LHC Injectors Upgrade

CERN

LHC Injectors Upgrade

Is Pb^{54+} in LEIR limitted by space charge?

Michael Bodendorfer

May 20^{h}, 2014

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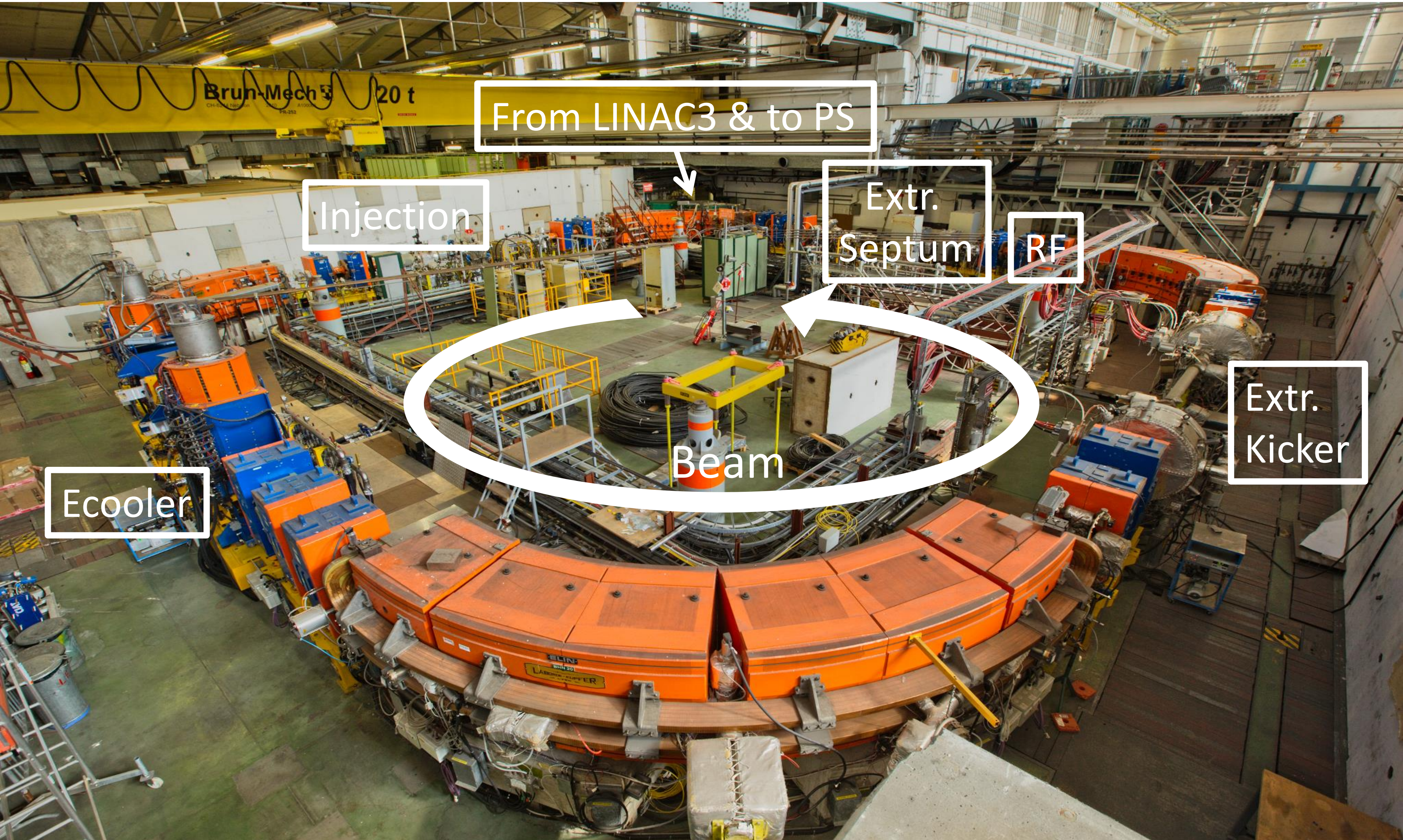
LEIR – Low Energy Ion Ring



Why upgrade LEIR Pb^{54+} performance?

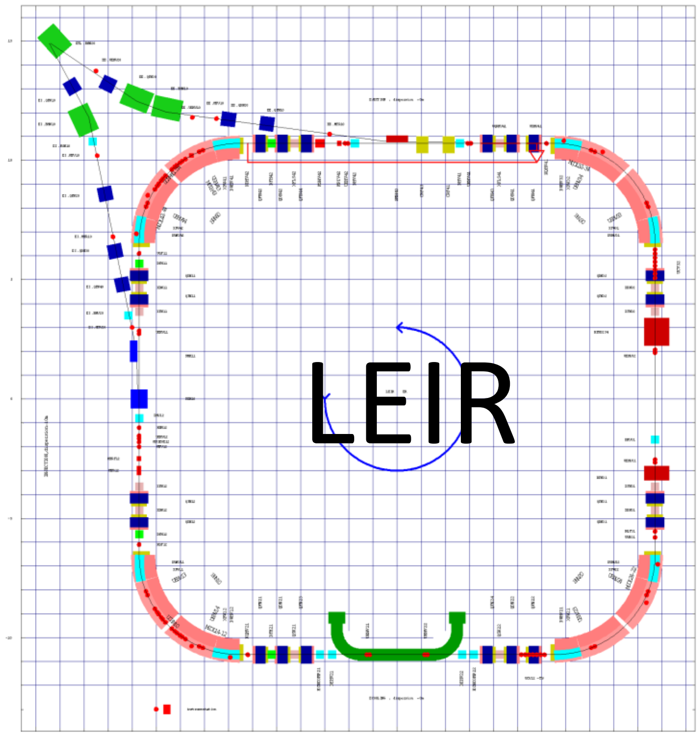
All HI LHC experiments want by 2035: $10 nb^{-1}$

Parameter	Unit	LEIR 2013 run	LEIR Baseline upgrade	LEIR Full upgrade
Pb charge state	[-]	54+		
Output Energy	[GeV/u]	0.0722		
In/Out Bρ	[Tm]	1.138 / 4.8		
Inject. to next machine	[-]	1		
Bunches/ring	[-]	2		
Charge at flat bottom	Charges	$\sim 6.0 \times 10^{10}$	6.0×10^{10}	1.1×10^{11}
Total extracted charge	Charges	$\sim 5.4 \times 10^{10}$	5.4×10^{10}	8.6×10^{10}

From: **PERFORMANCE OF THE INJECTORS WITH IONS AFTER LS1**
D. Manglunki for the LIU-Ions team, CERN, Geneva, Switzerland, 2013

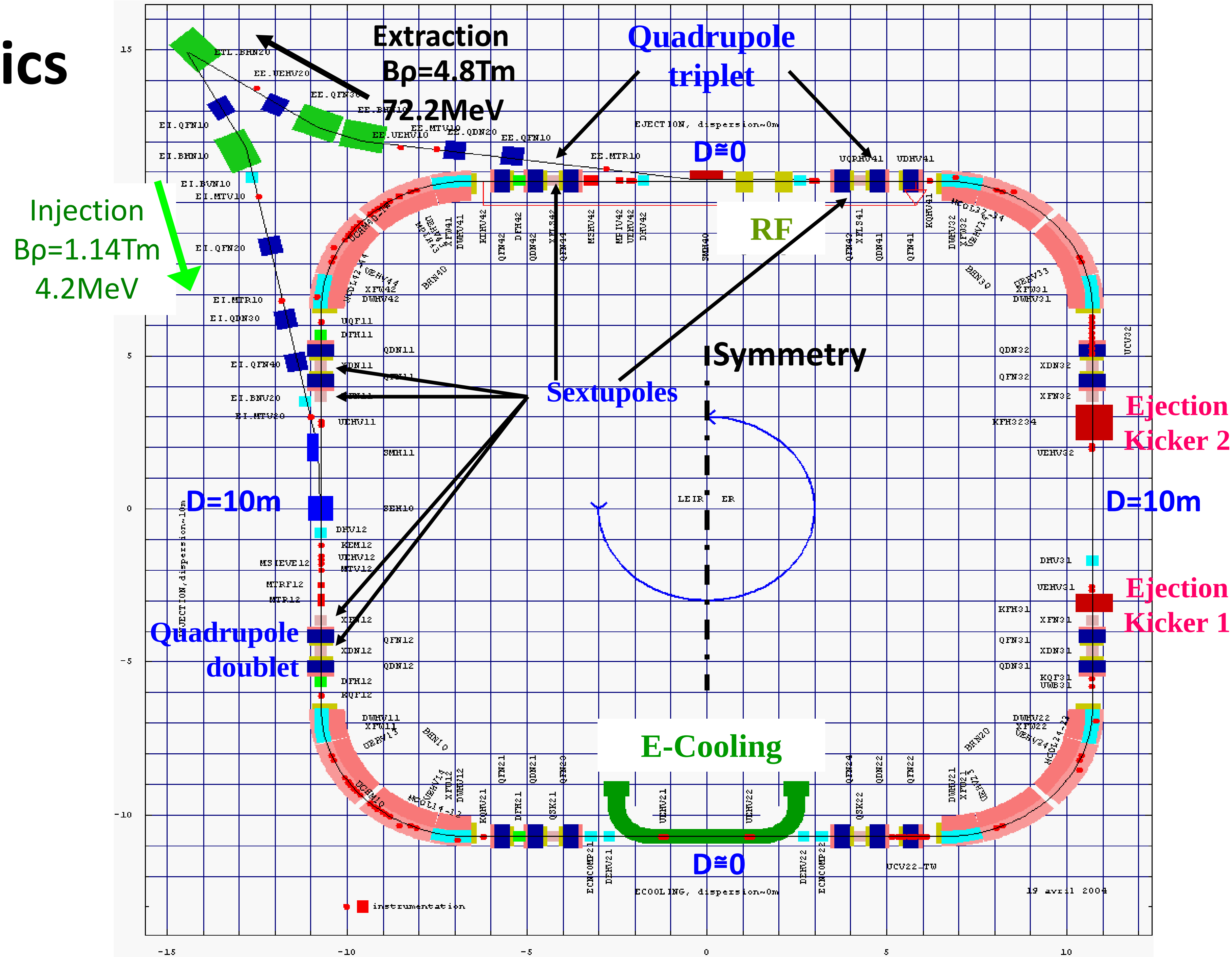
Machine specifications

Machine	Output Energy	Charge state
ECR ion source	2.5 keV/n	…,29+,…
LINAC3	4.2 MeV/n	29+/54+
LEIR	**72.2 MeV/n**	**54+**
PS	5.9 GeV/n	54+/82+
SPS	176.5 GeV/n	82+



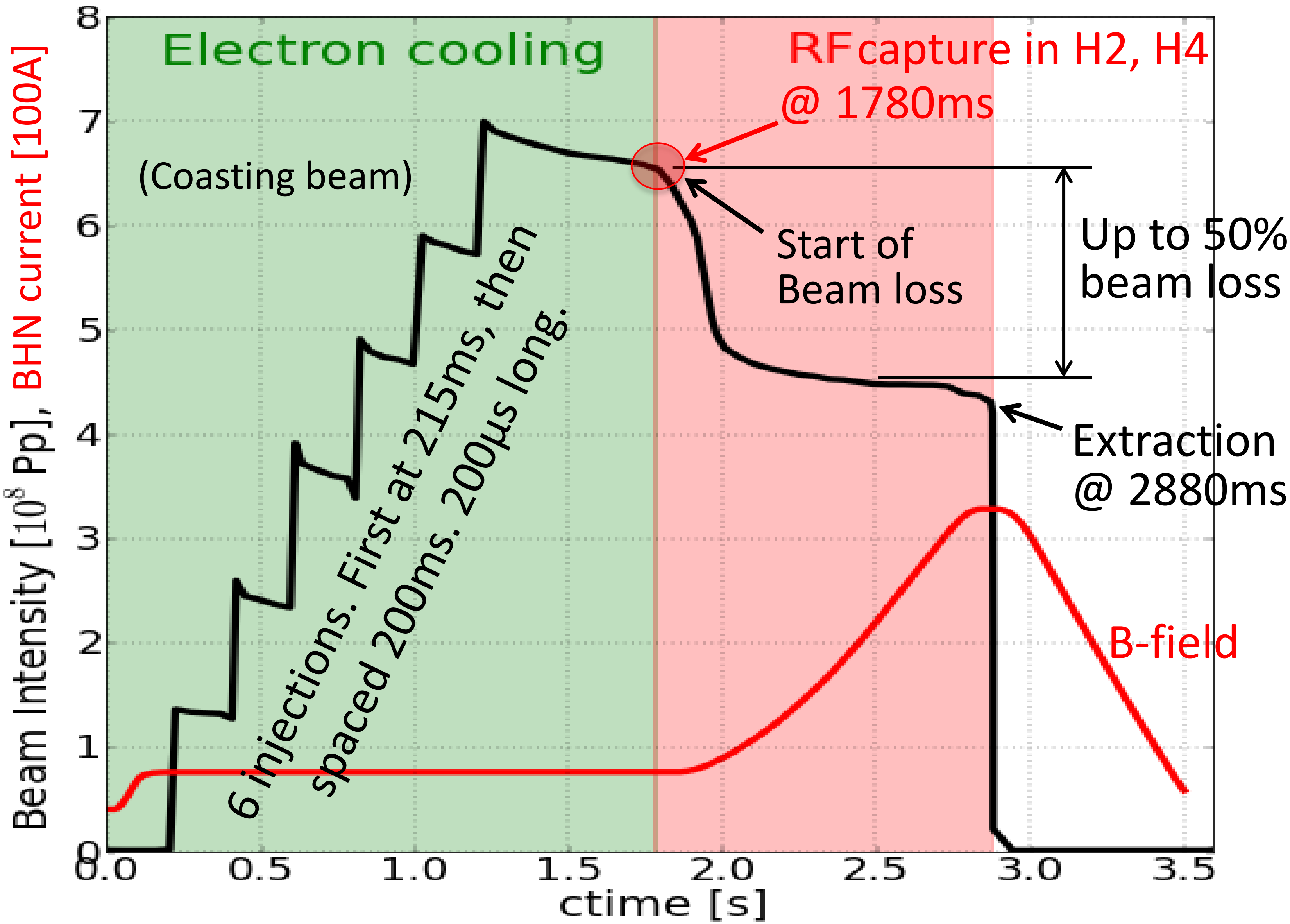
LEIR Design Parameter	Value Injection	Extraction
Length	78m	
$\beta_{rel.}$(Inj. | Ej.)	0.095	0.392
$\gamma_{rel.}$ (Inj. | Ej.)	1.0045	1.087
$\gamma_{transition}$	2.84	
$\Sigma^{*}_{transv.}$ (Hor.|Vert.)	6µm|4µm	0.65|0.7µm
$\Sigma_{long.}$ (Inj. | Extr.)	0.015eVs/u	0.1eVs/u
Tune (Hor. | Vert.)	1.82|2.72	1.82|2.72

Optics



Extraction
Bρ=4.8Tm
72.2MeV
Quadrupole
triplet
EJECTION, dispersion~0m
D≅0
RF
Injection
Bρ=1.14Tm
4.2MeV
Symmetry
Sextupoles
Ejection
Kicker 2
D=10m
LEIR
ER
D=10m
Ejection
Kicker 1
Quadrupole
doublet
E-Cooling
D≅0
ECOOLING, dispersion~0m
instrumentation
19 avril 2004

Standard LEIR nominal cycle: low energy beam loss.

