# Availability and Reliability Issues for the XFEL

Tom Himel
SLAC/DESY

Presented at XFEL/ILC joint meeting 14Nov07

# Contents

- Introduction and purpose of studies
- The availability simulation
- Wake up ILC people
- What was modeled (important assumptions)
- Some results
- Conclusions

# Introduction

- Availsim is a Monte Carlo simulation developed over several years for linear collider studies.
- Given a component list and MTBFs and MTTRs and degradations it simulates the running and repairing of an accelerator.
- It can be used as a tool to compare designs and set requirements on redundancies and MTBFs.
- It has now been applied to the XFEL.

# Why a simulation?

- We chose to go with a simulation instead of a spreadsheet calculation for the following reasons:
  - Including tuning and recovery times in a spreadsheet calculation is difficult.
  - Fixing many things at once (during an access) is also difficult to put in a simple spreadsheet formula.
  - If later, one wants to more carefully model luminosity degradation on recovery from downtimes a simulation is simpler
  - A disadvantage of a simulation is its use of random numbers so one needs high enough statistics to get a meaningful answer. This is particularly a concern if one wants to compare two slightly different cases.
    - Random number seeds are handled in a way to allow meaningful comparisons of similar cases.
    - A 20 year simulation which gives good enough statistics takes 90 seconds on my laptop

# The Simulation includes:

1. Effects of redundancy such as 21 DR kickers where only 20 are needed or the large energy overhead in the main linac
2. Some repairs require accelerator tunnel access, others can't be made without killing the beam and others can be done hot.
3. Time for radiation to cool down before accessing the tunnel
4. Time to lock up the tunnel and turn on and standardize power supplies
5. Recovery time after a down time is proportional to the length of time a part of the accelerator has had no beam. Recovery starts at the injectors and proceeds downstream.
6. Manpower to make repairs can be limited.

# The Simulation includes:

7. Opportunistic Machine Development (MD) is done when part of the accelerator is down but beam is available elsewhere for more than 2 hours.
8. MD is scheduled to reach a goal of 1 - 2% in each region of the accelerator.
9. All regions are modeled in detail down to the level of magnets, power supplies, power supply controllers, vacuum valves, BPMs …
10. The cryoplants and AC power distribution are not modelled in detail.
11. Non-hot maintenance is only done when the accelerator is broken.  Extra non-essential repairs are done at that time though.  Repairs that give the most bang for the buck are done first.

# The Simulation includes:

12. PPS zones are handled properly e.g. can access linac when beam is in the injector. It assumes there is a tuneup dump at the end of each region.
13. Kludge repairs can be done to ameliorate a problem that otherwise would take too long to repair. Examples: Tune around a bad quad in the cold linac or disconnect the input to a cold power coupler that is breaking down.
14. During the long (1 month) shutdown, all devices with long MTTR's get repaired.

# Wake Up ILC people

# ILC – XFEL – SyncLight differences

| | ILC | XFEL | SyncLight |
|---|---|---|---|
| Expt. Duration | years | week | shift |
| Care about | int lum | unsched downs | unsched downs |
| Allowed unsched downtime (%) | 25 | 10 (e- only) | 5 |
| Budgeted unsched downtime (%) | 15 | 7 (e- only) | |
| Downtime held as Contingency % | 10 | 3 | |
| Scheduled maintenance days | none | 2 wks 8+4 | |
| Run length (months) | 9 | 11 | |
| Num. of components (thousands) | 250 | 17 | |
| Cost (accel+expts) ($B) | 7.6 | 1.4 | |
| cool down time (minutes) | 60 | 15 | |
| access recovery time (minutes) | 60 | 30 | |

