Status of ILC cost uncertainty analysis

- Introduction
- Method
- First Results
- Next Steps
- from cost uncertainty to risk analysis

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Introduction

- initiated by Nick and Wilhelm
- Goals
  - value costs need uncertainties
  - develop probabilistic cost model for ILC value
  - evaluate inherent uncertainty of value cost estimate
- procedure
  - use expert inputs to quantify costs, uncertainties and correlations
  - run MC simulation to obtain aggregated ILC cost distributions
  - give feedback to experts, iterate on expert‘s input, when necessary
  - determine in final round the main statistical quantities for reporting/presenting

ILC component breakdown

- breakdown according to WBS with roll-up of smaller items.
- We consider the following ‚cost modules‘:
  - LINAC
    - Cavities, Niobium, Cryostats, RF, Klystrons…
    - 22 independent cost items, total 2.5B$
  - CF&S
    - Civil Engineering (underground facilities, surface, engineering design & study, site development)
    - Electrical, Water/Air, Safety & Handling
    - 9 independent cost items, total 2.3B$
  - BDS & Damping Rings (not yet implemented)
    - 3-4 items each
- Aim for # of total items O(50) – find principal components, no need to have each WBS item in simulation (total 240)

Method

- use point estimate of value cost for item i
- require expert(s) input on
  - cost uncertainty category for item i
  - estimate of relative cost variances Var(i) (correlated & uncorrelated) for item i
- determine correlation matrix corr(i,j)
- Monte Carlo Simulation for cost aggregation:
  - use @RISK – professional software
  - cross-checked with own Matlab code for some examples

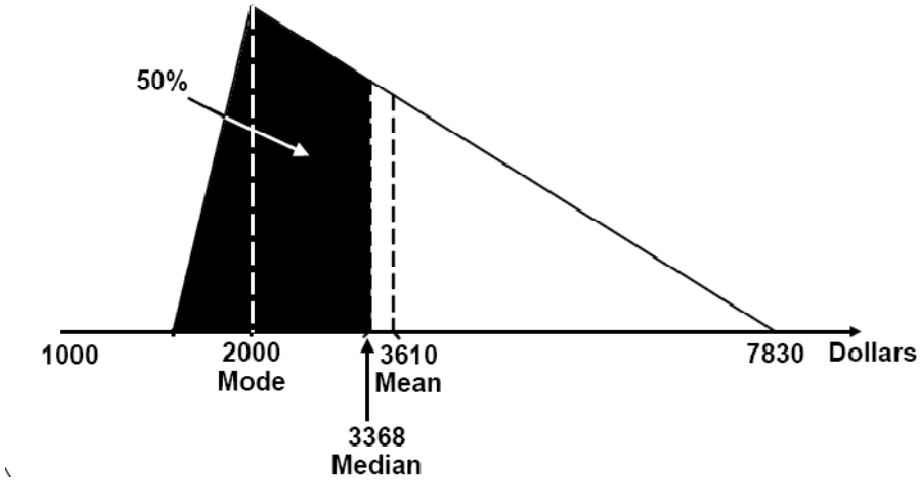
Standard cost uncertainty categories

Category	definition	lower/upper range
C1	good experience and present price for this component/sub-system are available, no cost scaling for large quantities has been applied	-10% / +10%
C2	experience and present price for similar components/sub-systems are available, no or only minor scaling to large quantities has been applied	-20% / +20%
C3	present price is available, significant (>25%) cost scaling to large quantities has been applied	-10% / +20%
C4	present price is available, price from industrial study is used which results in significant (>25%) cost reduction for production of large quantities	-10% / +20%
C5	present price not available, price from industrial study is used	-10% / +20%
C6	Required technology pushes state-of-the art, significant R&D still required	-10% / +50%

XFEL approach: use standard categories for cost uncertainties. This should provide guidance for quantification.
Lower/upper range defined through triangular function, simple and easy to understand/interpret. Intuitive Ansatz.
However, expert can add own categories if necessary.

