Cost Impacts of Reduced # Bunches per Train

purpose:
not to generate a new ILC estimate,
but to facilitate SB2009 decisions

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latest modification: 19jan2011- 1400 PST

filename: PHG-BAW_Cost_Impact_LowP.ppt

Outline of this presentation

- Don't call it "Low Power"
- Questions: savings, upgrade/restore, invest
- Cost Differentials … today vs. tomorrow
- What we can quickly learn from RDR estimate
- RF System Choices for ML for KCS and DRFS
- DR tunnel: 6.4 km @ 5 m => 3.2 km @ ***7.5 m*** and changes in RF and wiggler quantities
- Electrical Power, Cooling, and Cryo comparisons
- Cost Difference Summaries and Roll-up
- Restoration back to 2625 bunches/train
- Ending notes

Let's not call this "Low Power"

- It is technically ***reducing the number of bunches*** from the RDR nominal baseline of ***2625*** bunches/train to ***1312*** bunches/train, and by ***restoring Luminosity*** by ***more optimized focusing*** at I.P. or by using ***traveling focus***.
- We need to maintain ***250x250 GeV*** capability and adequate luminosity
- Cannot start with RF for lower Energy and then upgrade later. This would only make sense if we installed fewer CMs & added more later

today…

- We ***start*** with the BAW-1 decisions: single-tunnel, KCS or DRFS, cavity gradient spread, plus 6.4 km racetrack DR.
- For calculational purposes, we also group the 2*12 RF units (= 3 CM = 26 cavities) associated with BC-2 with the ML CMs and HLRF, assuming they can be similarly powered. This is just an assumption and does not imply a choice of single-stage Bunch Compressor.
- ***Question:*** How much can we ***save*** if we reduce number of bunches/train 2625 => 1312?
- What is the ***upgrade path*** back to 2625 bunches?
  - **What would it *cost to restore* 2625 bunch capability?**
  - **What should we *invest* in utilities: civil, electrical, cooling, cryo, etc. from to *facilitate* restoration?**

cost differentials

- We will not generate complete estimates, just see how much the configuration changes under consideration could save relative to the ***6.618 B ILCU*** RDR estimate.
- Today, we will not consider “10 Hz” which is really ***150 GeV e-*** for positron production & ***125x125 GeV e+e-*** collisions at IP where both pulses are interspersed at ***5 Hz*** each nor impact of moving e+ source to end of ML

….. tomorrow!

preamble

- Thank you to many people who have worked hard to produce these ***quantitative*** impacts:
  DR: Susanna, RF: ChrisN, ChrisA, Shigeki
  Cryo: TommyP,
  CFS: Vic, Tomski, Emil, Randy, Lee …
- Again, information, specifications, requirements
  came late
- CFS and I struggled to get these data on paper,
  we knew what we had to do,
  but ***insufficient opportunity for cross checking***
  I'll point out errors, omissions, inconsistencies

Cost Impact Matrix

Reduce # bunches 2625 => 1312 @ 250x250 GeV

reduced # bunches	Tech. Comps.	RF Power	Cryo Power	Civil Tunnels	Civil Cavern*	Civil Buildings	Electrial Power	Thermal Cooling	Notes * includes alcoves & tunnel widenings
e- source	√	√	√				√	√	reduced laser and cryo RF
e+ source	√	√	√				√	√	cryo RF and cooling of photon dump
DR	√	√	√	√	√	√	√	√	reduced circumference to 3.2 km
RTML	√	√	√				√	√	only BC1 (BC-2 included under ML)
ML (& BC-2)	√	√	√			KCS	√	√	# HLRF components (LLRF impact)
BDS	√	slight	slight				slight	slight	traveling focus components only
Exp Hall									no impact yet
Common							√		only Master Substation

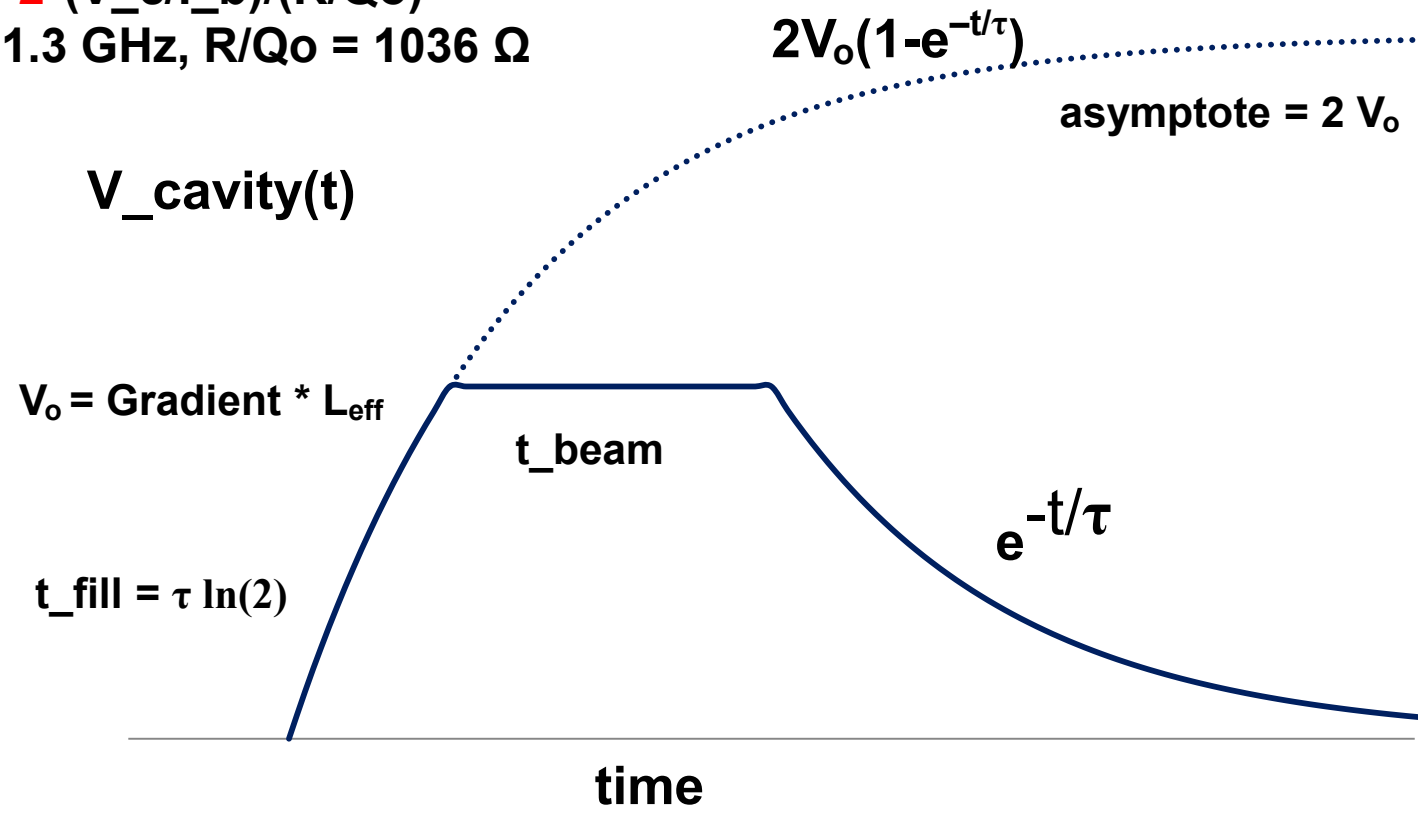
Major costs are for ***Main Linacs*** & ***Damping Rings***,
so we will concentrate only on these systems.
e- & e+ Sources, and RTML have reduced power
BDS traveling focus systems ~ small extra costs
CFS did include impact on Master Substation

