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Performance optimization of linear collider operation including accelerating gradient of copper structures and yield of polarized positrons.

1. INTRODUCTION

The International Linear Collider (ILC), once construction starts, will be a very large construction project, thus requiring sophisticated management structures and tools to facilitate smooth cooperation of hundreds to thousands of globally distributed scientists and engineers.

Since the ILC has first been proposed to be built in Japan, there has been a change in the project's initially proposed centre-of-mass energy, which has been changed to 250 GeV. ICFA/LCB now has adopted a so-called staging approach for the ILC, with a start-up energy of 250 GeV as baseline ("ILC250"). Future energy upgrades to 350 and 500 GeV later in the lifetime of the machine are still discussed by the scientific commnunity. At the same time, the luminosity of the machine has been increased, which required detailed assessment of the beam-related backgrounds in the detectors and their potential impact on the physics programme. Various staging scenarios have been discussed for the initial tunnel design focussing on the tunnel length (options A, B, C) and also on an increased acceleration gradient of 35 MV/m instead of 31.5 MV/ m (options A', B', C') [1]. The status and realisability of all the options beyond the baseline ILC250 – in case this gets approved – is unclear. The increased gradient both reduces the required number of cavities and potentially also the necessary tunnel length.

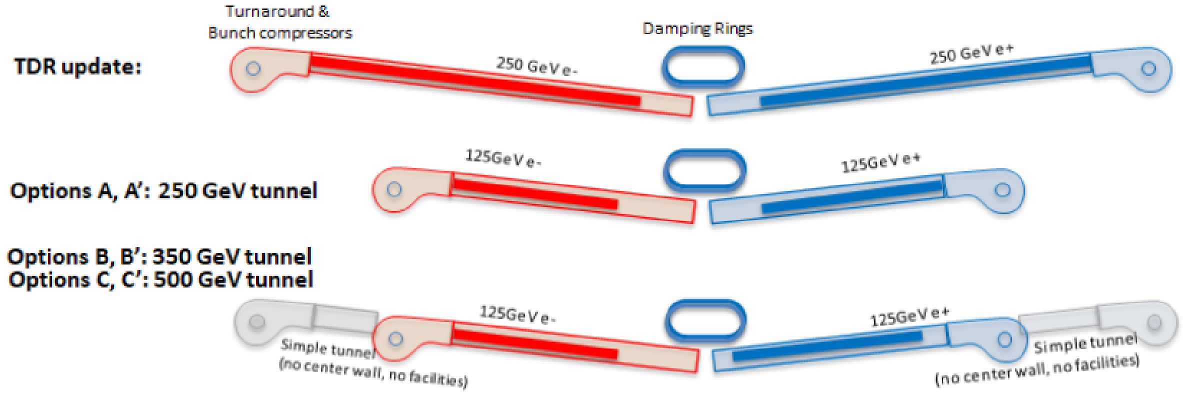

Figure 1: The staging scenarios for the ILC project, starting with the ILC250. The updated TDR design with a 500 GeV machine is shown on the top. Options A, B and C focus on the tunnel length only, while A', B,'C' also consider an increased acceleration gradient of 35 MV/m instead of 31.5 MV/ m [1].

Currently, the international community is eagerly waiting for a statement from Japan that clarifies whether or not Japan is willing to host the ILC. It is now understood, that the timescale of such a statement will be before the end of 2018, so it can still be part of the discussion for the next update of the "European Strategy for Particle Physics", which will start in 2019. The updated strategy is scheduled to be published in May 2020.

Further optimization as envisioned in the original plan will happen once there is a positive decision from Japan, a final site decision and an international agreement on the scope of the ILC project.

All these activities have been supported by E-JADE secondments, and this support has been crucial for many aspects of these studies.

2. THE 250 GEV ILC AND POTENTIAL FUTURE UPGRADES

In 2017, discussions started to stage the ILC project, by not starting at a centre-of-mass energy of 500 GeV right away, but to start at 250 GeV and operate as a Higgs factory for an extended period. This staging approach was also driven by the potential cost reduction, which is in the order of a third of the entire project. The 250 GeV baseline machine would then be approved stand-alone, with potential future upgrades being part of later proposals, quite similar to the HL-LHC project.