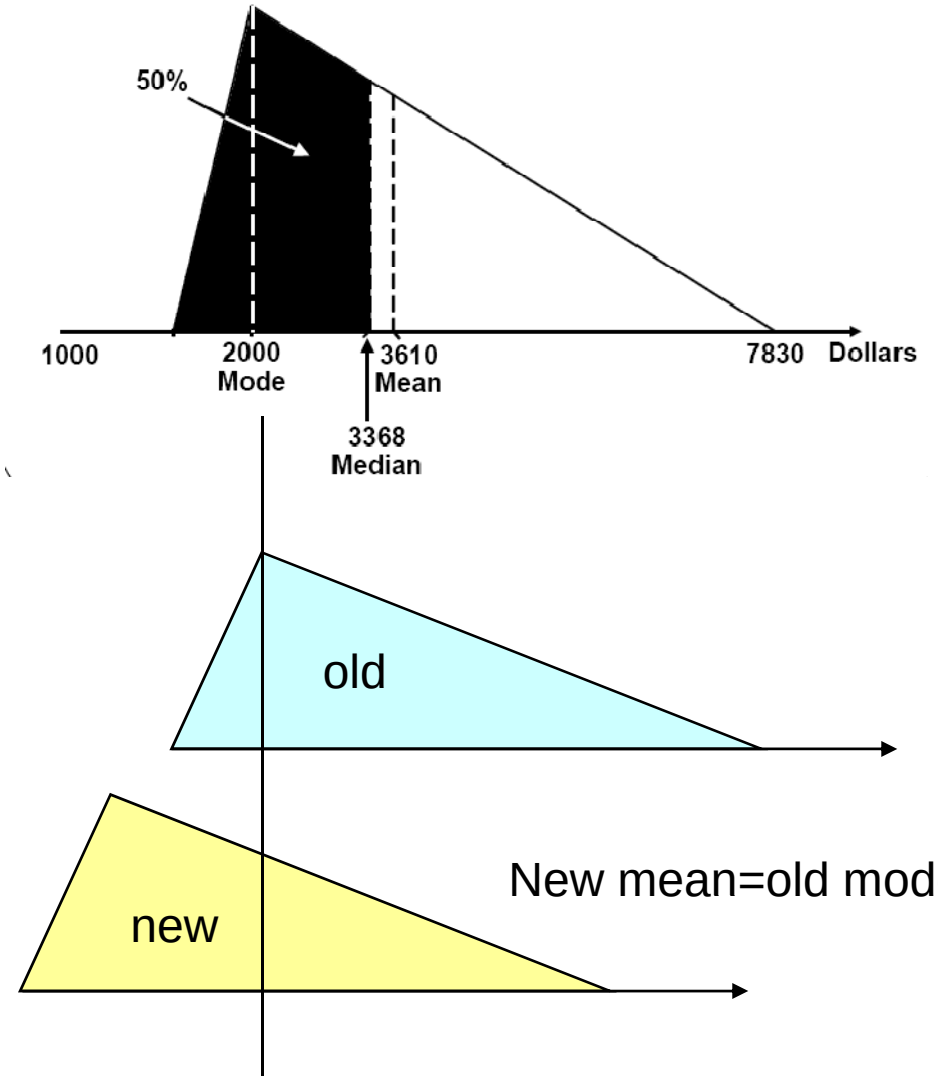
Triangular functions

- triangular functions as single item pdfs are widely used in cost estimation business
- they are defined through min, max and a most probable value (mode)
- they are intuitive and well suited for estimating
- use of other pdfs (lognormal, Beta etc.) is more fancy but is leading essentially to same results



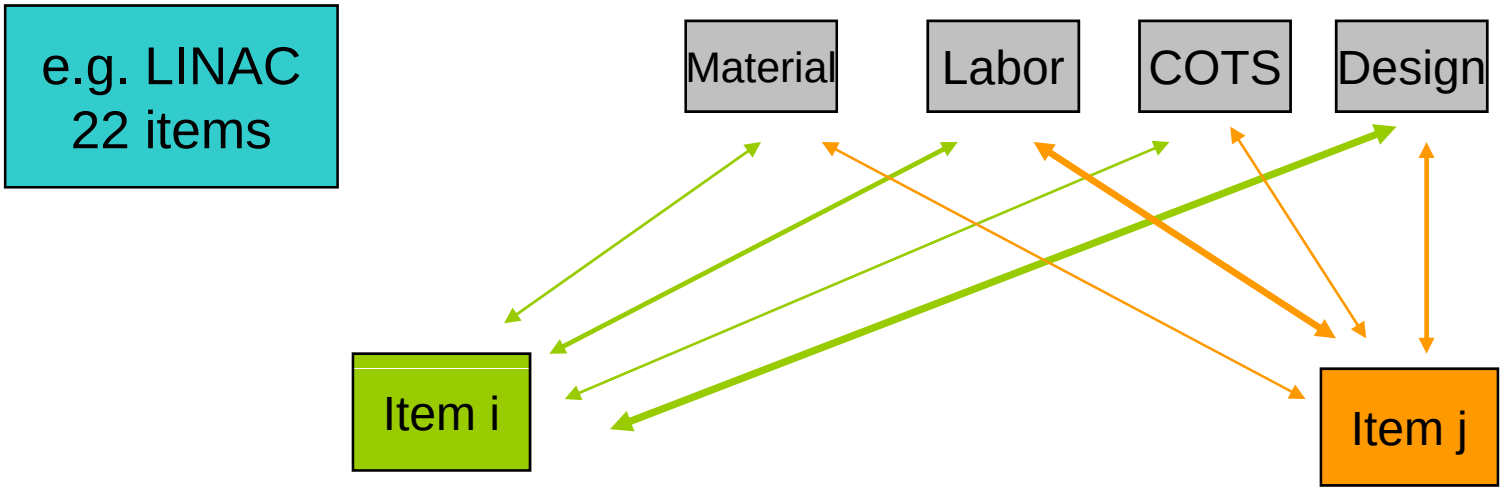
Triangular Function

- ILC people were asked to provide median (50%/50%) values as point estimate
- However: „it became apparent that what people gave was most probable value or mode“
- after aggregation the final mode changes w.r.t. to simple roll-up of most-likely cost item values (due to asymmetric tails)
- only the mean value is invariant, since it is a linear function
- we require invariance and want to preserve our rolled up estimate as quoted in the RDR
- hence, the point estimation of item i has to be re-scaled to the mean value by shifting the triangle by an offset (mode-mean)



note, that all preliminary results that I show are unshifted.

