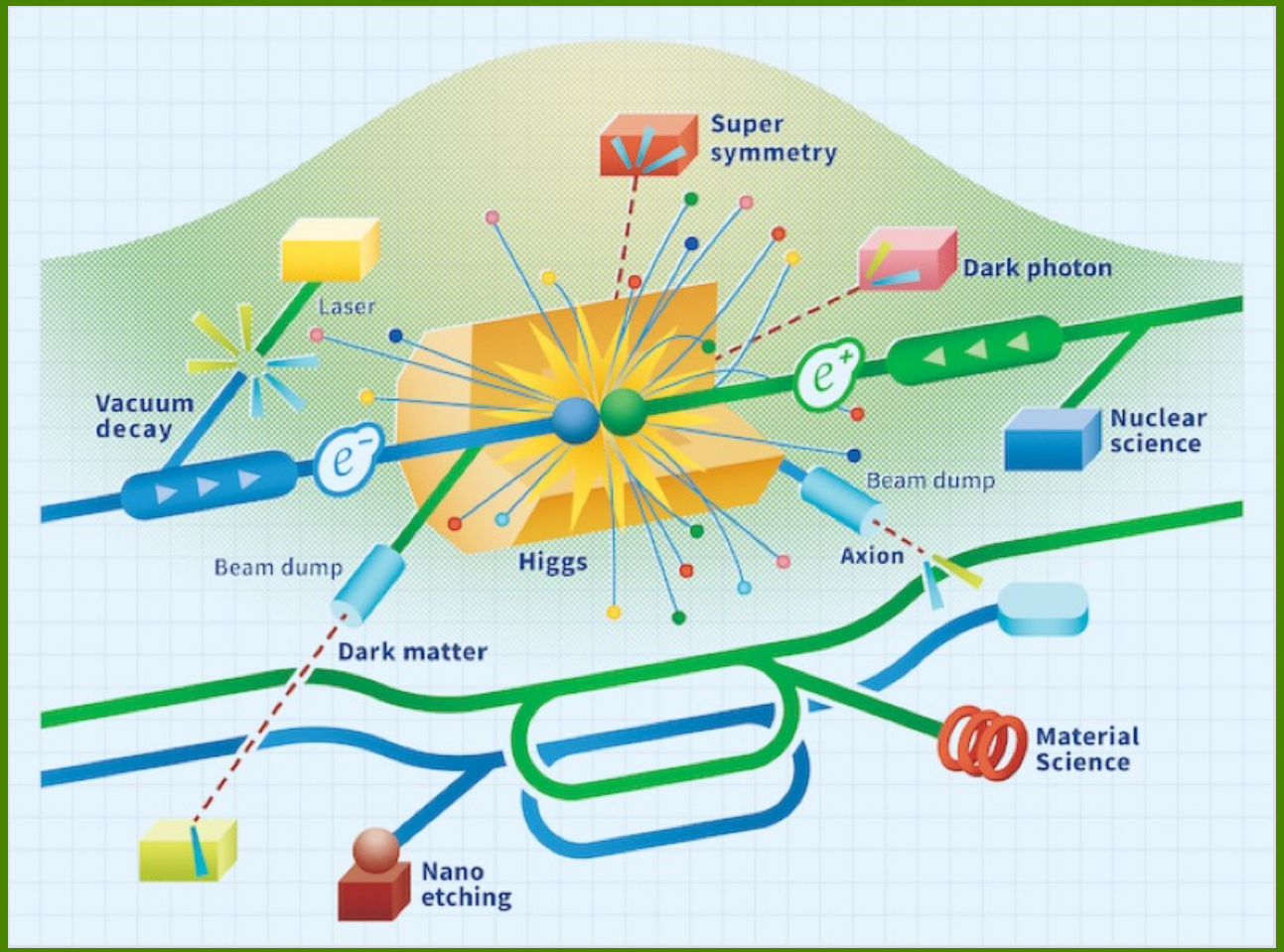


(Towards a) Costing of an LCF@CERN

Benno List, DESY

LCVision Community Event
10.1.2025

Linear Collider Vision

CERN based facility and the ILC

- LCF at CERN is not “ILC at CERN”, important technical differences:
  - Different site
    - different tunnel and building costs
      -> **addressed by separate study, in progress**
    - Different designs for electrical distribution, cooling water services, heating and ventilation
    - CERN is not a green field site –potential cost savings, to be evaluated
  - Different baseline
    - Build full 33km tunnel (for 550 GeV) from start?
    - Second interaction region, crossing angle
    - Different energy and luminosity stages
    - Laser straight
  - Different time line
    -> opportunities to be more ambitious in performance goals for components, e.g.
    - Cavity gradient (31.5 -> 35MV/m) and Q_0 (1E10 -> 2E10)
    - Klystron efficiency (65% -> 80%)
  - Positron source
  - Many differences To be addressed by a future study

- Organisational differences:
  - ILC is an international in-kind contribution project, with a very large fraction of total value provided in kind, procured by collaborators
  - CERN based project would be centrally organised, with most of procurement done by CERN on a global market, from CERN funds
    - Different accounting
    - Benefits from strong Swiss Franc
    - Opportunities for cost optimisation: buy where it is least expensive
  - -> different procurement model has important consequences for the way component costs from international sources are translated into a common currency, i.e. ILCU vs CHF
  - **There is NOT a single, simple conversion factor between ILCU and CHF!**