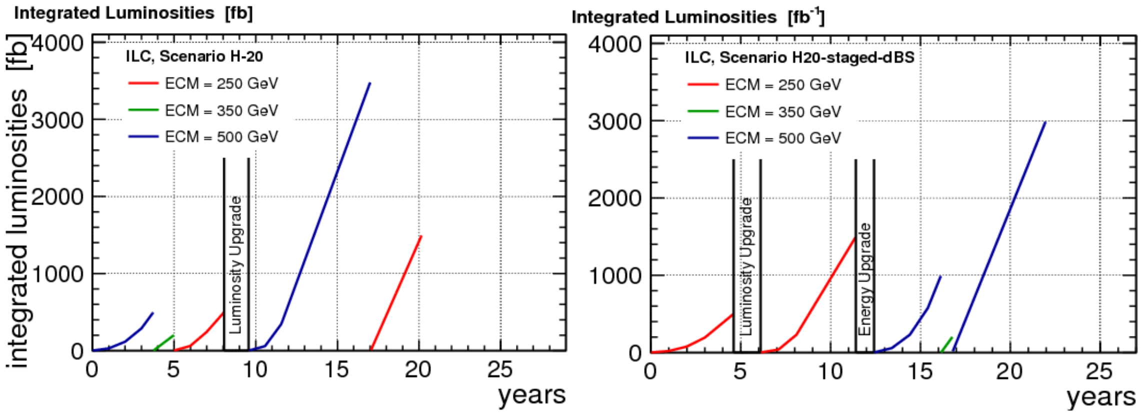

Figure 2: The initial H-20 scenario [1] with a start-up at 500 GeV and a luminosity upgrade later in the run (left) and the staging scenario [2] with a start-up at 250 GeV and a luminosity upgrade before a final energy upgrade will push the machine to 500 GeV.

The original running plan (the so-called “H-20” scenario [1]) is shown in Figure 2 (left), while the adapted staging scenario is shown in Figure 2 (right) [2]. It shows the start-up of the ILC at 250, then a luminosity upgrade after 5 years and – as an outlook into an undefined future –an energy upgrade after 12 years to reach a centre-of-mass energy of 500 GeV.

This change in the running plan and the operation scenarios has a significant impact on the physics potential and the background conditions. This will be discussed in sections 2.1 and 2.2 of this report.

2.1. RE-ASSESSING THE ILC PHYSICS CASE

The staging scenario implies that the physics case will have to be explicitly re-assessed with respect to the 250 GeV baseline that is currently seeking approval by the Japanese government. The compelling argument for running at 250 GeV is of course the precision measurement of the Higgs-boson properties and, in particular, the measurement of all its branching ratios. This is highly complementary to what is possible at with the HL-LC programme. The strength of the ILC at 250 GeV lies in the model-independent analysis of the Higgs couplings, which is not possible at the LHC or HL-LHC, where constrained fits using model assumptions are necessary. The potential of the ILC250 is shown in Figure 3, which illustrates the improvements possible by including the ILC 250 GeV data in these fits.

Clearly, the Higgs-factory mode possible at the ILC with a 250 GeV centre-of-mass energy gives almost an order of magnitude increase on the coupling precision for most decays or even facilitates first measurements of the couplings (like that of the Higgs boson to the charm quark). All these results could be achieved in a model-independent way.

