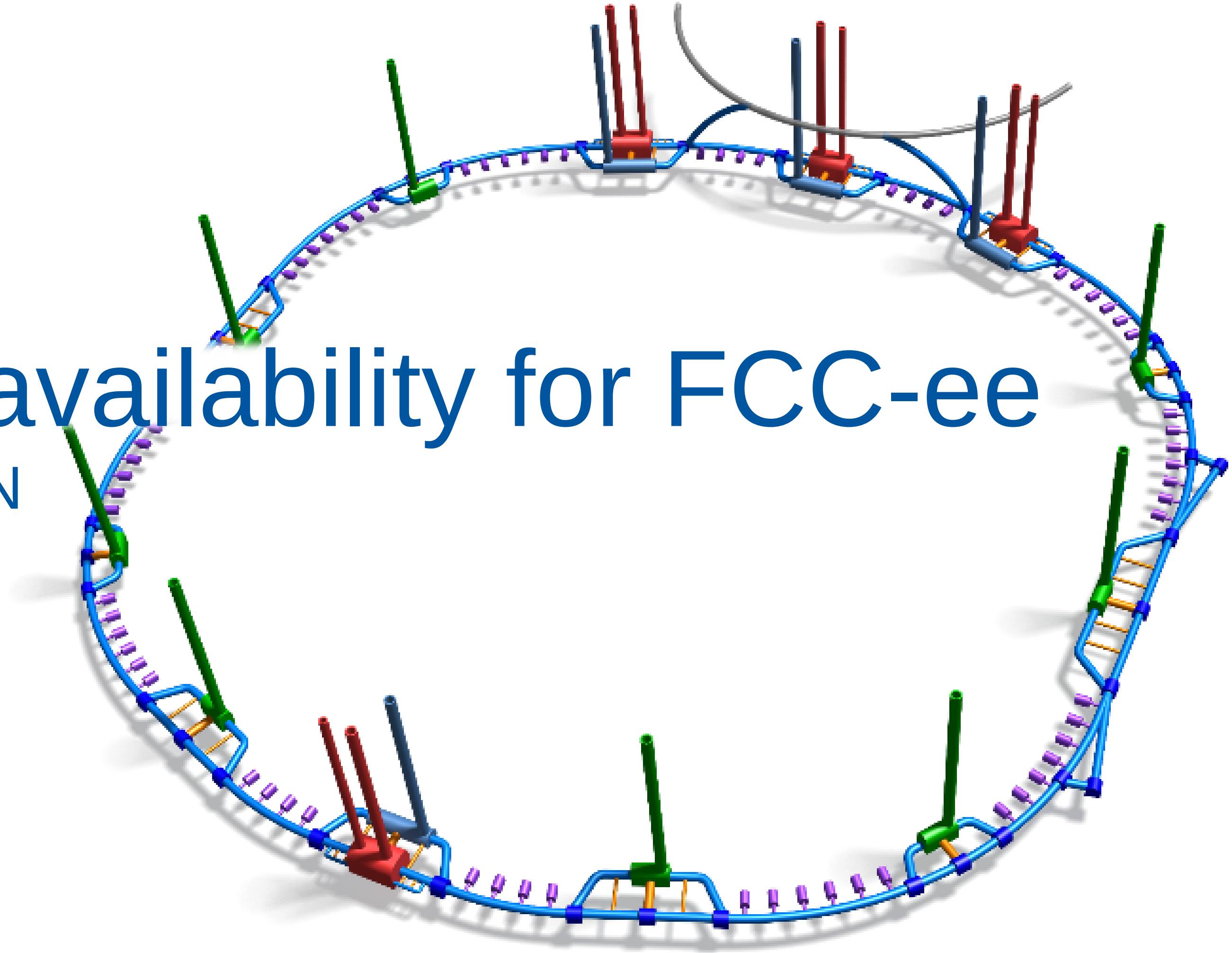
CERN

Machine availability for FCC-ee

Arto Niemi, CERN



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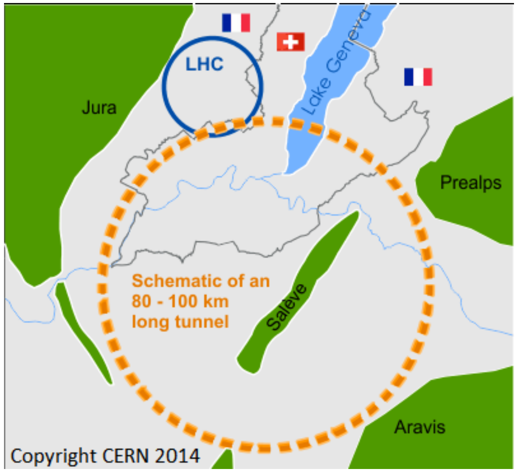
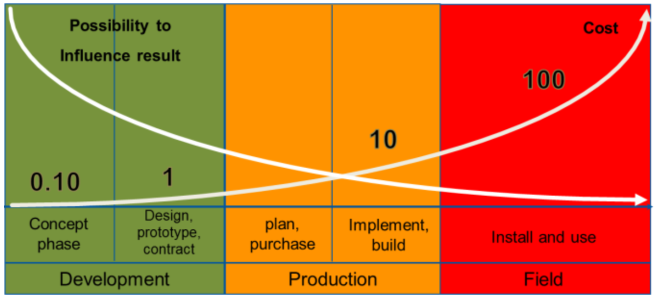
Sustainable operations

- Purpose of the FCC-ee is to study high energy physics
- Creating scientific findings depends on producing collisions
- **Risk:** Unavailability & inefficiencies can slow down the production
  - **Immediate effect**: Reaching scientific results require more time and is costlier
  - **Worst case scenario**: Failure to reach some physics program targets

Study objectives

- Existing e^+e^--colliders have a good availability track record
- FCC-ee will be larger & operate with higher energy
- Goal to identify aspects where:
  - New technologies are used
  - System complexity scales up
  - Known technology in new environment
- Ability to affect project outcome decreases as project matures → Early identification important

