# Long-range beam-beam compensation at HL-LHC

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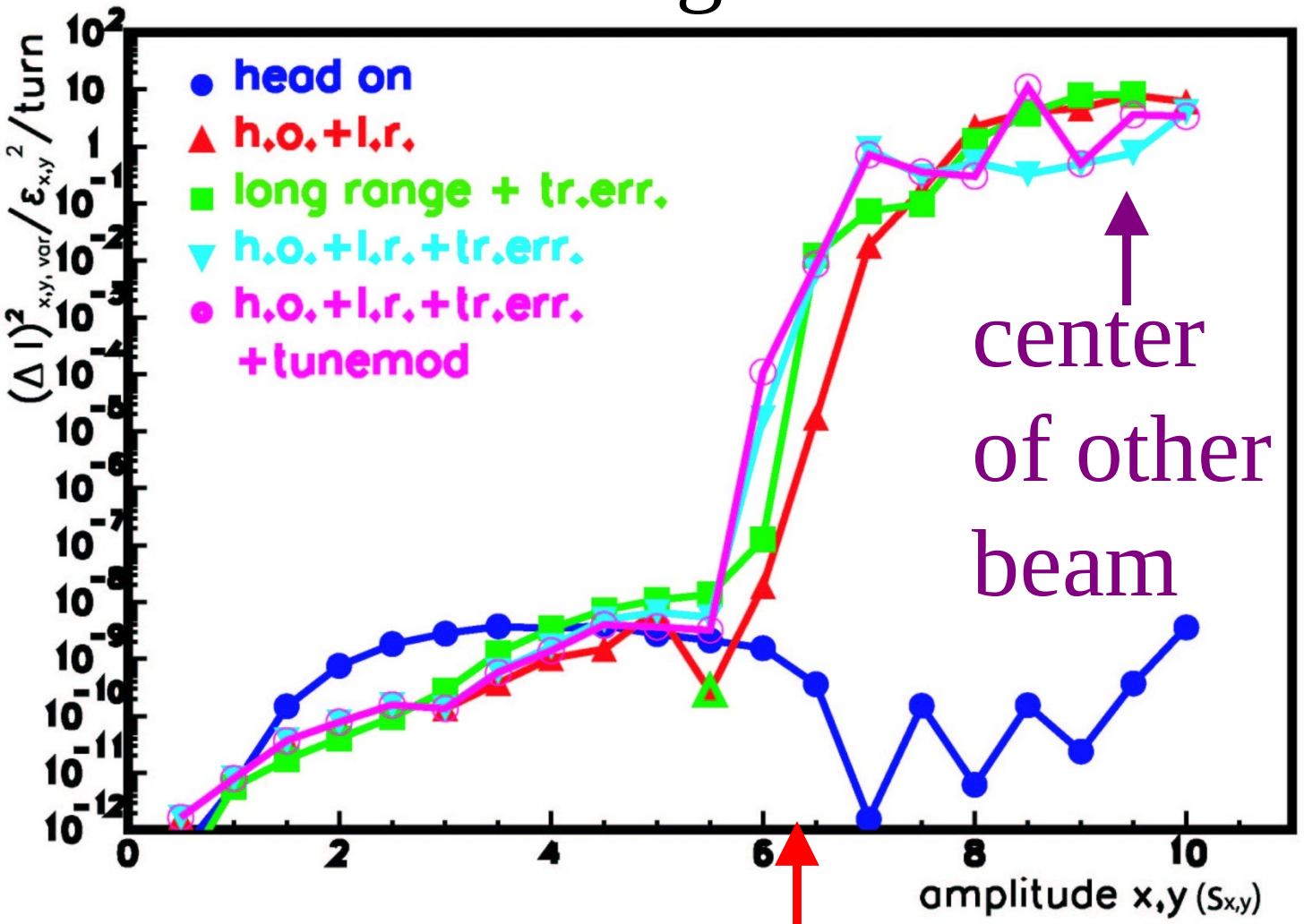
ColUSM #19 - 01/03/2013

# long-range beam-beam collisions

- perturb motion at large betatron amplitudes, where particles come close to opposing beam
- cause ‘diffusive aperture’ (Irwin), high background, poor beam lifetime
- increasing problem for SPS, Tevatron, LHC,... that is for operation with larger # of bunches

| | #LR encounters |
|---|---|
| SPS | 9 |
| Tevatron Run-II | 70 |
| LHC | 120 |

