Simulating the wire compensation of LHC long-range beam-beam effects

T.L. Rijoff, F. Zimmermann

22 August 2012, Warnemunde

ICAP 2012

Outline

Introduction

- Objective
- Tools

Stability

- Why Lyapunov
- New Lyapunov criterion
- Check of goodness

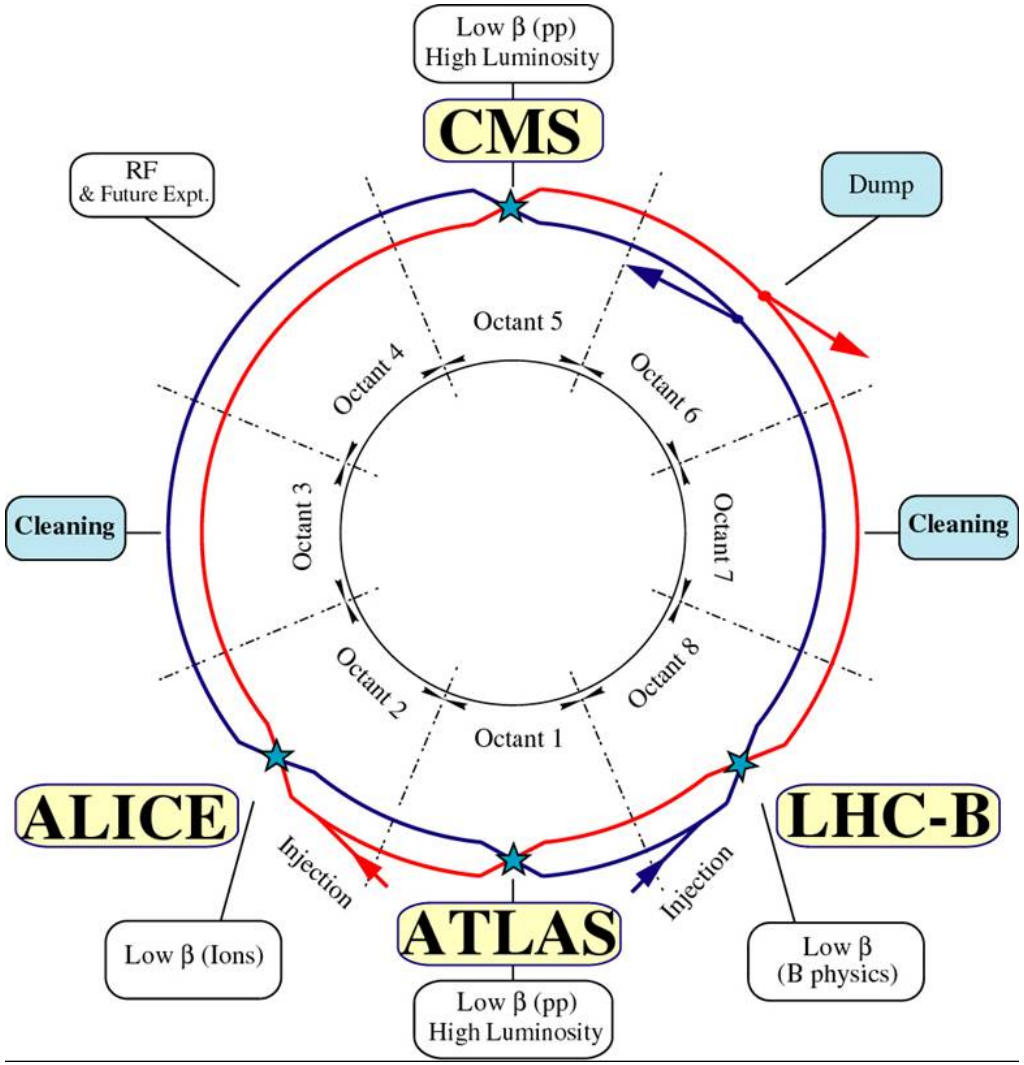
Tune

- Used Method
- Central tune moved back

Studied Cases

- Best Cases
- First Proposal
- Crossing angle Analysis
- Wire Shape

LHC



Ring of 27 Km
Two counterrotating beams
(p or Pb^{82})

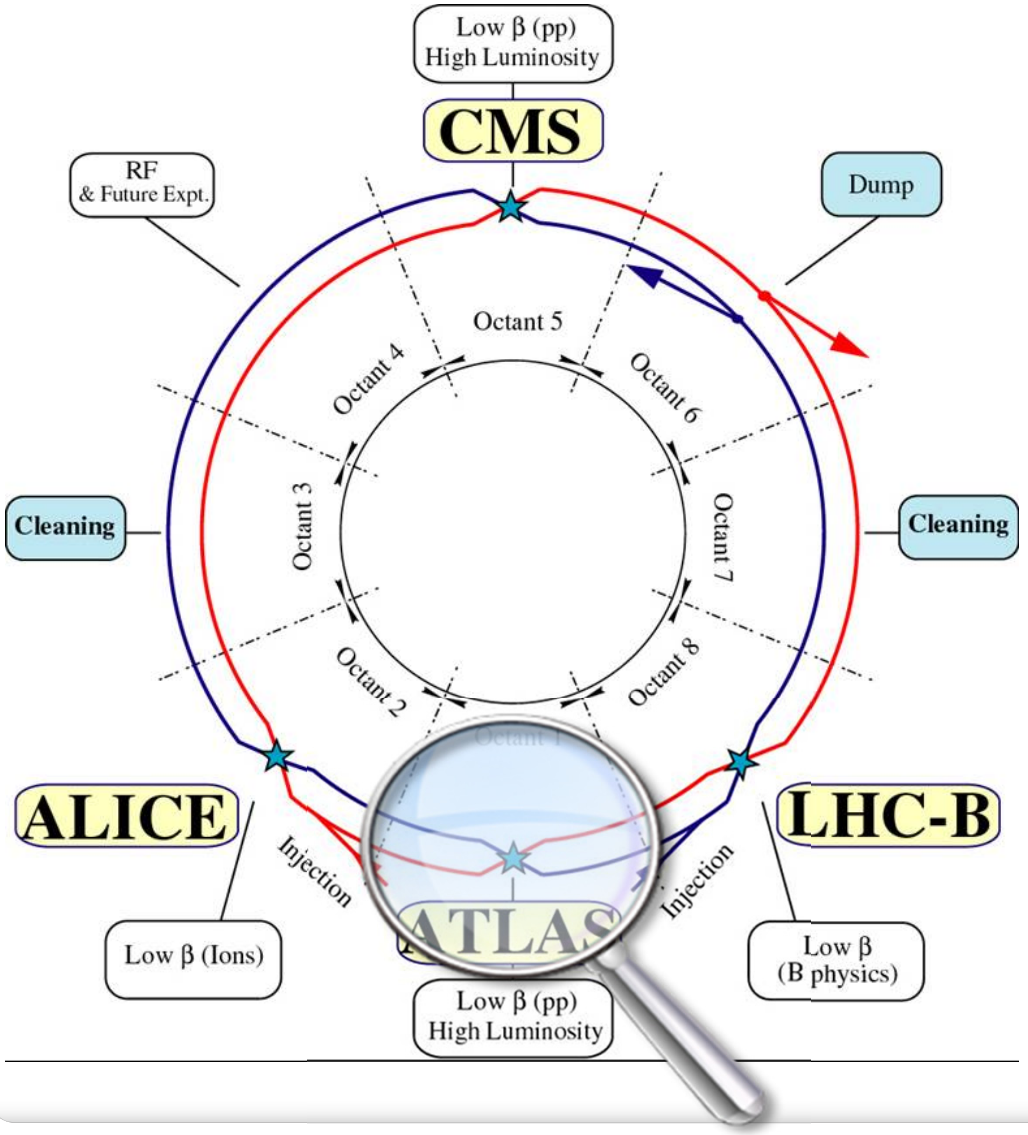
4 Interaction points (IP)

Main IP (interaction Point):
IP1 ATLAS (A Toroidal LHC Apparatus)
IP5 CMS (Compact Muon Solenoid)

Nominal Luminosity :
10^{34} cm^{-2} s^{-1}
(on 2012 0.6 10^{34} cm^{-2} s^{-1})

Nominal Energy :
7 TeV
(on 2012 4 TeV)

LHC



Ring of 27 Km
Two counterrotating beams
(p or Pb^{82})

4 Interaction points (IP)

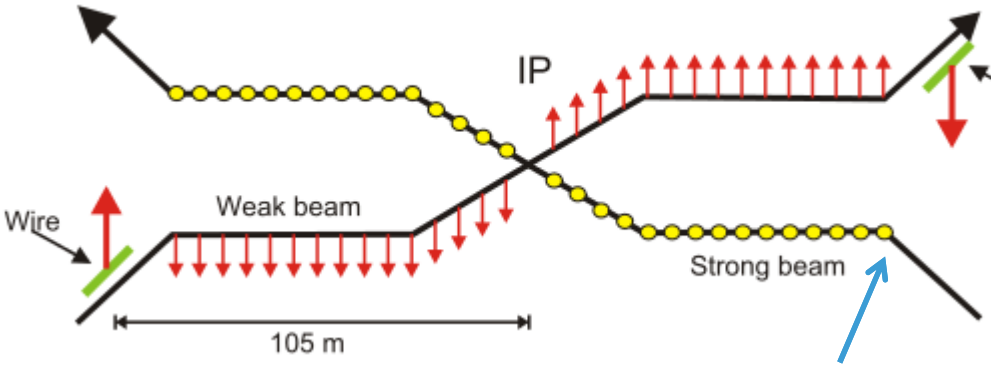
Main IP:
IP1 ATLAS (A Toroidal LHC Apparatus)
IP5 CMS (Compact Muon Solenoid)

Nominal Luminosity :
10^{34} cm^{-2} s^{-1}
(on 2012 0.6 10^{34} cm^{-2} s^{-1})

Nominal Energy :
7 TeV
(on 2012 4 TeV)

The wire compensator

Compensate long range beam beam with a wire

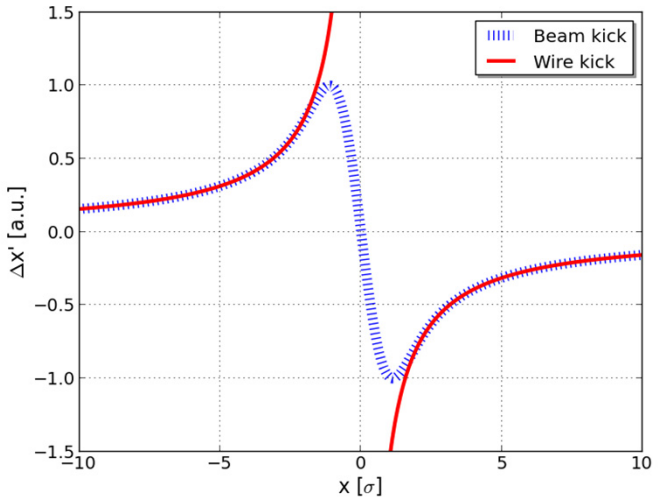


Nominal Cross = 9.5 σ

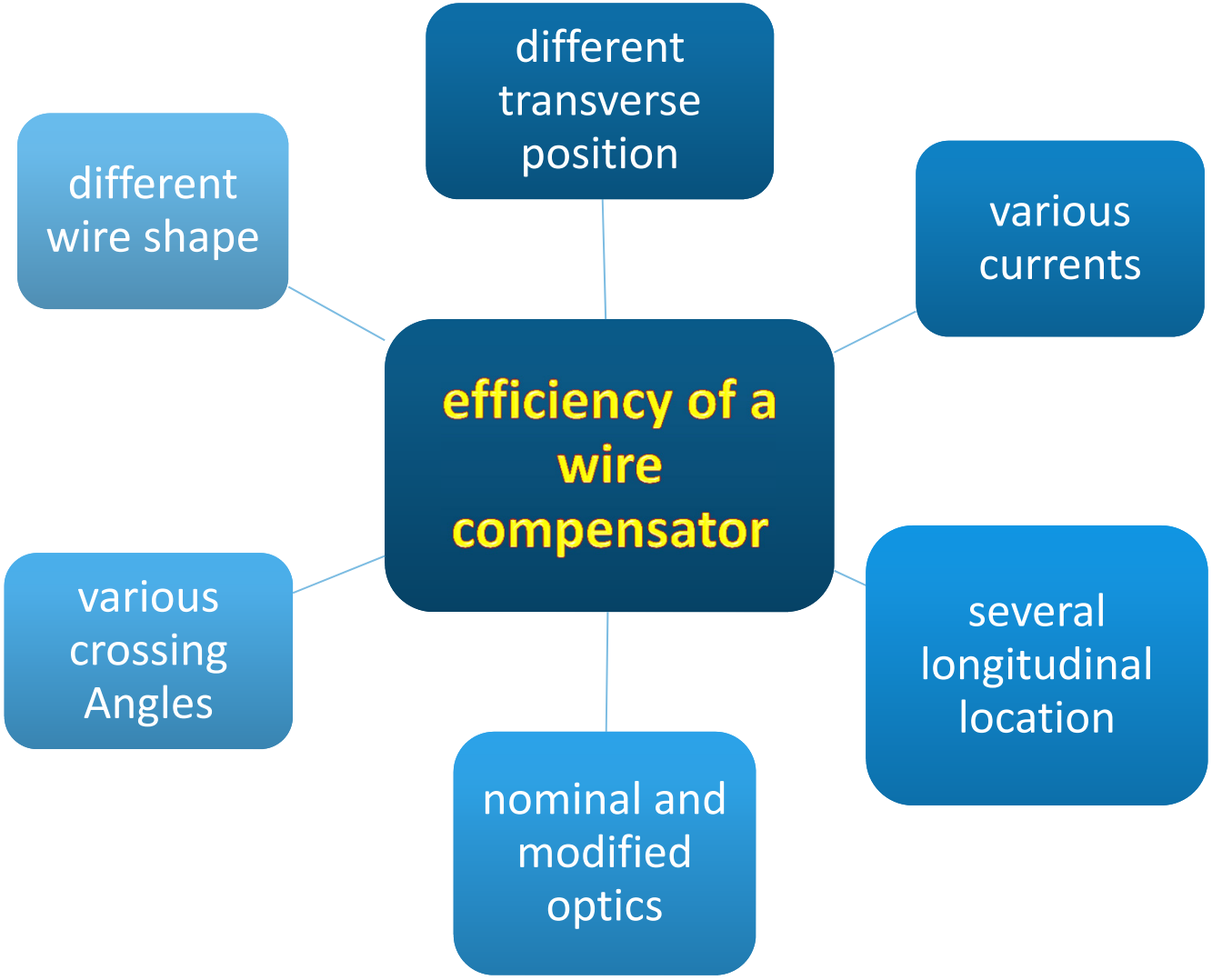
$\sigma_x = \sigma_y = 1.662 \quad 10^{-5}$

1.15 10^{11} protons

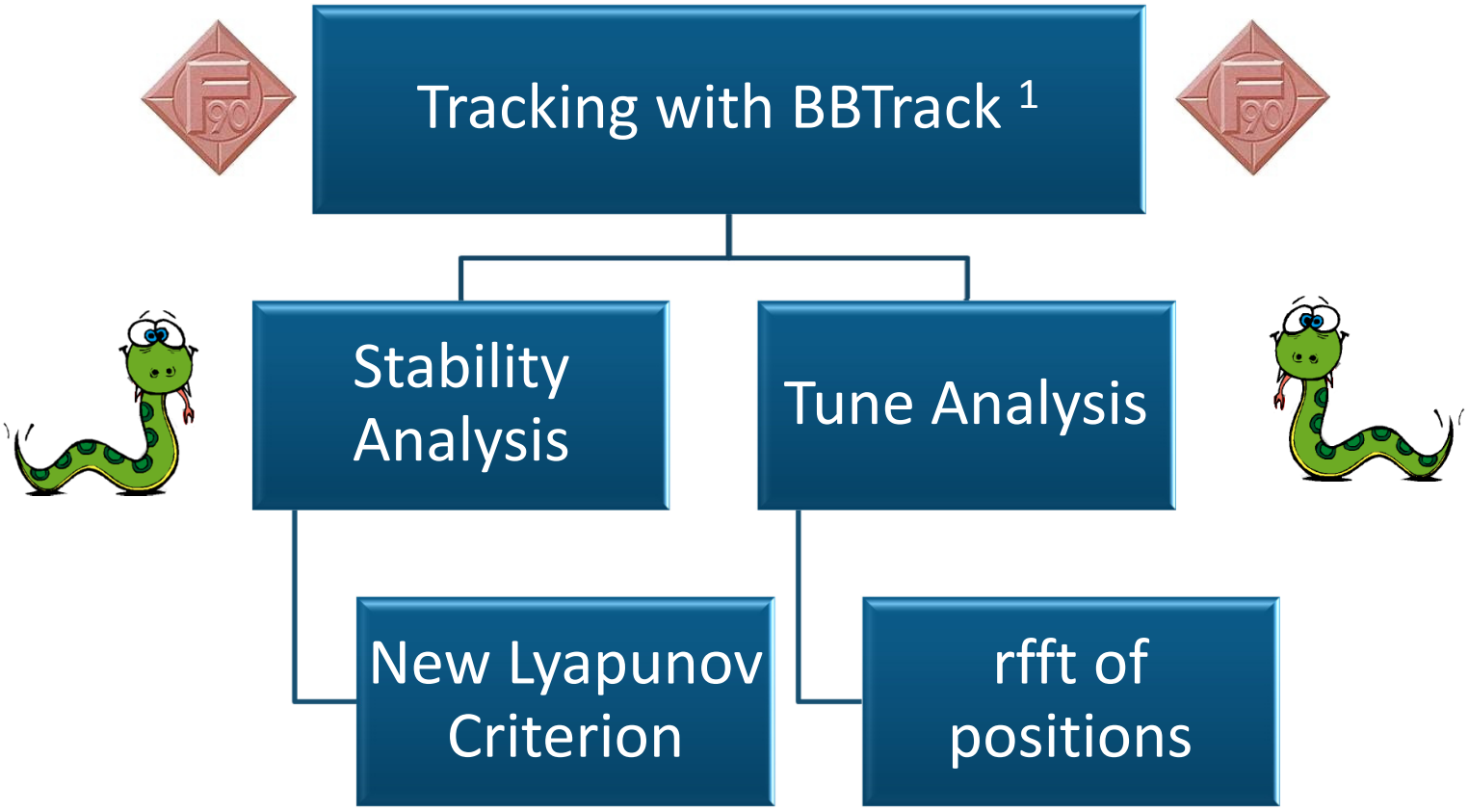
Motivation:



Objective

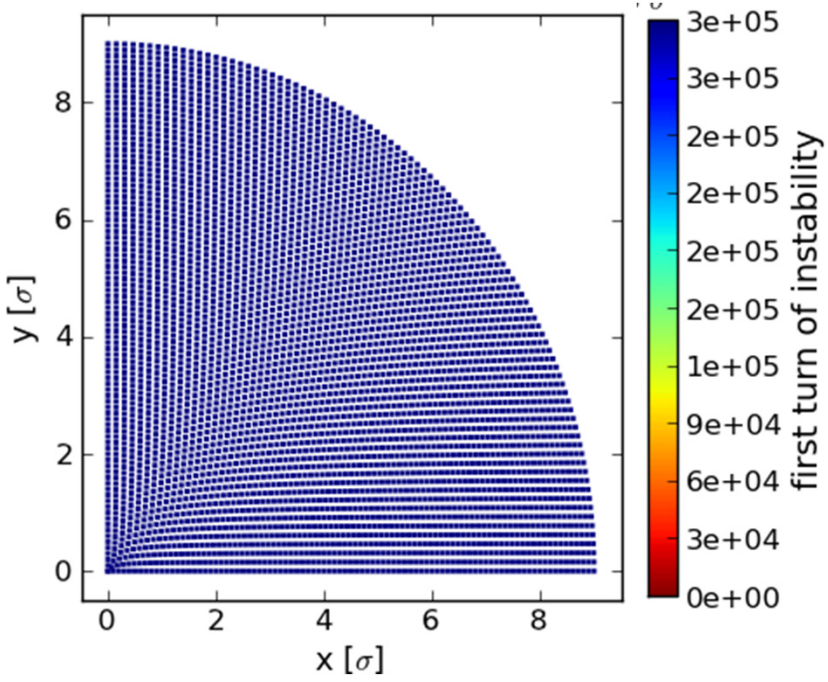


Tools



1) Fortran 90 code developed by U. Dorda

Stability Criterion



- More than 4000 particles with max radius [0,9] σ
- Tracked for at least 300.000 turns
- Particles set unstable when λ[j] > 2.8

λ[j] = Lyapunov coefficient at turn j

Lyapunov Criterion: Why?

