LC Availability Simulation -- An Update with Concentration on e+ Source and Tunnel Configuration

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Contents

- Introduction and purpose of studies
- Recent improvements to availability simulation
- What was modeled (important assumptions)
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Introduction (1 of 3)

- The ILC will be an order of magnitude more complex than any accelerator ever built.
- 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 3)

- Availsim is a Monte Carlo simulation under development for 2 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.

Introduction (3 of 3)

- It includes
  - Component lists down to the level of magnets, power supplies, power supply controllers, and AC breakers
  - Tracking of energy overheads and DR kicker overhead (20 of 21 kickers)
  - Repairs need access or not or can be done hot
  - Cool-down and start-up time for accesses
  - PPS regions: beam in one, people in next
  - Downtime planning: fix things with most bang for the buck first. Fix more than just the item which caused the downtime.
  - Recovery time is proportional to the time without beam.
  - Machine development (opportunistic and scheduled)
  - Summary outputs which tell what regions and components caused the downtime.

Co-conspirators

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

Recently Widened Collaboration

- Have regular phone meetings with DESY
- Have web page:
  - from the SLAC ILC web page menu: Accelerator Design: Operations: Availability.
  - http://www-project.slac.stanford.edu/ilc/acceldev/ops/avail/
- Code is in CVS and available via above URL.

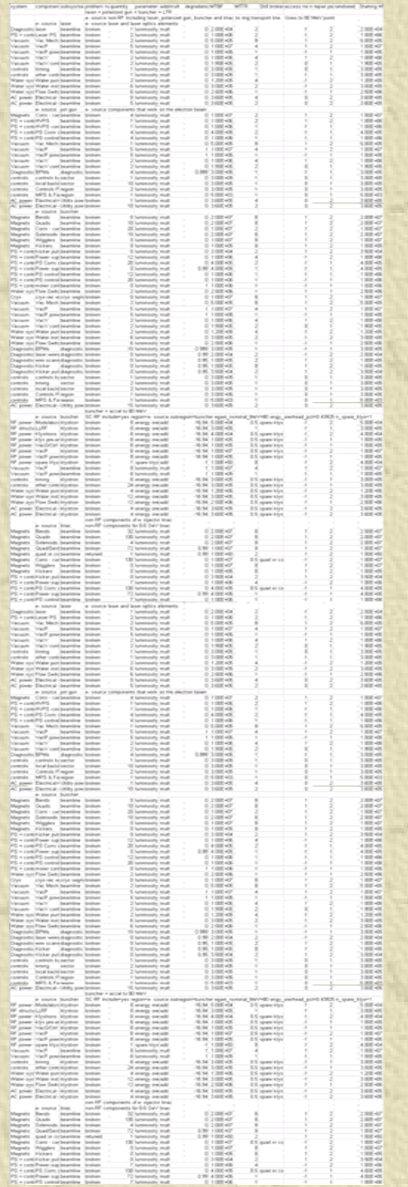
Improvements

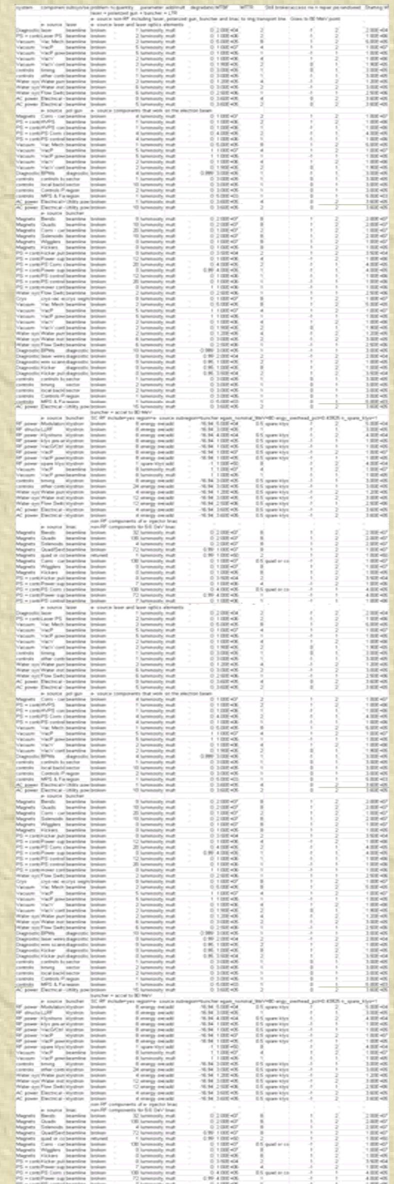
- All regions now have detailed component lists, not just DR and linac. Only cryo-plant and site power are lumped systems
- Program features added to handle more complex decks
  - Sped up factor of 10 (had slowed down due to extra components)
  - Allow comments in decks
  - Allow sub-decks which get variables set and then copied to main component list
  - Add concept of subregions
  - Make component properties object oriented
- Make it easy to change tunnel configurations
- Specify minor variants all in the one excel component file.
- Simulate e+ keep-alive source

