Karlsruhe Institute of Technology (KIT, Karlsruhe, Germany)

Institute for Beam Physics and Tehcnology,
KIT, Karlsruhe, Germany

Karlsruher Institut für Technologie

Non-linear beam dynamics studies at the Karlsruhe Research Accelerator KARA

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-
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* **outlined** are people involved into Beam dynamics experiments

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Outline

•The IBPT of KIT operates the 2.5 GeV electron storage ring KARA (former ANKA) as an accelerator test research facility and synchrotron radiation source

•Two high field superconducting wigglers (CLIC=3T and CATACT=2.5 T) are installed in the ring straights. While CLIC is located in the LONG straight section with small vertical beta-function (≈0.5 m) the CATACT wiggler is displaced in short straight where vertical beta-function is large (≈13 m)

•The lifetime of the electron beam degraded from ~15 hours to ~12 h at high level of CATACT wiggler field even though the coherent shift of vertical tune was compensated locally

•Computer simulations show non-linear nature of the effect --

1) Strengths of chromatic sextupoles are strong in order to operate ring at high positive chromaticity
2) Residual octupole components of wiggler field, even at tolerance level, reduce the dynamic aperture for particles with momentum offset;
3) At high chromaticity the betatron tune for off-momentum particles shifts toward weak octupole resonance. As a consequence, particles from beam halo are lost with higher probability and life time is reduced
4) vertical betatron tune WAS in vicinity of sextupole resonance **Qy=8/3**. Large resonance stop-band and proximity to **Qy=2.667…** harmed lifetime, beam stability during injection and ramp

•CURE

•Working point of ring has been shifted away from suspected high-order resonances and beam lifetime as well as stability at injection, ramp and plateau were essentially improved

•MORE

•Reduced compaction factor settings at high vertical tune have been implemented and successfully tested

Model of KARA ring created in OPA*

CATACT - short straight section **CLIC** - long straight section

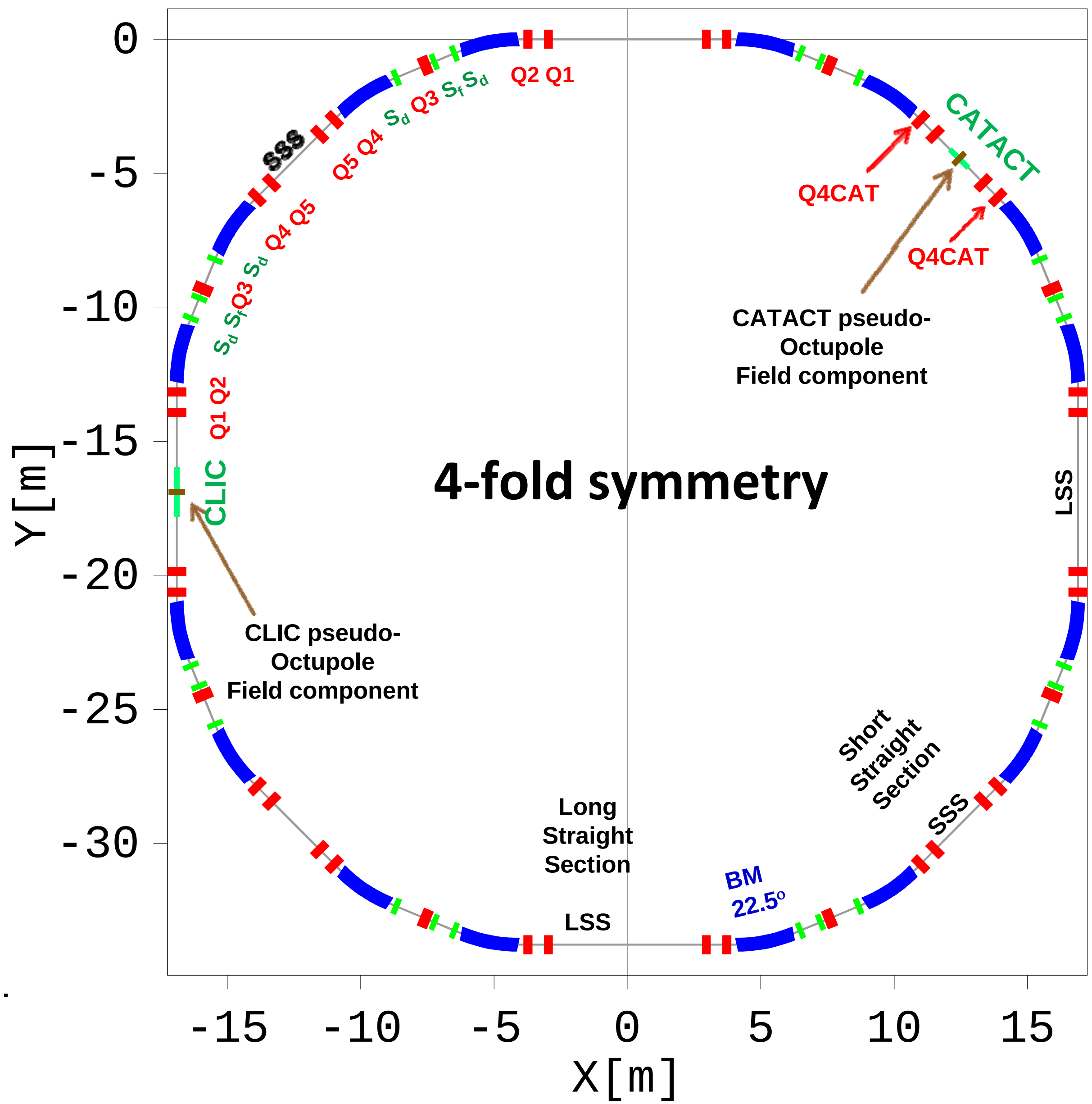
RING

E =2.5 GeV | B·R = 8.33 T·m
4-fold symmetry | L = 110.4 m
Long/short straight sections 5.604 / 2.236 m

Bends (16) B = 1.5 T L=2.183 m,
Bending angle θ=22.5°,
Bending radius R=5.559 m
Parallel edges $\theta 1=\theta 2$=11.25°
Gradient G=0 (flat) | Vertical gap=40 mm
Pole width =160 mm | Field index = 0
Current = 900 A | N*I=54kA×Turns
Power=23.5 kW

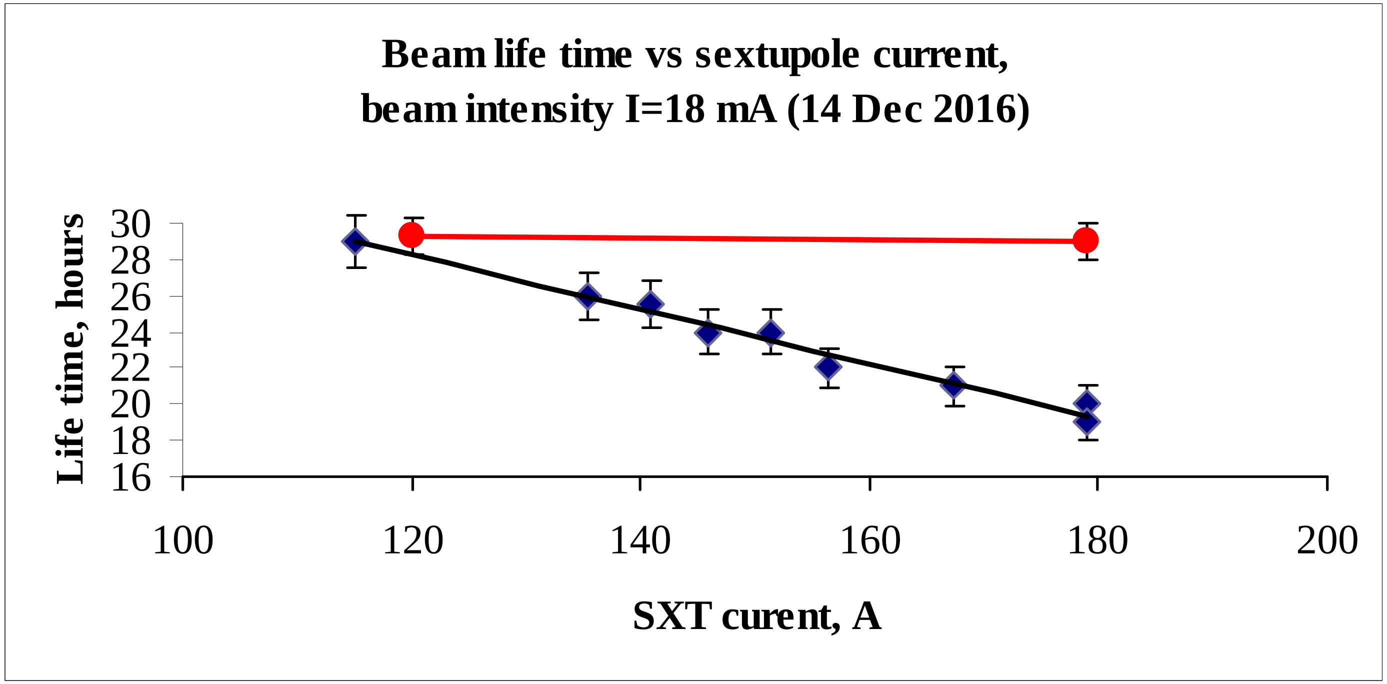
Quads (32 + 8) Aperture ∅ = 70 mm
Length LQ1,2,4,5=0.32 / 0.35 m (iron/eff)
Length LQ3=0.39 /0.42 m (iron/eff)
Gradient $\partial B/\partial R \leq$ 22T/m
Strength $k=(1/BR)\cdot(\partial B/\partial R) \leq$ **2.6 m^{-2}**

Sextupoles (16+8) Aperture ∅=75 mm
SXT Grad $G_s = \partial^2 B/\partial R^2 \leq 800$ T/m^2
SXT Str. $k_S=(1/BR)\cdot(\partial^2 B/\partial R^2) \leq 90$ m^{-3}
SXT Length L_S = 0.12 m
SXT Integr strength $k_S \cdot L_S \leq$ **10 m^{-2}**



* A.Streun. Computer code OPA. Version 3.81. SLS Design note. 2016.

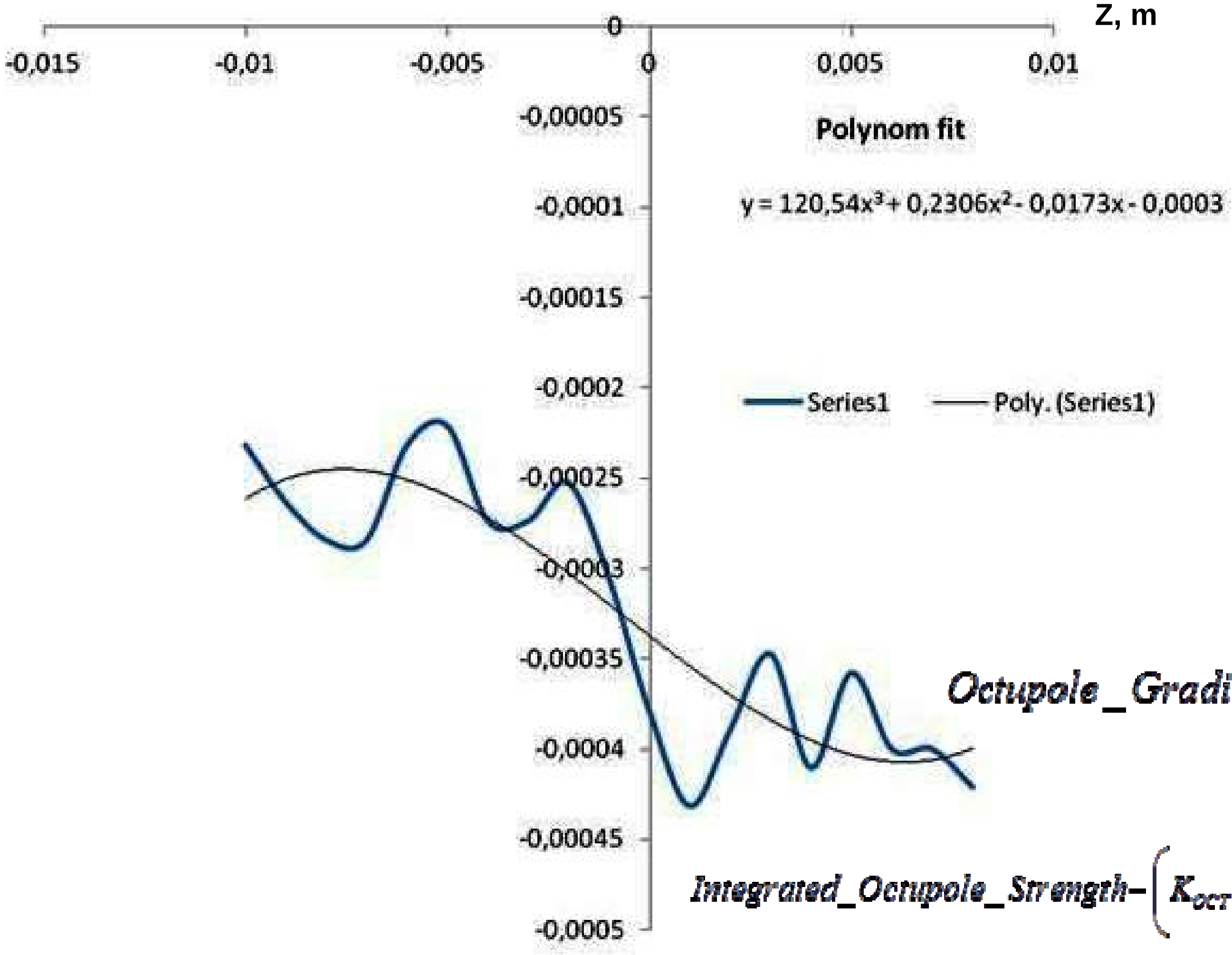
Life time measurements.
E=2.5 GeV.   Original tune Qy=2.69



Life time (hours) as function of current of vertical sextupole.
I=18 mA. ANKA tests 15 Dec 2016

Red – CATACT is OFF**.**
Black – CATACT=2.5 T.

High order magnetic field components of CATACT (measured)



$$Octupole\_Gradient - \left(\frac{\partial^3 B}{\partial y^3} = 120 T / m^3 \right)$$

$$Integrated\_Octupole\_Strength - \left(K_{OCT} \cdot L_w = \left(\frac{1}{B \cdot R} \right) \cdot \frac{\partial^3 B}{\partial y^3} \cdot L_w \approx 15 m^{-3} \right)$$

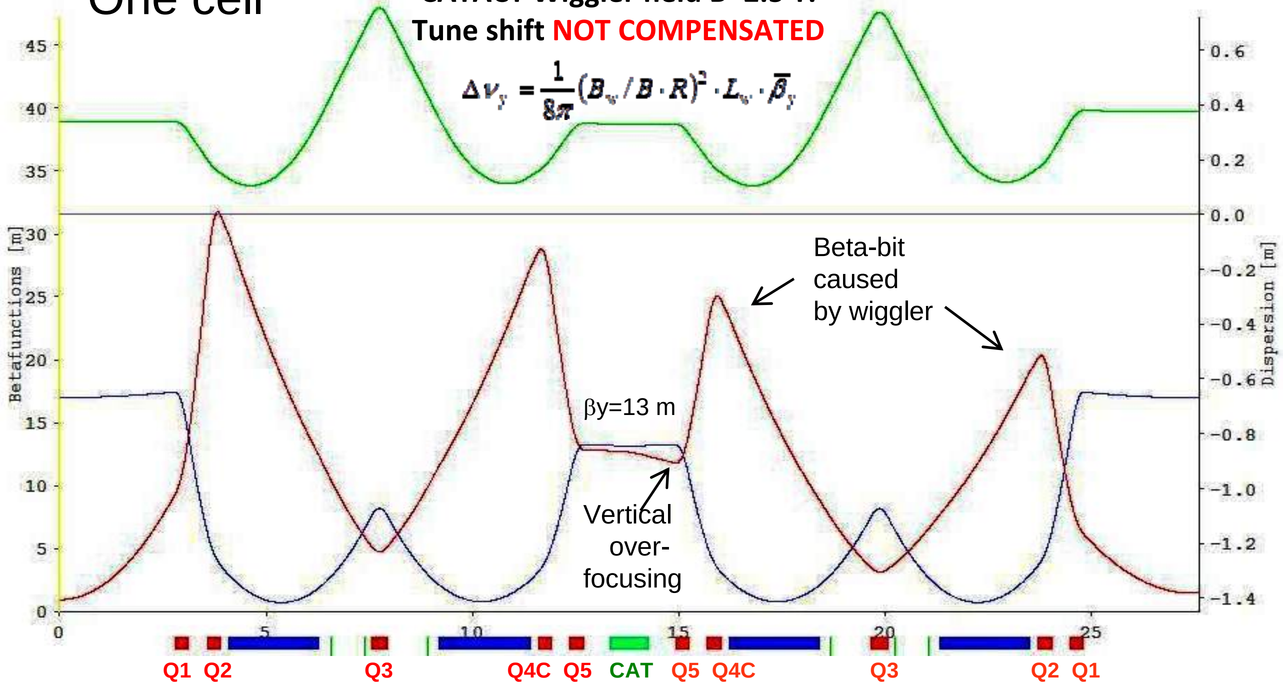
Integrated Octupole gradient of CATACT wiggler measured during BINP on-site tests does not exceed tolerances set by design specifications

GR_OCT * L ≈ 100 T/m²

One cell

CATACT Wiggler field B=2.5 T.
Tune shift NOT COMPENSATED

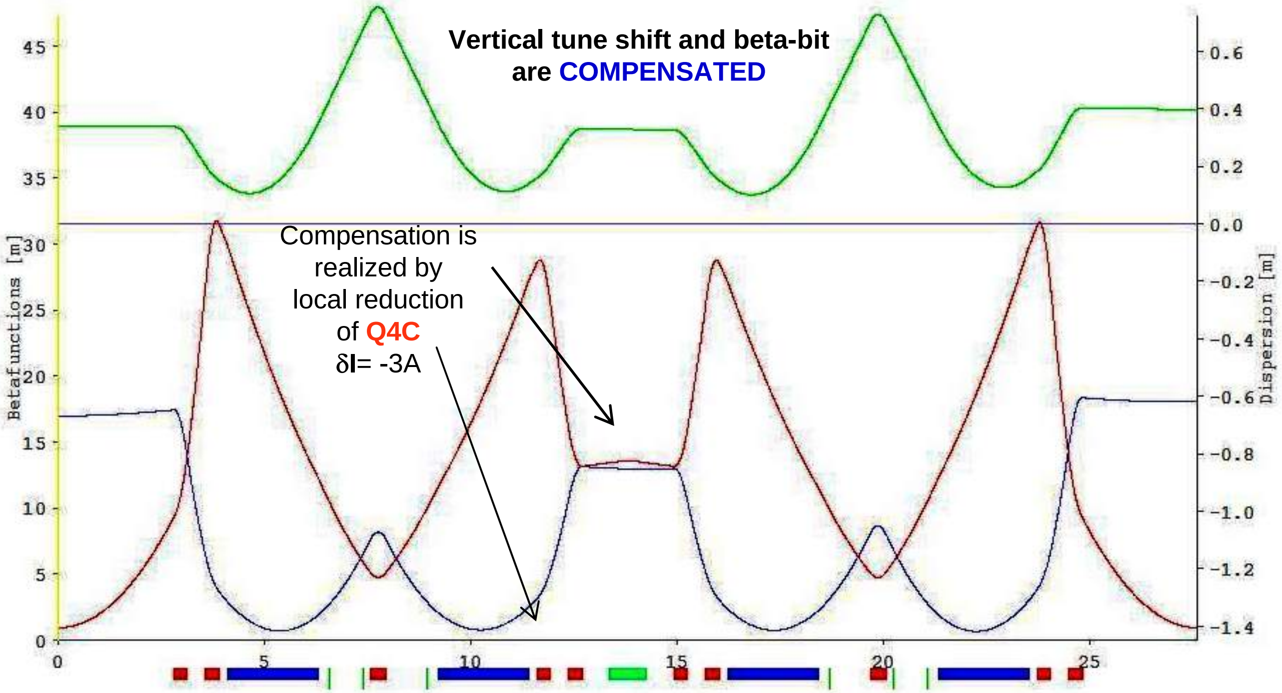
$$\Delta\nu_y = \frac{1}{8\pi}(B_w/B\cdot R)^2\cdot L_w\cdot\bar{\beta}_y$$



CATACT cell
STR Q4CAT = -1.82 m-2
Qy(CAT_cell) = 0.7177
Qx (CAT-cell)=1.6889

Regular cell
STR Q4 = -1.82 m-2
Qy(reg_cell) = 0.6720
Qx (reg-cell)=1.6888

Vertical tune shift and beta-bit are COMPENSATED

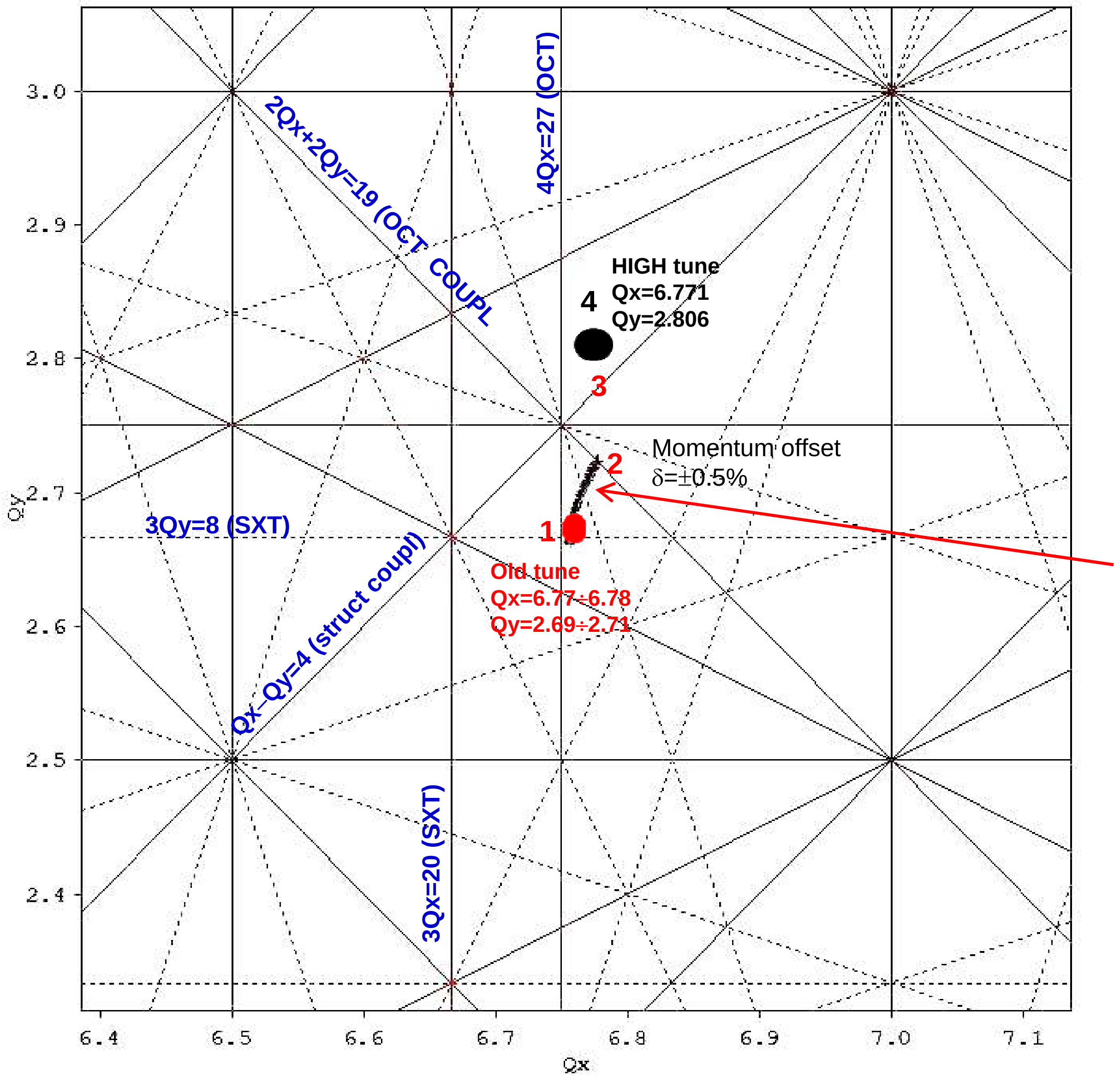


Regular cell
Q4 STR = -1.82 m-2
Qy(reg_cell) = 0.6720
Qx (reg-cell)=1.6889

CATACT cell
Q4CAT STR=-1.79155 m-2
Qy(CAT_cell) = 0.6720
Qx (CAT-cell)=1.6964

I (Q4) ≈ - 196 A δ**I** = -3 A

Tune diagram of KARA ring



RED spot (1) – original betatron tune

BLACK spot (4) – high betatron tune

Ring operation at old tune suffered from proximity to SXT resonance Qy=8/3 (2,667) and coupling octupole resonce excited by CATACT wiggler at high field level (2÷2.5 T).

