Availability Task Force Progress Report

Putting the Linac in a single tunnel

Tom Himel for the Availability Task Force

Outline

- Goal of taskforce
- Configurations studied
- Conclusions
- **Assumptions made to achieve design availability**

Initial Goals of the Task Force

- Develop two models, one for DRFS and one for KlysCluster.
  – Each model will include a **viable** single tunnel design which is **consistent** with **good availability** performance. All non-linac areas still have their support equipment accessible with beam on.

1. Each model will include an analysis done using the Excel/Matlab Monte Carlo tool 'Availsim. (Group 1)
2. Each model will have an appendix which outlines a proactive, practical plan for realizing the component performance and operations model included in it. (Group 2)
3. Each model will include a 'first-principles' availability estimate for ML availability performance done using a direct formulaic approach, as a check and as a way to benchmark the ML availability performance. (Group 3)

Co-Conspirators

- Group 1 (Availsim)
  - **Tom Himel (lead)**
  - **Eckhard Elsen**
  - **Nick Walker**
  - **Ewan Paterson (unofficially)**
- Group 2 (Analysis)
  - **John Carwardine (lead)**
  - **Marc Ross (chair of full group)**
  - **Ewan Paterson**
- Group 3 (Spreadsheet availability calculation)
  - **Tetsuo Shidara (lead)**
  - **Nobuhiro Terunuma**
- Contributions from Chris Adolphsen, Nobu Toge, Akira Yamamoto

Only availability studied

- This task force only studied availability due to component failures.
- Other effects of a single tunnel design must be considered separately
  - Safety
  - Space to install extra equipment in accelerator tunnel
  - Installation logistics
  - Radiation shielding of electronics and effect of residual single event upsets
  - Debugging of subtle electronics problems without simultaneous access to the electronics and beam