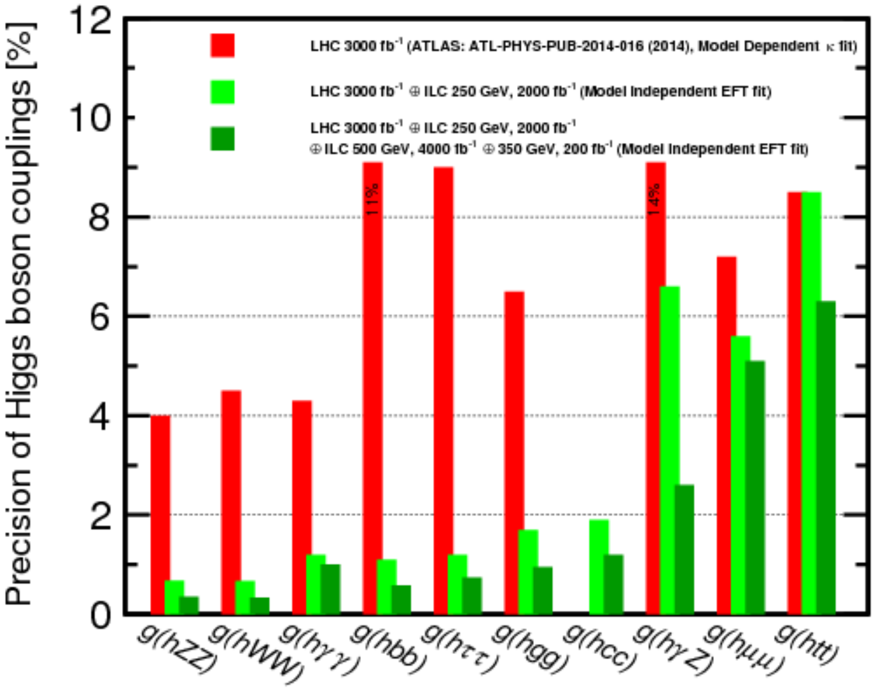

Figure 3: The projected accuracy on Higgs-boson couplings as presented in [2].

New physics may manifest itself by deviations of the Higgs-boson couplings compared to the expected Standard Model values. The energy scale of the new physics that can be probed is tightly related to the coupling precision: a reduction of an order of magnitude in coupling accuracy roughly corresponds to an order of magnitude increase in the energy scale that can be probed.

This approach is nicely illustrated in Figure 4, where the χ^2 separation of the SM and various "Beyond the Standard Model" scenarios is shown together with the accuracy of separating these models from each other. Over a large range, already the ILC250 can exclude or discover new physics scenarios with quite good accuracy, in many cases exceeding the necessary 5σ discovery limit.

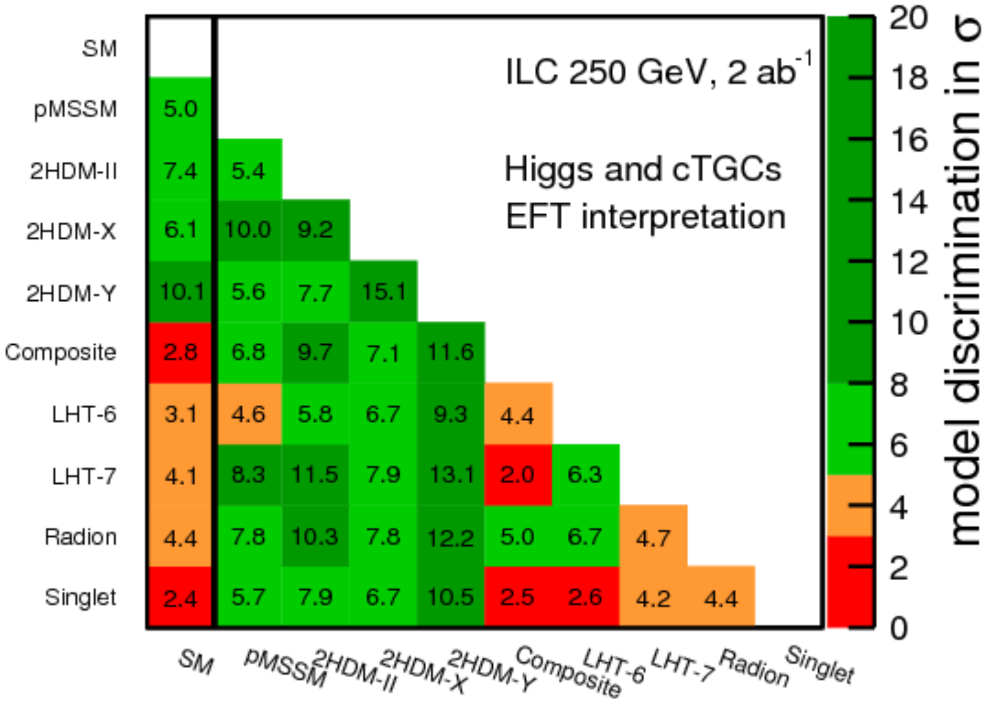

Figure 4: The χ^2 separation between the Standard Model and several "Beyond the Standard Model" scenarios with the ILC250 dataset. Figure taken from Ref. [2].