Strategy for the Cost Estimate of an LCF @ CERN

- **Basis: ILC cost estimate, 2024 update, commissioned by the IDT for ILC Japan**
  -> cf presentation by A. Yamamoto
- For **civil construction facilities** (tunnels, caverns, shafts, buildings): dedicated cost estimate for CERN
  -> cf presentation by J. Osborne
- For civil services (water, power, heating&ventilation):
  use European TDR estimate or translate Japanese estimate
  -> work in progress
- For accelerator: use updated 2024 ILC cost estimate data,
  translated from original quotes into Swiss Francs

Previous Cost Estimates for the ILC

- Cost estimates for ILC in 2012 US$ (ILC Currency Unit ILCU), for the Japanese site:
  - TDR: **500GeV, 31.5km tunnel: 7.98 BILCU** + 13.5 kFTE-y for Japanese site, operation 390 MILCU/y + 850 FTE
  - Higgs factory: **250GeV, 20.5km tunnel**: **5.26 BILCU** + 10.1 kFTE-y, operation 316 MILCU + 638 FTE
  - + 2 detectors: 0.71 BILCU + 2.1 kFTE-y
  - Costs include accelerator and civil construction, exclude site activation (roads, power lines) and land acquisition
- TDR had also site-dependent costs; European (CERN based) study was 426MILCU less expensive than Japanese design

APPENDIX A: ILC250 PROJECT COSTS

	TDR: ILC500 [B ILCU] (Estimated by GDE)	ILC250 [B ILCU] (Estimated by LCC)	Conversion to: [B JPY] (Reported to MEXT/SCJ)
Accelerator Construction: sum	**n/a**	**n/a**	**635.0 ~ 702.8**
Value: sub-sum	7.98	4.78 ~ 5.26	515.2 ~ 583.0
Tunnel & building	1.46	1.01	111.0 ~ 129.0
Accelerator & utility	6.52	3.77 ~ 4.24	404.2 ~ 454.0
Labor: Human Resource	22.9 M person-hours (13.5 K person-years)	17.2 M person-hours (10.1 K person-years)	119.8
Detector Construction: sum	**n/a**	**n/a**	**100.5**
Value: Detectors (SiD+ILD)	0.315+0.392	0.315+0.392	76.6
Labor: Human Resource (SiD + ILD)	748+1,400 person-years	748+1,400 person-years	23.9
Operation/year (Acc.) : sum	**n/a**	**n/a**	**36.6 ~ 39.2**
Value: Utilities/Maintenance	0.390	0.290 ~ 0.316	29.0 ~ 31.6
Labor: Human Resource	850 FTE	638 FTE	7.6
Others (Acc. Preparation)	**n/a**	**n/a**	**23.3**
Uncertainty	**25%**	**25%**	**25%**
Contingency	**10%**	**10%**	**10%**
Decommission	**n/a**	**n/a**	**Equiv. to 2-year op. cost**

ILC 250 cost estimate

http://www.mext.go.jp/component/b_menu/shingi/toushin/__icsFiles/afieldfile/2018/09/20/1409220_2_1.pdf

FIG. 7. Costs of the ILC250 project in ILCU as evaluated by the Linear Collider Collaboration (LCC), converted to JPY and re-evaluated by KEK, and summarised in the MEXT ILC Advisory Panel report, in July, 2018.

Region	Site-Specific	Shared	Total
Asia	1,756	6,226	7,982
Americas	1,413	6,310	7,723
Europe	1,330	6,304	7,634
Average	1,499	6,281	7,780

TDR Vol 3.II Tab 15.12

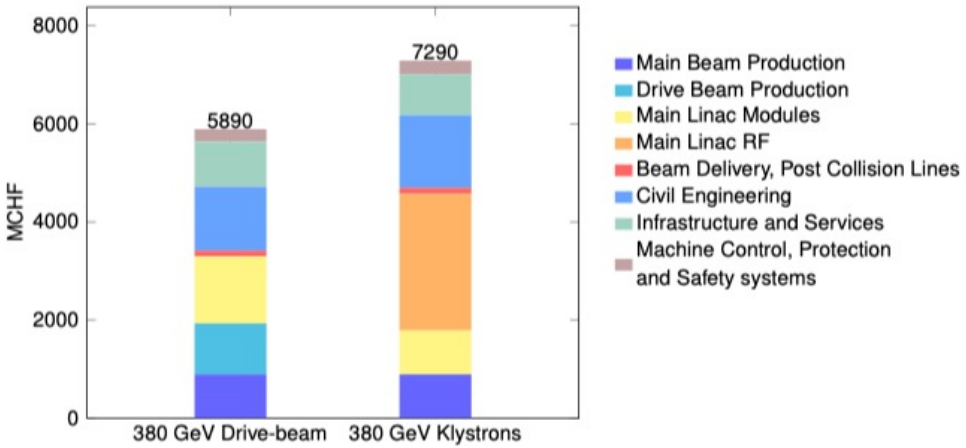
CLIC Costs

Machine has been re-costed bottom-up in 2017-18 (LINK)

- Methods and costings validated at review on 7 November 2018 – similar to LHC, ILC, CLIC CDR
- Technical uncertainty and commercial uncertainty estimated

- From 380 GeV to 1.5 TeV, add 5.1 BCHF (drive-beam RF upgrade and lengthening of ML)
- From 1.5 TeV to 3 TeV, add 7.3 BCHF (second drive-beam complex and lengthening of ML)
- Labour estimate: ~11500 FTE for the 380 GeV construction

