Cavity Yield-Cost Models

Peter H. Garbincius

Fermilab

IWLC2010 – Geneve

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filename: PHG cavity yield-cost models oct2010.ppt

introduction

following Jim Kerby at BAW-1 – KEK -10sept2010

How does cost of cavities vary with yield, reprocessing, and spread of operating cavity gradients (± 20% with <G> ≥ 35 MV/m)?

f = processing/(materials + fabrication + processing)
Wilhelm B => f = 0.35 (TESLA model)
Jim Kerby => f = 0.30 so I'll use <f> = 0.325

cavity cost factor =
average price paid per useful cavity/production cost
= 1.00 if Y=100% & no need to reprocess

yield vs. cost models analyzed:

- <f> = 0.325 = processing fraction = < WB + JK>
- RDR: Y = 80% - no reprocessing => **ccf** = 1/Y = **1.25**
- Y1=Y2=80%, reprocess, $Y_{composite}$= 96%, ccf = **1.11**
- $Y_{composite}$=90%, Y1=Y2=68.4% reprocess, ccf = **1.22**

simple calculation for above 3 cases, see below for:

- ILC processed cavities in DB, reprocess < 35 MV/m
- ILC DB, grad spread for G ≥ 25, 28, 30, 35, reprocess
- Rong-Li's 8 most recent ACCEL/RI cavities
  - fixed G ≥ 35 MV/m => Y1 = 62.5% (Y2 = 67%) $Y_{composite}$ = 87.5%
  - for accepted G ≥ 31 MV/m => Gradient spread => ± 15%
- Peter's class of toy models of cavity performance

