ILC-CC Design Down-Select Review

April 4-6, 2023 - KEK

An ad-hoc committee was invited to review five proposals for the development of a crab cavity for the ILC project. The committee was presented material from each of the groups responsible for the five variants and received further information through subsequent discussion and homework. The list of the Committee members participating in this meeting along with sub-committee assignments is given in Appendix 1. The criteria for judging are given in Appendix 2.

Executive Summary

The committee thanks our KEK hosts and international ILC crab cavity coordination team for their organization of this event and hospitality during our stay. The Committee also thanks all teams for presenting a clear and comprehensive overview of their design and for providing helpful feedback to our questions and requests for follow-up material. We acknowledge that the contributions represent a significant investment on a best effort basis and thank all of them for their engagement. Regardless of our recommended outcome the study of all variants will make the final product better. The global crab cavity community is small and many variants have similar features and so it is strongly recommended that the two successful variants reach out for support as they move through the design and prototyping phase.

The five variants presented at the review are described below.

The **Double Quarter Wave** (DQW) is a variant that has been accepted by the Hi-Lumi project for vertical deflection. As such several 400MHz cavities have been built and tested with good performance. A 1.3GHz variant of the DQW is proposed by the ILC and is modeled after the Hi-Lumi cavity with small modifications and operation at 90 degrees to the Hi-Lumi application. Two cavities on each beam would be required to generate the 1.8MV for crabbing the 125/125GeV beams with a margin of 55% on the specified peak surface fields.

The **Elliptical Racetrack** variant uses the TM110-like mode to generate a transverse kick. Several crab cavities of this type were prototyped including a 3.9 GHz 3-cell cavity at FNAL for CKM and a 2.8 GHz single-cell cavity at JLab for APX XPS. Two 508 MHz single-cell crab cavities of this type are installed in the KEK-B e+e- circular collider and have been routinely operated with beam. The proposal re-optimized the original ILC crab cavity design evolving to a 3.9 GHz 3-cell cavity design. Using a racetrack geometry gives improved separation to the same-order mode and minimizes the peak magnetic fields. The frequency choice of 3.9 GHz allows a lower required kick voltage, providing comfortable operational margins. One cavity for each beam would deliver the specified kick of 0.615MV for the 125/125 GeV beams with 20% margin in peak magnetic field. A second two cell variant with two cavities per beam was also presented that delivered a margin of 82%.

The **RF Dipole** (RFD) cavity has been used for several prototype studies ranging from 400MHz to 952MHz with the 400MHz version chosen for the Hi-Lumi project for horizontal deflection. As such several 400MHz cavities have been built with good performance. A 1.3GHz cavity has been proposed for the ILC. Two cavities on each beam would be required to generate the 1.8MV for crabbing the 125/125GeV beams with a margin of 47% on the specified peak surface fields.

The **Wide Open Waveguide** (WOW) variant was proposed based on developments towards damping HOMs in the EIC. In the ILC variant a 1.3GHz RFD cavity is proposed but with HOM mitigation via an open waveguide that propagates the HOMS to a dissipative load. One proposal was to use waveguides a short distance from the cavity on either end to transport the modes to a coaxial load. A second variant would use in-line dissipative connections between cavities to absorb the load. The open beam-port reduces somewhat the peak surface field so that two cavities would give a margin of 72% if two cavities per beam are used for the 125/125GeV beams. However, the cavity is longer than the RFD variant due to the open waveguide concept.

The **Quasi-waveguide multi-cell** (QMiR) resonator was initially developed for an application at 2.8GHz for the APS SPX project. The ILC proposal calls for 2.6GHz with a 3-cell cavity, no HOM coupler and a WG coupler. The HOMs propagate down the beampipe or out the input waveguide. At the operating volage for the ILC a single three cell variant provides 14% head room compared to the peak field limits in the specification. The cavity could be produced with machining in two halves as for APS.

A summary of the cavity variants and their relative peak surface fields at the operating point are given in the table. Two variants of the elliptical racetrack were presented; a three cell and a two cell.