- Updated cost in preparation



Domain	Sub-Domain	Cost [MCHF] Drive-Beam	Klystron
Main Beam Production	Injectors	175	175
	Damping Rings	309	309
	Beam Transport	409	409
Drive Beam Production	Injectors	584	—
	Frequency Multiplication	379	—
	Beam Transport	76	—
Main Linac Modules	Main Linac Modules	1329	895
	Post decelerators	37	—
Main Linac RF	Main Linac Xband RF	—	2788
Beam Delivery and Post Collision Lines	Beam Delivery Systems	52	52
	Final focus, Exp. Area	22	22
	Post-collision lines/dumps	47	47
Civil Engineering	Civil Engineering	1300	1479
Infrastructure and Services	Electrical distribution	243	243
	Survey and Alignment	194	147
	Cooling and ventilation	443	410
	Transport / installation	38	36
Machine Control, Protection and Safety systems	Safety system	72	114
	Machine Control Infrastructure	146	131
	Machine Protection	14	8
	Access Safety & Control System	23	23
Total (rounded)		**5890**	**7290**

CLIC 380 GeV Drive-Beam based: 5890^{+1470}_{-1270} MCHF;

CLIC 380 GeV Klystron based: 7290^{+1800}_{-1540} MCHF.

The ILC TDR Cost Estimate and the 2024 Update

- TDR cost estimate was a bottom-up cost estimate, down to component level
- WBS with 2000 lines
- Conventional accelerator systems (vacuum system, magnets ar power supplies, instrumentation, control system) were estimated by experts, based on a full lattice and counts of individual components
- Superconducting RF components (cavities, cryo modules, klystrons, RF distribution, cryogenics) were costed based on actual procurement results and industrial studies for mass production
- Cost uncertainty was evaluated for each line item according to reliability of basis of estimate and technical risk
- Cost estimate was reviewed in 2013 by international committee (chair: N. Holtkamp)
- Updated cost estimate was reviewed Dec 2024 by international committee (chair: L. Rivkin)

Figure 15.4
Breakdown of the ILC TDR Value estimate, by cost basis type

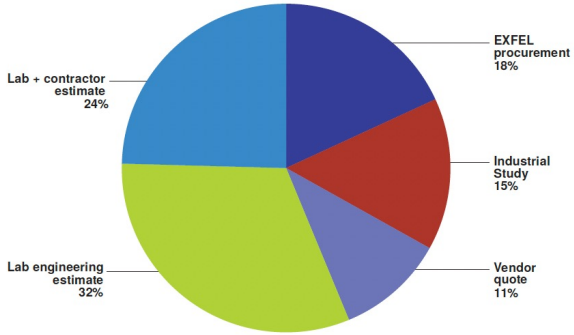
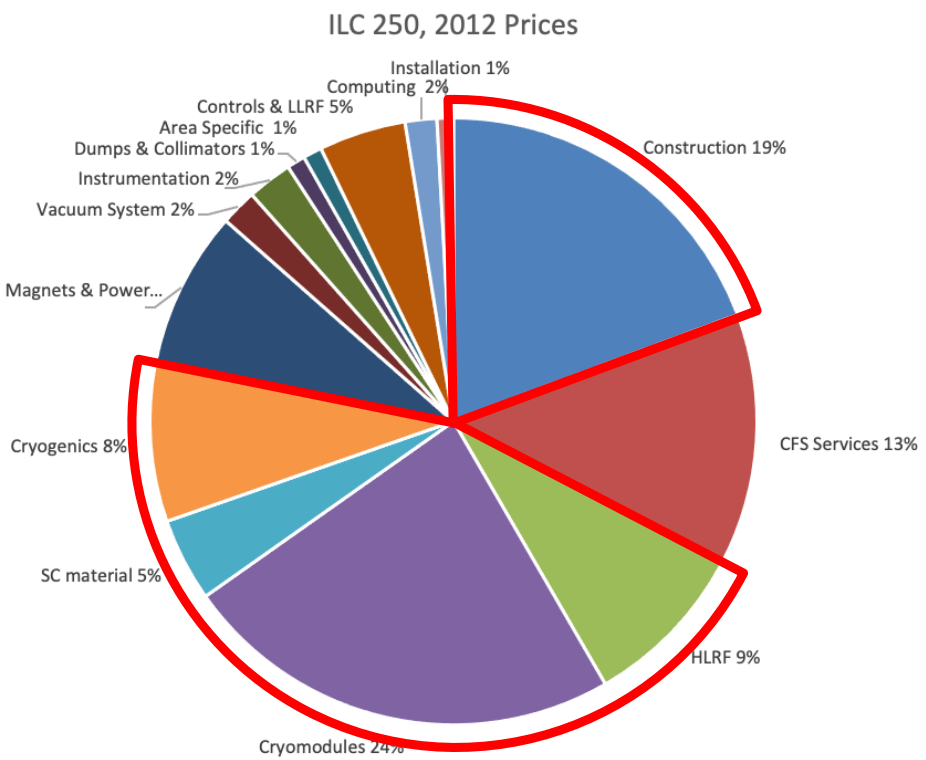