Simulates particles exceeding a certain amplitude

Is not enough

1.000.0000 of turns → only **9 seconds**!!!

Lyapunov coefficient: rates of divergence of nearby trajectories in phase space

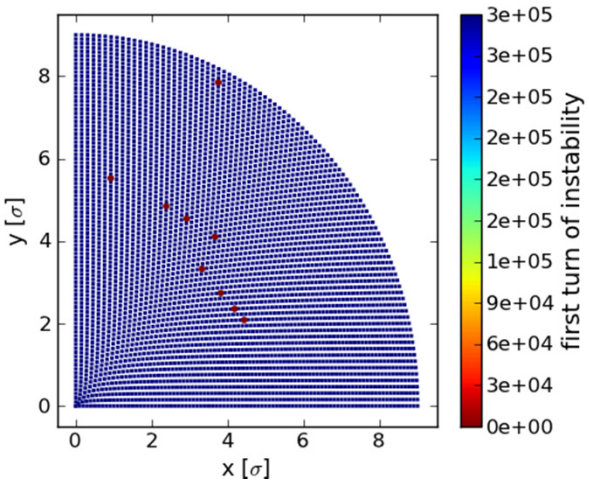
$$\lambda = \lim_{N\to\infty} \lim_{d(0)\to 0} \frac{1}{N} \log \frac{d(N)}{d(0)}$$

d(N) = distance between trajectories at turn N

Lyapunov Criterion: How?

Bbtrack Lyapunov formula

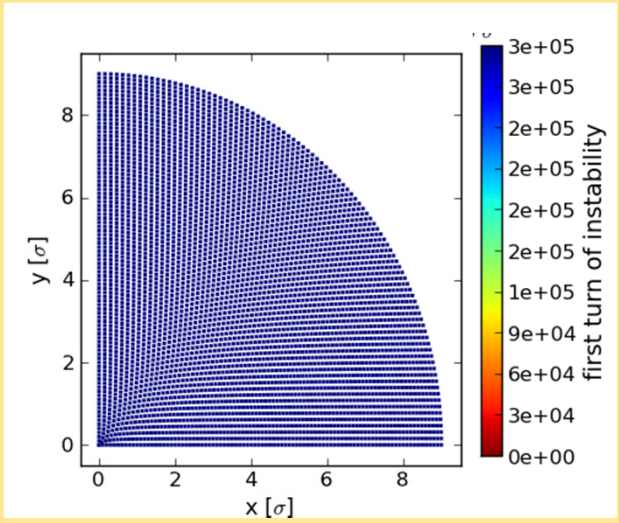
$$\lambda[j] = \frac{d_r(j) - d_r(0)}{2 d_r(j/2)} \geq K$$



Unstables with only HO??

Modified Lyapunov formula

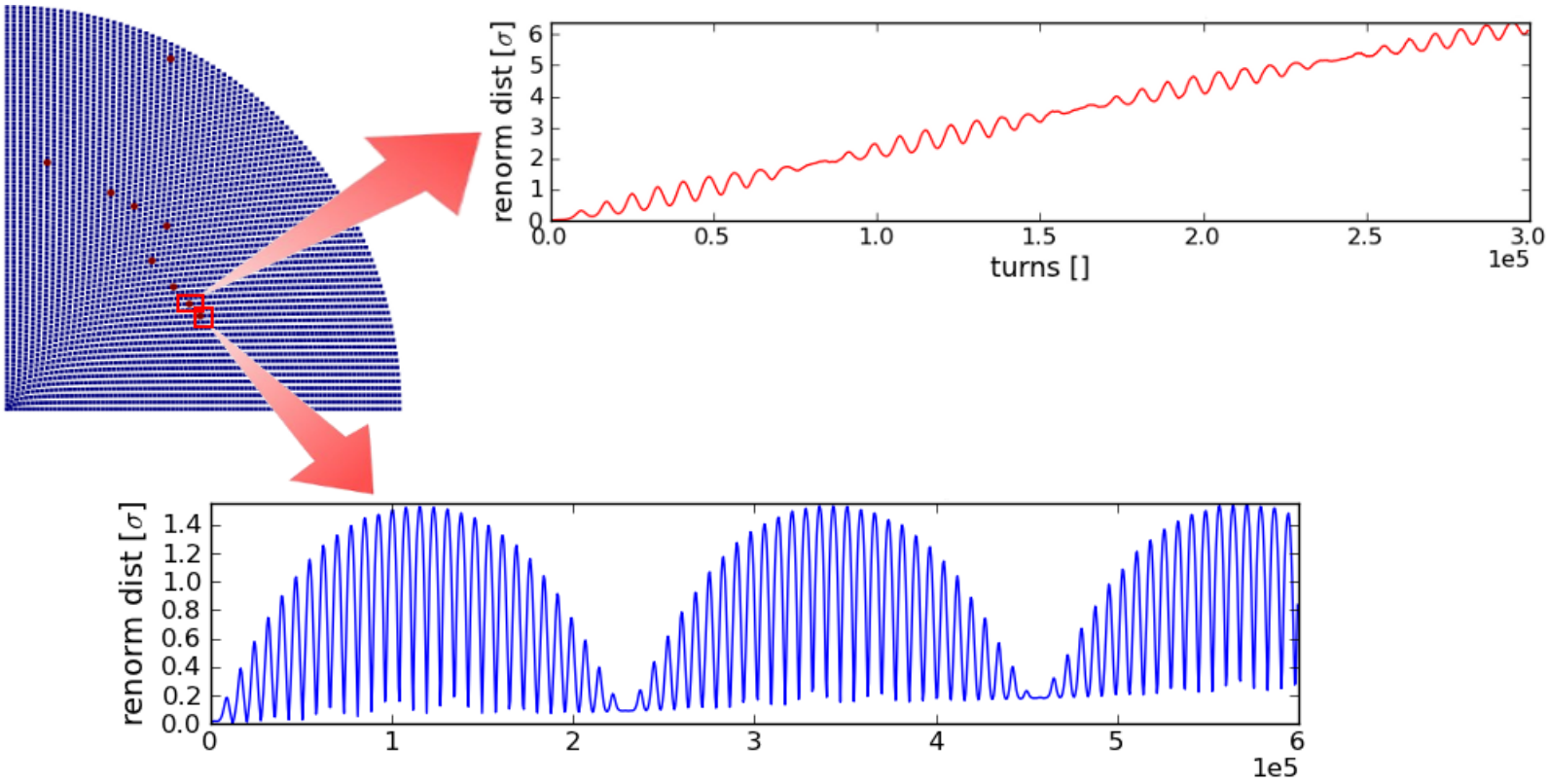
$$\lambda[j] = \frac{\left\langle d_r[\frac{j}{2} : j] \right\rangle - \left\langle d_r[0 : \frac{j}{2}] \right\rangle}{\left\langle d_r[\frac{j}{4} : \frac{3j}{4}] \right\rangle} \geq K$$



d_r = normalized distance in 4 dim

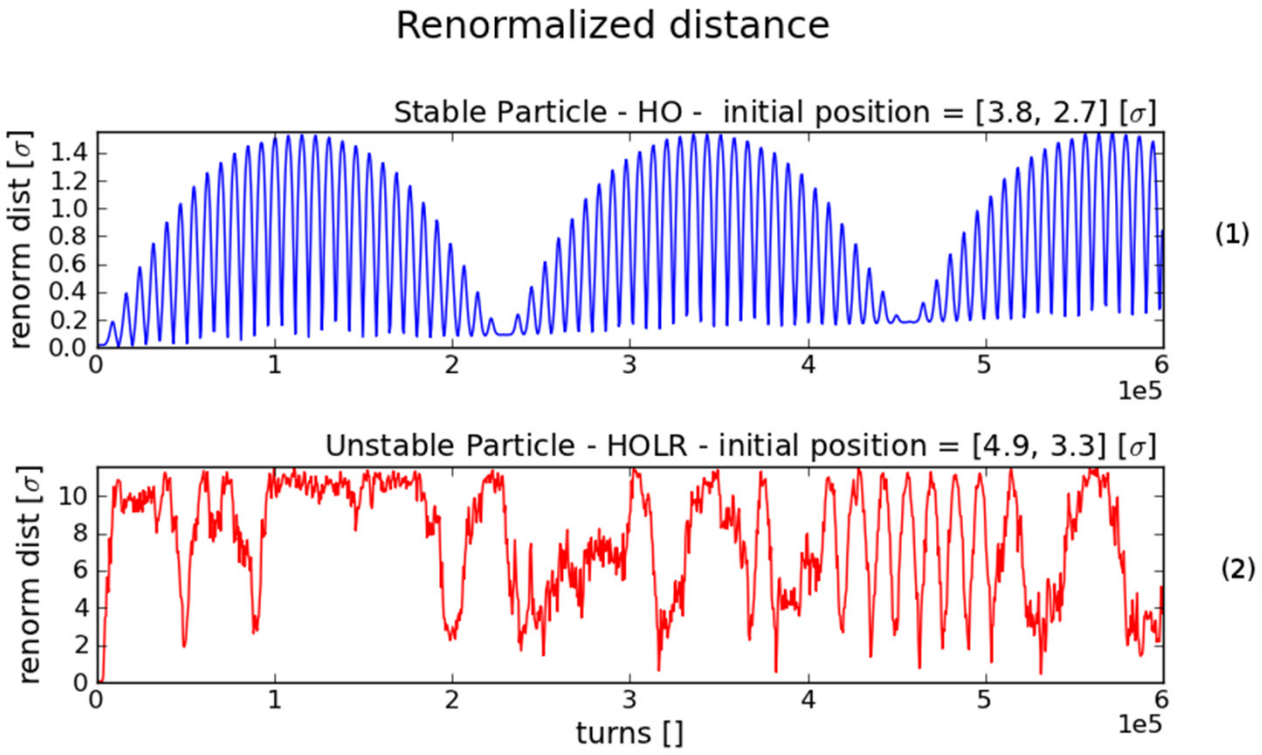
K = 2.8 in our tests

Lyapunov Criterion: Old Criterion



Stable particles marked as unstable

Lyapunov Criterion: Check

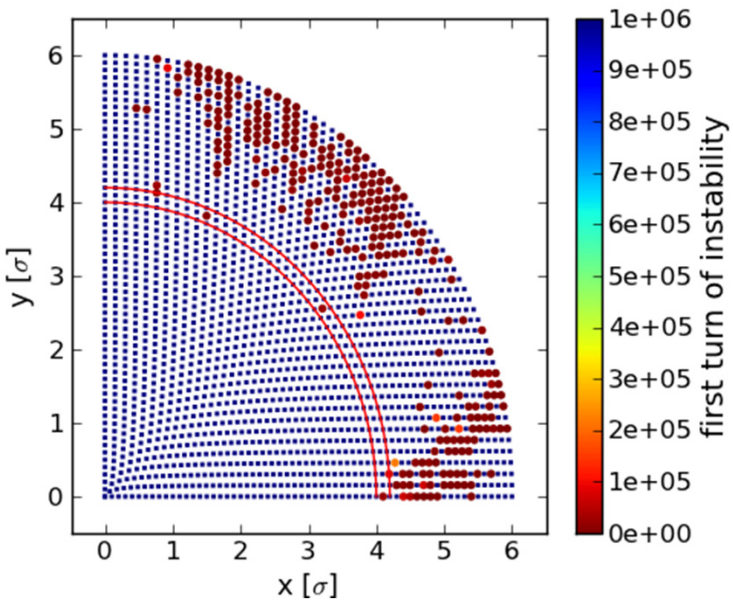


	Bbtrack Formula	Mod Formula
Particle 1	unstable	stable
Particle 2	unstable	unstable

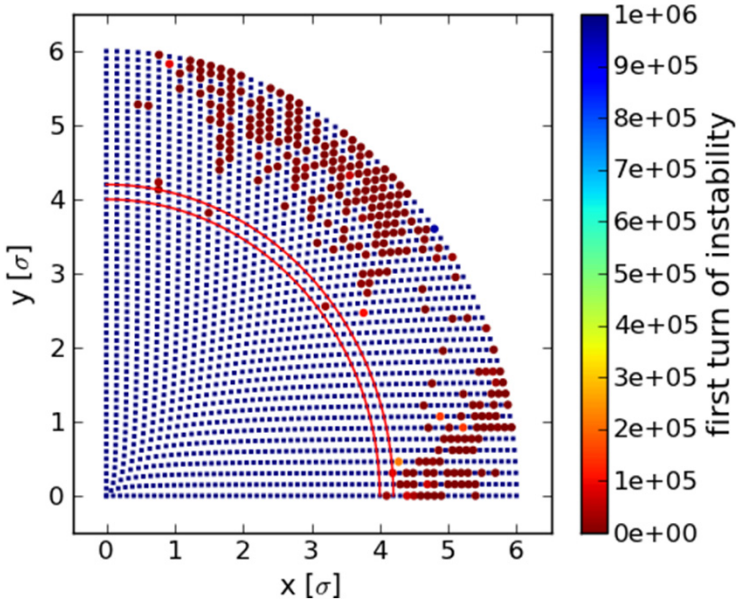
Lyapunov Criterion: Check

Head On + Long Range – crossing angle 6.3 σ

600.000 turns

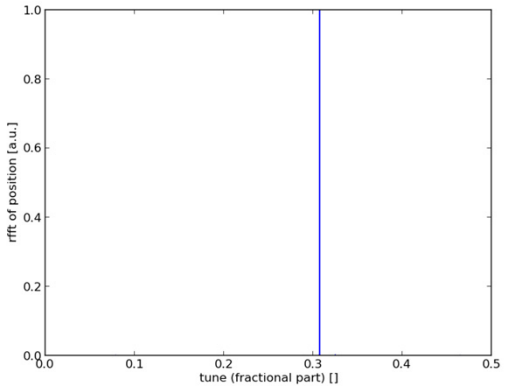


1.000.000 turns



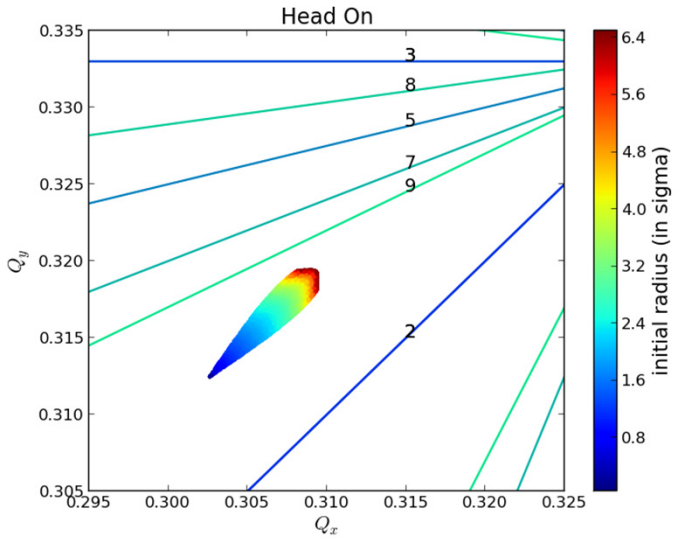
Criterion stable increasing the number of turns!

Tune Analysis

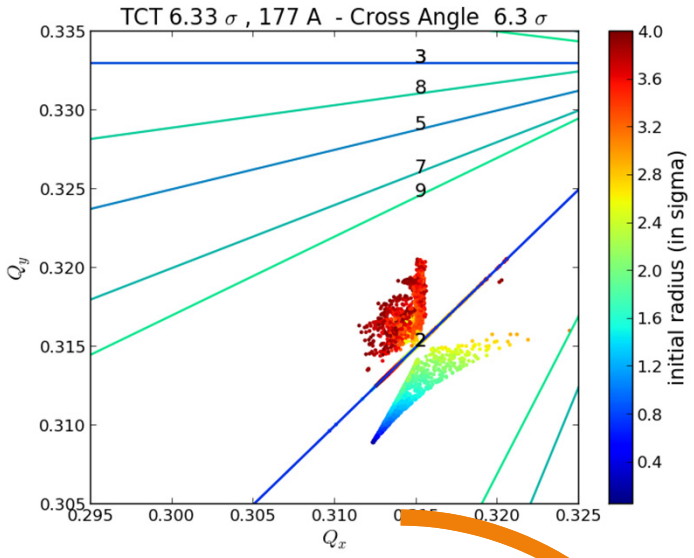


- Tracked 10.000 particles
- For each particles after 50.000 turns rfft of position

- Plot fractional tune and resonance lines order < 10
- Verify tune doesn't touch resonance line



Central Tune Moved back

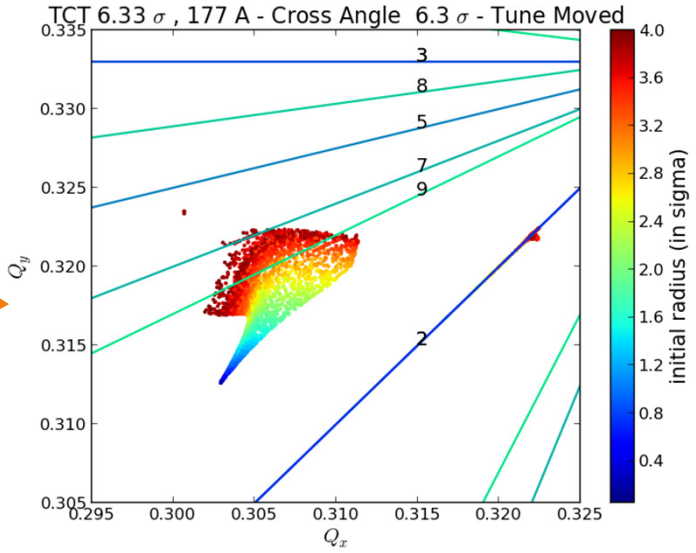


d_w = wire distance
r_0 = classical radius
I_w = wire current
L_w = wire length
β_u = betatron function

