Proton Operation Cycles in SIS100

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WP 2.8.1 SIS100 Beam Dynamics

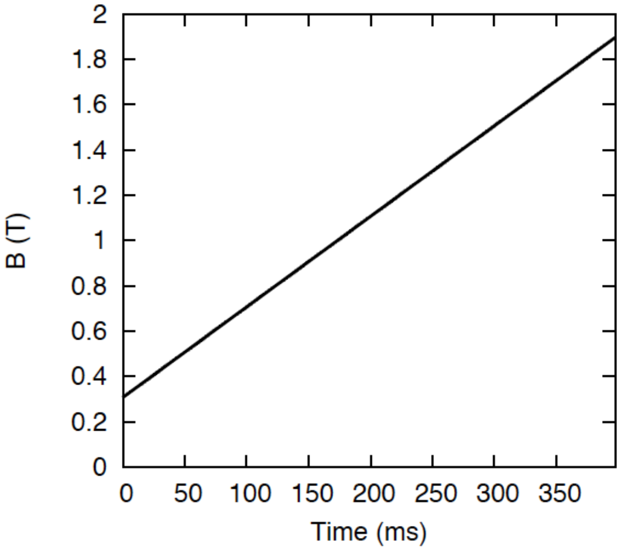
SIS100 Planungsgruppensitzung 31.03.2014

PROTON OPERATION IN SIS100

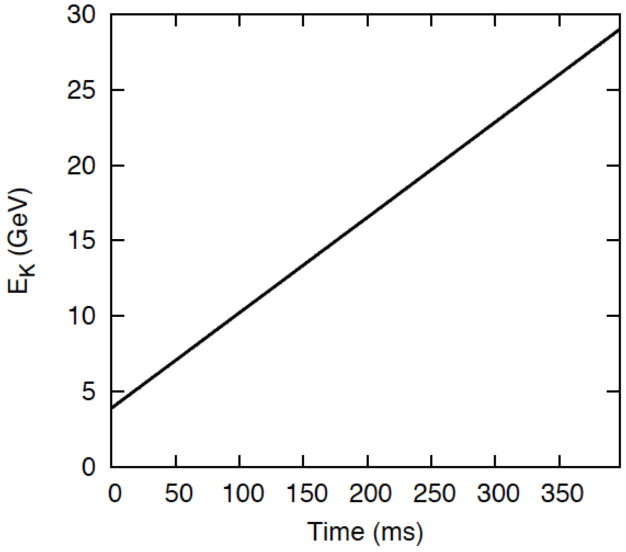
4 bunches from SIS18 in 4 cycles;
N_p = 4x5e12 = 20e12;
Bunch area A_z = 4x0.53 eV-s = 2.13 eV-s;
Transverse Emittance 13/4 mm mrad.
Bρ = 18Tm -> 100Tm