# result of weak-strong simulations for LHC

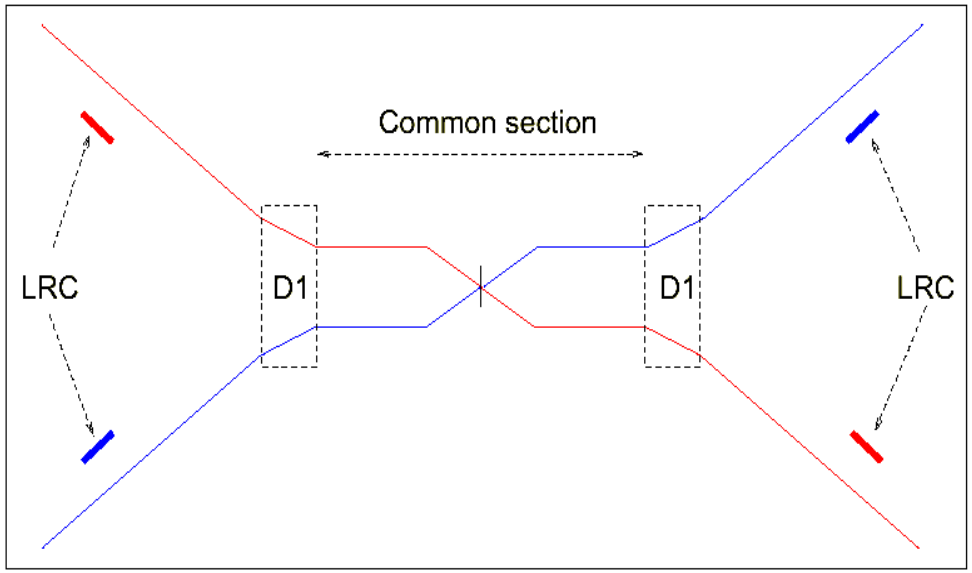


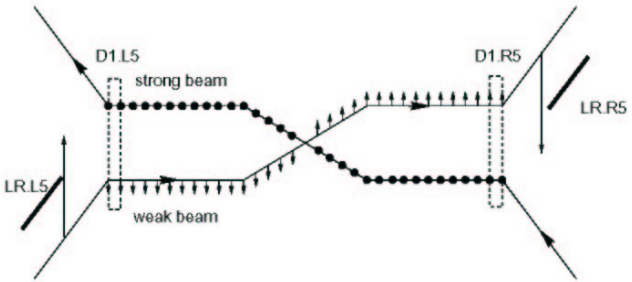

Y. Papaphilippou
& F.Z., LHC 99

‘diffusive aperture’

# Proposed Long-Range Beam-Beam Compensation for the LHC

- To correct **all** non-linear effects correction must be **local**.
- Layout: 41 m upstream of D2, both sides of IP1/IP5

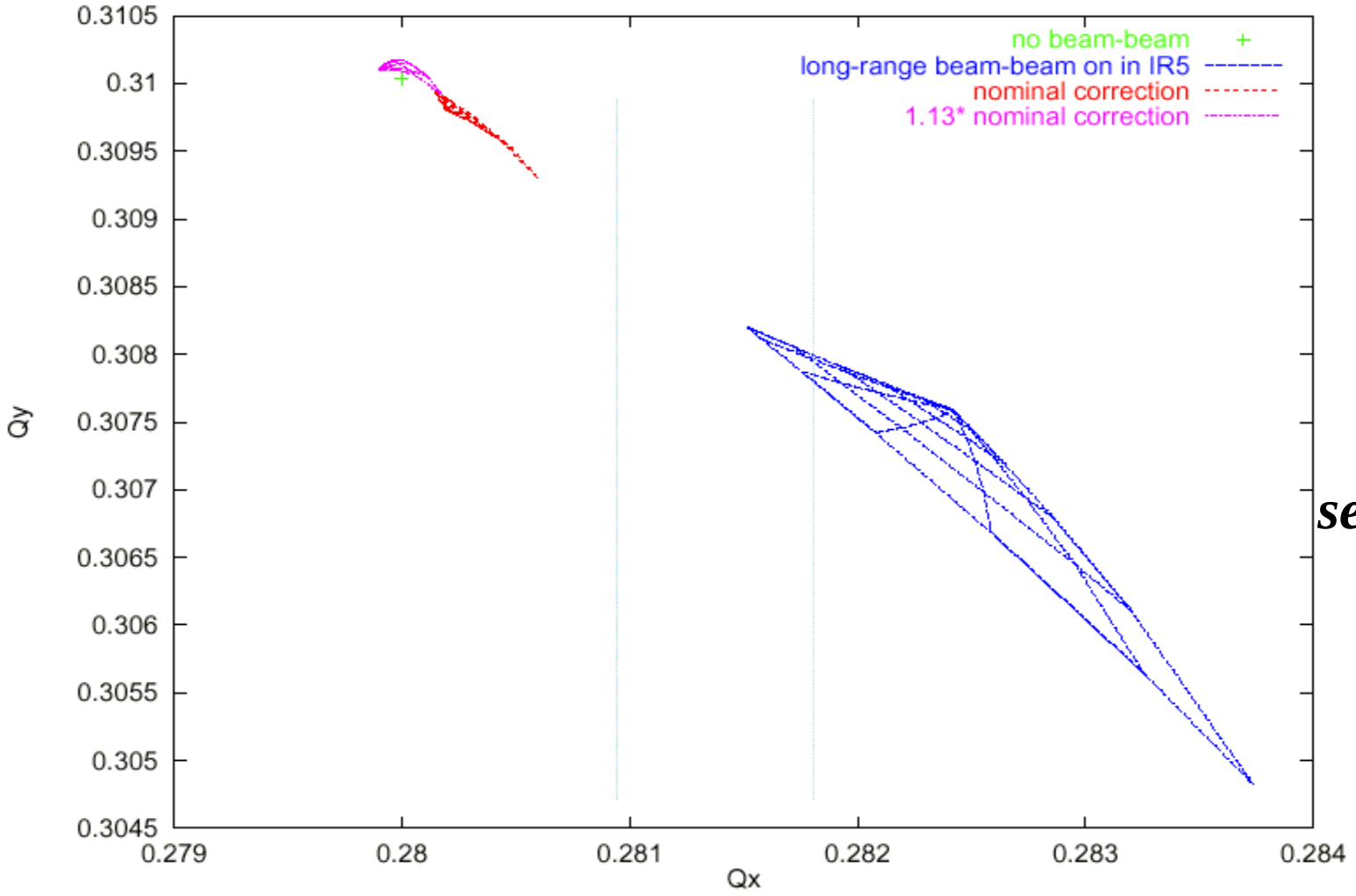



Phase difference between BBLRC & average LR collision is 2.6o

(Jean-Pierre Koutchouk)