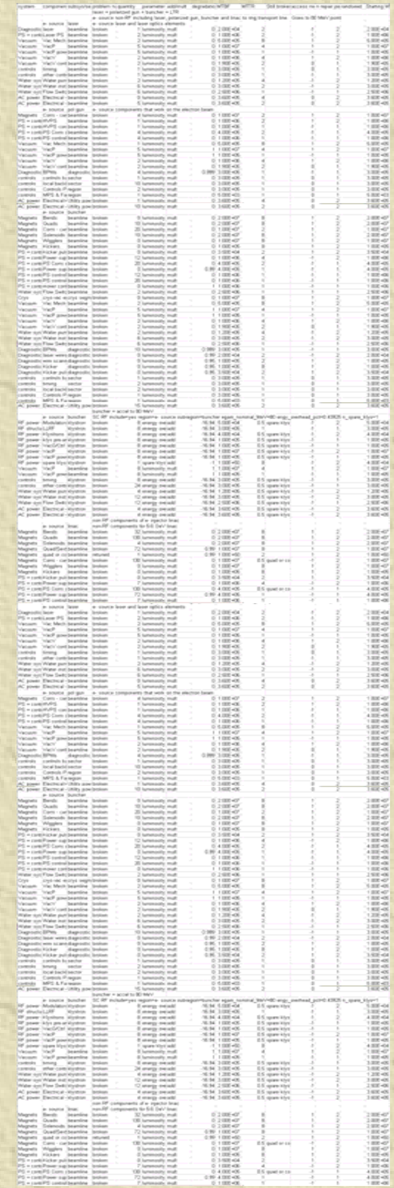
List of sub-decks

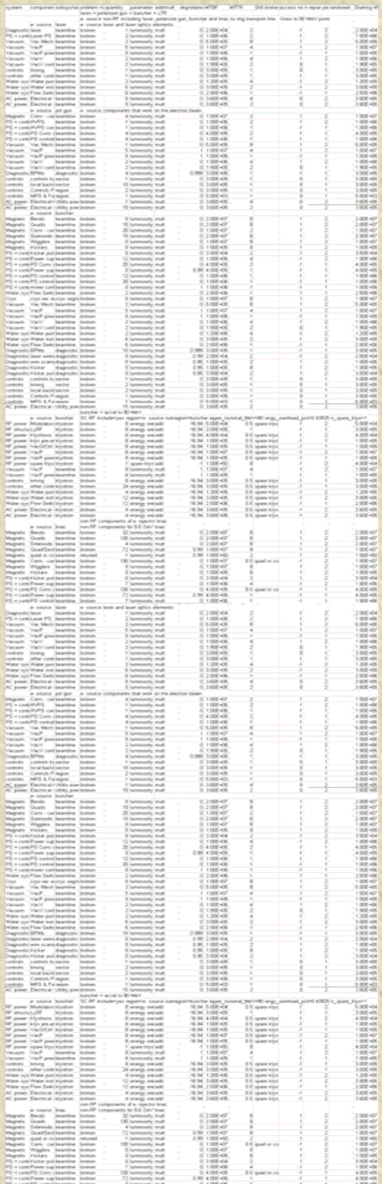
sheet	include	region	subregion	egain_nominal_MeV	engy_overhead_pct	n_spare_klys	description
	Electron injector						
e- source	yes	e- source					laser + polarized gun + buncher + LTR
warm RF	yes	e- source	buncher	80	0.44	1	buncher + accel to 80 MeV
inj	yes	e- source	linac				non RF components of e- injector 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 + contr	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 + contr	HVPS	beamline	broken	1	luminosity	mult	0	1.00E+06	2		1	2		1.00E+06
PS + contr	HVPS con	beamline	broken	1	luminosity	mult	0	1.00E+06	1		-1	1		1.00E+06
PS + contr	PS Corrs c	beamline	broken	4	luminosity	mult	0	4.00E+05	2		-1	1		4.00E+05
PS + contr	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

Added 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.