From the work presented in Ref. [2], it is clear that the physics case for a 250 GeV stand-alone programme is strong and more than justifies the construction of such a machine.

2.2. ILC250 BEAM BACKGROUNDS

Given the various luminosity upgrades required to reach the projected performance, detailed re-assessments of the beam backgrounds had to be made in order to approve the new beam parameter sets. This required combining accelerator and detector simulations, and for these studies the SiD detector was used as an example.

Three new parameter sets were studied in detail (see Figure 5), and the impact of the increased background levels on the SiD detector were studied.

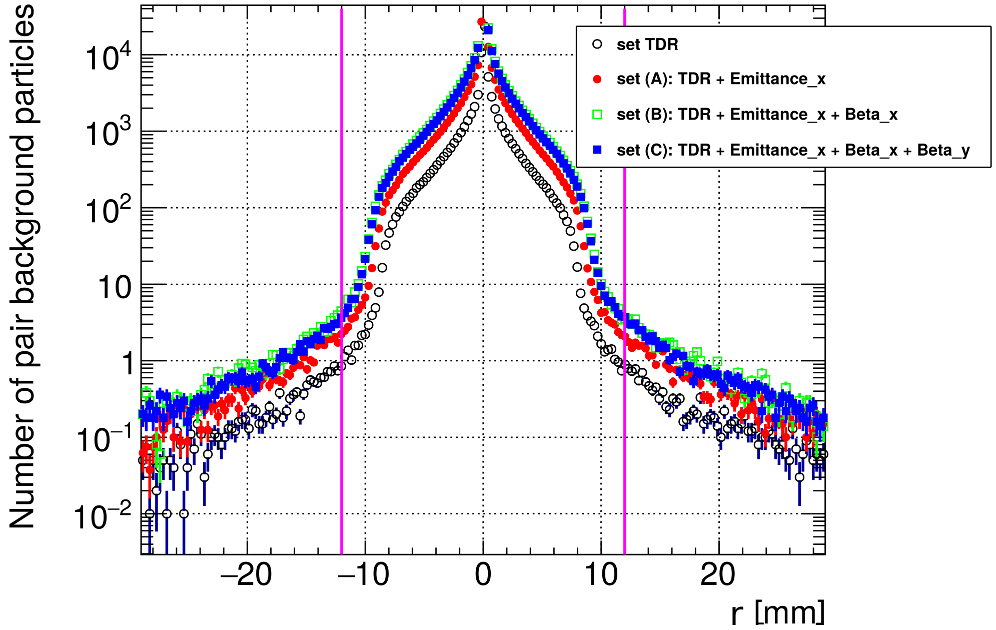

Figure 5: The number of particles generated by the beam background due to pair production. The TDR baseline is compared to three different parameter sets with increased luminosities (A, B, C). The pink line denotes the location of the beam pipe in the SiD Detector [4].

Based on these studies, the parameter set A’ was chosen as the new baseline for the ILC250. The so-called pair background is not the only background currently being studied. Halo muons from the beam collimation system and the neutron background stemming from the beam dump also form very important background sources.

