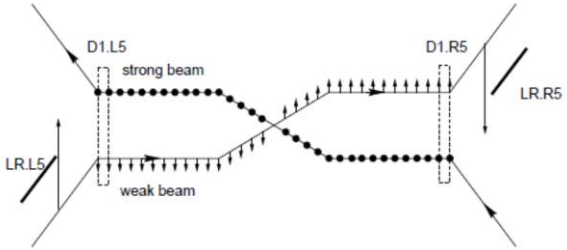

Operational and interlocking strategy for long-range beam-beam wire compensators in IP5 (TCT, TCL)

A. Rossi on behalf of the whole team:

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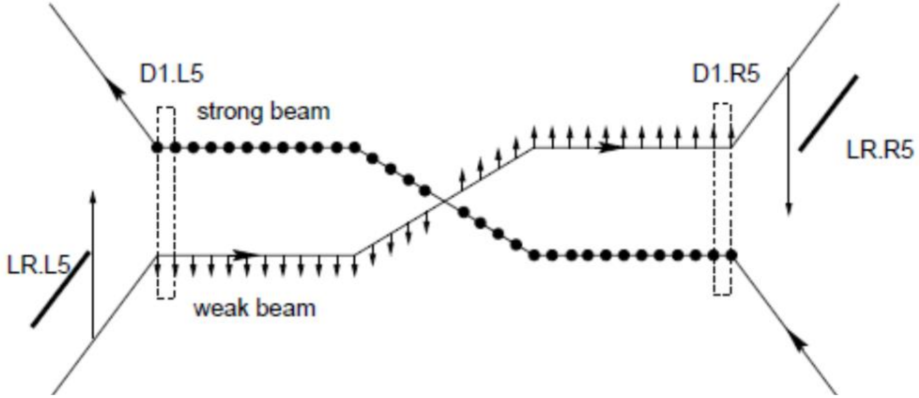
With thanks to S. Redaelli, S. Fartoukh, D. Wollman, M. Zerlauth, V. Montabonnet, M. Magrans de Abril, Q. King

134th MPP September 30, 2016

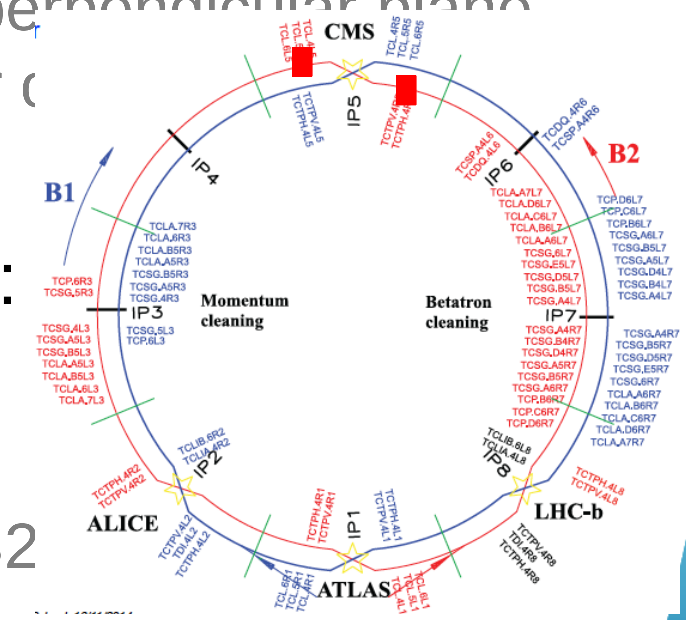
Motivations for the wires

- Beam-beam interactions: linear & non-linear kicks causing
  - orbit change and tune shift (linear effects)
  - dynamic aperture reduction (non-linear, excitation more pronounced on beam tails)
- Demonstrate long range beam-beam compensation using a local wire on both sides of the IP on a “weak” beam, where the BB effects from the “strong” beam are enhanced

