10 years of wire excitation experiments in the CERN SPS

Frank Zimmermann

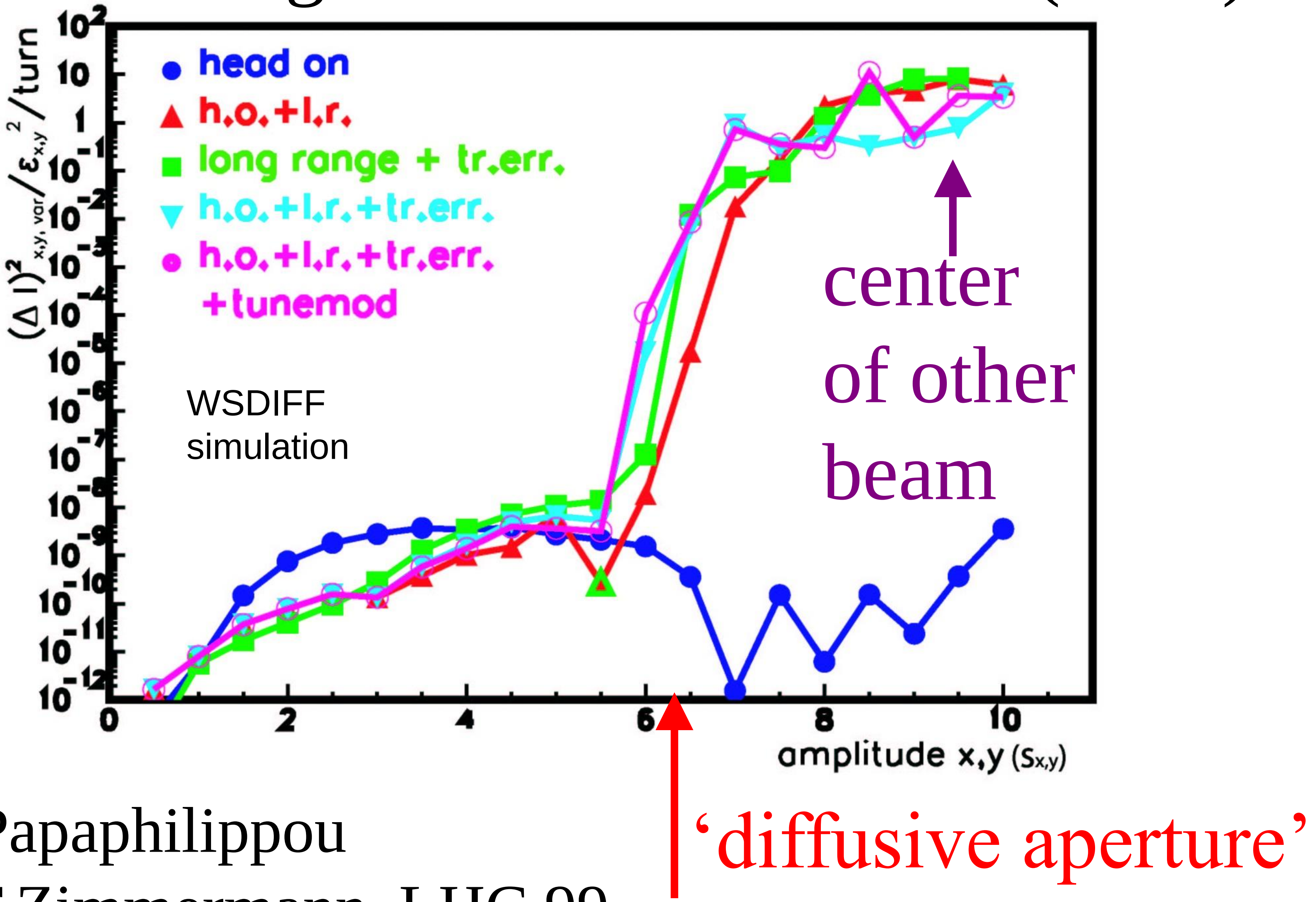
ICFA Beam-Beam Workshop

CERN, 20 March 2013

Players: Gerard Burtin, Rama Calaga, Jackie Camas, Gijs de Rijk, Octavio Dominguez, Ulrich Dorda, Jean-Pierre Koutchouk, Elias Métral, Yannis Papaphilippou, Federico Roncarolo, Tannaji Sen, Vladimir Shiltsev, Guido Sterbini, Rogelio Tomas, Jörg Wenninger

work supported by the European Commission under the FP7 Research Infrastructures project EuCARD, grant agreement no. 227579

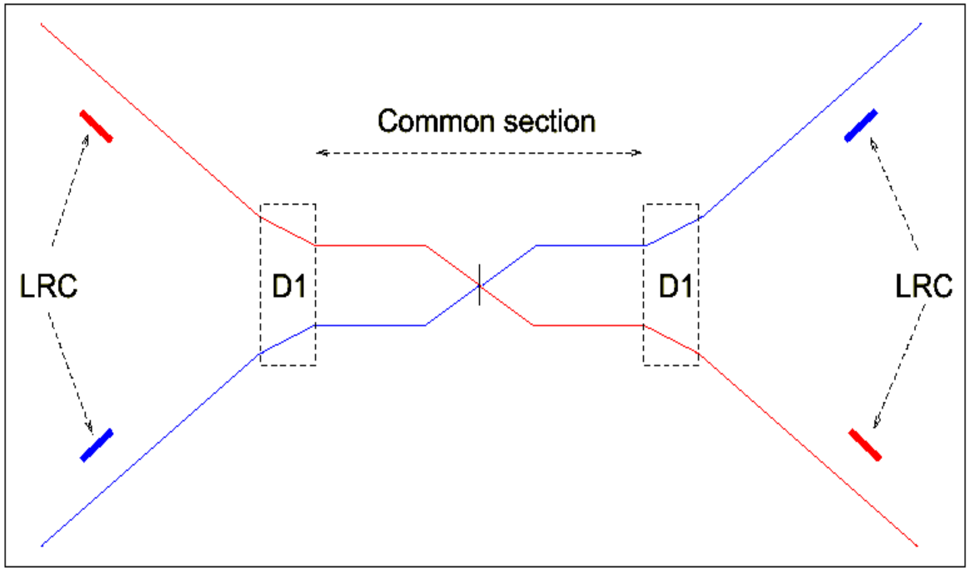
weak-strong simulations for LHC (1999)

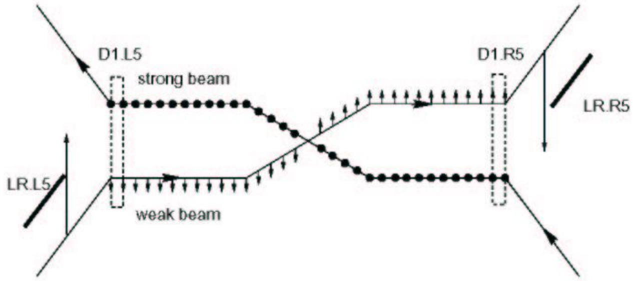


Y. Papaphilippou
& F.Zimmermann, LHC 99

proposed long-range beam-beam compensation for the LHC (2000)

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



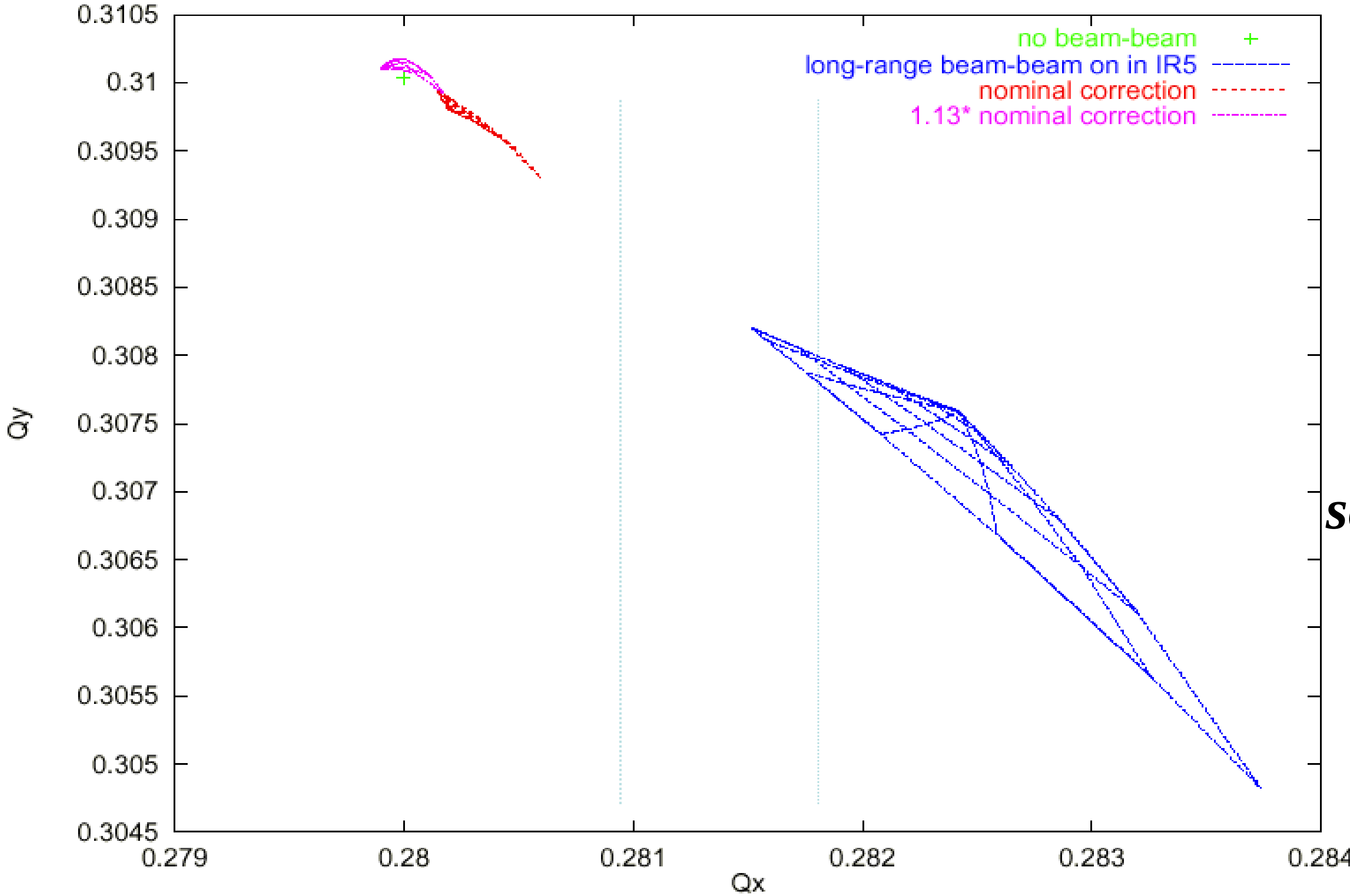


Phase difference between BBLRC & average LR collision is 2.6^o

(Jean-Pierre Koutchouk)

J.P. Koutchouk, J. Wenninger, F. Zimmermann,

simulated LHC tune footprint with & w/o wire correction

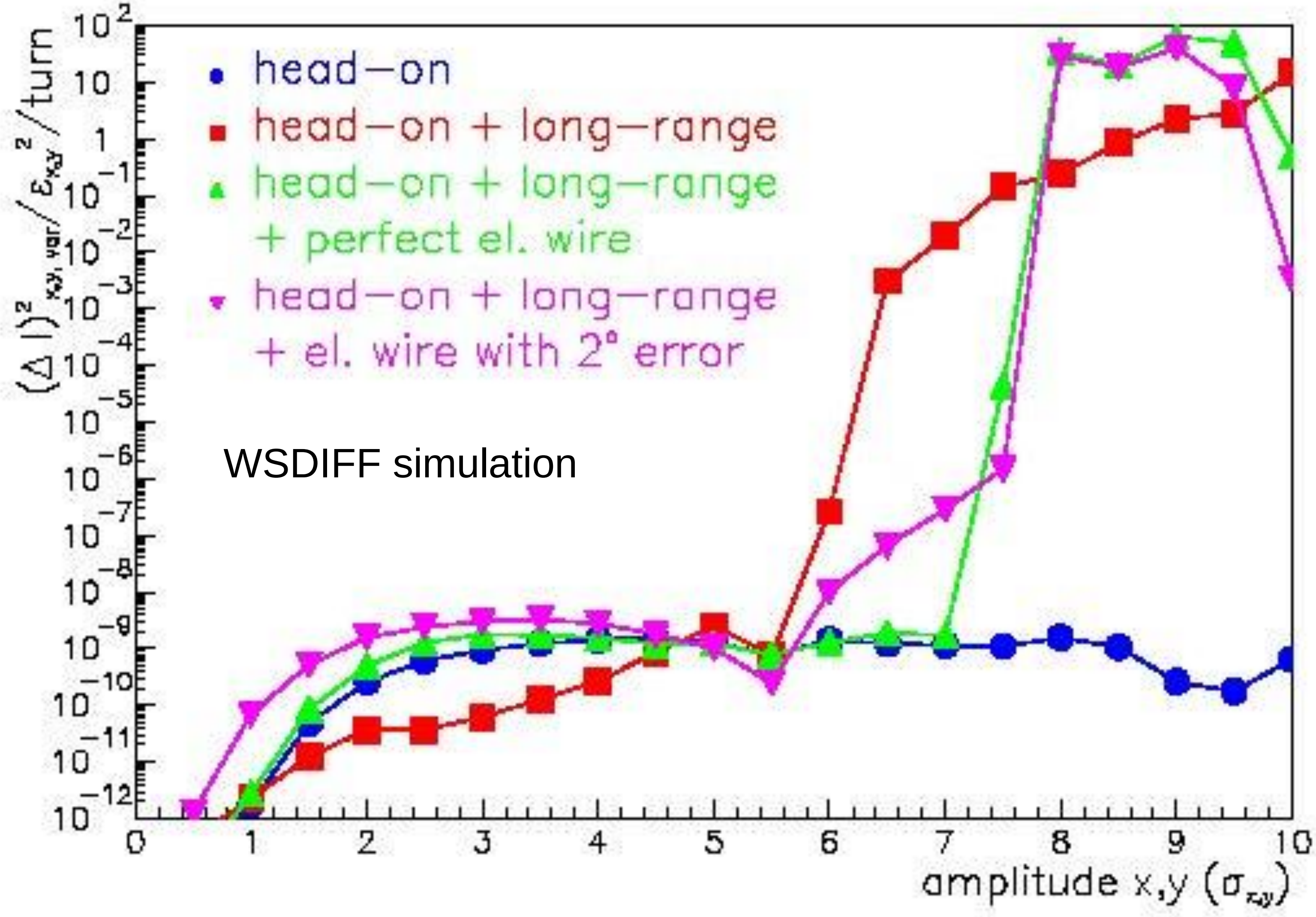


- .16σ
- .005σ
- .016σ

Beam separation at IP

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

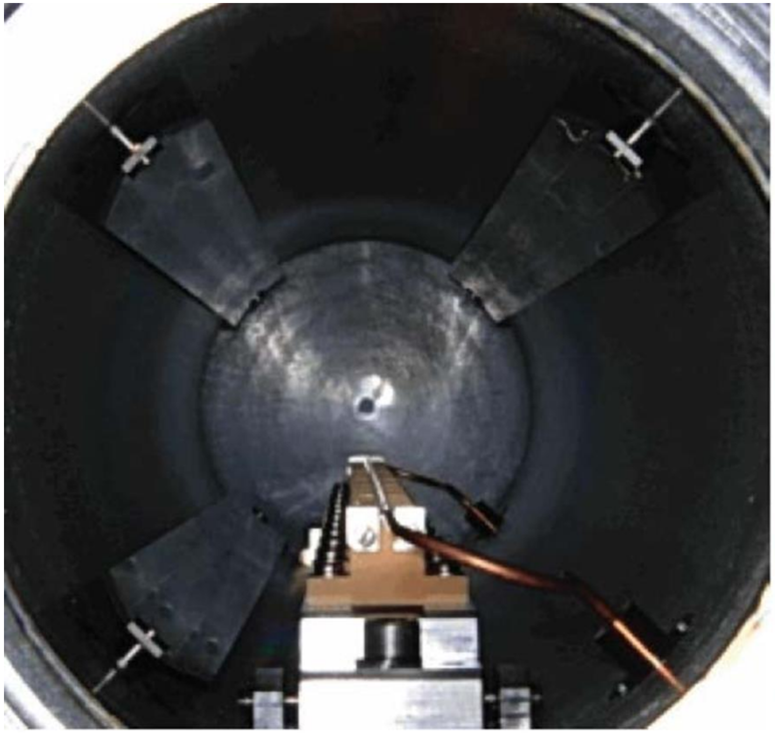
nominal LHC: wire gain ~1.5 σ



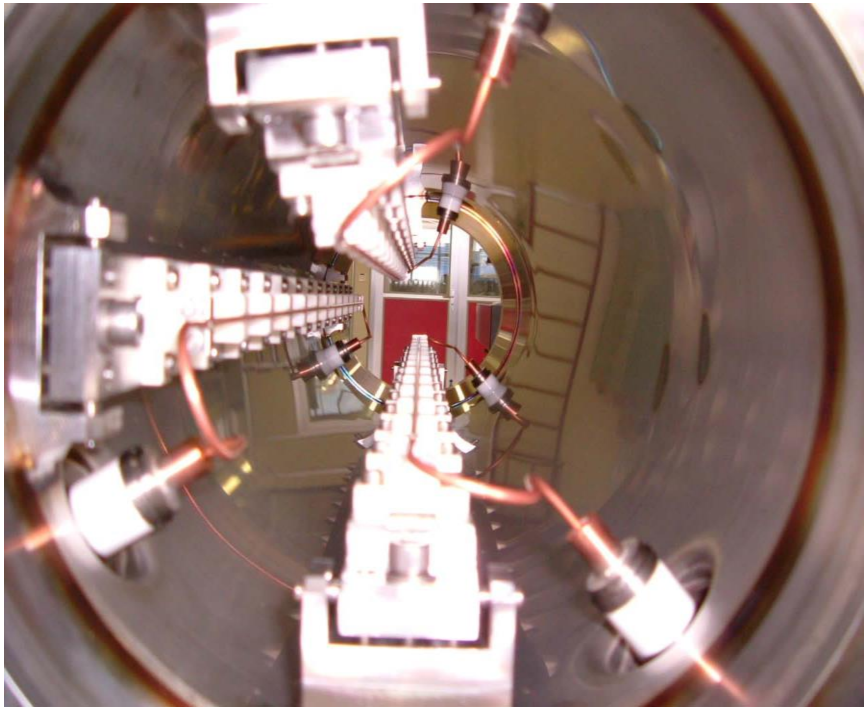
Frank Zimmermann, 2001 Beam-Beam Workshop, Fermilab

SPS wire “BBLRs”

1st (2002)