At the same, the ring operates at **high positive chromaticity** to avoid HEAD-TAIL instability.

Tune shift at HIGH CHRx,y=+2/+6 push OFF-MOMENTUM particles towards high order resonances (2) driven by residual octupole comp. of CATACT field. Particles with momentum offset cross OCT RES (2)

Ring Operation at reduced chromaticity (+1,+1) AND at High vertical tune (Qy=2.81) does not affected by sextupole either octupole reasonances.

The life time of beam at high tune (4) was restored to nominal value and even improved

Tune diagram – up to 4th order incl. Skew resonances

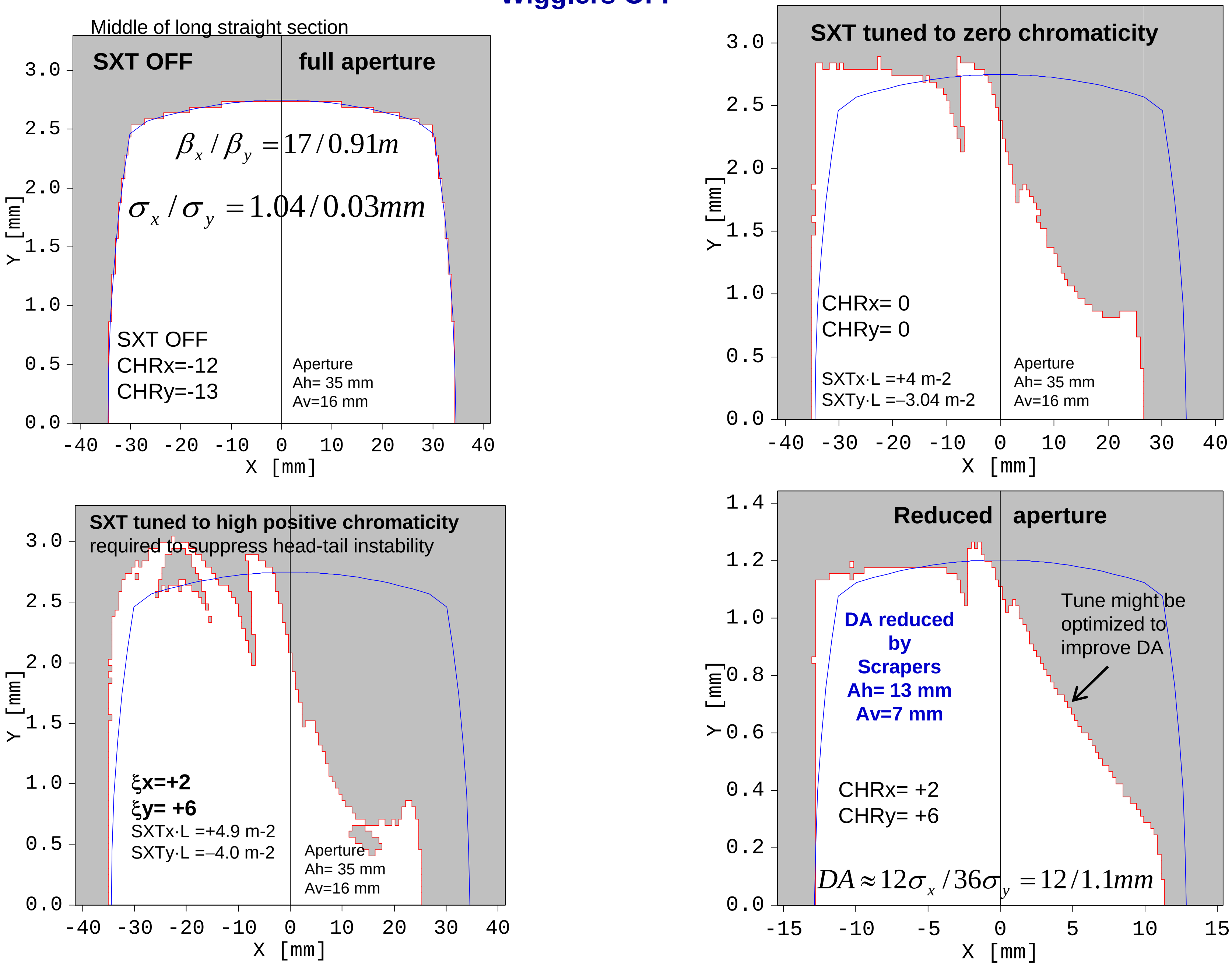
1 – unstable operation close to SXT resonance Strong sextupoles create Large stop-band of resonance

2– reduced life time Cross coupl Oct Res excited by CATACT at high field level

3 -- Reduction of life time Cross coupl Str res Qx-Qy=4 excited by field Errors & misalignments of quads

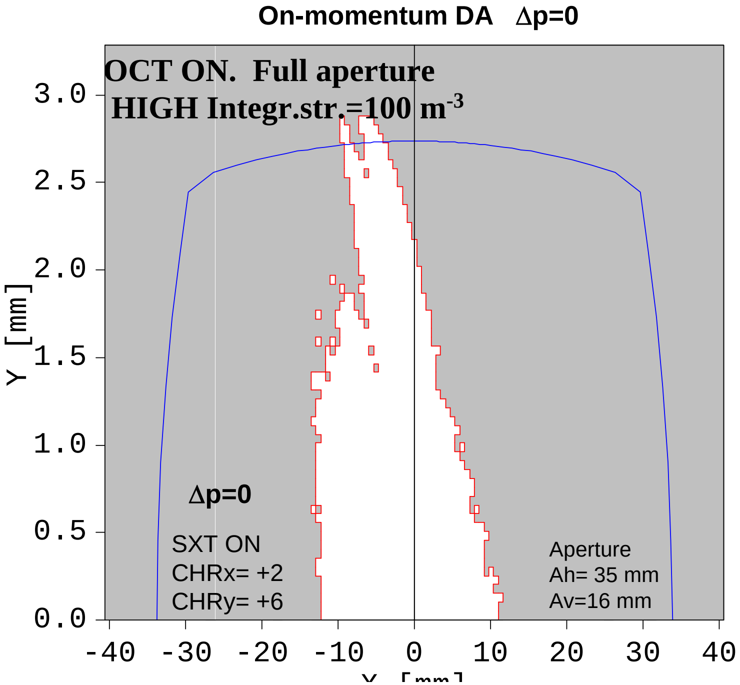
Dynamic Aperture of KARA ring
and
effects of high order components
of
residual field
of
CATACT wigler

Dynamic Aperture (DA). Original tune Qy=2.69.
Wigglers OFF

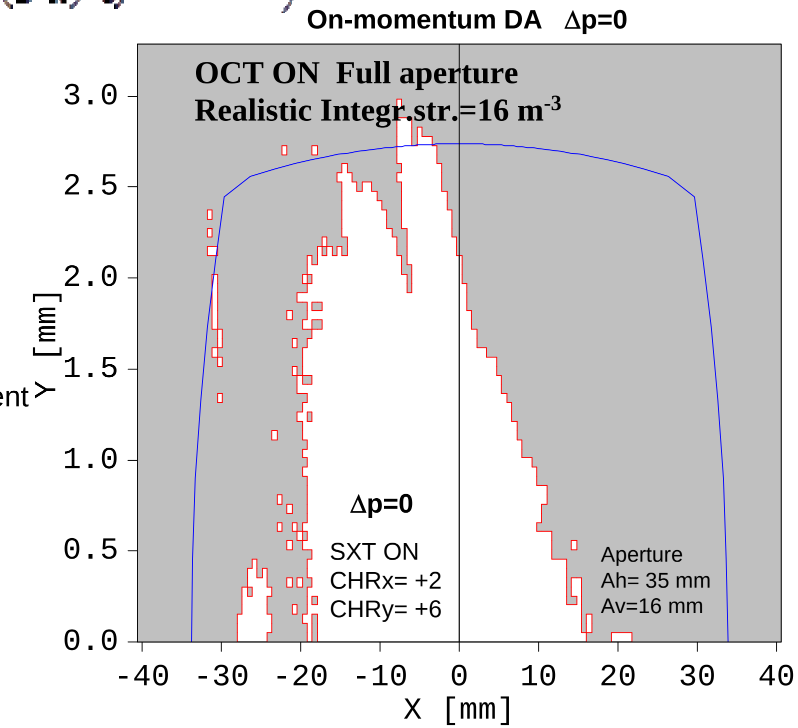


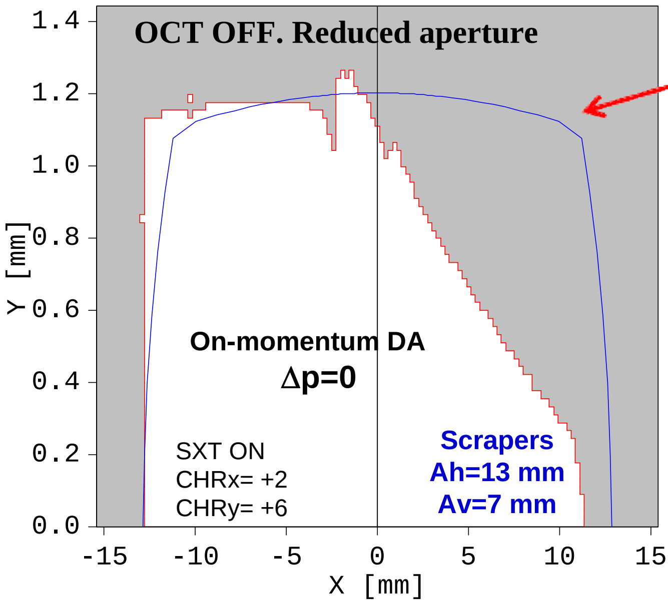
Dynamic Aperture for ON momentum particles. OLD tune Qy=2.69. Wiggler B=2.5 T

$$Integrated\_Octupole\_Strength - \left(K_{OCT} \cdot L_w = \left(\frac{1}{B \cdot R} \right) \cdot \frac{\partial^3 B}{\partial y^3} \cdot L_w \approx 15 m^{-3} \right)$$



Octupole field drastically reduces Dynamic Aperture (and life time) due to ADTS if beam is wide ($\Delta X > 15$ mm) - even at WEAK (RESIDUAL) OCTUPOLE component

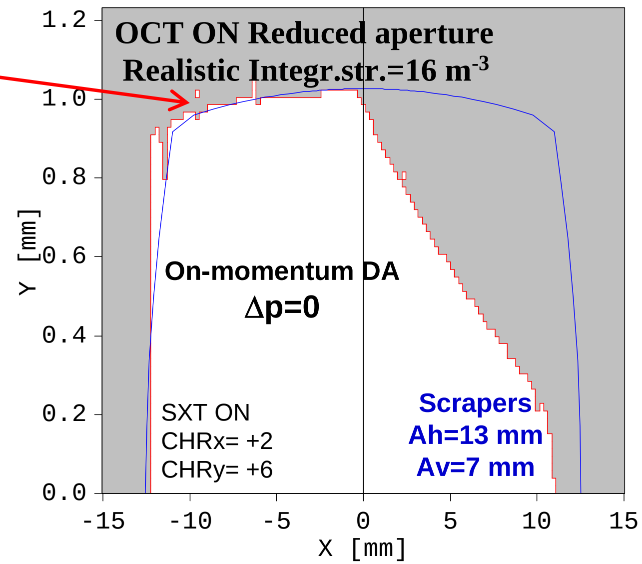




If ring DA is restricted by scrapers

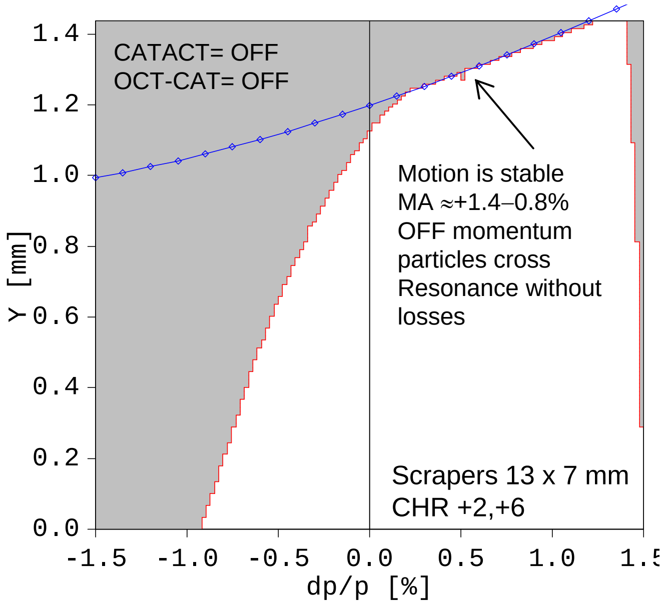
The effect of residual OCTUPOLE component of CATACT field Is NOT VISIBLE for <u>ON-momentum</u> particles

BUT !



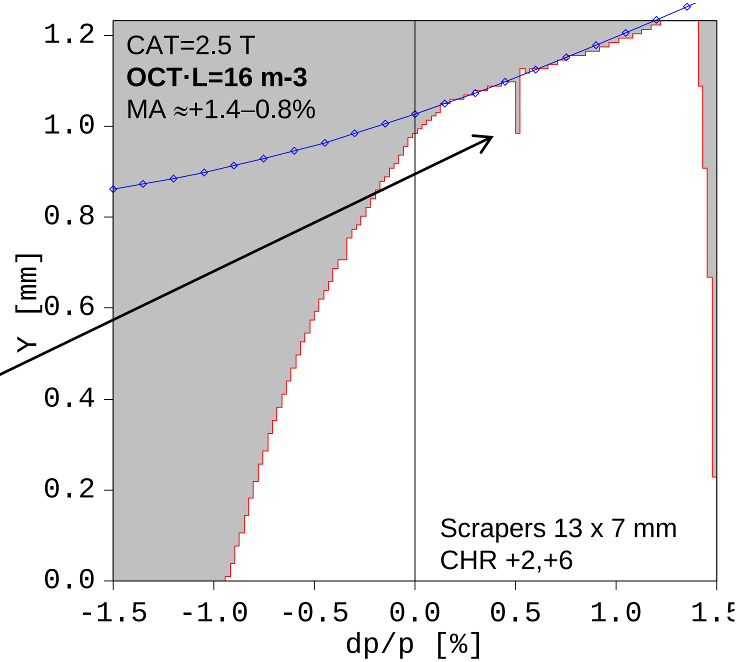
Momenutm acceptance. Original tune Qy=2.69

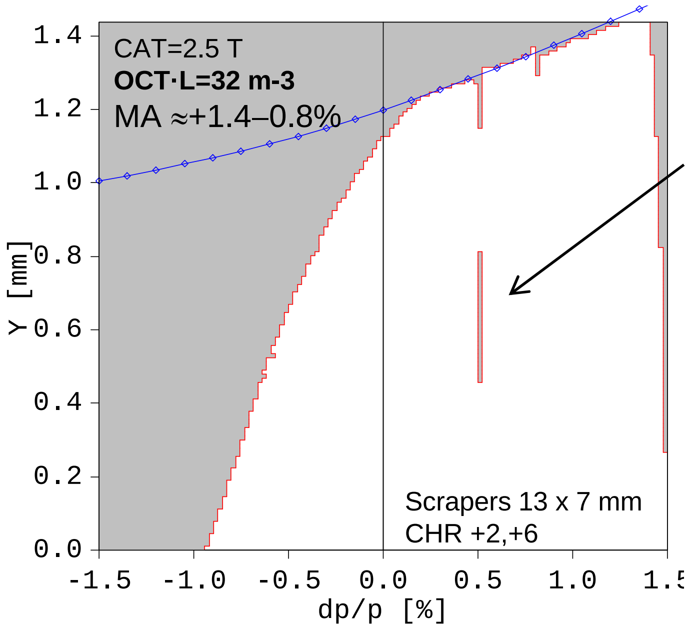
Wiggler field B= 2.5 T.



Resonance
2Qx+2Qy=19
for OFF-Momentum
particles δp/p≈+0.5%
driven by octupole
appears

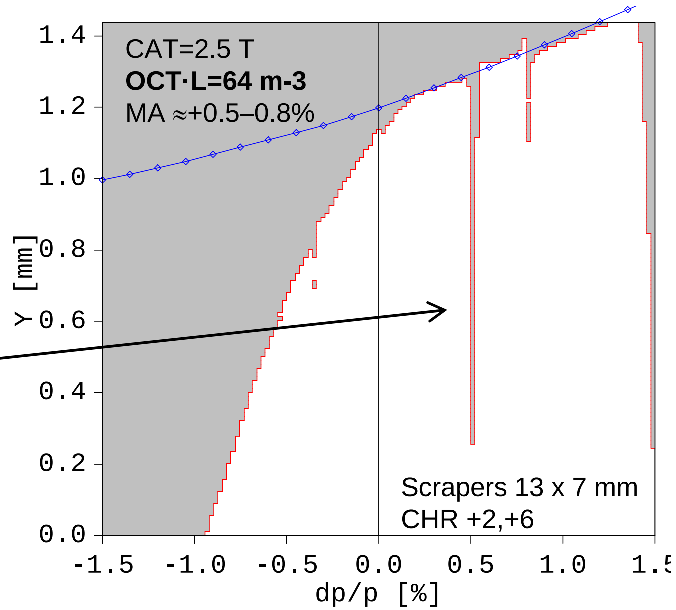
Octupole strength
does not exceed
tolerance set
on CATACT wiggler





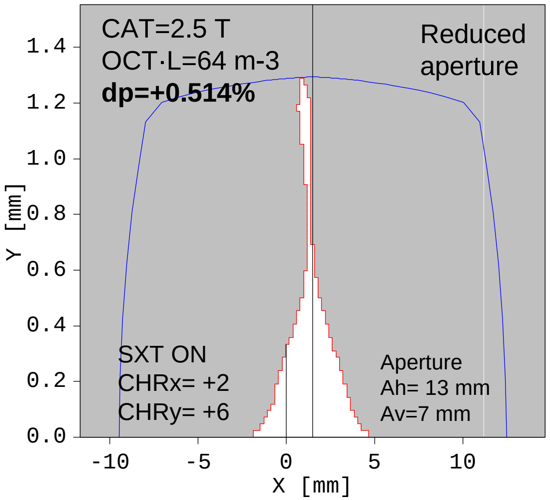
Resonance
2Qx+2Qy=19
for OFF-Momentum
particles δp/p =+0.5%
driven by octupole
grows

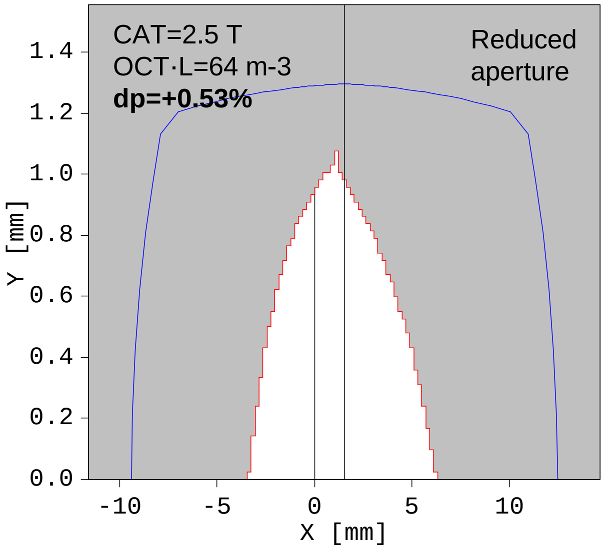
Resonance
2Qx+2Qy=19
for OFF-Momentum
particles δp/p =+0.5%
driven by octupole
SHRINKS DA to < 0.2 mm

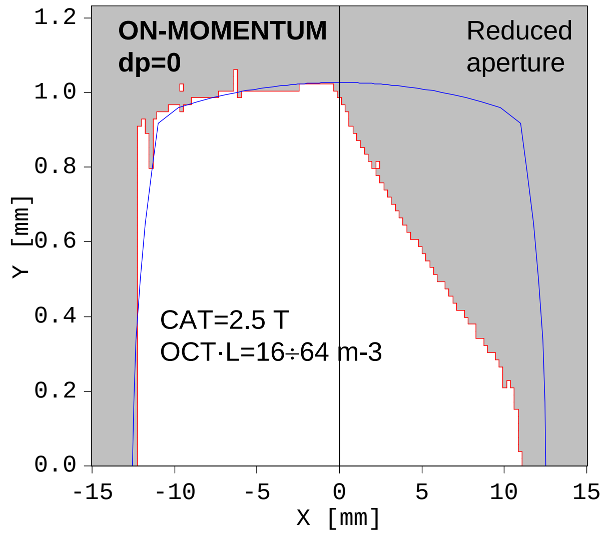


Dynamic Aperture at different momentum offset. OLD tune Qy=2.69.

