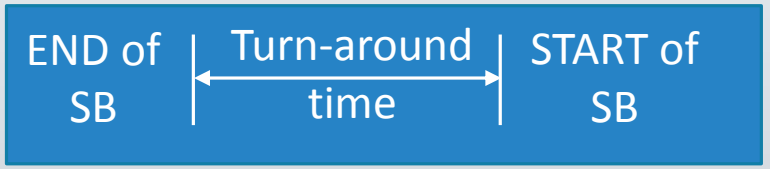
FCC-hh turn-around cycle



SB: Stable Beams

A. APOLLONIO (TE-MPE), W. BARTMANN (TE-ABT),

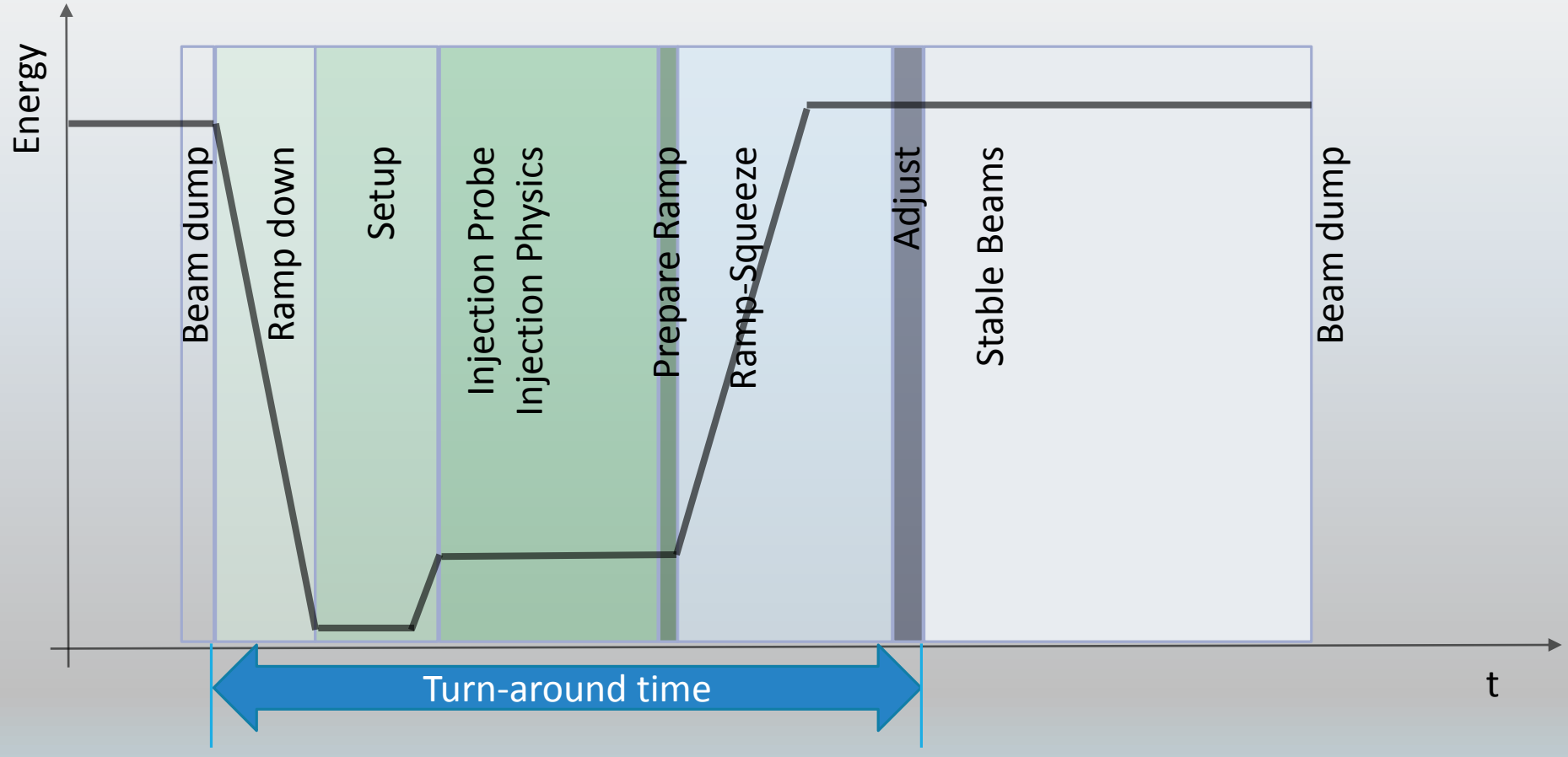
X. BUFFAT (BE-ABP), A. NIEMI (BE-ICS),

D. SCHULTE (BE-ABP), M. SOLFAROLI (BE-OP),

L. S. STOEL (TE-ABT), R. ALEMANY (BE-OP)

Acknowledgment: D. Jacquet (BE-OP)

FCC-hh operational cycle (= LHC)



Injection phase in FCC

Ref: "Hadron Injectors, Injection and TLs", **L. Stoel**, FCC Week Rome 2016

Opt	LINAC 4	PSB	PS	SPS	LHC	100 km HEB	FCCinj	Tinj (min)
	Flattop beam energy (GeV)							
LHC x5	0.160	2	26	450	3300		3300	40
			72 b	9 PS->SPS = 648b	2x4 SPS->LHC = 2592 b/ring		4 LHC->FCC = 10368 b/ring	
HEB @FCC	0.160	2	26	450		3300	3300	29
				10 PS->SPS=720b		15 SPS->HEB =10800 b	1 HEB->FCC = 10800 b/ring	
HEB @SPS	0.160	2	45	1550			1550	34
			80 b	8 PS->SPS=640 b			2x17 SPS->FCC =10880 b/ring	

Tinj = filling time + ramp up/ramp down + 10 s.
No extra possible overheads.