		125/125					250/250	500 /500
Variant	Frequency (GHz)	Required kick (MV)	# of cavities	Operating Bp (mT)	Operating Ep (MV/m)	Minimum Margin	# cavities	# cavities
DQW	1.3	1.85	2	49.5	29	55%	4	6
Elliptical	3.9	0.615	1	67	23	20%	2	4
RFD	1.3	1.85	2	54	30	47%	4	6
WOW	1.3	1.85	2	46	26	72%	4	5
QMiR	2.6	0.923	1	70	35	14%	1 or 2	1 to 4
Elliptical (2 cell)	3.9	0.615	2	44	14	82%	2	4

The selection process was done in the following way. Two members of the committee, a lead and a second, were assigned to each variant and led the discussion for each proposal. One member of the committee was assigned to look at integration and another at normalization of scoring. The scoring of each variant was based on several criteria as defined in our charge and listed in Appendix 2. The criteria were: cavity design, plans for prototype development, HOM analysis and mitigation strategy, concept for RF ancillaries, multi-pacting analysis, pressure sensitivity, LFD analysis, fabrication concept, cryomodule implementation concept, compliance with requirements and overall risk.

The timetable proposed by the WPP-3 conveners for prototyping and testing is aggressive and so favours more mature designs. The expectation is that the vertical test of the prototype with HOM mitigation be completed in 18 months and the fully dressed test of a jacketed cavity with FPC and tuner be completed 18 months later. The readiness of designs to advance to prototyping as opposed to the potential of a certain variant was an important aspect in our ranking. The panel saw no technical show-stoppers in any of the variants. Given sufficient time all of the variants should be able to reach the design performance for the 125/125GeV application.

The total points from all reviewer inputs were tallied with the final score shown below.

Proposal	**Average**	**Rank**
RFD	82.4	1
QMiR	76.4	2
Elliptical	74.4	3
DQW	61.6	4
WOW	61.6	4

The committee recommends that the RFD and the QMiR cavities move to the prototyping phase. Of the other variants it was felt that the DQW design was not advanced enough, the WOW concept was not an improvement over the RFD variant and added complexity and the elliptical racetrack fabrication design and plan were less developed than the top two variants. The RFD was well developed with a well defined fabrication plan based on hybrid machining/forming. The QMiR also relies heavily on machining that should be more straightforward to prototype. The QMiR team is advised to try to increase the head room at the operating point.

Finally, the WPP-3 team is encouraged to determine whether there is an advantage to have multiple cavities on each side of the IP for redundancy and to correct clocking errors in the cavities via a vector sum correction approach.

Charge Response

Review Charge:

1. To review the crab cavity (CC) designs proposed, to assess their predicted compliance against the functional Specifications for the ILC-250, extended capability for the ILC-500, and the feasibility for higher energy (1TeV).
   All variants are in compliance with extended capability from 125/125 to 250/250 – margins are reduced if the variants are forced to the 3.8m CM installation length for 500/500.
2. To review the status of the design of these CC solutions and identify their risk in comparison to other comparable systems presently in operations or in development elsewhere in the world.
   The main risk is that some variants are not as advanced as they should be to move to prototyping phase. The readiness for prototyping was one of the criteria used in this review.
3. To review the proposed CC solutions for their choices of materials, fabrication processes, tuning analysis, power coupler, HOM couplers, SRF performance, etc.
   All these were taken into account in the detailed scoring process that the committee engaged in.
4. To review the plan for the prototype development including possible cooperation (or consortium effort) with other laboratories and companies/industry.
   The prototyping and collaborating teams were presented by each group in the homework session. The results were used in the scoring of each project with respect to the readiness for prototyping.
5. To provide appropriate advice and feedback for the criteria and further processes to be scoped for the final CC down-selection, based on the prototype development and subsequent high-power tests.

   It is advisable for WPP-3 to coordinate planning for a nm scale tuning system for the RFD style cavities. This is not required for the cavity prototyping but will be required for the fully dressed test in Phase 2.

   The WPP-3 team is encouraged to determine whether there is an advantage to have multiple cavities on each side of the IP for redundancy and to correct clocking errors in the cavities via a vector sum correction approach.

6. To identify the 2 most optimum crab cavity designs which can provide the operational requirements for ILC and which can be taken forward to prototype and high power validation, in conjunction with its associated input and HOM coupler components, without helium jacket.
   The two optimum crab cavity designs chosen in the review are the RFD and the QMiR.