other savings not considered:

- Water Cooling for Main Dumps (2), Tune-Up Dumps in BDS (2), & Photon Dump (e+ Src): the mechanical systems and capacities are sized for 500x500 GeV operations, so could reduce number of pumps and HEXs for reduced bunch number, and add later
- Cryogenics Plant cost estimates include multiple compressors, some of which might be able to be deferred for low bunch number configuration and added later to restore full Power

RF pulse for constant klystron power

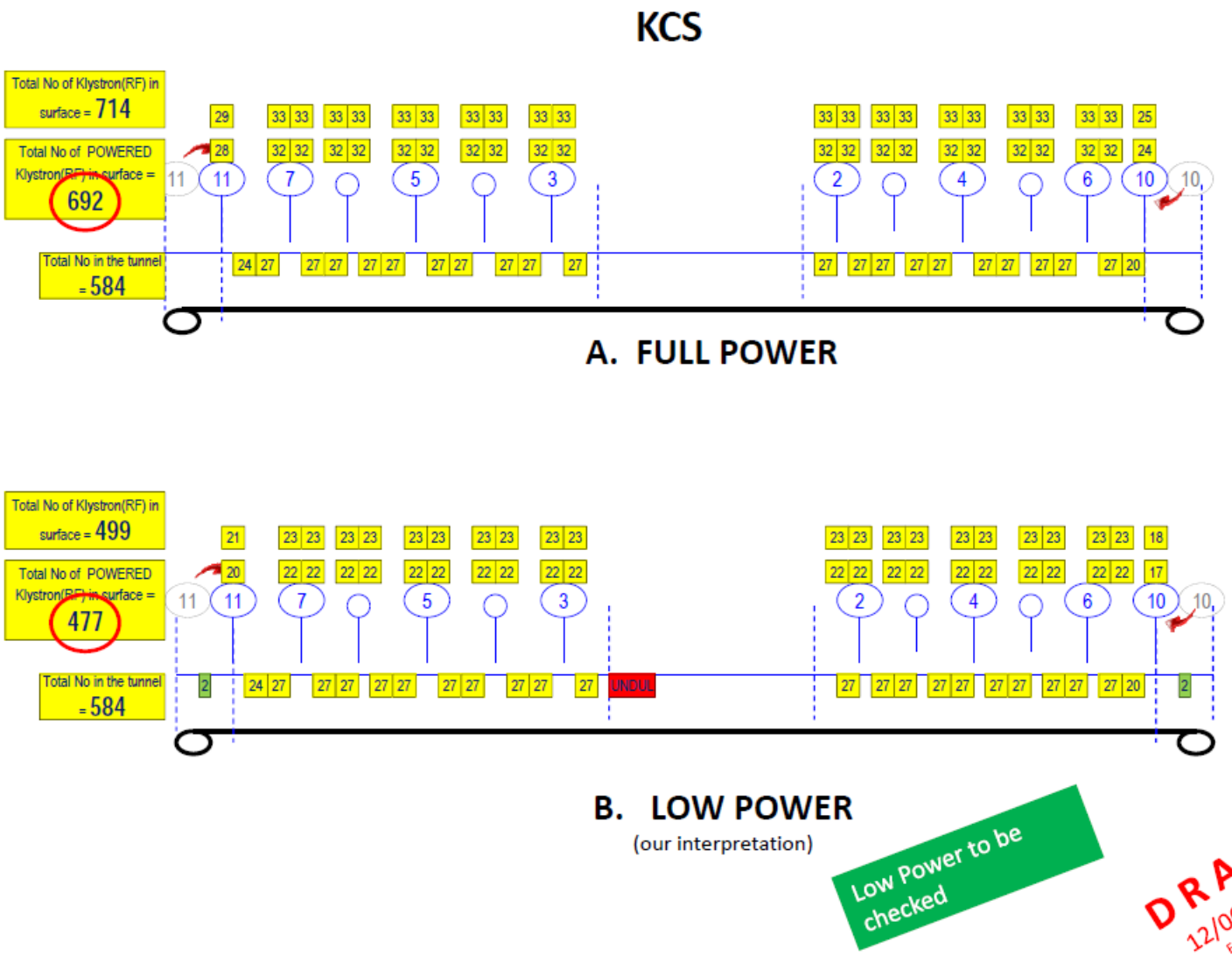
$\tau = 1/(2\pi f_o)*2*(V\_c/I\_b)/(R/Qo)$
where f_o = 1.3 GHz, R/Qo = 1036 Ω