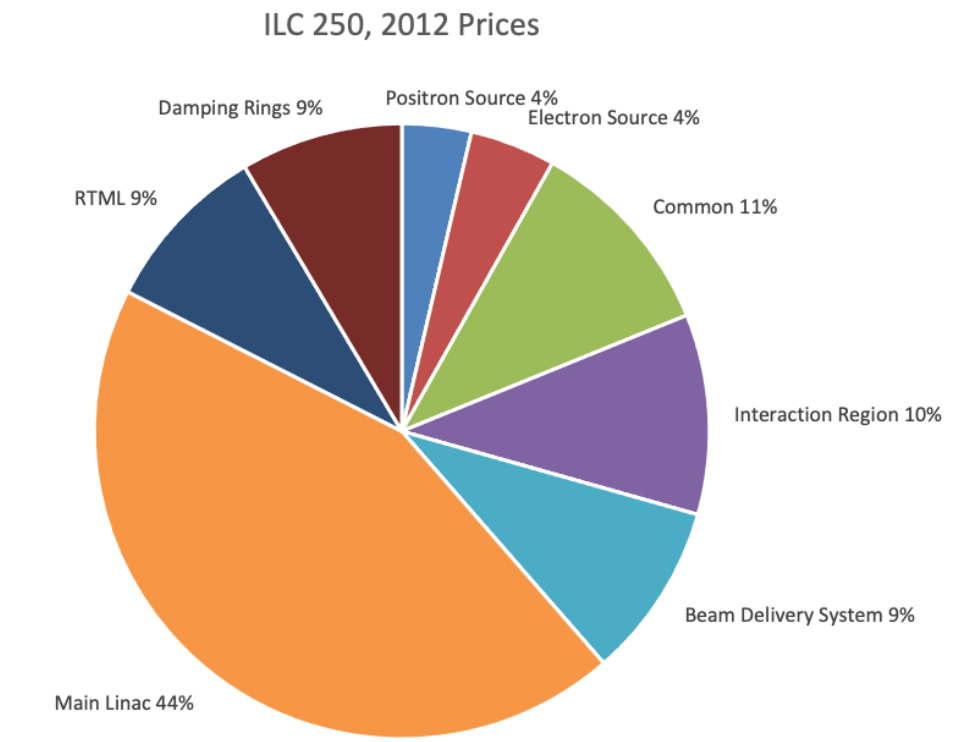
Table 15.6
Value basis for cavities and cryomodules

Sub-component	Basis Type	Basis Source (Date)	Number of units
Superconducting material	Procurement[a]	EXFEL (2011)	17804[b]
Cavity fabrication	Industrial study	qualified vendor	17804[b]
Cavity chemical processing	Industrial study	qualified vendor	21365[c]
Cavity qualifications	Engineering estimate	FNAL (2007)	21365[c]
Power coupler	Procurement[a]	EXFEL (2011)	16024
Power coupler processing	Engineering estimate	qualified vendor	16024
Tuner	Procurement[a]	EXFEL (2011)	16024
Helium vessel	Procurement[a]	EXFEL (2011)	17804[b]
Magnetic shield	Vendor quote[d]	qualified vendor	17804[b]
Cavity shipping and handling	Engineering estimate	FNAL (2007)	21365[c]
Magnet system	Vendor quote	qualified vendor	673
Magnet qualification	Engineering estimate	FNAL (2007)	673
Cryostat materials	Procurement[e]	EXFEL (2011)	1855
Cryomodule assembly	Industrial study	qualified vendor	1948[f]
Cryomodule qualification	Engineering qualification	FNAL (2007)	711[g]
Cryomodule shipping and handling	Engineering estimate	FNAL (2007)	1948[f]
Cryomodule vacuum	Vendor quote	INFN (2007)	1855
Cavity fabrication and chemical procesing infrastructure	Industrial study	qualified vendor	2
Cryomodule assembly infrastructure	Industrial study	qualified vendor	3
Infrastructure for coupler processing, and for cavity and cryomodule test	Engineering[h] estimate	FNAL (2007)	≥ 3

[a] discounted by 16 %, based on a 95 % learning curve
[b] assuming 90 % overall yield
[c] assuming 80 % first pass yield
[d] discounted by 6 %, based on a 95 % learning curve
[e] discounted by 15 %, based on a 95 % learning curve
[f] assumes 5 % more than the baseline, to account for re-work
[g] assumes 38.3 % of CM's are tested
[h] cost for maintenance and upgrades of existing facilities at collaborating labs is taken as 50 % of the estimated facility cost

Cost Breakdown





~65% (CFS and SRF) of costs updated / newly evaluated for LCF@CERN

Technological Readiness and Risk

ILC can be built

- Technological readiness of subsystems and key components was evaluated in preparation of ILC technology network and in Snowmass process
- No show stoppers found,
  - positron source is technologically most challenging (TRL 5-6, score 2 from Snowmass implementation task force (arXiv:2208.06030)
- SRF technology fully industrialised (E-XFEL, LCLS-II) -> low technology and cost risk