Final Bunch Length 50ns
29GeV
0.2Hz

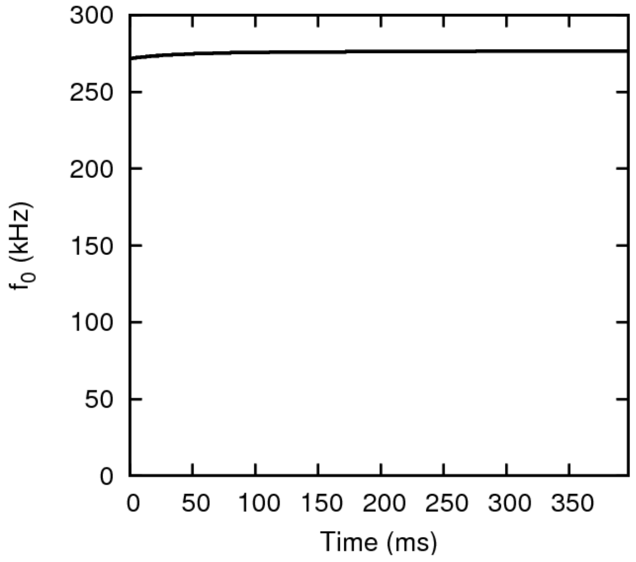
Bending Magnetic Field



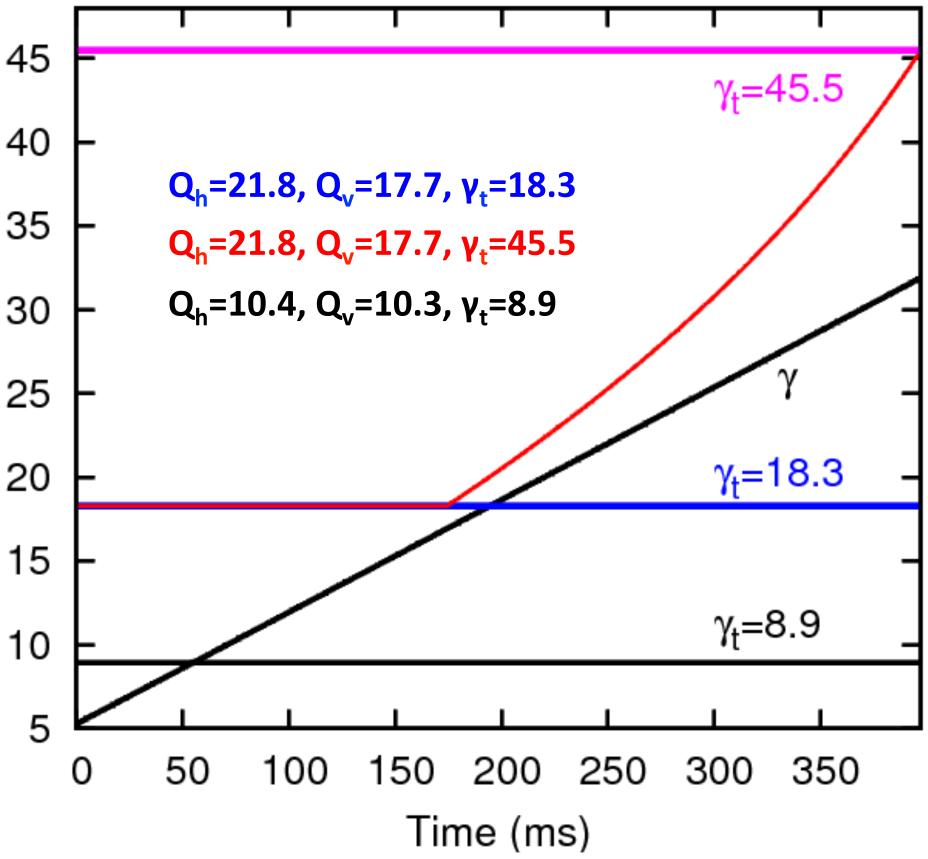
Kinetic Energy

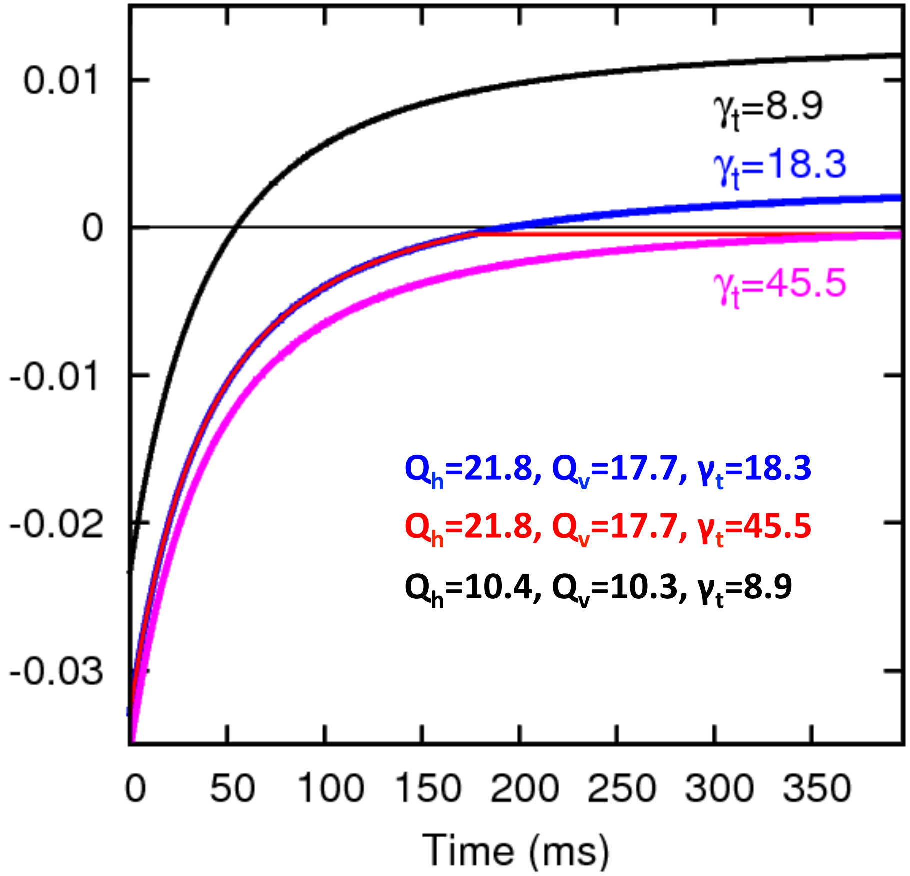


Revolution Frequency



CANDIDATES: PROTON OPERATION CYCLES


Lorentz Factor γ and Transition γ_t


Slip-Factor $\eta = 1/\gamma_t^2 - 1/\gamma^2$

1. Staying under Transition γ_t=45.5;
2. Using the "standard" lattice γ_t=18.3 => transition crossing, γ_t-jump not possible;
3. Low Tune lattice γ_t=8.9 => transition crossing, γ_t-jump possible.

CANDIDATES: PROTON OPERATION CYCLES

γ_t=8.9

small |η|<1e-3: 10ms
γ_t-jump should provide a safe crossing
(Ondreka, Aumon, MAC10)

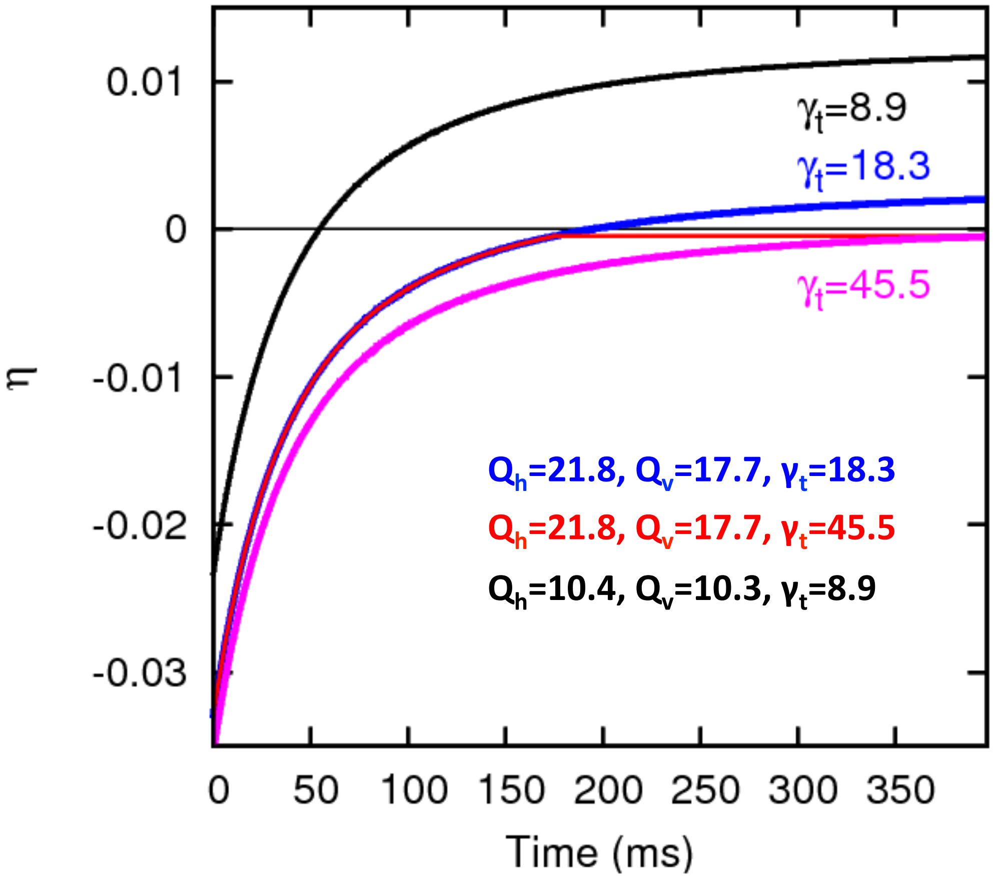
γ_t=18.3

small |η|<1e-3: 100ms
γ_t-jump not possible

γ_t=45.5

|η|<0.5e-3 at the top.
results at 29GeV: $\Delta Q_x, \Delta Q_y$<0.05 with
a sophisticated sextupole sequence (S.Sorge)

Slip-Factor $\eta = 1/\gamma_t^2 - 1/\gamma^2$



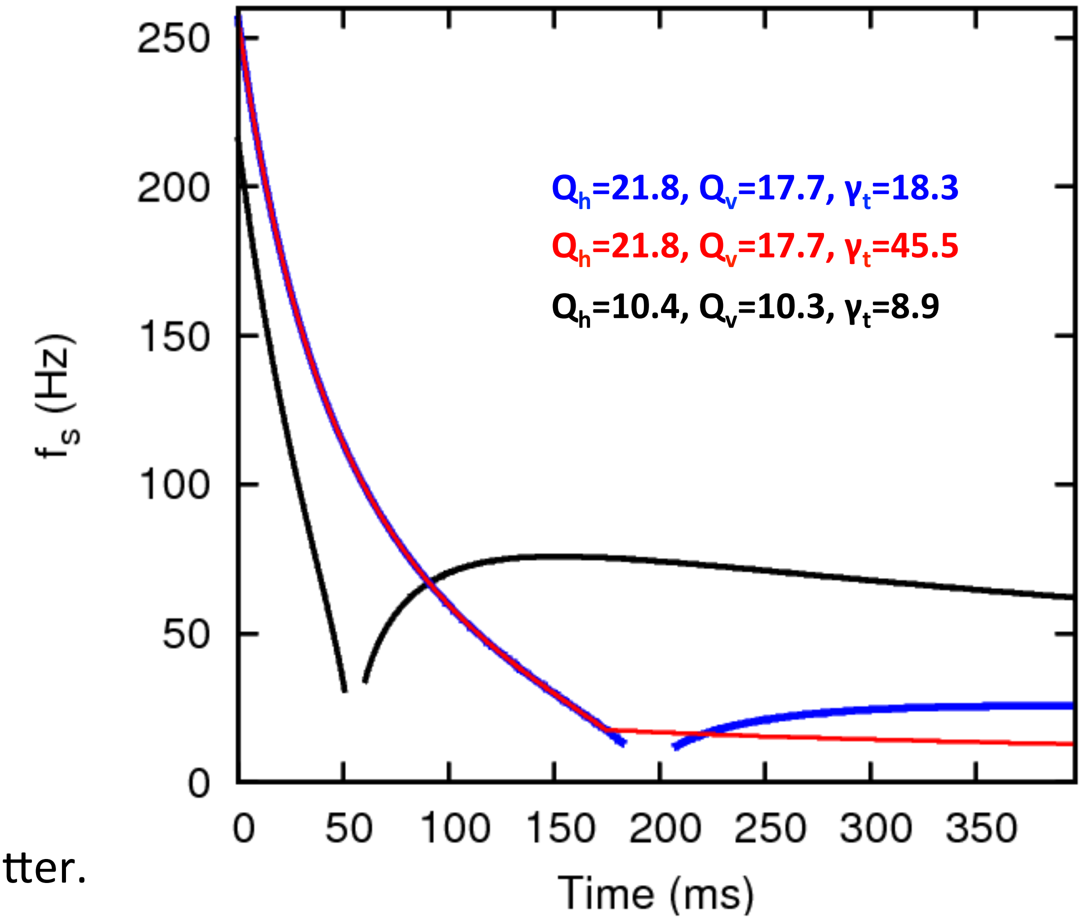
Q_h=21.8, Q_v=17.7, γ_t=18.3
Q_h=21.8, Q_v=17.7, γ_t=45.5
Q_h=10.4, Q_v=10.3, γ_t=8.9