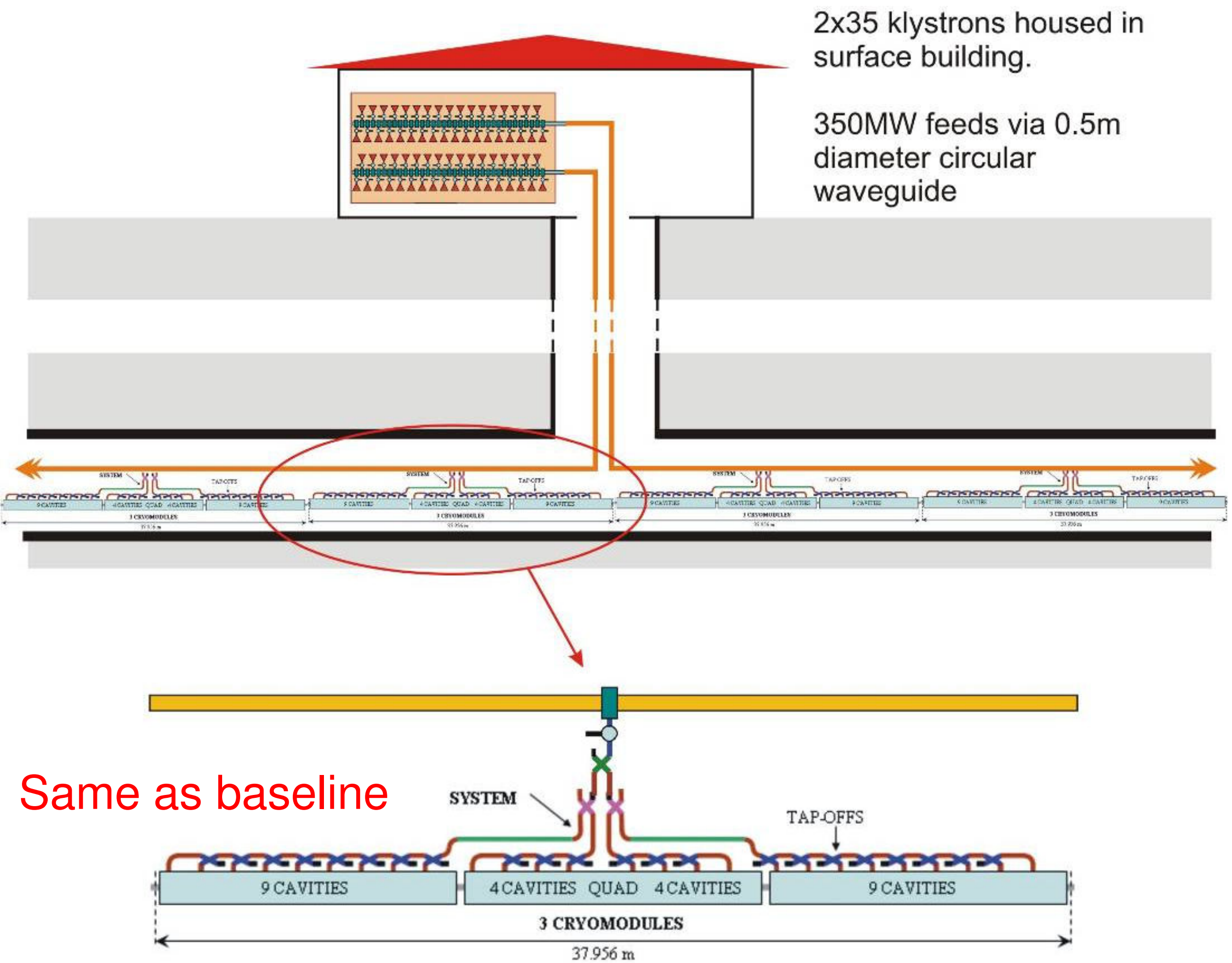
Configuration Studied

- Modeled RDR + some SB2009 changes:

1. Two 6 km DRs in same tunnel near IR
2. Linac in 1 or 2 tunnels
3. Low power (half number of RDR bunches and RF power)
4. RF systems: RDR, KlyClus, and DRFS
5. RTML transport in linac tunnels
6. Injectors in their own separate tunnels
7. E+ source is undulator at end of linac
8. E+ Keep Alive Source
9. Injectors, RTML turn-around, DRs, BDS have all power supplies and controls accessible with beam on. (pre-RDR 1 vs. 2 tunnel studies had these inaccessible for 1 tunnel)

- Other SB2009 options will be evaluated later.

