LHC Beam-Beam Compensator

Considerations to make it compatible with Machine Protection

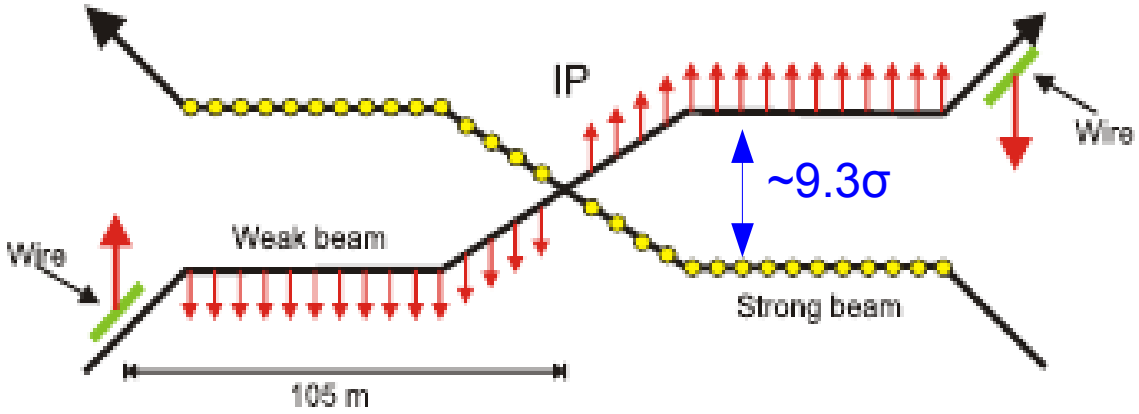
R.J. Steinhagen

for and with input from:

A. Bertarelli, A. Dallocchio, R. Jones, J.-P. Koutchouk, F. Bertinelli,
D. Perini, T. Rijoff, R. Assmann, R. Veness,
J. Wenninger, F. Zimmermann (ABP lead), M. Zerlauth

Motivation for Installing a BBC Prototype in the LHC I/II - Passed several Milestones

- Initial proposal based on to J.-P. Koutchouk's note: CERN-SL-2001-048-BI

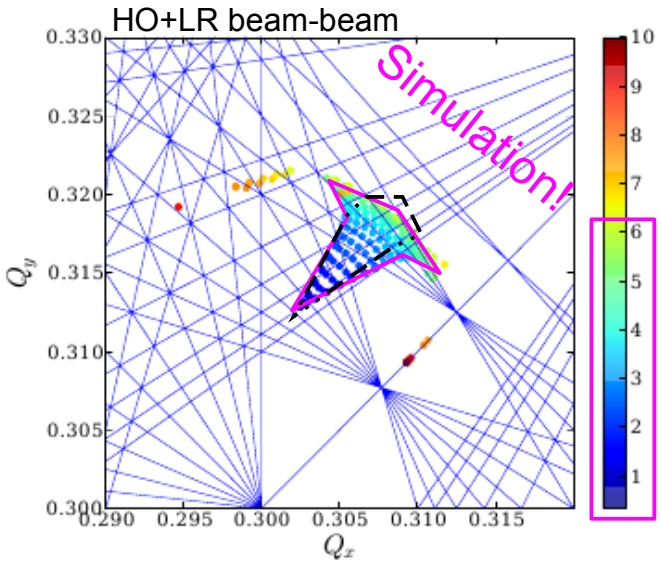


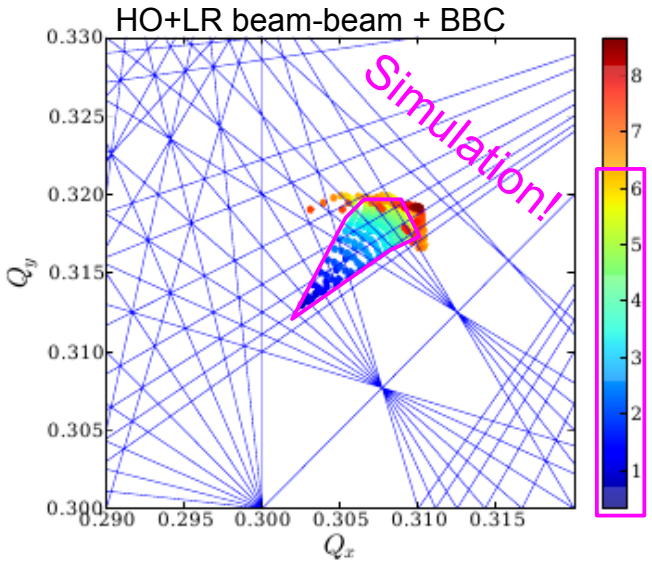
- Since, SPS wire-wire and RHIC beam-wire experiments demonstrated that:
  (for details → F. Zimmermann, e.g. Chamonix' 11 & http://http://cern-ab-bblr.web.cern.ch/)
  1. *"detrimental wire effect on life-time can be compensated by another wire"*
  2. *Benchmark of numerical tool chain → indication of what to expect at LHC*
  - What could be tested at the SPS and RHIC has been tested,
  - *Still,* no direct/consistent demonstration of beneficial effect on life-times

- Further tests require a true long-range beam-beam limited machine...