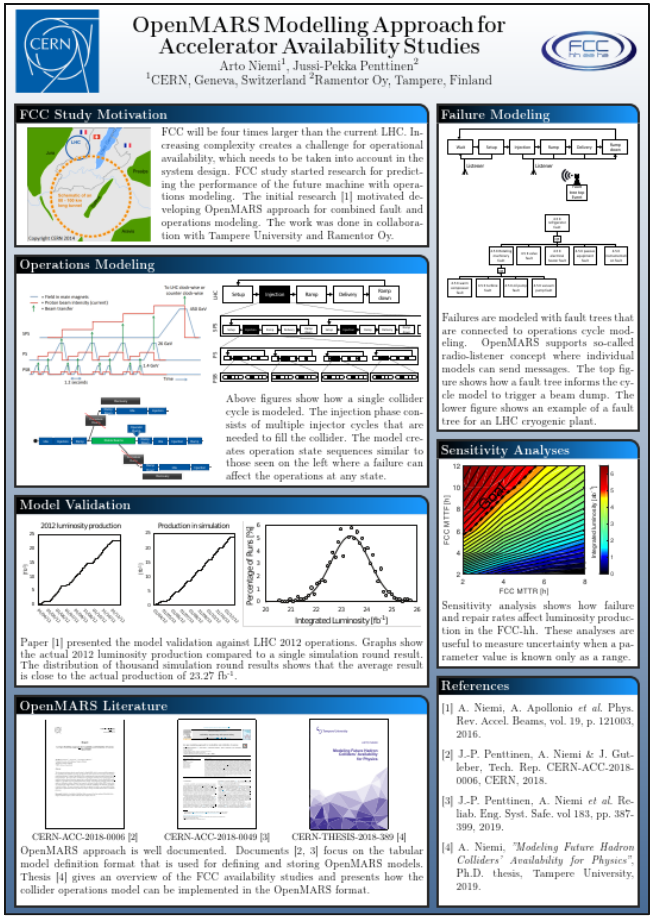




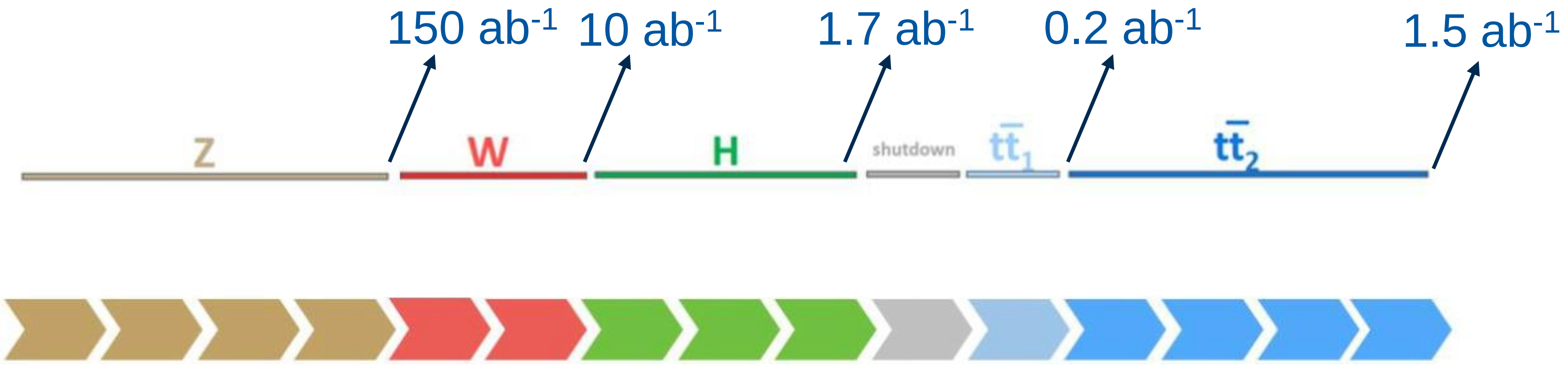
Existing availability studies

- Early focus was on the modelling approach:
  - Requirements identification
  - Creating an early prototype
  - Current technology readiness level NASA rank 4-5
- Main areas of research were combined operations & availability modelling