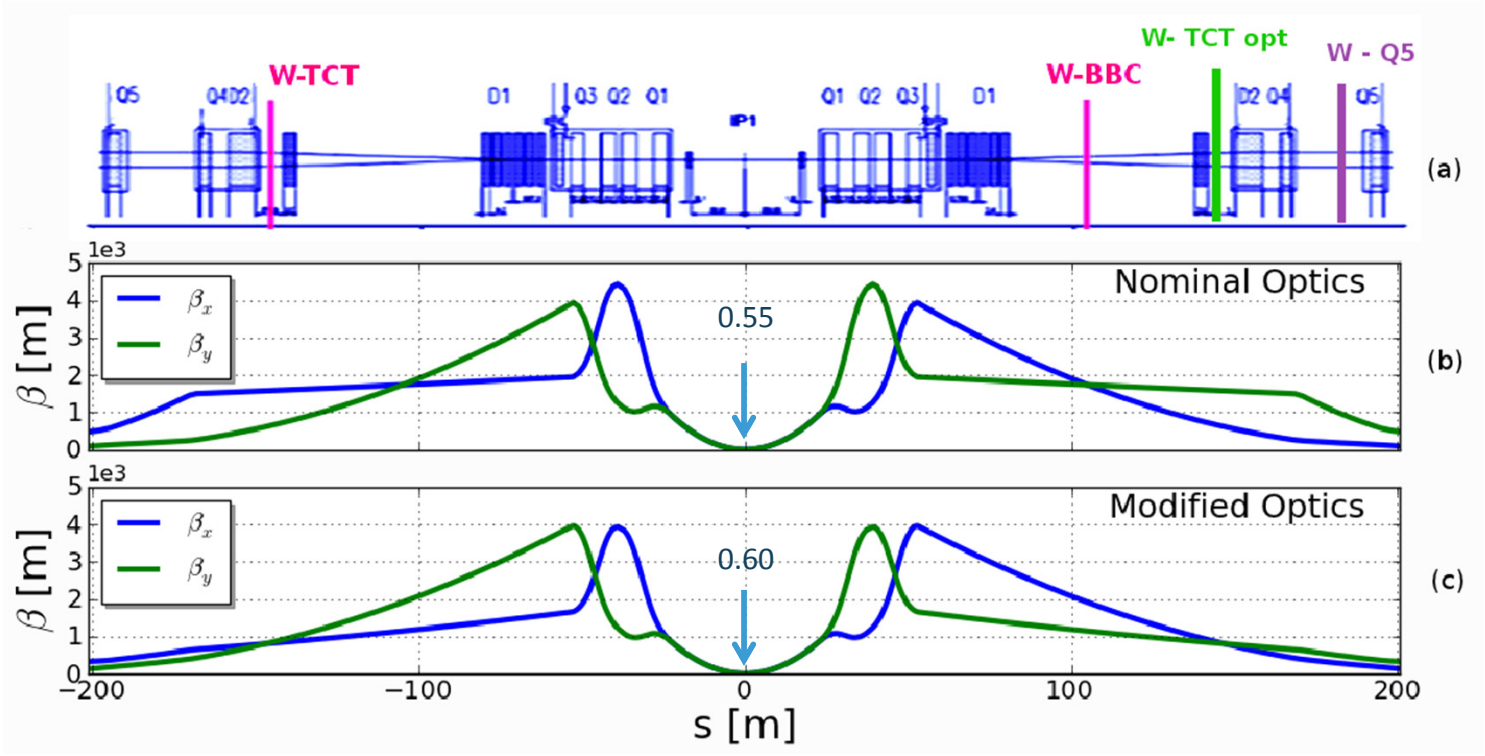
u = x, y

$$\Delta Q_u = \mp \frac{r_0 I_w L_w \beta_u}{2\pi\gamma e c d_w^2}$$

'-' in the crossing plane

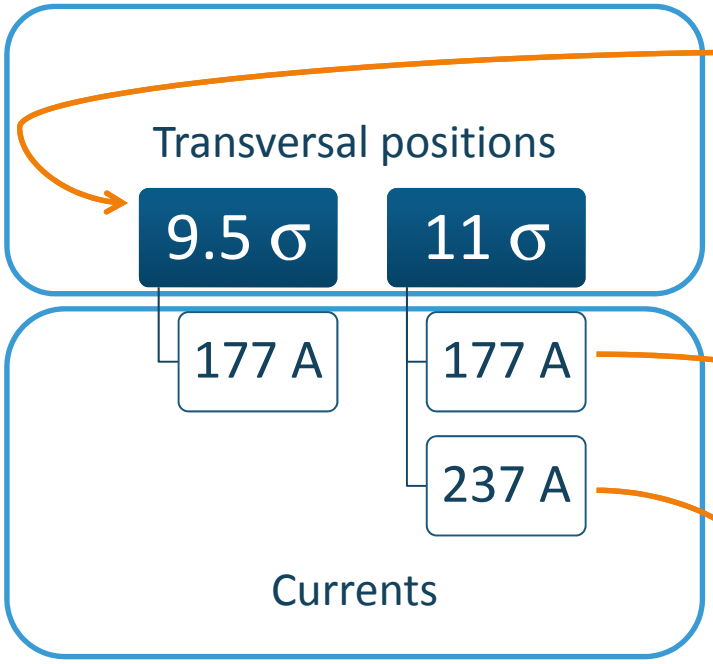


Analyzed cases



Wire position	BBC	TCT	Q5	TCT opt β_1	TCT opt β_2
from IP1 [m]	105	-147	199	147	-147
from IP5 [m]	105	-147	199	-147	147

