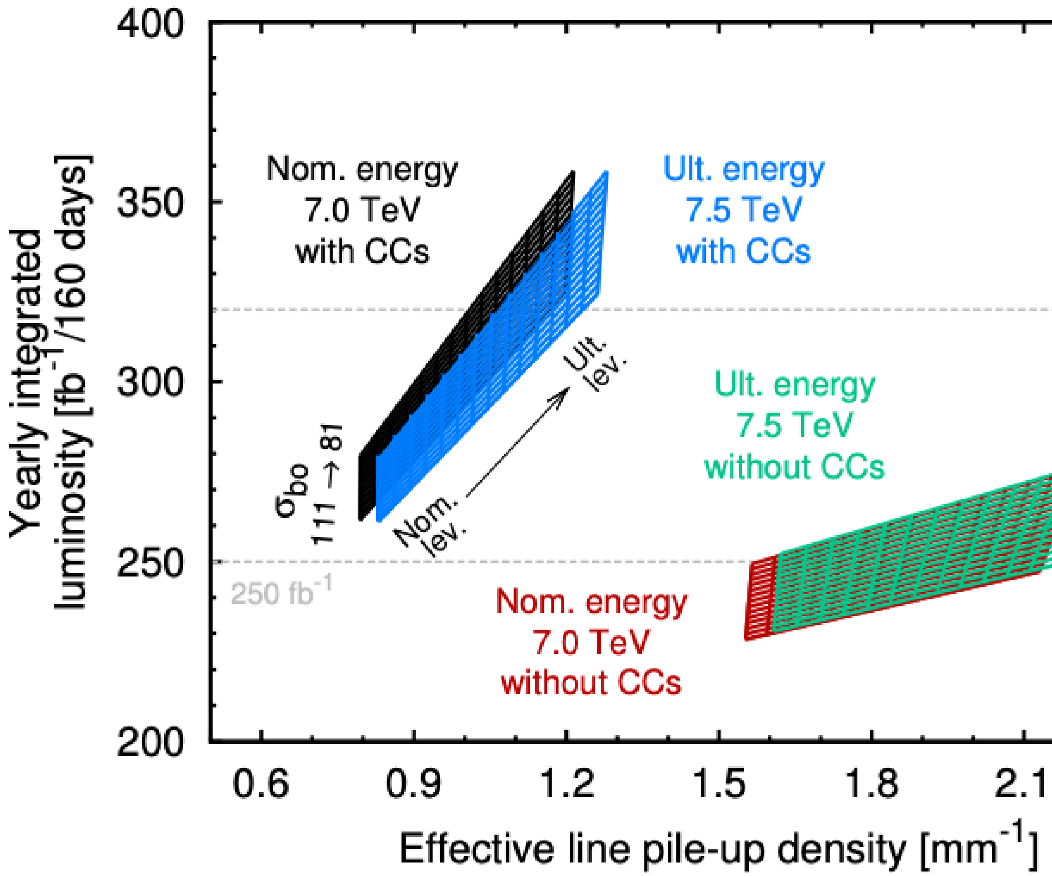
Luminosity and Pileup evolution during fill



