# Assessment of LCLS-II Module Production at FNAL

Version 2.0

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(thanks to T. Argan, S. Berry, J. Blowers, C. Ginsburg,
N. Walker, G. Wu and to the Clean Room technicians)

# Part I: Field Emission

# Part II: Investigation of Discrepancy Reports

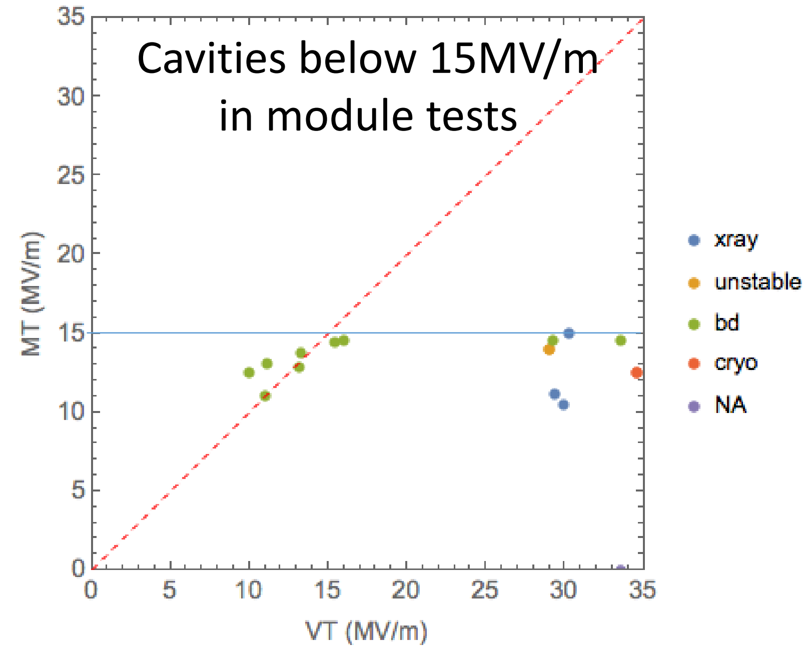
# Part III: Observation of coupler cold end assembly

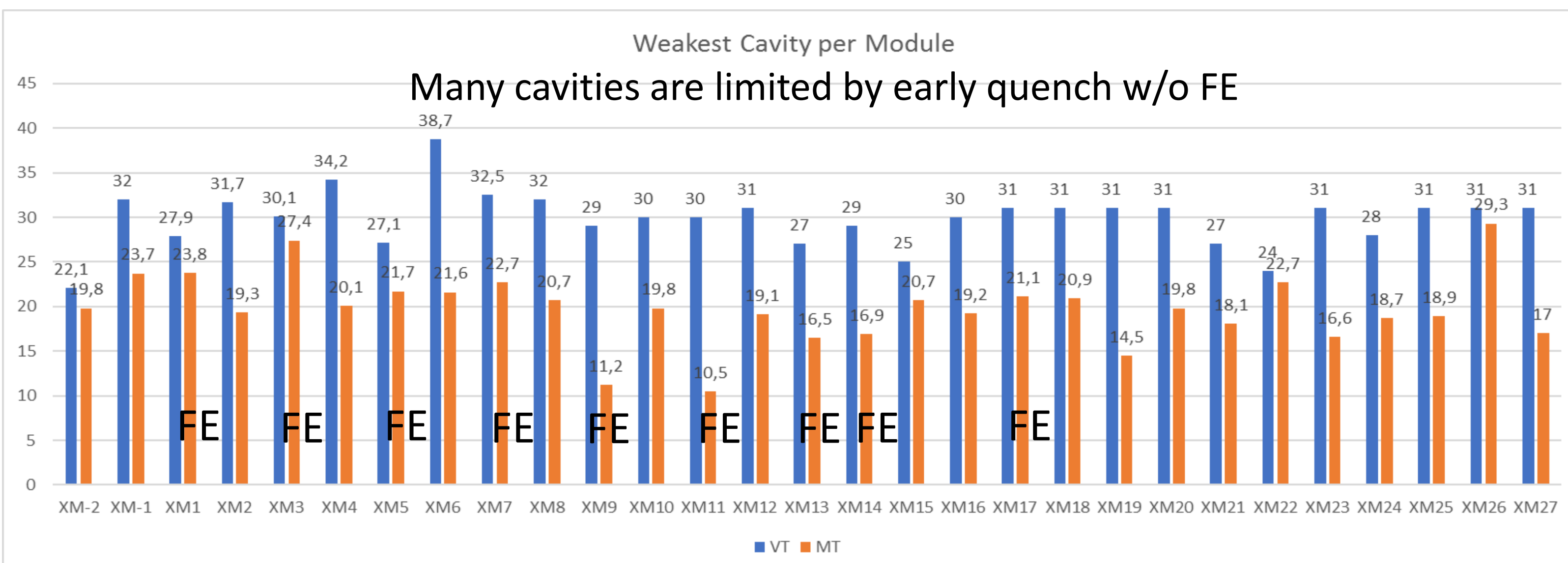
# Comments about Field Emission in CM tests (specific to Fermilab)

