Availability and Reliability Issues for the ILC

Tom Himel
SLAC

Presented at PAC07 26 June 07

Contents

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

Co-conspirators

- Eckhard Elsen
- Tom Himel
- Janice Nelson
- Marc Ross
- Sebastian Schaetzel
- John Sheppard

Introduction (1 of 2)

- The ILC will be an order of magnitude more complex than most present accelerators.
- If it is built like present HEP accelerators, it will be down an order of magnitude more.
- That is, it will always be down.
- The integrated luminosity will be zero.
- Not good.

Introduction (2 of 2)

- Availsim is a Monte Carlo simulation developed over several years.
- 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.

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 3% 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 LC 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 LC.
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 LC 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:

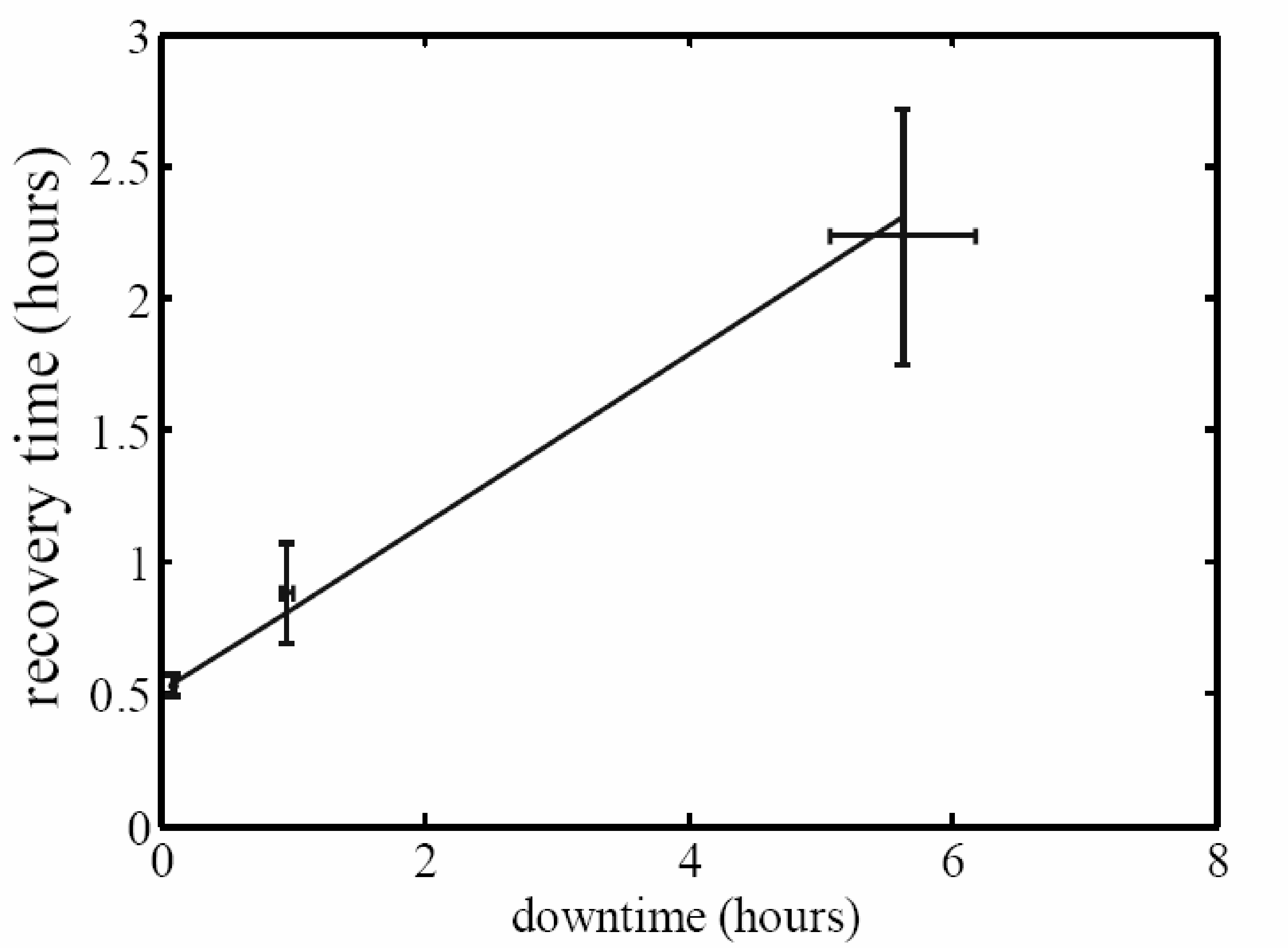
12. PPS zones are handled properly e.g. can access linac when beam is in the DR. It assumes there is a tuneup dump at the end of each region.
13. Kludge repairs can be done to ameliorate a problem that otherwise would take too long to repair. Examples: Tune around a bad quad in the cold linac or a bad quad trim in either damping ring or disconnect the input to a cold power coupler that is breaking down.
14. During the long (3 month) shutdown, all devices with long MTTR’s get repaired.