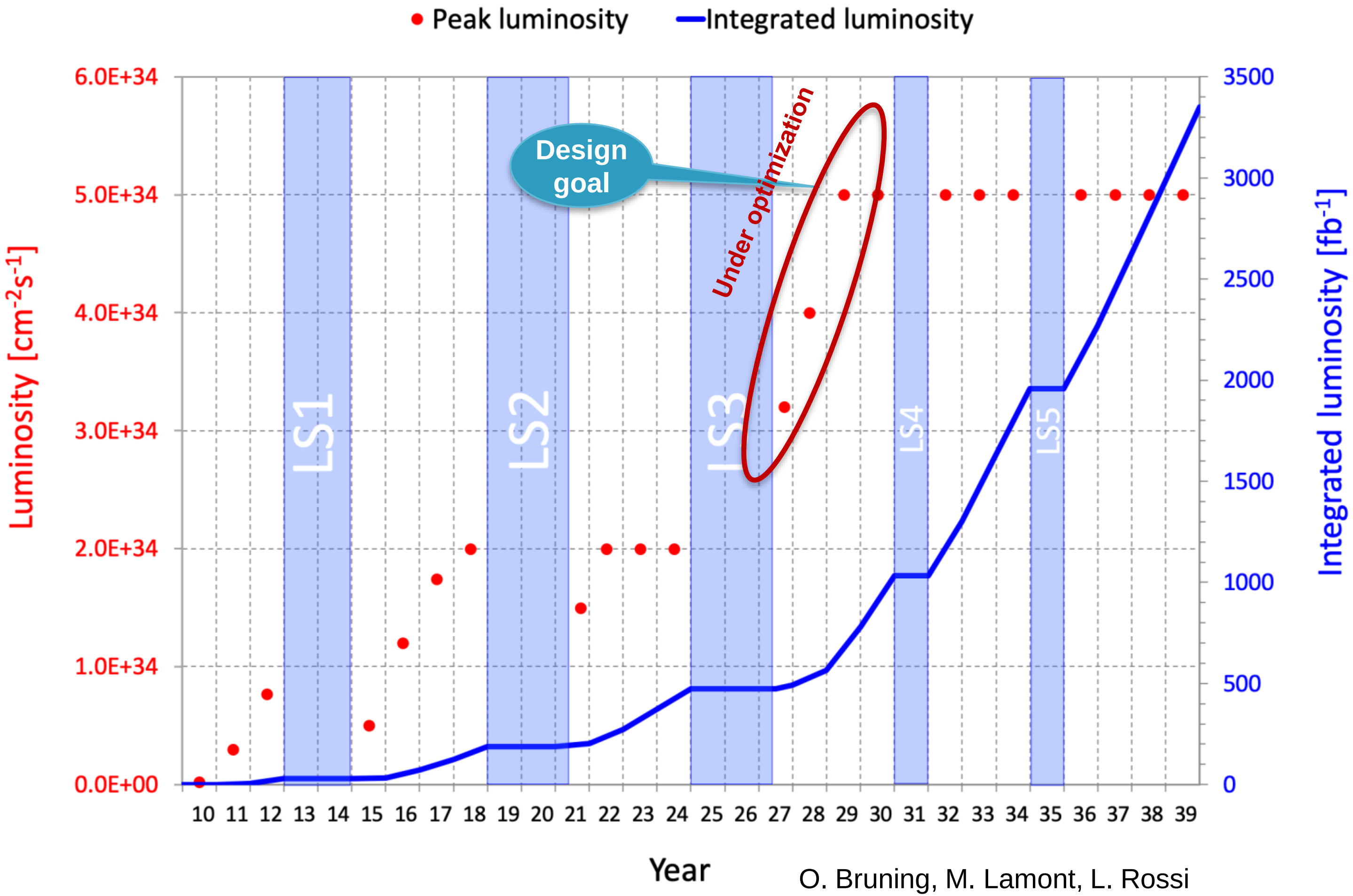
R. Tomas @ ACES'18

Performance Reach versus Pileup density

R. Tomas @ ACES'18



HL-LHC performance



O. Bruning, M. Lamont, L. Rossi

Performance Ramp-up During Run4

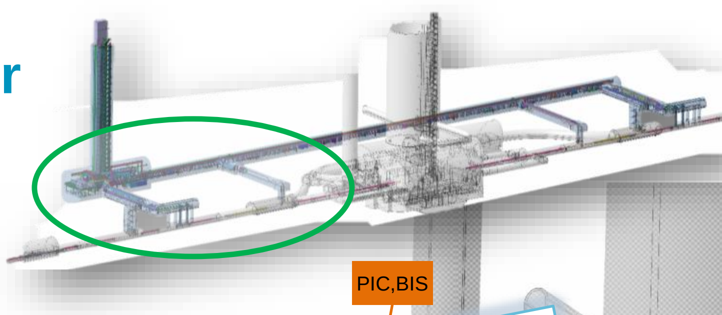
- Year 1 - Re-establishing Run3 performance:
  N_b = 1.6 / 1.7 10^{11}; β^* = 30cm; CC off and HEL commissioning ➔ L < 3 $10^{34}cm^{-2}s^{-1}$
  3 month intensity ramp-up without encountering hard limits [e.g. UFO's etc]
  Full year of operation ➔160 days after training to 7TeV; 40% ➔ up to 100fb^{-1}/year