- Work was done in a collaboration with Tampere Uni. & Ramentor Oy

- **Dedicated poster with references→**



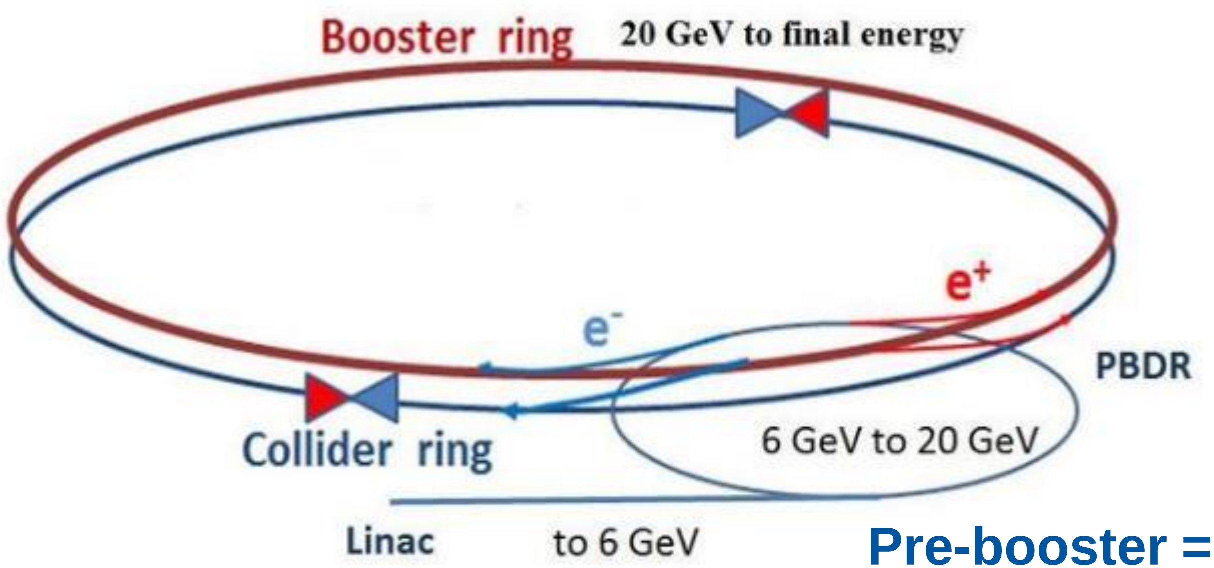
FCC-ee use scenario



$$\boxed{L_{int} = T * E * L_{nom}}$$

- E = Effectiveness, Design goal 75%
- <u>Requires about 80% hardware availability</u>

