FCC Availability Studies

Andrea Apollonio – CERN TE-MPE
Arto Niemi – CERN BE-ICS

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Outline

- Introduction
- FCC integrated luminosity production goals – Availability considerations
- Estimates of system availability budgets
- Impact of injector chain performance on integrated luminosity production

FCC Availability Study - Collaboration

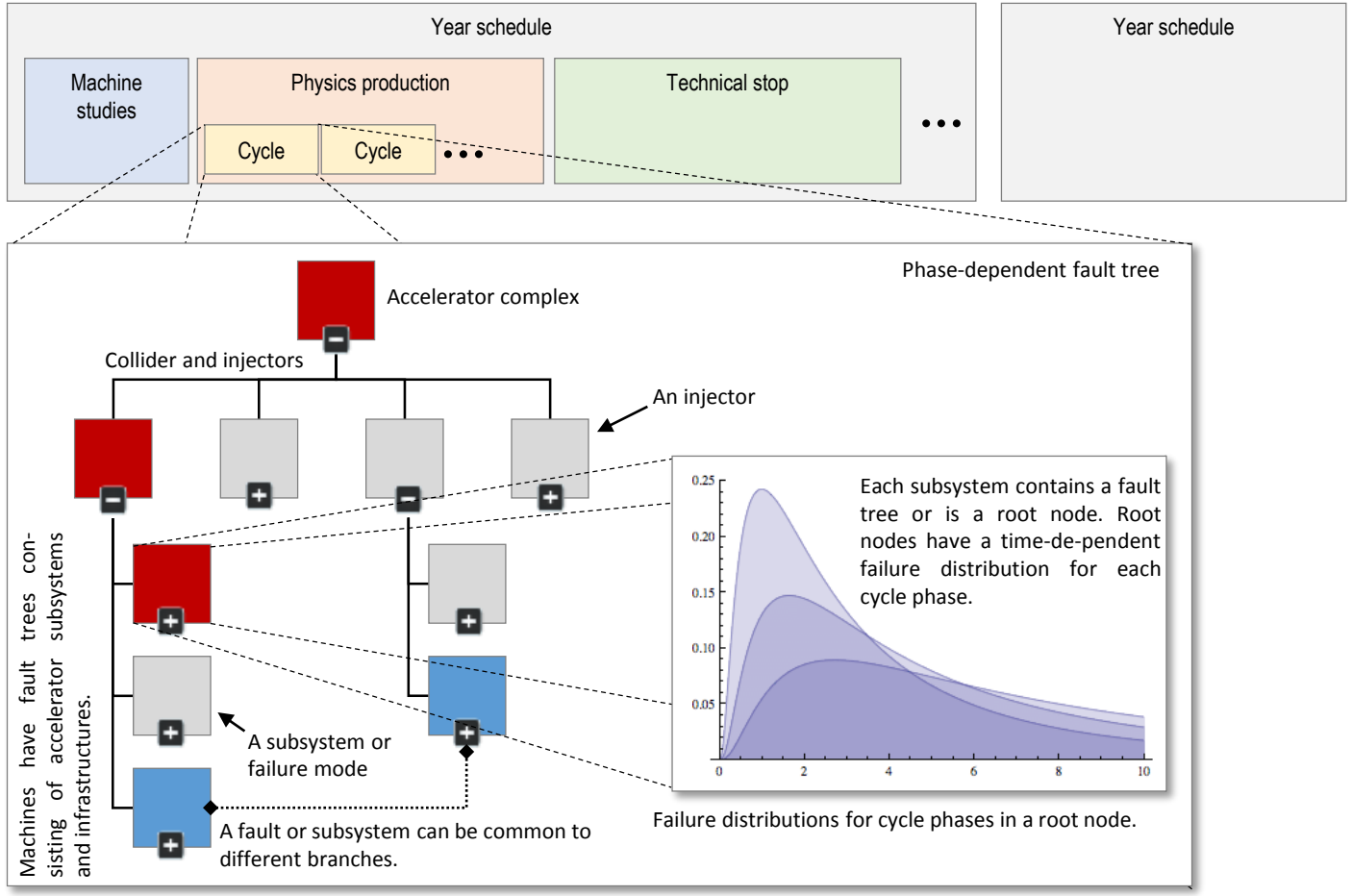
CERN
Coordination, modelling, simulation use-case definition

Tampere University of Technology
RAMS Training, academic supervision

Ramentor Oy
TUT spin-off company, ELMAS software for modelling and simulations, RAMS training

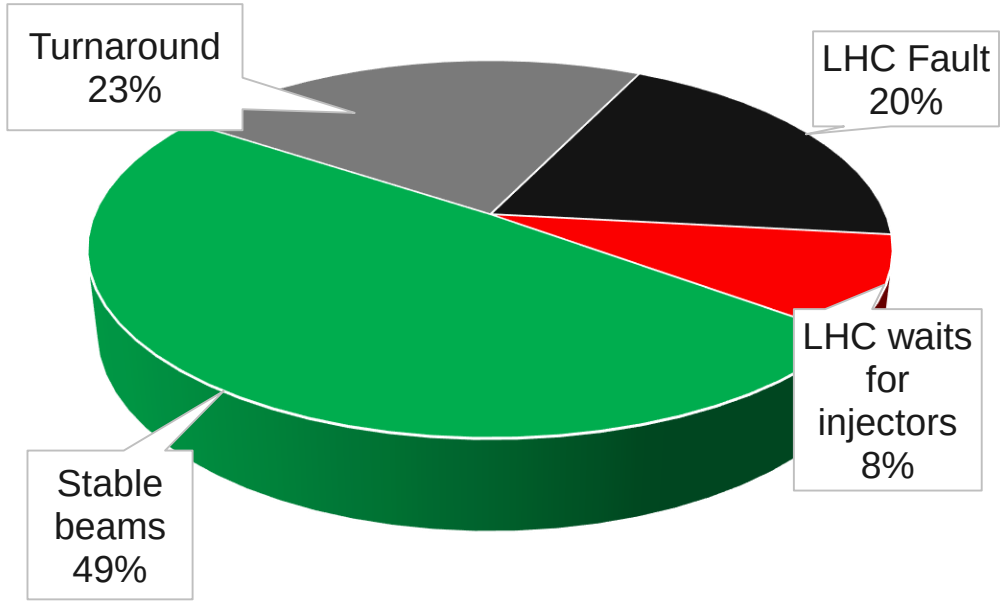
Modelling Approach

- Monte Carlo model of accelerator Operation:
  - accelerator cycles, injections & luminosity production
- Fault tree model of system availability/reliability:
  - Failure rates + repair times