1. LCLS-II cavities have low gradients, in the 20 -24 MV/m range in VTS, compared to XFEL cavities: this is due to N2-doping and to administrative limits. Most of these cavities are free from FE.
2. About 50% of cavities suffer from field emission during the CMTS tests, and about 20% with onset below 14 MV/m:
   → particle contamination occurs during module assembly.
   I am assuming that such a claim is beyond any doubt arising from cross-calibration of *VTS/CMTS X-Ray signals.*
3. Several LCLS-II cavities have field-emission limited gradients in the 10-14 MV/m range in CMTS. This is a low gradient range compared to XFEL cavities in AMTF module test. *See next page*
4. This may be due to:
   - Different surface RF behavior of N2 doped cavities ? ☹☹
   - CW operation vs. Pulse operation, like heated emitter ? ☹
   - Different specs on X-Ray limits ?
   - Another effect ?

# XFEL lowest performing cavities per modules

- FE limited usable gradients, represented in both figures, are more in the range of 19 MV/ or higher.
- Very few cavities are limited by FE below 15 MV/m, like in XM9 and XM11.



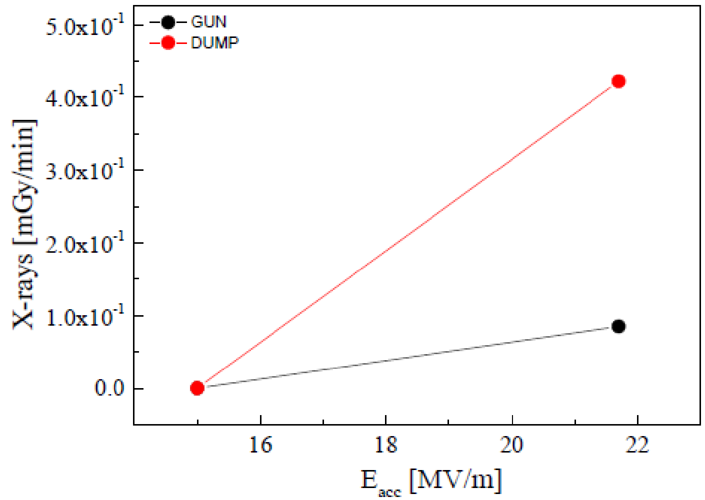
# Comparing X-Rays dose-rates between XFEL and LCLS-II