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

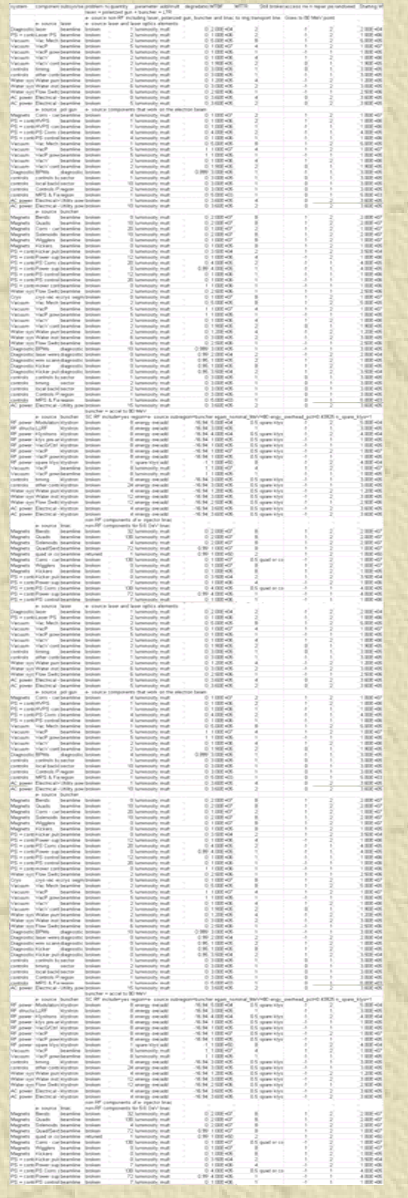
Recovery Time for PEP-II

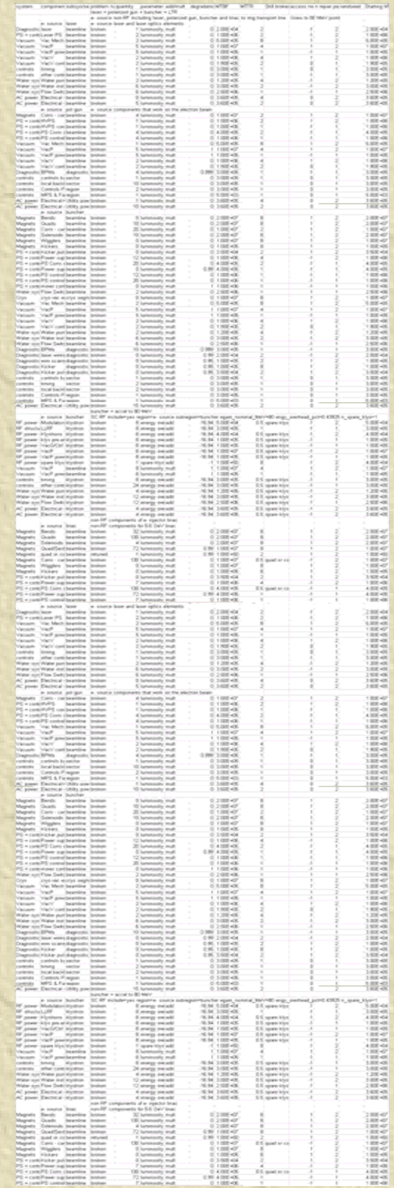


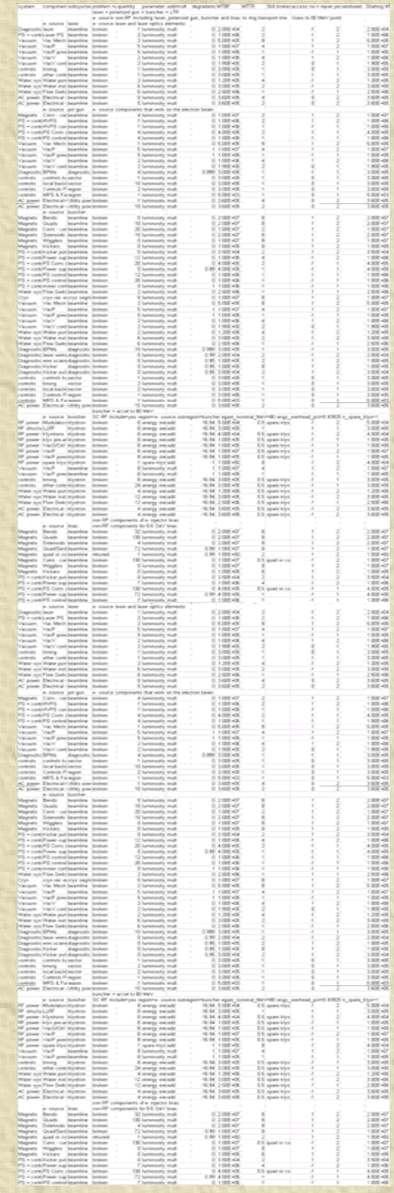
List of sub-decks

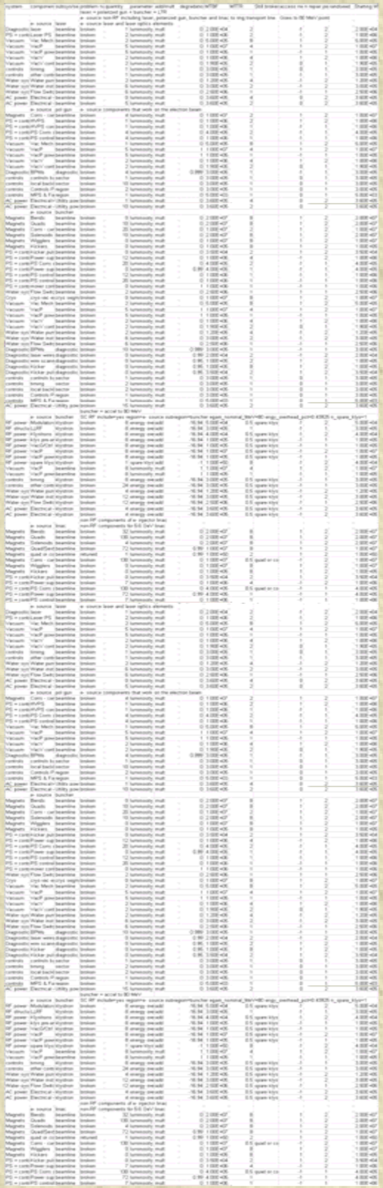
sheet	include	region	subregion	egain_nominal_MeV	engy_overhead_pct	n_spare_klys	description
	Electron injector						
e- source	yes	e- source					laser + polarized gun + buncher + LTR
warm RF	yes	e- source	buncher	80	0.44	1	buncher + accel to 80 MeV
inj	yes	e- source	linac				non RF components of e- injector linac
cryomodule	yes	e- source	linac	4,920	0.05	1	RF components of e- injector linac
	e- damping ring						
DR	yes	e- DR					All e- damping ring components
	e- compressor						
compressor	yes	e- compressor					non RF e- compressor hardware
cryomodule	yes	e- compressor		7,500	0.79	1	RF for e- compressor
	e- linac						
main linac	yes	e- linac					main e- linac
cryomodule	no	e- linac		237,500	0.06	0	RF for main e- linac without undulator (conventional e+ sourc
cryomodule	yes	e- linac	upstream	137,500	0.06	0	RF upstream of undulator in main e- linac
cryomodule	yes	e- linac	downstream	105,232	0.03	0	RF downstream of undulator in main e- linac. Includes 7 klyst