Assumptions:

- Bunch intensity 1e11 p+
- Staggered transfer assumed to cause no significant delay
- SPS cycle time = 10.8 + n x PS cycle time for n PS batches (except for HEB@SPS)

Injection phase in LHC: theory vs reality

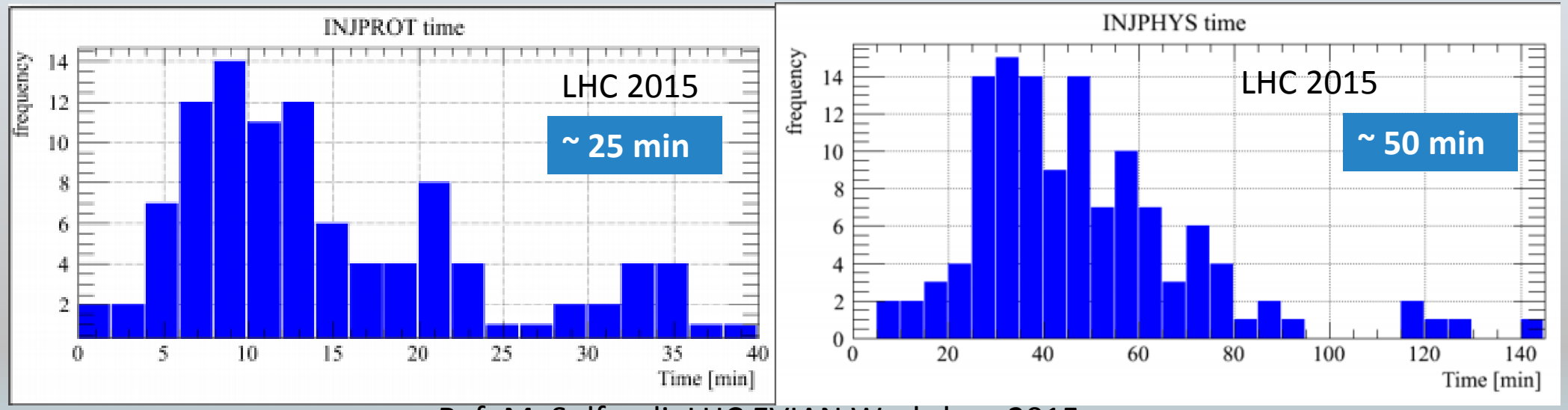
LHC minimum injection time =

number of injections required x SPS super cycle (SC) length:

Average number of injections per fill = 22

SPS SC length = 59 s (not optimized for a dedicated LHC filling!)

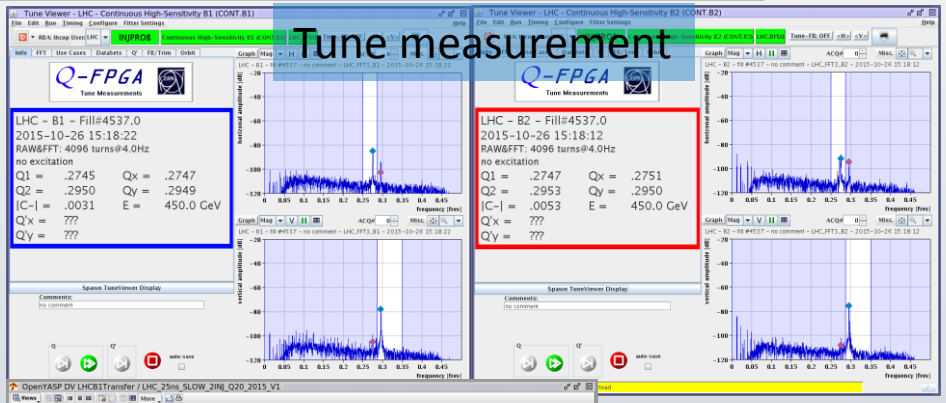
Minimum injection time in LHC = **22 minutes**



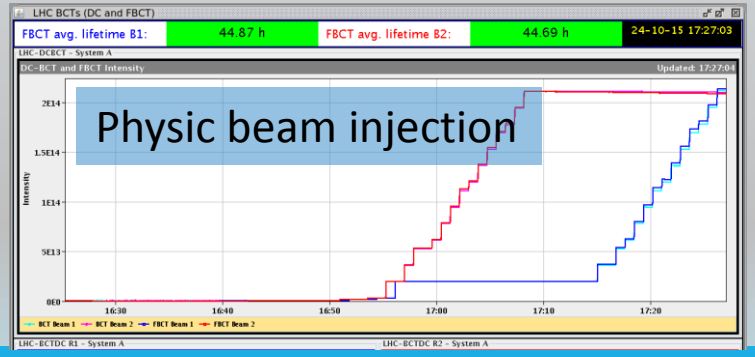
Ref: M. Solfaroli, LHC EVIAN Workshop 2015