Motivation for Installing a BBC Prototype in the LHC II/II - Experimental Verification with Beam

- Next step in view of HL-LHC operation (Chamonix'11-Session8 and LMC#82)
  "Launch a project for the LRBB compensating wire in present LHC..."





N.B. beam halo scraped by TCP at 6σ

U. Dorda, F. Zimmermann et al.

  - *... to put the prediction to the test using a prototype BBC.*

- My task: coordinate/evaluate the impact of installing a prototype, possibly during the next long shut-down, to assess the BBC under realistic conditions
  - Tight constraints: design and production requires about a 1 year
    → would need a finalised design/specification by the end of this year
  - Preparation of targeted location for subsequent BBC installation:
    vacuum valves, pumps, girders, water, 600 A PC, BPM signal, cables, ...

Constraints for the proposed LHC BBC Prototype

- LHC-BBC scheme (→ ABP, F. Zimmermann et al.)
  - provide a adequate test-bed to experimentally assess its potential performance for present and future HL-LHC upgrade scenarios

- LHC Machine Protection (MPP → this meeting)
  - should not become an aperture bottleneck during regular operation
  - should either cope with asynchronous beam-dump scenario or not deteriorate machine performance after such an event
  - This will be a prototype tool for MD purposes
    → can assume special simplified run, optics and beam configurations:
    - e.g. limited number of bunches (e.g. <72), small emittances, etc.

- LHC Beam Cleaning (Collimation WG, R. Assmann et al.)
  - preserve/provide the same function as present collimator hierarchy

- Practical considerations, 'KISSS' – Keep the Impact Simple, Small and Safe:
  - feasibility from an engineering point of view
  - Should not deteriorate present machine performance (e.g. impedance..)
  - required instrumentation to setup, assess and verify its performance

Initial Plans: LHC Beam-Beam Compensators I/III

- Reservations around IR1&IR5, LHC-BBC-EC-0001:

	name	Position and longitudinal dimensions
IR1	BBC.4L1	-104.931 m ± 1.5m wrt IP1
	BBC.4R1	104.931 m ± 1.5m wrt IP1
IR5	BBC.4L5	-104.931 m ± 1.5m wrt IP5
	BBC.4R5	104.931 m ± 1.5m wrt IP5

CERN
CH-1211 Geneva 23
Switzerland

the Large Hadron Collider project

LHC Project Document No. LHC-BBC-EC-0001
EDMS Document No. 503722
Engineering Change requested by / Name & Div./Grp.) : C.Fischer AB/BDI

Date: 2004-10-27

Engineering Change Order – Class I

RESERVATIONS FOR BEAM-BEAM COMPENSATORS IN IR1 AND IR5

Brief description of the proposed change(s) :

Reservations on the vacuum chamber in IR1 and IR5 for beam-beam compensator monitors.
We propose to include these modifications in the next v.6.5 machine layout version.

Equipment concerned :	Drawings concerned :	Documents concerned :
BBC	LHCLSX–0001 LHCLSX–0002 LHCLSX–0009 LHCLSX–0010	

PE in charge of the item :	PE in charge of parent item in PBS :
J.P. Koutchouk AT/MAS	C. Rathjen AT/VAC