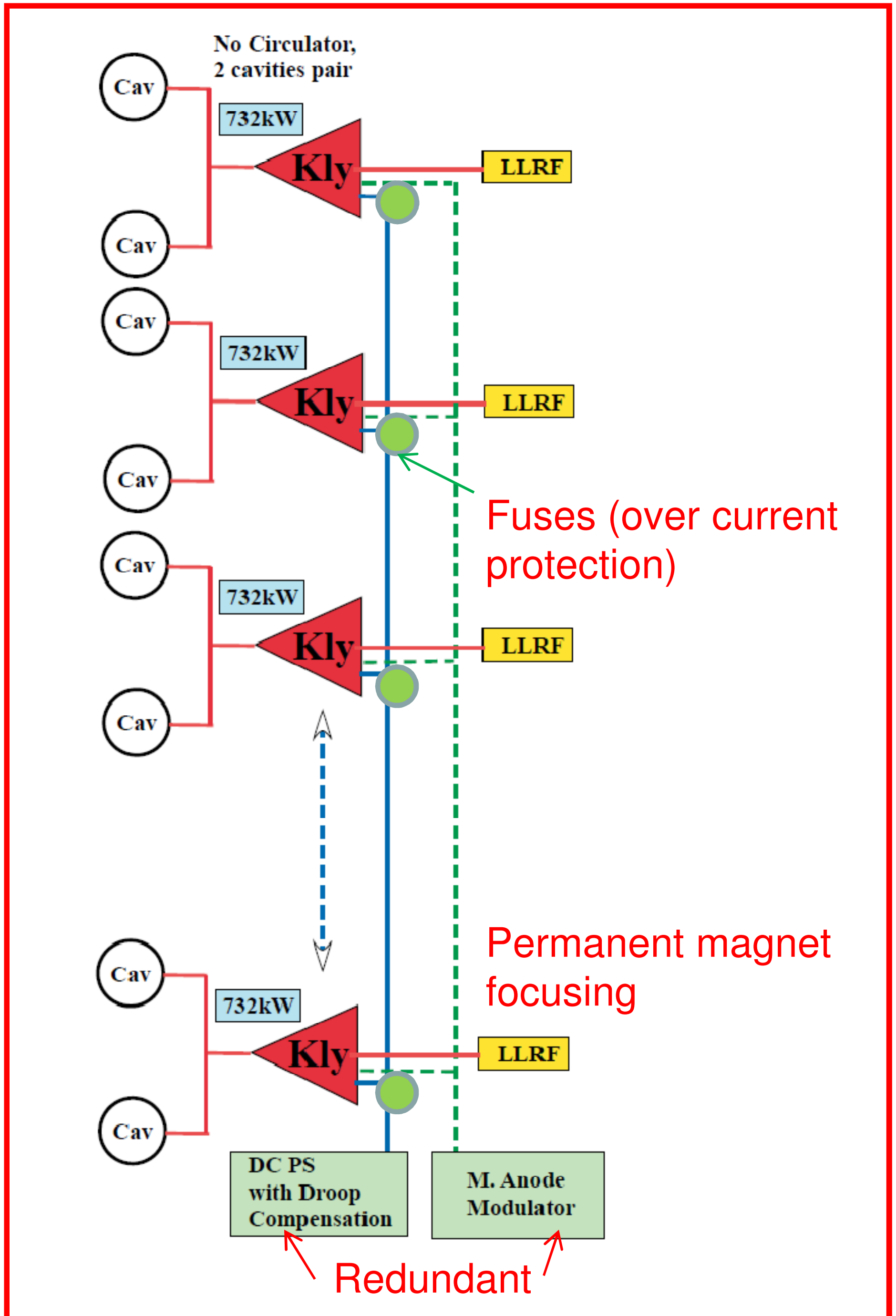
Klystron Cluster Concept



Each tap-off from the main waveguide feeds 10 MW through a high power window and probably a circulator or switch to a local PDS for a 3 cryomodule, 26 cavity RF unit (RDR baseline).

- Concept has evolved since this picture.
- RF power "piped" into accelerator tunnel every 2.5 km
- 1 tap-off with remote shut-off per cryomodule
- 2 hot spare klystrons per cluster
- Klystrons replaceable with RF and beam on.

DRFS Scheme



- Low P has 4 cavities per klystron
- 13 klystrons fed from single DC PS and modulator. Both are redundant.

