Report from the Cost & Schedule WG
Cost aspects

Philippe Lebrun
on behalf of the C&S WG
Mick Draper, Katy Foraz, Lau Gatignon, Claude Hauviller,
Bernard Jeanneret, John Andrew Osborne, Yannis Papaphilippou,
Germana Riddone, Louis Rinolfi, Karl-Martin Schirm

CLIC'09 Workshop
CERN, 12-16 October 2009

CLIC Cost & Schedule WG
Mandate

April 2009

- Establish and optimize the cost of the CLIC complex at the nominal colliding beam energy of 3 TeV, as well as that of an optional first phase with a colliding beam energy of 500 GeV
- Define and optimize the general schedule for the 3 TeV and 500 GeV projects defined above
- Estimate the electrical power consumption of the 3 TeV and 500 GeV projects defined above
- Identify possible modifications of parameters and/or equipment leading to substantial capital and/or operational cost savings, in order to define best compromise between performance and cost
- Develop collaboration with ILC project on cost estimate methodology and cost of common or comparable systems, aiming at mutual transparency
- Document the process and conclusions in the CDR in 2010

Organization

- CLIC C&S WG communication and reporting lines established
- Web node active (access protected)
- PBS updated and completed for 3 TeV and 500 GeV phases, including standardization of level 4 technical systems
- Role and names of domain/subdomain coordinators established

CLIC Cost and Schedule

" Optimize the cost and the general schedule of the CLIC complex at the nominal colliding beam energy of 3 TeV and 500 GeV projects. "

Members of the Working Group:

Chairperson: Philippe Lebrun
Scientific Secretary: Germana Riddone
Other Members: Bernard Jeanneret, Claude Hauviller, Jean-Pierre Delahaye, John Andrew Osborne, Karl-Martin Schirm, Katy Foraz, Louis Rinolfi, Mick Draper, Sylvain Weisz, Yannis Papaphilippou

Mandate (Link)

Meetings:

- CLIC Cost and Schedule meetings (Protected)
- Joint CLIC / ILC cost meetings

Relevant information:

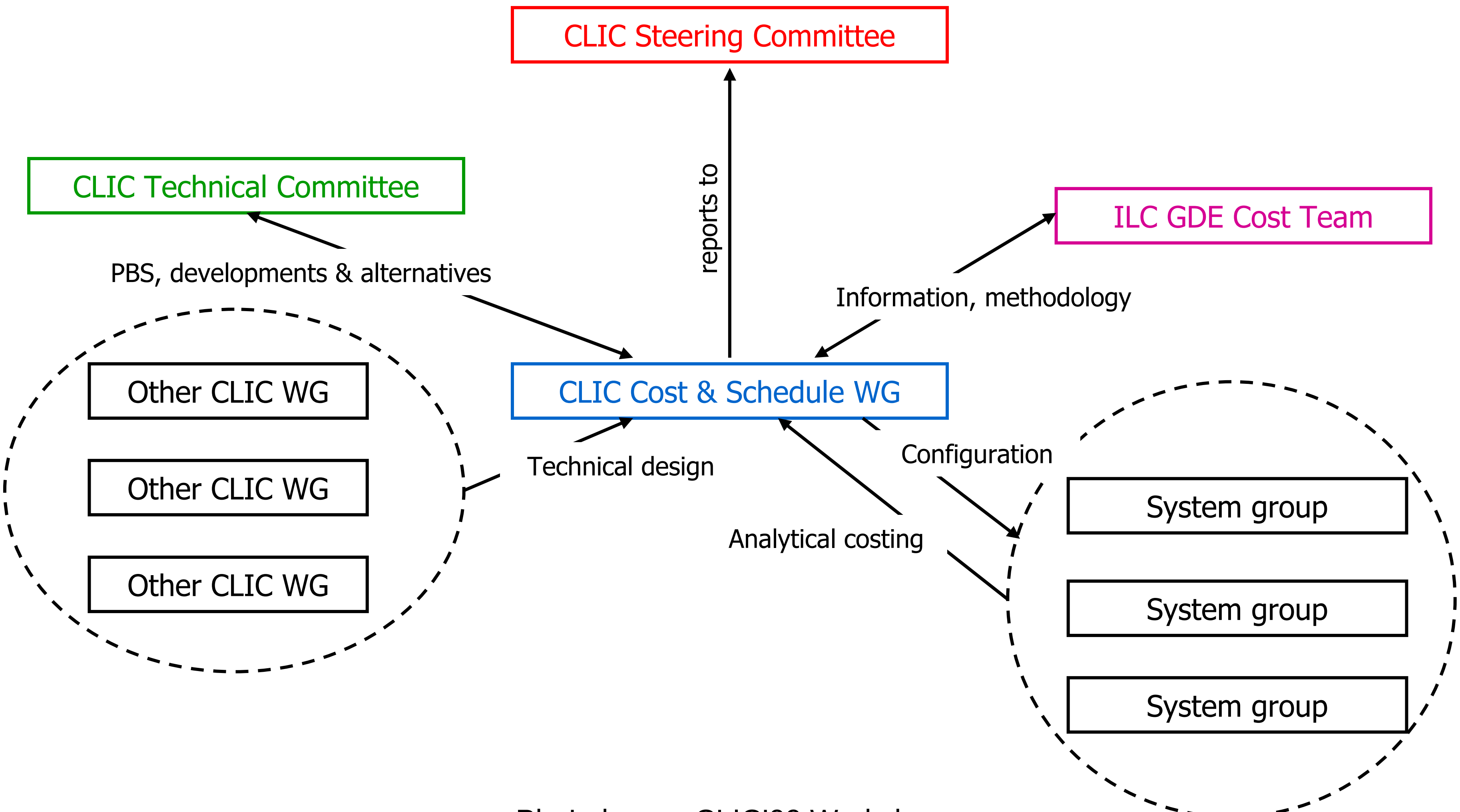
- CLIC Study Cost Estimate
  - Costing tool
  - Cost Report
- EDMS CLIC
- EDMS Cost and Schedule
- Hardware baseline at 3 TeV
- Hardware baseline at 500 GeV

Upcoming Events

- Linear Collider Workshop of the Americas (Link)
  September 29th - October 3rd, 2009
  Albuquerque, New Mexico