For more details: https://doi.org/10.1103/PhysRevAccelBeams.19.121003

LHC Availability in 2016



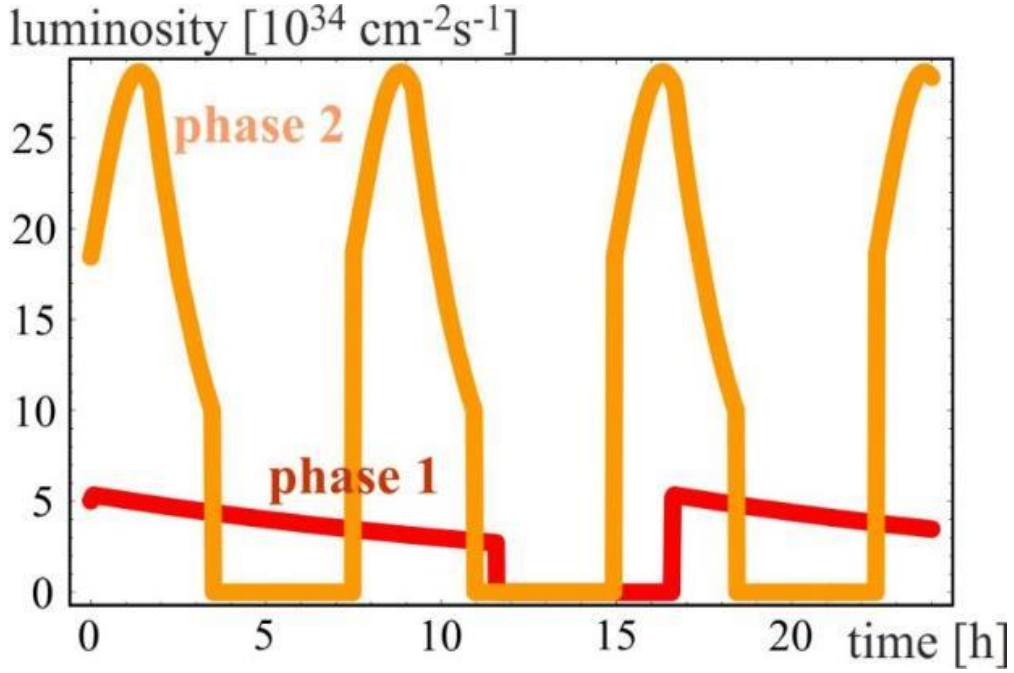
49 % of time in collisions is the LHC record

2016 downtime dominated by 5 systems

Root Cause System	Root Cause Duration [h]	% of Total Duration
Injector Complex	313.21	25.4
Technical Services	278.35	22.6
Cryogenics	90.32	7.3
Power Converters	75.05	6.1
Magnet Circuits	68.75	5.6

= 825.7 hours ≈ 67 % of total downtime

FCC Integrated Luminosity Production



- Reminder: a ‘run’ has 900 days for operations
- Luminosity productions goals per run
  - **Phase 1**: 1.25 ab^{-1}
  - **Phase 2**: 5 ab^{-1}

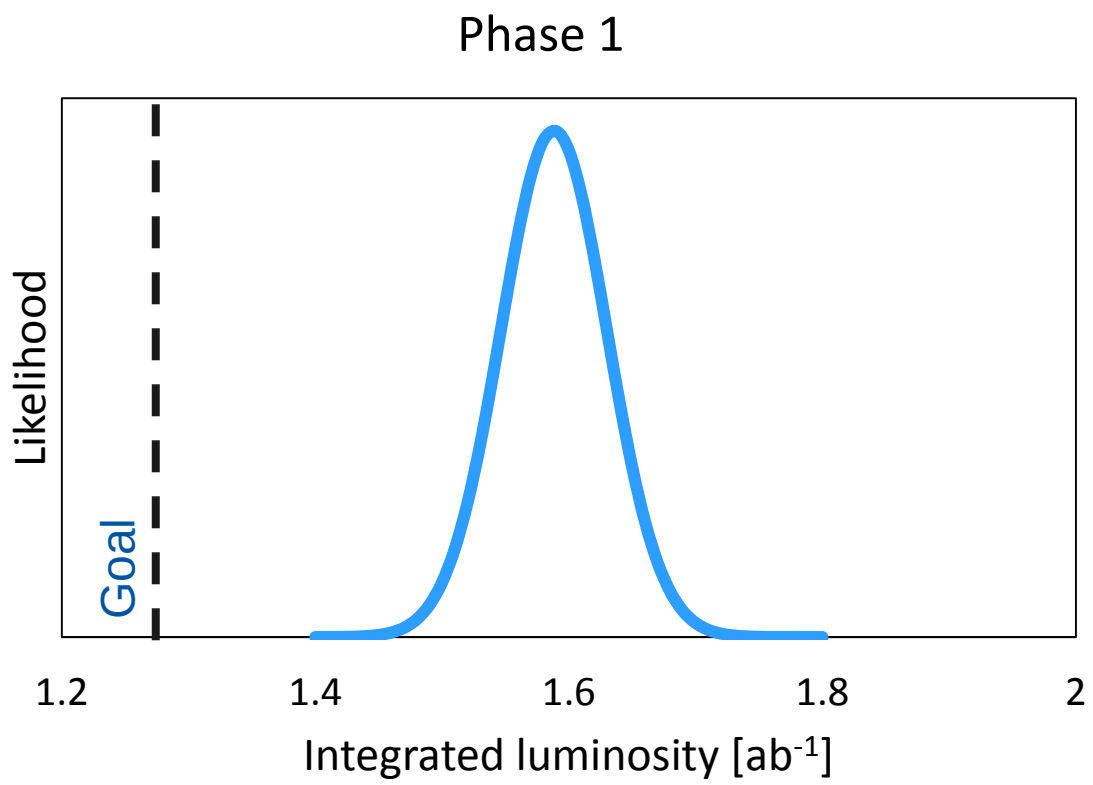
FCC Availability - Assumptions

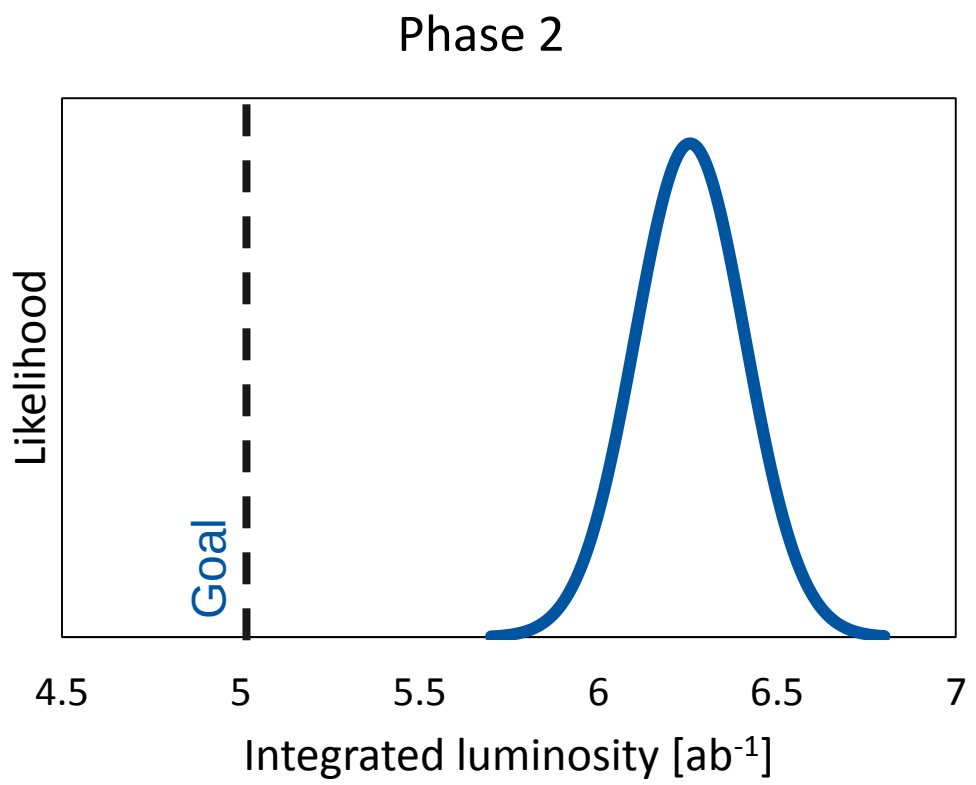
The goal is to demonstrate that FCC integrated luminosity targets are achievable under certain conditions

