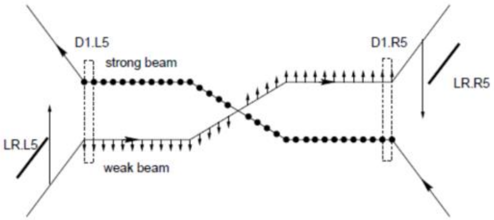


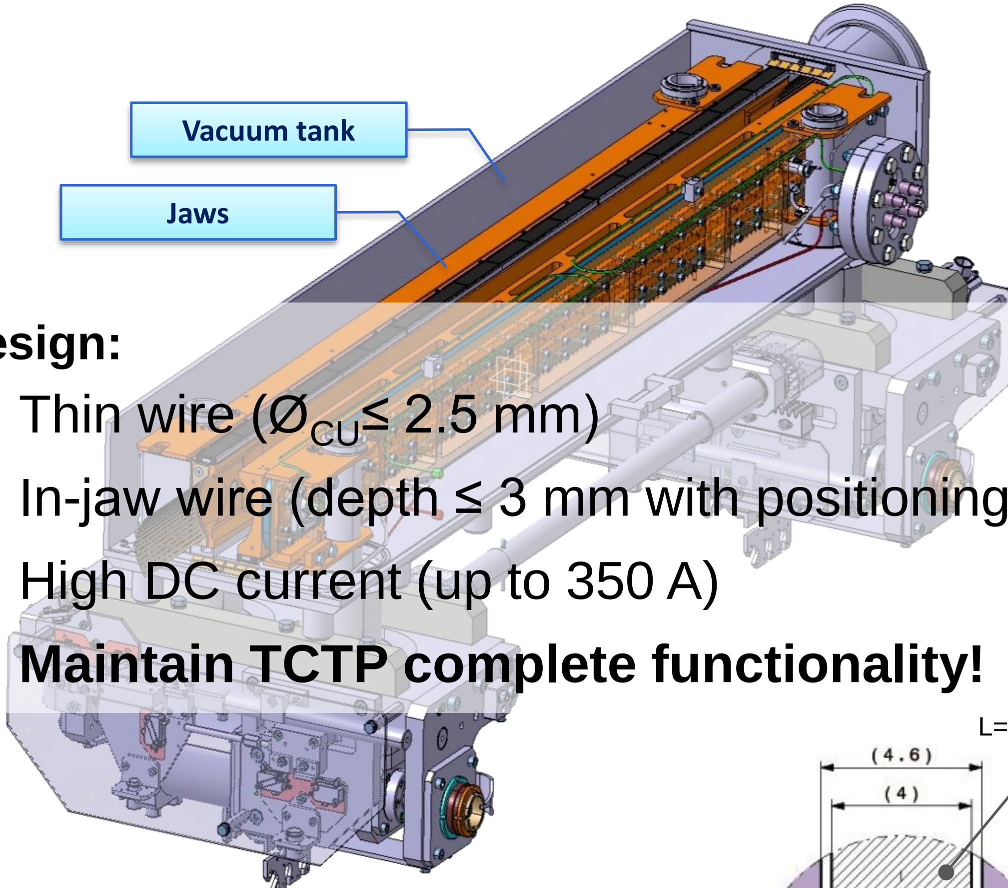
Status of wire-in-jaw collimator and e-lens studies for BBLR compensation

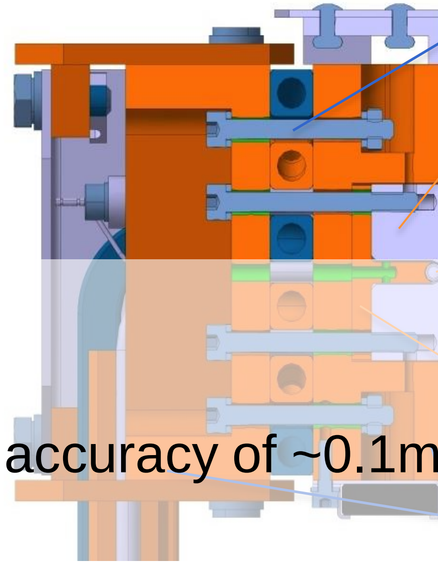
A. Rossi on behalf of the whole team

Outline

- Wire-in-jaw collimators
  - Design
  - Overview of installation in 2016-17
  - Few details on hardware
- Electron lenses for LRBB compensation
  - Location in HL-LHC and derived e-lens parameters
  - Preliminary e-lens (and 20A e-gun) simulations results
- Electron lenses test stand at CERN

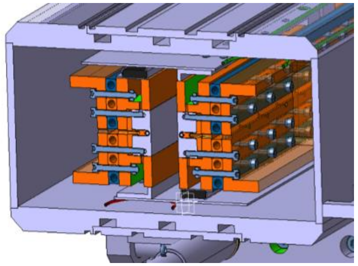
Recall of design of wire in-jaw collimator

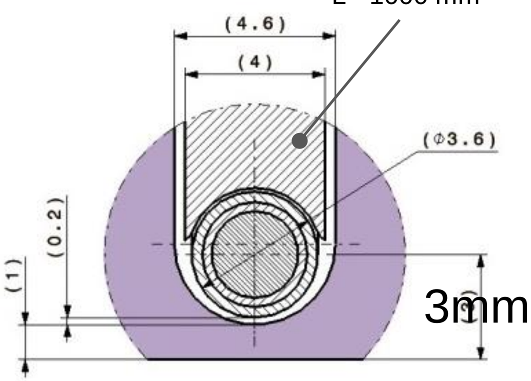


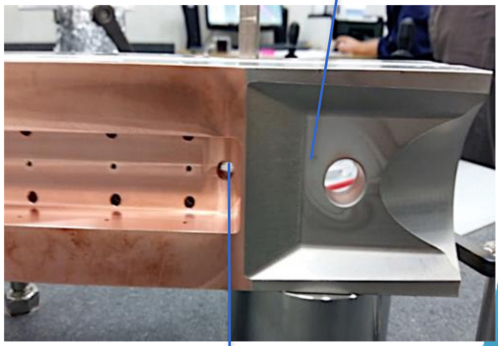


Design:

- Thin wire ($Ø_{CU}$≤ 2.5 mm)
- In-jaw wire (depth ≤ 3 mm with positioning accuracy of ~0.1mm)
- High DC current (up to 350 A)
- **Maintain TCTP complete functionality!**



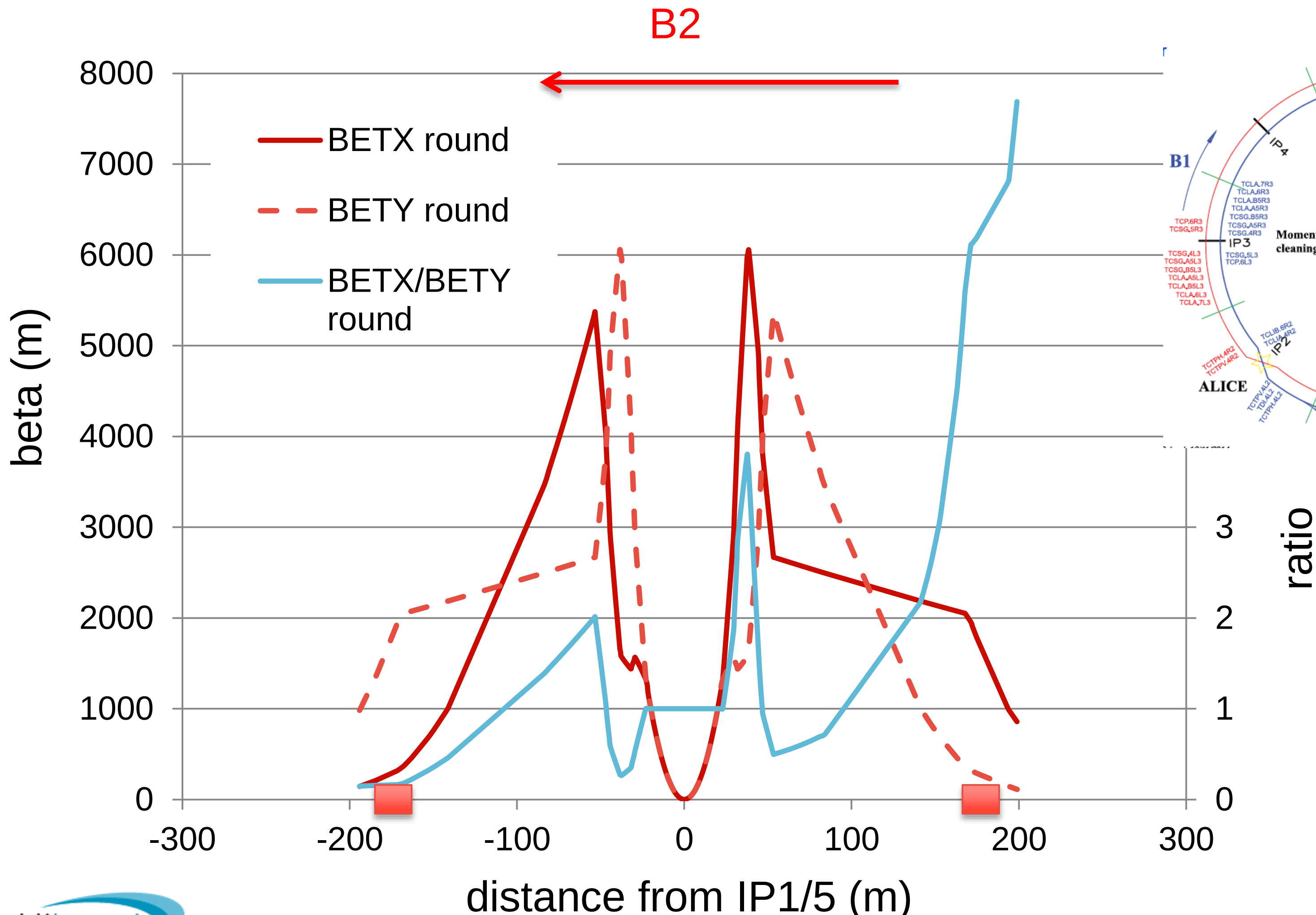


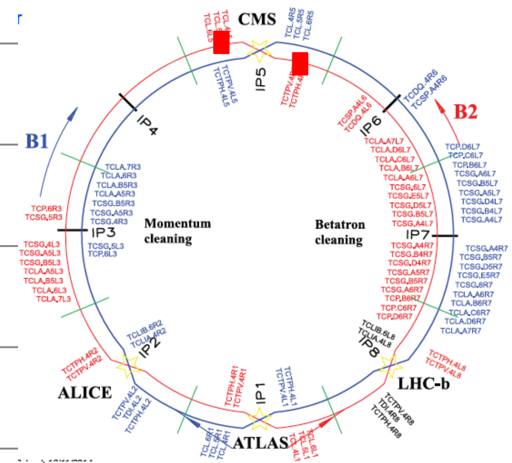


O. Aberle EN-STI

LHC – optics RunII 2016 – collision round 40cm

Optimal wire position at π/2 from IP and beta ratio ~ 0.5 and 2
[S. Fartoukh, 10.1103/PhysRevSTAB.18.121001]