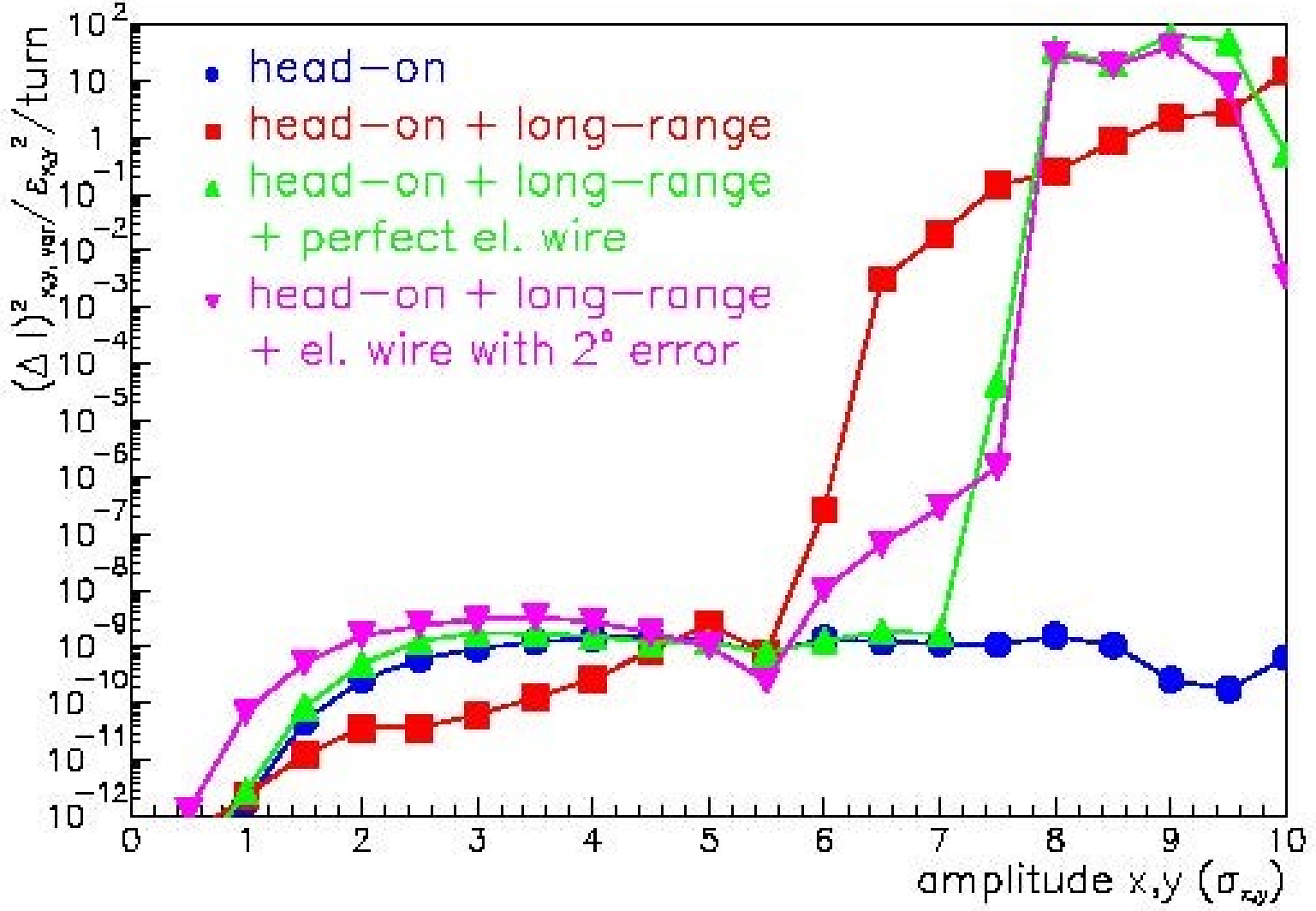
# simulated LHC tune footprint with & w/o wire correction