Cost components - correlations



- Consider four sources S_k of correlations that would affect items i,j in identical way:
  - Material
  - Labor
  - Components off the shelf (COTS)
  - Design/Engineering
- Assume that Corr(S_k,S_l)=0
- Estimate relative fraction of Var(i) due to source S_k on cost element i
- =>calculate then linear correlation coefficient Corr(i,j) due to source S_k

Cost Components - correlations

- Model requires decomposition of cost variance into uncorrelated and correlated part
- Linear correlations are introduced through four (systematic) sources or factors among cost items:
  - Material, Labor, COTS and Design
- presently, correlations are only considered for items within a cost module (e.g. within LINAC) and not (yet) for items between modules (LINAC <=> CF&S)

Remarks on Expert(s) input

- The most crucial element in the analysis is the expert input and the elicitation of expert‘s knowledge (=formulating the expert‘s knowledge and belief into a pdf)
- Elicitating expert‘s responses is by no means a trivial task and also subjective. It has to be optimized and improvements for further cost uncertainty studies are necessary.
- We should use multiple, unbiased and independent expert assessments that are complementary in the best of all cases and that are treated in the simulation as a linear opinion pool, hoping to better approximate the truth.
- Even if experts disagree in single estimation, everybody agrees that combining multiple estimations is best we can do
- Elicitation should be an iterative process. After presenting the first (complete) result, experts should be invited to assess and adjust uncertainties and variances again.

Expert input

- independent input on/from:
- LINAC (3x)
  - Wilhelm B. ☺
  - US estimate ☺
  - DESY general / XFEL experts ☺
  - Asia region – ?
- CF&S (2.5x)
  - Wilhelm ☺
  - common estimate USA/Asia/Europe (gaussian uncertainties, no correlations) 😐
  - DESY general – only estimates on buildings
  - further input difficult to obtain ☹

Example LINAC sheet

	total				Systematic Sources of Correlations for uncertainties							
	2.509.160.115	relative	cumulative							Cost Uncertainty		
Component/cost item	**Mtotal**	**fraction (%)**	**(%)**		**Material**	**Labor**	**COTS**	**Design**		**Category**	**min**	**max**
Niobium RRR300	284.941.590	11,36	11,36									
Cavity Preparation	227.336.200	9,06	20,42									
Vacuum Vessel & Cold Mass	222.231.169	8,86	29,27									
Power Coupler	186.056.148	7,42	36,69									
RF power distribution	165.300.114	6,59	43,28									
Klystron(1,3GHz,10MW)	161.240.760	6,43	49,70									
Modulator	157.375.440	6,27	55,97									
Low Level RF	153.492.798	6,12	62,09									
SC resonator machining	118.498.750	4,72	66,81									
Pulse Transformer	104.916.600	4,18	71,00									
Assembly	101.920.000	4,06	75,06									
HV power supply	66.263.400	2,64	77,70									
Tuner Mechanics	61.865.424	2,47	80,16									
Modulator Interlock	61.846.200	2,46	82,63									
Titanium vessel	54.102.690	2,16	84,78									
Klystron Interlock	44.728.200	1,78	86,57									
Module Beampipe Connection	41.745.419	1,66	88,23									
Cavity Interlock	38.743.838	1,54	89,78									
SC resonator assembly&welding	34.813.420	1,39	91,16									
RF cable	30.962.740	1,23	92,40									
Tuner Electronics	28.778.556	1,15	93,54									
Remaining 30 parts	162.000.660	6,46	100,00									

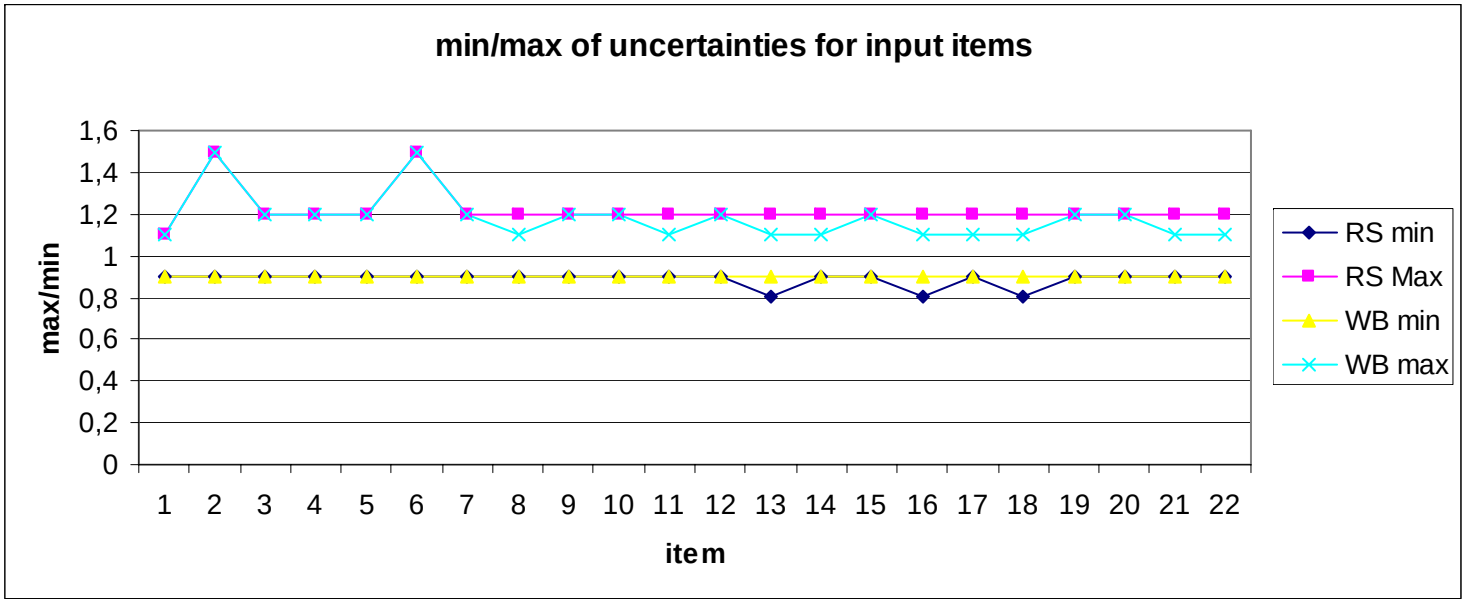
Define in this matrix the relative fraction (in %) of the total cost variance (sigma^2) related to the corresonding systematic source (Material, Labor, Components off the shelf COTS, Design). These fractions are treated as correlated. The sum of the four contributions is then the total correlated part of the full cost variance.