FCC-ee Complex

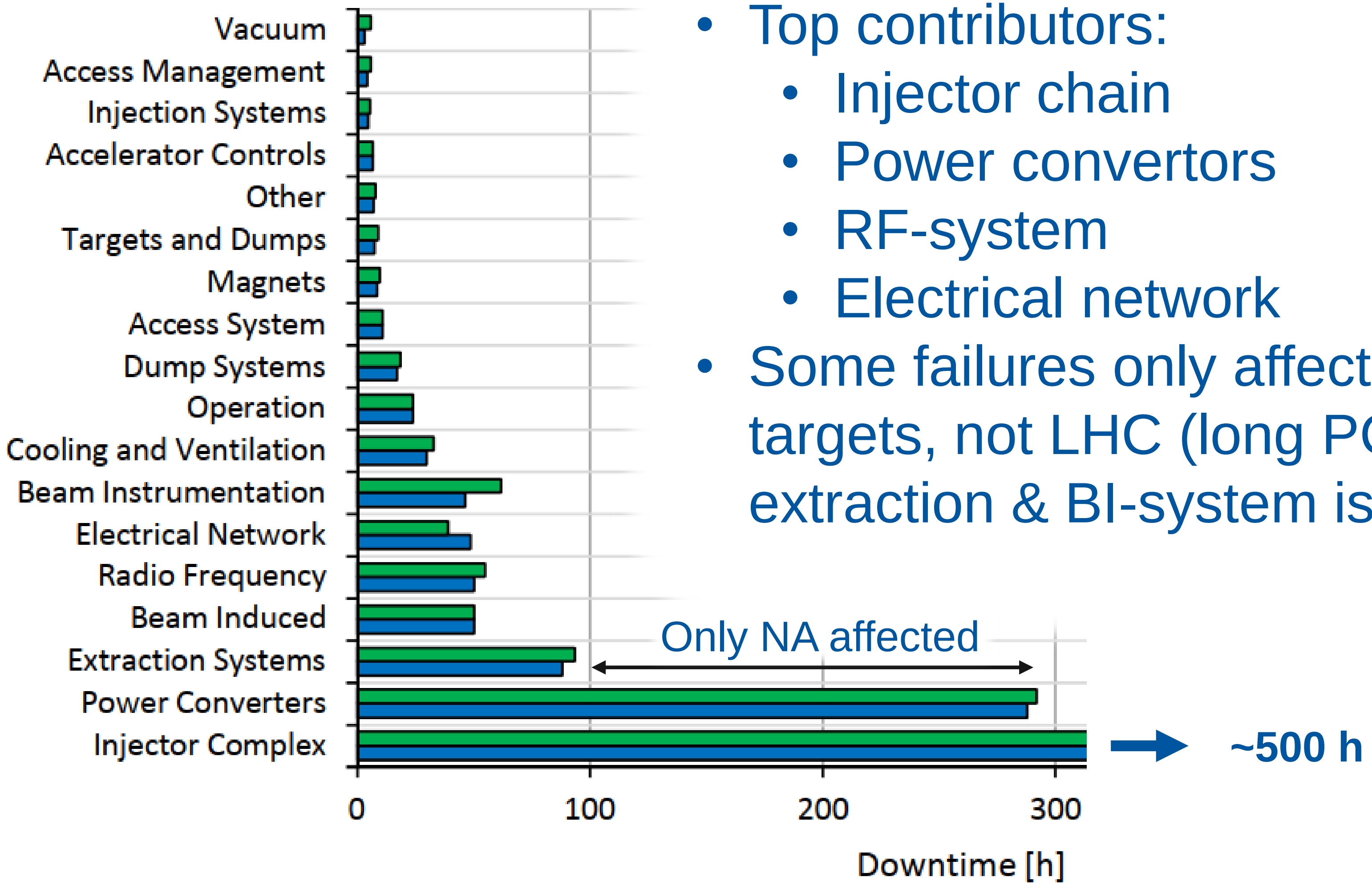


Pre-booster = SPS or a new Linac

Initial naïve allocation:

- Pre-booster 98 – 99% availability
- Booster 90 – 91% availability
- Collider ring 90 – 91% availability

SPS experience

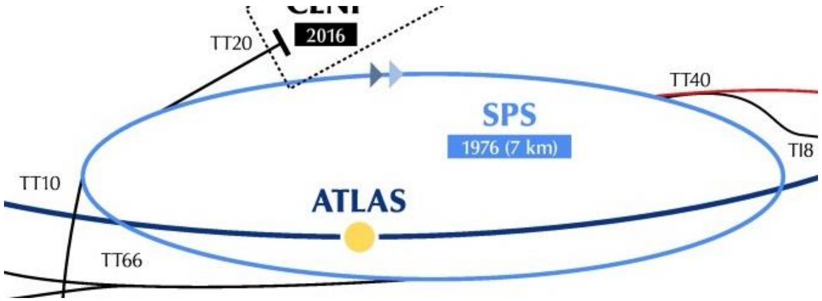


- Top contributors:
  - Injector chain
  - Power convertors
  - RF-system
  - Electrical network
- Some failures only affect fixed targets, not LHC (long PC fault, extraction & BI-system issues)

A. Niemi *et al.* CERN-ACC-NOTE-2019-0003

Pre-booster options & availability

SPS



Assumptions:

- No injector failures
- Remove failures that affect only fixed targets

→ Availability = ~96%

Linear accelerator

Example LCLS @ SLAC:

- Free electron laser with 17 GeV energy
- Over 96% hardware availability

On paper, both options can achieve high availability

Critical systems: Radio frequency

LEP experience[1]

- LEP2: 288 sc-cavities + 56 copper cavities
- In year 2000, average trip rate was 1 trip in 14 min,
- Redundancy is vital

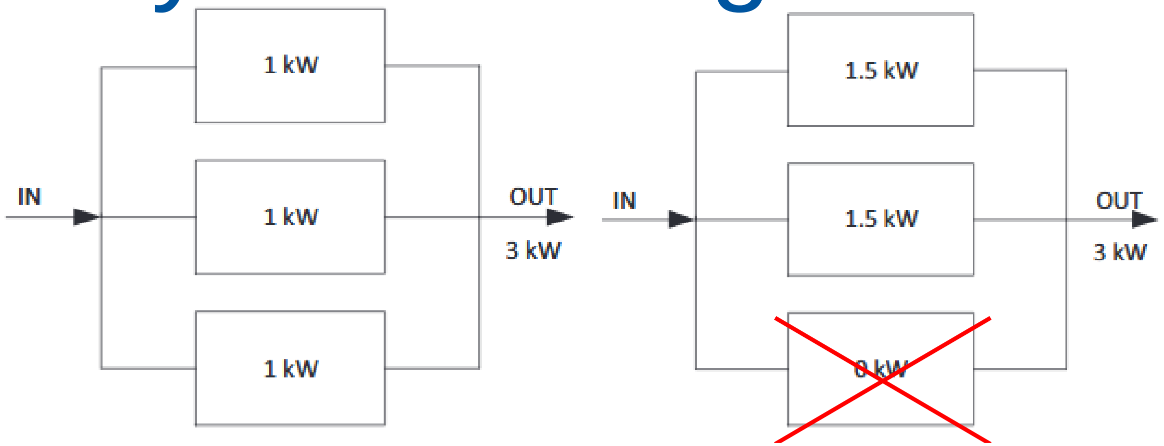
Redundancy	Collision time
None	14 min
1 cavity	1.5 h
2 cavities	Not limited by trips

Powering

- Solid state amplifier instead of klystrons?
- Enables build-in redundancy
- Soleil has 11 years of experience with excellent availability[2]