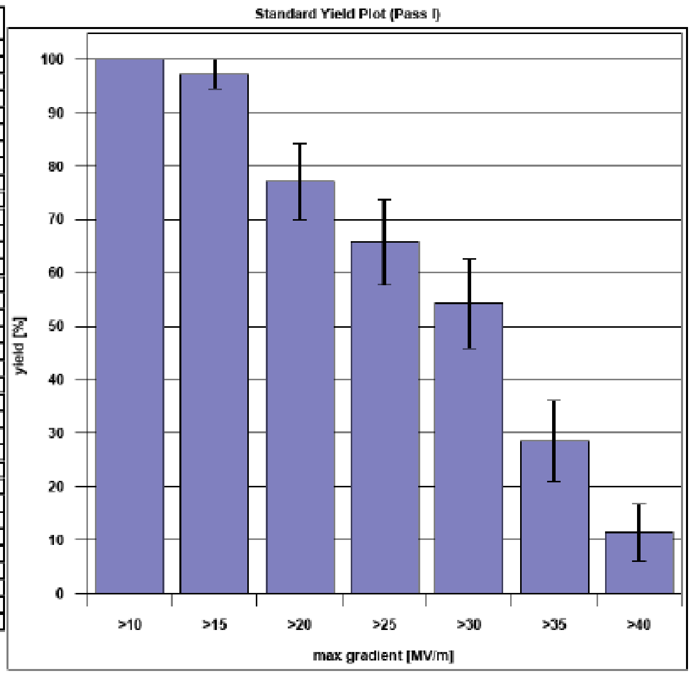
A Brief Look Forward

TDP/R&D plan release 5

for G ≥ 35 MV/m

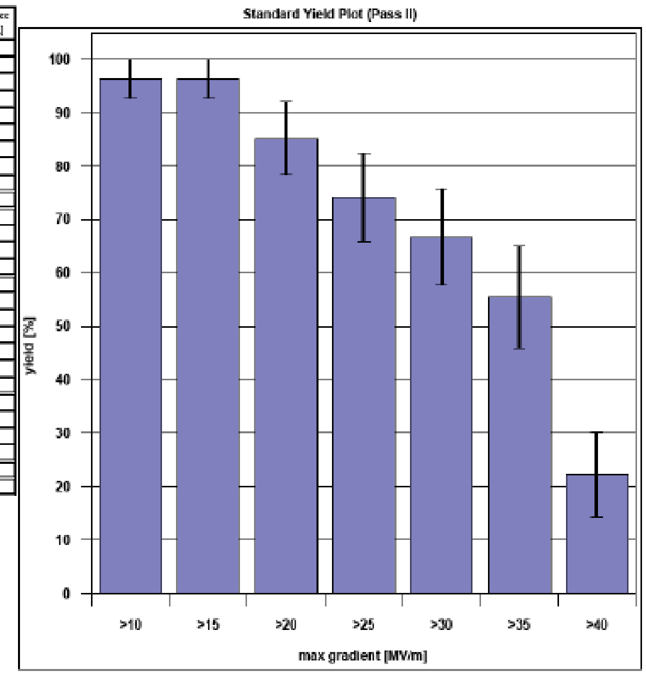
1st Pass, 35 cavities, ~29%

No.	Cavity	Test Date	Max. Eacc [MV/m]
1	TB9ACC013	01.Dec.08	41.80
2	TB9ACC014	09.Feb.09	41.50
3	TB9ABS008	26.Aug.09	41.10
4	TB9ABS007	16.Mar.10	41.00
5	AC122	26.Aug.08	38.88
6	AC115	11.Dec.07	38.60
7	TB9RI019	11.Jun.10	38.00
8	TB9ABS010	06.Nov.09	37.70
9	TB9ACC011	21.Aug.08	37.00
10	TB9ACC012	07.Jul.08	35.10
11	Z134	13.Nov.09	34.94
12	AC125	15.Jun.08	34.59
13	AC150	30.Jan.09	34.33
14	TB9ABS009	18.Aug.09	33.40
15	TB9RI018	15.Apr.10	33.10
16	Z143	09.Oct.08	32.57
17	Z106	21.Feb.07	31.70
18	AC127	13.Feb.09	31.25
19	TB9ACC016	14.Dec.09	31.20
20	ACCEL7	05.Sep.06	29.00
21	AC149	28.Jan.09	26.51
22	AC124	05.Feb.09	26.01
23	Z137	24.Feb.09	25.23
24	Z139	12.Sep.08	24.93
25	AC146	06.May.10	23.63
26	Z142	01.Jul.09	20.58
27	TB9ABS005	27.Mar.09	20.50
28	ACCEL6	12.Dec.06	19.00