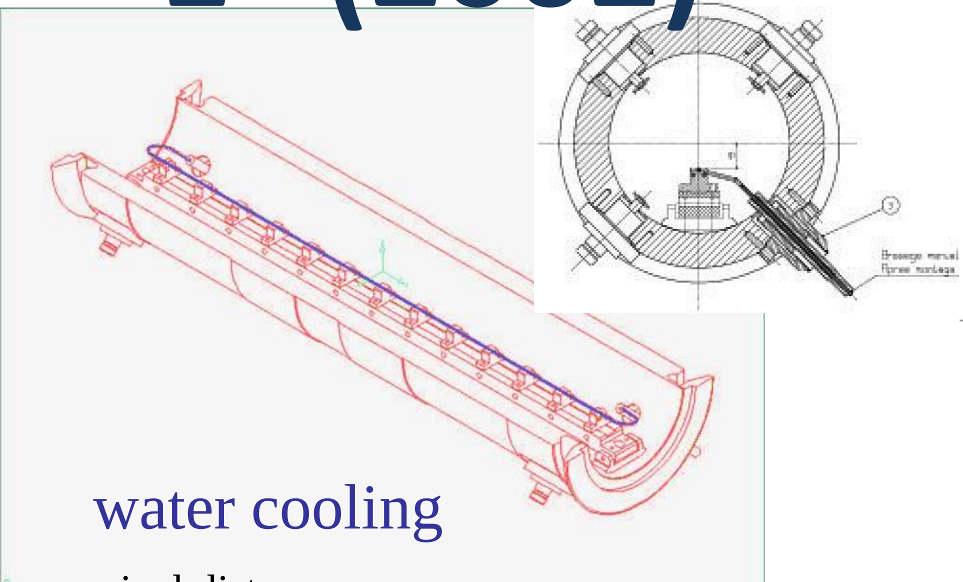
2nd (2004)



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

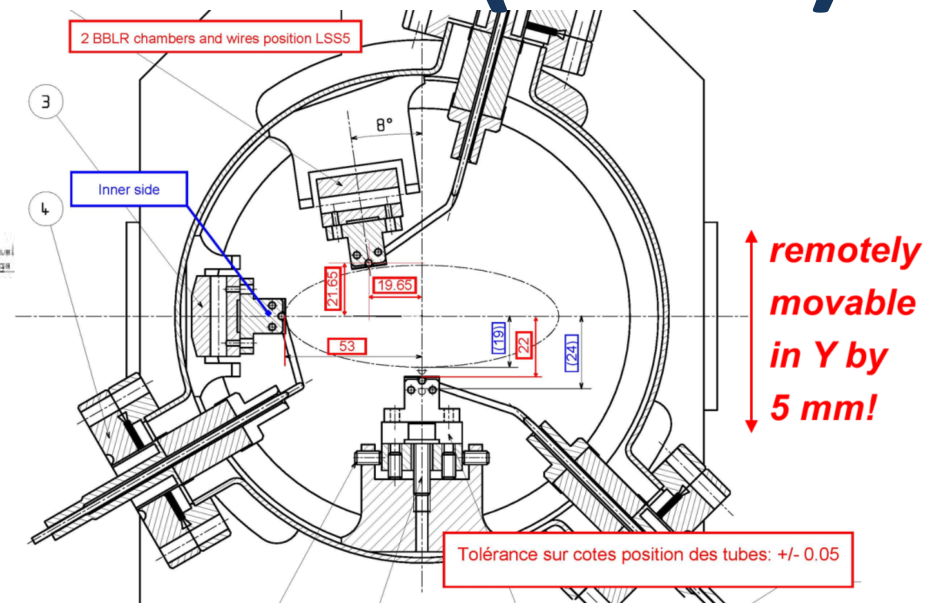
SPS wire "BBLRs"

1st (2002)



nominal distance 19 mm (in the shadow of the arc aperture)

2nd (2004)



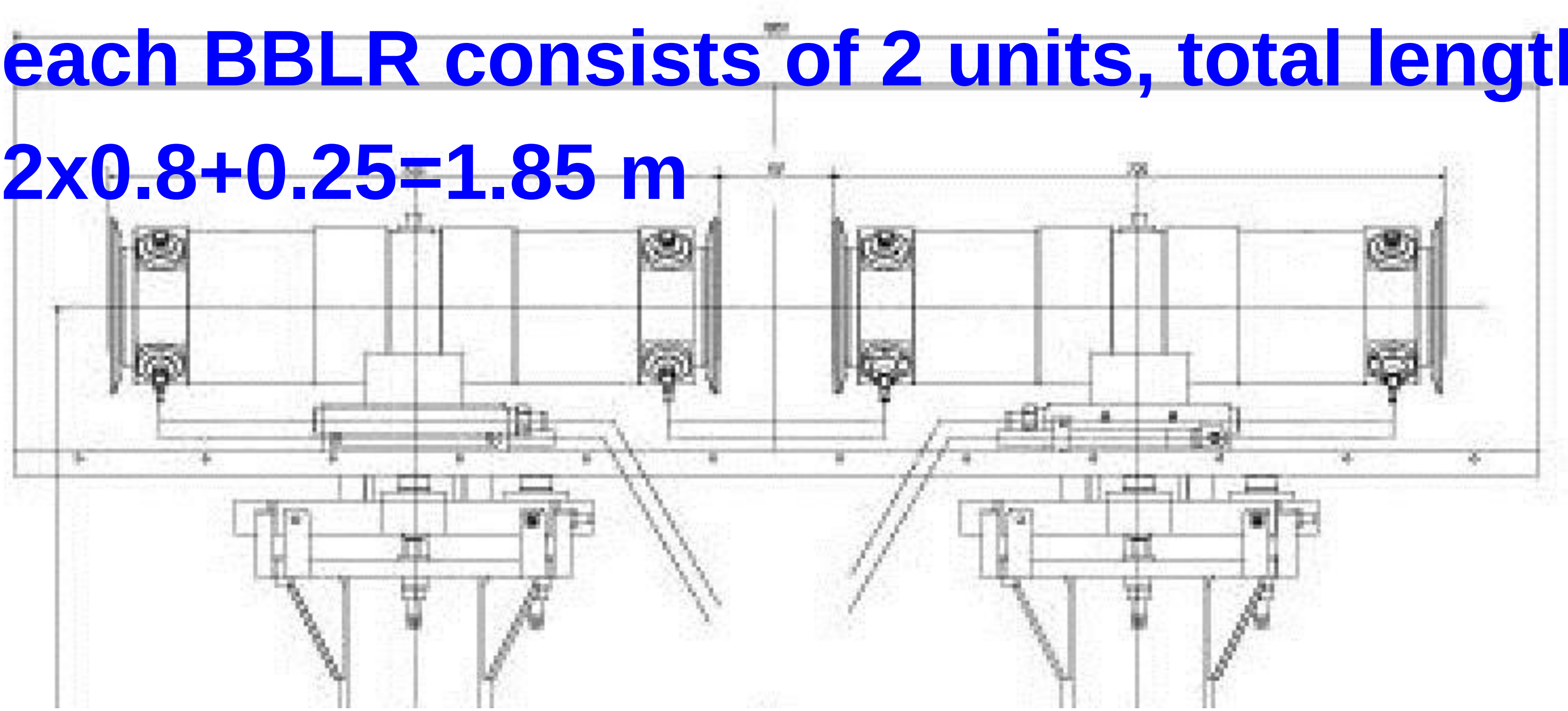
$$I_{wire}=N_b\ e\ c\ \#\mathbf{LR}/l_{wire}$$

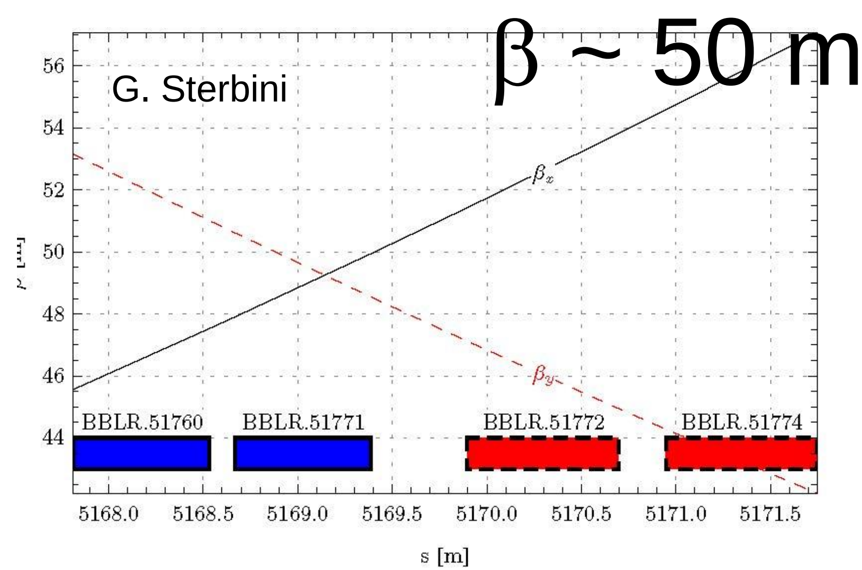
wire current — wire length

separated from 1st – BBLR by about 3°

two 60-cm long wires with 267 A current equivalent to 60 LHC LR collisions (e.g., IP1 & 5)

each BBLR consists of 2 units, total length: 2x0.8+0.25=1.85 m





additional wires at CERN

1x2 spare units ready (repaired after leak)

two air-cooled RHIC BBLRs shipped & stored
at CERN
(thanks to Michiko Minty & Tony Curcio)

in total 5 sets are available!

scaling

perturbation by wire:

$$\Delta y' = \frac{2 r_p l_w I_w}{\gamma e c (y - d)}$$

relative perturbation:

$$\frac{\Delta y'}{\sigma_{y'}} = \left(\frac{2 r_p l_w}{ec}\right)\left(\frac{I_w}{(\gamma\varepsilon)\tilde{n}_{da}}\right)$$

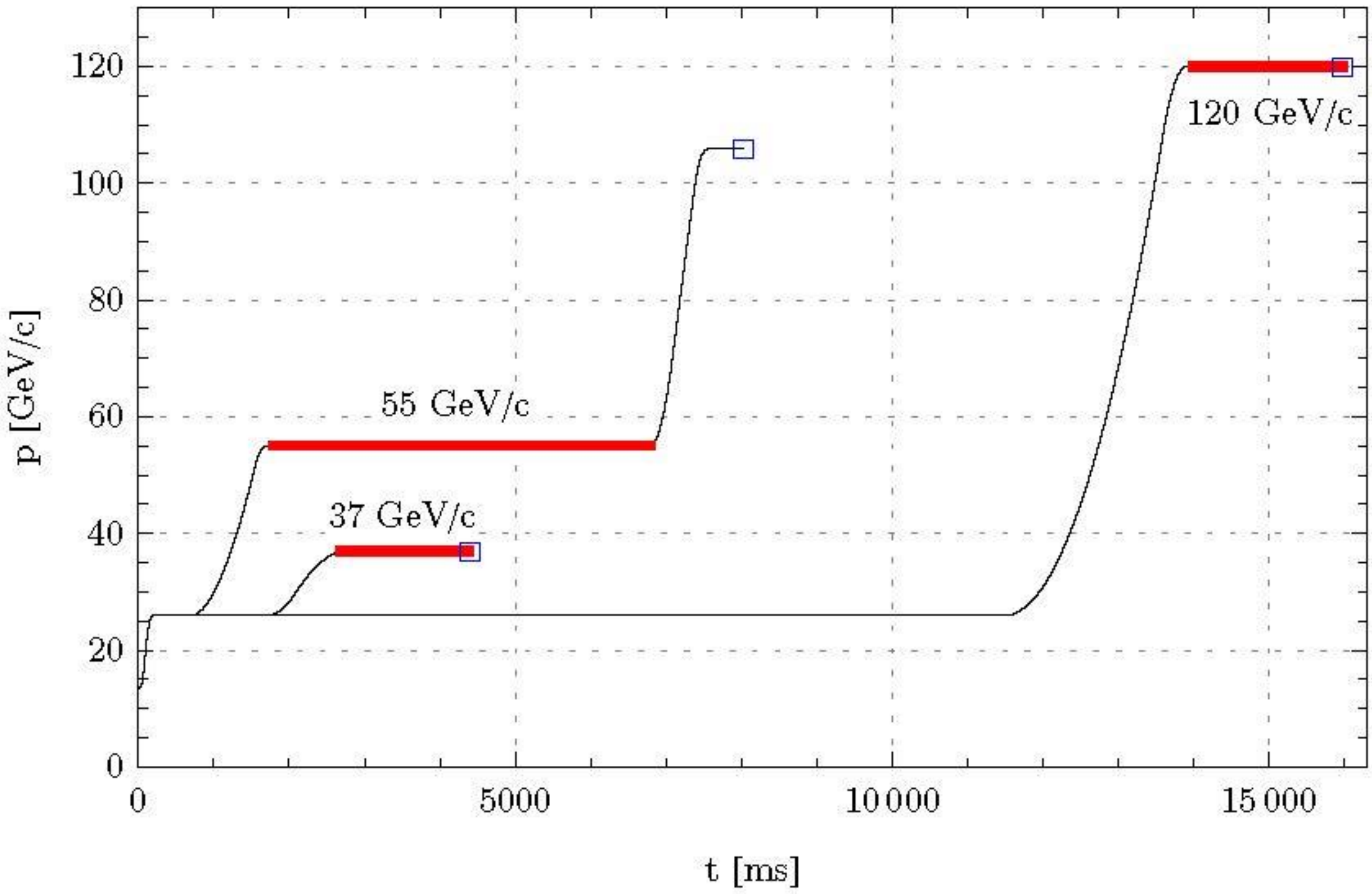
for constant normalized emittance, effect in units of sigma is independent of energy & beta function!

scaled experiment: wire current ~ emittance!

history of SPS BBLR studies

- **single wire as LHC LR simulator** (2002-2003)
- **two wire compensation, scaled exp.** (2004)
- tests of **crossing schemes** (2004)
- 1 & 2 wires at **different energies: 26, 37, & 55 GeV/c; scans of Q', distance, current** (2007)
- comp: Q, I_w, Q' scans @ 55 GeV/c (2008)
- comp.& excitation in **coasts @120 GeV/c** (2009)
- comp. & excitation in **coasts @55 GeV/c** (2010)

SPS cycles during 2008-09 experiments



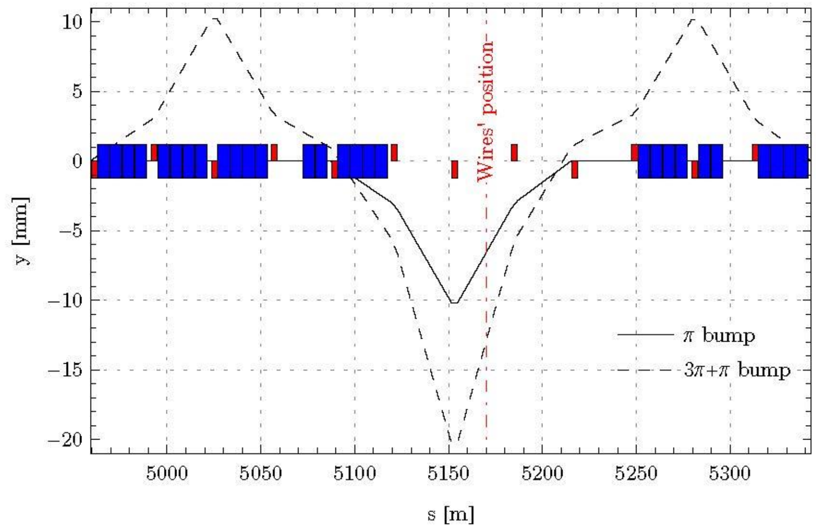
G. Sterbini

technical issues

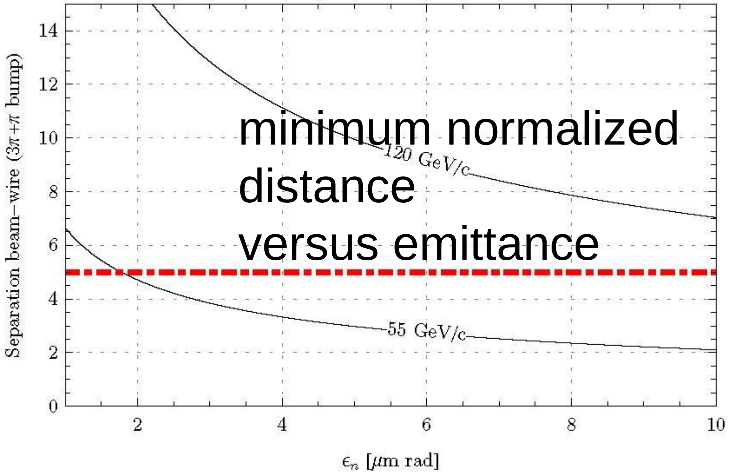
- dedicated **ion chambers & PMTs**
- inductive coil to **suppress current ripple**
- **wire heating** computed and verified
- **emittance blow up by damper** or injection
  mismatch & resonance crossing
  to reproduce LHC or to increase sensitivity
- **wire scanners, scrapers**
- **dedicated dipole** to correct orbit change locally
- always correct tune
- multiple **orbit bumps** to vary beam-wire distance
- (later) energy = **55 or 120 GeV/c (good lifetime)**
- (later) experiments in **coast** (avoid transient data)

experimental details (2008-09)

wire-beam distance was varied by combination of 3+5 corrector bumps



emittance blown up with transverse feedback & resonance crossing



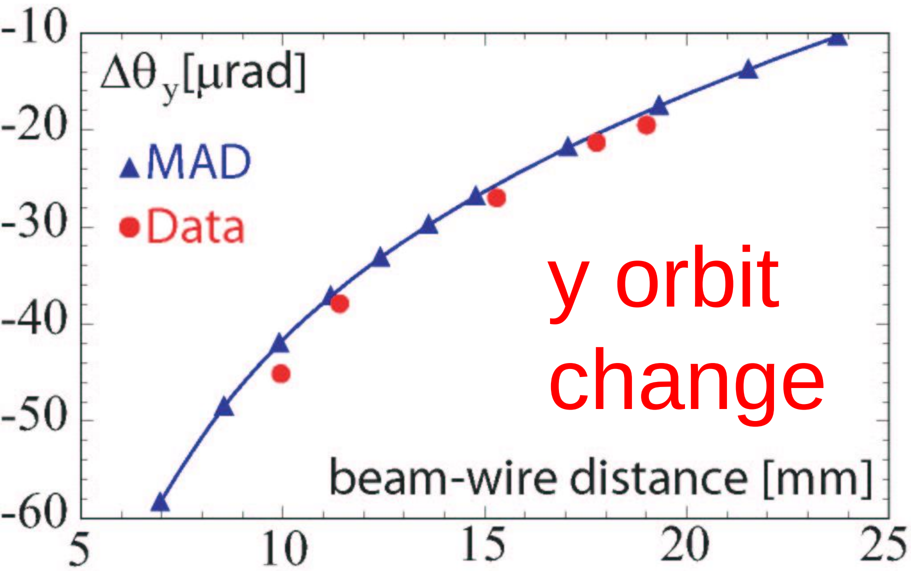
G. Sterbini

natural SPS beam lifetime:
~30 h at 55 GeV/c
~5-10 min at 26 GeV/c (physical aperture ~4 σ)

