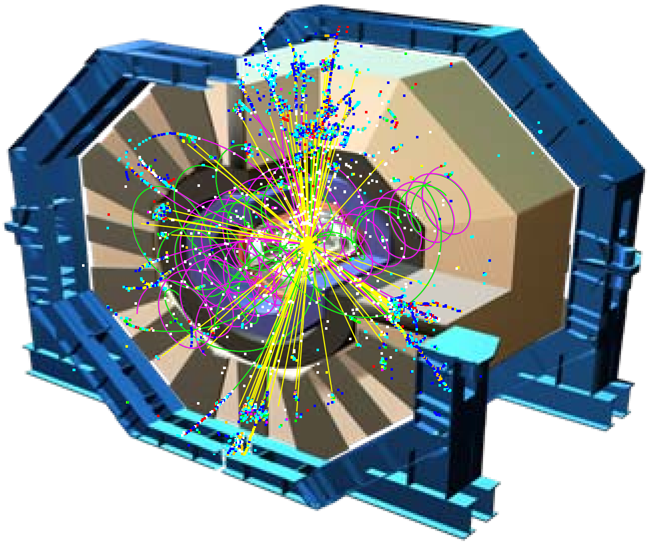
ILC Detector Cost Estimating



Issues

Numbers

GLD A. Miyamoto; R. Settles

LCD H. Videau

SiD M. Breidenbach

Motivation

- Gain understanding of the cost scale of these detectors.
- Attempt to provide a basis for comparing detector costs.
- Develop tools for cost optimizing the detector concepts.

- SiD has beginnings of WBS and parametric cost tools.
- LDC has WBS and is intending a parametric approach
- GLD is beginning cost estimation

- All policy issues reflect our understandings- and are not official in any way.

- ILC is beginning to develop a cost methodology. ITER is possible model. ITER has “Core Values” in “ITER Units”, which are used as a basis for distributing responsibilities.
- Tasks are “Key” (interesting to most everyone) and “Conventional” (boring??). Attempts are made to fairly allocate both varieties.
- ITER model is that host country pays all Facilities Costs.

Issues

- Accounting Rules:
  - US versus European accounting:
    - US convention is to cost all technical labor –
      - Engineering
      - Technicians
      - Trades
      - But not faculty, physicists, students
    - European convention (appears to) cost none of the labor.
    - European system makes sense if adequate labor is permanently employed by the participating universities and labs – and conversely!!
    - Both systems cost full M&S.
    - France is tending towards accounting of all labor by program.
  - Japanese accounting seems similar to European, except that there is relatively little "in-house" labor. Consequently labor appears to be costed M&S.
  - ILC: Account for M&S in ILC Units
  - Account for labor by type in Man-Years.

Other Costs

- Preliminary Engineering - is it a cost?
  - Conceptual design stage may well be considered R&D – as is generic detector R&D. The R&D is usually not included…
  - But there are substantial costs in all stages of development of complex systems:

  - Preliminary Engineering (No!!!)
    - R&D
    - Design & Prototype
  - Final Engineering (Yes, but country dependent)
    - Production Prototypes
  - Production (Yes, but country dependent)
  - Installation & Commissioning (Yes, but country dependent)
  - ILC: Account labor as before, then country dependent.

Base and Contingency

- US convention is to generate base cost at ~66% confidence level, with explicit contingency that should take estimate to ~high 90's% confidence. (Confidence that project can be completed satisfactorily for the cost)
- European "style" appears to be less overt contingency, with more "hidden" in the base.
- European approach tends to use time (non-costed labor) as contingency.
- France requires risk analysis of projects.
- Japan has no explicit contingency.

- Contingency treatment is rather regional

- ILC: Core cost would be 50-50 probability of completing project for stated cost. No explicit contingency. Risk will be managed by local custom.

Escalation

- We all like to estimate in this year's $$.
- But inflation is real – and we will be judged by the sum of then year $$ that we spend.
- Particularly important because there will be a noticeable Δt between now and construction start.
- Assuming inflation at 3%/year (optimistic?) and construction start in 2011 (optimistic?), escalation is a factor of ~1.3.
- Appears to be regional agreement that escalation is real! There is some difference of opinion as to stating escalation.

- ILC: Forget about it in Core Values. Worry about it at home.

Indirects

- Indirects pay for services at the host institutions. Services include purchasing, legal, accounting, etc.
- SiD estimate uses SLAC rates for large projects:
  - 6% on M&S
  - 20% on labor
    - These rates may be optimistic. FNAL appears to be:
      - ~16% on M&S
      - ~30% on labor
- Significant regional differences – Europe would not include indirects....
- Japan would not include indirects, but awaits organization of ILC.
- ILC: Forget about it in Core Values. Worry about it at home.

GDE Request

- GDE would like a representative cost per detector.
- Need a decision $N_{detectors}$.
- No concept has done much aligned with the ILC Cost methodology, but there are some regional beginnings.

Uniform Unit Costs

- The detectors have significant technology overlap-
  - Superconducting solenoids
  - Si detectors
  - Fe flux returns
  - W calorimeter radiator
  - Large area detectors for HCal and muon systems
  - Etc

- We need a mechanism to develop a uniform (although not necessarily correct) basis for estimating unit costs for significant technologies…if inter-detector comparisons are to mean anything. But in the ITER scheme, it's not clear what the comparisons mean.
- Will this happen in Snowmass??? (NO)

Some Critical Unit Costs

- Solenoid $0.81E(MJ)^{0.662}M\$$ PDG + inflation. Seems to fit CMS
- Significant differences among detectors – needs to be cleared up!!!

• Si Detector	$2/cm^2	Extrapolation and hints…
• Tracker & EMCal		
Read Out Chips (ROC)	$100 each	TSMC fab should be <$40
• HCal W (7mm)	$75/Kg	extrapolation from quote on thinner material.
• HCal Detector	$2000/m^2	Babar RPC + square pixel readout
• Magnet iron	$3.48/Kg	Babar Kawasaki experience. Note iron is a commodity with big fluctuations.

GLD

- Beginning Cost Estimation

Cost Estimates

Reference: M.A.Green, S.J.St.Lorant, “**Estimating the Cost of Large Superconducting Thin Solenoid Magnets**”, Advances in Cryogenic Engineering, 39A,pp. 271-pp.276, Plenum Press, New York(1991)

Solenoid magnet

$C1(m\$)=0.458\times[E(MJ)]^{0.700}$ E(MJ): Stored energy

$= 0.458\times1600^{0.7000}$

$= 80$ M$

= 9 billion Yen ← Chosen!!