- I will not touch on the ‘FE onset’ values, to big a job.
- ‘Usable gradient’ limits on X-Rays dose-rates:
  - LCLS-II (FNAL): 50 mrd/h = $8.3\times10^{-3}$ mGy/min
  - XFEL : $10^{-2}$ mGy/min
- These two limits are almost identical, probably for good reasons (dark current ?, radioprotection ?). **But is the XFEL limit the peak (over 1 ms) or the average (> 1s) ?**
- The 1 liter sphere detector at XFEL has a ‘response’ time, defined by the collections of the ions, of about 40 ms. It allows to pick-up the 1 ms RF-pulse generated X-Rays every 100 ms period. But what about the dosimeter ?
- The most likely assumption, checked with DESY, is that the XFEL dose-rate is averaged: hence the 1 ms-peak dose-rate is 1mGy/min, **120 times higher than at CMTS**.

# XFEL XM40 Module Test X-Rays Measurement

**X-rays vs $E_{acc}$**

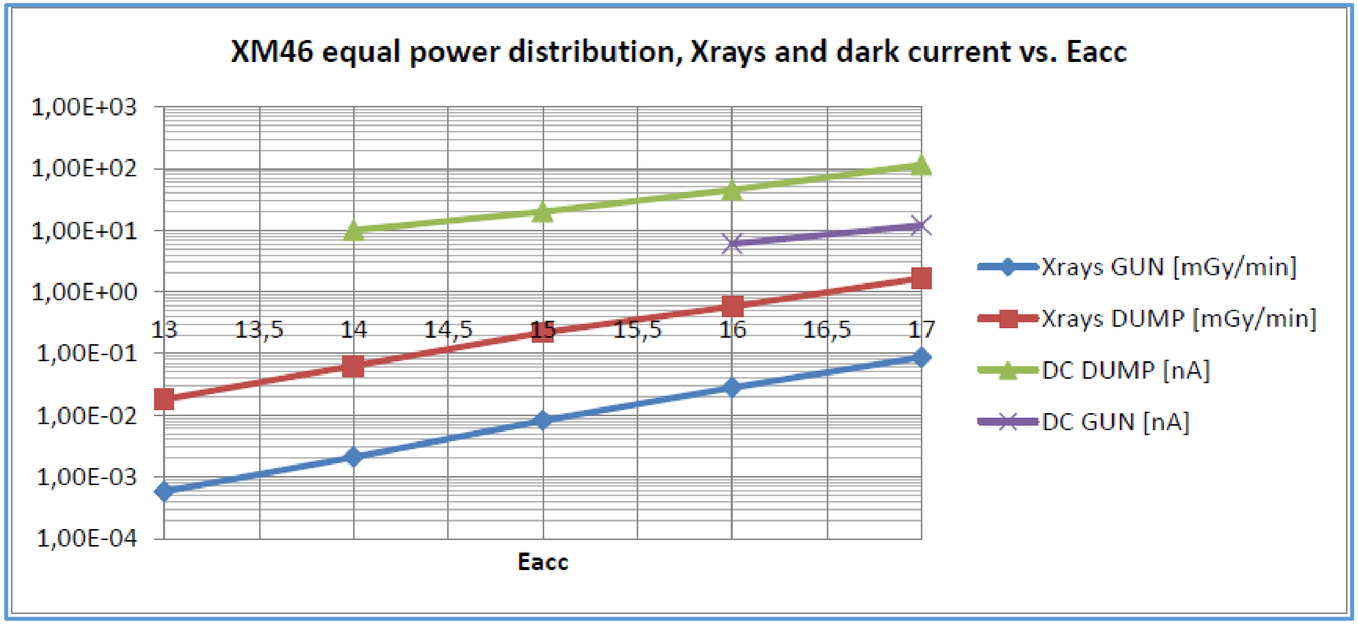
| Power $E_{acc}$ $\left[\frac{MV}{m}\right]$ | Avg $P_{forw}$ [kW] | X-rays $\left[\frac{mGy}{min}\right]$ | | Comment |
|---|---|---|---|---|
| | | GUN | DUMP | |
| 15 | 60.0 | 4.9E-5 | 1.59E-4 | |
| 21.7 | 113.9 | 8.51E-2 | 4.22E-1 | |




| | GUN | DUMP | | |
|---|---|---|---|---|
| MV/m | mGy/min | mGy/min | | |
| 15 | 4,90E-05 | 1,59E-04 | | |
| 21,7 | 8,51E-02 | 4,22E-01 | | |
| | **2,07** | **1,96** | (MV/m)/decade | |