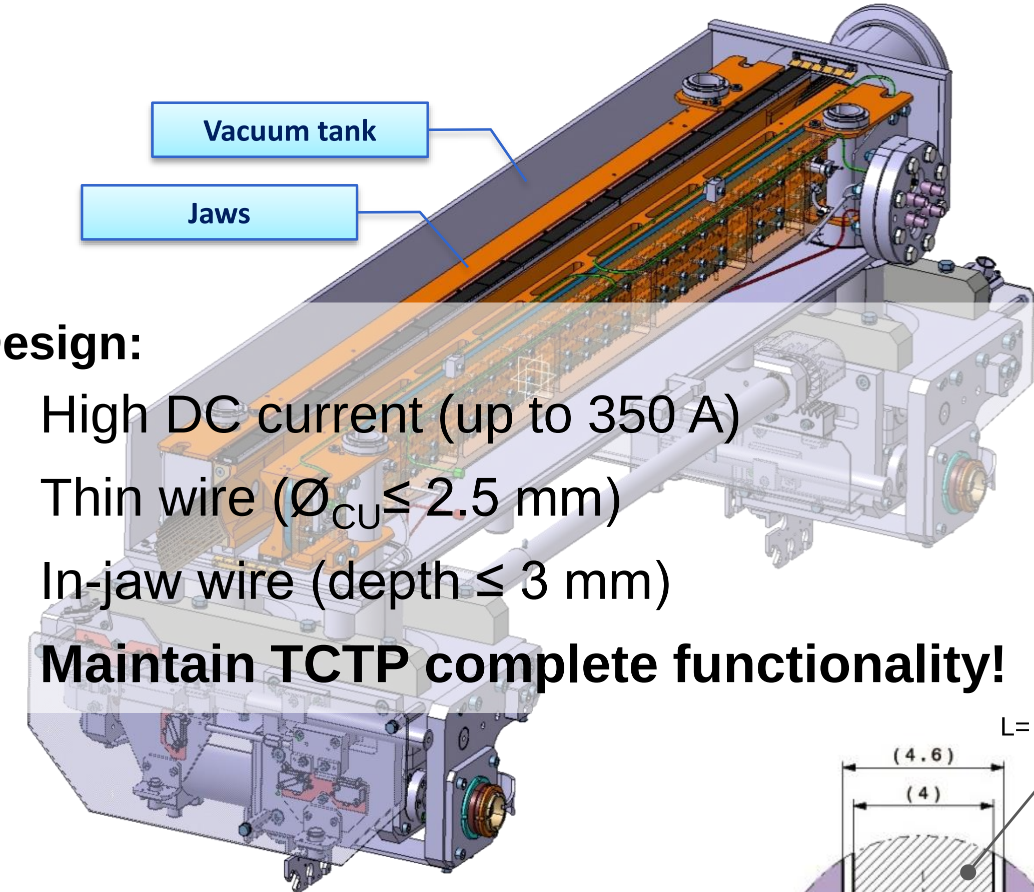


Motivations for the in-jaw wire collimators

- Collimator with wire in-jaw offer:
  - 1 wire per IP side, on incoming and on outgoing beam at a favourable location
  - Wire moving in same plane as beam crossing
  - Possibility to move the wire in pe
    (collimator 5th axis) to adjust for c
  - Current up to 350A + cooling
- At LRBB review in Lyon 2015:
  - Install 1 collimator per side in IP5 on beam 2
  - TCTPH.4R5.B2 and TCL.4L5.B2