CANDIDATES: PROTON OPERATION CYCLES

1 Bunch from 4 Bunches,
RF Manipulations necessary:

- Bunch merging
  (4b, h=10 => 2b, h=5)
- Batch compression 5 stages
  (2b, h=5 => 2b, h=10)
- Bunch merging
  (2b, h=10 => 1b, h=5)

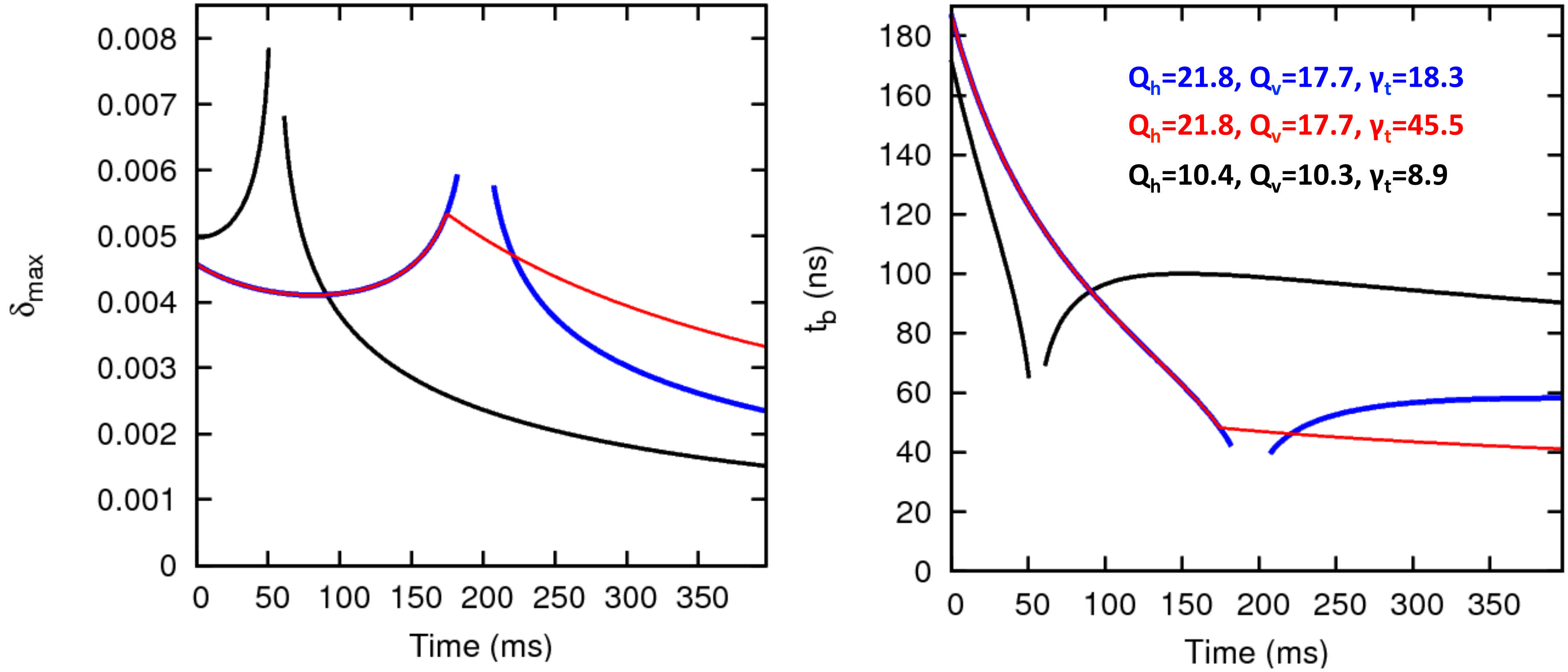
Calculated (Chorniy, Feb 2012)
with Beam Loading, Space Charge:
  needs time,
  blow-up necessary (x3),
  higher synchrotron frequency better.



V_0=280kV, h=5

BUNCH PARAMETERS

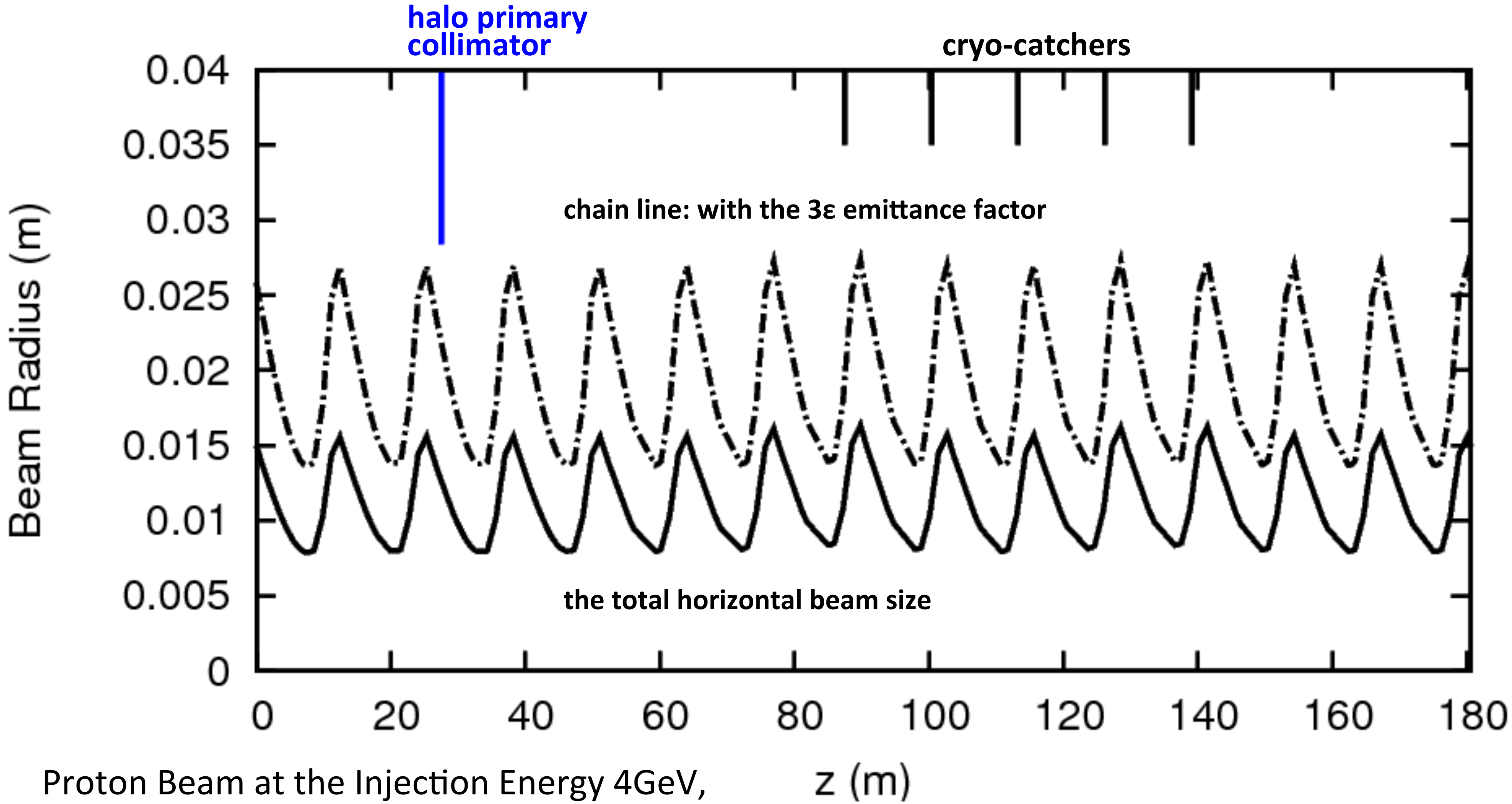
here: 1 bunch, bunch area 6.4eV-s (blow-up ×3), h=5, nonadiabatic not included