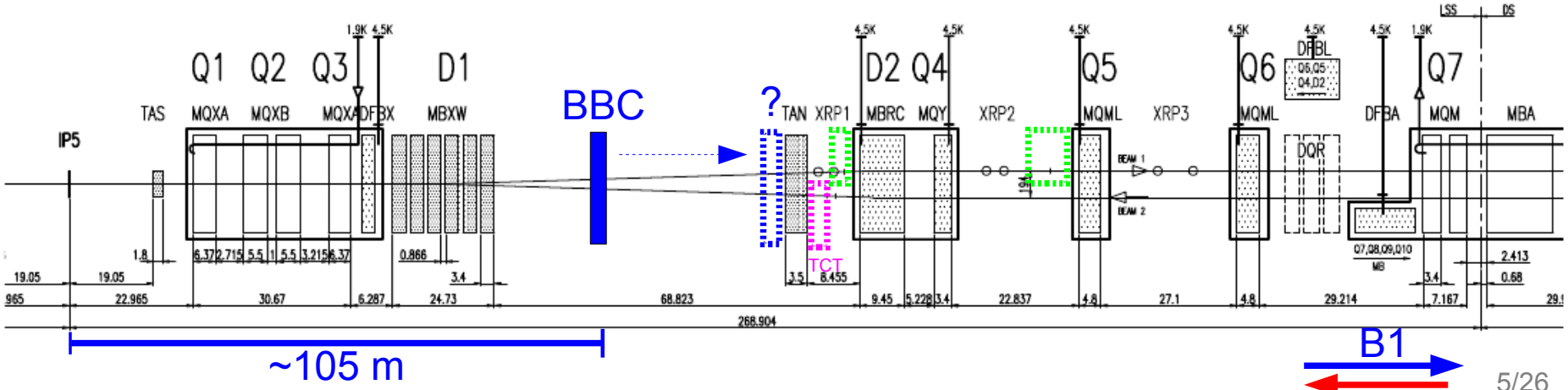
Decision of the Project Engineer :	Decision of the PLO for Class I changes :
☐ Rejected.	☐ Not requested.
☐ Accepted by Project Engineer, no impact on other items. *Actions identified by Project Engineer*	☐ Rejected.
☑ Accepted by Project Engineer, but impact on other items. *Comments from other Project Engineers required Final decision & actions by Project Management*	☑ Accepted by the Project Leader Office. *Actions identified by Project Leader Office*
Date of Approval : 2004-10-27	Date of Approval : 2004-10-27

Actions to be undertaken :
Modify the drawings and Equipment codes concerned to reflect the changes described in this ECO.

Date of Completion : 2004-10-27 | Visa of QA Officer :

Note : when approved, an ***Engineering Change Request*** *becomes an* ***Engineering Change Order/Notification.***

- Min. LRBB → BBC phase advance: $\Delta\mu \approx 2.6°$ (→ 3.1°)
- Symmetric beta-function: $\beta_{x/y} \approx 1000$ m (for $\beta^* = 0.55$ m)
- N.B. single vacuum pipe for B1 & B2:
  110 mm full beam separation (only D1 only)
  (→ 165 mm, if shifted more towards TAN)



Physical Space IR5

- Reservation request is being honoured → common beam pipe still available

- Alternate location:

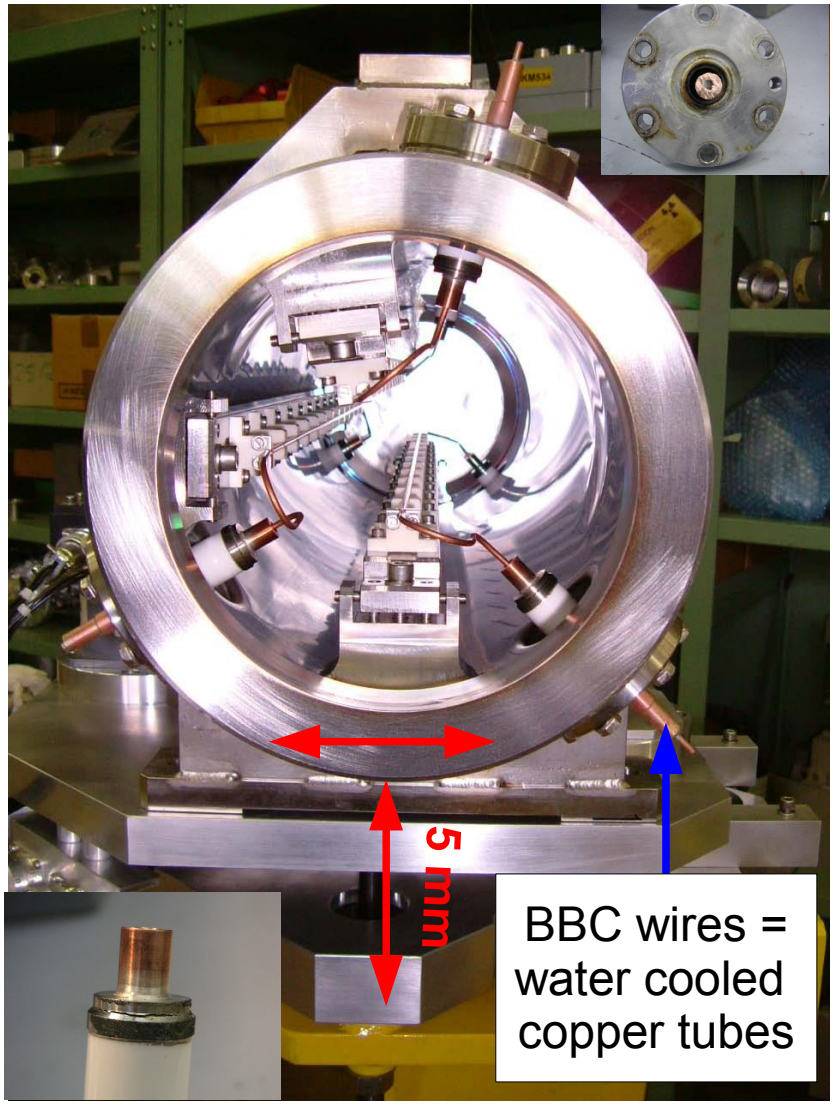

TCT and roman pots


Between Q4 and Q5

Initial Plans: LHC Beam-Beam Compensators II/III

- SPS and donated RHIC design are incompatible for installation in LHC:
  - Diff. aperture, beam pipe, mechanics, ...
  - Wire needs to be in between beams
  - Free-standing wire & RF resonances ↔ classic λ/n-antenna (impedance issues)
  - Not robust w.r.t. beam impact
  - Moveable tank bears the inherent risk of breaking and of bursting of:
    - vacuum bellows ↔ require movement of > 10 mm
    - water cooled interconnects
    - bursting/water leaks inside the vacuum chamber ie. in response to impact of nominal bunch, n-flux fatigue or 1kW of inherent heat → A. Bertarelli's Chamonix'11 talk

→ inacceptable due to too big impact on LHC operation in case of failure.



Initial Plans: LHC Beam-Beam Compensators III/III

- Initially 2 BBC per beam/IP requested → H-V pair for one beam only, based on H-V crossing scheme, propose:
  - 1 x BBC-H.B1 in IR5, and
  - 1 x BBC-V.B1 in IR1

- Wire parameters:
  - Solid wire radius of ~ 1mm → 1kW power dissipation
    - Wire diameter is a trade-off between available aperture and cooling
  - sub-σ level of position control
  - Nominal scheme: $I = I_{peak} \cdot \sqrt{2\pi} \cdot \sigma_s \cdot n_{parasitic} = 72 \ldots 350$ Am (max.)
  - Pulsed wire to accommodate differences for PACMAN bunches
    → not feasible/practical at this stage, stick to DC compensation only

- Wire-beam distance: average LR beam-beam separation of 9.7 σ
  → implies a-priori similar nominal BBC position
  - closer than present and possibly future TCT settings
  - critical w.r.t. asynch. dump failure mode, in particular for B2 in IP5
    → Not without issues, the motivation of revalidating this with MPP …

Proposal to make BBC compatible with LHC Machine Protection

- The LHC BBC Prototype will need to be …

A)… either operated always in the shadow of the TCTs[1] → Collimation WG

  - more relaxed in terms of mechanical design choices
  - some indication on trade-off possibilities → ongoing studies

B)… or provide a similar/combined function as the TCTs (wire-in-jaw design)

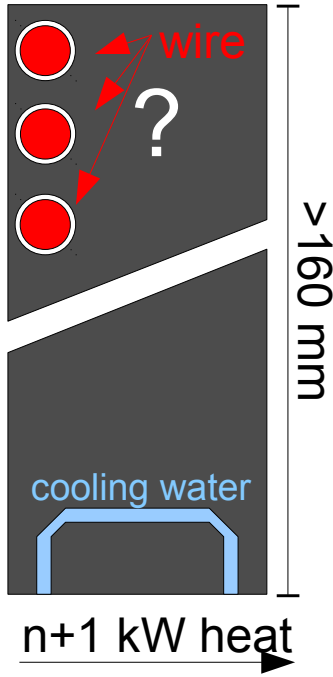
  - similar issues as for the TCT: setup, robustness issues related to material choices (Copper → Tungsten → Carbon?)

- Further, aim to reuse as much of established infra-structure as possible to aid/simplify controls integration into an operational LHC environment:
  - Collimator type girders, motor control and to embed the wire into jaws
  - standard e.g. LHC-type 600 A power converter (OK w.r.t. ripple requirement)
  - Integration of buttons as done for the TCT to aid the wire re-alignment

- In addition, the BBC prototype is targeted to be an MD tool → special run conditions, reduced intensity and time which should reduce the probability of e.g. asynchronuous dump failure impacting the wire
  - Failure rather impacts device rather than machine availability

Combined Wire-In-Jaw Design

- Using collimator-type design 'kills several birds with one shot':
  1. provides necessary mechanical stability (N.B. 1 m long wire)
  2. easy wire position control, integration and exchange option
  3. intrinsic heat sink, conducting thermal losses far away to where these can be safely coupled out of the tank
  4. Easy/we have experience w.r.t. integration BPM buttons, etc.
  5. Depending on jaw-material choice, shielding of RF beam IC to reduce impedance and potential wire resonances
     - Min. insulation + copper surface (skin depth): 0.3 mm tbc.)