CLIC Cost & Schedule WG

Communication & reporting lines



Analytical costing based on PBS

level 1		level 2	level 3	level 4	level 5
Beam and Services	Domain	Technical responsible	Sub-domain	System	Component
Main Beam Production					
	1.1 Injectors	L. Rinolfi			
			1.1.1. Thermoionic gun unpolarized e-		
			1.1.2. Primary e- beam linac for e+		
			1.1.3. e-/e+ Target		
			1.1.4. Pre-injector Linac for e+		
			1.1.5. DC gun Polarised e-		
			1.1.6. Pre-injector Linac for e-		
			1.1.7. Injector Linac		
	1.2 Damping Rings	Y. Papaphilippou			
			1.2.1. Pre-damping Ring e+		
			1.2.2. Pre-damping Ring e-		
			1.2.3. Damping Ring e+		
			1.2.4. Damping Ring e-		
	1.3. Beam transport	L. Rinolfi			
			1.3.1. Bunch Compressor #1 e+		
			1.3.2. Bunch Compressor #1 e-		
			1.3.3. Booster Linac		
			1.3.4. Transfer to Tunnel e+		
			1.3.5. Transfer to Tunnel e-		
			1.3.6. Long Transfer Line e+		
			1.3.7. Long Transfer Line e-		
			1.3.8. Turnaround e+		
			1.3.9. Turnaround e-		
			1.3.10. Bunch compressor #2 e+		
			1.3.11. Bunch compressor #2 e-		
Drive Beam Production					
	2.1 Injectors	tbc			
			2.1.1. Linac e+		
			2.1.2. Linac e-		
	2.2. Frequency Multiplication	B. Jeanneret			
			2.2.1. Delay Loop e+		
			2.2.2. Delay Loop e-		
			2.2.3. Combiner Ring #1 e+		
			2.2.4. Combiner Ring #1 e-		
			2.2.5. Combiner Ring #2 e+		
			2.2.6. Combiner Ring #2 e-		
	2.3 Beam transport	B. Jeanneret			
			2.3.1. Transfer to Tunnel e+		
			2.3.2. Transfer to Tunnel e-		
			2.3.3. Long Transfer Line e+		
			2.3.4. Long Transfer Line e-		
			2.3.5. Turnaround and Bunch Compressor e+		
			2.3.6. Turnaround and Bunch Compressor e-		
Two-beam accelerator					
	3.1. Two-beam modules	G. Riddone			
			3.1.1. Two-Beam Modules Type 0 e+		
			3.1.2 Two-Beam Modules Type 1 e+		
			3.1.3 Two-Beam Modules Type 2 e+		
			3.1.4 Two-Beam Modules Type 3 e+		
			3.1.5 Two-Beam Modules Type 4 e+		
			3.1.6 Two-Beam Modules Type 0 e-		
			3.1.7 Two-Beam Modules Type 1 e-		
			3.1.8 Two-Beam Modules Type 2 e-		
			3.1.9 Two-Beam Modules Type 3 e-		
			3.1.10 Two-Beam Modules Type 4 e-		
	3.2. Post decelerator	B. Jeanneret			
			3.2.1. Post Decelerator e+		
			3.2.2. Post Decelerator e-		
Interaction Region					
	4.1. Beam Delivery Systems	tbc			
			4.1.1. Beam Delivery System e+		
			4.1.2. Beam Delivery System e-		
	4.2. Machine-Detector Interface	tbc			
			4.2.1. Experiment A		
			4.2.2 Experiment B		
	4.3. Experimental Area	tbc			
			4.3.1. Common Facilities		
			4.3.2. Experiment A		
			4.3.3. Experiment B		
	4.4. Post-collision line	tbc			
			4.4.1. Post-collision line e+		
			4.4.2. Post-collision line e-		
Infrastructure and Services					
	5.1. Civil Engineering	J. Osborne			
			5.1.1. Underground Facilities		
			5.1.2. Surface Structures		
			5.1.3. Site Development		
	5.2. Electricity	J. Osborne (C. Jach)			
			5.2.1 AC network		
			5.2.2 DC network		
	5.3. Access and Communications	H. Schmickler			
			5.3.1. Personnel Access Control		
			5.3.2. Global Accelerator Control		
			5.3.3. Industrial Control		
			5.3.4. Data Network		
	5.4. Fluids	J. Osborne (J. Inigo-Golfin)			
			5.4.1. Water systems		
			5.4.2. HVAC		
			5.4.3. Cryogenics		
			5.4.4. Gas		
	5.5. Transport / installation	J. Osborne (K. Kershaw)			
			5.5.1. Surface and Vertical Shafts		
			5.5.2. Tunnels and Inclined Shafts		
	5.6. Safety	J. Osborne (F. Corsanego)			
			5.6.1. Radiation Safety		
			5.6.2. Fire Safety		
	5.7. Survey	J. Osborne (H. Mainaud-Durand)			
	5.8. Machine Operation	tbd			

Coordinators per domain/subdomain

Identified for analytical costing based on level 5 description

Component level

Level 4 system

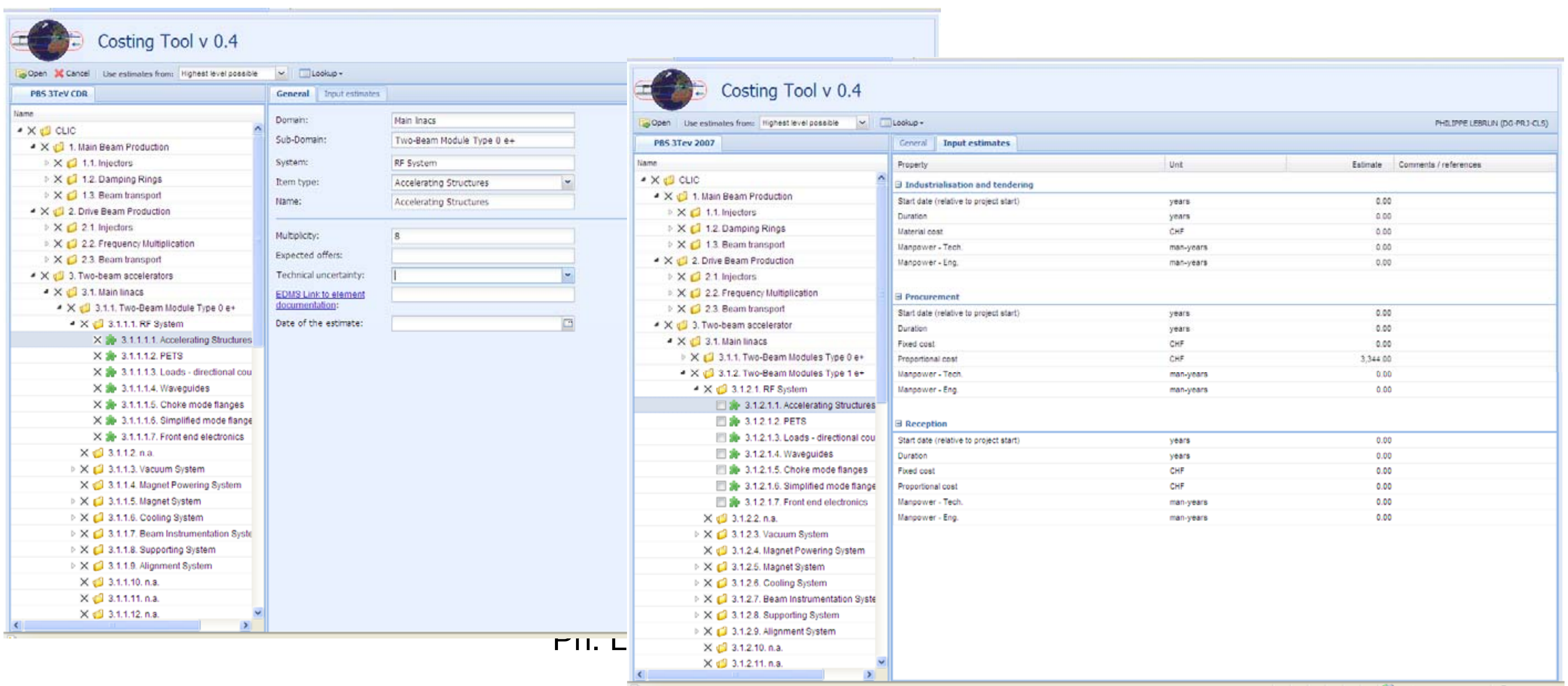
1 RF System
2 RF Powering System
3 Vacuum System
4 Magnet Powering System
5 Magnet System
6 Cooling System
7 Beam Instrumentation System
8 Supporting System
9 Alignment system
10 Kicker system
11 Cryogenic system
12 Laser system
13 Collimation system
14 Stabilisation System
15 Absorbers
16 Damping system
17 Electron Gun
18 RF deflectors
19 Installation
20 Commissioning

List of systems standardized

Contact experts per system

CLIC Study Costing Tool

- CLIC Study Costing Tool v 0.4 receptioned and operational, on-line from C&S WG web page (access protected)
- CLIC cost estimate 2007 entered in Costing Tool
- Demonstrations to domain coordinators in C&S WG meetings
- Study of cost variance factors and use of LHC experience
- Method for currency conversion, price escalation and cost uncertainty arrested