γ_t=8.9 cycle:
- due to the δ_p<0.005 limit, 2-bunches ramp.
- for the 50ns bunch: batch compression + bunch merging + bunch stretching + rotation at the top.

high γ_t cycles:
- all the rf manipulations at the injection energy, one-bunch ramp.
- the 50ns bunch at the top due to shrinking

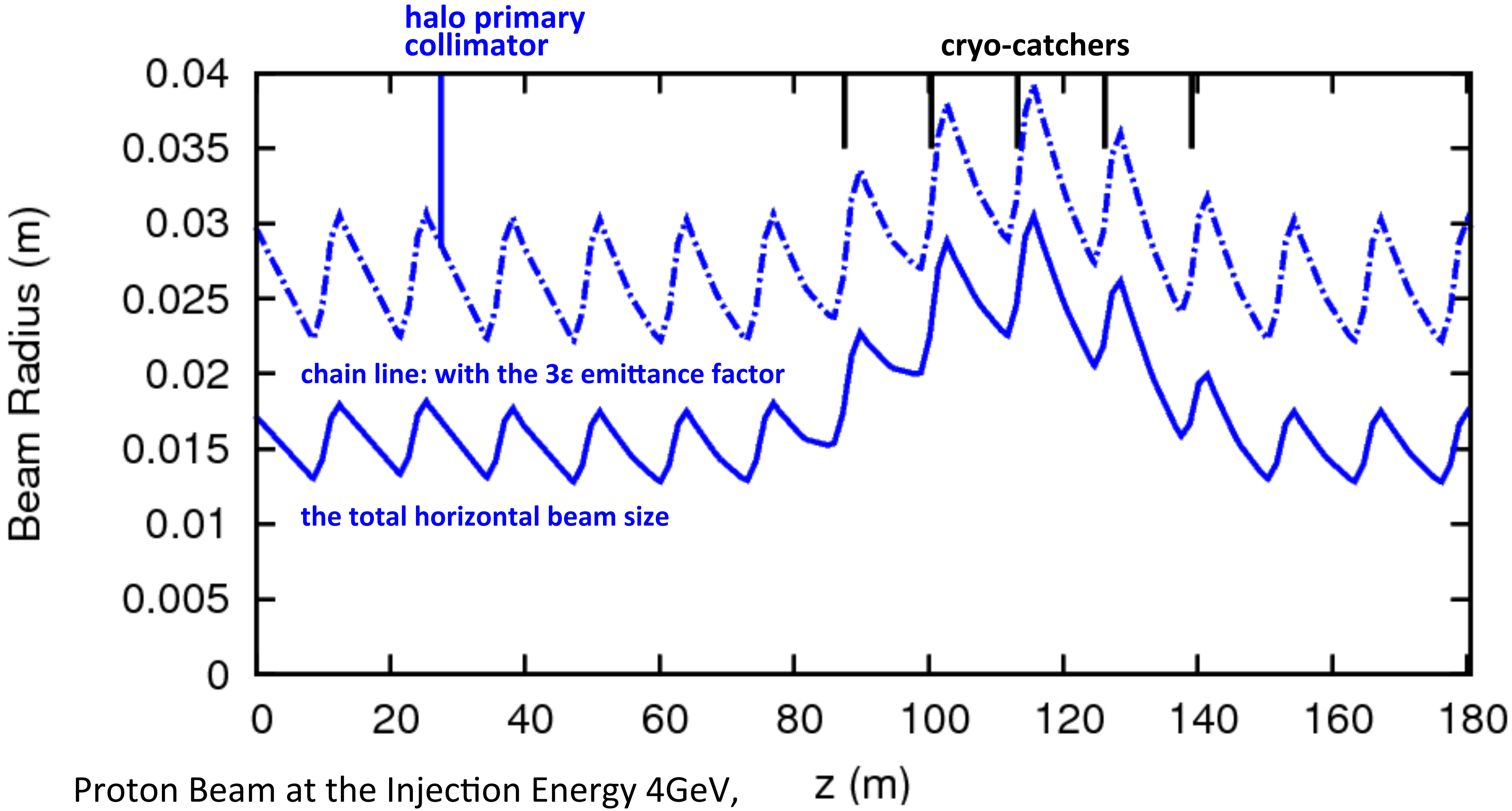
Q_h=21.8, Q_v=17.7, γ_t=18.3



Proton Beam at the Injection Energy 4GeV,
ε_h = 13 mm mrad

Large safety margin for accumulation and rf manipulations

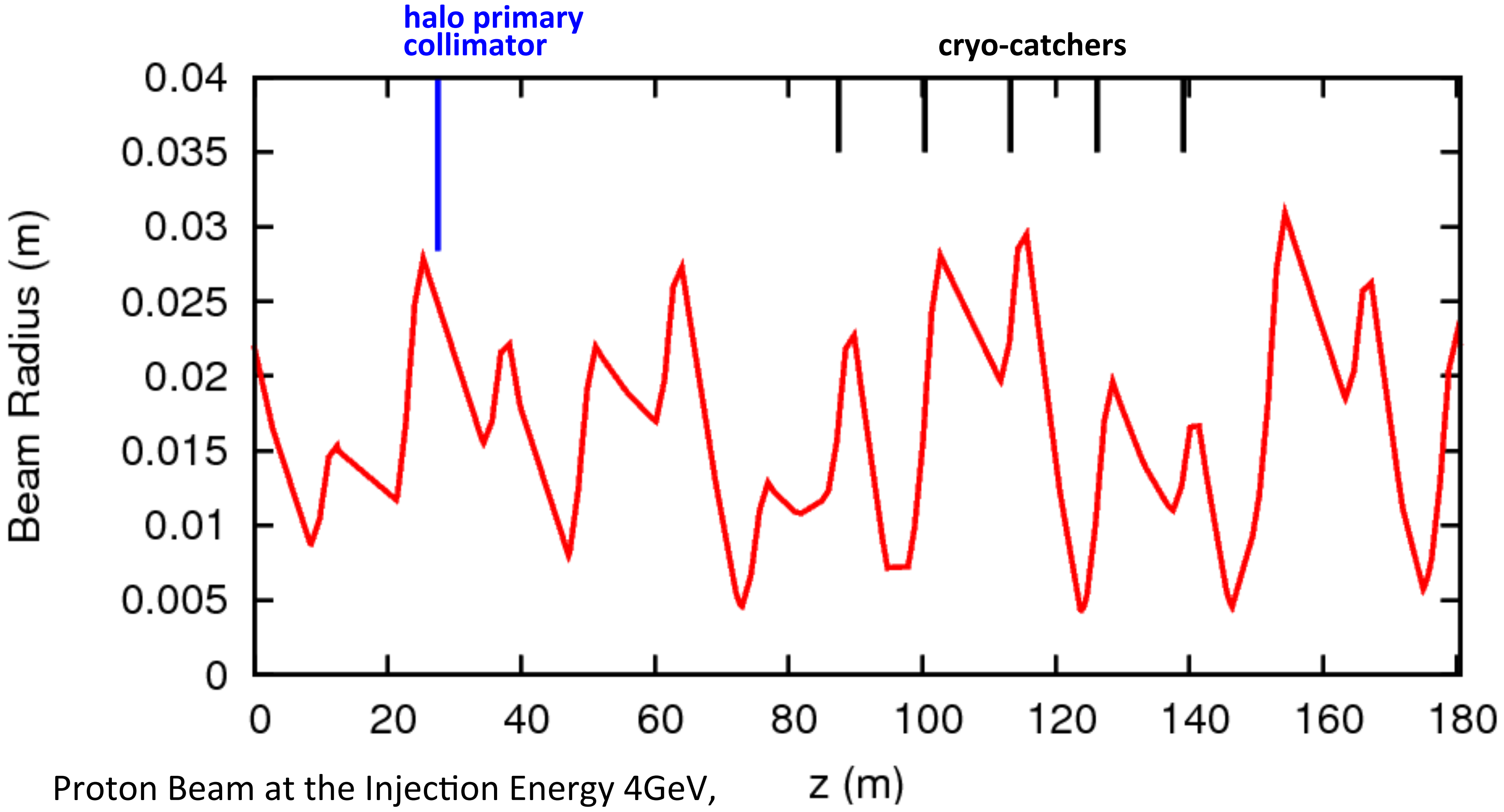
Q_h=10.4, Q_v=10.3, γ_t=8.9



Proton Beam at the Injection Energy 4GeV,
ε_h = 13 mm mrad

Magnet Field Quality and RF Manipulations:
Involved Beam Loss studies necessary