# Scheduled Maintenance Days

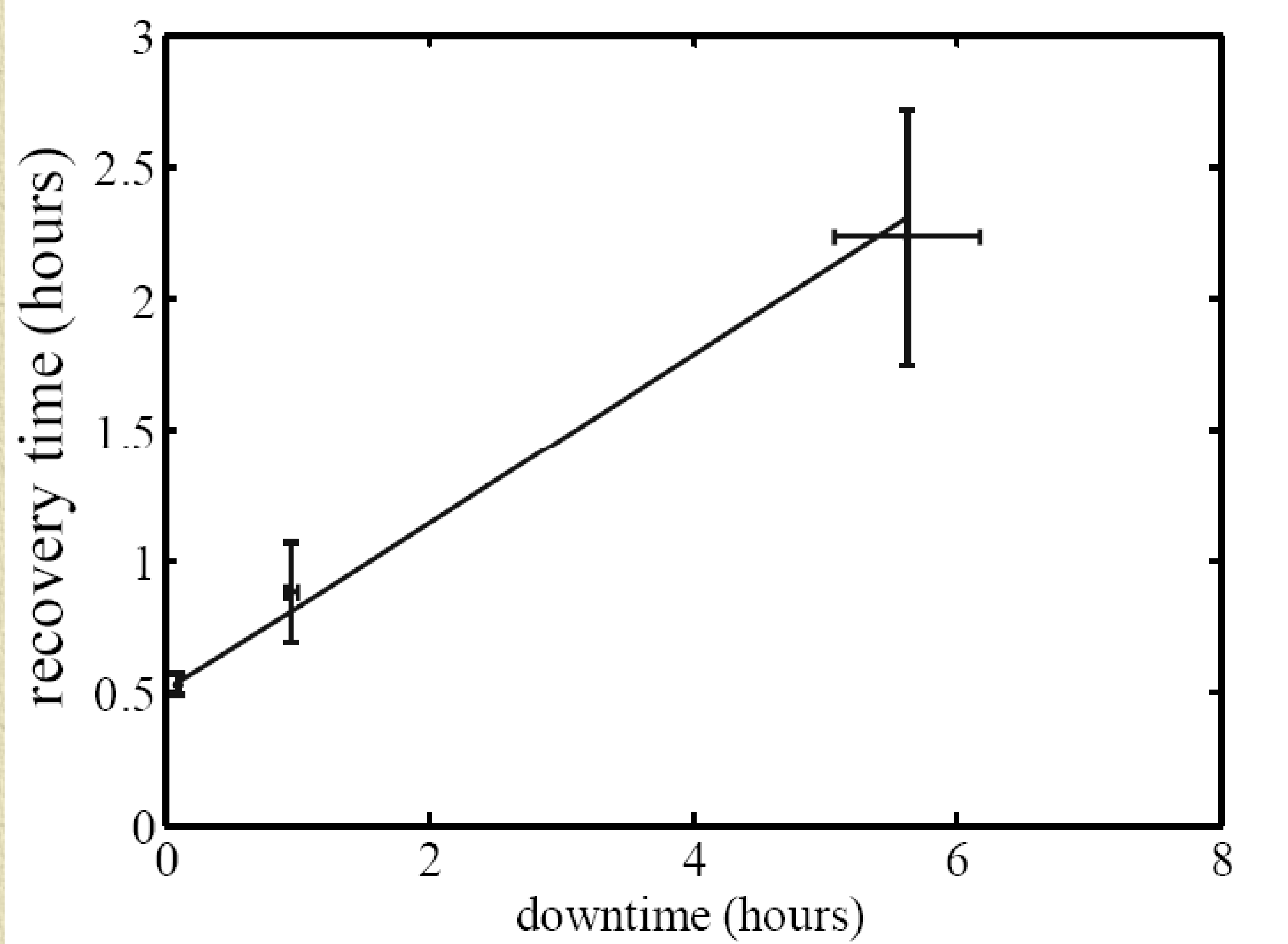
- New feature added for XFEL
- Regular shutdown for repairs/maintenance
- Counts as scheduled downtime, not unscheduled. Better for short term users.
- All repairs which can be completed with available manpower in available time are done. Most bang for buck first.
- Maintenance items (e.g. cleaning filters) which don't break things are not simulated.
- If recovery is longer than scheduled, extra is unscheduled down.
- If recovery is > 2 hours early, opportunistic MD is done.
- If we were down at beginning of maintenance day, remaining down is changed to scheduled.