What if…

- No operational issues (automated operation)
- No beam instabilities (mature machine)
- FCC system failure rates and repair times = 2016 LHC run (no scaling)
- 90 % available injector chain (estimated failure rate)
- 50 % injection success rate
- 90 % efficiency due to intensity ramp-up

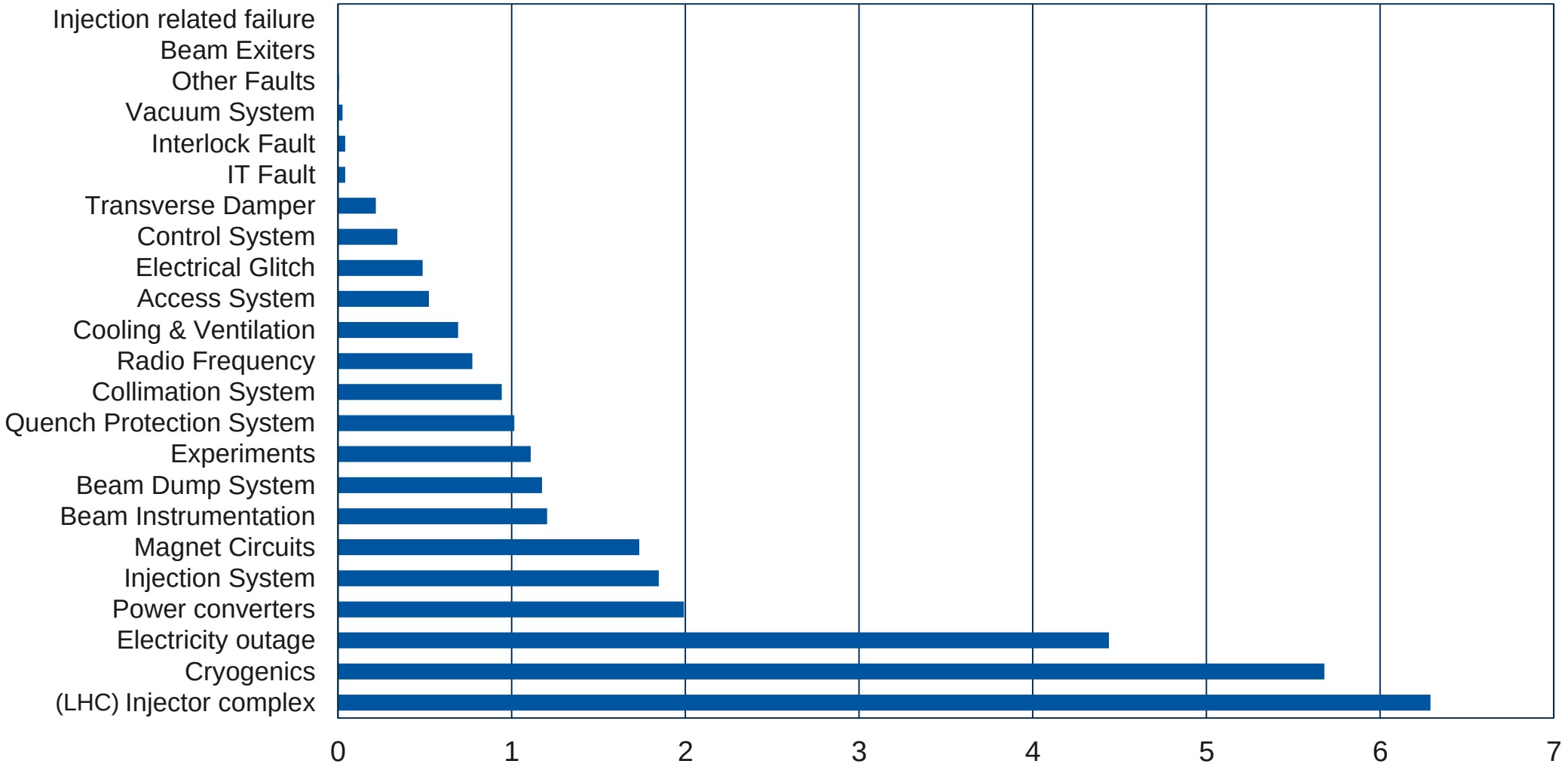
FCC Luminosity Production for LHC-like Availability



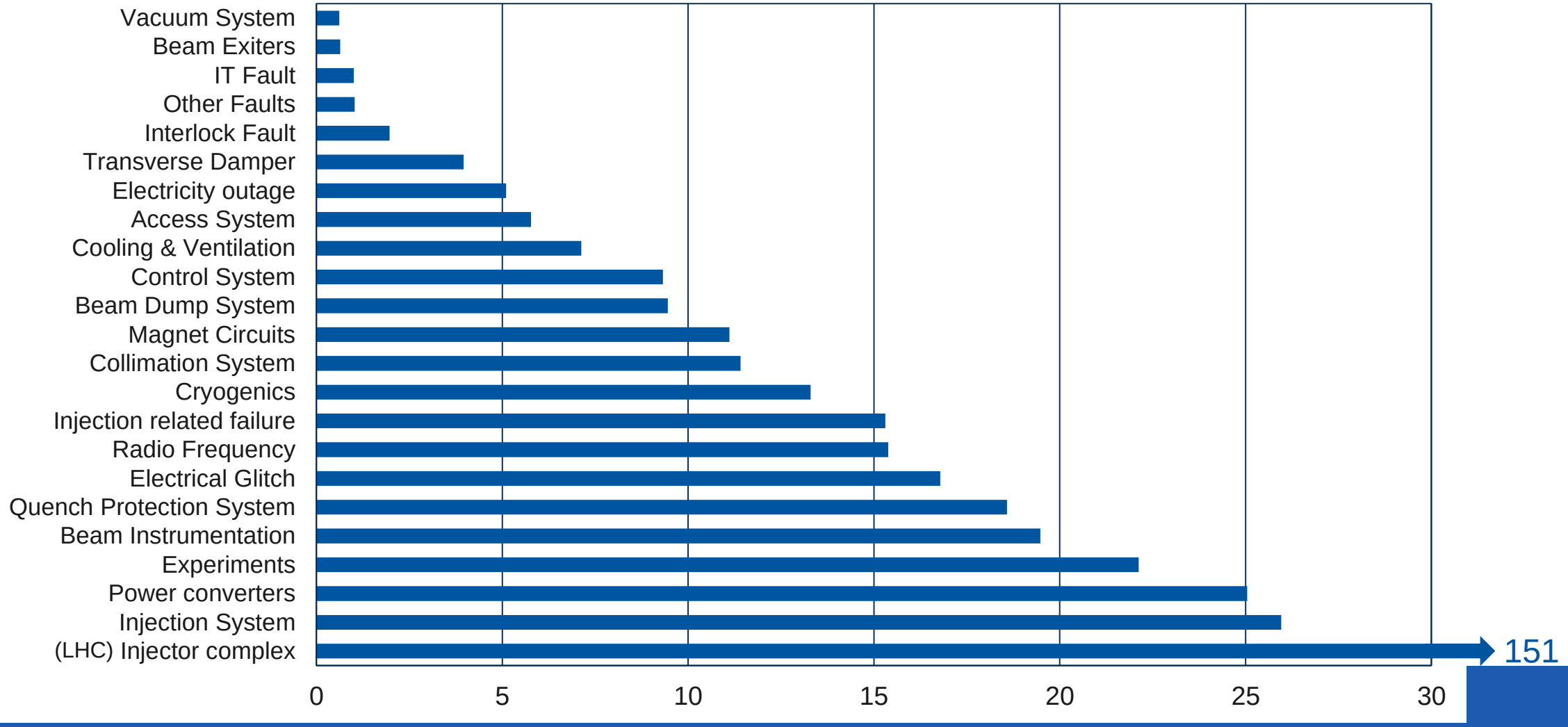


IF the FCC will exhibit the same overall LHC availability, the production goals can be achieved (NB: <u>despite the increased number of systems and higher energies</u>)