- .16σ
- .005σ
- .016σ

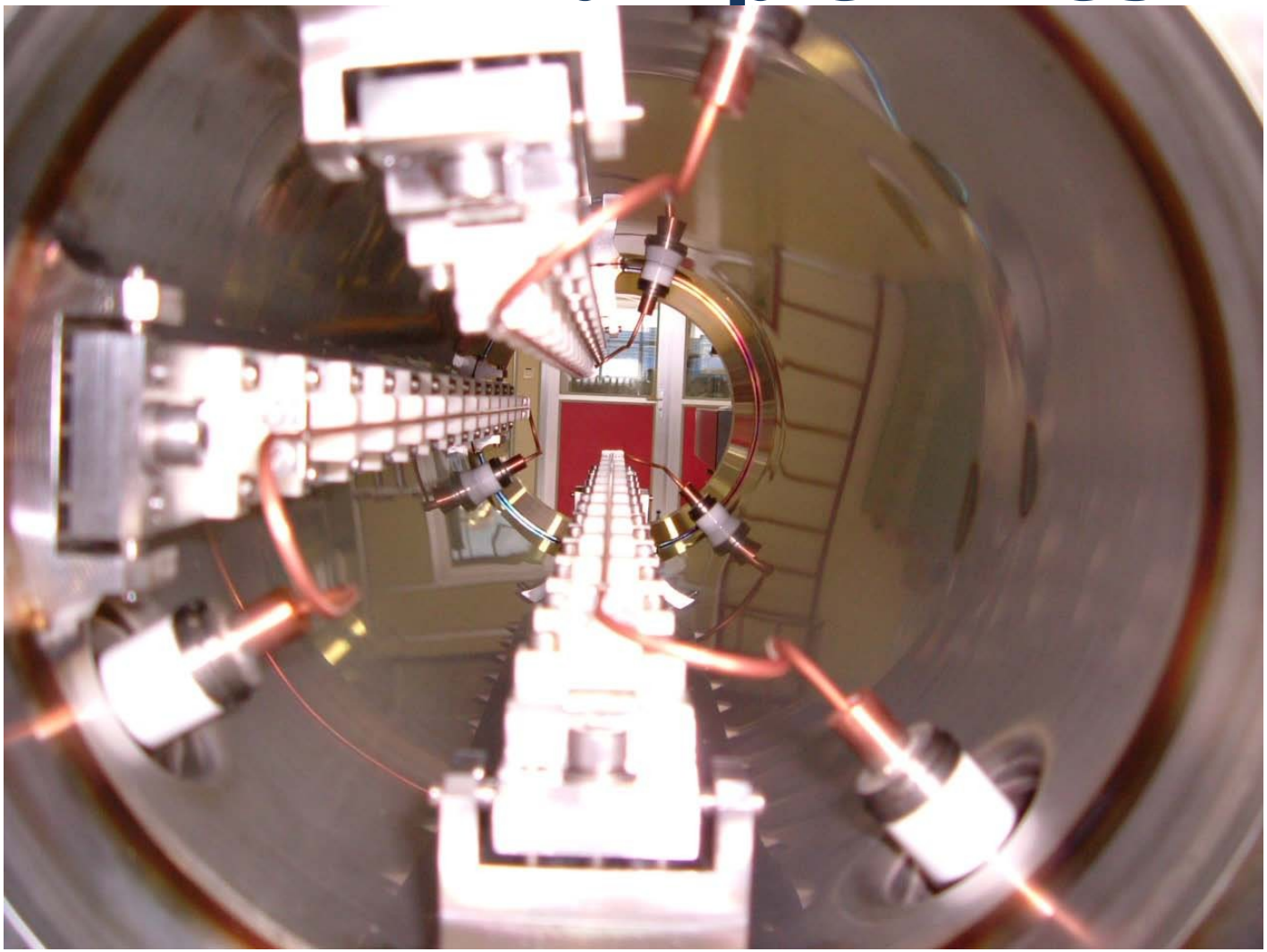
***Beam separation at IP***

(Jean-Pierre Koutchouk, LHC Project Note 223, 2000)




Frank Zimmermann, 2001 Beam-Beam Workshop, Fermilab

# SPS single-beam MDs with multiple wires



J.-P. Koutchouk, G. Burtin, J. Wenninger, U. Dorda, G. Sterbini, F. Zimmermann, et al

2x2 water-cooled units presently installed in the SPS (two with remote control)