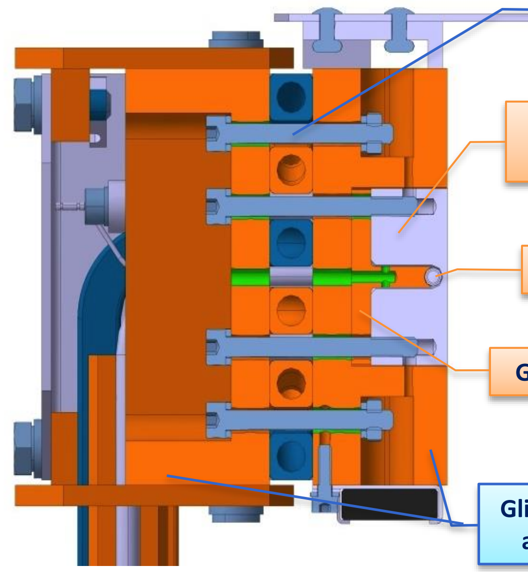


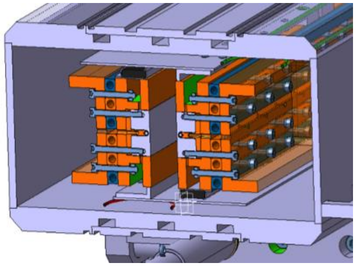
Design of wire in-jaw collimator

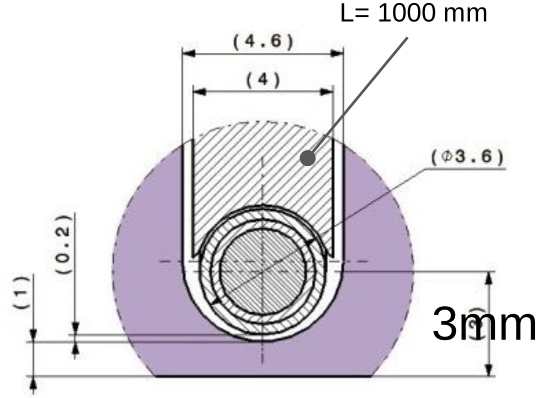


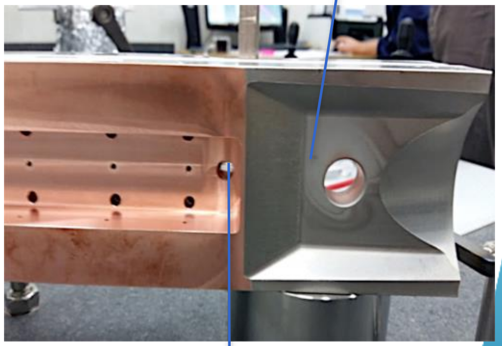
Design:

- High DC current (up to 350 A)
- Thin wire ($\varnothing_{CU} \leq 2.5$ mm)
- In-jaw wire (depth ≤ 3 mm)
- **Maintain TCTP complete functionality!**