Example:
cost item i: Material(30%), Labor(25%)
cost item j: Material (50%) COTS (40%)
etc.

Define here the cost uncertainy category C1-C6, see sheet 'category'

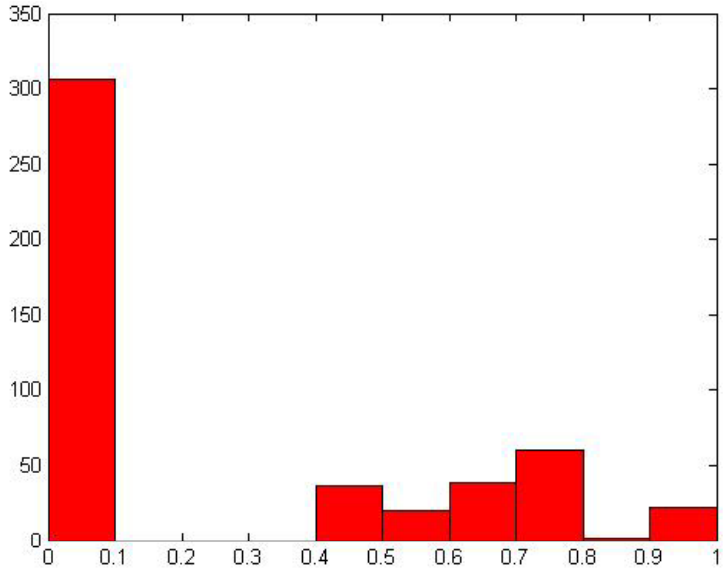
Preliminary results

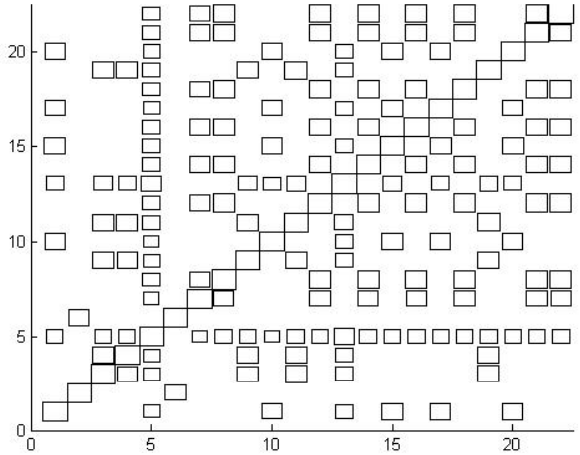
- LINAC, input from Wilhelm B and Rich S. (US)

