DEVELOPMENTS AND PROGRESS WITH ESS ELLIPTICAL CRYOMODULES AT CEA-SACLAY AND IPN-ORSAY

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• Introduction and context
• ESS elliptical cryomodule description
• Medium beta cryomodule demonstrator M-ECCTD
  – Cavities and couplers individual performances
  – Cryomodule assembly
• High beta cryomodule demonstrator H-ECCTD
• Series cryomodule production preparation
  – Procurement plan
  – Series power couplers RF conditioning
  – Series cryomodules integration plan
• Conclusion
ELLIPTICAL CRYOMODULES IN THE ESS LINAC

Proton Beam

ELLiptical cavity cryomodules = 55% of the linac length

<table>
<thead>
<tr>
<th>MEDIUM-β</th>
<th>HIGH-β</th>
</tr>
</thead>
<tbody>
<tr>
<td>β</td>
<td>0.67</td>
</tr>
<tr>
<td># CM</td>
<td>9</td>
</tr>
<tr>
<td>Cav./CM</td>
<td>4</td>
</tr>
<tr>
<td># Cav.</td>
<td>36</td>
</tr>
<tr>
<td>CM L [m]</td>
<td>6.584</td>
</tr>
<tr>
<td>Sector L [m]</td>
<td>77</td>
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</table>
COLLABORATIONS

• Cryomodule requirements and interfaces
• Cryomodule transport
• Cryomodule test stand
• Tunnel installation and operation

• Cryomodule and cavity design
• M-ECCTD and H-ECCTD construction and test
• Series cryomodule components procurement and assembly
• Series couplers
• Cryomodule test stand

• Medium Beta Cavity design
• Medium Beta Cavity procurements
• Medium Beta Cavity vertical tests

• High Beta Cavity procurements
• High Beta Cavity vertical tests

• Cryomodule engineering design
• M-ECCTD cryostat components procurements

• Cavity horizontal test
ELLIPTICAL CRYOMODULE MAIN FEATURES

- 704 MHz, 3.6 ms RF pulse at 14 Hz
- $\text{Eacc } = 16.7 \text{ MV/m (MB) and } 19.9 \text{ MV/m (HB) (Epeak } = 40/44 \text{ MV/m)}$
- $Q_0 > 5e9$ at 2 K
- Fundamental power coupler: 1.1 MW peak, 55 kW avg.
  - $Q_{ext} = 7.5e5$
  - Coaxial type, single window, fixed coupling
- Mechanical slow tuner (600 kHz range, 1 Hz resolution)
- 1+1 Piezo fast tuner
- No HOM couplers

- Spaceframe concept (JLAB/SNS)
- Segmented design
- Similar design for medium and high beta cavities
M-ECC Ted CAVITIES PERFORMANCES IN VERTICAL CRYOSTAT

- All cavities chemically treated with BCP
- Three cavities reach the ESS specification
- Very good Q0 at low field for CEA cavities, very good accelerating gradient for LASA cavity
- Origin of this Q drop is not fully understood, but probably due to field emission and secondary emission effect inside inner cells (triggered by surface quality obtained after chemical treatment)
M-ECCTD POWER COUPLER RF CONDITIONING

- Coupler pairs mounted on stainless steel air cooled coupling boxes in clean room
- Baking at 170 °C
- Multipactor regions found at 100, 300 and 900 kW during power ramping but easily conditioned without the use of the DC bias system
- Three pairs have been successfully tested for now
First validation of assembly toolings and assembly procedures
Integration until the vacuum vessel
M-ECCTD CRYOMODULE CLEAN ROOM ASSEMBLY

- Performed in the ISO4 Saclay clean room
- Nitrogen venting and slow pumping during assembly process, XFEL type aluminium gaskets
- Cavities pre-aligned, under vacuum before rolling out of the clean room
Welding of the titanium diphasic line

Assembly of the MLI, magnetic shields, cold tuners and cryogenic piping
CAVITY STRING INSERTION INSIDE THE SPACEFRAME

- Thermal shield preliminary prepared with MLI and instrumentation, and fixed on the spaceframe
- Spaceframe aligned with cavity string before insertion

May 2017
CAVITY STRING MASS TRANSFER ON THE SPACEFRAME

- Assembly of the cavity tie rods
- Cavity alignment
- The clean room cavity posts can be removed
SPACEFRAME INSERTION INSIDE THE VACUUM VESSEL

- Jumper connection assembly
- Cryogenic connections at the cryomodule extremities
- Leak check of all the cryogenic circuits
Last assembly operations: atmospheric compensation system on coupler flanges, doorknob transitions

- Beam line and insulating vacuum pumping
- Instrumentation cabling, cryogenic and waveguide connections
- First cooldown to 2K and warm conditioning of couplers are planned in July / August 2017
H-ECCTD CRYOMODULE PROCUREMENT STATUS

- **Five new high beta cavities ordered at Research Instrument GmbH** (deep drawing of half cells and RF controls in progress)
- Four RF windows and antenna already available. New external conductors (copper plated) recently manufactured
- Magnetic shields, cold tuners, motors, piezo-actuators, internal RF cables and titanium bellows available
- Titanium diphasic tubes procurement anticipated
- Inter-cavities bellows and cold warm transitions, 2K heat exchanger, cryogenic piping and the internal instrumentation procurements to be launched
- All the other cryomodule components are procured as pre-series of the series cryomodule contracts. The vacuum vessel, spaceframe and thermal shield have been ordered, with deliveries expected for the first quarter of 2018.