Cost variance factors

- Technical design
  - Evolution of system configuration
  - Maturity of component design
  - Technology breakthroughs
  - Variation of applicable regulations
- Industrial execution
  - Qualification & experience of vendors
  - State of completion of R&D, of industrialization
  - Series production, automation & learning curve
  - Rejection rate of production process
- Structure of market
  - Mono/oligopoly
  - Mono/oligopsone
- Commercial strategy of vendor
  - Market penetration
  - Competing productions
- Inflation and escalation
  - Raw materials
  - Industrial prices
- International procurement
  - Exchange rates
  - Taxes, custom duties

Engineering judgement of responsible

Contract adjudication

Procurement

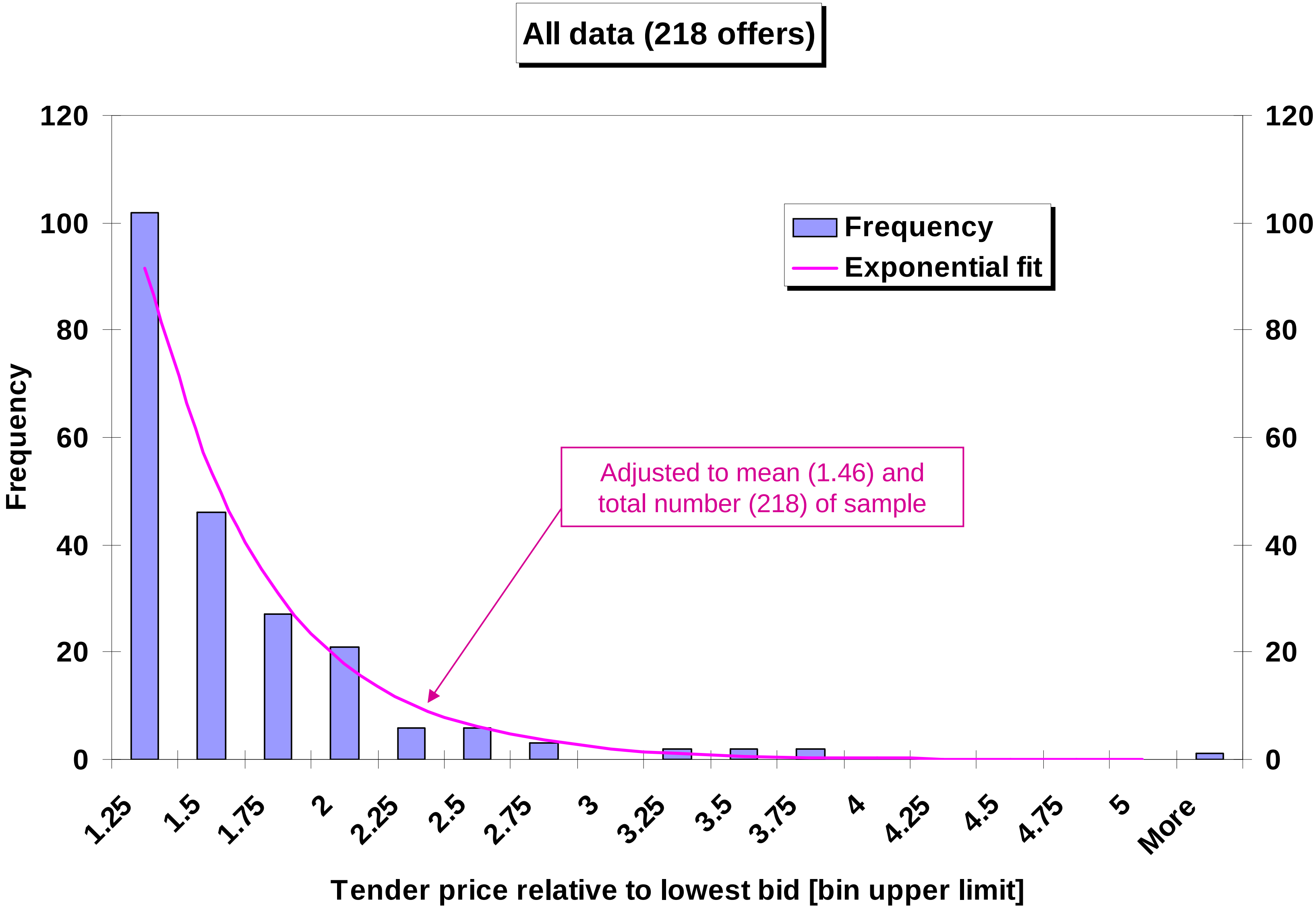
Reflected in scatter of offers received from vendors (LHC experience)

Tracked and compensated

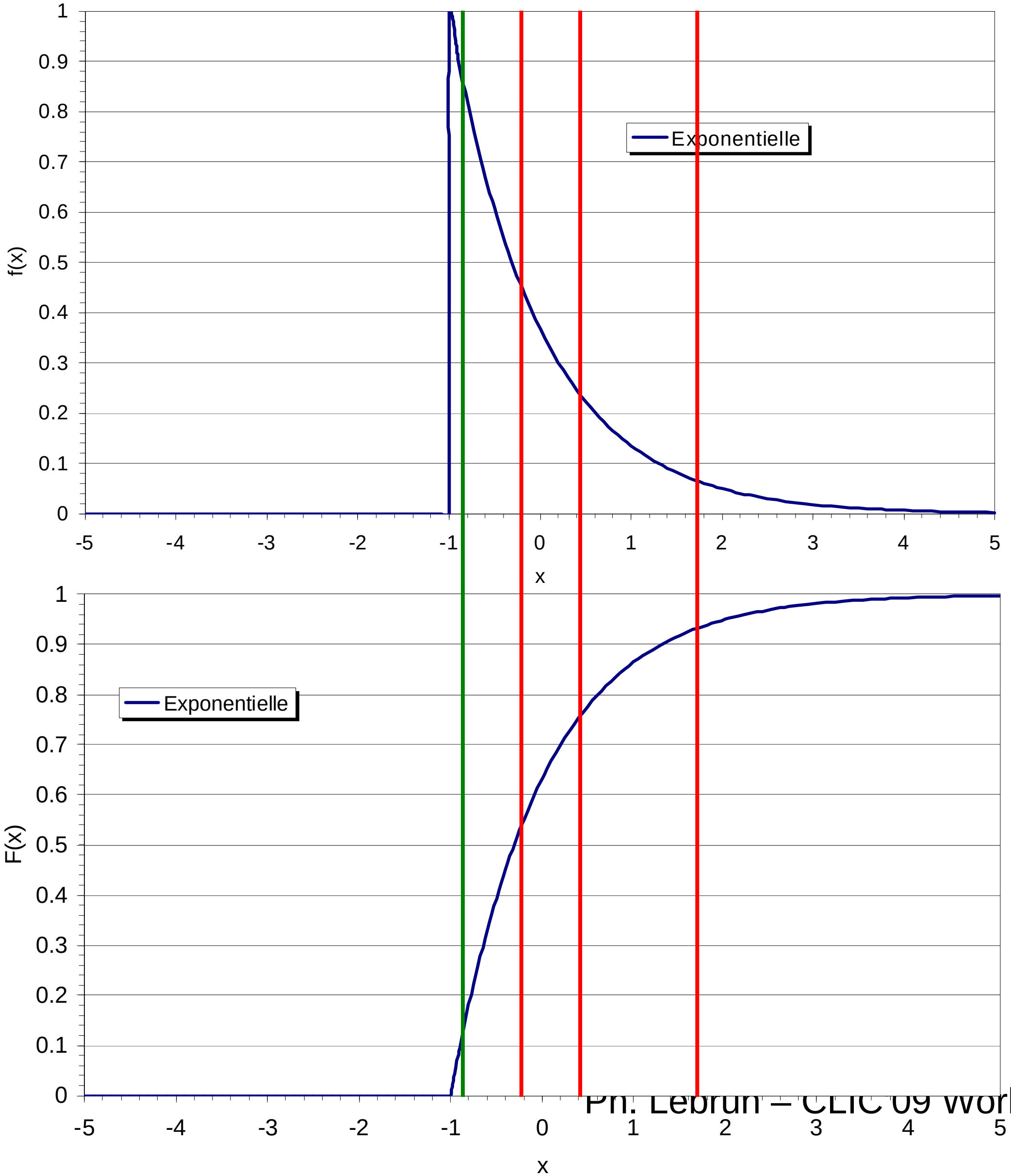
Outside project control

Decreasing control of project responsible

Observed tender prices for LHC accelerator components



Sampling from an exponential PDF
(m=0, σ=1)



