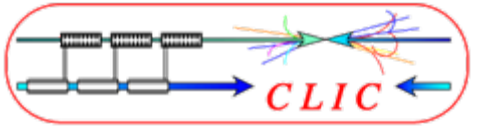




# Cost-related issues

Philippe Lebrun

4th CLIC Advisory Committee
CERN, 26-28 May 2009

# CLIC Cost & Schedule WG
## Mandate

- 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

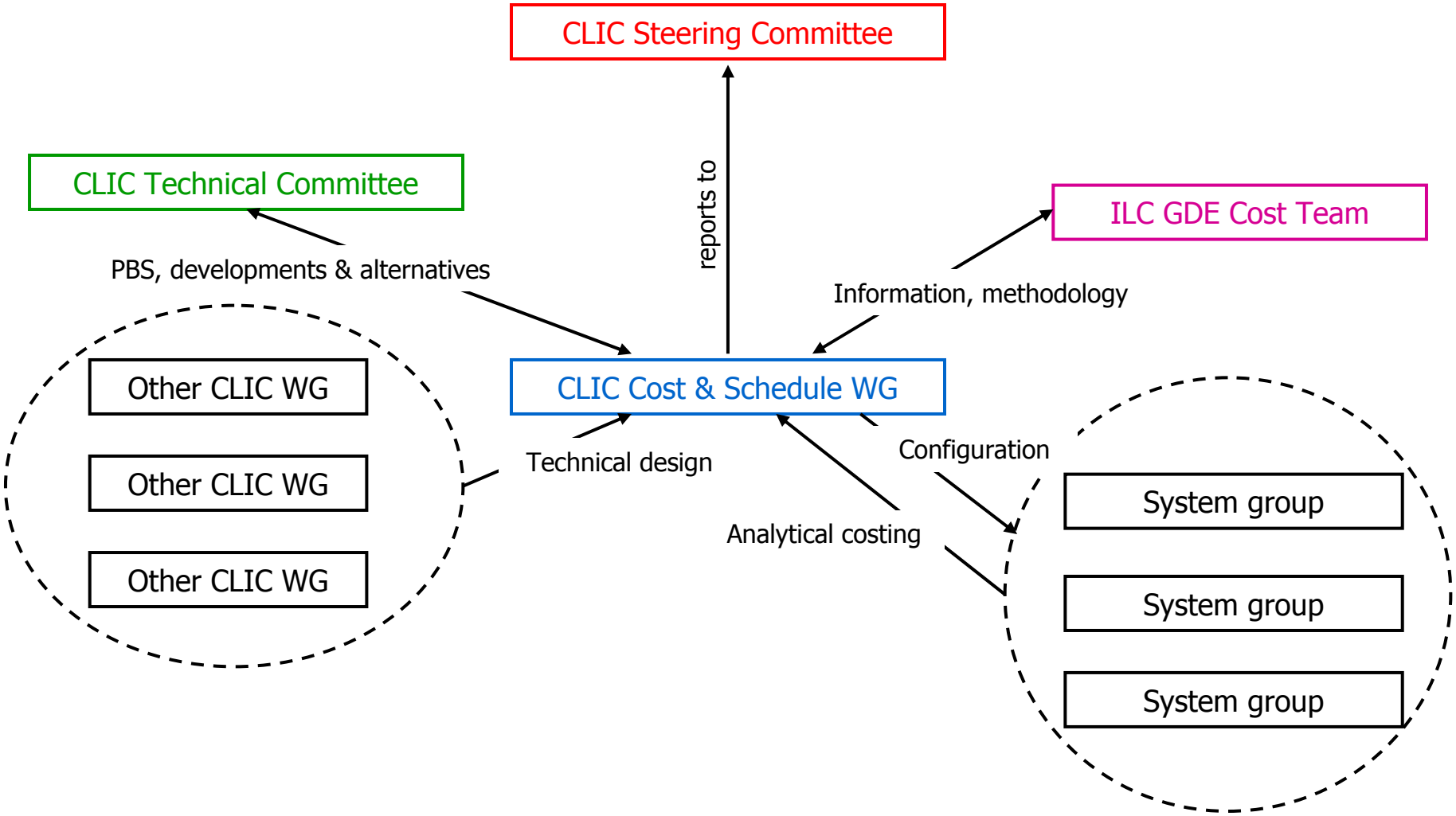
# CLIC Cost & Schedule WG
## Activities 2009

- Establish responsibilities, procedures & workpackages in cost assessment
- Identify domains of analytical costing and perform estimates
- Identify cost drivers and areas of potential cost reduction
- Reception specified cost tool, including currency conversion & price escalation procedures, and start applying it
- Conduct first round of analytical costing of CLIC 3TeV
- Establish proper technical/cost scaling of CLIC 500 GeV
- Refine general schedule and derive manufacturing/reception testing/installation constraints
- Update estimates of power & energy consumption, including part-load operation
- Collaborate with ILC on previously defined cost topics
  - Cost risk analysis
  - Cost of normal conducting magnets

# CLIC Cost & Schedule WG
## Activities 2009

- Establish responsibilities, procedures & workpackages in cost assessment
- Identify domains of analytical costing and perform estimates
- Identify cost drivers and areas of potential cost reduction
  - Reception specified cost tool, including currency conversion & price escalation procedures, and start applying it
  - Conduct first round of analytical costing of CLIC 3TeV
  - Establish proper technical/cost scaling of CLIC 500 GeV
  - Refine general schedule and derive manufacturing/reception testing/installation constraints
  - Update estimates of power & energy consumption, including part-load operation
  - Collaborate with ILC on previously defined cost topics
    - Cost risk analysis
    - Cost of normal conducting magnets