# XFEL XM46 Module Test X-Rays Measurement

*"XM46 is one of our dark current 'light bulbs' " (N. Walker)*




| | | | | |
|---|---|---|---|---|
| | GUN | DUMP | | |
| MV/m | mGy/min | mGy/min | | |
| 13 | 5,80E-04 | 8,70E-02 | | |
| 17 | 1,80E-02 | 1,68E+00 | | |
| | **2,68** | **3,11** | (MV/m)/decade | |

# Conclusion on FE

The 100 ratio between XFEL vs. LCLS-II duty cycles has an impact of 4-6 MV/m in the ‘usable gradients’ difference, when Field Emission is the limiting factor:
i.e. 14 MV/m at LCLS-II modules corresponds to 18-20 MV/m at XFEL modules.

As a consequence, there is no FE-driven indication of difference between the quality of XFEL and LCLS-II string assembly processes.

Part I: Field Emission

# Part II: Investigation of Discrepancy Reports

Part III: Observation of coupler cold end assembly

# Vector Discrepancy Reports (all)
# 8 Sept. 2017

| | CM01 | CM02 | CM03 | CM04 | CM05 | CM06 | CM07 | CM08 | Total |
|---|---|---|---|---|---|---|---|---|---|
| Reception | | | | | | | | | |
| WS0 464176 | 9 | 9 | 0 | 3 | 0 | 0 | 0 | 0 | **21** +2 |
| WS1 464179 | 1 | 9 | 1 | 2 | 1 | 0 | 1 | 1 | **16** |
| WS2 464229 | 11 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | **18** |
| WS3 464252 | 7 | 8 | 1 | 2 | 2 | 0 | 0 | 0 | **20** |
| WS4 464253 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | **4** |
| WS5 464254 | 5 | 2 | 4 | 0 | 0 | 1 | 0 | 0 | **12** |
| **Total** | **36** | **32** | **10** | **7** | **3** | **1** | **1** | **1** | **91** |

# Impact of DRs: Assumptions

- xx DRs describe defective Aluminum seals: except in one explicit case, it is assumed that the QC of Al seals is performed while cavities are closed w/o any impact on module performance
- Yy DRs describe defective inter-cavity bellows: it is assumed that QC os bellows is performed ahead of string assembly w/o any impact on module performance.

# Discrepancy Reports (with potential impact on RF performance e.g. Field Emission)

| | CM01 | CM02 | CM03 | CM04 | CM05 | CM06 | CM07 | CM08 | Total |
|---|---|---|---|---|---|---|---|---|---|
| Reception | | | | | | | | | |
| WS0 464176 | 3 (9) | 3 (9) | 0 | 0 | 0 | 0 | 0 | 0 | **6** |
| WS1 464179 | 1 (Cu bellows) | 4 (9) | 0 | 0 | | 0 | | | **5** |
| WS2 464229 | *0* | *0* | *0* | *0* | *0* | *0* | *0* | *0* | **0** |
| WS3 464252 | *0* | *0* | *0* | *0* | *0* | *0* | *0* | *0* | **0** |
| WS4 464253 | *0* | *0* | *0* | *0* | *0* | *0* | *0* | *0* | **0** |
| WS5 464254 | *0* | *0* | *0* | *0* | *0* | *0* | *0* | *0* | **0** |
| **Total** | **4** | **7** | **0** | **0** | **0** | **0** | **0** | **0** | **11** |