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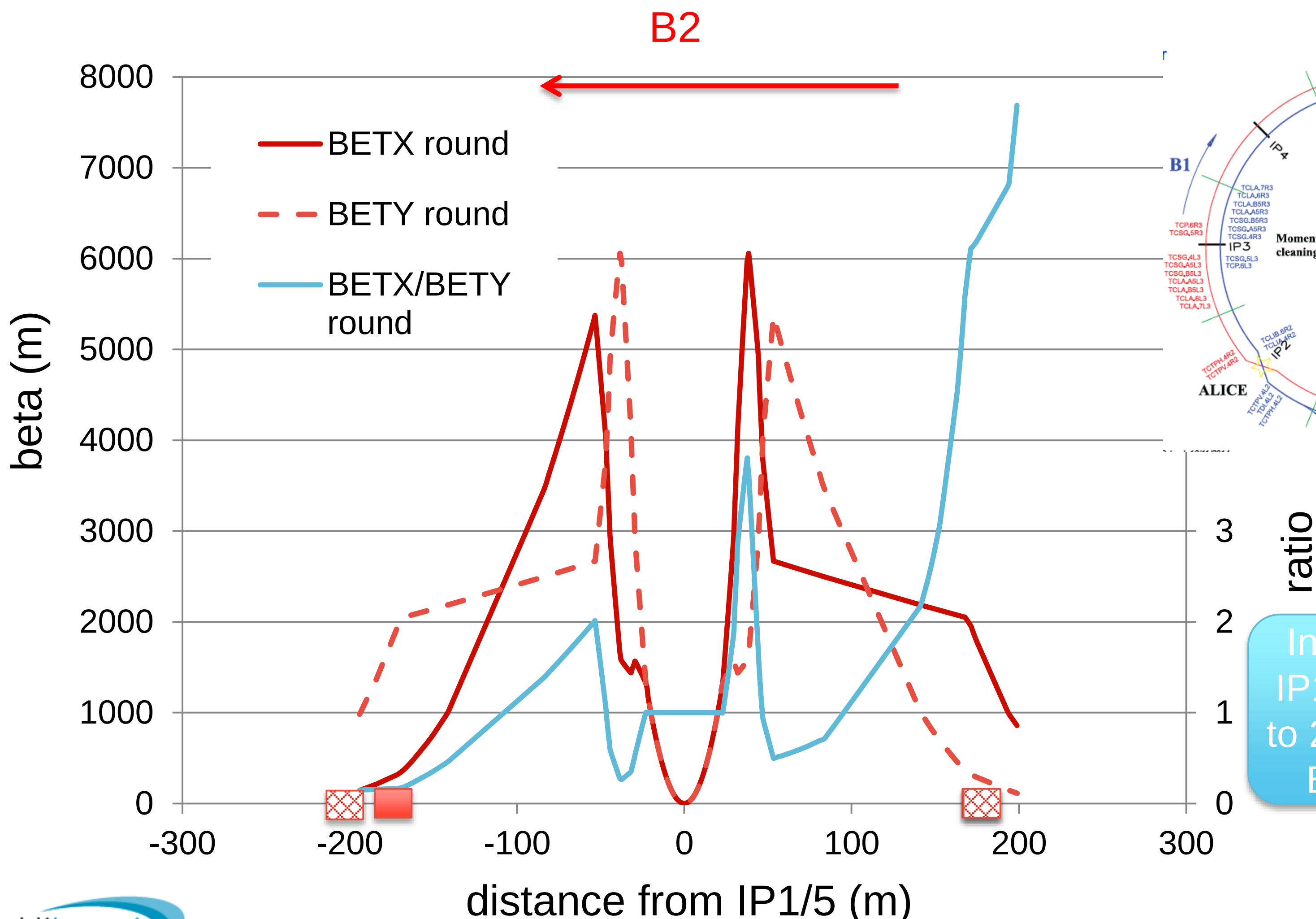
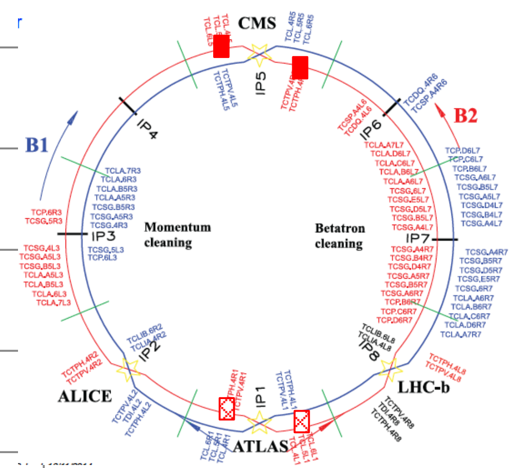




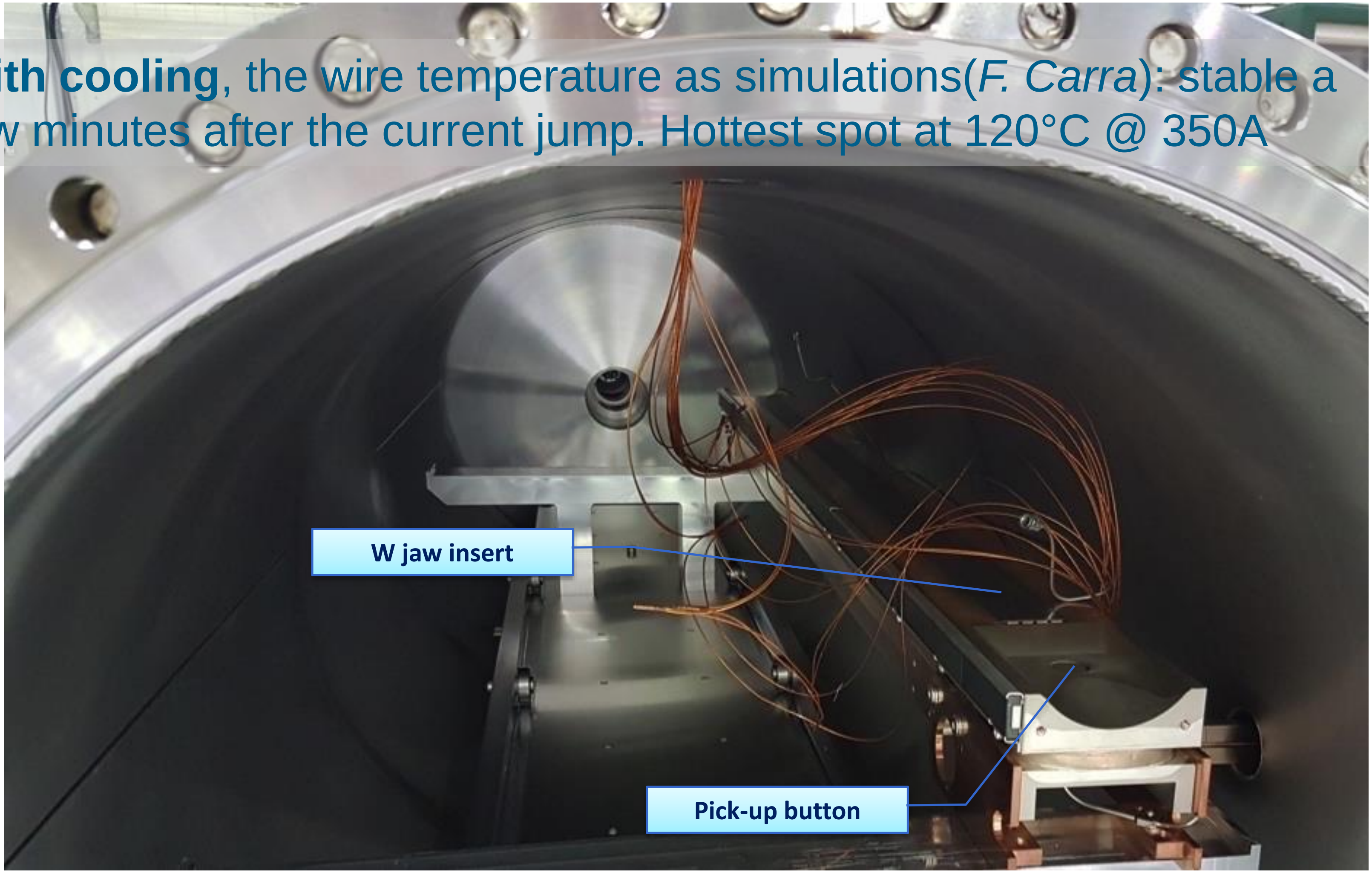
Installation in IP1 postponed to 2017/8 (Lyon BBLR WS)

Wire-in-jaw collimators

- Installation and operation:
  - 1 wire @ ±150m from IP5 in crossing plane
    - incoming beam TCTPH.4R5.B2
    - outgoing beam TCL.4L5.B2
  - Current limited to 300A + 10A/s (cooled)
  - Wire moving in plane of beam crossing
    - 5 µm measured reproducible accuracy of jaw position
    - < 200µrad tilt
  - Possibility to move the wire in transverse plane (collimator 5th axis) to align to orbit
    - ~ 100µm from BPM (to be confirmed with measurements)
- Machine protection discussed at #134 & #135 MPP:
  - 300A by accident @ inj. and coll, kick < σ'_{beam} → time to react with SIS (orbit correctors will act before)
  - Overheating of wire during MDs addressed – U(T).