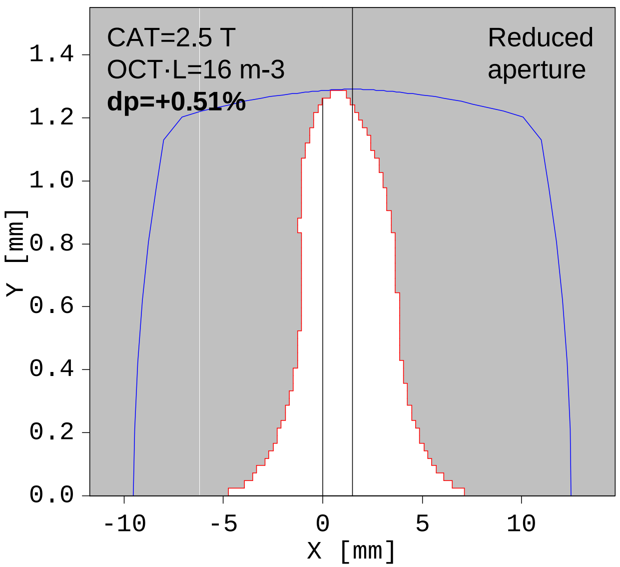
Wiggler field B= 2.5 T

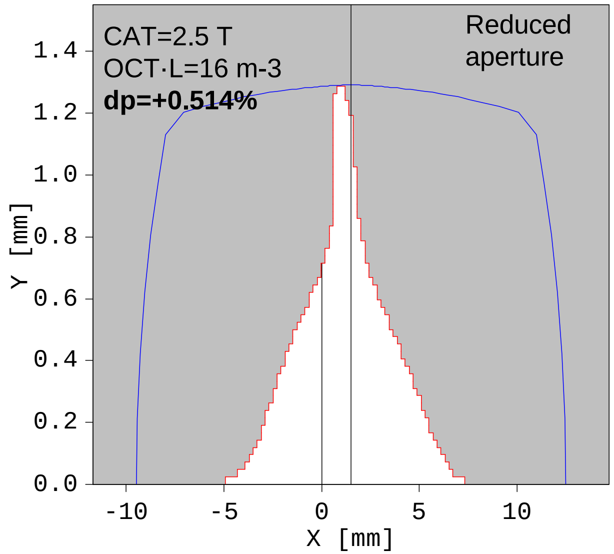


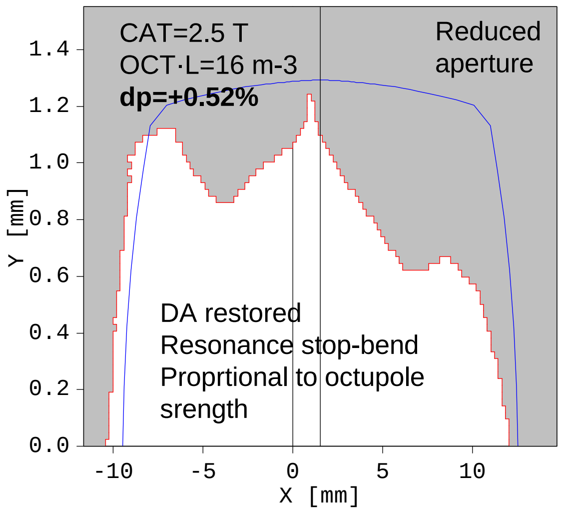




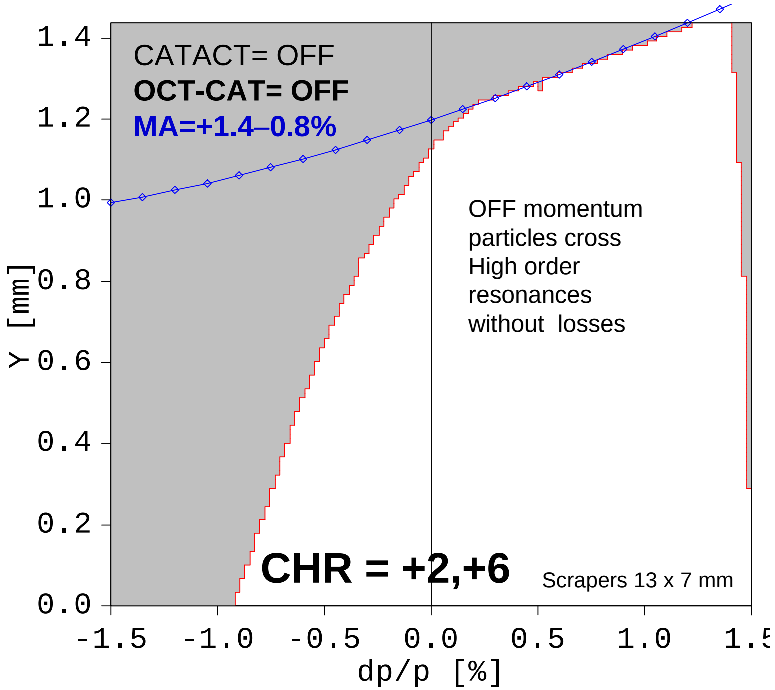
Providing the strength of Octupole component exceeds tolerance in few times the OFF –momentum DA might srhinks to Zero and beam might be LOST. Life time in ANKA is defined by Touschek inelastic scattering with large momentum deviation at high beam current and inelastic scattering on residual gas on large momentum offset >±1 % (ANKA MA is measured as ±1%). Providing the OCTUPOLE resonance appears at dp=0.5% the off-momentum DA shrinks but not to ZERO, Thus MA and life time should be reduced

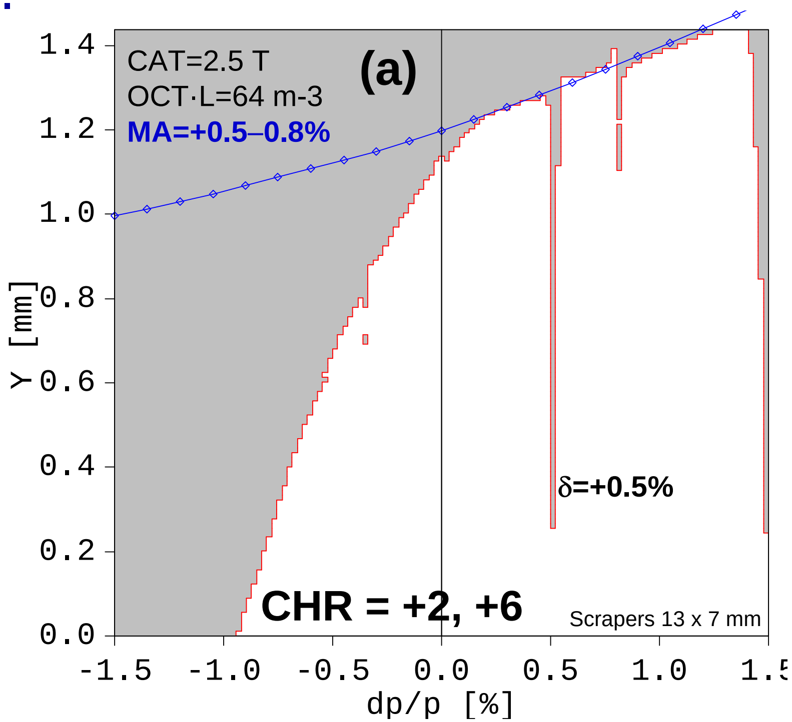






Effect of Chromaticity reduction to improve momentum acceptance (old tune). Wiggler B=2.5 T.



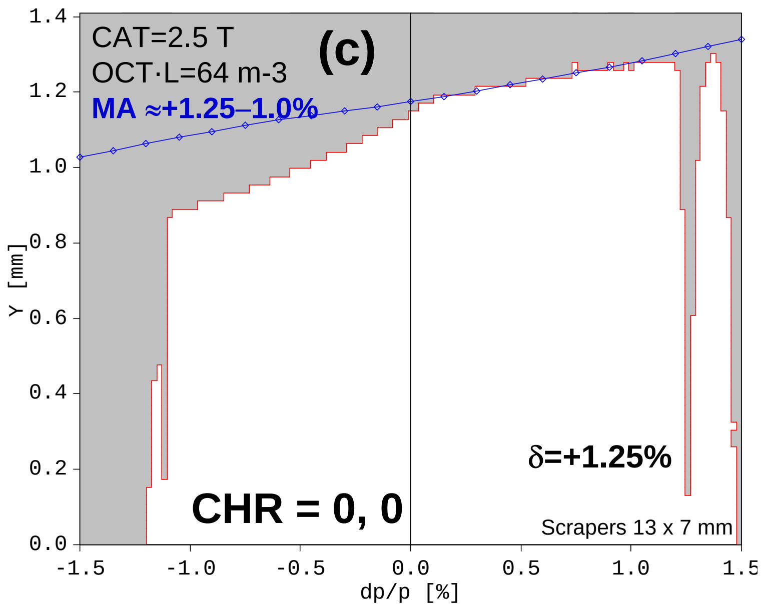


Resonance
2Qx+2Q=19
Driven by octupole
Component of CATACT
shrinks DA for particles
with momentum offset

(a)δp/p = +0.5%
CHR = +2,+6

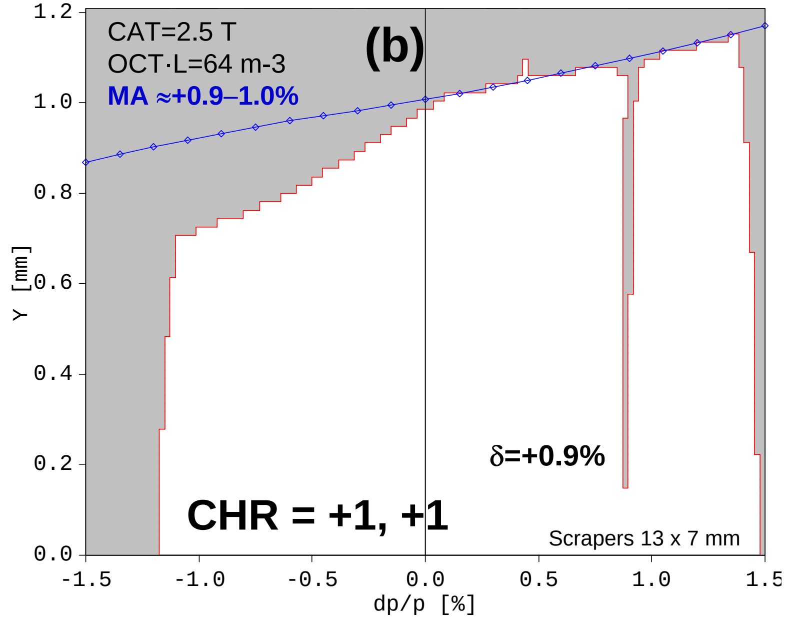
(b) δp/p = +0.9%
CHR = +1,+1

(c) δp/p = +1.24%
CHR = 0, 0

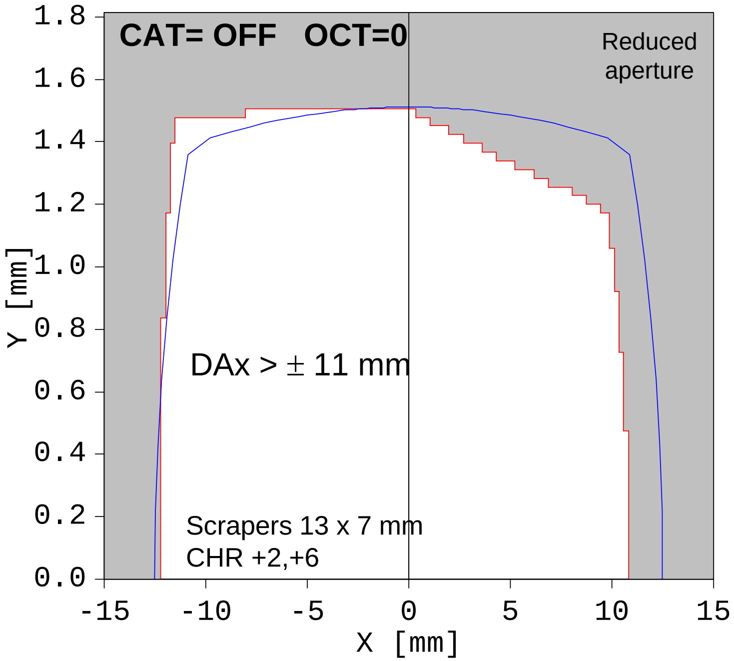


Momentum offset of resonance is shifted off reference energy while Chromaticity is reduced

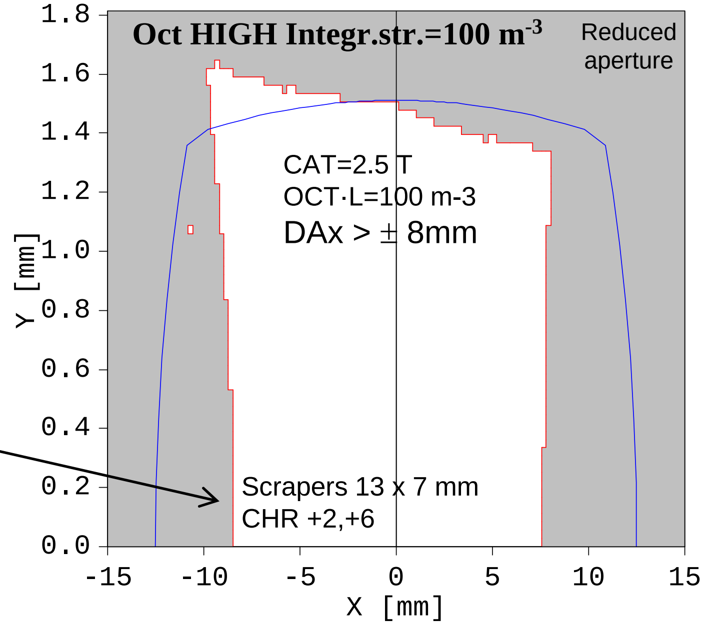
The life time might be RESTORED by reducing of Chromaticity at 2.5 GeV and Feedback ON while CATACT at top field level B=2.5 T



Dynamic Aperture. HIGH tune Qy = 2.81
CATACT Wiggler ON. B= 2.5 T

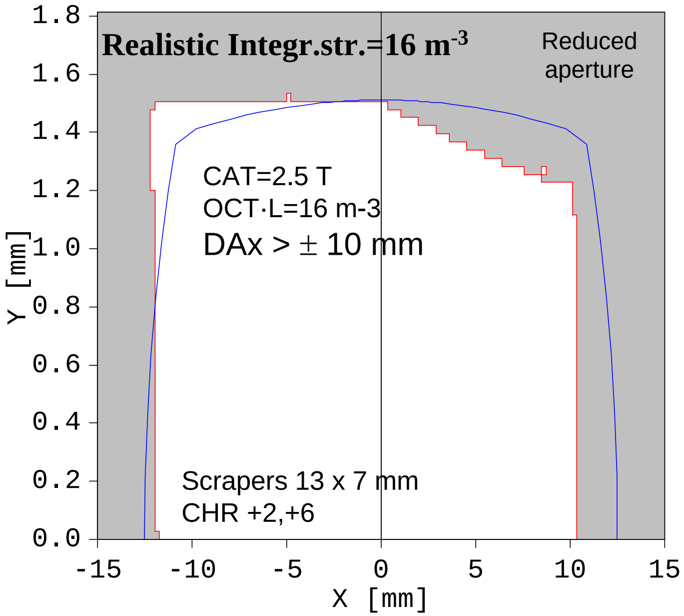


High tune
Qy = 2.81

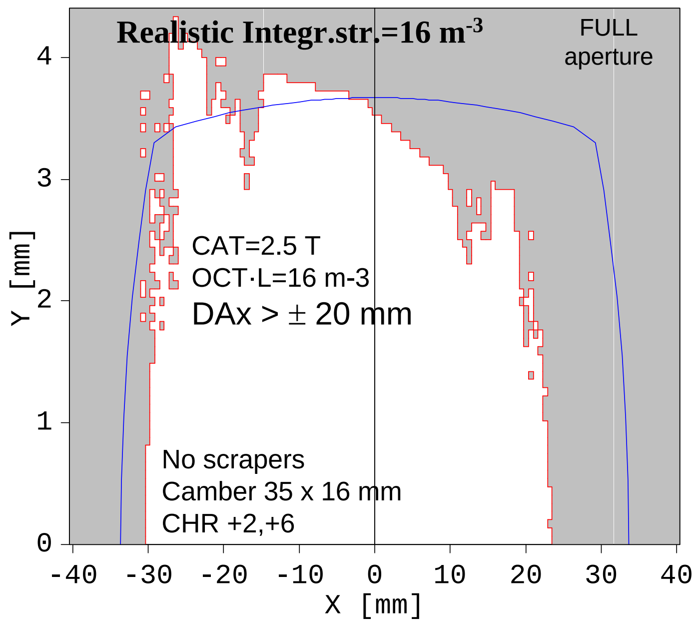


Life time might be
Slightly reduced
at high intgr. octupole
Strength > 100 m-3

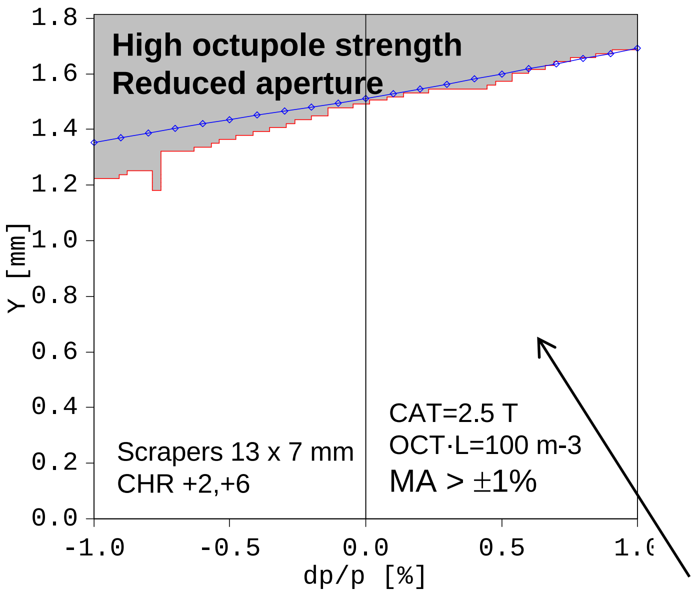
$\sigma_x / \sigma_y = 1.04 / 0.03mm$



No CATACT neither CLIC
Wigglers with small
octupole components
set by tolerances
OCTGR*L< 100T/m3
Should NOT restrict
ring operation at
proposed workig point



Momentum acceptance at HIGH TUNE Qy=2.81.
CATACT Wiggler ON. B= 2.5 T



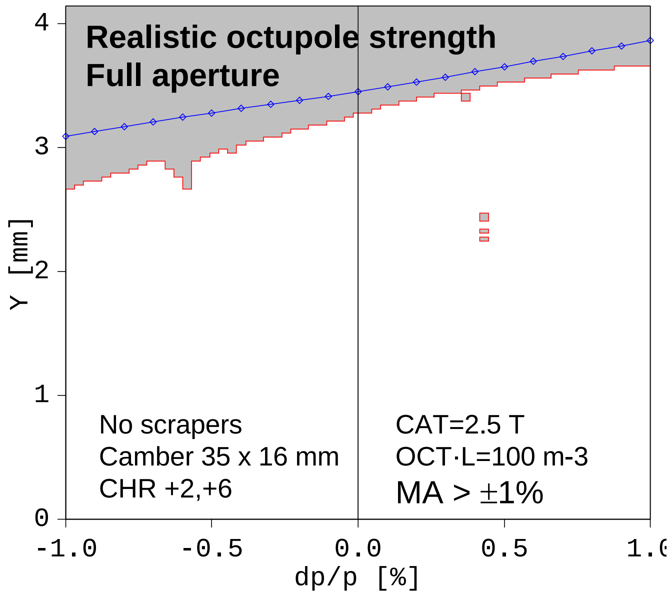
Betatron tune is chosen away of SXT and OCT resonances