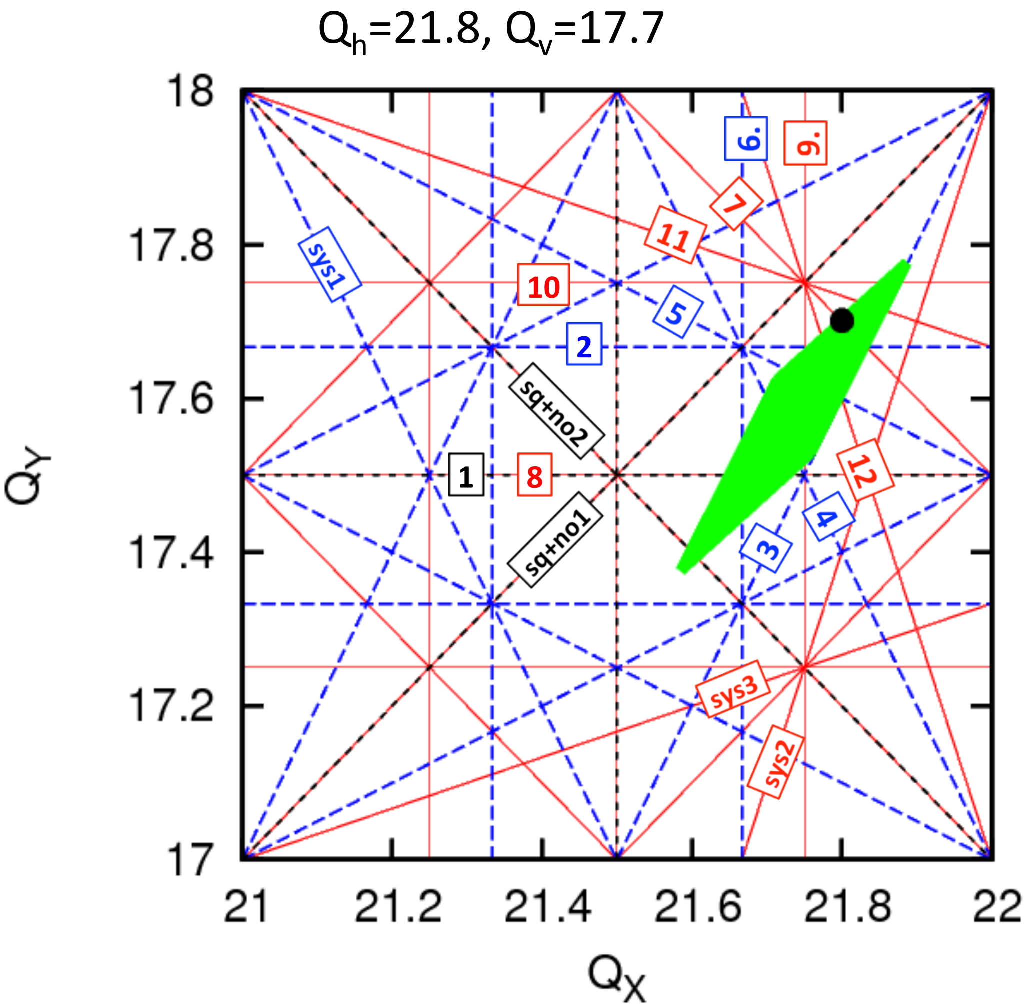
$Q_h=21.8$, $Q_v=17.7$, $\gamma_t=45.5$



Proton Beam at the Injection Energy 4GeV,
ε_h = 13 mm mrad

Magnet Field Quality and RF Manipulations:
Involved Beam Loss studies necessary

CHROMATICITY CORRECTION



Systematic Resonances:

(sys1)	$2Q_X + Q_Y = 60$	(skew sext, sum)
(sys2)	$3Q_X - Q_Y = 48$	(skew oct, diff)
(sys3)	$-Q_X + 3Q_Y = 48$	(skew oct, diff)

Watchful eye on:

(sq+no1)	$Q_X - Q_Y = 4$	(skew quad, diff)
	$2Q_X - 2Q_Y = 8$	(norm oct, diff)
(sq+no2)	$Q_X + Q_Y = 39$	(skew quad, sum)
	$2Q_X + 2Q_Y = 78$	(norm oct, sum)

The “sys2”-Resonance: $|Q\xi|<20$

γ_t=45.5: $|Q\xi|<11$

CHROMATICITY CORRECTION

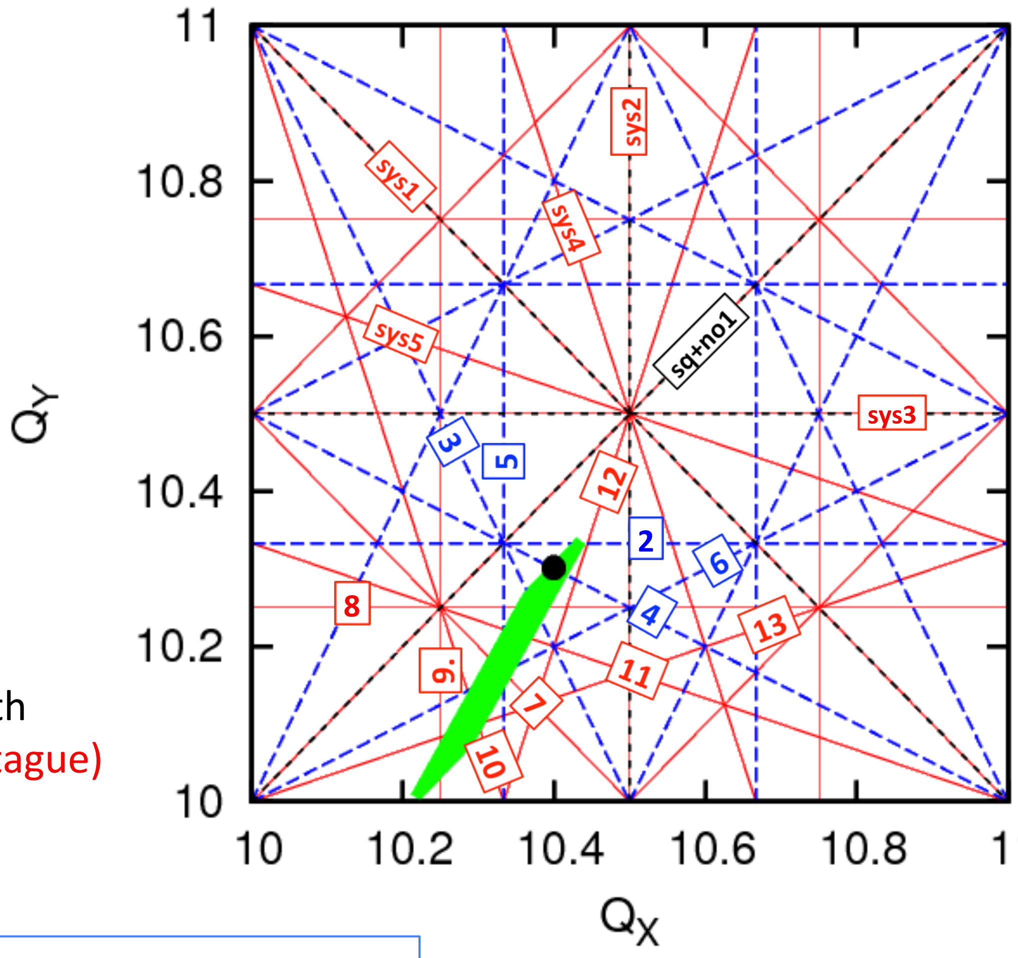
Systematic Resonances:

(sys1)	$2Q_X + 2Q_Y = 42$	(norm oct, sum)
(sys2)	$4Q_X = 42$	(norm oct)with
	$2Q_X = 21$	(norm quad, no sys)
(sys3)	$4Q_Y = 42$	(norm oct) with
	$2Q_Y = 21$	(norm quad, no sys)
(sys4)	$3Q_X + Q_Y = 42$	(skew oct, sum)
(sys5)	$Q_X + 3Q_Y = 42$	(skew oct, sum)

Watchful eye on:

(sq+no1)	$Q_X – Q_Y = 0$	(skew quad, diff) with
	$2Q_X – 2Q_Y = 0$	(norm oct and Montague)

Q_h=10.4, Q_v=10.3



no special requirements;
a transition crossing scenario needed.

CHROMATICITY CORRECTION

The present ξ-sextupoles:
42 Magnets, SL_{eff}=175T/m
(S=350T/m^2, L_{eff}=0.5m)

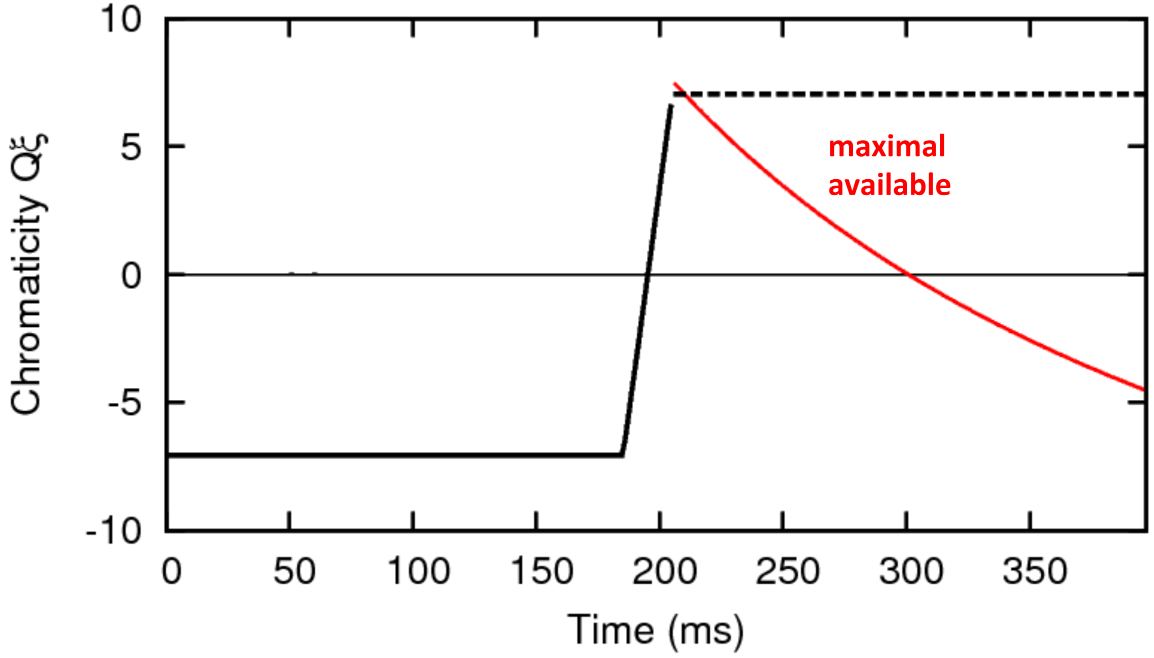
For a safe operation up to 100Tm:
SL_{eff}=260T/m needed.

U^{92+} 10GeV/u, Ion Lattice:
SL_{eff}=170T/m for full compensation.
narrow margin

Q_h=10.4, Q_v=10.3, γ_t=8.9: a large margin (SL_{eff}=20T/m for a full compensation)

Q_h=21.8, Q_v=17.7, γ_t=45.5:
SL_{eff}=120T/m (no error),
SL_{eff}=140T/m (Comp Model errors)
narrow margin

Q_h=21.8, Q_v=17.7, γ_t=18.3



usual requirement:
ξ<0 below transition
ξ>0 below transition

general standpoint:
ability to the full ξ-compensation

CHROMATICITY CORRECTION

1. Possible to get SL_{eff}=260T/m for a safe operation up to 100Tm?

2. Operation with $\xi<0$ above transition?

- instabilities have thresholds: safe operation below this intensity
- feedback (TFS) to cure instabilities also above threshold
- octupoles to increase the thresholds and to cure instabilities

Various possibilities:

- compensate only one plane (vertically)
- usage of the resonance sextupoles (6 magnets, 110T/m)

Up to what beam intensity the safe operation is possible with the present ξ-sextupole magnets?

