CLIC CDR
Schedules & Value Estimates

Philippe Lebrun
on behalf of the CLIC Cost & Schedule WG

LCWS 12
University of Texas at Arlington, USA
22 – 26 October 2012

Contents

- Scope of the CLIC CDR study
- Construction & operation schedules
- Value estimate methodology
- Uncertainty & risk
- Escalation & exchange rate fluctuations
- CDR value estimates
- Potential for cost reduction

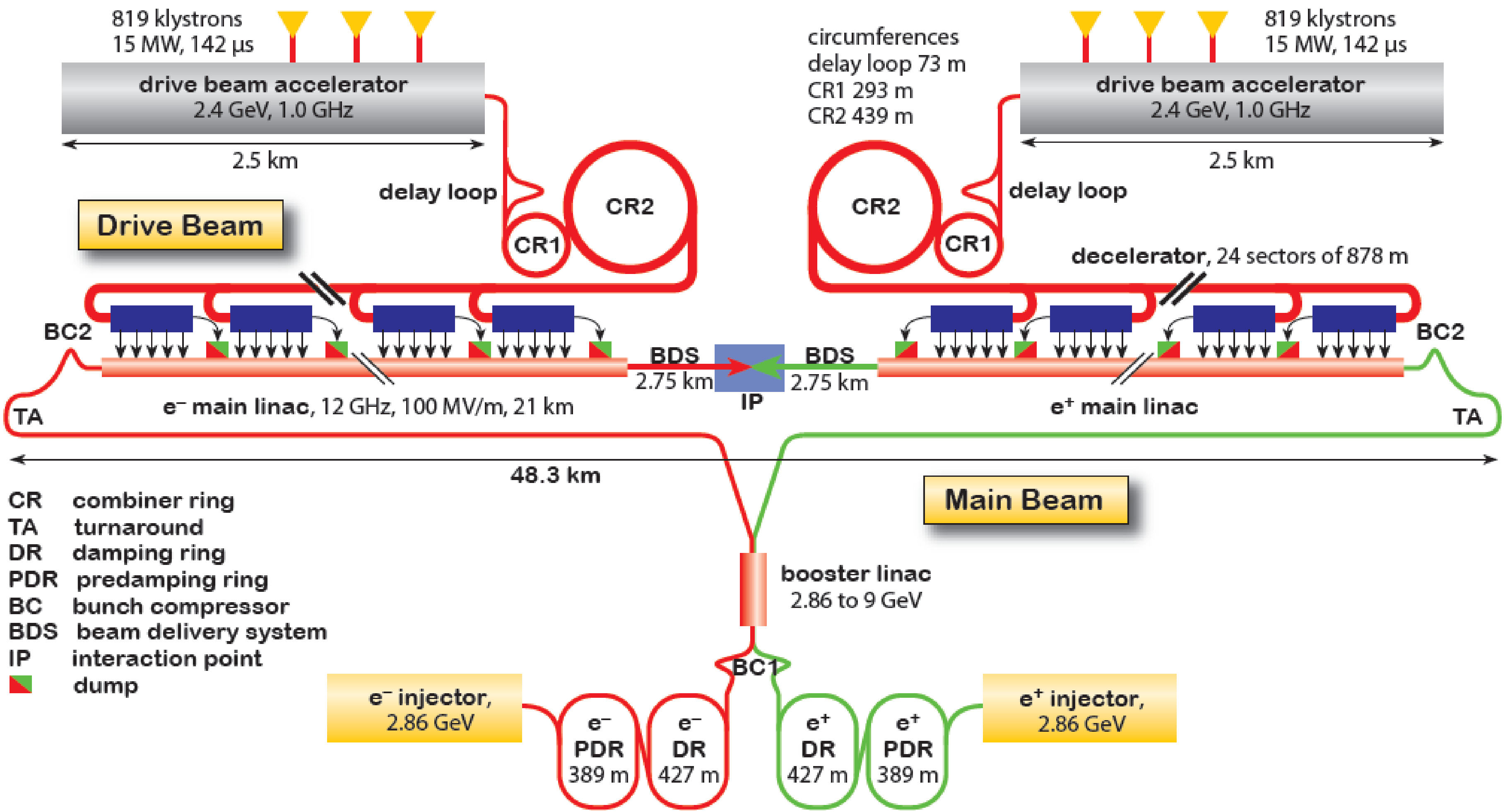
Contents

- Scope of the CLIC CDR study
- Construction & operation schedules
- Value estimate methodology
- Uncertainty & risk
- Escalation & exchange rate fluctuations
- CDR value estimates
- Potential for cost reduction

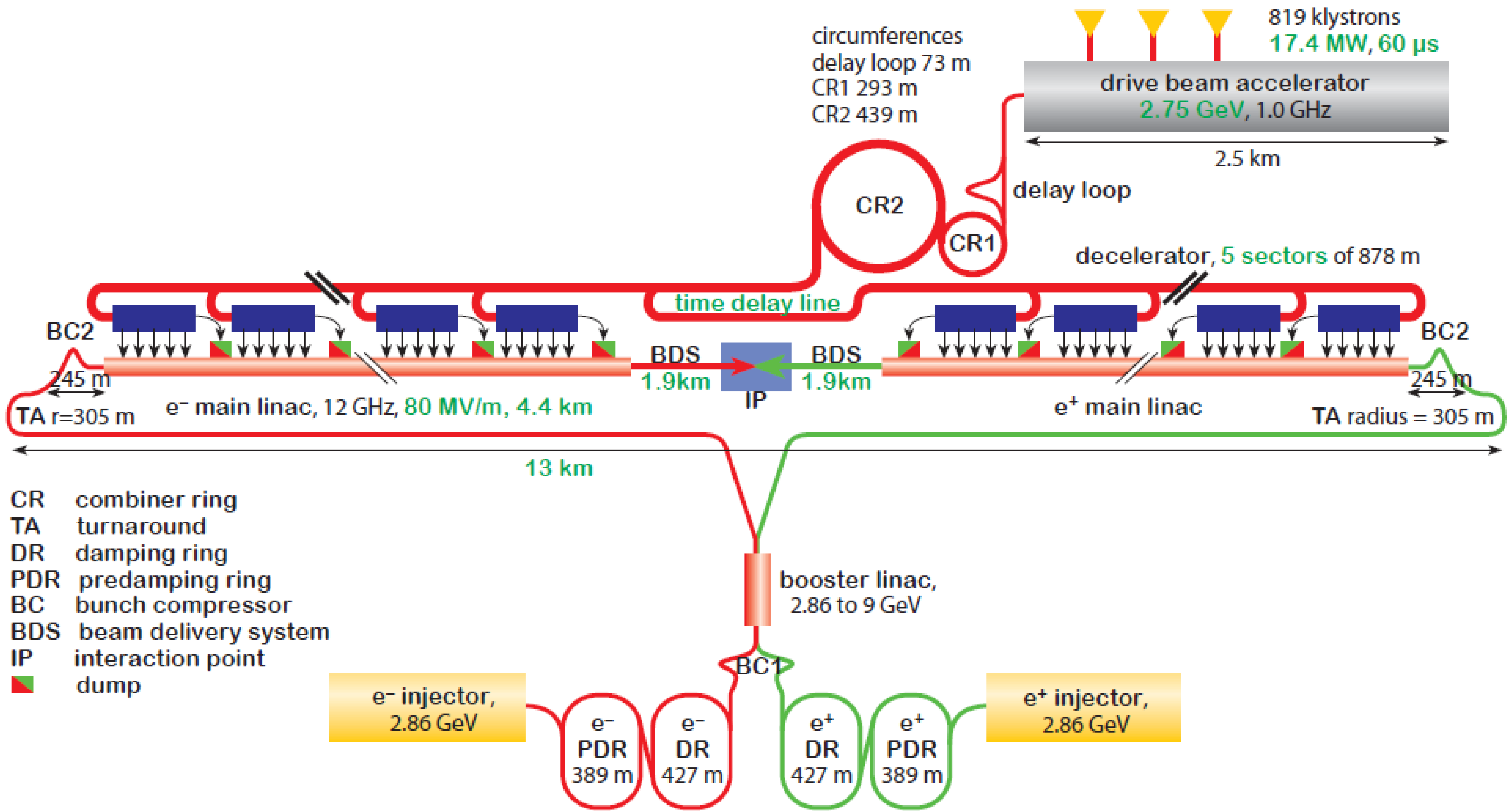
Scope of the CLIC CDR study
CDR Volume 1

- The basic parameters for the CLIC CDR study are optimized for a collision energy of 3 TeV and a peak luminosity of 2 E34 cm^{-2} s^{-1}
- The study includes a first stage at 500 GeV, for which a single drive-beam production complex is sufficient to power both main linacs
- The bunch charge must be almost doubled to preserve luminosity at 500 GeV. This results in
  - Main linac accelerating structures with larger iris and lower gradient (80 MV/m)
  - Longer main linacs (2 x 5 sectors)
  - Increased RF power in the drive-beam and main-beam production complexes
- The schedule aims at reaching the 3 TeV stage as early as permitted by civil construction and machine installation constraints: operation at 500 GeV only occurs in the shade of the 3 TeV construction schedule
- Supply of series components matches the dates of availability for installation of the 3 TeV stage, thus demanding high production rates and corresponding fixed costs
- Industrial contracts for production of series components are established from the onset for the 3 TeV quantities, to benefit from extended learning curves and lower average unit costs

CLIC layout at 3 TeV

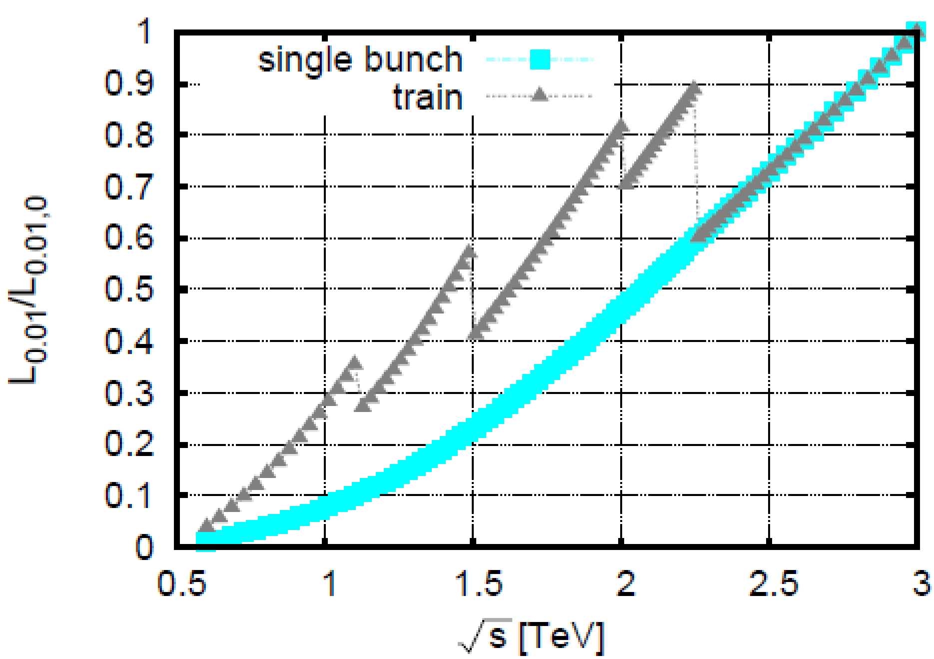


CLIC layout at 500 GeV



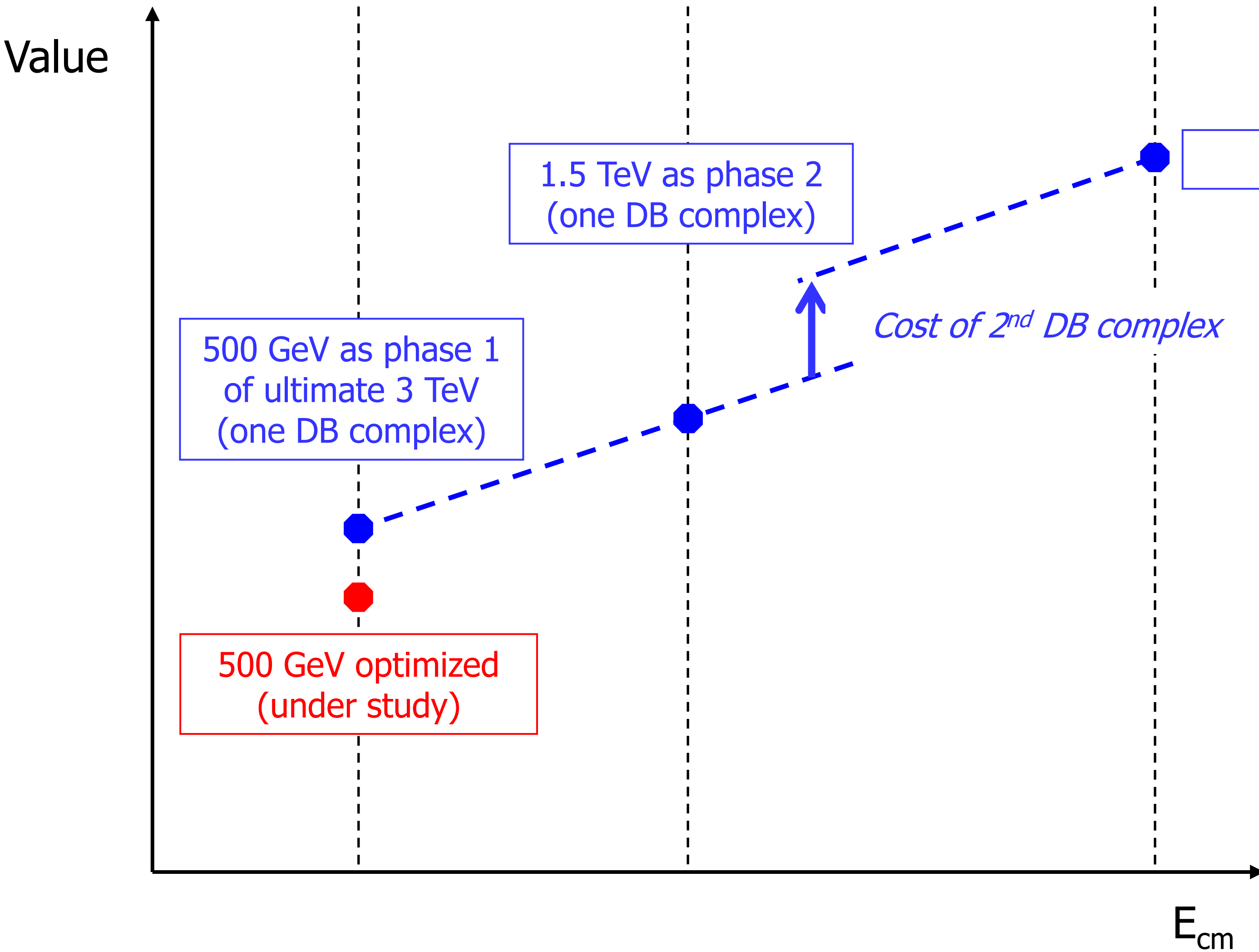
Scope of the CLIC CDR study
Changes in CDR Volume 3 [1/3]

- Introduction of an <u>intermediate energy stage</u>
  - Physics case may require collision energy at or above 1 TeV
  - Introduction of intermediate energy stage is the optimum approach for covering the full range of collision energy with sufficient luminosity
  - The stepwise increase in cost/complexity resulting from the second drive-beam complex leads to choose this intermediate stage at around 1.5 TeV