# FNAL CM01

| Cavity Serial # | Usable Gradient* [MV/m] | FE onset [MV/m] |
|---|---|---|
| TB9AES021 | 18,2 | 14,6 |
| TB9AES019 | 18,8 | 15,6 |
| TB9AES026 | 19,8 | No |
| TB9AES024 | 20,5 | No |
| TB9AES028 | 14,2 | 13,9 |
| TB9AES016 | 16,9 | 14,5 |
| TB9AES022 | 19,4 | 12,7 |
| TB9AES027 | 17,5 | No |

- WS0
  - DR10676:AES019(C2):'angle-valve orientation up'
  - DR10677:AES026(C3):'angle-valve orientation up'
  - DR10690:AES016(C6):'piece of tape on CF40 flange, far outer knife'
- WS1
  - DR10679:CS001:'Cu flakes on bellows'

    *Potentially harmful but I don't know the history*

No Data specifically on AES028 and AES022 !

# FNAL CM02

| Cavity Serial # | Usable Gradient* [MV/m] | FE onset [MV/m] |
|---|---|---|
| CAV0008 | 20,5 | 21 |
| CAV0003 | 21,0 | No |
| CAV0006 | 21,0 | No |
| CAV0007 | 21,0 | No |
| CAV0016 | 18,2 | 12,5 |
| CAV0013 | 16,5 | No |
| CAV0011 | 20,5 | 17,5 |
| CAV0015 | 21,0 | No |

- WS0
  - DR10915:CAV003(C2):’NW40 seal replaced while cavity opened’:9/12/16
  - DR10921:CAV003(C2):’difficulty to remove cavity blank flange’: 9/15/16 (?)’
  - DR10957:CAV011(C7):’chip found inside of cavity port, removed’
- WS1
  - DR10930:CS002:’bellow dent and crease’:’ *use as is, low risk*’
  - DR10932:CS002:’bellow dent and crease’:’*use as is, low risk*’
  - DR10944:CS002:’CAV008 w/o washers, hard to blow holes clean’:
  - DR10930:CS002:’NW78 seal rejected during C1-bellow connection’:

*Was CAV008 already opened ?*

No Data specifically on CAV016 !

# FNAL CM03

| Cavity Serial # | Usable Gradient* [MV/m] | FE onset [MV/m] |
|---|---|---|
| CAV0034 | 21,0 | No |
| CAV0039 | 21,0 | 15,1 |
| CAV0040 | 10,0 | No |
| CAV0026 | 9,2 | 9,2 |
| CAV0027 | 21,0 | 16,8 |
| CAV0029 | 21,0 | No |
| CAV0042 | 16,8 | 11 |
| CAV0032 | 21,0 | 15,4 |

- WS0
  - None
- WS1
  - None

No Data on CAV026, CAV042 !

# FNAL CM04

| Cavity Serial # | Usable Gradient* [MV/m] | FE onset [MV/m] |
|---|---|---|
| CAV0052 | 21,0 | no |
| CAV0036 | 21,0 | 15,2 |
| CAV0019 | 16,0 | 12 |
| CAV0041 | 21,0 | no |
| CAV0030 | 21,0 | 16,5 |
| CAV0020 | 19,3 | 13,9 |
| CAV0051 | 19,6 | No |
| CAV0221 | 19,5 | No |

- WS0
  - None
- WS1
  - None

Much data on CAV0019 and CAV0020, w/o impact on RF.