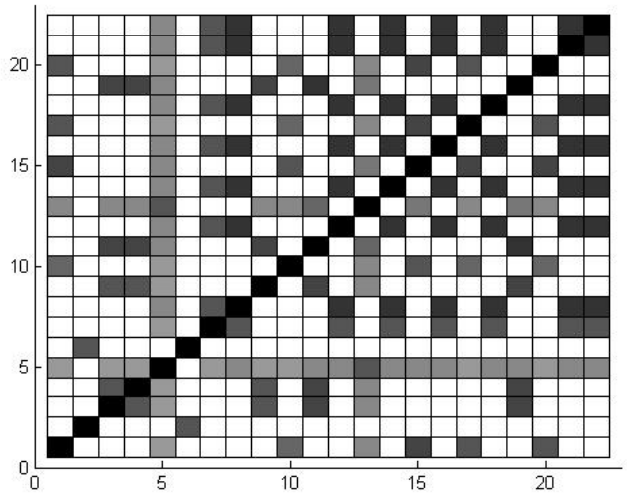


WB LINAC correlation input

- 178 out of 484 elements > 0
- average correlation across 22x22 elements: 0.25

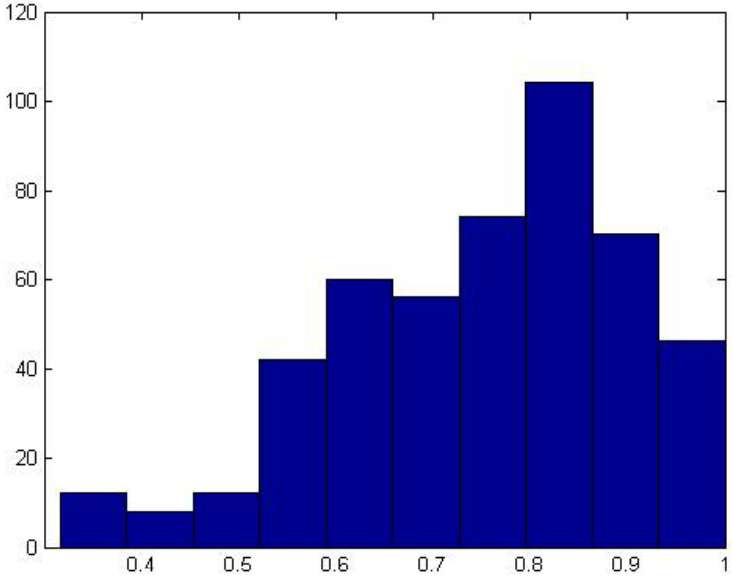


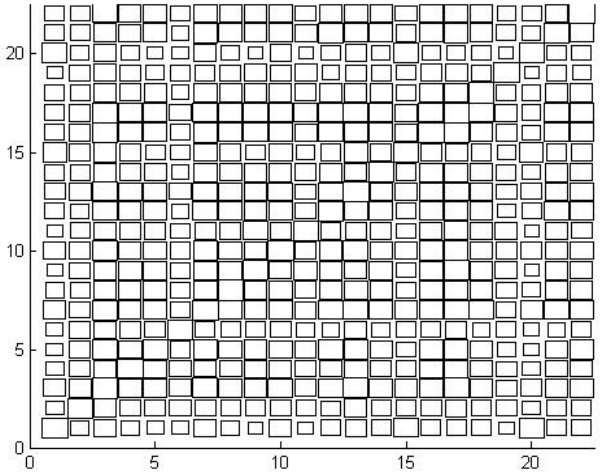


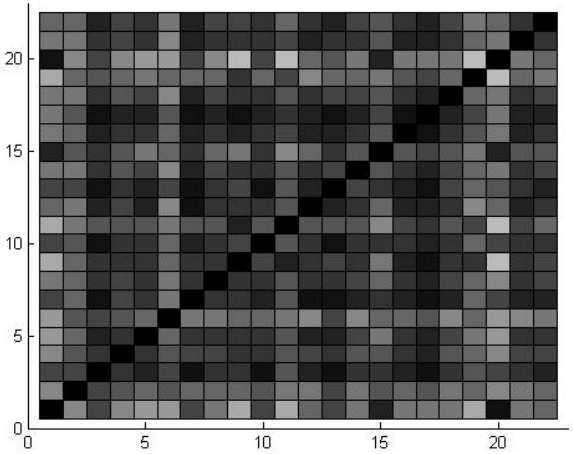


RS LINAC correlation input

- all elements >0
- average correlation across 22x22 elements: 0.75

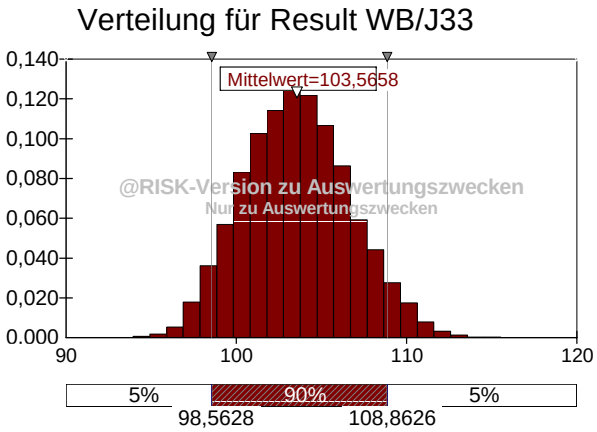




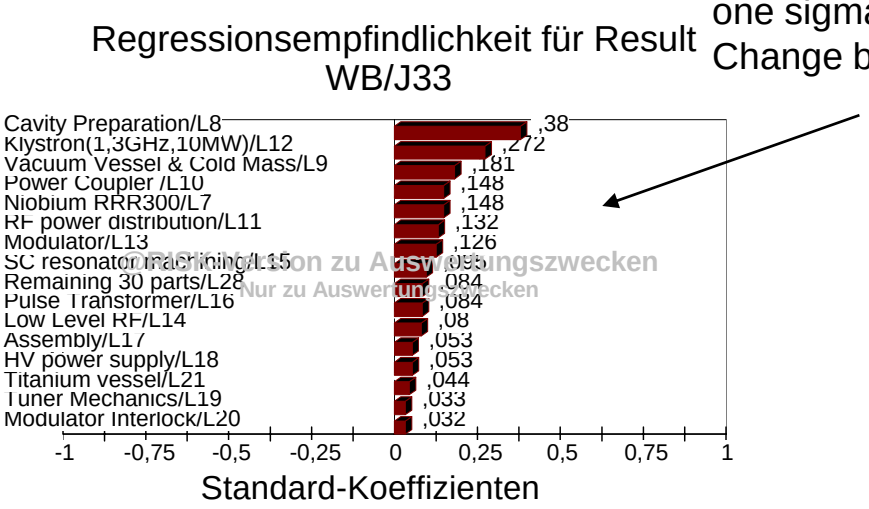


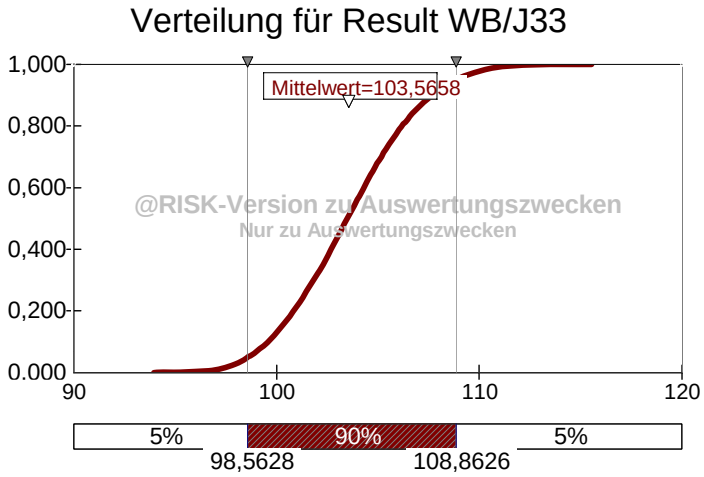
Result LINAC WB

- Mean: 103.6
- Median: 103.5
- Mode: 103.1
- RMS: 3.1
- 5%-Percentil: 98.6
- 95%-Percentil: 108.9
- 95%-VaR: 5.8
- Main cost drivers: cavity preparation, klystrons