single BBLR

“excitation” studies

changes in orbit & tunes (2002)
→ precise measure of beam-wire distance

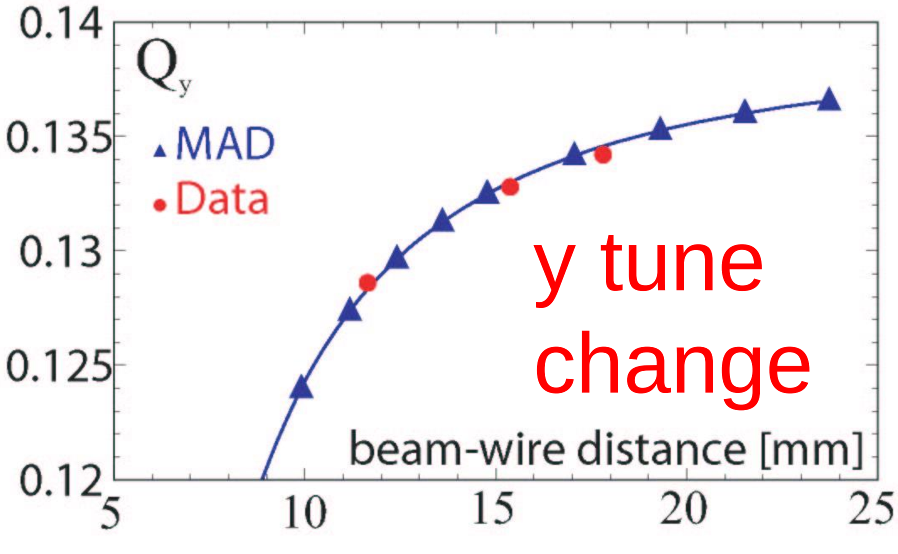


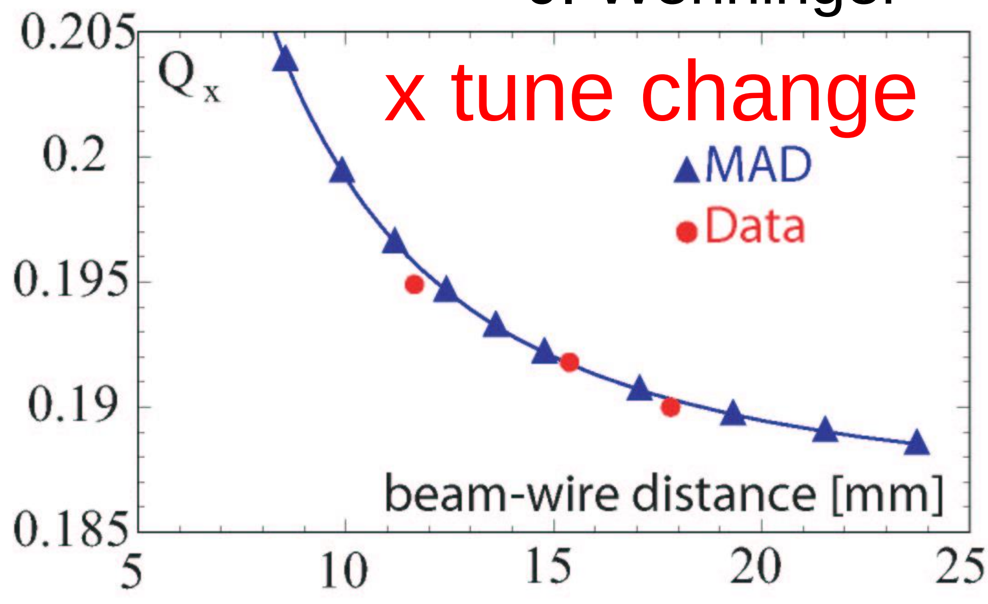
$$\Delta d = \frac{\beta_y I_w l_w r_p}{\gamma e c (d + \Delta d) \tan\left(\pi\left(Q_y + \Delta Q_y\right)\right)}$$

$$\Delta Q_{x,y} = \mp \frac{r_p \beta_{x,y} I_w l_w}{2\pi\gamma e c} \frac{1}{(d + \Delta d)^2}$$

later used Q change only

J. Wenninger





non-linear optics

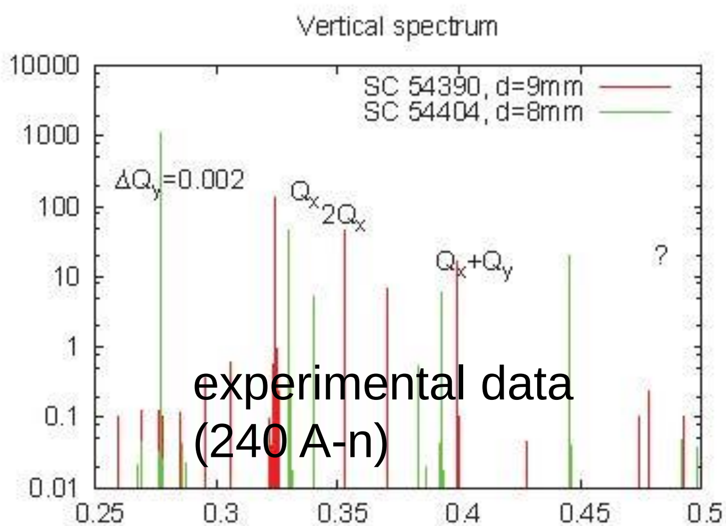
- turn-by-turn BPM data after kicks

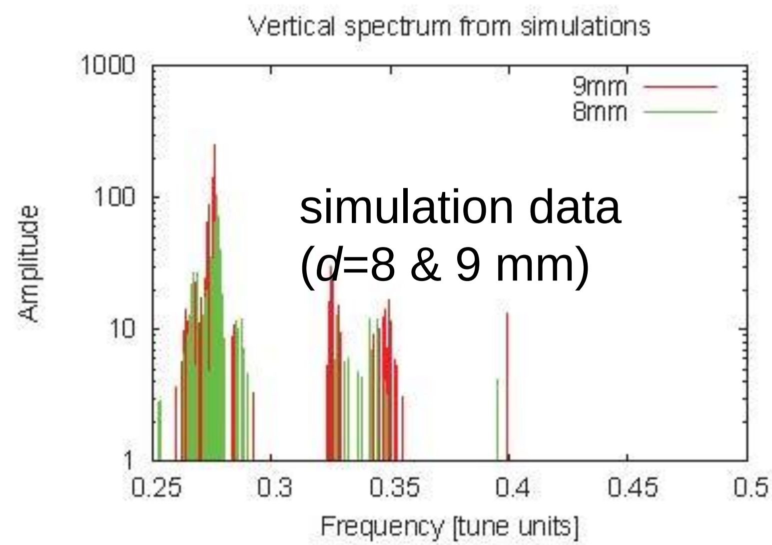
→ reduced decoherence time

→ tune shift amplitude, consistent w

$$\Delta Q_x \approx \frac{3}{4}\frac{I_w l_w r_p}{\gamma e c}\frac{\beta_x}{d^4}\hat{y}^2 \qquad \Delta Q_y \approx -\frac{3}{8}\frac{I_w l_w r_p}{\gamma e c}\frac{\beta_x}{d^4}\hat{y}^2$$

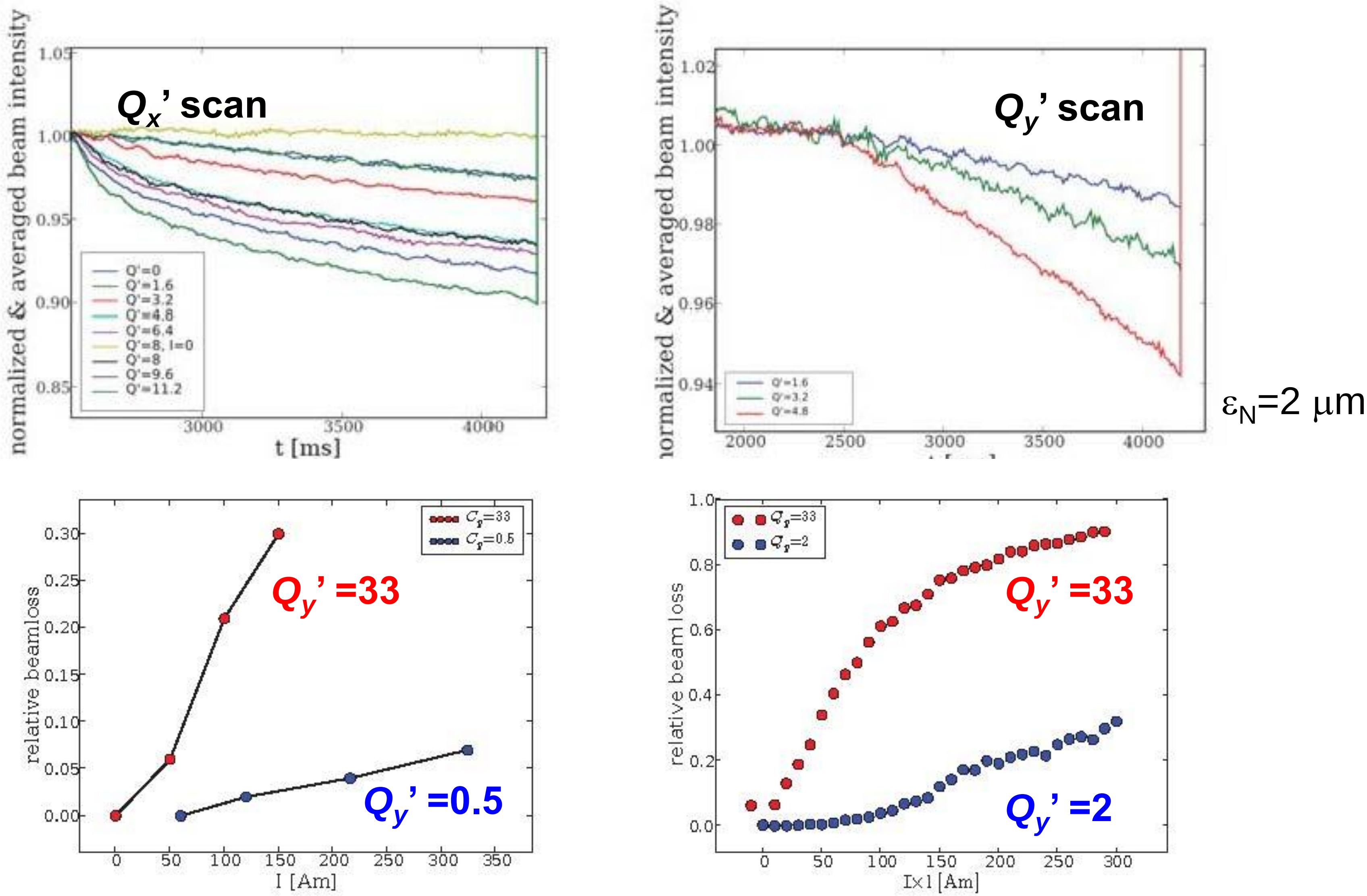
→ spectral resonance lines





U. Dorda

effect of chromaticity (37 GeV/c)



(a) Experimental data

(b) Simulations

U. Dorda

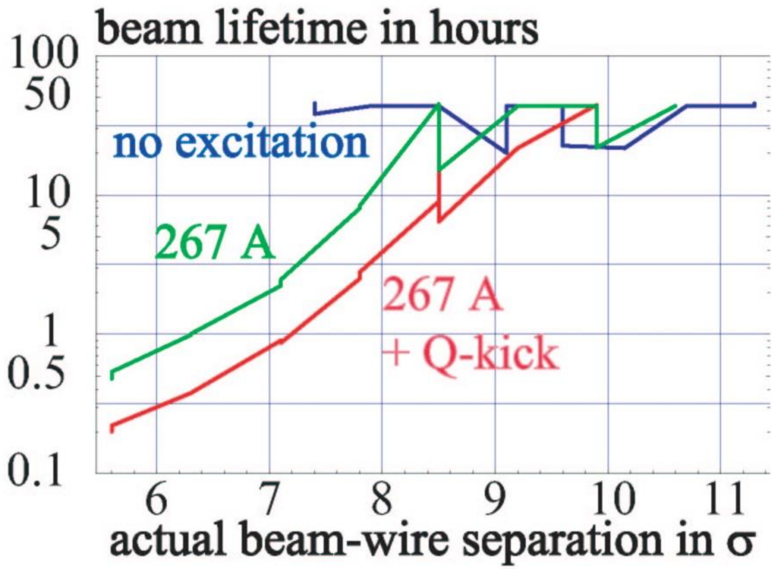
measuring the "diffusive" or dynamic aperture

three types of signals:

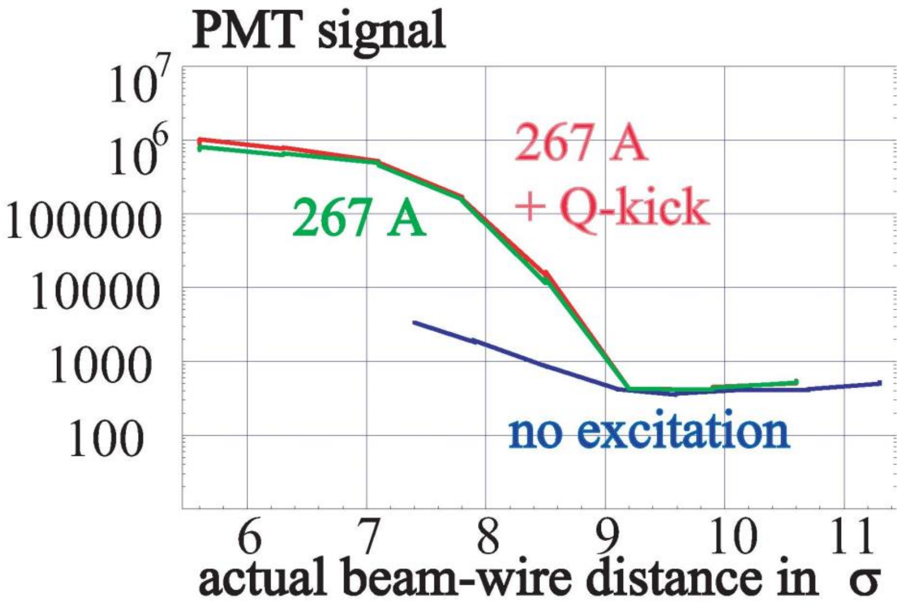
- lifetime and background
- beam profiles & final emittance
- diffusion rate w scraper retraction

lifetime and background (55 GeV/c)

lifetime vs. separation



beam loss vs. separation

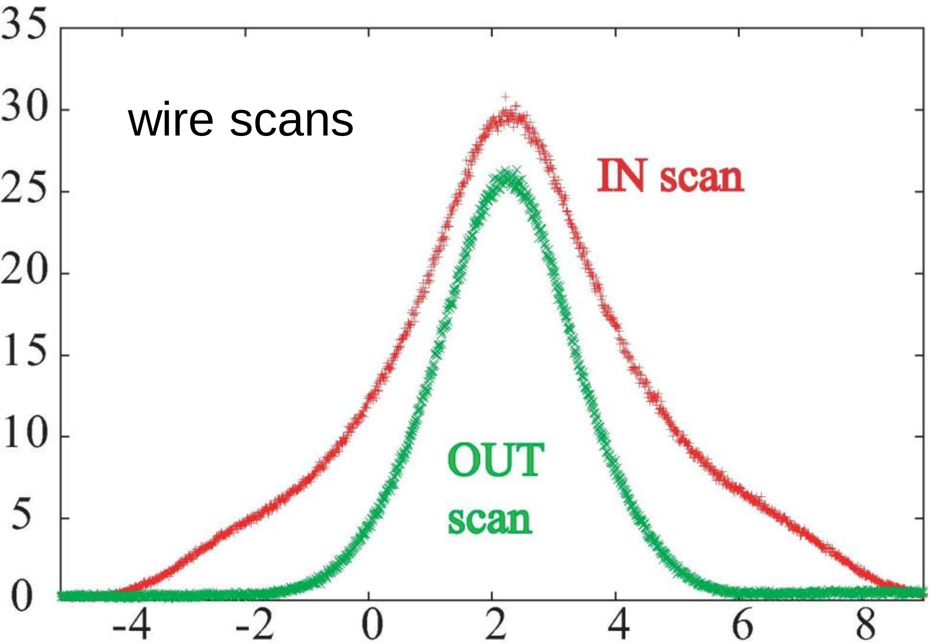


J.P. Koutchouk

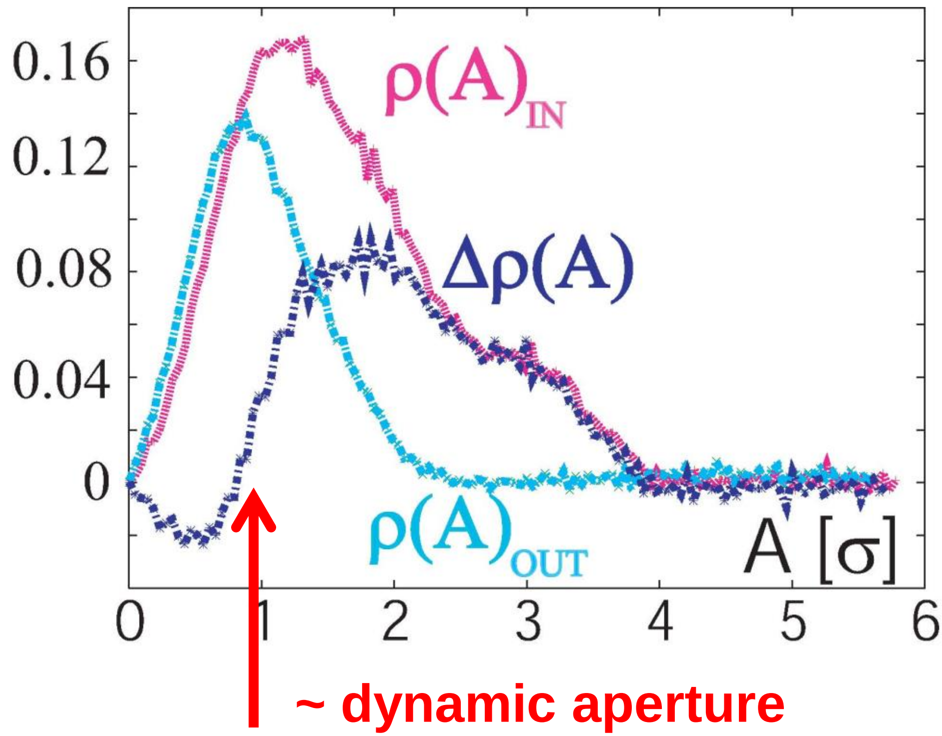
drop in the lifetime and increased losses for separations less than 9σ;

at 7-8σ separation lifetime decreases to 1-5 h

initial & final profile (26 GeV/c)