1. Elliptical Racetrack

Findings:

- The Elliptical/Racetrack crab cavity team presented a comprehensive design of a 3.9 GHz racetrack shape crab cavity for ILC.
- Their design has its root in the original ILC crab cavity design carried out by an international team circa 2008.
- The hook type lower-order-mode (LOM) coupler design was confirmed by its prototype over the frequency range of 2.79 - 2.84 GHz.
- The same-order-mode (SOM) coupler is a coaxial type.
- The original higher-order-mode (HOM) coupler was based on the EU-XFEL 3rd harmonic HOM coupler with some modification.
- The original ILC crab cavity was re-optimized with an aim of increasing the SOM separation beyond 10 MHz.
- Cell optimization resulted in a minimized peak surface electric field (Epk) and peak surface magnetic field (Bpk).
- A 2-cell cavity design and a 3-cell cavity design were evaluated and presented.
- The 3-cell cavity design requires a choice in approaches for damping the trapped mode in the middle cell.
- The 2-cell cavity design does not suffer from trapped mode problem. Two 2-cell cavities are required in order to meet the requirement of the peak surface fields.
- Multipacting in the 3-cell cavity is calculated using the code SPARK. A higher-order multipacting band is found at 5.5 MV/m on minor axis iris of the end cell to beam pipe transition. Another band is found in the middle cell at 3 MV/m.
- A modified old ILC HOM coupler is designed aimed at large transmission of LOM and SOM while filtering 3.9 GHz crabbing mode.
- Two identical HOM couplers are used.
- The transverse Impedance for the coax damped 3-cell cavity meets the ILC spec except for the other modes in the crabbing passband.
- A coaxial RF input power coupler with a Qext of 1E7 is designed which requires a 200 W input RF power.
- The multipoles and short-range wake fields are evaluated.
- The Lorentz force detuning is 120 Hz at 5 MV/m.
- The pressure sensitivity is 90 Hz/mbar.
- The maximum stress is 5.4 MPa under 1 bar external pressure.
- The team concluded that a 3-cell cavity with coax HOM dampers meets the ILC impedance specification.
- A helium vessel jacketed 3-cell cavity has a dimension of 370 mm L x 200 mm H x 140 mm W, corresponding to a helium tank internal volume of 4.3 litres which is a PED Category I.
- A cryomodule design concept is presented with an over length of 1014 mm for a 1-cavity module and 2520 mm for a 4-cavity module.

Comments:

- The racetrack design team lends itself well to re-optimizing the original ILC crab cavity design and reaching a new 3.9 GHz 3-cell cavity design.
- The frequency choice of 3.9 GHz allows a lower required kick voltage, providing comfortable operational margins in view of the surface fields accessible by today's SRF technology. It also allows a compact cavity size and cryomodule dimension, making efficient use of the limited space allotted for the crab cavities. These features are recognized to be very important for reducing the technical risk of the crab cavity system from the operational point of view and for upgrading the ILC to 500 GeV and perhaps ultimately 1 TeV.
- The 3.9 GHz crab cavity design as presented is appropriate for the current stage of the project. Its system design including the HOM couplers, the tuners could benefit from the operational 3.9 GHz elliptical 9-cell cavities operated in the TM010 mode with beam at E-XFEL. This may result in significant saving in the development time and cost as well as in the reduction of the technical risk.
- The racetrack cavity has lower order modes which need to be damped. The results presented at this review do not meet their damping specification, but the team expects the input RF power coupler to provide sufficient damping.
- The racetrack shape cavity structure fabrication is expected to be well within the standard sheet metal niobium technology. Its small cavity size may open alternative possibilities as well such as direct machining from niobium ingot.
- A 2-cell cavity design was presented at the Q&A session and the team updated their baseline to two 2-cell cavities for 125/125 GeV. This updated baseline design increases the margin in the operational field and potentially provide flexibility in compensating the clocking errors in one cavity by the other. The lower order mode damping in the 2-cell variant is much improved relative to the 3-cell variant.
- The fabrication plans for prototyping were less defined than some other variants leading to concerns that prototyping would extend past the project defined milestone.