# Mined data from old accelerators

| Component | MTBF (hr) | MTTR (hr) | comment |
|---|---|---|---|
| Water cooled magnet | 1,000,000 | 8 | Average from SLC. There have been magnet families with MTBF > 13,000,000 |
| Air cooled magnets | 10,000,000 | 2 | SLC |
| Super conducting magnet | 10,000,000 | 472 | MTBF given is 10 times that of Tevatron dipole magnet as the SC quads in ILC are much lower current. We assumed a failed SC quad would be tuned around in 2 hrs as a kludge repair |
| Kicker pulsar | 10,000 | 2 | SLC |
| Magnet Power supplies | 50,000 | 2 or 4 | SLAC and FNAL average. The larger MTTR is for large not easily replaceable supplies |
| Electronics modules | 100,000 | 1 | This is a crude average over many types of electronics modules |
| Water flow switch | 250,000 | 1 | SLAC |
| Movable collimators and stoppers and valves | 100,000 | 8 | SLAC |
| DR klystron | 30,000 | 8 | SLAC |
| Linac Modulator | 50,000 | 4 | SLAC |

- MTBF data for accelerator components is scarce and varies widely

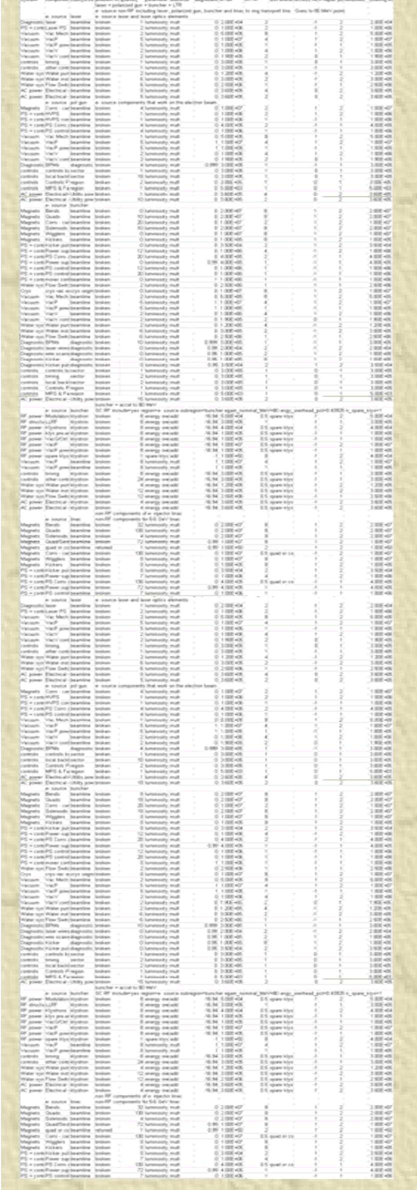
# Recovery Time for PEP-II

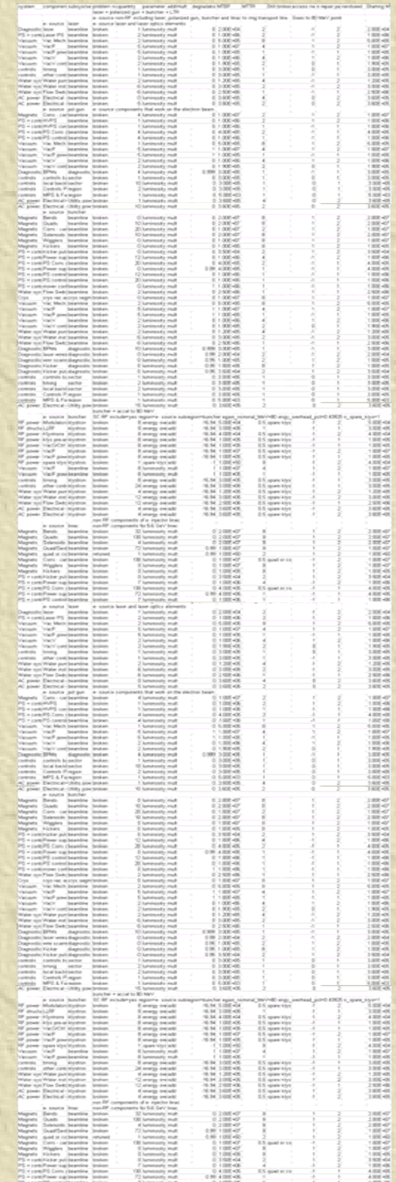


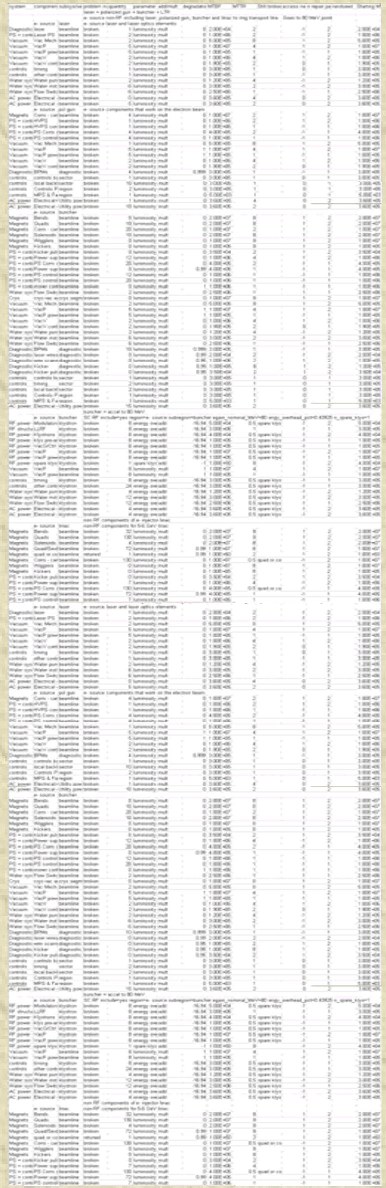
# List of sub-decks

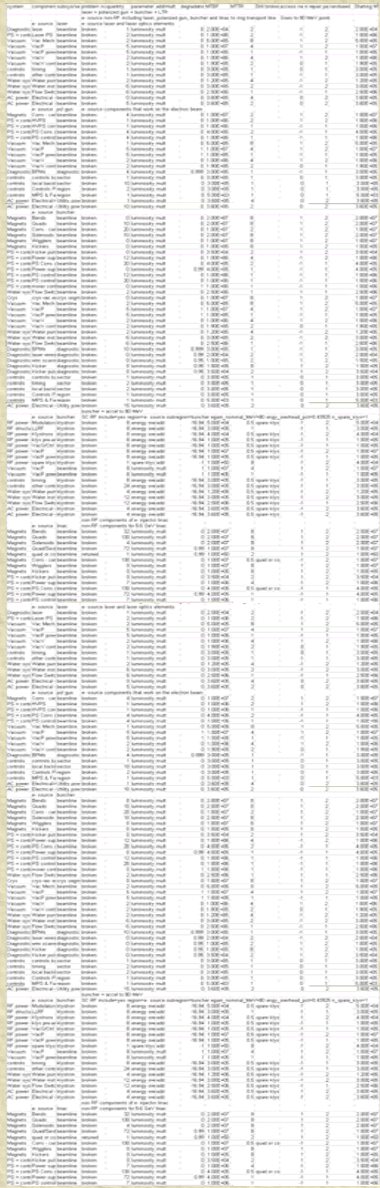
| sheet | include | region | subregion | egain_nominal_MeV | ncavities_section | n_spare_klys | description |