initial/final emittance = 3.40/1.15 μm



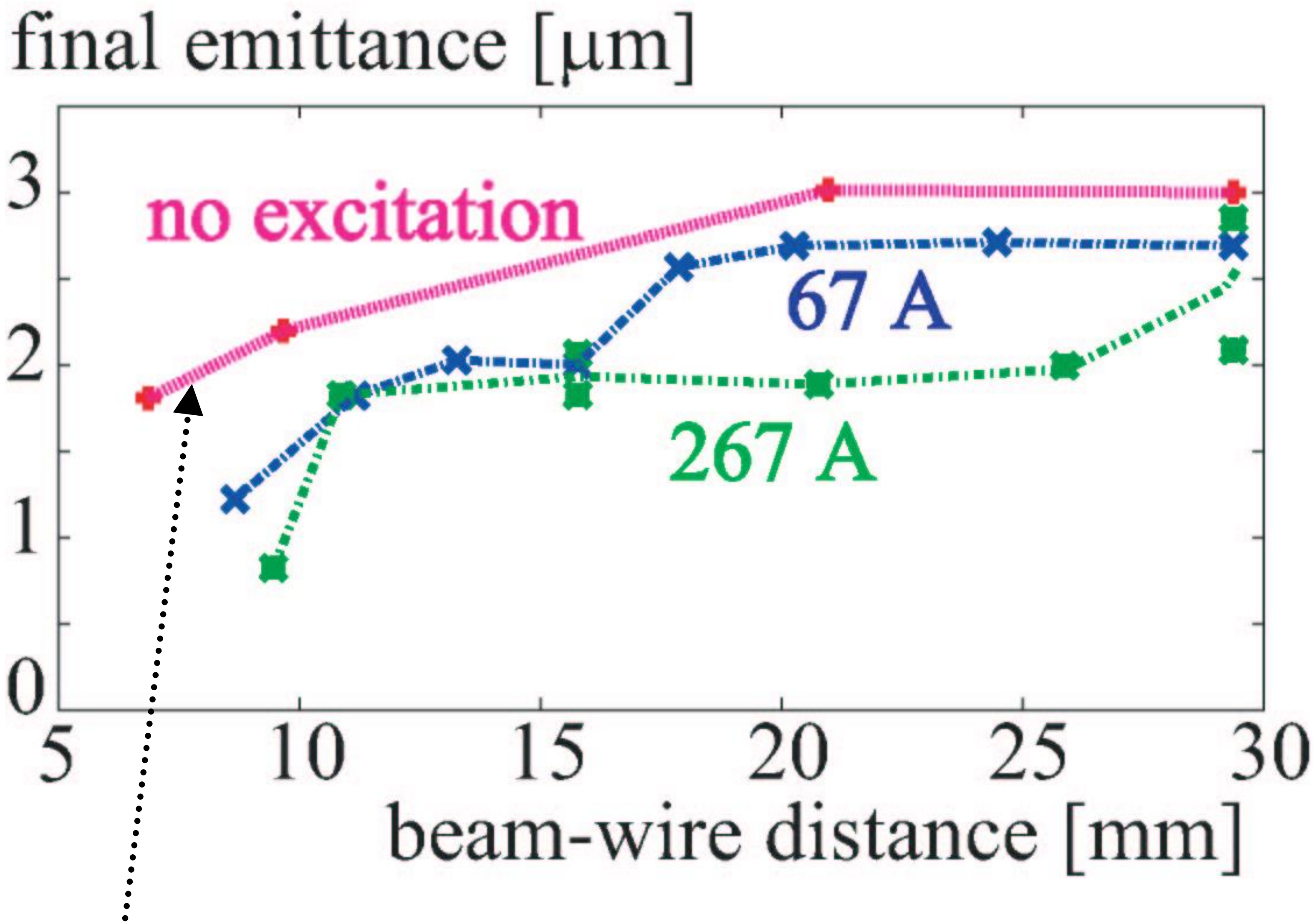
Abel transformation of wire-scan data gives change in (norm.) amplitude distribution:

promising method

$$\rho(A) = -2A\int_A^R d\eta \frac{g'(\eta)}{\sqrt{\eta^2 - A^2}}$$

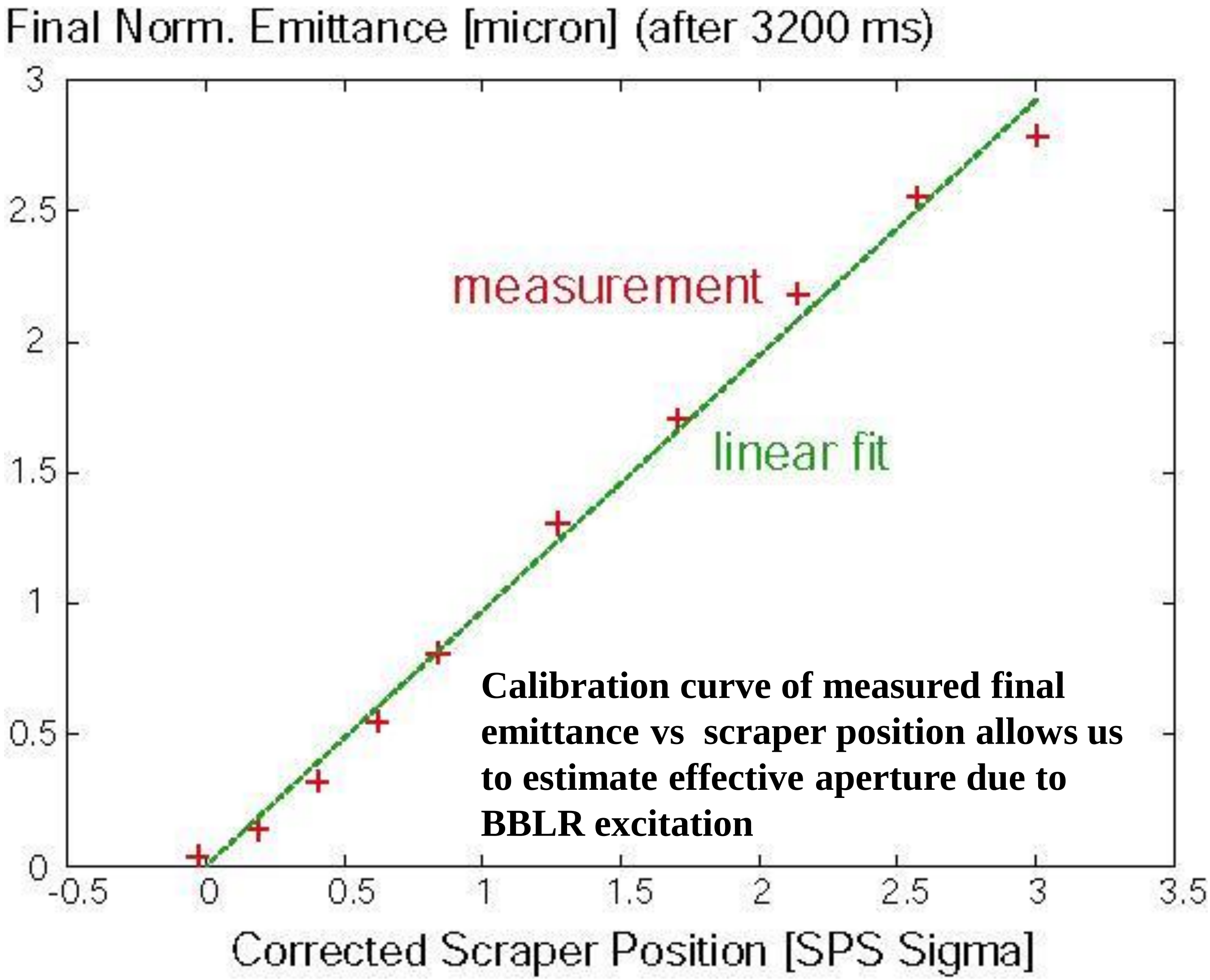
(Krempl, Chanel, Carli)

final emittance (26 GeV/c)



mechanical scraping by edge of wire

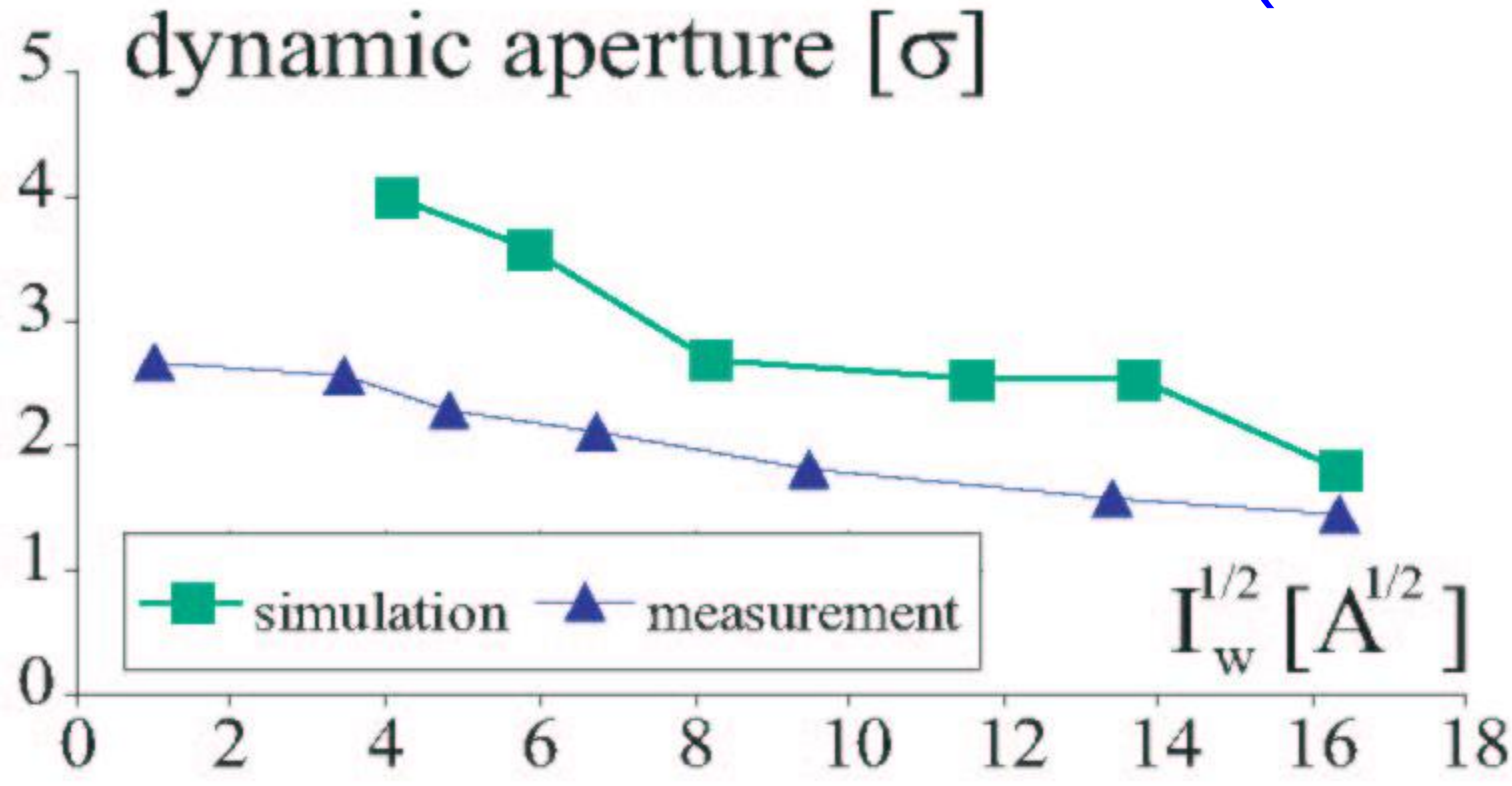
Calibration of final emittance by scraper



Calibration curve of measured final emittance vs scraper position allows us to estimate effective aperture due to BBLR excitation

effect of wire current on SPS dyn.ap.

(26 GeV/c)

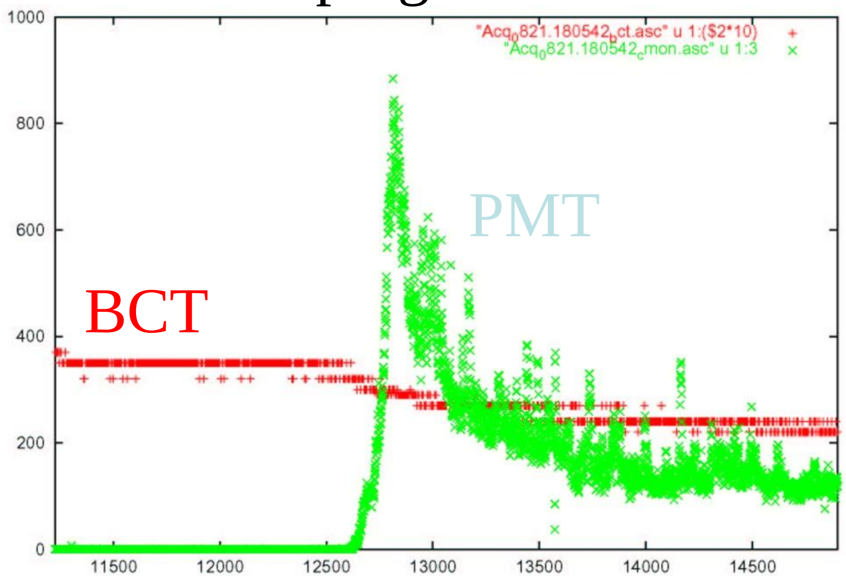


linear dependence DA($I_w^{1/2}$) consistent with Irwin scaling law; measured dynamic aperture is smaller than simulated

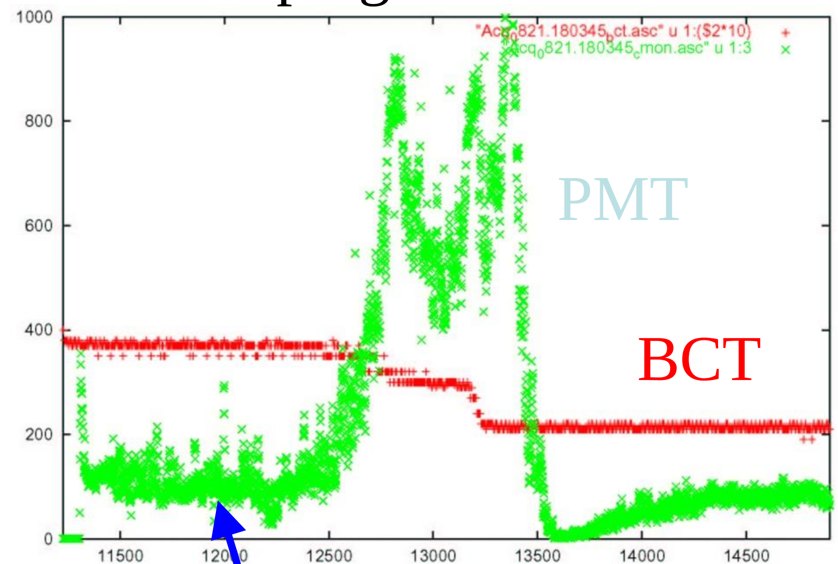
scraper retraction attempt

not very successful

only BBLR (at 12725 ms), w/o scraping



BBLR at 12725 ms, scraping at 13225 ms

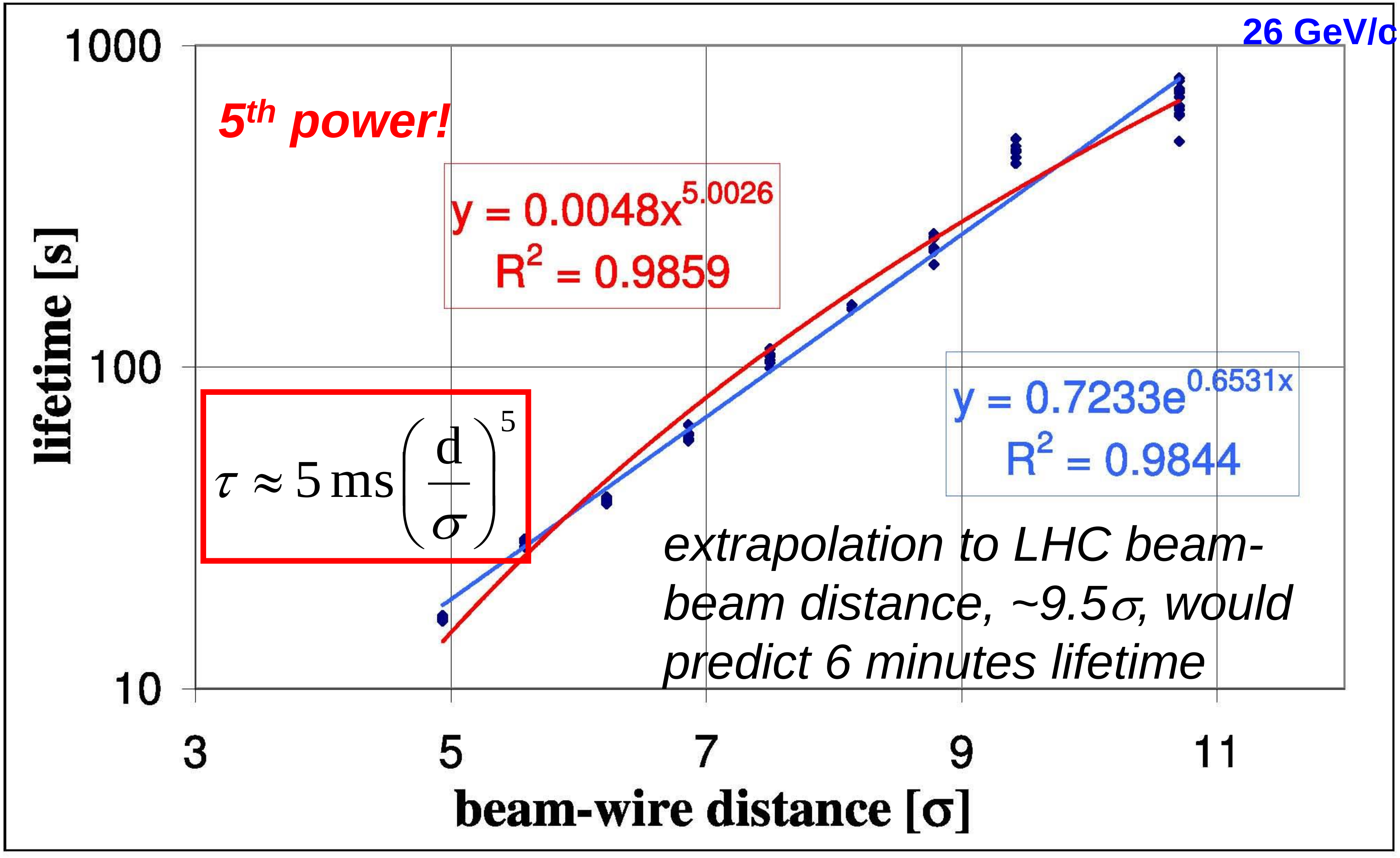


can we fit a diffusion constant?