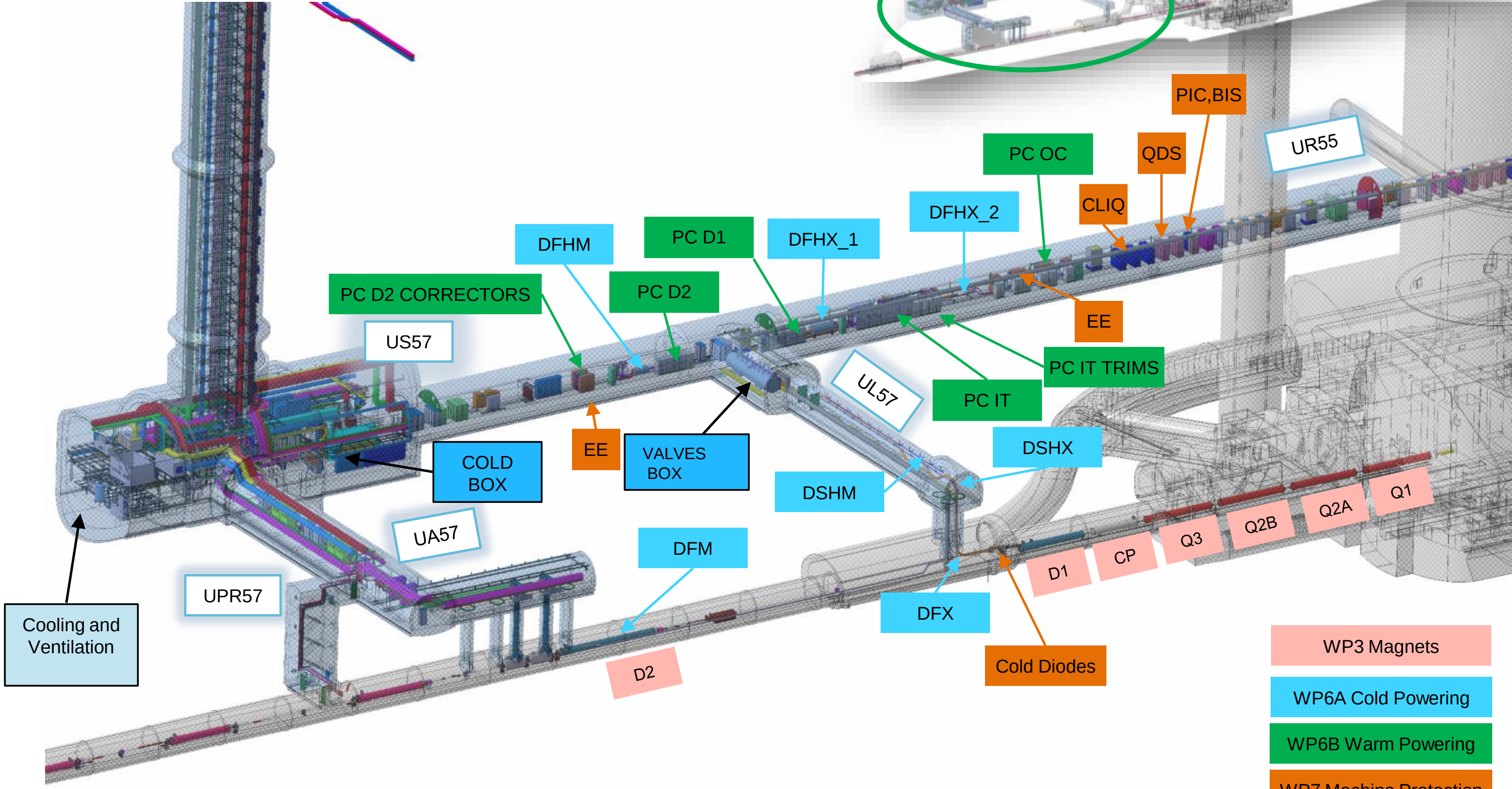
- Year 2 - Establish full HL-LHC bunch population:
  N_b = 2.2 10^{11}; β^* = 25cm; CC commissioning and HEL on ➔ L_{virt} < 6 $10^{34}cm^{-2}s^{-1}$
  Operation with levelling ➔ ca. 200fb^{-1} / year