- In response to an invitation to tender, consider n (valid) offers distributed according to an exponential PDF: application of the CERN purchasing rule will lead to select the lowest bidder
- What is the PDF of the lowest bidders, i.e. of the prices effectively paid?
- In the following, reasoning on the integral PDF

From distribution of offers to distribution of prices

- Consider two valid offers X1, X2 following same exponential distribution with **P**(Xi<x) = F(x) = 1 – exp[-a(x-b)]

  ⇒ m = b + 1/a and σ = 1/a
- Price paid (lowest valid offer) is Y = min(X1, X2): what is the probability distribution of Y?
- Estimate **P**(Y<x) = **P**(X1<x **or** X2<x) = G(x)
- Combined probability theorem

  P(X1<x **or** X2<x) = **P**(X1<x) + **P**(X2<x) – **P**(X1<x **and** X2<x)
- If X1 and X2 uncorrelated, **P**(X1<x **and** X2<x) = **P**(X1<x) * **P**(X2<x)
- Hence, **P**(X1<x **or** X2<x) = **P**(X1<x) + **P**(X2<x) – **P**(X1<x) * **P**(X2<x) and G(x) = 2 F(x) – $F(x)^2$ = 1 – exp[-2a(x-b)]

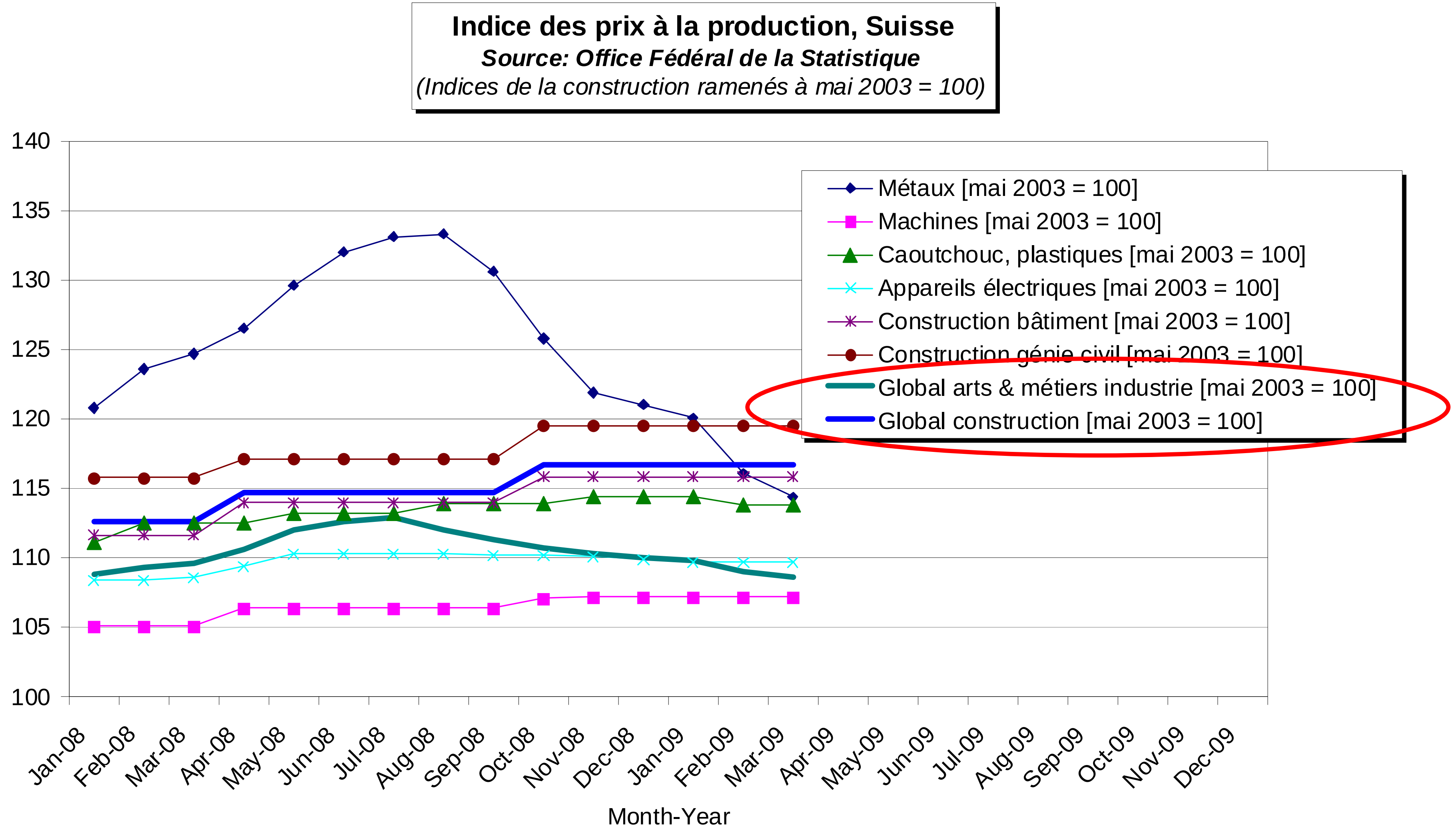
  ⇒ Y follows exponential distribution with m = b + 1/2a and σ = 1/2a
- By recurrence, if n uncorrelated valid offers X1, X2,…Xn are received, the price paid Y = min (X1, X2,…Xn) will follow an exponential distribution *with m = b + 1/na and σ = 1/na*