Recommendations:

- Complete the LOM damping simulation with the integrated model including an input RF power coupler.
- Consider direct machining from ingot to reduce prototyping time

2. Double Quarter Wave

Findings:

- The design of the 1.3GHz cavity stem from CERN experience with similar type of cavities at lower frequency (400MHz) in the framework of HL-LHC, and more recently on the EIC development.
- The proposal is presented as a "collection of ideas" but still based on deep past experience on similar type of cavities.
- Optimization on the RF module has been performed taking into account the minimum aperture requirement (25mm) and the maximum allowable surface peak fields.
- A preliminary mechanical stress analysis has been performed taking into account a 3mm niobium plate as base material.
- A concept for the helium tank and the tuning system has been presented based on the HL-LHC experience, the tuning sensitivity and pressure sensitivity are missing.
- Multipole analysis has been presented but should not be an issue for single pass machine
- A concept for alignment system has been presented based of the HL-LHC experience, where they can obtain a 20µm stability between different warm-up and cool downs
- The selected type of FPC is a hook type antenna (B-coupling)
- The optimal coupling around 1x10^7 has been proposed, assuming 50Hz of µ-phonics and 0.5mm of beam offset
- The required power to operate the cavity at its nominal field is about 300W
- HOM study is still at preliminary phase, HOMs were calculated for a bare cavity
- An HOM damping scheme is not yet in place (HOM coupler position and type), only a preliminary analysis has been performed by using a HOM coupler similar to the one used on TESLA cavities, options with a demountable coupler have been shown.
- An attempt of HOM damping with waveguide is on-going
- MP study will be performed only after HOM coupler design and position will be finalized
- The design can reach the requirements of 1.86MV (125/125GeV) with two cavities with about 55% overhead.
- The design can be expanded to (500/500GeV) with 6 cavities.
- The dimension of the cavities would allow it to be machined at least the main body and interfaces, the complete fabrication process will depend on the HOM scheme that will be adopted.
- On the 400MHz version a shape tolerance about +/-300µm was required
- A concept design for the cryomodule has been presented (based on HL-LHC) and respect the envelope requirement, it will use a top load approach.

Comments:

- The design looks very promising, and it is rooted on the past experience of similar cavity shape for HL-LHC. It would be worth it to have more manpower to invest on the development phase
- The cryomodule and cavity alignment method prove to be reliable and robust during HL-LHC prototype test on SPS.

- A complete HOM damping scheme (HOM coupler and position) is still missing, some preliminary result looks promising and potentially compliant with the requirements. The choice of an HOM coupler similar to the one used for the TESLA cavities showed good results, based on a consolidated design. By looking at the first simulation results it seems possible to have just two HOM couplers on the cavity (not three as HL-LHC cavities). A demountable coupler will also ease the chemistry and cleaning of the cavity surface.
- A pre-tuning method has been presented and showed reliable results for the 400MHz cavities, a similar approach could be implemented for the 1.3GHz. This in combination with a machined cavity body should lead to precise frequency control in the pre-tuning phase at warm.
- Despite part of the analysis is missing, the quality of the work presented is very high and encouraging for future applications.

Recommendations:

- Consider securing some extra work force in order to complete a preliminary design, the whole crab cavity community could benefit from this promising concept.

3. RF Dipole

Findings:

- Several variants have been prototyped
- Vertical power test demonstrated capability of reaching the desired target of deflecting voltage, but displayed some MP activity at low fields.
- Bpk and Epk are below the maximum value for ILC with 47% margin in the required gradient when operating with 2 cavities (for 250 GeV)
- Design of FPC and HOM coupler based on the well consolidated TESLA design (already used for LCLS-II)
- HOM transverse impedance below threshold can be achieved with 2 HOM couplers
- Preliminary study of wakefield longitudinal impedance for 0.3 mm bunch length, obtained by extrapolation of simulations for longer bunch lengths
- Different manufacturing options are presented (based on sheet forming and machining)
- Cryomodule and Tuner “conceptual” design presented, basing on previous experience.