|---|---|---|---|---|---|---|---|
| | injector 1 | | | | | | I1 + I1D |
| RF gun | yes | injector 1 | RF gun | | 1 | 0 | RF gun components including laser and klystron |
| inj | yes | injector 1 | linac | | | | non SCRF components of e- injector linac and dump |
| cryomodule | yes | injector 1 | linac | 130 | 8 | 0 | SCRF components of e- injector linac |
| | compressor 1 | | | | | | L1+B1+B1D |
| compressor 1 | yes | compressor 1 | | | | | non RF compressor 1 hardware |
| cryomodule | yes | compressor 1 | linac | 370 | 32 | 0 | RF for L1 in front of compressor 1 |
| | compressor 2 | | | | | | L2+B2+B2D |
| compressor 2 | yes | compressor 2 | | | | | non RF compressor 2 hardware |
| cryomodule | yes | compressor 2 | linac | 1,500 | 96 | 0 | RF for L1 in front of compressor 1 |
| | main linac | | | | | | L3 |
| main linac | yes | main linac | | | | | main linac |
| cryomodule | yes | main linac | | 18,000 | 800 | 0 | RF for main e- linac |
| | collimation | | | | | | CL+TL+TLD+T1 |
| collimation | yes | main linac | | | | | Collimation, transport, dump |
| | SASE 1 | | | | | | SASE 1 + SASE 3 = T2 + SA1 + T4 + SA3 + T4D |
| SASE 1 | yes | SASE 1 | | | | | Collimation, transport, dump |
| | SASE 2 | | | | | | SASE2 + U1 + U2 = SA2 + T3 + UN1 + T5 + UN2 + T5D |
| SASE 2 | yes | SASE 2 | | | | | Collimation, transport, dump |