Injection phase in LHC: injection probe & injection physics beam

1. Pilot bunch injection (~1e10 p+)
   (pilot reinjection might be required)
2. Measure/correct: Q, Q', C, orbit, phase error
3. Injection of 2x12 bunch train per beam:
   1. check transfer line and injection oscillations
   2. If not good ➔ transfer line steering (takes time)
   3. If good ➔ measure emittance
4. Injection of the rest of the physics beam
5. Once machine full ➔ PREPARE RAMP

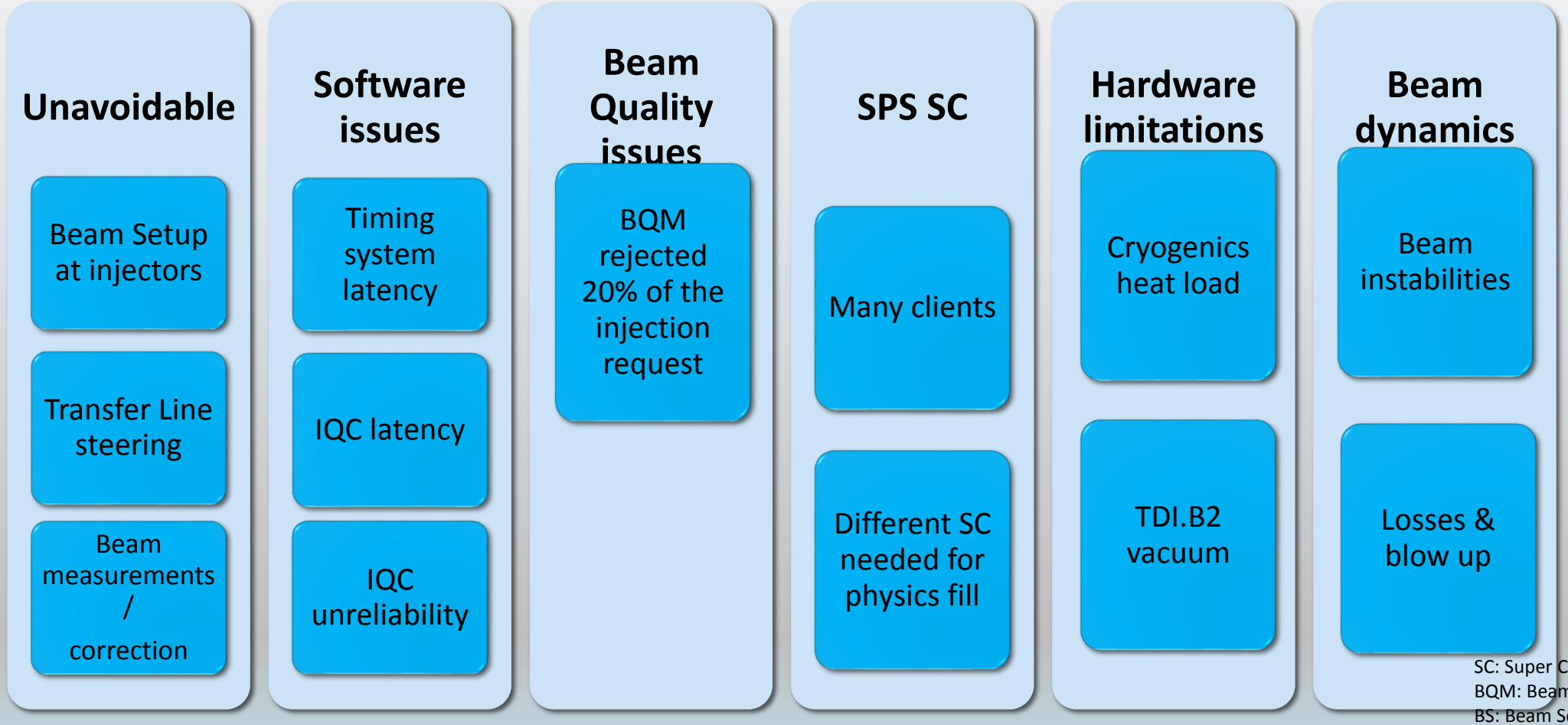