Dispersion of prices due to procurement uncertainties

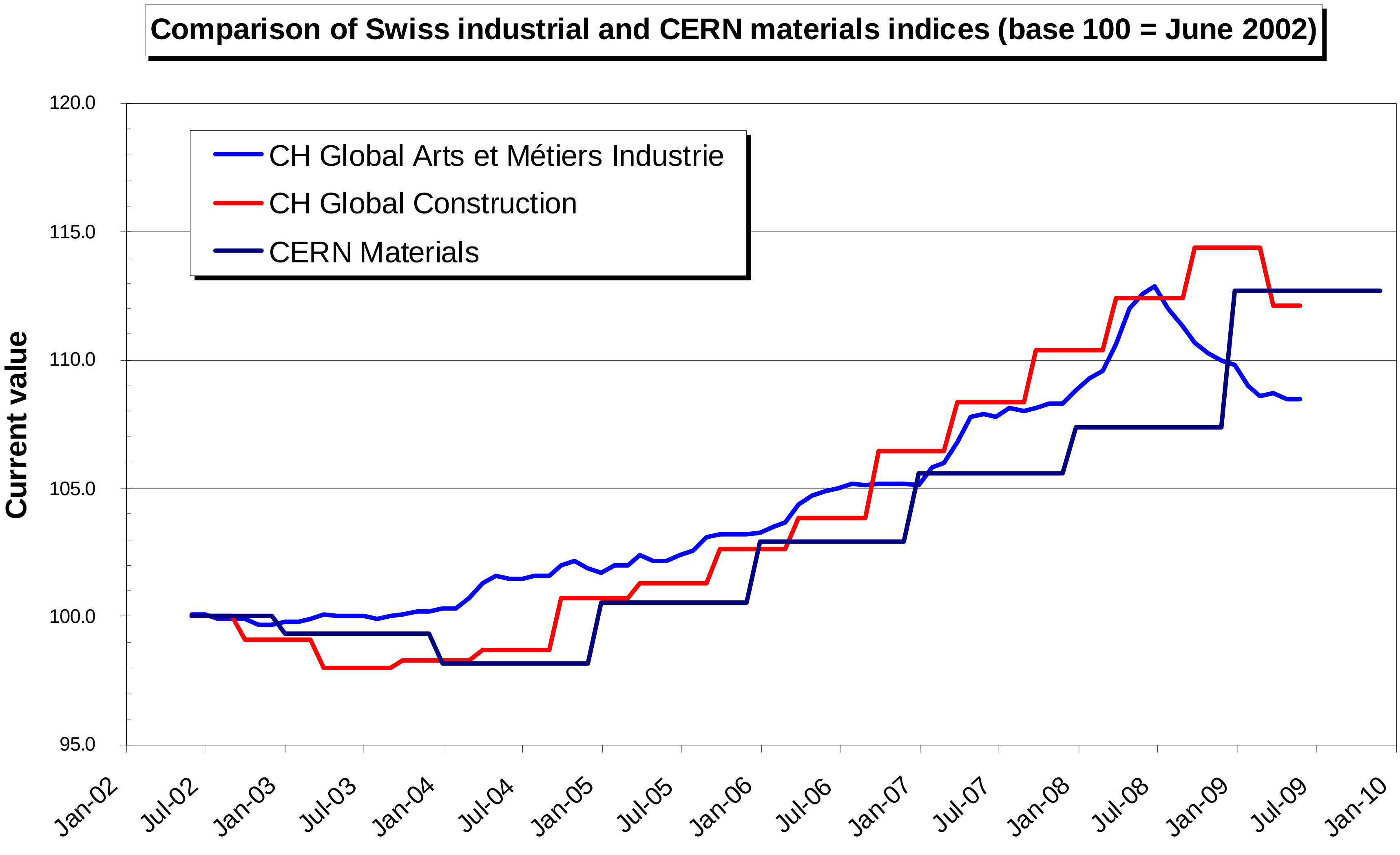
- For LHC accelerator components
  - 48 contracts
  - 218 offers, i.e. 4.54 offers per contract on average
- From exponential fit of statistical data on offers, m = 1.46, σ = 0.46
- We can therefore estimate the expected relative dispersion on paid prices
- $\sigma = 0.46/4.54 \approx 0.1$

$\Rightarrow$ based on LHC experience, the relative standard deviation on component prices due to procurement uncertainties can be taken as 50/n %, where n is the expected number of valid offers

Industrial price indices (CH)



Swiss vs CERN indices



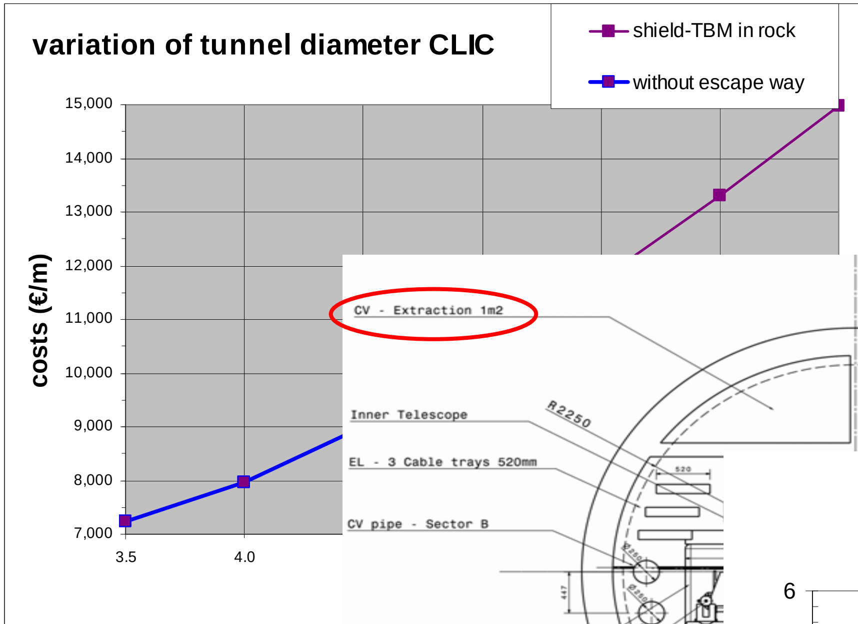
Towards a method for CLIC cost risk assessment

- Separate cost risk factors in three classes, assumed independent
  - Technical design maturity & evolution of configuration
    - Judgement of « domain responsible »
    - Rank in 3 levels, numerical values of σ_{config} tbd
  - Price uncertainty in industrial procurement
    - Estimate n number of valid offers to be received
    - Apply $\sigma_{industry} = 50/n$ %
  - Economical & financial context
    - Deterministic
    - Track currency exchange rates and industrial indices
- Estimate r.m.s. sum of σ_{config} and $\sigma_{industry}$
- Compensate economical & financial effects
  - Choice of CHF as reference currency
  - Applications of compound indices from *Office Fédéral de la Statistique (CH)*
    - *Arts et métiers – Industrie* for technical components
    - *Construction* for civil engineering

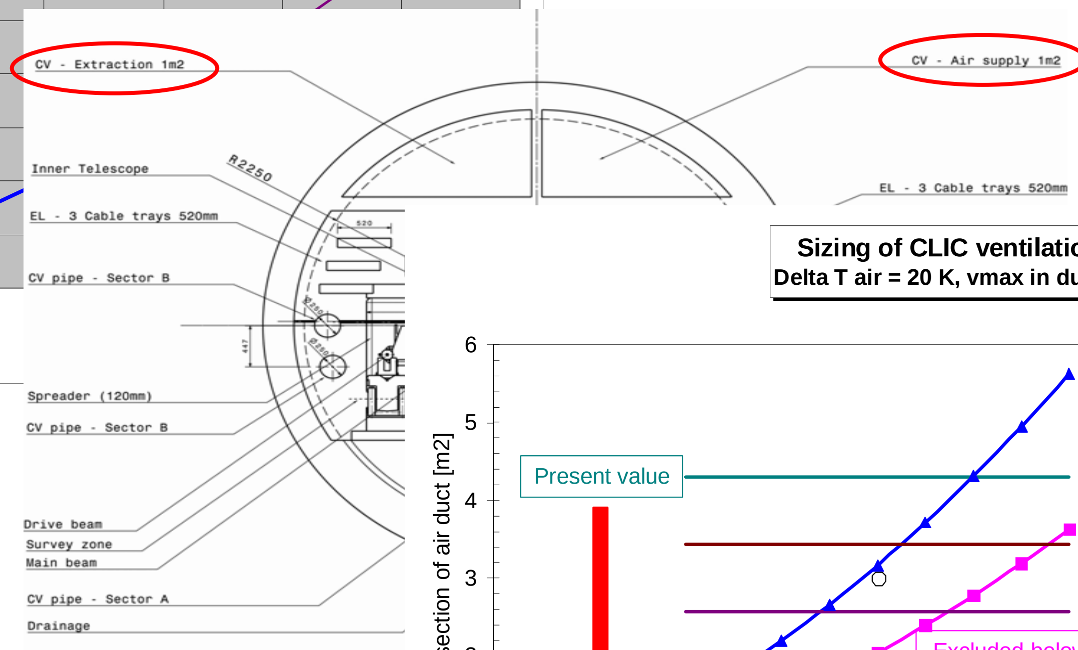
Cost drivers, cost models and analytical costing