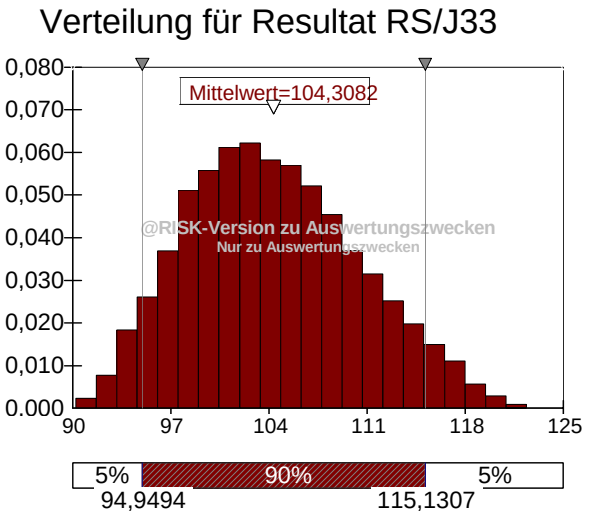
‘Tornado-plot’:
If I change one item by one sigma, then cost Change by xxx sigma

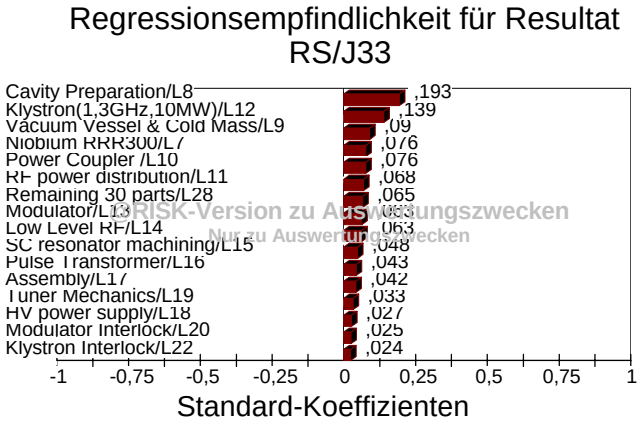


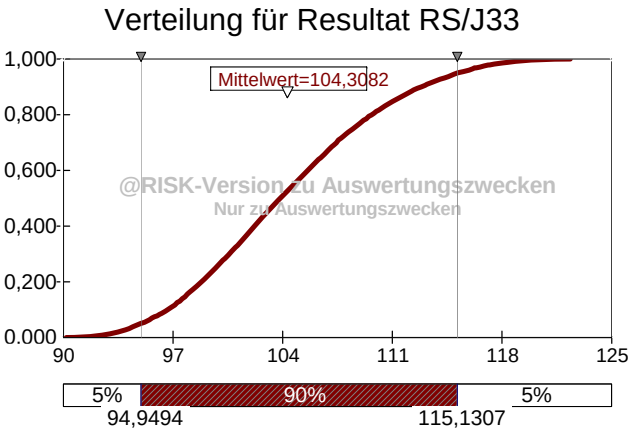


Result LINAC RS

- Mean: 104.3
- Median: 103.8
- Mode: 102.2
- RMS: 6.1
- 5%-Percentil: 94.9
- 95%-Percentil: 115.1
- 95%-VaR: 12.9
- Main cost drivers: cavity preparation, klystrons