[1] R. W. Aßmann in CERN-SL-2001-003
[2] P. Marchand in IPAC2017

Critical systems: Magnet utilities



Powering

- Modular power converters have been developed for multiple accelerators
- Enables build-in redundancy where failing module can be replaced in real time
- Diamond light source, years without PC beam trips[1] (Compare PS 188 in 2018)

Water cooling

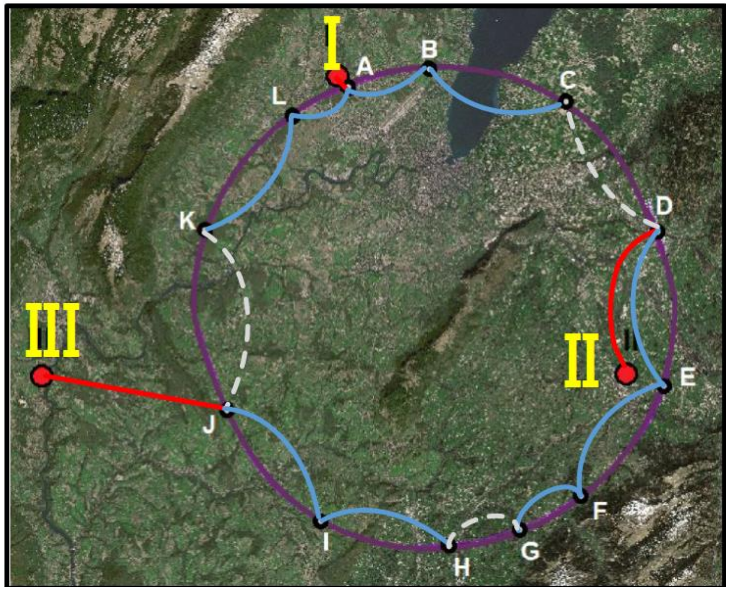
- Cooling failure **halts** magnet operations
- Modes e.g. blockage, water leak in connection or hose
- In SLAC, MTBF for a water cooled magnet 0.6 – 3 million h[(2)]
- FCC-ee & booster will have ~10000 magnets → With current rate: leak every 0.5 - 2 weeks

[1]V.C. Kempson in PAC 2017

[2]C. M. Spencer & S. J. Rhee in PAC 2003

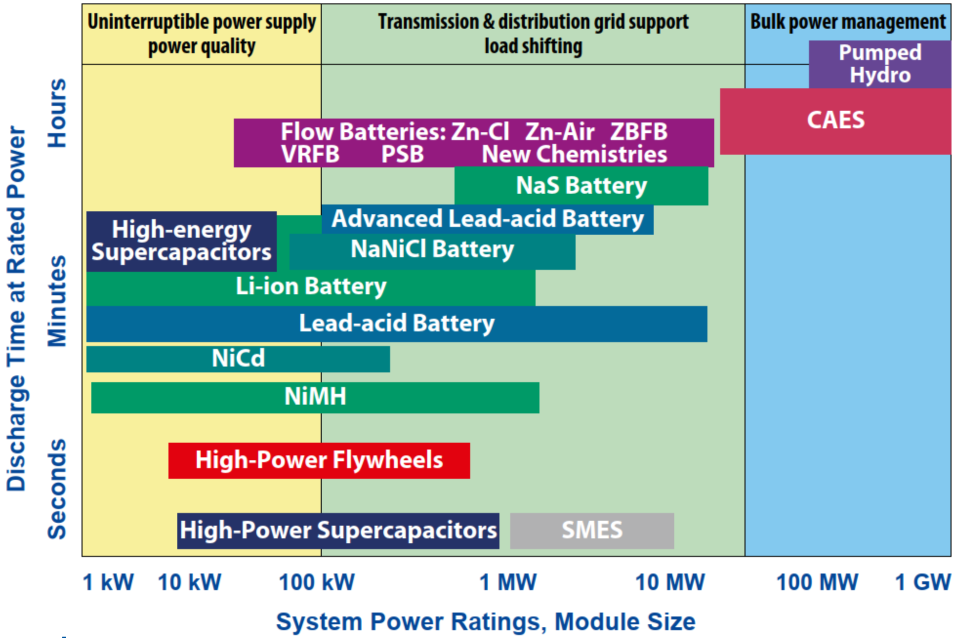
Critical systems: Electricity distribution