$C2(m\$)=0.376\times[G(T\cdot m^3)]^{0.655}$ G(T・ m3): TeslaxVolume

$= 0.376\times(3\times\pi/4\times8^2\times8.83)^{0.655}$

$= 42$ M$

=5 BYen

$C3(m\$)=0.559\times[M(tons)]^{0.719}$ M(tons): Weight(Coil+Cryostat)

$= 0.599\times(78 + 191)^{0.719}$

$= 34$ M$

= 4 BYen

$CR(m\$)^{2)} = 1.51\times[R(kW)]^{0.7}$

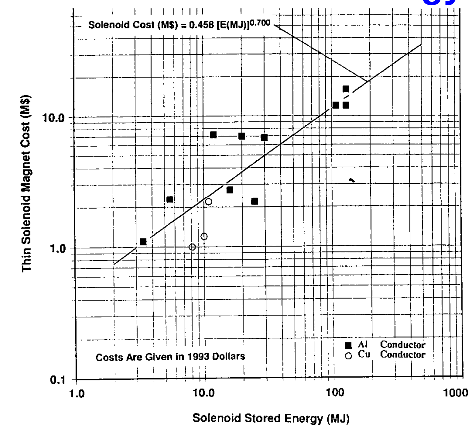
Total Cost

9 BYen + 1BYen(Refrigerators + alpha)

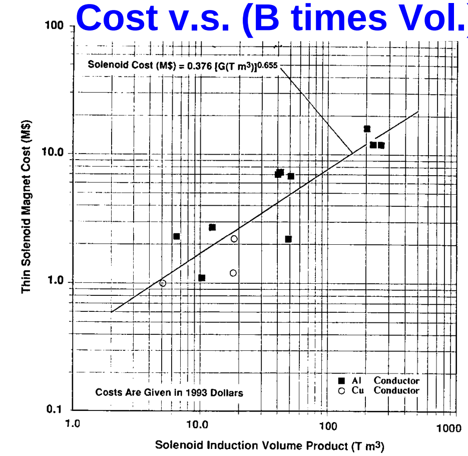
= 10BYen (85M$)

2): M.A.Green, R.A.Byrns, S.J.St.Lorant, “**Estimating the Cost of Superconducting Magnets and the Refrigerators needed to keep them cold**”, Advances in Cryogenic Engineering, 37A,pp. 637-pp.643, Plenum Press, New York(1991)

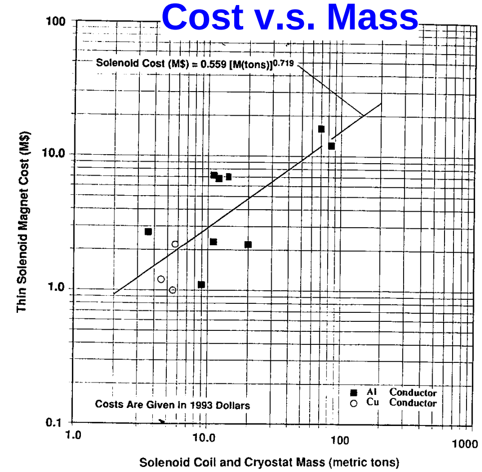
Cost v.s. Stored energy



Cost v.s. (B times Vol.)



Cost v.s. Mass



Return Yoke

○ Law material

\180/kg x 14900e3kg = 2.7BYen

2.7 x 1.2(+alpha) = 3BYen

○ Machining

Total area for machining of Barrel yoke

$400m^2$

End Yoke:

$661m^2$

Machining cost per $1m^2$

\200,000/m^2

Total:

(400+601)m^2x \200,000/m^2 = 0.2BYen

0.2 x 1.2(+alpha) = 0.24BYen

○ Design cost

0.1BYen

○ Cost for Quality Control

50 MYen

○ Profit

20%

3.24BYenx0.2= 1BYen

Total

4BYen(35M$)

LCD

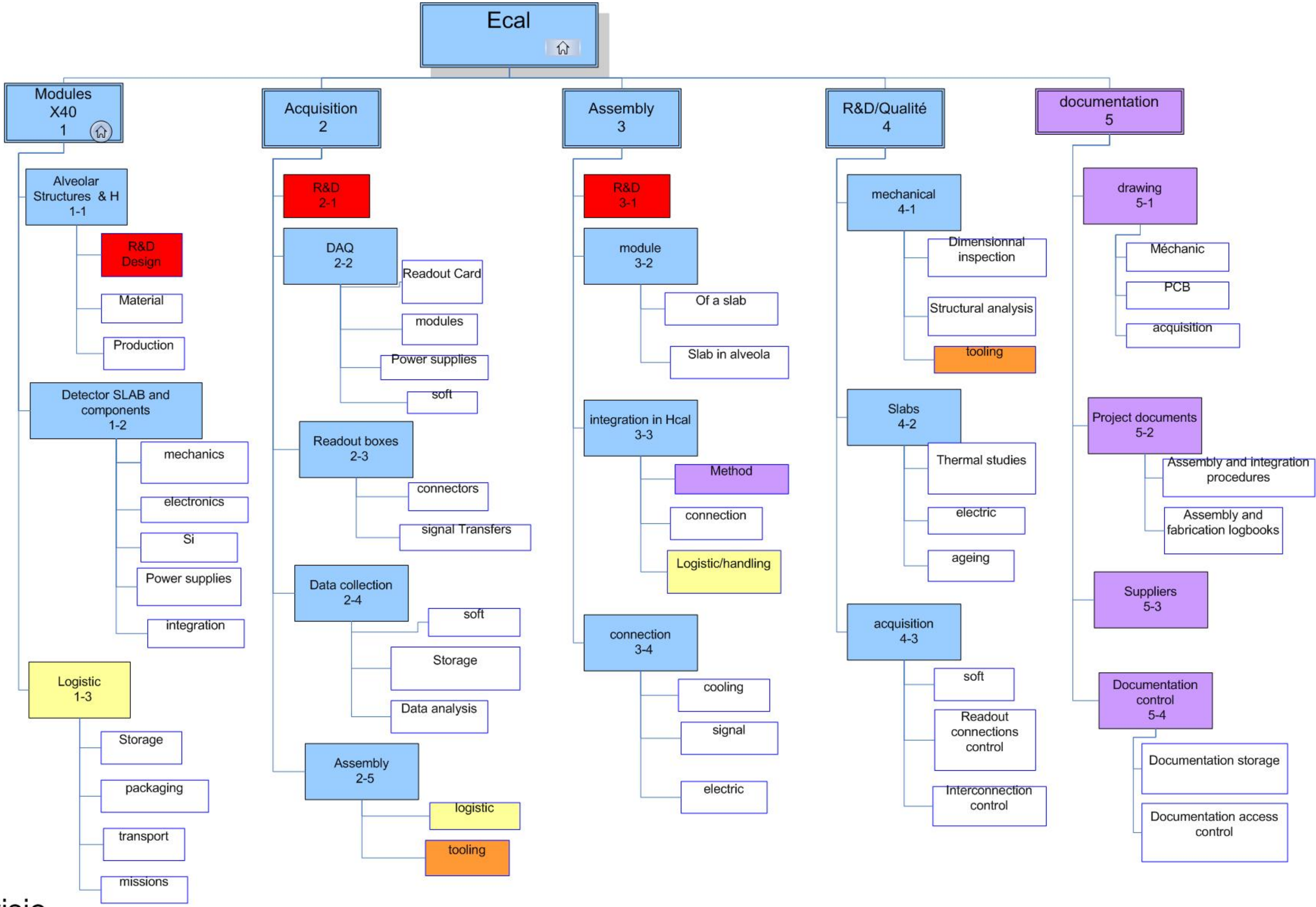
- Has developed WBS + some costs.
- Intends to develop parametric models
- No totals yet.