# CLIC Cost & Schedule WG
## Communication & reporting lines



# Analytical basis is 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 acceleration | | | | |
| | 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 not yet defined

**Level 4 system**

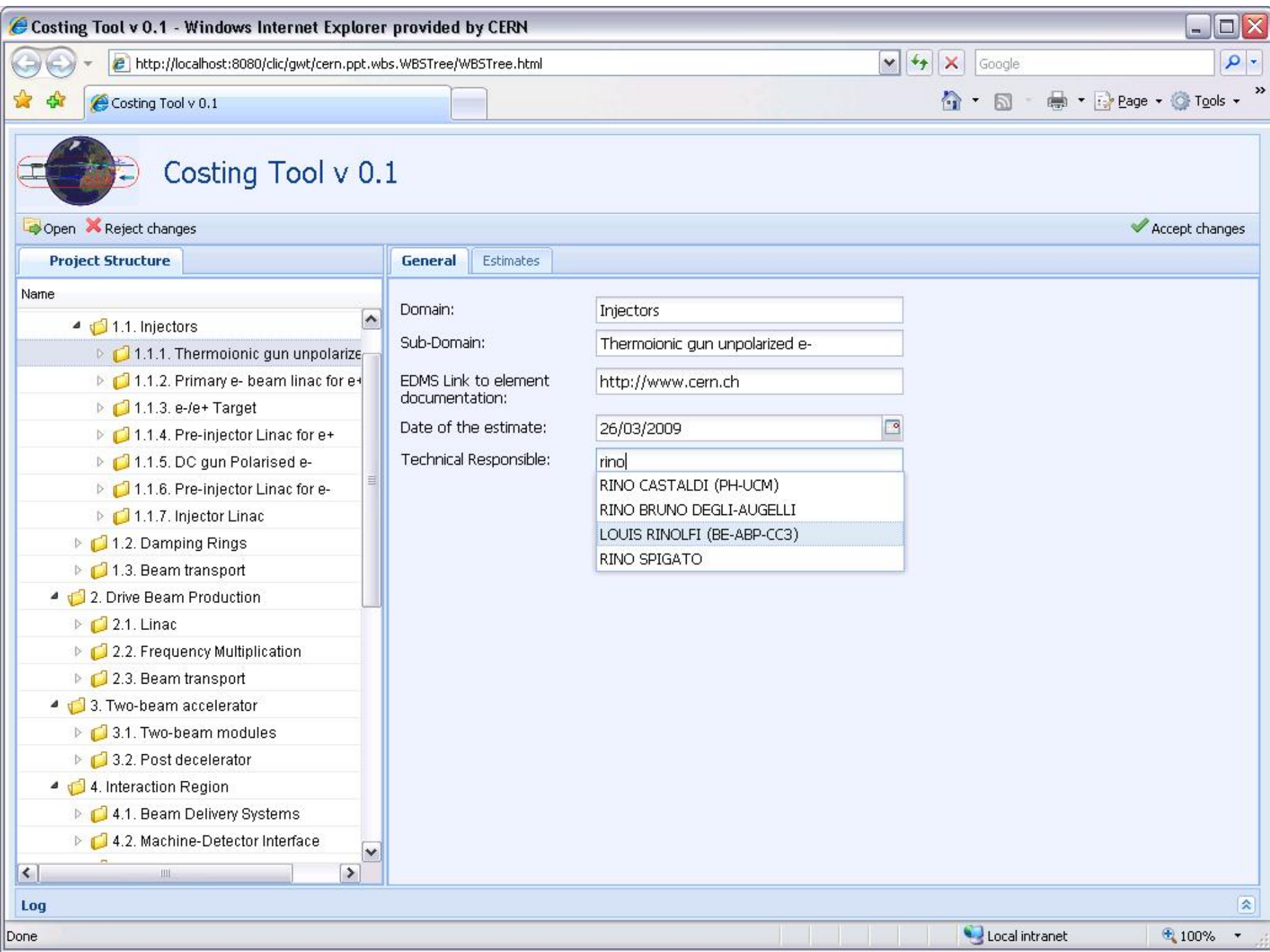
1 RF System
2 RF Powering System
3 Vacuum System
4 Magnet Powering System
5 Magnet System
6 Cooling System
7 Beam Instrumentation System
8 Supporting System
9 Alignment system
10 Kicker system
11 Cryogenic system
12 Laser system
13 Collimation system
14 Stabilisation System
15 Absorbers
16 Damping system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