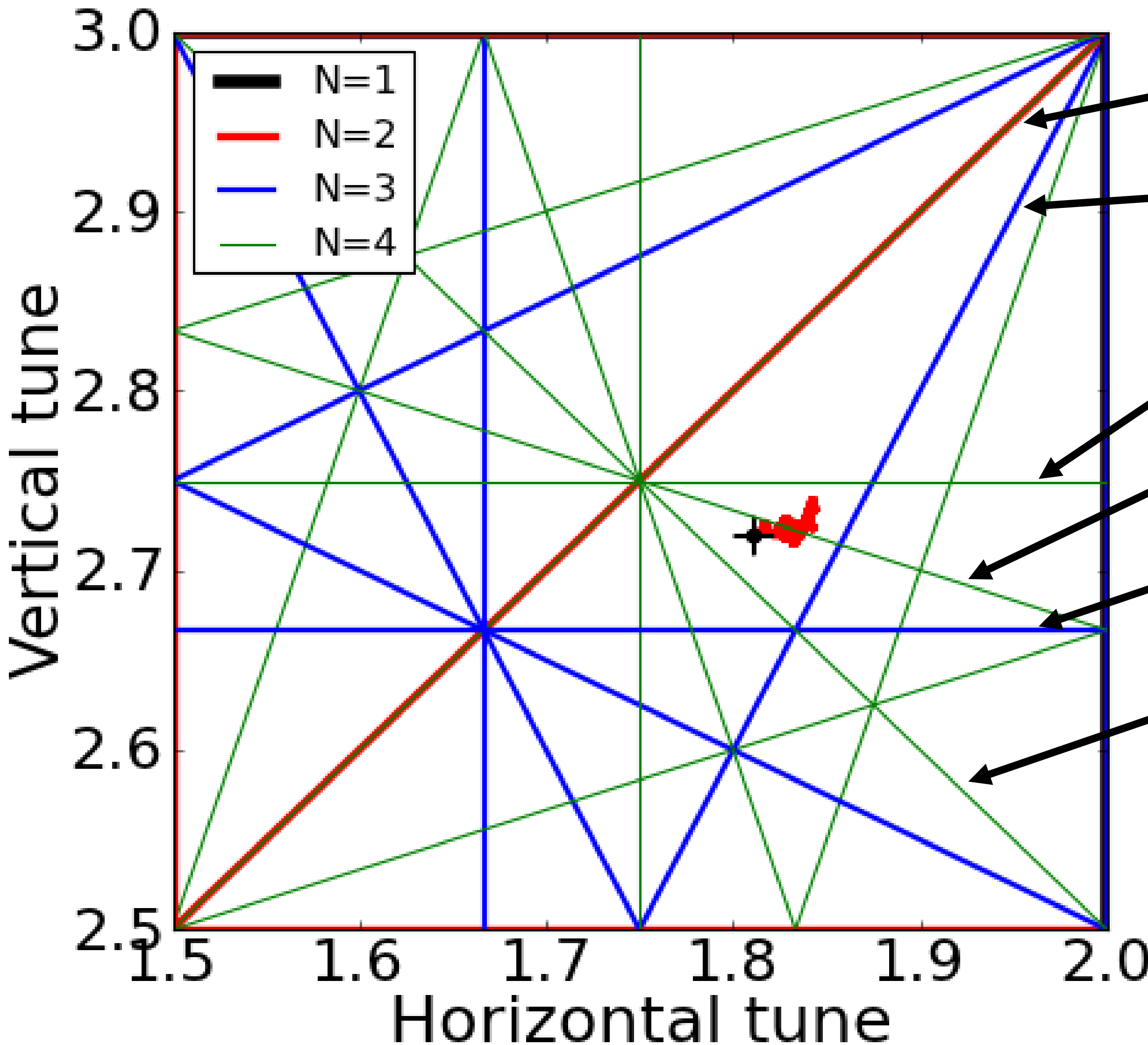


Finding a solution for LEIR

What we have found so far:

1. Working point on 4th order resonance
2. Transverse instability at RF capture
3. Positive chromaticity in the vertical plane
4. Beam loss associated to RF-capture rather than magnetic Ramp.

1. Design tune: Q_H=1.82, Q_V=2.72



$Q_x - Q_y = -1$

$2Q_x - Q_y = 1$

$4Q_y = 11$

$Q_x + 3Q_y = 10$

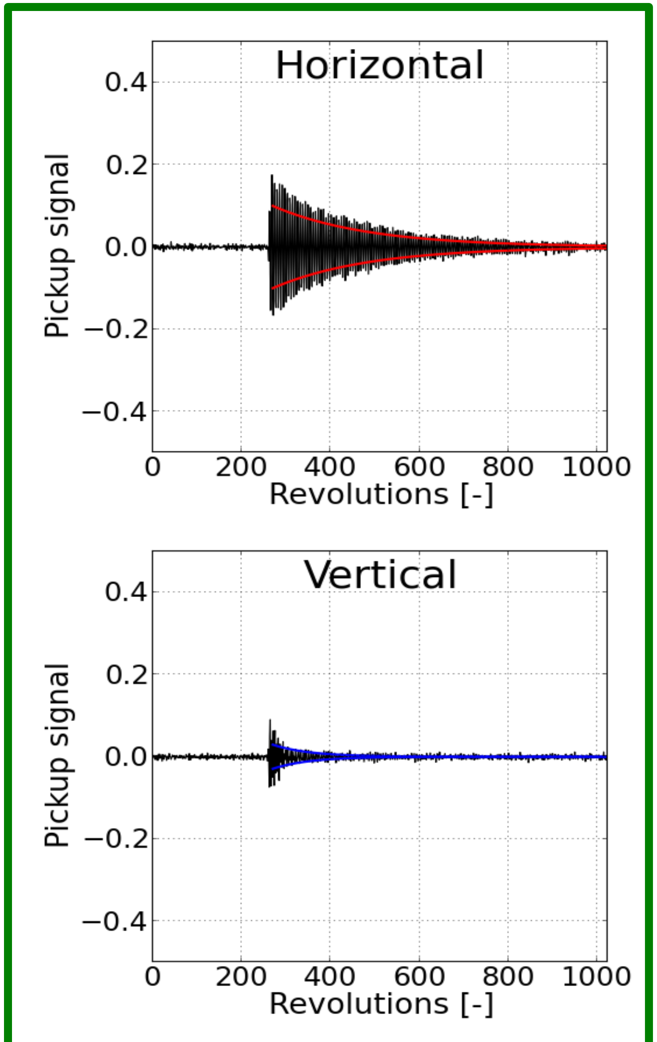
$3Q_y = 8$

$2Q_x + 2Q_y = 9$

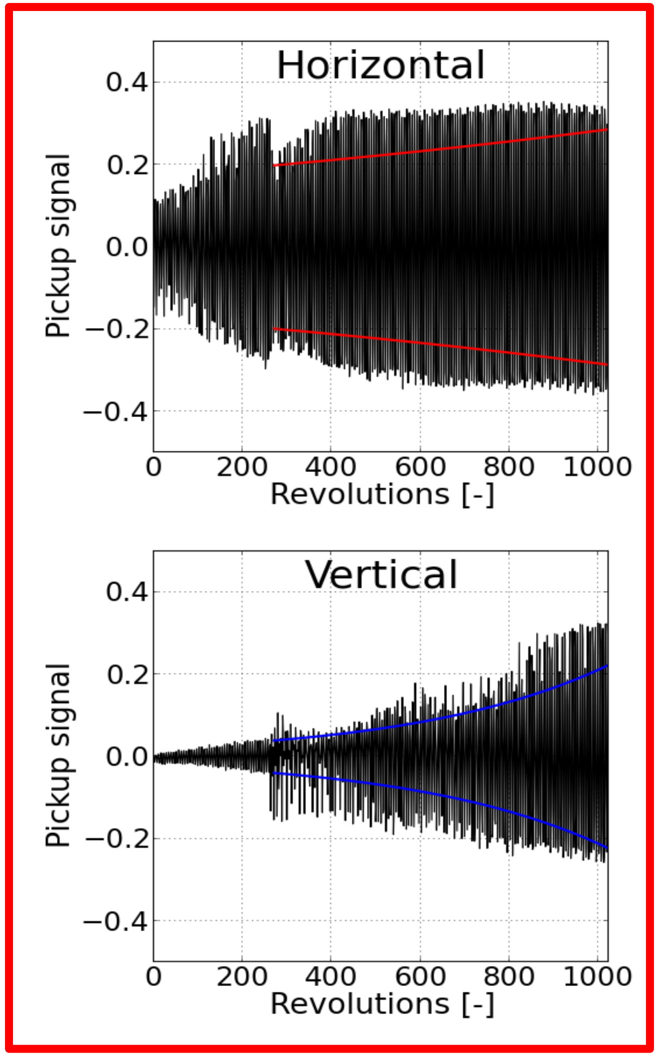
2. LEIR Instability at RF capture and magnetic ramp

Pickups output:

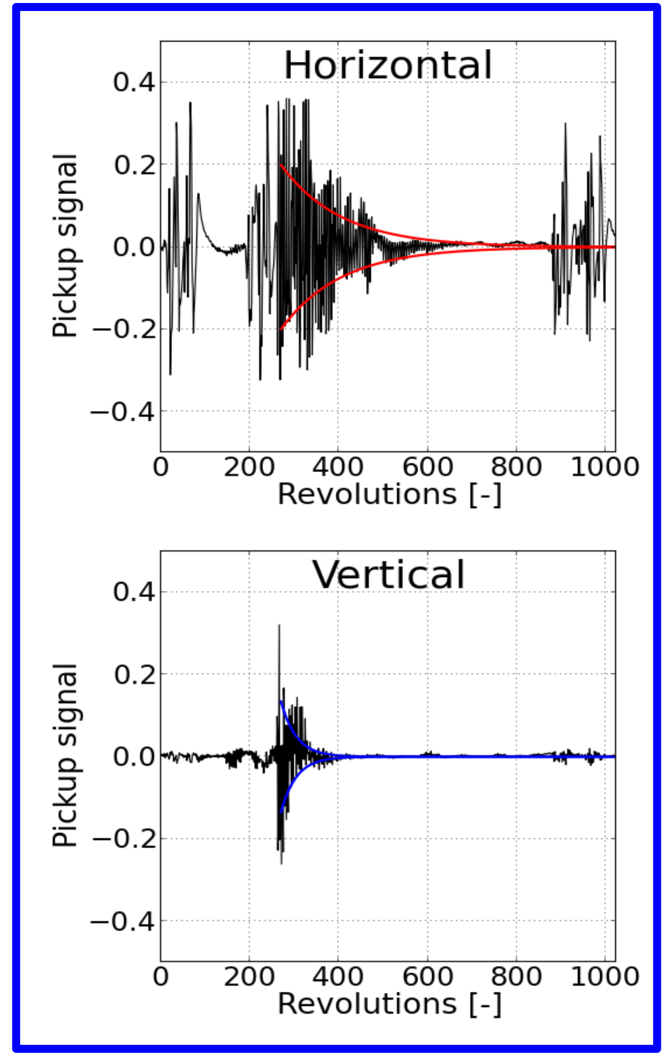
Before: -20ms



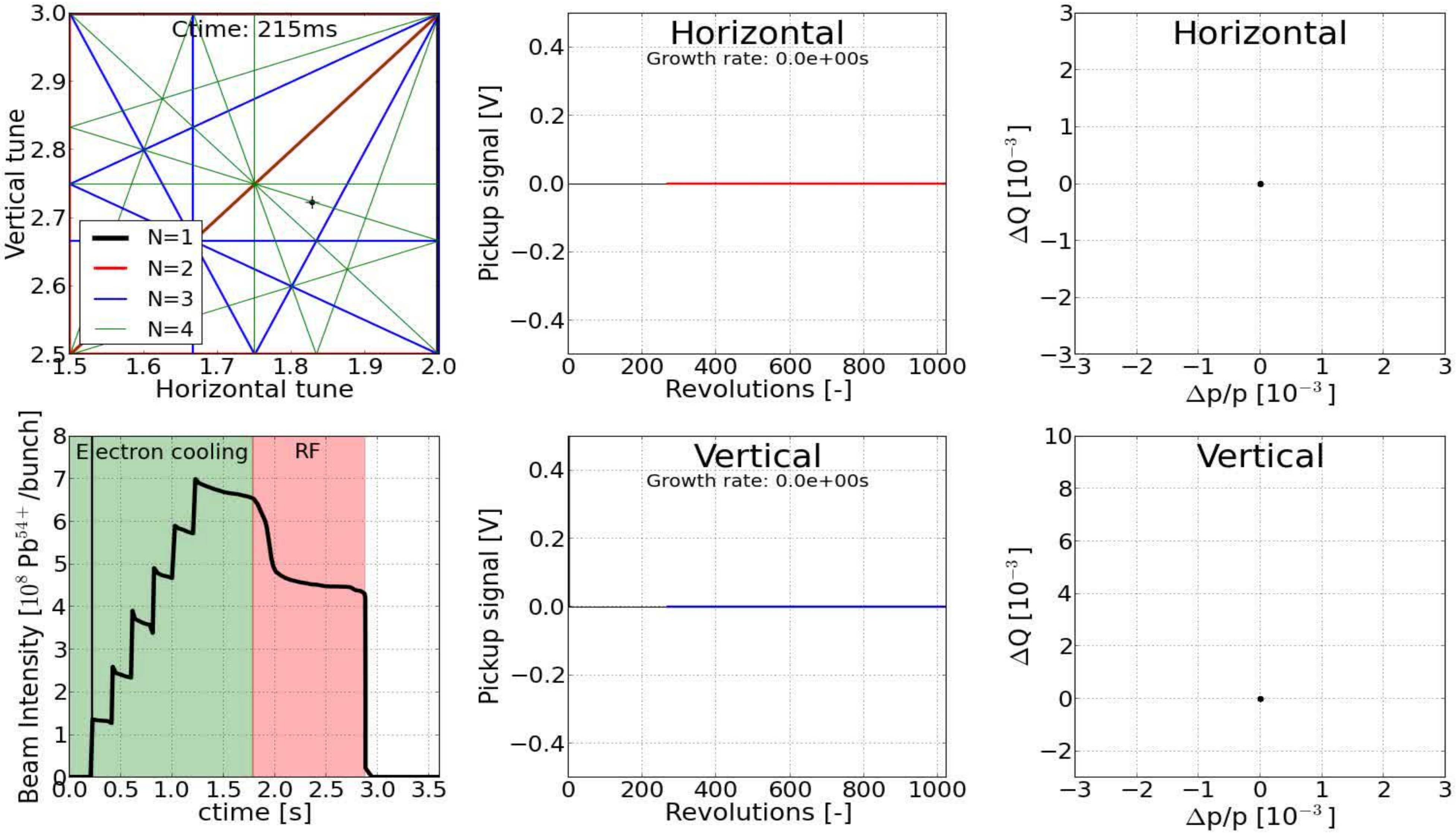
1815ms
Beam loss **starts** here



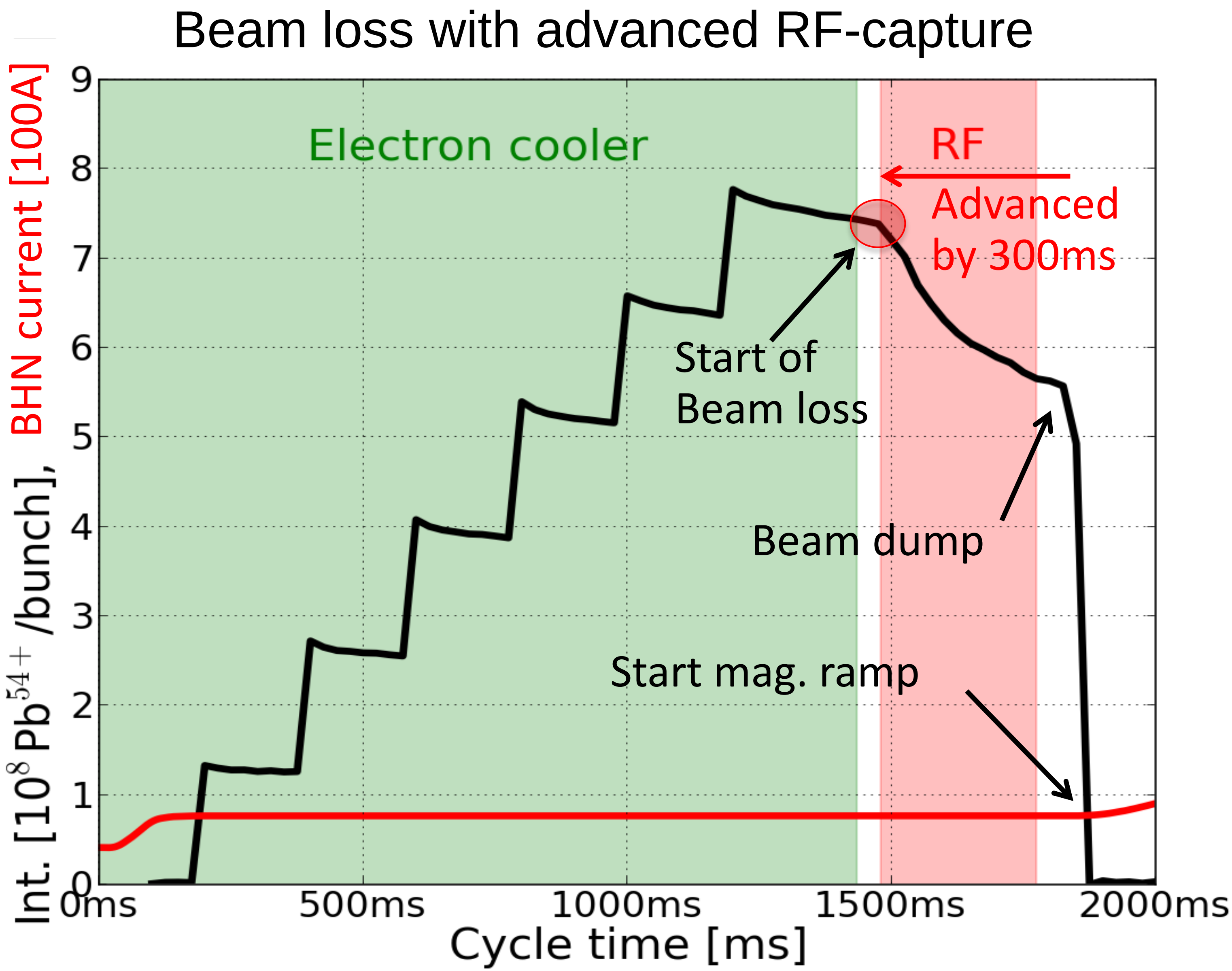
After: +20ms
Beam loss **continues**



3. LEIR chromaticity



Elliminated working hypothesis “B-ramp”:



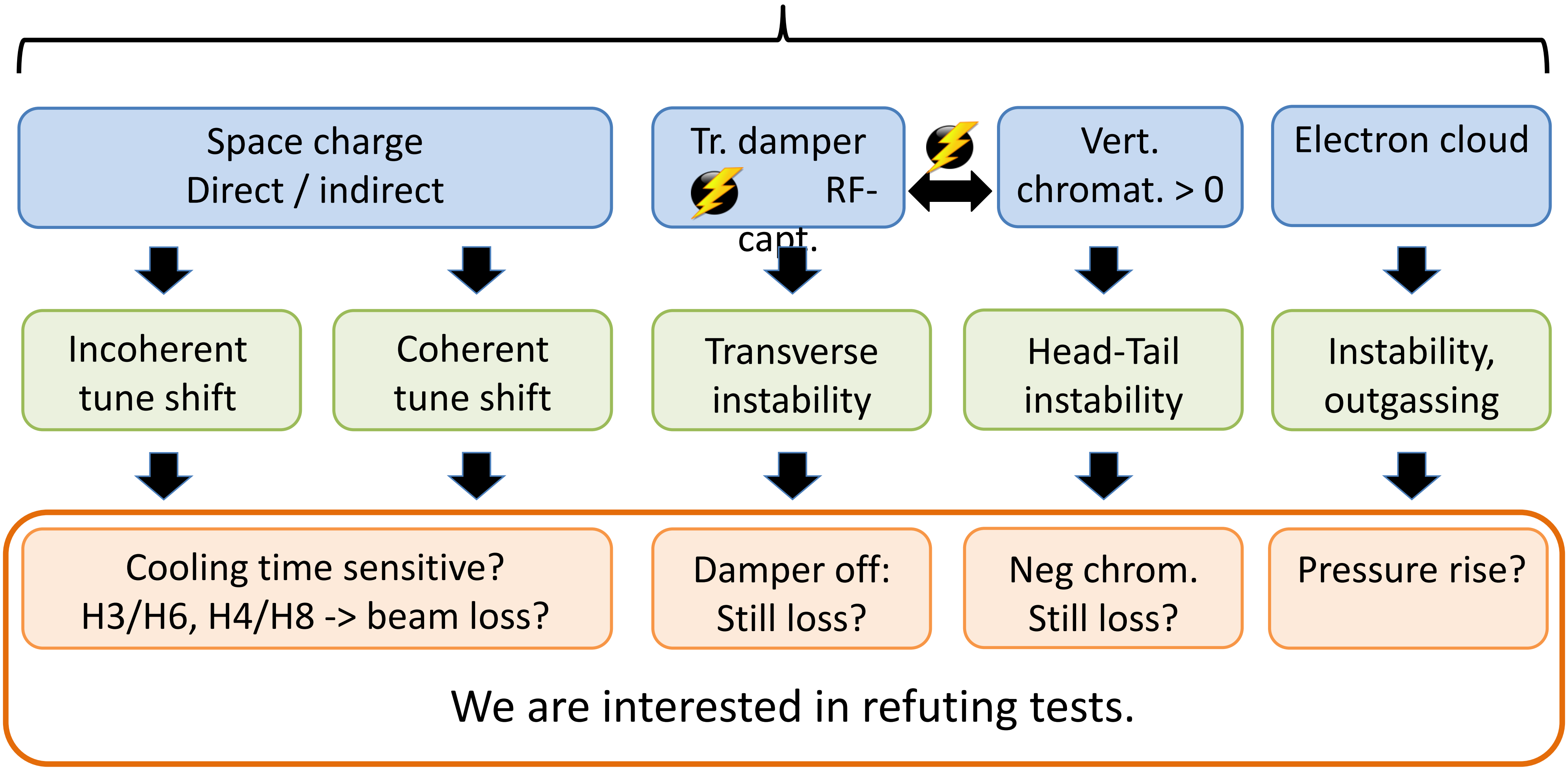
Elliminated working hypothesis “B-ramp”:

What can we do with this?

We can study the phenomenon **without** a magnetic ramp:

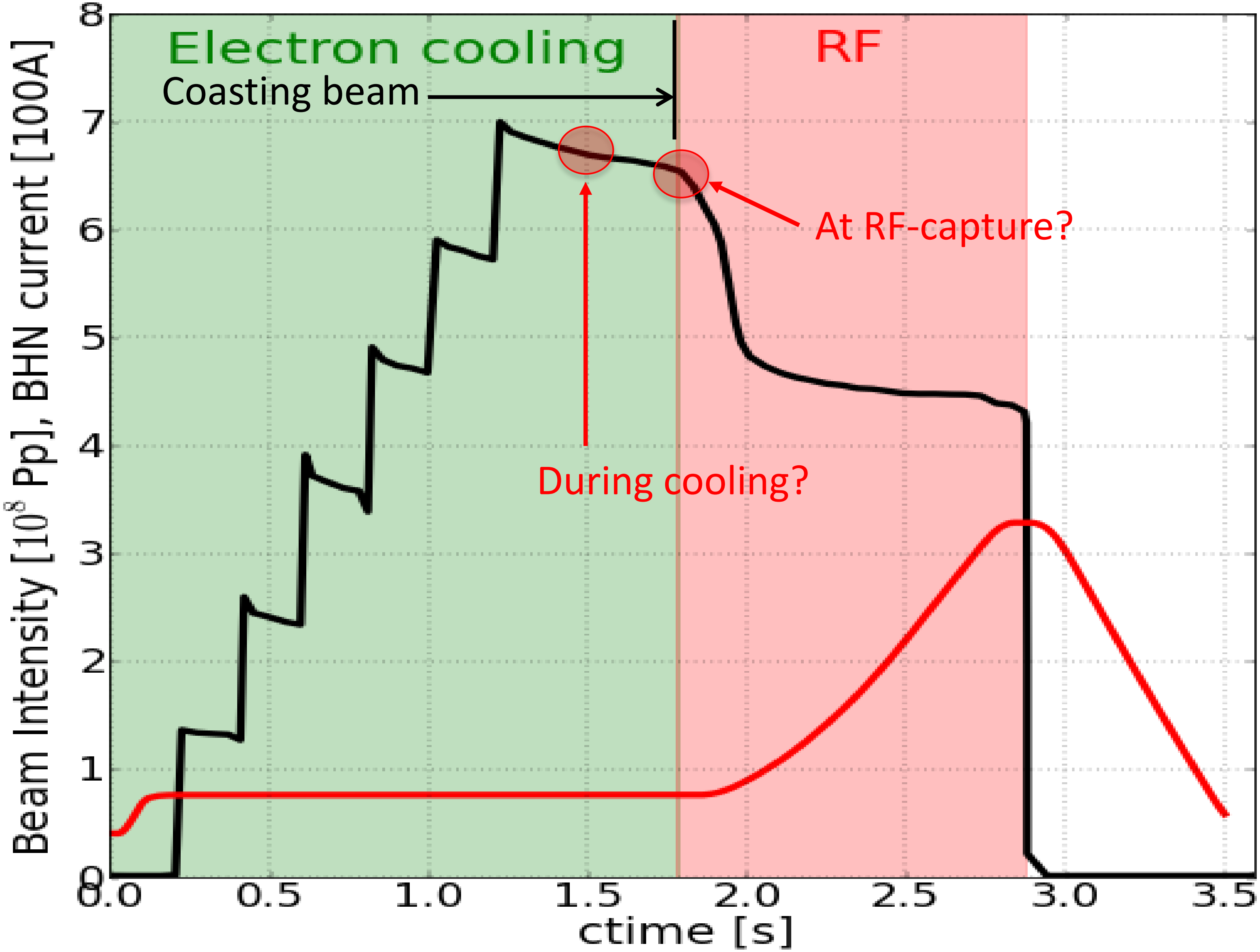
- Flat bottom cycle
- RF-capture with different beam parameters (emitt.)
- Use of ionization pressure gages during beam loss

Remaining working hypotheses for the LEIR low energy beam loss



Can we eliminate further working hypotheses?

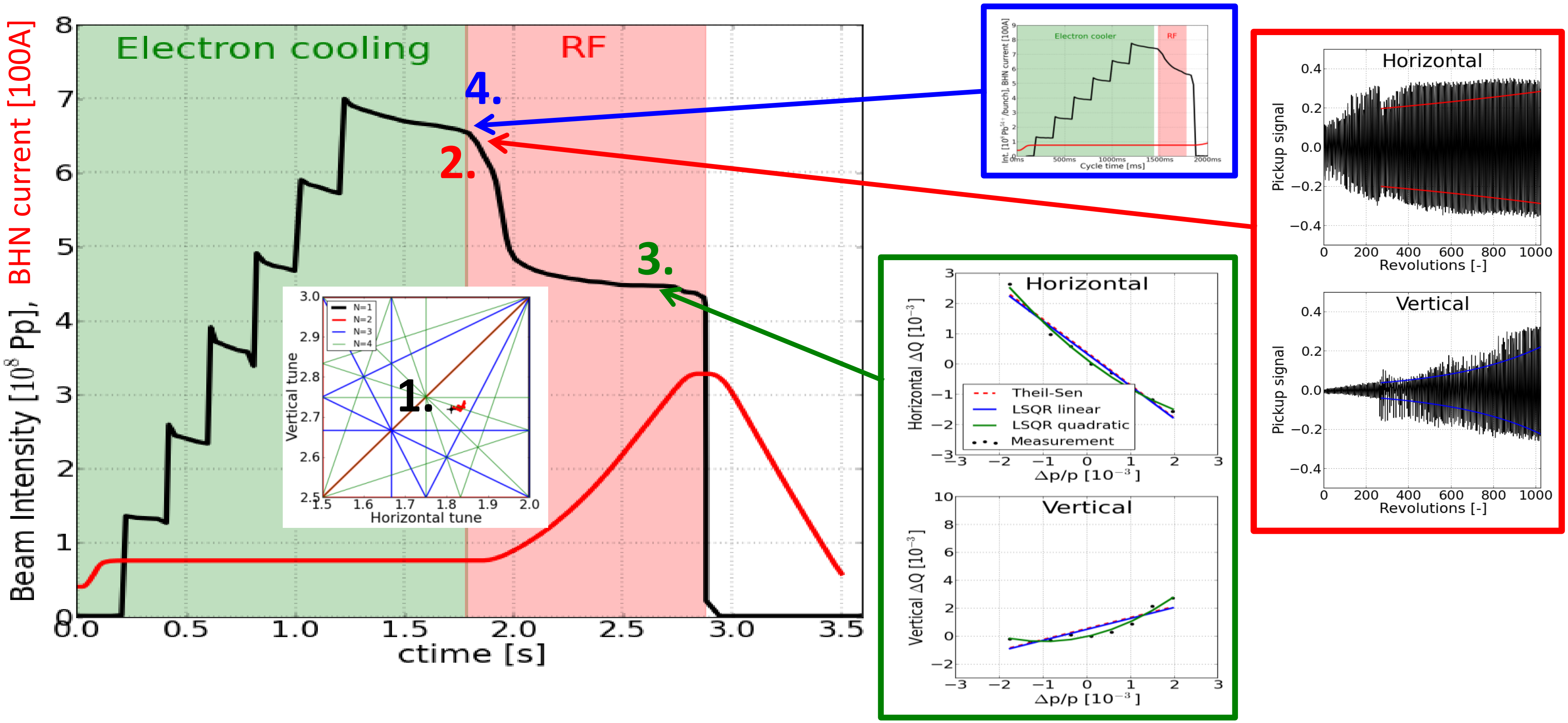
Space charge limitation in LEIR?