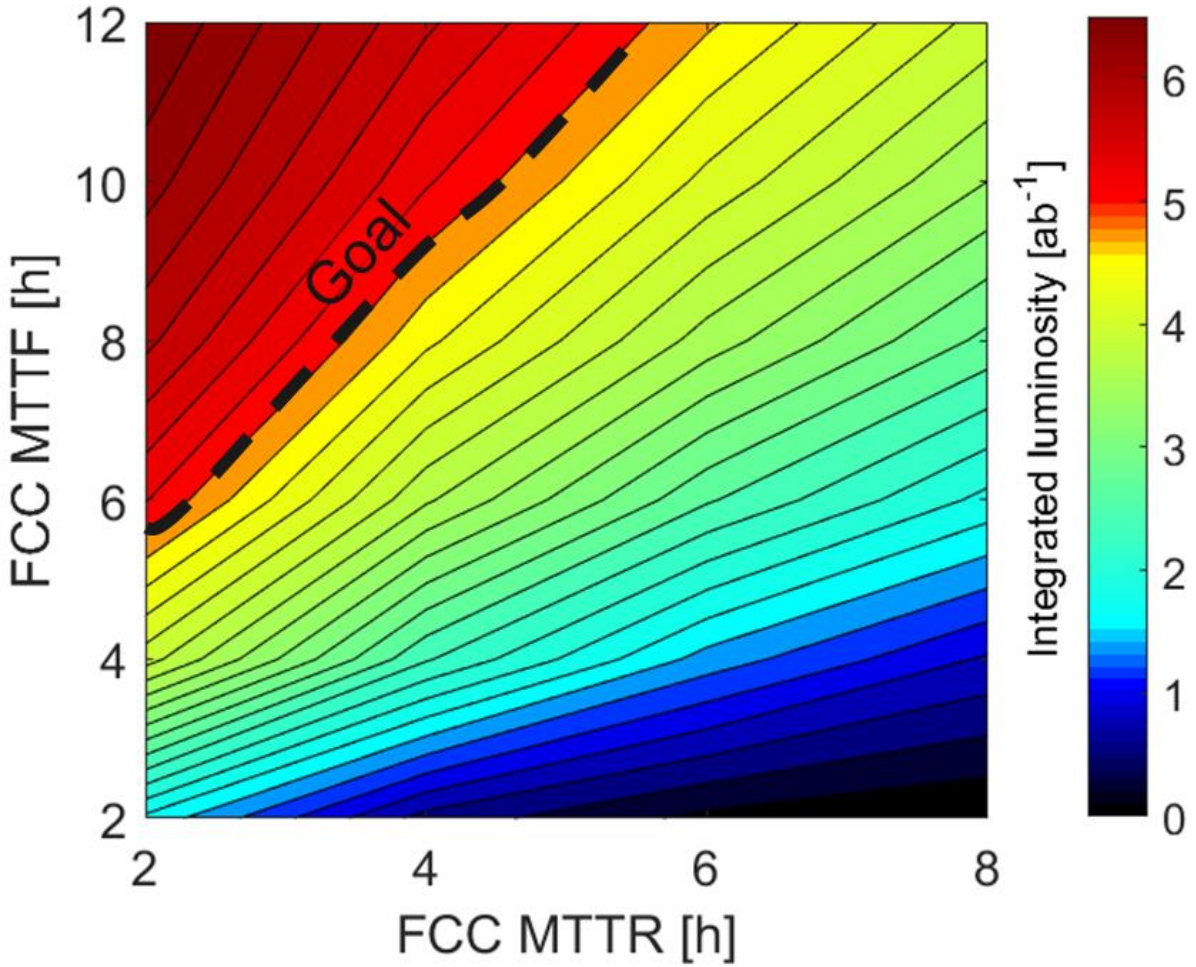
Availability budget: Unavailability [%] – Phase 2



Availability budget: Failures / 100 days – Phase 2



Sensitivity analysis – Phase 2



FCC Injector Options

Upgraded LHC:

- Flat-top energy 3.3 TeV
- Upgrade to 5 times faster ramps (up & down)
- 4 Cycles to fill the FCC
- 66 Injections / cycle
- Cycle duration = 10-12 min

Superconducting SPS:

- Flat-top energy 1.3 TeV
- 33 Cycles to Fill the FCC
- 8 times 80 b Injections / cycle
- 4 times 160 b extraction / cycle
- Cycle duration = 1 min

From F. Burkart

Injector Options - Assumptions

Scenario 1

Upgraded LHC:

- Present day LHC failure rates
- No experiments
- No failures due to high energies (UFOs, flat-top quenches)