Installation in IP1 postponed to 2017/8 (Lyon BBLR WS)

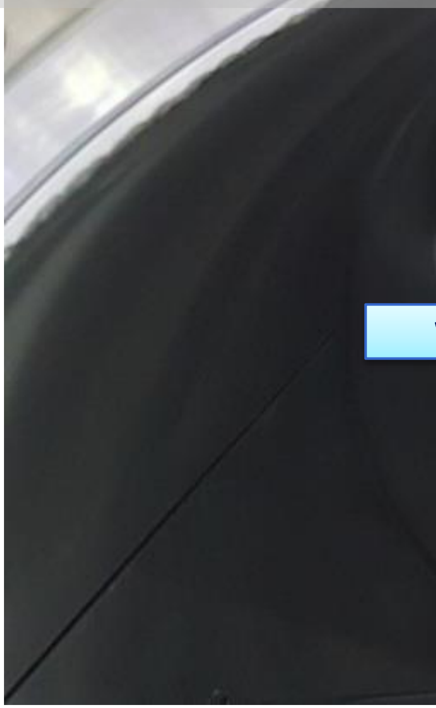
- **With cooling**, the wire temperature as simulations(*F. Carra*): stable a few minutes after the current jump. Hottest spot at 120°C @ 350A

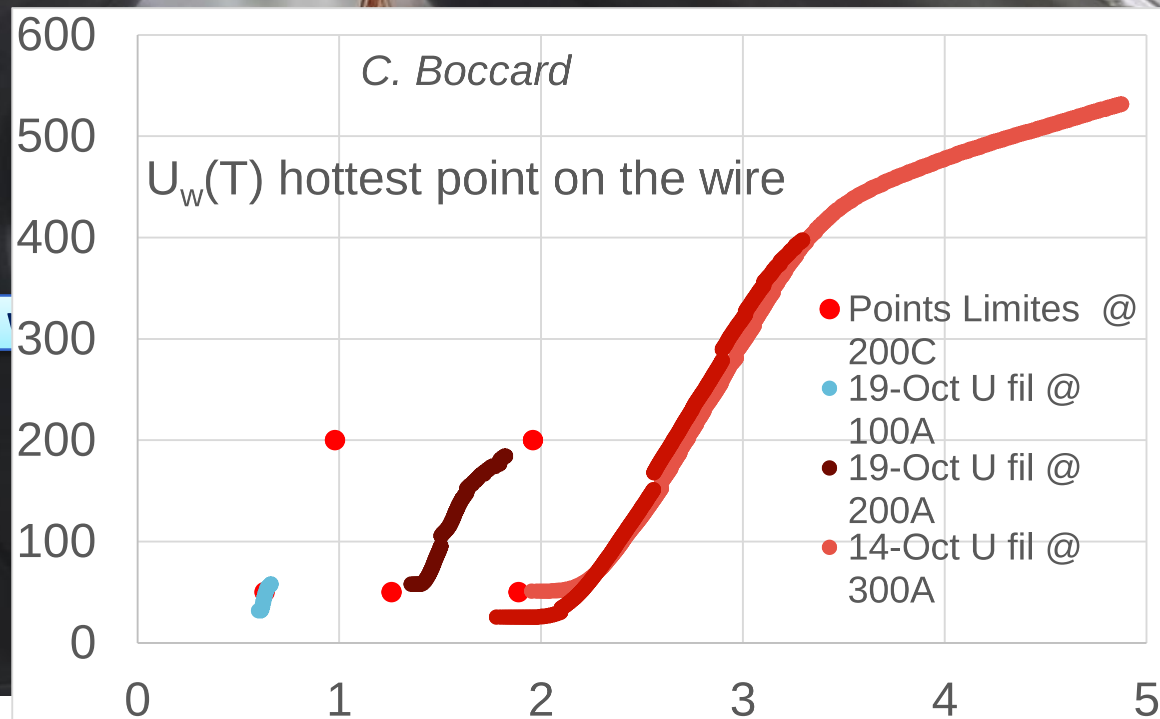


Prototype jaw:

- Used for wire testing and $U_w(T)$ measurements under vacuum

- **With cooling**, the wire temperature as simulations(*F. Carra*): stable a few minutes after the current jump. Hottest spot at 120°C @ 350A
- **Without cooling**, tests at 100 – 200 – 300A:
  Tw <200-300°C for U_w < 2-3V.





Prototype jaw:

- Used for wire testing and U_w(T) measurements under vacuum

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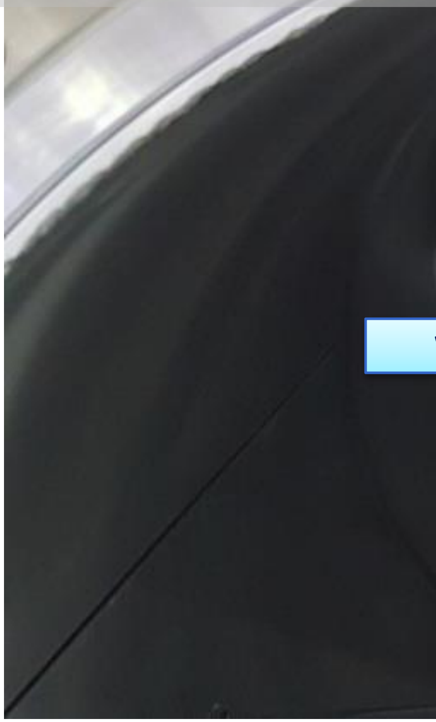
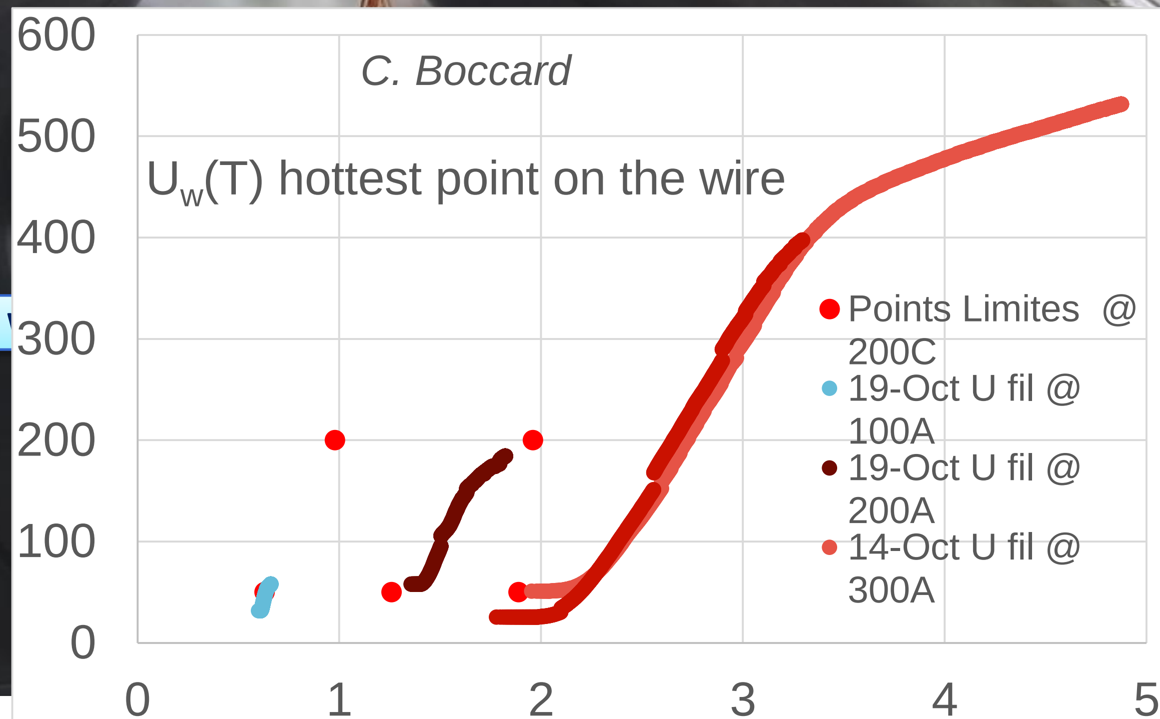