Findings:

Clues from measurements:

1. Working point on 4th order resonance
2. Transverse instability at RF capture
3. Positive chromaticity in the vertical plane
4. Beam loss associated to RF-capture rather than mag. ramp



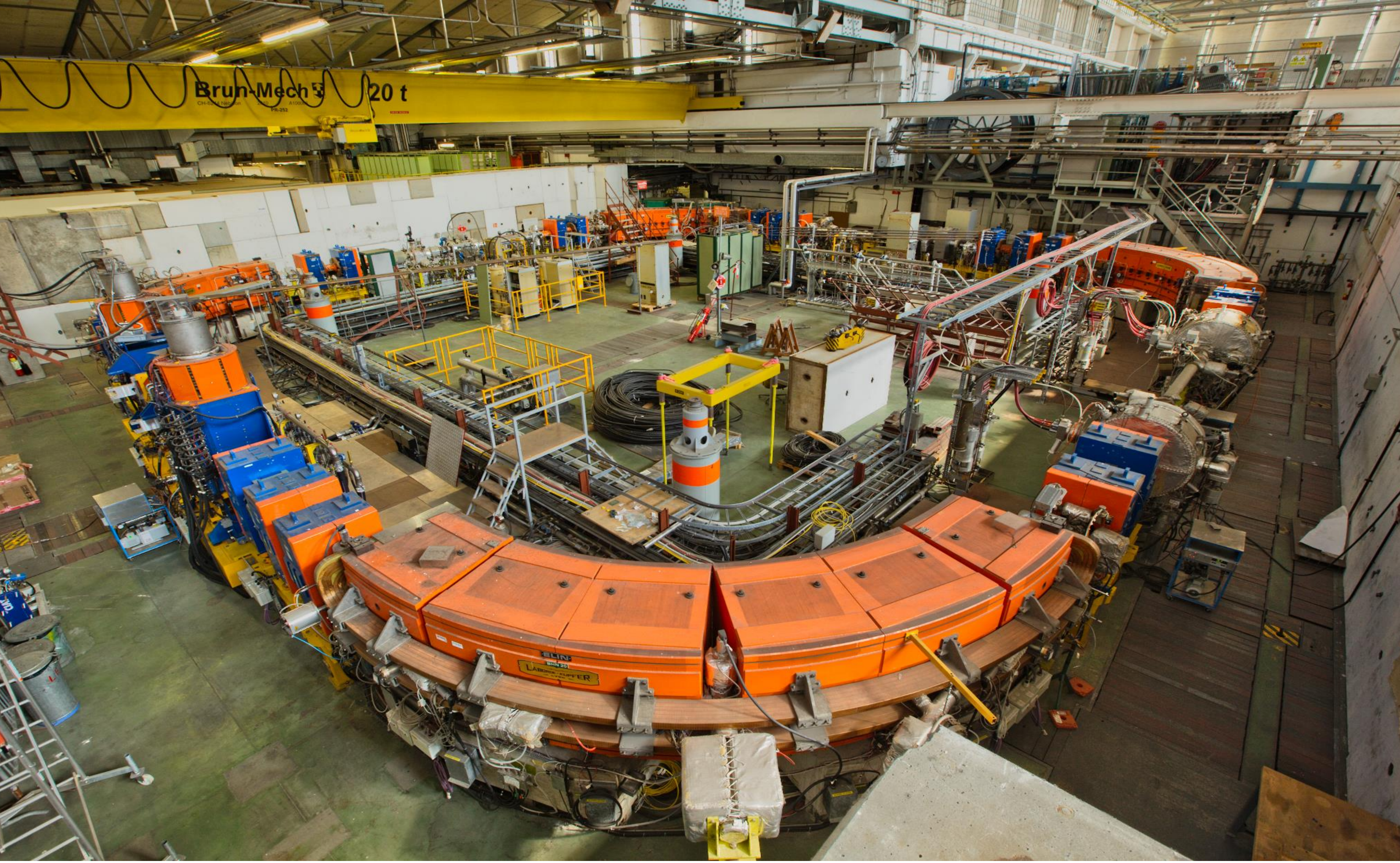
MD roadmap excerpt:

MD series with flat bottom cycle:

- Beam loss associated to RF-capture rather than magnetic ramp
  1. Try RF-capture with different beam parameters (bunch length and transverse emittances) to check the impact of **space-charge**.
  2. Capture at different harmonics than H2/H4
  3. Study the interaction of electron cooling and RF-capture.

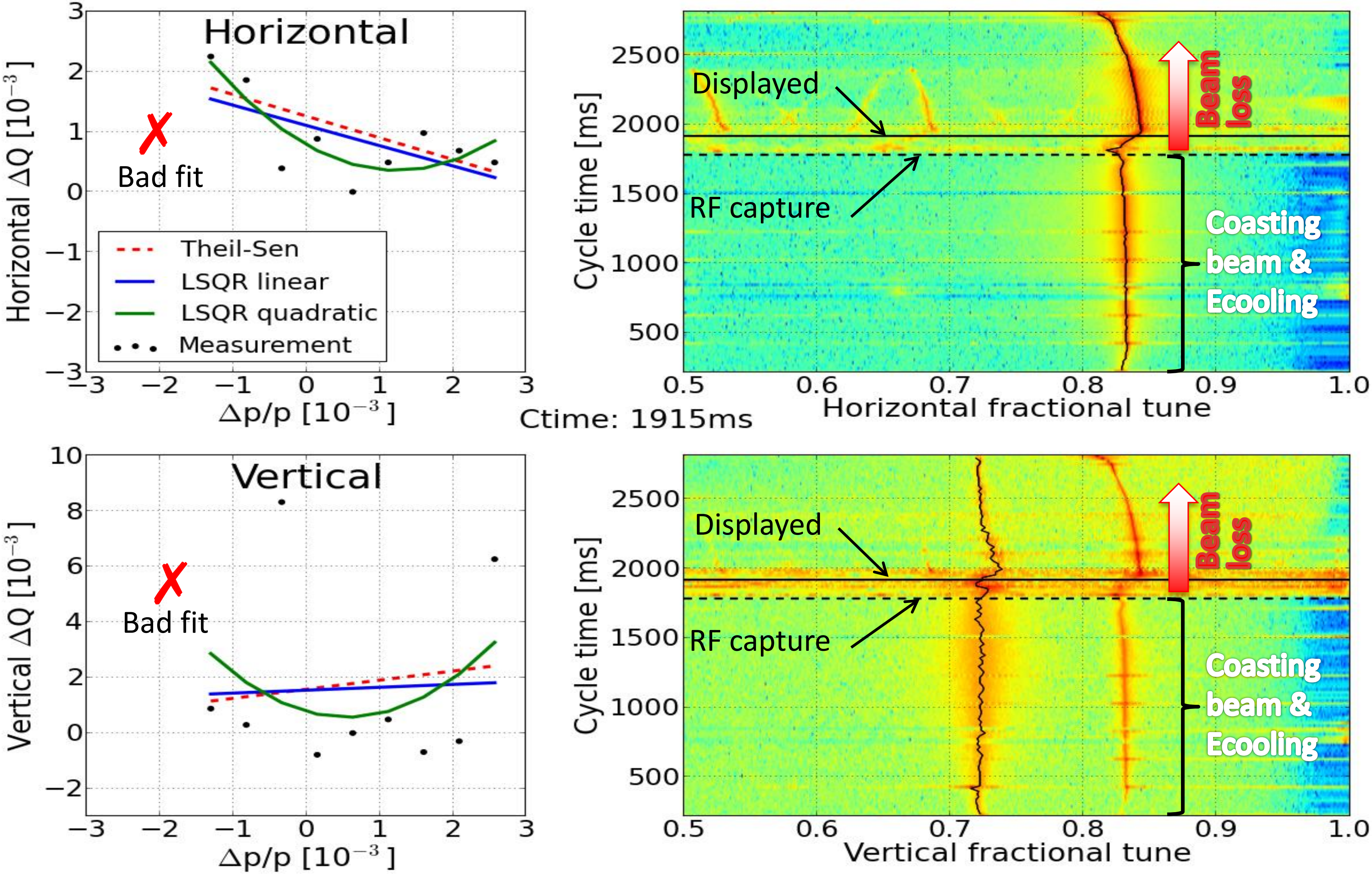
Summary and outlook

- List of working hypotheses established
- Working hypothesis of B-ramp eliminated
- Flat bottom analysis ahead on MD roadmap
- LEIR optical model with and without electron-cooler
- PTC-Orbit simulation of:
  - Flat bottom
  - Multiturn injection
  - RF-capture

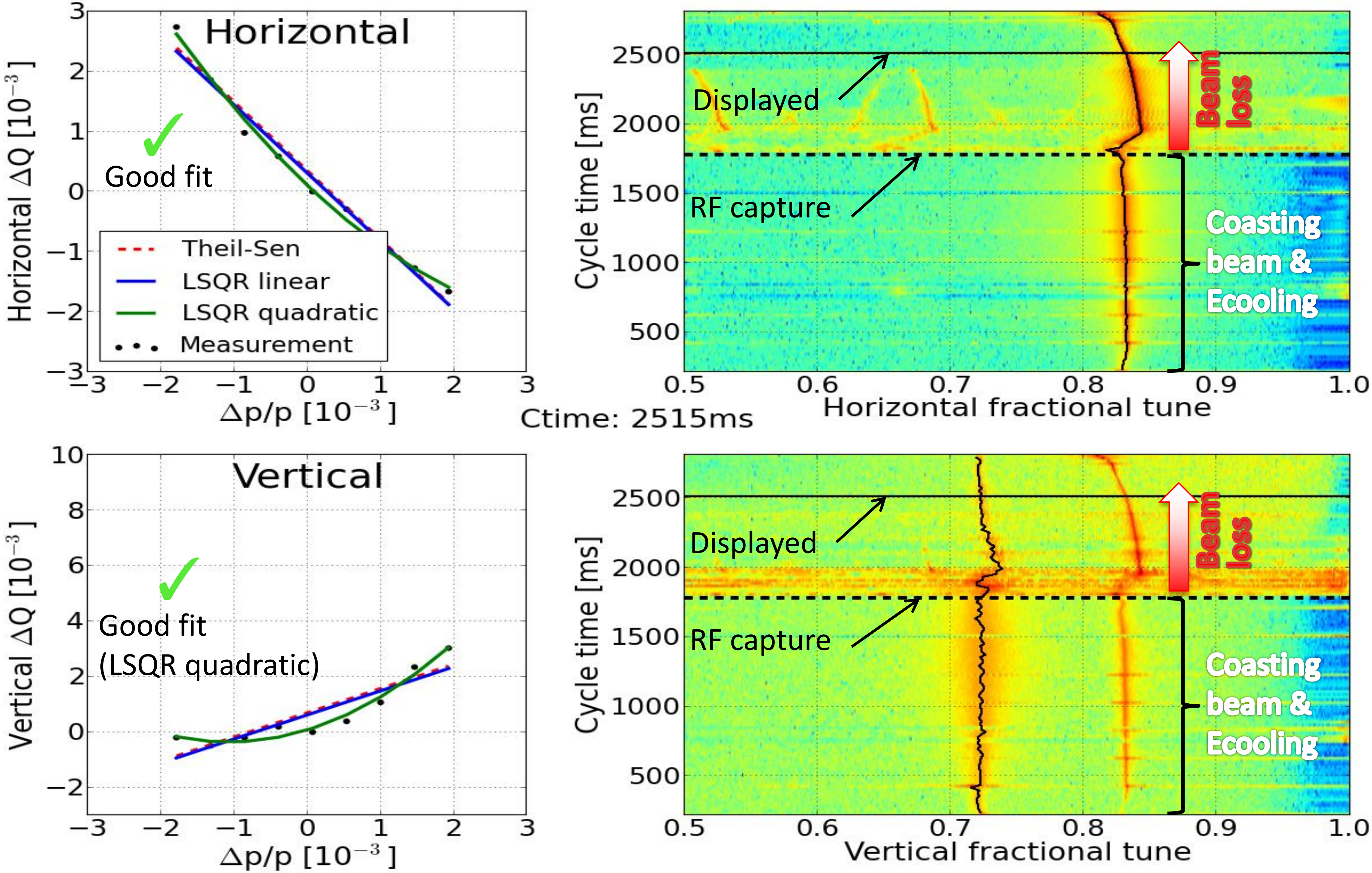


Thank you for your attention!

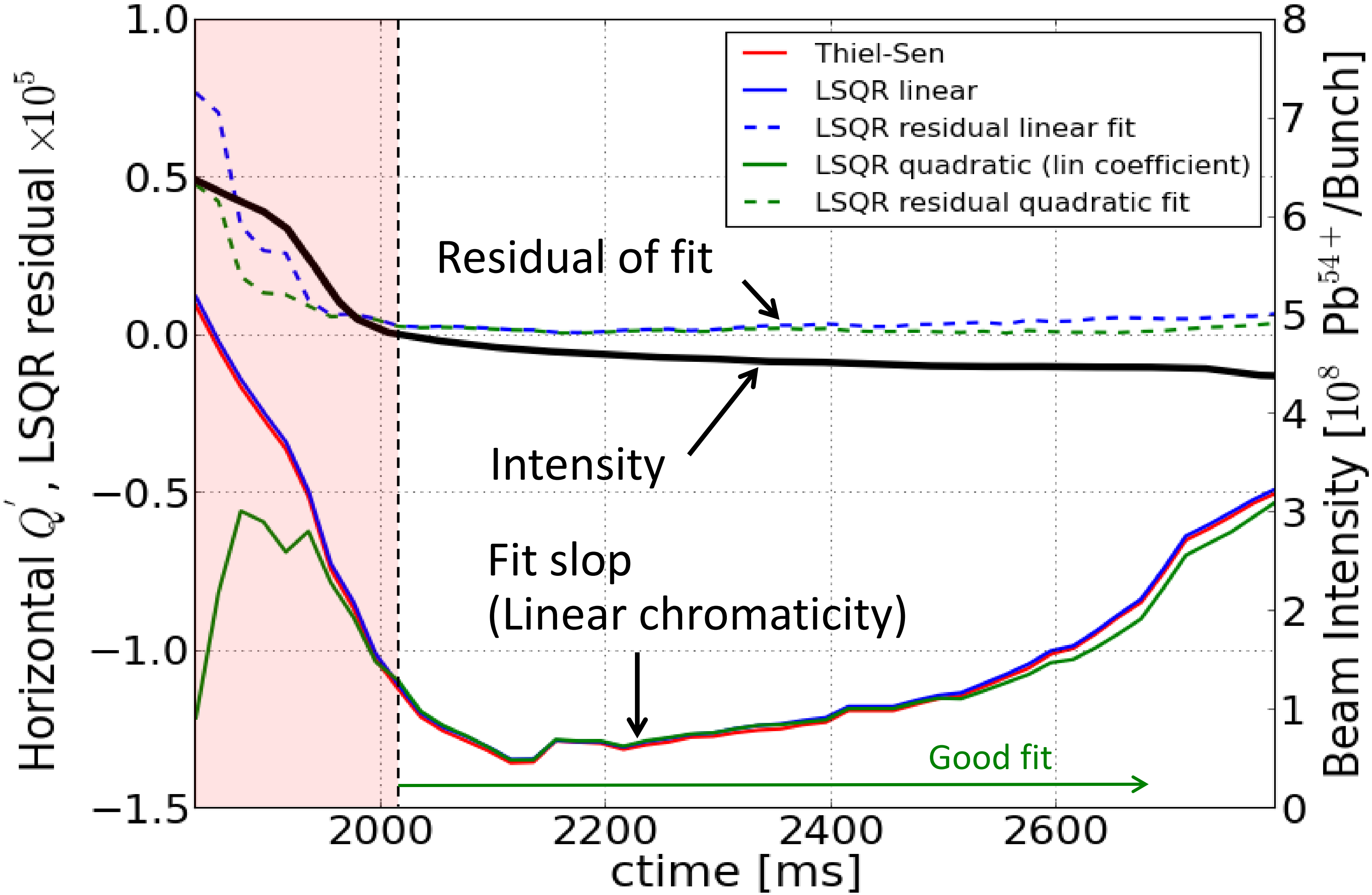
3. Tune and chromaticity measurement after RF-capture