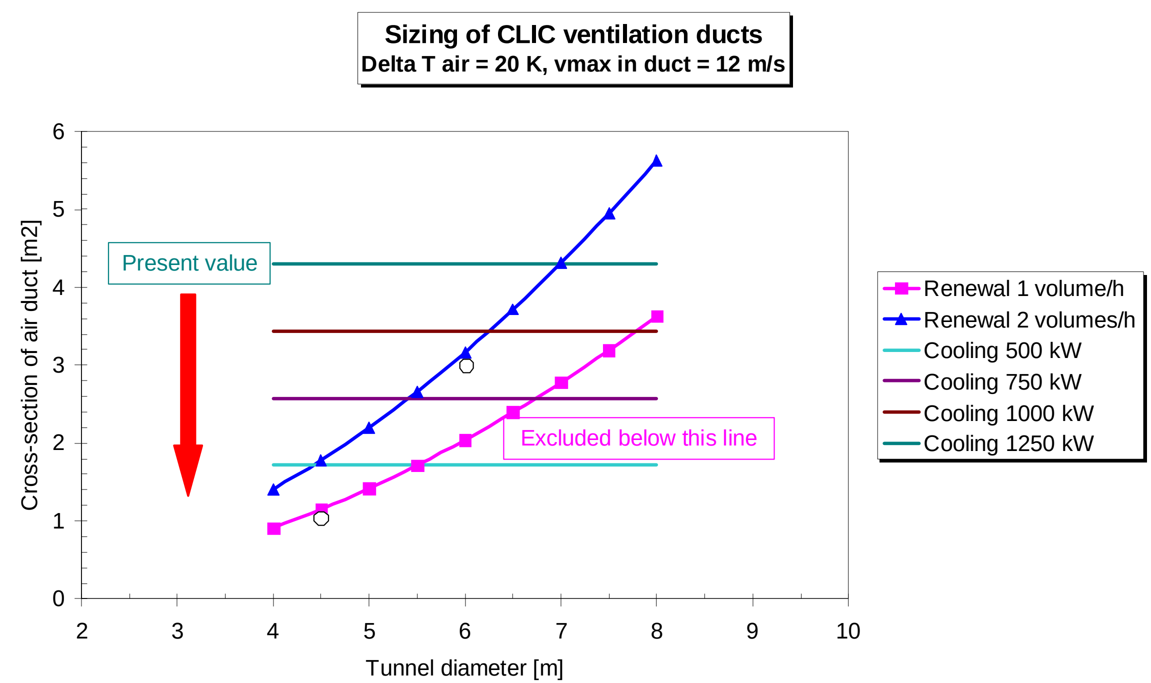
- Cost consciousness well established in CLIC technical working groups (Module, RF structures, CES,…)
- Some cost drivers and cost reduction areas identified - as well as their interplay - analysis not yet exhaustive
- Cost scaling models only exist for limited number of components or subsystems
- Analytical costing exercise under way by domain coordinators with input from technical system experts
- Significant differences observed w r to 2007 cost estimate (e.g. instrumentation, accelerating structures)
- Feedback provided to technical system design
- Targeted cost studies by industrial companies considered, in particular for large-series components

Tunnel size, a cost driver…



…itself driven by ventilation…

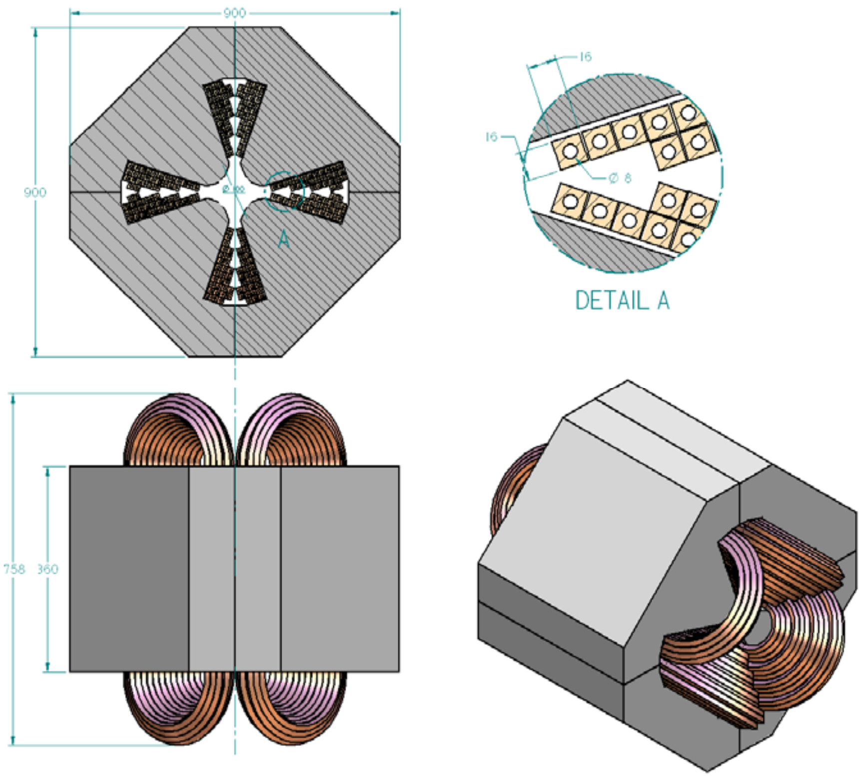




…sized by power dissipation

Ph.

Example of preliminary design for analytical costing of component



PBS 1.2.1 and 2 Pre-Dumping Ring	QUADRUPOLE 30 T/m
Length	758 mm
Weight	1720 kg
Power	17.4 kW
N. of units	408
Cost/unit	[illegible] kCHF
TOTAL COST	[illegible]4 kCHF

M. Modena & A. Vorozhtsov

Example of analytical costing of system, based on scaling of unit costs

Overview of beam instrumentation

	Nº Devices	Cost (MCHF)
Intensity	627	[redacted]
Position	52821	[redacted]
Beam Size	1045	[redacted]
Energy	291	[redacted]
Energy Spread	50	
Bunch Length	238	[redacted]
Beam Loss /Halo	4	
Beam Polarization	23	
Tune	8	
Beam Phase	336	[redacted]
Luminosity	4	
Wakefield monitors	142812	[redacted]
	Total (MCHF)	[redacted]

T. Lefèvre

CLIC-ILC collaboration on costing

- Cost risk analysis
  - Open exchange of views with ILC team in face-to-face and Webex meetings
  - Different methods imposed by regional rules and procedures, but full awareness of each other's approaches
  - Common document in preparation
- Learning curves for large series production
  - Standard methodology applied by CLIC and ILC
  - Extrapolation needed from previous projects to very large series components $\Rightarrow$ conservative approach recommended

Learning curve: theory

- T.P. Wright, *Factors affecting the cost of airplanes,* Journ. Aero. Sci. (1936)

- Unit cost c(n) of nth unit produced

  $$c(n) = c(1)\ n^{\log_2 a}$$

  with a = « learning percentage », i.e. remaining cost fraction when production is doubled