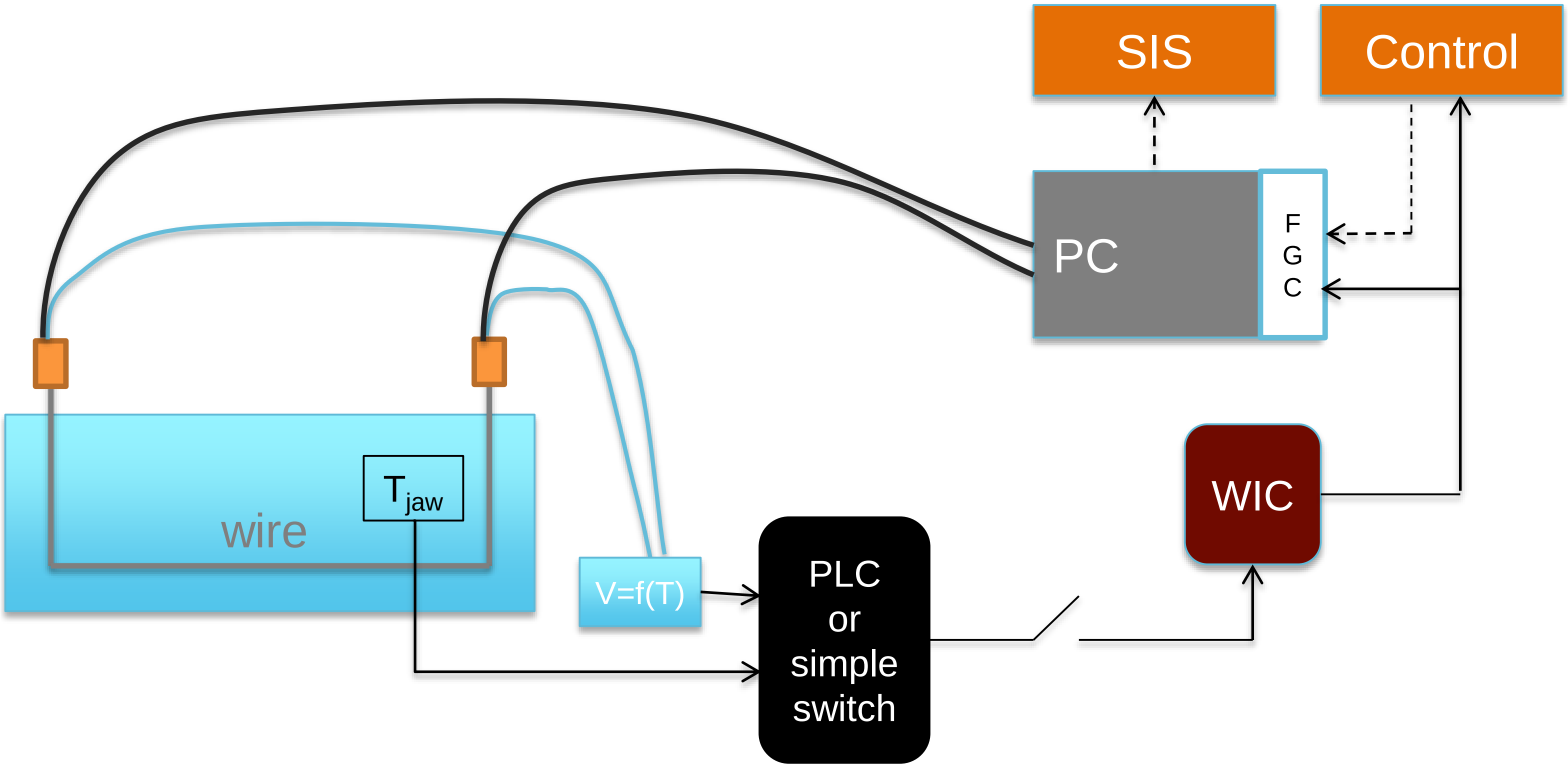




O. Aberle EN-STI

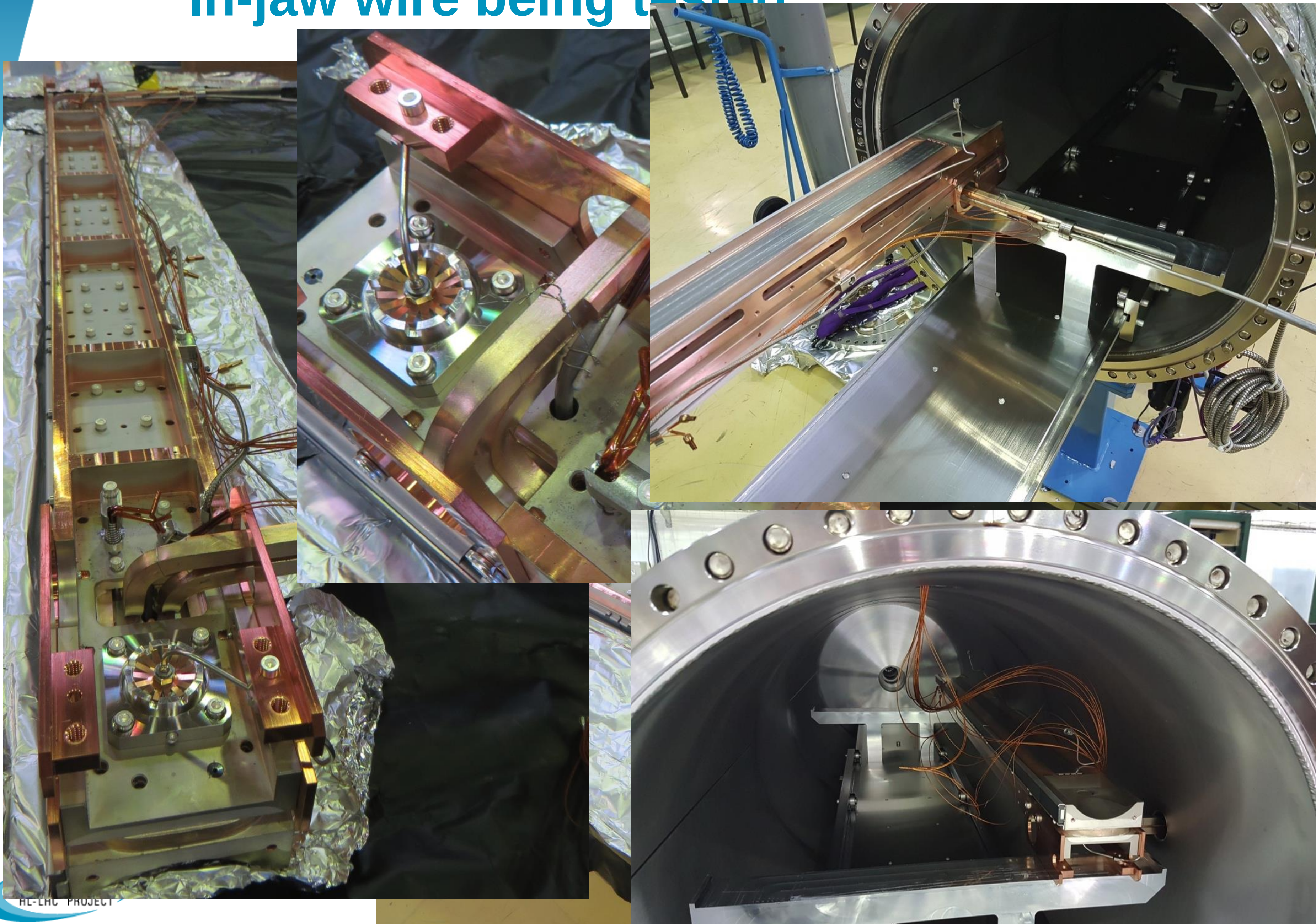
Wire protection and interlocks

- Connection scheme

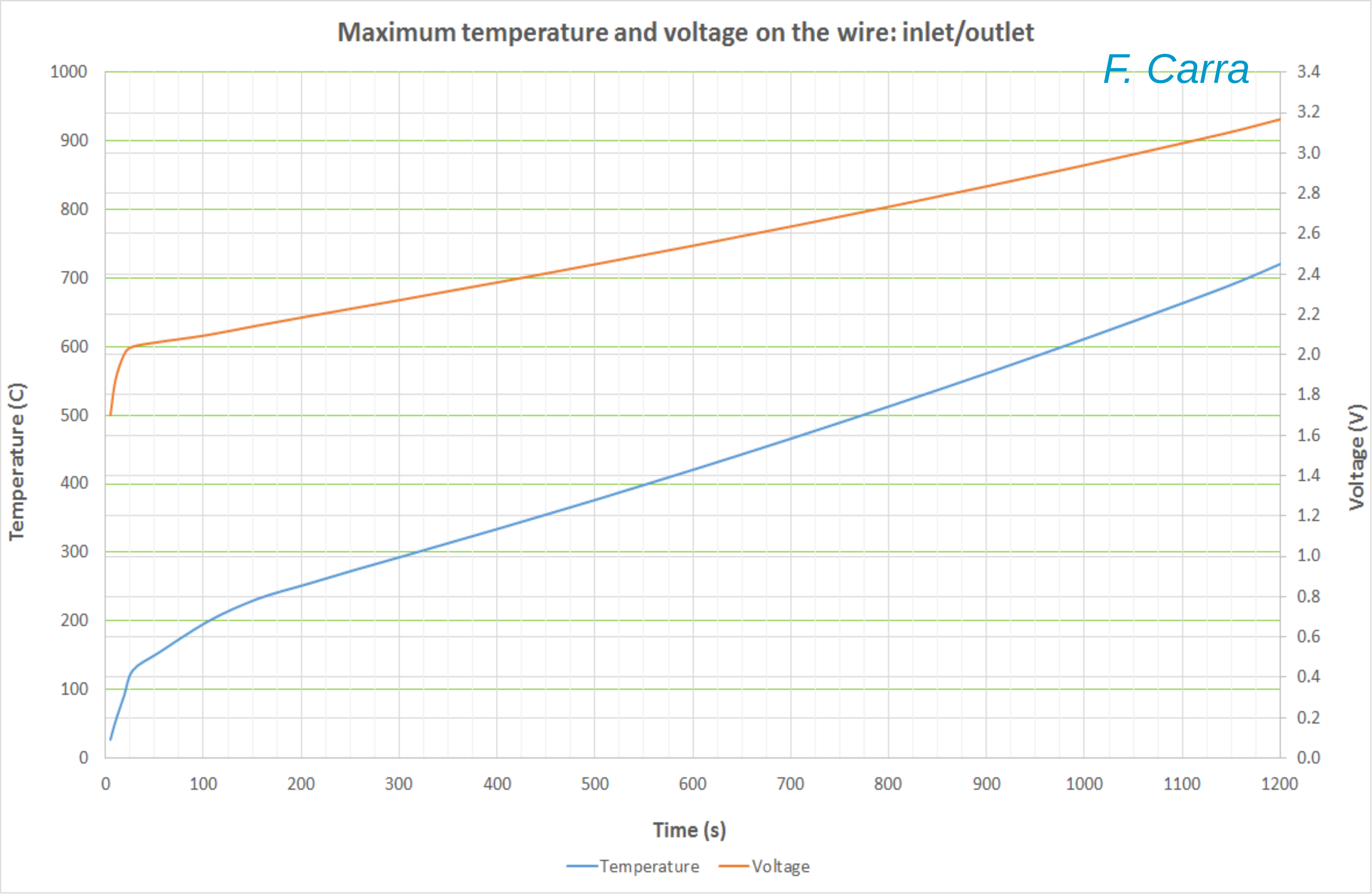


- PC hardware limited to 300A + 10A/s

In-jaw wire being tested



Wire temperature and voltage simulations to compare to test



Time evolution of the wire temperature (blue line) at locations where it reaches maximum temperature; and of the corresponding voltage (red line) between the wire extremities, assuming a current of 378 A, no water-cooling in the jaw, no thermal losses due to radiation, only heat conduction

Failure scenarios: standard operations

- Wire switched on during standard operations by mistake:
  - Maximum current = 300A, at rate 10A/s
  - LHC Optics Web Home:
    - LHC RunII pp physics – injection, optics 2016
    - LHC Run II pp physics – Collision (0.4m), optics 2016
  - Kick given by a magnetic field B_w to a beam of rigidity $(B\rho)$

$$\Delta r' = -\frac{B_w L_w}{(B\rho)}$$

  - Biot-Savart law

$$B_w = \frac{\mu_0 I_w}{2\pi r}$$

Failure scenarios: standard operations

	TCT.4R5.B2		TCL.4L5.B2	
