HiRadMat

Summary of Phase-I and plans for Phase-II commissioning

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On behalf of the HiRadMat Primary beam line working group
Beam Line Geometry

Beam

TI 2

TT60

TT66

Experimental area

25 m

C. Magnier
Beam Line Layout

Beam

SPS extraction point

End of common part with TT60

MBS switching magnets

MBB

QTL

Exp. area

50 m
Flexible optics to provide beam radii of $\sigma = 0.1\text{mm}$ to $2.0\text{ mm}$ at the focal points.

Focal point longitudinal location continuously variable between positions 1 and 3.

Predefined optics for 3 focal points and 6 beam sizes.
Equipment Inventory

- 25 magnets installed (+ de and re-installation of 4 TI 2 magnets)
- 13 power converters installed (+1 new for TT60)
- 17 beam instrumentation elements installed
- ~200 m of new vacuum system installed (+ adaption of TI 2 vacuum system)
- ~460 new cables with a total length of 4000 m installed (+ dismantling of 300 old cables)

→ All was done during 4-day technical stops, the Xmas stop and short accesses between LHC injections.

Thanks to all equipment groups!
# Beam Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Protons</th>
<th>Ions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy</td>
<td>440 [GeV]</td>
<td>173.5 [AGeV]</td>
</tr>
<tr>
<td>Bunch intensity</td>
<td>$3 \times 10^9$ to $1.7 \times 10^{11}$ [protons] (\text{(current: } 1.2 \times 10^{11})</td>
<td>$3 \times 10^7$ to $7 \times 10^7$ [ions]</td>
</tr>
<tr>
<td>Max. pulse intensity</td>
<td>$4.9 \times 10^{13}$ [protons]</td>
<td>$3.64 \times 10^9$ [ions]</td>
</tr>
<tr>
<td>Number of bunches</td>
<td>1 to 288 (current: 144)</td>
<td>52</td>
</tr>
<tr>
<td>Bunch spacing</td>
<td>25 [ns] (current: 50 ns)</td>
<td>100 [ns]</td>
</tr>
<tr>
<td>RMS bunch length</td>
<td>11.24 [cm]</td>
<td>11.24 [cm]</td>
</tr>
<tr>
<td>Pulse length</td>
<td>7.2 [μs]</td>
<td>5.2 [μs]</td>
</tr>
<tr>
<td>Number of pulses per cycle</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Min. cycle length</td>
<td>21.6 [s]</td>
<td>13.2 [s]</td>
</tr>
<tr>
<td>Transverse norm. emittance (1σ)</td>
<td>2 to 4 [μm]</td>
<td>1.4 [μm]</td>
</tr>
</tbody>
</table>

More efficient to get your total number of protons by using the proton beam which is set-up for the on-going LHC operation.
**Beam Optics (1)**

- Example of a typical beam with $\sigma=0.5$ mm and focal point at position 1:

![Graph showing beam optics parameters](image-url)
• Example of a typical beam with $\sigma=0.1$ mm and focal point at position 1:
Example of a typical beam with $\sigma=2.0$ mm and focal point at position 1:
Trajectory Correction and Orthogonal Steering

Example:

- Orthogonal steering on target +/- 4 mm independently in both planes. If larger range is needed, the test object will be moved.
- Max. accuracy of angle: \(~0.05\) mrad

C.Hessler
## Beam Instrumentation

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Type</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPM (dual plane)</td>
<td>LEP buttons</td>
<td>6</td>
</tr>
<tr>
<td>BPKG* (dual plane)</td>
<td>CNGS</td>
<td>1</td>
</tr>
<tr>
<td>BTVI</td>
<td>LHC</td>
<td>3</td>
</tr>
<tr>
<td>BCTFI</td>
<td>CNGS</td>
<td>1</td>
</tr>
<tr>
<td>BLM</td>
<td>LHC</td>
<td>6</td>
</tr>
</tbody>
</table>

* operated in air

L. Jensen and team
- Beam interlock controller: Extension of existing interlock system to handle new interlock signals from HiRadMat facility.
- New energy flag E_440 for HiRadMat.
- FMCMs for main bending magnets.
- TBSE in TI 2 to ensure accessibility of TI 2 / LHC during HiRadMat operation.
- Interlock system of LSS6 extraction has now exactly the same layout than in LSS4 where CNGS and LHC beams coexist. This system has proven to be very reliable.