optimizations

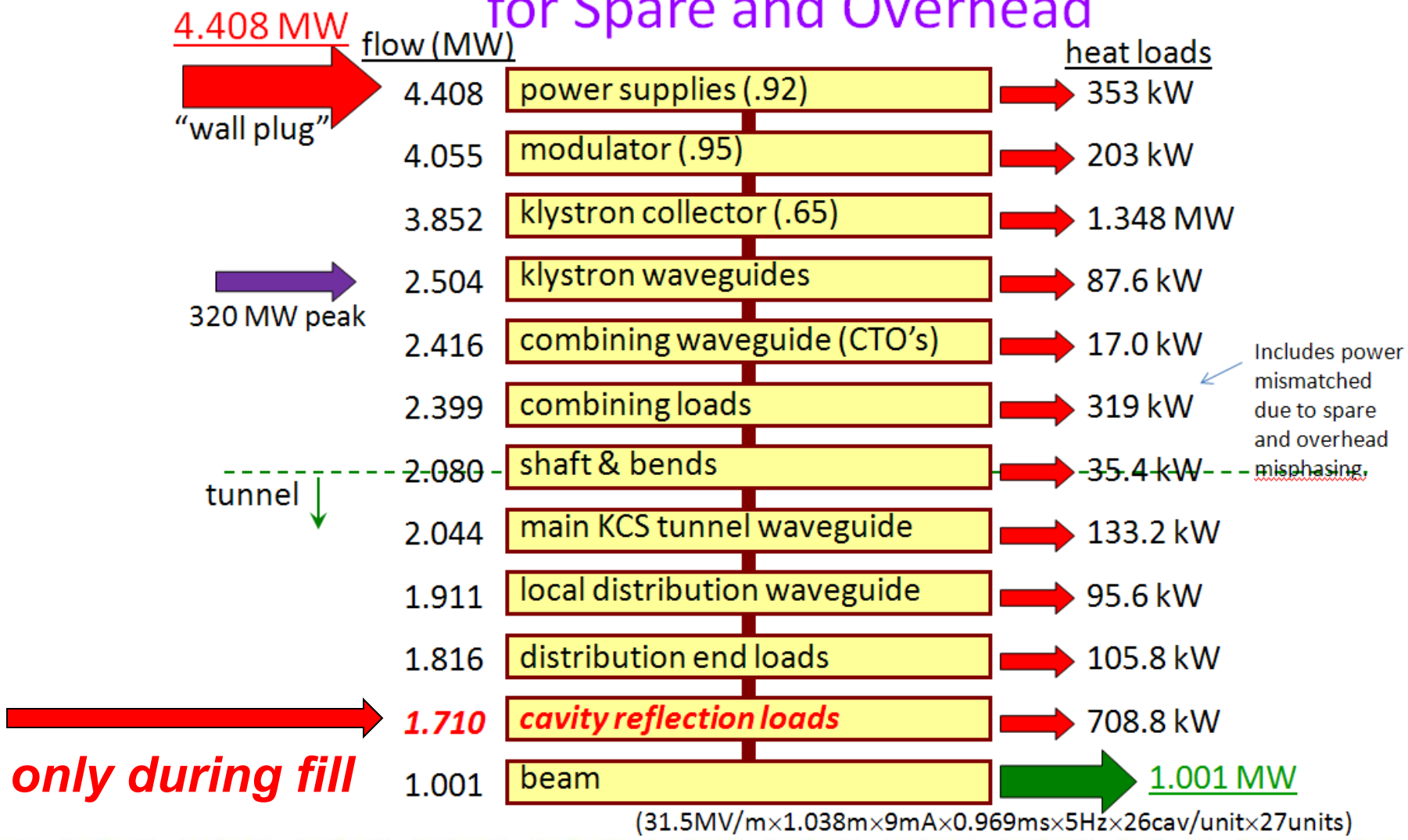
- Both accelerates 1312 bunches per train
- ChrisA – KCS reduces beam current from 9 mA => 6.2 mA, reducing t_beam and keeping t_rf constant which minimizes power, cooling, and dynamic load on cryogenics but only reduces # klystrons from 714/699 to 499/477 or 70%/68% (installed/powered)
- Shigeki – DRFS drops every other bunch keeping t_beam constant, which reduces # klystrons by 50%, but increases t_fill and τ which increases power, cooling, and dynamic load on cryogenics
- Which is more optimal approach?