Work Breakdown Structure for LDC

Product Breakdown Structure for ECA

WBS Number	Detector concept / detector items	Unit	Unit cost (€	Quantity	total m&s	associated unit labor	labor cost	Contact
[redacted]								
2.1	Vertex detector							
2.2	Forward Tracker							
2.3	Luminosity Calorimeter							
2.4	Beam calorimeter							
2.5	Intermediate Tracker							
2.6	Silicon envelope							
2.7	Time projection Chamber							
2.7.1	Field cage							
2.7.1.1	inner							
2.7.1.2	outer							
2.7.1.3	central cathode							
2.7.1.4	field termination grid							
2.7.1.5	Assembly							
2.7.2	Endplate							
2.7.2.1	Mechanicalstructure and support							
2.7.2.2	readout pads							
2.7.2.3	gas amplification system							
2.7.3	Gas system							
2.7.3.1	recirculation system components							
2.7.3.2	piping							
2.7.3.3	gas properties monitors							
2.7.4	Laser calibration system							
2.7.4.1	Laser							
2.7.4.2	laser transport							
2.7.5	High voltage distribution							
2.7.5.1	power supplies, cables, connectors							
2.7.5.2	monitoring , interlocks, control							
2.7.6	Readout electronics							
2.7.6.1	front end readout							
2.7.6.2	cables and connectors							
2.7.6.3	cooling							
2.7.6.4	back end readout							
2.7.7	Assembly and installation							
2.8	Forward Chambers							
2.9	**Electromagnetic Calorimeter**							
2.9.1	**Barrel**							
2.9.1.	**Mechanics (material W&prepreg&mold, fabrication)**							
2.9.1.	**Detector (Si) and components (VFE, PCB)**							
2.9.1.	**DAQ**							
2.9.1.	**Calibration system**							
2.9.1.	**Assembly and installation**							
2.9.2	Endcap							
2.10	Hadron Calorimeter							
2.10.1	Barrel							
2.10.1.1	Mechanics (design,material, fabrication)							
2.10.1.2	Photodetectors							
2.10.1.3	Scintillators							
2.10.1.4	Electronics, VFE, PCB							
2.10.1.5	DAQ							
2.10.1.6	HV/LV power supply and slow control							
2.10.1.7	Calibration systems							
2.10.1.8	Cabling and cooling							
2.10.1.9	Assembly and installation							
2.10.2	endcap Barrel							
2.11	Muon Detector							
2.12	Magnet							
2.12.1	Coil							
2.12.2	Return Yoke							
2.13	Electronics							
2.14	Offline computing							
2.15	Infrastructure							
2.16	Integration/installation							
3	**GLD**							

WBS Number Ecal	detector items	Unit	Unit cost ($)	Quantity	total m&s	associated unit labor	labor cost	datasheet N°
1	Modules			40				
1.1	Alveolar structures			40				
1.1.1	R&D and design							
1.1.1.1	structural analysis							
1.1.1.2	thermal analysis							
1.1.1.3	drawing							
1.1.1.4	documentation							
1.1.2	Material							
1.1.2.1	Mold							
1.1.2.2	fixing system							
1.1.2.3	W for Alveaolas and H	tonnes	150	82				
1.1.2.4	Prepreg							
1.1.2.5	endcap							
1.1.3	Production							
1.1.3.1	assembly and fabrication procedures							
1.1.3.2	Fab. Of H and alveolas							
1.1.3.3	tooling							
1.2	Detector SLAB and components							
1.2.1	Mechanics							
1.2.1.1	H							
1.2.1.2	PCB							
1.2.1.2.1	Shielding							
1.2.1.2.2	ground foil							
1.2.1.2.3	glue							
1.2.1.2.4	assembling tools							
1.2.1.3	SLAB							
1.2.2	electronics							
1.2.2.1	components VFE, chips							
1.2.2.2	PCB							
1.2.2.2.1	design							
1.2.2.2.2	production							
1.2.2.2.3	integration							
1.2.3	Silicium							
1.2.3.1	wafers	m²	0,5$/cm²	1510				
1.2.3.2	process	m²	2$/cm²	1510				
1.2.3.3	control							
1.2.4	Power supplies							
1.2.5	Integration							
1.2.5.1	R&D							
1.2.5.2	Wafers on PCB							
1.2.5.3	SLAB							
1.3	*Logistic*							
2								
2	Acquisition			40				



Ecal.visio

17/08/2005

Cost of the coil

From F. Kircher

Item	Cost (Y2000 M€) Long magnet (9.25 m) (TESLA TDR)		Short magnet (7.0 m)	
Coil				
Conductor	9.5		7.8	
Winding operation	10.0		8.2	
Internal cryogenics and suspension	3.0		2.5	
Tooling for assembly	1.2		1.1	
Total for coil		**23.7**		**19.6**
Yoke and vacuum tank				
Total for yoke and vacuum tank		**25.0**		**20.5**
Ancillaries				
Cryogenic plant	4.3		3.8	
Electrical power circuit	1.9		1.5	
Control/monitoring system	1.3		1.3	
Total for ancillaries		**7.5**		**6.6**
Miscellaneous (external manpower, test…)				
Total for miscellaneous		**8.8**		**8.8**
Total for magnet		**65.0**		**55.5**

NB. The manpower costs listed are those for external manpower only (cost of manpower from laboratories is not included)
There is no contingency

Cost of ECAL

From C. Clerc

does not contain the industrialisation R&D cost and manpower

Item	unit	Unit cost	total
Si barrel endcap	1510 m² 623 m²	Material: 0,5 $ /cm² Process:2 $ /cm² (in 2010 ???)	Barrel: 38 M $ Endcap:16 M $ **Σ ≈ 54 M $**
W barrel endcap	82 t 34 t	150 $ /kg (pure, rolled)	Barrel: 12,3 M $ Endcap:5,1 M $ **Σ ≈ 17,4 M $**
Prepreg barrel endcap	≈6000 m² ≈2500 m²	97 $ /m²	Barrel: 0,585 M $ Endcap:0,245 M $ **Σ ≈ 0,83 M $**
Chips (TECH2) barrel endcap	420 000 180 000 (21 Mchannels,)	4 $ /chip 0,12 $ /ch	Barrel: 1,7 M $ Endcap:0,7 M $ **Σ ≈ 2,4 M $**
PCB : barrel endcap	33600, 13900 25% of various length	According to last estimation for EUDET same cost than for chips : 0,12 $ /ch	Barrel: 1,7 M $ Endcap:0,7 M $ **Σ ≈ 2,4 M $**

Other aspects of cost

- **Contingencies + spare**:

Si	5%
W	5% (1 module? Endcap+Barrel)
Chips	20%
PCB	5%

- **Pre-studies** for industrialization stage? To which extent is it to be included in the final cost?
- **Quality tests** and controls
- **Logistics**: storage, packaging, transportation
- **Assembly** : tooling and FTE ?
- **Inflation** ?