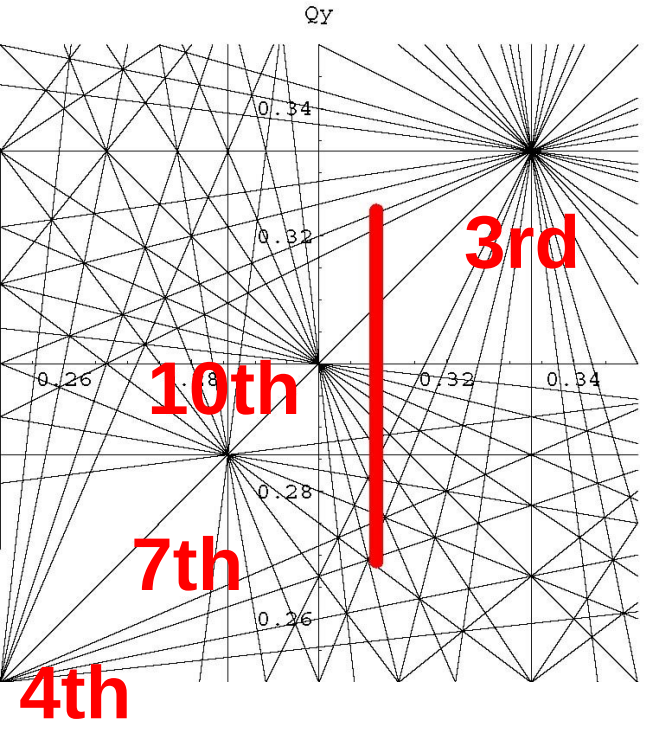
1x2 spare units ready

1st RHIC BBLR stored at CERN

2nd RHIC BBLR being shipped

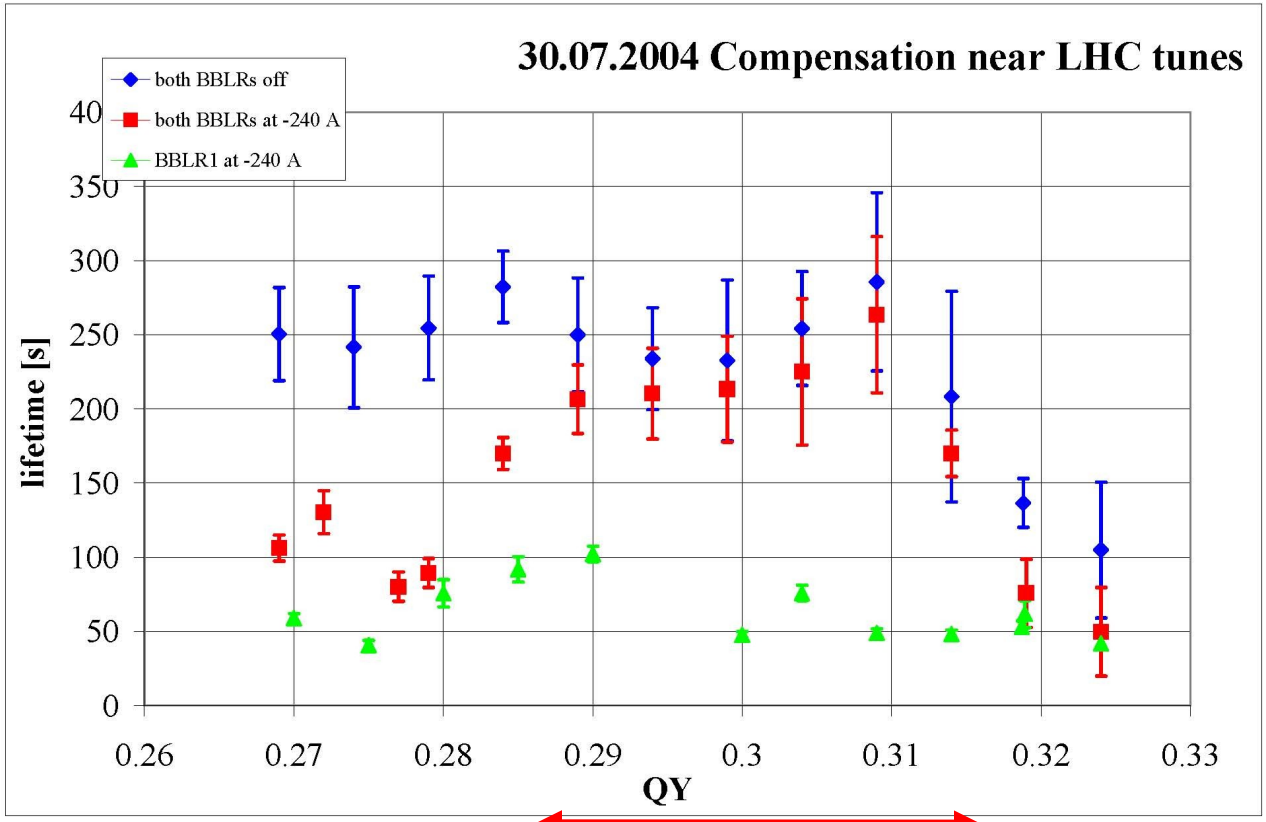
in total 5 sets available

# *measured BBLR compensation efficiency vs. working point - scan around LHC tunes*




*we scanned QY w/o BBLRs, with BBLR1 only, and with BBLR1 & BBLR2*

*30.07.04*




what happens here?

nearly perfect compensation

LHC BBLR

compensate BBLR1 by BBLR2

**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**<br>**LHCLSX—0002**<br>**LHCLSX—0009**<br>**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 :***

- ☐ Rejected.
- ☐ Accepted by Project Engineer, no impact on other items.
  *Actions identified by Project Engineer*
- ☑ Accepted by Project Engineer, but impact on other items.
  *Comments from other Project Engineers required*
  *Final decision & actions by Project Management*

***Date of Approval :*** 2004-10-27

***Decision of the PLO for Class I changes :***

- ☐ Not requested.
- ☐ Rejected.
- ☑ Accepted by the Project Leader Office.
  *Actions identified by Project Leader Office*