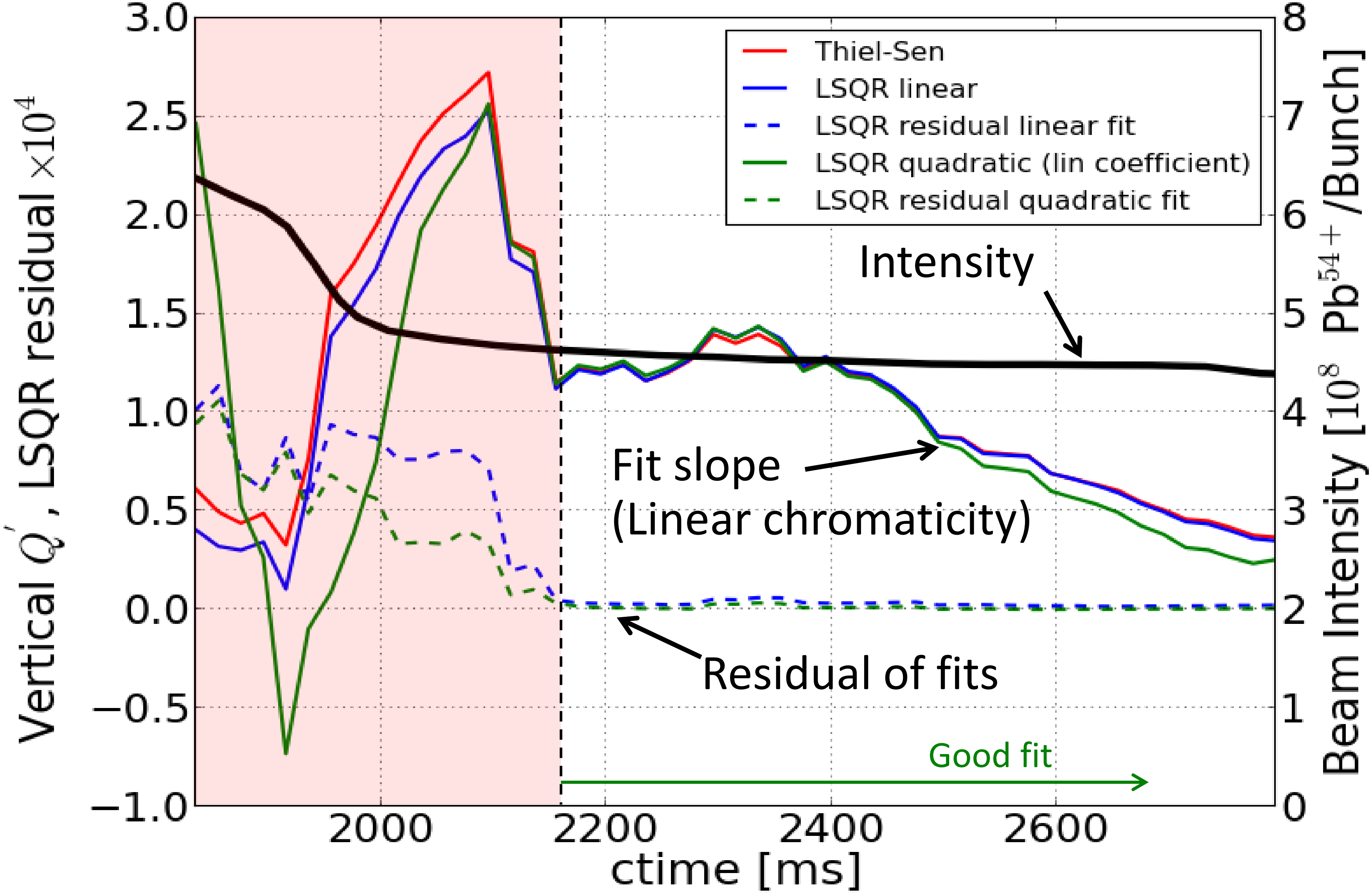
3. Tune and chromaticity measurement



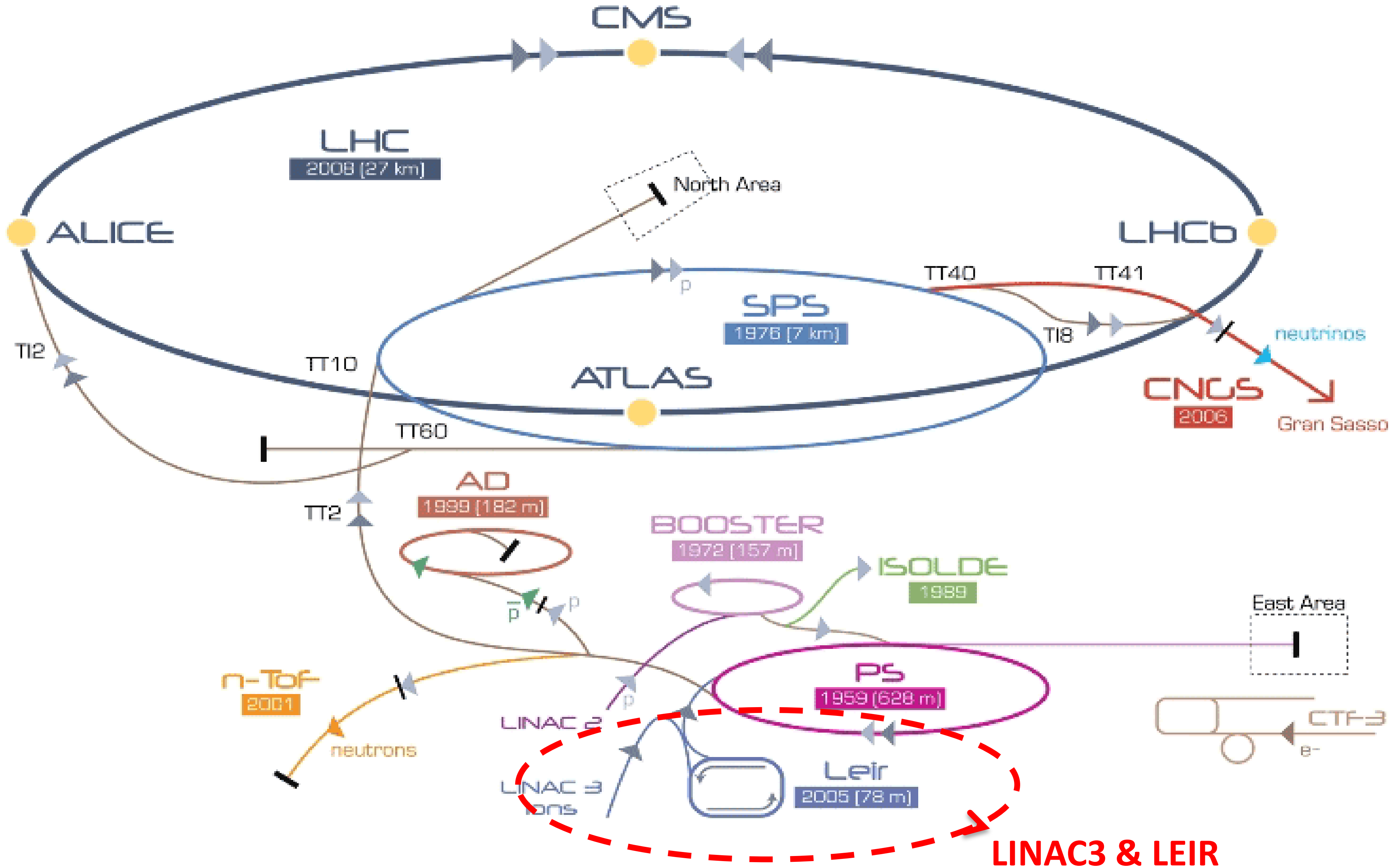
3. Horizontal chromaticity < 0 (after RF capt.)
(Horizontal design chromaticy = -1)



3. Vertical chromaticity > 0 (after RF capt.) (Vertical design chromaticy = -1)

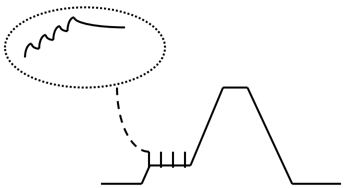


Overview

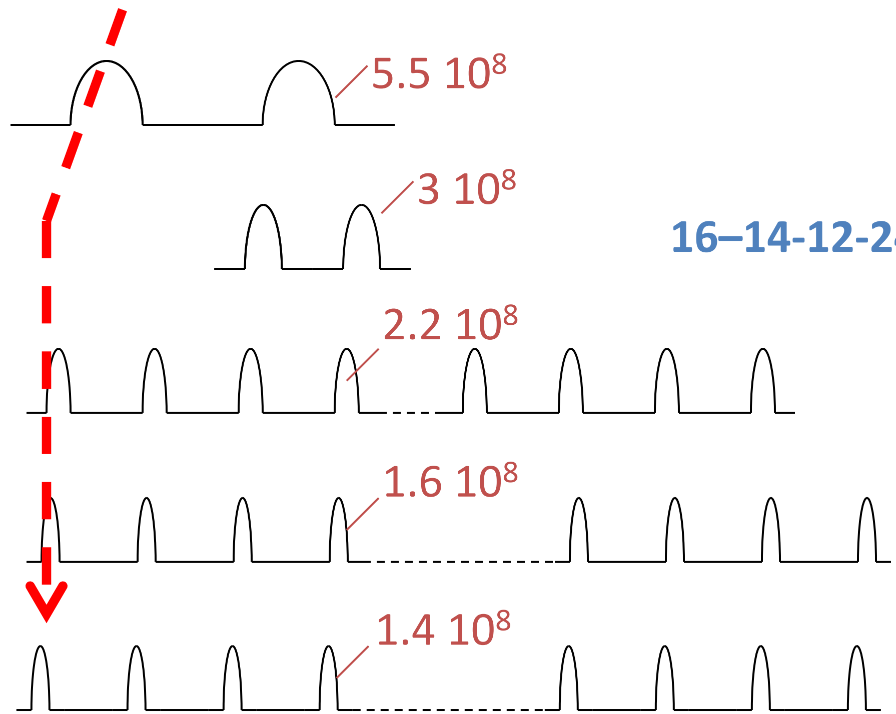


LINAC3 & LEIR

Current scheme
(“intermediate” in 2011, with 2013 performance)



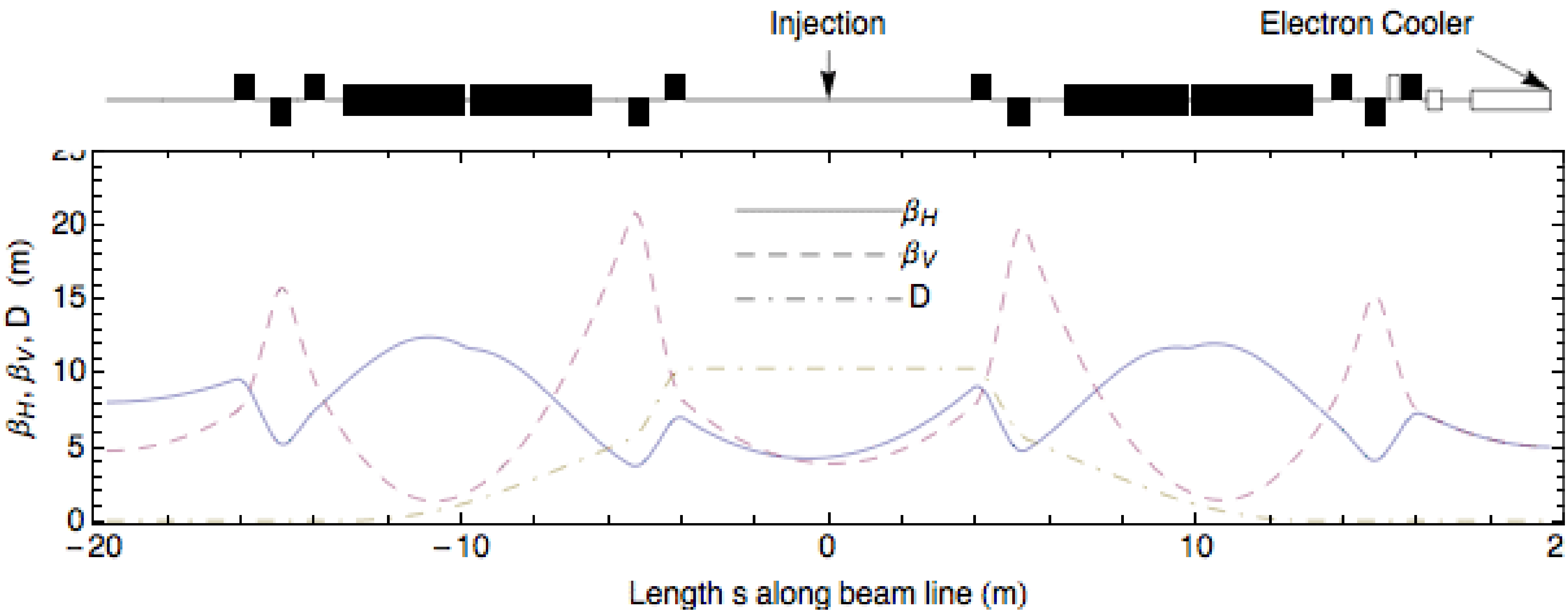
7 injections



	Nb of bunches	Pb ions / (future) LHC bunch	Harmonic number / Frequency
LEIR:(1.1 10^9 Pb ions / 3.6 s)	2	5.5 10^8	2
PS (NO splitting) bunch spacing = 200ns	2	3 10^8	16–14-12-24 / 24-21-169
SPS at extraction, after 12 transfers from PS, Batch spacing = 200 ns as well	24	2.2 10^8	200 MHz
LHC at injection, after 15 transfers from SPS	358	1.6 10^8	400 MHz
LHC in collision	360	1.4 10^8	

b* = 1 m -> L = 5.10^{26} cm^{-2} s^{-1}

TWISS parameters (MADX)



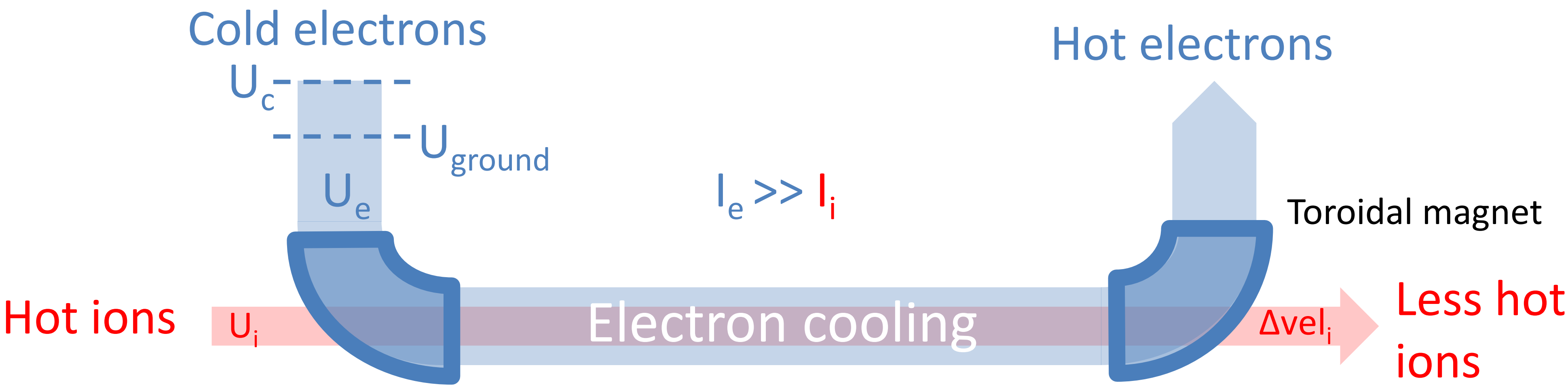
From: **Low Energy Ion Ring LEIR**, C. Carli, 14th March 2012

Electron cooling: Cooling rate

U_c = Cathode potential

U_e = Space charge potential of electron beam

U_i = Space charge potential of ion beam



How quick?