2005-2006 :

The Mechanical prototype under study will provide first answers

SiD Fixed & Parametric Costs

- In general, each subsystem has:
  - Fixed costs, such as engineering, assembly tooling, etc which scale weakly (or not at all) with reasonable variation of the detector parameters.
    - The fixed costs have been tabulated in the SLAC program WBS.
    - Labor is based on real SLAC costs with benefits.
    - Contingencies are estimated for each item.
  - Parametric costs are those that scale with detector parameters, such as Tracker radius, HCal gap thickness, B, etc.
    - A self consistent SiD model is generated by the EXCEL program Parametric_Detectors_... (MB).
    - Quantities of various materials and associated labor are estimated and multiplied by unit costs. Labor estimates are crude.
    - Contingency is applied as fixed fraction.

SiD Working Assumptions

- All technical labor included
- Contingency is explicit
- All engineering is included
- Indirects are included
- Escalation is included

- Comparison among detectors requires agreement on the accounting issues!

Highest Level WBS

SiD May 05.wbs - SLAC WBS

WBS	Component	Number	Unit	Materials	MContingency	Material Total	Labor	LContingency	Labor Total	Total
1	NLC Detectors	1	each	30,324,700	10,313,870	40,638,570	57,851,541	19,618,907	77,470,448	118,109,018
	Parts List									
1.1	SiD	1	each	30,324,700	10,313,870	40,638,570	57,851,541	19,618,907	77,470,448	118,109,018
	Parts List									
1.1.1	Vertex Det	1	each	4,000,000	2,000,000	6,000,000	0	0	0	6,000,000
1.1.2	Tracker	1	each	3,940,000	1,485,000	5,425,000	6,624,400	2,754,920	9,379,320	14,804,320
1.1.3	Calorimeters	1	each	2,400,000	2,120,000	4,520,000	10,448,800	4,529,840	14,978,640	19,498,640
1.1.4	Muon Tracl	1	each	1,000,000	500,000	1,500,000	1,970,060	783,268	2,753,328	4,253,328
1.1.5	Electronics	1	each	7,758,400	1,654,600	9,413,000	21,639,330	6,457,926	28,097,256	37,510,256
1.1.6	Magnet	1	each	7,687,500	1,860,250	9,547,750	5,642,201	1,920,276	7,562,477	17,110,227
1.1.7	Installation	1	each	2,617,800	522,320	3,140,120	4,746,050	1,677,383	6,423,433	9,563,553
1.1.8	Management	1	each	921,000	171,700	1,092,700	6,780,700	1,495,295	8,275,995	9,368,695

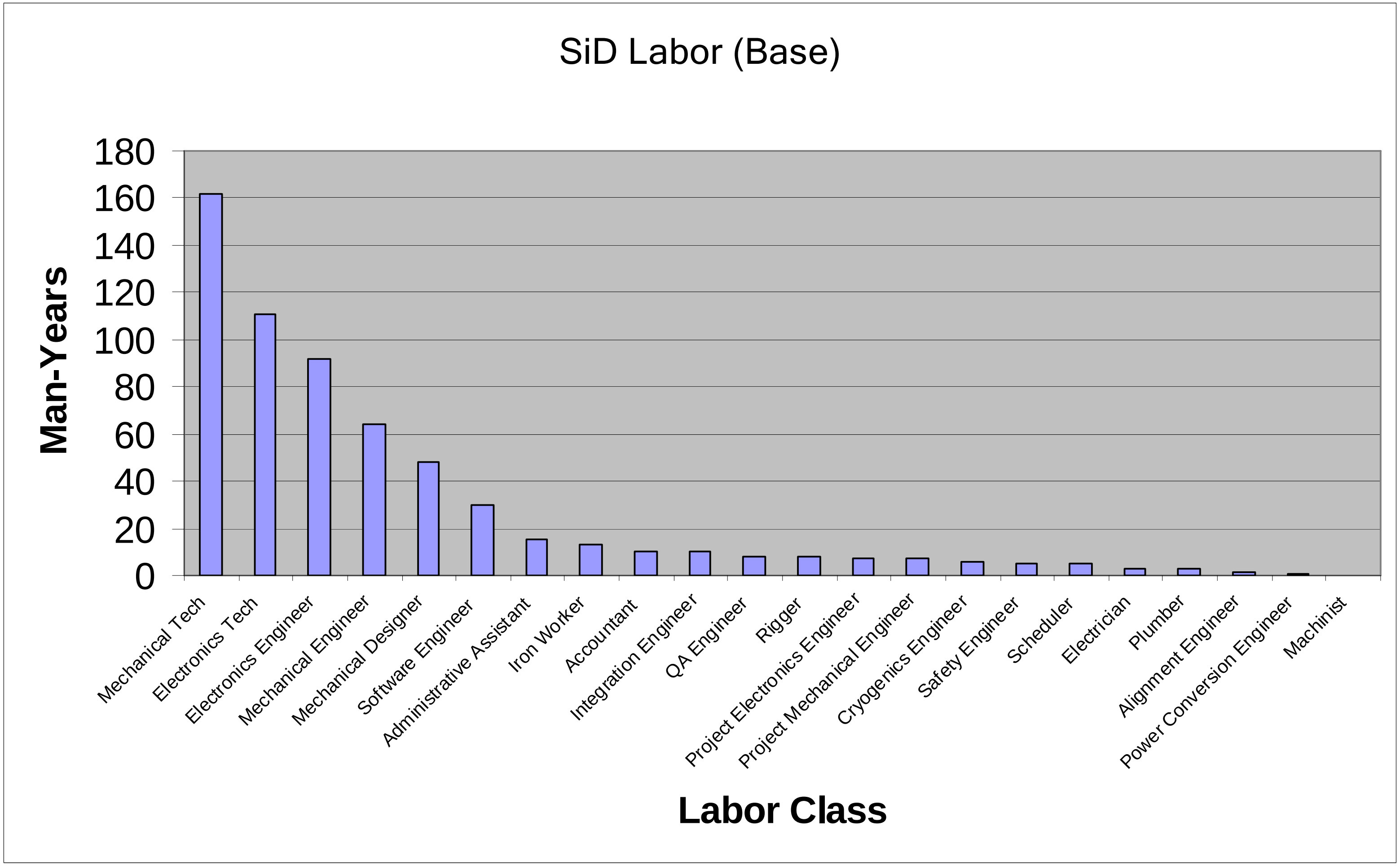
2nd Level (example)