- Year 3 - push performance
  N_b = 2.2 10^{11}; β^* = 20cm; CC and HEL on ➔ L_{virt} < 15 $10^{34}cm^{-2}s^{-1}$
  Operation with levelling; 50% ➔ ca. 250fb^{-1} / year

Challenges: cryogenic heat load in triplet, CC operation, halo diagnostics, high beam intensity, emittance preservation

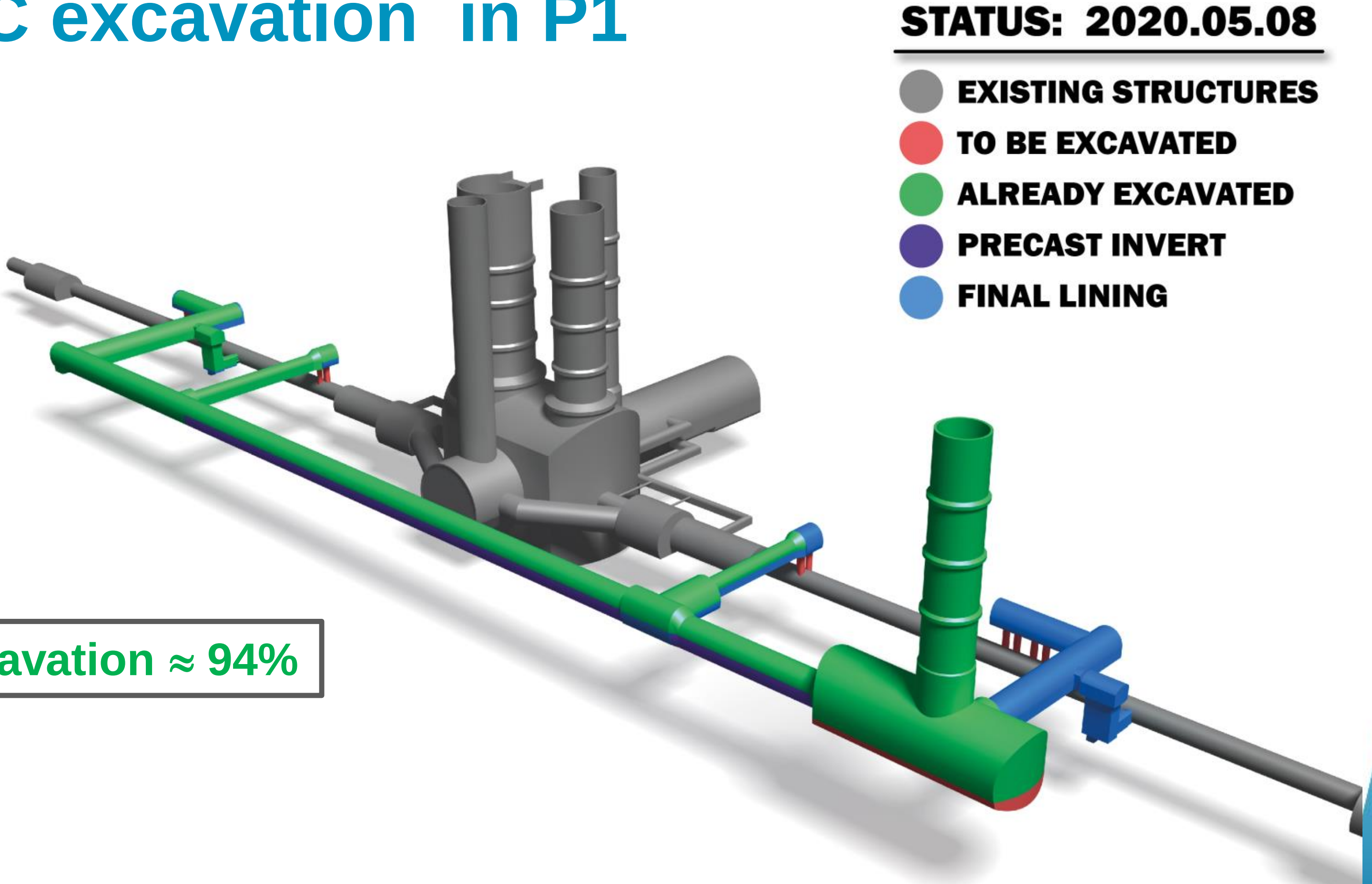
R2E and new underground Installations for Maintainability and High Efficiency