Part I: Field Emission

Part II: Investigation of Discrepancy Reports

## Part III: Observation of coupler cold end assembly

# WS0: Observations of CM08 cold end coupler assembly on 08/23-24 and 09/15

1. Cavity CAVX is positioned on WS0
2. Cold end coupler was already disconnected from coupler box, with antenna in clean room air
3. CAVX is connected to WS0 pumping system through its angle valve
4. The connection with flex hose is pumped and leak checked (no He signal) by aspersion
5. Active pumping is stopped until gauges 'equalize'
6. The angle valve is opened slowly and pressure rise is recorded (cavity empties in the hose)
7. The pumping system is restarted and CAVX is pumped overnight
8. CAVX RGA is started in the night the leak check by aspersion performed in the morning
9. CAVX is backfilled (vented) with N2 to CR atmospheric pressure plus 50 mbar (?): *no slow backfilling 3l/mn system above 1 mbar pressure in the cavity.*
10. Cold end coupler antenna is cleaned with nitrogen gun: *is the counting rate recorded ?*
11. Cold end coupler is moved to ISO6 and 8 flange holes are cleaned with nitrogen gun: *done in ISO4 for XFEL*
12. All eight nuts of the CAVX coupler blind flange are torqued to specs ( ?? N.m)
13. Two M6 bolts are removed and holes are blown with nitrogen gun
14. N2 flow is restarted while the removing of the bolts from coupler blind flange: *flushing regime with 1 N2 l/mn (instead of 10 l/mn for XFEL)*
15. Cavity-coupler assembly is pumped during the afternoon and leak checked in the morning: *no slow pumping 3 l/mn process (~12 min) above 1 mbar.*
16. *Cavity-coupler assembly is backfilled with N2: no slow backfilling*
17. *The angle valve is disconnected and the cavity is move to ISO4: the angle valve (facing down) is not tapped after disconnection and on hold for string assembly.*
18. Coupler assembly in ISO5, antenna cleaning in ISO6, 8 torques are checked with torque wrench

# Observations

- Operators work is ideally careful and ergonomical.
- A new cavity venting procedure is in place as of July 1st, 2017 : what is the motivation and what are the changes ?