Value estimate vs energy

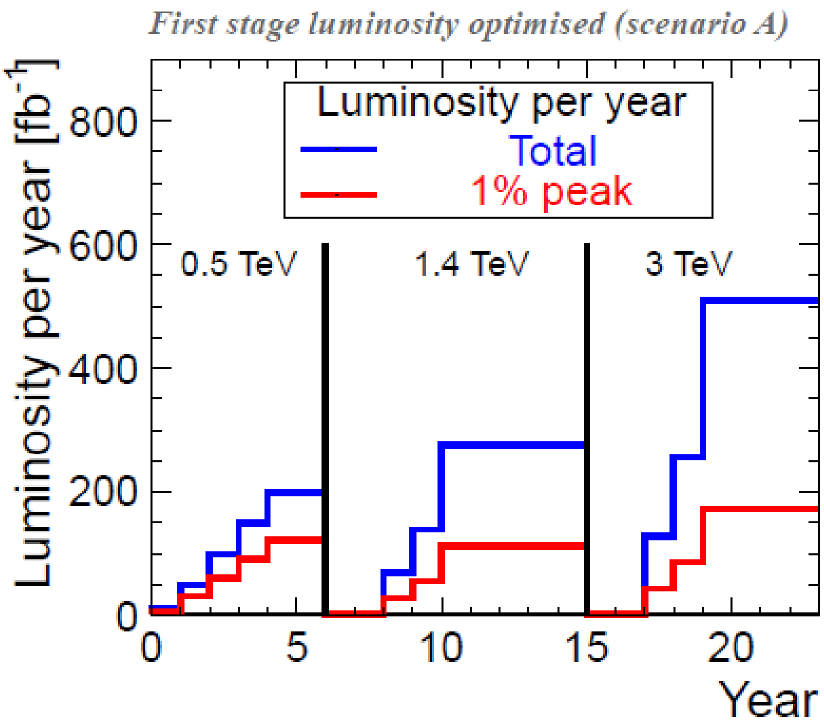
Scope of the CDR study

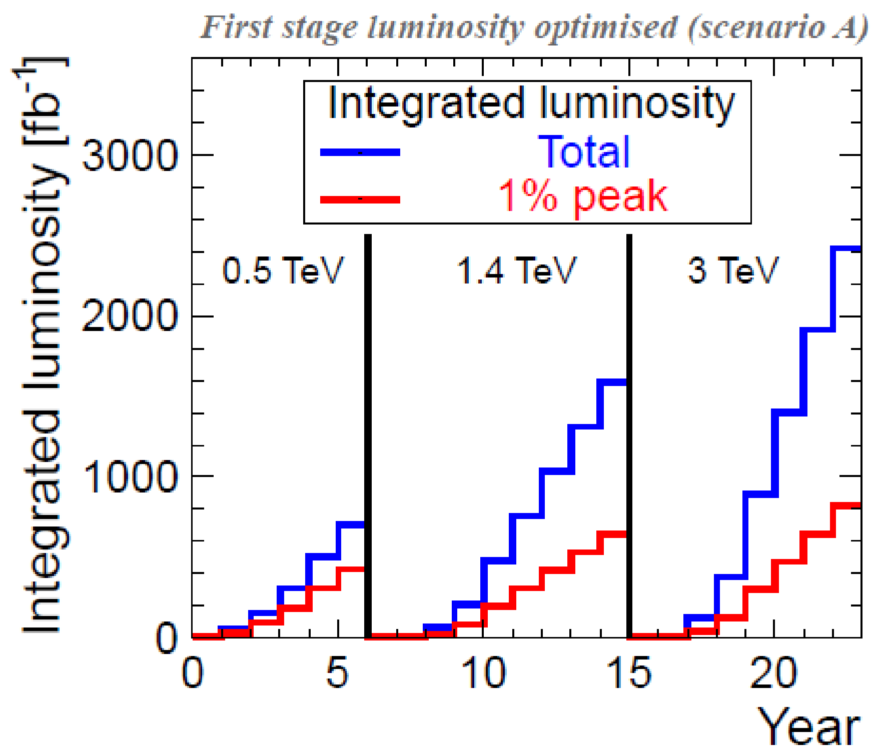


Scope of the CLIC CDR study
Changes in CDR Volume 3 [2/3]

- Inclusion of operation schedule driven by physics requirements and expected machine performance
  - Integrated luminosity goals of 500 fb^{-1} at 500 GeV, 1.5 ab^{-1} at ~1.5 TeV, and 2 ab^{-1} at 3 TeV
  - Operational efficiency (collider & detectors) taken at 0.5 for 200 days/year, with ramp-up in the first years of each stage
  - As a consequence, the complete program develops over >20 years, well beyond the horizon of any industrial contract
  - The supply of series components must now only match the dates of availability for installation of each stage, leading to production rates ~3 times lower (and thus lower fixed costs)
  - The industrial production contracts of series components only concern quantities corresponding to each stage, leading to shorter learning curves and thus higher average unit costs

Operation for physics





Luminosity ramp-up

- Four years in first stage
- Two years in subsequent stages

Integrated luminosity targets

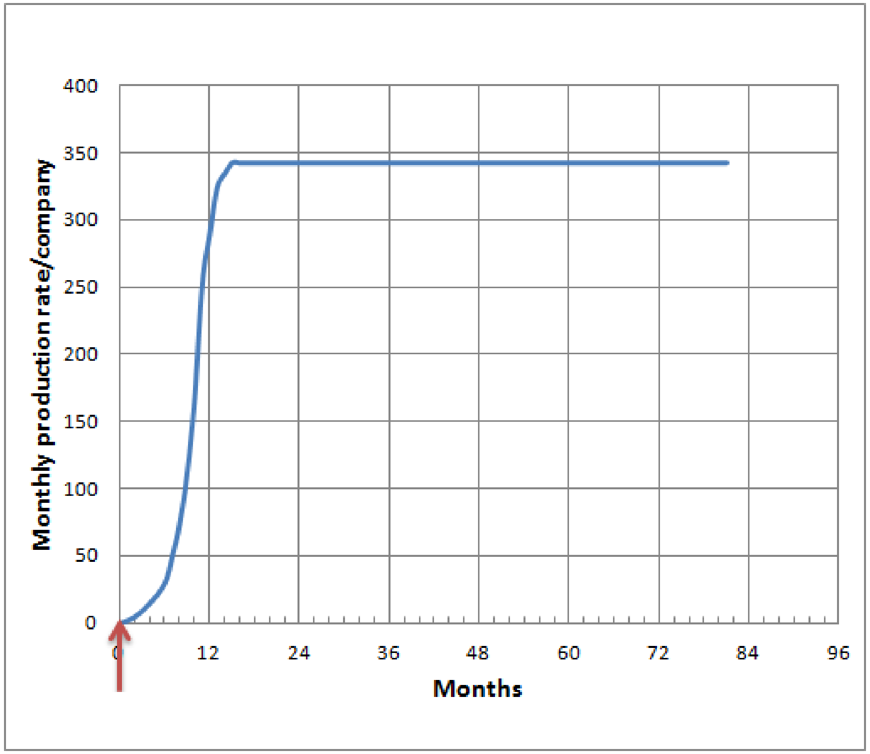
- 500 fb^{-1} at 500 GeV
- 1.5 ab^{-1} at 1.4/1.5 TeV
- 2 ab^{-1} at 3 TeV

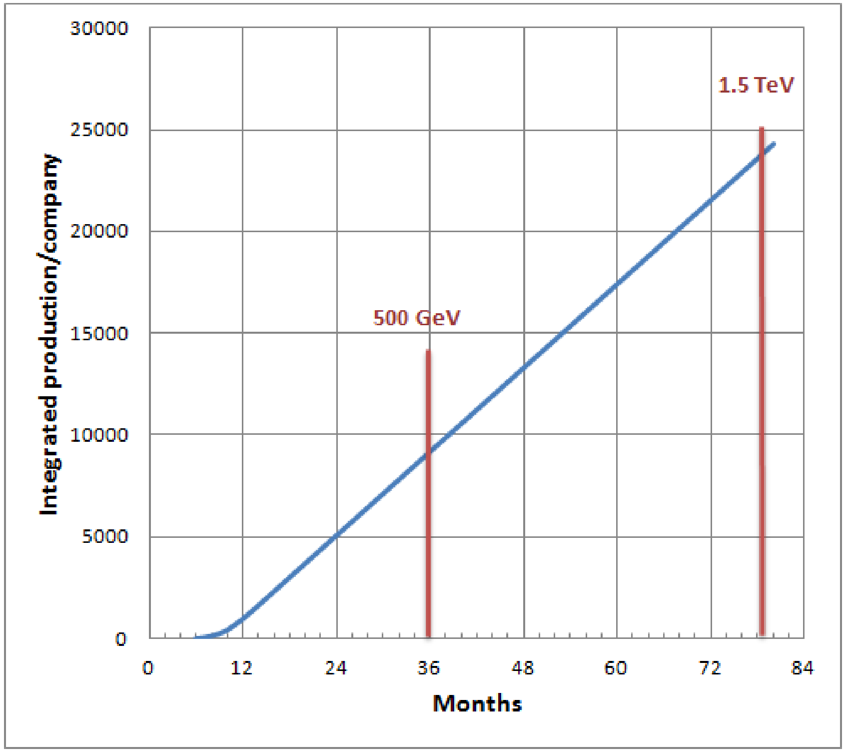
Production of accelerating structures

Assumptions		
Continuous production 500 GeV ==> 1.5 TeV		
Reuse of AS at 500 GeV for 1.5 TeV		
Production period for 500 geV		
months	36	**(3 years)**
quantity	27500	produced

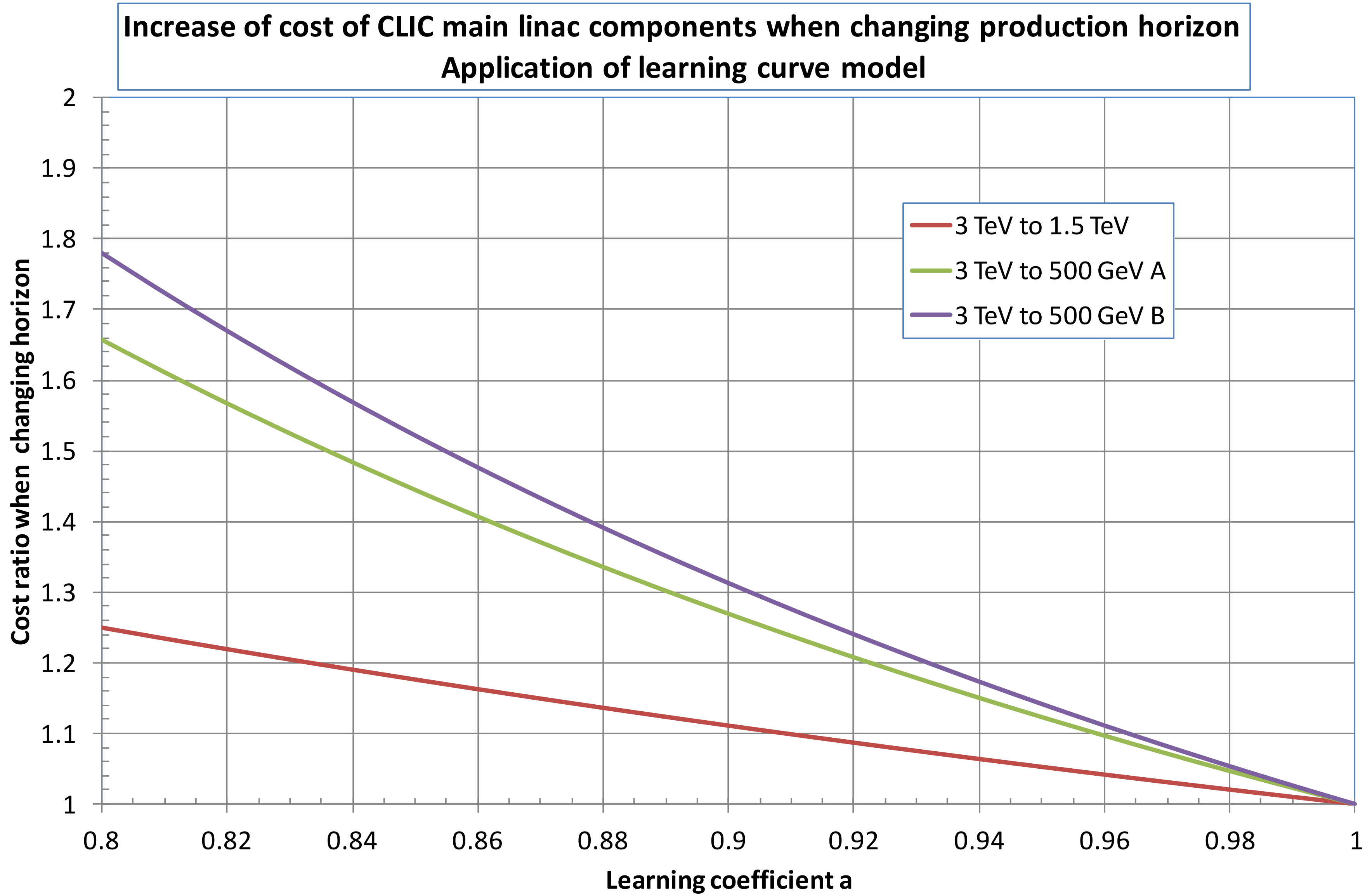
No. of AS	
26920	500 GeV
71402	1.5 TeV

500 GeV	
N. of companies	
3	
9166	total units per companies
254	average rate/month
343	final rate/month





G. Riddone


Increase of cost of CLIC main linac components when changing production horizon
Application of learning curve model
3 TeV to 1.5 TeV
3 TeV to 500 GeV A
3 TeV to 500 GeV B
Cost ratio when changing horizon
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
Learning coefficient a

Scope of the CLIC CDR study
Changes in CDR Volume 3 [3/3]

- Two alternative staging scenarios
  - Each with three stages: 500 GeV, ~1.5 TeV and 3 TeV
  - Scenario A: « optimized for luminosity in the first stage »
  - Scenario B: « optimized for lower entry cost »
  - First and last stages of scenario A are identical to CDR Volume 1
  - Reuse of 80 MV/m structures in scenario A limits the energy of the second stage to 1.4 TeV
  - Scenario B has nominal bunch charge at all stages, resulting in
    - Use of final (100 MV/m) gradient structures already at 500 GeV
    - Shorter main linacs (2 x 4 sectors)
    - Lower installed RF power in the main-beam and drive-beam production complexes

Parameters for Scenario A

« optimized for luminosity at 500 GeV »

Parameter	Symbol	Unit			
Centre-of-mass energy	$\sqrt{s}$	GeV	500	1400	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		354	312	312
Bunch separation	Δ_t	ns	0.5	0.5	0.5
Accelerating gradient	G	MV/m	80	80/100	100
Total luminosity	$\mathscr{L}$	10^{34} cm^{-2}s^{-1}	2.3	3.2	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	10^{34} cm^{-2}s^{-1}	1.4	1.3	2
Main tunnel length		km	13.2	27.2	48.3
Charge per bunch	N	10^9	6.8	3.7	3.7
Bunch length	σ_z	µm	72	44	44
IP beam size	σ_x/σ_y	nm	200/2.6	≈ 60/1.5	≈ 40/1
Normalised emittance (end of linac)	$\varepsilon_x/\varepsilon_y$	nm	2350/20	660/20	660/20
Normalised emittance (IP)	$\varepsilon_x/\varepsilon_y$	nm	2400/25	—	—
Estimated power consumption	P_{wall}	MW	272	364	589