Transfer line steering



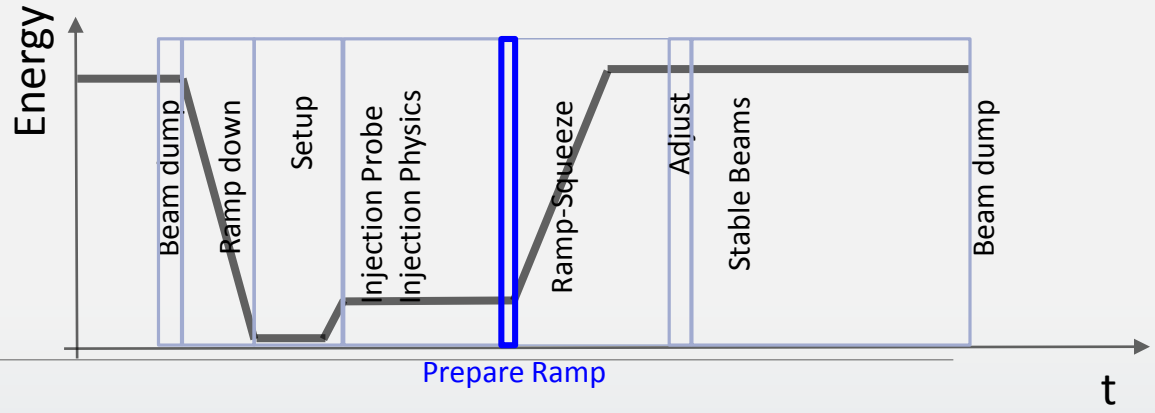
Injection phase in LHC: what can go wrong

Ref: D. Jacquet LHC EVIAN Workshop 2015



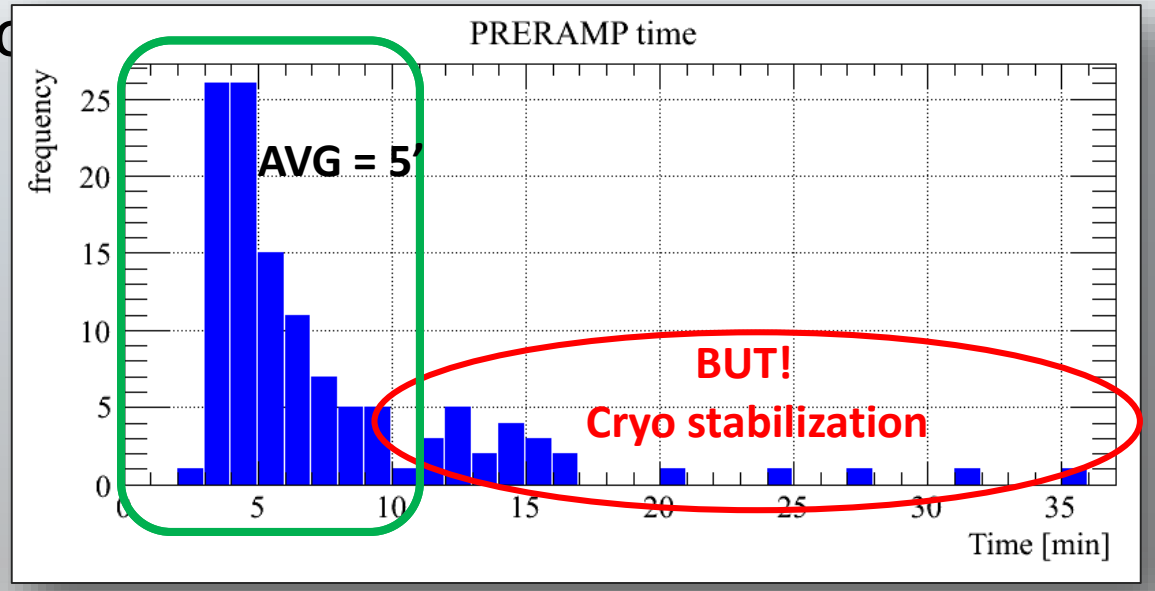
SC: Super Cycle
BQM: Beam Quality Monitor
BS: Beam Screen

Prepare ramp



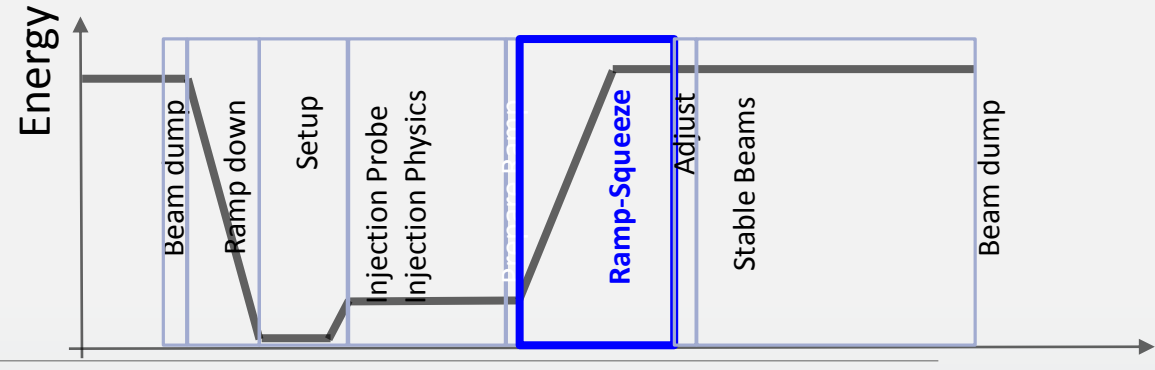
Prepare ramp in LHC:

- Injection protection collimators to parking
- Settings incorporation in the ramp function
- Load settings in RF, PC, collimators, transverse dampers
- Prepare feedbacks to follow the ramp