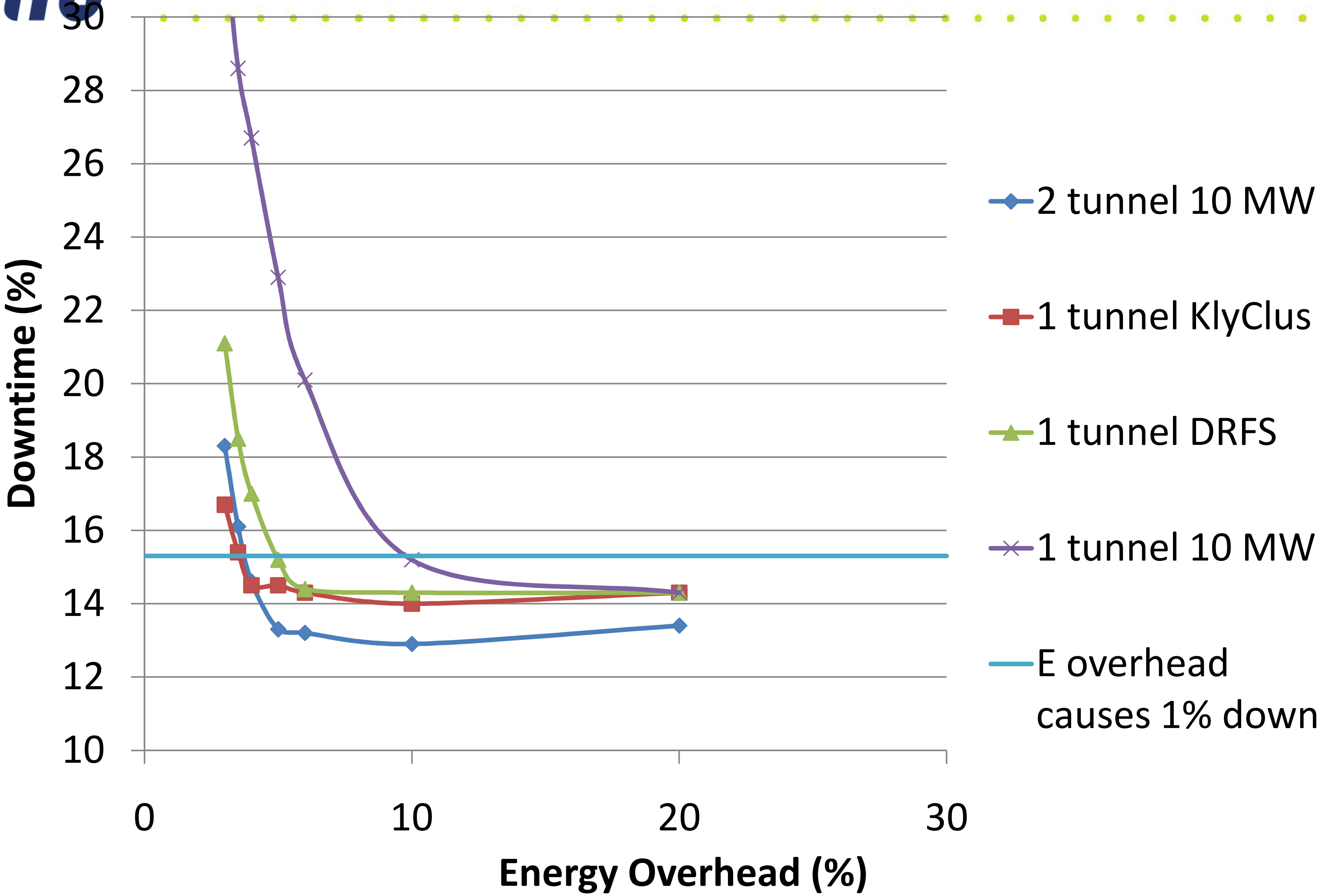
Results are Preliminary

- Numbers WILL change
- There are input details we're not thrilled with and may change
  - **Scheduled downs have 9 hours of repair and 15 hours of scheduled recovery. If recovery takes longer it counts as unsched downtime. If shorter, no credit is given. Perhaps should give credit.**
  - **Cryo plants and AC power disruptions are the largest single downtime causes. Perhaps need to be still more aggressive in improving their availability.**
  - **Have not limited the number of people making repairs**
- Still expect comparisons to be valid

Results are Preliminary

- Lots of inputs
  - **45 each MTBF, MTTR, number people to repair**
  - **1120 types of parts (e.g. DR power supply controller), each with a quantity (sometimes known from RDR, sometimes estimated)**
  - **We assume similar parts have same MTBFs. E.g. linac PS controller same as DR PS controller or all electronics modules have same MTBF. Otherwise would have 3*1120 parameters to tune.**
  - **~100 misc parameters like length and freq of scheduled downs, recovery times**
- 1 constraint: the calculated availability
- Problem is **slightly** under constrained
- Ideally would add minimum cost constraint. Very difficult. We just guess at it in setting parameters.