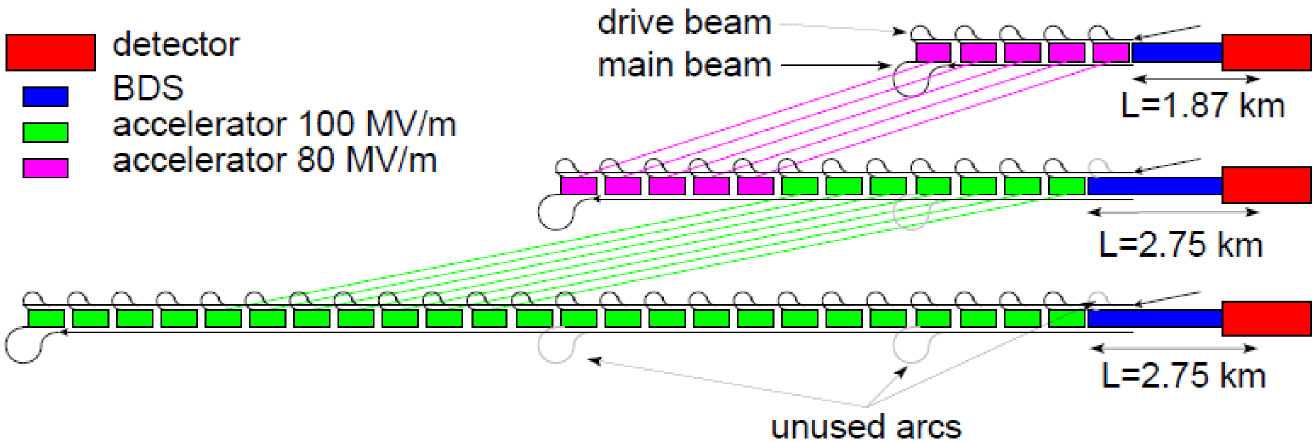
Parameters for Scenario B

« lower entry cost »

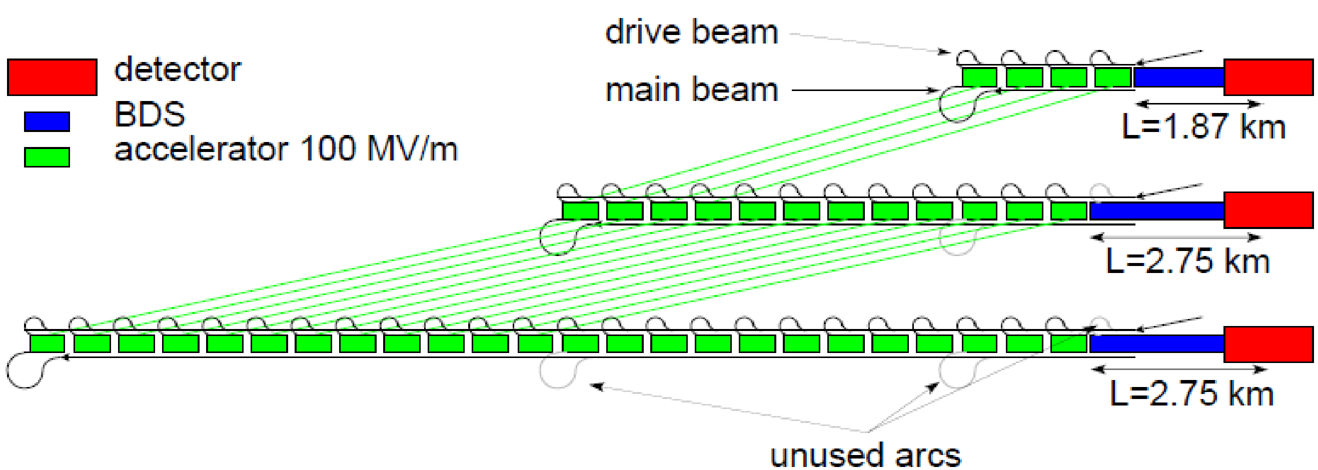
Parameter	Symbol	Unit			
Centre-of-mass energy	$\sqrt{s}$	GeV	500	1500	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		312	312	312
Bunch separation	Δ_t	ns	0.5	0.5	0.5
Accelerating gradient	G	MV/m	100	100	100
Total luminosity	$\mathscr{L}$	10^{34} cm^{-2}s^{-1}	1.3	3.7	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	10^{34} cm^{-2}s^{-1}	0.7	1.4	2
Main tunnel length		km	11.4	27.2	48.3
Charge per bunch	N	10^9	3.7	3.7	3.7
Bunch length	σ_z	μm	44	44	44
IP beam size	σ_x/σ_y	nm	100/2.6	≈ 60/1.5	≈ 40/1
Normalised emittance (end of linac)	$\varepsilon_x/\varepsilon_y$	nm	—	660/20	660/20
Normalised emittance	$\varepsilon_x/\varepsilon_y$	nm	660/25	—	—
Estimated power consumption	P_{wall}	MW	235	364	589

Upgrade paths for both Scenarios

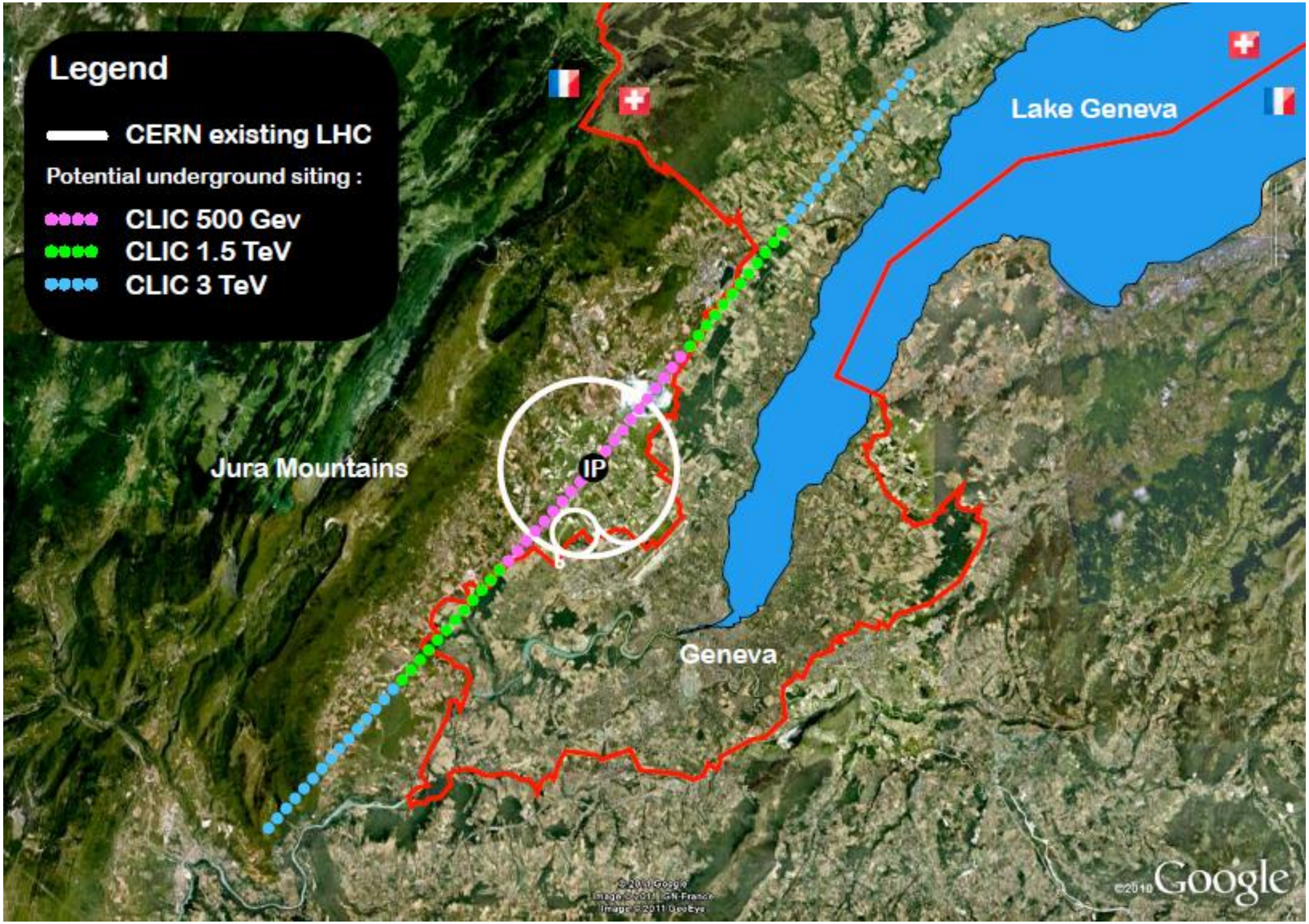
Scenario A



Scenario B



CLIC footprints near CERN

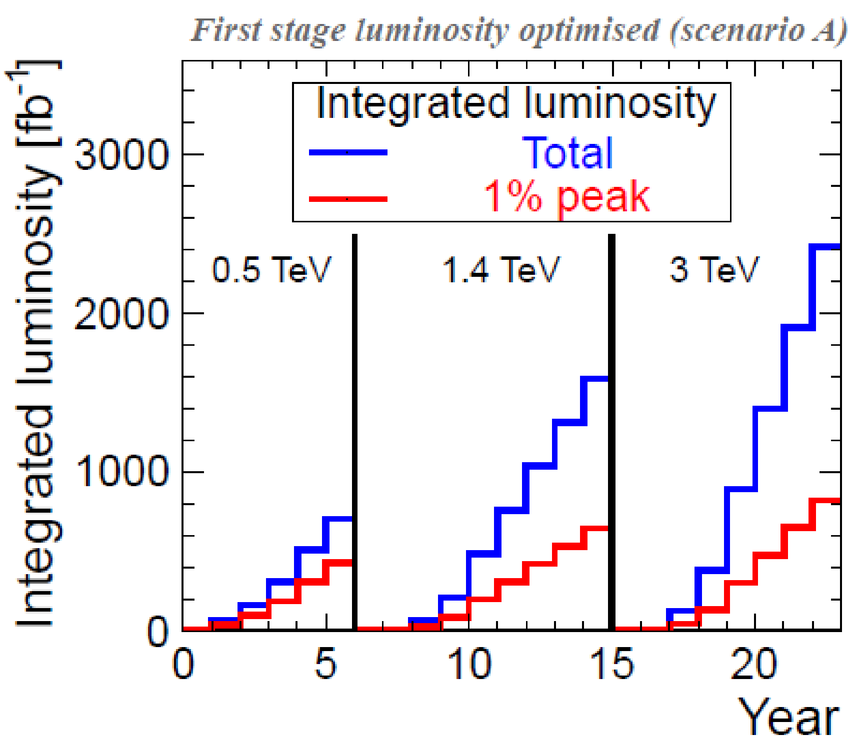


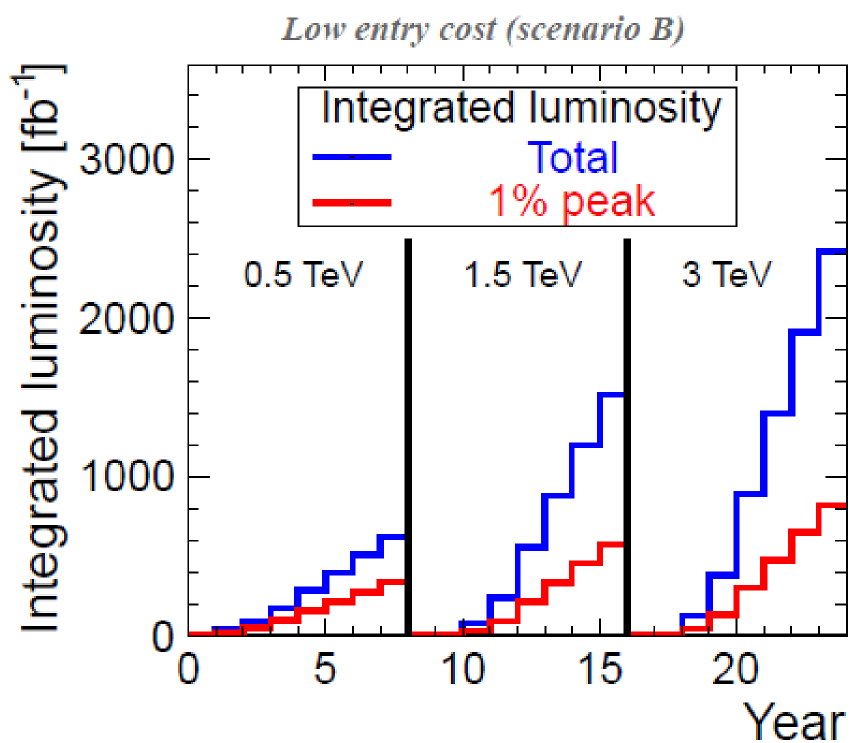
Contents

- Scope of the CDR study
- Construction & operation schedules
- Value estimate methodology
- Uncertainty & risk
- Escalation & exchange rate fluctuations
- CDR value estimates
- Potential for cost reduction

Operation for physics

- Integrated luminosity targets for physics
  - 500 fb^{-1} at 500 GeV
  - 1.5 ab^{-1} at 1.4/1.5 TeV
  - 2 ab^{-1} at 3 TeV



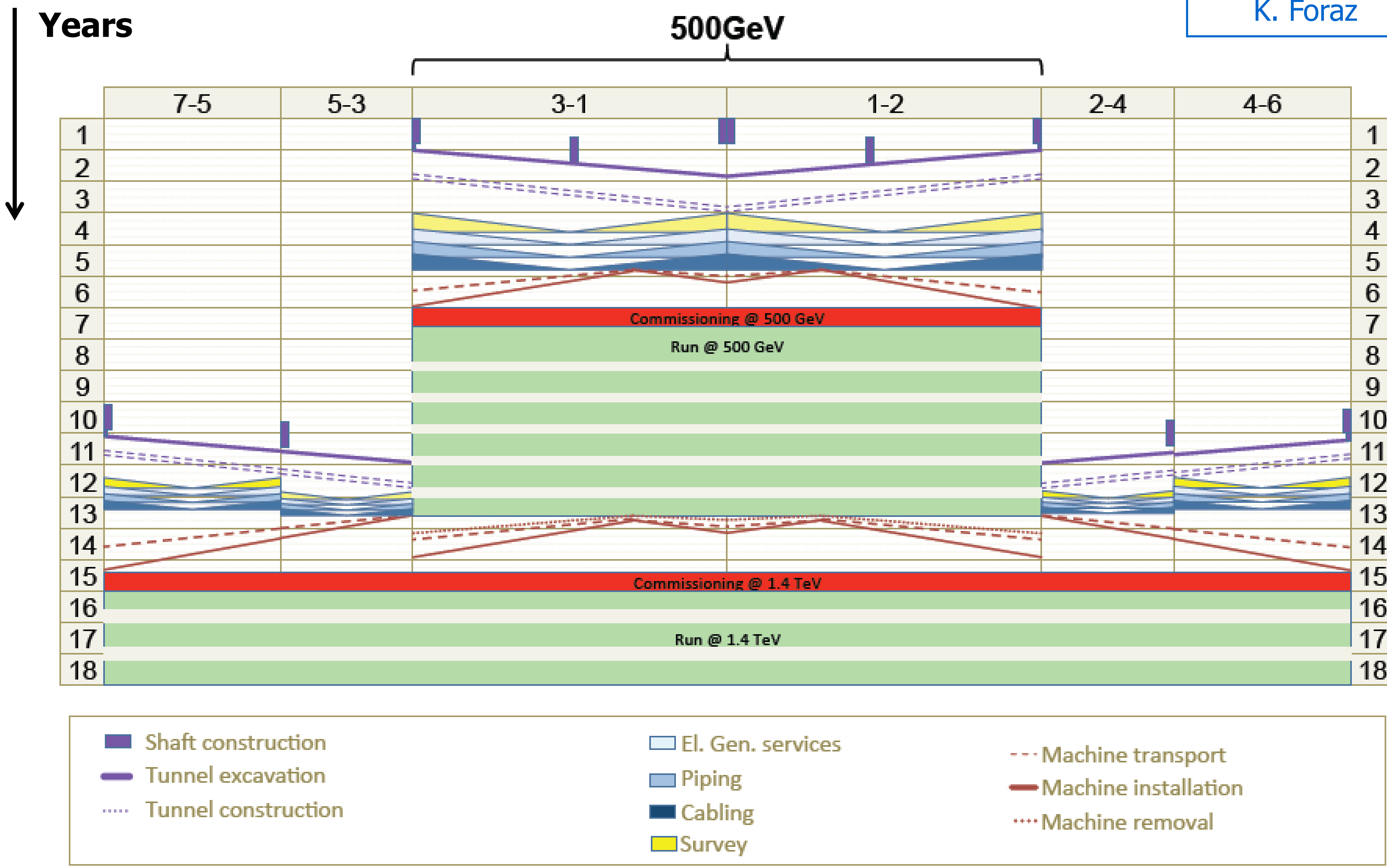


Progress rate assumptions

- Civil engineering
  - site installation: 15 weeks
  - shaft excavation and concrete:
    - 180 m deep: 30 weeks
    - 150 m deep: 26 weeks
    - 100 m deep: 15 weeks
  - service caverns: 35 weeks
  - excavation by tunnel-boring machine (TBM): 150 m/week
- Installation of general services
  - Survey & floor markings: 9 weeks/km/front
  - electrical general services: 8 weeks/km/front
  - cooling pipes & ventilation ducts: 8 weeks/km/front
  - AC and DC cabling: 8 weeks/km/front
- Installation of main linacs
  - Transport of two-beam modules: 500/month
  - Interconnection of two-beam modules: 300 to 400/month