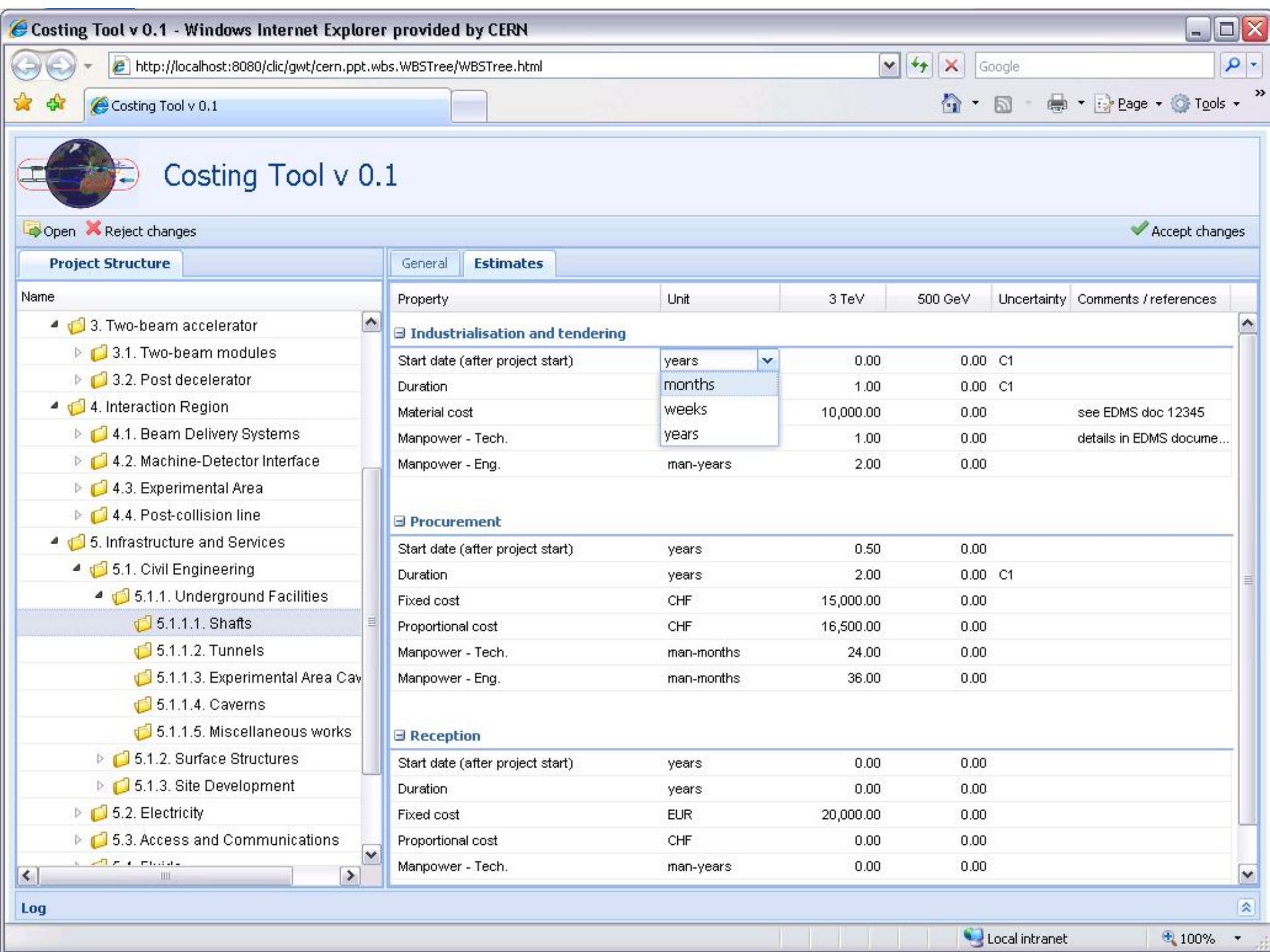
List of systems standardized

Contact experts per system

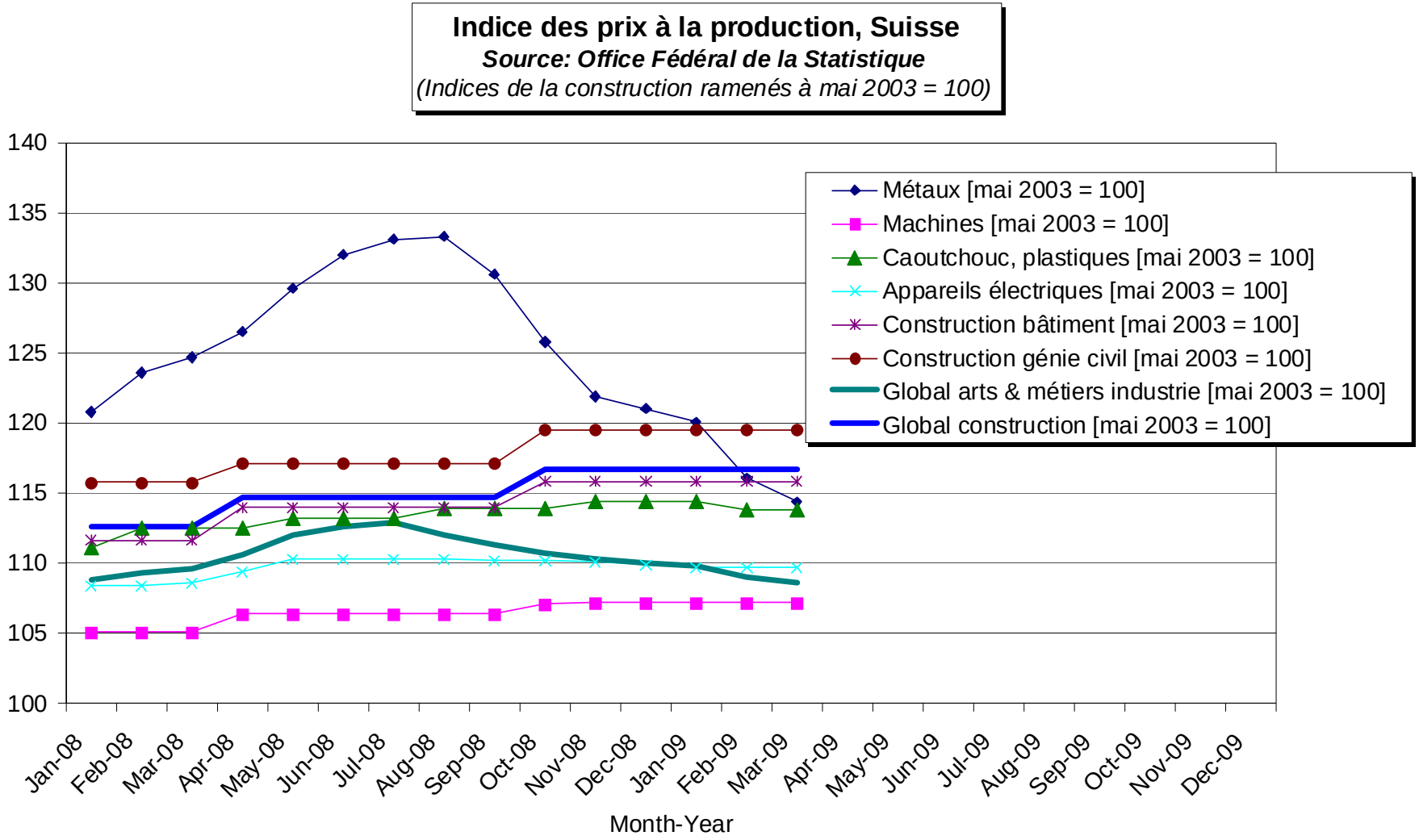
# CLIC Cost & Schedule WG
## Activities 2009