File Edit WBS View Help

WBS | Materials | Labor Rates

WBS	Component	Number	Unit	Materials	MContingency	Material Total	Labor	LContingency	Labor Total	Total
1	NLC Detectors	1	each	30,324,700	10,313,870	40,638,570	57,851,541	19,618,907	77,470,448	118,109,018
	Parts List									
1.1	SiD	1	each	30,324,700	10,313,870	40,638,570	57,851,541	19,618,907	77,470,448	118,109,018
	Parts List									
1.1.1	Vertex Detector	1	each	4,000,000	2,000,000	6,000,000	0	0	0	6,000,000
1.1.2	Tracker	1	each	3,940,000	1,485,000	5,425,000	6,624,400	2,754,920	9,379,320	14,804,320
1.1.3	Calorimeters	1	each	2,400,000	2,120,000	4,520,000	10,448,800	4,529,840	14,978,640	19,498,640
1.1.4	Muon Tracker	1	each	1,000,000	500,000	1,500,000	1,970,060	783,268	2,753,328	4,253,328
1.1.5	Electronics	1	each	7,758,400	1,654,600	9,413,000	21,639,330	6,457,926	28,097,256	37,510,256
	Parts List									
1.1.5.1	Vertex Electronics	1	each	1,158,400	234,600	1,393,000	3,469,800	998,870	4,468,670	5,861,670
1.1.5.2	Tracker Electronics	1	each	1,100,000	220,000	1,320,000	3,469,800	998,870	4,468,670	5,788,670
1.1.5.3	EMCAL Electronics	1	each	1,100,000	220,000	1,320,000	3,469,800	998,870	4,468,670	5,788,670
1.1.5.4	HCAL Electronics	1	each	1,100,000	220,000	1,320,000	3,469,800	998,870	4,468,670	5,788,670
1.1.5.5	Muon Tracker Electronics	1	each	1,100,000	220,000	1,320,000	3,469,800	998,870	4,468,670	5,788,670
1.1.5.6	Trigger	1	each	0	0	0	0	0	0	0
1.1.5.7	Monitoring & Controls	1	each	200,000	40,000	240,000	577,530	164,096	741,626	981,626
1.1.5.8	Local Computing	1	each	2,000,000	500,000	2,500,000	3,712,800	1,299,480	5,012,280	7,512,280
1.1.5.9	Other Electronics	1	each	0	0	0	0	0	0	0
1.1.6	Magnet	1	each	7,687,500	1,860,250	9,547,750	5,642,201	1,920,276	7,562,477	17,110,227
1.1.7	Installation	1	each	2,617,800	522,320	3,140,120	4,746,050	1,677,383	6,423,433	9,563,553
1.1.8	Management	1	each	921,000	171,700	1,092,700	6,780,700	1,495,295	8,275,995	9,368,695

SiD Technical Labor Estimate - Base

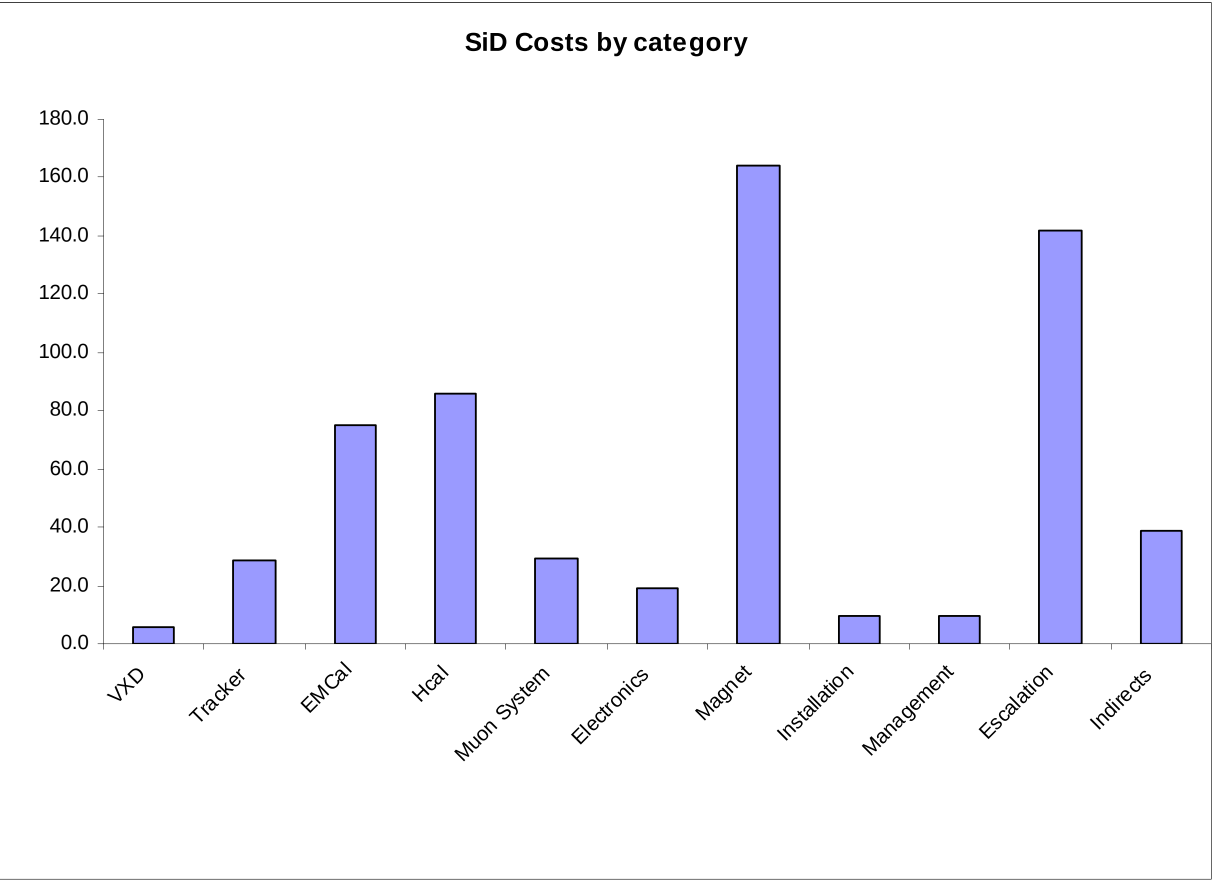


Caveats

- The estimates have ***not*** been reviewed.
- Every time the estimates have been re-visited, errors have been found. There is ***no*** reason to believe the errors are gone.
- The unit costs have ***no*** documented basis – there are no catalogs, bids, etc. – (but there is some experience). There is no Basis of Estimate.