# Full list of Components









| system | componen | subsys/se | problem na | quantity | parameter | add/mult | degradatio | MTBF | MTTR | Still broken | access ne | n repair pe | randseed | Starting M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | laser + polarized gun + buncher + LTR | | | | | | | | | | | |
| | | | e- source non-RF including laser, polarized gun, buncher and linac to ring transport line. Goes to 80 MeV point. | | | | | | | | | | | |
| | e- source | laser | e- source laser and laser optics elements | | | | | | | | | | | |
| Diagnostic | laser | beamline | broken | 1 | luminosity | mult | 0 | 2.00E+04 | 2 | | -1 | 2 | | 2.00E+04 |
| PS + conti | Laser PS | beamline | broken | 2 | luminosity | mult | 0 | 1.00E+06 | 2 | | -1 | 2 | | 1.00E+06 |
| Vacuum | Vac Mech | beamline | broken | 2 | luminosity | mult | 0 | 5.00E+05 | 8 | | 1 | 2 | | 5.00E+05 |
| Vacuum | VacP | beamline | broken | 5 | luminosity | mult | 0 | 1.00E+07 | 4 | | 1 | 2 | | 1.00E+07 |
| Vacuum | VacP pow | beamline | broken | 5 | luminosity | mult | 0 | 1.00E+05 | 1 | | -1 | 1 | | 1.00E+05 |
| Vacuum | VacV | beamline | broken | 2 | luminosity | mult | 0 | 1.00E+06 | 4 | | 1 | 2 | | 1.00E+06 |
| Vacuum | VacV cont | beamline | broken | 2 | luminosity | mult | 0 | 1.90E+05 | 2 | | 0 | 1 | | 1.90E+05 |
| controls | timing | beamline | broken | 1 | luminosity | mult | 0 | 3.00E+05 | 1 | | 0 | 1 | | 3.00E+05 |
| controls | other contr | beamline | broken | 1 | luminosity | mult | 0 | 3.00E+05 | 1 | | -1 | 1 | | 3.00E+05 |
| Water sys | Water pum | beamline | broken | 2 | luminosity | mult | 0 | 1.20E+05 | 4 | | -1 | 2 | | 1.20E+05 |
| Water sys | Water inst | beamline | broken | 6 | luminosity | mult | 0 | 3.00E+05 | 2 | | -1 | 2 | | 3.00E+05 |
| Water sys | Flow Switc | beamline | broken | 6 | luminosity | mult | 0 | 2.50E+06 | 1 | | -1 | 1 | | 2.50E+06 |
| AC power | Electrical - | beamline | broken | 0 | luminosity | mult | 0 | 3.60E+05 | 4 | | 0 | 2 | | 3.60E+05 |
| AC power | Electrical - | beamline | broken | 5 | luminosity | mult | 0 | 3.60E+05 | 2 | | 0 | 2 | | 3.60E+05 |
| | e- source | pol gun | e- source components that work on the electron beam | | | | | | | | | | | |
| Magnets | Corrs - car | beamline | broken | 4 | luminosity | mult | 0 | 1.00E+07 | 2 | | 1 | 2 | | 1.00E+07 |
| PS + conti | HVPS | beamline | broken | 1 | luminosity | mult | 0 | 1.00E+06 | 2 | | 1 | 2 | | 1.00E+06 |
| PS + conti | HVPS con | beamline | broken | 1 | luminosity | mult | 0 | 1.00E+06 | 1 | | -1 | 1 | | 1.00E+06 |
| PS + conti | PS Corrs c | beamline | broken | 4 | luminosity | mult | 0 | 4.00E+05 | 2 | | -1 | 1 | | 4.00E+05 |