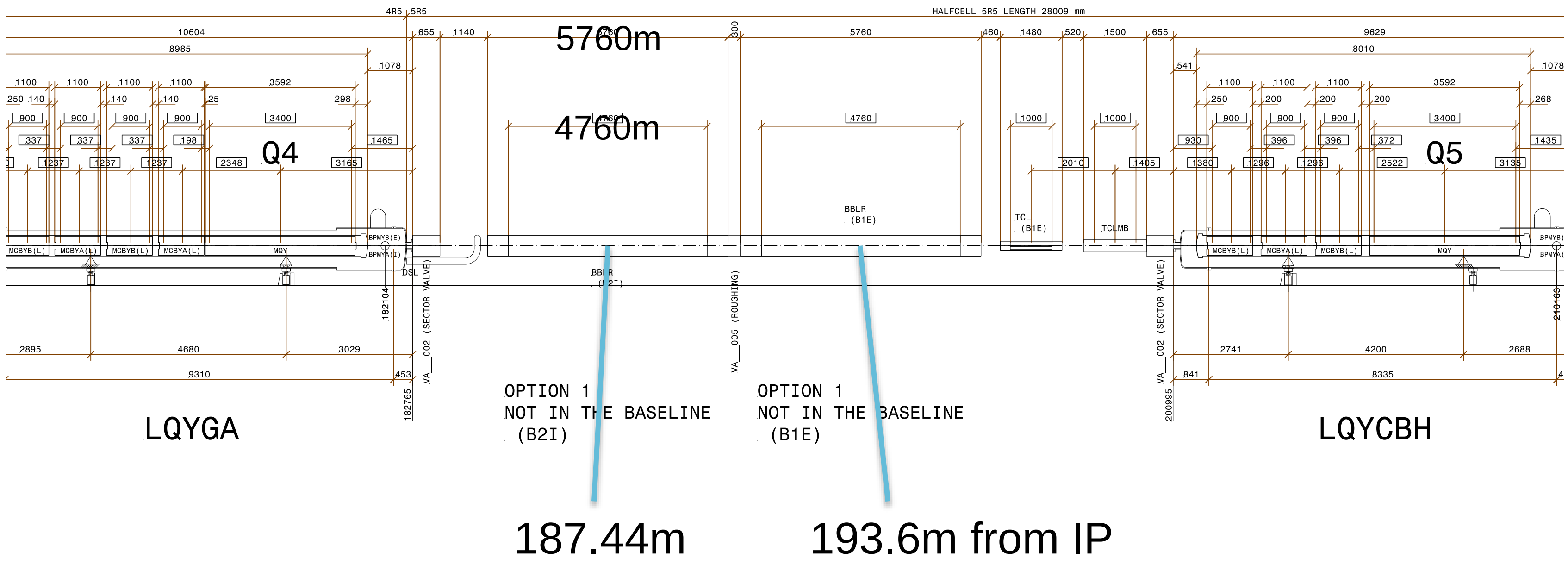
Prototype jaw:

- Used for wire testing and U_w(T) measurements under vacuum

2 horizontal collimators delivered at CERN on 08.11.2016 – now acceptance tests for EYETS 2016-17 installation

BBLR compensation with e-lenses

Assumptions for e-lens simulations so far

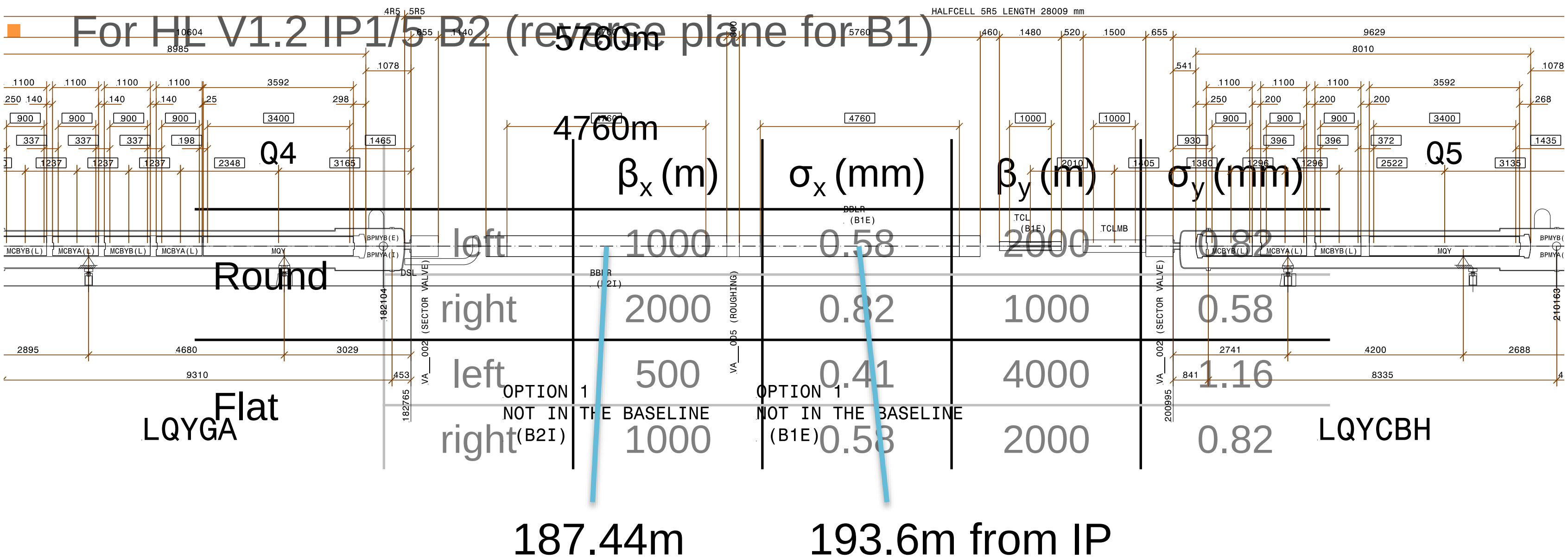


BBLR compensation with e-lenses

Assumptions for e-lens simulations so far

- For HL V1.2 IP1/5 B2 (reverse plane for B1)

		β_x (m)	σ_x (mm)	β_y (m)	σ_y (mm)
Round	left	1000	0.58	2000	0.82
	right	2000	0.82	1000	0.58
Flat	left	500	0.41	4000	1.16
	right	1000	0.58	2000	0.82

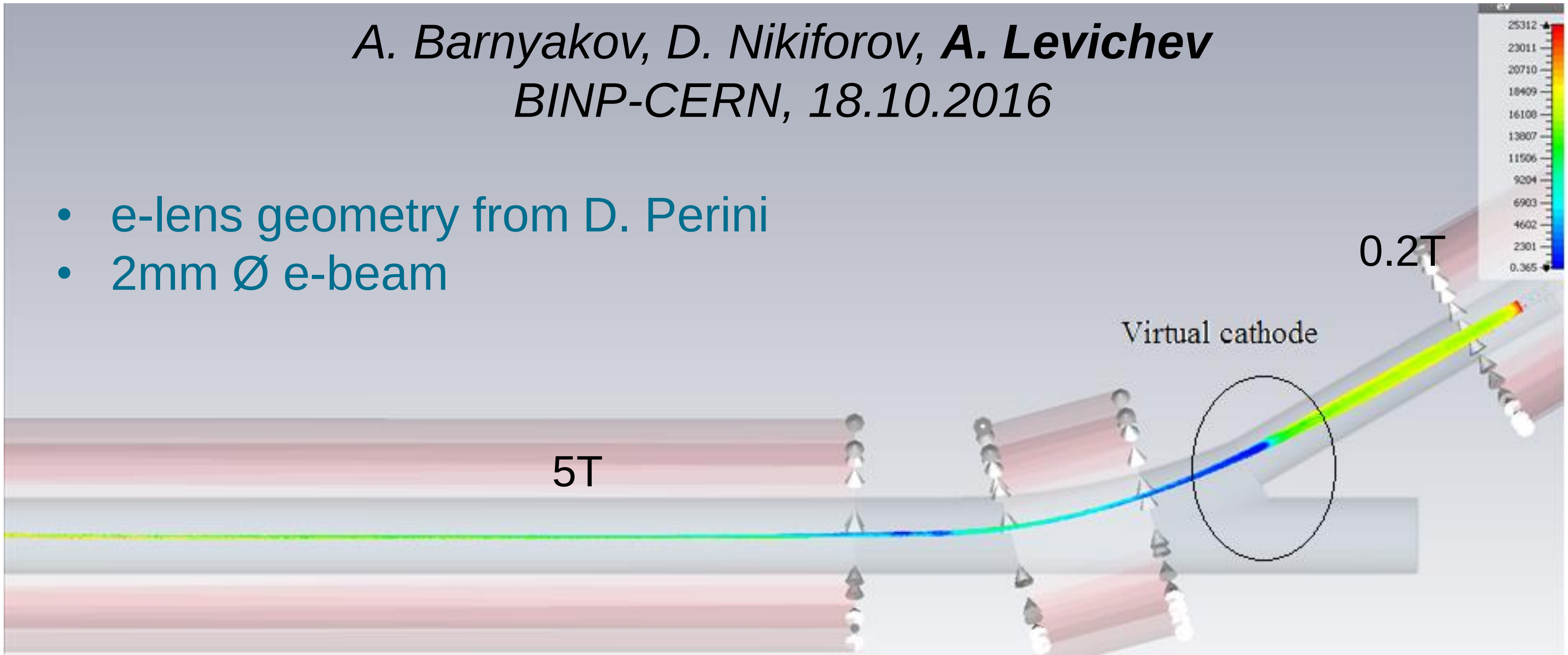


- Proton beam dimension important only in the crossing plane
- In the simulations by A. Levichev et al., given space available if electron beam wire placed at 10 σ_x , it was assumed an electron beam of Ø 2 mm

Beam dynamics I=20A, U=25V

*A. Barnyakov, D. Nikiforov, **A. Levichev***
BINP-CERN, 18.10.2016

- e-lens geometry from D. Perini
- 2mm Ø e-beam



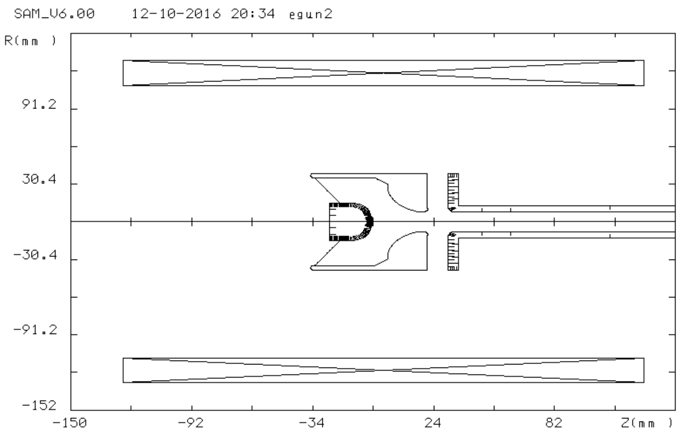
$$P_t = \frac{\sqrt{2e/m}}{3\sqrt{3}} \frac{4\pi\varepsilon_0}{\ln R_t/R_b} \qquad I = P_t U_a^{\frac{3}{2}}$$

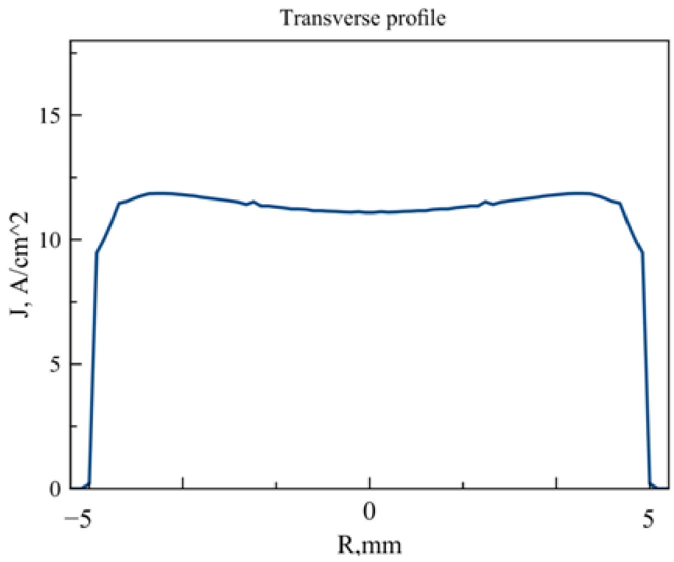
If e- beam compressed to $R_t / R_b > 12.5$ ➔ virtual cathode*

At constant geometry the beam potential has to be increased (**~35 kV**).