- However, a true 'TCT' like functionality implies some constraints on material choice and trade-off w.r.t. robustness vs. cooling vs. Impedance

	Th. Cond.	El. Cond.	δ@40 MHz	δ@1 GHz
	[W m^{-1} K^{-1}]	[Ω m]	[μm]	[μm]
Copper	401	$1.7 \cdot 10^{-8}$	~10	~2
Tungsten	173	$5.6 \cdot 10^{-8}$	~10	~2
SiC*	360 - 490	$8.3 \cdot 10^{-3}$ - 3	~mm	~mm
Carbon		$3 \cdot 10^{-6}$ … $8 \cdot 10^{-4}$		
Diamond	900...2320...41k	$\sim 10^{12}$		

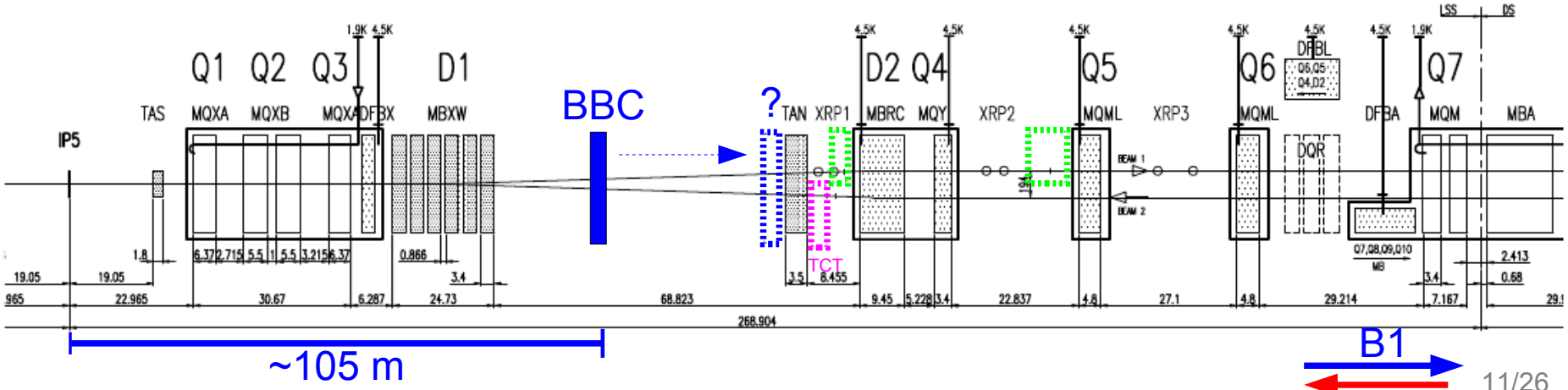
more robust

better impedance

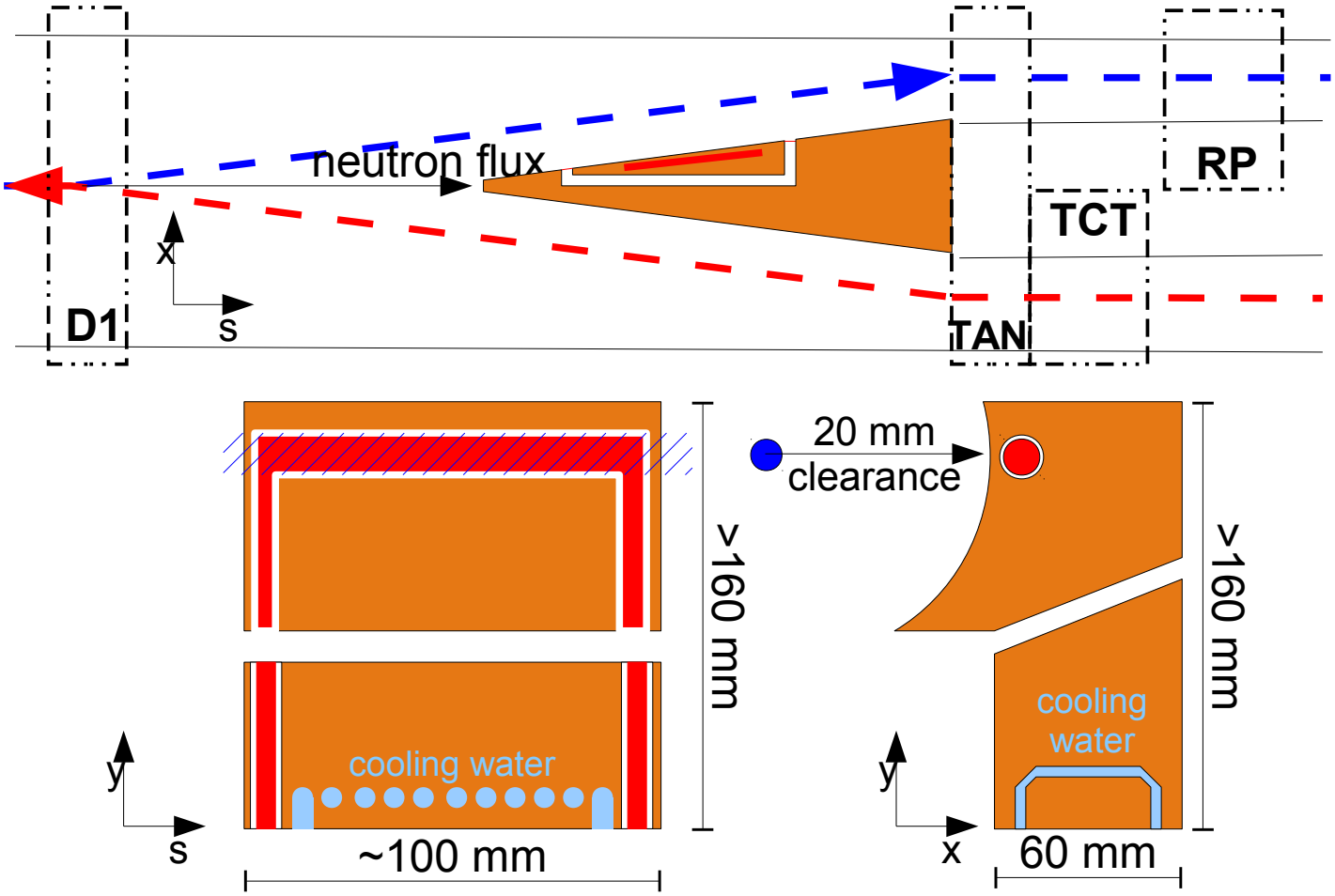
Proposed LHC Beam-Beam Compensators Prototypes I/III – Option I (nominal): between D1 ↔ TAN

- The ideal/reserved BBC location is more challenging