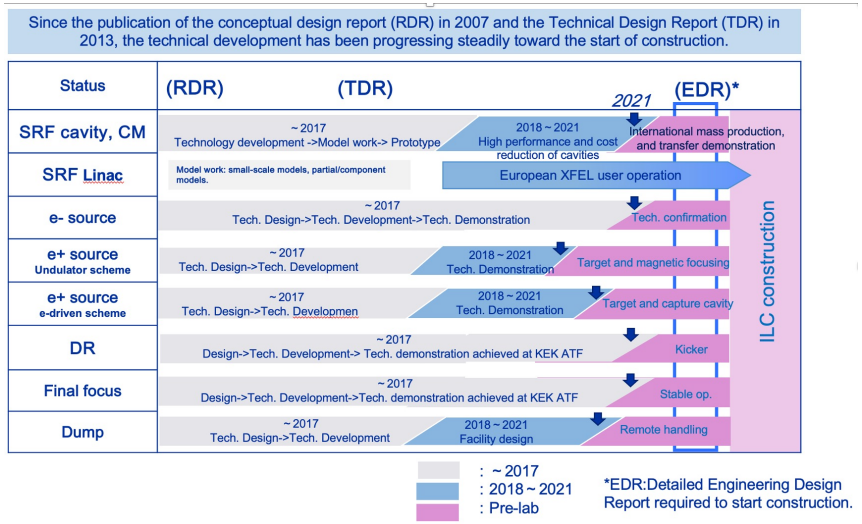
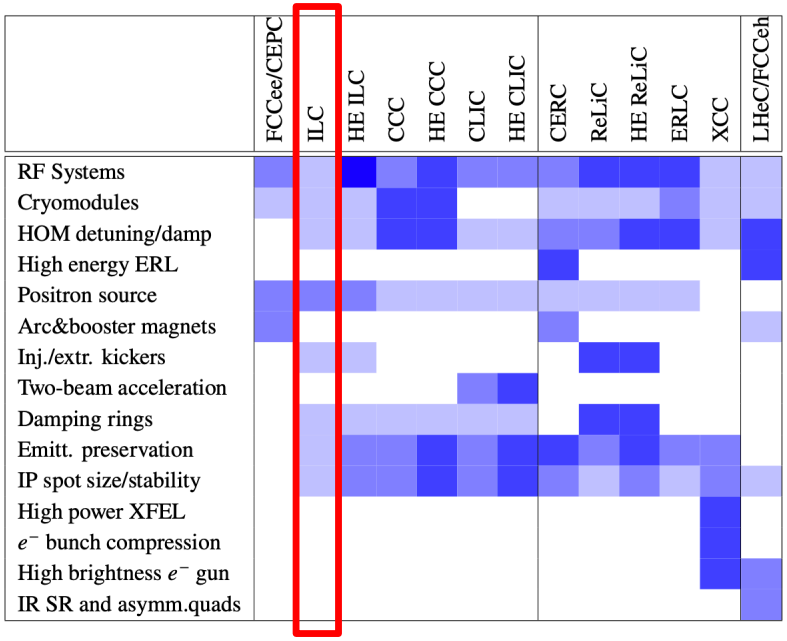
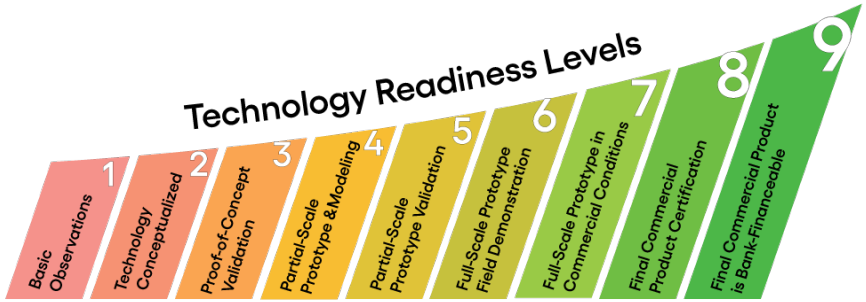


Table 2. Technical risk registry of accelerator components and systems for future e^+e^- and ep colliders: lighter colors indicate progressively higher TRLs (less risk), white is for either not significant or not applicable.