Results

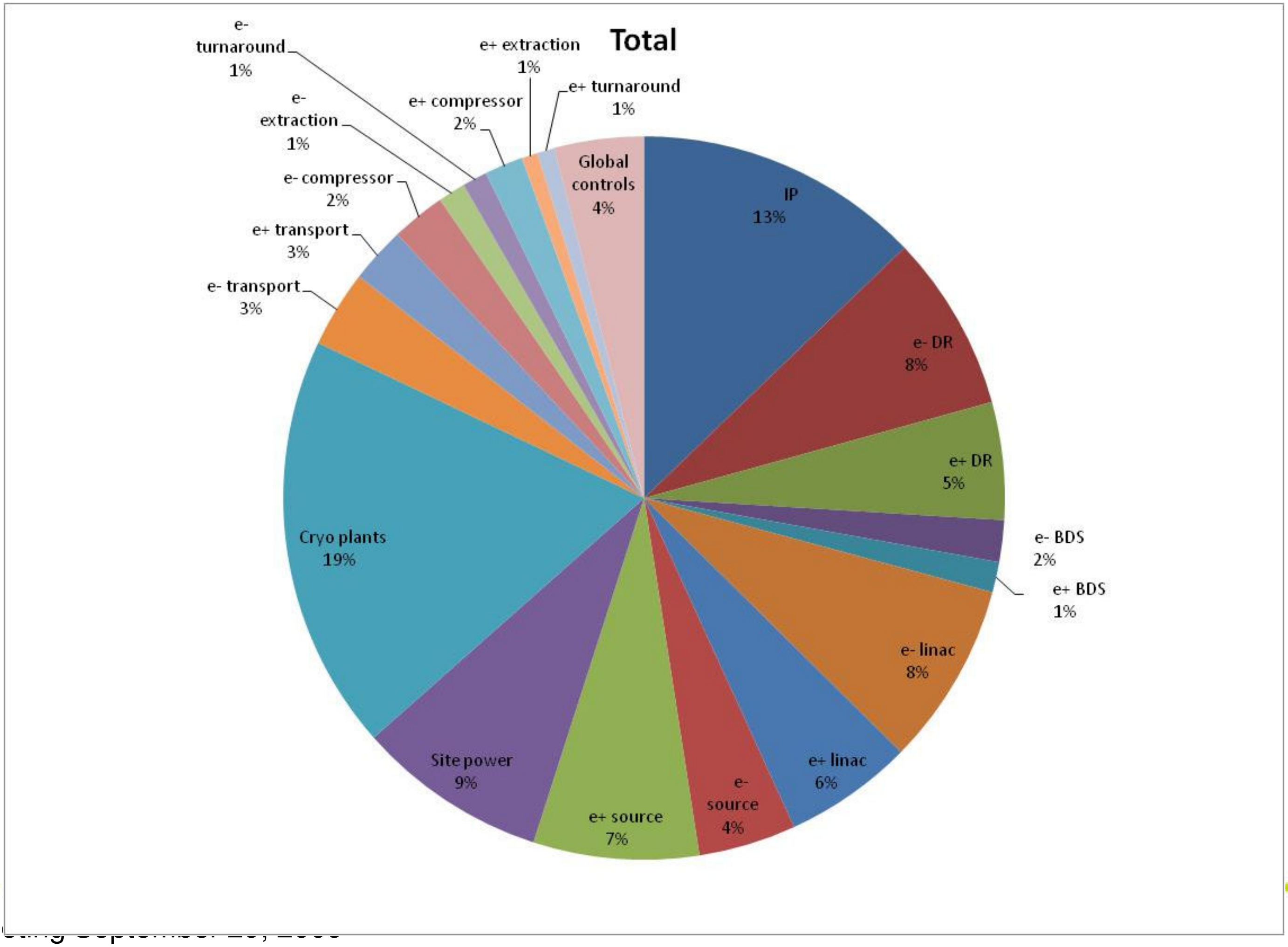


30
28
26
24
22
20
18
16
14
12
10
Downtime (%)
0
10
20
30
Energy Overhead (%)
2 tunnel 10 MW
1 tunnel KlyClus
1 tunnel DRFS
1 tunnel 10 MW
E overhead causes 1% down