  - Physical margin of 110 → 165 mm & $\beta_{x/y} \approx 1000$ m (for $\beta^* = 0.55$ m), depends highly on planned HL-LHC scenario, cons./safe assumption: $\sigma \approx 0.7 \ldots 1$ mm for nominal optic, $\varepsilon = 3.6$ µm and 7TeV → 3.5 TeV
    - would gain for larger β^* and/or smaller ε, e.g. 2 µm

- Assuming that we require a minimum physical 20 sigma clearance (x2) for the BBC in the parking position → leaves only about 70 mm for BBC
  - Re-check whether we can move closer towards TAN



Proposed LHC Beam-Beam Compensators Prototypes II/III – Option I (nominal): between D1 ↔ TAN



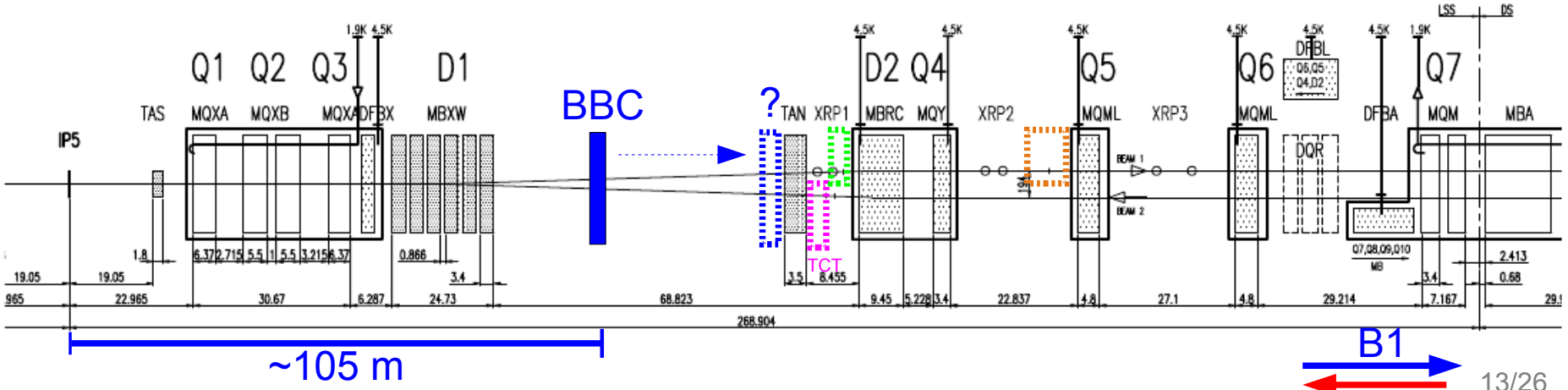
- Non-neglible *n*-flux, impedance and TAN aspects need detailed simulations
- Materials choices: Cu, W, Carbon, SiC (doping issues?), (CVD) Diamond
- Major design and qualification effort, unlikely to be ready before LS1!