B. Puccio, M. Zerlauth, V. Kain, J. Wenninger
Comparison extraction layout LSS6 (TI 2, HiRadMat) versus LSS4 (TI 8, CNGS):

B. Puccio, M. Zerlauth, V. Kain, J. Wenninger
Interlock (3)

System layout:

HiRadMat interlock application:

B. Puccio, M. Zerlauth, V. Kain, J. Wenninger
Control Applications (1)

- All standard equipment → extension of existing applications:
  - Steering, logging: Extension of YASP
  - BTVs, BLMs, BCT: Extension of the corresponding application

- New dedicated application for an easy change of the HiRadMat beam line optics:

![Hi Rad Mat Current Optics](image)

HiRadMatTransfer-F1-0_10-0_10-2011v1, TT66

V. Kain
Control Applications (2)

- New dedicated application for requesting beam for HiRadMat. Each pulse sent to HiRadMat must be requested with this application (= 1 pulse per click).
- Use will be restricted to authorised operators only (using RBAC).

Click here to request beam

V. Kain
The following beam line equipment is logged in TIMBER:

- BTVs (also in SDDS)
- BLMs
- BPMs
- BCTFI
- Power converter currents
- Beam interlocks
Dry Run Results (1)

- All magnets powered and polarity checked.
- Applications for beam instrumentation have been successfully checked (BTV, BCTFI, BLM).

V. Kain, J. Wenninger, J. Blanco
Dry Run Results (2)

- YASP acquires data for TT66.
- Logging has been successfully checked.
- Interlock successfully tested.
- Application for beam optics change successfully tested.
- Beam request application successfully tested.

V. Kain, J. Wenninger, J. Blanco
Extraction Tests on TT60 TED

- First extraction of probe bunches with HiRadMat cycle onto TT60 TED (= far upstream the start of TT66):

V. Kain,
J. Wenninger,
J. Blanco
Beam Commissioning Plan (1)

- Different kind of beams to be used:
  - LHC probe “pilot”: ~8×10^9 p/bunch
  - LHC2 “nominal”: up to ~1.3×10^{11} p/bunch
    - 1 batch of 12 bunches with 50 ns bunch spacing
    - 2 batches of 12 bunches
    - 1 batch of 36 bunches
    - 2 batches of 36 bunches → max. 72 b. per extraction

- Beam budget estimate:
  - 1^{st} period:
    - 24 h of pilot bunches
    - total # of protons: ~10^{13}
  - 2^{nd} period:
    - Pre-checks with pilot beam
    - 4 h of multi-bunches, mostly with 1 batch of 12 bunches
    - total # of protons: ~2×10^{14}
<table>
<thead>
<tr>
<th>Test</th>
<th>Beam type</th>
<th># bunches</th>
<th>Bunch intensity</th>
<th># shots</th>
<th>Max. total intensity</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Send beam onto TED.610321</td>
<td>LHC probe</td>
<td>1</td>
<td>10(^{10})</td>
<td>50</td>
<td>10(^{15})</td>
<td>2h</td>
</tr>
<tr>
<td>Test of the extraction from SPS</td>
<td>LHC probe</td>
<td>1</td>
<td>10(^{10})</td>
<td>90</td>
<td>7.2(^{10})</td>
<td>2h</td>
</tr>
<tr>
<td>Sending beam “LHC Probe” to HiRadMat</td>
<td>LHC probe</td>
<td>1</td>
<td>10(^{10})</td>
<td>180</td>
<td>14.4(^{10})</td>
<td>4h</td>
</tr>
<tr>
<td>Beam line bare trajectory and steering</td>
<td>LHC probe</td>
<td>1</td>
<td>10(^{10})</td>
<td>30</td>
<td>2.4(^{10})</td>
<td>0.5h</td>
</tr>
<tr>
<td>Beam instrumentation (incl. calibration, check response, checks of corrector and pickups)</td>
<td>LHC probe</td>
<td>1</td>
<td>10(^{10})</td>
<td>240</td>
<td>19(^{10})</td>
<td>5h</td>
</tr>
<tr>
<td>Controls, logging</td>
<td>LHC probe</td>
<td>1</td>
<td>10(^{10})</td>
<td>30</td>
<td>2.4(^{10})</td>
<td>0.5h</td>
</tr>
<tr>
<td>Steering on target</td>
<td>LHC probe</td>
<td>1</td>
<td>10(^{10})</td>
<td>60</td>
<td>4.8(^{10})</td>
<td>1h</td>
</tr>
<tr>
<td>Interlocking tests (interlock limits)</td>
<td>LHC probe</td>
<td>1</td>
<td>10(^{10})</td>
<td>30</td>
<td>2.4(^{10})</td>
<td>0.5h</td>
</tr>
<tr>
<td>Aperture checks (knobs needed, to be done with 1 reference optics)</td>
<td>LHC probe</td>
<td>1</td>
<td>10(^{10})</td>
<td>60</td>
<td>4.8(^{10})</td>
<td>1h</td>
</tr>
<tr>
<td>Beam parameters checks</td>
<td>LHC probe</td>
<td>1</td>
<td>10(^{10})</td>
<td>90</td>
<td>7.2(^{10})</td>
<td>2h</td>
</tr>
<tr>
<td>Beam size and focal point position adjustment</td>
<td>LHC probe</td>
<td>1</td>
<td>10(^{10})</td>
<td>180</td>
<td>14.4(^{10})</td>
<td>4h</td>
</tr>
<tr>
<td>Position/intensity stability</td>
<td>LHC probe</td>
<td>1</td>
<td>10(^{10})</td>
<td>60</td>
<td>4.8(^{10})</td>
<td>1h</td>
</tr>
<tr>
<td>Change of beam line optics + repetition of some tests</td>
<td>LHC probe</td>
<td>1</td>
<td>10(^{10})</td>
<td>180</td>
<td>14.4(^{10})</td>
<td>4h</td>
</tr>
<tr>
<td>Sending beam “LHC2 nominal” to HiRadMat</td>
<td>LHC2 nominal</td>
<td>12</td>
<td>1.3(^{10})</td>
<td>10</td>
<td>1.6(^{10})</td>
<td>0.5h</td>
</tr>
<tr>
<td>Re-check trajectory</td>
<td>LHC2 nominal</td>
<td>12</td>
<td>1.3(^{10})</td>
<td>20</td>
<td>3.2(^{10})</td>
<td>1h</td>
</tr>
<tr>
<td>Check beam instrumentation (BTV Ti screens, readings for high intensities, etc.)</td>
<td>LHC2 nominal</td>
<td>12</td>
<td>1.3(^{10})</td>
<td>20</td>
<td>3.2(^{10})</td>
<td>1h</td>
</tr>
<tr>
<td>Beam parameters checks</td>
<td>LHC2 nominal</td>
<td>12</td>
<td>1.3(^{10})</td>
<td>20</td>
<td>3.2(^{10})</td>
<td>1h</td>
</tr>
<tr>
<td>Increase intensity in steps and check consistency of nominal beam with probe beam</td>
<td>LHC2 nominal</td>
<td>24</td>
<td>1.3(^{10})</td>
<td>5</td>
<td>1.6(^{10})</td>
<td>0.5h</td>
</tr>
<tr>
<td>LHC2 nominal</td>
<td>36</td>
<td>1.3(^{10})</td>
<td>5</td>
<td>2.3(^{10})</td>
<td>0.5h</td>
<td></td>
</tr>
<tr>
<td>LHC2 nominal</td>
<td>72</td>
<td>1.3(^{10})</td>
<td>5</td>
<td>4.7(^{10})</td>
<td>0.5h</td>
<td></td>
</tr>
</tbody>
</table>
Beam Commissioning Plan (3)