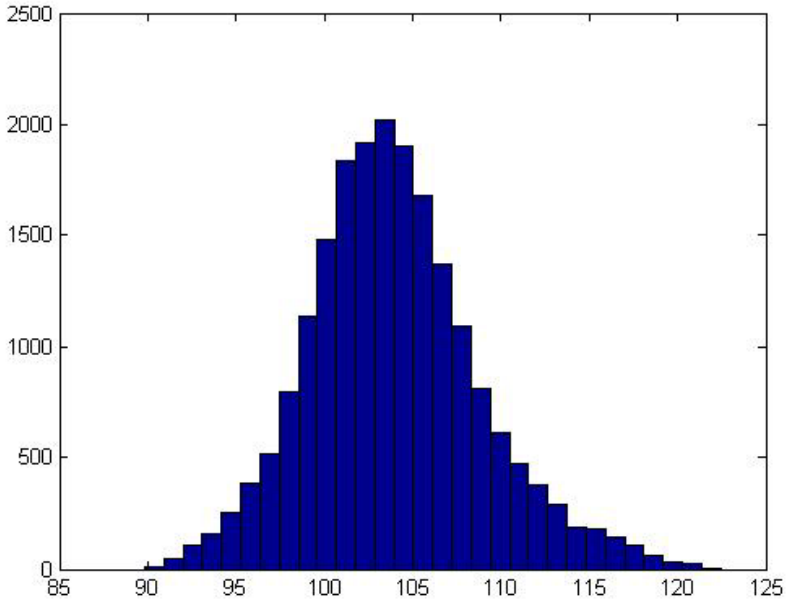






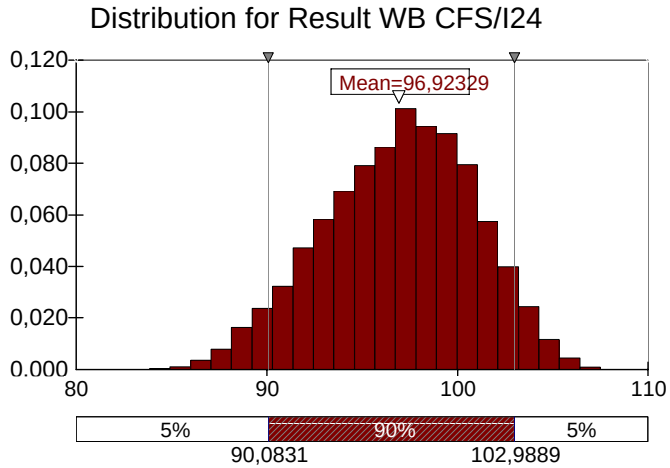
RS/WB combined LINAC distribution

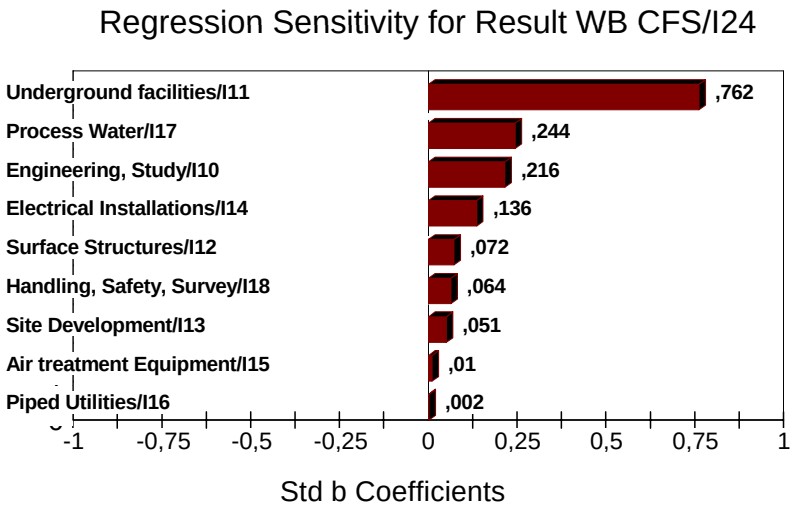
- RS& WB equally weighted distribution
- Mean=103.9
- Median=103.6
- Mode=103.4
- RMS=4.8
- 5%-percentile=96.5
- 95%-percentile=112.7
- value at risk=9.3 (95%-percentil-mode)

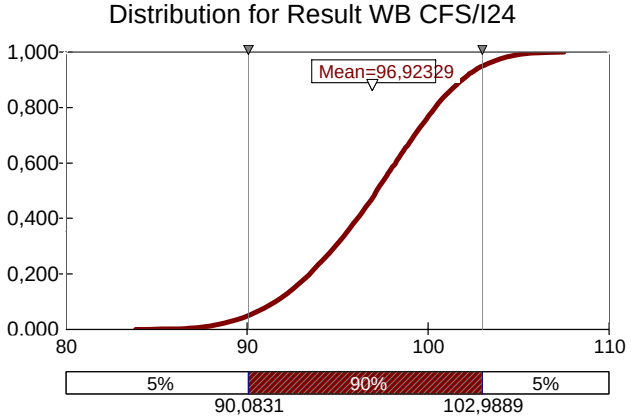


Result WB on CF&S

- Mean: 96.9
- Median: 97.2
- Mode: 98.2
- RMS: 3.9
- 5%-Percentile: 90.1
- 95%-Percentile: 103.0
- 95%-VaR: 4.8
- Main cost driver: underground facility