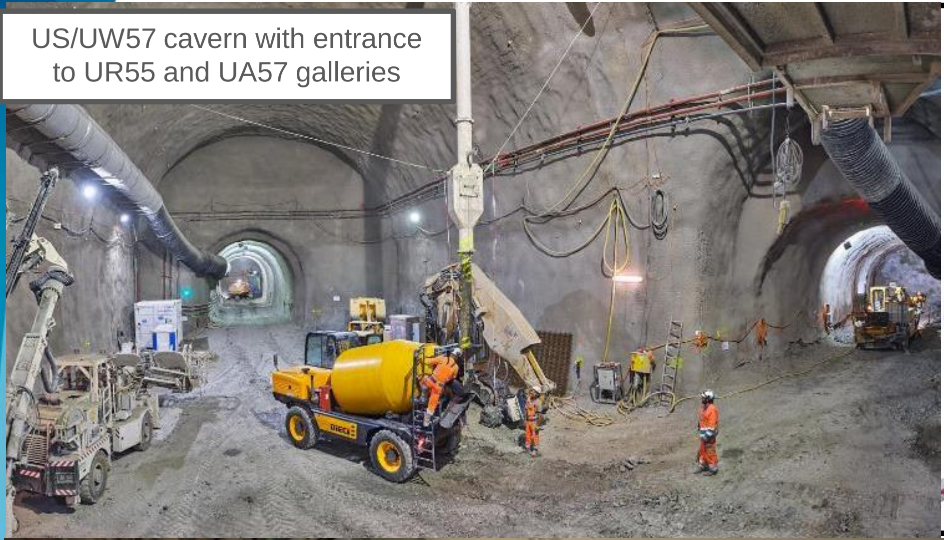


M. Modena on "Circuits Integration" at 2019 "International Review of HL-LHC Magnet Circuits"

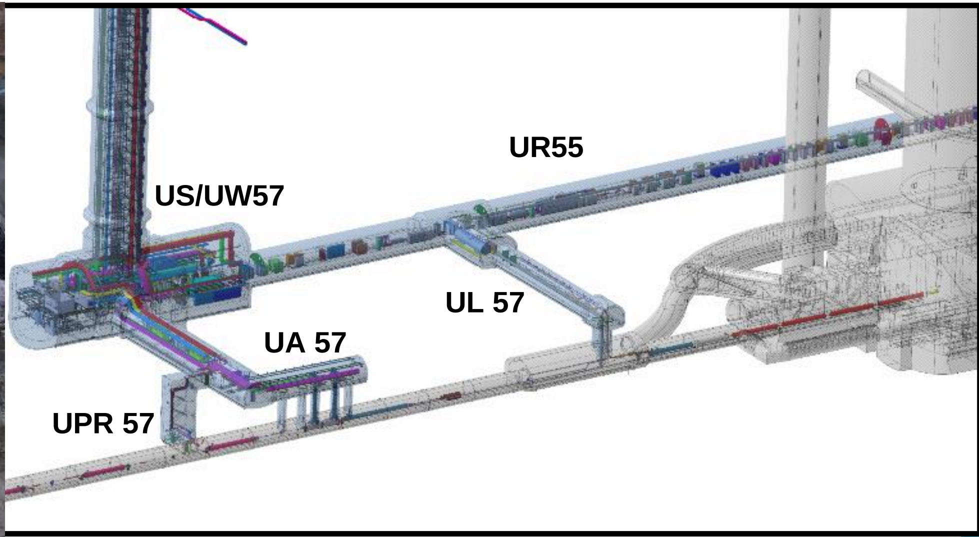
HL-LHC excavation in P1