29	Z141	16.Apr.08	18.29
30	TB9ACC015	02.Jul.08	18.00
31	Z130	01.Sep.08	17.30
32	Z131	20.Aug.08	17.17
33	Z132	19.Aug.08	16.83
34	AC126	05.Sep.08	16.37
35	TB9ABS006	09.Apr.09	14.10



2nd Pass, 27 cavities, ~56%

No.	Cavity	Test Date	Max. Eacc [MV/m]
1	TB9ACC013	01.Dec.08	41.80
2	TB9ACC014	09.Feb.09	41.50
3	ACCEL7	18.Jun.07	41.20
4	TB9ABS008	26.Aug.09	41.10
5	TB9ABS007	16.Mar.10	41.00
6	Z143	12.Nov.08	41.00
7	TB9ACC016	11.Feb.10	39.30
8	TB9RI018	02.Jun.10	39.00
9	AC122	26.Aug.08	38.88
10	AC115	11.Dec.07	38.60
11	TB9RI019	11.Jun.10	38.00
12	TB9ABS010	06.Nov.09	37.70
13	TB9ACC011	21.Aug.08	37.00
14	TB9ABS009	07.Oct.09	36.00
15	TB9ACC012	07.Jul.08	35.10
16	AC150	08.May.09	33.23
17	Z139	20.Oct.08	32.75
18	AC124	10.May.09	30.93
19	ACCEL6	23.Jan.07	29.00
20	AC127	11.Jun.09	27.85
21	TB9ABS006	11.Sep.09	22.20
22	Z141	14.May.08	20.70
23	TB9ABS005	09.Apr.09	20.50
24	TB9ACC015	14.Jul.08	19.00
25	Z131	25.Nov.08	17.96
26	Z130	15.Oct.08	16.60
27	AC126	21.Oct.08	6.14