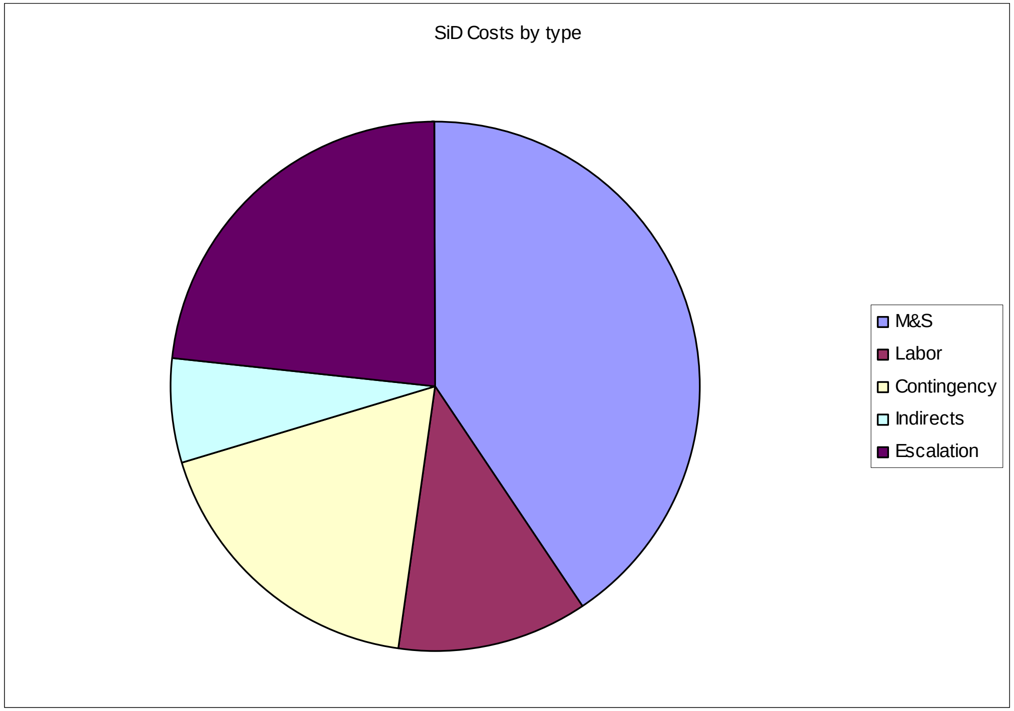
The Answer

Summary	
VXD	6.0
Tracker	19.9
EMCal	74.7
Hcal	74.2
Muon System	26.0
Electronics	37.5
Magnet	164.1
Installation	9.6
Management	9.4
Escalation	140.2
Indirects	38.5
Total	600.2



SiD Costs by type

SiD Costs by type	
M&S	$244
Labor	$70
Contingency	$107
Indirects	$39
Escalation	140.2
Total	$600



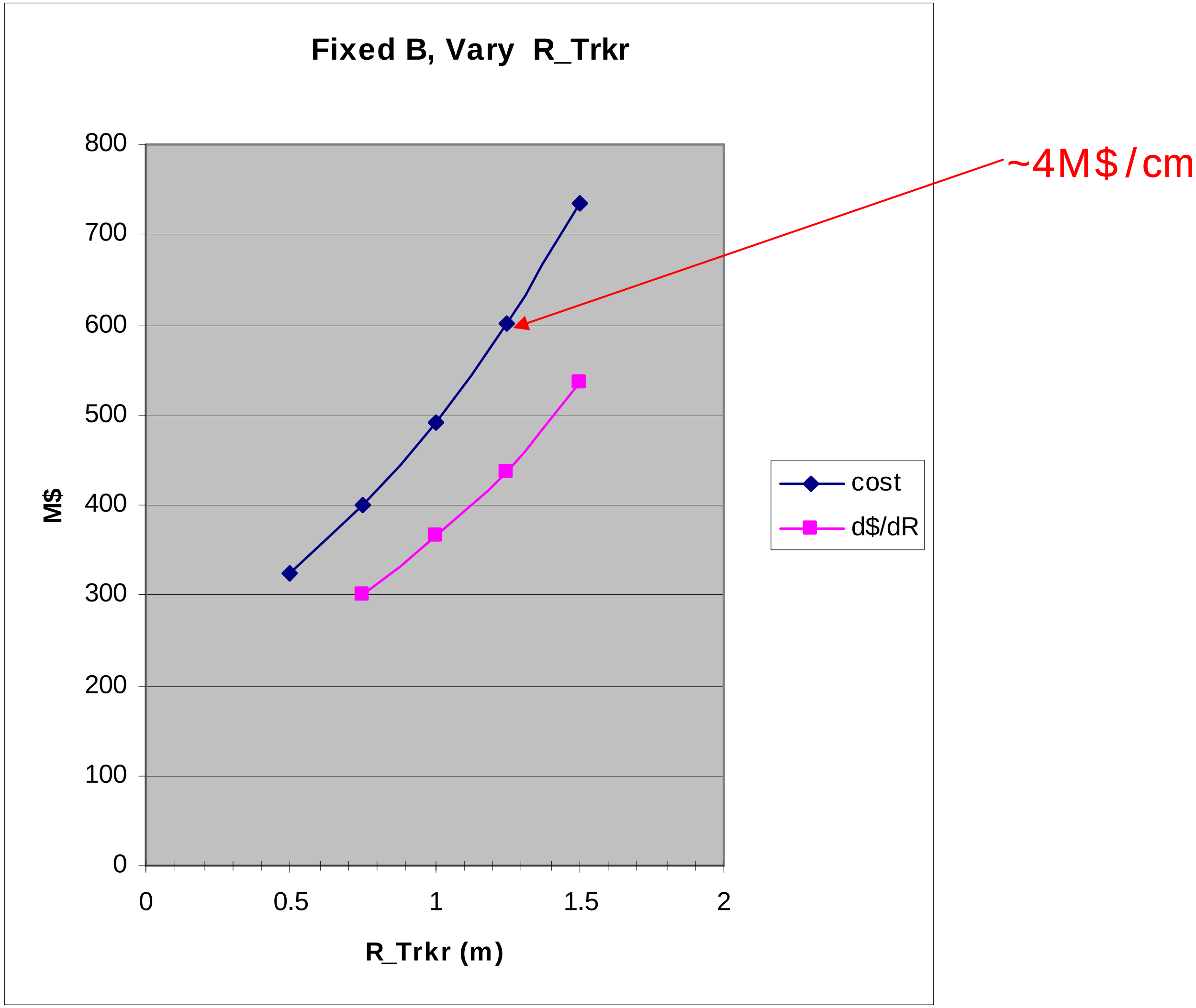
Some Analysis

	M&S	Labor	Totals
Base	$263	$73	$336
Contingency	$90	$25	$115
Total	$353	$97	$451
Indirect rates	0.06	0.20	
Indirects	$21	$19	$41
Totals w indirects	$375	$117	$491

