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ESS AD Technical Note  
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Accelerator Division

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**The ESS Cryomodule Design:  
Change towards a Segmented Linac**

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## Current Baseline

The cryomodule concept in the 2011\_11\_23 linac baseline, as described in the CDR, is a hybrid between segmented and continuous cryostats. The hybrid cryomodule design consists of separate modules with an independent, external cryogenic distribution line, while using interconnecting sleeves between the modules to provide continuous cryogenic temperatures and an isolation vacuum between cryomodules, see Figure 1.

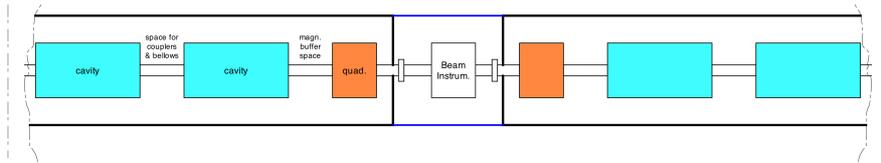


Figure 1: hybrid design schematic

Our latest considerations have shown a number of disadvantages of the hybrid design. The main issues are the significantly more complicated mechanical design and cryogenic flow scheme as well as the increased production cost associated with the increased complexity.

A secondary issue is the type of quadrupoles that can be used in the utility sections between cryomodules: in a hybrid design, the quadrupoles must be superconducting (SC), because there is no warm space for normal conducting (NC) magnets - whereas in a segmented design, the quadrupoles can either be SC magnets located inside the cryomodules or NC magnets located in the warm utility section.

## Alternatives

This Technical Note shows the major criteria that need to be considered when deciding whether to replace the hybrid design by a segmented design, which consists of a string of cryomodules separated by utility sections at room temperature.

The designs being compared are therefore:

Design 1: hybrid design

Design 2a: segmented design with warm NC quadrupoles, see Figure 2

Design 2b: segmented design with cold SC quadrupoles, see Figure 3

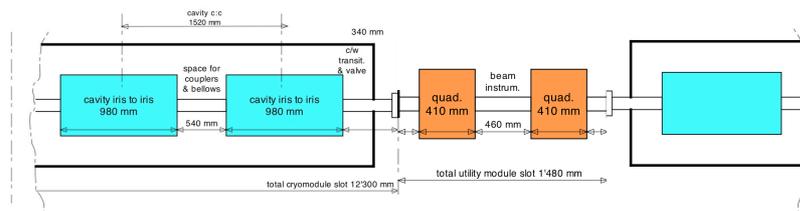


Figure 2: segmented design - warm quads

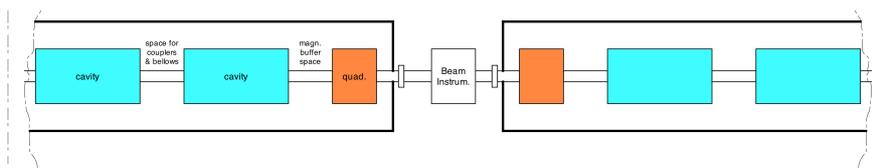


Figure 3: segmented design - cold quads

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## Decision criteria

List of criteria:

- Cr.1. Heat load: What is the expected heat load reduction in a hybrid cryomodule ?
- Cr.2. Design: What is the expected increase in effort for the design of a hybrid cryomodule ?
- Cr.3. Alignment: What is the expected decrease in alignment precision for SC quadrupoles in a hybrid cryomodule vs warm quadrupoles outside a segmented module ?
- Cr.4. Length: What is the expected effort for adapting the existing manufacturing facilities and transport infrastructure to a hybrid 8-cavity cryomodule ?

## Discussion

### 1. Heat Load

A separate study (see ESS AD Technical Note ESS/AD/0028) of the heat loads on two of the three design alternatives shows that:

- a) using the hybrid design, there is no heat load reduction expected w.r.t. the segmented design - the hybrid design might even have a higher heat load than the segmented design;
- b) the explanation for b) is that the cold beam pipe in a hybrid cryomodule is longer than in a segmented module - the cold part of the hybrid module receives therefore more of the beam's heat load which is approximately evenly distributed along the beam pipe;
- c) with the currently available rough estimates for beam losses, it is not possible to give more precise values for beam induced heat load.

### 2. Design

There are at present no studies of the hybrid cryomodule principle and no designs. It would take considerable efforts - in the order of many man-years - to bring the hybrid design to the point where segmented cryomodule design is today. There are many different segmented designs to choose from, and a lot of conceptual and experimental work has been done in the last decades. Segmented cryomodules have successfully been built and deployed in a number of accelerators.

### 3. Alignment

SC quadrupoles in design alternatives 1 and 2b are housed inside the cryomodules and suffer therefore a number of disadvantages concerning alignment:

- a) the quadrupoles are inaccessible once the cryomodule has been closed and cooled down - this means that they can not be actively aligned;
- b) the cryomodule structure is optimised for heat load reduction by minimisation of structural cross sections, which is detrimental to dimensional stability - this means that the quadrupoles are susceptible to misalignment during cooldown.

Presently, there are no values available for the permitted alignment tolerances, so a quantitative evaluation of the alignment issues of SC quadrupoles can not be made. However, the disadvantages listed above speak clearly against the hybrid design.

### 4. Length

The series production of the elliptical cryomodules for ESS is foreseen to re-use the existing XFEL infrastructure, namely the clean rooms at Saclay. The admissible maximum length for a cryomodule to be assembled in the biggest clean room in Saclay is around 12.5 m. The hybrid version of the high-beta elliptical cryomodule with 8 cavities would have a length of 13.8 m, so it would not fit in the clean room. Modification of the clean rooms is (i) very costly and (ii) not possible without major structural changes in the production hall - which are also very costly and possibly not even feasible. Furthermore, there are limitations on the length of goods transported by road, which result in increased cost and complexity for loads longer than 13.7m.

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## Conclusion

The hybrid cryomodule design was initially conceived to reduce heat load on the cold parts of the linac. This Technical Note shows that there are no significant heat load gains possible. A list of other criteria weigh against the hybrid design, while no arguments for it have been found. Given the option of warm utility sections between the cryomodules, NC quadrupoles are to be preferred over SC quadrupoles.

## Recommendation

It is therefore our recommendation to abandon the hybrid cryomodule design and to introduce a segmented cryomodule - with normal conducting quadrupoles in the warm utility sections - for the next iteration of the linac layout.

Lund, 2012-02-07  
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