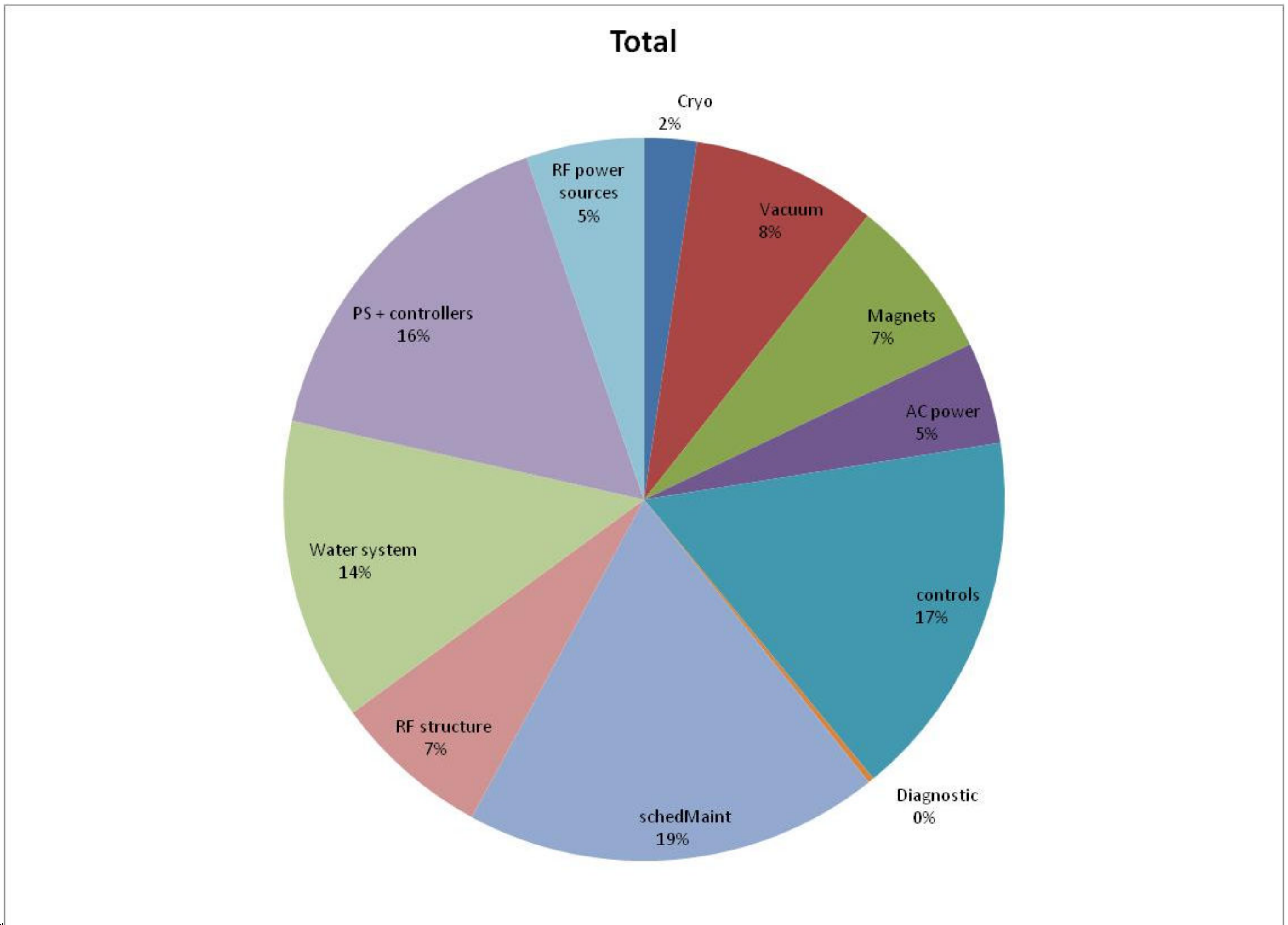
Interpretation of Results

- Ignoring RF, going from 2 to 1 linac tunnel reduces availability by 1%. This is due to putting power supplies, controls etc. for the linac and much of the RTML in the accelerator tunnel and hence repairs take more time.
- As design energy overhead is decreased, the different RF schemes degrade differently. (Energy overhead needed to avoid >1% extra downtime)
  - **1 tunnel 10 MW degrades fastest prob. due to the 40k and 50k hr MTBFs assumed for the klystron and modulator. (10%)**
  - **DRFS does better prob. due to the redundant modulator and 120k hour klystron MTBF assumed. (5%)**
  - **KlyClus does still better due to ability to repair klystrons and modulators while running. (3.5%)**

Downtime by Section for KlyClus 4% energy overhead (Will change to 3.5%)



Downtime by System for KlyClus 4% energy overhead (Will change to 3.5%)



Preliminary conclusions of impact of single main linac tunnel on availability (1 of 2)

- The assumptions made to obtain the desired availabilities for all designs are quite aggressive and considerable attention will have to be paid to availability issues during design, construction and operation of the ILC to achieve the simulated availabilities.
- The RF power system as described in the RDR is unsuitable for a single linac tunnel design as there is a significant decrease in availability without further improvements in MTBF's, an increase in energy overhead and/or changes in maintenance schedules.

Preliminary conclusions of impact of single main linac tunnel on availability (2 of 2)

- There are two alternate RF power system designs proposed for single tunnel linac operation. (The Klystron Cluster and the Distributed RF System). Either approach would give adequate availability with the present assumptions. The Distributed RF System requires about 1.5 percent more energy overhead than the Klystron Cluster Scheme to give the same availability for all other assumptions the same. This small effect may well be compensated by other non availability related issues.
- With the component failure rates and operating models assumed today, the unscheduled lost time integrating luminosity with a single main linac tunnel is only 1% more than the two tunnel RDR design given reasonable energy overheads. Note that all non-linac areas were modeled with support equipment accessible with beam on.

Assumptions Introduction

- Goal was to find a viable single tunnel design which is consistent with good availability performance.
- We think we have done so.
- The good availability is **NOT** the major result of our work. The assumptions and design which produced it **ARE**.
- It is essential to understand the assumptions so the ILC can be built to meet them.
- The assumptions are not formally optimized. There may be better (cheaper, easier to implement) solutions
- The rest of this talk is a description of the assumptions

DRFS redundancy

- The modulated anode modulator and DC supplies for the DRFS are assumed to be redundant and hence were given very large (10 times nominal) MTBFs.
- It was obvious that without this and their nominal MTBFs of 50k hr too much energy overhead would be needed.

KlyClus hot spares

- Each klystron cluster is assumed to have 2 spare klystrons and modulators.
- A klystron can be exchanged while the RF is on and there is beam (requires good 10 MW waveguide valve).
- This was modeled as a very long MTBF (100 times nominal) for all the components in the cluster.

KlyClus high power transport

- Any fault (e.g. breakdown or vacuum leak) in the half meter diameter high power waveguide is a single point of failure and will cause downtime.
- Availsim assumes these faults do NOT happen.
- If they do, that downtime must be added into the Availsim results.

Preventive Maintenance

- The RDR had a 3 month annual shutdown and when the ILC broke, opportunistic repairs were made in the time needed to repair the faulty part.
- Here we assume no opportunistic repairs as they were felt to be unrealistic.
- We have a 1 month shutdown every 6 months and a 1 day shutdown (PM day) every 2 weeks where 9 hours is used for repairs and 15 for scheduled recovery.
- Believe results would be same if had 2 month annual shutdown plus 1 PM day every 2 weeks
- Total scheduled running time in RDR and now are same.

Preventive Maintenance

- PM days are needed to avoid larger energy overhead for DRFS
- At some labs, may be more costly to distribute downtimes in 1 day chunks (peak power costs and shift differentials)
- During each 1 month shutdown 10% of the cryo systems are warmed and accumulated problems repaired. Each section gets warmed once every 5 years.
- The PM days may well be needed to do the PM necessary to get some of the high MTBFs assumed. This is not explicitly modeled.
- No limit was placed on the number of people performing repairs. Downtime as a function of this limit is on our TO DO list.