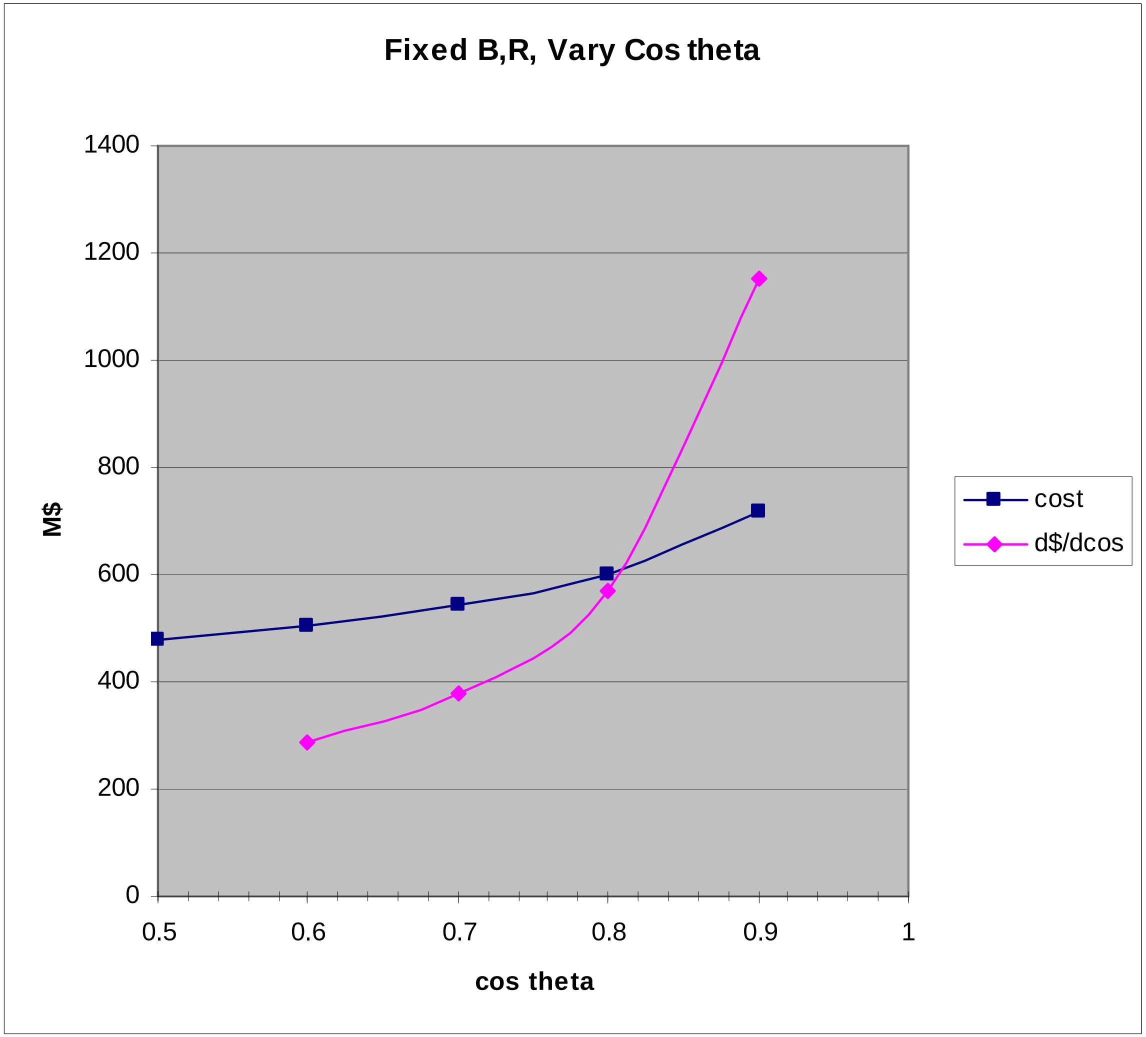
Total Contingency		$115
Fraction of base=		0.25
Total Labor (inc contingency)		$97
Fraction of base =		0.22
base defined as M&S+Labor+contingency; no escalation, no indirects		

Total in FYXXXX M$	2005		**491.2**
Start Year	2011		
Construction Duration	6	years	
Inflation	1.03	per year.	
Factor	1.305		
Total Escalation			149.7
Total, TYM$			***641.0***