KCS configurations



KCS power flow

27 Unit KCS Average Power Diagram Corrected for Spare and Overhead

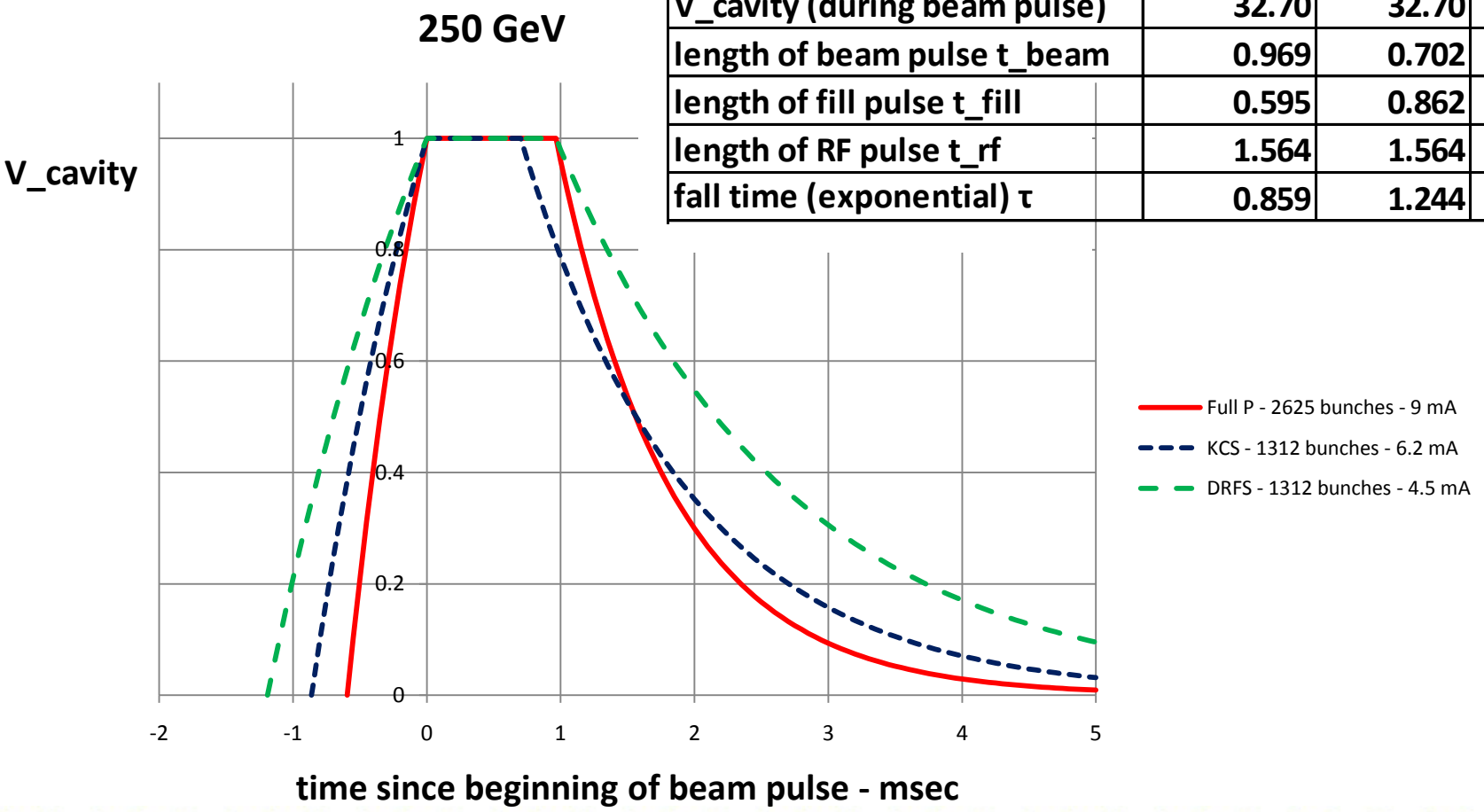


DRFS for Reduced # Bunches

- Shigeki sent multiple choices on Sunday, Jan 16: designated 091216, 100327, 100601, 110115A
- I'll use 110115A which includes extra cost for extra capacity needed for longer t_rf for DC PS and Modulators, but not for Klystron
- Shigeki did apply "learning curves" of 89-90% or quantity pricing reduction for klystrons, modulators, & power supplies
- Shigeki previously said details with new estimates will not be available until Summer 2011

RF parameters

Scenario	Full Power	Reduced # bunches	
RF configuration	KCS & DRFS	KCS	DRFS
beam current I_beam	9	6.2	4.5
# bunches/train	2625	1312	1312
# trains per second	5	5	5
max energy	250	250	250
V_cavity (during beam pulse)	32.70	32.70	32.70
length of beam pulse t_beam	0.969	0.702	0.969
length of fill pulse t_fill	0.595	0.862	1.19
length of RF pulse t_rf	1.564	1.564	2.159
fall time (exponential) τ	0.859	1.244	1.717



Dependence of Cryo Dynamic Loads

RF load ~ $V^2_{cav}*(t_{beam}+1.11*t_{fill})$

Input Coupler load ~ $V_{cav}*(t_{beam}+t_{fill})*I_{beam}$

HOM (beam) load ~ I_{beam}

Don't ask, I don't have simple breakdown by dynamic load component, or even dynamic to static sum, only listed as function of coolant temperature (2 K, 5 K, 40 K)

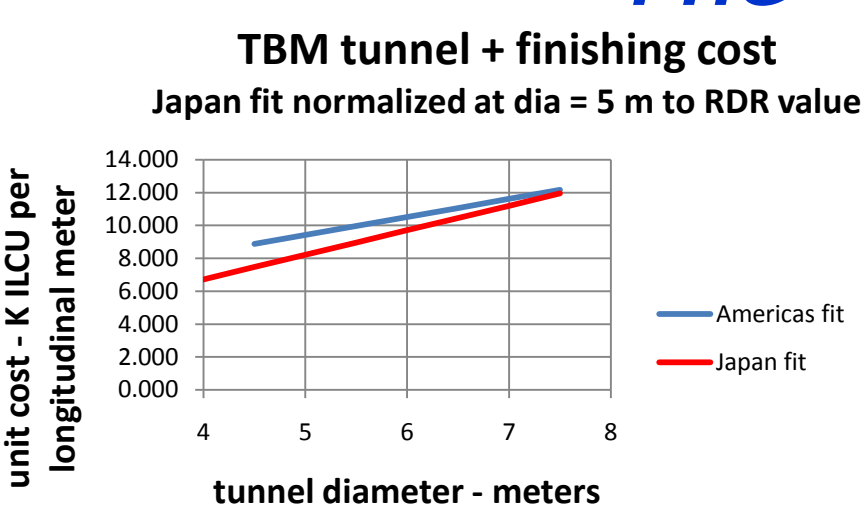
Cryo Loads: Full Power (both) 10* 4.42 MW
Reduced # bunches: KCS 10* 4.12 MW
DRFS 10* 4.72 MW