Overall excavation ≈ 94%

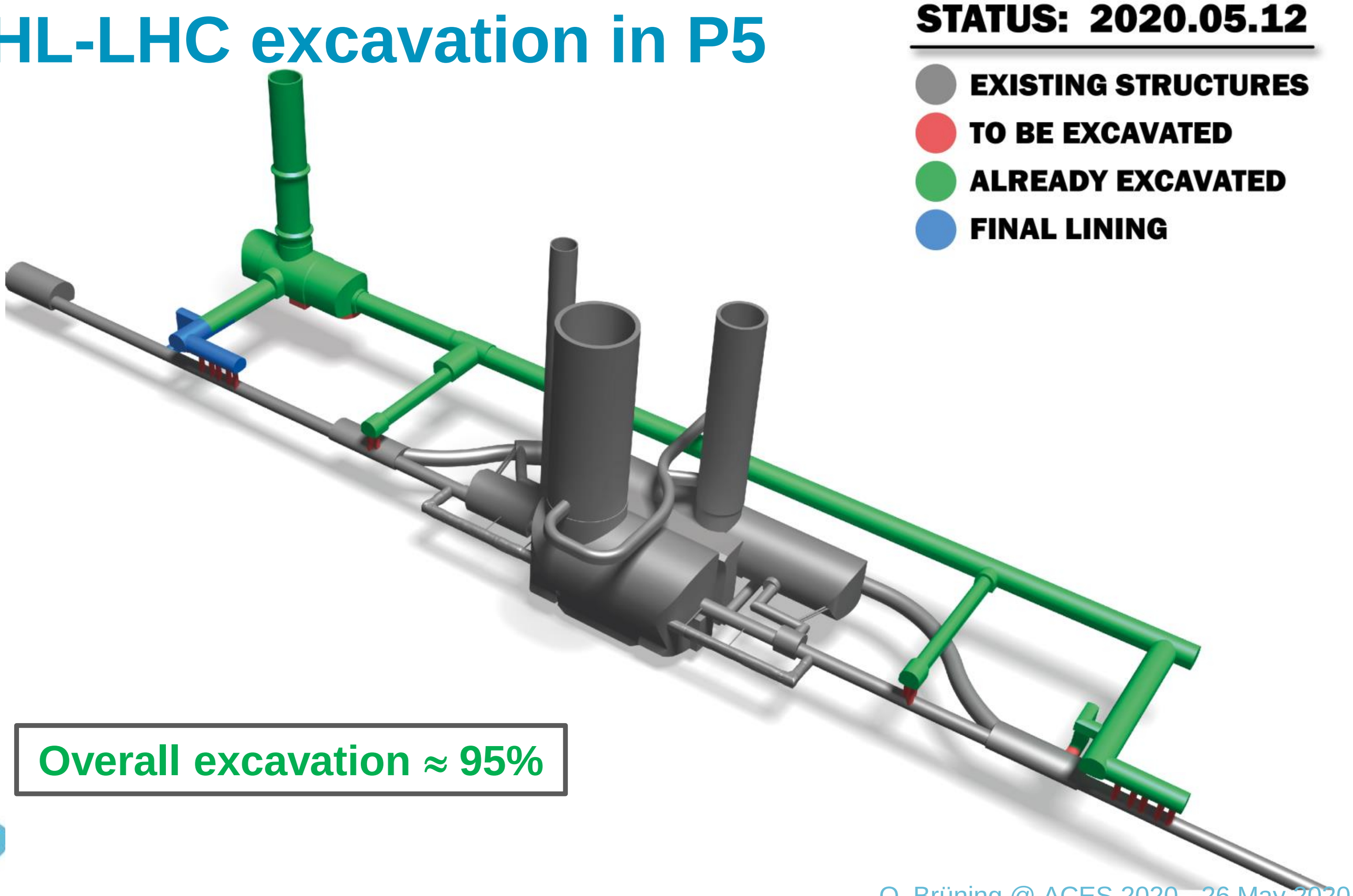


US/UW57 cavern with entrance to UR55 and UA57 galleries



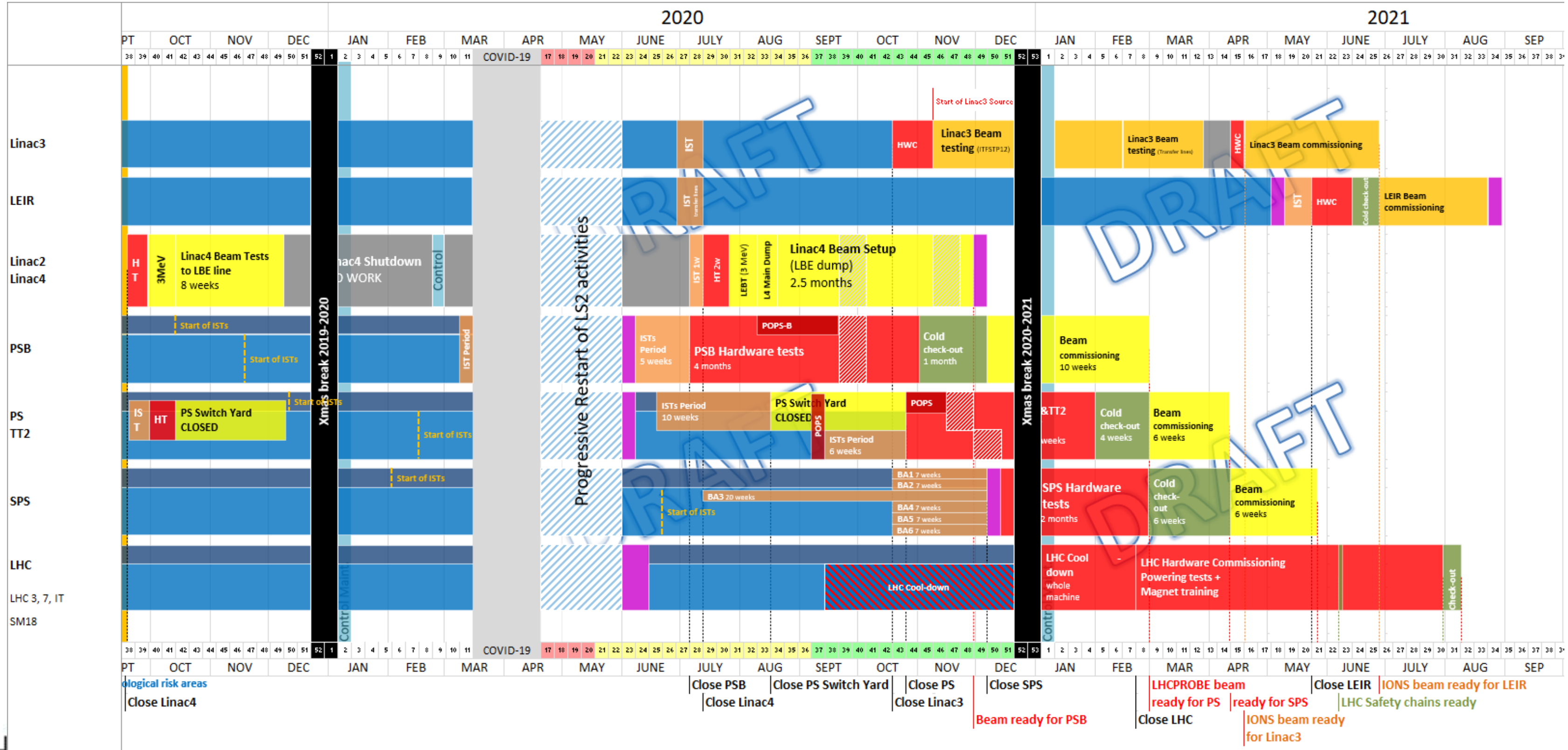
HL-LHC excavation in P1

HL-LHC excavation in P5