	Injection energy	Collision energy	Injection energy	Collision energy
β at collimator (m)	159	2148	79	772
σ (mm)	1.08	1.04	0.76	0.62
collimator setting (σ)	13	9	25	15
r (mm)	17.00	12.38	21.98	12.37
B (T)	3.53E-03	4.85E-03	2.73E-03	4.85E-03
Δr' (μrad) @ 300A	2.61	0.25	2.02	0.25
σ' (μrad)	6.77	0.48	9.61	0.81
ratio Δr'/σ'	0.39	0.51	0.21	0.31

- The maximum kick < beam-beam effect, which so far has not caused any machine protection issues
- SIS interlock on the status of the PC will dump beam before maximum kick is ever be reached

Failure scenarios: MDs

- During MDs, the intensity of the weak beam limited by maximum 2 full bunches. Full machine protection analysis will be prepared for the MDs, also to approach the weak beam with the TCTW

- The wire is on and the power converter trips:
  - The current excursion will follow the time-constant of the L-R circuit and the PC crowbar, so it will be faster than 10A/s, but we should simply go back to “non compensated LRBB”
  - The effect of electromagnetic induction of this rather slow rapture of the 300 A circuit into neighbouring cables should be low, since the power cables are symmetrically laid

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During MDs

	TCT.4R5.B2		TCL.4L5.B2	
	Injection energy	Collision energy	Injection energy	Collision energy
β at collimator (m)	159	2148	79	772
σ (mm)	1.08	1.04	0.76	0.62
collimator setting (σ)	-	4	-	4
r (mm)	-	7.17	-	5.5
B (T)	-	8.37E-03	-	1.09E-02
Δr' (μrad) @ 300A	-	0.43	-	0.56
σ' (μrad)	6.77	0.48	9.61	0.81
ratio Δr'/σ'	-	0.88	-	0.89

- With only 2 nominal bunches maximum

Conclusion (1)

- In-jaw wire collimators provide a mean for LRBB proof of concept
- Installed in IP5 during EYETS 2016-17
- Protection of the wire from overheat via WIC and integral temperature measurements
  - Note, T should never reach melting, and StSt casing of the copper wire will assure no vacuum degradations nor deterioration of collimator performance

Conclusion (2)

- Machine protection foreseen is believed adequate
- Maximum kick from wire estimated for accidental powering
  - Max kick < beam-beam < beam divergence
  - SIS should act before it is reached thanks to limits in di/dt
- MDs scenarios will need further definition and full MP studies
  - Max kick < beam-beam < beam divergence
  - Weak beam limited to 2 nominal bunches