on the right, scraper position is about 1σ;
at larger amplitudes the diffusion seems much faster than the speed of the SPS scraper

scraper moving to target position already intercepts halo

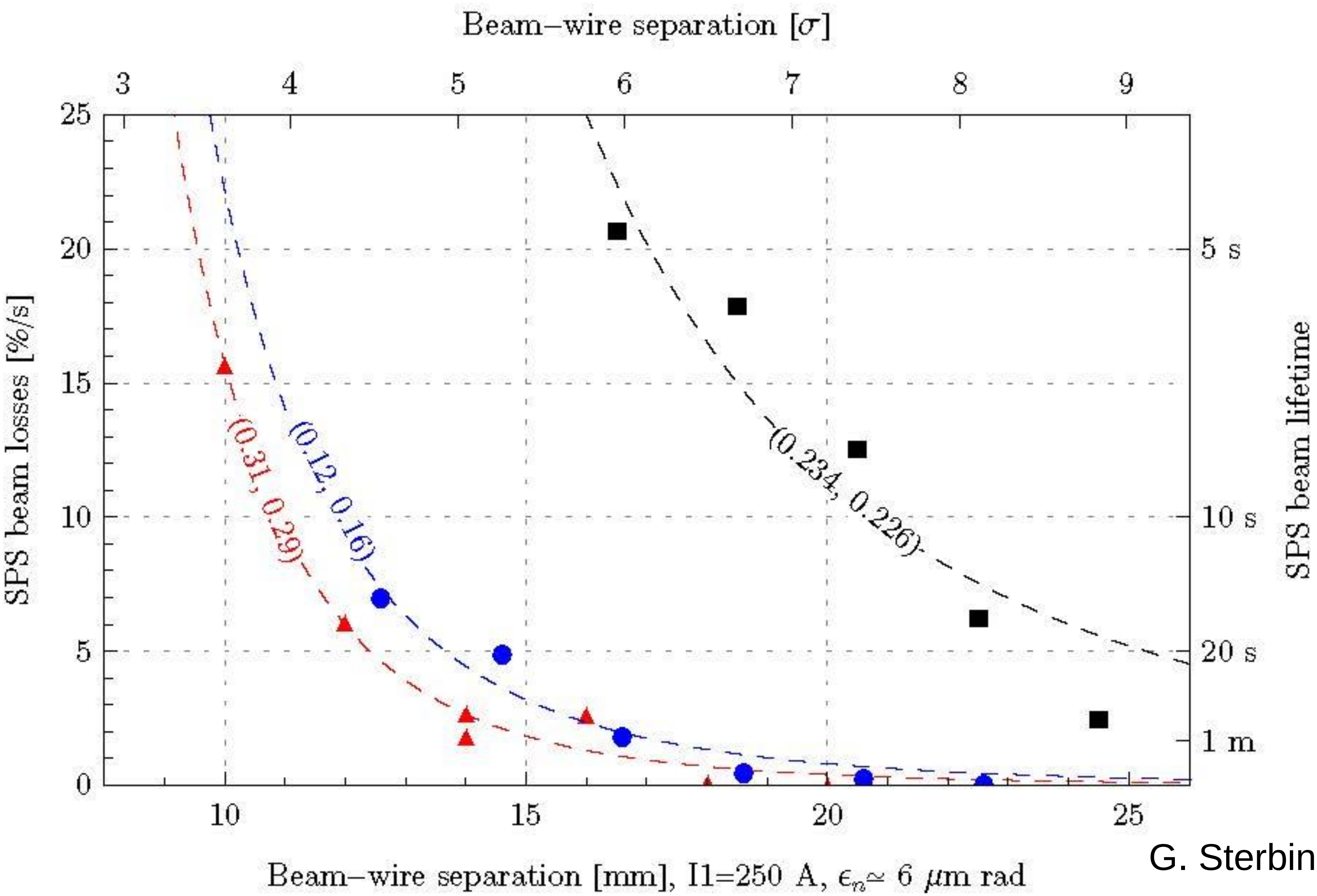
effect of beam-wire distance on lifetime



Q_x=0.321, Q_y=0.291

"τ vs *d*" changes with tune

(37 GeV/c, 1.1 s)



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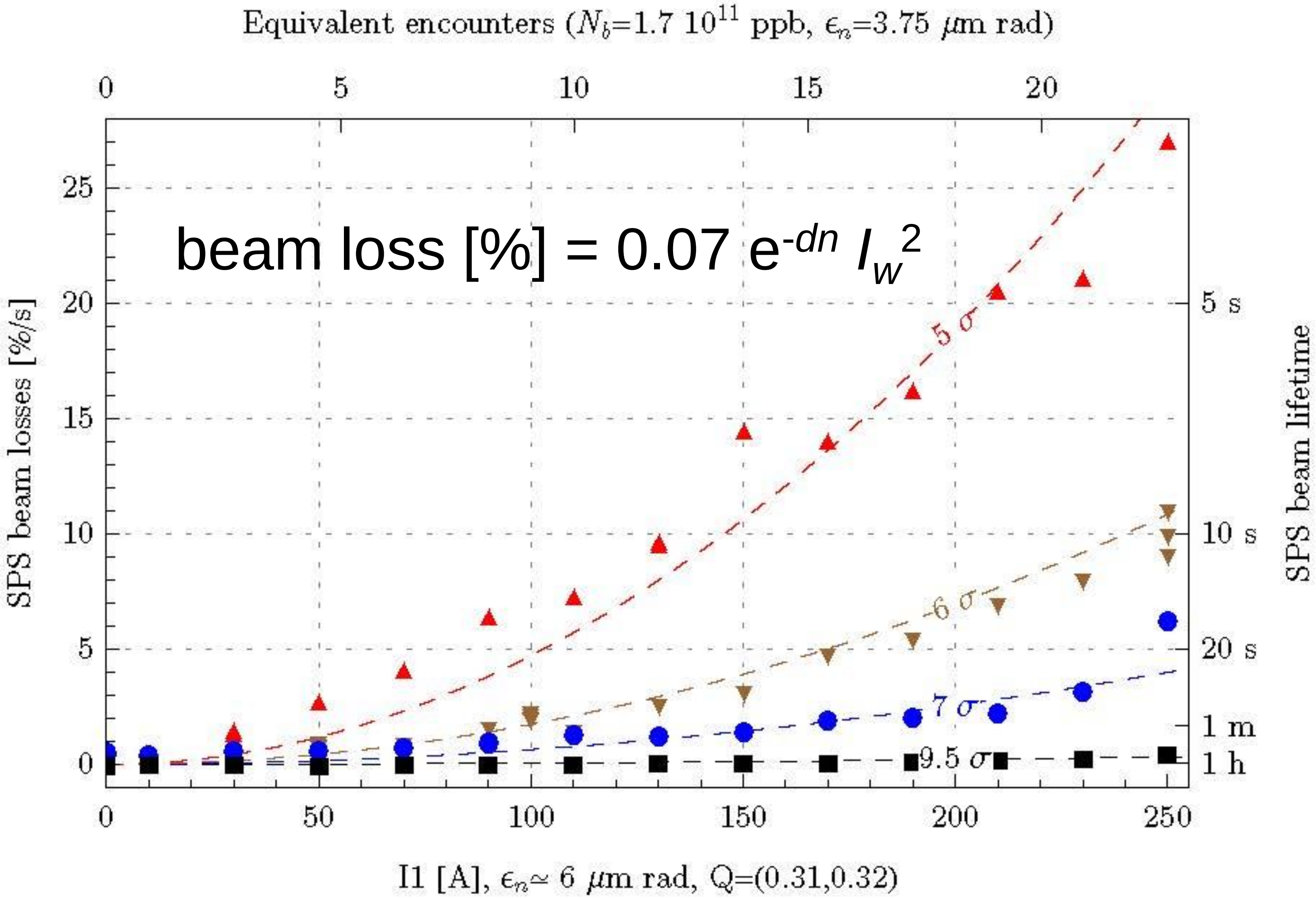
τ vs I_w (37 GeV/c; 1.1 s)



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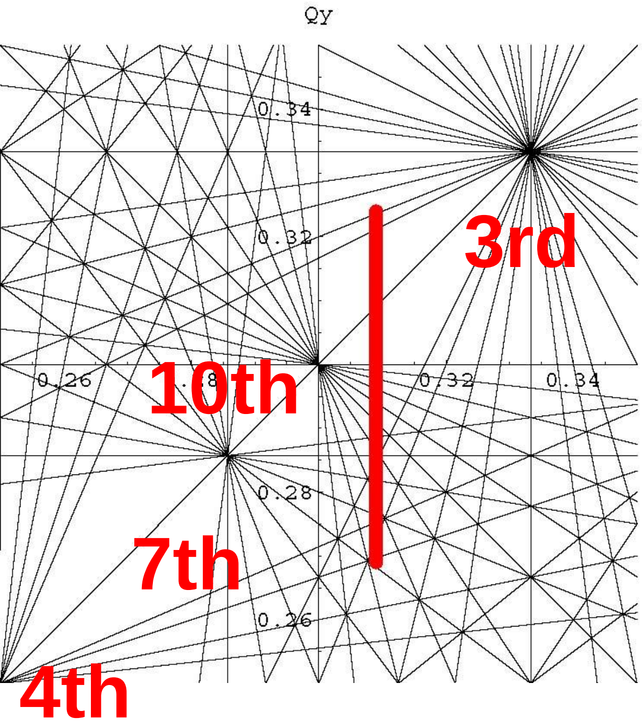
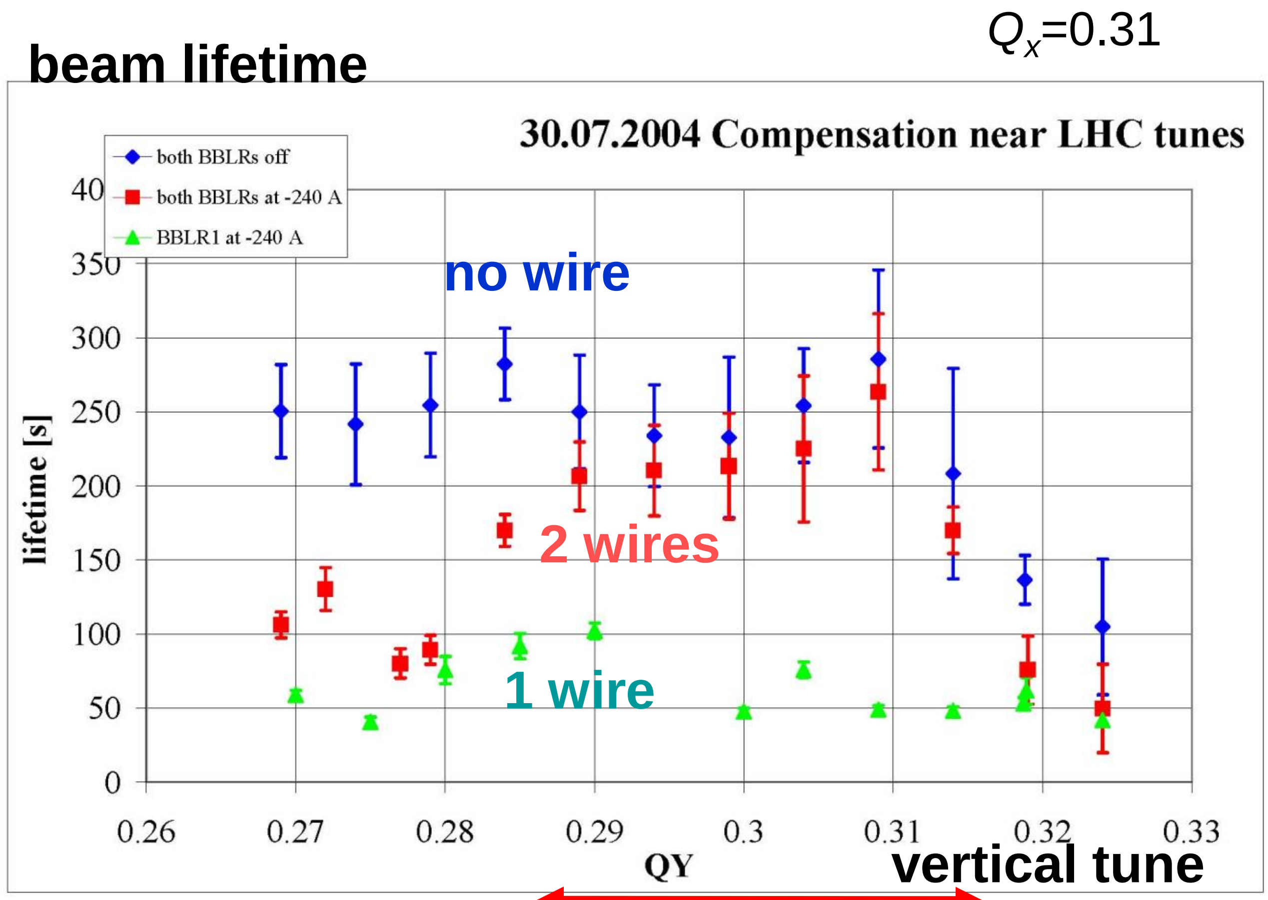
two BBLRs

“compensation” studies

two-wire compensation: tune scan (2004), 26 GeV/c



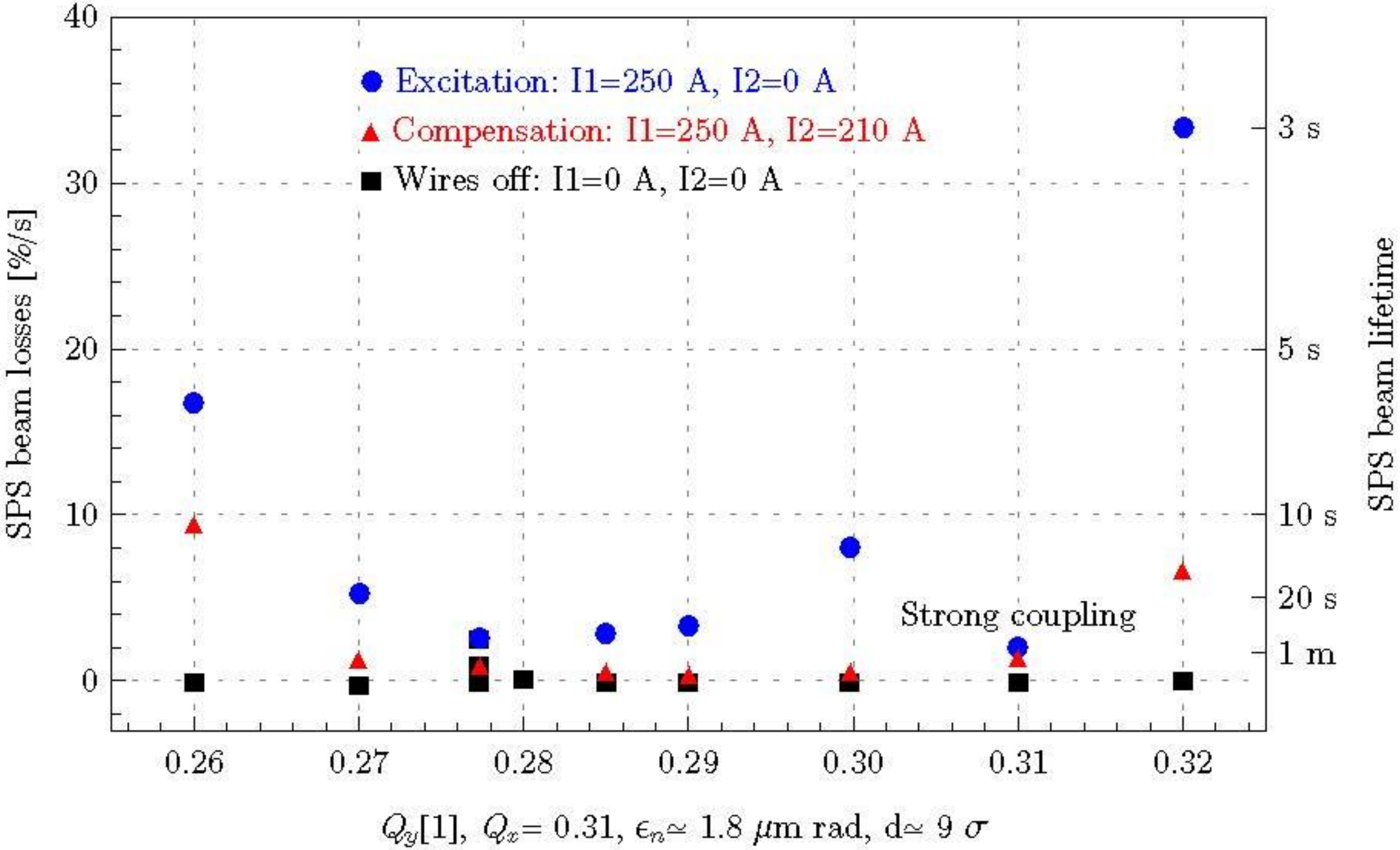


what happens here?

nearly perfect compensation

lifetime recovered over large tune range, except at Q_y<0.285

two-wire compensation: another tune scan (2008); 37 GeV/c; 1.1 s



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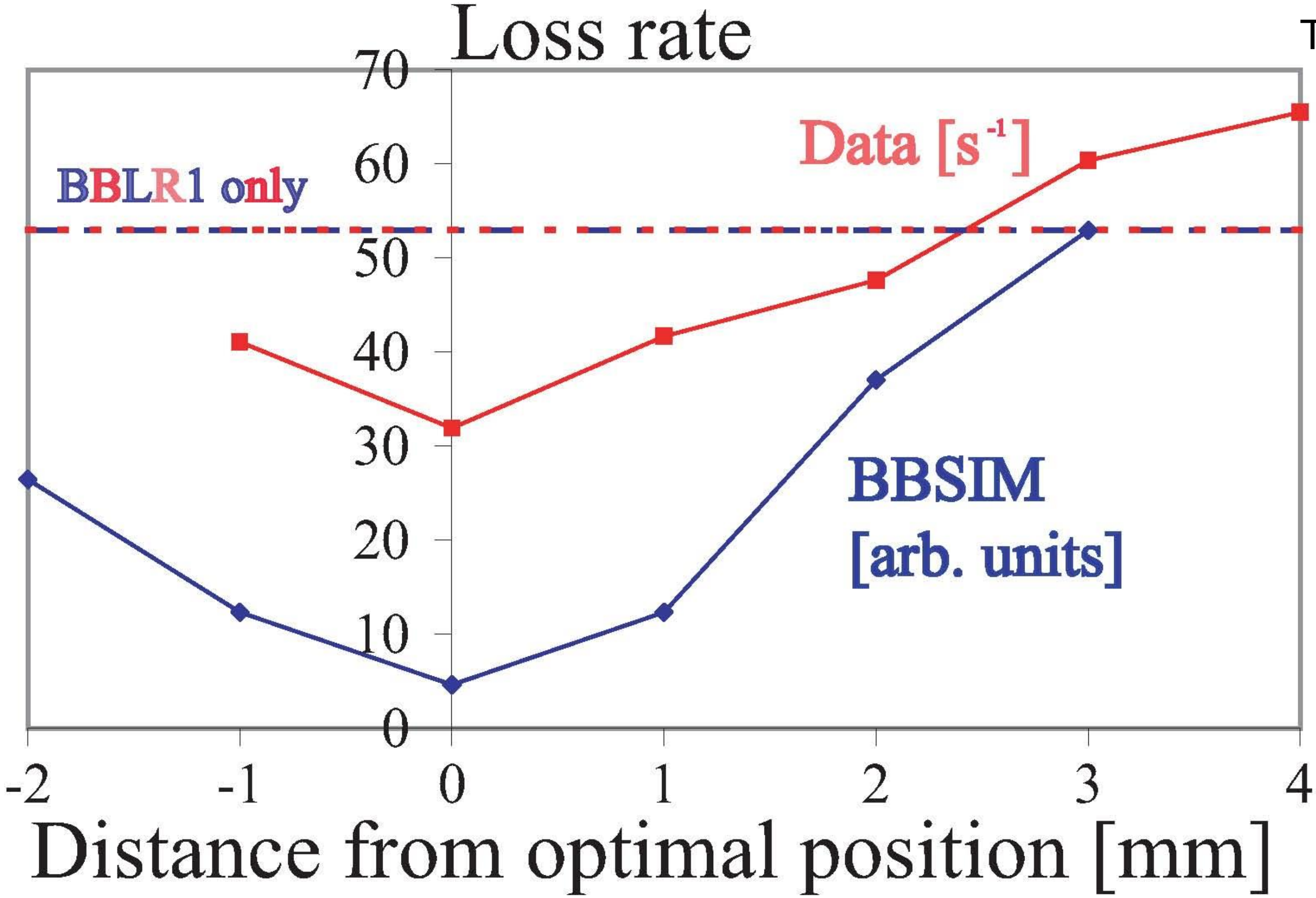
two-wire compensation: distance scan