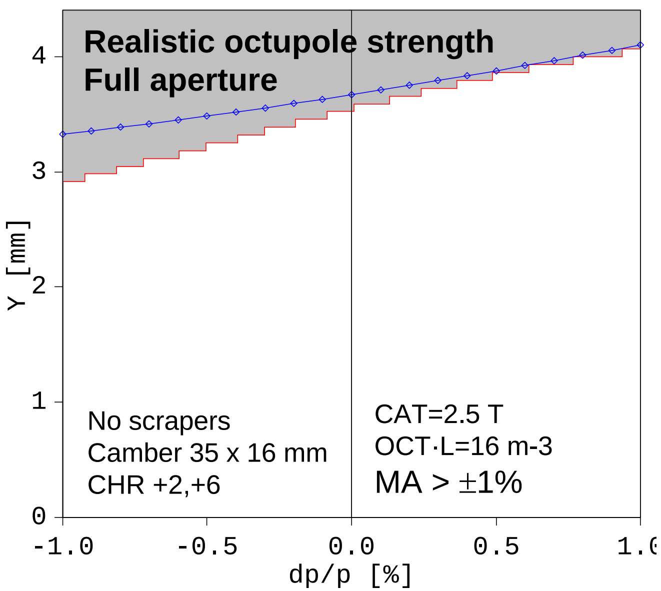
High tune
Qy = 2.81

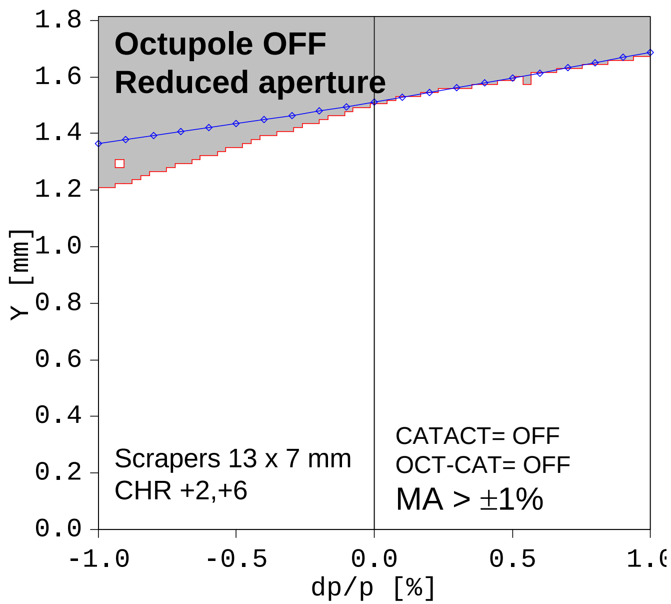
Stable motion for ON- momentum and OFF-momentum particles

No distortion of Phase space even at HIGH INTGR. OCTUPOLE Strength
- 100 m-3 and large
- oscilation amplitude
- ANKA operates at safe
- margins of SCrapers

One might consider an option to introduce octupoles for manipulation with compaction factor and Landau damping of instabilities thus increasing stored beam current

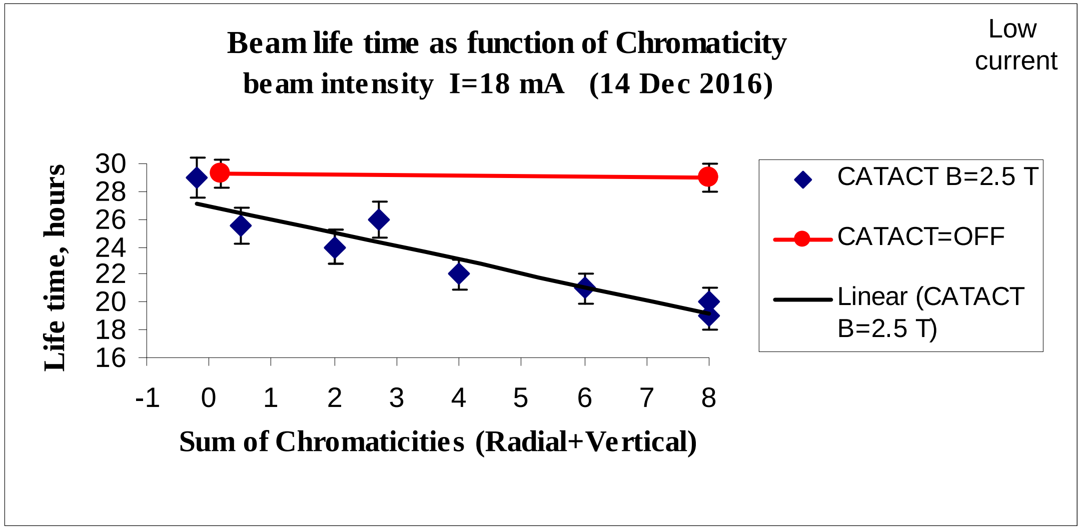






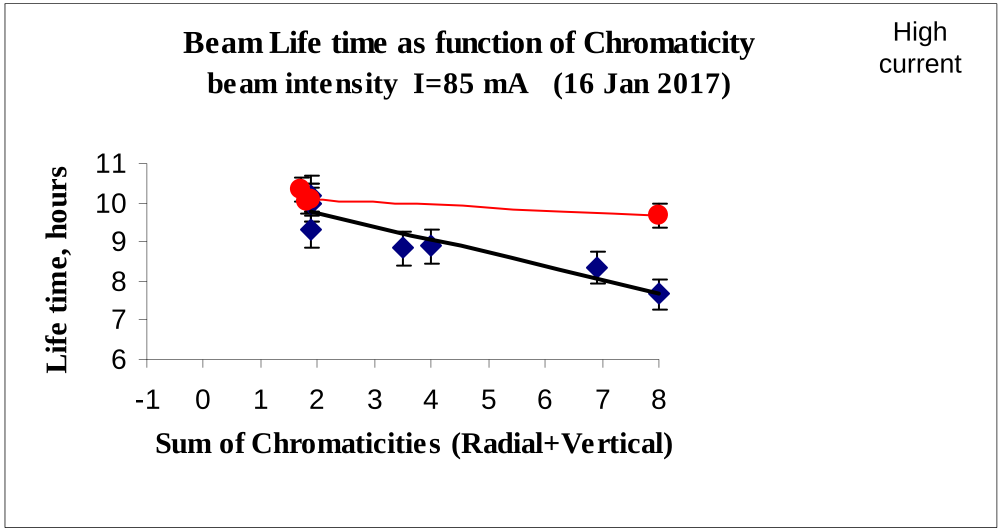
Ring tests

Life time measurements 2.5 GeV Qy=2.69



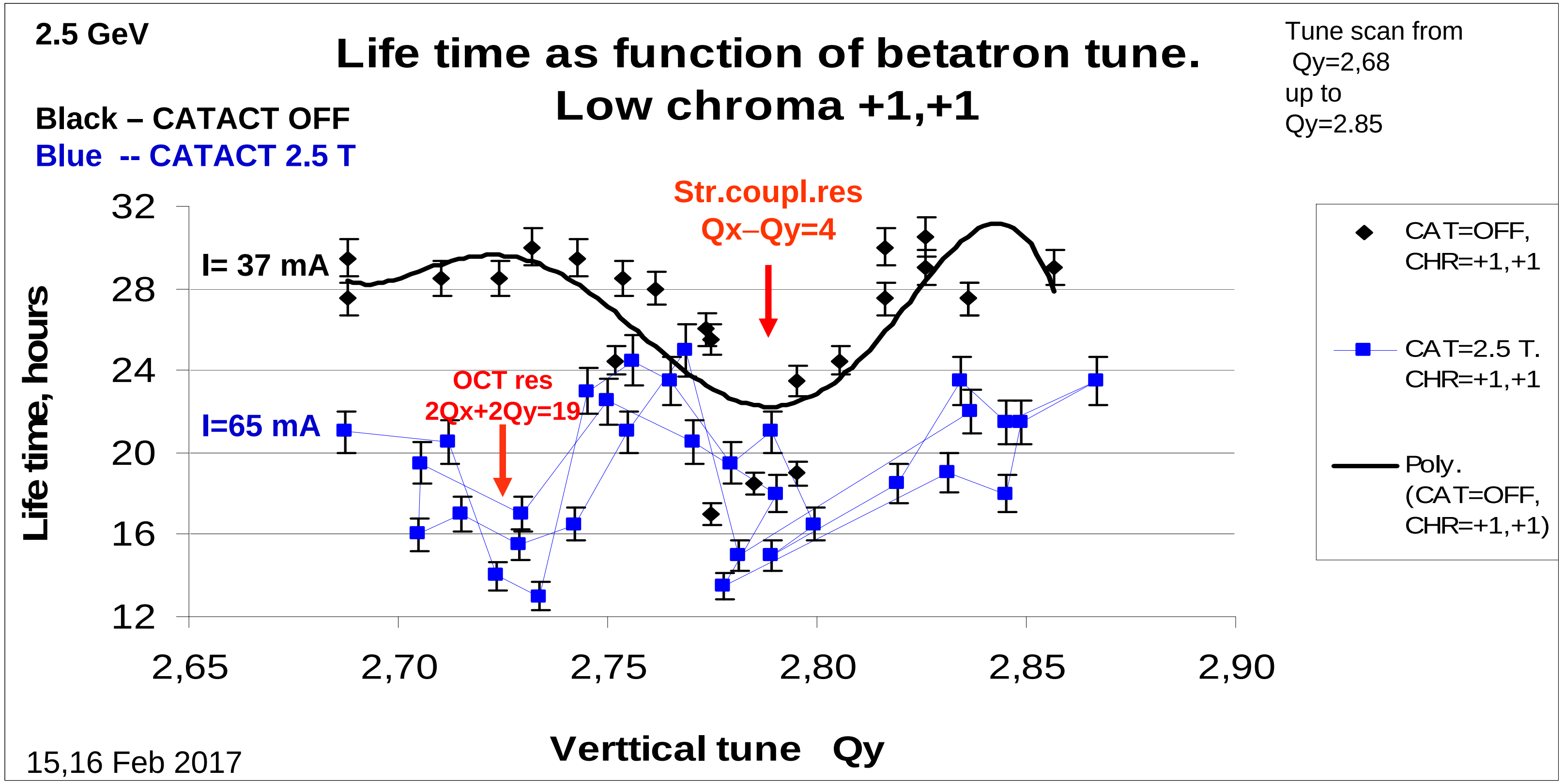
Red – CATACT OFF
Blue – CATACT=2.5 T

Dependence of Life time on chromaticity (sum of CHR=$\xi x + \xi y$). E=2.5 GeV.
Beam current 18 mA ANKA tests 15 Dec 2016.

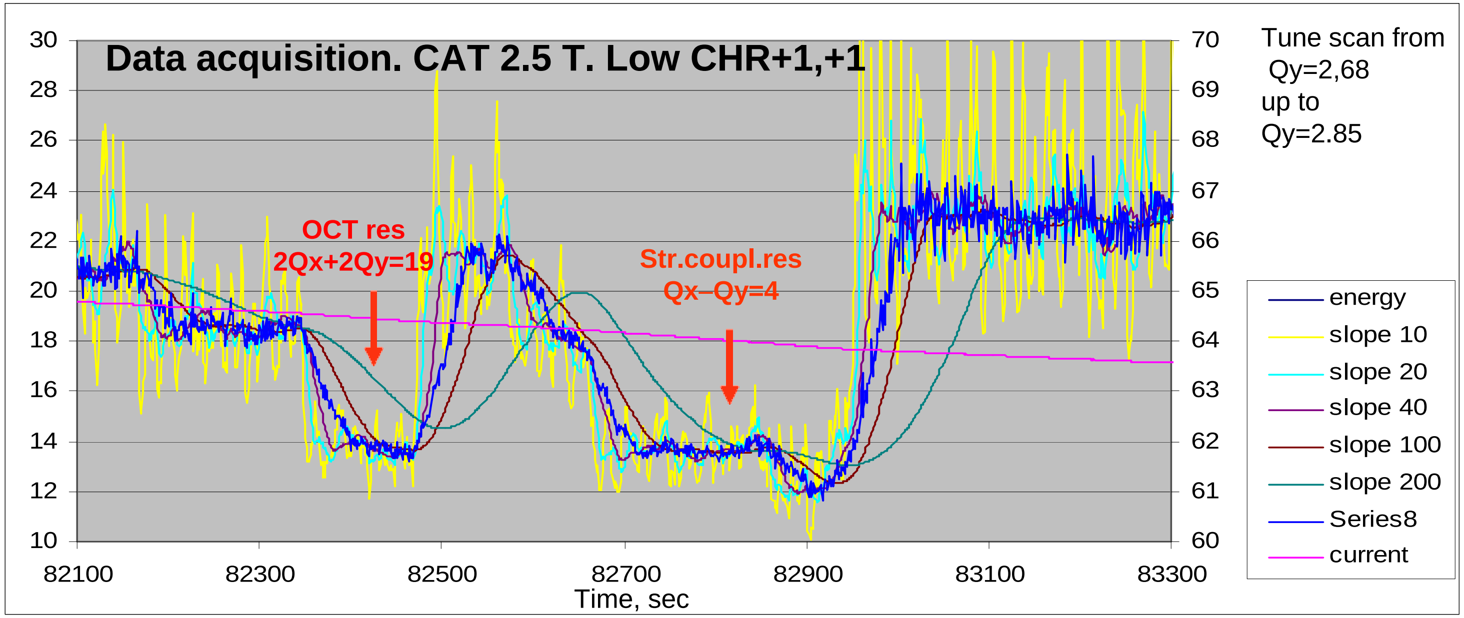


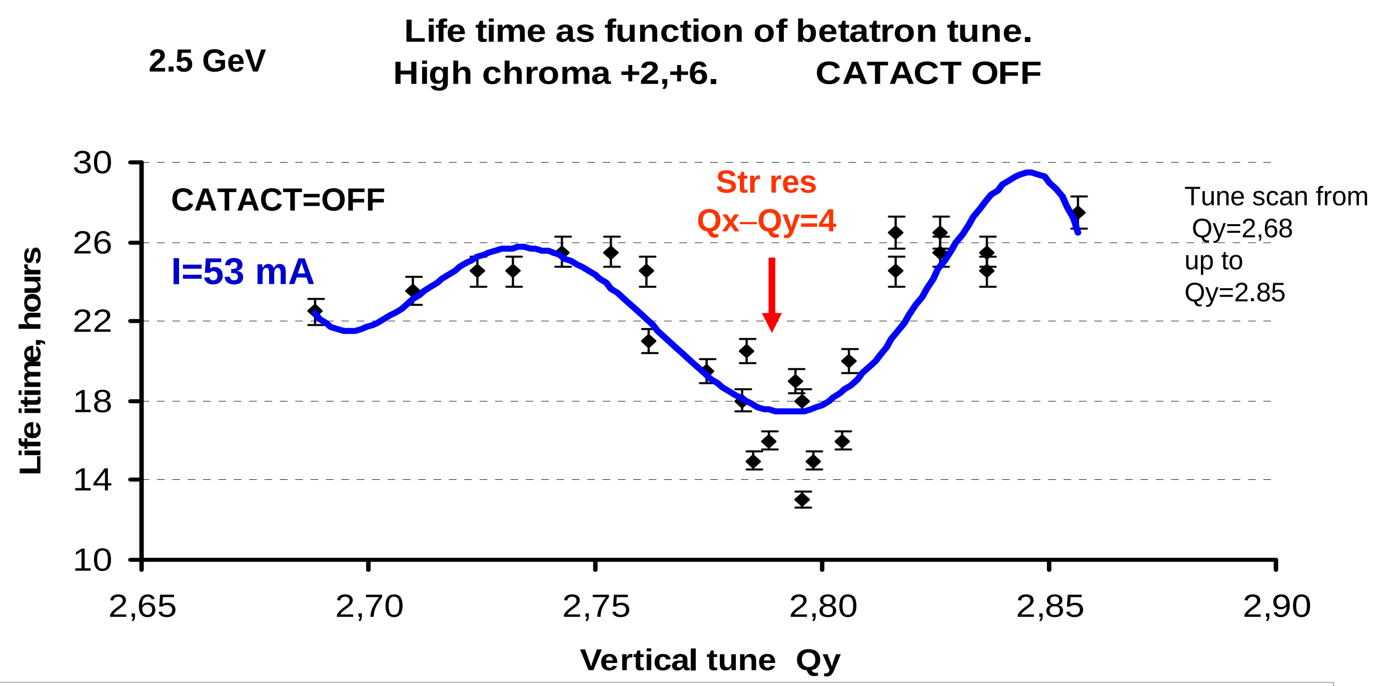
Red – CATACT OFF
Blue –CATACT=2.5 T

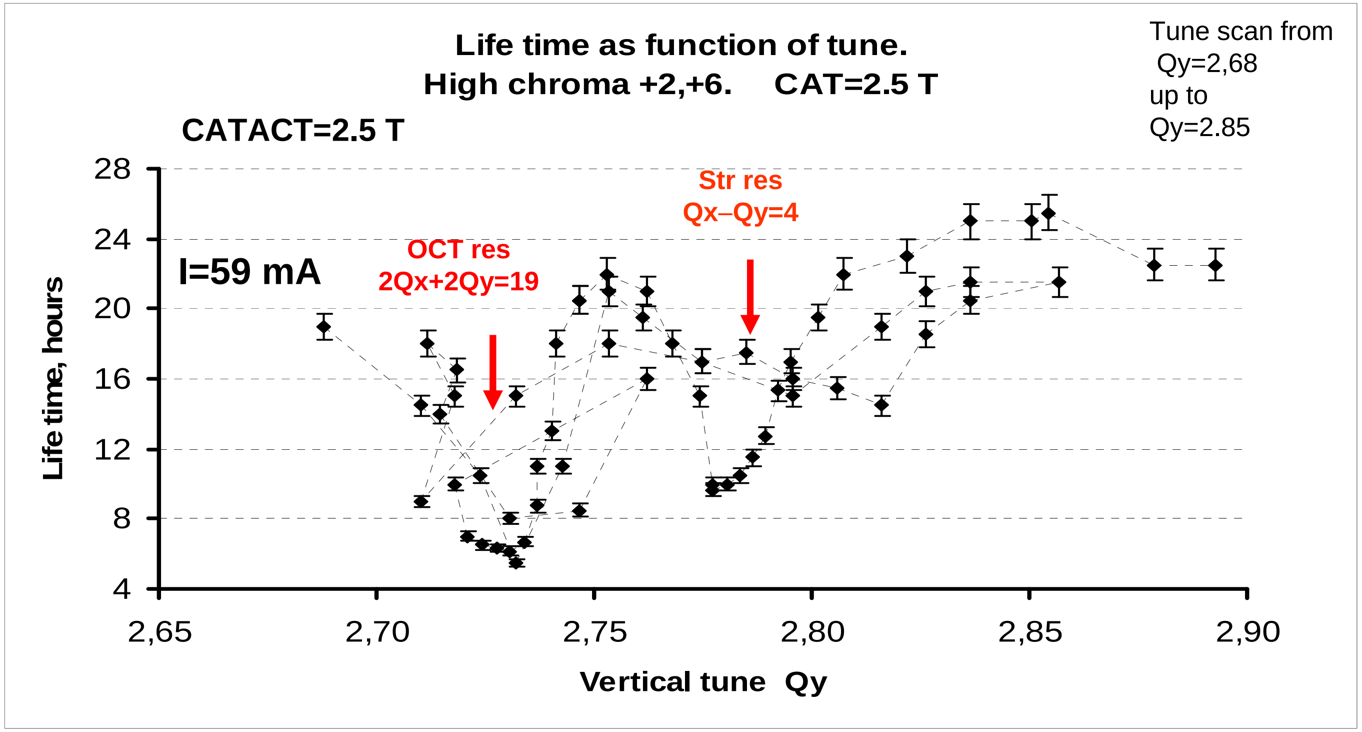
Life time as function of chromaticity (total=$\xi x + \xi y$). E=2.5 GeV.
Beam current = 85 mA ANKA tests 16 Jan 2017.