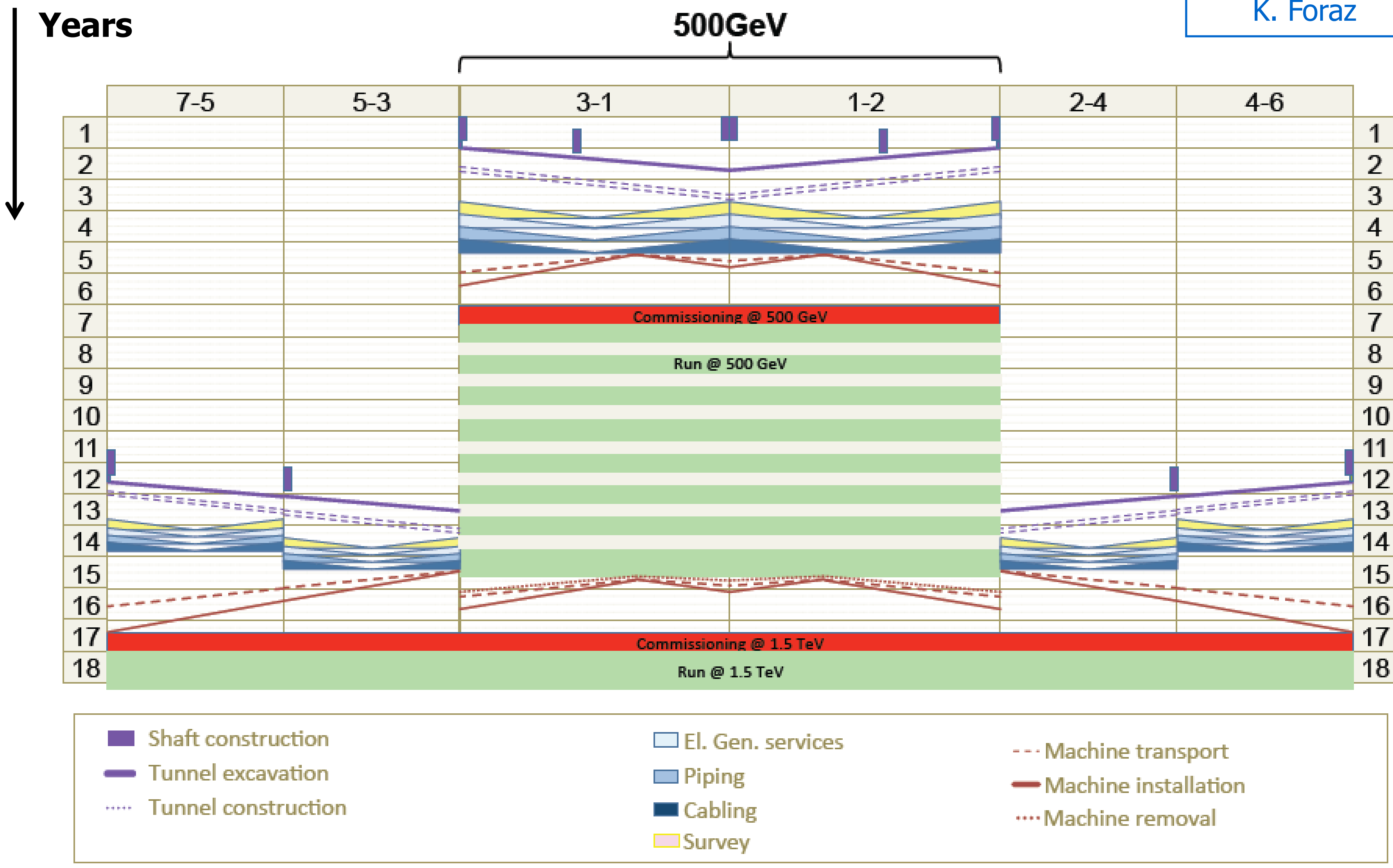
Main linac construction schedule – Scenario A

K. Foraz



Main linac construction schedule – Scenario B

K. Foraz



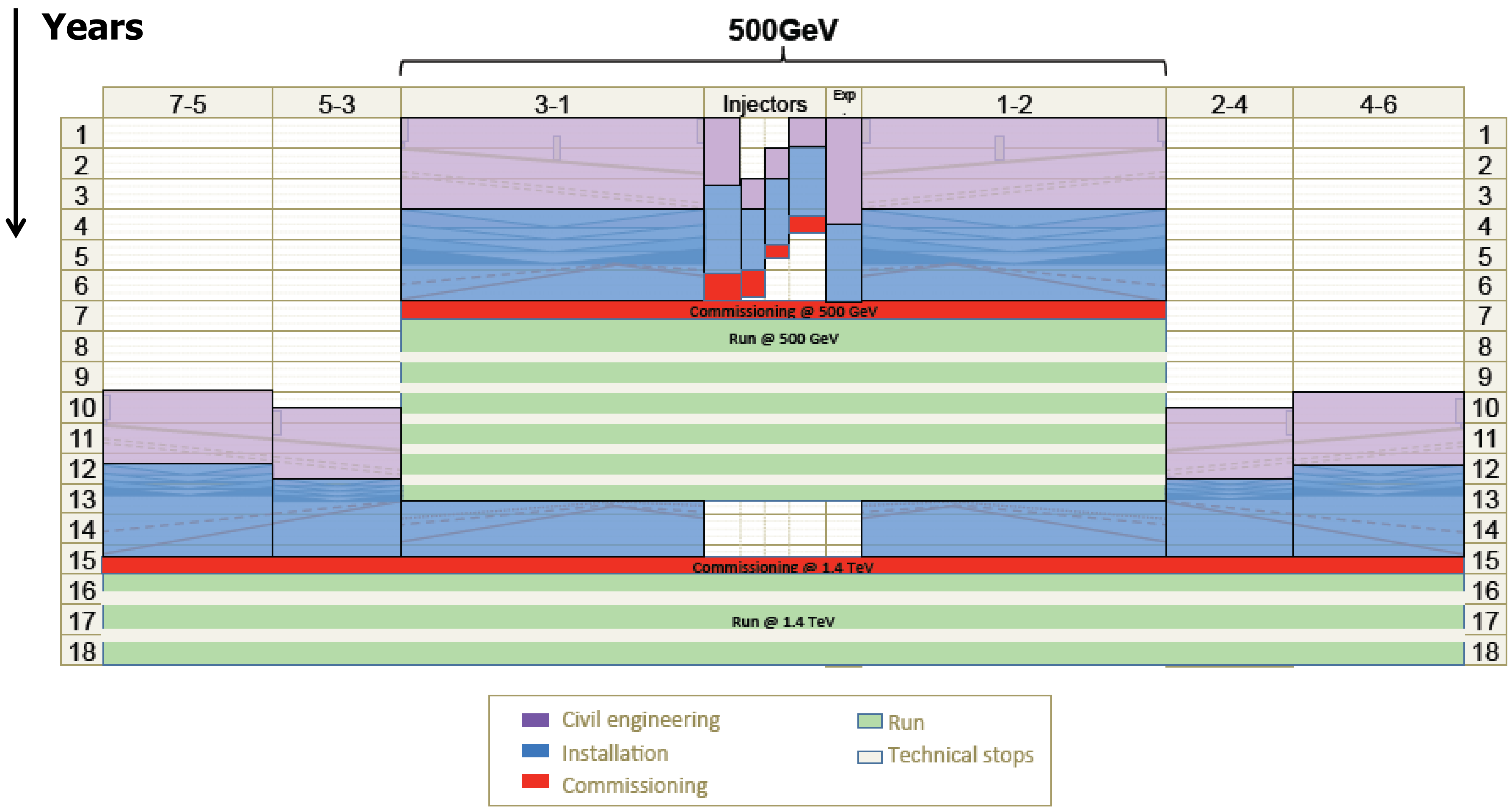
Interaction region schedule

Year	Underground work	Surface work
1	Excavate two experimental shafts in parallel.	Construction of part (2/3) of two detector assembly halls in parallel, including services.
2	Excavate and carry out finishing of experimental caverns and transfer tunnel (2.5 years).	Assemble two detectors in their dedicated assembly halls (1st of 4 years). Construct service buildings (cooling & ventilation, electrics, gas, counting rooms, etc.).
3	Proceed with finishing of the two experimental Caverns and transfer tunnel.	Assemble two detectors in assembly halls (2nd of 4 years).
4	Finish the two experimental caverns and transfer tunnel. Install infrastructure and services in two experimental caverns and transfer tunnel (1.5 years). See details in Fig. 9.24.	Assemble two detectors in assembly halls (3rd of 4 years). Complete construction of last third of two assembly halls.
5	Complete installation of infrastructure and services in two experimental caverns and transfer tunnel.	Complete assembly of two detectors in assembly halls. Installation of heavy-load gantry crane for lowering detectors.
6	Connect two detectors to the caverns' on-detector services and cable chains (6 months).	Lower two detectors (6 months).
7	Perform magnet tests. Trial run with cosmic rays. Commission safety systems. Test push–pull system including forward shielding.	

M. Gastal

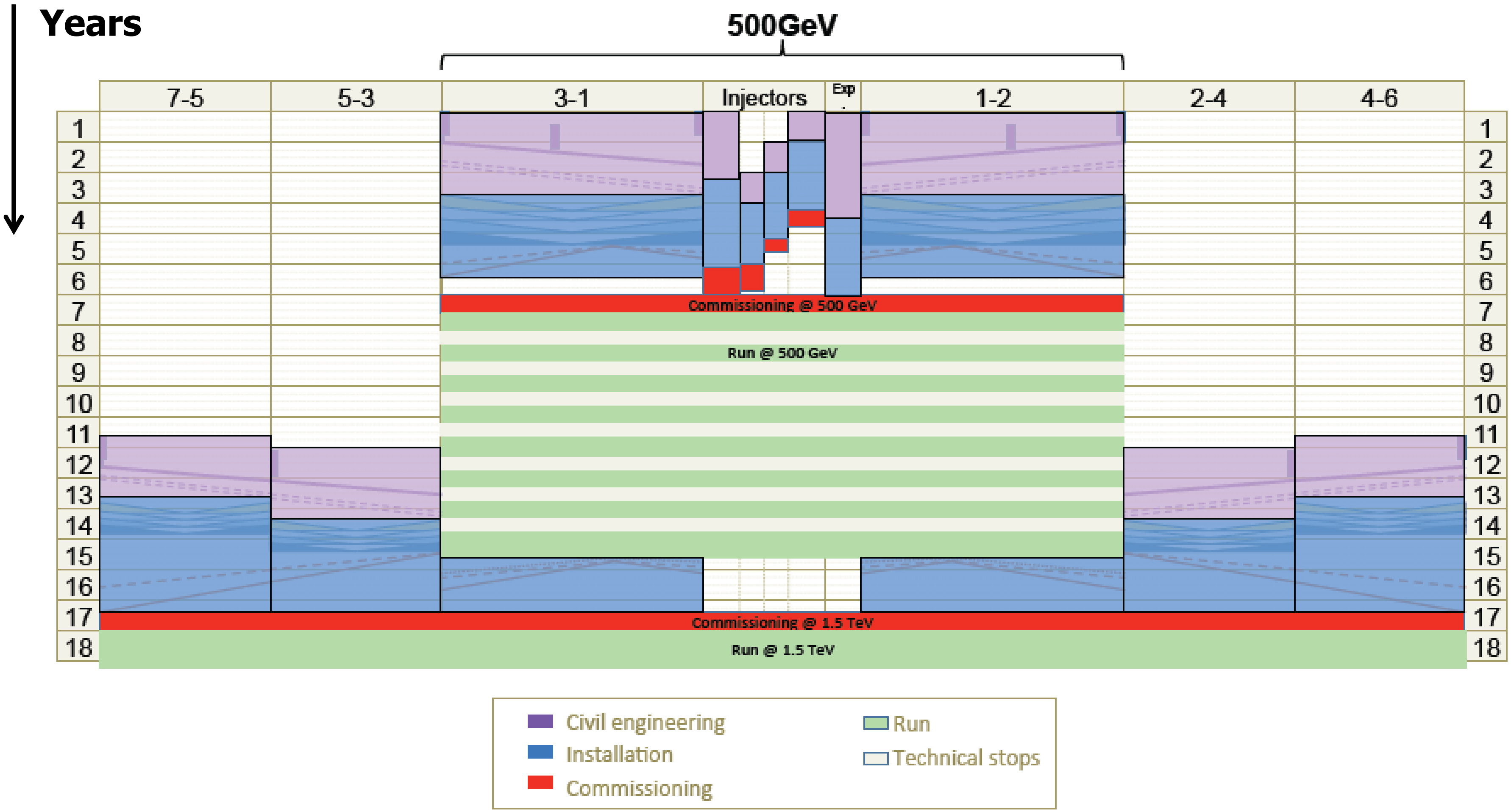
Overall construction schedule - Scenario A

K. Foraz



Overall construction schedule - Scenario B

K. Foraz



Contents

- Scope of the CDR study
- Construction & operation schedules
- Value estimate methodology
- Uncertainty & risk
- Escalation & exchange rate fluctuations
- CDR value estimates
- Potential for cost reduction

Value, explicit labor & cost

- CLIC will be a global project
  - with contributions in different forms (in-cash, in-kind, in personnel)
  - from different regions of the world
  - using different accounting systems
- « Value & explicit labor » methodology
  - independent of any particular accounting system
  - compatible with this diversity
  - adopted by ITER, ILC RDR
- Value
  - lowest reasonable estimate of the price of goods and services procured from industry on the world market in adequate quality and quantity
  - expressed in CHF of December 2010
- Explicit labor
  - personnel provided by central laboratory and collaborating institutes
  - expressed in person.years

Value estimates are given in December 2010 CHF

1 EUR = 1.28 CHF   1 USD = 0.96 CHF   1 JPY = 0.0116 CHF

Euro to Swiss franc

US dollar to Swiss franc

Scope of the value estimate

- Included
  - « Project construction » costs, i.e. from project approval to commissioning with beam
  - DB injector complex, MB injector complex, main linacs, infrastructure for experiments, beam disposal
  - Specific tooling dedicated for production of components
  - Reception tests and pre-conditioning of components
  - Commissioning of technical systems (w/o beam)
  - « Explicit labor » including dedicated services e.g. project office, monitoring & oversight of collaborations: counted separately
- Excluded
  - R&D, prototyping & pre-industrialization
  - Land acquisition & underground rights-of-way
  - Detectors
  - Computing
  - General laboratory infrastructure e.g. library, fire brigade, hostel, cafeteria
  - General laboratory services, e.g. administration, human resource management, purchasing, finance, communication & outreach
  - Commissioning with beam, operation, decommissioning
  - Spares (charged to operations budget)
  - Taxes & custom duties