- Establish responsibilities, procedures & workpackages in cost assessment
- Identify domains of analytical costing and perform estimates
- Identify cost drivers and areas of potential cost reduction
- **Reception specified cost tool, including currency conversion & price escalation procedures, and start applying it**
- Conduct first round of analytical costing of CLIC 3TeV
- Establish proper technical/cost scaling of CLIC 500 GeV
- Refine general schedule and derive manufacturing/reception testing/installation constraints
- Update estimates of power & energy consumption, including part-load operation
- Collaborate with ILC on previously defined cost topics
  - Cost risk analysis
  - Cost of normal conducting magnets


Costing Tool v 0.1 - Windows Internet Explorer provided by CERN
http://localhost:8080/clic/gwt/cern.ppt.wbs.WBSTree/WBSTree.html
Google
Costing Tool v 0.1
Page
Tools
Costing Tool v 0.1
Open
Reject changes
Accept changes
Project Structure
General
Estimates
Name
1.1. Injectors
1.1.1. Thermoionic gun unpolarize
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
1.3. Beam transport
2. Drive Beam Production
2.1. Linac
2.2. Frequency Multiplication
2.3. Beam transport
3. Two-beam accelerator
3.1. Two-beam modules
3.2. Post decelerator
4. Interaction Region
4.1. Beam Delivery Systems
4.2. Machine-Detector Interface
Domain:
Injectors
Sub-Domain:
Thermoionic gun unpolarized e-
EDMS Link to element documentation:
http://www.cern.ch
Date of the estimate:
26/03/2009
Technical Responsible:
rino
RINO CASTALDI (PH-UCM)
RINO BRUNO DEGLI-AUGELLI
LOUIS RINOLFI (BE-ABP-CC3)
RINO SPIGATO
Log
Done
Local intranet
100%


Costing Tool v 0.1 - Windows Internet Explorer provided by CERN
http://localhost:8080/clic/gwt/cern.ppt.wbs.WBSTree/WBSTree.html
Google
Costing Tool v 0.1
Page
Tools
Costing Tool v 0.1
Open
Reject changes
Accept changes
Project Structure
General
Estimates
Name
3. Two-beam accelerator
3.1. Two-beam modules
3.2. Post decelerator
4. Interaction Region
4.1. Beam Delivery Systems
4.2. Machine-Detector Interface
4.3. Experimental Area
4.4. Post-collision line
5. Infrastructure and Services
5.1. Civil Engineering
5.1.1. Underground Facilities
5.1.1.1. Shafts
5.1.1.2. Tunnels
5.1.1.3. Experimental Area Cav
5.1.1.4. Caverns
5.1.1.5. Miscellaneous works
5.1.2. Surface Structures
5.1.3. Site Development
5.2. Electricity
5.3. Access and Communications
Property
Unit
3 TeV
500 GeV
Uncertainty
Comments / references
Industrialisation and tendering
Start date (after project start)
years
0.00
0.00
C1
months
weeks
years
Duration
1.00
0.00
C1
Material cost
10,000.00
0.00
see EDMS doc 12345
Manpower - Tech.
1.00
0.00
details in EDMS docume...
Manpower - Eng.
man-years
2.00
0.00
Procurement
Start date (after project start)
years
0.50
0.00
Duration
years
2.00
0.00
C1
Fixed cost
CHF
15,000.00
0.00
Proportional cost
CHF
16,500.00
0.00
Manpower - Tech.
man-months
24.00
0.00
Manpower - Eng.
man-months
36.00
0.00
Reception
Start date (after project start)
years
0.00
0.00
Duration
years
0.00
0.00
Fixed cost
EUR
20,000.00
0.00
Proportional cost
CHF
0.00
0.00
Manpower - Tech.
man-years
0.00
0.00
Log
Local intranet
100%