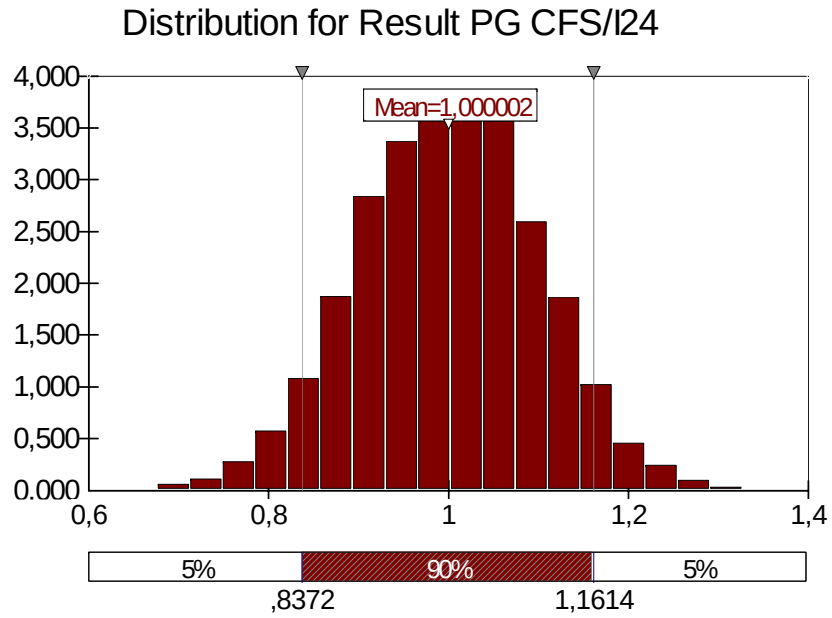


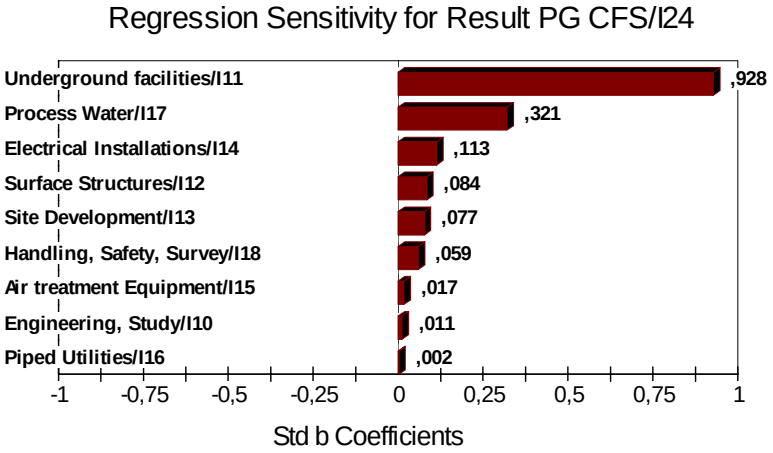




Result common estimate on CF&S

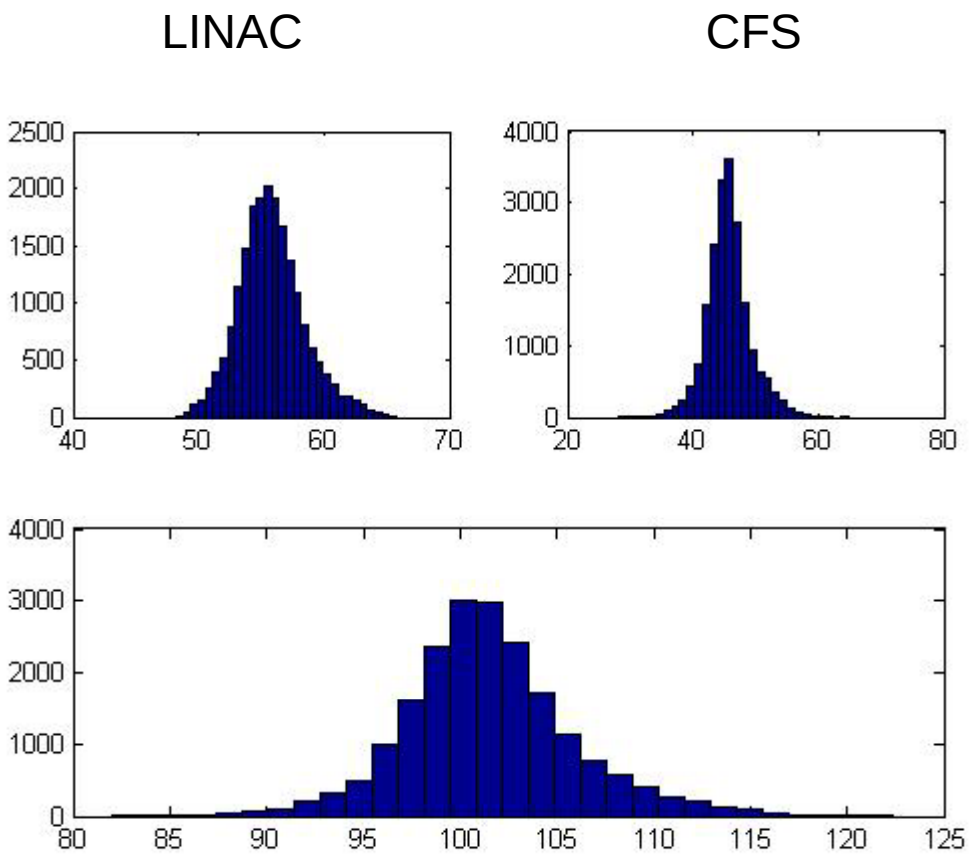
- gaussian
- Mean=1
- RMS=0.1
- No correlations
- Main cost driver: underground facility





Aggregation (LINAC & CFS)

- aggregate using cost fractions for LINAC (54%) and CF&S (46%)
  - Mean: 101.5
  - Median: 101.2
  - Mode:100.7
  - RMS: 4.4
  - 5%-percentile: 94.8
  - 95%-percentile: 109.5
  - 95%-VaR: 8.8
- Not yet included: DESY-LINAC and DESY CF&S



Further steps

- implement BDS & damping ring items?
- seek for further input on LINAC, CF&S etc.
- responses hopefully from Asia to present a strong case (input from the different regions)

- Run first (complete) analysis and provide feedback to experts (if possible), allow for adjustments in one iteration step
- final MC and reporting of results

From cost uncertainty to risk management

- presently, this is a cost value uncertainty analysis, but not a risk analysis
- we parameterize our uncertainties and propagate errors – at the level of our discussion of value OK
- but sooner or later we have to consider ‘risks’ or ‘risk events’ that are characterized by a certain likelihood of occurrence with impact on cost/schedule/scope
- risk analysis should consist of
  - identifying and quantifying risks (technical, procurement, organizational, market etc.)
  - managing and mitigating those risks
- first approach of such a risk analysis was done by professional company (Noetzold & Noetzold) for the cryomodules as pilot study

Risk catalogue – after expert interview