Proposed LHC Beam-Beam Compensators Prototypes III/III – Option II TCT-like BBC

- Alternate options implying an easier integration and potential LS1 installation
  - B) Combined TCT-BBC at the present TCT locations
    - some constraints on material
  - C) Replacing roman pots (BBC targets HL-LHC)
  - D) Between Q4 & Q5 → needs further simulations

  } similar in terms of impact on MP

- Advantage could re-use even the same vacuum tank design as TCTs
  - Could be integrated and deployed
  - beside n-flux, other aperture/MP issues remain the same)
  - Need some early indication to prepare machine for additional vacuum valves, BPM and control cables, water, power cables, etc.



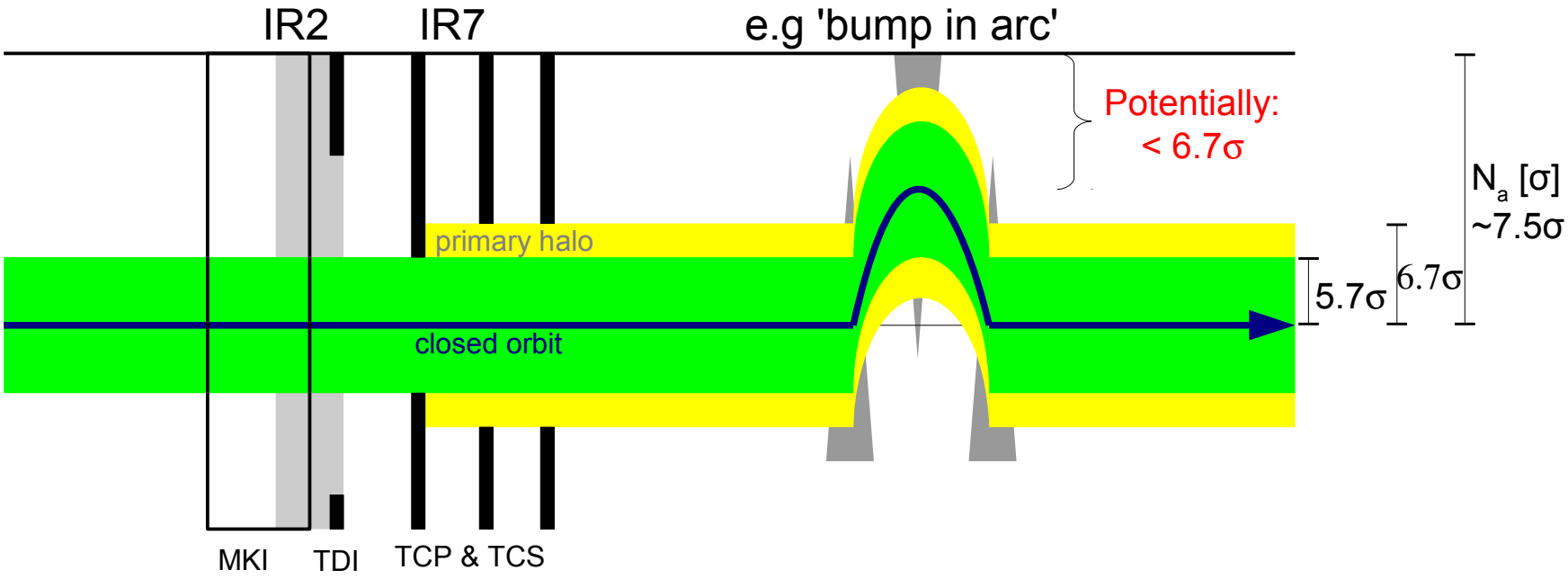
Conclusions

- Planned BBC prototype deployment to assess its potential in view of HL-LHC
- 'Wire-in-jaw' design: robustness, thermal and impedances management
  - originally BBC between D1↔TAN: possible but likely only for LS2
  - Preference for TCT-style design (could be prepared/installed for LS1):
    - combined with TCT, replacing roman pots, or between Q4-Q5 (tbc.)
- LHC BBC can be made compatible with MP requirements, provided it is either
  - a) always in the shadow of the TCT
  - b) or provides similar combined function as TCT (wire-in-jaw design)