➢ Cryomodule design improvements, limited to minor changes after lessons learnt from M-ECCTD assembly
HIGH BETA PROTOTYPES TESTED IN 2014

ESS prototype cavities $\beta=0.86$

P01 vs P02  @ 2K

Limited by the cavity performances, quench ??

Limited by RF power
$P_{\text{inc}} = 330\, \text{W}$
@ 24.9 MV/m

$Q_0$ Processing from 10 to 15 MV/m

$Q_0$ vs Accelerating gradient (MV/m)  @ Beta=0.86

- $Q_0$ P01 @2K 26/06/2014
- $Q_0$ P02 @ 2K 18/09/2014
- $Q_0$ iso $P=100\, \text{W}$
- $Q_0$ iso $P=50\, \text{W}$

ESS specifications in cryomodule
• Cryomodule components procurement:
  – Divided in several procurement contracts adapted to the skills of the companies

• Cryomodule assembly:
  – Assembly rate of one cryomodule per month
  – Will be performed in the former “XFEL Village” which becomes officially now the “ESS Village”
  - Fully dedicated to the ESS cryomodule (no interference with other projects at Irfu)
  – Will be done by an industrial partner on CEA Saclay site, under the supervision of CEA team
    - The contract include an industrialization phase and training on the first cryomodules
    - Include clean room cavity string assembly, roll–out activities, alignment and cryostating (XFEL like)

• Cryomodule tests at CEA:
  – Will be done on the three first series MB and HB cryomodules only
  – These tests are mandatory to have a fast feedback on the quality of the cryomodule assembly
PROCUREMENT PLAN

- Procurement plan deals with 40 contracts of ~1 M€ average for the cryomodule workpackage
- 32 contracts dedicated to components procurement
  -> with 19 contracts for specific machining/manufacturing systems
- 60% of the tenders have been published and 20% awarded
- Some critical tenders are in stand by and wait for the first cryomodule testing

<table>
<thead>
<tr>
<th>Contract title</th>
<th>Qty</th>
<th>Company</th>
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<tbody>
<tr>
<td>1 Vacuum vessel</td>
<td>30 + 2</td>
<td>ACPP</td>
</tr>
<tr>
<td>2 RF Couplers</td>
<td>120</td>
<td>PMB</td>
</tr>
<tr>
<td>3 Tuners (mechanical parts)</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>4 Stepper motors for tuners</td>
<td>120+2</td>
<td>PHYTRON</td>
</tr>
<tr>
<td>5 2K Heat exchangers</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>6 Coupling boxes for coupler conditioning</td>
<td>12 + 3</td>
<td>SDMS</td>
</tr>
<tr>
<td>7 Diphasic pipes, cryogenic circuits</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>8 Intercavity belows / cold warm transitions</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>9 Titanium belows for diphasic lines</td>
<td>31</td>
<td></td>
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<tr>
<td>10 Cryomodule assembly at CEA Saclay</td>
<td>30</td>
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<tr>
<td>11 Spaceframe</td>
<td>30 + 2</td>
<td>SDMS</td>
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<tr>
<td>12 Magnetic shieldings</td>
<td>120</td>
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<tr>
<td>13 Thermal shieldings</td>
<td>30 + 2</td>
<td>SDMS</td>
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<tr>
<td>14 Multi Layer Insulation</td>
<td>31</td>
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<tr>
<td>15 Screws set (for clean room assembly)</td>
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<td>16 Piezo for tuners</td>
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<td>17 Cavity supports</td>
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<tr>
<td>18 RF cable</td>
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<td>19 RF feedthrough</td>
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<tr>
<td>20 Aluminium gaskets</td>
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<td>21 Copper gaskets</td>
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<td>GAVARD</td>
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<tr>
<td>22 Internal instrumentation</td>
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<tr>
<td>23 Vacuum gauge for couplers</td>
<td>120</td>
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<tr>
<td>24 Cryogenic valves</td>
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<tr>
<td>25 Thermal sensors (Cernox)</td>
<td>325 + 480</td>
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<tr>
<td>26 Safety valve</td>
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<td>27 Pressure sensor</td>
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<td>28 Controled safety valve</td>
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<td>29 Rupture disks</td>
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<tr>
<td>30 Vacuum components</td>
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<td>31 Helium level sensor</td>
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<td></td>
</tr>
<tr>
<td>32 Thermal braids</td>
<td>31</td>
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Order placed
Tendering launched
Tendering in stand by
Shared procurement with ESS
Tendering process in preparation
- 120 couplers shall be RF conditioned at CEA in the next 3 years
- Two coupler pairs will be powered in parallel in a clean testing area (except when a cryomodule is under test)
NEW 704 MHZ RF SOURCE FOR POWER COUPLERS RF CONDITIONING

- Contract launched in July 2016 with THALES
- Installation of components will start in July 2017
- Fully operationnal in October 2017

1.6 MW – 704 MHz klystron
Modulator capacitor bank
RF pre-amplifier
Control rack
- Workstations definition is finalized
- Assembly tooling design upgrade is in progress
CONCLUSION

• CEA Saclay and IPN Orsay are developing together high gradient / high power / long pulse cryomodules for the ESS elliptical cavities

• Important effort to conduct four activities in parallel:
  - first prototyping phase: final assembly and RF tests of the medium beta demonstrator will occur this summer 2017
  - fabrication of a second high beta cryomodule demonstrator in progress
  - Anticipation of the series component procurement with more than 60% of contracts launched
  - Preparation of the industrialization phase of the series cryomodules assembly with an industrial partner
Thank you