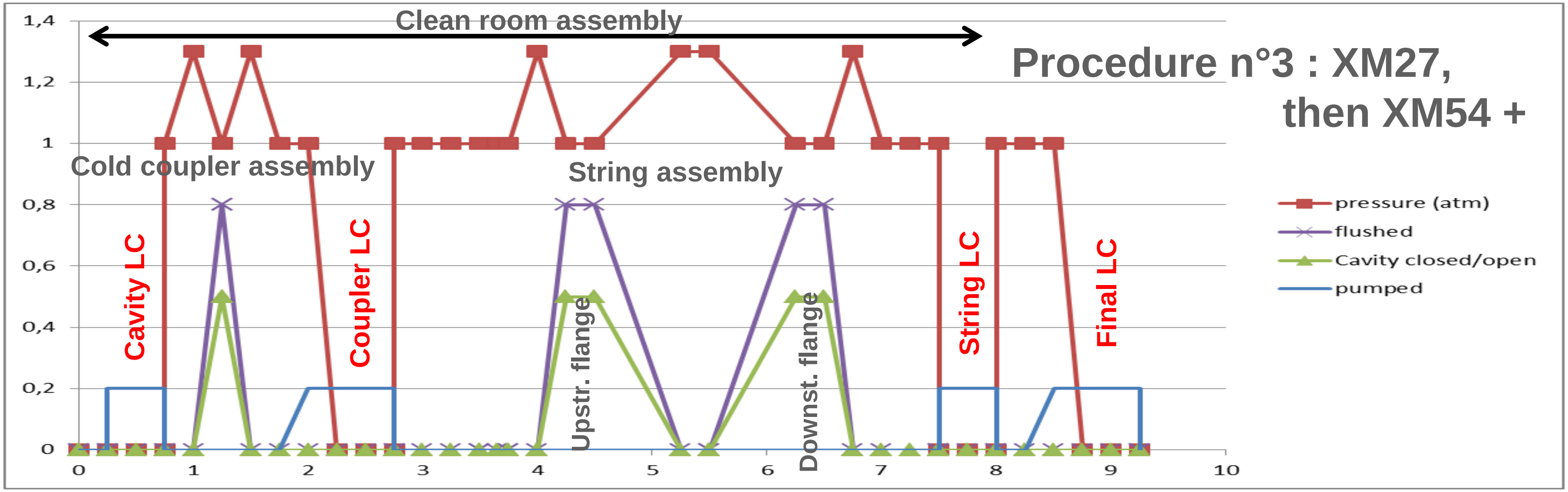
# Recommendations

- Increase purging flux to 3 N2 l/min, if possible.
- QC diamond seals ahead of assembly, no open cavity ports during control
- Close the angle-valve flanges with plastic caps (cavities, coupler pumping manifold) during standby.
- Consider assembly schemes which reduce the number of valve openings and of pumping/venting cycles (see next slide for XFEL).

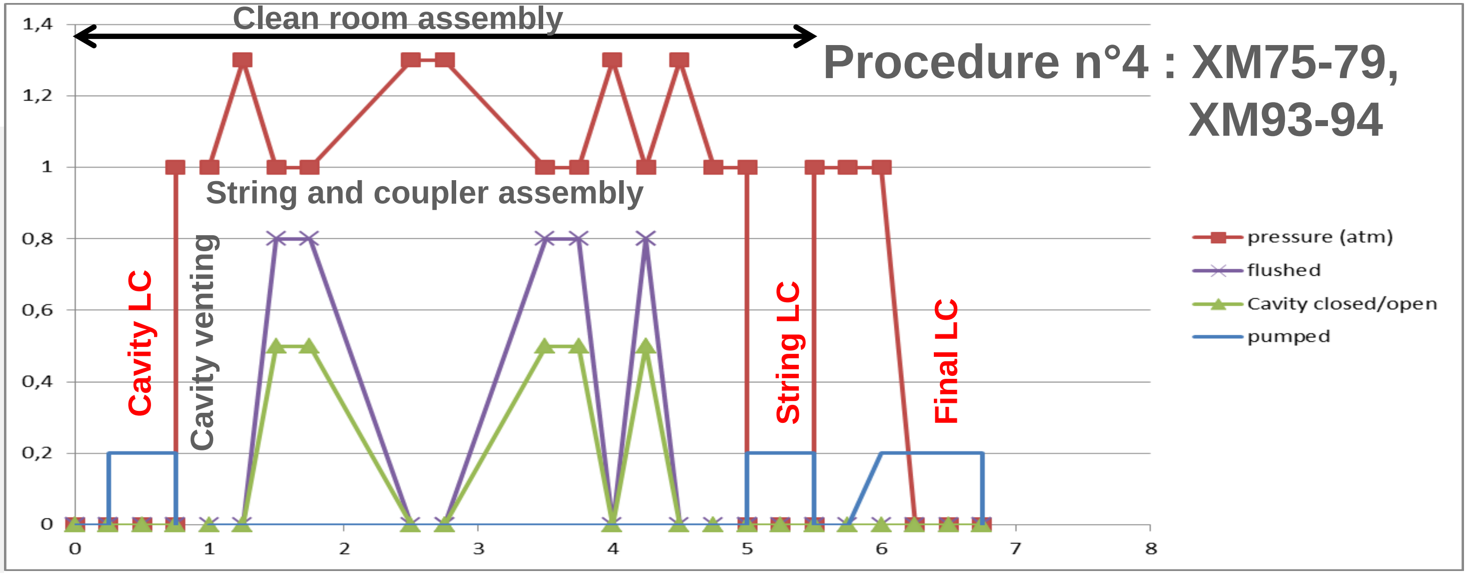
# Questions

- What is the criteria for particle counting: < 10 particles / min ? Or higher ?
- Are particle countings recorded during coupler and cavity flange ‘top-gun’ cleaning.

# Clean Procedures: Cavity History




## Cavity history




Cavity string assembly is followed by connection of the 8 cold couplers w/o pumping. This solution was implemented during coupler shortage periods: it saves labor and and vacuum operation.

Six days are needed to assemble a full cavity string.