*A minimum in potential in a space charge or electron beam, from which electrons are repelled

Possible design of e-gun I=20A, U=35V

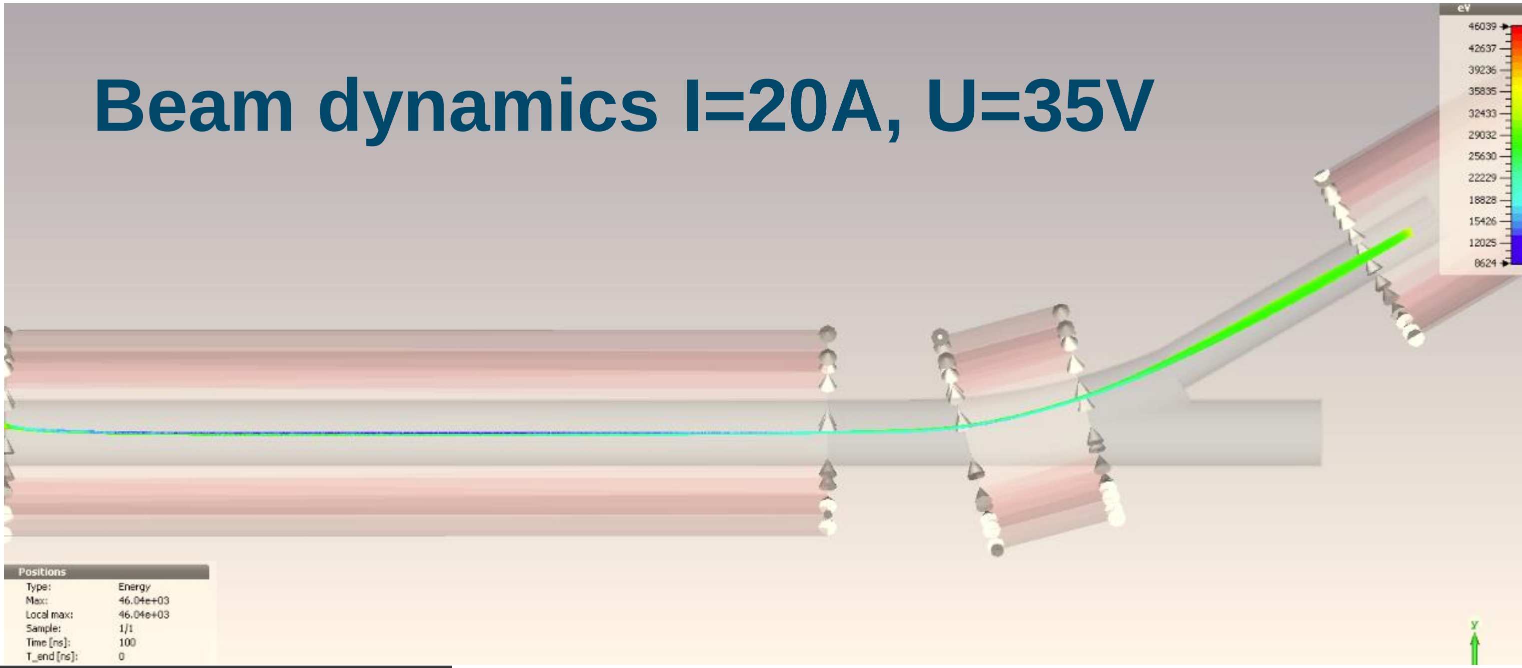


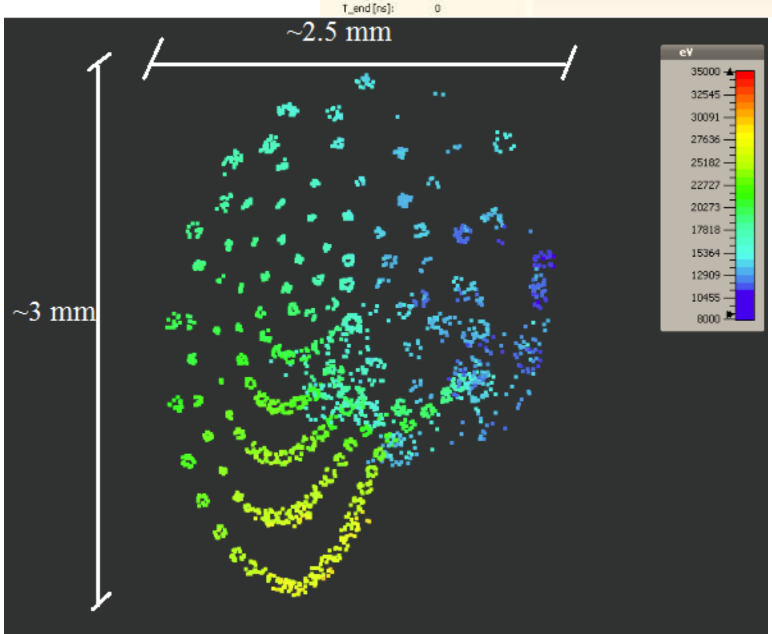


Gun parameters	
Cathode diam.	10 mm
Cathode material	Ir-Ce
Energy	Up to 35 kV
Current	21 A
Tr. Profile	Flat top
Emit (gun exit)	7.8 mm mrad