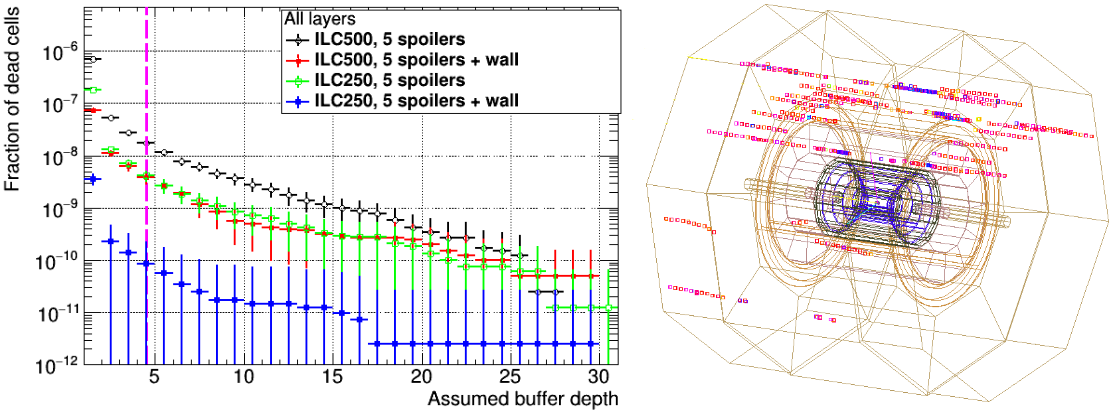

Figure 6: Left: The occupancy in the SiD detector with two shielding scenarios both for ILC250 and ILC500. Right: A typical event display of a set of halo muons traversing the SiD detector [4].

Muons are generated mainly in the collimators close to the interaction point (IP). Those muons that propagate towards the IP tend to be mostly parallel to the beam pipe. Given that these are highly energetic muons, they penetrate the detector leaving parallel tracks. This is a significant background source and hence several shielding options were studied. This includes a set of massive 5 m long magnetized spoilers and also a magnetized shield wall to further deflect the muons. From the studies it is clear that the combination of both shielding elements is most effective (see Figure 6).

Neutrons from the beam dump are another source of detector background. When the electron and positron beams are dumped 300 m downstream of the IP, a huge number of low-energy neutrons are created (see Figure 7). A fraction of these then propagates to the detector via the post-collision beam line. Since there is quite a distance between the dumps and the IP, the neutrons will hit the detector only around 180 microseconds after the bunch has hit the dump.

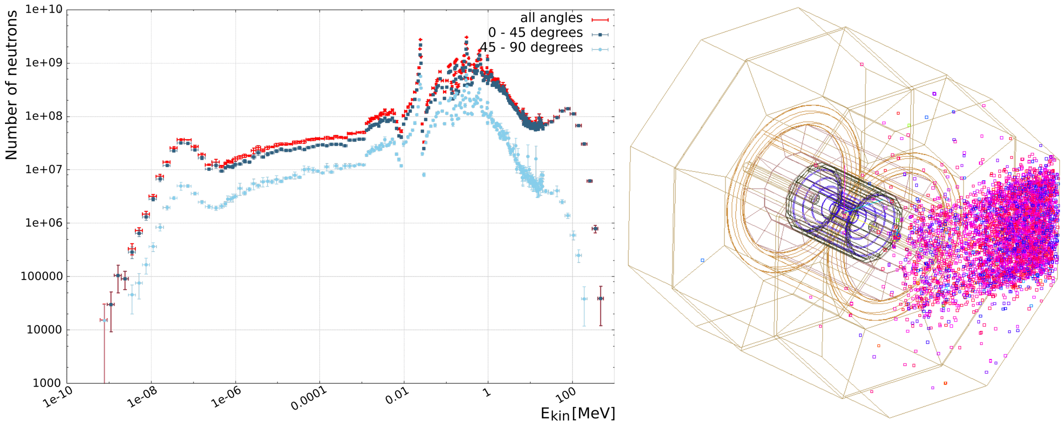

Figure 7: The energy spectrum of the neutrons leaving the beam dump through the entrance window (left) and the neutron flux from one dump hitting the SiD detector (right) [4].

3. POLARISED POSITRON SOURCE

During the staging discussions, the necessity of positron polarisation has been discussed again. The TDR design for the 500 GeV ILC included an electron polarisation of 80% and a positron polarisation of 30%. For the 250 GeV machine, this was discussed again as the TDR design of the undulator-based polarised positron source may not be appropriate for the ILC250, and an alternative approach of classical positron source without polarisation has been put forward again. Therefore, the physics impact of positron polarisation needs to be clarified again as shown in e.g. Ref. [5].