- Cumulative cost of first nth units

  $$C(n) = c(1)\ n^{1+\log_2 a} / (1+\log_2 a)$$

  with C(n)/n = average unit cost of first nth units produced

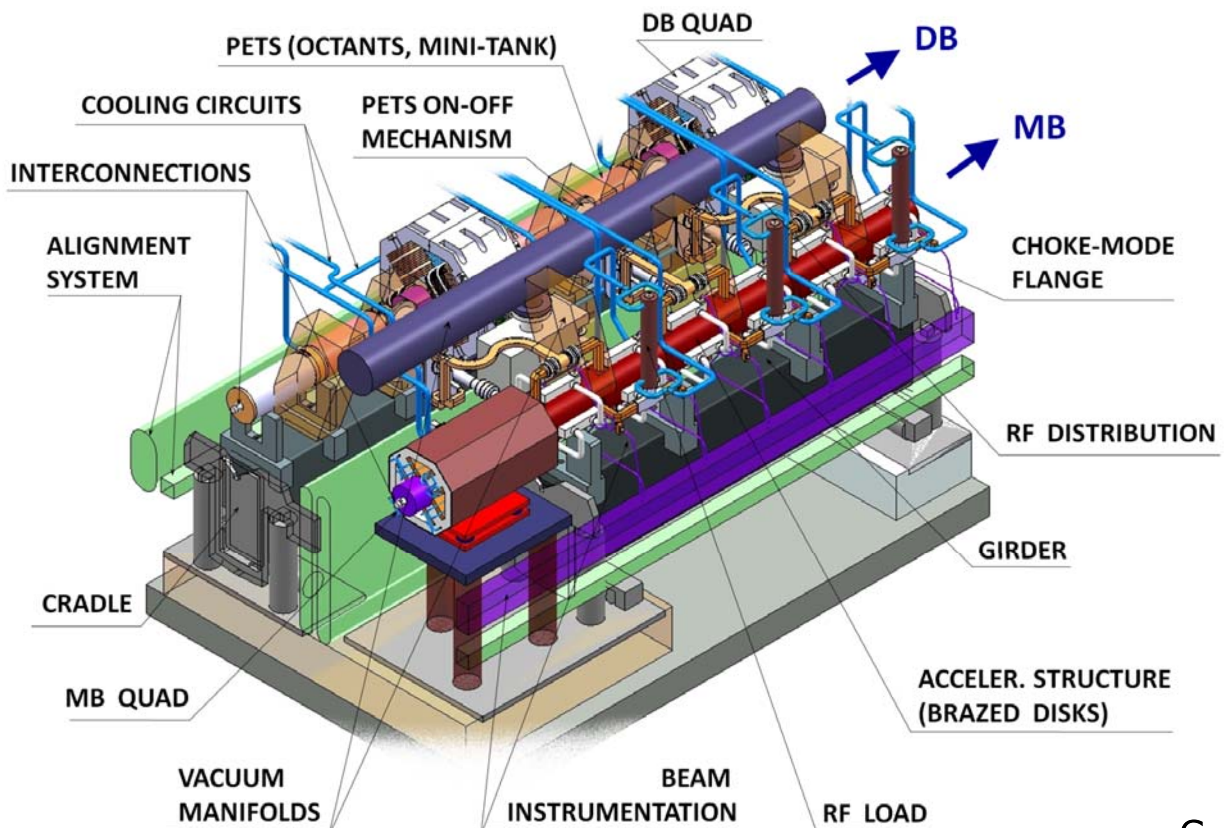
- n = number per production line ≠ total number in project

Learning coefficients

TABLE IV
LEARNING PERCENTAGE OF SELECTED REFERENCE INDUSTRIES

Industry	ρ
Complex machine tools for new models	75%-85%
Repetitive electrical operations	75%-85%
LHC magnets	80%-85%
Shipbuilding	80%-85%
Aerospace	85%
Purchased Parts	85%-88%
Repetitive welding operations	90%
Repetitive electronics manufacturing	90%-95%
Repetitive machining or punch-press operations	90%-95%
Raw materials	93%-96%