- CERN complex experience:
  - Few long failures per year (1 – several days)
  - Dozens of beam dumps per year due to lightning strikes
- FCC will have multiple grid connections → Risk that event frequency scales up
- DC-grid with buffers is a potential solution to power dips



Critical systems: Energy storage

- Booster ring will have cycle time of 5 – 50 s
- Potential strain for network (~60MW)
- Might necessitate use of an energy storage

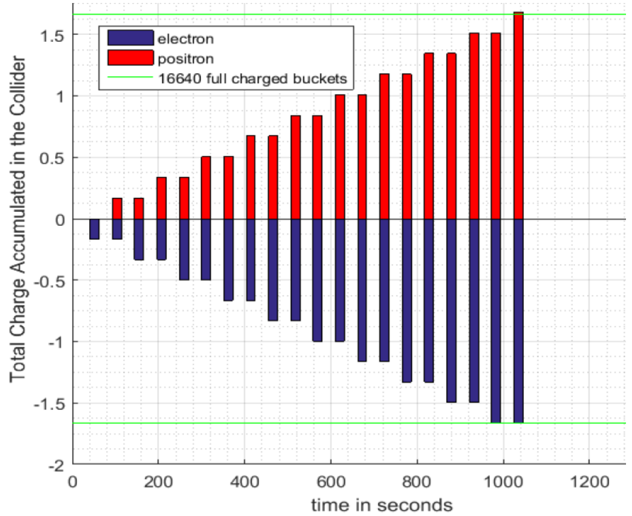


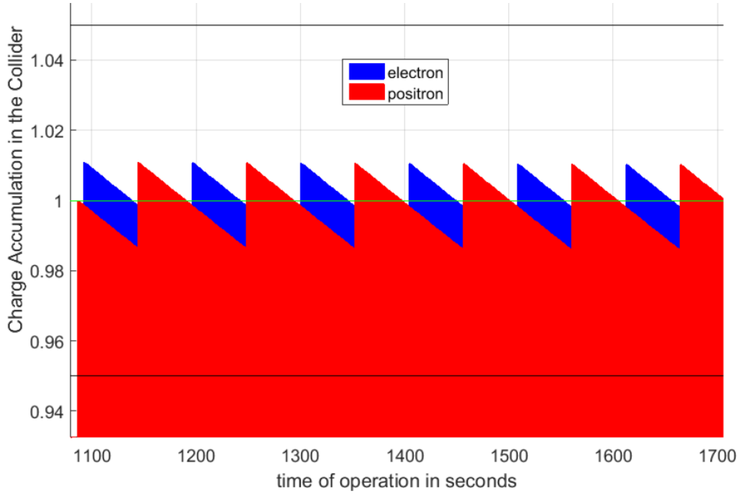
- Multiple ways to implement:
  - CERN's PS has had flywheel & capacitor based storages
  - Studies on use of SMES as a reserve power source in DESY & J-PARC

*Based on ~10 years old image

Operational effectiveness

- Fill time for Z run about 18 min
  - 3 fills/day ~5% loss in efficiency
  - Note: Luminosity production starts during the fill
- After fill production level is maintained
  - Currently ~5% bunch asymmetry budget for filled machine





Bunch charge asymmetry

- SPS-LHC injections 20% are rejected, reasons:
  - Machine protection
  - Beam quality requirements
- Probably much less severe in FCC-ee
- LHC Injector complex experience: High number of short failures:
  - Under 1 min failures: not recorded systematically
  - 1-5 min: 430 occurrences in ~200 days
  - Over 5 min: 631 occurrences in ~200 days
- Short disruptions will occur also in FCC-ee
- **Necessary to understanding the effects to the operations & luminosity production → Criticality of injector failures**

Conclusions

- Lepton colliders have operated with high availability
- FCC-ee has several key systems where build-in redundancies can increase availability
- **Recommendation:** Identify & document potential risks & solutions for availability
  - ➢ Helps to focus research on solving issues

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