Crab cavity test installation in SPS

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LHC Performance Workshop (Chamonix 2016) session 7, 28th January 2016
Outline

Where & what do we install?
- Integration in SPS layout
- General architecture
- Open issues

When do we install?
- General planning and milestones
- Activities in (E)YETS2016 and 2017
- What is being done in YETS2015 for planning
- Open issues

How do we use it?
- Commissioning scenario
- Test program outline
- Open issues
Test motivation and priority

PDR/TDR October 2015

- **Commission** crab-cavities in operational conditions with proton beams
- Study **failure** modes and system **reliability** during operation with beam;
- (Prove crab-cavities can be **transparent** to beam);
- **Probe** crab-cavities with high-intensity proton beams;

**Series production for HL-LHC launched only after validation in SPS**

Cryomodule test in SM18 required prior to installation, to guarantee the feasibility of SPS tests

NB
Where & What?

CCCM = Crab-Cavity Cryo Module
Integration in SPS layout - rationale

- Overall ~10m available drift length
- Least interference with operation;
- Integration of large equipment: wider tunnel cross section
- Aim at a permanent SRF test bench with beam
  - Limited radiation dose: test equipment, may need extended dwelling time
  - Accessibility
- Alcove
- Wider cross section
- VVS: vacuum sectorization
- Fast valve: obsolete
- New TPSG + cardan in LS2
System architecture

Cable and pipework length: ~150-200m

Cold-box + SPS fire safety

CCCM

200 m²

65m
System architecture - overview

- **Cryo Service Module**
  - 2x Helium pumps (2K) and heater
  - Buffer tank (Dewar)
  - Cryogenic Transfer Line 65m φ400
  - Flex line 5m φ200 $R_{bend}=1m$

- **Cryo Cavity Cryo Module**
  - 2 cavities, one type

- **RF Power Circulators Loads**

- **Warm compressor**
  - HP-LP Warm pipework 180m φ100

- **Cryo Cold-Box**

- **Tetrode**
  - Shaft
  - Coax cables

- **BA6 tunnel**
System inventory and architecture - tunnel
System inventory and architecture - tunnel

Supporting and moving table
System inventory and architecture - tunnel

Supporting and moving table
Y-chambers and by-pass
System inventory and architecture - tunnel

Cryogenics:
Service Module

Supporting and moving table
Y-chambers and by-pass
System inventory and architecture - tunnel

Cryogenics:
Service Module

Service Module and CCCM are connected together also in SM18 for cold tests

Supporting and moving table
Y-chambers and by-pass

Crab-Cavity CryoModule
CCCM+ Service module
System inventory and architecture - tunnel

Cryogenics:
- Service Module, connected to Dewar via a flexible line
- Helium pumps for 2K
- Transfer Line to cold-box

Supporting and moving table
Y-chambers and by-pass

Crab-Cavity CryoModule
System inventory and architecture - tunnel

Alignment & survey
4 BCAMs for alignment

Survey pillar for referenced installation of optical equipment

Pilier géomètre

BCAM Implanté en position Travail
Vacuum Layout in LSS6

- 2x VVS beam vacuum sectorization valves, interlocked
- Y-chambers and by-pass chamber
- NEG on Y-chambers, to reach $10^{-12}$ mbar on the CCCM
- 4x valves to preserve NEG conditioning when removing CCCM
RF power
Waveguides
2x Circulators
2x Loads
Connection to RF Power amplifiers in BA6 by co-axial cables (80kW max)
Integration issues

Cold-box and cryo transfer line integration with SPS fire safety system, including **fire door** sectorizing the shaft

Routing of (not so) flexible coaxial cables and cryo transfer line

Integration with new TPSG and Cardan chamber …

…and with (potential) additional BPM downstream of CCCM?
When?
General installation scenario

**CM**
- Cavity Fabrication
- Cold tests, cavities
- Cold tests, cavities ready for CM
- CM Assembly
- CM cold tests
- CM ready to install