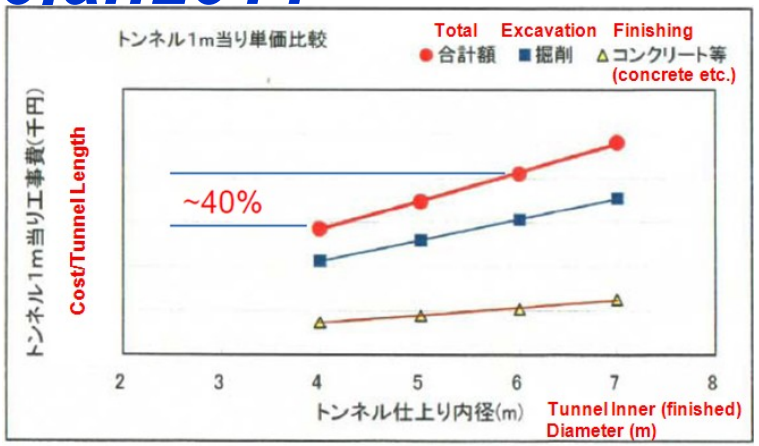
7.5 m diameter DR tunnel for 3 rings

- Prior SB2009 had 6.5 m dia DR tunnel
- US 6.5 m 11.067 K/m, Asia 6.5 m 10.458 K/m
- US 7.5 m 12.166 K/m, Asia 7.5 m 11.952 K/m
- Difference between 7.5 m and 6.5 m diameter tunnel for for 3,223 meter DR:
  US 3.6 M ILCU, Asia 4.8 M ILCU
- Both US and Asia estimates include excavation & concrete finishes
- This above analysis of US estimate did ***NOT*** include extra costs for tighter turning TBM for 3.2 km DR, although detailed CFS estimate did

TBM Tunnel Cost vs. Diameter

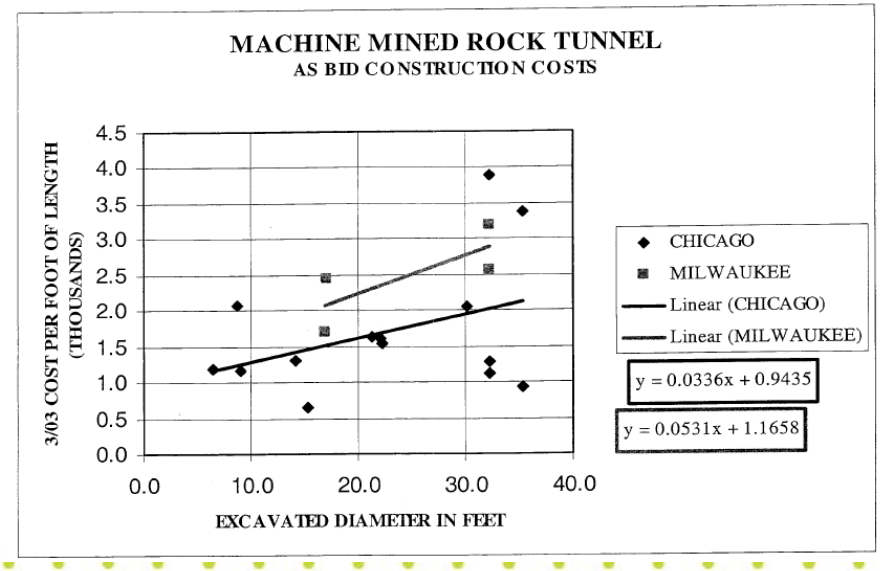
– PHG – 10jan2011



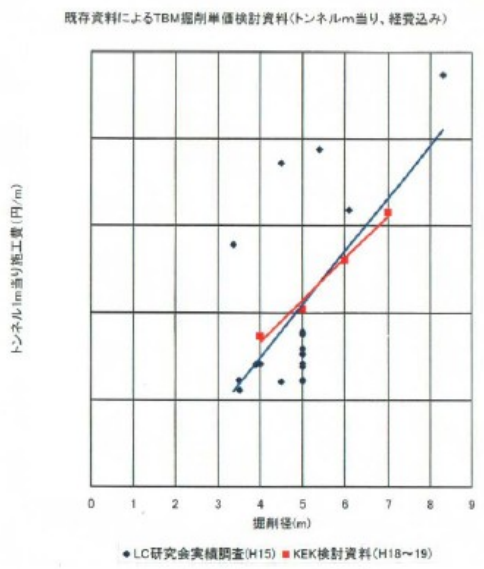


(This does not include land developing cost.)