Scenario 2

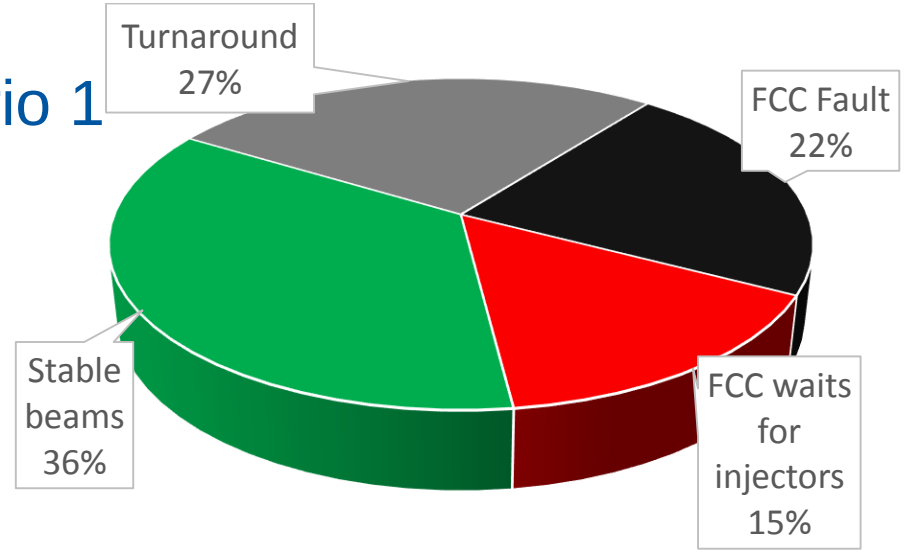
Superconducting SPS

- SC-magnets
- Quench protection
- Power converters
- 3 Cryogenic plants

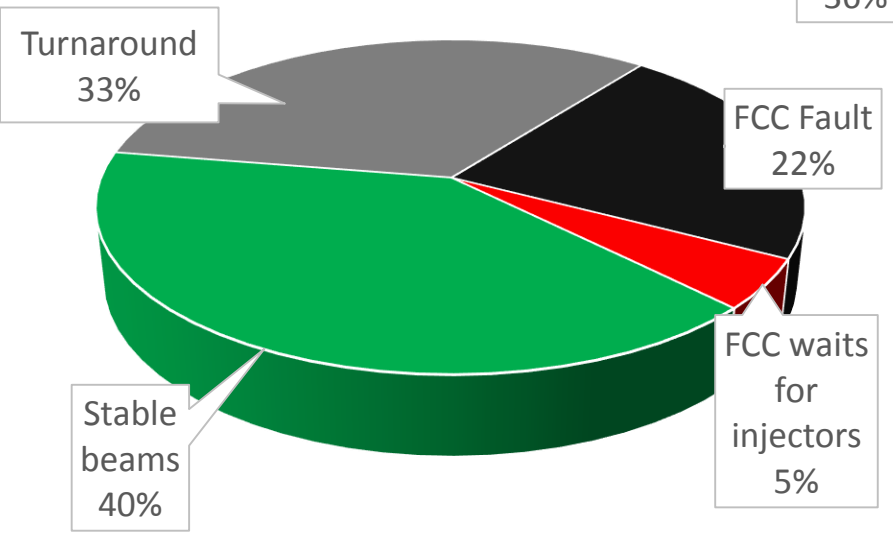
IMPORTANT: Availability is not the only parameter to be considered when comparing injector options. This study does not include considerations on costs, electricity consumption, magnets' field quality, constraints on transfer lines design, work required to replace existing accelerator systems, project schedule, etc.)

Injector Options Results (Phase 2)

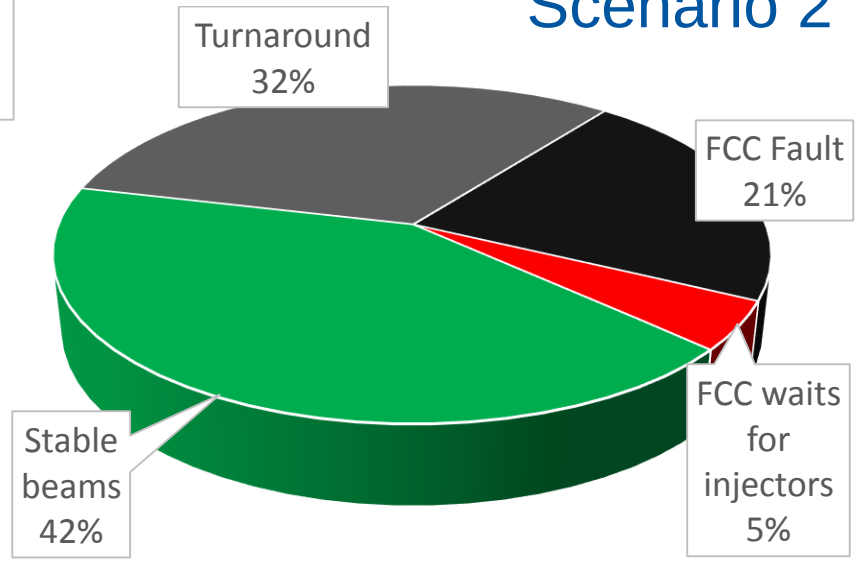
Scenario 1



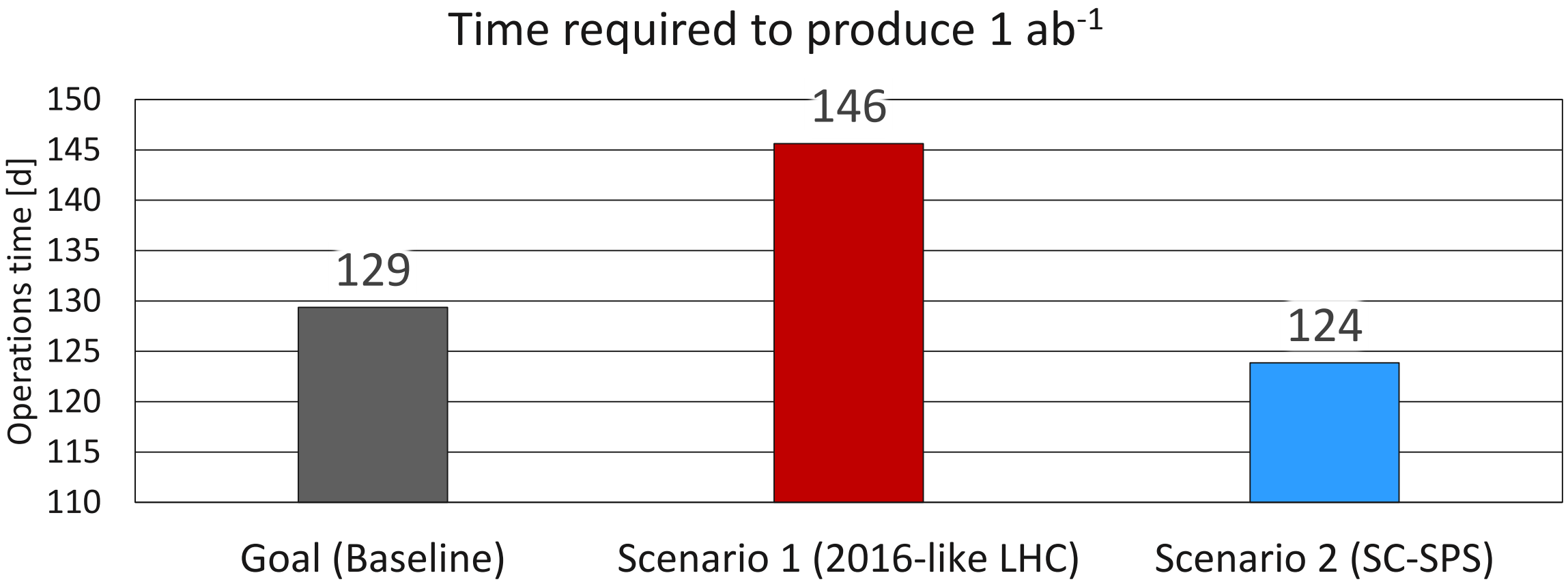
Goal (LHC)