Analysis of ILC EP Cavity Performance
Kerby_BAW-1_page2.xls + Akira-23sept 2010

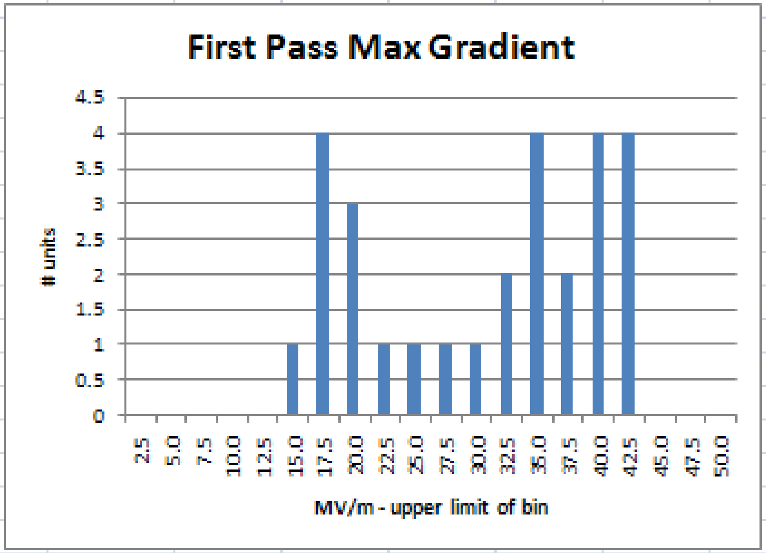
Kerby_BAW-1_page2.xls [Compatibility Mode]

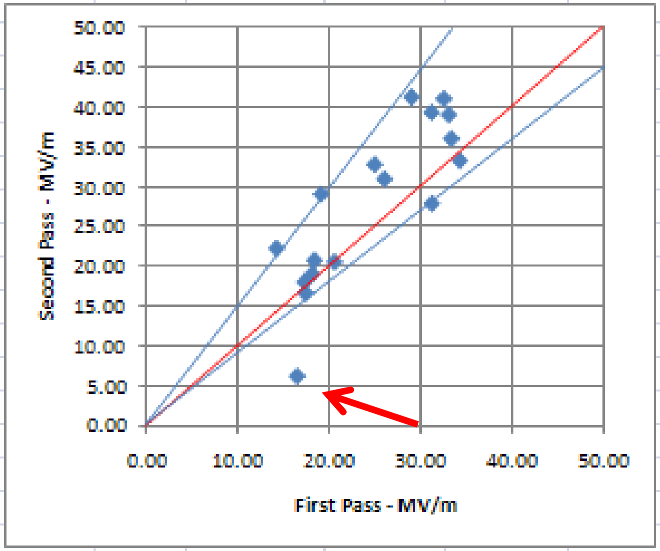
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Kerby_BAW-1_page_2.xls/ILC data							ILC Summary			Acceptance Threshold - MV/m	35	30	28	25	35(1) & 28(2)
2				fractional cost for processing =				PHG-22sept2010			Yield-1st pass	36%	57%	60.7%	64%	35.7%
3	PHG-14sept2010			RDR had, doesn't matter much							Yield-2nd pass	29%	27%	30.0%	22%	52.9%
4		cavity	G(1)	G(2)		if you choose					composite Yield for 2 passes	54%	68%	71.4%	71%	67.9%
5	1	TB9AAC013	41.80	41.80	1	not reprocessed					Avg Gradient - MV/m	39.1	36.4	35.4	35.2	37.5
6	2	TB9ACC014	41.50	41.50	2						plus/minus %	+7%/-10%	+15%/-15%	+18%/-18%	+19%/-26%	+11%/-23%
7	3	TB9AES008	41.10	41.10	3						average cavity cost (equals 1.00 for Y1=100%)	2.24	1.66	1.56	1.55	1.76
8	4	TB9AES007	41.00	41.00	4									no diff between 28 & 25		Akira - 28sept2010
9	5	AC122	38.88	38.88	5											
10	6	AC115	38.60	38.60	6		Acceptance Threshold =		35	MV/m		Acceptance Threshold		30	25	
11	7	TB9RI019	38.00	38.00	7		# tested		28					28	28	
12	8	TB9AES010	37.70	37.70	8		# pass 1		10					16	18	
13	9	TB9ACC011	37.00	37.00	9		Y1 =		35.7%					57.1%	64.3%	
14	10	TB9ACC012	35.10	35.10	10		# trashed (Z132)		1					1	1	
15	11	AC150	34.33	33.23	11		# reprocessed		17					11	9	
16	12	TB9AES009	33.40	36.00	12		# pass 2		5					3	2	
17	13	TB9RI018	33.10	39.00	13		Y2 =		29.4%					27.3%	22.2%	
18	14	Z143	32.57	41.00	14		f = process/(cavity+process)		0.325	0.3 = Kerby model, 0.35 = Wilhelm model				0.325	0.325	
19	15	AC127	31.25	27.85	15		pass either 1 or 2		15		take avg			19	20	
20	16	TB9ACC016	31.20	39.30	16		net yield		53.6%	expect this to increase				67.9%	71.4%	
21	17	ACCEL7	29.00	41.20	17		what is total cost paid		33.525					31.575	30.925	
22	18	AC124	26.01	30.93	18		avg cost per cavity		2.24	where => 1 for Y1 = 100%				1.66	1.55	
23	19	Z139	24.93	32.75	19					this is 2.21 for Kerby, 2.26 for Wilhelm						
24	20	TB9AES005	20.50	20.50	20											
25	21	ACCEL6	19.00	29.00	21		Sum of Gradients, pass #1 =		390.68					586.53	641.54	
26	22	Z141	18.29	20.70	22		Sum of Gradients, pass #2 =		196.50					104.88	61.75	
27	23	TB9ACC015	18.00	19.00	23		Sum Gradients, pass 1+2		587.18					691.41	703.29	
28	24	Z130	17.30	16.60	24		# cavities passing 1+2		15					19	20	
29	25	Z131	17.17	17.96	25			avg Gradient	39.15					36.39	35.16	
30	26	AC126	16.37	6.14	26			spread +/-	6.8%					14.9%	18.9%	
31	27	TB9AES006	14.10	22.20	27			spread +/-	-10.3%					-15.0%	-26.0%	
32	28	Z132	16.83	ILC processing, but known defect, not reprocessed - Jim Kerby - 15sept2010												