    - robustness issues affecting material choices (Copper → Carbon?)
- Need an indication of the level of robustness required, e.g.
  - TCT-type BBC: needs to rely on more robust materials
  - MD-type BBC: moved-in only during special MDs → is Cu an option?
- Next steps:
  - Detailed specification including MP and collimation considerations
  - Re-evaluate shifted location → ongoing T. Rijoff
  - Comparison with alternate schemes (e.g. half-integer WP)
  - LR-BB Compensation Workshop...

Reserve slides

Compromised Machine Protection via Orbit Bumps

- Combined failure: Local orbit bump and collimation efficiency (/kicker failure):

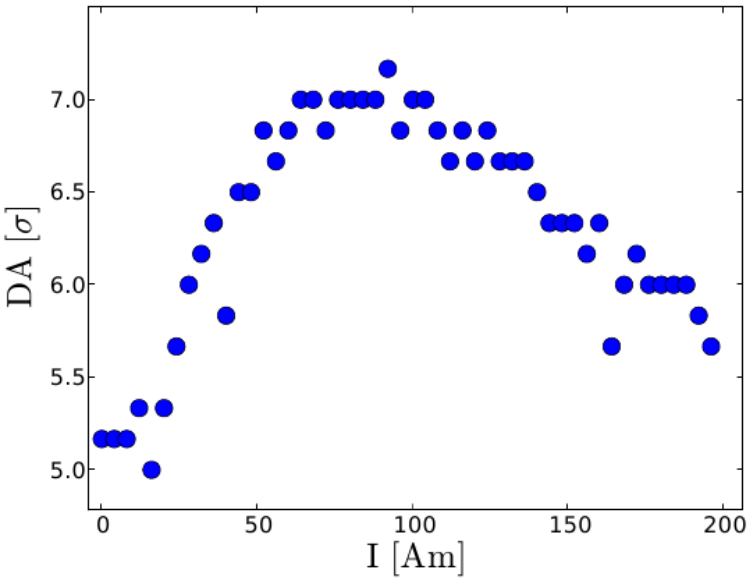


- Primary collimator (TCP) limits $|x_\beta(s)|_{max}$ locally to <5.7σ, secondary collimator (TCS) at~ 6.7σ
- To guarantee two stage cleaning efficiency/machine protection:
  - Local: TCP must be >0.7σ closer than TCS w.r.t. the beam → Orbit FB
  - Global: no other object (except TCP) closer to beam than TCS

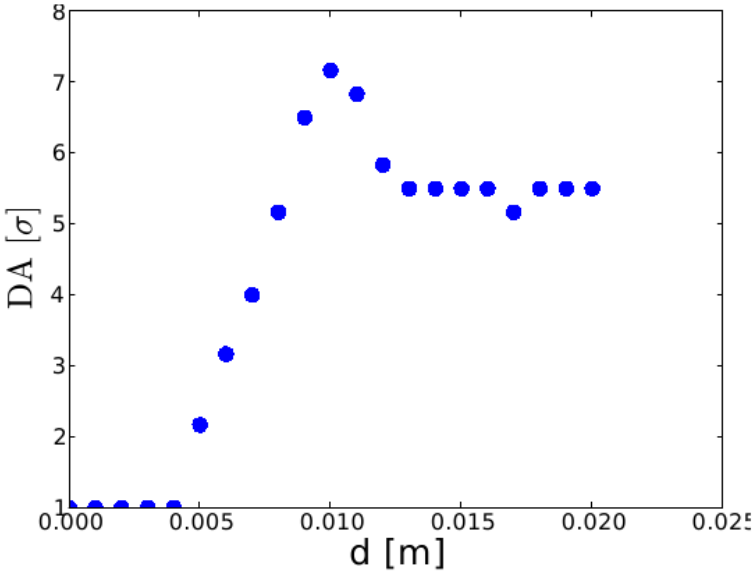
→ Orbit bumps may compromise function of machine protection/collimation

→ tackled by LHC Orbit Feedback

BBC Beam-Wire Distance Dependence



(a) A current scan of the BBLR at 9.5σ shows a wide current region where the compensation is efficient.



(b) The DA as a function of the beam-wire separation d for I=82Am.