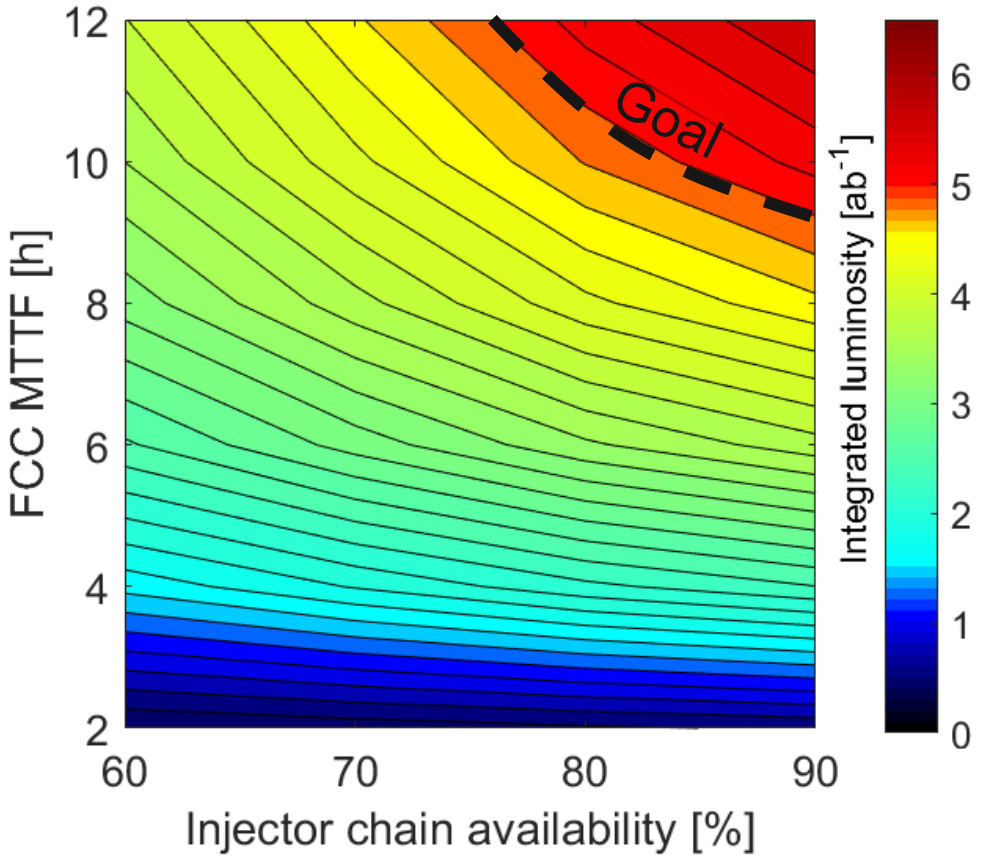
Scenario 2

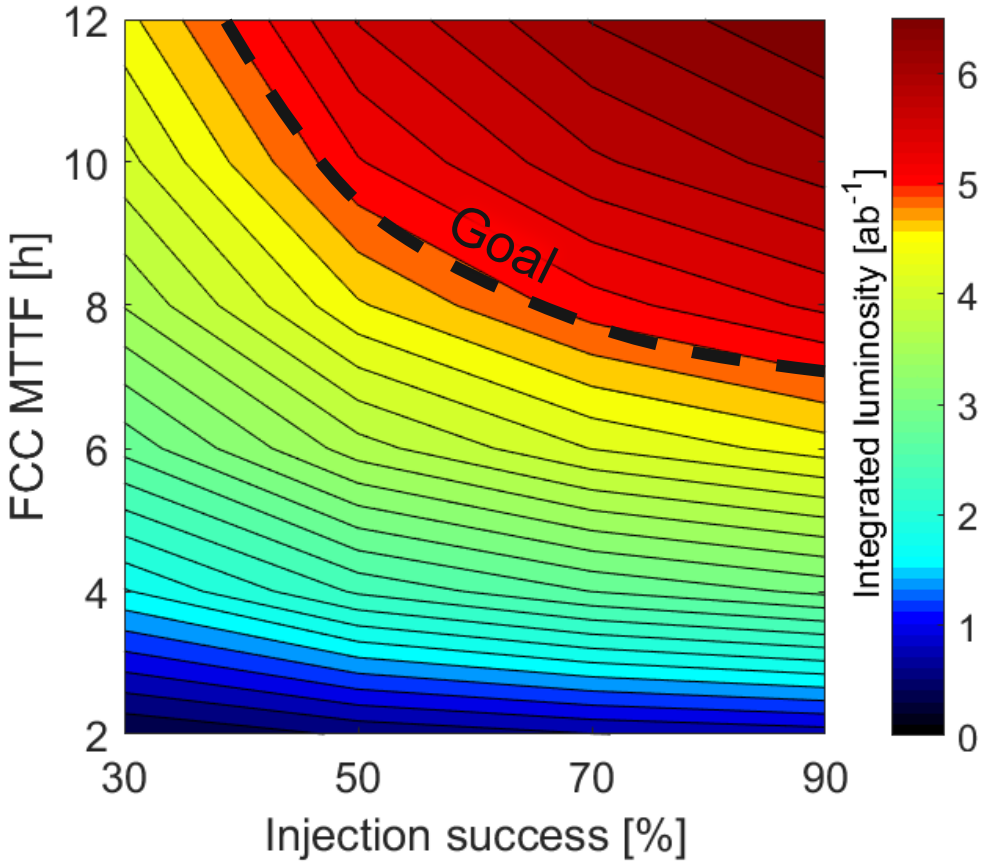


Comparison of Physics Production



Effect of injector chain (Phase 2)





Recommendations for System Design

- High system **availability is essential** for the next generation of large-scale accelerators and needs to be pursued from early design phases

- Solutions to achieve the required availability:
  - Design systems with a high degree of redundancy / fault tolerance → Target maintenance-free operation
  - Reduce logistics time → Robotics for remote maintenance
  - Limit number of radiation induced failures → Only the essential system equipment located underground
  - Invest in advanced diagnostic techniques → Anticipate failure occurrence (beam quality in injectors, failure prediction via pattern recognition,…)

- Tight operation schedules leave limited time for planned maintenance:
  - Reduce the number of technical stops (synchronize with injectors)
  - Define strategies for fast commissioning (with and without beam)

- NB: tailoring these recommendations for individual system designs requires detailed knowledge of system failure modes and effects. This study cannot give specific guidelines for individual systems (unless required).

Conclusions

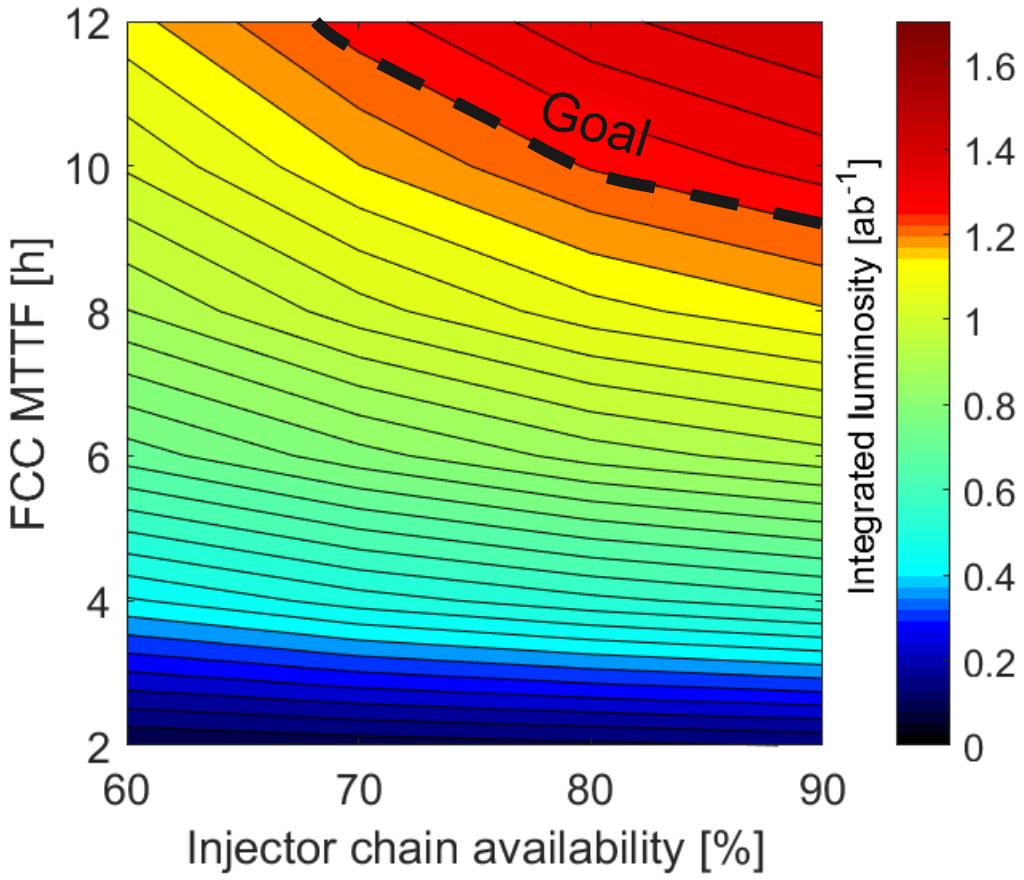
- FCC luminosity goals are in reach if LHC-like overall availability can be achieved (**very challenging**! → see recommendations)