MAGNET FIELD ERRORS

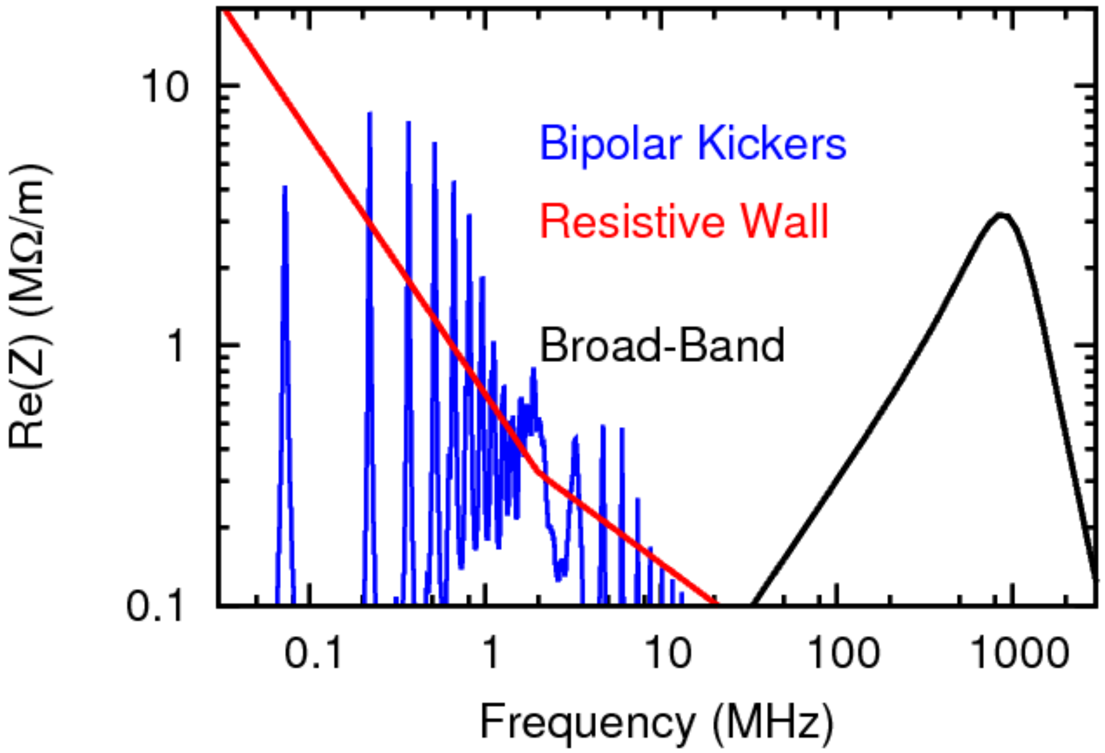
EXAMPLE: Dipole Magnet FoS

Q_h=21.8, Q_v=17.7, $Q_h\xi$=−30, $Q_v\xi$=−26, γ_t=18.3
goes to
Q_h=21.68, Q_v=17.84, $Q_h\xi$=−36, $Q_v\xi$=−19, γ_t=18.18

Q_h=10.4, Q_v=10.3, $Q_h\xi$=-12, $Q_v\xi$=−12, γ_t=8.9
goes to
Q_h=10.16, Q_v=10.53, $Q_h\xi$=−72, $Q_v\xi$=+38, γ_t=8.4
more sensitive to the magnet errors

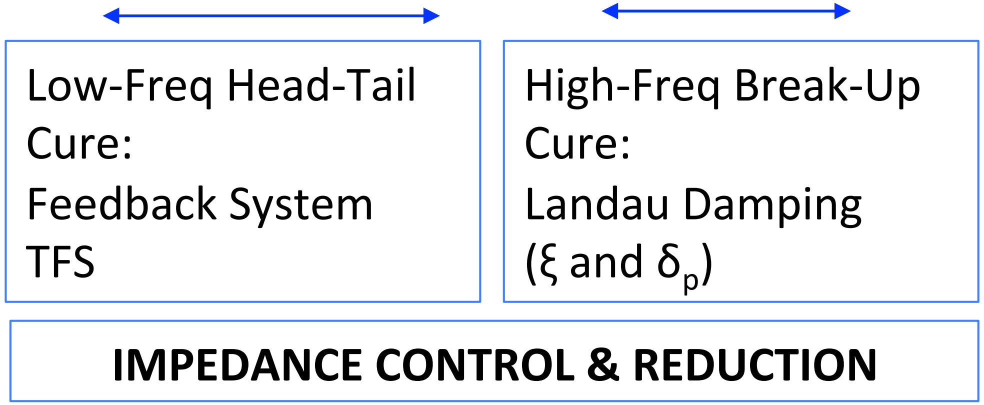
Magnet Field Quality: 3ε-DA for the U beam means 8ε-DA for p

COLLECTIVE STABILITY



The Brad-Band Impedance: adopted from the CERN PS data

Bipolar Kicker PFN Calculations: U.Niedermayer, U.Blell



Low-Freq Head-Tail
Cure:
Feedback System
TFS

High-Freq Break-Up
Cure:
Landau Damping
(ξ and δ_p)