**SPS**
- VISUALIZE
- PREPARE
- INSTALL

**CM 2016**
- YETS
- EYETS

**CM 2017**
- YETS

**SPS 2017**
- Clear BA6
- Un-cable BA6 and tunnel
- Optical 3D Scan
- TL Bidder’s visit
- Measure magnetic field

**SPS 2017**
- BA6 floor reinforce
- Cabling & Services
- RF power & infrastr.
- Cryogenic infrastr.
- Cryo Transfer-Line
- Vacuum sectorization
- Cold-box
- Moving table
- **CCC**M + Service Module
- RF connections
- Cryo connections
- Validation tests
- Commissioning
General installation scenario

YETS 2016

2017

YETS

CM

Cavity Fabrication

Cold tests, cavities

CM Assembly

CM cold tests

SPS

Challenging CCCM plan (CM review final report)

Challenging installation schedule for YETS2017

SM18 tests slot too short

Demanding co-activity planning for EYETS2016

Clear BA6

Un-cable BA6 and tunnel

Optical 3D Scan

TL Bidder’s visit

Measure magnetic field

BA6 floor reinforce

Cabling & Services

RF power & infrastr.

Cryogenic infrastr.

Cryo Transfer-Line

Vacuum sectorization

Cold-box

Moving table

CCCM + Service Module

RF connections

Cryo connections

Validation tests

Commissioning

G.Vandoni 22
## EYETS17-18 PREPARATION

| BA6 | Civil engineering  
| Cabling, x200, 2000cm²  
| Cryo ancillaries  
| RF power equipment |

| PA6 | Control cables  
| RF coax cables  
| Warm cryo pipework, x2 |

| Tunnel | Supports and Handling eq  
| Cabling  
| Cryo Transfer Line  
| Vacuum sectorization |

- Non-negligible volumes
- Co-activity in tunnel

## EYETS17-18 INSTALLATION & COMMISSIONING

| Connections  
| Tests  

### Installation & Hard-ware commissioning

→ challenging schedule

| Cold box  
| Moving table  
| Y-chambers  
| Service Module  
| **Crab cavity CryoModule**  
| Connections, tests  

| Hardware commissioning |

**Detailed planning with EN-ACE SPS Coordination**

G.Vandoni
How?
Compatibility of CCCM with SPS Operation

**Fast extraction to LHC**
Not enough aperture for extracted beam at nominal location close to QDA.617

**Slow extraction of fixed target beam**
at 400GeV, incl. extraction bump

purple: raw beam envelope
red: beam envelope + tolerance

Crab cavity at QD617 is compatible with slow extraction to North Area

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H.Bartosik @
SPS Test Day, I
https://indico.cern.ch/event/463435/
Crab-cavity SPS experimental program

**Dedicated MDs**
- 3 x LHC Technical stops
- 48h SPS stops: 3x3 blocks of 24h shared with Coldex

**Commissioning with beam**
Operation and reliability

**High intensity beam**
≤ 4 trains, at injection energy 26GeV, check beam induced cavity issues; machine protection; impedance.

**Emittance growth study**
1 x (~8hours) coasting beam

**Wednesday MDs**
10h weekly but compatible with LHC beam request
- Minimal time (≤10min) to displace table
- No need for access time

**SPS Test Day, I**
https://indico.cern.ch/event/463435/
- Cavity RF measurements
- Cavities with beam
- Beam instrumentation
- Operation aspects

G.Vandoni
Typical test run

Open issues:
• Time from IN to OUT ≤10min
• No access to move the table
• Keep CCCM cold throughout, if no impurities in the cryo circuits (else warm-up and regenerate)
First test run

BEAM

Frequent access to LSS6

Access LSS6 (30’)

Stable, defined beam through CCCM

Access LSS6 (30’)

CCCM cooldown

CCCM commissioning

CCCM IN

CCCM OUT

CCCM warmup

CCCM+SM, plug-and-play? …≥10 days

G.Vandoni
## What is going on now (YETS15-16)?