A. Barnyakov, D. Nikiforov, ***A. Levichev***
BINP-CERN, 18.10.2016

Beam dynamics I=20A, U=35V

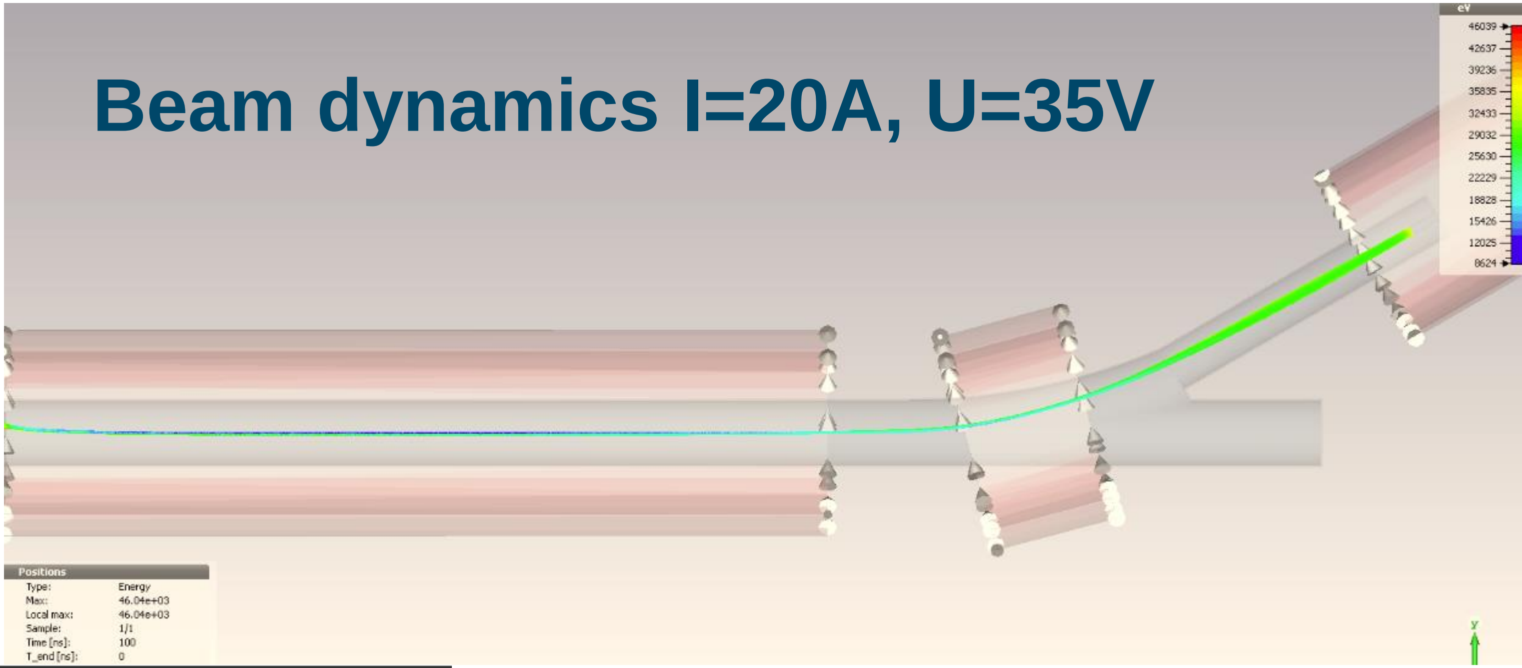


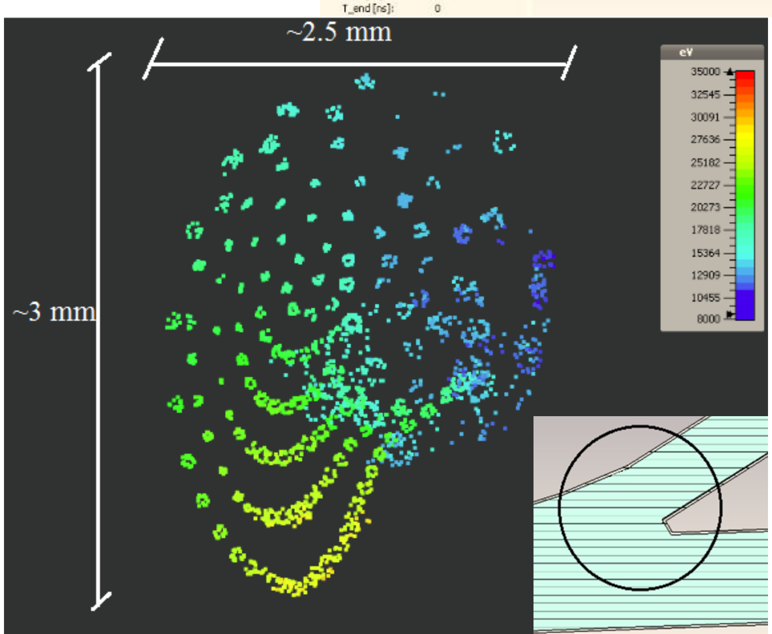


- The e-beam goes through
- Due to the compression (v×B) and asymmetry of vacuum chamber at insertion, the beam potential is decreased and becomes also asymmetric with particles at different velocities
- Alternatives are being studied + effects on LRBB compensations

*A. Barnyakov, D. Nikiforov, **A. Levichev***
BINP-CERN, 18.10.2016

Beam dynamics I=20A, U=35V





- The e-beam goes through
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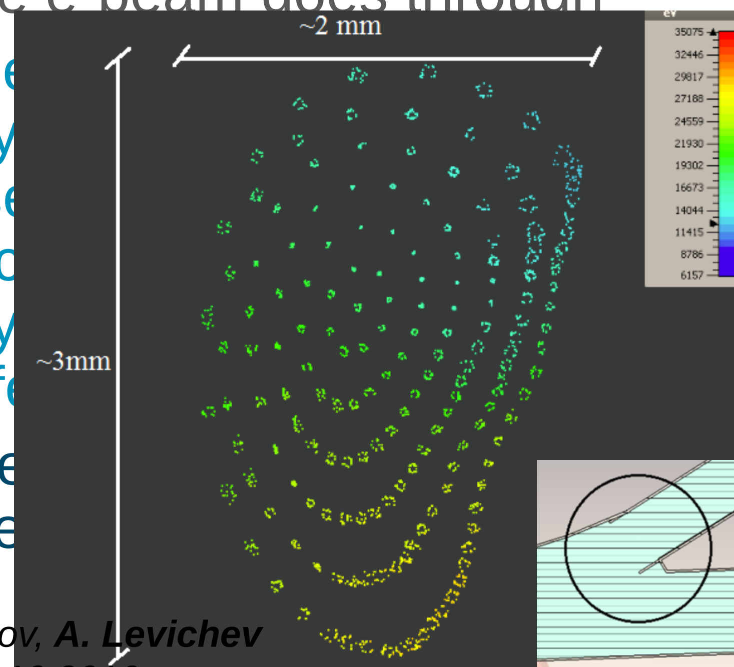


Research objectives for a CERN test stand

General research topics, mainly driven by applications for long-range beam-beam compensation, space-charge compensation, and hollow e-beam collimation

- demonstrate magnetized electron beams with currents up to 20 A
- develop new cathodes with higher current densities and controllable current-density profiles
- on/off of e- beam to act on individual LHC bunch trains (10 MHz)
- develop new instrumentation and diagnostics

  imaging of electrons and protons through gas fluorescence, ...
- test propagation of elliptical electron beams

Electron-lens test stand at CERN

A preliminary design study for a CERN electron-lens test stand was completed [FERMILAB-TM-2629-APC, in preparation]. Estimates depend on required electron beam intensity, shape and size.

Parameter definition and cost by Feb. '17.

Barium oxide dispenser cathodes are appropriate but bulky. Scandium-based cathodes or other new designs are worth exploring for higher current densities.

Followed up at CERN (D. Perini + BINP)

The required electron beam kinetic energy is > 25 keV.

Currently estimated to 35keV for 20A

Some research topics may be studied with a resistive setup (<1 T), but with a limited range of beam sizes. A superconducting main solenoid (6 T) is necessary to explore the effects of magnetic compression.

A configuration with at least one bend between gun and main solenoids is recommended. A progressive approach, with a straight configuration first and subsequent addition of bends, is discouraged because of the cost of reconfiguration.

Status of LRBB compensation project

Big thanks to Collimation Team, EN-STI, EN-MME, BE-BI

- Wire-in-jaw collimators
  - 2 delivered: acceptance tests + installation planned
  - Tests on single jaw under vacuum conclusive for protection strategy
  - Second WS for details of LHC experiment foreseen in March ’17
- Collaboration with BINP well started
  - 3 wks x 3 scientists at CERN: preliminary parameter set for LRBB-compensation investigated
    - With current p+ beam parameters need of 2mm e- beam x 35 kV
    - Further studies with HEL parameters + failure scenario and e- beam losses
  - BBLR compensation with larger e-beam?
- ARIES program accepted:
  - First meeting on ARIES collaboration (WP16)
    RTU (RIGA Technical University), Frankfurt University, GSI, CERN
  - CERN is committed to set-up a test-stand for an experimental program on HEL & BBLR & SCC: specifications + cost estimate until February ’17
- Development of instrumentation
  - LHC coronagraph: see G. Trad’s presentation at this workshop
  - Fluorescence overlap monitor: see C. Welch’s presentation.

Thank you

Many thanks to: H. Schmickler, G. Stancari, D. Perini, C. Boccard, J. Albertone, O. Aberle, F. Carra, L. Gentini, J. Lendaro, G. Cattenoz, R. Combo, A. Levichev, A. Barnyakov, D. Nikiforov, C. Zanoni, S. Redaelli, Y.Papaphilippou. S. Fartoukh, D. Wollman, M. Zerlauth, V. Montabonnet, M. Magrans de Abril, Q. King, R. de Maria and others

Wire 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

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

Wire 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

Wire 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

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

G. Valentino, 10.1103/PhysRevSTAB.15.051002

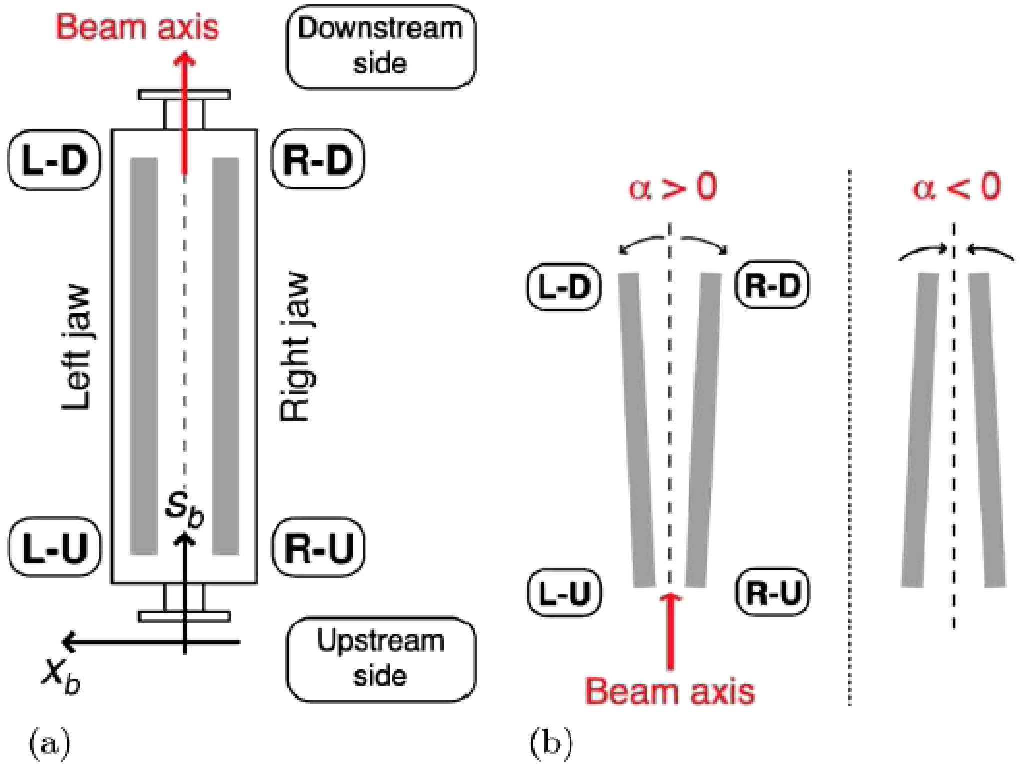
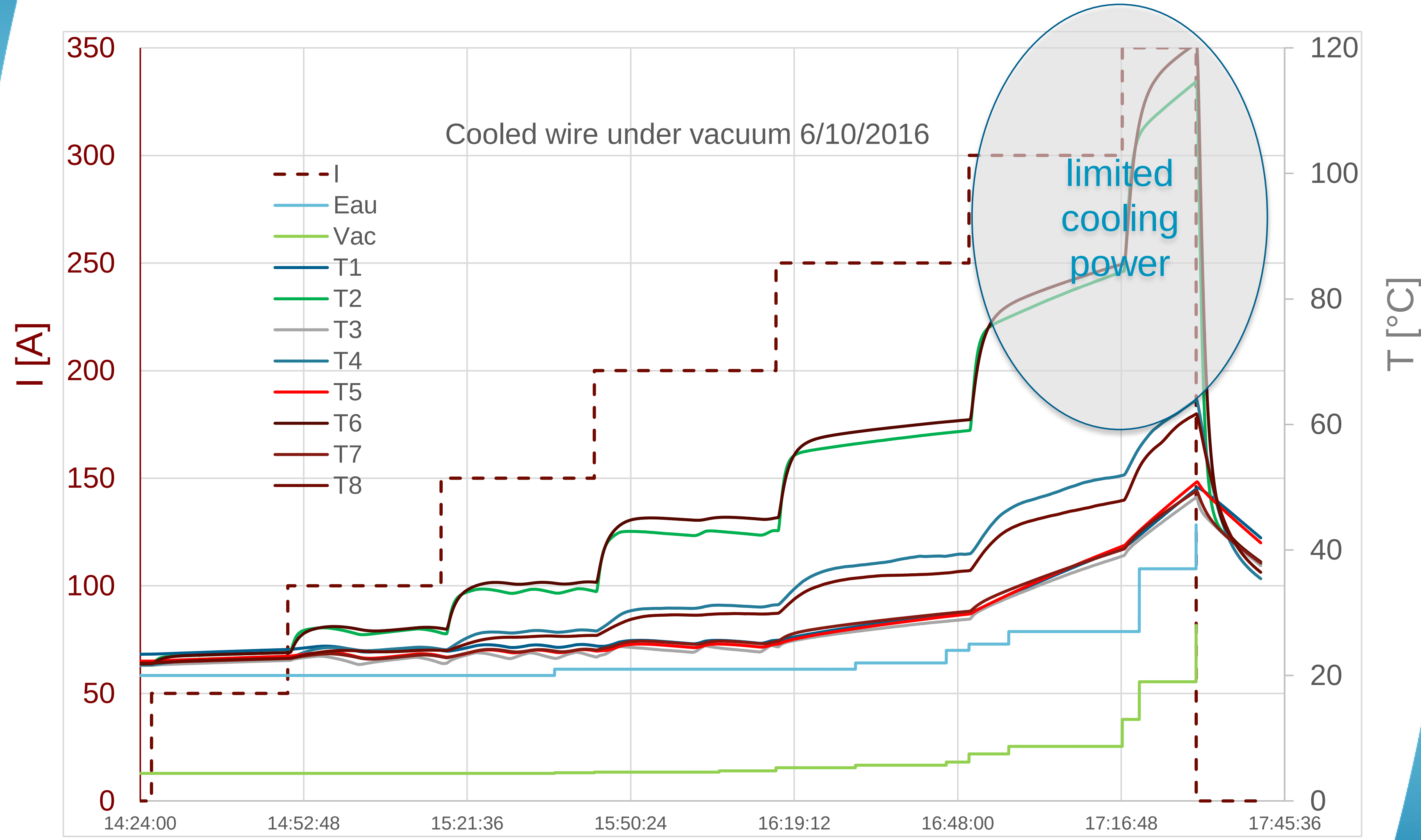