Hanson/Tracy Lundin: Chicago TARP – Deep Tunnel

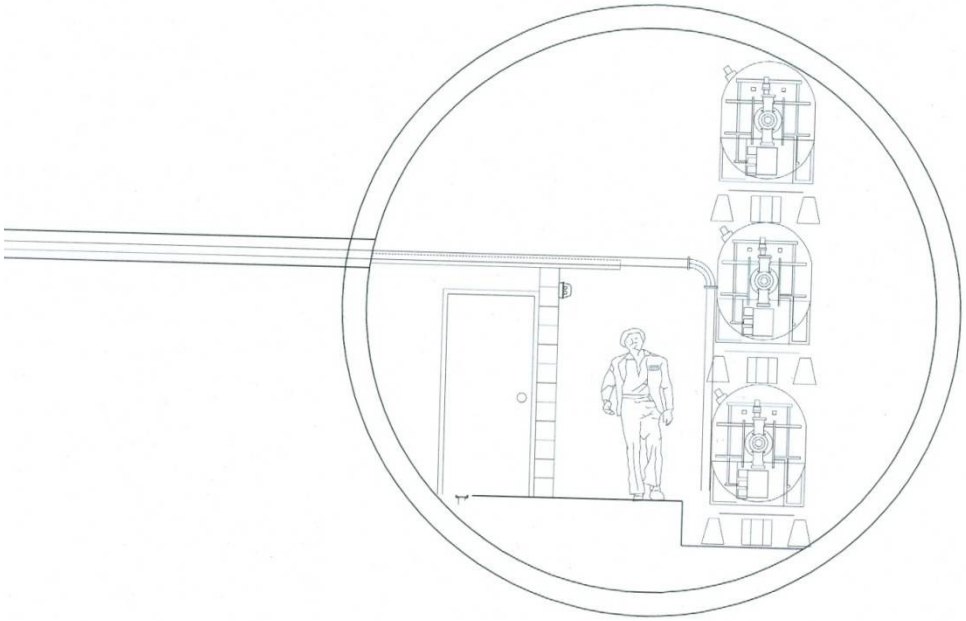


Atsushi @ BAW-1



How can 3 rings fit in the DR tunnel?

CEBAF 4-ring circus



3 CM IN ONE TUNNEL
6 METER TUNNEL SHOWN WITH NOTCHED FLOOR
(VERY DIFFICULT SOLUTION)
THE OUTER CIRCLE IS 6.5 METERS

Damping Ring Magnets

RF cavities & wigglers on next page

Positron-Source-Location-PHG-19nov2010.xls/DR-counts				1.0323			dipole KLs are OK					3. how do the cost of sextupoles scale with Sx term? F					
Peter H. Garbincius - re-do damping ring counts				7dec2010-3:30 PM													
https://wiki.lepp.cornell.edu/ilc/bin/view/Public/DampingRings/#Damping_Rings_Parameters_and_Lat																	
		from RDR table		k1 arcs =	0.287	k max=			max k1 =	0.585	all quads are 0.3 m						
per ring - 5 GeV	OCS6 - RDR DR & Magnets - 6.7 hex						per ea	per tot	DCO4 - Susanna 10/09 - 6.4 race				per ea	per tot	SB2009 - 14dec09 - 3.2 race				per ea	per tot
Main e- DR & e+ DR each	#	length m	max KL	unit	field		K 2006	K 2006	#	lgt	field		2006	2006	#	lgt	field		2006	2006
RDR Dipoles 6 m	114	6	0.0524	1	0.145	T	63.66	7,257												
RDR Dipoles 3 m	12	3	0.0262	1	0.145	T	38.82	466												
DCO4 arc dipoles			above is		about right				200	2	0.27	T	39.51	7,902						
DSB3 arc dipoles - type 1			bend angle												68	2.7	0.26	T	51.36	3,493
DSB3 arc dipoles - type 2			at 1 m per												60	2.7	0.36	T	71.12	4,267
chicane dipoles - 1 m - 0.27	no chicanes?		6 m dipole	Susanna: chicanes omitted but needed					48	1	0.27	T	19.76	948	48	1	0.27	T	19.76	948
Quads V1	551	0.3	0.31	1/m	6.1	T/m	12.24	6,747												
Quads V2-V3-V4	196	0.3	0.31	1/m	17.3	T/m	16.84	3,301												
Quadrupoles - 0.3 m - 12 T/m		Q is bend at 1 m			right range				692	0.3	12	T/m	16.84	11,654						
Quadrupoles # 1 Q30L300 V2	but RDR was Q60 L30 but pole tip radius was 0.03 m								all = 0.3 m		interpolate below				204	0.3	11	T/m	14.31	2,920
Quadrupoles # 2			K1 V1 =	0.287		2.8361			are these quads all the same?						128	0.56	8.3	T/m	26.95	3,449
Quadrupoles # 3			K1 V2-4 =	0.725	0.3 m	2.5261			use same cost as RDR V2						128	0.73	11.9	T/m	32.84	4,204
Quadrupoles # 4				0.939	0.15 m						Gmax=	12.434	close!		4	0.215	16.9	T/m	10.44	42
Quadrupoles # 5															30	0.43	14.7	T/m	20.71	621
sum # main Quadrupoles =	747								692						494		interpolate below			
sextupoles	480	0.25	0.24	1/m^2	16.76	T/m^2	4.799	2,303	392	0.25	215	T/m^2	11.22	4,400	280	0.25	150	T/m^2	9.956	2,788
orbit corrector magnets	300	0.25	0.002	1	0.133	T	4.756	1,427	300	0.25	0.133	T	4.756	1,427	300	0.25	0.133	T	4.756	1,427
skew quads	240	0.25	0.03	1/m	2.0	T/m	12.1	2,903	240	0.25	2.2	T/m	12.1	2,903	240	0.25	2.2	T/m	12.1	2,903
check arc dipoles int B*dL (T-m)	104	expect	104.4	T-m	sum07	25,192	sum06	24,404	108	T-m -	sum07	30,179	sum06	29,234	106	close	sum07	27,936	sum06	27,062
Common Injection/Extraction/Abort																				
RTML6 dipoles (inj/extr/abort	3	D60L2000							same						same					
Quads V2 (inj/extr)	12								same						same					
inj/extr kickers	40								same						same					
inj/extr septa	4								same						same					
abort kickers	1								same						same					
abort septa	1								same						same					