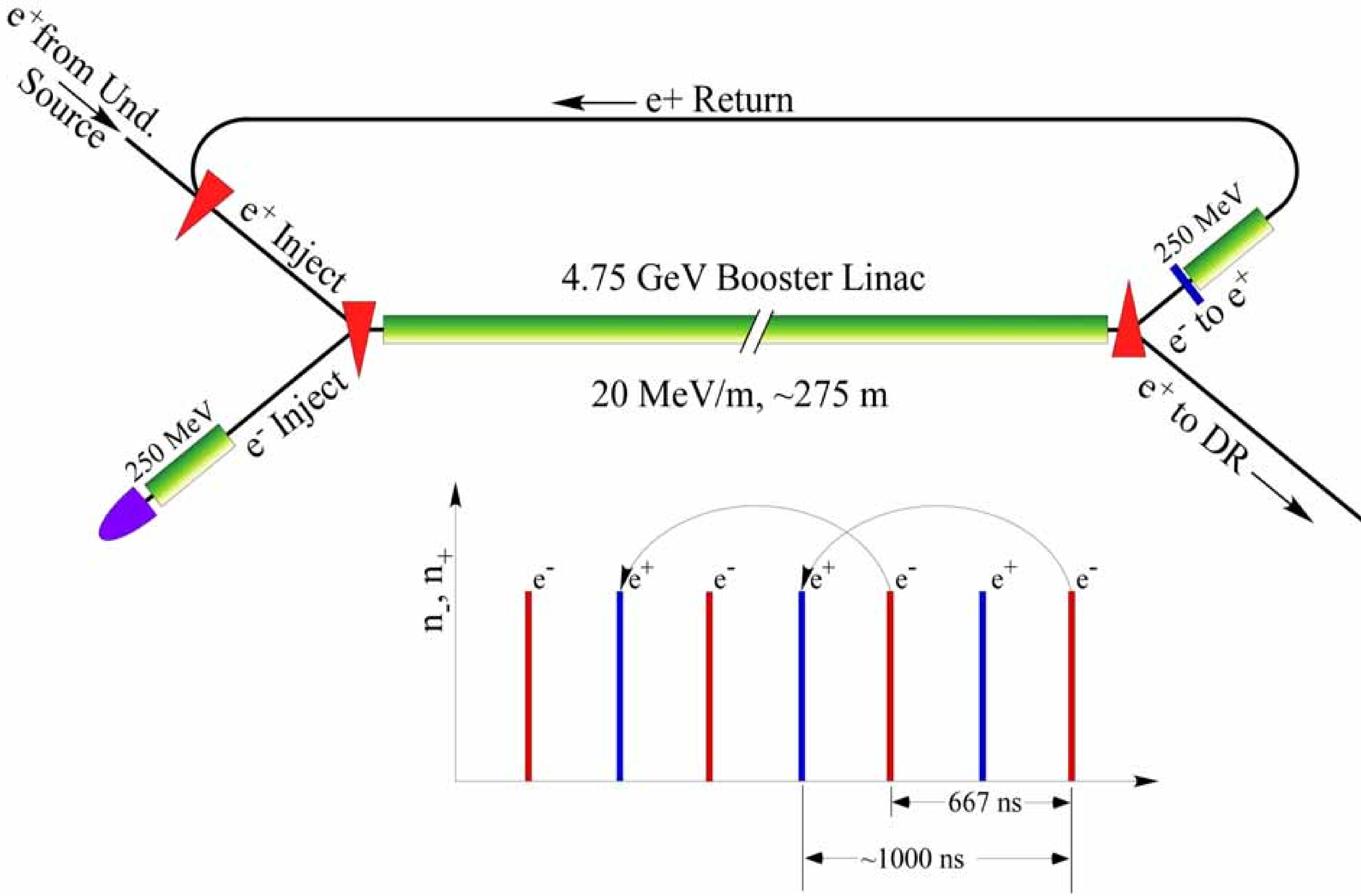
Keep-Alive e+ Source

- Assume it injects into the 5 GeV linac which is near the e+ DR.
- Assume it takes 2 hours to switch to using the alternate source.
- Assume a fraction, tune_low of the tuning time can be done with the low intensity beam.
- Assume a fraction, MD_low of the MD time can be done with the low intensity beam.
- Allow scheduled MD to be done simultaneously in e.g. e- DR and e+ linac with low intensity source.

4 Sources considered

1. A 20% intensity 100 bunch per pulse 5 pps source. This would presumably use about a 750 MeV superconducting linac. The intensity is chosen to not degrade the diagnostic resolution too much while decreasing the demand on the drive linac and target
2. A 100% intensity 1400 bunch/pulse 5 pps source. This would use the 5 GeV linac that normally accelerates the positrons to co-accelerate electrons that would be used to make the positrons.
3. A 100% intensity single bunch/pulse 5 pps source. This might be made with a low energy e- beam Compton scattered off a laser.
4. A 1% intensity single bunch. This was chosen because its target would be very easy to produce.