Analysis of ILC EP Cavity Performance Kerby_BAW-1_page2.xls summary & plots

ILC Summary	Acceptance Threshold - MV/m	35	30	28	25	35(1) & 28(2)
PHG-22sept2010	Yield-1st pass	36%	57%	61%	64%	36%
	Yield-2nd pass	29%	27%	30%	22%	53%
	composite Yield for 2 passes	54%	68%	71%	71%	68%
	Avg Gradient - MV/m	39.1	36.4	35.4	35.2	37.5
	plus/minus %	+7%/-10%	+15%/-15%	+18%/-18%	+19%/-26%	+11%/-23%
	average cavity cost (equals 1.00 for Y1=100%)	2.24	1.66	1.56	1.55	1.76

no diff between 28 & 25 Akira - 28sept2010

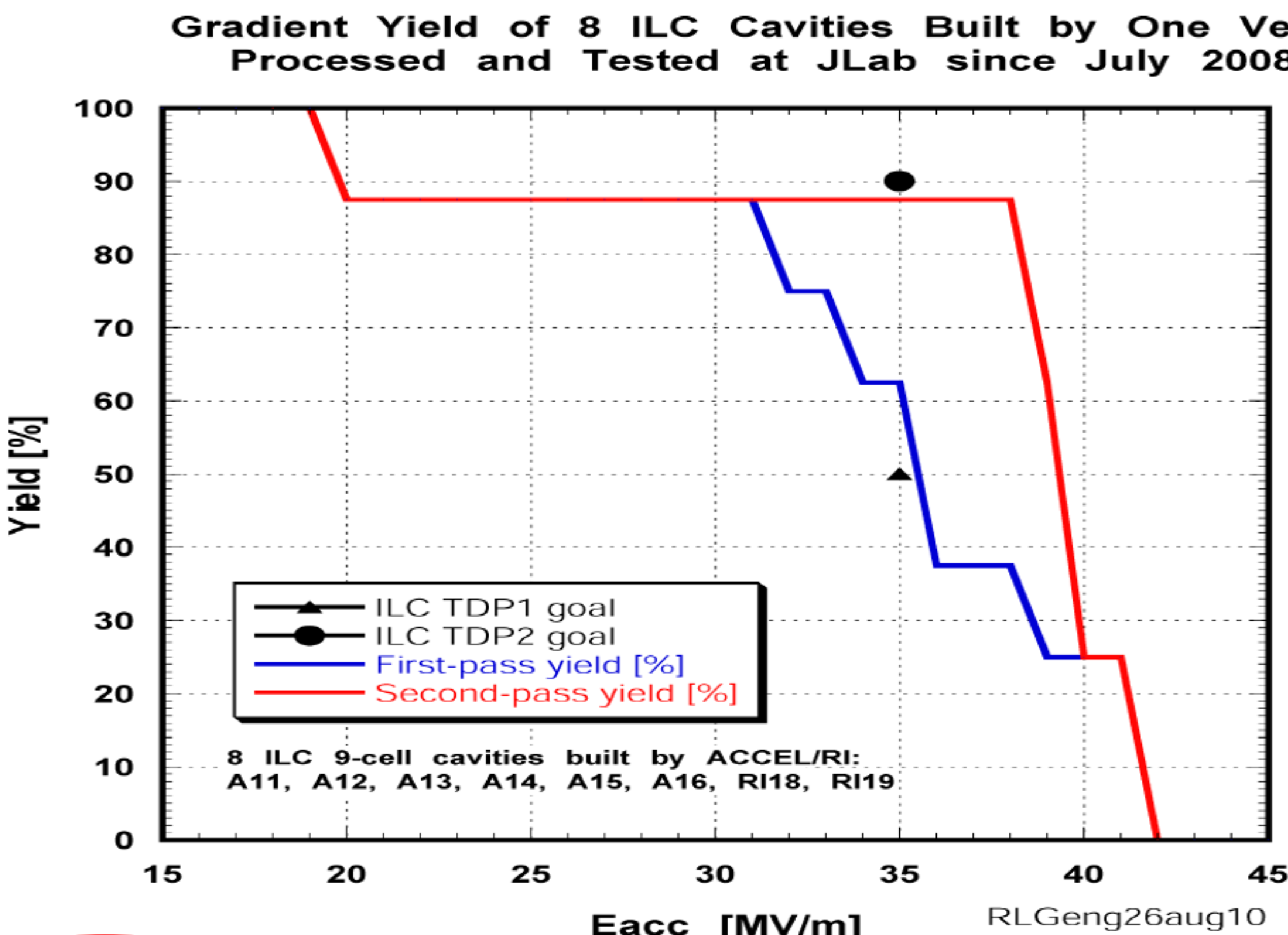




simple observation
except for odd-ball point # 26
(1 out of 17 cavities for pass 2)
G2 goes from 0.9*G1 to ~ 1.5*G1

might need .pdf to prevent
moving of these lines on
G1 vs. G2 scatter plot

An Example of ~ 90% Yield at 35 MV/m



Rong-Li's 8 latest ACCEL/RI cavities

cavity	pass 1	pass 2
A11	37.0	
A12	35.1	
A13	41.8	
A14	41.5	
A15	18.0	19.0
A16	31.2	39.3
RI18	33.1	39.0
RI19	38.0	

- For fixed G ≥ 35 MV/m
  - Y1 = 62.5%, reprocess all 37.5% that fail
    Y2 = 67%, Ycomposite = 87.5% ccf = **1.28**
  - But A15 had little hope of passing, so only reprocess 2, both pass 2nd test => ccf = **1.24**
- Accepting a spread in G:

- just first pass: Y1 = 87.5%, G ≥ 31, <G>= 36.8 => ± 15% ccf = **1.14**

- reprocess only A15 => find Y2 = 0, same <G> & spread ccf = **1.19**

indicates that 87-90% is attainable

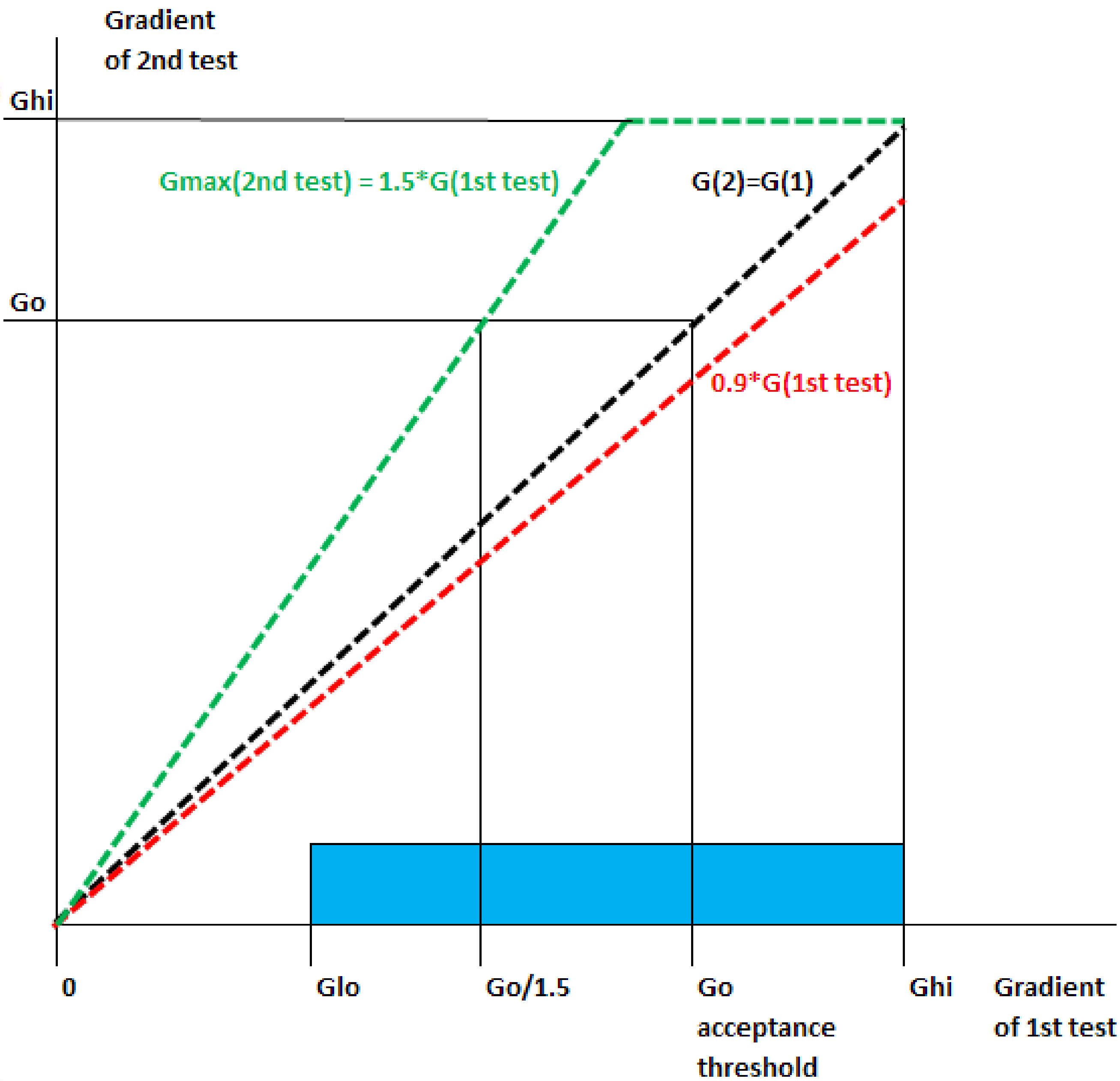
but some small % will never pass

need larger statistical sample

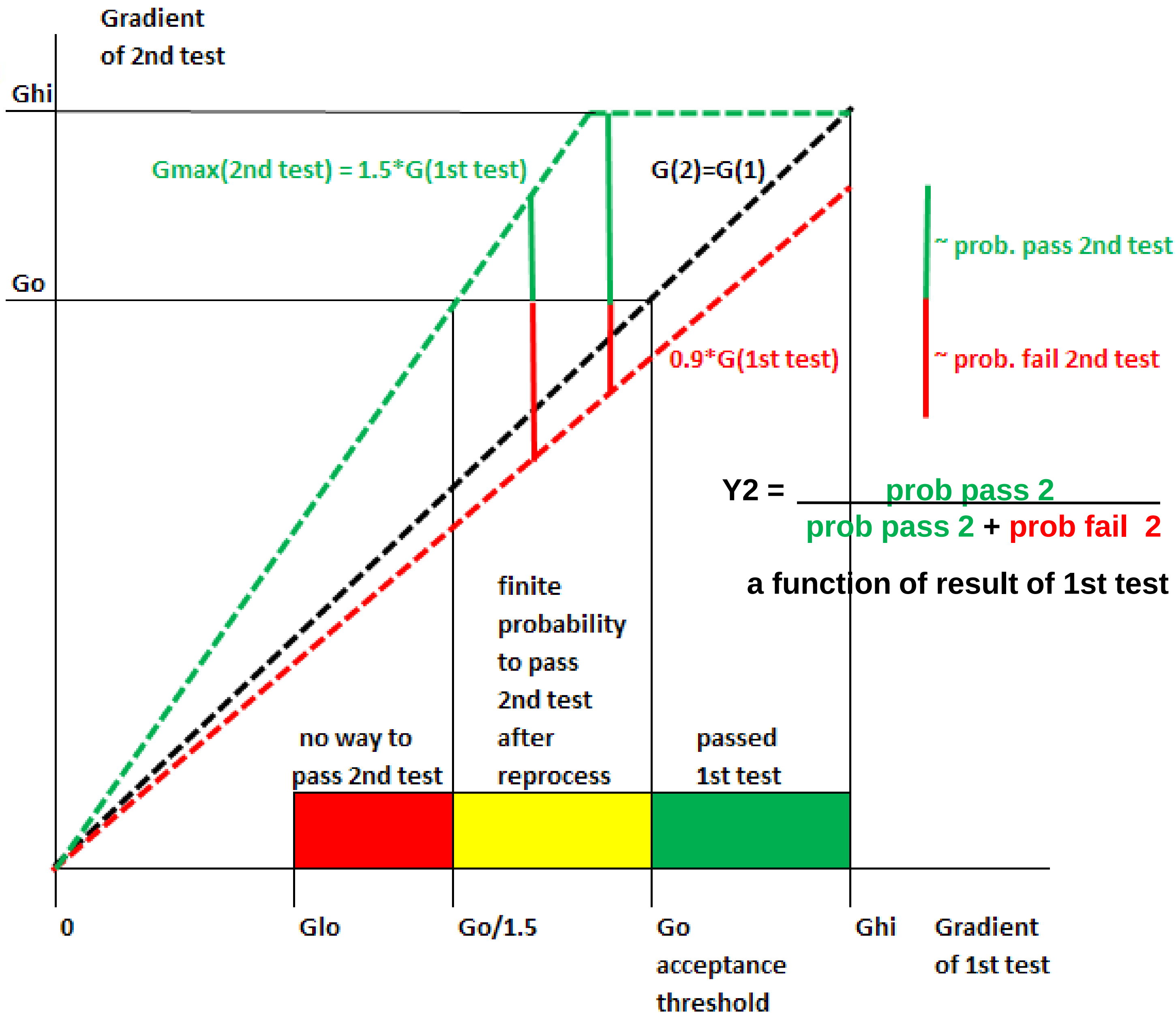
Peter's simple model – vary parameters

- (Glo,Ghi) = range of Gradients in first test
- assumed flat for this example, can change
- Ghi = absolute maximum G for these cavities
- Go = Gradient threshold for acceptance
- f = processing/(materials + fabrication + processing)
- ccf = cavity cost factor (defined above)

Peter's simple model (2)



Peter's simple model (3)



Peter's Y1=flat model – vary parameters

cavity-reprocessing-cost-model-PHG-29sept2010.xls			
			processing cost is a substantial fraction (~1/3) of the cost of producing the cavity
Input parameters	f	0.325	cost of reprocessing (relative to initial cost of materials + fabrication + 1st processing)
first pass distrib	Ghi	43	assumed flat between Glo and Ghi
first pass distrib	Glo	29	assumed flat between Glo and Ghi