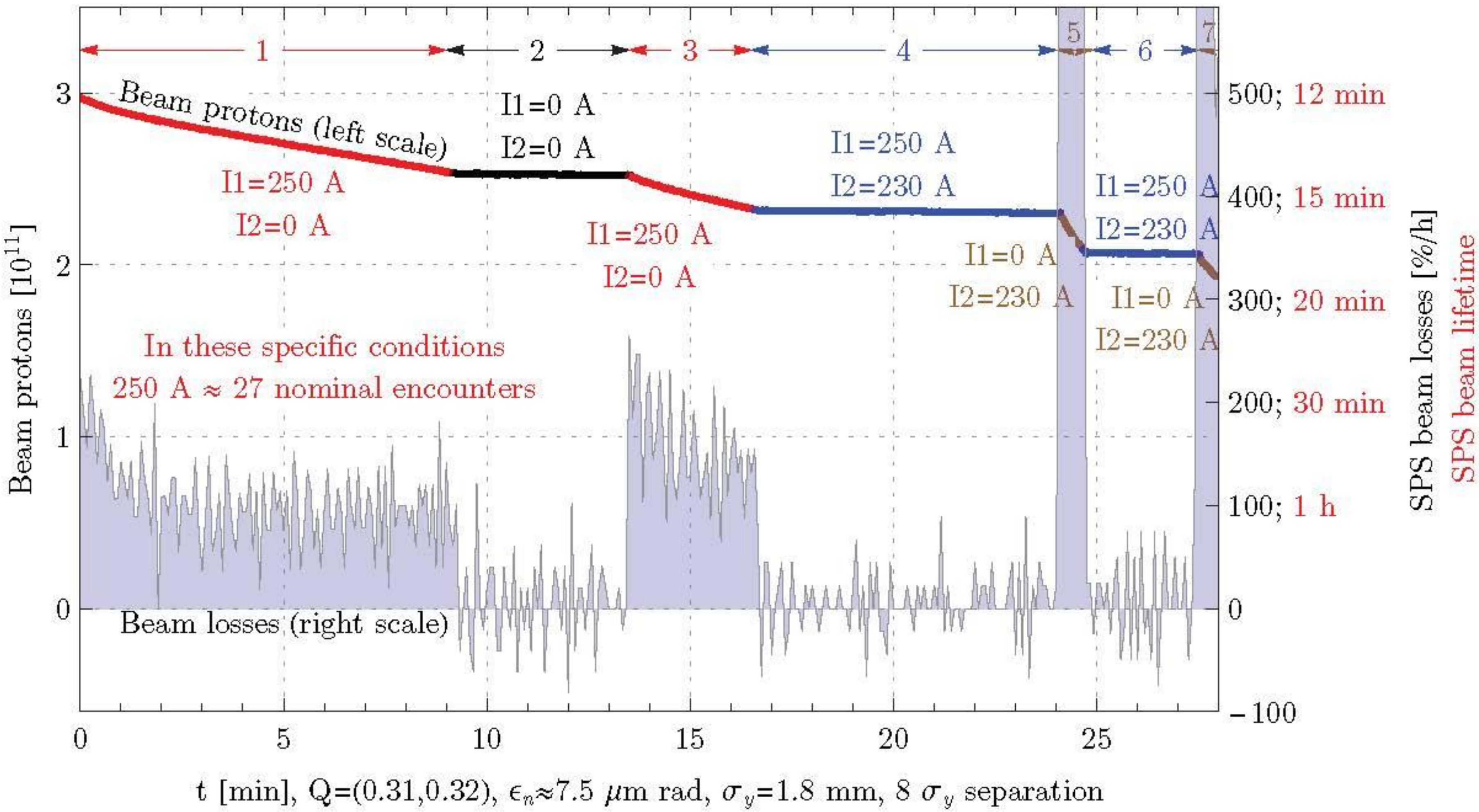
T. Sen



BBSIM simulation: No compensation beyond ~3 mm

Measurement: Compensation fully lost beyond ~2.5 mm from optimum (≤2 σ)

two-wire compensation: On / Off at 8σ distance, coast at 120 GeV/c (2009)



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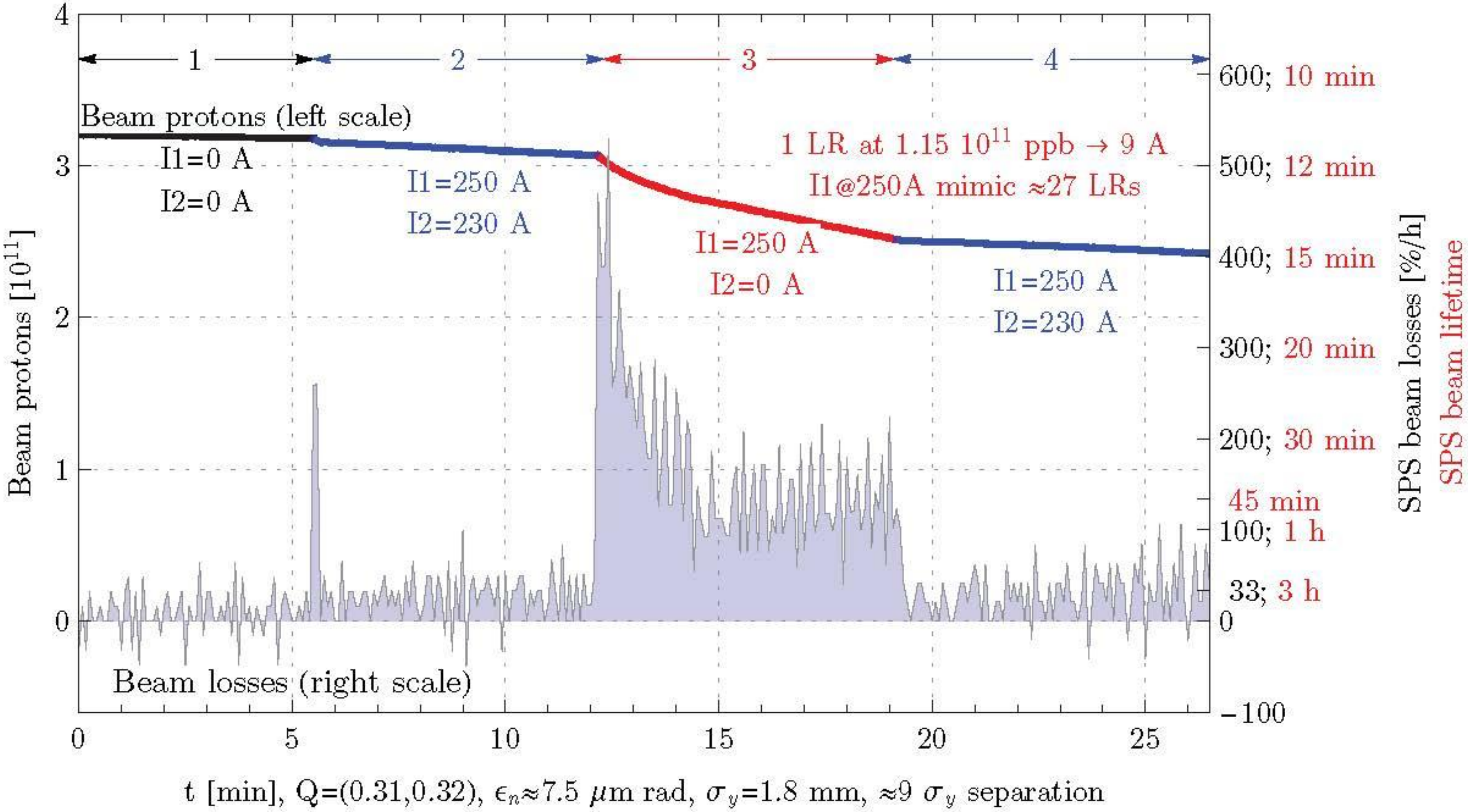
two-wire compensation: On / Off at 9σ distance, coast at 120 GeV/c (2009)



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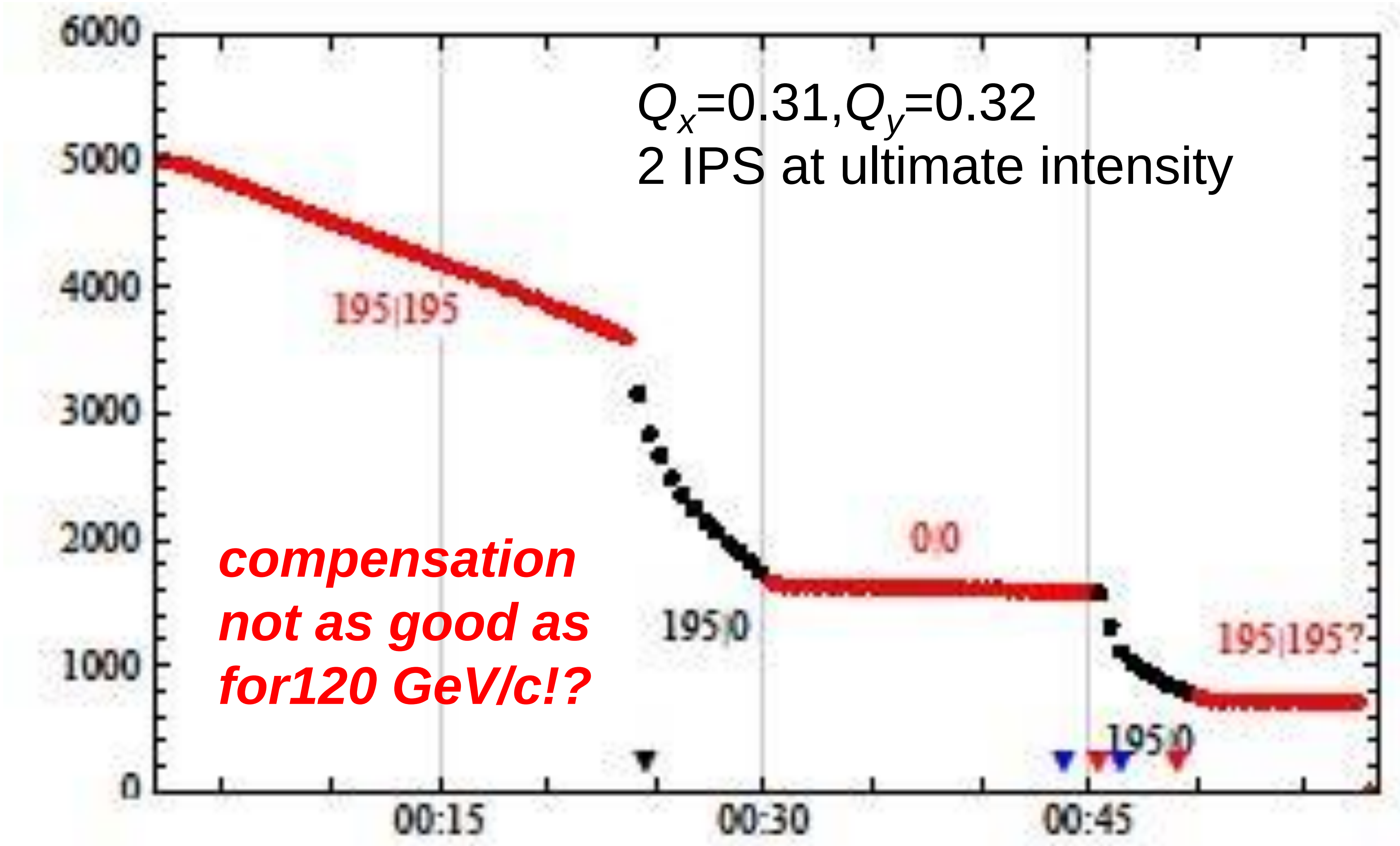
two-wire compensation: On / Off at 9.5σ distance, coast at 55 GeV/c (2010)

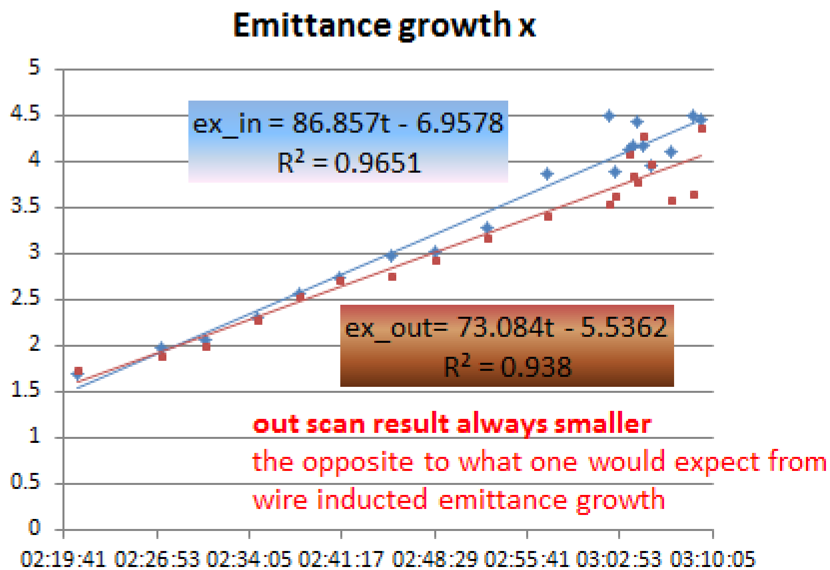


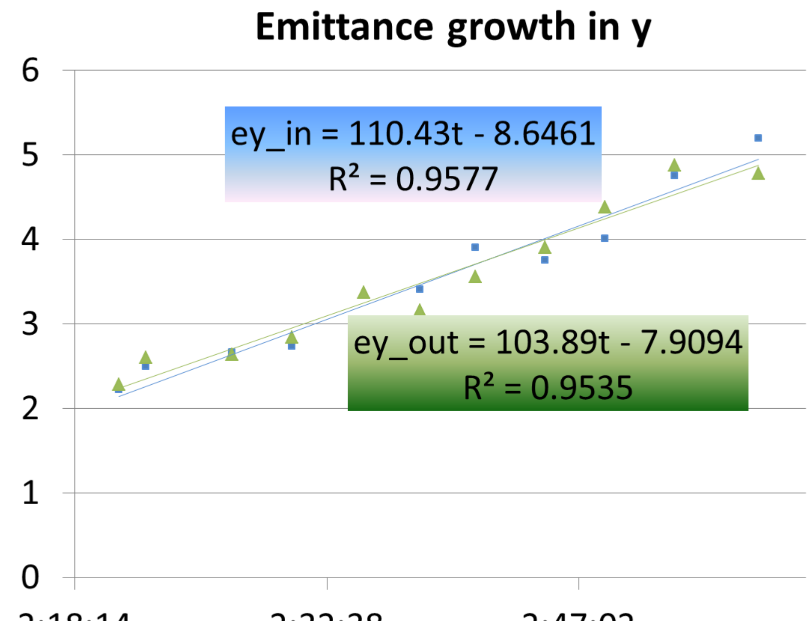
Q_x=0.31,Q_y=0.32
2 IPS at ultimate intensity

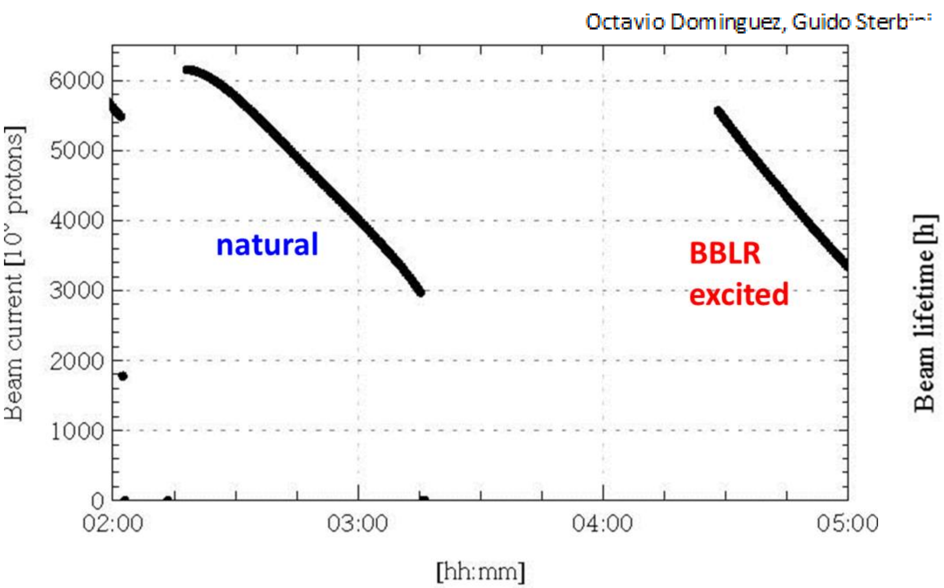
compensation not as good as for120 GeV/c!?