10 data points slope
20 data points slope
40 data points slope
100 data point slope
200 data point slope



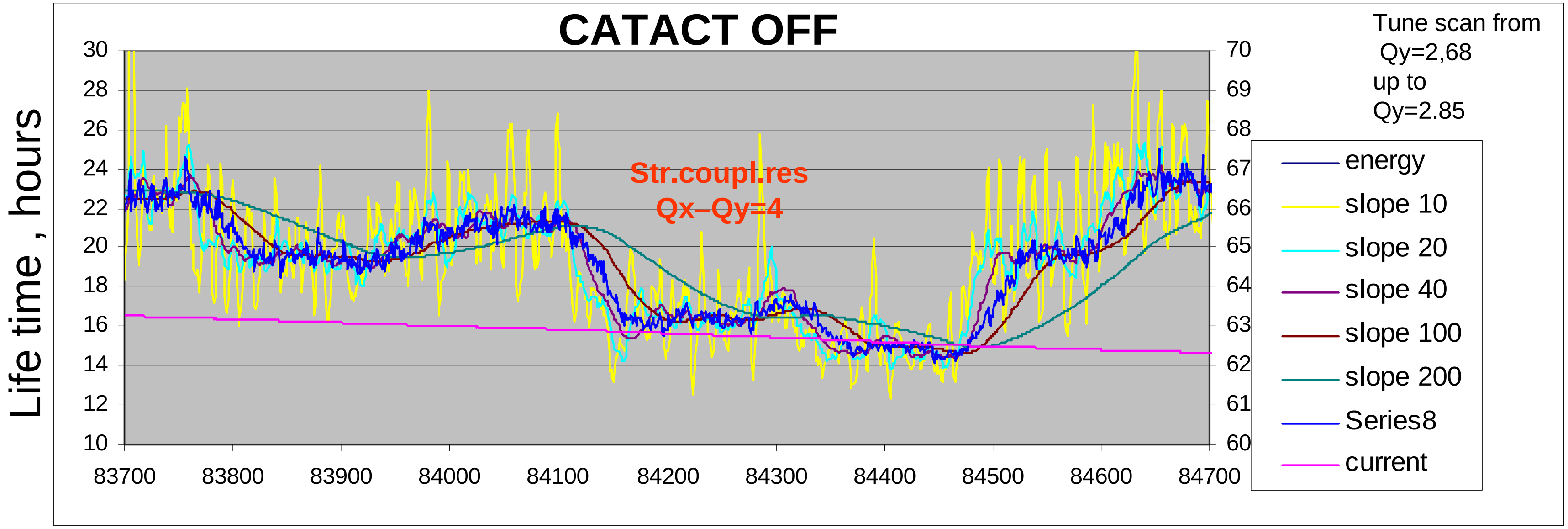


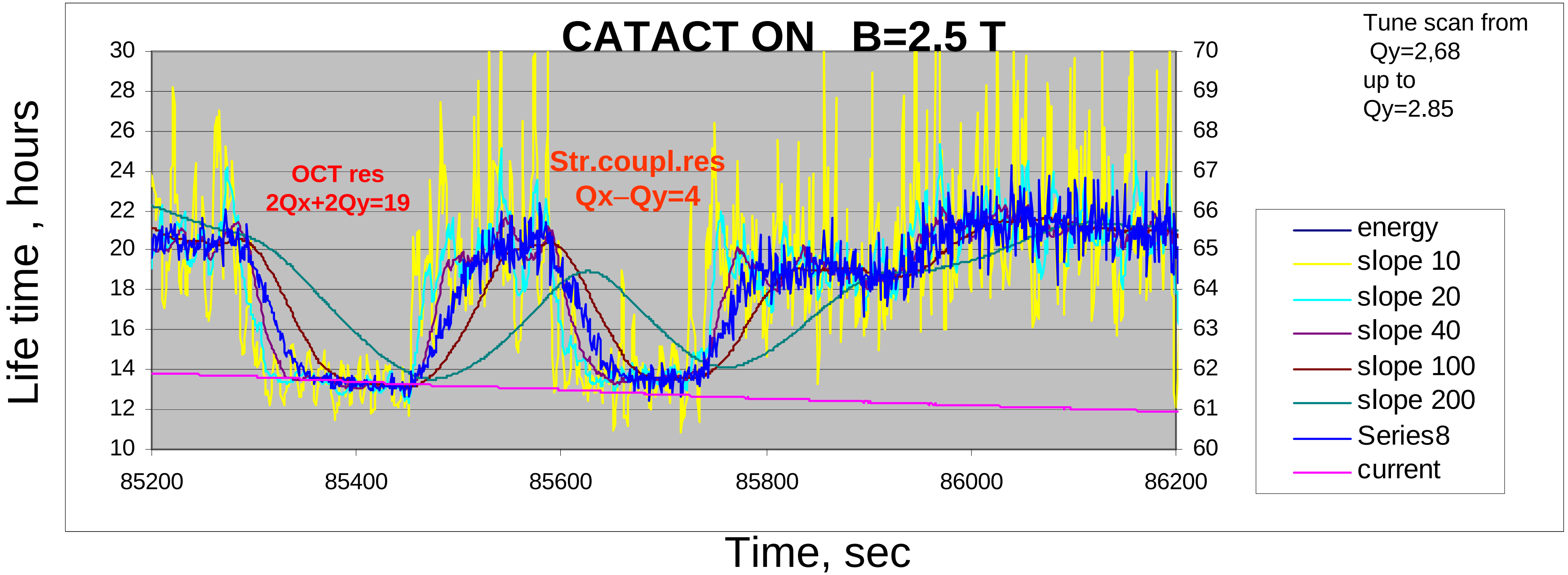


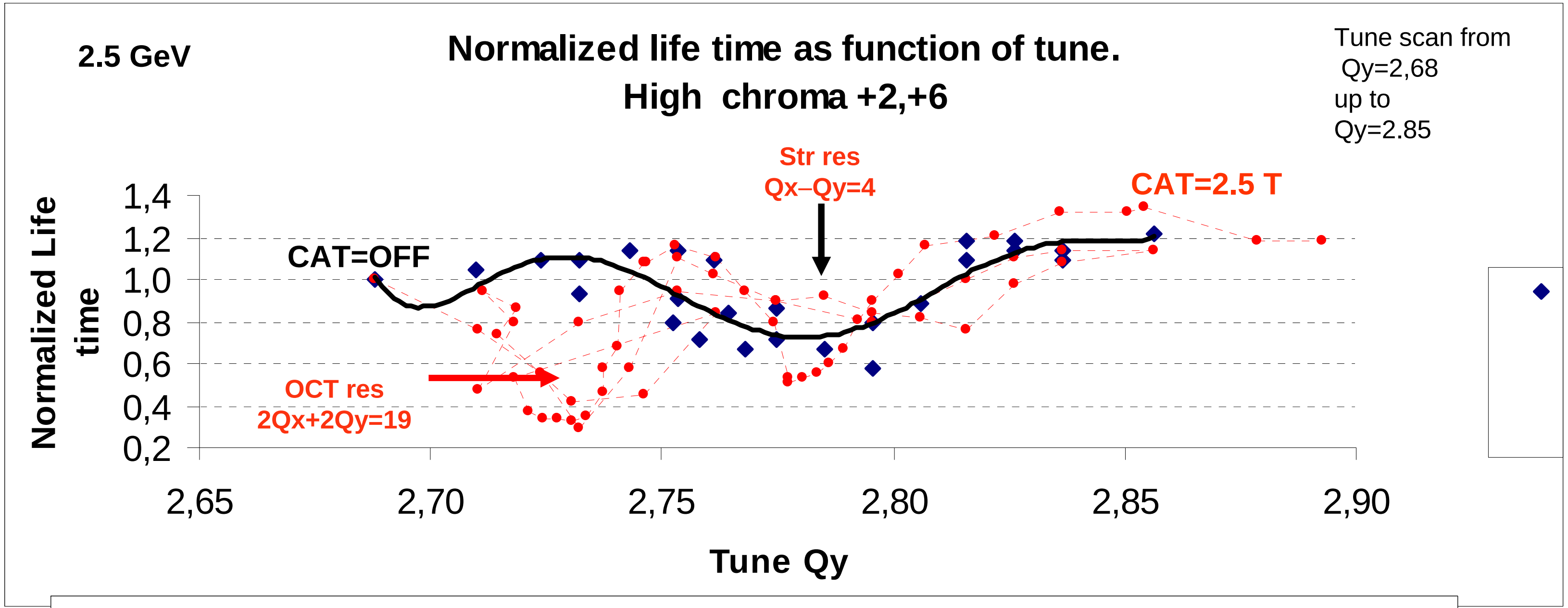
16,17 Feb 2017

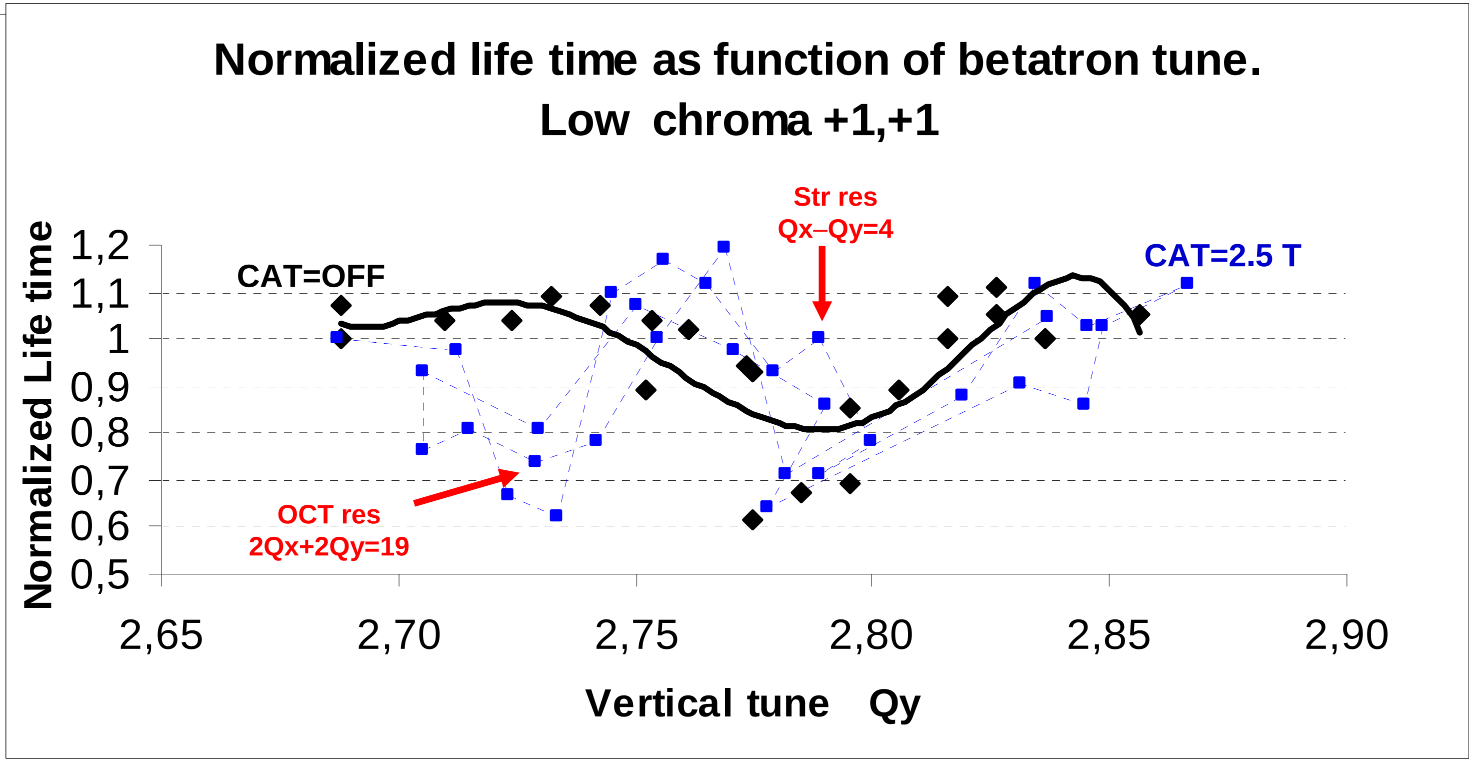
Life time data acquisition.
High chromaticity +2,+6

2.5 GeV





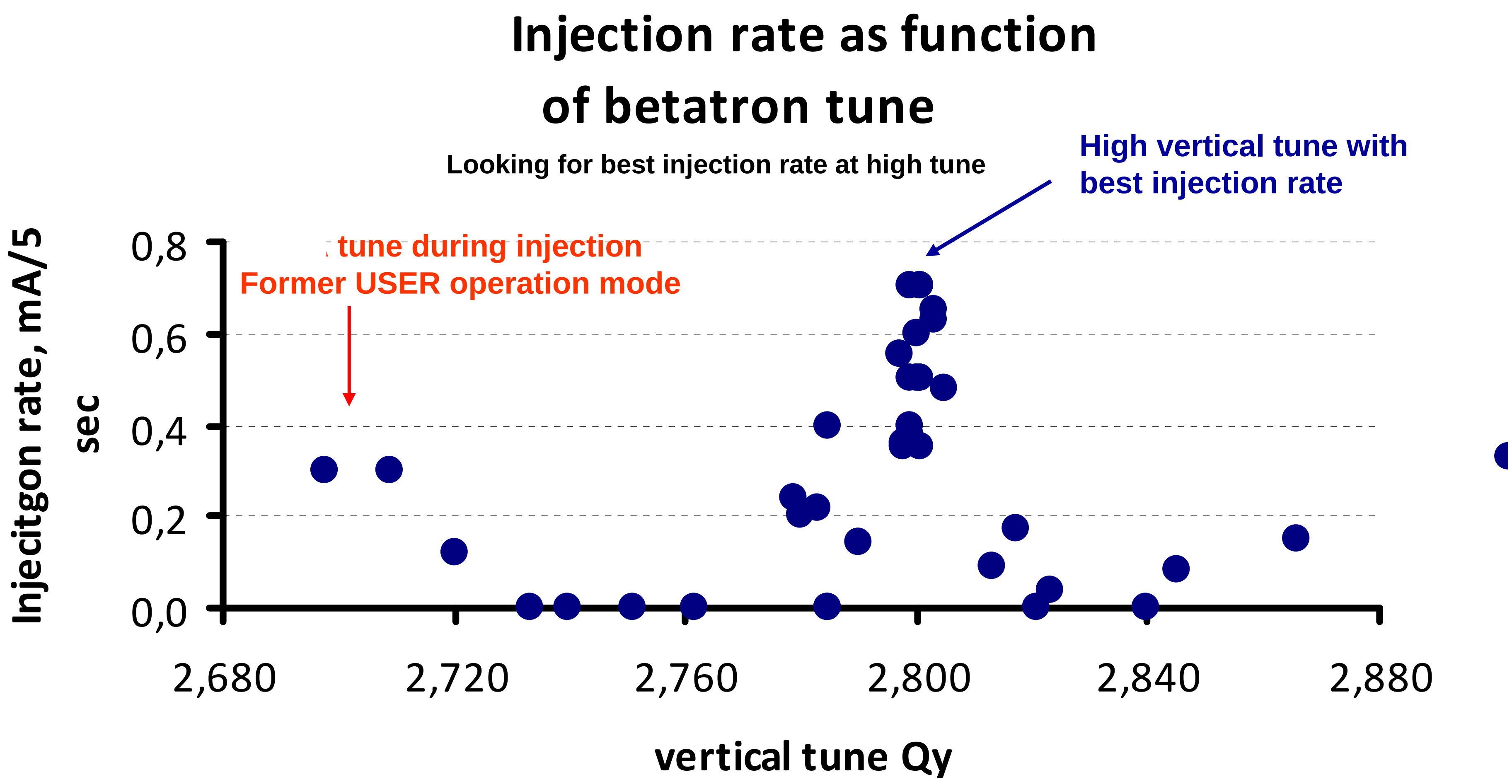




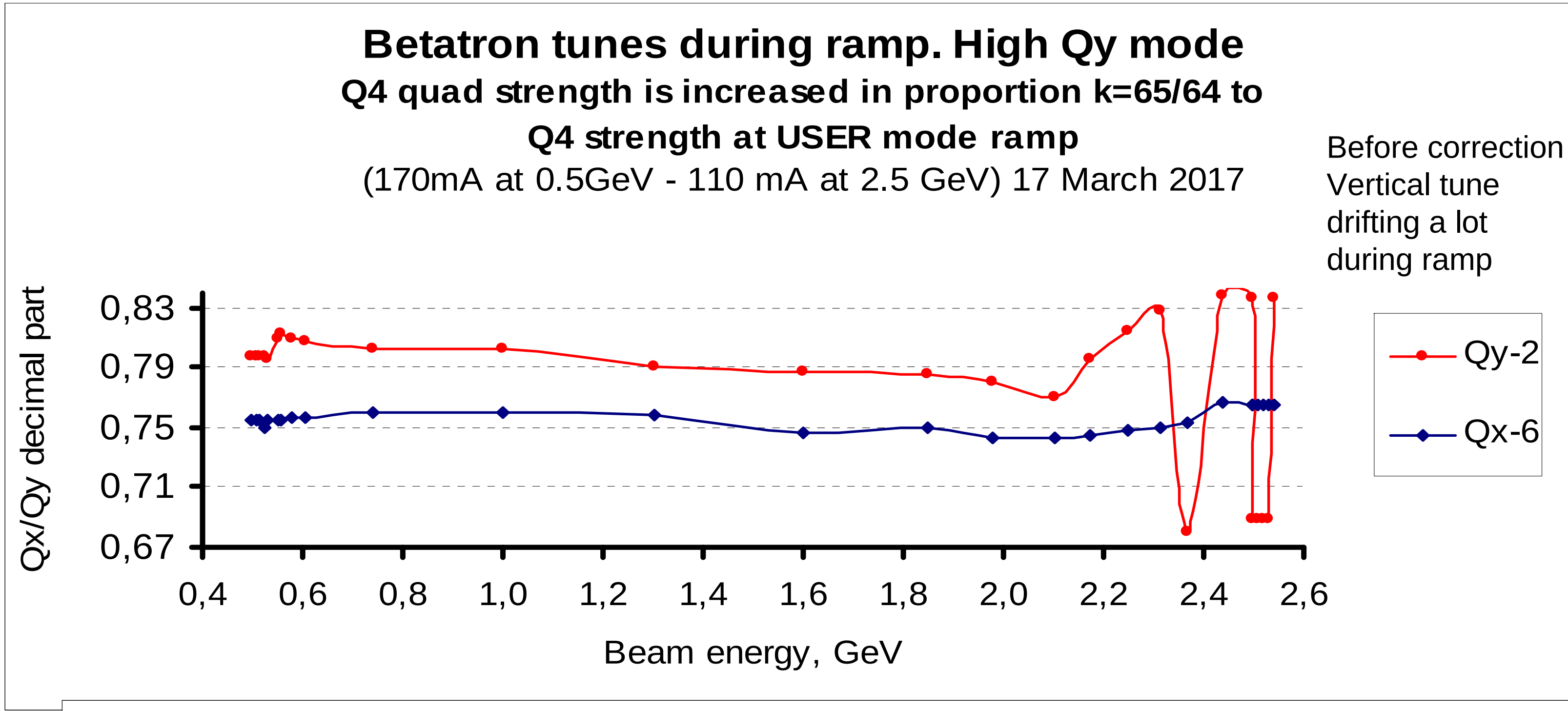
Tune scan from
Qy=2,68
up to
Qy=2.85

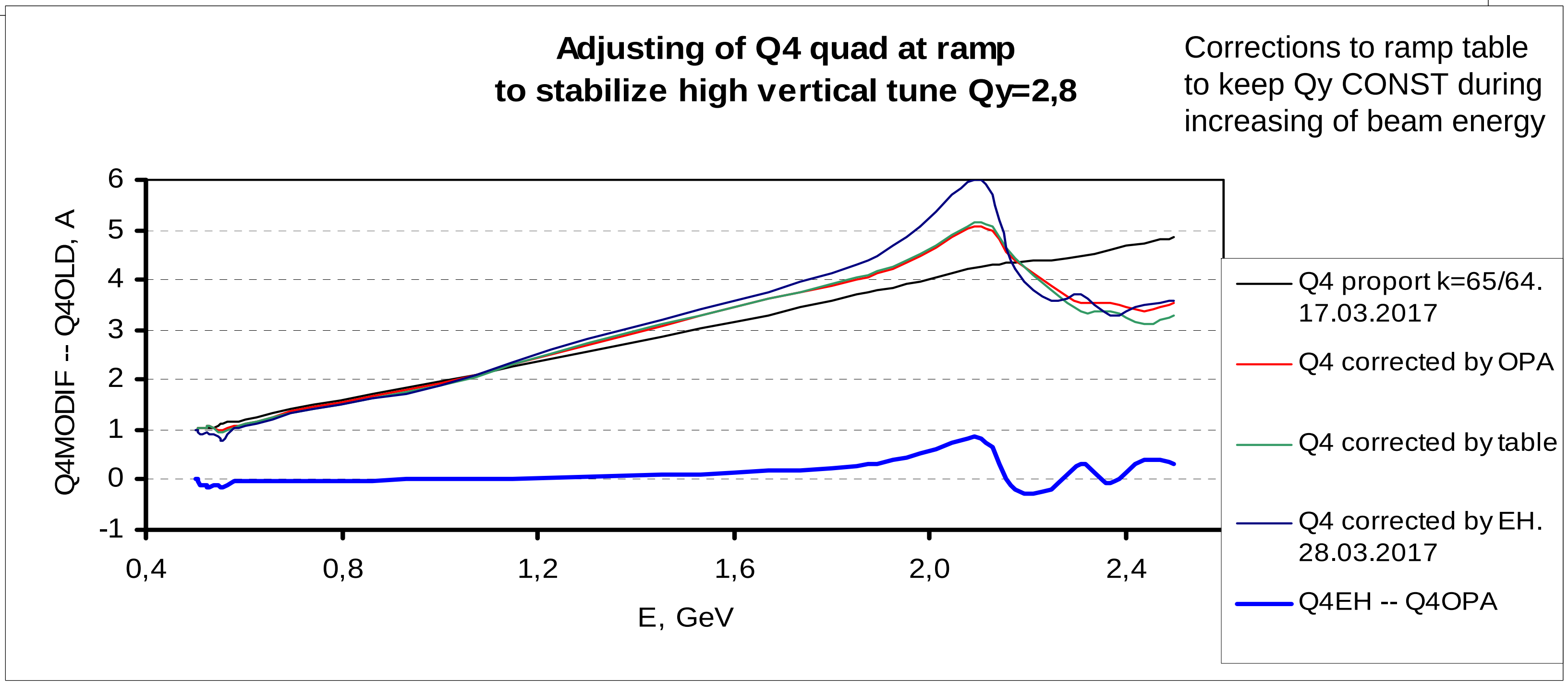
Injection
and
ramp tables

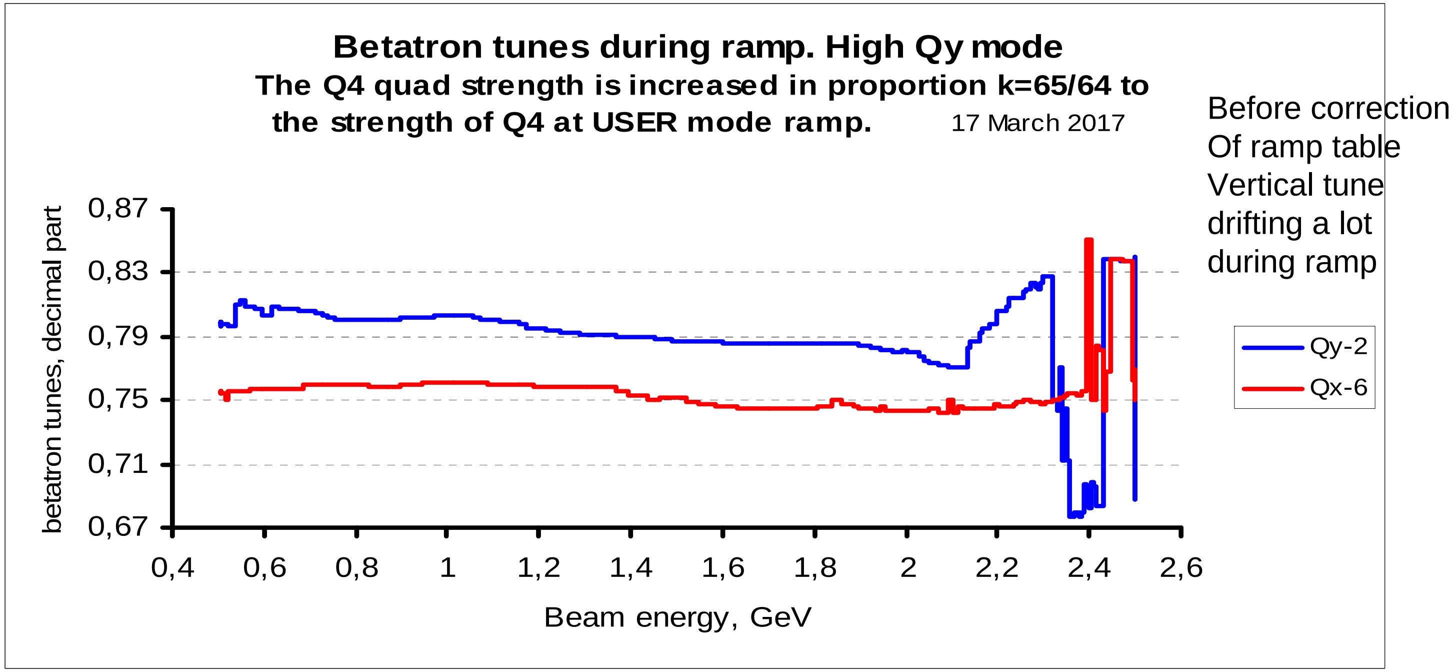
We found new settings
of focusing elements
to operate ring
(injection + ramp + plateau)
at one high tune working point