Ref: M. Solfaroli, LHC EVIAN Workshop 2015

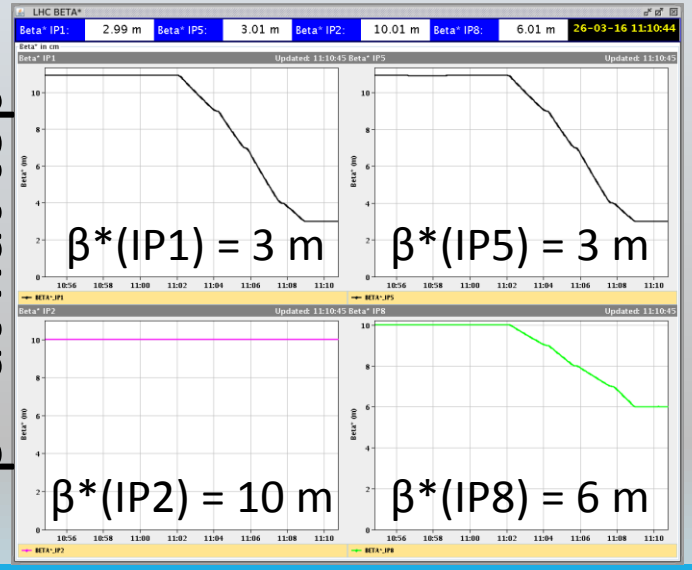
Ramp-Squeeze



Ramp-squeeze in LHC:

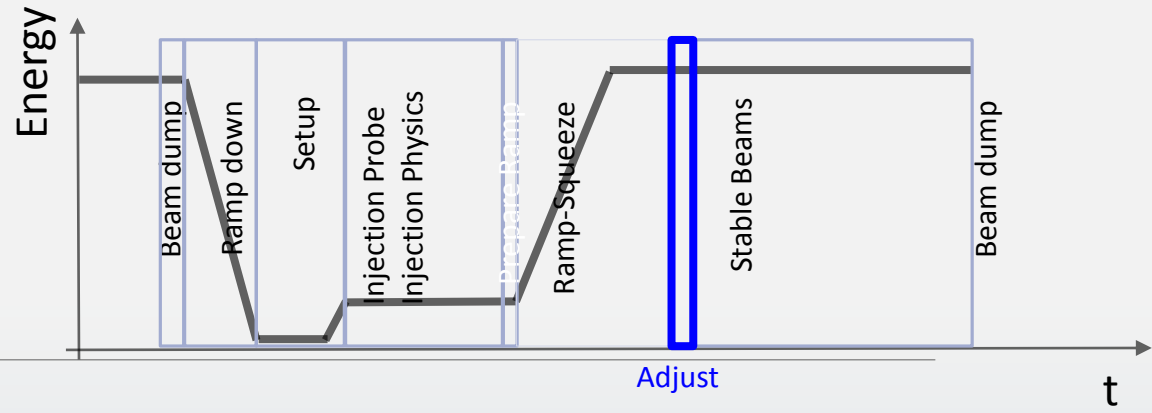
- Function playing (automatic procedure)
- Q, Orbit and Transverse Feedbacks on

β* at flat top



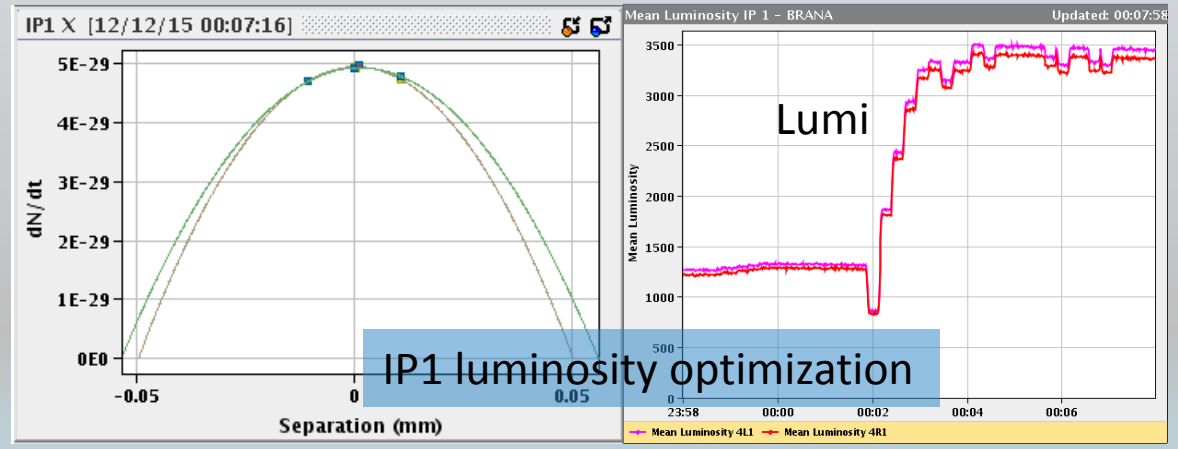
- **RAMP TIME in FCC**:
  20 min ➔ Ref: "Concepts for magnet circuit powering and protection", M. Prioli, FCC Week Rome 2016
- **SQUEEZE TIME in FCC**:
  - LHC squeeze from 11 m to 0.8 m (IP1&5) = 12.5 minutes
  - FCC-hh baseline squeeze from 5 m to 1.1 m ➔ half of the LHC squeeze ➔ **6 min**
  - Since combined with the ramp, part remains in the shadow ➔ **3 min**
- **FLAT TOP in FCC**: operator sequential actions ~ **5 min**