Value estimate follows PBS/WBS

Level 1 PBS/WBS		Level 2 PBS/WBS		Domain coordinators
1	Main Beam Production			
		1.1	Injectors	*S. Doebert*
		1.2	Damping Rings	*Y. Papaphilippou*
		1.3.	Beam transport	*J. B. Jeanneret*
2	Drive Beam Production			
		2.1	Injectors	*B. Jeanneret*
		2.2.	Frequency Multiplication	*B. Jeanneret*
		2.3.	Beam transport	*B. Jeanneret*
3	Two-beam accelerators			
		3.1.	Two-Beam Modules	*G. Riddone*
		3.2.	Post decelerators	*B. Jeanneret*
4	Interaction Region			
		4.1.	Beam Delivery Systems	*L. Gatignon*
		4.2.	Experimental Area	*L. Gatignon*
		4.3.	Post-collision Line	*L. Gatignon*
5	Infrastructure and Services			
		5.1.	Civil Engineering	*J. Osborne*
		5.2.	Electricity	*J. Osborne*
		5.3.	Survey and Alignment	*J. Osborne*
		5.4.	Fluids	*J. Osborne*
		5.5.	Transport / installation	*J. Osborne*
		5.6.	Safety	*J. Osborne*
6	Machine Control and Operational Infrastructure			
		6.1.	Machine Control Infrastructure	*M. Jonker*
		6.2.	Machine Protection	*M. Jonker*
		6.3.	Access Safety & Control System	*M. Jonker*
		6.4.	Technical Alarm System	*M. Jonker*

PBS/WBS levels

- Architecture
  - Level 1: Domain — *Main beam production*
    - Level 2: Subdomain — *Injectors*
      - Level 3: Component — *Pre-injector linac for e-*

        Multiplicities of components included
        - Level 4: Technical system — *RF system*

          List standardized
          - Level 5: Subcomponent — *Klystron*

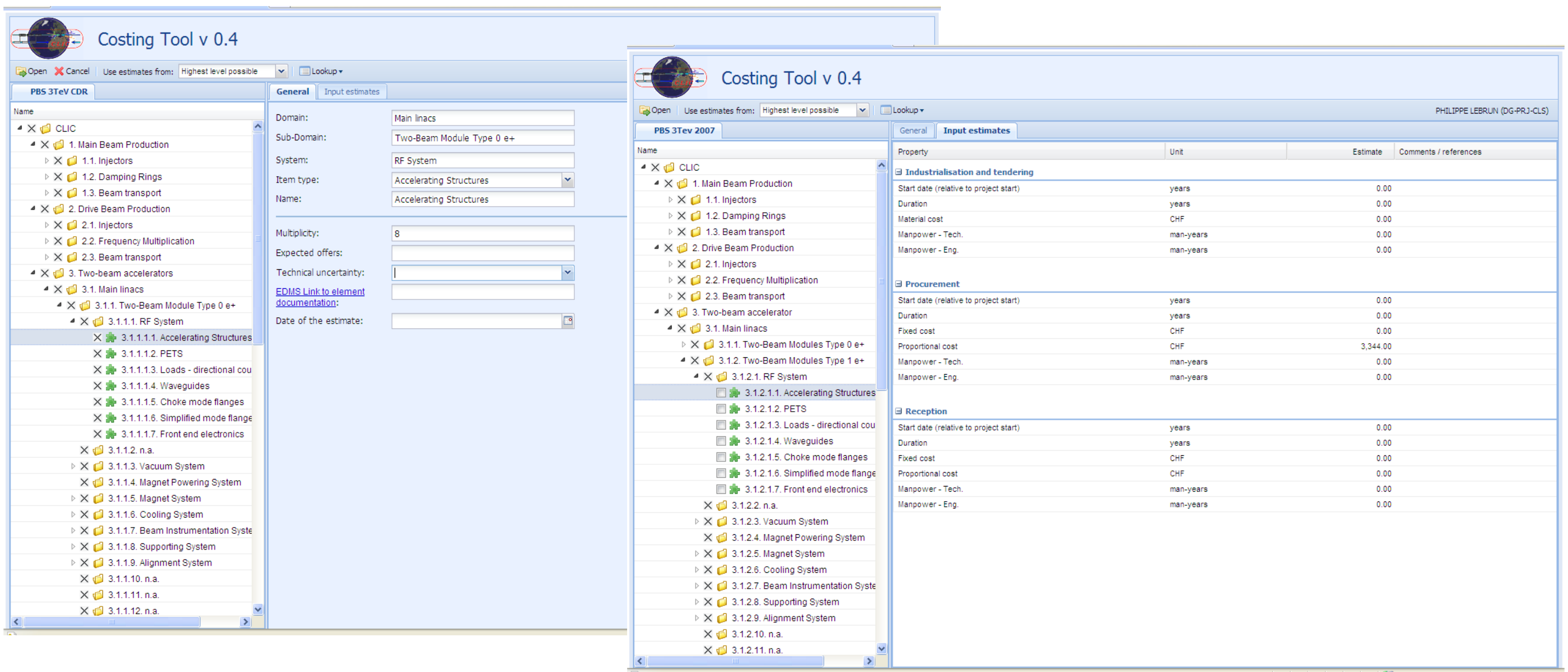
- Depending upon type of domain and estimation method, elementary value estimates entered at level of component, technical system or subcomponent

Value estimate methods

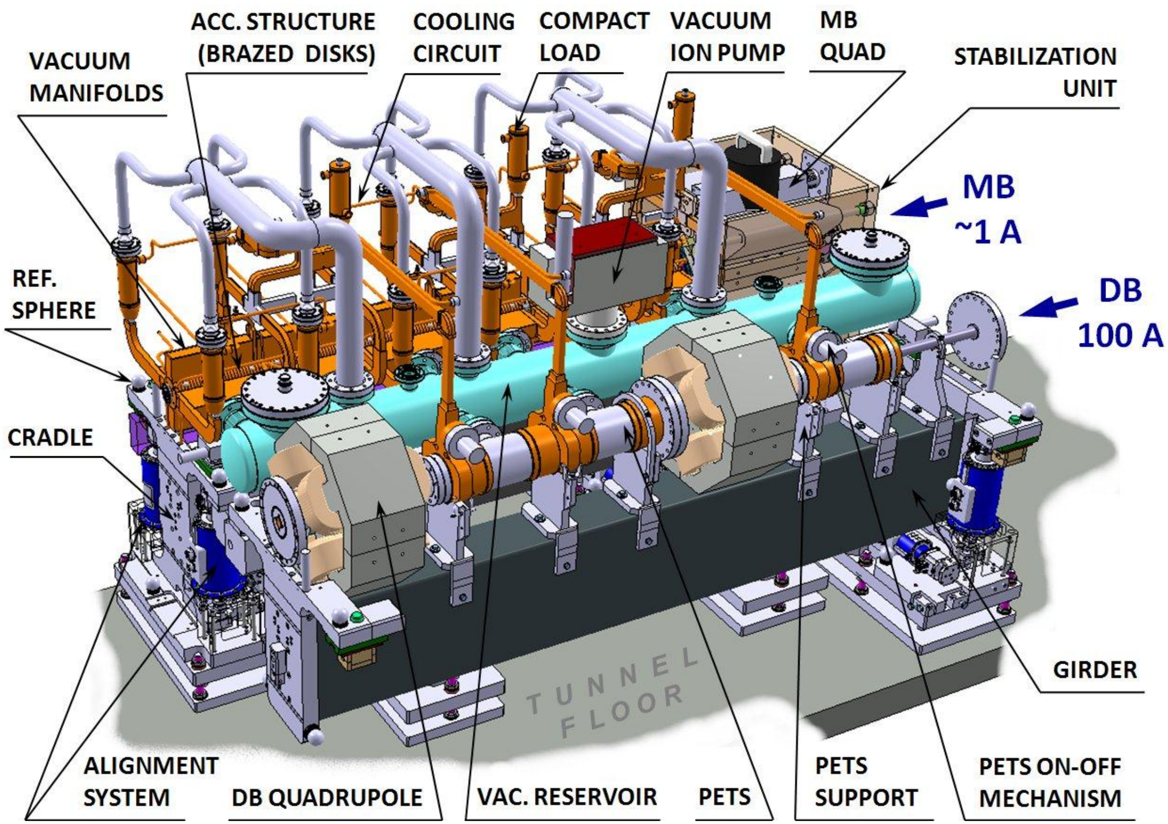
- Analytical
  - Based on project/work breakdown structure
  - Define production techniques
  - Estimate fixed costs
  - Establish unit costs & quantities (including production yield and rejection/reprocessing rates)
  - In case of large series, introduce learning curve (see later)
- Scaling
  - Establish scaling estimator(s) and scaling law(s), including conditions & range of application
    - Empirical
    - « First-principles » based
  - Define reference project(s) and fit data
- In most cases, hybrid between these methods

CLIC Study Costing Tool

- CLIC Study Costing Tool developed & maintained by CERN GS-AIS
- Operational, on-line from C&S WG web page (access protected)
- Includes features for currency conversion, price escalation and uncertainty
- Production of cross-tab reports exportable to EXCEL
- Full traceability of input data



CLIC two-beam modules
Complexity, number, integration



CLIC at 500 GeV (4’232 modules)
26’920 Accelerating Structures
13’460 PETS
~ 70’000 RF components

CLIC at 1.5 TeV (10’730 modules)
71’380 Accelerating Structures
35’690 PETS
~ 200’000 RF components

G. Riddone

Learning curves: from airplanes to accelerator components

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

- Unit cost c(n) of nth unit produced

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

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

- Cumulative cost of first nth units

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

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

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

⇒ *verified on LHC main magnets up to series of ~400 units/manufacturer*

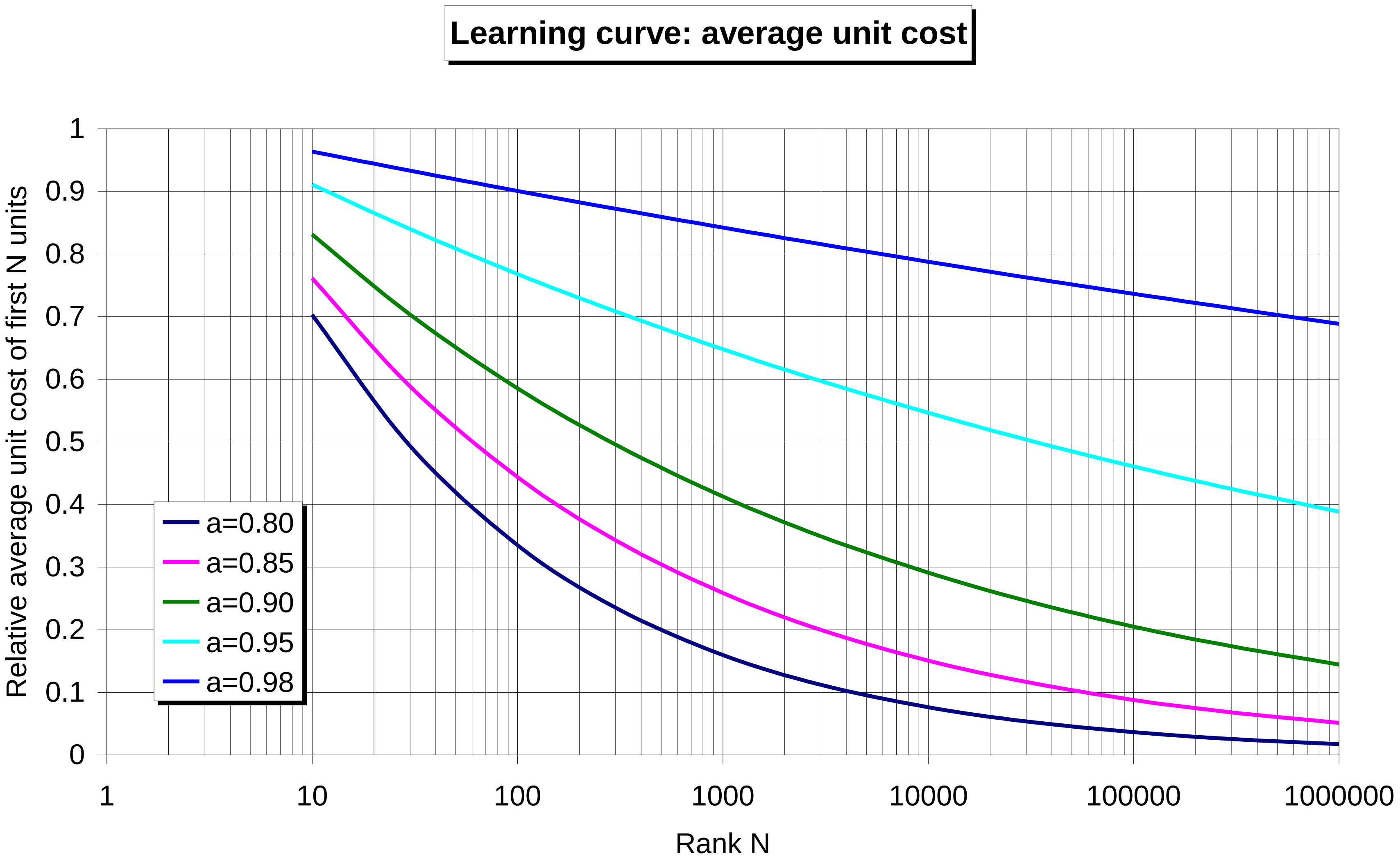
Learning coefficients

TABLE IV
LEARNING PERCENTAGE OF SELECTED REFERENCE INDUSTRIES

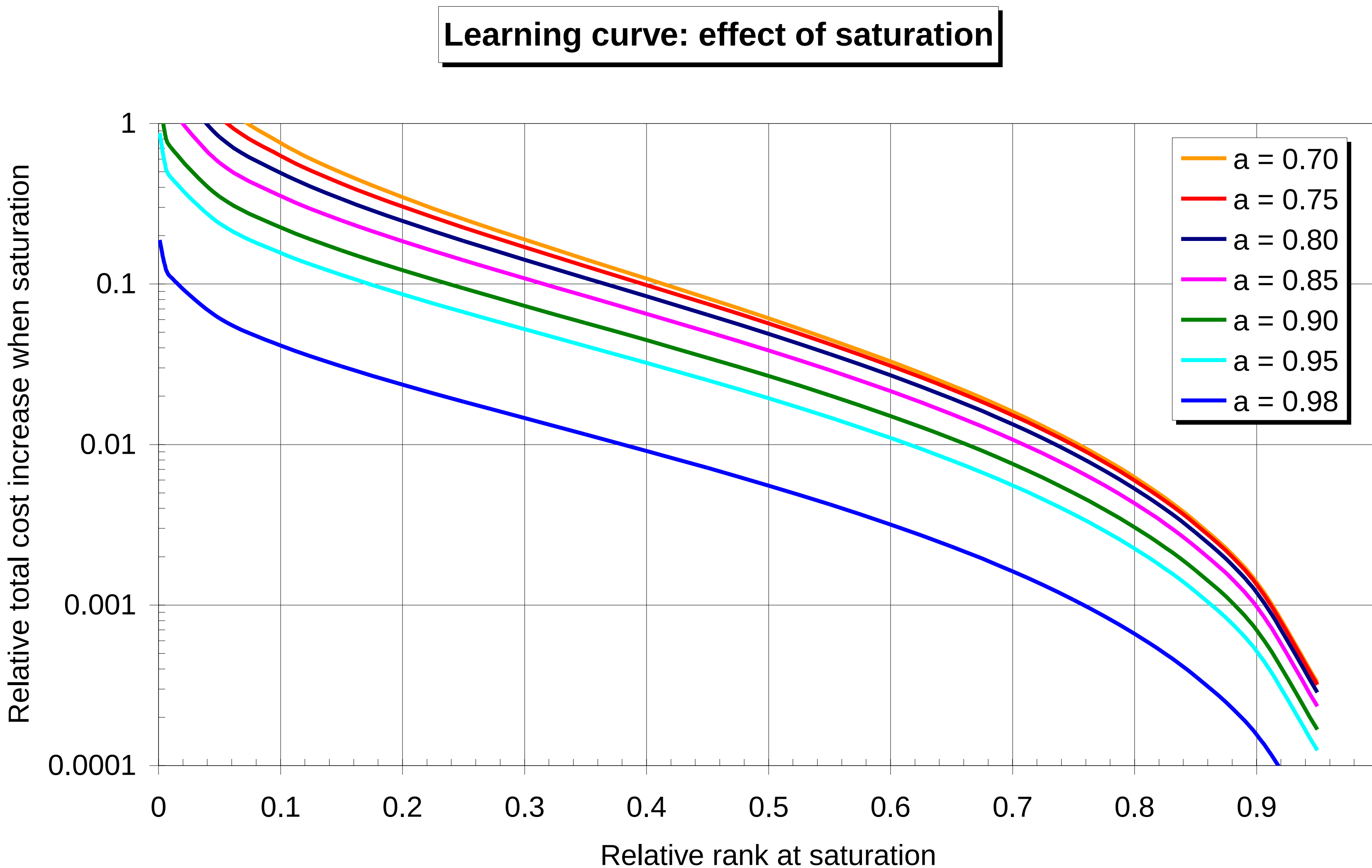
Industry	ρ
Complex machine tools for new models	75%-85%
Repetitive electrical operations	75%-85%
LHC magnets	80%-85%
Shipbuilding	80%-85%
Aerospace	85%
Purchased Parts	85%-88%
Repetitive welding operations	90%
Repetitive electronics manufacturing	90%-95%
Repetitive machining or punch-press operations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