FIG. 3. The collimator coordinate system (a) and the jaw tilt angular convention (b) as viewed from above, from [20]. The four motors positioned at the edges of each jaw allow 4 degrees of freedom.

Wire T(I) – cooling on:

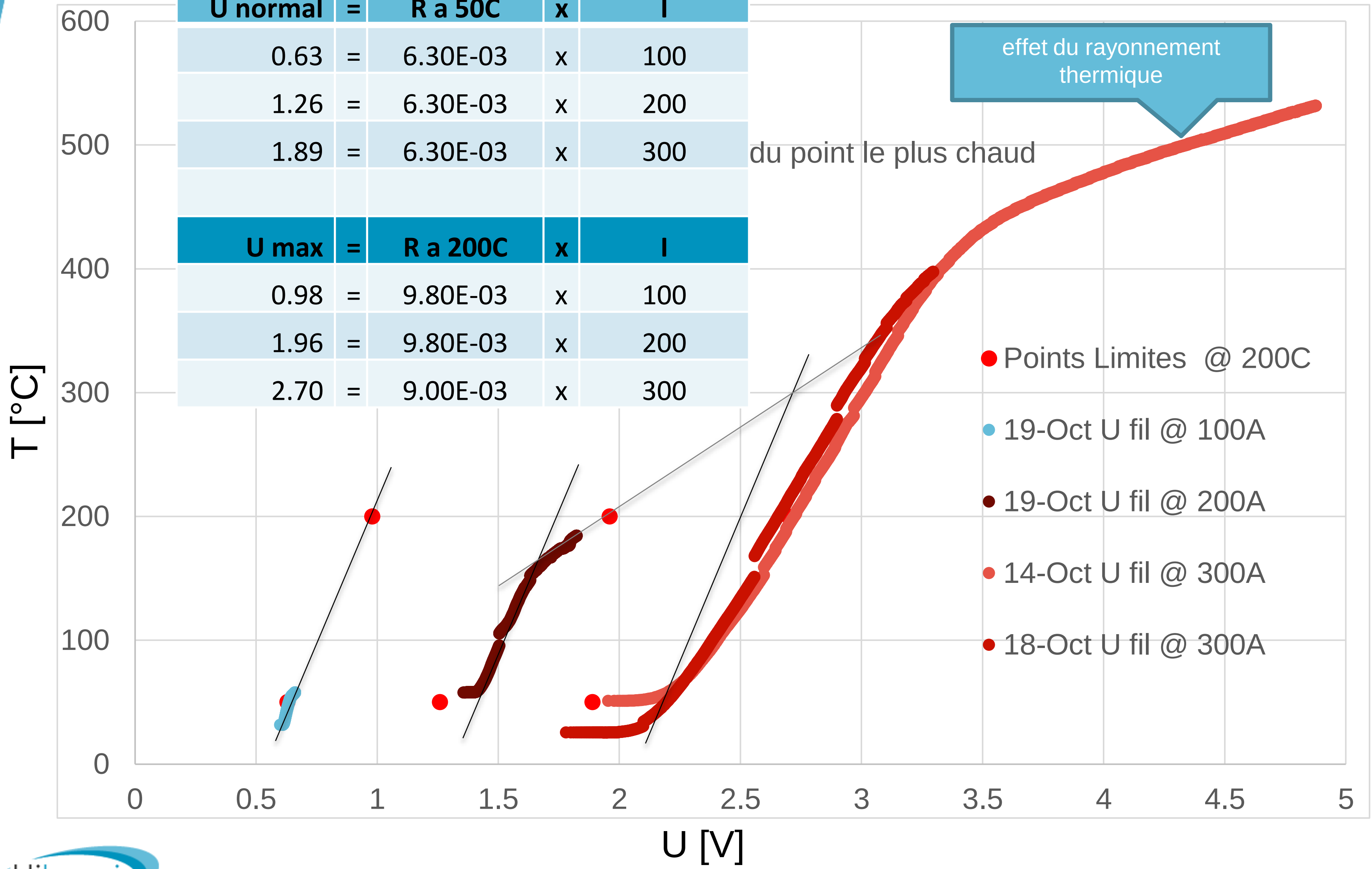
behaviour as expected but cooling not sufficient at I>200-250A



T(V) for 3 values of current – no cooling

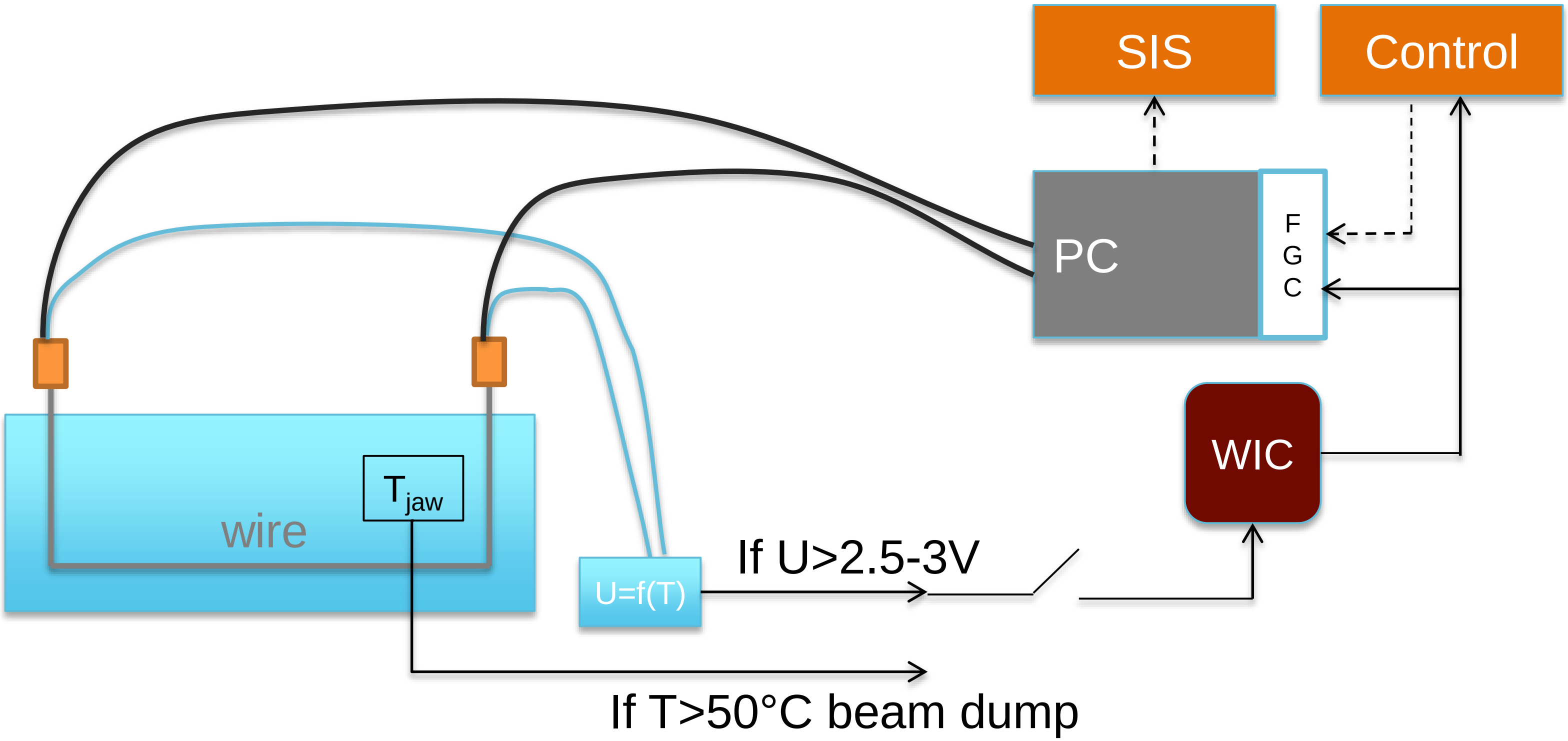
U normal	=	R a 50C	x	I
0.63	=	6.30E-03	x	100
1.26	=	6.30E-03	x	200
1.89	=	6.30E-03	x	300