<table>
<thead>
<tr>
<th>Task</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear BA6 area from TE/ABT storage</td>
<td>✓</td>
</tr>
<tr>
<td>Scan Tunnel area</td>
<td>✓</td>
</tr>
<tr>
<td>Un-cable BA6 and tunnel from unused MKE cables</td>
<td>planned</td>
</tr>
<tr>
<td>Scan BA6 and shaft extremity</td>
<td>planned</td>
</tr>
<tr>
<td>Locate water pipework for tunnel</td>
<td>✓</td>
</tr>
<tr>
<td>Study integration of cryogenic equipment, shaft and tunnel</td>
<td>✓</td>
</tr>
<tr>
<td>Study integration of RF power equipment</td>
<td>✓</td>
</tr>
<tr>
<td>Identify installation paths</td>
<td>ongoing</td>
</tr>
<tr>
<td>Remove cryogenic equipment from BA4</td>
<td>✓</td>
</tr>
<tr>
<td>TL bidder’s visit to the tunnel</td>
<td>planned</td>
</tr>
<tr>
<td>Assess best location for cold-box with installation constraints</td>
<td>ongoing</td>
</tr>
<tr>
<td>Measure magnetic field at the CCCM location</td>
<td>pending</td>
</tr>
</tbody>
</table>
What are the next milestones?

<table>
<thead>
<tr>
<th>Task</th>
<th>Timeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integration pre-study</td>
<td>January-February</td>
</tr>
<tr>
<td><strong>Space Reservation Request</strong></td>
<td>February</td>
</tr>
<tr>
<td>Safety, access and interlocks study</td>
<td>February-March</td>
</tr>
<tr>
<td>New vacuum layout</td>
<td>February-March</td>
</tr>
<tr>
<td>Integration</td>
<td>February-March</td>
</tr>
<tr>
<td><strong>Engineering Specification</strong></td>
<td>31 March</td>
</tr>
<tr>
<td><strong>Engineering Change Request</strong></td>
<td>After approval in plan.cern.ch</td>
</tr>
<tr>
<td>Demande d’Installation de Cables</td>
<td>see above (29 April)</td>
</tr>
<tr>
<td>Planning EYETS16-17</td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

Integration well advancing

<table>
<thead>
<tr>
<th>Open integration &amp; operation issues</th>
<th>Critical schedule issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable and pipe routing TPSG + BPM?</td>
<td>Cryomodule fabrication schedule</td>
</tr>
<tr>
<td>Moving table dynamics</td>
<td>EYETS2016 co-activity</td>
</tr>
<tr>
<td>Guarantee operation without access</td>
<td>YETS2017 tight schedule</td>
</tr>
<tr>
<td></td>
<td>Slot for SM18 too short to acquire certitude that the SPS tests will be feasible</td>
</tr>
</tbody>
</table>

All teams keep a coordinated pace
Thank you

The BE-RF-SRF team
The HiLumi WP4 Team
Activity 10843 - HL-LHC Crab-cavity cryomodule in SPS

### 1: Preparation

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BE-ABP</td>
<td>Survey, alignment</td>
</tr>
<tr>
<td>BE-BI</td>
<td>Production of new BPM</td>
</tr>
<tr>
<td>BE-ICS</td>
<td>Study of access conditions, in collaboration with SPS</td>
</tr>
<tr>
<td>EN-ACE</td>
<td>Planning; Integration; Scans; Reinstallation at injection</td>
</tr>
<tr>
<td>EN-CV</td>
<td>Remove unused water pipework</td>
</tr>
<tr>
<td>EN-EL</td>
<td>Uncable unused TE-ABT cables</td>
</tr>
<tr>
<td>EN-MME</td>
<td>Design of components</td>
</tr>
<tr>
<td>HSE-SEE</td>
<td>Assessment of reinforcement needed</td>
</tr>
<tr>
<td>TE-ABT</td>
<td>Clear BA6, identify unused cables</td>
</tr>
<tr>
<td>TE-CRG</td>
<td>Procurement of mobile refrigerator</td>
</tr>
<tr>
<td>TE-VSC</td>
<td>Production of Y chamber and NEG</td>
</tr>
</tbody>
</table>