Analyzed cases

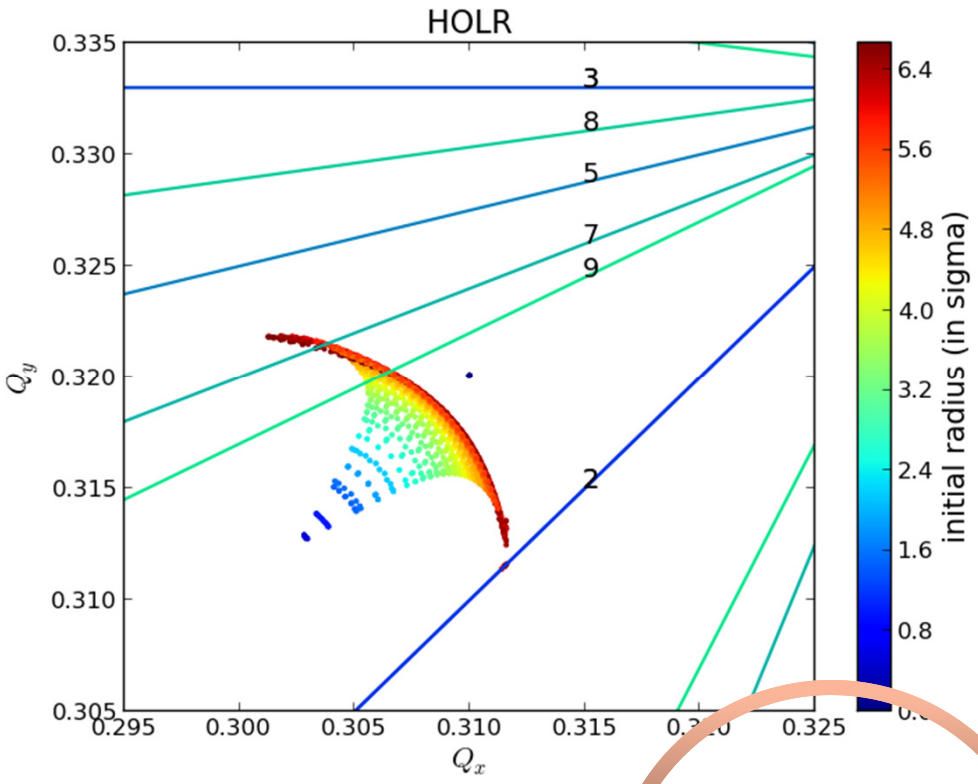


Average long range beam-beam distance

$$I_{opt} = \frac{n_{LR} c e N_b}{L_w}$$

$$I_{d_2} = I_{d_1} \left(\frac{d_2}{d_1} \right)^2$$

Transversal position analysis



- Small compensation

θ > 11 σ

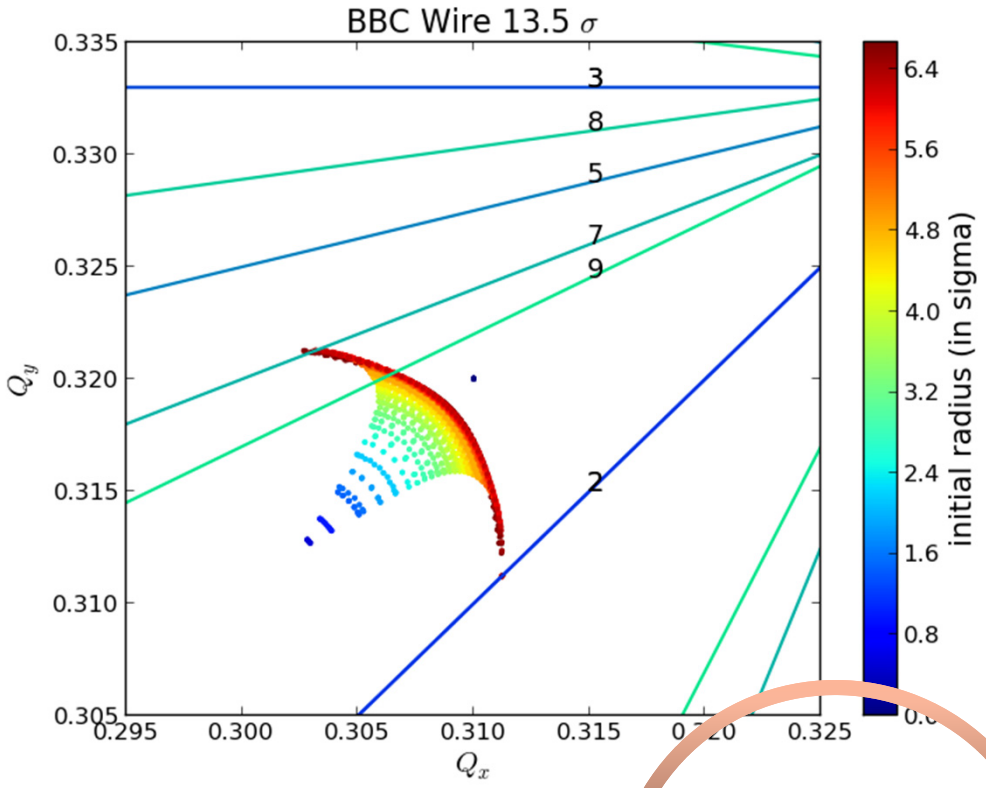
θ = 9.5 σ

- Best compensation

- Dangerous effects

θ < 9 σ

Transversal position analysis



- Small compensation

θ > 11 σ

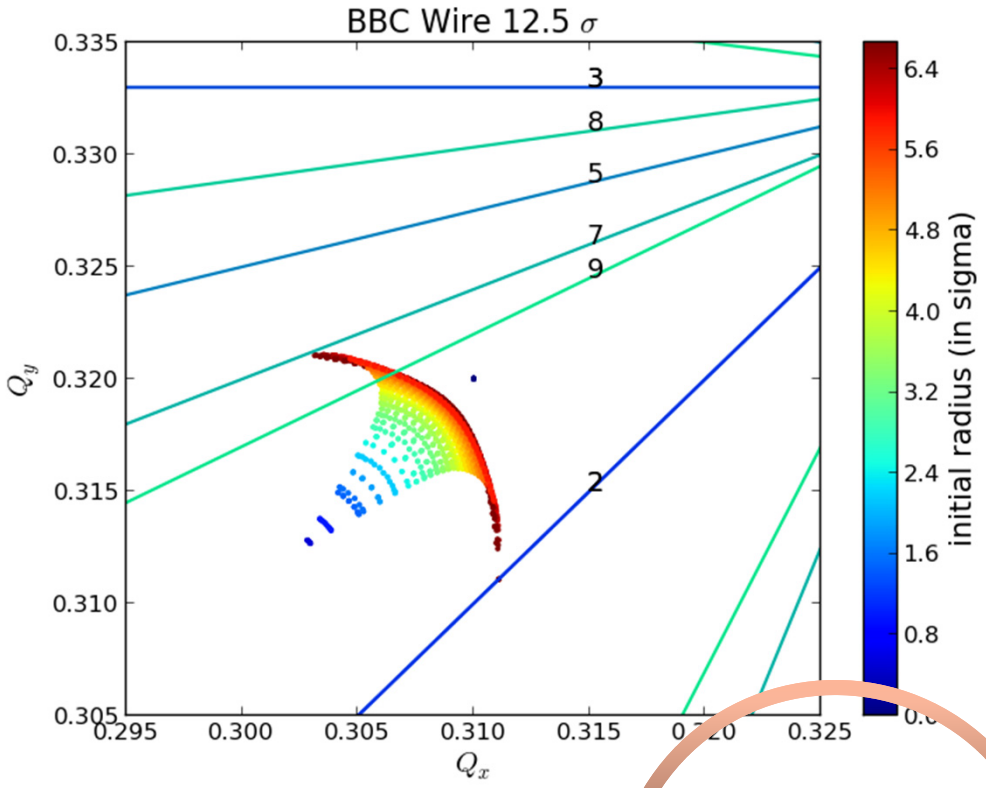
θ = 9.5 σ

- Best compensation

- Dangerous effects

θ < 9 σ

Transversal position analysis



- Small compensation

θ > 11 σ

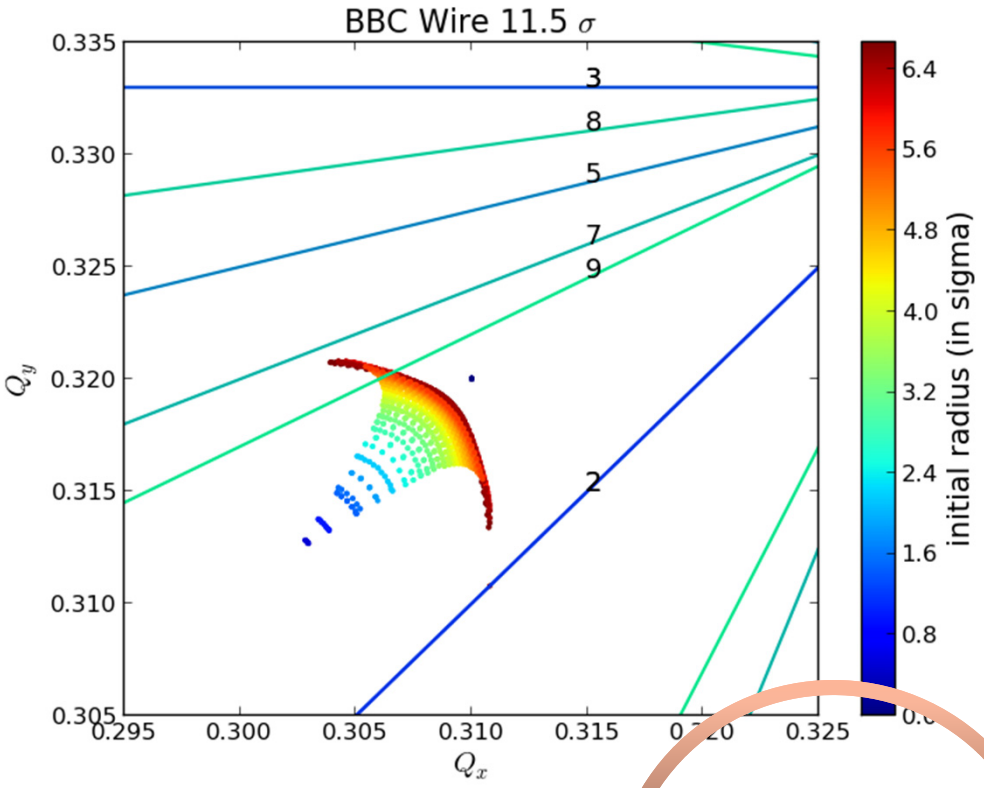
θ = 9.5 σ

- Best compensation

- Dangerous effects

θ < 9 σ

Transversal position analysis



- Small compensation

θ > 11 σ

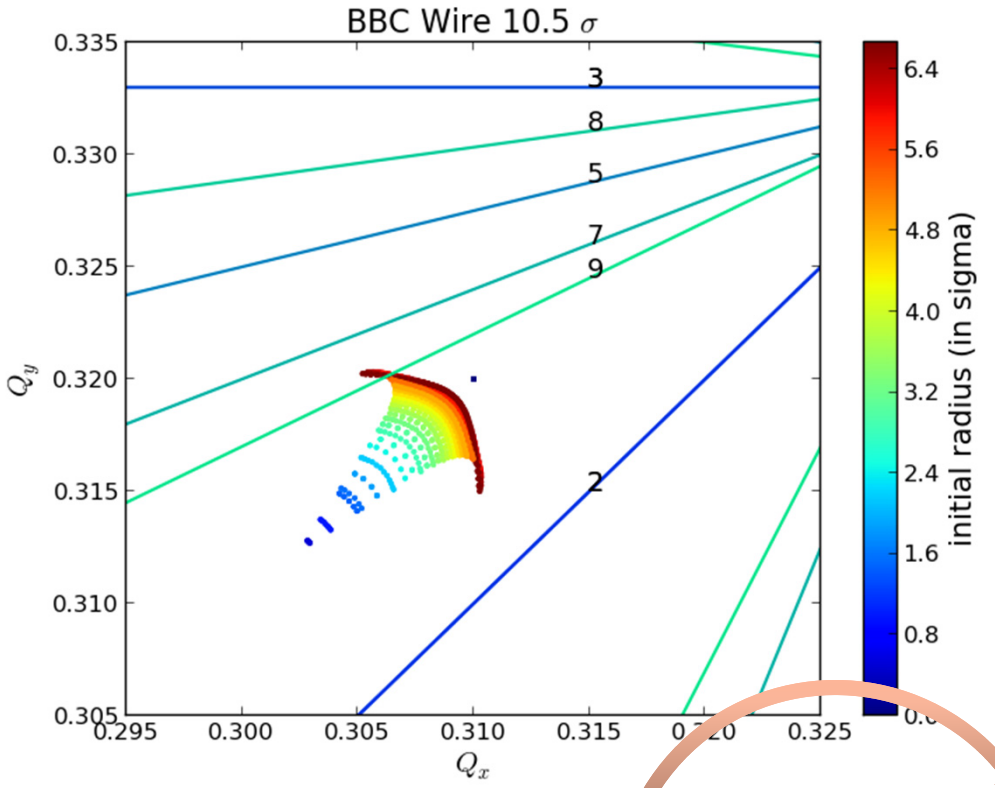
θ = 9.5 σ

- Best compensation

- Dangerous effects

θ < 9 σ

Transversal position analysis



- Small compensation

θ > 11 σ

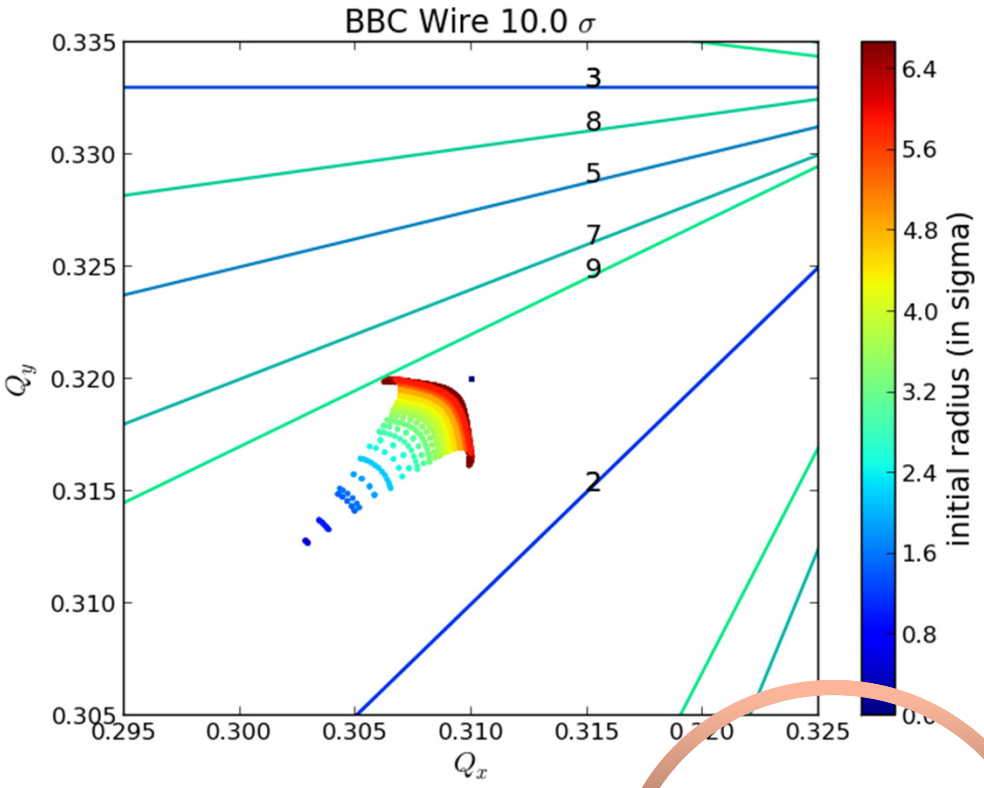
θ = 9.5 σ

- Best compensation

- Dangerous effects

θ < 9 σ

Transversal position analysis



- Small compensation

θ > 11 σ

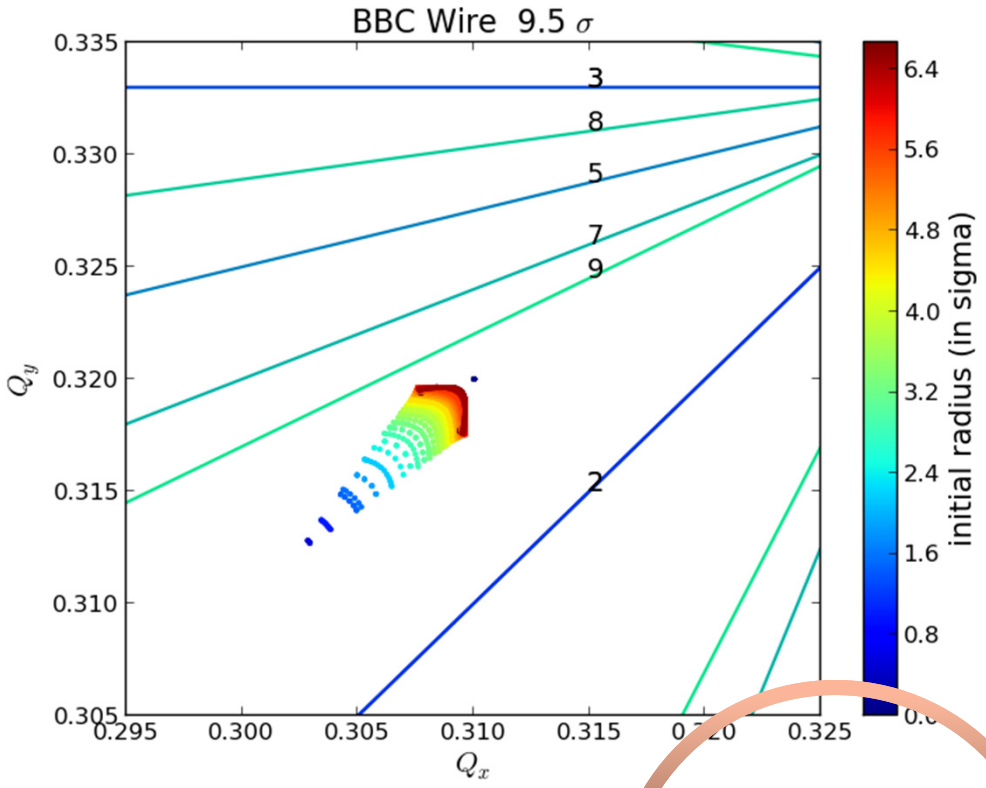
θ = 9.5 σ

- Best compensation

- Dangerous effects

θ < 9 σ

Transversal position analysis



- Small compensation

θ > 11 σ

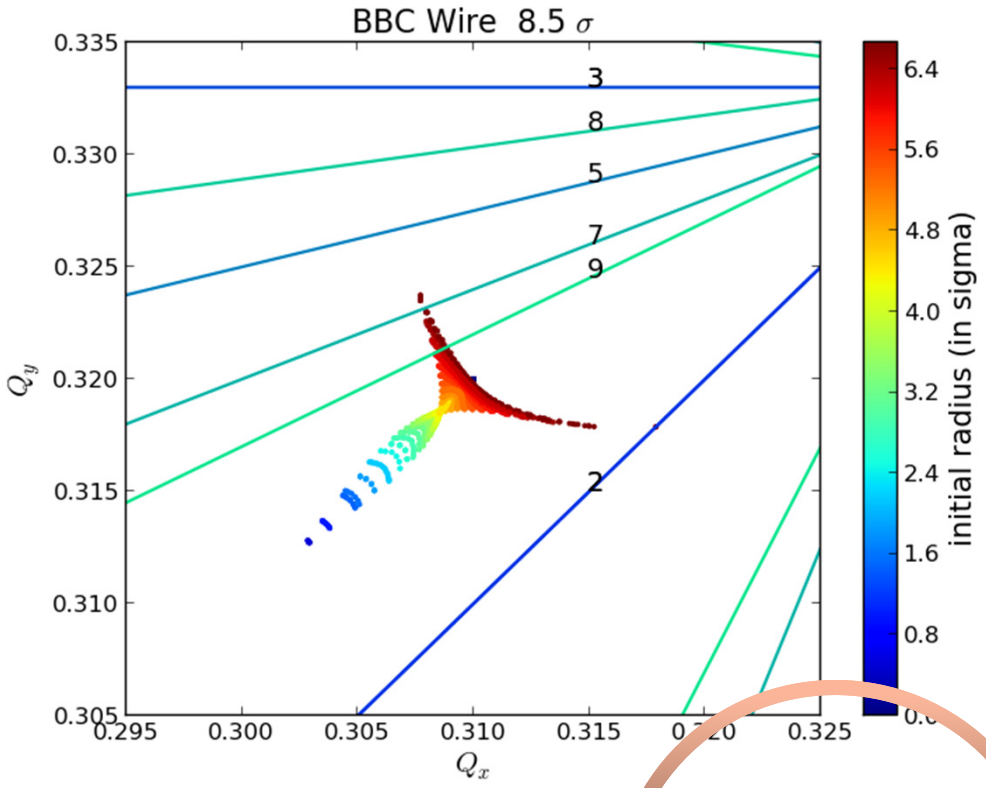
θ = 9.5 σ

- Best compensation

- Dangerous effects

θ < 9 σ

Transversal position analysis



- Small compensation

θ > 11 σ

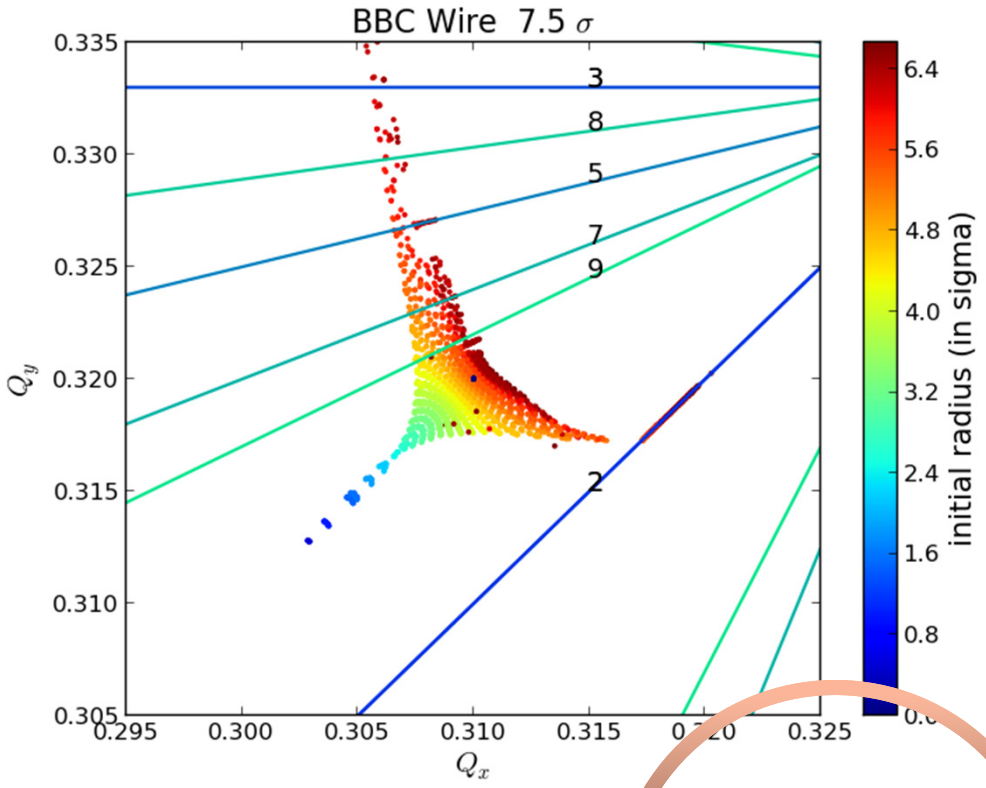
θ = 9.5 σ

- Best compensation