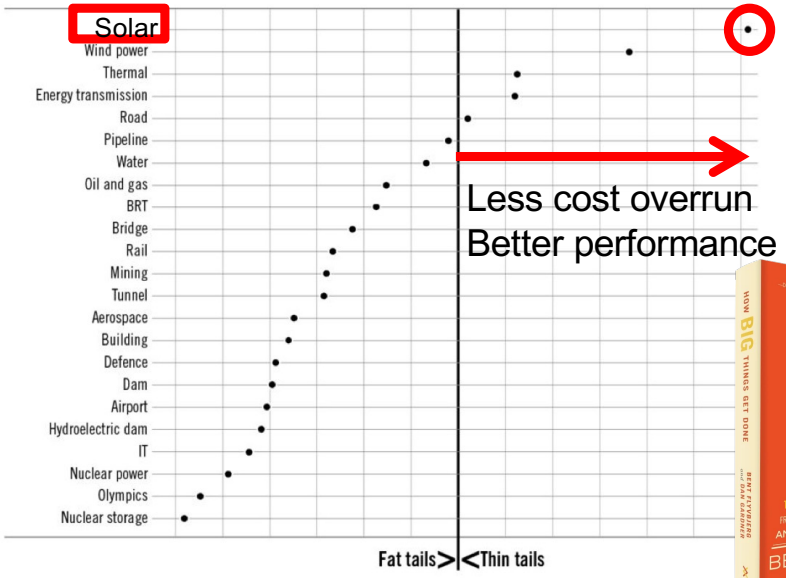
Modularity as success concept

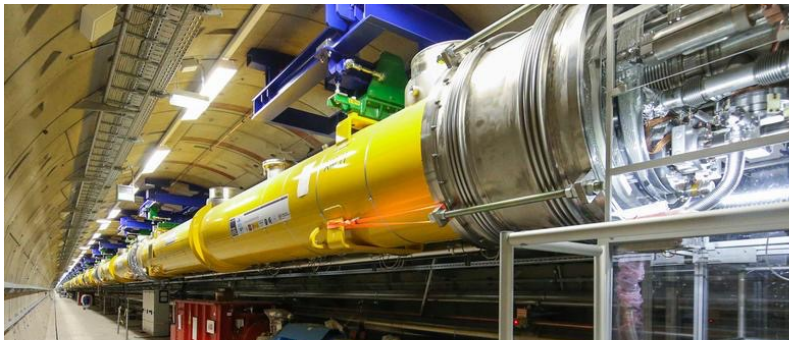
- Study by B. Flyvbjerg and D. Gardner identifies modularity as key factor to success of mega projects
  - **“What is your lego?”**
  - Evidence: Most successful mega project type are solar power plants owing to inherent modularity
- Cryomodules are the central building block of a superconducting accelerator, large fraction of value
  - Get them right, get the project right

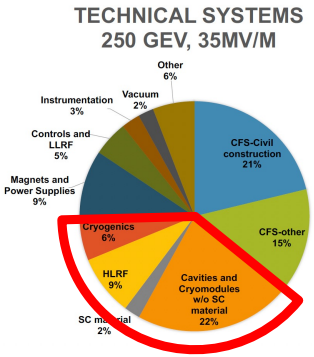
“Get a small thing, a basic building block. Combine it with another and another until you have what you need. … Modularity delivers faster, cheaper and better … for building at a truly huge scale … modularity is not just valuable, it’s indispensable.”

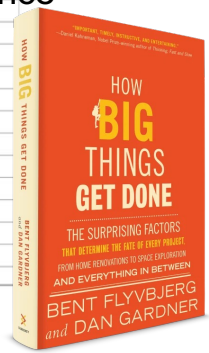
Flyvbjerg, Gardner “How big things get done”

Study: performance of 16000 mega projects according to project type









Flyvbjer, Gardner: How big things get done.
https://sites.prh.com/how-big-things-get-done-book

ILC Staging configurations

- IDT update: Will provide cost estimates for
  - $\sqrt{s}$ = 500 GeV,
  - t-t threshold, i.e. 350 GeV and a
  - **Higgs factory, i.e. 250 GeV**
- Staging report (arXiv:1711.00568) defines the possible options. Tunnel length defines maximum energy:
  - 500-550 GeV: 33.5km (TDR: 31.5km)
  - 350-380 GeV: 27km
  - 250GeV: 20.5km
- TDR design assumed 31.5km, was changed to 33.5km in CR-0004 (timing constraint)
  -> would permit installation of more cryo modules to reach **550 GeV**
- **For LCF@CERN: build 33.5km right away?**

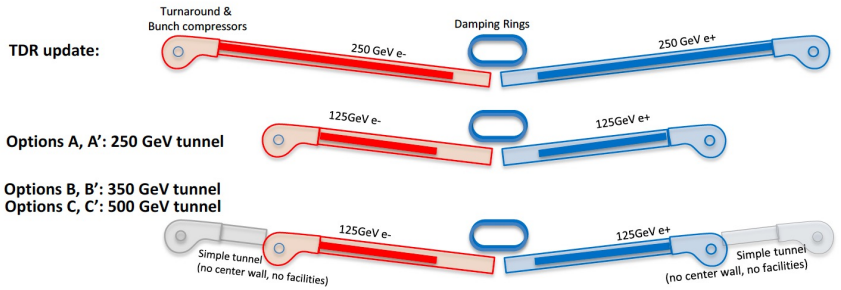


Figure 3-1 Staging options.

Table 3-1: Summary of baseline configurations.

Options	Gradient [MV/m]	E_{CM} [GeV]	Total E_{CM} Margin	n	Space margin	Reserved tunnel (each end)	Total tunnel
TDR update	31.5	500	2%	10	1,473 m	0 m	33.5 km
Option A		250	6%	6	583 m	0 m	20.5 km
Option B				6&8		3,238 m	27 km
Option C				6&10		6,477 m	33.5 km
Option A'	35			6	1,049 m	0 m	20.5 km
Option B'				6&8		3,238 m	27 km
Option C'				6&10		6,477 m	33.5 km

Which baseline to cost?