- Sending beam “LHC Probe” to HiRadMat. Tests to be carried out:
  - Beam line bare trajectory and steering
  - Beam instrumentation (incl. calibration, check response, checks of corrector and pickups)
  - Controls, logging
  - Steering on target
  - Interlocking tests (interlock limits)
  - Aperture checks (knobs needed, to be done with 1 reference optics)
  - Beam parameters checks
  - Beam size and focal point position adjustment
  - Position/intensity stability
  - Change of beam line optics + repetition of some tests

- Some high intensity shots to check the consistency with the nominal beam intensity.
First HiRadMat proton beam extracted from the SPS to the HiRadMat beam dump.

Bare trajectories
Trajectory after energy matching and trajectory excursion corrections

Beam on the 2 of the HiRadMat primary beam line screens
Kick response measurements: correct polarity sign of BPM, Correctors and no phase advance / optics errors
Beam line aperture checks
Orthogonal steering onto the future test stand location

Steering of the beam on the last BTV screen independently in both planes within the range +/- 4 mm

Example trajectory for the case that the beam was steered to +4 mm in the vertical plane
Multiple Optics changes – example of F1

Difference of the trajectory after changing the optics from F1-0_50mm-0_50mm to F1-0_20mm-0_20mm

New steering for F1-0_20mm-0_20mm optics
Readings (Sv/h) of the residual dose rate monitor PMIHR05 installed next to the dump in the HiRadMat experimental area. It can be seen that with the exception of the spikes due to the prompt radiation the residual dose rate before and after the commissioning remained unchanged at ~80 uSv/h.

None of the radiation monitors raised any concern and the first commissioning phase of HiRadMat can be considered as a success also from the radiation protection point of view.
Outcomes

- Beam commissioning with pilot intensity allowed to check the correct functioning of the primary beam line equipment, optics and beam quality
- High intensity beam commissioning scheduled as mid-August (week 33)
- Thanks again to all equipment groups for their work and assistance through the whole project lifetime and to the SPS Operation Team