RF & wigglers for DRs – 5 Hz

full P – 3 rings

lattice	RDR-OCS 6	DCO 4	SB2009	SB2009	SB2009
	20-Apr-07	full-P 5 Hz	LowP 5 Hz	full-P 5 Hz	full-P 5 Hz
beams	e+/e-	e+/e-	e+/e-	e-	2* e+
reference-page	ref 3 p 31	ref 4 p 3	4-11,30	ref 4 p 30	ref 4 p 30
Circumference (m)	6695	6476	3238	3238	3238
# bunches per DR	2610	2610	1305	2610	1305
damping time ms	26	21	24	24	24
RF Voltage MV/DR	24	21	7.5	7.5	3.75
# RF cavities/DR	18	16	6	12	6
# klystrons/DR	5	4	2	4	2
Wiggler B (Tesla)	1.67	1.6	1.6	1.6	1.6
Wiggler period (m)	0.4	0.4	0.4	0.4	0.4
Wiggler lgt ea (m)	2.45	2.45	2.45	2.45	2.45
Wiggler lgt/DR (m)	200	216	78	78	78
# wigglers/DR	80	88	32	32	32

Cost Differentials for ML

Main Linac -KCS	Full Power 2625		Reduced # 1312		cost	Notes: basis = ChrisA's cartoon
	Quantity	Cost - M	Quantity	Cost - M	diff - M	27unitKCSpowerflow.pptx
Klystrons - 10 MW	714	206.3	499	153.7	-52.6	cost includes Learning Curve
Modulators & PS	714	377.7	499	282.4	-95.3	assumes same performance
KCS Pipe - meters	1428	1.4	998	1.0	-0.4	differential in RF Building
CTO Couplers - pairs	714	7.1	499	5	-2.1	klystrons to pipe in building
W.G. Switches - pairs	714		499			safety - have no unit cost
Cryogenics Plants - MW	10*4.42	228.1	10*4.12	218.8	-9.3	same cryo accessories & distrib
CFS: Civil		609.5		593	-16.5	
CFS: Electrical - MW	151.6	142.5	119.7	125.5	-17.0	red = changed since draft
CFS: Air + Cooling - MW	79.8	117.3	63.6	107.49	-9.8	
totals		1689.9		1486.9	-203.0	

Main Linac - DRFS	Full Power 2625		Reduced # 1312		cost	Notes:
modified 18jan2011	Quantity	Cost - M	Quantity	Cost - M	diff - M	based on DRF-Cost 110115A
Klystrons - 800 KW	7592	493.5	3796	247.0	-246.5	includes extra capaity for Low P
Magic Tees - Hybrids	7592	52.0	11690	80.0	28.0	for DC PS and Modulators
DC PS (incl backup)	584	174.0	584	65.1	-108.9	did not include "learning curves"
MA Pulser (incl backup)	876	52.6	437	35.0	-17.6	
Cryogenics Plants - MW	10*4.42	228.1	10*4.72	237.2	9.1	same cryo accessories & distrib
CFS: Civil		632.9		632.9	0.0	
CFS: Electrical - MW	182.3	186.7	167.8	171.8	-14.9	
CFS: Air + Cooling - MW	92.8	171.1	61.3	159.1	-12.0	
totals		1990.9		1628.1	-362.8	

tab: low-P

DR & Summary Cost Differentials

Damping Rings	Full Power 2625		Reduced # 1312		cost	restore 2625 bunches 1 e- & 2 e+ DRs		Notes:
	Quantity	Cost - M	Quantity	Cost - M	diff - M	Quantity	Cost - M	
Technical Elements		425.8		276.3	-149.5		426.1	see DR detail sheet(s)
Cryogenic Plants - MW	2.16	19.9	0.77	9.6	-10.3	need info	need info	two cryo plants
Cryogenic Distribution		8.5		8.3	-0.2		12.8	50% more for 3 rings
CFS: Civil	6.4 @ 5	127.8	3.2 @ 7.5	107.3	-20.5		107.3	note 7.5 m tunnel to allow 3 rings
CFS: Electrical - MW	26.3	20.1	12.8	16.3	-3.8	19.2	18.1	
CFS: Air + Cooling - MW	19.5	32.0	8.5	24.2	-7.8	14.8	30.3	
totals		634.1		442.0	-192.1		594.5	

Summary (in M ILCU)	ML	DR	Total	wrt 6,618 M ILCU
Savings with KCS	-203	-192	-395	-6.0%
Savings with DRFS	-363	-192	-555	-8.4%

tab: low-P

restoration of 2625 bunches/train

- KCS – relatively easy, increase size of RF building, install klystrons & modulators, on surface. Minimum impact on accelerator operations. Should install full Cryo plants from start (don't save that 9 M ILCU earlier)
- DRFS – need to add many more klystrons in tunnel, interrupting accelerator operations. Due to higher cryo load for DRFS reduced # bunches, larger plants were installed and will not need upgrading.
- Damping Ring – install a second Positron Ring, inj/extr e+ switches, and more cryo and power.

restoring 2625 bunches/train

Main Linac -KCS	Full Power 2625	to restore 2625 initiallly	to restore 2625 defer	terminate at 1312	Notes
	Cost - M	Cost - M	Cost - M	Cost - M	red = PHG guess
Klystrons - 10 MW	206	154	53	154	
Modulators & PS	378	282	95	282	
KCS Pipe - meters	1	1	0	1	
CTO Couplers - pairs	7	5	2	5	
W.G. Switches - pairs					
Cryogenics Plants - MW	228	228	0	219	could defer some compressors
CFS: Civil	610	593	17	593	defer buildings
CFS: Electrical - MW	143	134	9	126	assume some fraction ~ 50%
CFS: Air + Cooling - MW	117	112	5	107	assume some fraction ~ 50%
totals	1690	1510	180	1487	

Damping Rings - 3.2 km 1 e+ & 1 e- => 2 e+ & 1 e-	Full Power 2625	to restore 2625 initiallly	to restore 2625 defer	terminate at 1312	Notes
	Cost - M	Cost - M	Cost - M	Cost - M	red = PHG guess
Technical Elements	426	276	150	276	maybe some extra/reconfigure
Cryogenic Plants - MW	20	20		10	could defer some compressors
Cryogenic Distribution	9	8	0	8	minor # new boxes
CFS: Civil	128	107	21	107	already paid for 7.5 m tunnel
CFS: Electrical - MW	20	18	2	16	assume some fraction ~ 50%
CFS: Air + Cooling - MW	32	28	4	24	assume some fraction ~ 50%
totals	634	458	176	442	

sums ML (KCS) + DR	2324	1968	356	1929	
difference = extra investiment cost =		1968	minus	1929	39 M ILCU (= 0.6% of 6.6 B ILCU)

check KSC optimization!