| PS + conti | PS control | beamline | broken | 4 | luminosity | mult | 0 | 1.00E+06 | 1 | | -1 | 1 | | 1.00E+06 |
| Vacuum | Vac Mech | beamline | broken | 1 | luminosity | mult | 0 | 5.00E+05 | 8 | | 1 | 2 | | 5.00E+05 |
| Vacuum | VacP | beamline | broken | 5 | luminosity | mult | 1 | 1.00E+07 | 4 | | 1 | 2 | | 1.00E+07 |
| Vacuum | VacP pow | beamline | broken | 5 | luminosity | mult | 1 | 1.00E+05 | 1 | | -1 | 1 | | 1.00E+05 |
| Vacuum | VacV | beamline | broken | 2 | luminosity | mult | 0 | 1.00E+06 | 4 | | 1 | 2 | | 1.00E+06 |
| Vacuum | VacV cont | beamline | broken | 2 | luminosity | mult | 0 | 1.90E+05 | 2 | | 0 | 1 | | 1.90E+05 |
| Diagnostic | BPMs | diagnostic | broken | 4 | luminosity | mult | 0.999 | 3.00E+05 | 1 | | -1 | 1 | | 3.00E+05 |
| controls | controls ba | sector | broken | 1 | luminosity | mult | 0 | 3.00E+05 | 1 | | 0 | 1 | | 3.00E+05 |
| controls | local backl | sector | broken | 10 | luminosity | mult | 0 | 3.00E+05 | 1 | | 0 | 1 | | 3.00E+05 |
| controls | Controls P | region | broken | 2 | luminosity | mult | 0 | 3.00E+05 | 1 | | 0 | 1 | | 3.00E+05 |
| controls | MPS & Fa | region | broken | 1 | luminosity | mult | 0 | 5.00E+03 | 1 | | 0 | 1 | | 5.00E+03 |
| AC power | Electrical> | Utility pow | broken | 1 | luminosity | mult | 0 | 3.60E+05 | 4 | | 0 | 2 | | 3.60E+05 |
| AC power | Electrical - | Utility pow | broken | 10 | luminosity | mult | 0 | 3.60E+05 | 2 | | 0 | 2 | | 3.60E+05 |
| | e- source | buncher | | | | | | | | | | | | |
| Magnets | Bends | beamline | broken | 0 | luminosity | mult | 0 | 2.00E+07 | 8 | | 1 | 2 | | 2.00E+07 |
| Magnets | Quads | beamline | broken | 10 | luminosity | mult | 0 | 2.00E+07 | 8 | | 1 | 2 | | 2.00E+07 |
| Magnets | Corrs - car | beamline | broken | 20 | luminosity | mult | 0 | 1.00E+07 | 2 | | 1 | 2 | | 1.00E+07 |
| Magnets | Solenoids | beamline | broken | 10 | luminosity | mult | 0 | 2.00E+07 | 8 | | 1 | 2 | | 2.00E+07 |
| Magnets | Wigglers | beamline | broken | 0 | luminosity | mult | 0 | 1.00E+07 | 8 | | 1 | 2 | | 1.00E+07 |

# Starting Modeling Assumptions (XFEL/ILC)

- The full complement of 117 cryomodules is installed.
- (Only 3 upstream /all) klystrons+modulators are accessible.
- Accelerator can run with any other klystron off.
- (Few/Most) electronics modules can be hot swapped.
- Tune up dump and shielding between each part of accelerator
- Global controls causes (0.2/0.2)% downtime
- Global water system causes (0.2/0.0)% downtime
- Some cryoplant is down 1% including outages due to their incoming utilities. There is (1/6) cryoplant.
- Major power circuits cause (0.5/0.5)% downtime