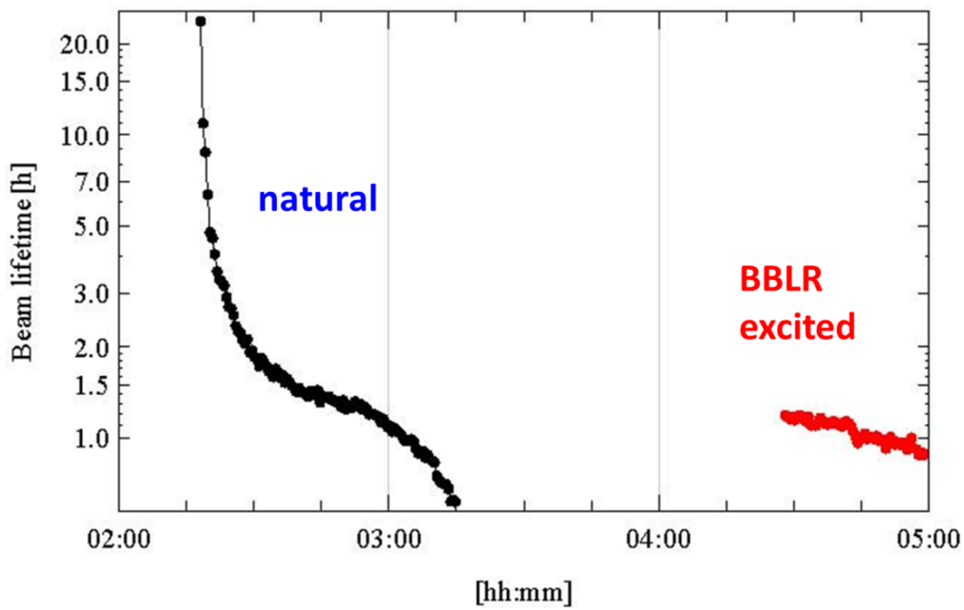
R. Calaga

2010: emittance growth, low lifetime in coast at 55 GeV/c







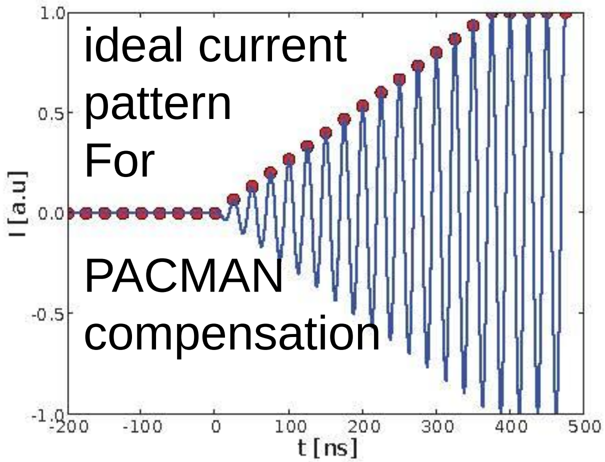


Octavio Dominguez, Guido Sterbini

advanced BBLR studies

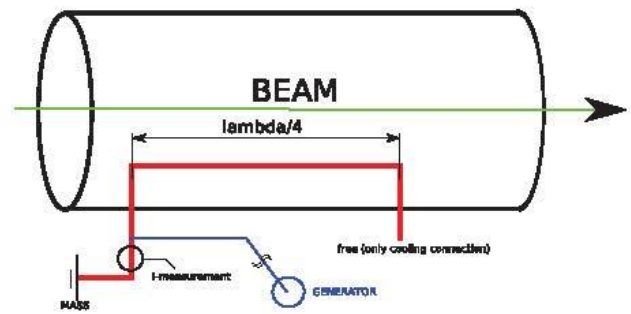
towards an "RF BBLR"

U. Dorda,
F. Caspers,
T. Kroyer



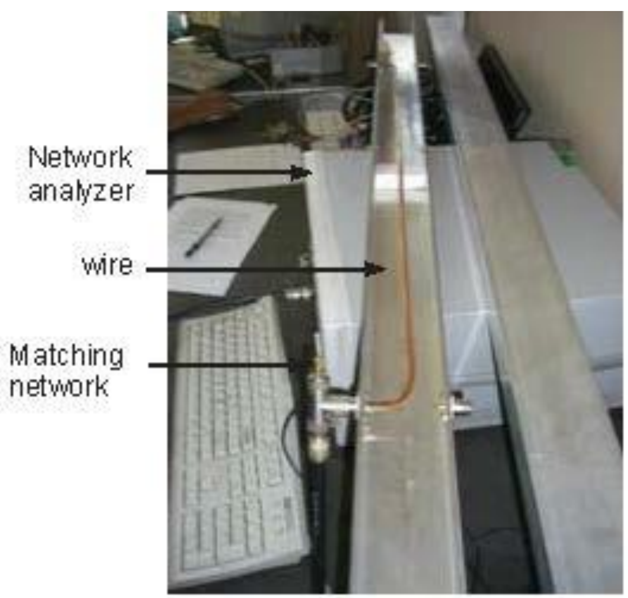
(a) The RF-BBLR current follows an amplitude modulated 40MHz sinus signal

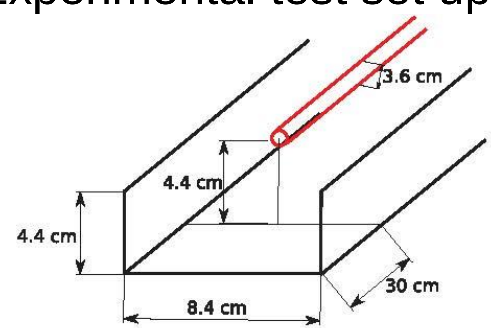
schematic



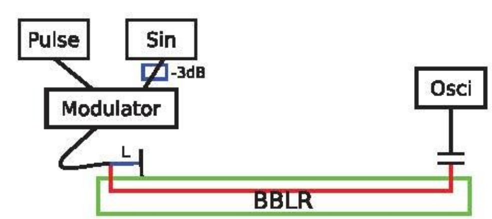
(b) A RF BBLR represents a $\lambda/4$ resonator

Experimental test set up & dimensions





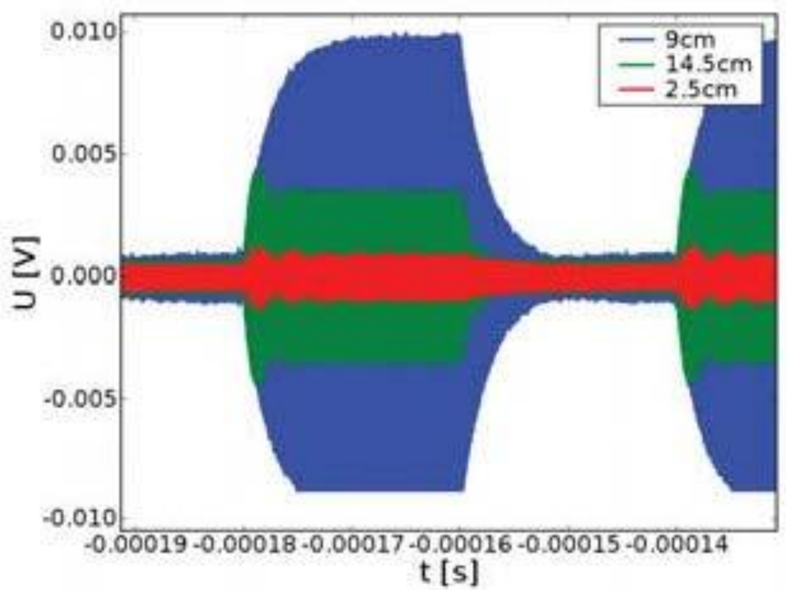
(a) Dimensioning of the RF-BBLR prototype # 2



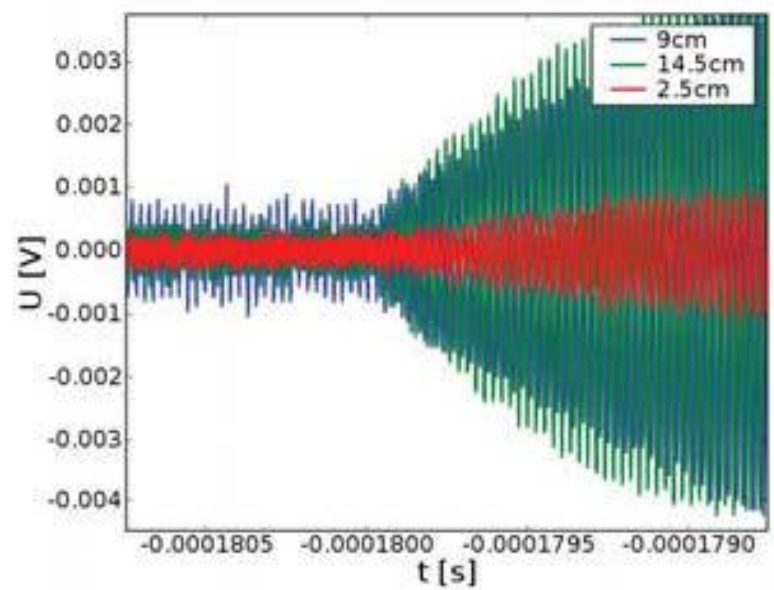
(b) Sketch of the measurement setup for RF-BBLR # 2. The cable length L can be changed for varying the coupling strengths. Port 2 is connected capacitively in order not to modify the resonating properties.

towards an “RF BBLR”

U. Dorda, F. Caspers, T. Kroyer



(a) An overview shows the various achievable resonator gains



(b) A zoomed view shows the different rise times for the different couplings.

test measurements showing effect of varying coupling strength (trade off: rise time ↔ gain)

conclusions

10 years of pioneering studies; a lot of lessons learnt; two PhD theses

experimental conditions in SPS not always ideal

nevertheless compensation by second wire almost always improved the beam lifetime significantly over a large range of parameters (current, distance, tune)

wire compensators will surely increase operational flexibility and performance in the LHC

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 :

- ☐ 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 BBLRs 3-m long sections were reserved in LHC at 104.93 m (center) on either side of IP1 & IP5

R. Steinhagen

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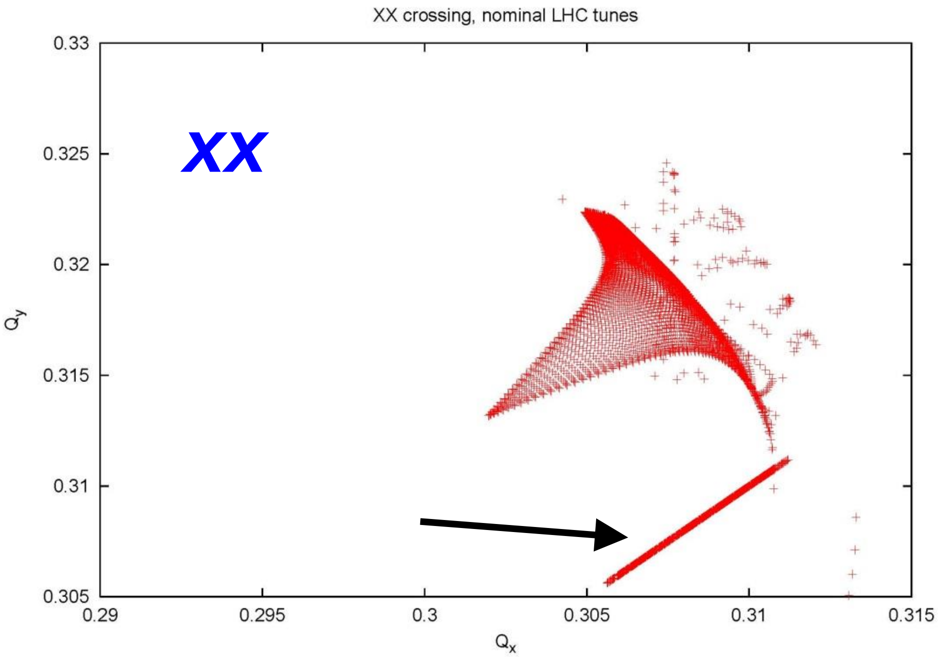
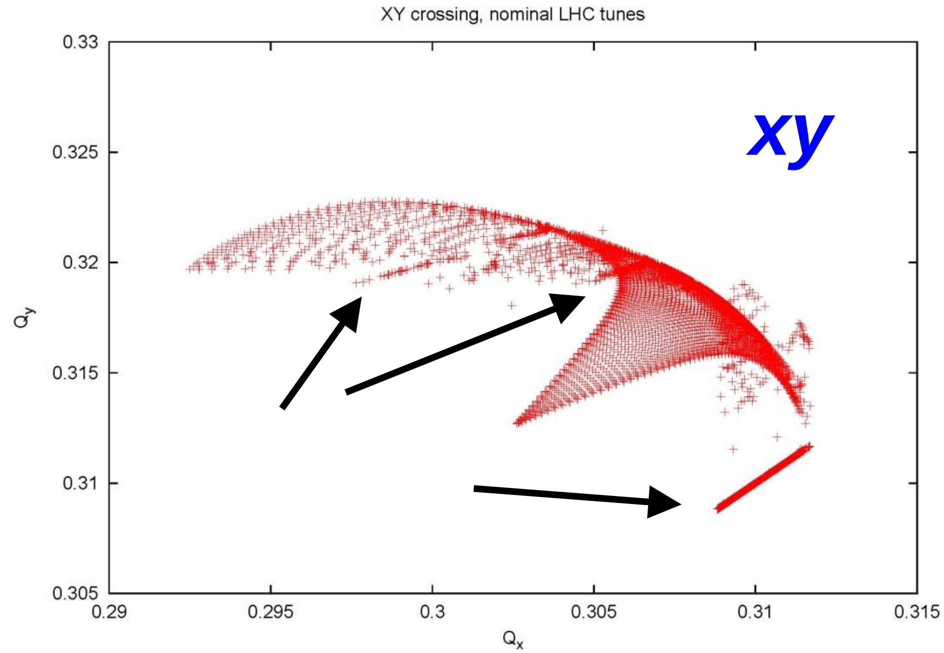
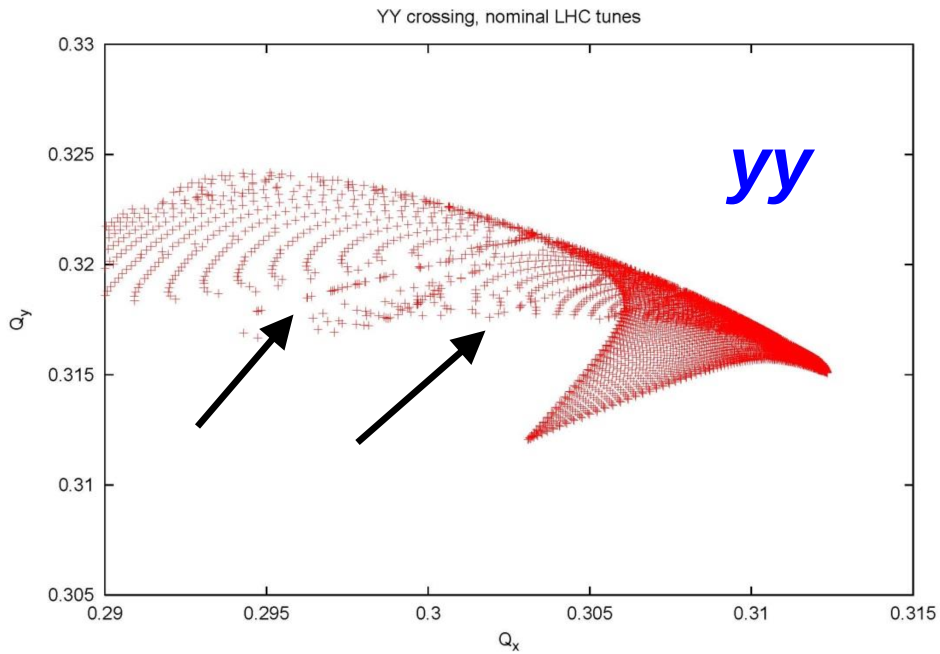
appendix:
crossing scheme studies