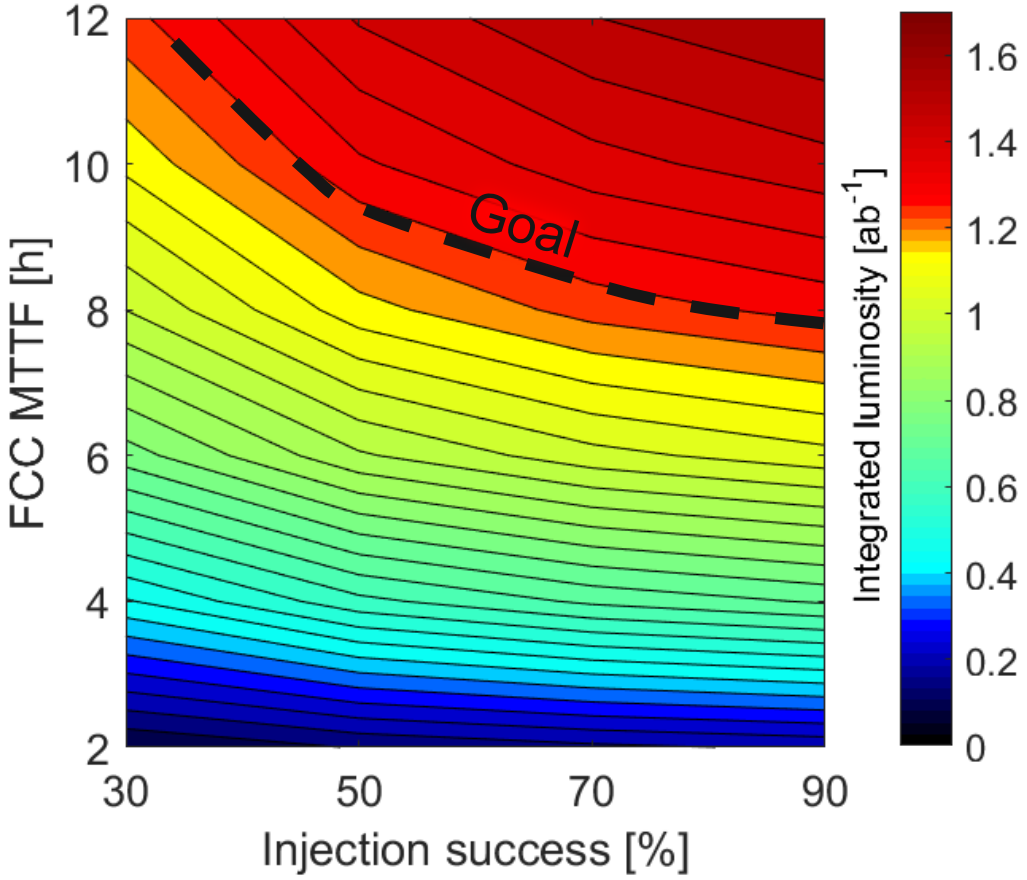
- Phase 2 integrated luminosity production is sensitive to the performance of the injector chain due to short cycles

- From the availability perspective, the SC-SPS option (scenario 2) allows maximizing the time for physics production

Extras

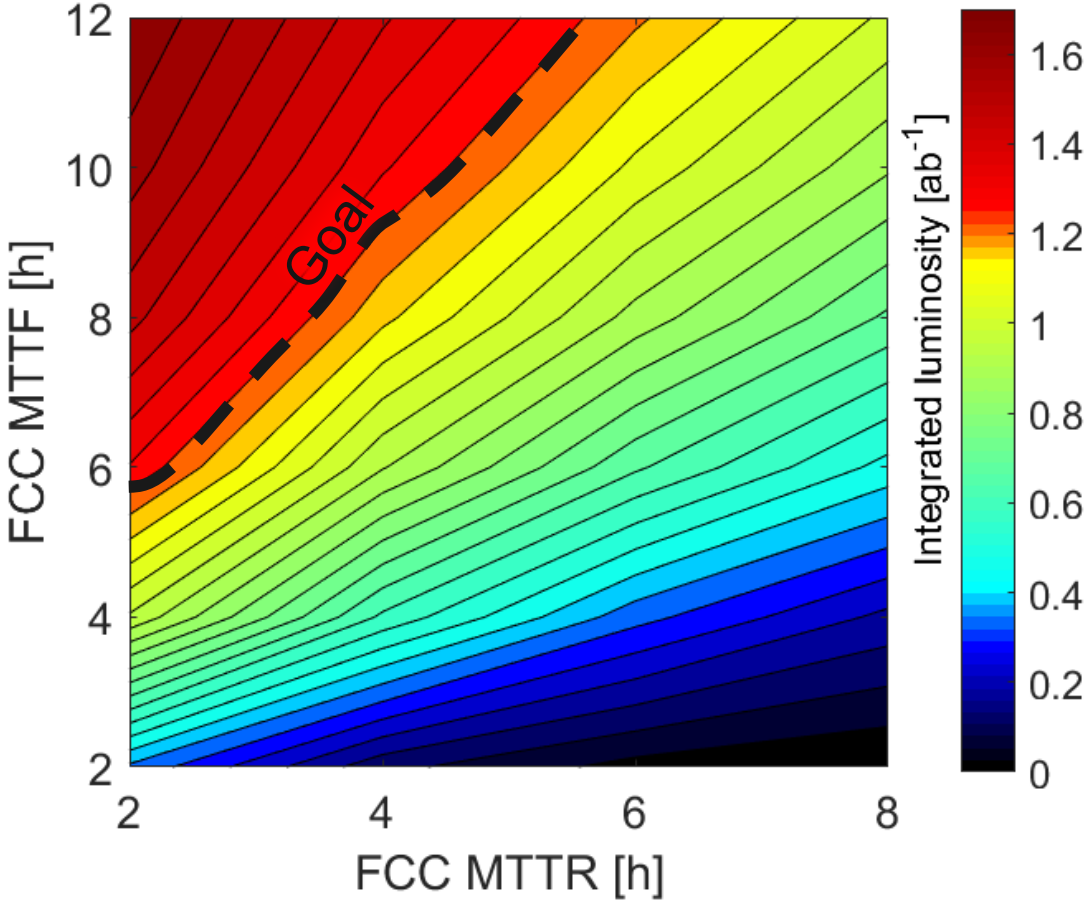
Effect of injector chain: Phase 1 parameters