- Dangerous effects

θ < 9 σ

Transversal position analysis



θ = 9.5 σ

- Best compensation

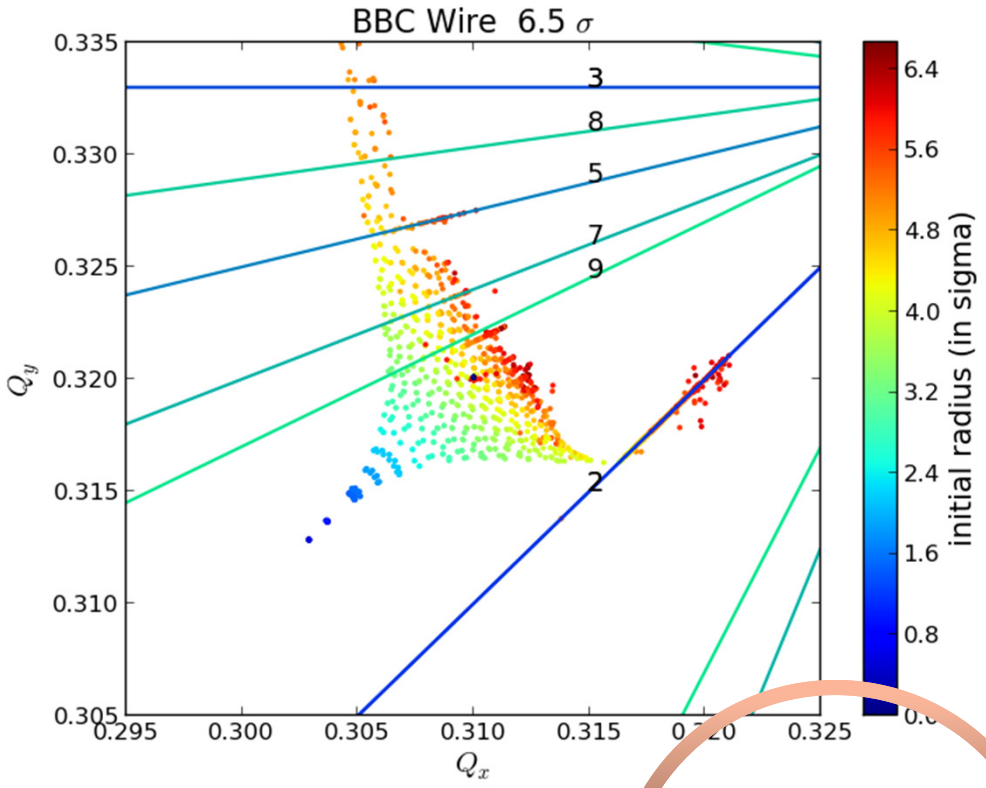
θ > 11 σ

- Small compensation

θ < 9 σ

- Dangerous effects

Transversal position analysis



- Small compensation

θ > 11 σ

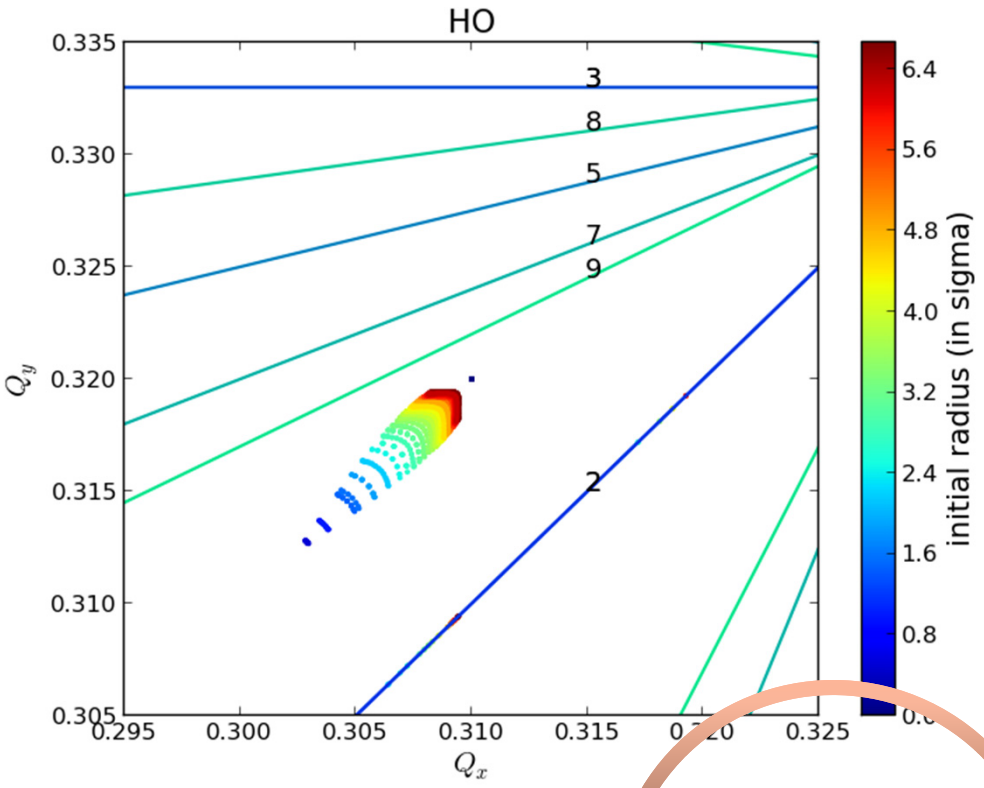
θ = 9.5 σ

- Best compensation

- Dangerous effects

θ < 9 σ

Current analysis



- No resonance touched

I > 130 A

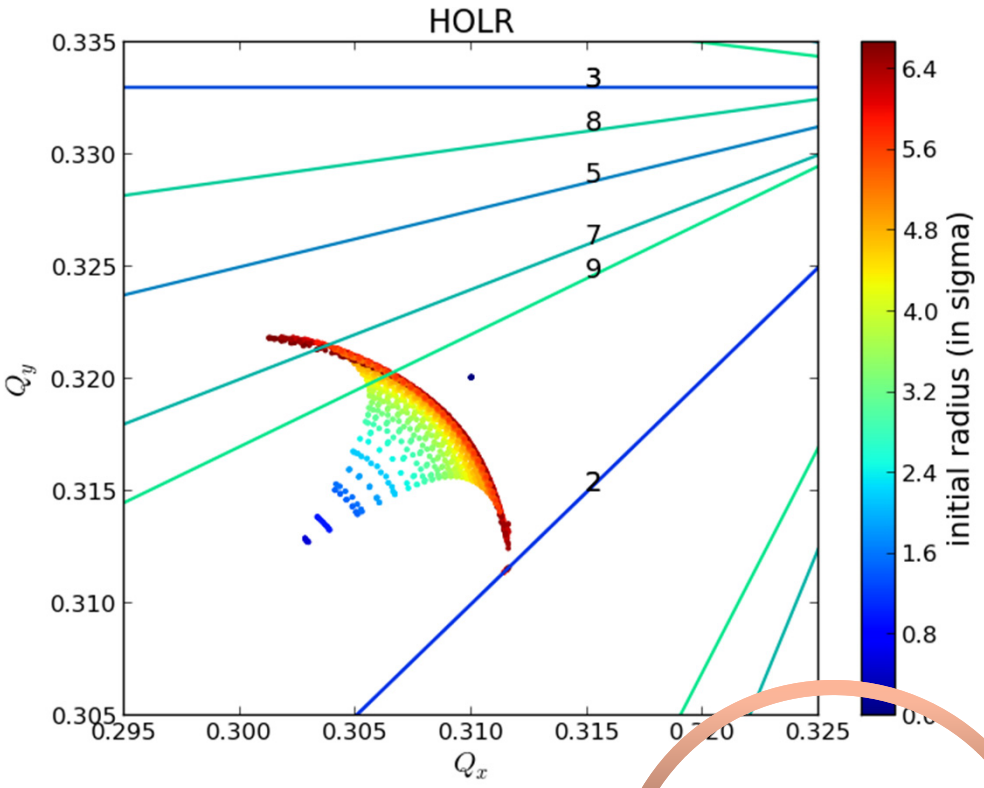
I = 177 A

- Almost equal HO

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

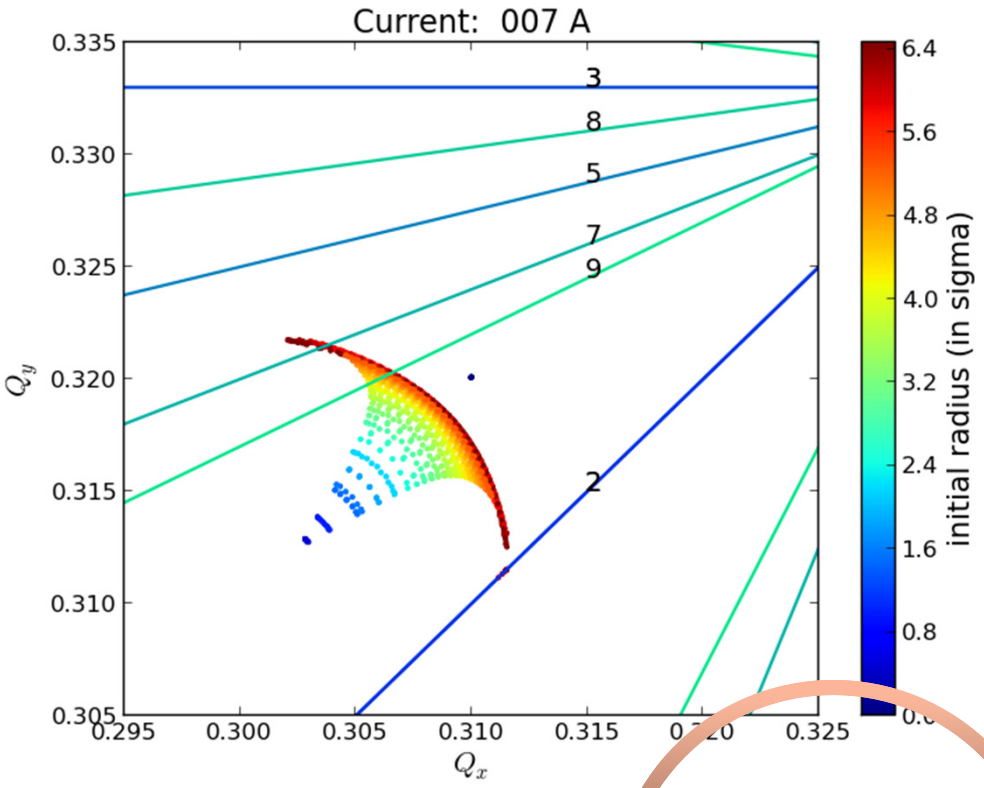
I = 177 A

- Almost equal HO

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

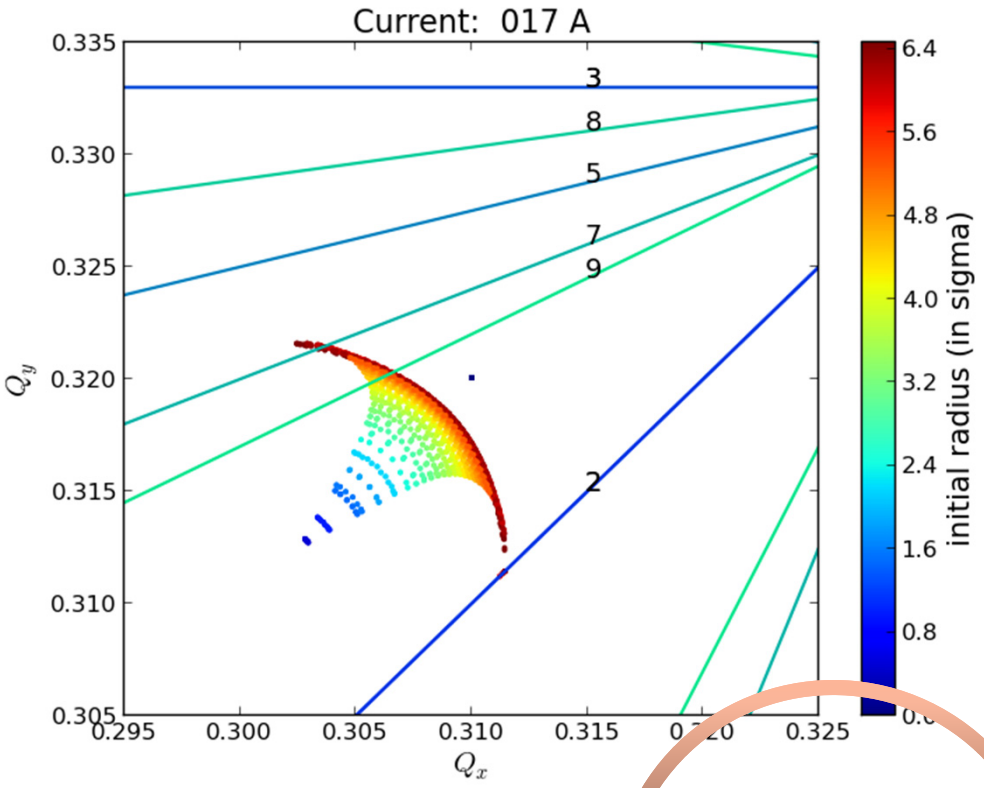
I = 177 A

- Almost equal HO

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

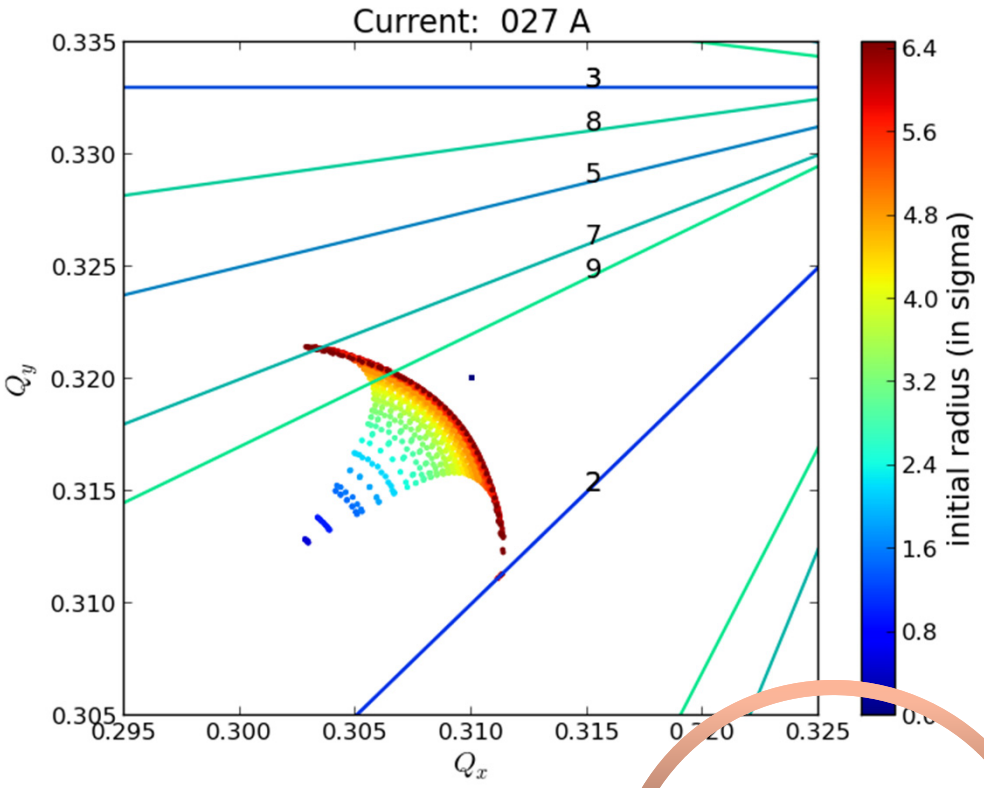
I = 177 A

- Almost equal HO

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

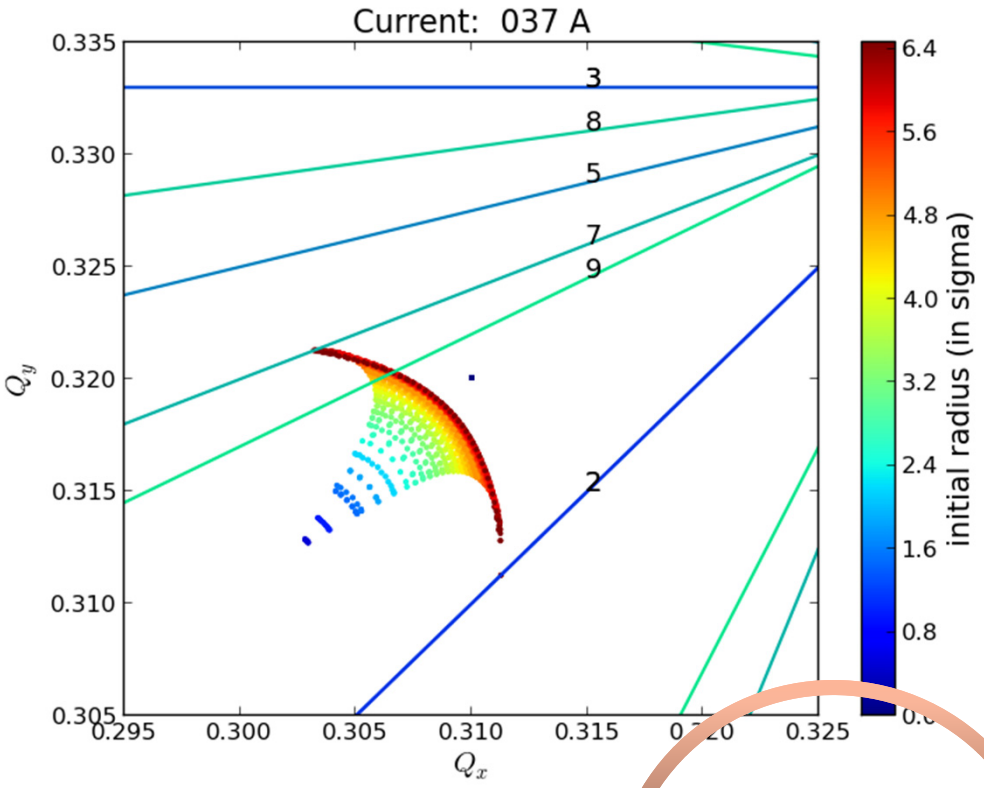
I = 177 A

- Almost equal HO

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

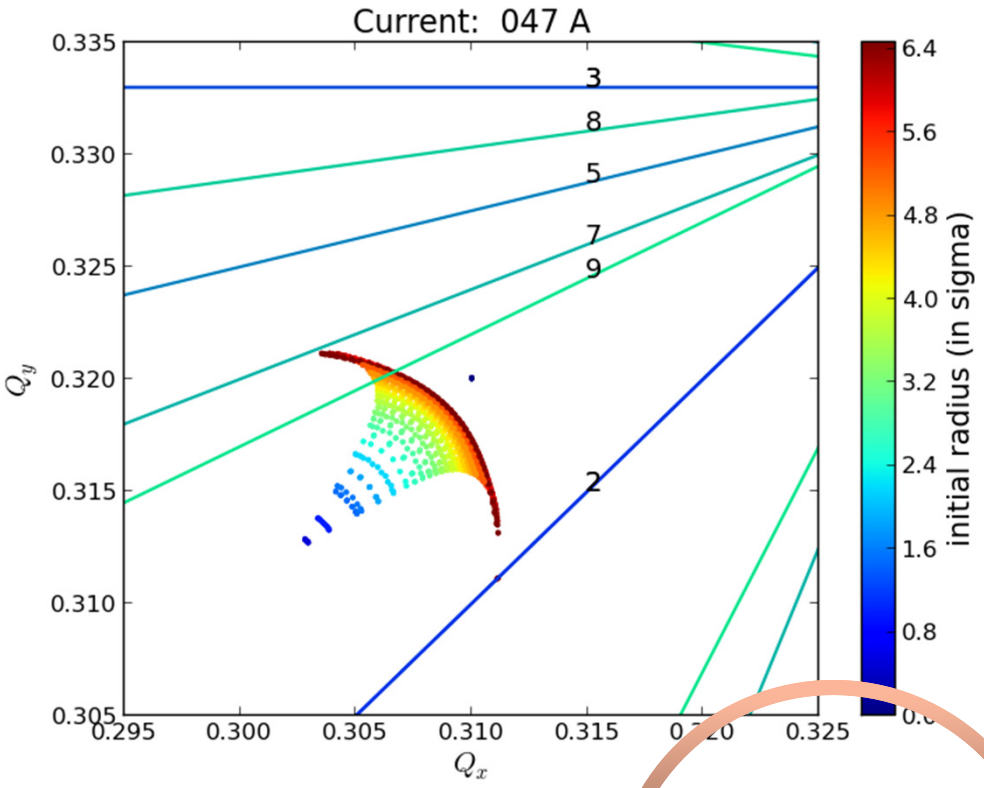
I = 177 A

- Almost equal HO

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

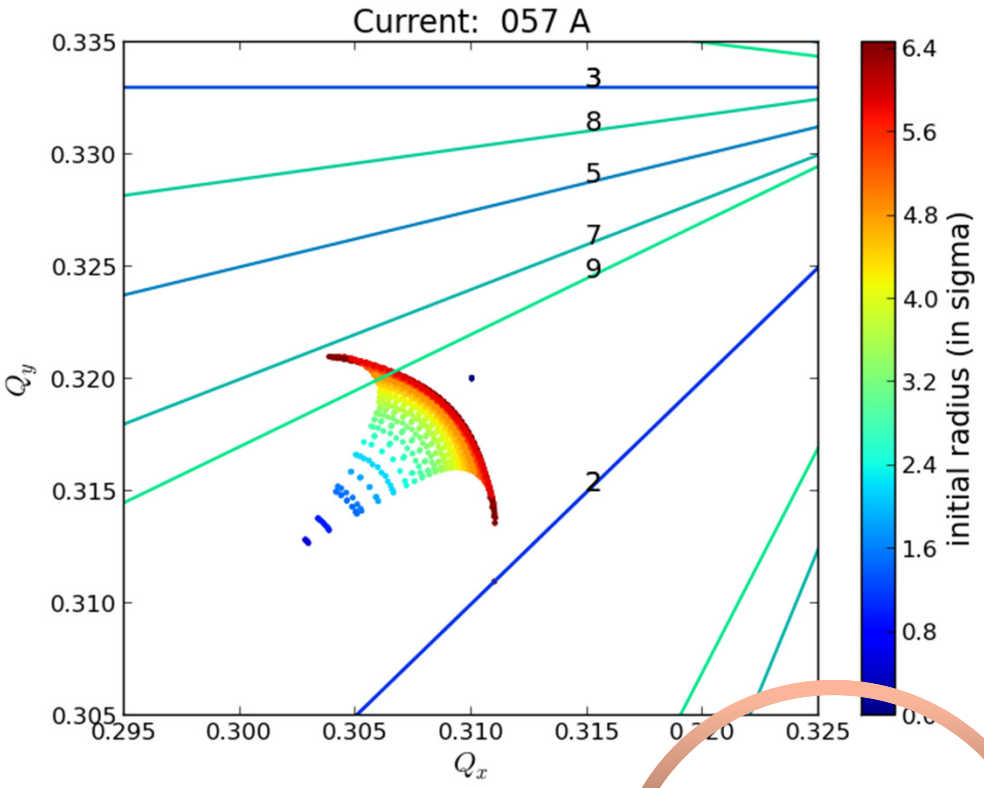
I = 177 A

- Almost equal HO

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

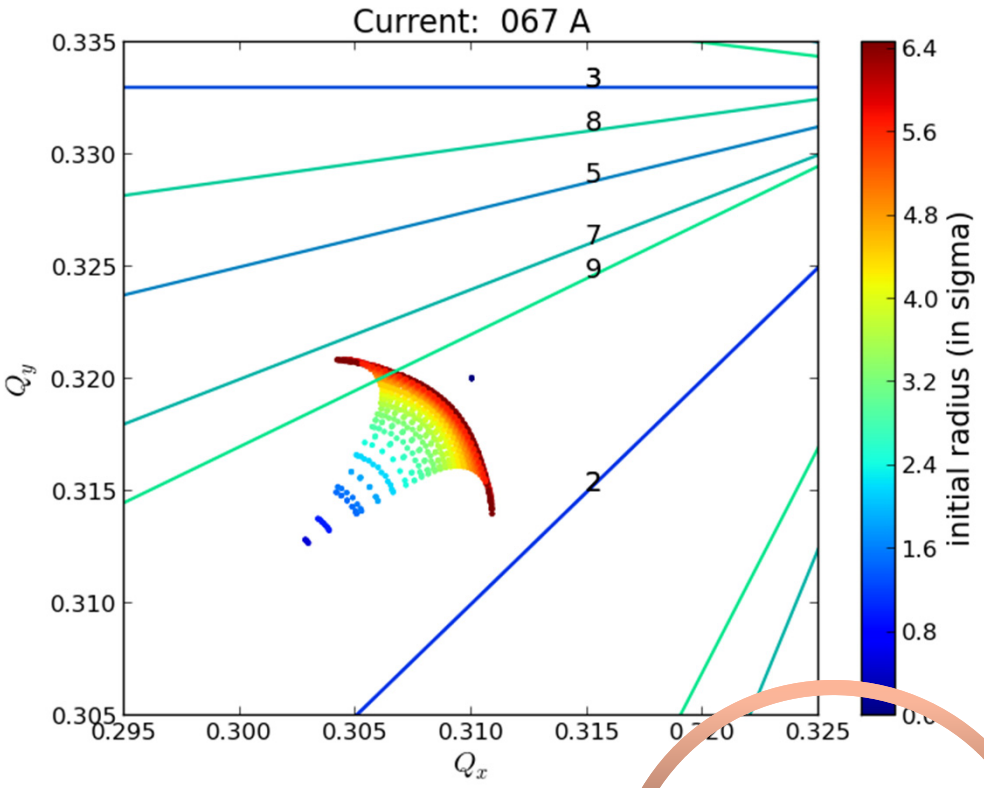
I = 177 A

- Almost equal HO

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

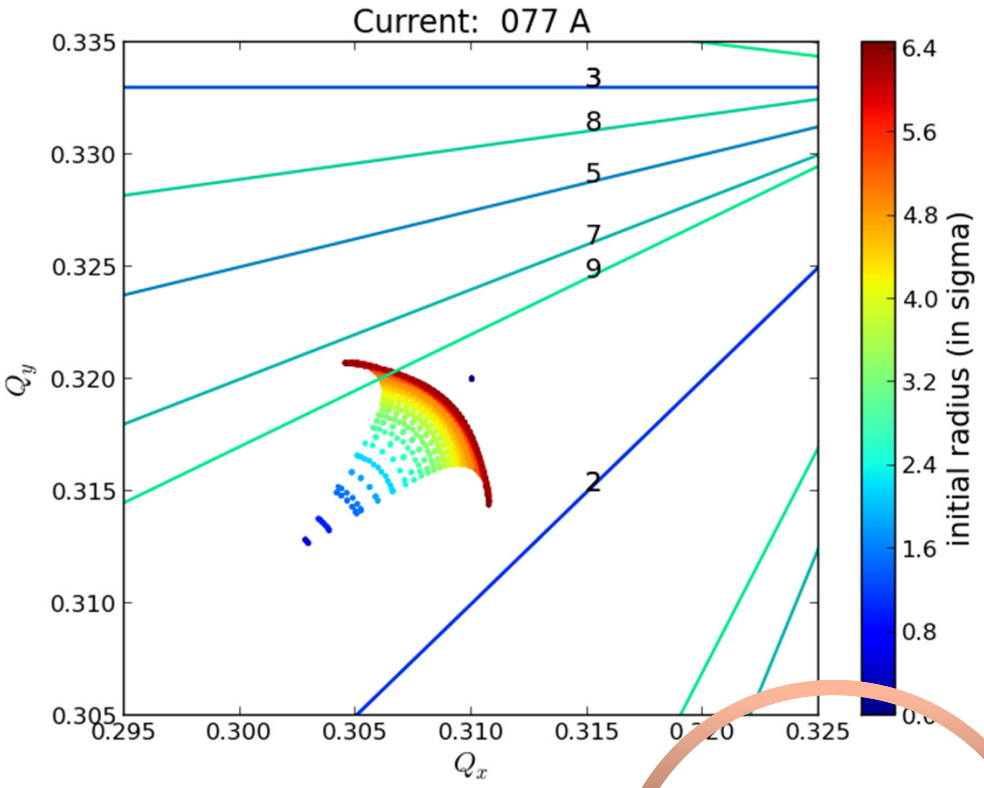
I = 177 A

- Almost equal HO