MTBFs

Device	RDR starting MTBF	RDR table A factor	RDR final MTBF	New starting MTBF	SLC MTBF	FNAL Tevatron MTBF	FNAL Main Injector MTBF	APS MTBF	other MTBF
mttf_electronic_module	1.0E+05	3	3.0E+05	1.0E+05	9.9E+03				
mttf_PS_controller	1.0E+05	10	1.0E+06	**1.1E+06**	8.0E+04	1.8E+05	1.1E+05	1.1E+06	
mttf_controls_local_backbone	1.0E+05	3	3.0E+05	1.0E+05					
mttf_magnet	1.0E+06	20	2.0E+07	**2.0E+06**	5.0E+05		2.0E+06		
mttf_sc_magnet	3.0E+07	1	3.0E+07	3.0E+07		1.6E+06			
mttf_small_magnet	1.0E+07	1	1.0E+07	**3.4E+07**	3.4E+07				
mttf_PM_magnet	1.0E+07	1	1.0E+07	1.0E+07					
mttf_PS_corrector	4.0E+05	1	4.0E+05	**1.1E+06**	4.3E+05	1.8E+05	1.1E+05	1.1E+06	
mttf_PS	2.0E+05	5	1.0E+06	**1.1E+06**	4.3E+05	1.8E+05	1.1E+05	1.1E+06	4.0E+04
mttf_kicker	1.0E+05	1	1.0E+05	1.0E+05	1.0E+05				
mttf_kickpulser	7.0E+03	5	3.5E+04	7.0E+03	6.6E+03				
mttf_modulator	5.0E+04	1	5.0E+04	5.0E+04	6.4E+04				
mttf_dr_klystron	3.0E+04	1	3.0E+04	3.0E+04					
mttf_mb_klystron	4.0E+04	1	4.0E+04	4.0E+04	5.0E+04				
mttf_DRFS_klystron	1.2E+05	1	1.2E+05	1.2E+05					1.7E+05
mttf_X_klystron	2.5E+04	1	2.5E+04	2.5E+04					
mttf_cavity	1.0E+08	1	1.0E+08	1.0E+08					
mttf_coupler_intlk	1.0E+06	5	5.0E+06	1.0E+06	9.6E+04				
mttf_coupler_intlk_electronics	1.0E+06	1	1.0E+06	1.0E+06	9.6E+04				
mttf_mover	5.0E+05	1	5.0E+05	5.0E+05	5.1E+05				
mttf_VacP	1.0E+07	1	1.0E+07	1.0E+07	3.8E+06				
mttf_VacP_power_supply	1.0E+05	1	1.0E+05	1.0E+05					
mttf_valve	1.0E+06	1	1.0E+06	1.0E+06	1.0E+06				
mttf_vac_valve_controller	1.9E+05	1	1.9E+05	1.9E+05	1.9E+05				
mttf_fs	2.5E+05	10	2.5E+06	2.5E+05	2.2E+05				
mttf_pulsed_cable	2.0E+05	1	2.0E+05	2.0E+05					
mttf_xfrmr	2.0E+05	1	2.0E+05	2.0E+05					
mttf_waterpump	1.2E+05	1	1.2E+05	1.2E+05	1.2E+05	1.3E+05			
mttf_water_instr	3.0E+04	10	3.0E+05	**1.3E+05**	3.0E+04	1.3E+05			
mttf_elec_small	3.6E+05	1	3.6E+05	**1.6E+06**	3.6E+05				1.6E+06
mttf_elec_big	3.6E+05	1	3.6E+05	**1.6E+06**	3.6E+05			6.7E+05	1.6E+06
mttf_vac_mech_device	1.0E+05	5	5.0E+05	1.0E+05					
mttf_laser_wire	2.0E+04	1	2.0E+04	2.0E+04					
mttf_wire_scanner	1.0E+05	1	1.0E+05	1.0E+05					
mttf_klys_preamp	1.0E+05	1	1.0E+05	1.0E+05					
mttf_vacG_controller	1.0E+05	1	1.0E+05	**4.7E+05**	4.7E+05				
mttf_cavity_tuner	1.0E+06	1	1.0E+06	1.0E+06	5.1E+05				
mttf_cavity_piezo_tuner	5.0E+05	1	5.0E+05	5.0E+05					
mttf_power_coupler	1.0E+07	1	1.0E+07	1.0E+07					
mttf_SLED	1.0E+05	1	1.0E+05	1.0E+05					
mttf_cryo_leak	1.0E+05	1	1.0E+05	1.0E+05					
mttf_JT_valve	3.0E+05	1	3.0E+05	3.0E+05					
mttf_cryo_big_prob	1.0E+07	1	1.0E+07	1.0E+07					
mttf_target	4.4E+04	1	4.4E+04	4.4E+04					
mttf_MPS_region	5.0E+03	1	5.0E+03	**3.0E+04**	5.0E+03			3.0E+04	

- New starting MTBF= value used in simulation
- **Bold**: had to improve it above start value

- Improve>10
- Improve>3
- Improve>1
- Improve<=1
- White: no data

We have WAY TOO LITTLE MTBF data.