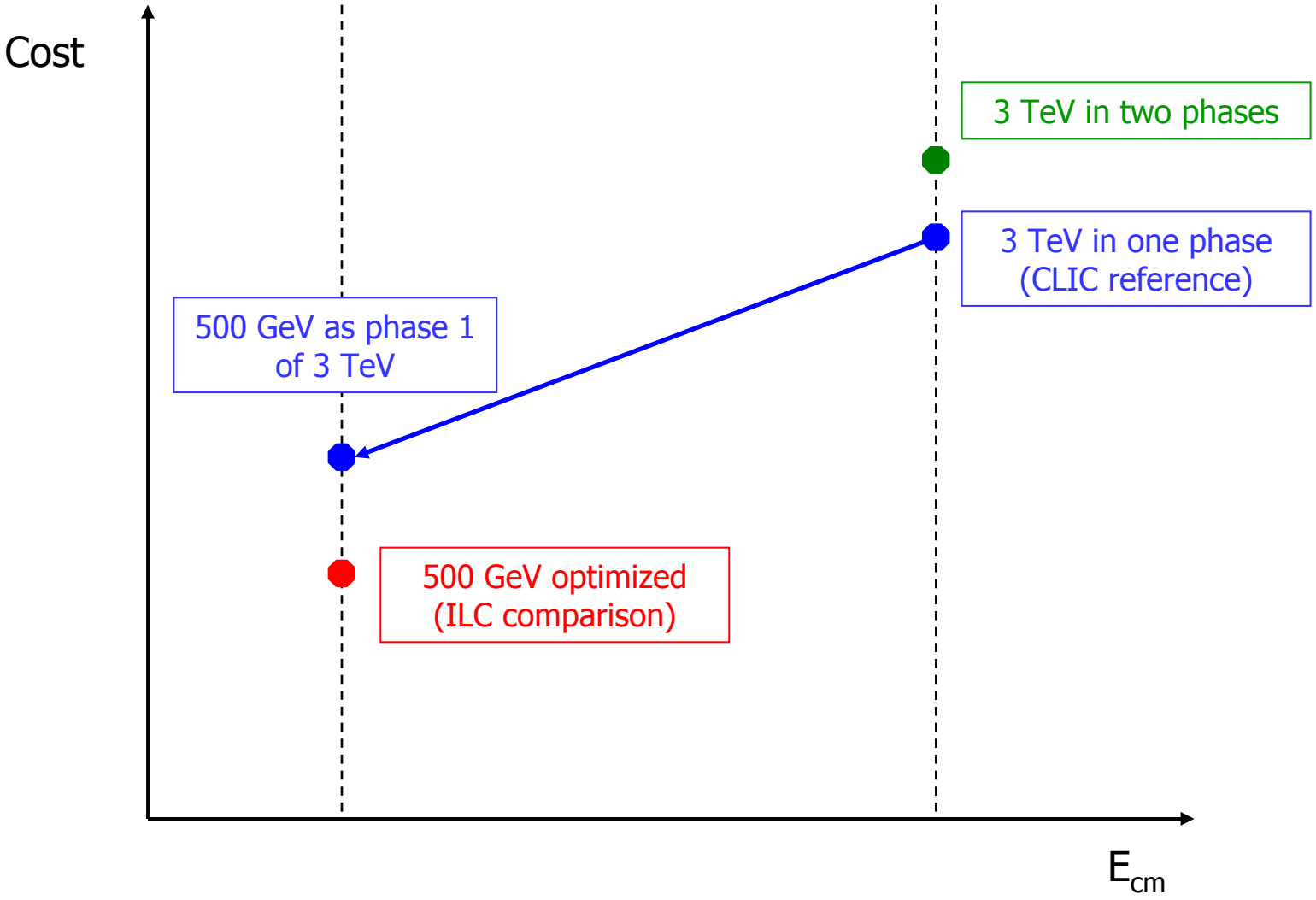
# Industrial price indices (CH)



# CLIC Cost & Schedule WG
## Activities 2009

- Establish responsibilities, procedures & workpackages in cost assessment
- Identify domains of analytical costing and perform estimates
- Identify cost drivers and areas of potential cost reduction
- Reception specified cost tool, including currency conversion & price escalation procedures, and start applying it
- Conduct first round of analytical costing of CLIC 3TeV
- Establish proper technical/cost scaling of CLIC 500 GeV
- Refine general schedule and derive manufacturing/reception testing/installation constraints
- Update estimates of power & energy consumption, including part-load operation
- Collaborate with ILC on previously defined cost topics
  - Cost risk analysis
  - Cost of normal conducting magnets

# Cost vs energy
## What are we comparing?



# CLIC Cost & Schedule WG
## Activities 2009

- Establish responsibilities, procedures & workpackages in cost assessment
- Identify domains of analytical costing and perform estimates
- Identify cost drivers and areas of potential cost reduction
- Reception specified cost tool, including currency conversion & price escalation procedures, and start applying it
- Conduct first round of analytical costing of CLIC 3TeV
- Establish proper technical/cost scaling of CLIC 500 GeV
- Refine general schedule and derive manufacturing/reception testing/installation constraints
- Update estimates of power & energy consumption, including part-load operation

- Collaborate with ILC on previously defined cost topics
  - Cost risk analysis
  - Cost of normal conducting magnets