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

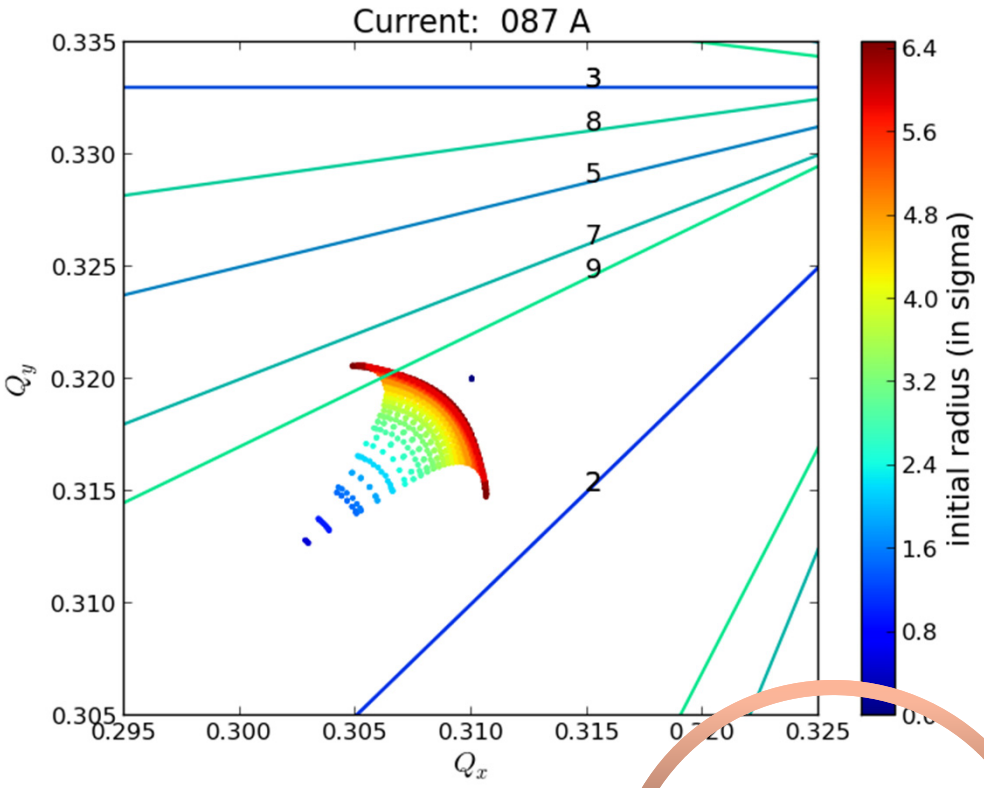
I = 177 A

- Almost equal HO

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

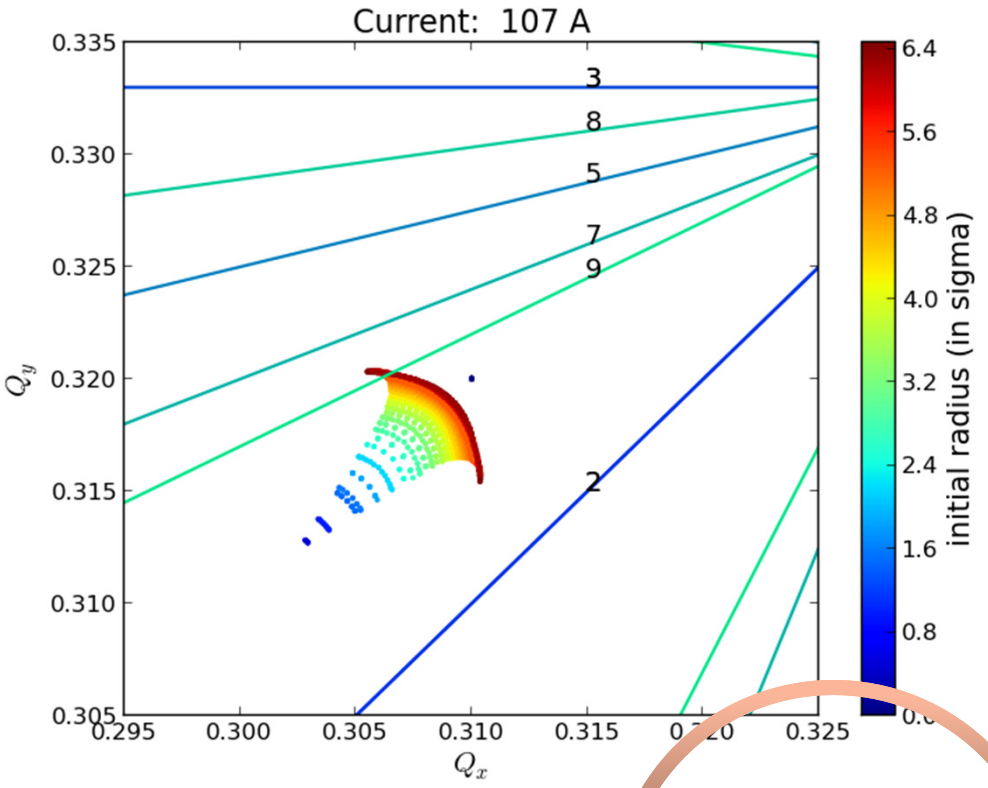
I = 177 A

- Almost equal HO

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

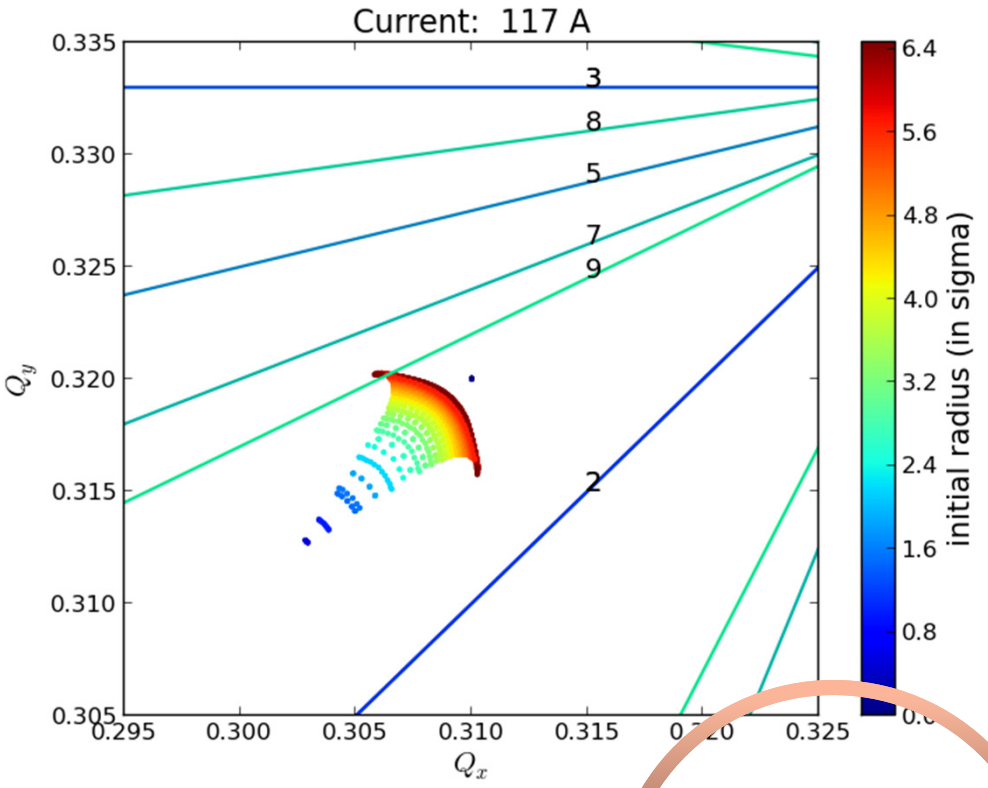
- Almost equal HO

I = 177 A

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

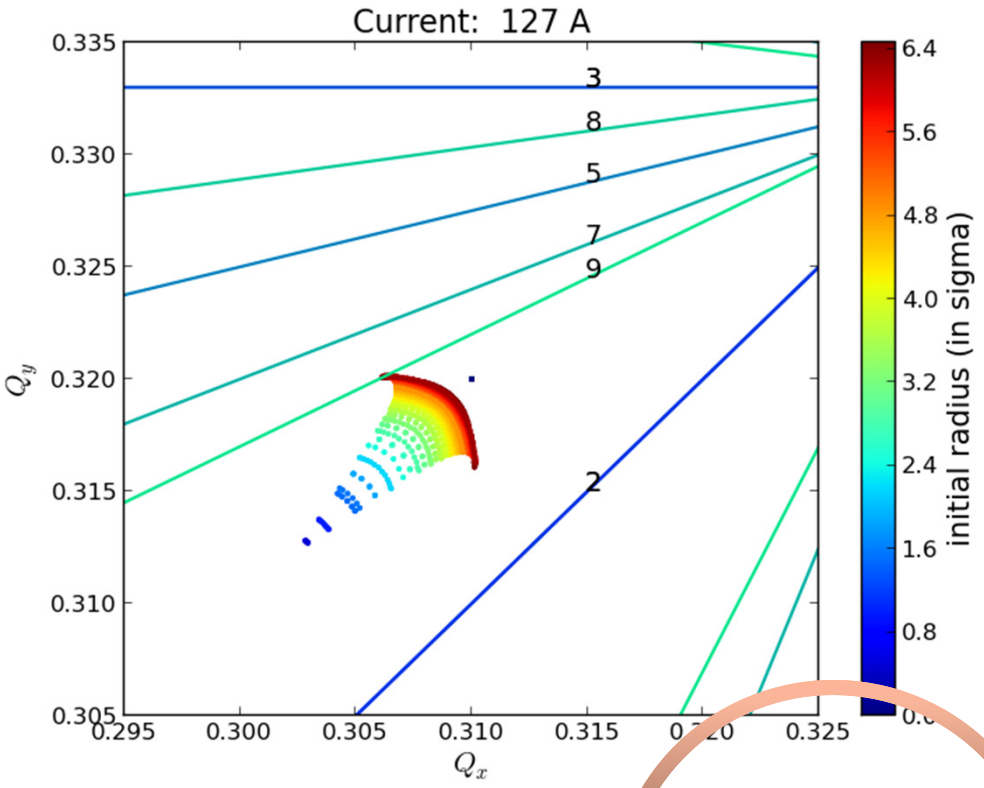
- Almost equal HO

I = 177 A

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

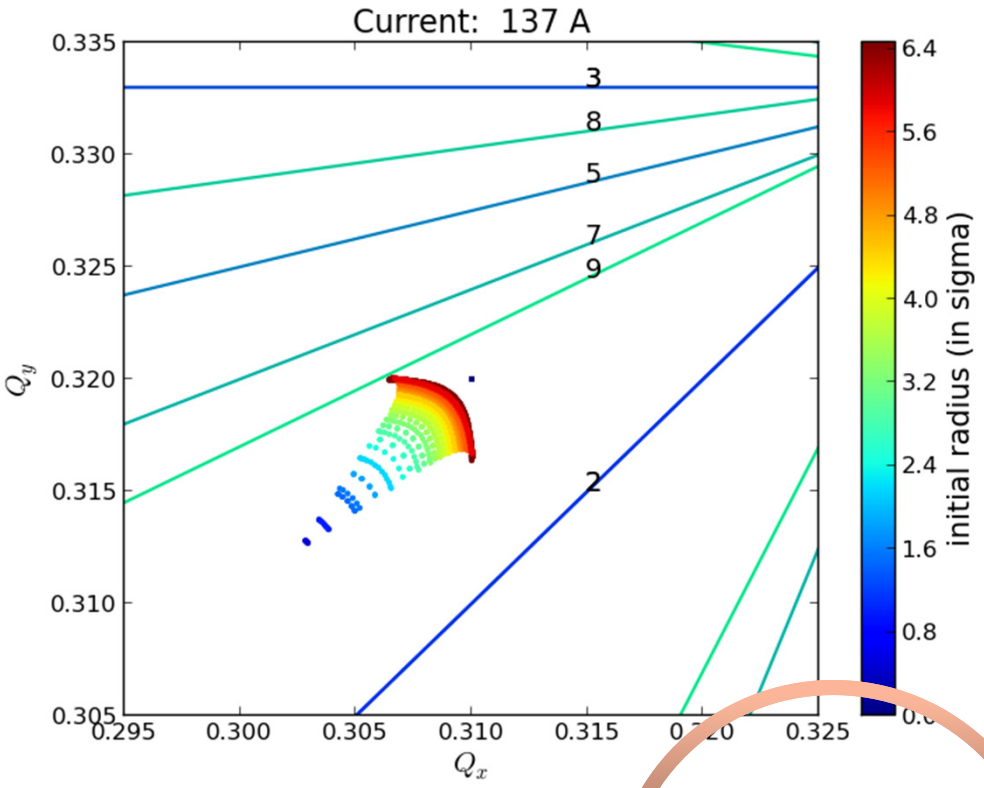
I = 177 A

- Almost equal HO

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

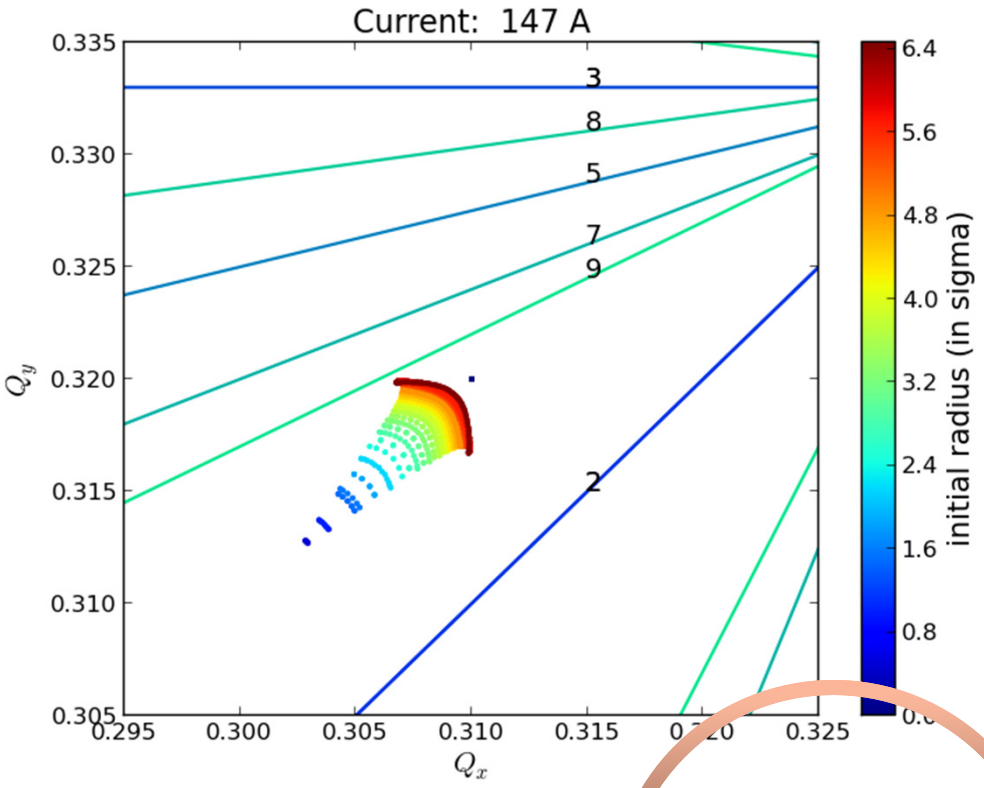
I = 177 A

- Almost equal HO

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

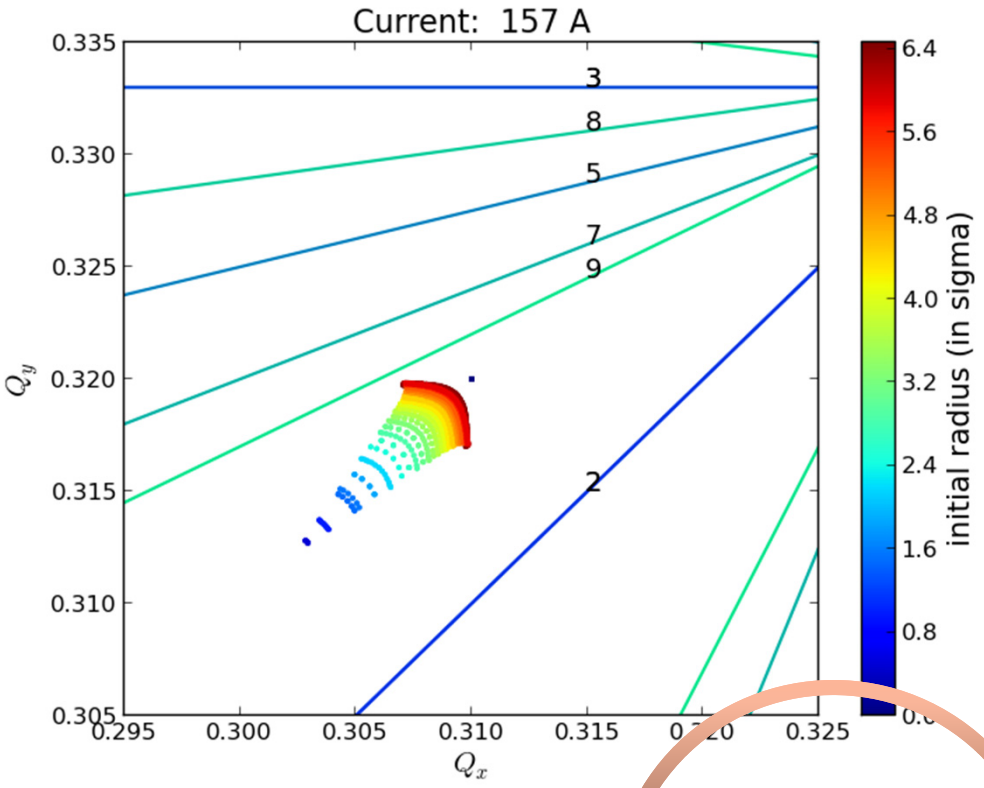
I = 177 A

- Almost equal HO

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

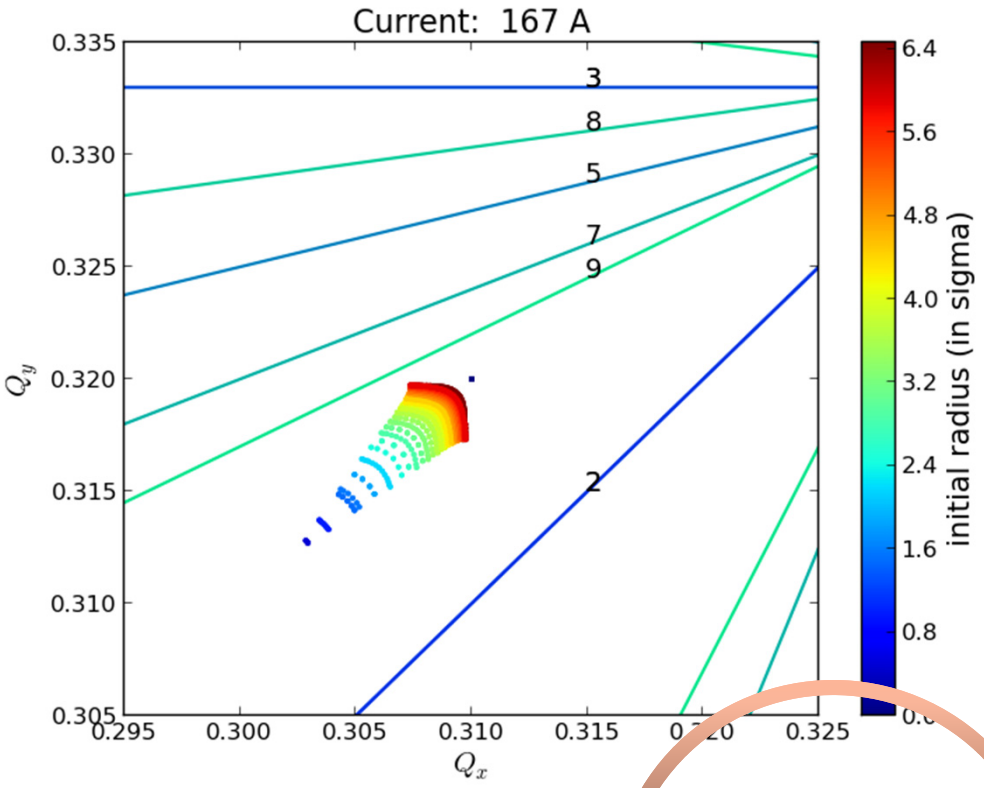
I = 177 A

- Almost equal HO

- No significant improvement

I > 177 A

Current analysis



I = 177 A

- No resonance touched

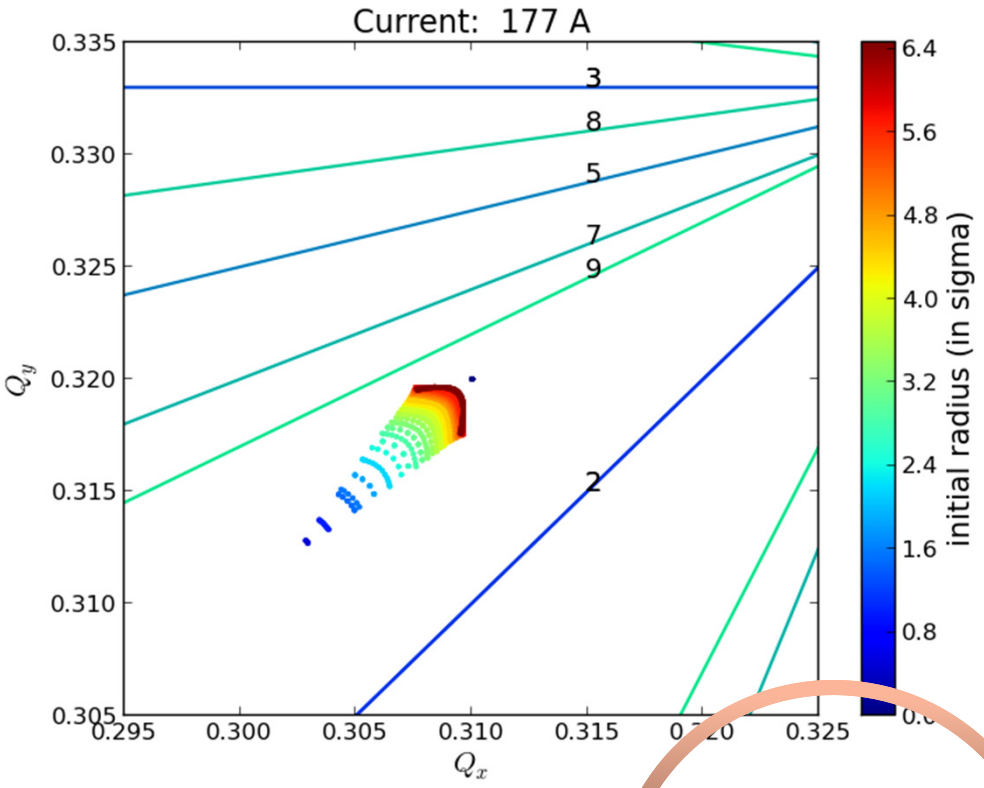
I > 130 A

- Almost equal HO

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

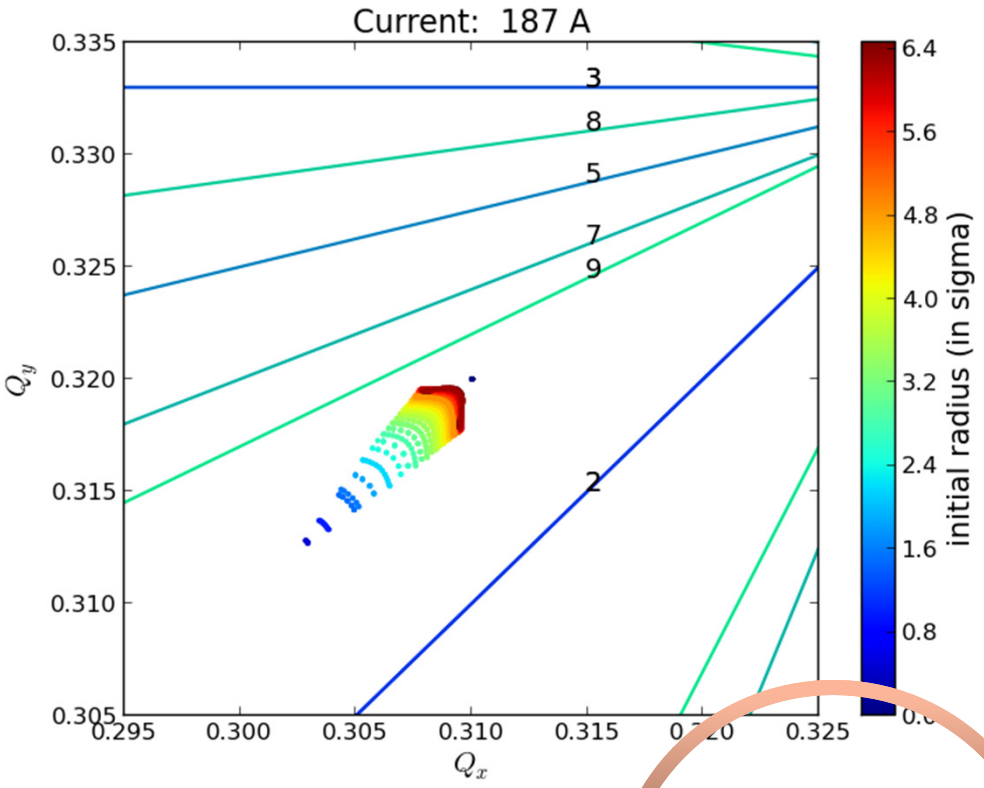
I = 177 A

- Almost equal HO

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

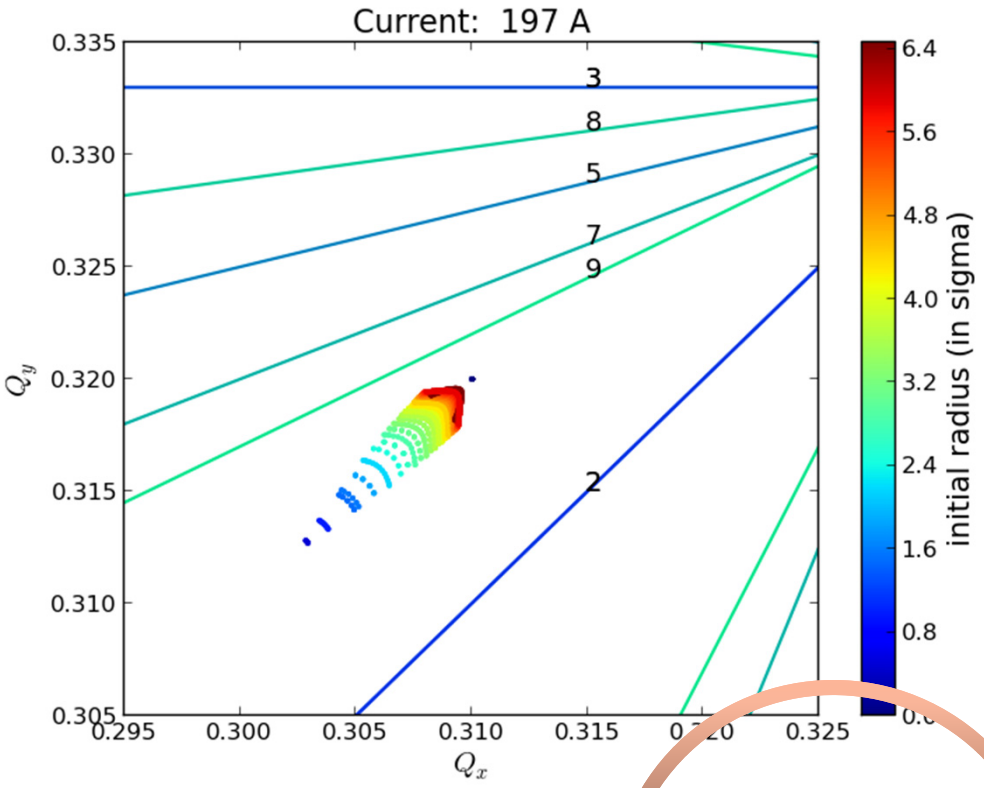
I = 177 A

- Almost equal HO

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

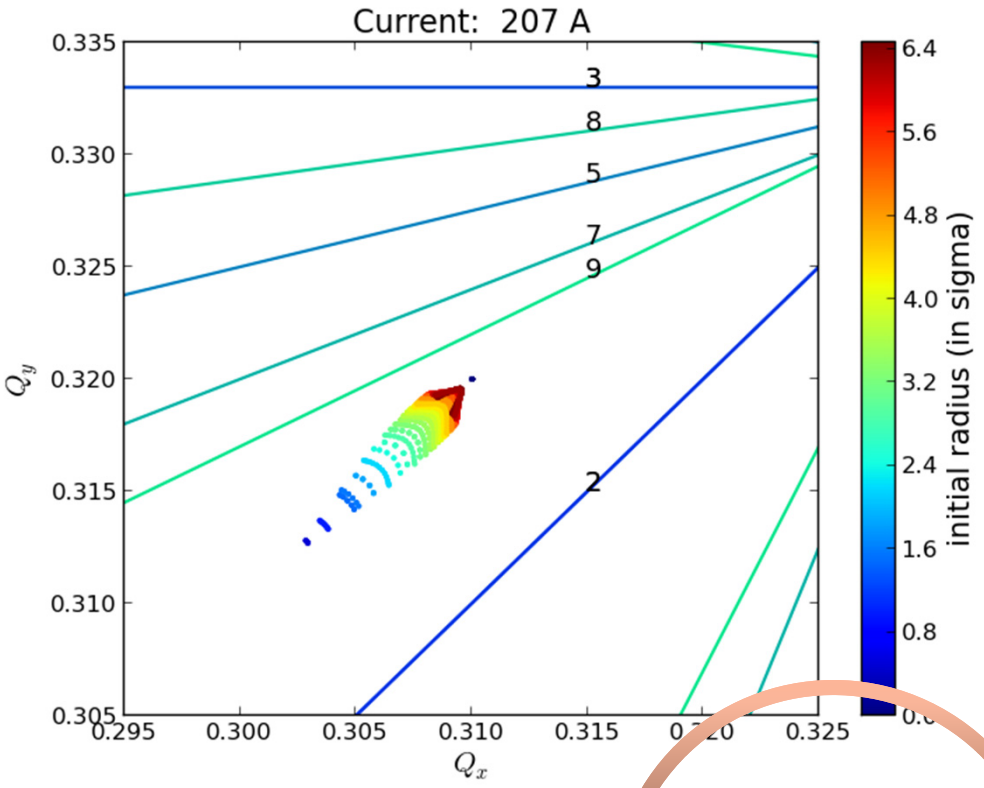