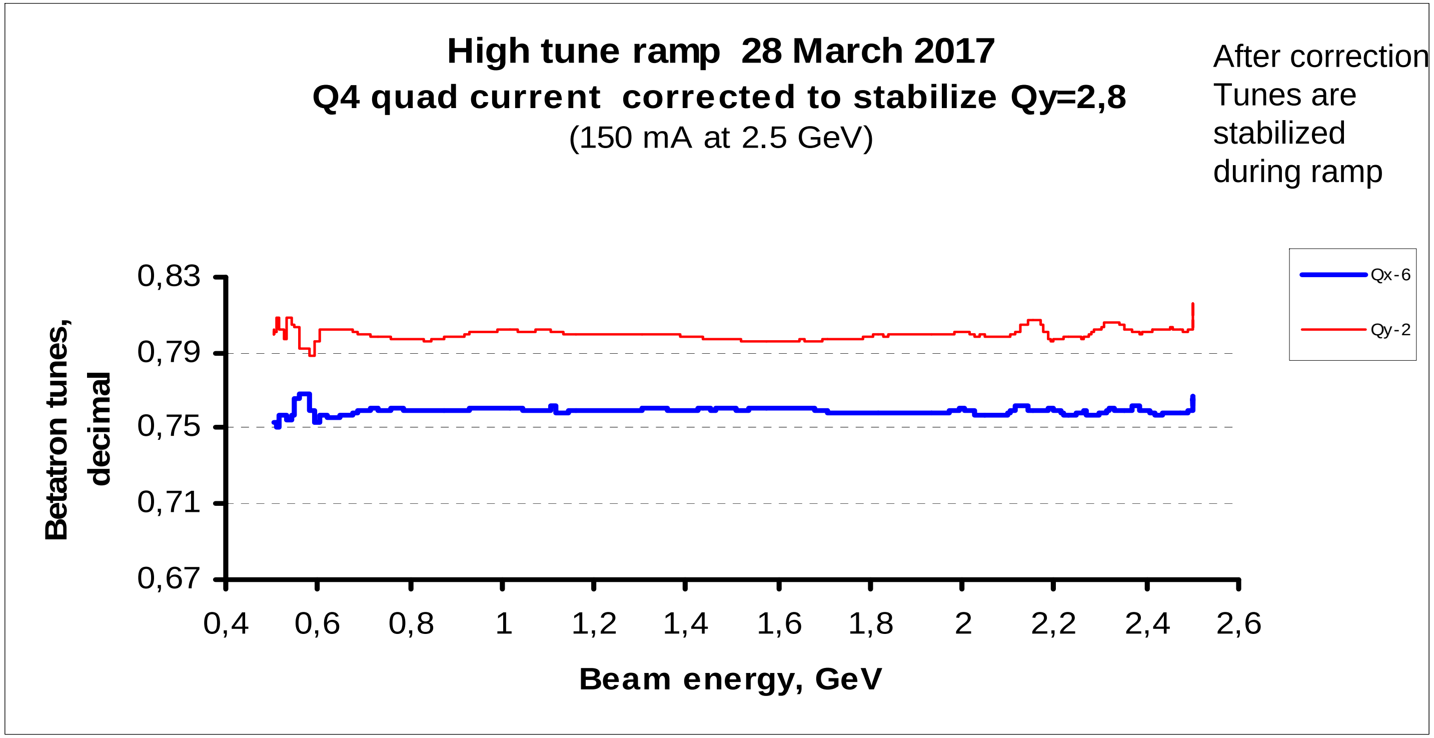


Highest Injection rate of 0.7 mA/5 sec has been achieved at Qy=2.80 and Qx = 6.75 (27/4)
This operation point corresponds to best Life time at 2.5 GeV and minimum of Resonance Driving terms (RDT). Phase dependent RDT are minimized by periodicity of 4 fold symmetry of ANKA ring.
One should explore benefits of ANKA operation at radial tune 6.75


Betatron tunes during ramp. High Qy mode
Q4 quad strength is increased in proportion k=65/64 to
Q4 strength at USER mode ramp
(170mA at 0.5GeV - 110 mA at 2.5 GeV) 17 March 2017
Before correction
Vertical tune
drifting a lot
during ramp
Qx/Qy decimal part
0,83
0,79
0,75
0,71
0,67
0,4
0,6
0,8
1,0
1,2
1,4
1,6
1,8
2,0
2,2
2,4
2,6
Beam energy, GeV
Qy-2
Qx-6


Adjusting of Q4 quad at ramp
to stabilize high vertical tune Qy=2,8
Corrections to ramp table
to keep Qy CONST during
increasing of beam energy
Q4MODIF -- Q4OLD, A
6
5
4
3
2
1
0
-1
0,4
0,8
1,2
1,6
2,0
2,4
E, GeV
Q4 proport k=65/64.
17.03.2017
Q4 corrected by OPA
Q4 corrected by table
Q4 corrected by EH.
28.03.2017
Q4EH -- Q4OPA


Betatron tunes during ramp. High Qy mode
The Q4 quad strength is increased in proportion k=65/64 to
the strength of Q4 at USER mode ramp.
17 March 2017
betatron tunes, decimal part
0,87
0,83
0,79
0,75
0,71
0,67
0,4
0,6
0,8
1
1,2
1,4
1,6
1,8
2
2,2
2,4
2,6
Beam energy, GeV
Qy-2
Qx-6
Before correction
Of ramp table
Vertical tune
drifting a lot
during ramp


High tune ramp 28 March 2017
Q4 quad current corrected to stabilize Qy=2,8
(150 mA at 2.5 GeV)
After correction
Tunes are
stabilized
during ramp
Betatron tunes, decimal
0,83
0,79
0,75
0,71
0,67
0,4
0,6
0,8
1
1,2
1,4
1,6
1,8
2
2,2
2,4
2,6
Beam energy, GeV
Qx-6
Qy-2

Merit of new quads settings

New quads settings at high vertical betatron tune $Q_y \approx 2.810$ are established at injection energy (0.5 GeV), during RAMP (0.5 – 2.5 GeV) and at TOP energy (2.5 GeV)

New quads setting stored in modified ramp tables allow:

(1) stay away from the sextupole resonance $Q_y = 8/3$

(2) improve operation conditions (life time, stability)

(3) escape reduction of life time at ANKA caused by combination of (a) + (b) + (c) +(d)

(a) high order (octupole) field components
of wiggler $B_w = 2.2 \div 2.5$ T
(b) proximity of old tune to coupling octupole resonance $2Q_x + 2Q_y = 19$
(c) proximity of old tune to sextupole rsonance $Q_y = 2.666\ldots$
(d) High chromaticity $\xi_{x,y} = +2,+6$

(4) new quads settings are adjusted to minimize SHAKING of betatron tunes during RAMP while quadrupole currents are changed a lot

(5)Small range of tune deviation allows to stabilize beam by applying of the fast feedback system
during injection, ramp, at TOP

Low compaction factor
Tests - 2017

We found new settings of quads

for

low alpha ramp-squeezing tables

operating at high betatron tune

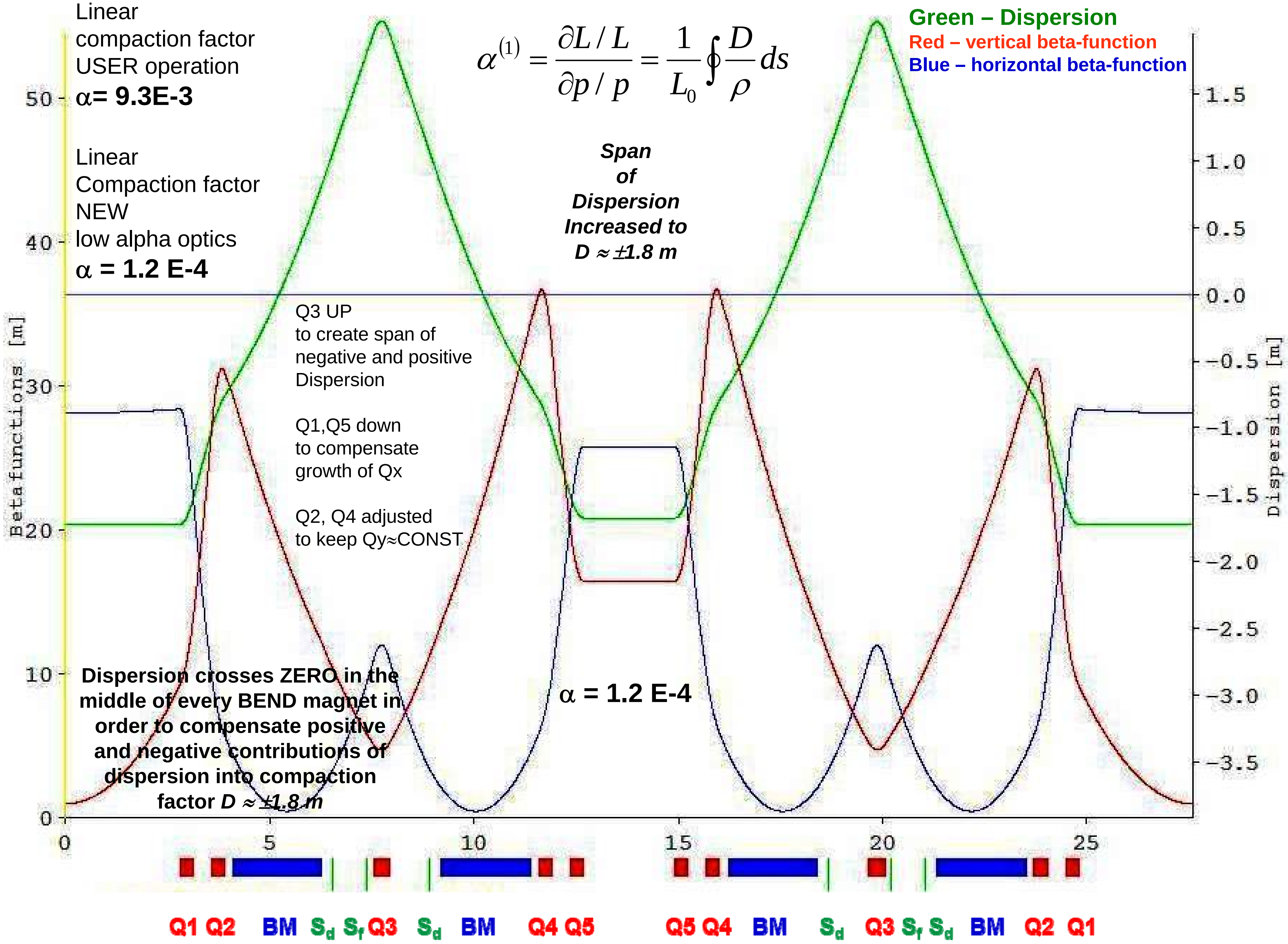
and

measured beam parameters

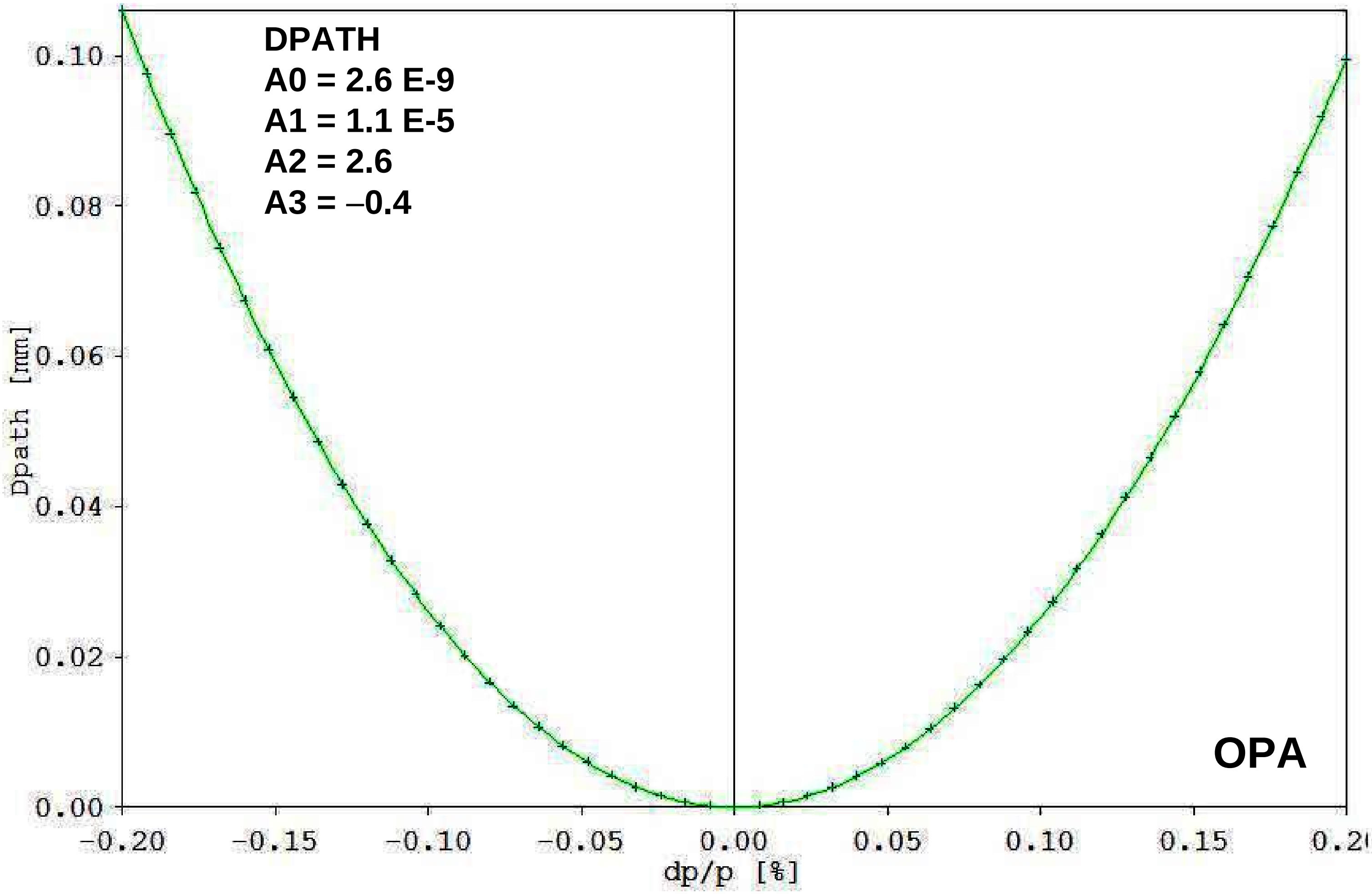
at

low alpha mode

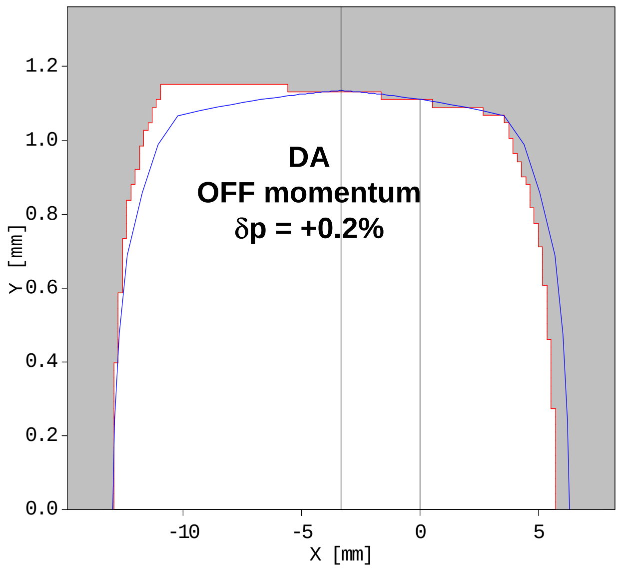
Low APLHA Optics. One Cell

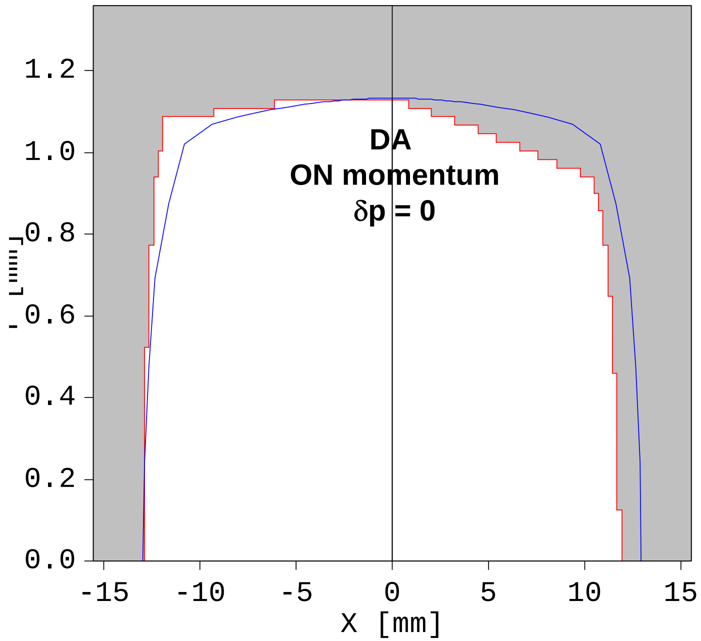


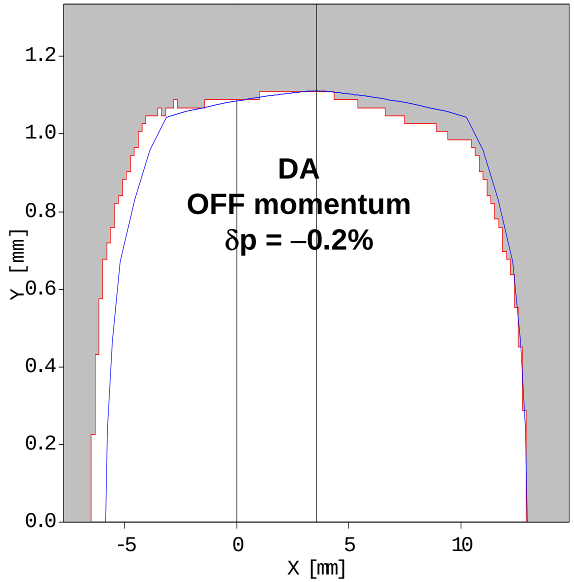
Low ALPHA Mode.
High order components of compaction factor

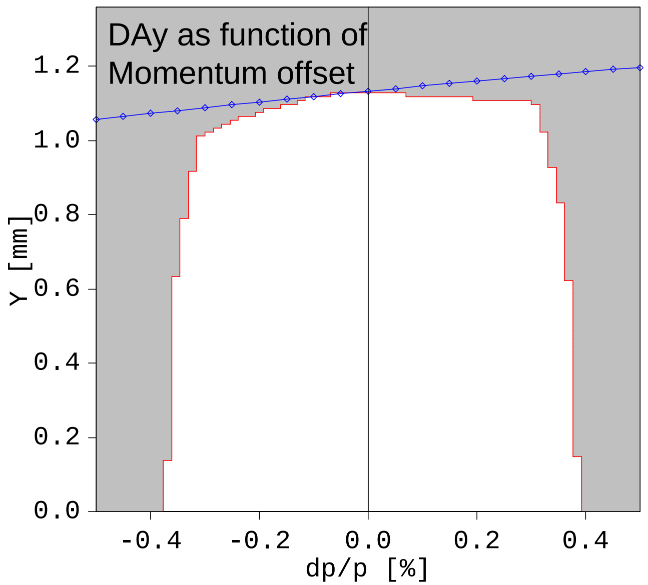


Simulations of Dynamic aperture at Low ALPHA mode (high tune). Synchrtorton motion is NOT included