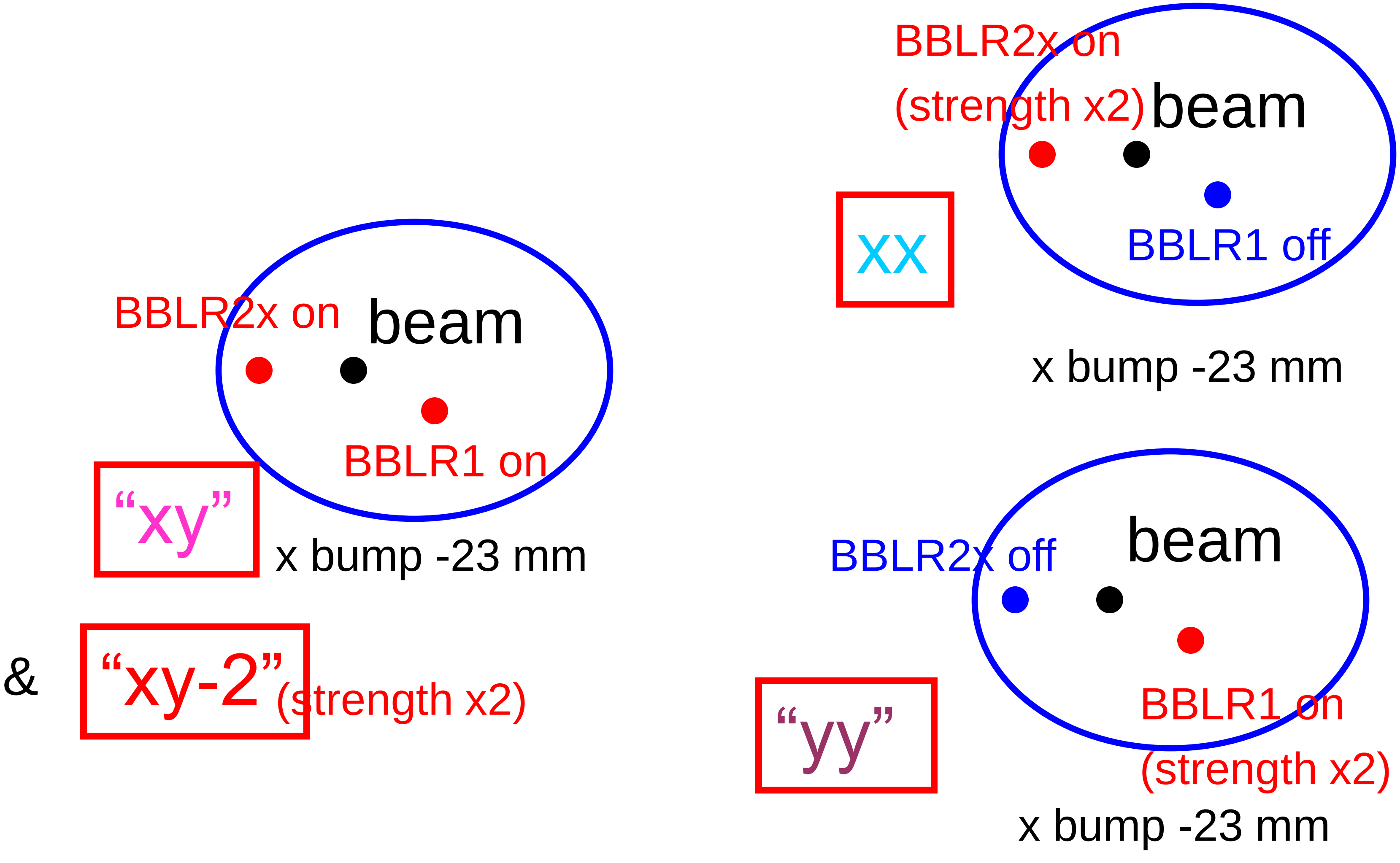
frequency maps for nominal LHC tunes

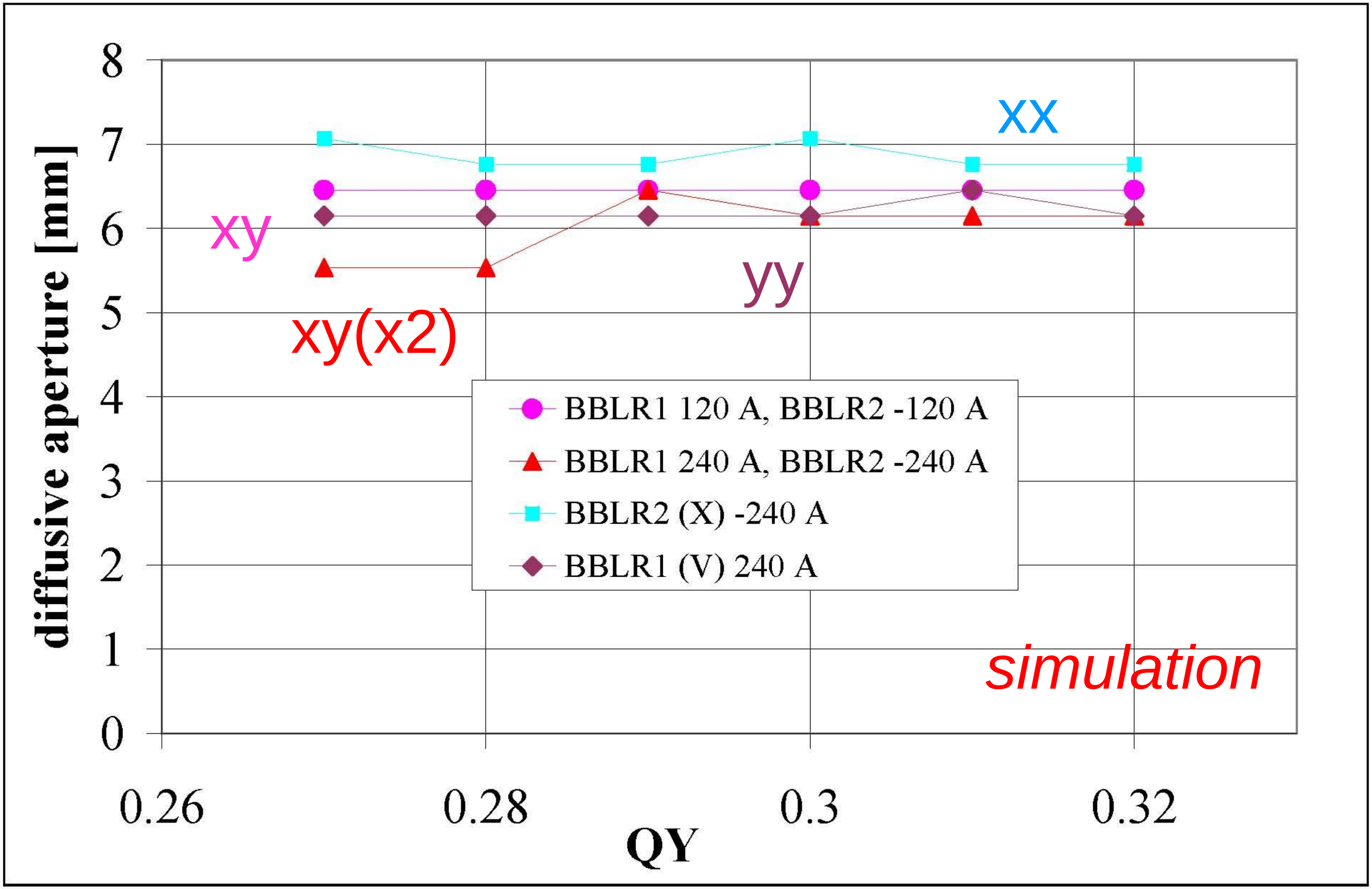


simulations

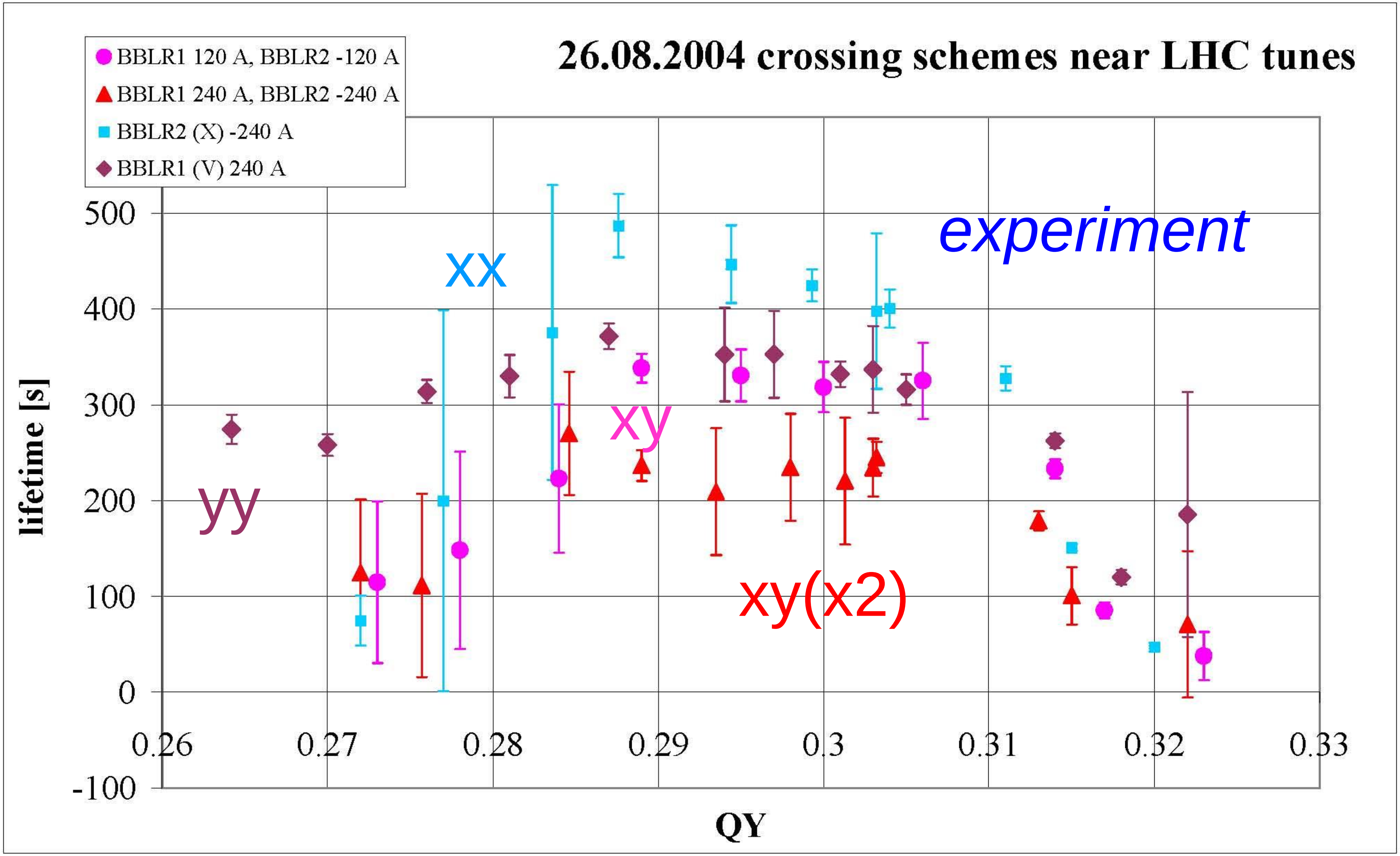
thanks to Yannis Papaphilippou for his help in calculating frequency maps!

crossing scheme test – configuration 1





simulated diffusive aperture for XX crossing is 10% larger than for 'quasi-XY' or 'quasi-YY' crossing



measured beam lifetime is best for XX crossing, second best for ‘quasi-YY’ crossing, lowest for ‘quasi-XY’ crossing

lifetime without wire excitation was comparable to *xy* case

crossing scheme test – configuration 2

BBLR1 (rotated) & BBLR2 (45 degrees)

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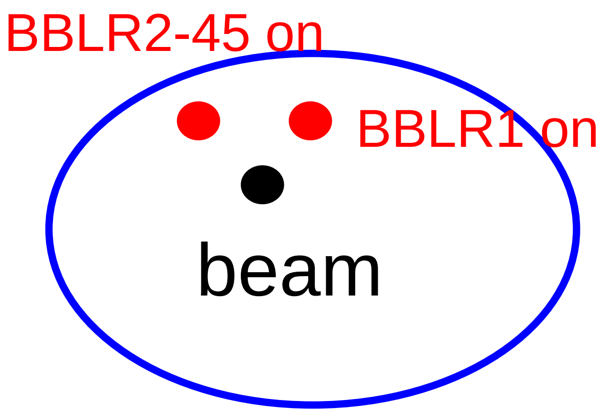
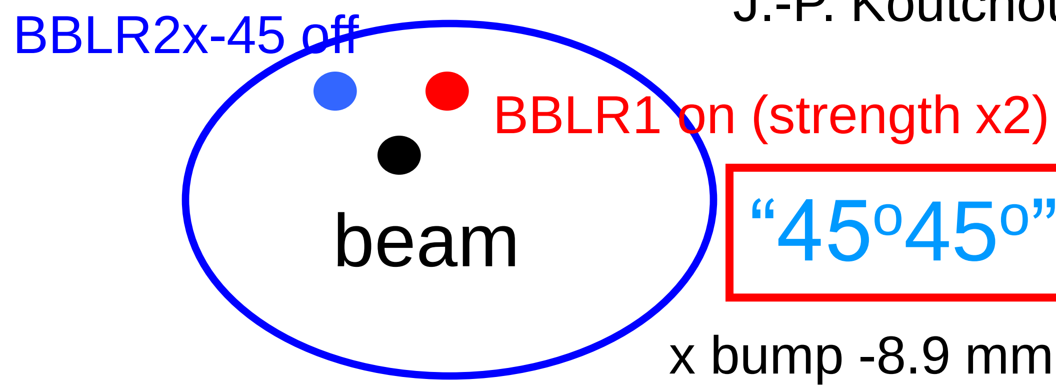


“45°135°”

x bump -8.9 mm

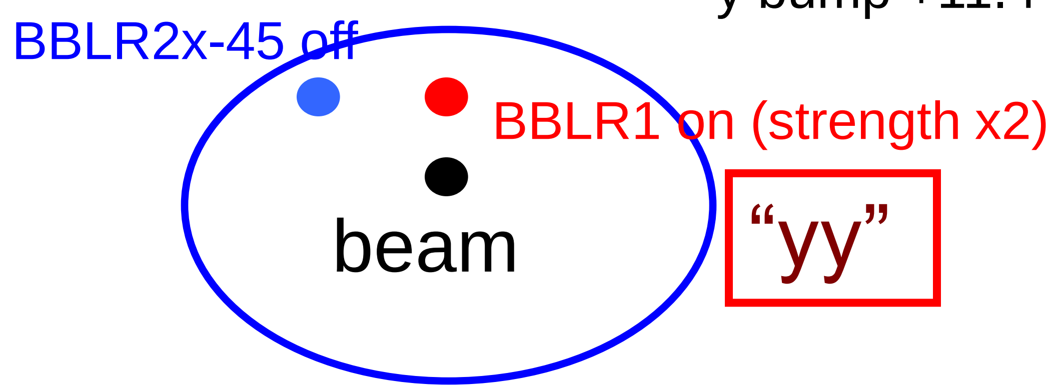
y bump +11.4 mm



“45°45°”

x bump -8.9 mm

y bump +11.4 mm

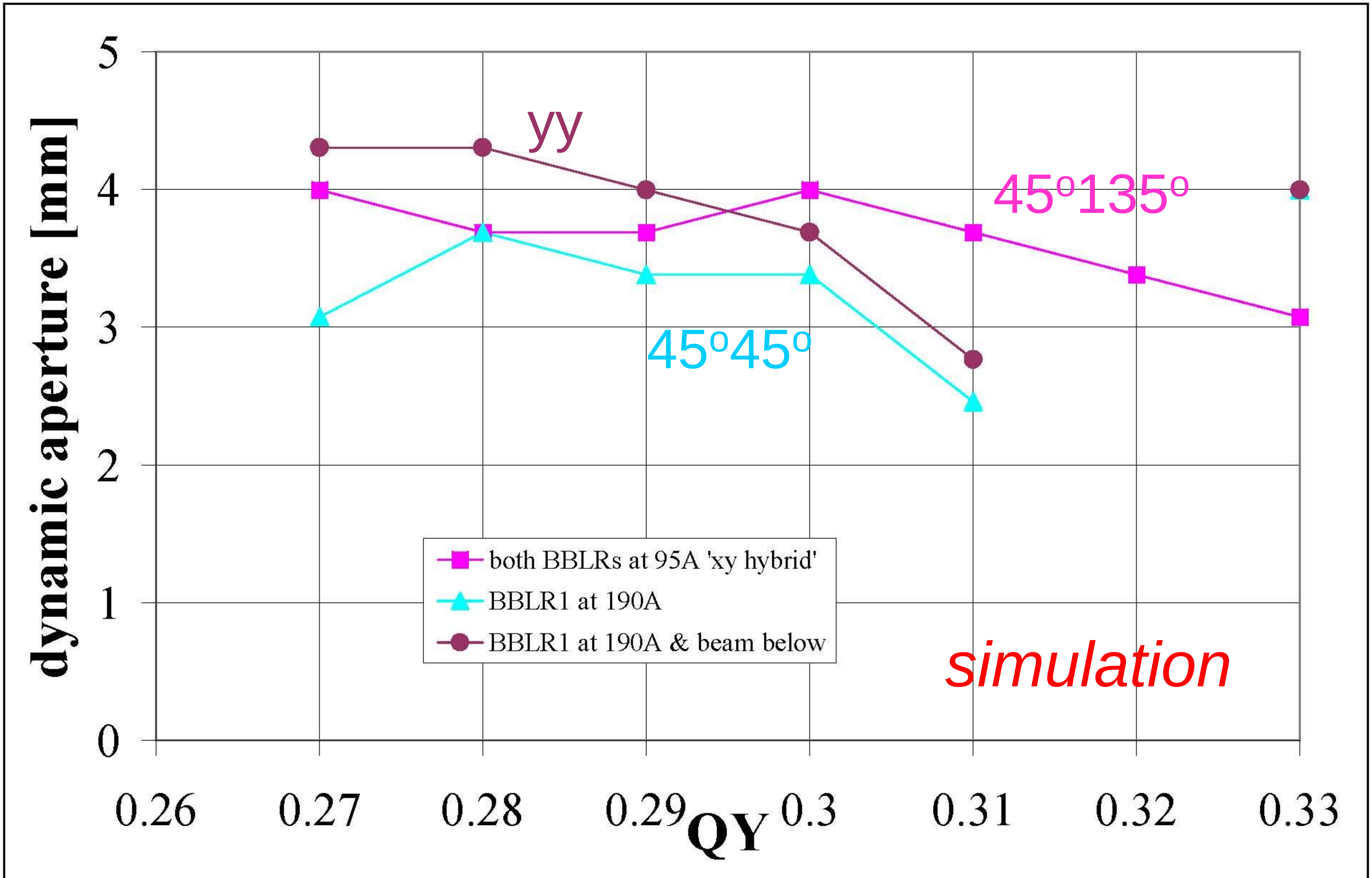


“yy”

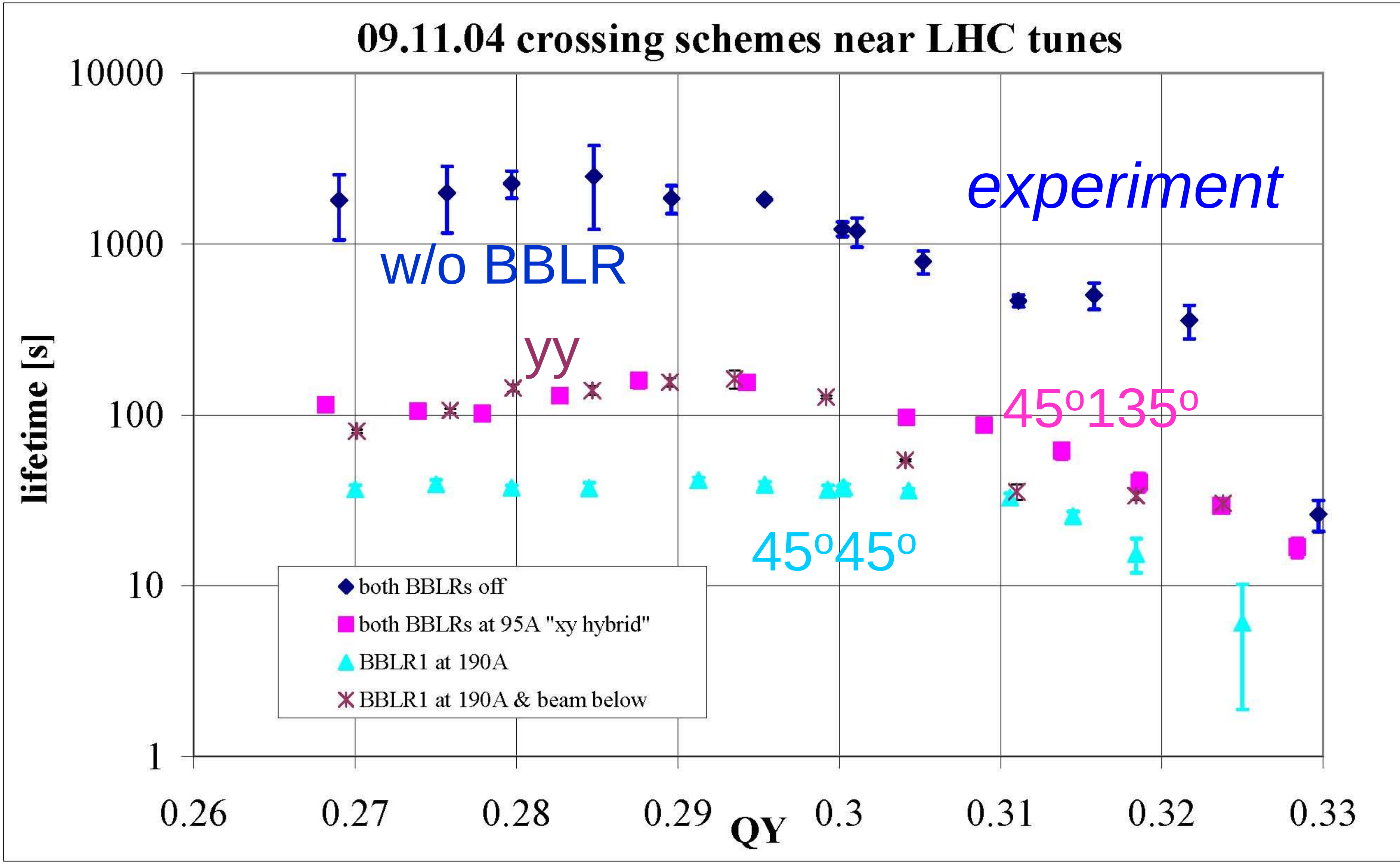
x bump 0 mm

y bump +8.5 mm

reduced emittance
“scaled” experiment



simulated diffusive aperture for '45º45º' crossing is worst; at tunes below 0.29 it is best for YY crossing & above 0.30 for '45º135º'



measured beam lifetime is worst for '45°45°' crossing, and at tunes above 0.3 best for '45°135°' crossing

relative beam lifetimes consistent with simulations