# DOE cost risk assessment method

| | Risk Factor | Weight |
|---|---|---|
| WBS Element #_____ Element Name _____ | | |
| Design Risk (check one of 4): (from RSVP at BNL, similar for US CMS, NCSX) | | |
| __ Concept only | 15% | 1 |
| __ Conceptual Design Phase: some drawings; many sketches | 8% | 1 |
| __ Preliminary Design > 50 % complete; some analysis complete | 4% | 1 |
| __ Detailed Design > 50% Done | 0% | 1 |
| Technical Risk (check one of 8 and answer Yes or No to two questions): | | |
| __ New design; well beyond current state-of-the art | 15% | 2 or 4 |
| __ New design of new technology; advances state-of-the art | 10% | 2 or 4 |
| __ New design; requires some R&D but does not advance the state-of-the-art | 8% | 2 or 4 |
| __ New design; different from established designs or existing technology | 6% | 2 or 4 |
| __ New design; nothing exotic | 4% | 2 or 4 |
| __ Extensive modifications to an existing design | 3% | 2 or 4 |
| __ Minor modifications to an existing design | 2% | 2 or 4 |
| __ Existing design and off-the-shelf hardware | 1% | 2 or 4 |
| Yes/No – does this element push the current state-of-art in Design? | | either = 2 |
| Yes/No – does this element push the current state-of-art in Manufacturing? | | both = 4 |
| Cost Risk (check one of 8 and answer Yes or No to two questions): | | |
| __ Engineering judgment | 15% | 1 or 2 |
| __ Top-down estimate from analogous programs | 10% | 1 or 2 |
| __ In-house estimate for item with minimal experience and minimal in-house capability | 8% | 1 or 2 |
| __ In-house estimate for item with minimal experience but related to existing capabilities | 6% | 1 or 2 |
| __ In-house estimate based on previous similar experience | 4% | 1 or 2 |
| __ Vendor quote (*or industrial study*) with some design sketches | 3% | 1 or 2 |
| __ Vendor quote (*or industrial study*) with established drawings | 2% | 1 or 2 |
| __ Off-the-shelf or catalog item | 1% | 1 or 2 |
| Yes/No – are the material costs in doubt? | | either = 1 |
| Yes/No – are the labor costs in doubt? | | both = 2 |
| Schedule Risk (check one) | | |
| __ Delays completion of critical path subsystem item | 8% | 1 |
| __ Delays completion of non-critical path subsystem item | 4% | 1 |
| __ No schedule impact on any other item | 2% | 1 |
| Prepared by: _____ date: _____ | | |
| Comments: | | |

# Cost variance factors
## (assumed statistically independent)

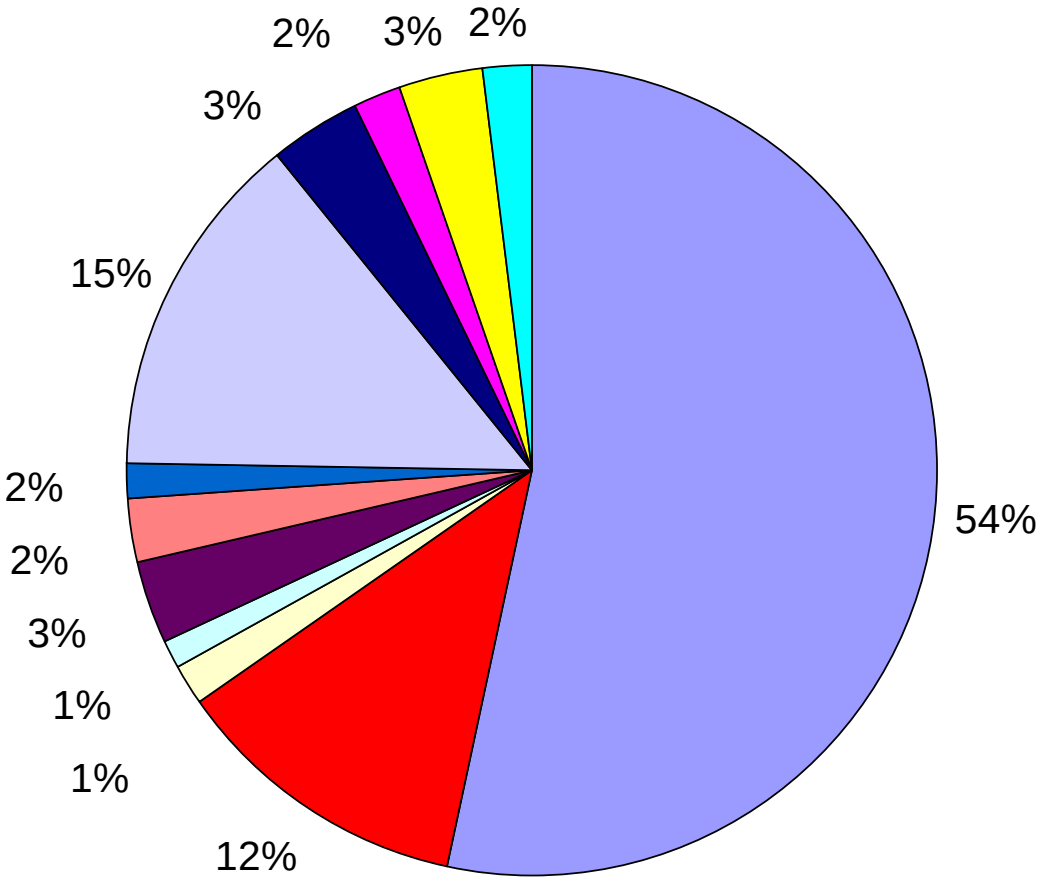
- Evolution of configuration
  - Maturity of design
  - Technology breakthroughs
  - Variation of applicable regulations
- Technical execution
  - Off-the-shelf or special product
  - Qualification & experience of vendors
  - State of completion of R&D, of industrialization
  - Series production, automation & 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 project team*