Is ChrisA's optimization of KCS for reduced # bunches optimal?
He tried to minimize dynamic load on cryogenics system

What if he took DRFS approach => cut # klystrons in half which forces longer t_rf pulse length?

Full Power		KCS approach		DRFS approach	
714 klys	206 M	499 klys	194 M	357 klys	116 M
714 mod	378 M	499 mod	282 M	357 mod*	251 M
Cryo 4.42	228 M	cryo 4.12	219 M	cryo 4.72	237 M
Total	812 M		695 M		604 M

This used LC = 90% for klystrons, 88.5% for mods

* I did multiply by modulator cost by sqrt(2.159/1.564) = 1.175

Have not looked at cost for increased pulse length for klystron

Have not looked at Electrical & Cooling ~ 27 M less for DRFS

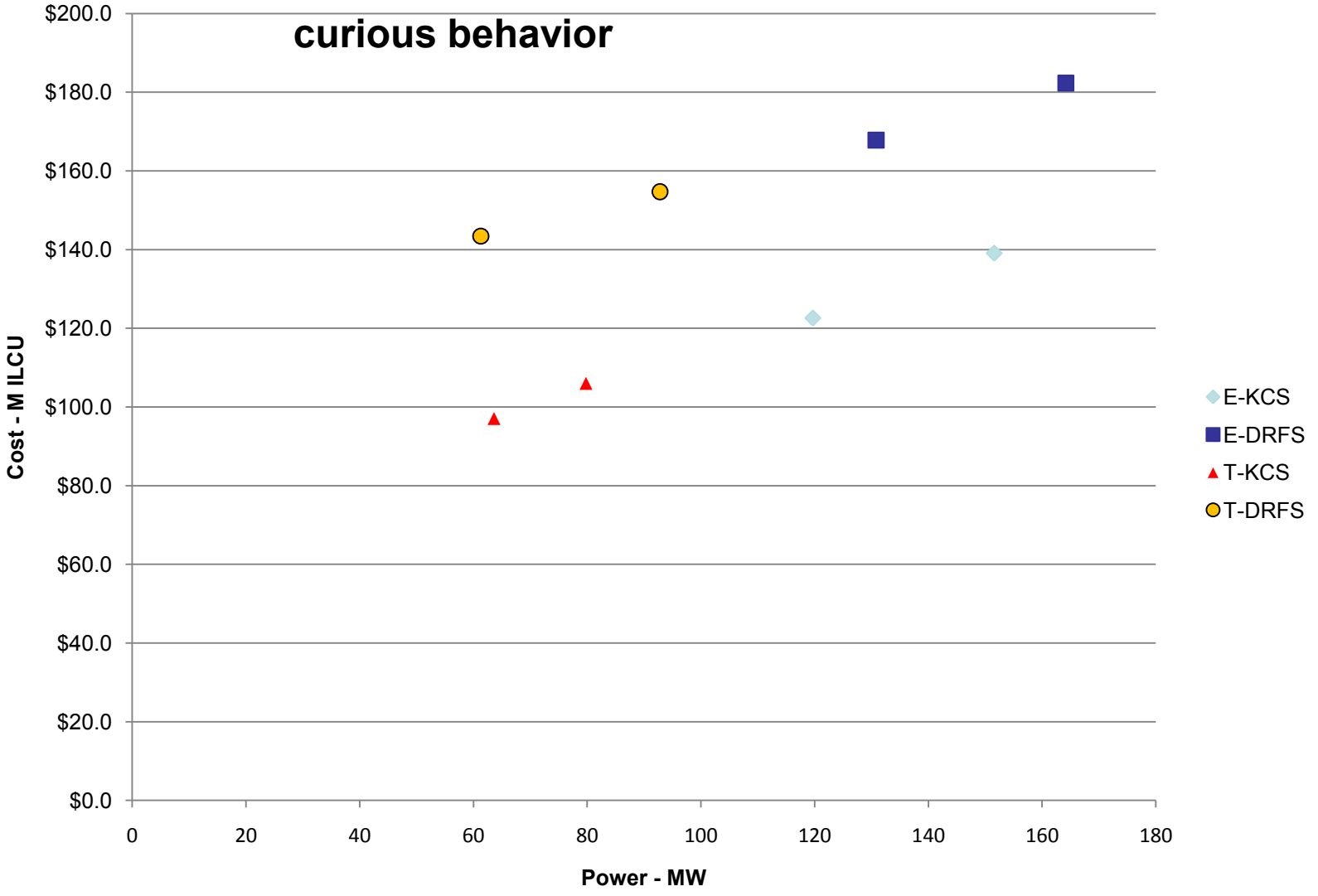
Backup notes

errors, omissions, inconsistencies

- CFS: no CMU fire-rated enclosure for DRs, however, this would be no differential cost

  Not needed for DR due to new understanding of fire protection reqs for single tunnels
- CFS did not vary the power requirements for Cryogenics Plants for DR (used RDR for all)
- CFS did not change capacity of DR service buildings for electrical and cooling, but did vary for cryogenics
- **CHECK THIS OUT!**

curious plot!



ILC-GDE Cost Disclosure Rules

http://www-ilcdcb.fnal.gov/cost-confidentiality-official-njw.pdf

This meeting will involve discussion of actual cost estimating numbers and data

"review" access has been granted by the GDE Executive Committee to cost data

– questions are allowed, but

– no hard copy or e-file

you must agree (or have previously agreed) not to discuss outside of context of this meeting, publish, or post on public web-site any cost estimating information