	e- Beam Delivery System						
BDS	yes	e- BDS					e- Beam Delivery System
cryomodule	yes	e- BDS	crab cavities	10	3.21	1	crab cavities
	e+ source (conventional - unpolarized)						
e+ source conv	no	e+ source					laser + RF gun + target
warm RF	no	e+ source	RF gun	7	4.55	1	RF for RF gun
cryomodule	no	e+ source	buncher	80	0.44	1	buncher + accel to 80 MeV
inj	no	e+ source	e- drive linac				non RF components of e- drive linac for conventional positron
cryomodule	no	e+ source	e- drive linac	5,920	0.05	1	RF of e- drive linac for conventional positron production
cryomodule	no	e+ source	rf separator 1	230	0.19	1	rf separater upstream of the multiple targets
warm RF	no	e+ source	after target	250	0.17	1	accelerate e+ after target with warm RF
cryomodule	no	e+ source	rf separator 2	230	0.19	1	rf separater downstream of the multiple targets
inj	no	e+ source	e+ linac				non RF components of e+ injector linac for conventional posit
cryomodule	no	e+ source	e+ linac	4,920	0.05	1	RF of e+ injector linac for conventional positron production
	e+ source (polarized using an undulator in the e- linac)						
e+ source pol	yes	e+ source					undulator + target + turnarounds + long transport