P. Fessia

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



Saturation of learning process has little impact on total cost



Contents

- Scope of the CDR study
- Construction & operation schedules
- Value estimate methodology
- Uncertainty & risk
- Escalation & exchange rate fluctuations
- CDR value estimates
- Potential for cost reduction

Cost variance factors and how to handle them

Decreasing control of project responsible

- 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 (one-off supply)
- Commercial strategy of vendor
  - Market penetration
  - Competing productions
- Inflation and escalation
  - Raw materials
  - Industrial prices
- International procurement
  - Exchange rates
  - Taxes, custom duties

Technical definition

Engineering judgement of responsible

Contract adjudication

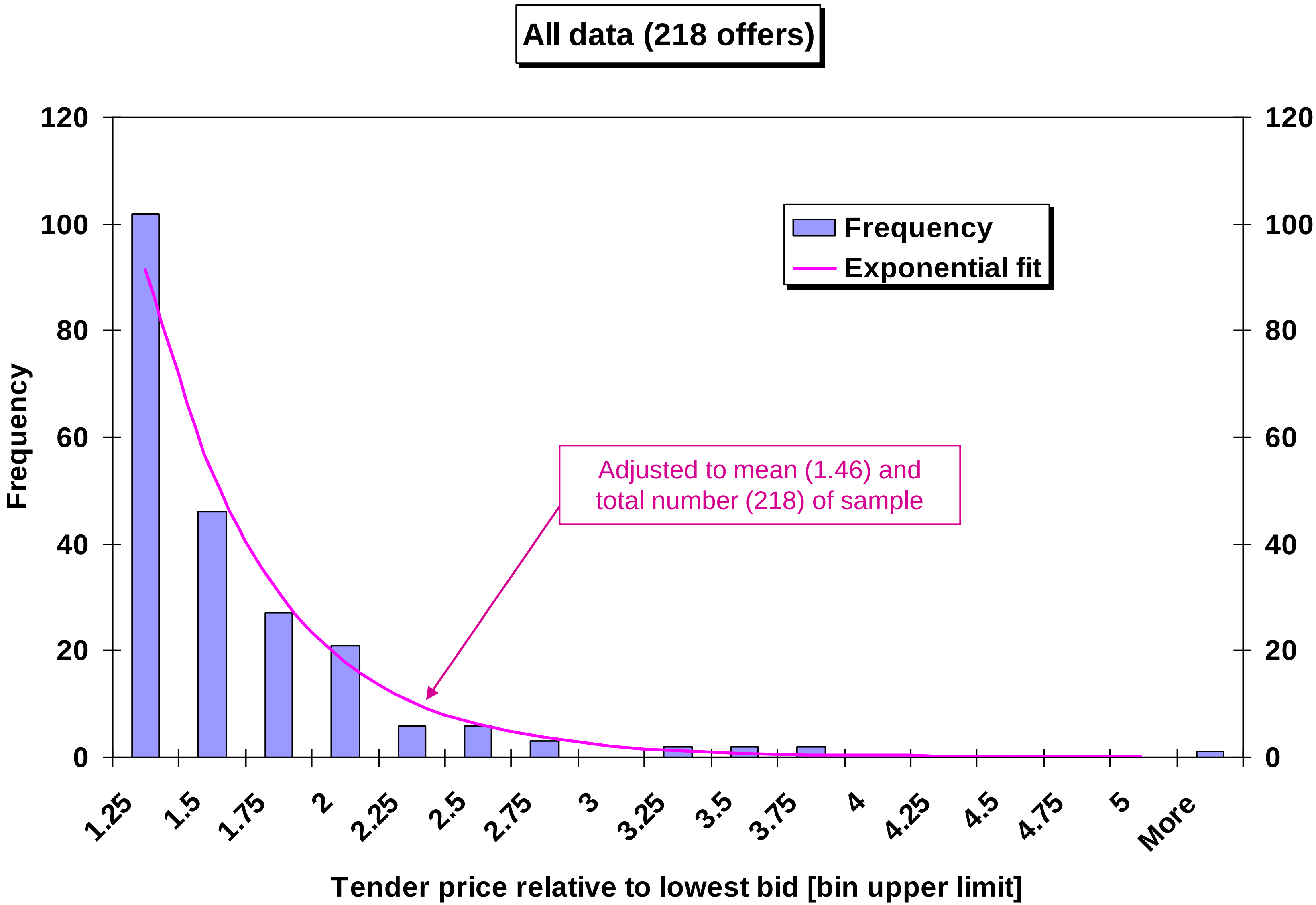
Procurement

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

Tracked and compensated

Outside project control

Observed tender prices for LHC accelerator components



Lowest-bidder from n valid offers

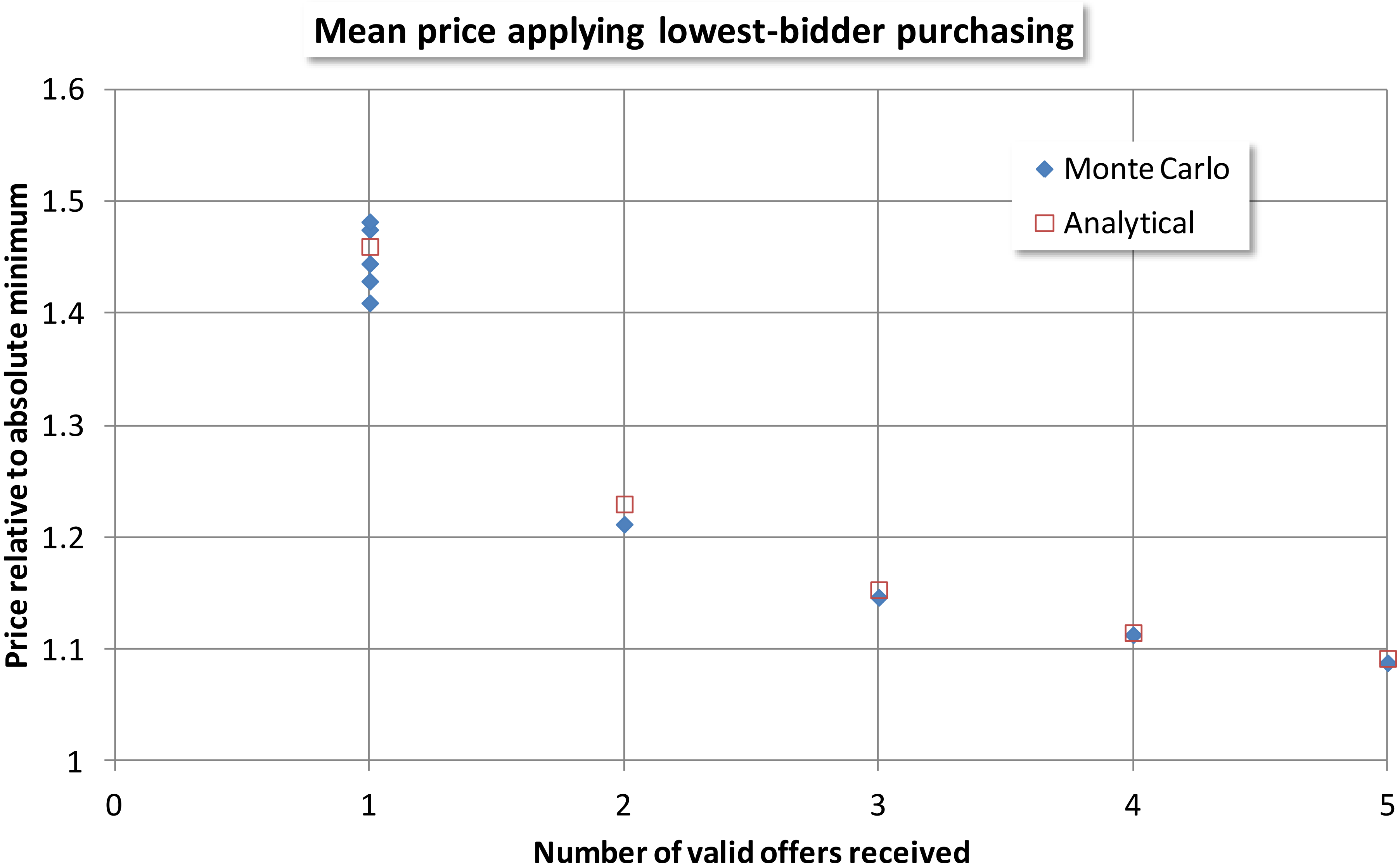
- Analytical solution
  - Consider two valid offers X1, X2 following same exponential distribution with **P**(Xi<x) = F(x) = 1 – exp[-a(x-b)]

    ⇒ 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 thus 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*
- Monte Carlo simulation
  - Produce 400 random drawings of sets of n values of X distributed according to F(x)
  - For each set, take Y = min(X1, X2,..Xn) and estimate mean and std dev of 400 realizations of Y
  - Monte Carlo simulation in accordance with analytical solution

Sampling from LHC tender price distribution to estimate lowest-bidder price vs number of offers



Method for CLIC value risk assessment
1. For each value element *k*

- Separate value risk factors in three classes, assumed independent
  - Technical design maturity & evolution of configuration
    - Represented by relative standard deviation $\sigma_{\text{technical}}(k)$
    - Rank in three levels yielding different values of $\sigma_{\text{technical}}(k)$
      - Known technology 0.1
      - Extrapolation from known technology 0.2
      - Requires R&D 0.3
  - Price uncertainty in industrial procurement
    - Represented by relative standard deviation $\sigma_{\text{purchase}}(k)$
    - Assume lowest-bidder purchasing rule
    - Estimate *n* number of valid offers to be received
    - Apply $\sigma_{\text{purchase}}(k) = 0.5/n$
  - Economical & financial context
    - Risk outside project value assessment
    - Deterministic, compensated *a posteriori* by adequate indexation
- Estimate risk on value c(*k*) of element *k*
  - $\Delta c_{\text{technical}}(k) = \sigma_{\text{technical}}(k) \times c(k)$
  - $\Delta c_{\text{purchase}}(k) = \sigma_{\text{purchase}}(k) \times c(k)$
  - $\Delta c_{\text{total}}(k)$ is the r.m.s. sum of $\Delta c_{\text{technical}}(k)$ and $\Delta c_{\text{purchase}}(k)$

Method for CLIC value risk assessment
2. For total project

- Value estimate of project $C = \Sigma\, c(k)$
- Uncertainties $\Delta C_{\text{technical}} = \Sigma\, \Delta c_{\text{technical}}(k)$

  $\Delta C_{\text{purchase}} = \Sigma\, \Delta c_{\text{purchase}}(k)$

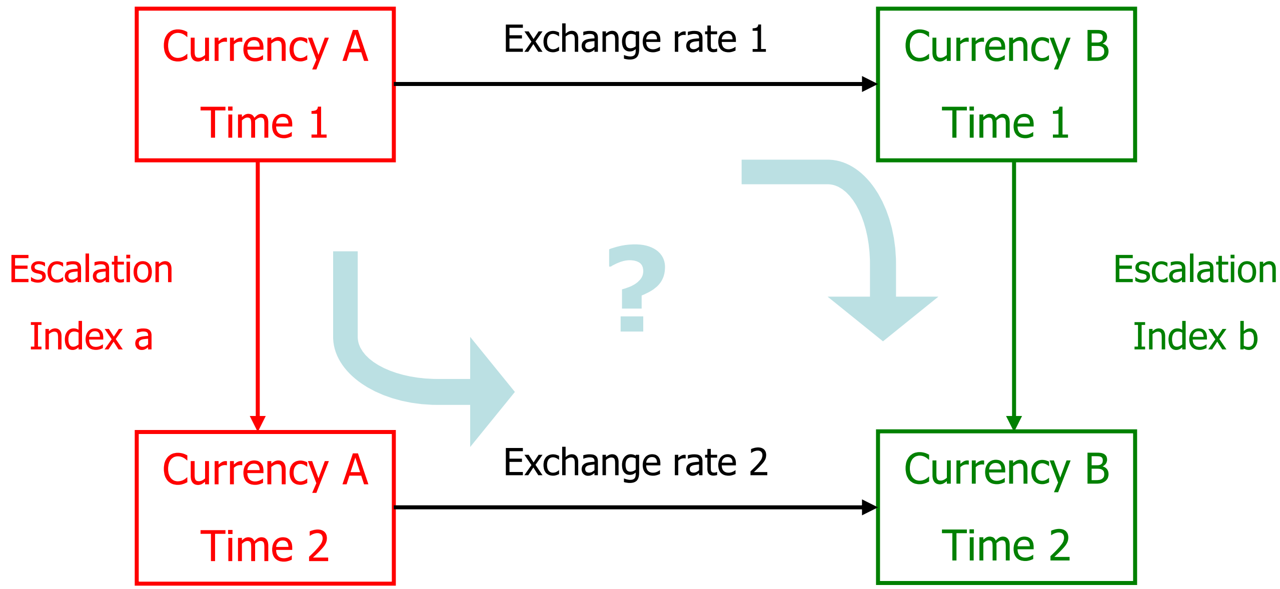
  $\Delta C_{\text{total}} = \Sigma\, \Delta c_{\text{total}}(k)$
- Estimate uncertainty band on project value estimate

$$[C - \Delta C_{\text{technical}};\ C + \Delta C_{\text{total}}]$$

Contents

- Scope of the CDR study
- Construction & operation schedules
- Value estimate methodology
- Uncertainty & risk
- Escalation & exchange rate fluctuations
- CDR value estimates
- Potential for cost reduction

Exchange rates and cost escalation



- Exchange rate fluctuations should ideally reflect evolution of purchasing power of currencies, but
  - Economic parities offset by financial effects
  - Variety of escalation indices in each currency
- Choose « reference currency » (CHF) and apply relevant escalation indices in reference country (Office Fédéral de la Statistique, Bern)

Why **not** use PPPs for comparing contract prices for global accelerator construction