As an example, the potential improvements for the Higgs-boson coupling measurements are shown in Figure 8. It should be noted that this result is based on scaling the statistical errors and assuming that the systematic effects remain the same for all the discussed scenarios. As is pointed out in Ref. [5], especially for the no-polarisation case an increase of the systematics is expected.

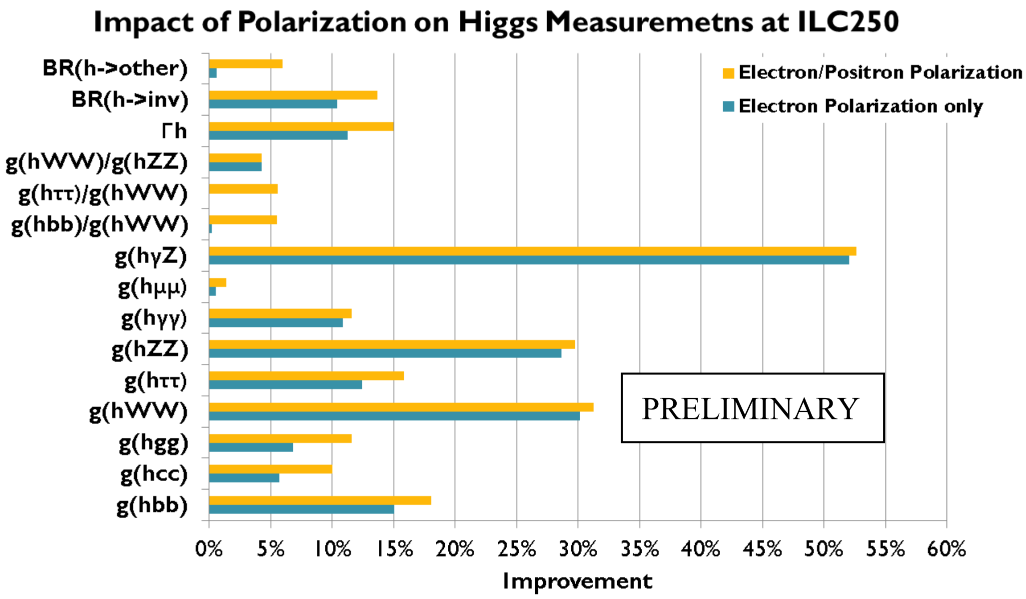

Figure 8: The potential improvements due the electron and electron/positron polarisation based on Ref. [5].

The use of polarisation reduces the average running time and hence the operation costs for the same achievable precision by about 20%. Besides the direct impact on the measurements, positron polarisation gives an additional handle to study systematic effects, particular if small deviations need to be studied, and it adds additional information to parameters fits [5].
Searches for new physics also benefit significantly from the presence of positron polarisation.

4. HIGH GRADIENT STRUCTURES

The issue of high accelerator gradients is pursued for all accelerators, circular or linear. Related to ILC the use of super-conducting RF structures is studied and developed in great detail (E-JADE WP3). Here, we briefly comment on common work between European groups and KEK-Japan on normal-conducting RF structures at X-band frequencies (~12 GHz is used), where KEK has been and remains a key partner and developer, see Fig. 9. Normal-conducting structures can reach 100 MV/m gradients with usable pulse-lengths (~200 ns) and acceptable breakdown rates. R&D on such structures are carried out to further optimize the basic design, reduce constructions costs, and understand the basic mechanism limiting further increases of the acceleration gradient.