### 2: Installation

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BE-BI</td>
<td>Installation of new BPM</td>
</tr>
<tr>
<td>BE-ICS</td>
<td>Installation (if needed) of a ODH setup</td>
</tr>
<tr>
<td>EN-ACE</td>
<td>Planning and Integration, Survey</td>
</tr>
<tr>
<td>EN-EL</td>
<td>Install cables for RF, cryogenics and support structures</td>
</tr>
<tr>
<td>EN-HE</td>
<td>Handling during installation of high vacuum</td>
</tr>
<tr>
<td>EN-MME</td>
<td>Installation of the supporting table</td>
</tr>
<tr>
<td>TE-CRG</td>
<td>Installation of cryogenic equipment</td>
</tr>
<tr>
<td>TE-VSC</td>
<td>Installation of a Y chamber and vacuum chamber</td>
</tr>
</tbody>
</table>

### 3: Commissioning

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BE-ABP</td>
<td>Alignment and commissioning</td>
</tr>
<tr>
<td>BE-BI</td>
<td>Commissioning with crab cryomodule</td>
</tr>
<tr>
<td>BE-OP</td>
<td>Commissioning with beam</td>
</tr>
<tr>
<td>EN-MME</td>
<td>Commissioning with motorized transport system</td>
</tr>
<tr>
<td>TE-CRG</td>
<td>Commissioning of cryogenic equipment</td>
</tr>
<tr>
<td>TE-VSC</td>
<td>Commissioning with crab cryomodule</td>
</tr>
</tbody>
</table>

[+] Request contribution
**System inventory and architecture - BA6**

<table>
<thead>
<tr>
<th>Cryogenics</th>
<th>RF</th>
<th>Control racks - services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm compressor</td>
<td>HV-Power Converter</td>
<td>Cryogenic operation and control</td>
</tr>
<tr>
<td>Oil removal system</td>
<td>2x 40kW Tetrodes</td>
<td>Beam instr and vacuum</td>
</tr>
<tr>
<td>Electrical cabinets</td>
<td>Driver Amplifiers</td>
<td>Alignment and table motorization</td>
</tr>
<tr>
<td>GHe storage</td>
<td>Control racks for power, close to RF power</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Faraday-cage</td>
<td>Control racks for LLRF</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Services</th>
<th>Transport</th>
<th>MKE surface equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity 400V</td>
<td>Crane</td>
<td>Additional switch</td>
</tr>
<tr>
<td>Water: raw and demi</td>
<td>Load bearing zone</td>
<td>Storage of spares for MKE</td>
</tr>
<tr>
<td></td>
<td>Transport reservation in equipment area</td>
<td></td>
</tr>
</tbody>
</table>

Control room (~30m²)  
Cryogenics  
RF
System inventory and architecture - tunnel

QDA 61710

QFA 61810

Alcove LSS6

QDA 61910

G.Vandoni

QCCM

Cold-box +SPS fire safety

PA6

TA6

←BA5

BA1→
Safety

Cryogenic safety study (from BA4 to BA6)
Liquid helium inventory in the tunnel ~300l/s

Same strategy for LHC RF and CCCM
- Cryo lock-out situation
- ODH number and position
- Accessibility and work conditions

Ventilation
Today: well controlled extraction flow.
Tomorrow: increase for dump in ECX5

Interlock strategy for
Access
Beam permit
Beam extraction
to be worked out with BE/OP

Safety analysis with the Engineering Specification
Test scopes

From the PDR/TDR October 2015 EDMS XXXXXXXXXXX

* Deflecting field with proton beam from 26-450 GeV.

* Establish and test operational cycle with crab cavities.

* Make crab cavities invisible, by counter-phasing the two cavities or by detuning.

* Measurements of beam orbit centering, crab dispersive orbit and bunch rotation with BI

* Demonstrate MFB operation.

* Demonstrate non-correlated operation of two cavities in a common CM (quench studies)

* Verification of machine protection aspects

* Test HOM coupler operation.

* Measure emittance growth induced by the crab cavities as far as possible.
Cryogenic flexible between Service Module and Dewar

- Ø 1.2 m
- DN 200

Parking position

Transport free zone

3 m

1,280 m

Parking position
Cryogenic flexible between Service Module and Dewar

Transport free zone

Operation position in beam

Ø 1,2 m

DN 200

3 m

0,510 m

1 m