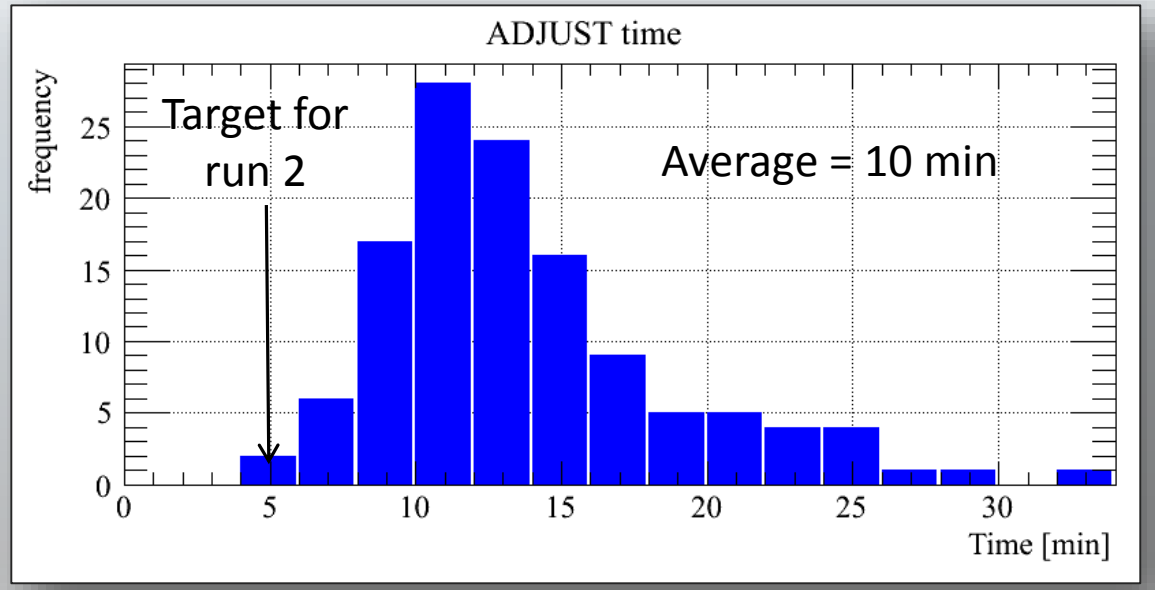
Adjust



Adjust in LHC:

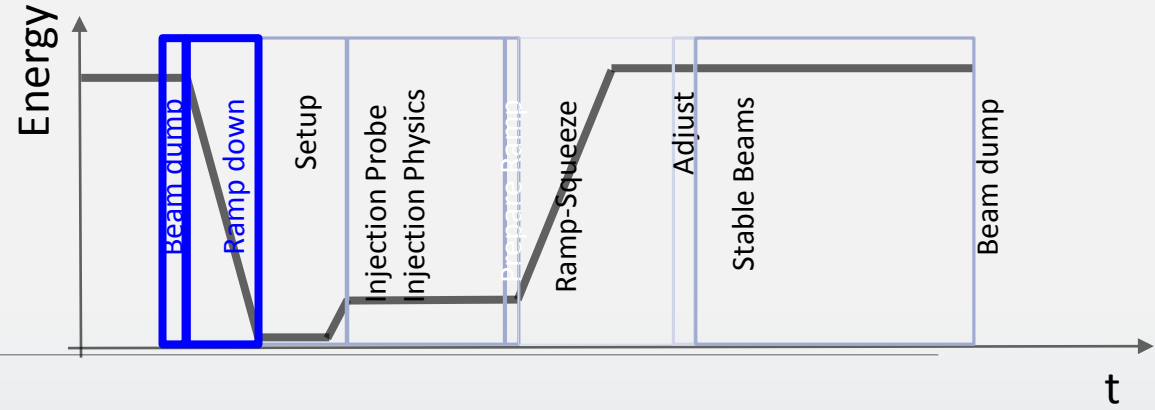
- Settings incorporation
- Functions playing (automatic procedure)
- Experiments luminosity optimization





Ref: M. Solfaroli, LHC EVIAN Workshop 2015

Beam dump – ramp down

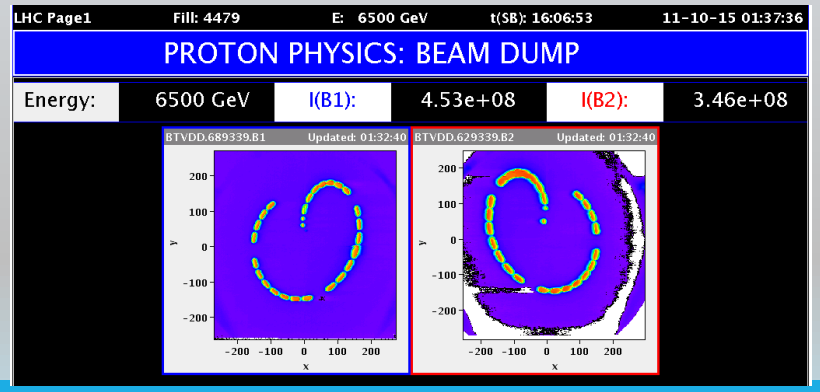


Beam dump – ramp down in LHC:

- Handshake for beam dump ~ 5 min (done in SB)
- Beams are dumped and the ramp down starts in parallel to many other tasks to prepare the rest of the machine for the next injection
- But the time is driven by the magnet circuits ramp down

Ramp down time in FCC:

- If all main power converters are four-quadrant ➔ ramp down = ramp = **20 min**
- In LHC is not the case and the ramp down is ~ 40 min (2xramp)

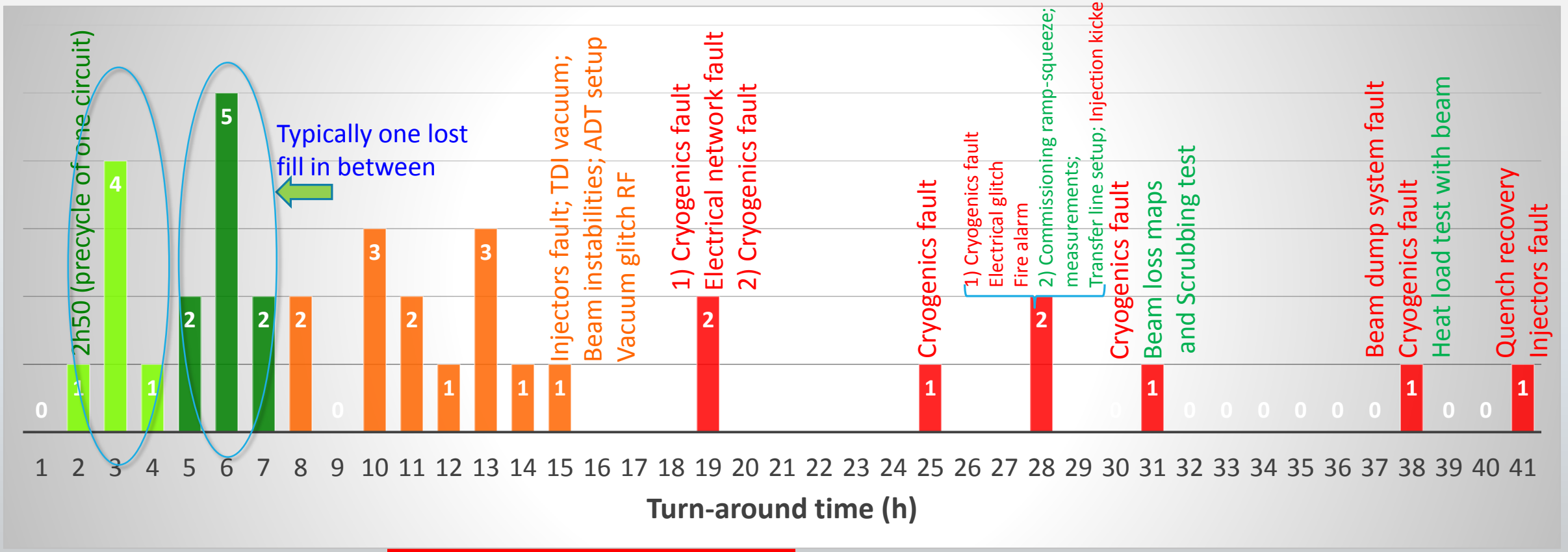


FCC-hh theoretical turn-around time

Mode	Time (min)
PRE-INJECTION TO INJECTION	10
INJECTION	40
PREPARE RAMP	5
RAMP-SQUEEZE-FLAT TOP	20+5+3
ADJUST	5
RAMP DOWN	20
TOTAL	108±10 (**1.8±0.2 h**)

≈ LHC theoretical turn-around time

LHC turn-around time (e.g. October 2015, 25 ns, > 1500 b physics production)