***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 :***

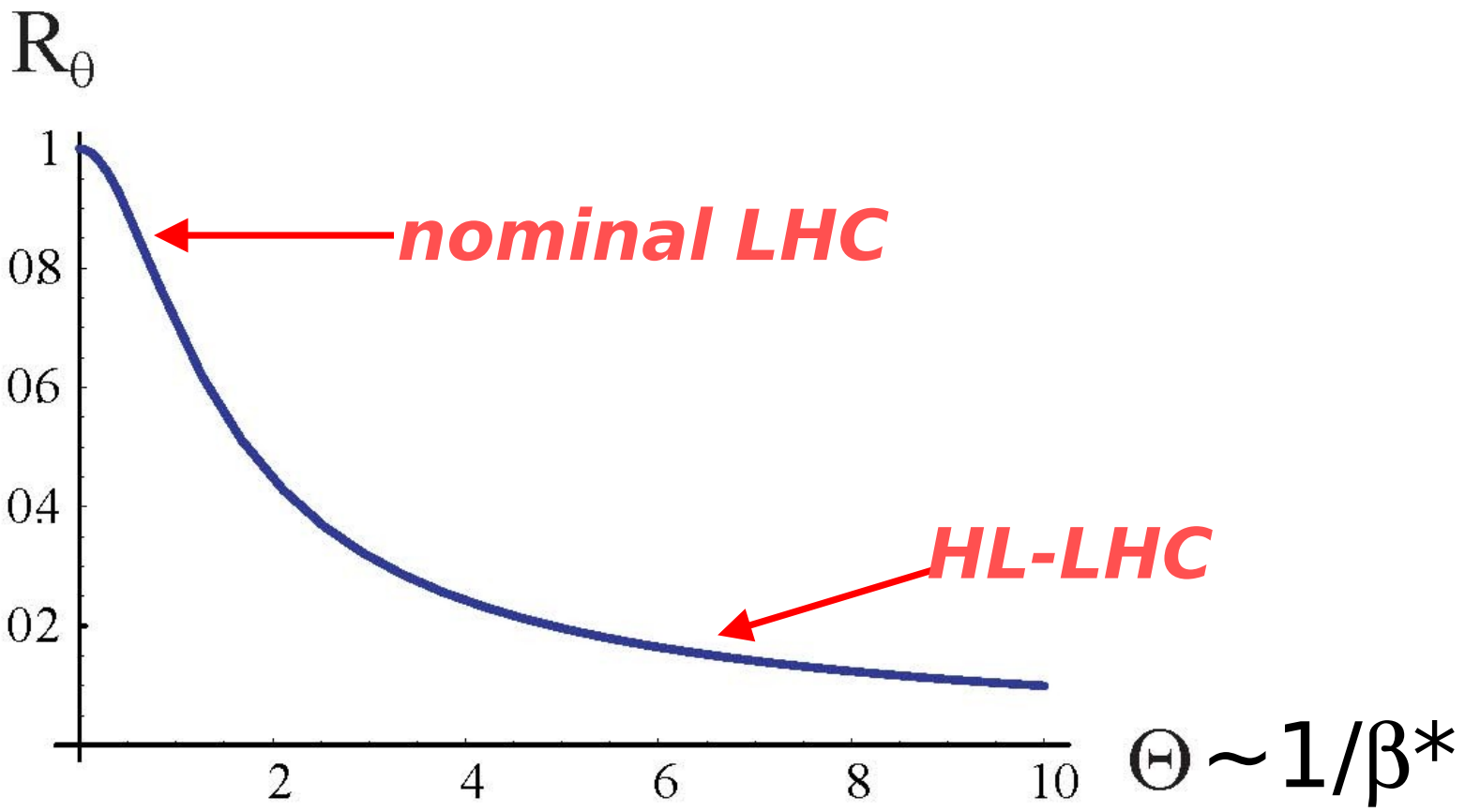
*Note : when approved, an **Engineering Change Request** becomes an **Engineering Change Order/Notification**.*

for future wire LR beam-beam compensators, 3-m long sections had been reserved in LHC at 104.93 m (center position) on either side of IP1 & IP5

$$R_\theta = \frac{1}{\sqrt{1+\Theta^2}}; \quad \Theta \equiv \frac{\theta_c \sigma_z}{2\sigma_x}$$

Piwinski angle

luminosity reduction factor



# minimum crossing angle from LR b-b

$$\theta_c \cong \sqrt{\frac{\varepsilon}{\beta^*}}\left(\frac{d_{da}}{\sigma} + 3\sqrt{\frac{k_{par}}{2x32}\frac{N_b}{10^{11}}\frac{3.75\mu\mathrm{m}}{\gamma\varepsilon}}\right)$$

*"Irwin scaling" coefficient from simulation*

note: there is a threshold - a few LR encounters may have no effect! (2nd PRST-AB article with Yannis Papaphilippou)

