FCC Availability Studies

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FCC Week – Berlin 2017
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

2016 downtime dominated by 5 systems

<table>
<thead>
<tr>
<th>Root Cause System</th>
<th>Root Cause Duration [h]</th>
<th>% of Total Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injector Complex</td>
<td>313.21</td>
<td>25.4</td>
</tr>
<tr>
<td>Technical Services</td>
<td>278.35</td>
<td>22.6</td>
</tr>
<tr>
<td>Cryogenics</td>
<td>90.32</td>
<td>7.3</td>
</tr>
<tr>
<td>Power Converters</td>
<td>75.05</td>
<td>6.1</td>
</tr>
<tr>
<td>Magnet Circuits</td>
<td>68.75</td>
<td>5.6</td>
</tr>
</tbody>
</table>

49 % of time in collisions is the LHC record

= 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
IF the FCC will exhibit the same overall LHC availability, the production goals can be achieved (NB: despite the increased number of systems and higher energies)
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)
  - Turnaround: 33%
  - FCC Fault: 22%
  - FCC waits for injectors: 5%
  - Stable beams: 40%

Scenario 2

- FCC Fault: 21%
- FCC waits for injectors: 5%
- Stable beams: 42%
- Turnaround: 32%
Comparison of Physics Production

Time required to produce 1 ab\(^{-1}\)

<table>
<thead>
<tr>
<th>Operations time [d]</th>
<th>Goal (Baseline)</th>
<th>Scenario 1 (2016-like LHC)</th>
<th>Scenario 2 (SC-SPS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>110</td>
<td>129</td>
<td>146</td>
<td>124</td>
</tr>
<tr>
<td>115</td>
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<td>150</td>
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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

FCC MTTF [h]

FCC MTTR [h]

Integrated luminosity [ab⁻¹]

Goal
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)

<table>
<thead>
<tr>
<th>Consequences</th>
<th>Catastrophic</th>
<th>Major</th>
<th>Moderate</th>
<th>Low</th>
<th>Negligible</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Downtime</td>
<td>3 month</td>
<td>3 weeks</td>
<td>3 days</td>
<td>3 hours</td>
</tr>
<tr>
<td>Very frequent</td>
<td>1/hour</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Frequent</td>
<td>1/day</td>
<td></td>
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<tr>
<td>Probable</td>
<td>1/week</td>
<td></td>
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<td></td>
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<tr>
<td>Occasional</td>
<td>1/month</td>
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<tr>
<td>Remote</td>
<td>1/year</td>
<td></td>
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<tr>
<td>Improbable</td>
<td>1/10years</td>
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<td></td>
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<tr>
<td>Not credible</td>
<td>1/100years</td>
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**Area of interest**