# Starting Modeling Assumptions (XFEL/ILC)

- Power coupler interlock electronics and sensors (do not have / have) MTBF of 1E6 due to redundancy.
- Cavity tuner motors have MTBF of 1E6, 2 times better than SLAC warm experience and MUCH better than TTF experience.
- Failed linac quads can be tuned around in 2 hours
- Most failed correctors can be tuned around in 0.5 hours
- LLRF, klystron support electronics, SC quad supplies (are/are not) in accel tunnel. Other power supplies are accessible
- Hot spare klystron/modulator with waveguide switches in (no/low energy) linac regions
- Magnet power supply MTBF of (50,000 for most magnets and 100,000 for SC magnets whose supplies are in the tunnel/200,000 ). ILC assumed redundant regulators.
- It takes (6/8) hours to replace a klystron

# Initial downtime causes

| Sum of % down * 100 | |
|---|---|
| comp name | Total |
| cryo plant beamline | 127.3 |
| Kicker pulser beamline | 104.9 |
| coupler interlock electronics coupler | 100.6 |
| coupler interlock sensors coupler | 99.8 |
| Power supplies strings beamline | 97.1 |
| Power supplies SC quad beamline | 65.5 |
| site power beamline | 65.2 |
| Quads beamline | 49.9 |
| Flow Switch - quads beamline | 44.0 |
| Electrical - .05<<0.5 Utility power | 35.1 |
| Vac Mech device beamline | 34.7 |
| PS controller - corr can tune around beamline | 34.5 |
| PS controller SC quad beamline | 27.8 |
| Central Water beamline | 25.2 |
| Kickers beamline | 24.8 |
| local backbone sector | 24.7 |
| Controls sitewide beamline | 23.1 |
| PS controller string beamline | 23.1 |
| schedMaintn | 17.9 |
| Klystrons klystron | 17.4 |

24 electronic cards + 6*24 sensors per RF unit – any failure trips it off

Lumped systems

Total XFEL downtime = 11.6% where budget = 7%

Total ILC downtime = 31% where budget = 15%, but ILC started with some components assumed better than now

# Needed XFEL MTBF Improvements

| Device | Needed Improvement factor | Downtime (%) due to these devices | Nominal MTBF (hours) | Nominal MTTR (hours) |
|---|---|---|---|---|
| coupler interlock electronics | **10** | 0.1 | 100,000 | 1 |
| coupler interlock sensors | **10** | 0.1 | 600,000 | 1 |
| power supplies - string | **5** | 0.2 | 50,000 | 2 |
| power supplies SC quads | **2** | 0.3 | 100,000 | 1 |
| add redundant kicker + Pulsar | **12->13** | 0.2 | 7,000 | 2 |
| flow switch | **3** | 0.2 | 250,000 | 1 |
| local controls backbone - sector | | 0.3 | 100,000 | 1 |
| cryoplant | | 1.4 | | |
| site power | | 0.7 | | |
| controls - global | | 0.2 | | |
| central water plant | | 0.2 | | |
| schedule maintenance overrun | | 0.2 | | |
| klystrons | | 0.2 | 40,000 | 6 |
| regional MPS system | | 0.2 | 5,000 | 1 |

# Comments on MTBF improvements

- There are 6 coupler sensors and interlock electronics channels per coupler with no redundancy. Not surprising it is a problem. However, not problem at FLASH, so maybe MTBF of 100k hours per 6 channel electronics card is too short? Can one require 2 problems before tripping (ILC assumes this)?
- Kicker problem easily fixed with extra kicker and pulser. Was already OK for 17.5 GeV energy
- Power supplies are single points of failure, commonly a problem in accelerators.
  - APS gets MTBF of 560,000 hrs, 10 times greater than SLAC/FNAL/DESY.
  - They stress the supplies before each run and monitor internal temperatures and voltages so degrading components can be replaced on scheduled maintenance days.