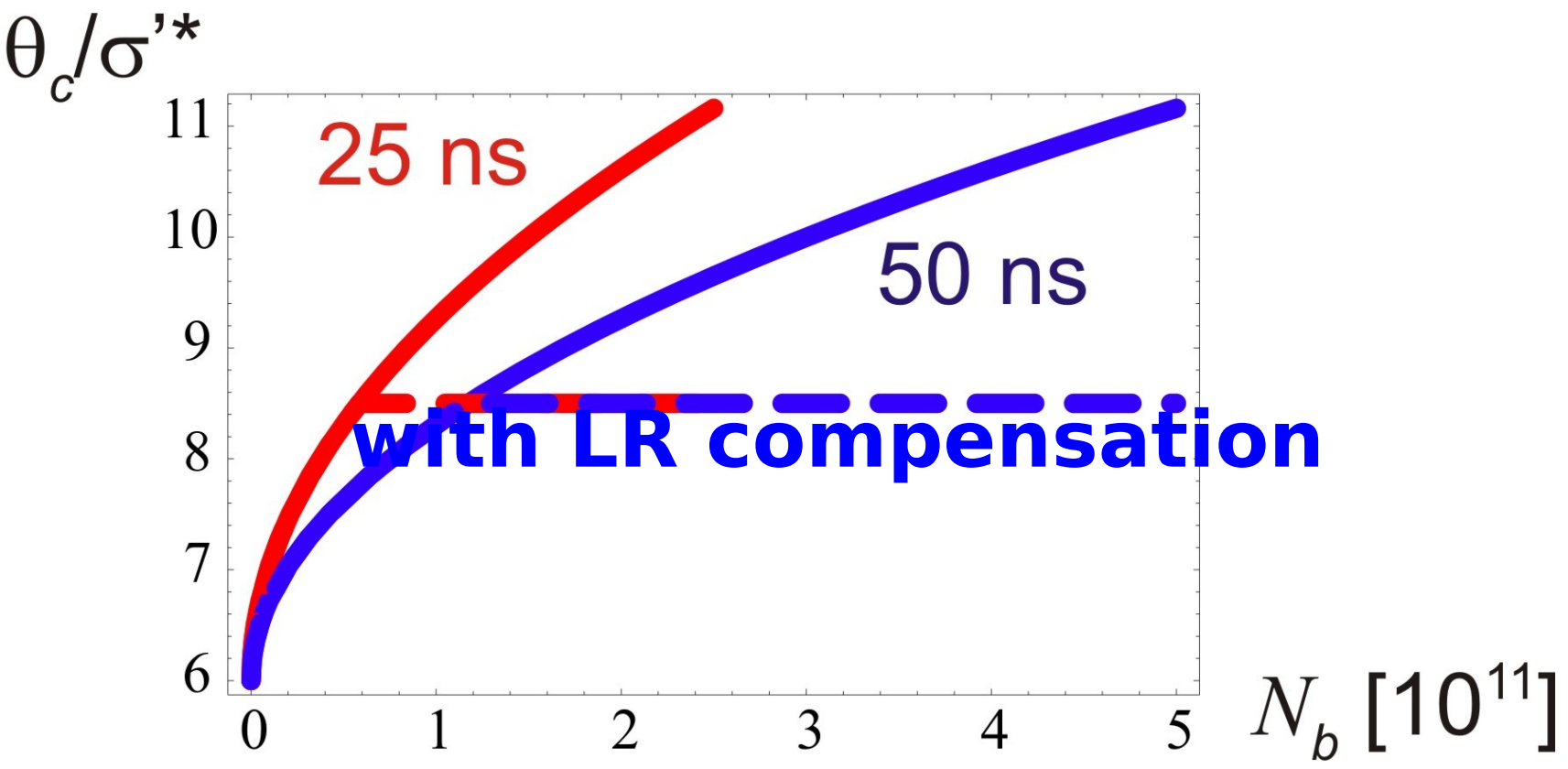
# minimum crossing angle with wire compensator

$$\theta_c \cong 8\sqrt{\frac{\varepsilon}{\beta^*}}$$

*need dynamic aperture of 5-6 σ & wire compensation not efficient within 2 σ from the beam center*

independent of beam current

# normalized crossing angle versus bunch intensity



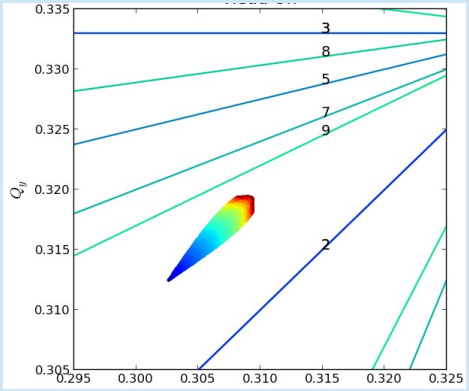

long range compensation will reduce the crossing angle

# wire compensation & crab cavities?

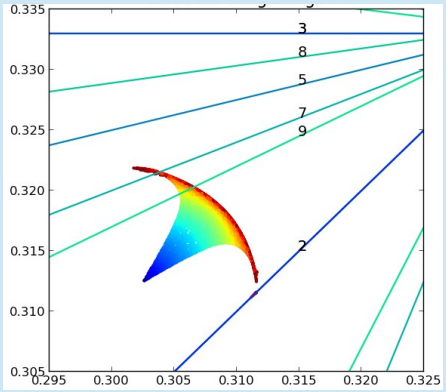
wire compensator allows for smaller crossing angle and hence smaller $\beta^*$ for a given triplet aperture;
it also reduces the required crab voltage (RF limits, machine protection issues,…)