I = 177 A

- Almost equal HO

- No significant improvement

I > 177 A

Current analysis



- No resonance touched

I > 130 A

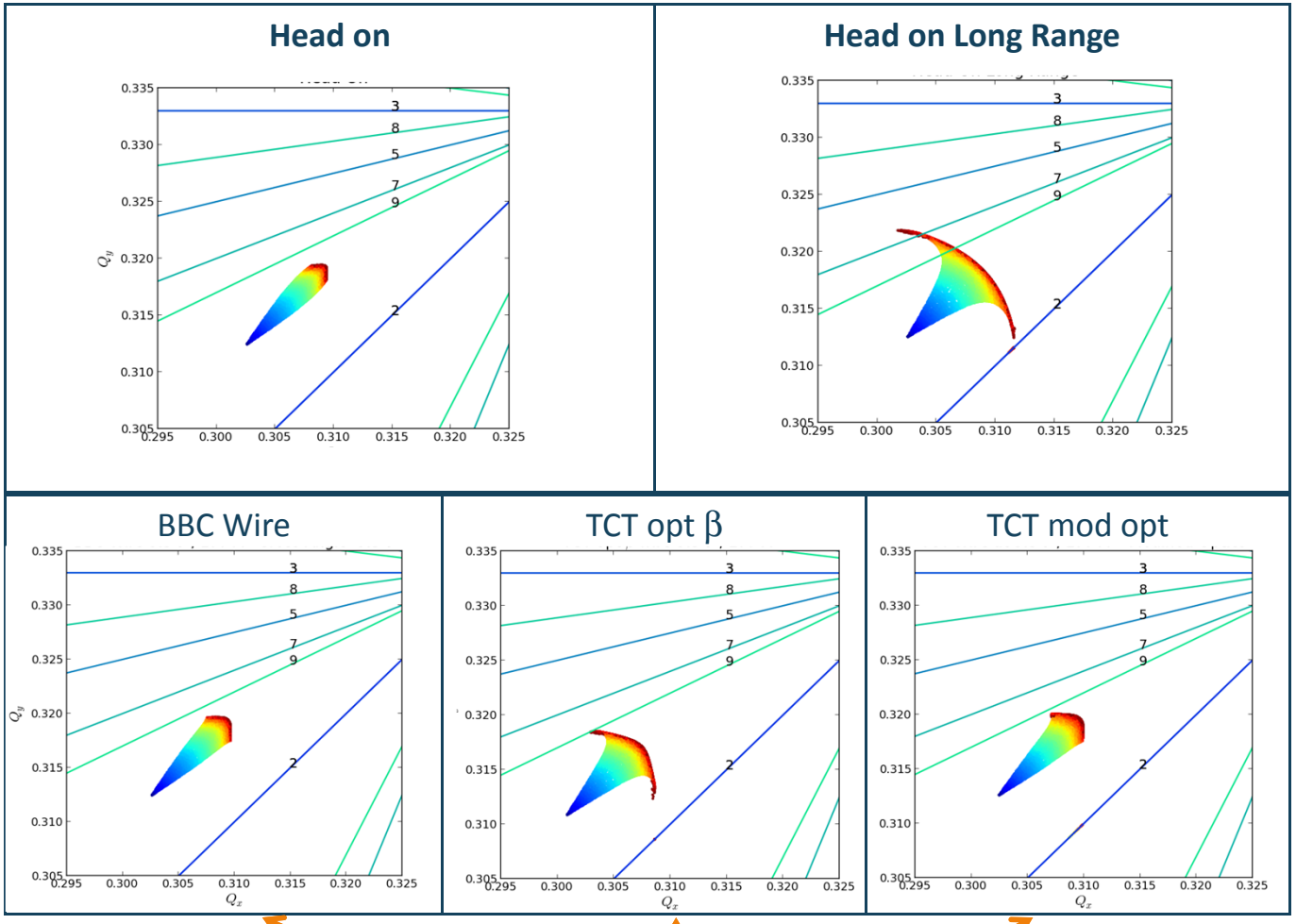
I = 177 A

- Almost equal HO

- No significant improvement

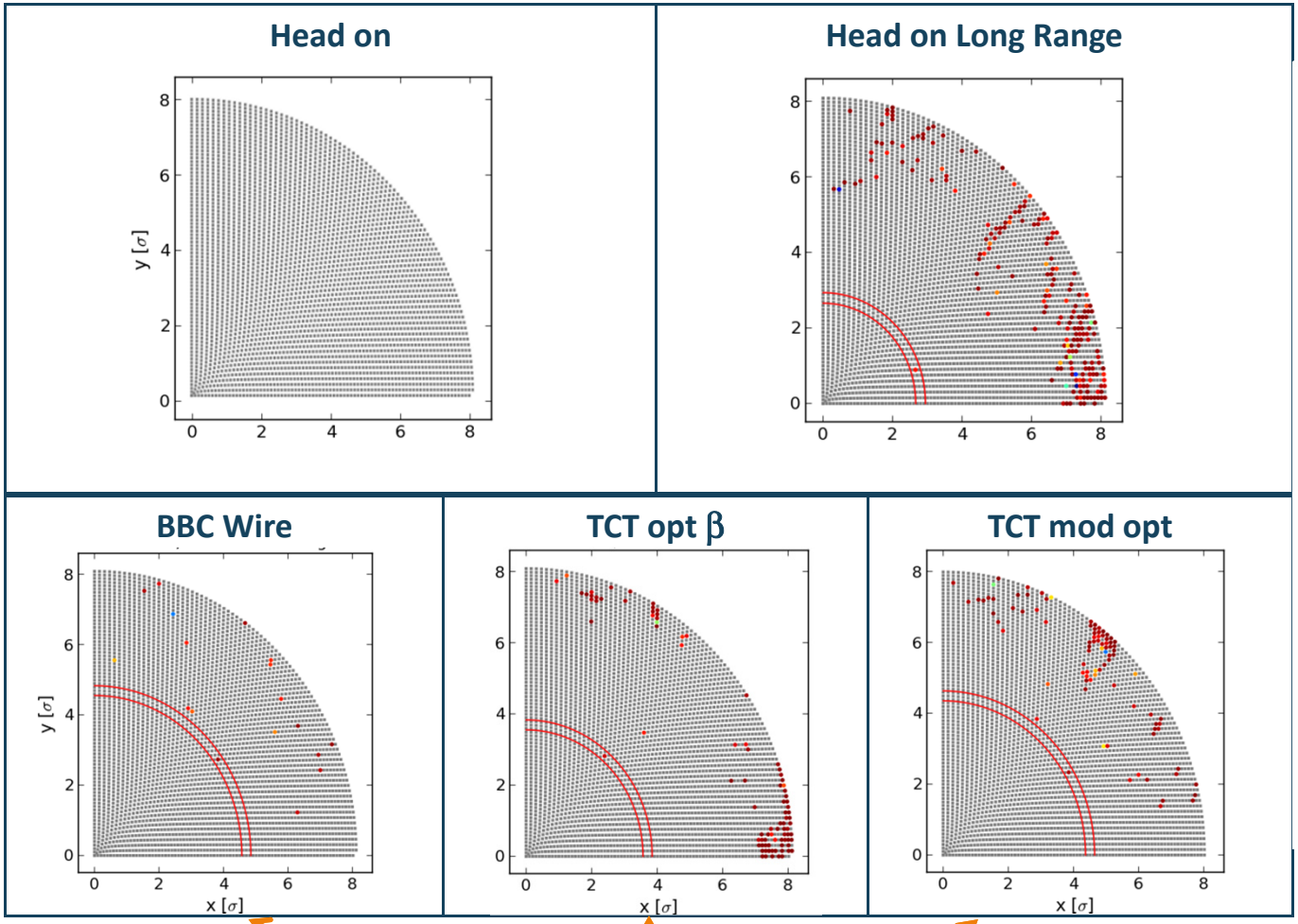
I > 177 A

Best Tune results



Wire at 9.5 σ – 177 A

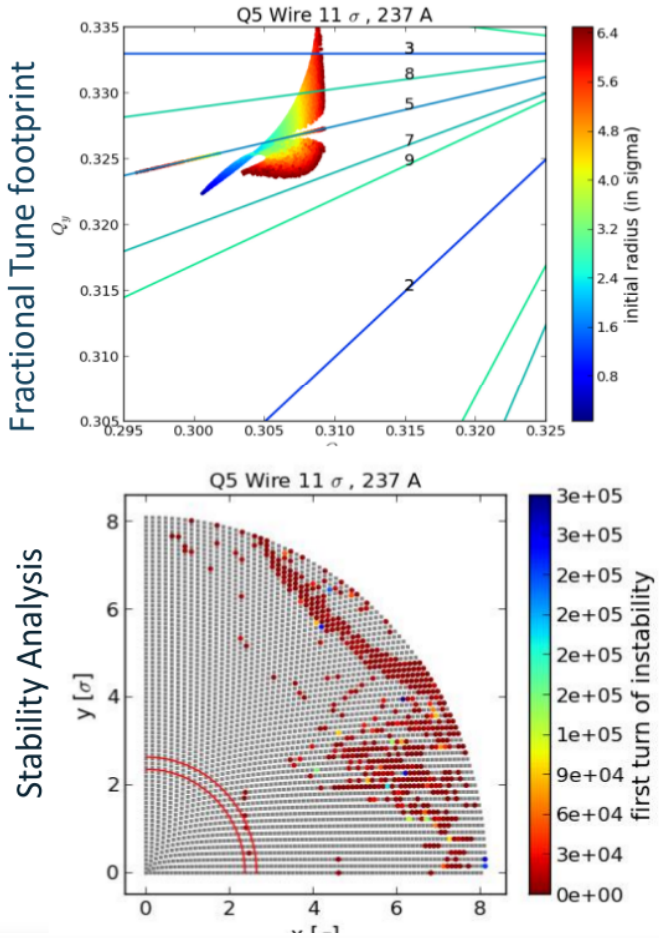
Best Stability results



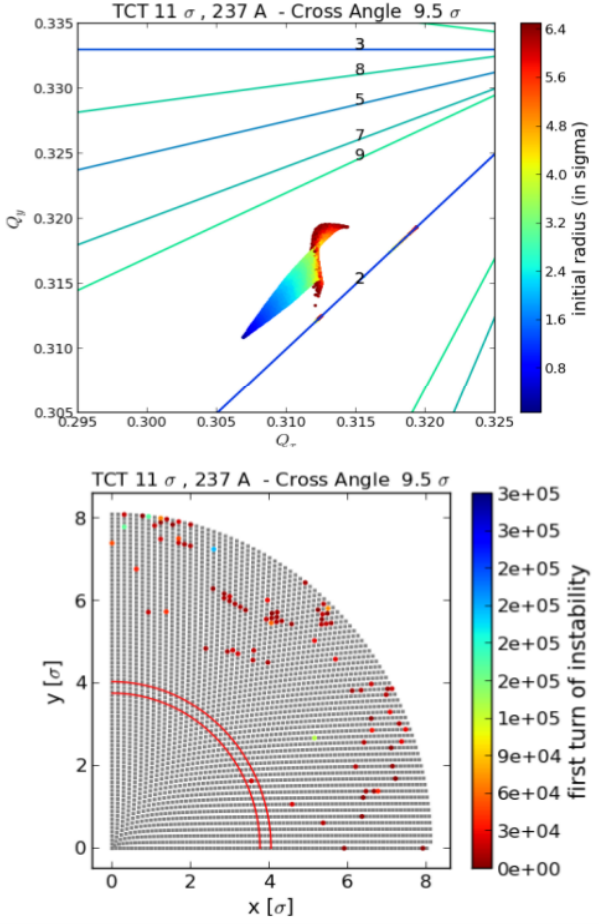
First proposal

Highlights

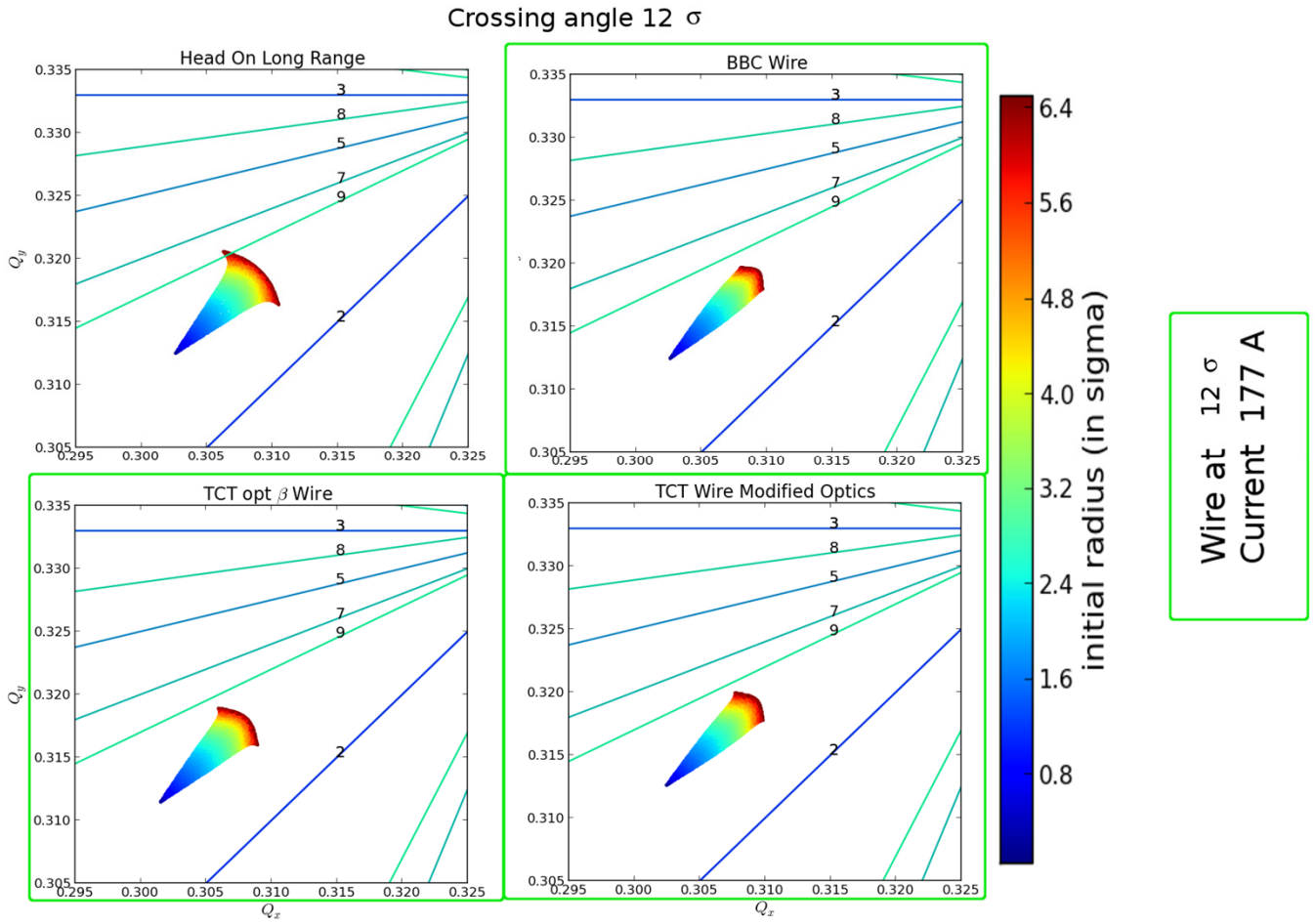
Q5 wire 11 σ 237 A



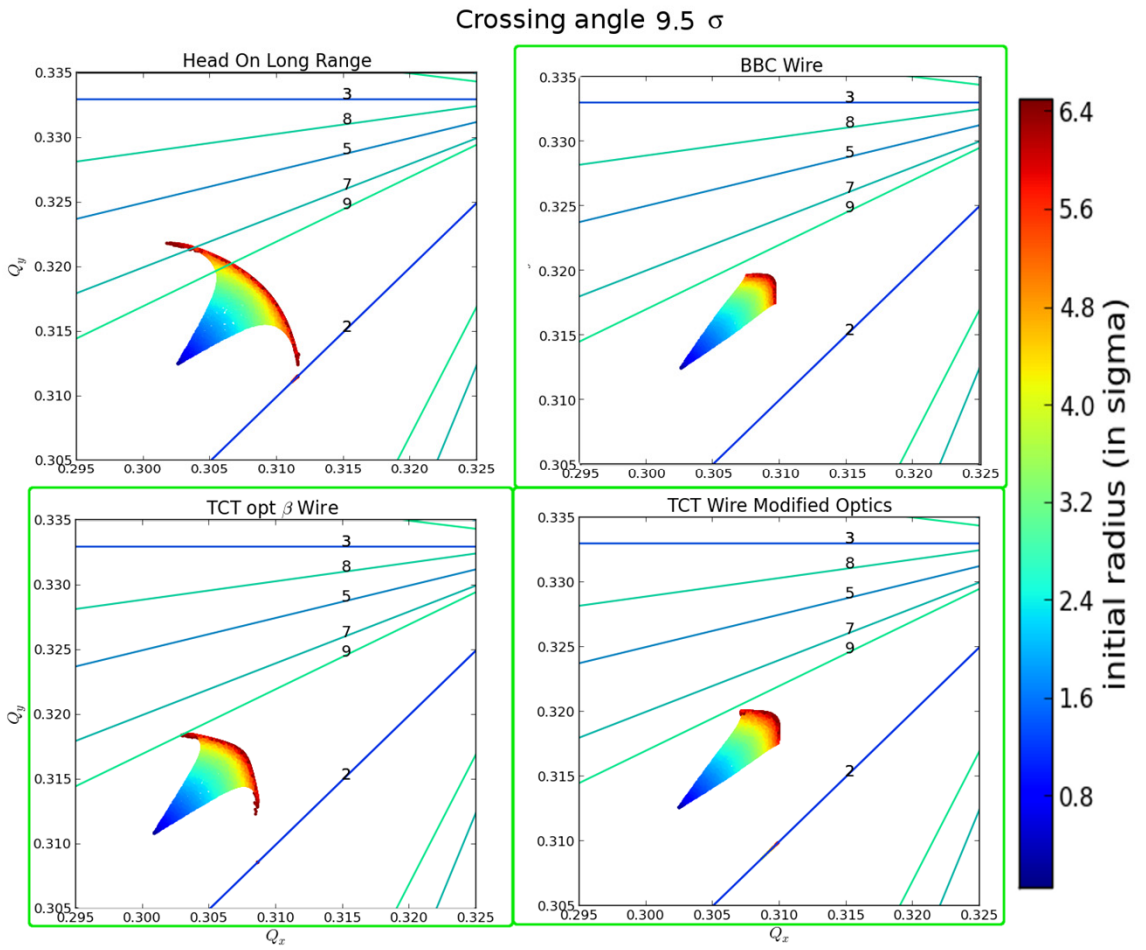
TCT wire 11 σ 237 A



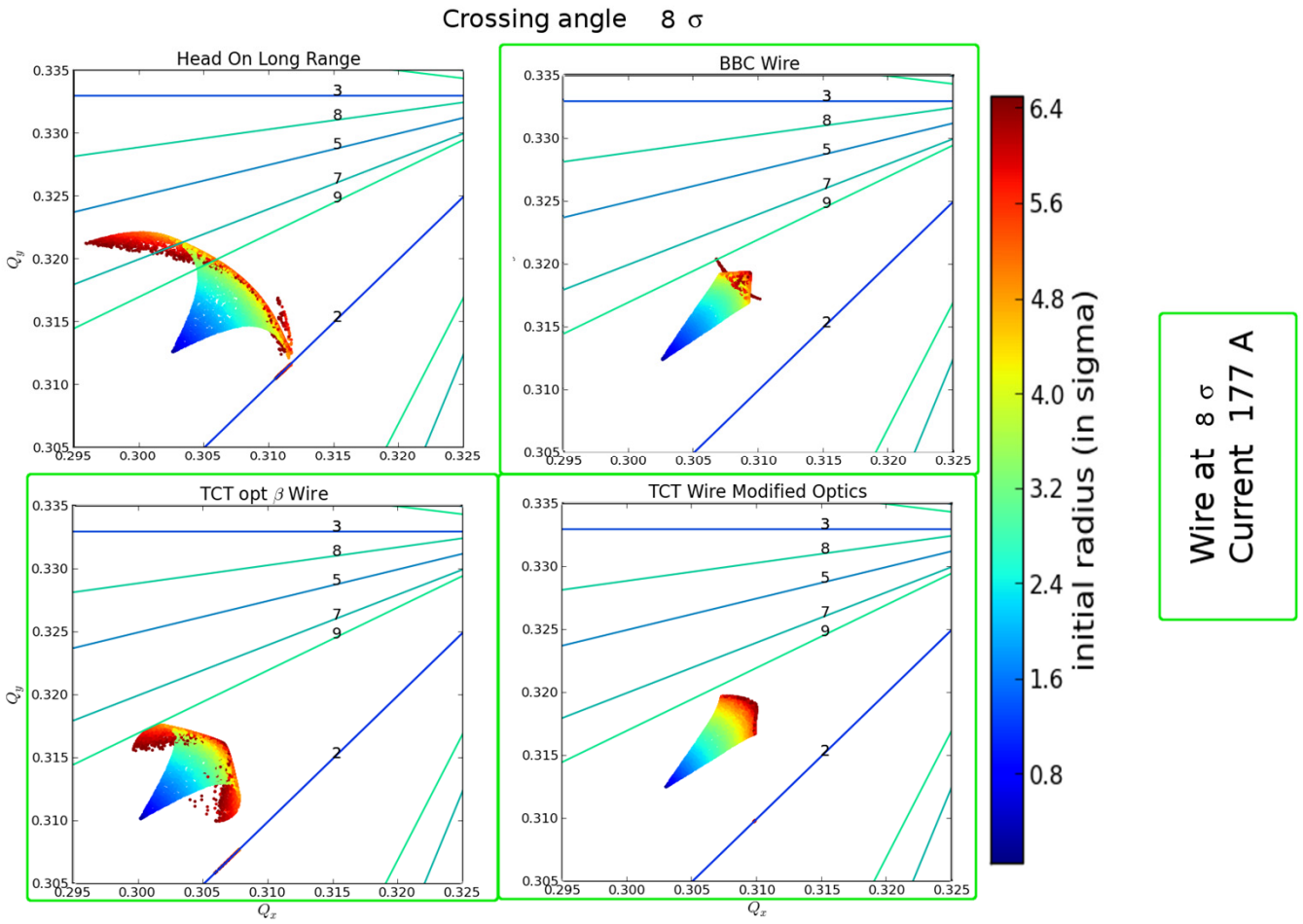
Crossing angle dependency



Crossing angle dependency

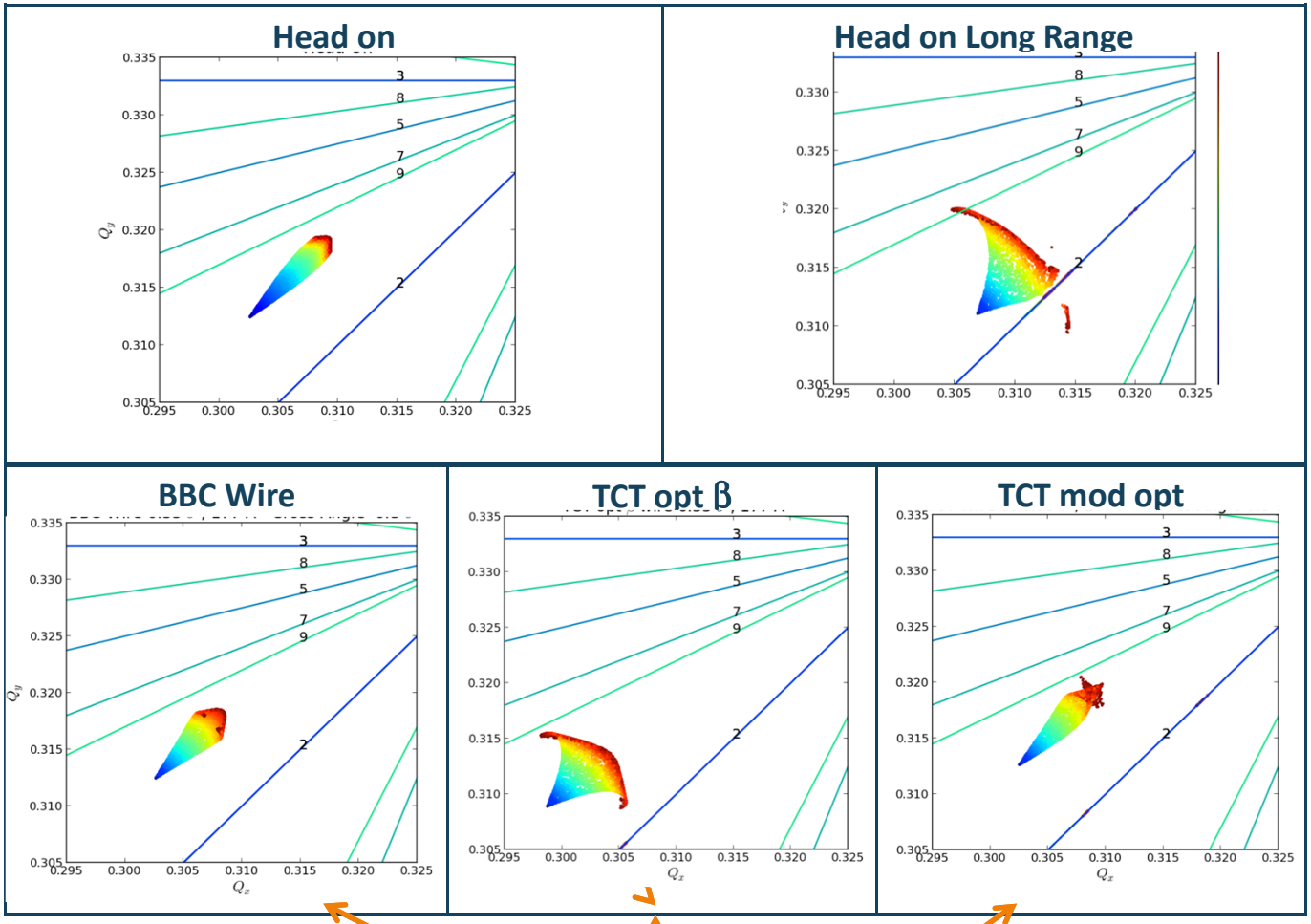


Crossing angle dependency



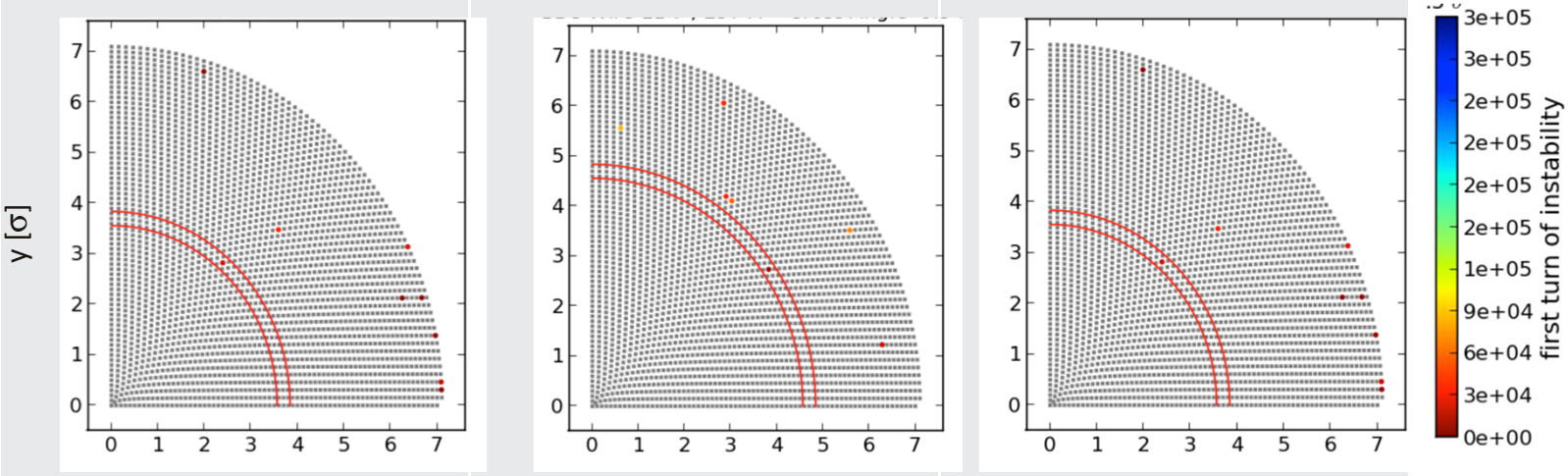
Cross. angle dep.: Tune

Crossing Angle 6.3 σ



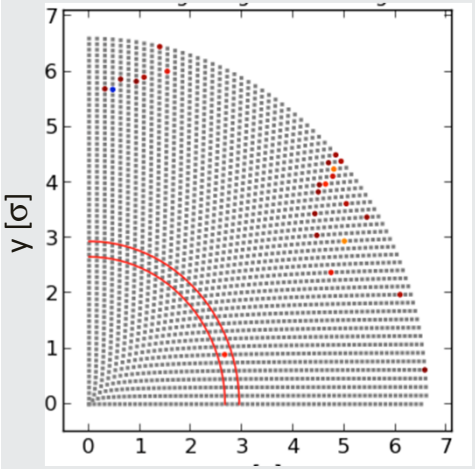
Cross. angle dep.: stability

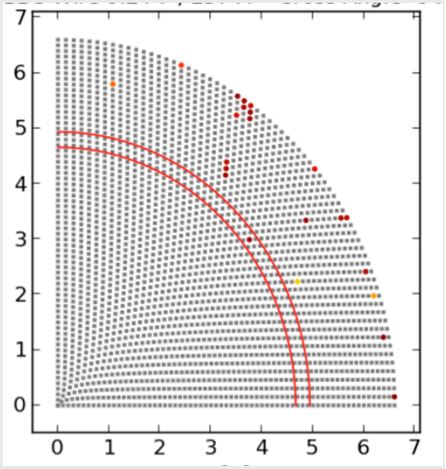
Cross Angle 12 σ	Cross Angle 9.5 σ	
HOLR	**BBC** 237 A 11σ	**TCT opt β** 237 A 11σ

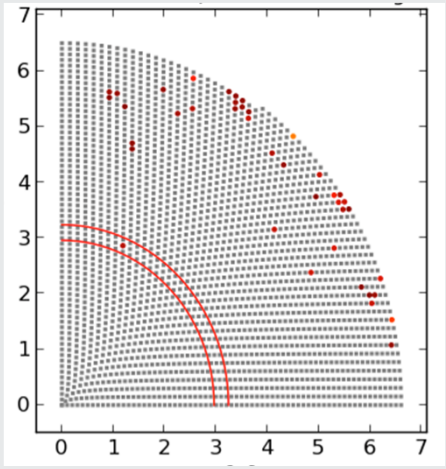


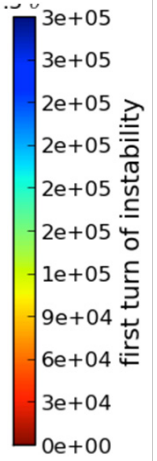
Cross. angle dep.: stability

Cross Angle 9.5 σ	Cross Angle 8 σ	
HOLR	**BBC** 237 A 9.24σ	**TCT mod opt** 237 A 9.24σ

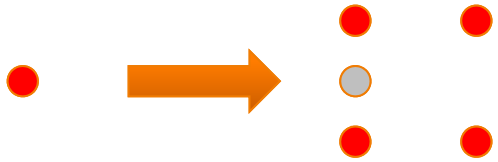




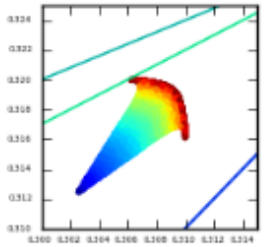
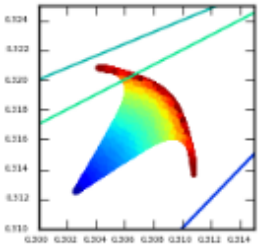
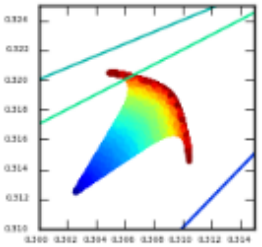
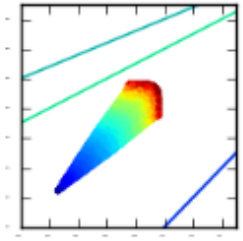
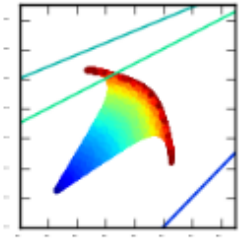