# Needed ILC MTBF Improvements

| Device | Needed Improvement factor | Downtime (%) due to these devices | Nominal MTBF (hours) | Nominal MTTR (hours) |
|---|---|---|---|---|
| power supplies | **20** | 0.2 | 50,000 | 2 |
| power supply controllers | **10** | 0.6 | 100,000 | 1 |
| flow switches | **10** | 0.5 | 250,000 | 1 |
| water instrumention near pump | **10** | 0.2 | 30,000 | 2 |
| magnets - water cooled | **6** | 0.4 | 3,000,000 | 8 |
| kicker pulser | **5** | 0.3 | 100,000 | 2 |
| coupler interlock sensors | **5** | 0.2 | 1,000,000 | 1 |
| collimators and beam stoppers | **5** | 0.3 | 100,000 | 8 |
| all electronics modules | **3** | 1.0 | 100,000 | 1 |
| AC breakers < 500 kW | | 0.8 | 360,000 | 2 |
| vacuum valve controllers | | 1.1 | 190,000 | 2 |
| regional MPS system | | 1.1 | 5,000 | 1 |
| power supply - corrector | | 0.9 | 400,000 | 1 |
| vacuum valves | | 0.8 | 1,000,000 | 4 |
| water pumps | | 0.4 | 120,000 | 4 |
| modulator | | 0.4 | 50,000 | 4 |
| klystron - linac | | 0.8 | 40,000 | 8 |
| coupler interlock electronics | | 0.4 | 1,000,000 | 1 |
| vacuum pumps | | 0.9 | 10,000,000 | 4 |
| controls backbone | | 0.8 | 300,000 | 1 |

# XFEL Simulation Results

| Run Number | XFEL description | Simulated % unsched time down incl forced MD | Simulated % time fully up taking data or sched MD | Simulated % scheduled maintenance |
|---|---|---|---|---|
| XFEL1 | TDR 20 GeV 8 + 4 sched down every 2 weeks | 11.6 | 84.8 | 3.5 |
| XFEL2 | XFEL1 but 17.5 GeV | 10.0 | 86.4 | 3.5 |
| XFEL3 | XFEL1 but MTBF table A | 7.0 | 89.4 | 3.5 |
| XFEL4 | XFEL3 but no sched down | 7.3 | 92.7 | 0.0 |
| XFEL5 | XFEL3 but sched down every 4 weeks | 7.1 | 91.1 | 1.8 |
| XFEL6 | XFEL3 but 8 + 8 hour sched down | 6.6 | 88.6 | 4.7 |

# For ILC availSim used as input for many design decisions

- Putting both DR in a single tunnel only decreased int lum by 1%. -- OK
- Is a hot spare e+ target line needed? -- Not if e+ target can be replaced in the specified 8 hours
- Confirm that 3% energy overhead is adequate in the linac.
- Showed that hot spare klystrons and modulators are needed where a single failure would prevent running.
- Showed 7% availability loss for single tunnel.

# For XFEL points out potential problems

- I've chosen particular items to improve.
- Project needs to look for optimum (cheapest, lowest risk) solution
- Could the cryoplant or site power be made more reliable than assumed?
- Can coupler interlocks require 2 problems before tripping?

# Benchmarking the Simulation

- A limited benchmark was done with HERA data. Using MTBFs and component counts taken from HERA as input, it correctly calculated the number of failures.
- Fancier features like repair time scheduling and recovery time have not been benchmarked.
  - Getting together list of components is real work.
  - MTBFs and MTTRs should be taken from accelerator under study. 50% errors easily happen. Real work.
  - Recovery time is usually accounted as "tuning" instead of downtime.
  - Often repairs are accounted as "scheduled downtime"
- Simulation results seem reasonable. Back-of-the-envelope checks are OK.
- Most important results are comparisons of two slightly different accelerators. Systematic errors cancel.

# Conclusions

- Component availability for ILC is a major challenge.  Must do R&D, plan, and budget for it up-front.
- For XFEL, it is not past state-of-the-art, but more attention must be paid to it than for a typical HEP accelerator.
- X-ray beam-lines have not been modeled. They have few parts but with unknown reliabilities.
- This simulation is a useful design tool for the ILC and XFEL and other accelerators.  Code is available.