- PPPs are used to compare prices for the **same goods/services** in different countries constituting **separate markets**
- They are therefore not good comparative indicators of the **value**, i.e. the lowest reasonable estimate of the price of goods and services procured from industry **on the world market**
- Example 1: **commodities**
  - World prices of commodities (e.g. oil or… niobium) are usually quoted in single currency, often USD $\Rightarrow$ relevant is the **exchange rate to the USD**
- Example 2: **specific supplies** such as accelerator components
  - Consider a producer from a **low-income region**: on this market, the equilibrium price for a given good/service will be lower than that in a high-income country, the ratio of these equilibrium prices is – by definition – the PPP for this good/service
  - When this producer enters the world market, e.g. to answer an invitation to tender from the Linear Collider Project, he will be tempted to **maximize his profit** by raising his price up to just below the world market equilibrium price, well above the equilibrium price in the low-income region which constitutes his usual market: the value of the supply will then be very different from the price in local currency converted by the PPP

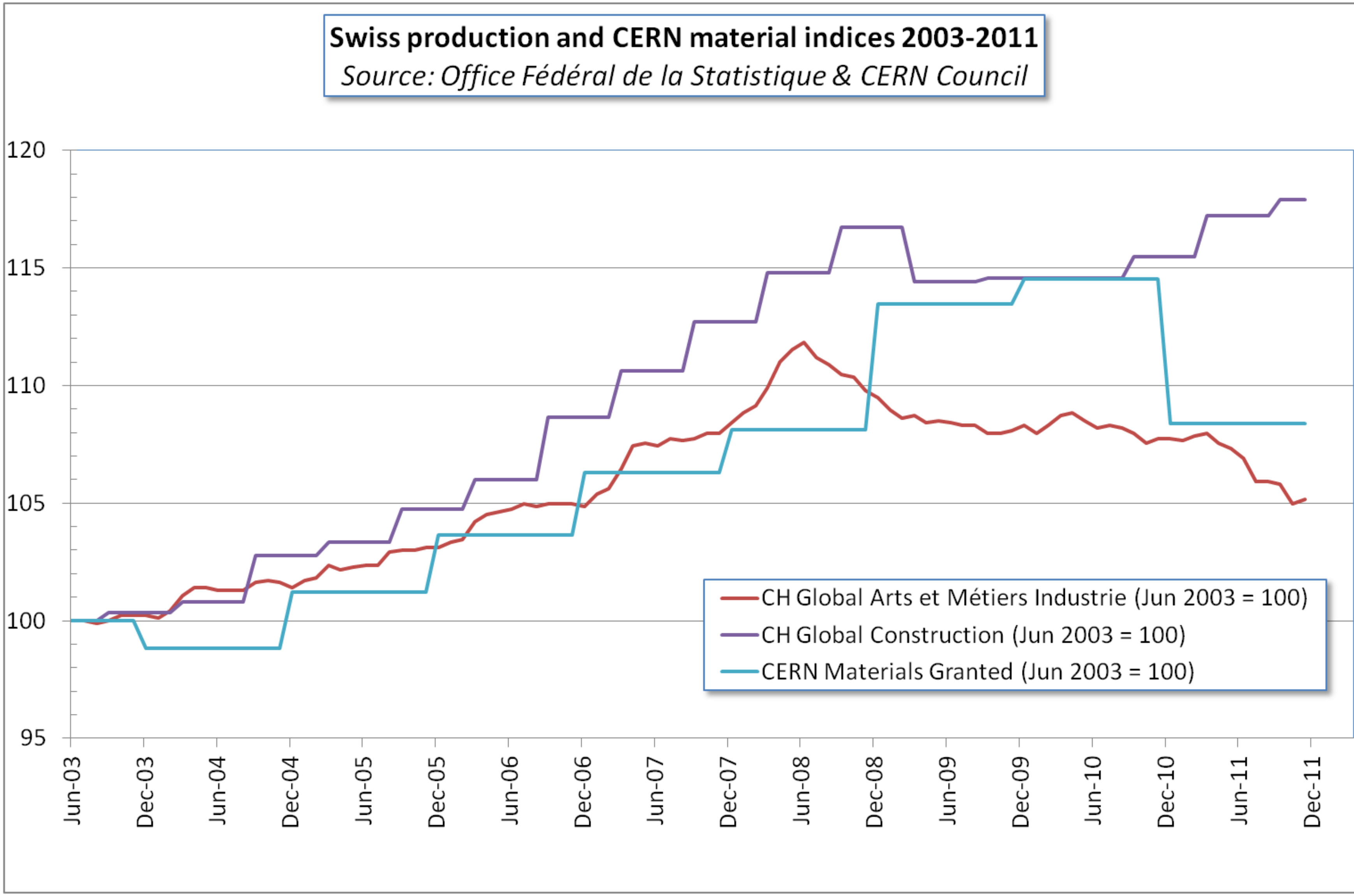
Eurostat-OECD recommendations on the use of PPPs

Recommended uses	• To make spatial volume comparisons of GDP (size of economies), GDP per head (economic welfare), GDP per hour worked (labour productivity); • To make spatial comparisons of comparative price levels; • To group countries by their volume index of GDP per head and/or their comparative price levels of GDP.
Uses with limitations	• To analyse changes over time in relative GDP per capita and relative prices; • To analyse price convergence; • To make spatial comparisons of cost of living; • To use PPPs calculated for GDP and its component expenditures as deflators for other values as, for example, household income.
Not recommended uses	• As precise measures to establish strict rankings of countries; • As a means of constructing national growth rates; • As measures to generate output and productivity comparisons by industry; • As measures to undertake price level comparisons at low levels of aggregation; • As indicators of the undervaluation or overvaluation of currencies; • As equilibrium exchange rates.

Method for indexation of CLIC value estimate

- Economical & financial effects are compensated *a posteriori*
  - Choice of CHF as reference currency
  - Applications of compound indices in CHF
    from *Office Fédéral de la Statistique (CH)*
    - *Arts et métiers – Industrie* for technical components
    - *Construction* for civil engineering
- This compensation is
  - assumed to be granted by the funding agencies on a yearly basis on the yet unspent part of the budget
  - therefore outside the value risk of the project

Swiss vs CERN indices



Contents

Review of CLIC CDR value estimates

- The study of the CLIC CDR value estimates developed over 2009-2011
- Scope, methodology and results were presented to an international review panel in February 2012
- The comments and recommendations of the review panel were taken into consideration to modify the February 2012 value estimates and produce the revised numbers presented hereafter, in particular by
  - inclusion of staging scenario B
  - basing unit costs on results of industrial studies, whenever possible
  - limiting learning curve horizon to 500 GeV quantities
  - estimating separately and rms summing uncertainties pertaining to technical and procurement risks, deemed statistically independent

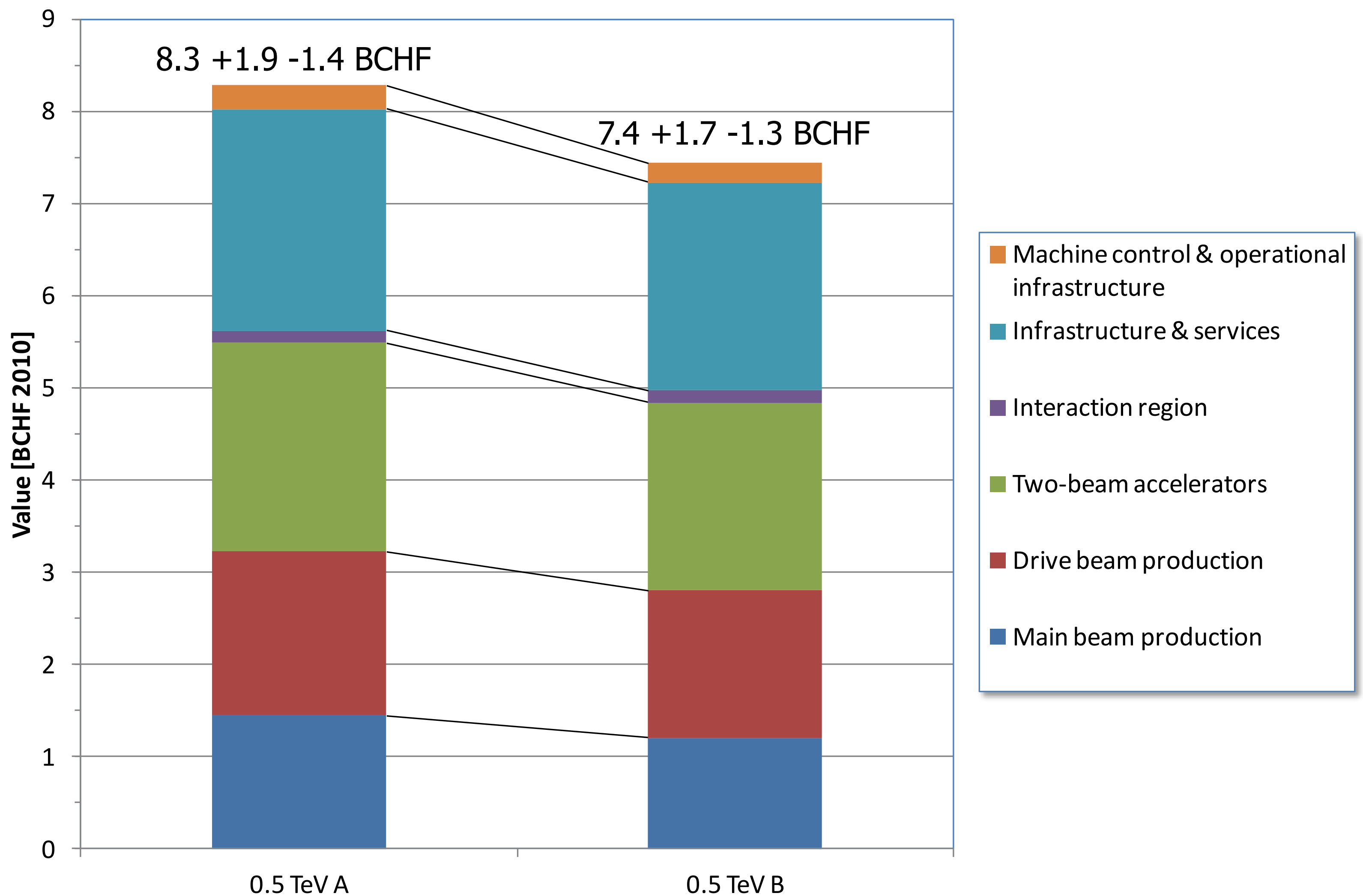
Value estimate CLIC 500 GeV A
[CHF Dec 2010]

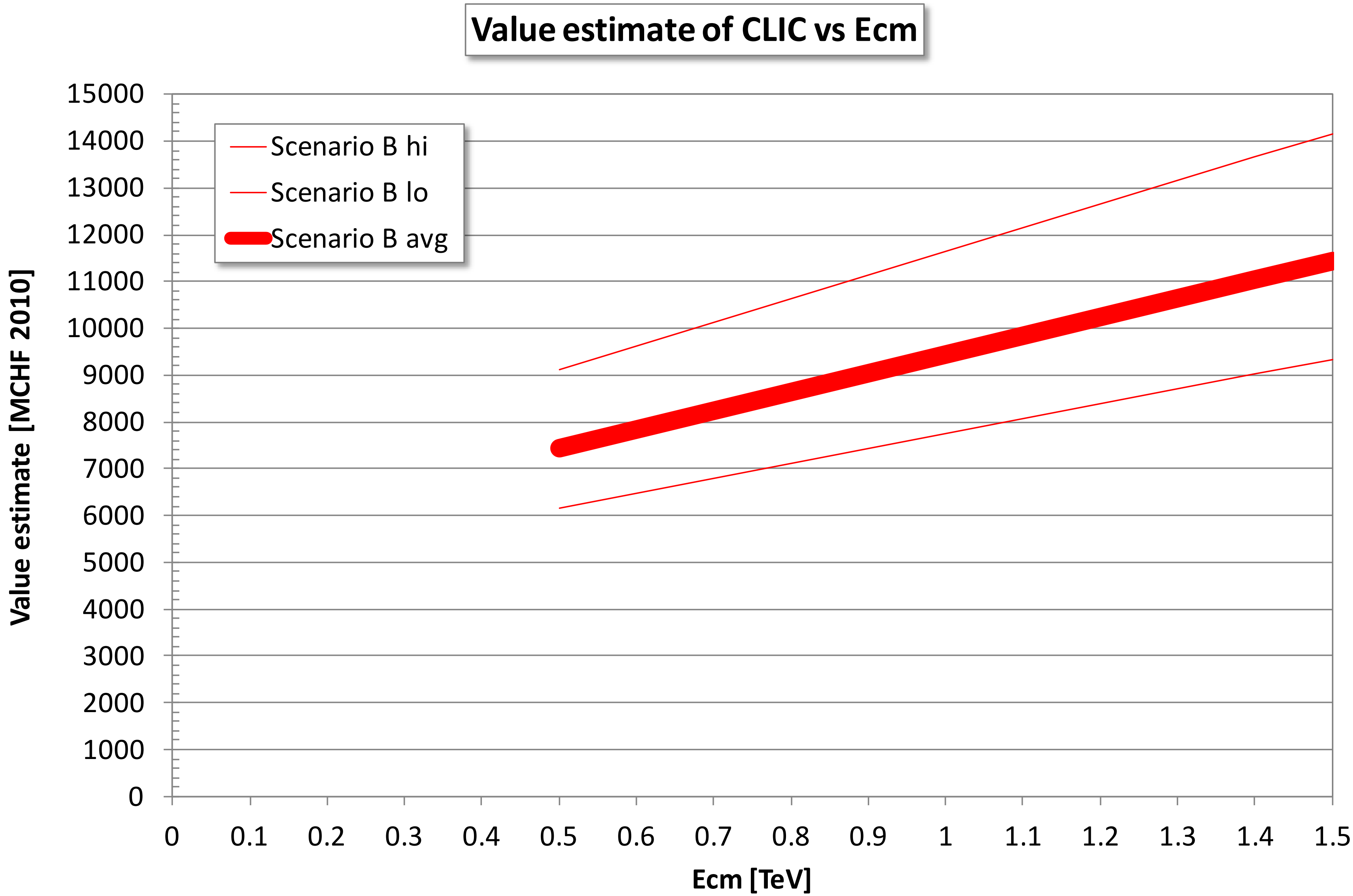
Main Beam Production	Injectors	448565000
	Damping Rings	383072232
	Beam Transport	611755698
	Main Beam Production Total	1443392930
Drive Beam Production	Injectors	1383940000
	Frequency Multiplication	134976300
	Beam Transport	260458000
	Drive Beam Production Total	1779374300
Two-beam accelerators	Two-Beam Modules	2214557035
	Post Decelerators	45656000
	Two-beam accelerators Total	2260213035
Interaction Region	Beam Delivery Systems	61740000
	Experimental Area	23260000
	Post-collision Line	47128000
	Interaction Region Total	132128000
Infrastructure and Services	Civil Engineering	1432382278
	Electricity	326370000
	Survey and Alignment	30500000
	Fluids	494000000
	Transport / installation	100000000
	Safety	20000000
	Infrastructure and Services Total	2403252278
Machine Control and Operational Infrastructure	Machine Control Infrastructure	226000000
	Machine Protection	3470000
	Access Safety & Control System	19820000
	Technical Alarm System	13000000
	Machine Control and Operational Infrastructure Total	262290000
	Grand Total	8280650543

Value estimate CLIC 500 GeV B
[CHF Dec 2010]