Sketch of Source 2



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Estimating tune_low and MD_low

- Listed all types of MD and tuning we could think of (about 80)
- Assumed equal time spent on each except 3x for steering and background tuning
- For each keep-alive source evaluated if it could be used for each MD and tuning

	Source1	Source 2	Source3	Source4
MD_low	0.71	1.00	0.87	0.05
Tune_low	0.66	1.00	0.9	0.02

- If assume BPMs work perfectly at 1% intensity, source4 is more like the others.

e+ Keep-Alive Results

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 opportunistic MD	Simulated % time useless down	Simulated number of accesses per month
ILC1	2 tunnels with min in accel tunnel; conventional e+; Nominal MTBFs	30.1	69.9	67.5	2.4	4.6	25.5	7.7
ILC2	ILC1 but table A MTBF's	14.9	85.1	80.0	5.1	1.9	13.0	2.9
ILC3	ILC2 but with undulator e+ and no keep alive e+ source	20.5	79.5	68.6	10.9	1.6	18.9	3.3
ILC4	ILC2 but with undulator e+ and keep alive e+ source **1**	16.5	83.5	78.0	5.5	1.7	14.8	3.4
ILC5	ILC2 but with undulator e+ and keep alive e+ source **2**	17.0	83.0	78.3	4.8	2.8	14.2	3.4
ILC6	ILC2 but with undulator e+ and keep alive e+ source **3**	16.8	83.2	78.5	4.8	2.6	14.2	3.4
ILC7	ILC2 but with undulator e+ and keep alive e+ source **4**	20.4	79.6	69.1	10.5	1.6	18.8	3.3

- Any e+ keep-alive source with bunch intensity high enough for diagnostics to work **well** is OK

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

Sensitivity Study

Run Number	LC description	Simulated % time down incl forced MD	Simulated % time fully up integratin g lum or sched MD	Simulated % time integratin g lum	Simulated % time scheduled MD	Simulated % time actual opportunis tic MD	Simulated % time useless down	Simulated number of accesses per month
ILC5	ILC2 but with undulator e+ and keep alive e+ source 2	17.0	83.0	78.3	4.8	2.8	14.2	3.4
ILC17	ILC5 but no hot spare klystron/modulator where there are single points of failure	18.8	81.2	77.0	4.2	3.3	15.5	3.3
ILC18	ILC5 but 'commissioning' (0.5xMTBF, 2xMD, 2xTuneTime)	44.9	55.1	45.5	9.6	4.9	40.0	4.2
ILC19	ILC18 but no keep-alive e+ source	52.8	47.2	25.4	21.8	2.7	50.1	3.5
ILC20	ILC5 but MTTRs twice as fast	12.9	87.1	81.8	5.3	2.2	10.7	3.4
ILC21	ILC5 but recovery time halved	12.6	87.4	82.5	4.9	2.6	10.0	3.6
ILC22	ILC5 but 3 hour cooldown instead of 1	18.2	81.8	77.1	4.7	2.8	15.4	3.3
ILC23	ILC5 but with DR in separate tunnel	16.9	83.1	79.0	4.1	3.4	13.5	3.4

Needed MTBF Improvements

Device	Improvement factor **A** for 2 tunnel conventional e+ source	Improvement factor **B** for 1 tunnel undulator e+ source, 6% energy overhead	Improvement factor **C** for 1 tunnel undulator e+ source, 3% energy overhead	Nominal MTBF (hours)
magnets - water cooled	**20**	20	20	1,000,000
power supply controllers	**10**	**50**	50	100,000
flow switches	**10**	10	10	250,000
water instrumention near pump	**10**	10	**30**	30,000
power supplies	**5**	5	5	200,000
kicker pulser	**5**	5	5	100,000
coupler interlock sensors	**5**	5	5	1,000,000
collimators and beam stoppers	**5**	5	5	100,000
all electronics modules	**3**	**10**	10	100,000
AC breakers < 500 kW		**10**	10	360,000
vacuum valve controllers		**5**	5	190,000
regional MPS system		**5**	5	5,000
power supply - corrector		**3**	3	400,000
vacuum valves		**3**	3	1,000,000
water pumps		**3**	3	120,000
modulator			**3**	50,000
klystron - linac			**5**	40,000
coupler interlock electronics			**5**	1,000,000
linac energy overhead		**3%**		3%

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, even with robotic repair. 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.
- Improving MTTRs and recovery time also help.

Backup Slides

Unavailability Defined:

- The time luminosity is not produced because hardware is broken.
- Plus the recovery time after hardware is repaired.
- The long annual shutdown and startup are not counted.
- “Scheduled maintenance days” are counted.
- MPS trips and recovery are not counted
- Luminosity loss due to non-optimal tuning is not counted except for the recovery time from hardware failure.