Full list of Components









system	componen	subsys/se	problem na	quantity	parameter	add/mult	degradatio	MTBF	MTTR	Still broker	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

- When klystrons are not in accelerator tunnel, they can be hot swapped.
- Most electronics modules not in accelerator tunnel can be hot swapped.
- Tune up dump and shielding between each part of accelerator
- Hot spare klystron/modulator with waveguide switches in all low energy linac regions
- Magnet power supply MTBF of 200,000 hours 4 times better than SLAC/Fermilab experience. Probably requires redundant regulators.

Starting Modeling Assumptions

- Power coupler interlock electronics and sensors 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. May require redundant motors or moving outside of cold volume.
- Each of the 6 cryo plants is up 99.85% including outages due to their incoming utilities. 3-6 times better than Fermilab and LEP.
- There is a spare e+ target beam-line with 8 hour switch-over
- Failed linac quads can be tuned around in 2 hours
- Most failed correctors can be tuned around in 0.5 hours

Needed 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

Need for a Keep-Alive e+ source

- The fact that high energy e- are needed to make e+ hurts the availability of the undulator e+ source for 4 reasons
  - Can't do MD simultaneously in e.g. e+ and e- DR
  - Can't do opportunistic MD in e.g. e+ linac when the e- linac is broken
  - Can't keep e+ system "hot" when e- are down, so extra tuning time is needed.
  - e- linac must have correct energy at both undulator and at the end.
- A keep-alive e+ source can ameliorate 3 of these problems.
- Improves % time int lum from 67 to 78%

Tunnel Configuration Study

Run Number	LC description	Simulated % time down incl forced MD	Simulated % time fully up integrating lum or sched MD	Simulated % time integrating lum	Simulated % time scheduled MD	Simulated % time actual opportunis tic MD	Simulated % time useless down	Simulated number of accesses per month
ILC8	everything in 1 tunnel; no robots ; undulator e+ w/ keep alive 2; Tuned MTBFs in table A	30.5	69.5	64.2	5.3	2.2	28.3	18.1
ILC9	1 tunnel w/ mods in support buildings; no robots; undulator e+ w/ keep alive 2; Tuned MTBFs in table A	26.5	73.5	68.1	5.5	2.0	24.4	11.1
ILC10	everything in 1 tunnel; with robotic repair ; undulator e+ w/ keep alive 2; Tuned MTBFs in table A	22.0	78.0	73.0	5.1	2.4	19.5	5.9
ILC11	2 tunnels w/ min in accel tunnel; support tunnel only accessible with RF off; undulator e+ w/ keep alive 2	22.9	77.1	72.3	4.8	2.7	20.2	3.7
ILC12	2 tunnels with min in accel tunnel; undulator e+ w/ keep alive 2; Tuned MTBFs in table A	17.0	83.0	78.3	4.8	2.8	14.2	3.4
ILC13	2 tunnels w/ some stuff in accel tunnel; undulator e+ w/ keep alive 2; Tuned MTBFs in table A	21.3	78.7	73.8	4.8	2.7	18.7	9.7
ILC14	2 tunnels w/ some stuff in accel tunnel w/ robotic repair; undulator e+ w/ keep alive 2; Tuned MTBFs in table A	17.0	83.0	78.2	4.8	2.8	14.3	3.5
ILC15	ILC9 but table B MTBFs and 6% linac energy overhead	14.7	85.3	79.4	6.0	1.5	13.1	5.6
ILC16	ILC15 but table C MTBFs and 3% linac energy overhead	15.2	84.8	79.2	5.6	1.9	13.3	6.5

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.

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 must be much better than ever before. Must do R&D, plan, and budget for it up-front.
- This is even more true if there is only 1 tunnel. Significant risk of not achieving it at first and having very rocky first few years of running.
- With undulator e+ source, a high bunch intensity keep-alive source is needed.
- This simulation is a useful design tool for both the ILC and other accelerators. Code is available.