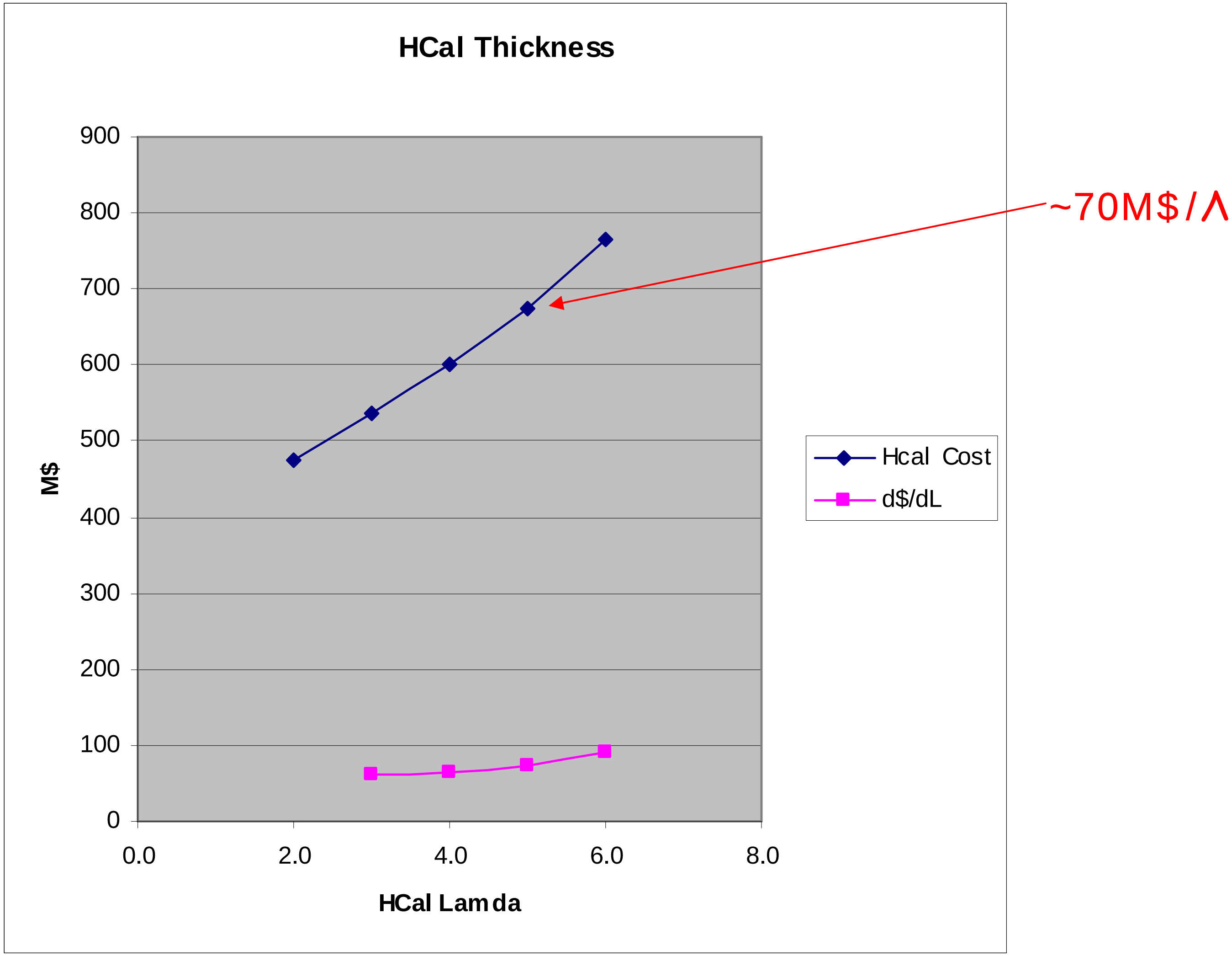
Variations – R_Trkr



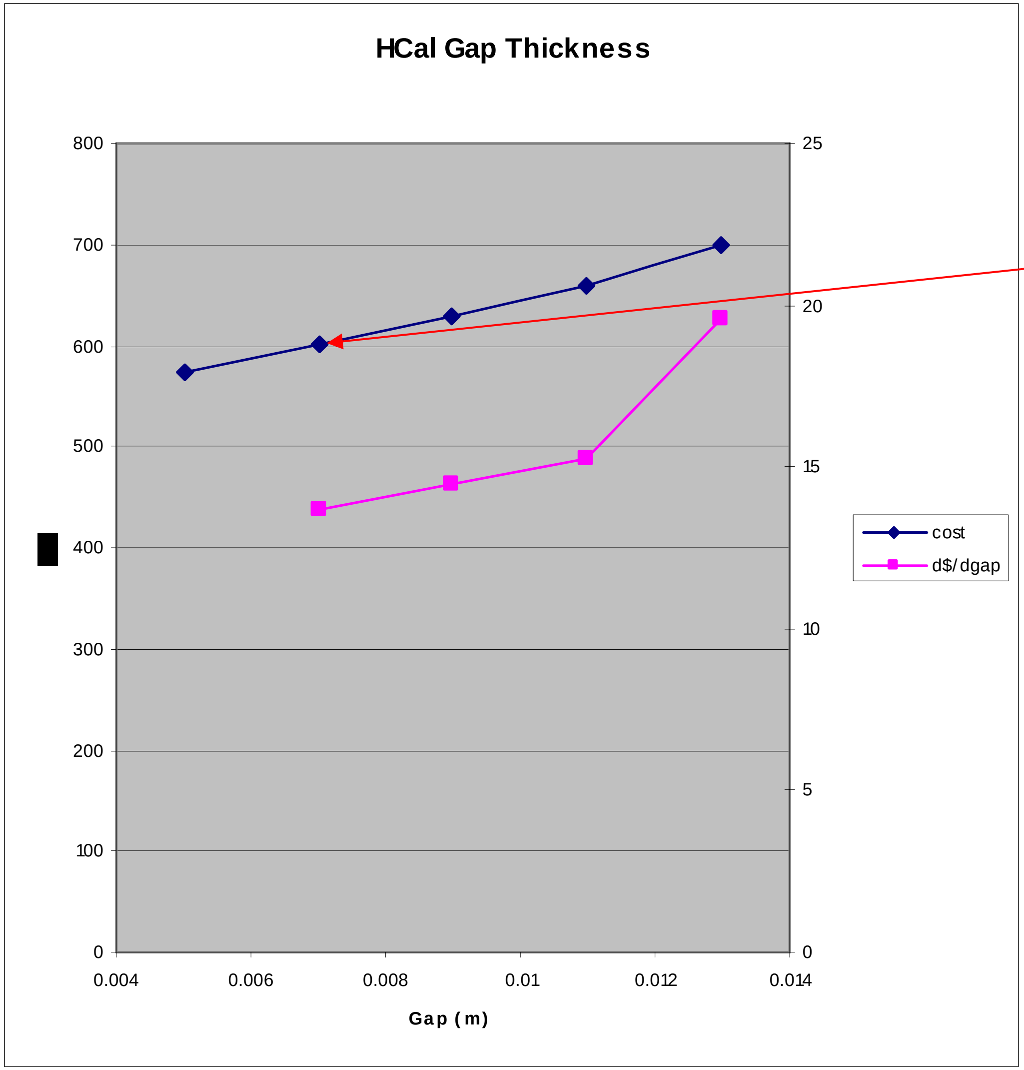
Variations – Cos(θ_{Barrel})



Variations – HCal Thickness (Interaction lengths)

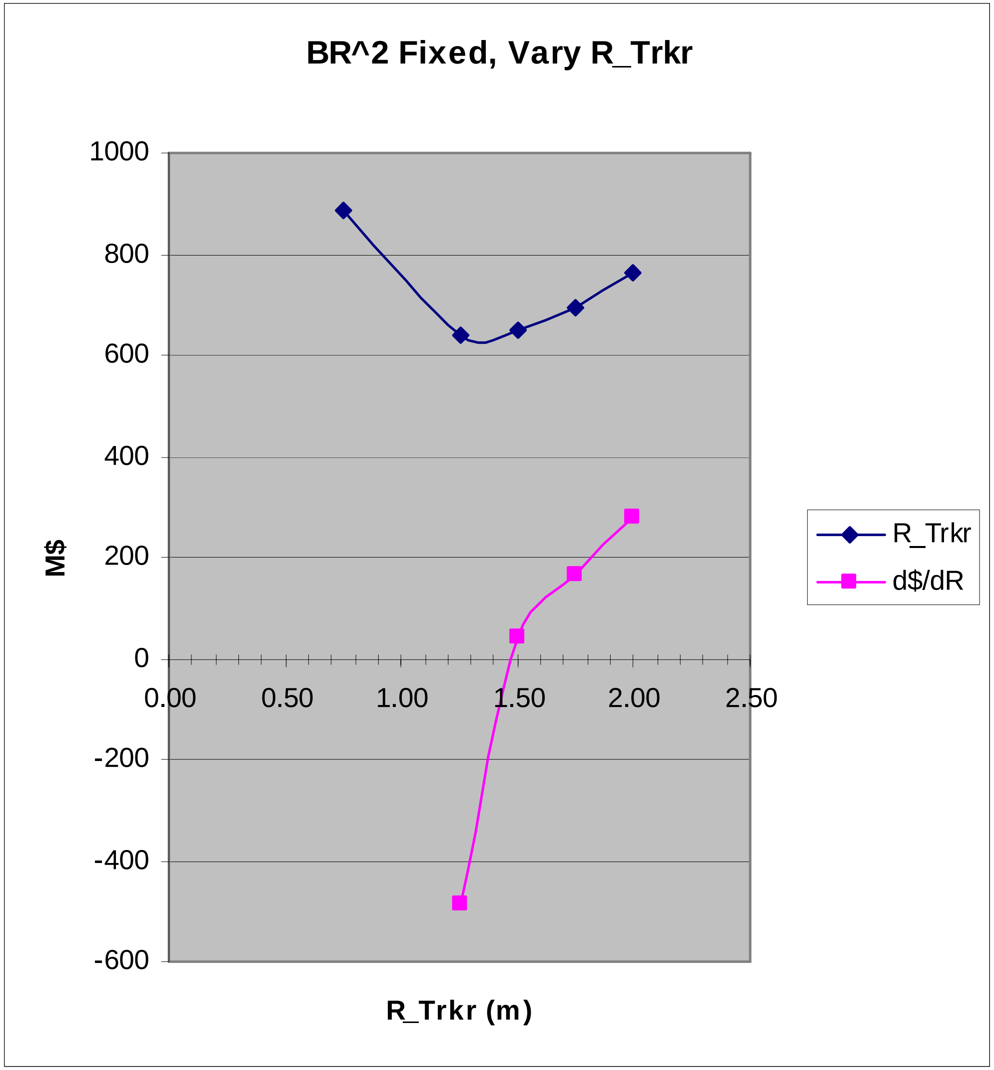


Variations – HCal Detector Gap



~15M$/mm

BR^2 Fixed, Vary R_{Trkr}



SiD Partials

- Already quite useful in influencing SiD choices.
- The SiD derivatives are probably not wildly wrong (but note they are fully loaded US style numbers).
- Easy to generate new ones as questions arise.

Conclusions

- The “rules” matter.
- The SiD estimate is not even version 0.
- Total costs are sensitive to the important unit costs – but relation to ILC Value may be confusing.
- A lot more work is needed. Nothing has been done in ILC Units.