Main Beam Production	Injectors	338902500
	Damping Rings	408040232
	Beam Transport	456005698
	Main Beam Production Total	1202948430
Drive Beam Production	Injectors	1247820000
	Frequency Multiplication	134976300
	Beam Transport	216689400
	Drive Beam Production Total	1599485700
Two-beam accelerators	Two-Beam Modules	2001960638
	Post Decelerators	36524800
	Two-beam accelerators Total	2038485438
Interaction Region	Beam Delivery Systems	61740000
	Experimental Area	23260000
	Post-collision Line	47128000
	Interaction Region Total	132128000
Infrastructure and Services	Civil Engineering	1382382278
	Electricity	282000000
	Survey and Alignment	30500000
	Fluids	445000000
	Transport / installation	90000000
	Safety	20000000
	Infrastructure and Services Total	2249882278
Machine Control and Operational Infrastructure	Machine Control Infrastructure	183000000
	Machine Protection	3154000
	Access Safety & Control System	17838000
	Technical Alarm System	11700000
	Machine Control and Operational Infrastructure Total	215692000
	Grand Total	7438621846

Value by PBS/WBS domain



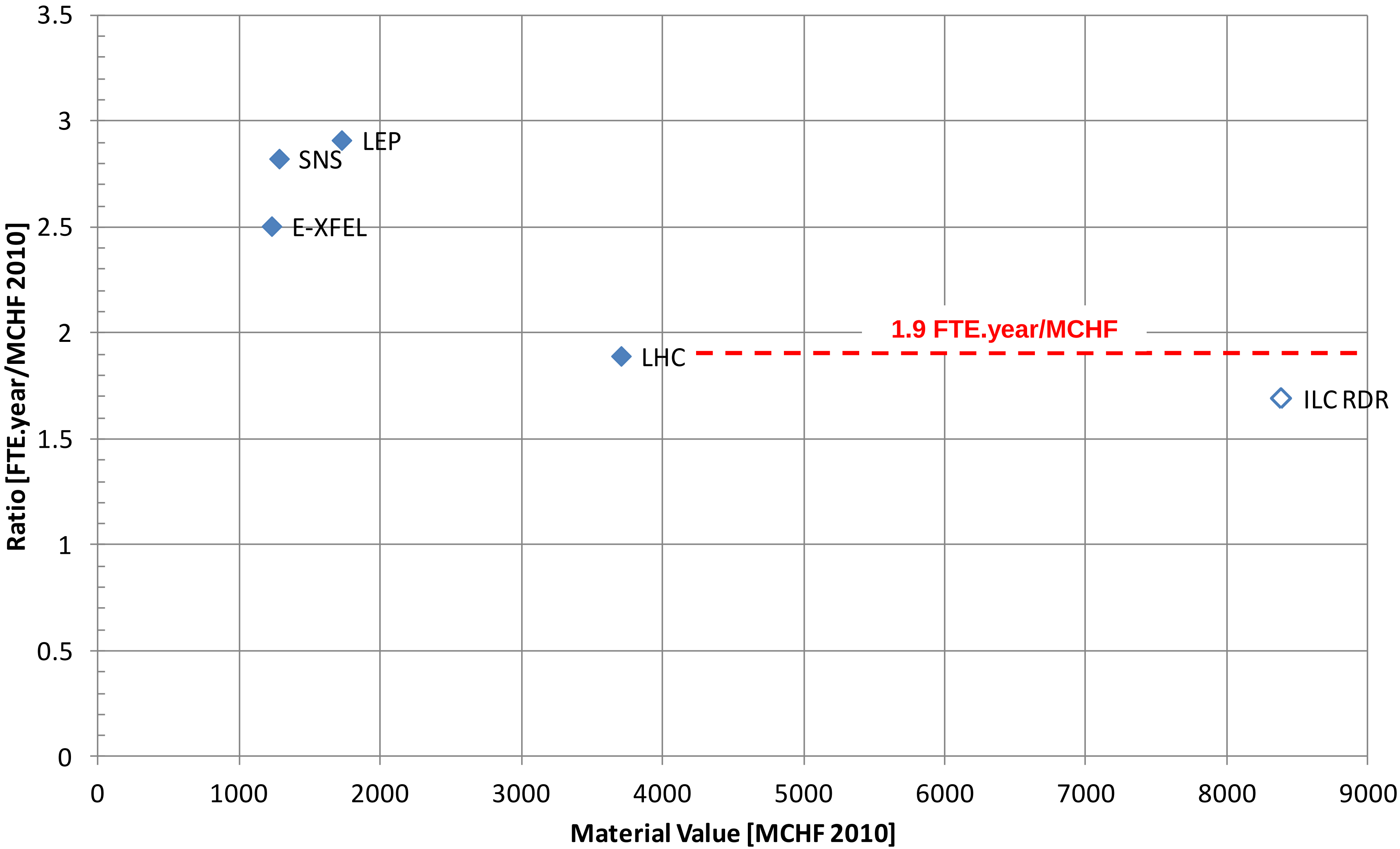


Value estimate of CLIC vs Ecm
Scenario B hi
Scenario B lo
Scenario B avg
Value estimate [MCHF 2010]
Ecm [TeV]
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5

A first look at personnel resources

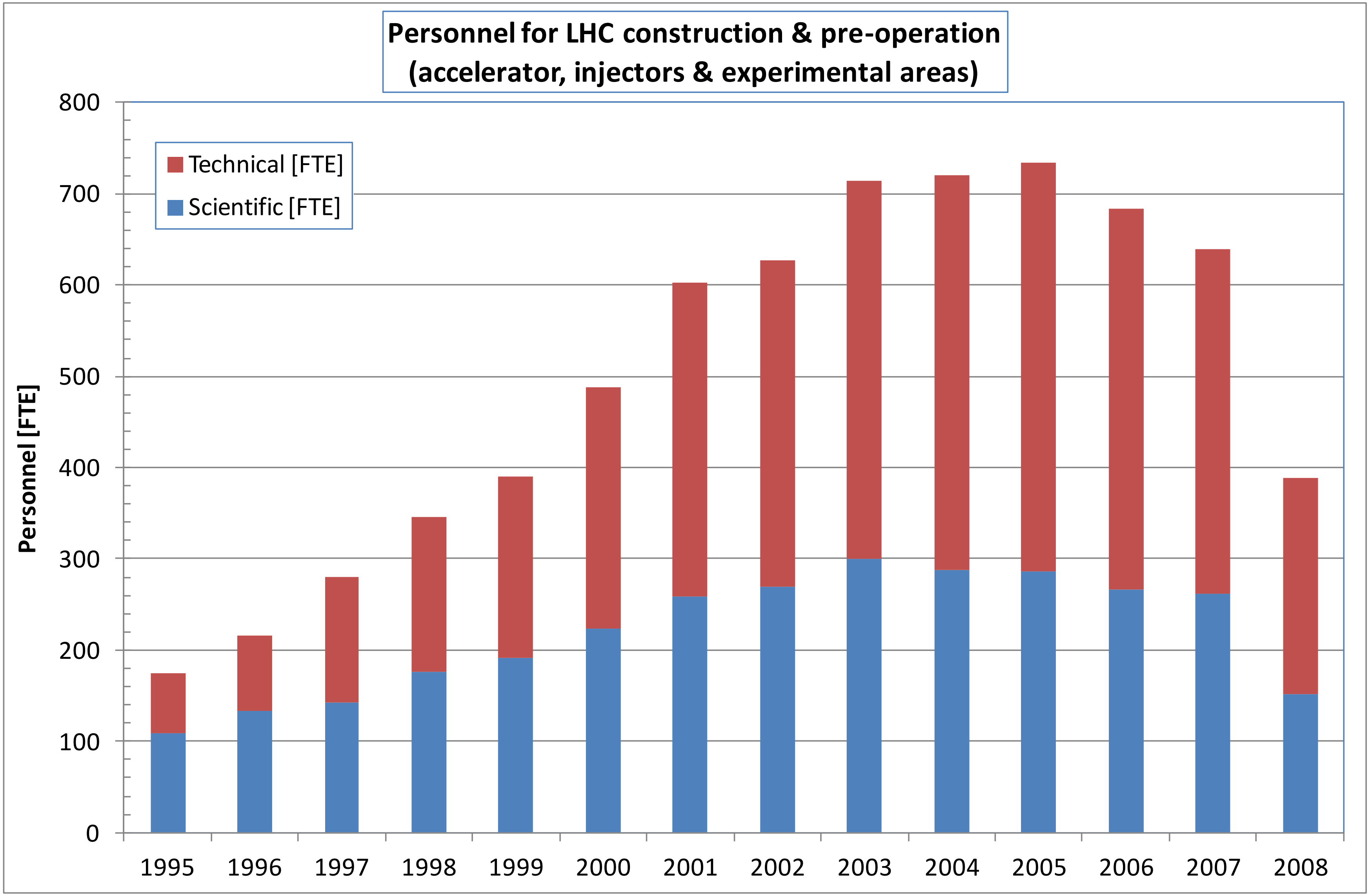
- Personnel [FTE.years]
  - Defined as « Explicit Labor » in ILC RDR
  - Staff+Fellows+Associates in home laboratory & collaborating institutions
  - Categories: « Scientific » & « Technical »
  - Industrial labor charged to Material Value estimate
- Analytical estimate
  - Provide technical system responsibles with WP description, project schedule and boundary conditions, and collect estimates from them
  - Not applied here
- Global scaling from previous projects
  - Ratio of FTE.year to Material Value for several large accelerator projects appears slowly decreasing with increasing Material Value > few BCHF
  - Assume Ratio remains about constant from LHC upwards
  - Analyse LHC data and scale to CLIC

Personnel-to-Material Ratio for Large Accelerator Projects



LHC personnel expenditure

Source: periodic reports to CERN Finance Committee



Scaling personnel from LHC to CLIC

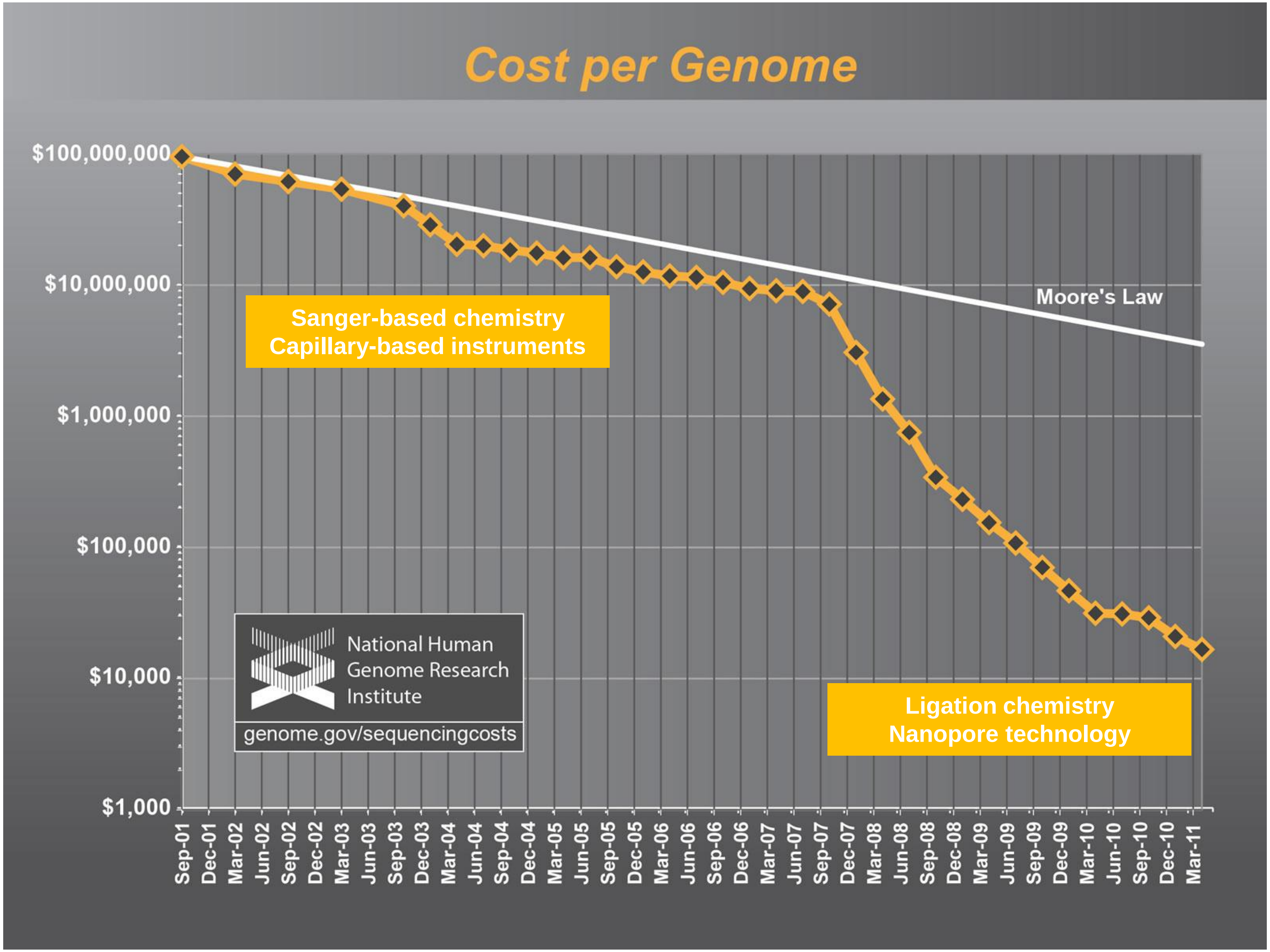
- LHC accelerator, injectors and technical areas
  - Included: construction, installation and pre-operation
  - Not included: R&D, commissioning with beam, operation
  - P ~ 7000 FTE.years => P/M ~ 1.9 FTE.year/MCHF 2010
  - About 40% scientific, 60% technical
- Scaling to CLIC @ 500 GeV
  - Assume P/M ratio is the same as for LHC construction
    - Scenario A 15700 FTE.years
    - Scenario B 14100 FTE.years

Contents

- Scope of the CDR study
- Construction & operation schedules
- Value estimate methodology
- Uncertainty & risk
- Escalation & exchange rate fluctuations
- CDR value estimates
- Potential for cost reduction

Breakthrough vs gradual progress

The case of human genome sequencing



Cost mitigation alternatives

- CDR cost drivers
  - A number of cost drivers have already been identified in the CDR phase, with cost mitigation alternatives . Some of these could already be studied and validated, and are implemented in the CDR and its value estimate. Others will be studied in the post-CDR phase
  - The maximum savings potential identified through this process is ~ 12% of the total value (500 GeV)
- Revision of basic parameters
  - The CLIC CDR study describes a machine optimized for the ultimate CM energy of 3 TeV, with a first stage at 500 GeV CM and a second one at 1.5 TeV CM. As a consequence, a number of technical choices for the lower energy stages are dictated by the optimization at ultimate energy, thus strongly impacting the cost of the lower energy stages.
  - Revising the CM energy chosen for CLIC technical optimization, while preserving the potential to reach ultimate energy, is expected to provide the main lever for cost reduction. This process has started

Conclusions

- Value estimates for first stage at 500 GeV CM (alternative scenarios A and B) of CLIC with ultimate 3 TeV CM
  - Based on PBS/WBS
  - Established by scientists & engineers having technical responsibility of PBS/WBS domains/subdomains, from unit data produced by technology groups
  - Reviewed by international panel of experts in February 2012
  - Uncertainty stemming from technical and commercial unknowns estimated according to normalized procedure to [-17 %; +23 %]
- Variation with CM energy
  - Indicates large zero offset for MB and DB production complexes
  - Scaled value for CLIC at 1.5 TeV CM gives access to incremental cost above 500 GeV of ~4 MCHF/GeV CM
- Personnel (« explicit labor ») estimated globally by scaling wrt LHC
  - First approach to be refined by analytical estimate
- Cost drivers and potential for cost reduction identified
  - Incremental cost mitigation actions identified on components/systems, totalling at maximum ~ 12%
  - Major effect expected from re-optimization of basic parameters for E_{CM} << 3 TeV