CLIC two-beam modules
Complexity, number, integration

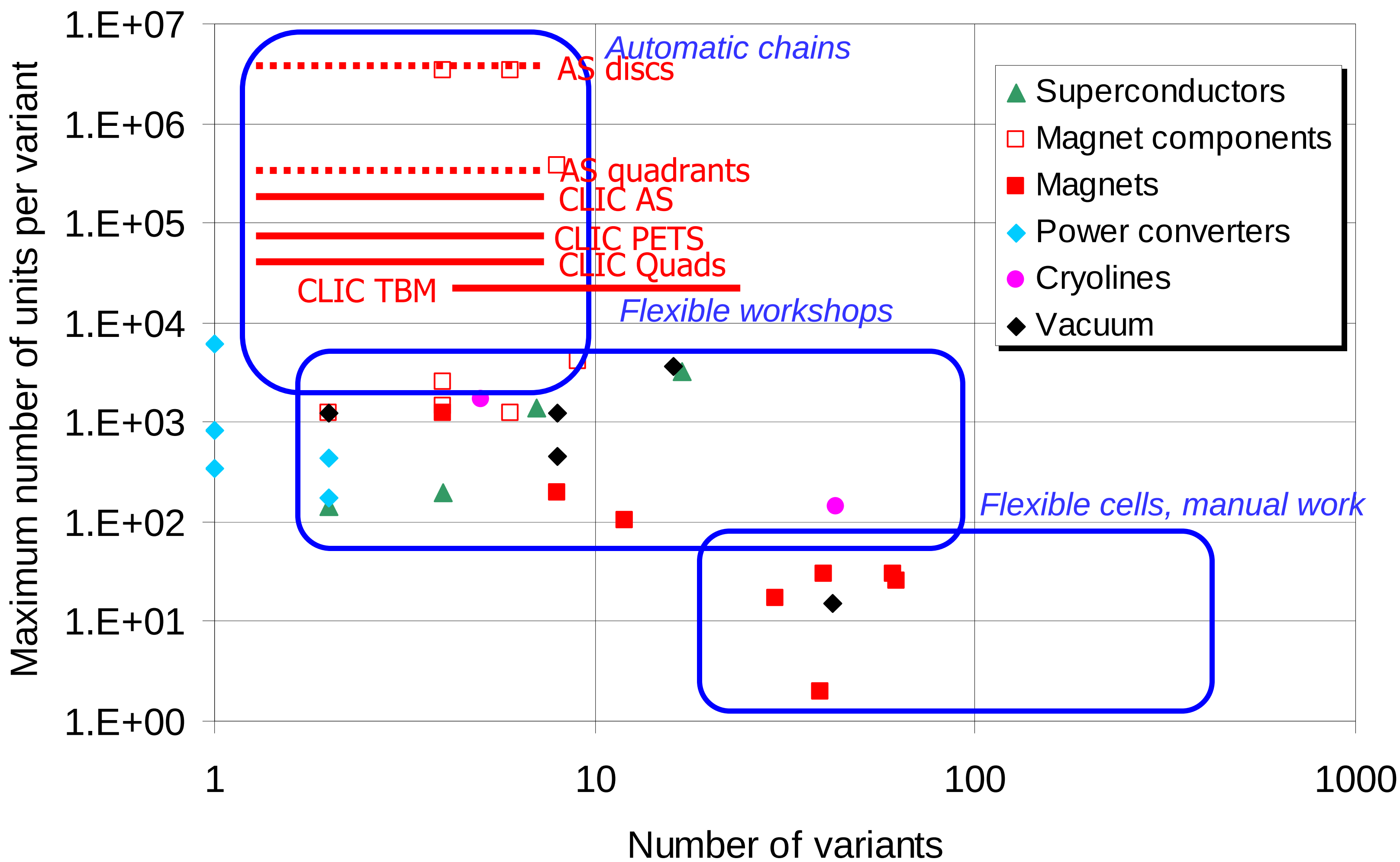


G. Riddone

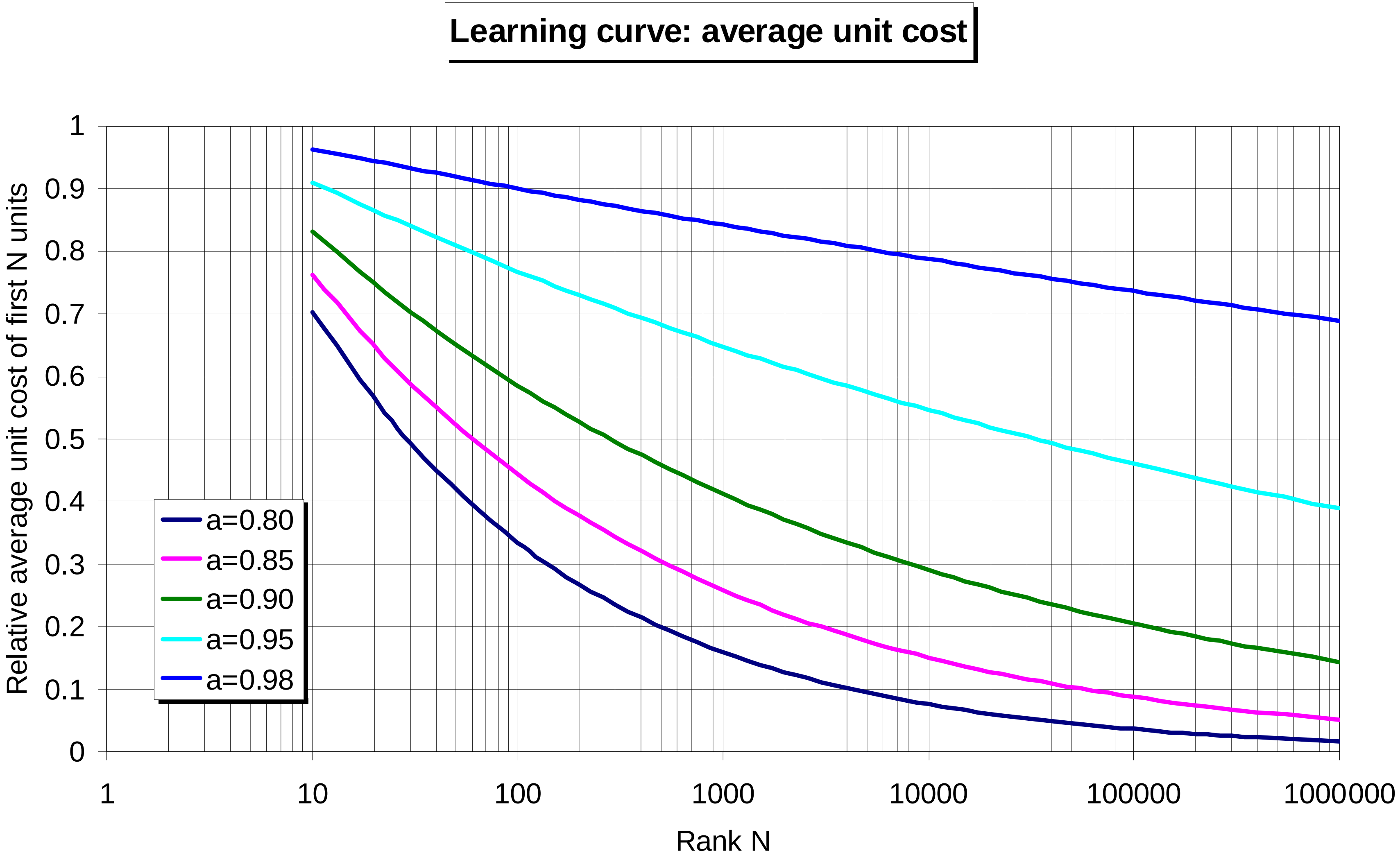
CLIC 3 TeV (per linac)
Modules: 10462
Accelerating str.: 71406 PETS: 35703
MB quadrupoles: 1996 DB quadrupoles: 20924

CLIC 500 GeV (per linac)
Modules: 2124
Accelerating str.: 13156 PETS: 6578
MB quadrupoles: 929 DB quadrupoles: 4248

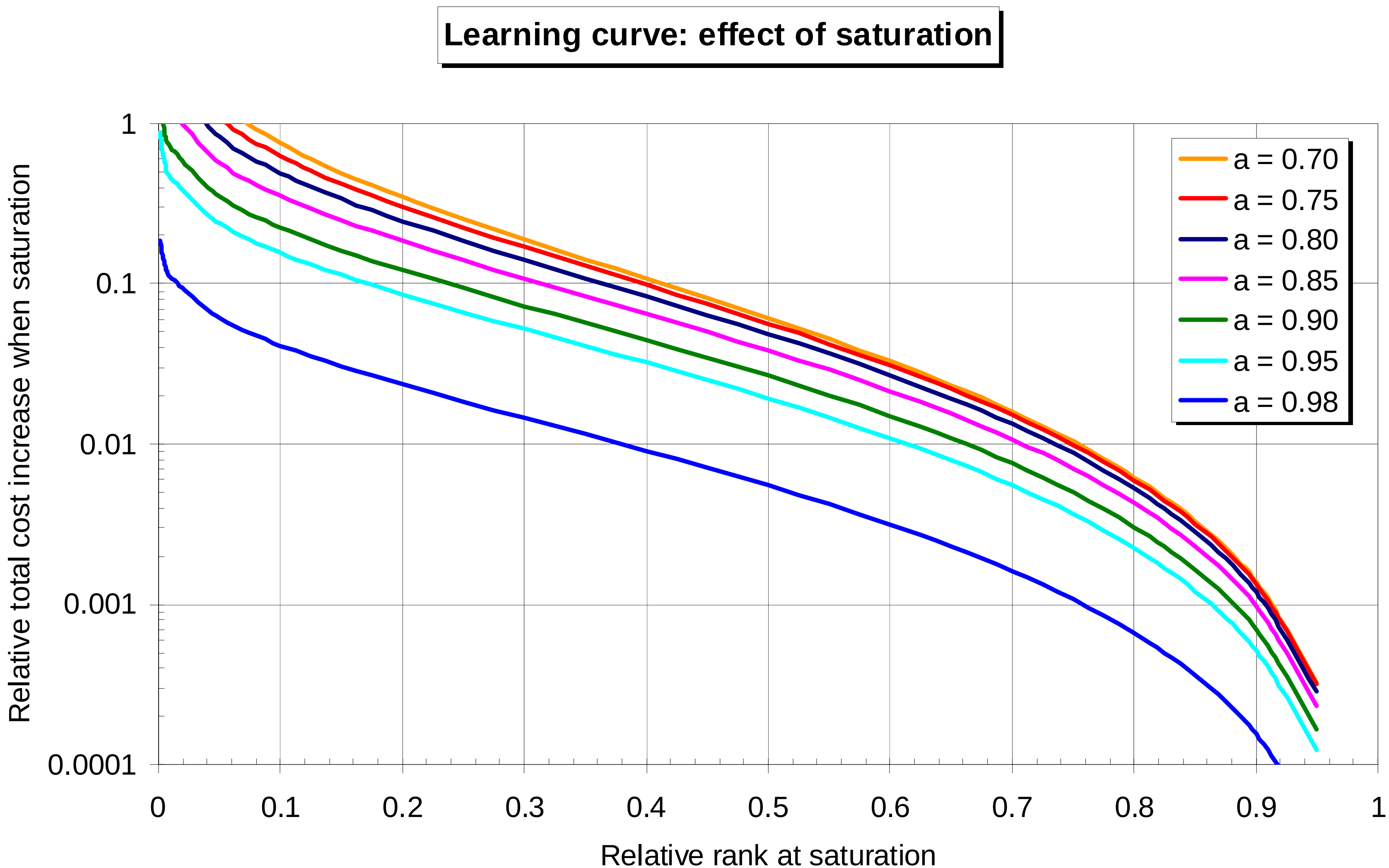
CLIC vs LHC components



Effect of learning coefficient on average unit cost up to rank N



Saturation of learning process has little impact on total cost



Summary

- CLIC Cost & Schedule (& Power/Energy) WG reorganized
- CLIC Study Costing Tool operational
- Methods for cost risk analysis and escalation established
- PBS of CLIC 3 TeV reorganized, PBS of CLIC 500 GeV established (CLIC TC)
- Analytical costing exercise of CLIC 3 TeV and 500 GeV started, based on updated PBS and expertise of PBS domain responsibles
  - Reporting September-November 2009
  - First iteration by end 2009
- Identification of cost drivers and cost reduction issues
  - Feedback to technical design on specific domains
- Good collaboration with ILC
  - Exchange of information: periodic meetings
  - Cooperation on specific topics, open information on others