# recent simulation results - tune footprints

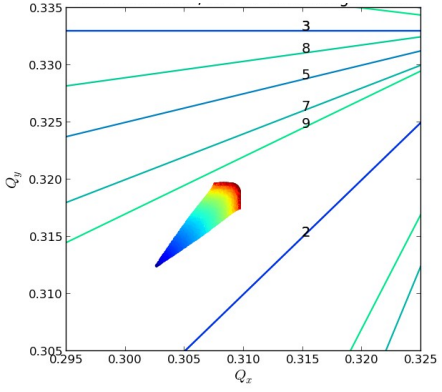
Head on



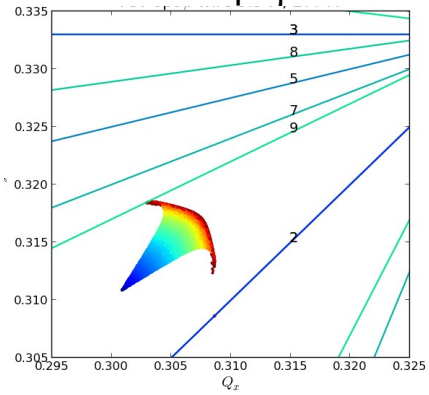

Head on Long Range



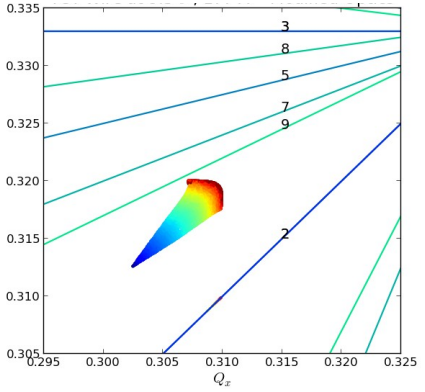

BBC Wire

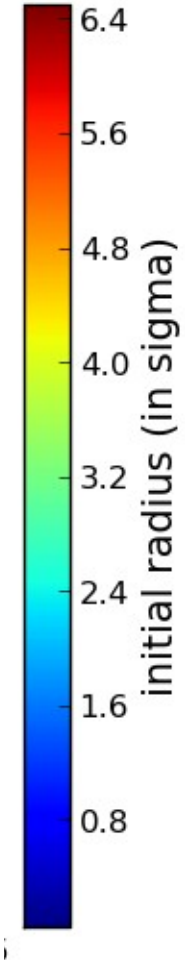



TCT opt β




TCT mod opt

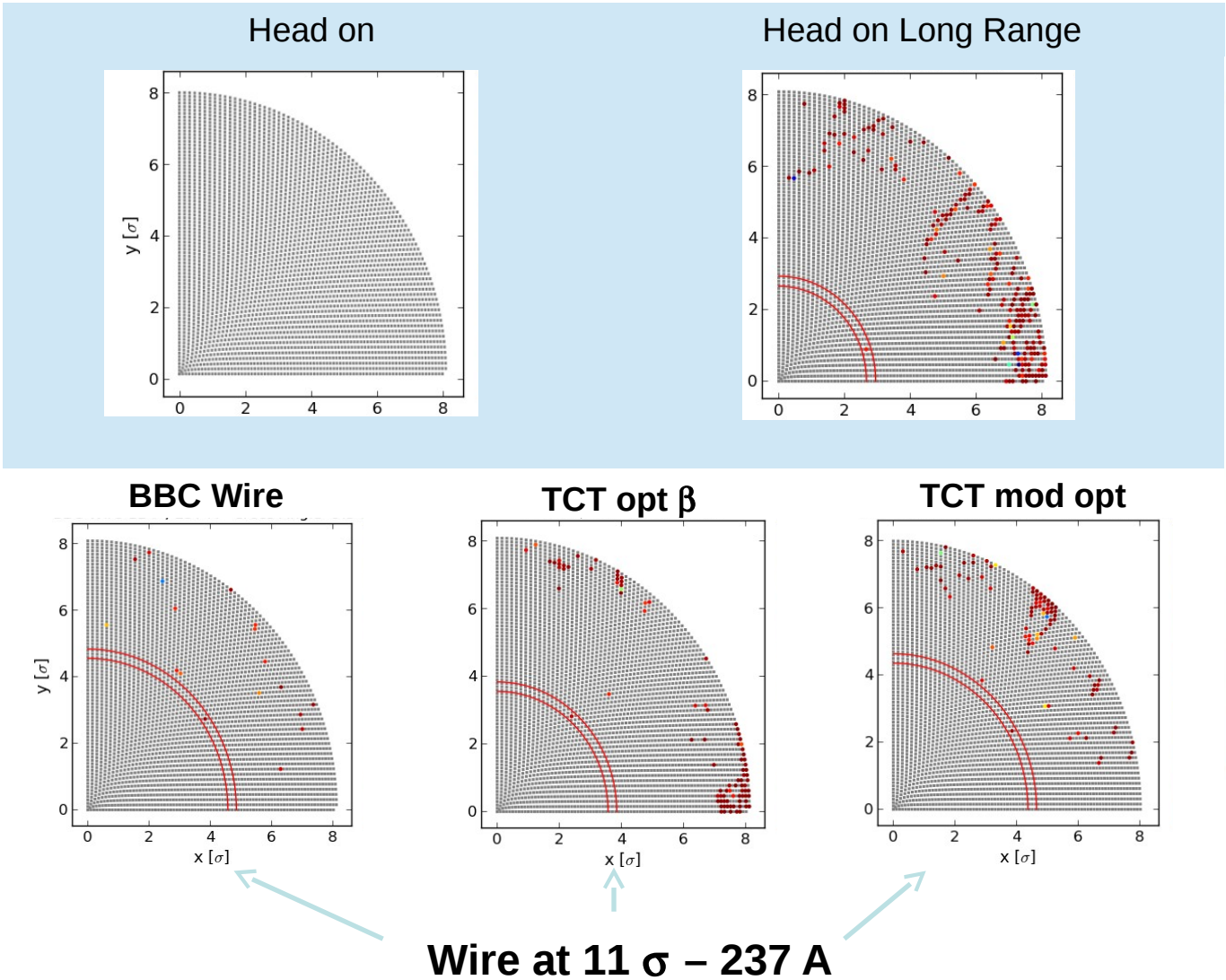



**Wire at 9.5 σ – 177 A**

T. Rijoff

# recent simulation results – unstable trajectories (Lyapunov)




T. Rijoff