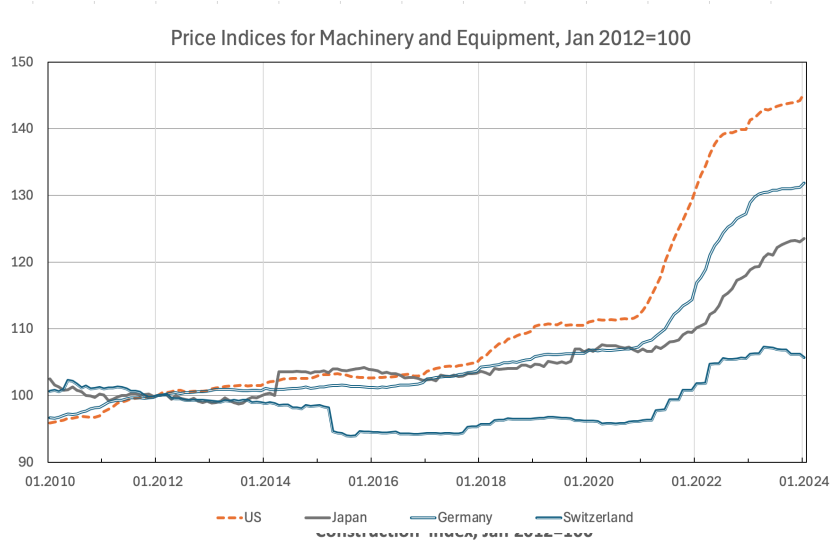
- Tunnel length – 20.5, 27, or 33.5km?
- Minimal Higgs factory (250 GeV), or equipped for 350-380 or 550 GeV?
- Upgrade path: run at 250GeV and shut down cavity/cryomodule production? Or continue production with existing facilities?
  - Cavity production takes ~4 years, with 2 ½ years ramp up, and sizeable infrastructure costs
    -> install & operate 250GeV machine while continuing cavity production would reduce costs significantly
- Cost for 2nd BDS: Mostly driven by cost for tunnel and experimental hall
  -> we will know more after CFS study
- Positron source:
  Build 2 sources or plan for a downselect?

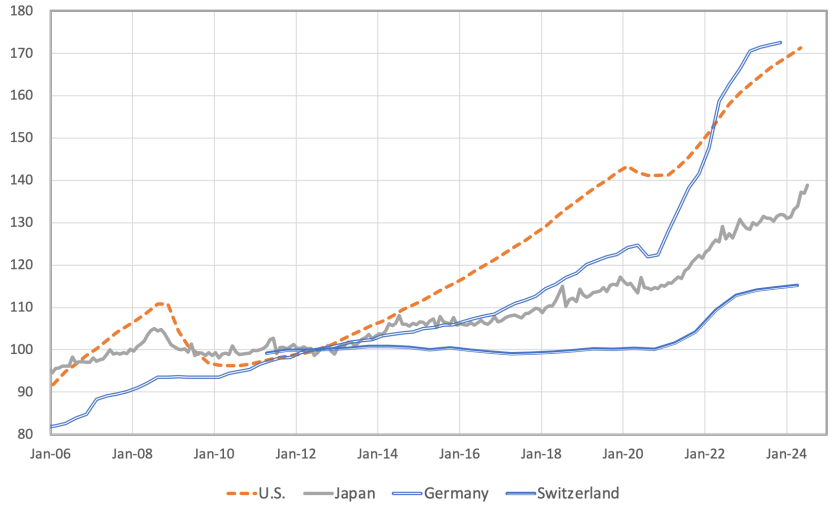
Cost and performance opportunities

- Cavity gradient and Q_0
  -> 10% more gradient at better Q_0 may be a realistic goal, more ambitious targets are possible
  -> reduction of cavity, cryomodule and cryogenics costs (10% reduction of total project cost)
- Worldwide procurement may reduce costs, even in 2 vendor mode
- Klystron efficiency could be 80% instead of 65%
  -> would reduce power (~5MW)
- CERN is not a green field site:
  Re-use of existing infrastructure and equipment will reduce costs
  - Computing centre
  - Electrical supply, water cooling
  - Cryo plants?
  - Helium inventory

Escalation Factors: How much will the cost rise?

- Significant inflation from 2021 on: Covid, Ukraine war
- Determine **escalation factors** from selection of price indices most appropriate
- For **machinery and equipment**:
  - Average of 3 specific indices
    (CPA (European product code) categories 25, 27, 28.1.&28.2)
  - Escalation factors 2012 -> 2024:
    - **US: +45.3%** ± 19.1%
    - Japan: +23.5% ± 18.8%
    - Europe / Germany: +31.9% ± 12.4%
    - Europe / Switzerland: +5.7% ± 14.5%
  - Uncertainties taken from RMS spread of sub-categories
  - **-> expect ILCU value to rise ~45% compared to 2012 price index**
- **Construction** price indices 2012 -> 2024 :
  - Japan: +30.4%
  - **Switzerland: +15.1%**
  - U.S: + 71%
  - **Construction prices in Switzerland have been very stable -> expect no large change compared to previous studies for CFS costs at CERN**

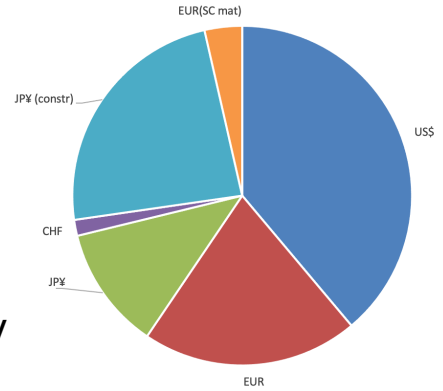




From ILCU to CHF

- "ILC Currency Unit" ILCU measures the **value** of a piece of equipment, in US$(2024)
- Translation between quotes in different regions and currencies to a single unit is done on the basis of purchasing power parity
  -> answers the **hypothetical** question "what would it cost to produce the same goods in the US, assuming a comparable vendor is available"
- This is a relevant question to measure the value of in-kind contributions in an in-kind dominated project
- Using PPP rates to convert ILCU to CHF would answer the question "what would it cost to produce this equipment in Switzerland" – not the relevant question!