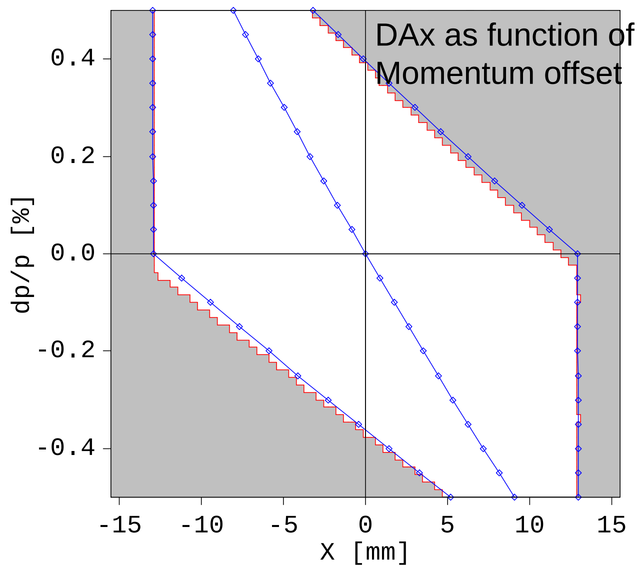




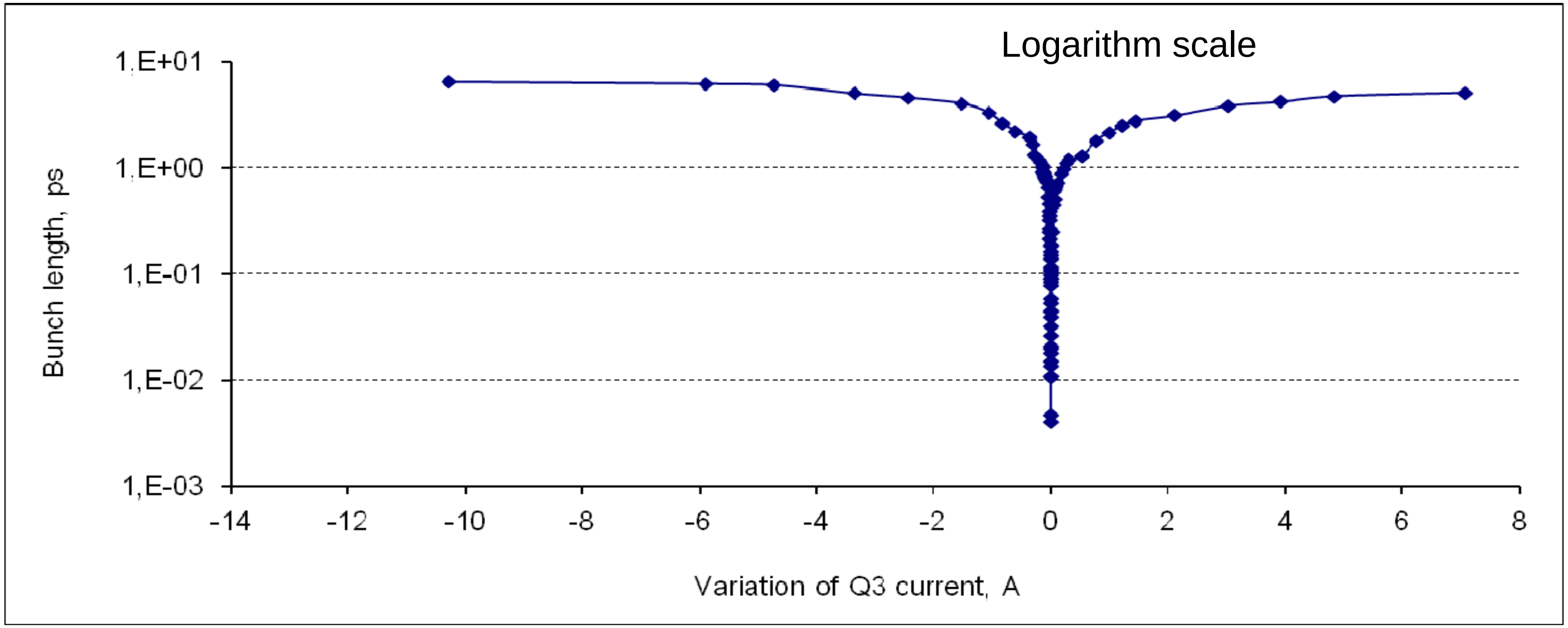


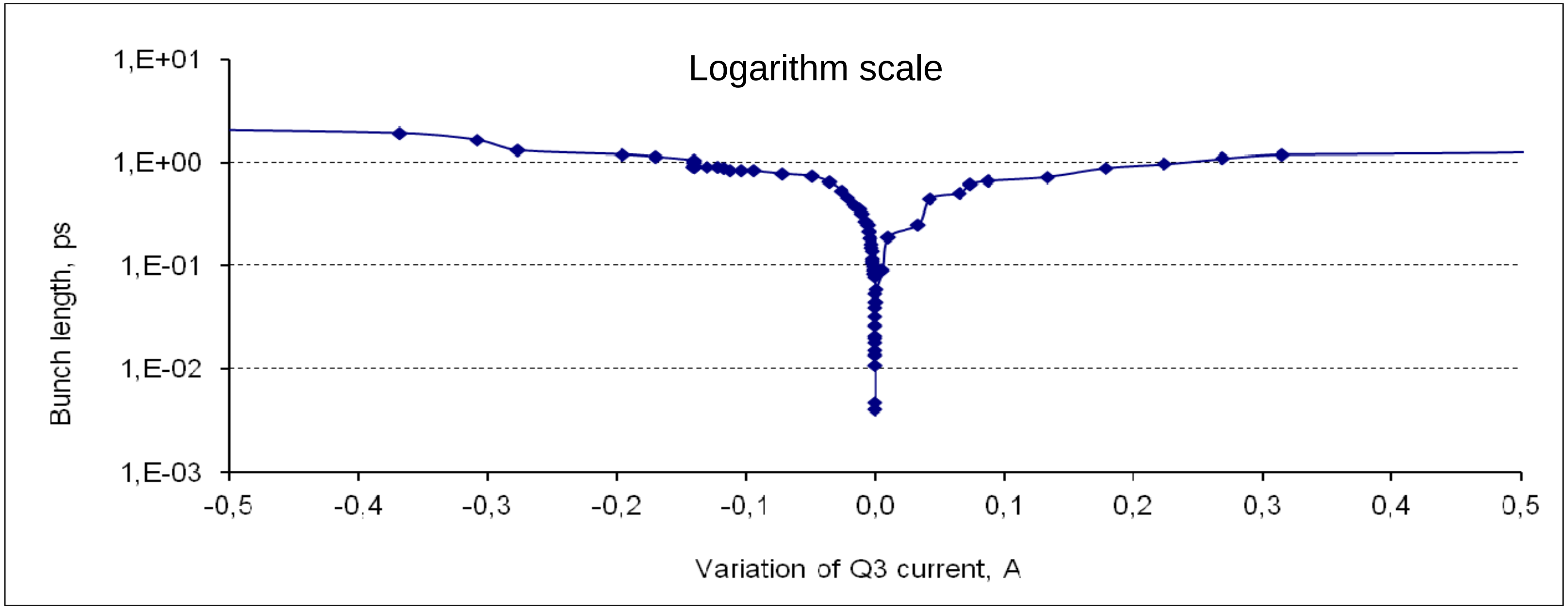


Momentum Acceptance at low alpha is reduced from $\Delta p/p \approx \pm 2\%$ down to $\Delta p/p \approx \pm 0.2\%$ Thus, Life time drops



Zero current Bunch length (simulations)





Reduction of chromaticity during Low–ALPHA operation

ADOL -- AMPLITUDE DEPENDENT ORBIT LENGTHENING

$$\delta C^{ADOL} = -2\pi \cdot (\xi_x \cdot J_x + \xi_y \cdot J_y)$$

$$2 \cdot J_{x,y} = \varepsilon_{x,y}$$

TO minimize smearing of bunch length as well as coupling between horizontal and longitudinal planes (Path lengthening caused by transverse oscillations) one should reduce ADOL

$$\frac{\delta C^{ADOL}}{C_0} << \alpha_0 \cdot \delta_0$$

Chromaticity tolerance limit during low–α operation (E=1.3 GeV)

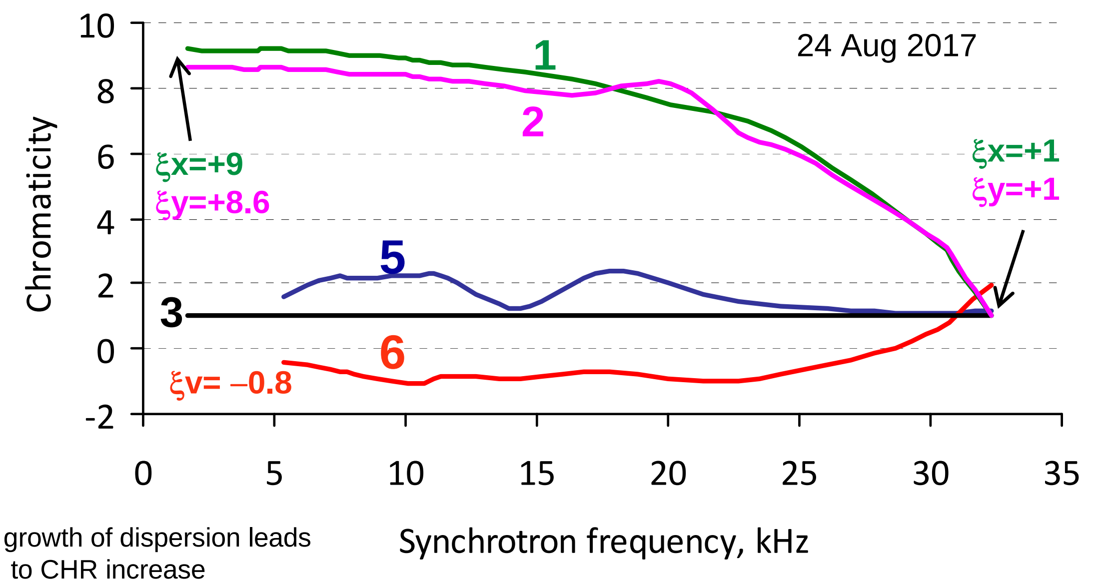
2Jx	αo	ξx,y
80 nm·r	1.E–4	≤+2
80 nm·r	2.E–5	≤+1
80 nm·r	2.E–6	≤+0.2

Chromaticity limit during low–α operation at MLS (0.63 GeV)

2Jx	**αo**	**ξx,y**
200 nm·r	**1.3E–4**	**+0.2**

Merit of SXT strength reduction during low alpha squeeze (24Aug 2017)

High SPAN of Disperions variation
Leads to essential increase of **chromaticity**
during low alpha Squeeze
IF SXT **strength** is **FIXED**
(**curve 1** and **curve 2**).
The effect is present at any beam energy
(0.5 GeV, 1.3 GeV etc.)

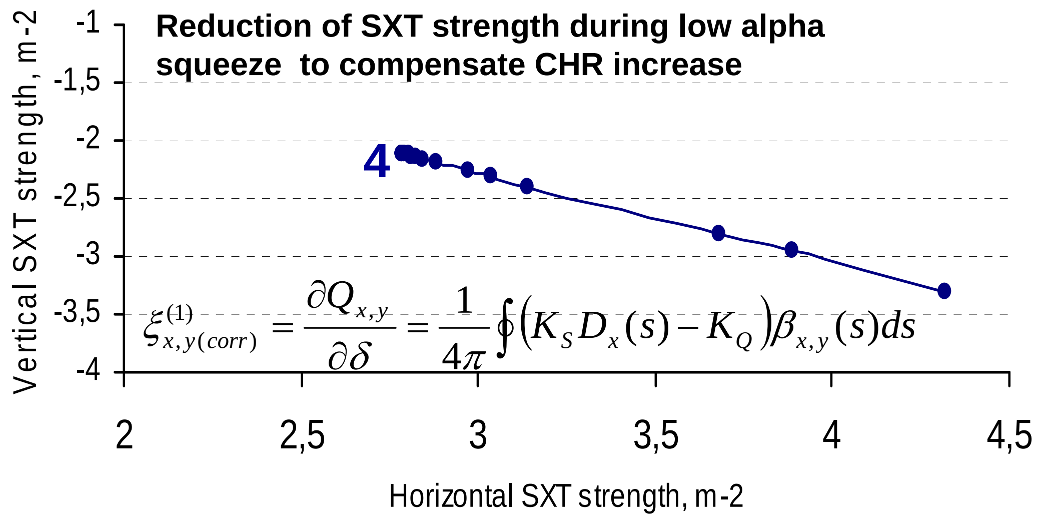


growth of dispersion leads to CHR increase

1 – kSF=+4,3 m-2 = const
2 – kSD =–3,3 m-2 = const

Reduction of SXT strength during low alpha squeeze compensates growth of CHR
(curves 3, 4, 5, 6)

To keep CHR **unchanged** during low alpha Squeeze (ξh,v = +1,+1),
see curve **3,**
SXT strength is reduced from
kSF=+4,3 down to +2,8 m-2
kSD =–3,3 down to –2,1 m-2,
see **curve 4**



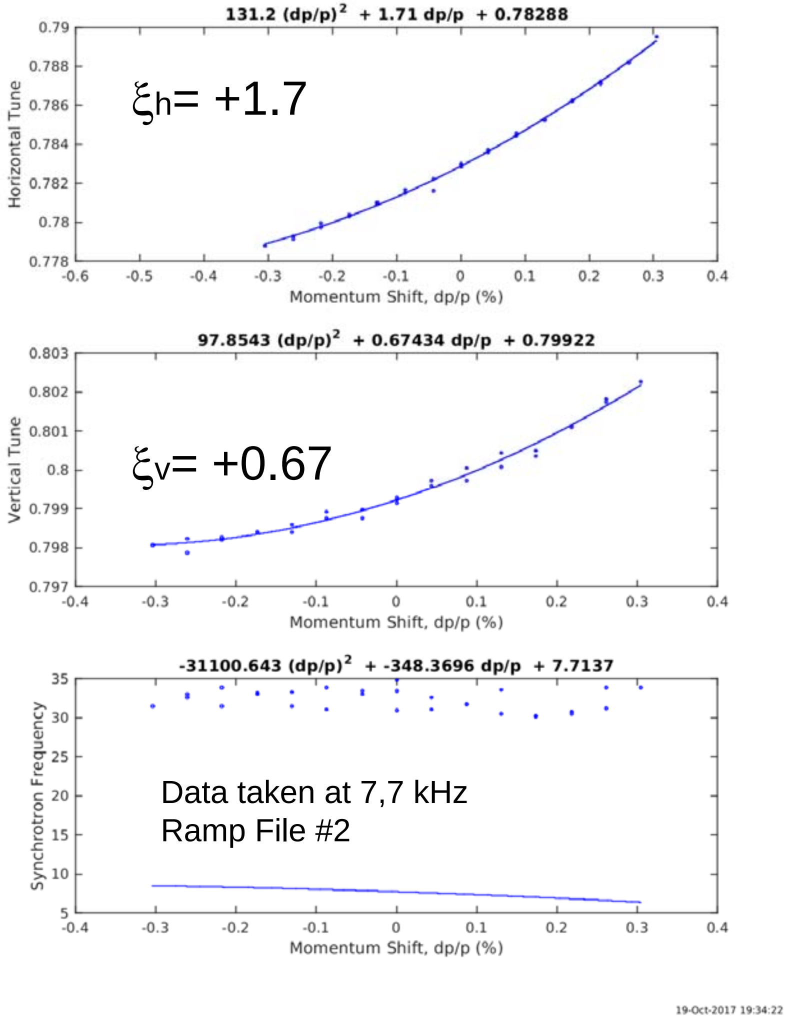
$$\xi^{(1)}_{x,y(corr)} = \frac{\partial Q_{x,y}}{\partial \delta} = \frac{1}{4\pi}\oint \left(K_S D_x(s) - K_Q\right)\beta_{x,y}(s)ds$$

Curve 5 and **curve 6** – CHRh and CHRv MEASURED during low aplha squeeze at 1.3 GeV (tests 24 Augustr 2017)
5 – ξh ≈ +1 to +2 (ISF = 76 A down to 61 A)
6 – ξv ≈ +2 to –0,8 (ISD = 70 A down to 54 A)

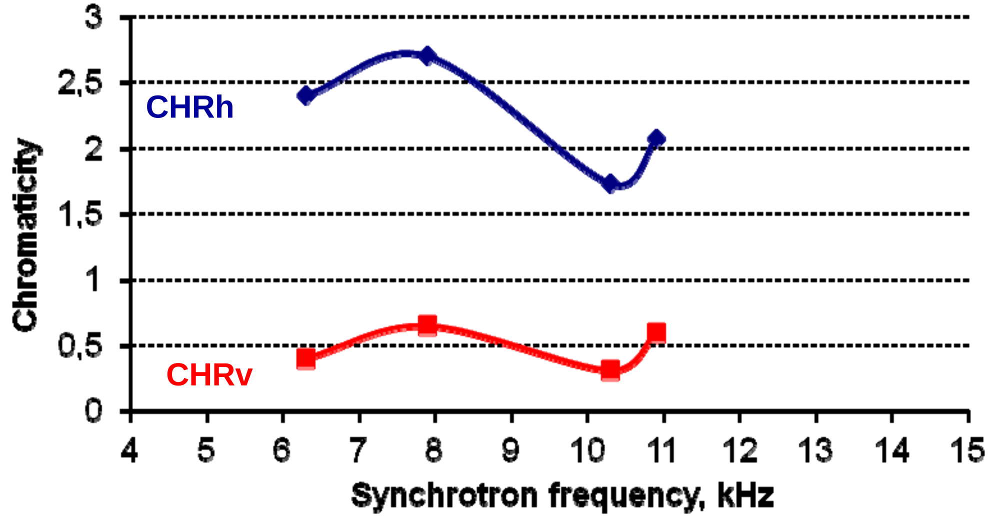
We should adjust CHR-h,v settings in the ramp/squeeze table in order to keep 0 < CHRh,v ≤ 2
We should measure Life Time and bunch stability during Squeeze at small (+1,+1)/high(+2,+6) CHR and choose OPTIMUM settings

Correction of SXT strength to keep CHR slightly positive during low-alpha squeeze (BP tests 16-19 October 2017)

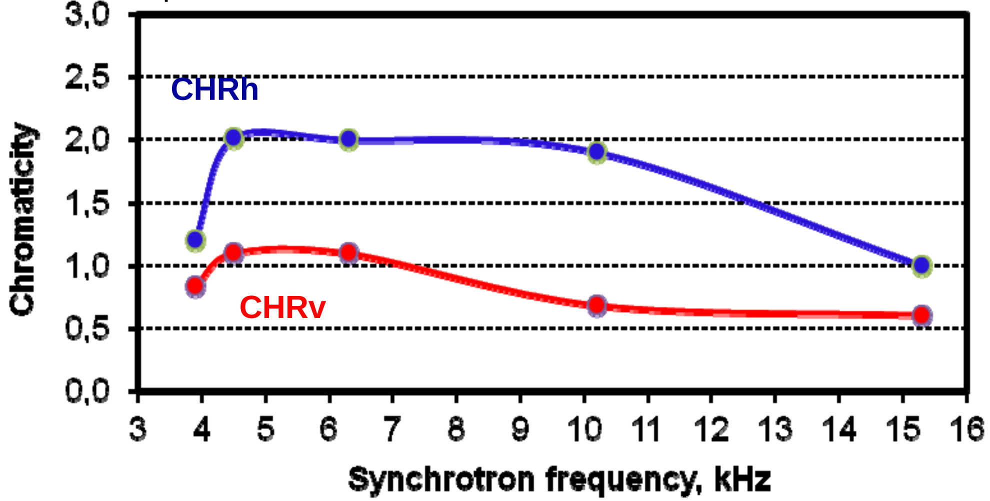
Chroma measurements of corrected ramp/squeeze file #2 (reduced SXT strength). Julian Gethmann 19 Oct 2017



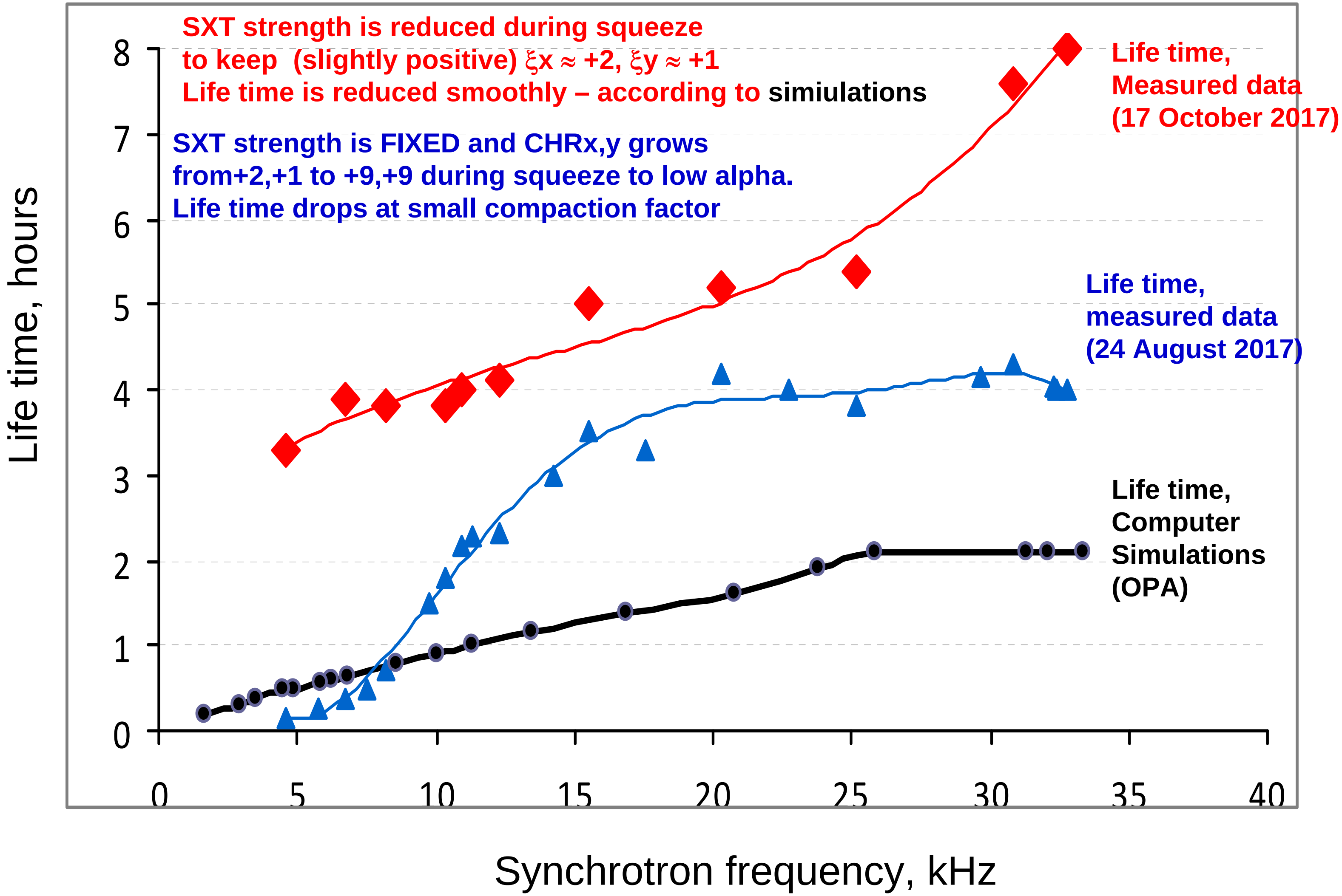
SXT strength corrected to keep positive chromaticity
Ramp File #1 from 31 Aug 2017