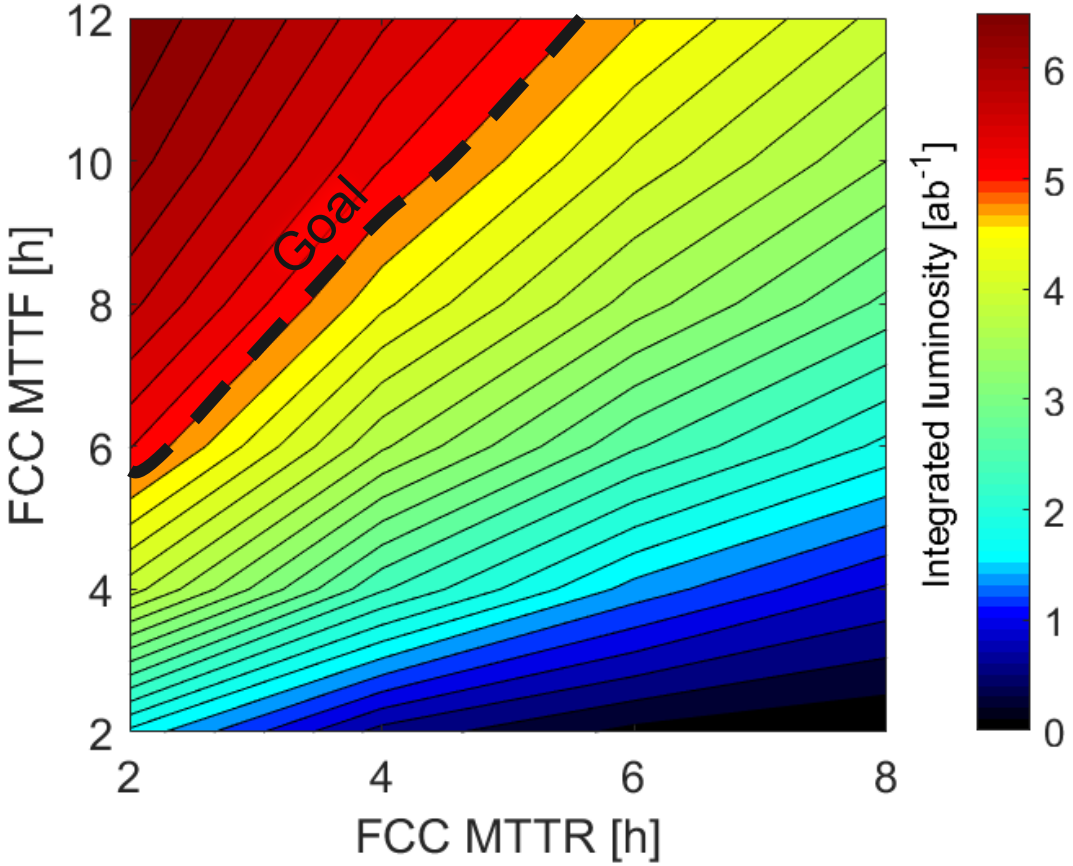


Sensitivity analysis – Phase 2

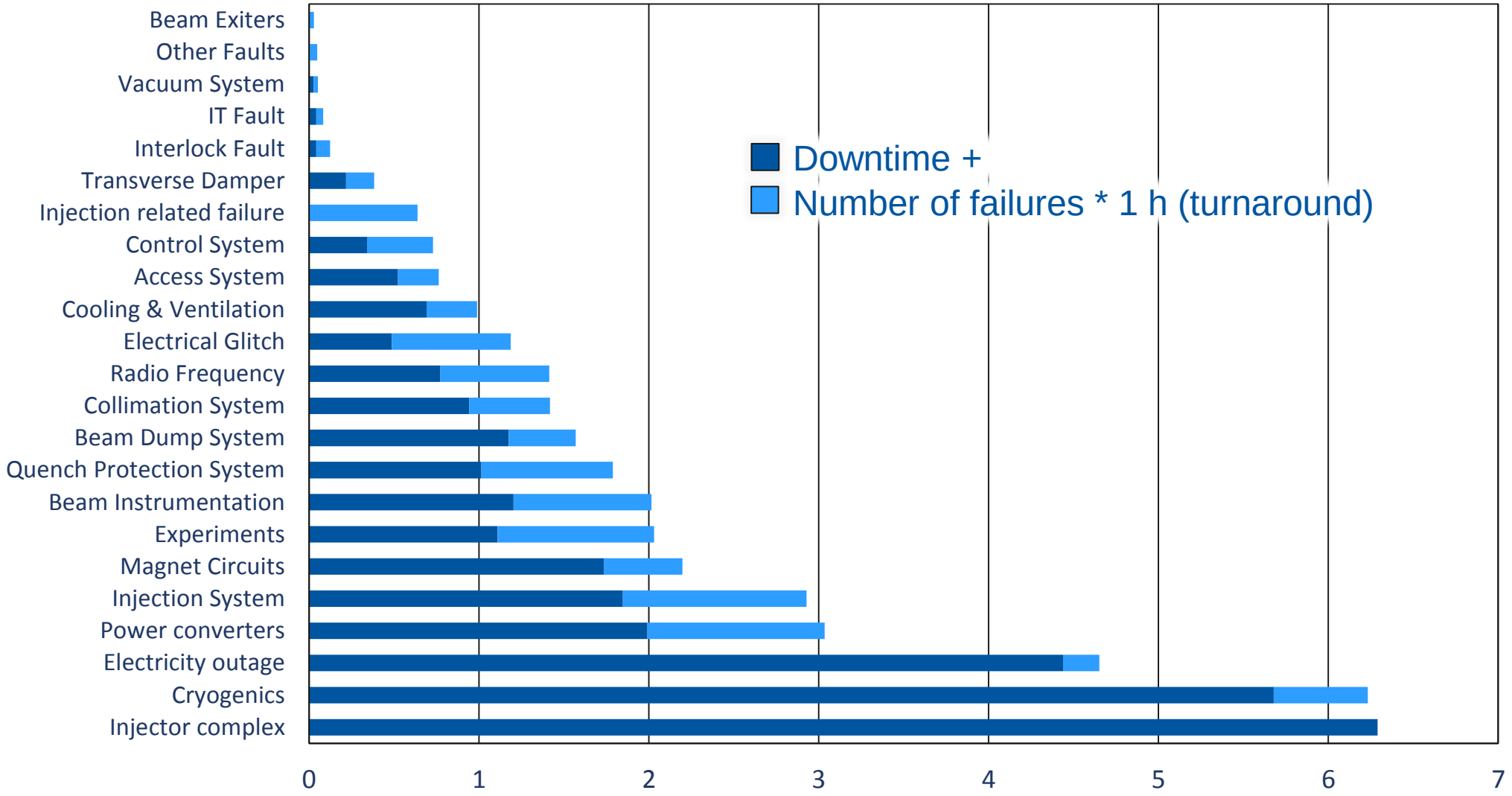
Phase 1



Phase 2



Availability budget: Effect estimate [%]



Availability studies

- Frequent failures are a risk for sustainable operations
- Individually effect of this type of failure can be minor (a beam dump or a injection delay)

Consequences		Catastrophic	Major	Moderate	Low	Negligible
	Downtime	3 month	3 weeks	3 days	3 hours	3 mins
Very frequent	1/hour					
Frequent	1/day					
Probable	1/week					
Occasional	1/month					
Remote	1/year					
Improbable	1/10years					
Not credible	1/100years					

Area of interest