Comments:

- The Rf dipole design @ 1.3 GHz comes after a long activity in time on various cavities at lower frequencies (the closest one at 952 MHz)
- 952 MHz cavity, manufactured by sheet forming, suffered of frequency mismatch (+8 MHz). Machining would be preferred for cavity manufacturing
- Some results of simulations need still to be defined, I. e. MP with coupler, wake longitudinal impedance @0.3 mm bunch length
- Piezo tuner is needed, given the high frequency tuning sensitivity – some prototyping of this tuner within the project would be recommended
- real mechanical design of cryomodule and tuner still need to be put on paper (even if the group is confident of having no issues)
- The plan to do a first prototype made in Cu followed by a reactor grade Nb variant is well thought out and will derisk the manufacture – the reactor grade cavity could find use in Phase II synchronization studies at the same frequency
- The suggested sequence of next priorities as presented in the homework session seems logical

Recommendations:

- Define an appropriate (and realistic) time schedule for cavity prototype production and test.
- Complete the simulations for long range wakefields and MP with couplers

4. Wide Open Waveguide

Findings:

(Introduction)

- CERN proposed WOW type crab cavity for LHC&FCC in 2015
- EIC proposed WOW+RFD for 394 MHz

(Cavity)

- 25mm gap between poles
- Beam pipe : 100mm diameter. → cut off frequency of 1.758 GHz for TE11, 2.297 GHz for TM01.
- 168mm longitudinal length of one gap
- 2 cavities per beam will be used for 125/125 GeV with 5 cavities required for 500 GeV with 41.6MV/m for Epk and 73.8 mT for Bpk (5 cavities)
- In the 125/125 GeV case we have 72 % margin when operating at peak values.
- Copper gasket will be set at 257 mm from cavity center.

(HOM)

- Nb waveguide will be set on both beampipe end. Total length can be shorter while comparing with using beam line absorber.
- The design does not use bellows to save space.
- RF loss of fundamental loss is need to be < 0.1 W. Therefore, waveguide 0.245 m long from the beam center.
- One damper unit with three waveguides were set on both ends. HOM damper coax load with RF feedthrough were used with 86mm x 32mm waveguides
- Horizontal impedance max is 0.99 MOhm/m, which is 1/10 of the impedance budget.
- Max longitudinal impedance is 186kOhm per cavity.
- Calculated HOM power: 2.71 V/pC: ~ 1W per cavity up to 8GHz.
- HOM spectrum of two cavities was not calculated yet (super structure case)

(FPC)

- Qe= 1e7 and160W input power is needed for 125 GeV: Qe = 3e6, 850 W, for 500GeV
- Coax window for 40mm port can be used.
- Propose same as LHC DQW HOM window → 3kW TW during 4hours ok.

(Multipoles and multipacting)

- Multipoles calculation was done → we have 8.62V of Vacc at Vt = 1.0MV. it is negligible small.
- No multipacting on dampers was observed up to 1.5MV (calculated by Spark3D)
- Multipacting on cavity body of 4th order appeared at 0.4-0.5MV. This multipacting also exists in LHC & EIC design. But it can be conditioned away.

(Pressure stability and tuning)

- Cavity material thickness is 3mm of Nb.

- Max stress is 28 MPa, which is lower than 43.5 MPa of acceptable stress.
- Tuner is similar with the LHC RFD cavity
- Tuning sensitivity is 10.2 MHz/mm
- Tuning range is 2.5MHz.
- Pressure sensitivity is 725Hz/mbar without tuner and 308Hz/mbar with tuner.
- Lorentz force detuning is -1.51kHz/MV^2

(Fabrication)

- Three dies will be used to fabricate the cavity. One is for cavity, one is for damper unit, and one is for corrugations on the circular pipe

(cryomodule) (preliminary)

- 2 cavities will be install in one cryomodule for 125/125 GeV , 5 cavities for 500/500GeV
- Total length 3.10m for 500 GeV case.
- No bellows for 5 cavities.

Comments:

- WOW cavity design is very simple. We believe that this has a potential for meeting the requirements in the ILC crab installation.
- It is better to complete the cavity design with flanges for waveguide connection.
- This design is based on EIC project where the beam intensity is much higher than the ILC. The design uses the waveguide system that seems more complex compared to HOM coupler. The WOW team needs to consider to match the HOM mitigation to the ILC beam current operation to optimize the solution
- It is better to calculate HOM spectrum with two cavities considering the superstructure
- The WOW team is very small. More resources will be required to successfully carry out the cavity fabrication.
- Cavity tuning sensitivity is a general problem of RFD cavity. A nm scale tuner will need to be developed for ILC crab cavities.