Breakdown into cost type and currency



- For a CERN based project with central procurement, ask "what does it **cost** in CHF to buy the equipment"
- Depending on country of origin, equipment of value 1ILCU costs more or less in CHF
- CERN would buy internationally and pay in CHF
- -> Take all estimates in original currency and translate into Swiss Francs with exchange rate
- Conservative: it may be possible to find vendors in cheaper regions
- Region and original currency is known for all cost items -> can convert to CHF
- **Take home messages:**
  - **for accelerator components, 1 ILCU is 0.8-0.9 CHF**
  - **Cost estimate for LCF at CERN will correspond to CERN procurement model**

Local cost	Value	Exchange rate: 1CHF=	Cost in CHF
1 USD	1 ILCU	1.136 USD	0.880 CHF
0.955 EUR	1 ILCU	1.050 EUR	0.880 CHF
133 JPY	1 ILCU	169 JPY	0.784 CHF
1.087 CHF	1 ILCU	1	1.087 CHF

Summary and Conclusions

- A cost estimate for an LCF@CERN, based on the ILC costs and a site-specific CFS design, for a central procurement model, will be provided for European strategy
- The strong Swiss Franc leads to
  - Little inflation in Switzerland (relevant for CFS)
  - Large buying power
  - -> 1 CHF buys equipment worth 1.1-1.25 ILCU
- An LCF@CERN based on ILC design is technically mature and has a very solid cost base
- Facility with 33km tunnel (space for 550GeV) starting at 250 GeV offers
  - Low initial cost
  - Early physics results
  - Relatively flat spending profile
  - Attractive opportunities for external (in-kind) contributions
- Cost and technological risk is relatively low
- Considerable opportunities for cost reduction

RESERVE MATERIAL

Purchasing Power Parity

- Goods are more or less expensive in different regions of the world
  -> same currency has different “purchasing power”
- Exchange rates fluctuate for other reasons than their purchasing power
- PPP conversion rate: what would the same goods cost elsewhere
- PPP for CHF to US$ (consumer goods): 1.20CHF per US$
  -> expect iPhone to cost 1200 CHF in Switzerland
- Purchasing power evolution consistent with ratio of inflation (in theory)

- Expect price quotes for same equipment from different regions to follow PPP
  -> price quote from one region can be used to estimate price in another region -> defines the intrinsic Value
- A good measure for a global in-kind project: **ILC in Japan**
- **Not appropriate** for a project with worldwide procurement from a central project budget of a single host lab, e.g. FCC

iPhone 15 Pro
6.1-inch display[1]
From $999
or $41.62/mo.
for 24 mo.*

U.S.

iPhone 15 Pro
6,1" Display[1]
Ab CHF 1083.–

Switzerland
=1212$

iPhone 15 Pro
6,1" Display[1]
Ab 1.199 €
oder 49,96 €/Rate
bei 24 Raten mit 0 %
eff. Zins p.a.****

Germany
=1281$

iPhone 15 Pro
6.1 英寸显示屏[1]
RMB 333/月起或
RMB 7999 起

China
=1103$

iPhone 15 Pro
6.1インチディスプレイ[1]
159,800円から
、または36回払いで
4,438円/月から‡

Japan
=1017$

Methodology of TDR Cost Estimate

- Methodology developed for a **global project**, dominated by **cost sharing** through **in-kind** contributions
- 2 Categories: “Value” and “Labour”
  - **Labour** is institutional labour (hours worked by personnel in participating institutions), measured in hours
  - **Value** is the value of purchased goods and services, measured in **2012 ILCU** (ILC Currency Unit)
- 1 ILCU: purchasing power in the U.S. of 1US$ in Jan 2012
  - Conversion between costs evaluated in other regions and ILCU based on **PPP**: **Purchasing Power Parity**
- TDR: Full bottom-up cost estimate based on individual components
  - 2017 estimate for 250GeV Higgs factory was derived by scaling costs (predominantly Main Linac)

4.2.4 ILCU Definition in terms of PPP Indices

For the TDR, the ILCU will be defined as equal to the USD on January 1, 2012. Conversions of estimates obtained in currencies other than USD to ILCU will be based on PPP indices (as of January 1, 2012) relating those currencies to the USD. The only exception to this rule is for the superconducting material for the cavities. There is only one supplier of RRR-niobium raw material in the world. Thus, it is appropriate to consider this cost element to be a commodity which must be purchased on the international market. In preparing the Value estimate, conversions from currencies other than USD to ILCU for this cost element have been based on exchange rates as of January, 2012. The PPP indices of four regional[7] currencies, relative to the USD, together with exchange rates, are shown in Fig. 2. Numerical values of the PPP indices and exchange rates for January, 2012, which are used in the Value estimate, are given in Table 2.

Table 2. Currency conversion factors between ILCU and national currencies (January, 2012). To convert a cost element from ILCU to the indicated currency, multiply by the factor appropriate for the type of cost element.

Cost element type	ILCU→USD	ILCU→Euro	ILCU→Yen	ILCU→CHF
Civil construction (PPP)	1	0.939	109.3	1.303
Machinery and equipment (PPP)	1	0.923	127.3	1.480
Superconducting material (EX)	1	0.776	76.9	0.939

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Cost element type	ILCU→$	ILCU→€	ILCU→¥	ILCU→CHF
Civil construction (PPP)	1	0.596	81.8	0.606
Machinery & Equipment (PPP)	1	0.955	132.8	1.087
Superconducting Material (EX)	1	0.924	149.1	0.887