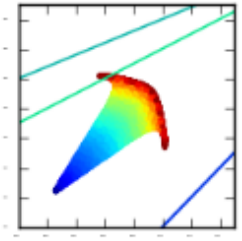




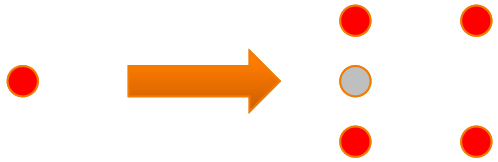
Wire shape

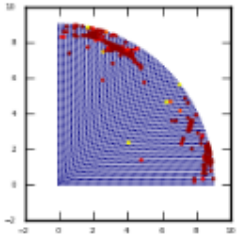
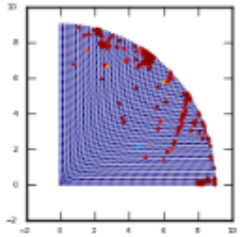
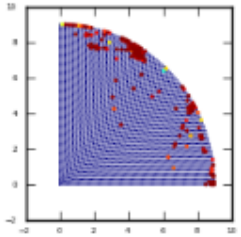
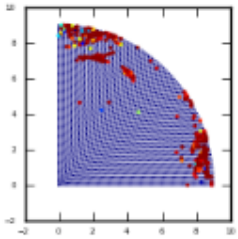
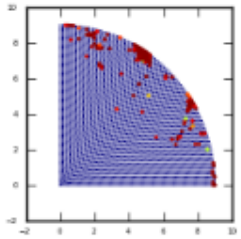
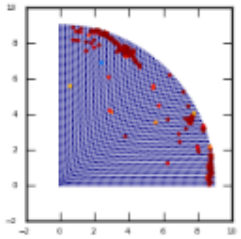


1mm

Footprint Summary			
Test	177 A 9.5 σ	177 A 11 σ	237 A 11 σ
Square Wire			
Pencil like wire			

Wire shape



Stability Summary			
Test	177 A 9.5 σ	177 A 11 σ	237 A 11 σ
Square Wire			
Pencil like wire			

Conclusions

Conclusions

- ✓ We studied a possible compensation of long range beam beam effects in LHC with a DC wire compensator
- ✓ We made our simulation with the weak-strong code bbtrack (with some additional scripts that allow us to automate and speed up the simulations
- ✓ We analyzed the tune and stability
  - ✓ For stability we defined a new method to calculate Lyapunov coefficient

- ✓ From tune analysis ➡ best transverse location 9.5 σ with current 177 A
- ✓ From stability analysis ➡ best transverse location 11 σ with current 237 A
- ✓ Longitudinally, best compensation at BBC location
- ✓ Promising results also at TCT opt β or TCT with modified optics

- ✓ Varying the crossing angle we see that wire compensator allows to reduce crossing angle of 1-2 σ maintaining the same stable region

Aknowledgments

✧ R. Steinhagen

✧ S. Fartoukh

✧ G. Sterbini

✧ R. De Maria

✧ U. Dorda

✧ C. Zannini

✧ G. Iadarola

✧ E. Benedetto

✧ S. Cengarle

Thank you!