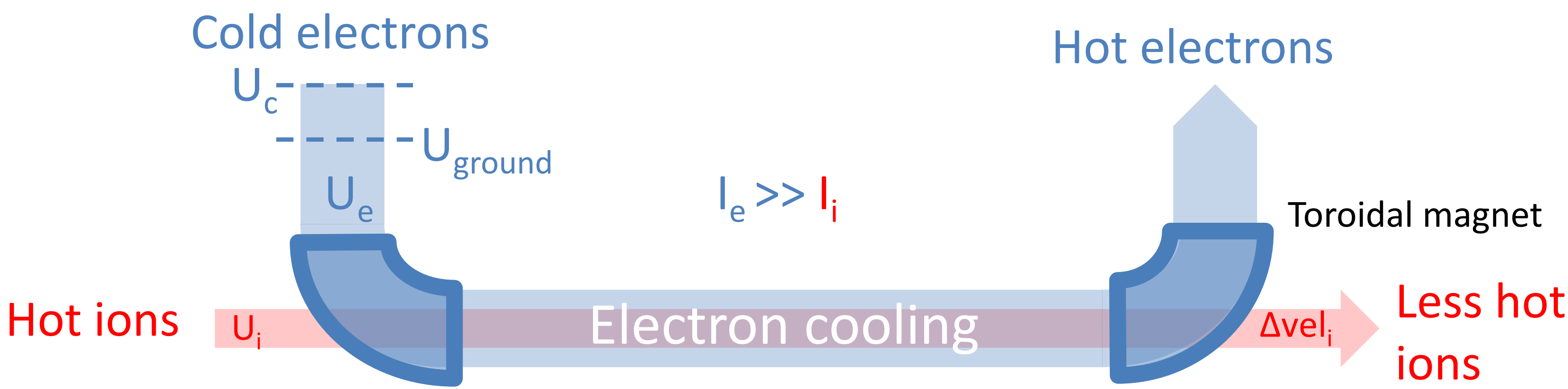
→ Cooling rate: $$\frac{1}{\tau} \approx \frac{Q^2}{A}\frac{1}{\beta_{rel}^4 \gamma_{rel}^5}$$

Electron cooling: beam potential

U_c = Cathode potential

U_e = Space charge potential of electron beam

U_i = Space charge potential of ion beam

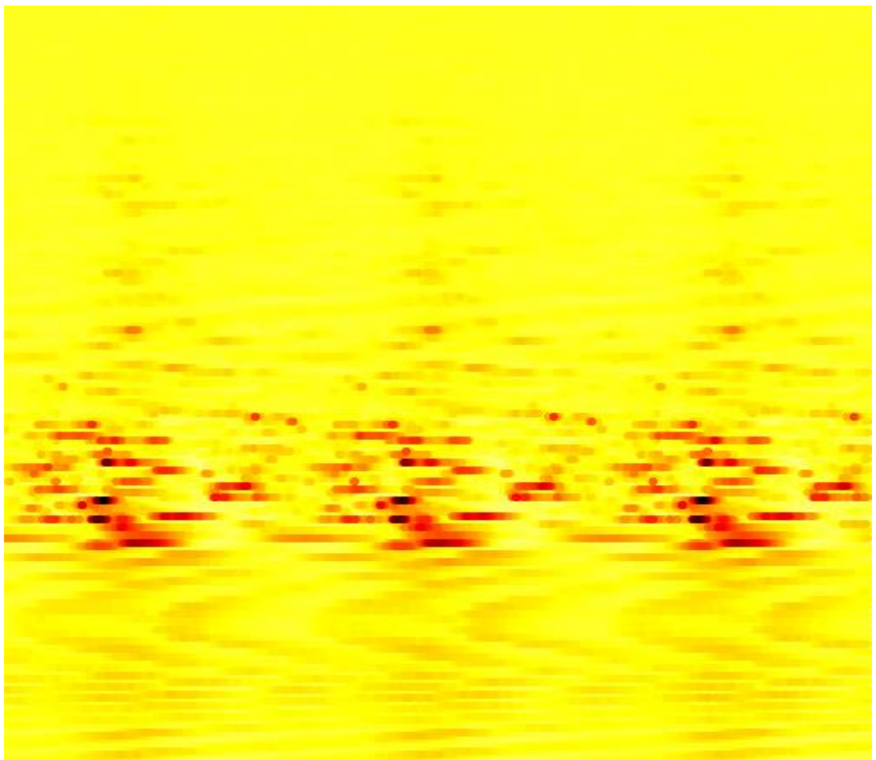


$E_{kin\_e} = q_{e-}(U_c + U_e + U_i)$ → vel_e → Cooling → Δvel_i → RF adjust $F_{revcorr}$ necessary

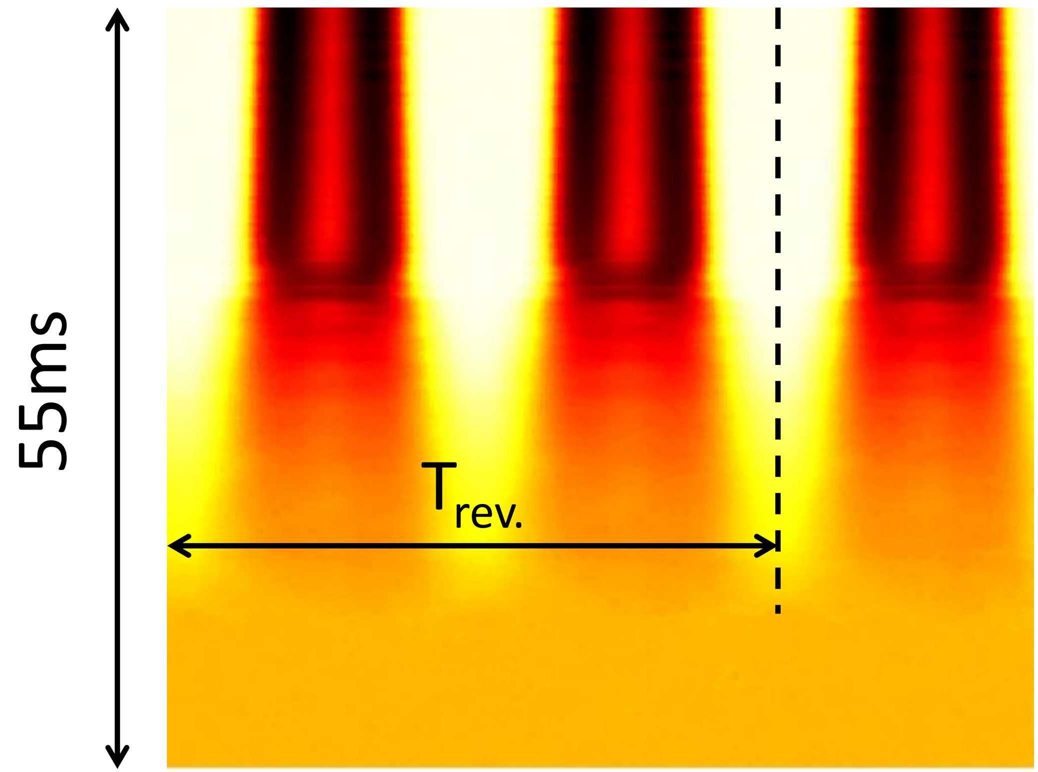
Higher accumulated intensity (before RF-capture)

- beam is lost at RF-capture
- Adjusting $F_{revcorr}$ -> RF-capture successful

Tomoscope @ RF capture **before**

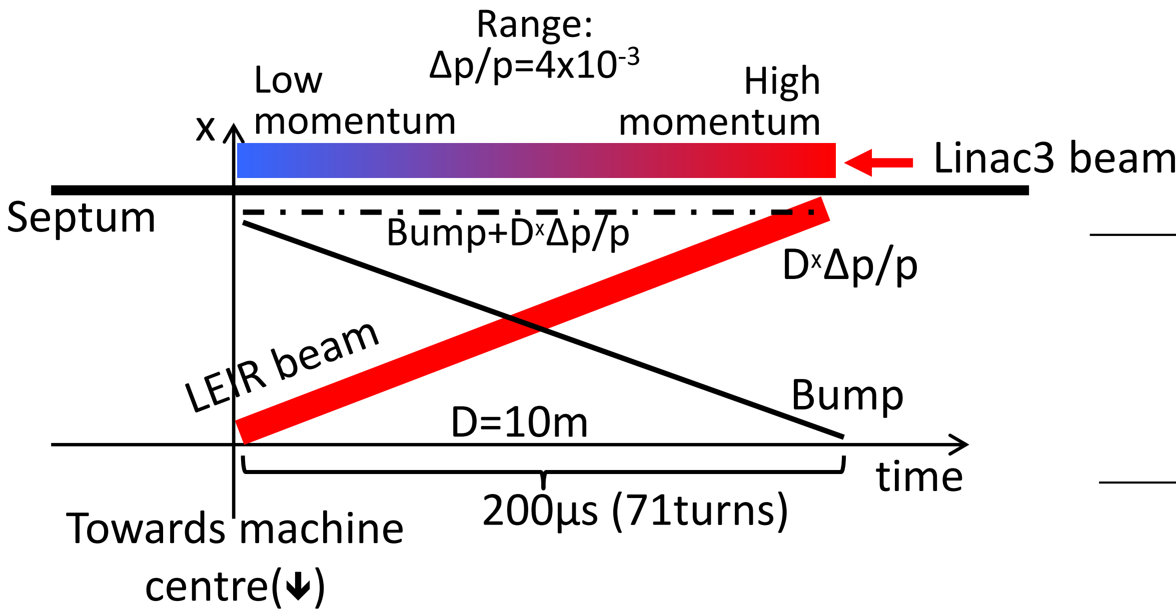


Tomoscope @ RF capture **after**



Measurements from Nov. 29th, 2012

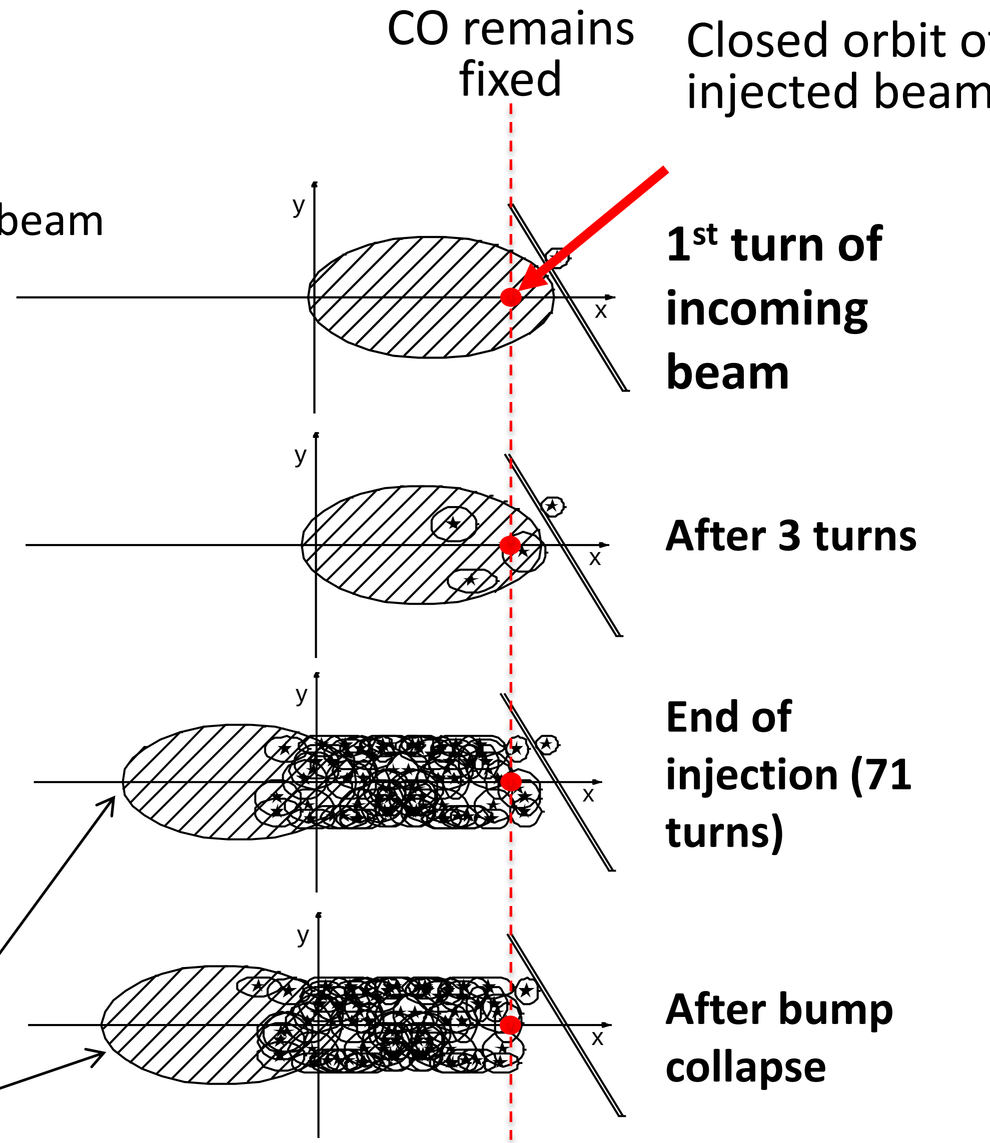
LEIR multi-turn injection (proposed by D.Möhl and S.Maury)



Mechanism:

- Bumper moves orbit **inwards**
- Momentum ramping moves orbit **outwards**

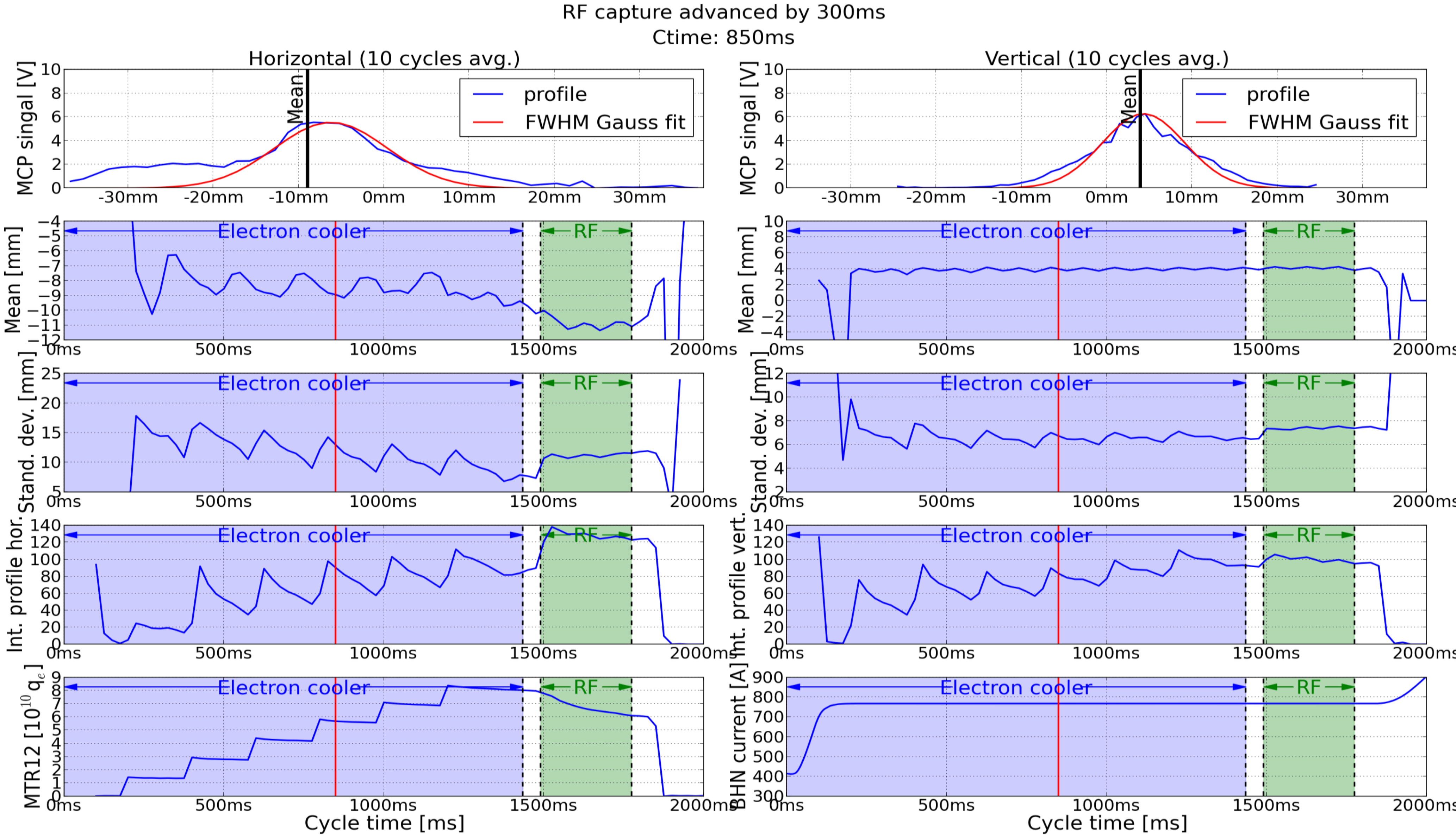
➢ Betatron amplitude for incoming beam remains **constant**



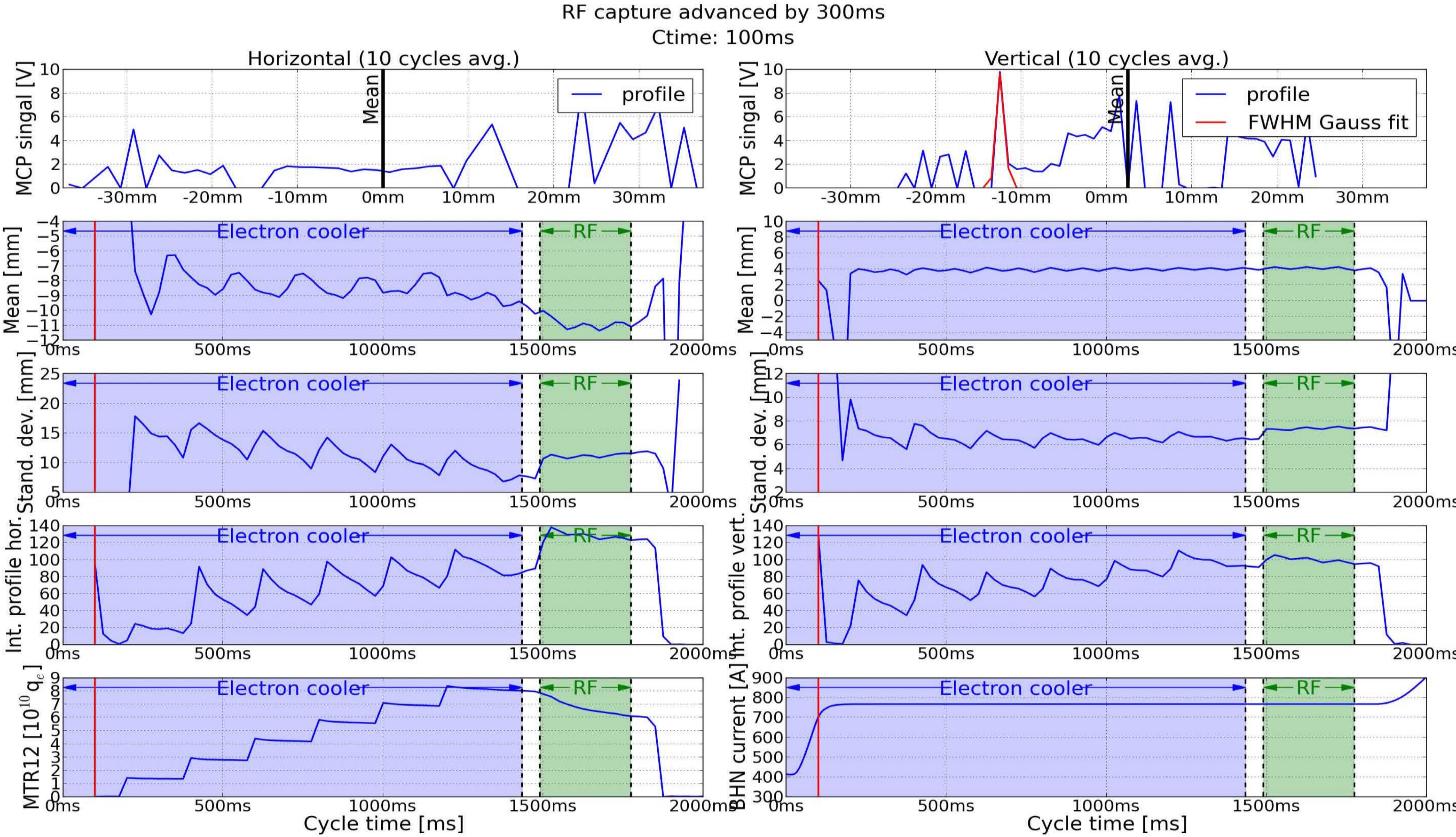
Stack "parked" with negative momentum offset

Pictures from: Low Energy Ion Ring LEIR, C. Carli, 14th March 2012

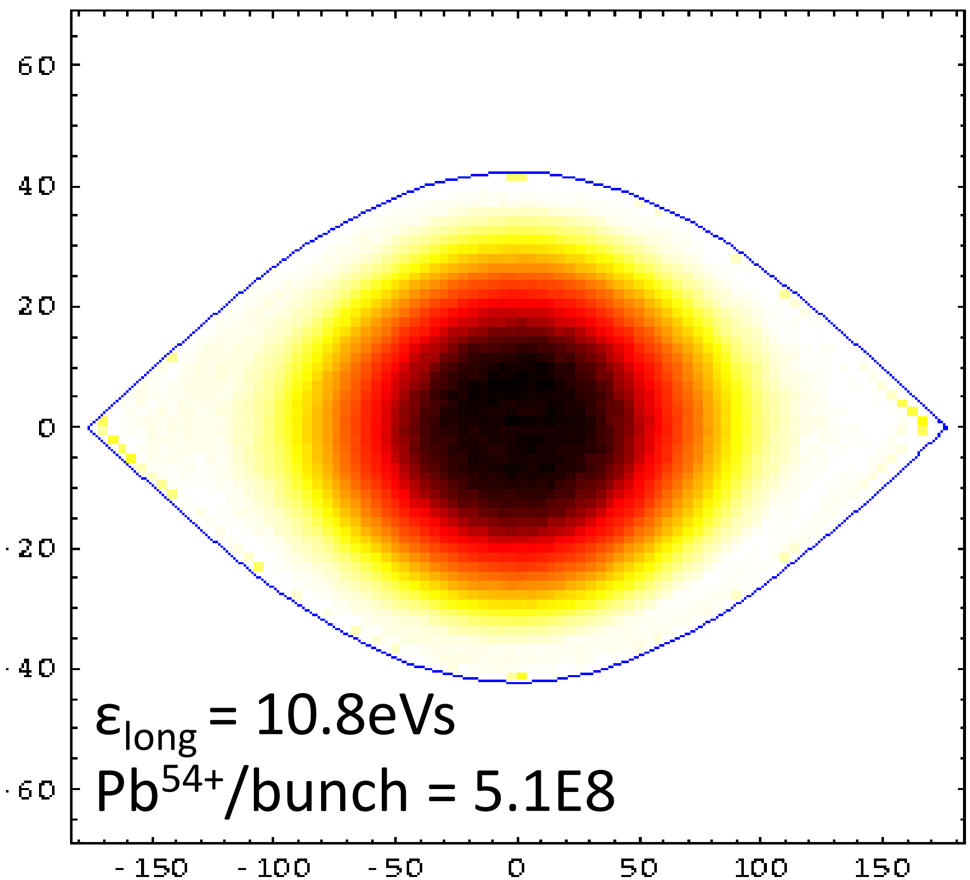
BIPM measurement

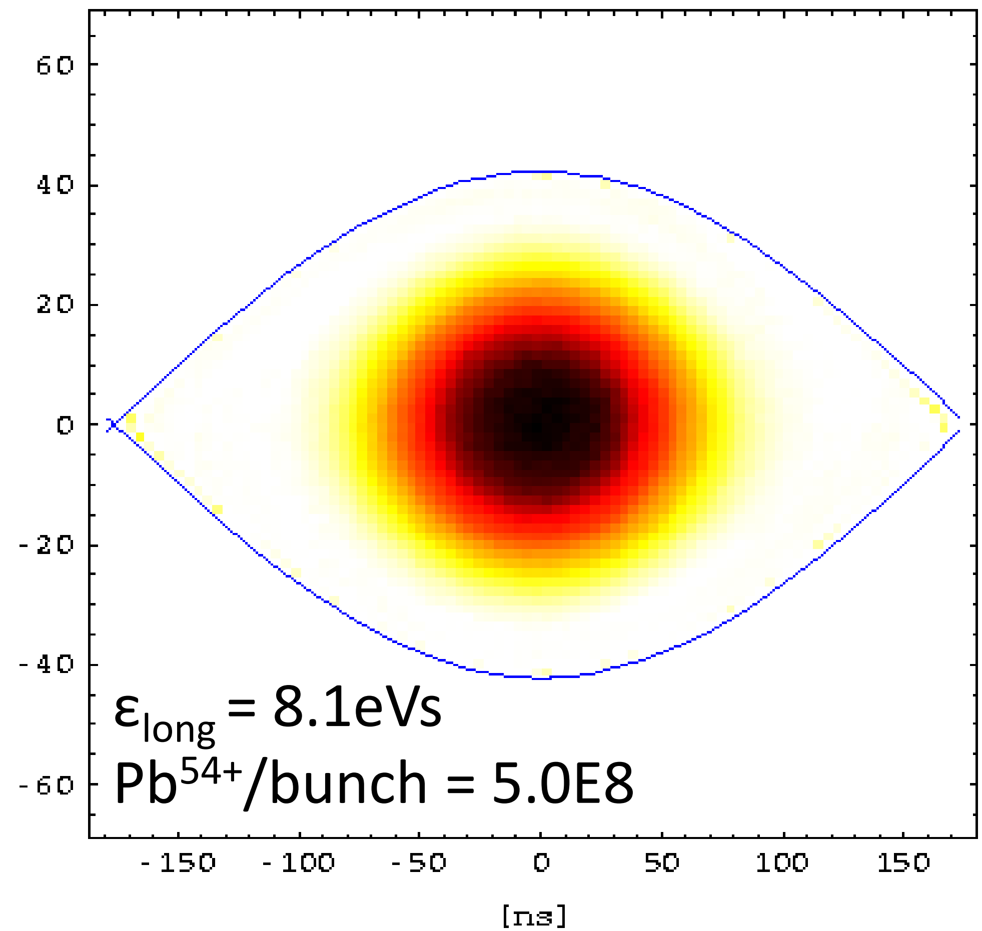


BIPM measurement

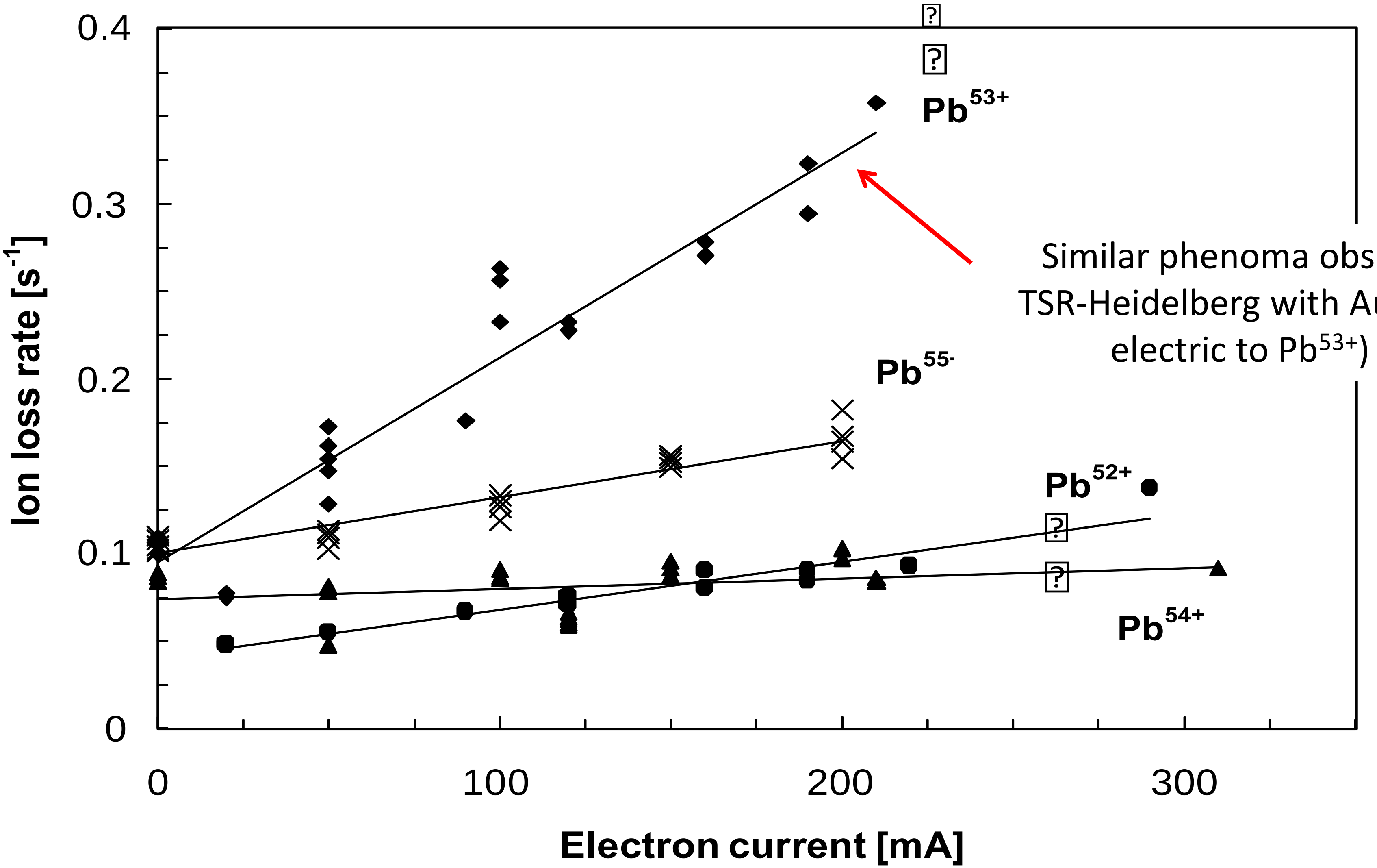


S. Hancock, 21.2.2013





Electron cooling: beam loss rate



Similar phenoma observed at TSR-Heidelberg with Au^{50+} (iso-electric to Pb^{53+}) in 1997.