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

*Tracked and compensated*

# LHC cost structure (material)

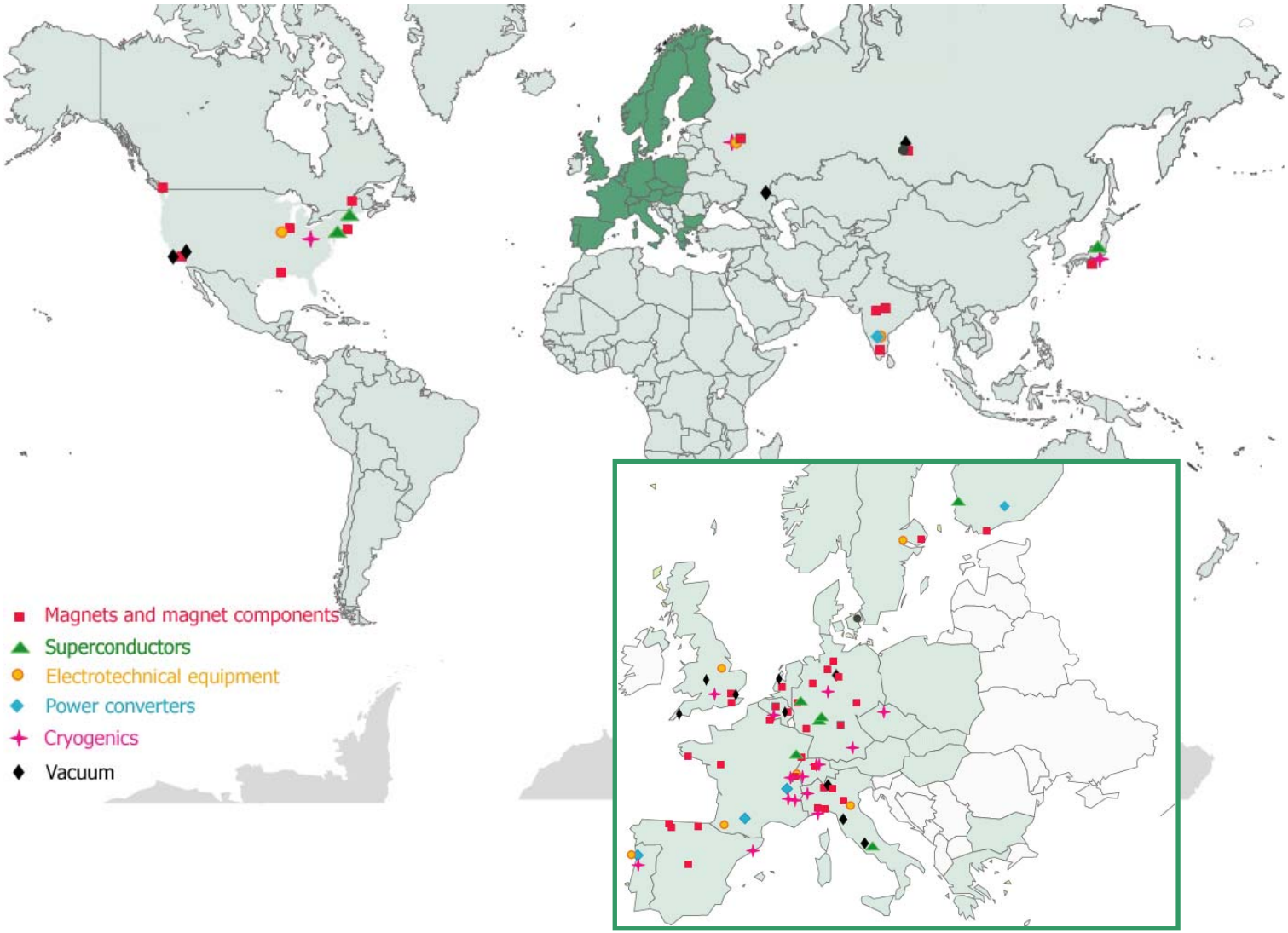



- Magnets
- Cryogenics
- Beam dump
- Radio-frequency
- Vacuum
- Power converters
- Beam instrumentation
- Civil Engineering
- Cooling & ventilation
- Power distribution
- Infrastructure & services
- Installation & coordination