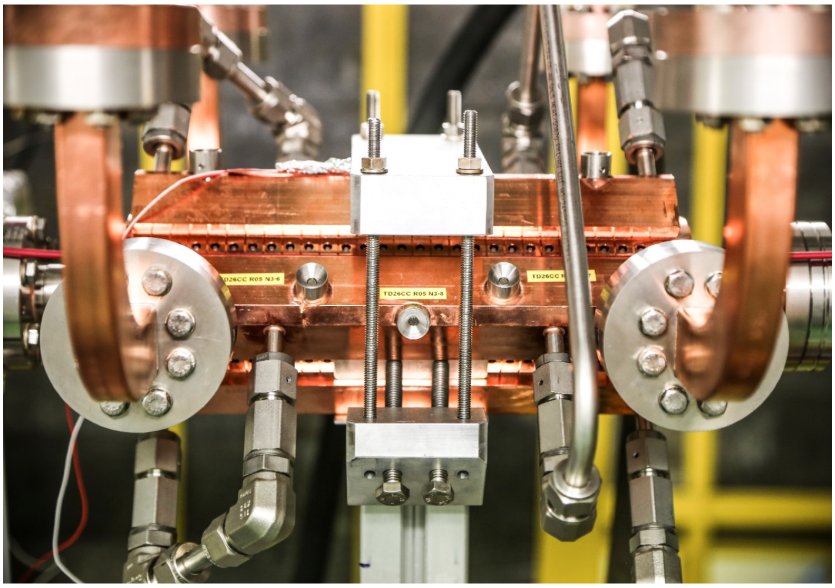

Figure 9: X-band RF structure.

The KEK NEXTEF facility (Fig. 10) carries out a test programme for X-band single cells and complete structures. The samples tested are developed in-house, in Japanese industry or with international partners, most notably SINAP (Shanghai Institute of Applied Physics) and Tsinghua University in Beijing. The overall programme is carefully coordinated with similar tests and sample developments at CERN, SLAC (Stanford) and PSI. The E-JADE programme is used extensively and consistently to support the necessary exchange of personnel to carry out the common R&D programme. More details about the R&D can be found in Ref. [6].

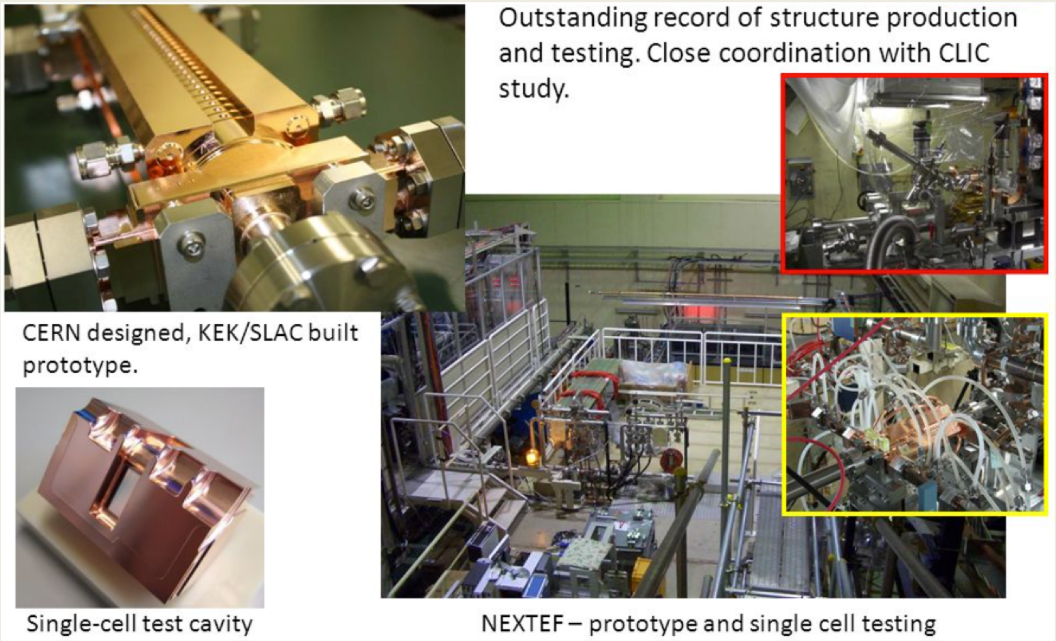

Figure 10: The NEXTEF test-system at KEK has been, and remains, one of the most central development centers for X-band technology for a decade, see summary of test results in next Figure 11.

The results of X-band structures tests at KEK and CERN showing the importance of the collaborative R&D between the partners are summarized in Fig. 11. The results are combined to provide an overall picture of the performance of the technology and how R&D can be used to optimize design, processing and test-procedures for X-band high gradient structures.