U max	=	R a 200C	x	I
0.98	=	9.80E-03	x	100
1.96	=	9.80E-03	x	200
2.70	=	9.00E-03	x	300



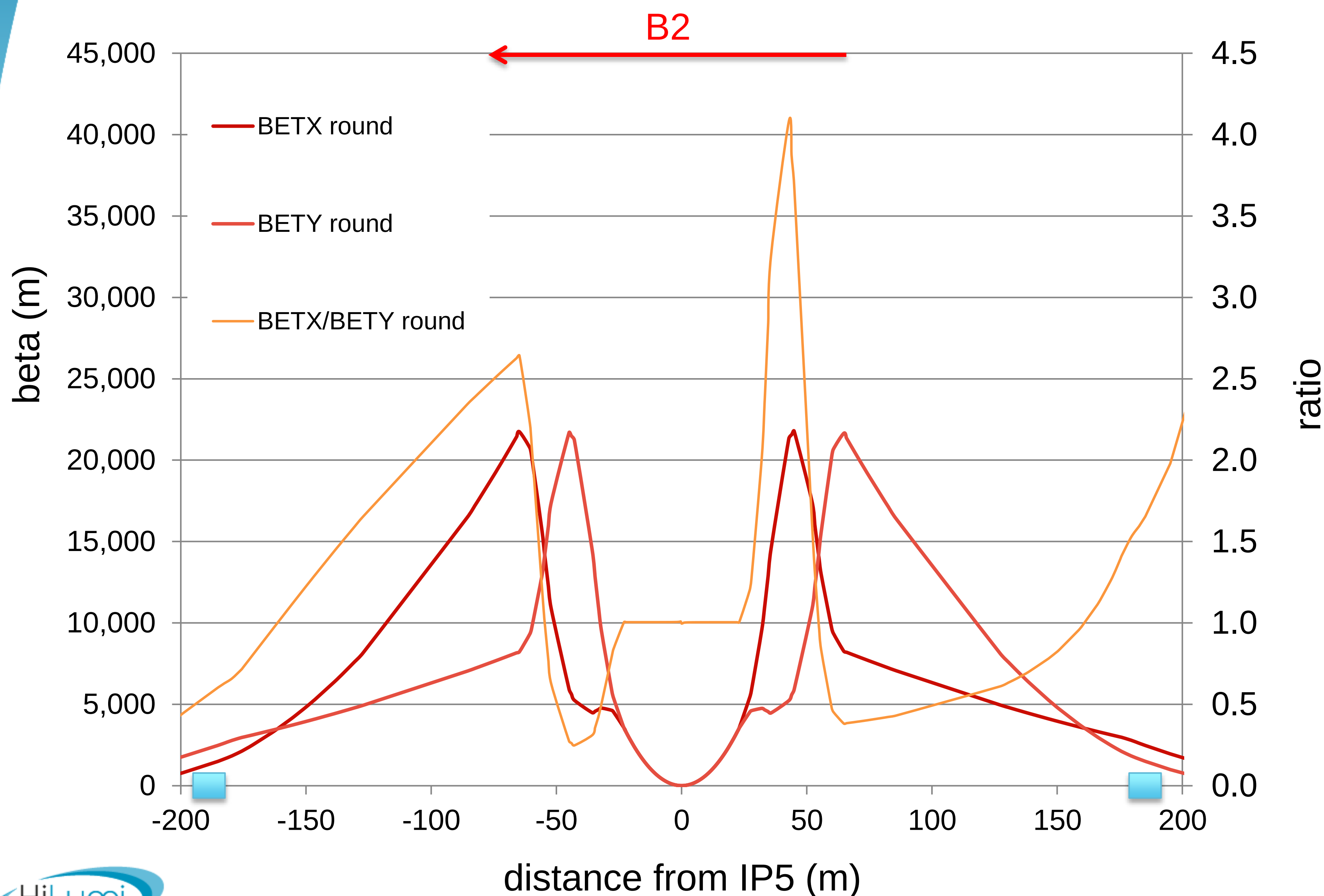
Wire protection and interlocks

Connection scheme

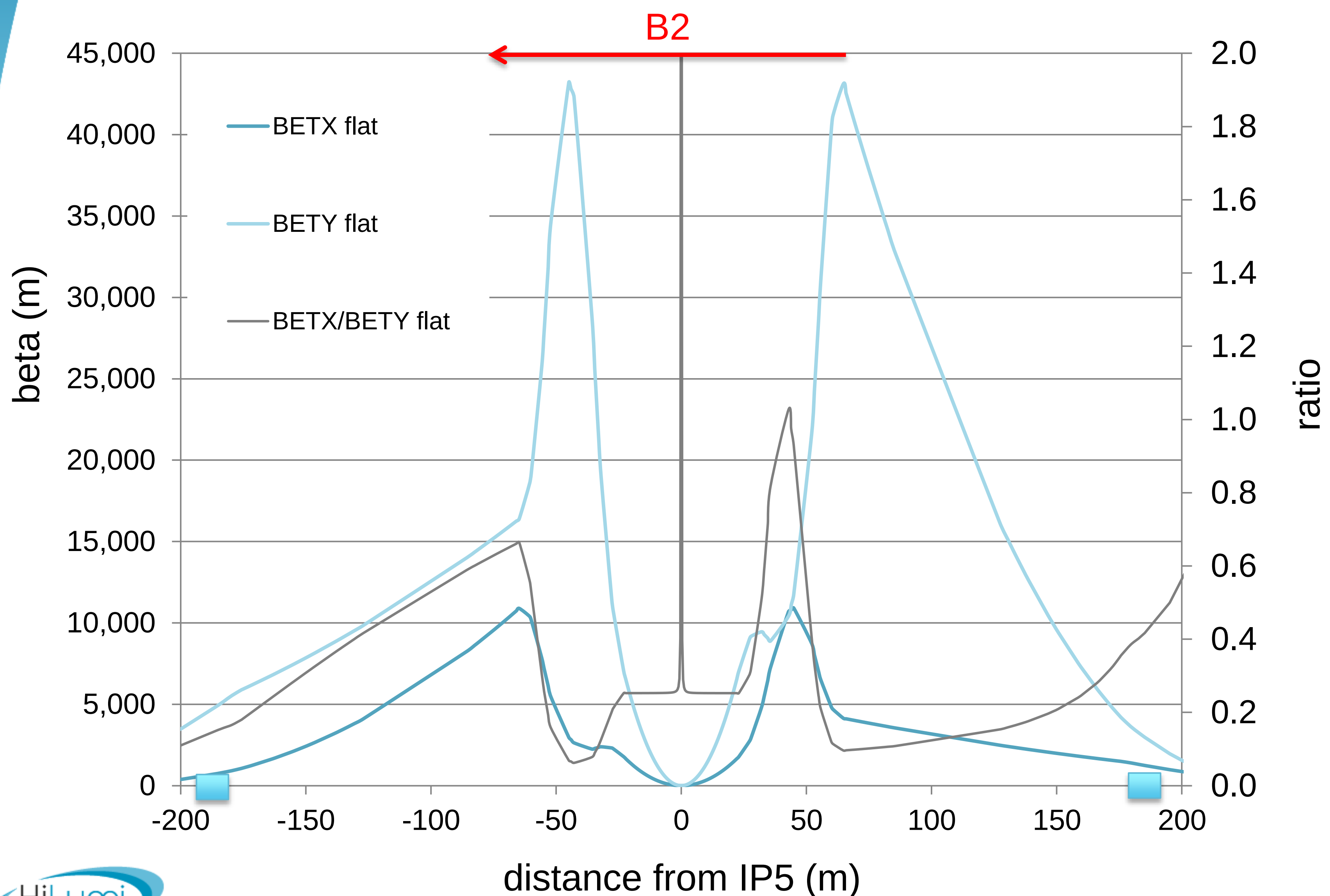


- PC hardware limited to 300A + 10A/s
- If U>2.5-3V T_{max} wire 200-300°C → PC off via WIC
- If T_{jaw} > 50°C → beam dump

Optics HL-LHC V1.2 collision round



Optics HL-LHC V1.2 collision flat



Test Stand Parameters (Giulio's + A.Levichev)

- **cathode size**: @ 20A/cm^2 (BINP)

10 A/cm^2 at FNAL

	current	p-beam	e-beam @	magnetic ratio	cathode dimensions
HEL	5 A	β ~ 200 m σ ~ 0.3mm (ε=3.5)	ring 4 – 6 σ	0.2T / 4T	IDØ10.96 - ODØ16.44 mm
LRBBC	**20 A**	**500 m σ ~ 0.4mm (ε=2.5)**	**dist. 10 σ**	**0.4T / 4T**	**Ø10 mm for Ø2mm e-beam**

- **e- energy**: @20A = 35keV (25keV for Ø7mm e-beam)
- **solenoid field**: 0.1 T sufficient for the beams to be magnetically confined (i.e., small Larmor radius compared to the transverse beam size), but combined axial magnetic fields and radial self electric fields induce azimuthal distortion of the current-density profiles (ExB drift), to be mitigated with high solenoidal **fields > 0.6 T** (preliminary)