Total 2.2 BEuro

# LHC procurement

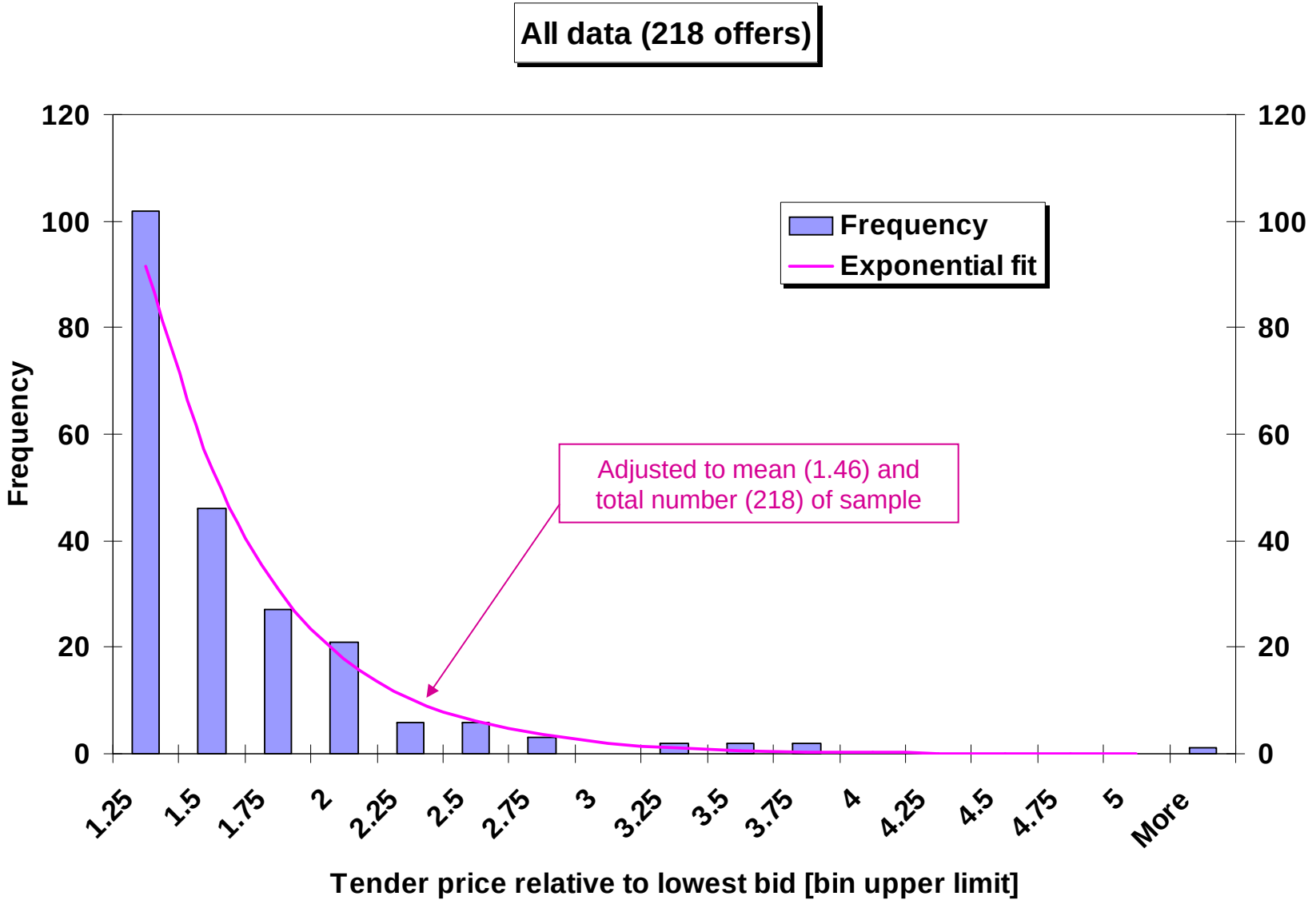
## 90 main contracts in advanced technology



# Scatter of LHC offers as a measure of cost variance

- Available data: CERN purchasing rules impose to procure on the basis of lowest valid offer ⇒ offers ranked by price with reference to lowest for adjudication by FC
- Postulate: scatter of (valid) offers received for procurement of LHC components is a measure of their variance due to technical, manufacturing and commercial aspects
- Survey of 218 offers for LHC machine components (48 contracts)
- Prices normalized to that of lowest valid offer, i.e. value of contract
- Exponential PDF fitted to observed frequency distribution with same mean value

# LHC tender prices for accelerator components



# 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 on 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, $\sigma$ = 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*

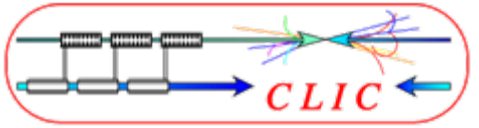
# Towards a method for CLIC cost risk analysis

- Separate cost risk factors in three classes, assumed independent
  - Risk of evolution of configuration
    - Judgement of « domain responsible »
    - Rank in 3 levels, numerical values of $\sigma_{config}$ 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 $\sigma_{config}$ and $\sigma_{industry}$
- Compensate economical & financial effects

# Summary

- CLIC Cost & Schedule (& Energy) WG reorganized
- CLIC Study Costing Tool launched
- Analytical costing exercise of CLIC 3 TeV started, based on updated PBS and expertise of PBS domain responsibles
- Refined definition of CLIC 500 GeV will allow parallel costing of this project phase
- Aim at first round by end 2009
- Identification of cost drivers and cost reduction issues
  - Feedback to technical design
  - Initiate specific studies
- Develop collaboration with ILC (TILC'09,…)
  - Exchange of information
  - Periodic WEBEX meetings
  - Cooperation on specific topics


CERN


CLIC

# Statistical modeling of tender prices

- Heuristic considerations
  - things tend to cost more rather than less ⇒ statistical distributions of tender prices $X_i$ are strongly skew
  - PDFs $f_i(x_i)$ are equal to zero for $x_i$ below threshold values $b_i$ equal to the lowest market prices available
  - commercial competition tends to crowd prices close to lowest ⇒ PDFs $f_i(x_i)$ are likely to be monotonously decreasing above threshold values $b_i$
- The exponential PDF is a simple mathematical law satisfying these conditions

| | |
|---|---|
| $f(x) = 0$ | for $x < b$ |
| $f(x) = a \exp[-a(x-b)]$ | for $x \geq b$ |

- Characteristics of the exponential law
  - only two parameters a and b
  - threshold b
  - mean value $m = 1/a + b$
  - standard deviation $\sigma = 1/a = m - b$
  - « mean value = threshold + one standard deviation »

# Exponential vs Gaussian PDFs