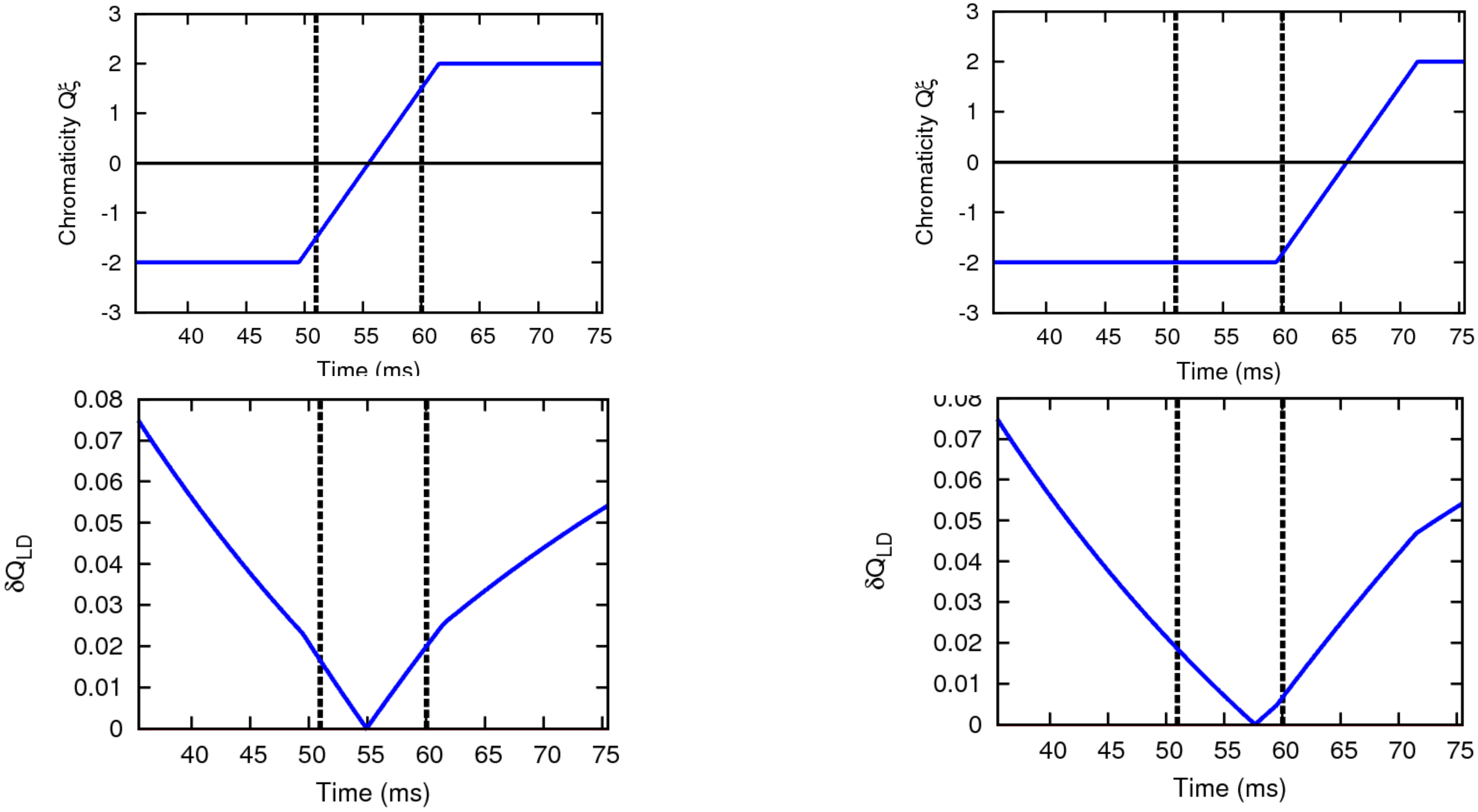
IMPEDANCE CONTROL & REDUCTION

FAST BROAD-BAND INSTABILITY: ξ-SCENARIO

Sextupole magnets maximal ramp rate 2000 T/m^2/s

Q_h=10.4, Q_v=10.3, γ_t=8.9

$\delta Q_{LD} = |\eta(n-Q_0)+Q_0\xi|\delta_p$

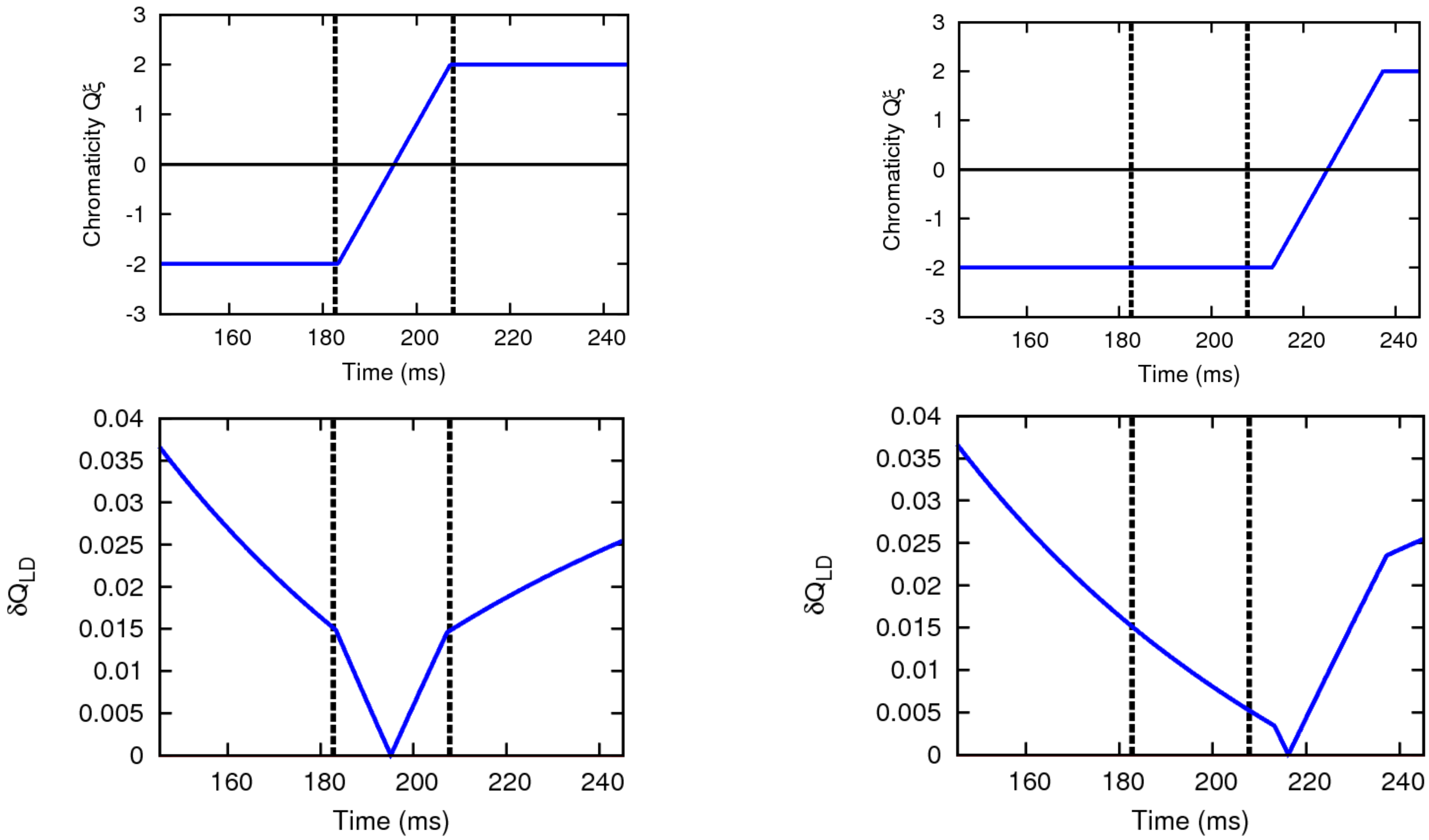


γ$_t$-jump is necessary to cure the Beam Break-Up Instability

FAST BROAD-BAND INSTABILITY: ξ-SCENARIO

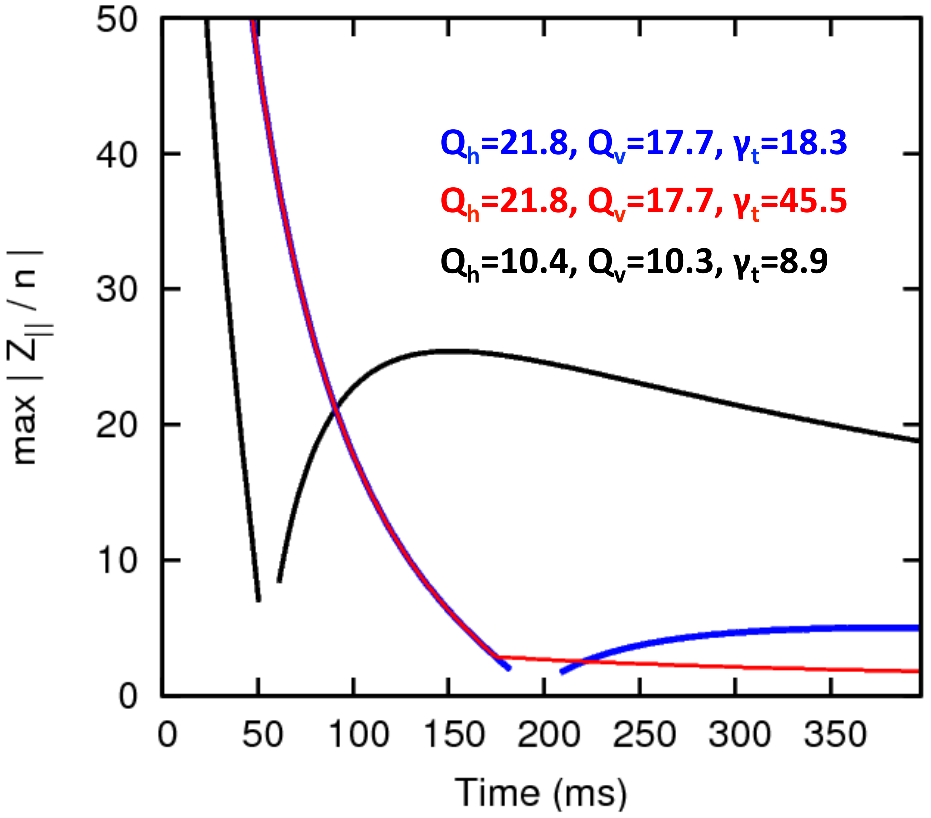
Sextupole magnets maximal ramp rate 2000 T/m^2/s

Q_h=21.8, Q_v=17.7, γ_t=18.3 $\delta Q_{LD}=|\eta(n-Q_0)+Q_0\xi|\delta_p$



Transition Crossing without jump might be possible (or below an Intensity Border)

LONGITUDINAL STABILITY



Boussard Criterion for the Microwave Instability
The inductive Broad-Band impedance measured at PS: $Z_{||}/n=i20\Omega$

Measures to control/minimize the SIS100 Broad-Band impedance are necessary.

PROTON OPERATION CYCLES

γ_t=8.9	**γ_t=18.3**	**γ_t=45.5**
safe transition crossing with γ_t-jump; no flexible ξ-scenario	no γ_t-jump possible: mismatch etc. flexible ξ-scenario	no transition crossing
2-bunches ramp needed; batch compression + bunch merging + stretching + rotation at the top (**rf hardware?**)	1-bunch ramp no rf-manipulations at the top	1-bunch ramp no rf-manipulations at the top
beam loss challenges at the bottom (rf manip): dispersion + strict δ_p-limit + magnet errors	good safety margin at the bottom for the accumulation and rf-manipulations	the γ_t=18.3 lattice needed at the bottom, beam loss still an issue; challenges at the top
safe ξ-compensation	no ξ>0 above 15GeV: operation above transition? + intensities? **or SL_{eff}=260T/m sextupoles needed**	sophisticated ξ-compensation necessary (magnet errors) **narrow margin of ξ-sextupoles**
(I.Strasik) halo collimation: 85%	halo collimation: 99%	high energy: no halo collimation
Beam Stability: Assessment of the machine Broad-Band Impedance (cold machine, later changes not possible) Bipolar Kickers: Feedback system TFS		