Recommendations:

- Consider optimizing the WOW with simpler damping solutions consistent with the lower beam intensities in ILC

5. Quasi-Waveguide Multi-cell

Findings:

- Proposed Quasi-Waveguide Multicell Resonator (QMiR) has a frequency of 2.6 GHz, 3-cell cavity, no HOM coupler, sparse low Q HOM, no issues with SOM, simple WG coupler.
- QMiR 2.8 GHz prototype cavity was fabricated and tested at 2K. The VT results of 2.8 GHz bare cavity showed 2.7 MV kick, no quench, no MP and Qo = 3 x 10^8.
- 2.6 GHz QMiR is three-cell structure with aperture of 25 mm, length of 500 mm, low surface field, strong SOM and HOM damping to waveguide coupler and beam pipes.
- QMiR HOM damping by stainless steel beam pipe with diameter of 48 mm and length of 250 mm. HOM power is less than 1.2 W.
- Required RF power is Min. 740 W without beam and Max. 1.5 kW with beam & microphonics in QL = 1.3 E+6. Solid state RF amplifier of 3 kW will be sufficient at 100% overhead.
- In multipactor analysis, simulation shows one-side MP on the wall at 26 MV/m and no MP at operating nominal gradient. No multipactor problem was observed in VT of 2.8 GHz prototype QMiR.
- LFD is less than -1.5 kHz and dF/dP is less than 150 Hz/mbar in wall thickness of 4 mm.
- Tuner system is compact double lever tuner with piezo. dF/dL is -34.5 kHz/um and tuning range is 2 MHz in wall thickness of 4 mm.
- In operation at 0.9 MV, Ep is 35 MV/m and Bp is 70 mT. SOM/HOM damped at SS section.
- Cryomodule design is similar to ASTA capture cryomodule at FNAL. Top plate support of the cryo-string and compact design of WG input coupler. Gate-valves at both side of cavity. Alignment tolerance is less than +/- 0.1 mm. Cryomodule size is 1650 x 1000 x 1500 mm.
- Experience of QMiR cavity fabrication in 2.8 GHz prototype. Size of Nb ingot is 80D x 500 mm and weight is 25 kg. Parts are milled with high precision and are joined by EB welding.
- Frequency change from 2.6 GHz to 1.3 GHz is not possible, because efficient HOM damping by beam pipe is difficult.
- 1 TeV option is possible in the present space.
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Comments:

- An almost completed cavity design and compact cryomodule design was presented.
- The chosen solution is very simple – there are no HOM couplers with damping provided at the stainless-steel beam pipes or in the waveguide input coupler – the coupler is also a simple waveguide
- The fabrication by milling from a small Nb ingot material of 80D x 500 mm (25 kg) will reduce fabrication cost and provide a quicker prototyping phase
- There could be some deformation during the welding that may move the rf frequency and external Q

- RF window location is inside insulation vacuum. So, heating of RF window or pumping of air in warm side is necessary.
- It is necessary to confirm that all HOM power can propagate in SS beam pipe of 48 mm diameter.
- More detailed tuner system should be considered.
- One cryomodule with a single 3 cell cavity may represent a higher risk for failure during beam operation.
- A clear procedure for the prototyping plan was presented including future R&D. A strong team for development was presented.

Recommendations:

- Consider ways to increase the margin in the kick voltage through design modifications or increasing the number of cavities per beam. For the 250/250GeV case one cryomodule per beam each with two 3-cell cavities would be preferable for reducing a failure risk in beam operation, would increase the margin in operating Bp and Ep and add the potential for clocking correction via vector-sum

Appendix 1: Review Committee

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Appendix 2: Scoring criteria

Criteria for scoring are listed below. Each committee member judged the various presentations on these 12 criteria.

Cavity design	Prototype development	HOM analysis/ mitigation	Rf ancillaries Tuners/FPC	MP analysis	df/dP
Expected performance, thoroughness of design, characteristic parameters	logic, cost, risk, timeline, can the suggested schedule be reached	thoroughness of analysis, appropriateness/complexity of mitigation	complexity, risk	thoroughness of analysis, issues related to design	evaluation and issues related to analysis
10	10	10	5	5	5

cavity tuning analysis	fabrication process	cryomodule implications	compliance with requirements	ILC500?	Overall risk
thoroughness of analysis, correctness of approach	appropriateness of suggested path - risk/chanllenge	risks, costs, complexity with integration,	margin and risks	Extendibility of design to ILC500	degree of confidence that the proposal will meet the specifications with reasonable cost and effort
5	10	10	10	10	10