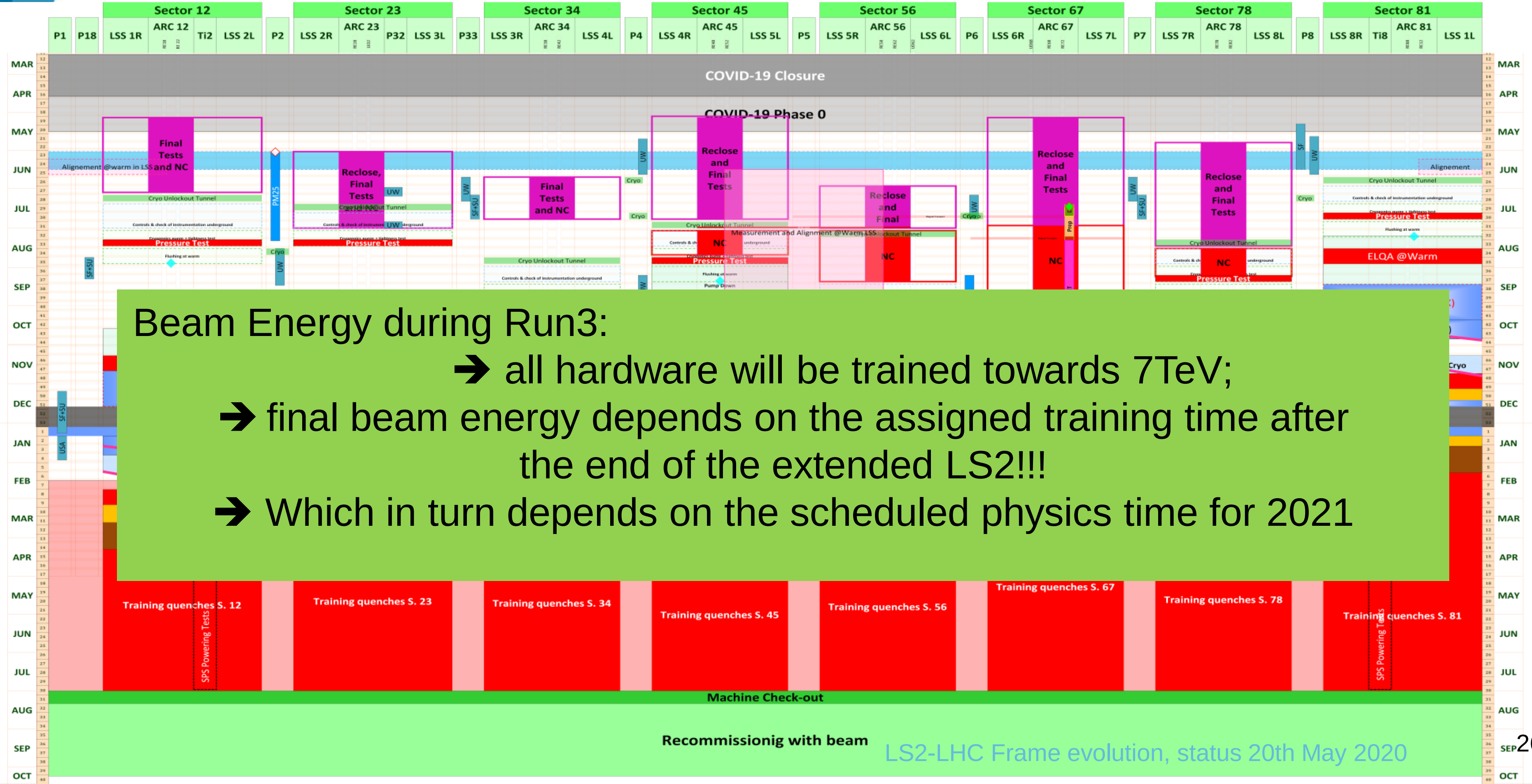
Overall excavation ≈ 95%

LS2 Master schedule *INWORK* EDMS ACC-PM-MS-0002 v.2.6



HL-LHC PROJECT

LHC LS2 Baseline V2.4 FRAME *INWORK* LHC-PM-MS-0018 v.2.4



Beam Energy during Run3:

➔ all hardware will be trained towards 7TeV;

➔ final beam energy depends on the assigned training time after the end of the extended LS2!!!

➔ Which in turn depends on the scheduled physics time for 2021

End