# Availability and Reliability Issues for the ILC

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Presented at PAC07 26 June 07

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## **Co-conspirators**

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# 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:

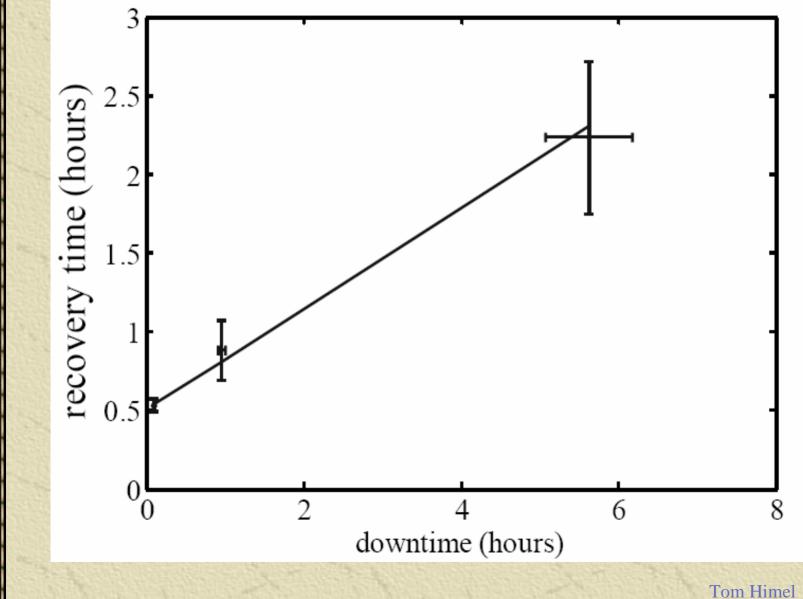
- 12. PPS zones are handled properly e.g. can access linac when beam is in the DR. It assumes there is a tuneup dump at the end of each region.
- 13. Kludge repairs can be done to ameliorate a problem that otherwise would take too long to repair. Examples: Tune around a bad quad in the cold linac or 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				
			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	100,000	8	SLAC				
stoppers and valves							
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**



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# List of sub-decks

sheet	include	region	subregion	egain_nomi nal_MeV	engy_over head_pct	n_spare klys	e description
	Electron i		Ű	_	_	,	
e- source	yes	e- source	and a state of the	12. 1. 2.	1.5.200	ROMES	laser + polarized gun + buncher + LTR
warm RF	yes	e- source	buncher	80	0.4	4	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	0.0	5	1 RF components of e- injector linac
	e- dampin	ng ring					
DR	yes	e- DR					All e- damping ring components
	e- compre	essor					
compressor	yes	e- compressor					non RF e- compressor hardware
cryomodule	yes	e- compressor		7,500	0.7	9	1 RF for e- compressor
	e- linac						
main linac	yes	e- linac					main e- linac
cryomodule	no	e- linac		237,500	0.0	6	0 RF for main e- linac without undulator (conventional e+ source
cryomodule	yes	e- linac	upstream	137,500	0.0	6	0 RF upstream of undulator in main e- linac
cryomodule	yes	e- linac	downstream	105,232	. 0.0	3	0 RF downstream of undulator in main e- linac. Includes 7 klyst
	e- Beam I	Delivery System					
BDS	yes	e- BDS					e- Beam Delivery System
cryomodule	yes	e- BDS	crab cavities	10	3.2	1	1 crab cavities
	e+ source	e (conventional -	unpolarized)				
e+ source conv	no	e+ source					laser + RF gun + target
warm RF	no	e+ source	RF gun	7			1 RF for RF gun
cryomodule	no	e+ source	buncher	80	0.4	4	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			1 RF of e- drive linac for conventional positron production
cryomodule	no	e+ source	rf separator 1	230			1 rf separater upstream of the multiple targets
warm RF	no	e+ source	after target	250	0.1	7	1 accelerate e+ after target with warm RF
cryomodule	no	e+ source	rf separator 2	230	0.1	9	1 rf separater downstream of the multiple targets
inj	no	e+ source	e+ linac				non RF components of e+ injector linac for conventional positi
cryomodule	no	e+ source	e+ linac	4,920		5	1 RF of e+ injector linac for conventional positron production
	e+ source	e (polarized using	an undulator i	n the e- linac)			
e+ source pol	yes	e+ source					undulator + target + turnarounds + long transport

## Full list of Components

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system	componen	subsys/se	problem na	quantity	parameter	add/mult	degradatio	MTBF	MTTR Still bro	ker access ne	n repair pe randseed	Starting M
			laser + pola	arized gun	+ buncher	+ LTR						
			e- source n	ion-RF incl	uding laser	, polarized	gun, bunche	er and linac	to ring transport lin	e. Goesto80	) MeV point.	
	e- source	laser	e- source la	aser and la	ser 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 <sup>.</sup>	Water purr	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 Swite	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 c	omponents	s that work	on the elec	ctron 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 o	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 P		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		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 switchover
- \* Failed linac quads can be tuned around in 2 hours
- Most failed correctors can be tuned around in 0.5 hours

# Needed MTBF Improvements

	Downtime		
Needed	(%) due to	Nominal	Nominal
Improvement	these	MTBF	MTTR
factor	devices	(hours)	(hours)
20	0.2	50,000	2
10	0.6	100,000	1
10	0.5	250,000	1
10	0.2	30,000	2
6	0.4	3,000,000	8
5	0.3	100,000	2
5	0.2	1,000,000	1
5	0.3	100,000	8
3	1.0	100,000	1
	0.8	360,000	2
	1.1	190,000	2
	1.1	5,000	1
Section Constants	0.9	400,000	1
	0.8	1,000,000	4
	0.4	120,000	4
	0.4	50,000	4
	0.8	40,000	8
	0.4	1,000,000	1
	0.9	10,000,000	4
N BIOSENNESSIE	0.8	300,000	Tom Himel
	Improvement factor 20 10 10 10 10 6 5 5 5 5	Improvement factorthese devices200.2100.6100.5100.260.450.350.250.331.00.81.11.11.10.90.80.40.90.50.40.60.40.70.80.80.40.90.40.40.40.50.40.60.40.70.40.80.40.90.40.90.40.90.40.90.40.90.40.90.40.90.40.90.9	Needed         (%) due to         Nominal           Improvement         these         MTBF           factor         devices         (hours)           20         0.2         50,000           10         0.6         100,000           10         0.5         250,000           10         0.2         30,000           6         0.4         3,000,000           5         0.3         100,000           5         0.2         1,000,000           5         0.3         100,000           6         0.4         3,000,000           5         0.3         100,000           6         0.4         3,000,000           7         0.3         100,000           6         0.4         3,000,000           7         0.3         100,000           6         0.4         100,000           7         1.1         5,000           7         0.8         1,000,000           7         0.4         120,000           7         0.8         40,000           7         0.8         40,000           7         0.4         1,000,000 </td

#### 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.