acceptance threshold	G0	27	
Factor-hi for 2nd test		50%	150%
Factor-lo for 2nd test		-10%	90%

avg cost	G0 = 25	G0 = 27	G0 = 29	G0 = 31	G0 = 33	G0 = 35
Glo = 15	1.402	1.527	1.680	1.863	2.105	2.452
Glo = 17	1.306	1.424	1.568	1.747	1.984	2.306
Glo = 19	1.203	1.315	1.466	1.625	1.836	2.160
Glo = 21	1.123	1.215	1.335	1.497	1.712	2.002
Glo = 23	1.058	1.134	1.233	1.368	1.559	1.842
Glo = 25	1	1.063	1.146	1.258	1.417	1.670
Glo = 27	1	1	1.068	1.168	1.304	1.518
Glo = 29	1	1	1	1.083	1.211	1.398

avg Grad	G0 = 25	G0 = 27	G0 = 29	G0 = 31	G0 = 33	G0 = 35
Glo = 15	31.82	31.76	31.56	31.25	30.88	30.28
Glo = 17	32.48	32.50	32.26	31.78	31.05	30.24
Glo = 19	33.23	33.28	33.07	32.61	31.81	30.51
Glo = 21	33.44	34.16	34.03	33.60	32.69	31.34
Glo = 23	33.73	34.61	35.04	34.67	33.88	32.57
Glo = 25	34.00	34.82	35.79	35.84	35.16	33.87
Glo = 27	35.00	35.00	35.91	36.96	36.41	35.25
Glo = 29	36	36	36	36.98	37.57	36.56
lower G	25	27	29	31	33	35
upper G	43	43	43	43	43	43
Δ/mid-range (±%)	26.5%	22.9%	19.4%	16.2%	13.2%	10.3%
			accept <G> ≥ 35 MV/m & range ≤ ±20%			

obvious lesson:
get Glo as high as possible!