SXT strength adjusted to optimize chromaticity during squeeze.
Ramp file #2 from 16 October 2017



Life time at low compaction factor was improved (red curve) because of synchronized reduction of chromaticity has been applied during low alpha squeeze



- New Low Alpha tables (1.3 GeV) are modified to MINIMIZE tune deviation during SQUEEZE. Feedback is **ON** and stabilizes beam during squeeze

- Orbit correction is NOT required during low alpha squeeze except last point at very low alpha

- We adjusted CHR-x,y settings in the ramp/squeeze table in order to keep small CHROMA ($1 \leq \xi_{x,y} \leq 2$) during reduction of compaction factor and low alpha operation

- We should measure Life Time and bunch stability during Squeeze at small (+1,+1) and high (+2,+6) CHR and choose OPTIMUM settings

- We should organize tests of influence of coupling between horizontal and vertical planes (from simulations – coupling up to 20%) on the beam life time at low alpha. Preliminary, RF noise on Y- Steerers might effectively increase hor/vert coulping , i.e. increase vertical emittance, thus improve life time at low alpha in a 2- 3 times

Mode	rms bunch Length (mm)	rms bunch width (ps)	Fs kHz	E GeV	α_0	Frf MHz
User	6.5	21.6	33.4	1.3	9.0E–3	500
Low-α	**0.8**	**2.4**	**5**	**1.3**	**1.2 e–4**	**500**
MLS User	**6**	**19**	**106**	**0.63**	**3.0 e–2**	**500**
MLS Low-α	**0.8/1.1 (THz/IR)**	**2.5/3 (THz/IR)**	**6.9**	**0.63**	**1.3 e–4**	**500**

Thanks

Backup Slides

Main parameters of CATACT and CLIC wigglers

Name	CATACT	CLIC
Field direction	Vertical	Vertical
Wiggler period λ_w, mm	48	51
Peak field B_w, T	2.5	3
Magnetic rigidity $B{\cdot}R$, T·m	8.33	8.33
Magnetic length L_w, mm	960	1836
Number of pole pairs @ full field	36	68
Number of pole pairs @ 1/4 field	2	2
Number of pole pairs @ 3/4 field	2	2
Number of full periods	18	34
Wiggler aperture, $V{\times}H$, mm	15×60	13×76
Scrapers opening, $V{\times}H$, mm	14×26	12×26
Undulator parameter $k_w = 2\pi/\lambda_w$, mm^{-1}	11.2	14.29
Orbit curvature $h_w = 1/\rho_w = B_w/B{\cdot}R$ m^{-1}	0.3	0.36
WGL bending angle $\theta_m = \lambda_w/2\pi\rho_w$ mr	2.3	2.9
Hor/vert beta at WGL position β_x/β_y, m	13.2 / 12.7	17 / 0.9
Hor/vert coupling	0.5÷1%	0.5÷1%
Equil. beam size $\left(\sqrt{\sigma_x^2 + (D\cdot\sigma_p)^2}\right)/\sigma_y$	0.86 / 0.11 mm	1.04 / 0.03 mm
Vertical betatron tune shift $\Delta\nu_y = \frac{1}{8\pi} h_w^2 L_w \bar{\beta}_y$	+0.0436	+0.0085
Action variable $J_y = A_y^2/(2\beta_y)$, m	$\approx 1.5\cdot10^{-6}[m]$	$\approx 5\cdot10^{-7}[m]$
ADTS Tune spread - pseudo-octupole field $\delta\nu_y = \left(\frac{1}{8\pi} L_w k_w^4 \theta_m^2 \bar{\beta}_y^2\right) J_y$	$1.2\cdot10^4\cdot J_y[m]$ $\delta\nu_y = 1.8\cdot10^{-2}$	$1.17\cdot10^2\cdot J_y[m]$ $\delta\nu_y = 6\cdot10^{-5}$

$$\Delta\nu_y = \frac{1}{8\pi}(B_w/BR)^2\cdot L_w\cdot\bar{\beta}_y$$

$$\left(\sqrt{\sigma_x^2 + (D\cdot\sigma_p)^2}\right)/\sigma_y$$

CLIC $\sigma_x/\sigma_y = 1.04/0.03mm$

CATACT $\sigma_x/\sigma_y = 0.86/0.11mm$

$DA \approx 12\sigma_x/36\sigma_y = 12/1.1mm$

$\beta_x/\beta_y = 17/0.91m$

BM=22.5°

Negative Compaction Factor (simulations)

Transition of compaction factor from positive to negative value.

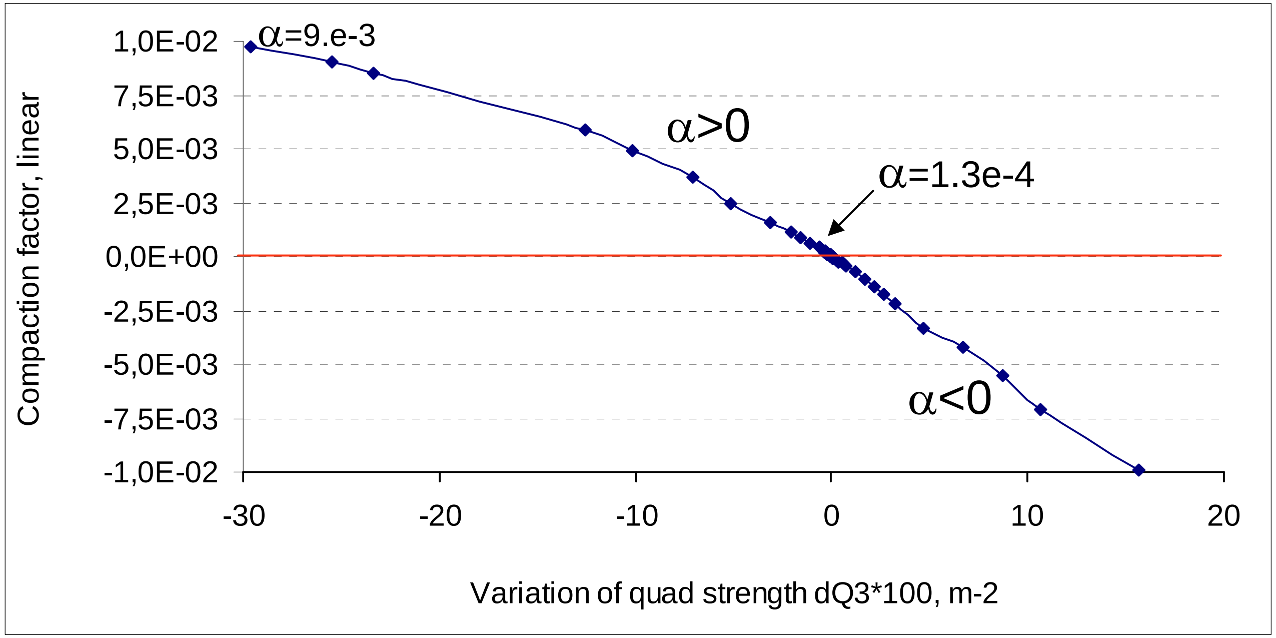
Linear scale

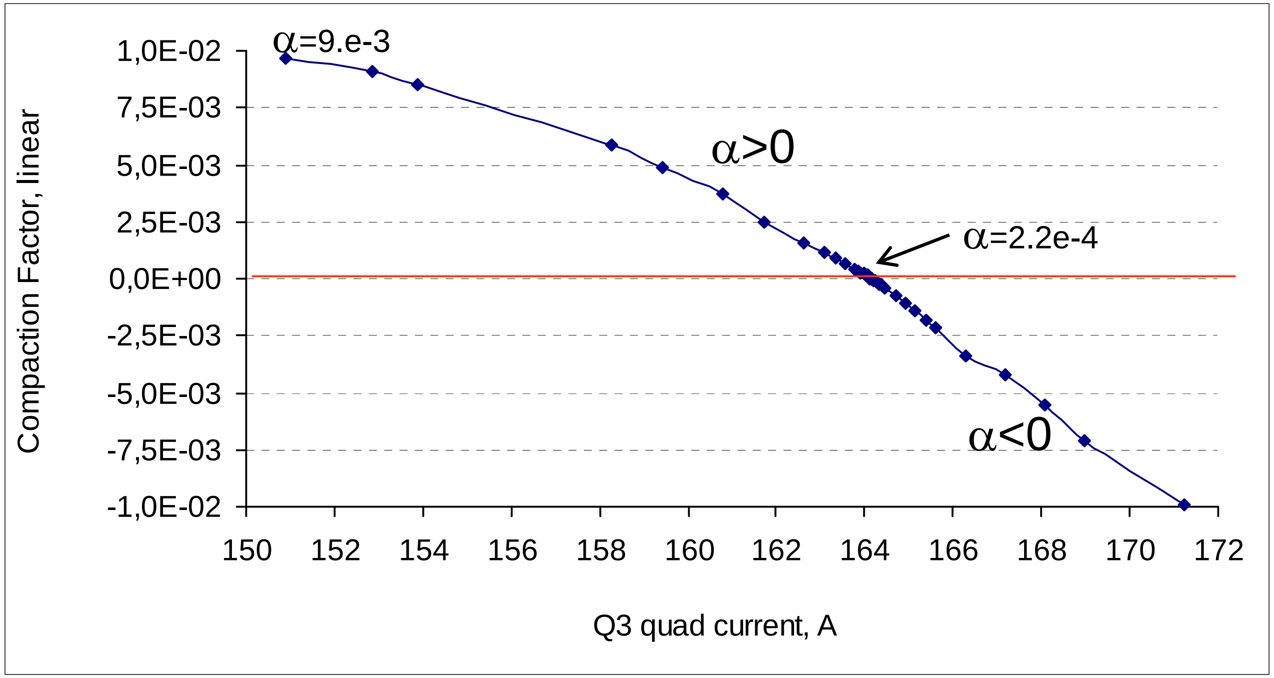
“zero“ is point where

alpha = 0

i.e. transition from

positive to negative value



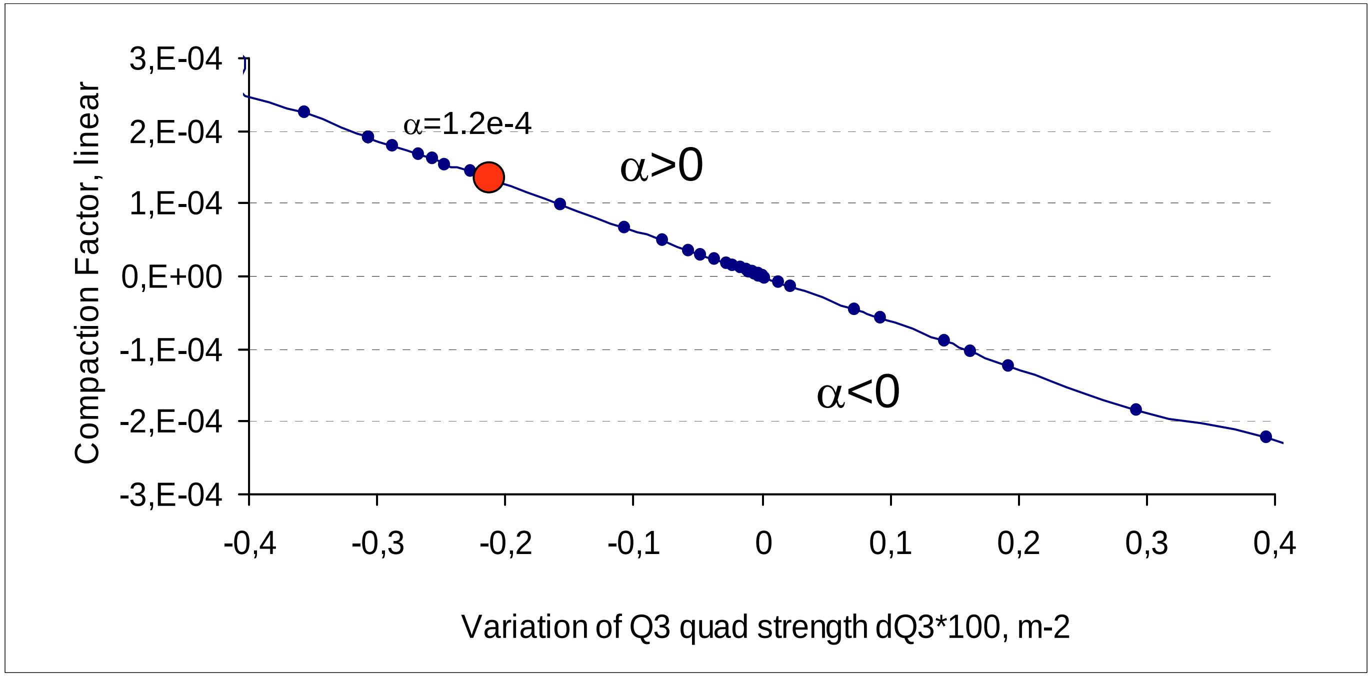


OPA simulations

ZOOMED

Transition of compaction factor from positive to negative value.

Linear scale



“zero“ is point where

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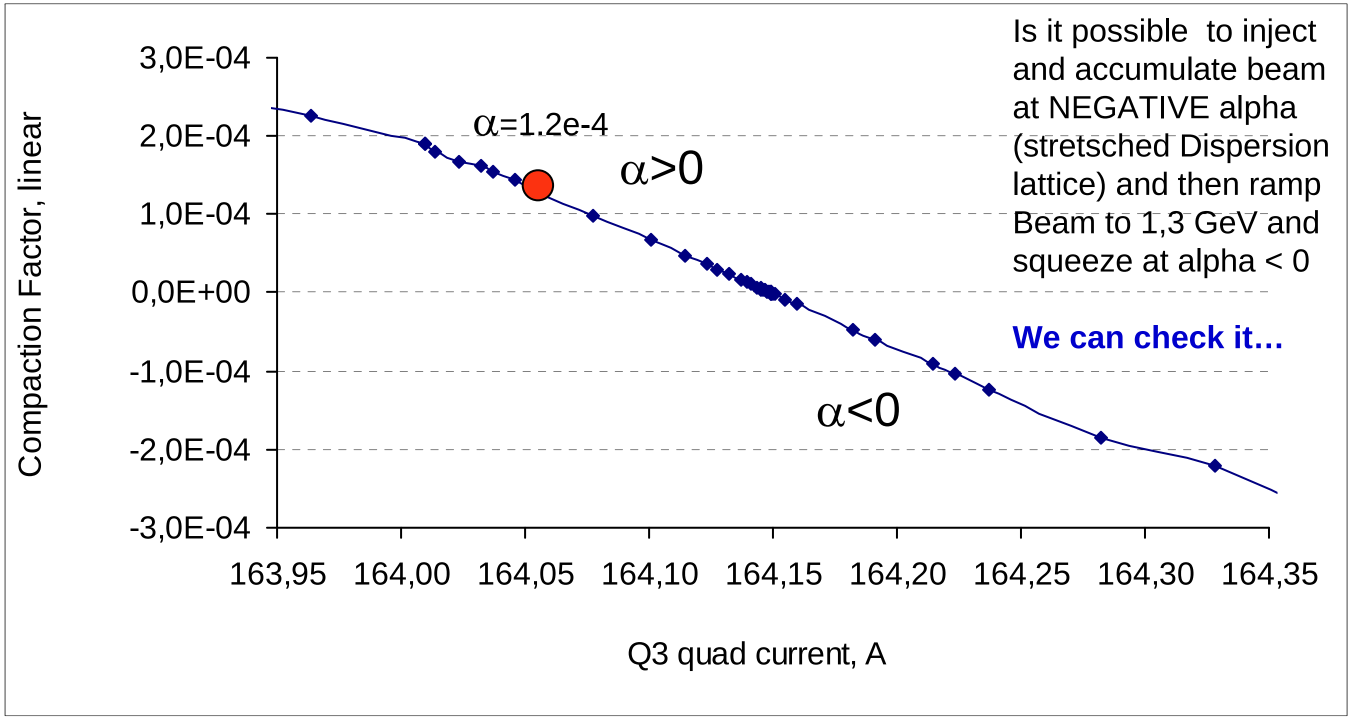
i.e. transition from

positive to negative value



Transition of compaction factor from positive to negative value.

Logarithmic scale

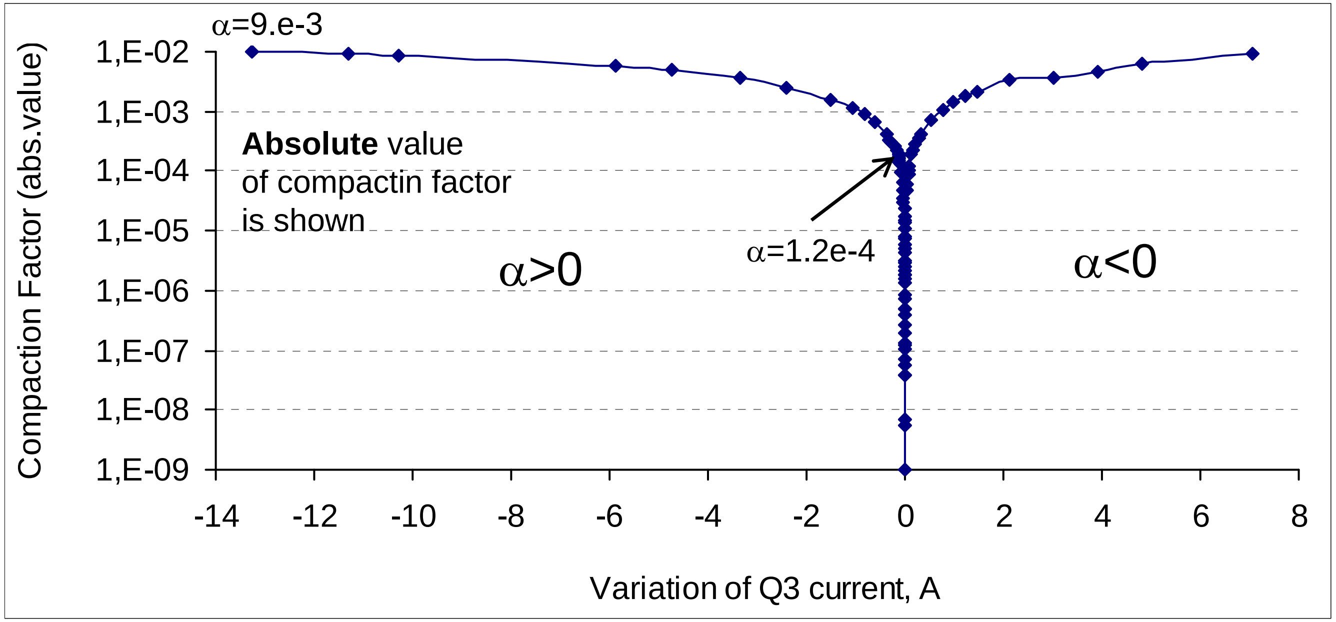
“zero“ is point where
alpha = 0
i.e. transition from
positive to negative value

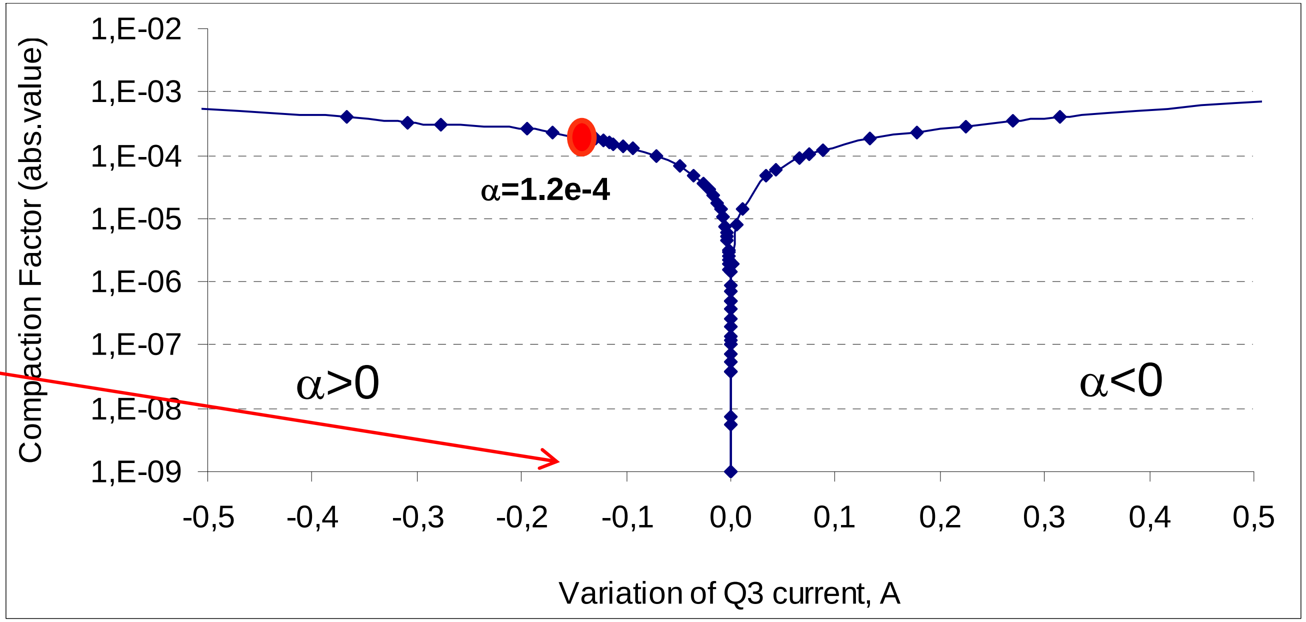
For discussion:

Assuming the beam is lost due to fluctuation of COMPACTION FACTOR to ZERO value because of the unstable gradient of quads field and/or magnetic rigidity of bends one could roughly estimate stability of PSQ to

δI/I=1.e-3 ???

Is it the case that the min allowable alpha at KARA is 1.2e-4 ???
One should check last measurements of alpha ≈5.5 e-5





Zero current Bunch length