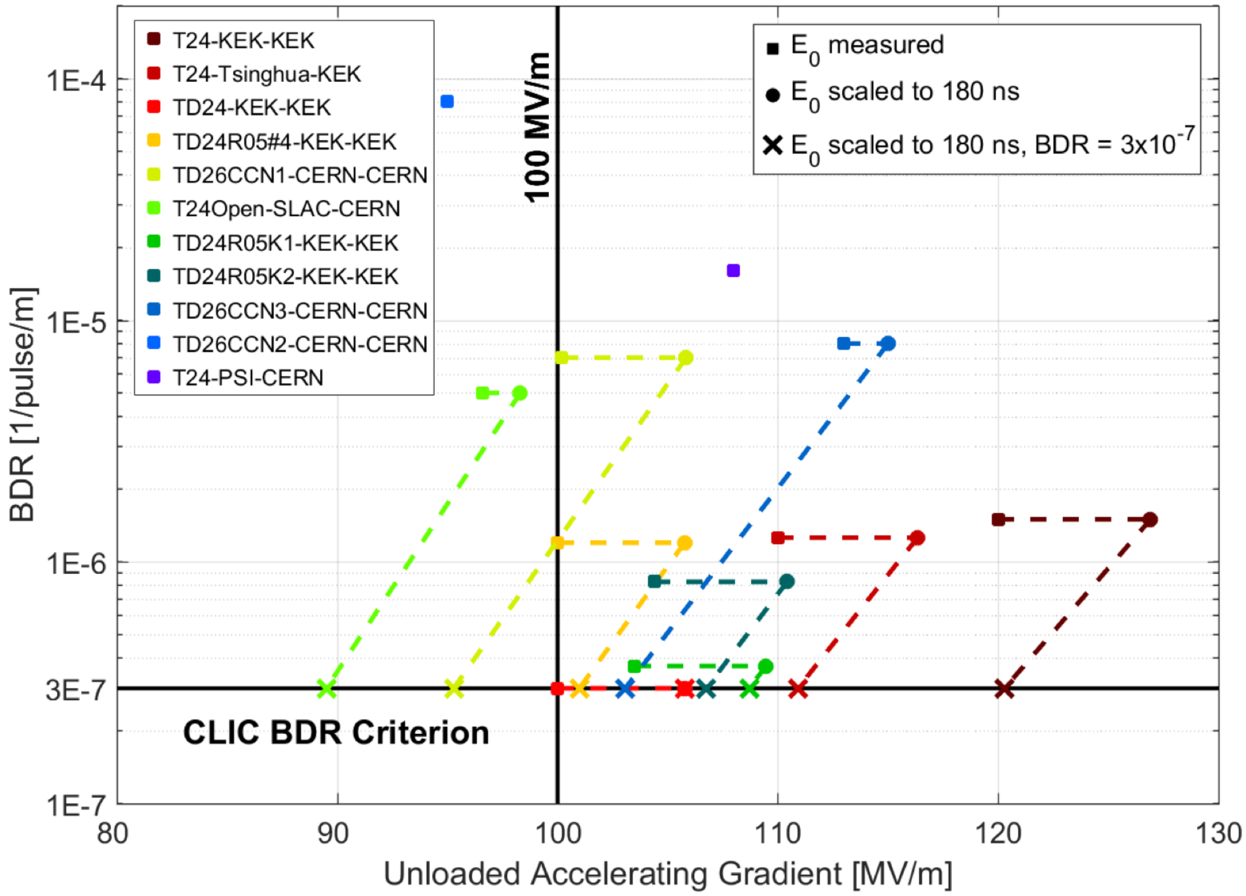

Figure 11: The performance of X-band structures can be characterized as achieved gradient (MV/m) at a given breakdown down rate (BDR/pulse/m) at the appropriate pulse length (180ns).

5. FUTURE PROSPECTS

The entire community eagerly awaits the outcome of discussions in Japan and the consecutive deliberations during the European strategy process. E-JADE has supported many studies and has put European physicists at the centre of many issues that will need to be addressed and studied in detail once the ILC moves ahead.

6. REFERENCES

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