conclusions

RDR model for disposable cavity yield ccf = 1.25 was simplistic and *maybe* somewhat conservative,

but, experience of entire ILC cavity database shows current yields are too low to attain even ccf = 1.25

Rong-Li's analysis of last 8 ACCEL/RI cavities is encouraging - latest results showing ***progress*** should be given higher weight in any projection

Watch out for pathologies, e.g. AC126, Z132, A15, these will limit cost savings

Accepting range of cavity operating gradients can reduce cost, but not quantatively demonstrated yet

Need more statistics!

back-up slides

Cavity Yield & Cost Model (2^{nd} process/test)

- Y1 = yield for first test, Y2 = yield of second process & test
  assume Y1 = Y2 – this may not be true:
  first failure may not be correctable by second processing
  assume all cavities failing first test are reprocessed & retested
  this may not be true: 1^{st} test may show non-recoverable defect
  let YF = desired final yield after 2 tests, then
  $Y1 + (1-Y1)*Y2 = YF$ => $Y + (1-Y)*Y = YF$ for $Y1=Y2=Y$
  to get YF = 90% (goal of R&D), can solve to get Y = 68.4%
- Currently for cavities w ILC processing Y1 = 36%, Y2 = 29%
- Seems pretty aggressive to get to Y = 68% and YF = 90%,
  may not be attainable cumulatively over all ILC R&D cavities,
  but hopefully this rate could be attained by end of TDP,
  such yield is needed for economics of cavity construction
- What is impact on average cost of acceptable cavities?

Cavity Cost Model (2^{nd} process/test)

- Assuming processing is fraction f of cavity initial production, then cost of cavity processed twice is (1+f) cost units
- Jim Kerby estimates f=0.30, Wilhelm Bialowons ests f= 0.35 then total cost thru second process test = 1 + Y1*f given final yield = YF, <cost per accepted cavity> = (1+Y*f)/YF and <u><cost per accepted cavity></u> = <cost for cavity production & 1^{st} processing>

  1.217 for Kerby's f= 0.30 and 1.234 for Wilhelm's f=0.35 both for Y = 68.4% to give YF = 90%

  some small net savings, wrt RDR, but at lower required yield Y compared to 1.250 for RDR "throw away" model for Y = 80%
- However, if ILC attains Y = 80%, the 2^{nd} process/test model would give YF = 96% and <cost per accepted cavity> = 1.104 for f=0.3 and 1.115 for f=0.35

summary of cavity processing

- RDR estimate used a very crude, conservative model:
  if a cavity failed its initial vertical test, it was discarded, not reprocessed, nor was the niobium recycled. However, the Yield for this first test was assumed to be 80%.
  These correspond to Y1=0.8, Y2=0, f=0 in my eqns.
- Reprocessing and retesting can have a major cost impact
  If Y1 = Y2 = 80%, the <cost of accepted cavities>
  decreases 1.25 => 1.11 (avg JK+WB)
  but if Y1 = Y2 = 68.4%, then although YF = 90%, the <cost of accepted cavities> only decreases1.250 => 1.225
- Costs (incl. Yield) for 15,801 cavities is 10.6% of RDR est.
  So with 2nd process & retest, we would save
  Y=80% => (1.25-1.11)/1.25 * 10.6% = 1.19% of RDR est
  Y=68.4% => (1.25-1.225)/1.25*10.6% = 0.26% of RDR est.

follow-up comments to Marc

- Relative to the cost of fabricating and processing the cavity once (= 1.00 unit cost)
- Average cost of accepted cavity for Y=80%
  without reprocessing (RDR model) is 1.25 units
  penalty = 0.25 units
- Average cost of accepted cavity for Y1=Y2=80%
  WITH one additional reprocessing is 1.12 units
  penalty = 0.12 units
- This agrees with Wilhelm's observation!, but
- Average cost of accepted cavity for Y1=Y2=68.4%
  WITH one additional reprocessing is 1.225 units
  penalty = 0.225 units, small savings wrt RDR
- Moral: reprocessing helps, but gotta ***IMPROVE YIELD***