- Lines with no colored cells indicate we guessed at the MTBF.
- MTBFs vary widely between labs and even within a lab.
- Cell comments describe source of data. Often there are guesses to go from measured data to what we needed.
- An optimist would say a green cell on a line means our needed MTBF has been achieved somewhere, so no problem.
- A pessimist would say if there are non-green colored cells then it is quite possible we won't achieve the needed MTBF.

MTBFs

- APS achieved power supply MTBFs a factor of 10-20 better than the other labs and good enough for ILC.
- They did not start that good.
- The cause of **every** failure was understood and correction applied to all supplies.
- In each long down
  - **All supplies are run 20% over nominal and problems fixed.**
  - **An IR camera is used to look for thermal anomalies**
- Access to PS is not allowed during runs to reduce human error.
- It takes real effort and money to achieve great MTBFs

Recovery/Tuning time

- Each section of the accelerator (e.g. e- DR, e- turnaround) takes 5-20% of the time it had no beam for recovery and tuning.
- The downtime would be reduced slightly more than a factor of 2 if recovery were instantaneous.
- Need excellent non-beam-based diagnostics so recoveries in sections can occur in parallel and excellent beam-based diagnostics to meet or exceed this goal.

Cryoplants

- The largest single source of downtime is caused by the cryoplants.
- They are assumed to be up 99% of the time.
- With 10 large plants planned for the main linac and 3 smaller plants for other systems the required availability of each plant is 99.9% including outages due to incoming utilities (electricity, house air, cooling water).
- This is 10-20 times better than the existing Fermilab or LEP cryo plants.

Site Power

- The second largest source of downtime is site power including the HV power distribution.
- It is assumed to be down 0.5%
- Present experience is that a quarter second power dip can bring an accelerator down for 8-24 hours.
- A single 24 hour outage would consume most of the downtime budget.

Klystron Replacement

- The 700 kW DRFS klystrons take 4 hours to replace including transport time.
- Two people are needed.
- A back of the envelope calculation:
  - **There are about 4200 such klystrons**
  - **With an MTBF of 1.2e5 hours and 14 days = 336 hours between scheduled repair days, an average of 12 are replaced each maintenance day with fluctuations to > 17 5% of the time.**

A klystron cluster has no single points of failure

- The LLRF is redundant for all pieces that effect more than a single cryomodule to avoid a single point of failure that loses the full energy gain from a klystron cluster.
- No other single points of failure are modeled
- These assumptions are not necessary for DRFS as the RF unit is so small.

Power distribution

- Failure rates for AC breakers are taken from the IEEE “gold book”
- The MTBFs are for actual failures, not trips.
- Presumably the breakers and transformers must be lightly loaded (80% of rating?) to avoid such trips and premature failures.
- Transformers are not included and should be added (or we have to assume they are in the 0.5% site power downtime allotment)

Tune-up dumps

- There are tune-up dumps and radiation shielding so beam can be in section A with people in section B.

A	B
E- source	E- DR and RTML and linac
DR	RTML and linac
BDS	IP

- Need to check if last line (BDS-> IP is correct

Scheduled recovery time

- A repair day has 9 hours for actual repairs and 15 hours for recovery.
- Sometimes recovery takes longer than 15 hours. This is accounted as unscheduled down time.
- Often recovery takes less than 15 hours. This is accounted as wasted time. (as was specified for the XFEL where it was assumed experimenters would not be ready for beam early)
- We should consider accounting this as unscheduled running time. (Availsim allows this.)

Keep Alive Source (KAS)

- There is a positron keep alive source.
- Its intensity is high enough so that tuning or MD that is done with it is just as efficient and thorough as can be done with the full intensity beam.
- The intensity required for this is not clear.

Positron Source

- The positron target and capture section will become too radioactive for hands-on maintenance.
- The design does not have a spare target and capture section on the beam line.
- They are designed so that the components can be replaced with the use of remote handling equipment in 8 hours.

RF overhead and redundancy

- The 5 GeV injector linacs have 20% energy overhead. This was needed to avoid month long shutdowns for cryo work prior to the 5 year planned outage.
- All RF sections where a single klystron failure would cause a downtime like crab cavities and the linac before the bunch compressor have hot spare klystrons and modulators that can be switched in via waveguide switches.