No fill made the LHC theoretical minimum of ~ 1.8 h

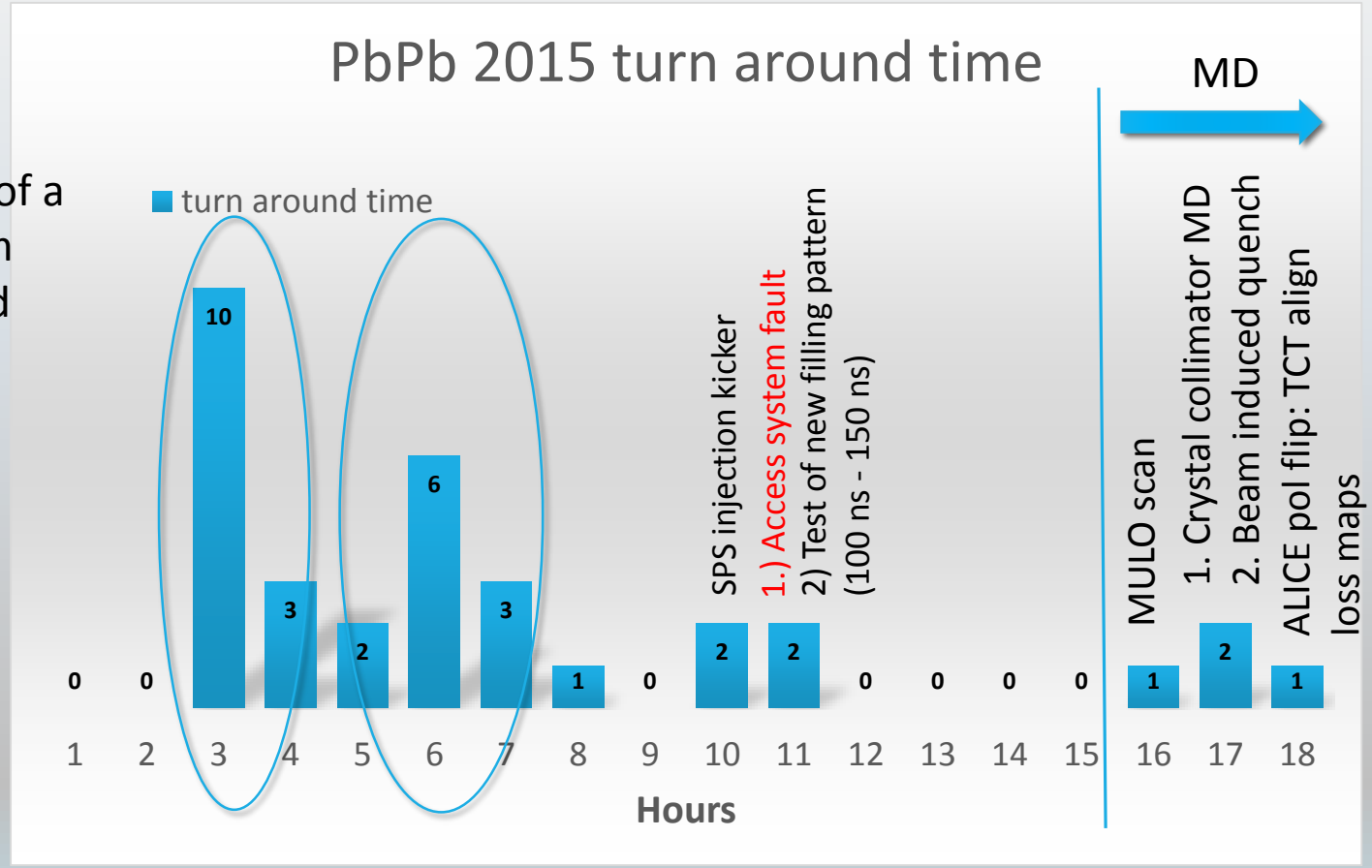
Distribution is a function of the **AVAILABILITY/RELIABILITY**

There are four categories:

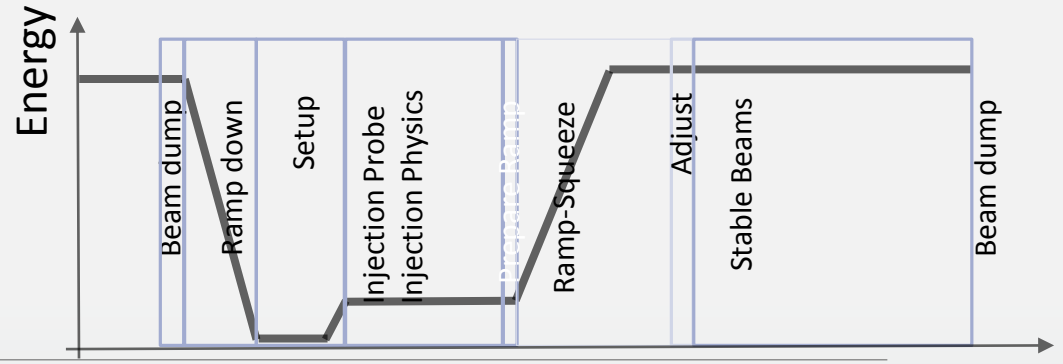
- Closest to theoretical value
- Typically one fill lost in between
- Miscelaneous faults: short-medium recovery time
- Long recovery time faults

LHC turn-around time PbPb 2015

Illustrates the behaviour of a machine without beam intensity problems and cryogenic heat load



Conclusions



- FCC-hh nominal cycle a la LHC
- Theoretical TURN-AROUND CYCLE TIME:

  1.8 hours
- Real machines behave different,

  e.g. injection phase will be more than beam production at the injectors and transfer into FCC

Mode	Time (min)
PRE-INJECTION TO INJECTION	10
INJECTION	40
PREPARE RAMP	5
RAMP-SQUEEZE-FLAT TOP	20+5+3
ADJUST	5
RAMP DOWN	20
TOTAL	108±10 (**1.8±0.2 h**)

- The turn-around cycle time is a crucial input to:
  1. **AVAILABILITY-RELIABILITY FOR FCC-hh** ➔ see "First results from availability studies", A. Apollonio, FCC Week Rome 2016
  2. **OPTIMAL TIME IN STABLE BEAMS**

     ➔ see "Luminosity Evolution in a Run", X. Buffat, FCC Week Rome 2016