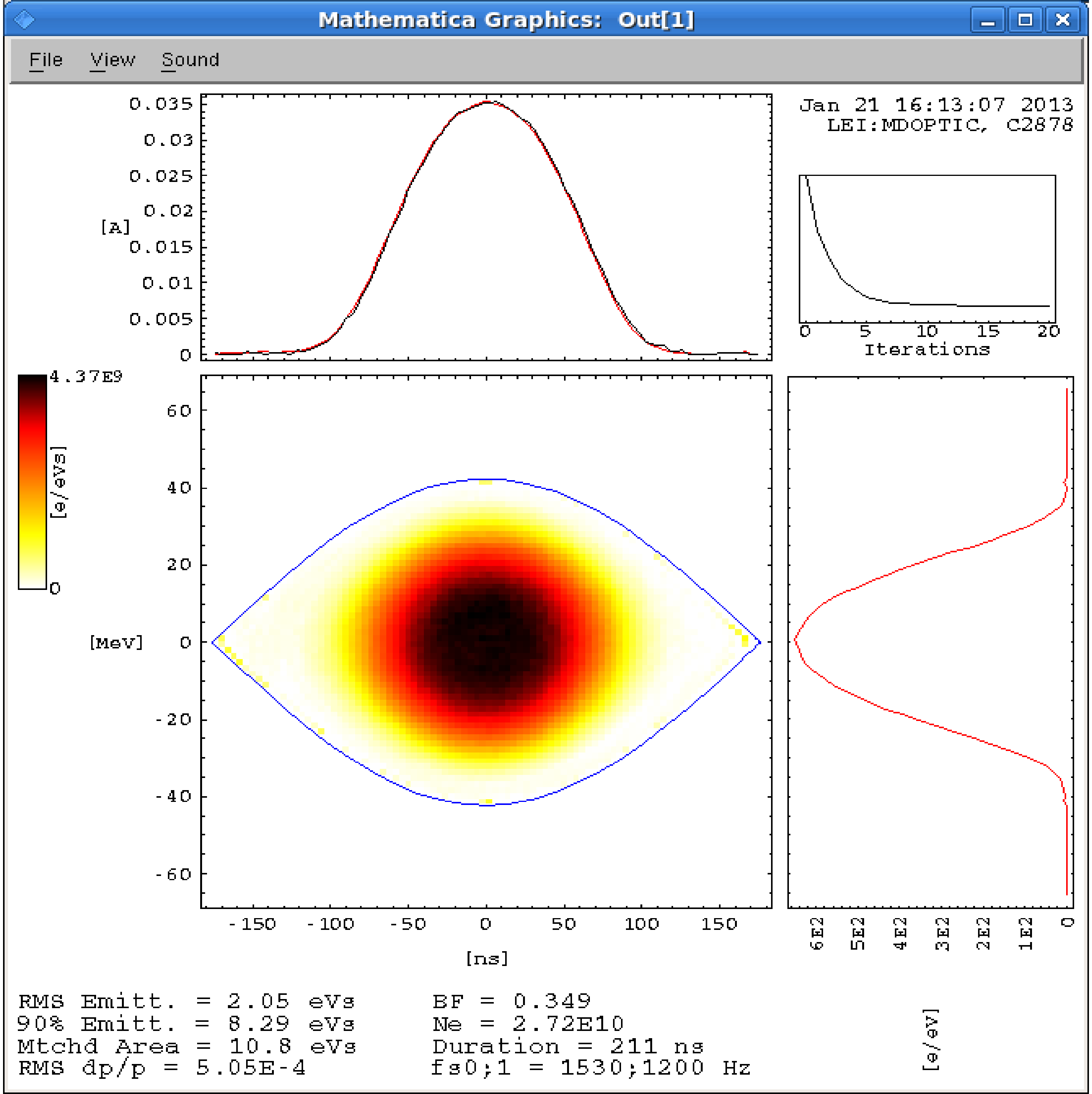
From: **Experimental Investigation of Electron Cooling and Stacking of Lead Ions in a Low Energy Accumulation Ring**, J. Bosser, C. Carli, M. Chanel et. al., CERN, 1999, p.22

Electron cooler loss rates for different Pb charge states

Loss-rate coefficients measured for lead ions of different charge states and different machine settings.

Run	Loss rate coefficient/(10^{-8} cm^{-3} s^{-1})				Machine no.
	Pb^{52+}	Pb^{53+}	Pb^{54+}	Pb^{55+}	
Dec. 94		64			4
June 95	11	60	9		1
Dec. 95		63	5	12	4
Mar. 96		60	9		1
		60	6		4
			8		7
1997		60	7		97–0

Experimental Investigation of Electron Cooling and Stacking of Lead Ions in a Low Energy Accumulation Ring
J. Bosser, C. Carli, M. Chanel, CERN, CH{1211 Geneva 23, Switzerland
April 27, 1999



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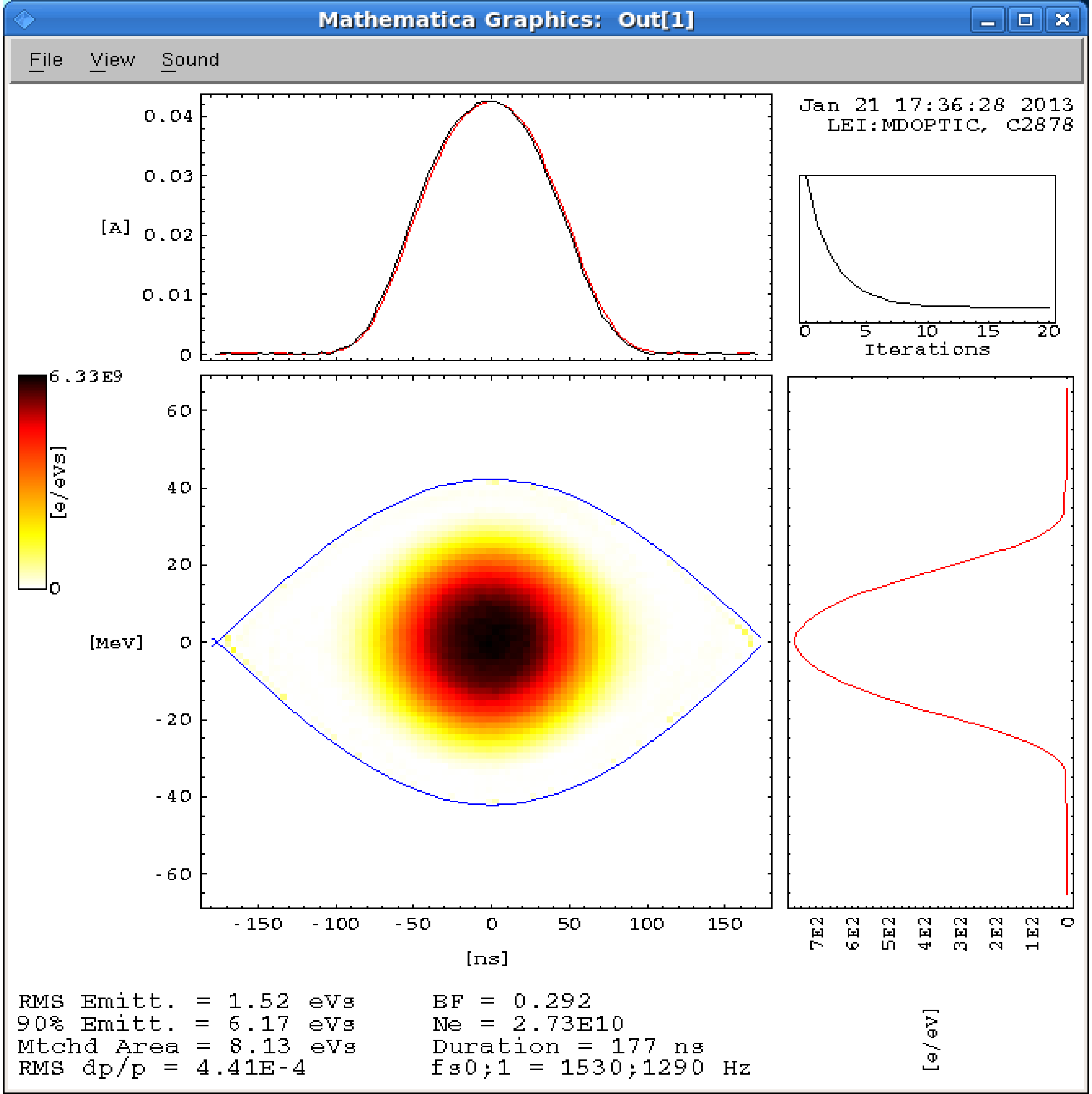
0.03
0.025
0.02
0.015
0.01
0.005
0
Iterations
0 5 10 15 20
4.37E9
[e/eVs]
0
[MeV]
60
40
20
0
-20
-40
-60
-150 -100 -50 0 50 100 150
[ns]
6E2 5E2 4E2 3E2 2E2 1E2 0
[e/eV]
RMS Emitt. = 2.05 eVs
90% Emitt. = 8.29 eVs
Mtchd Area = 10.8 eVs
RMS dp/p = 5.05E-4
BF = 0.349
Ne = 2.72E10
Duration = 211 ns
fs0;1 = 1530;1200 Hz



Mathematica Graphics: Out[1]
File View Sound
Jan 21 17:36:28 2013
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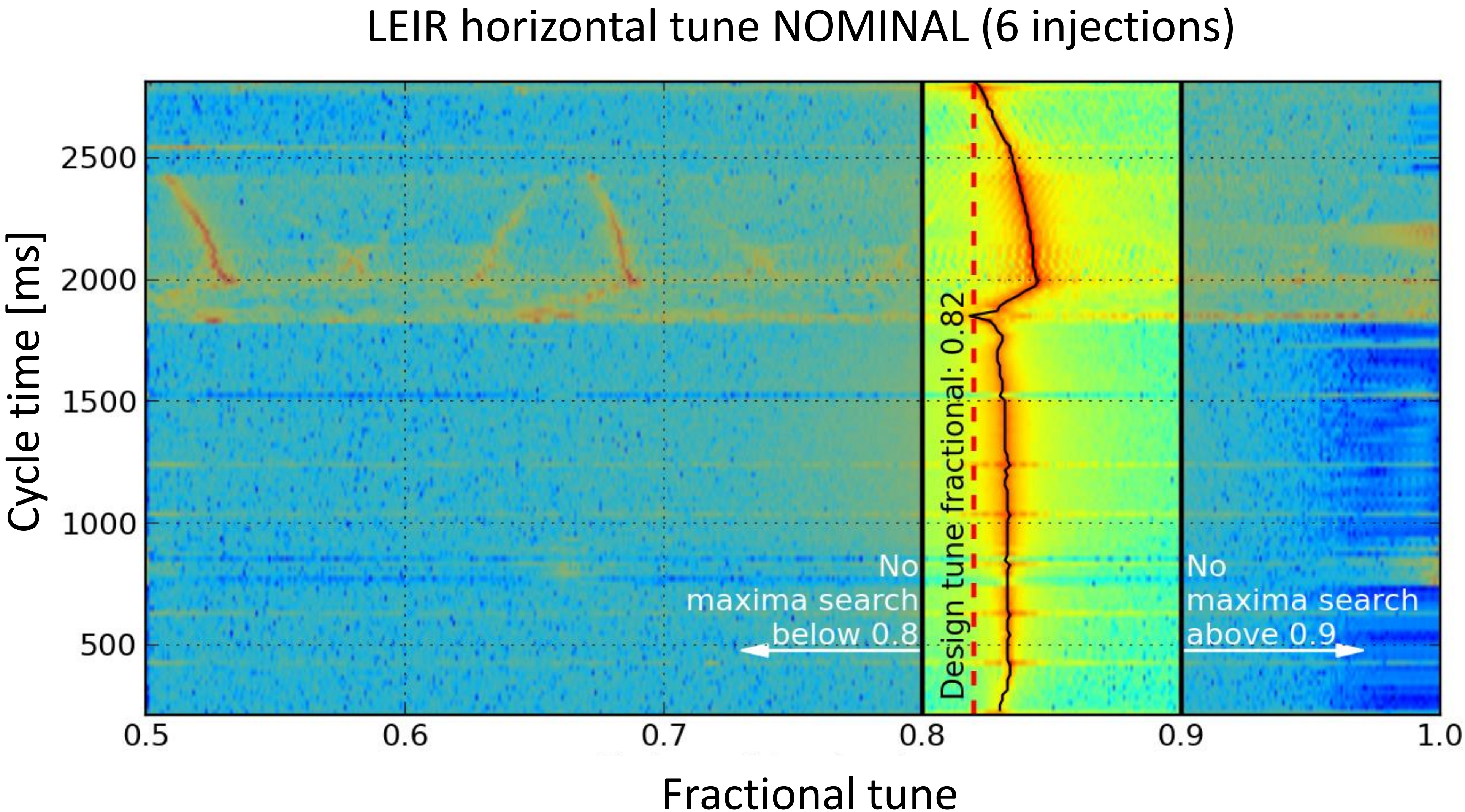
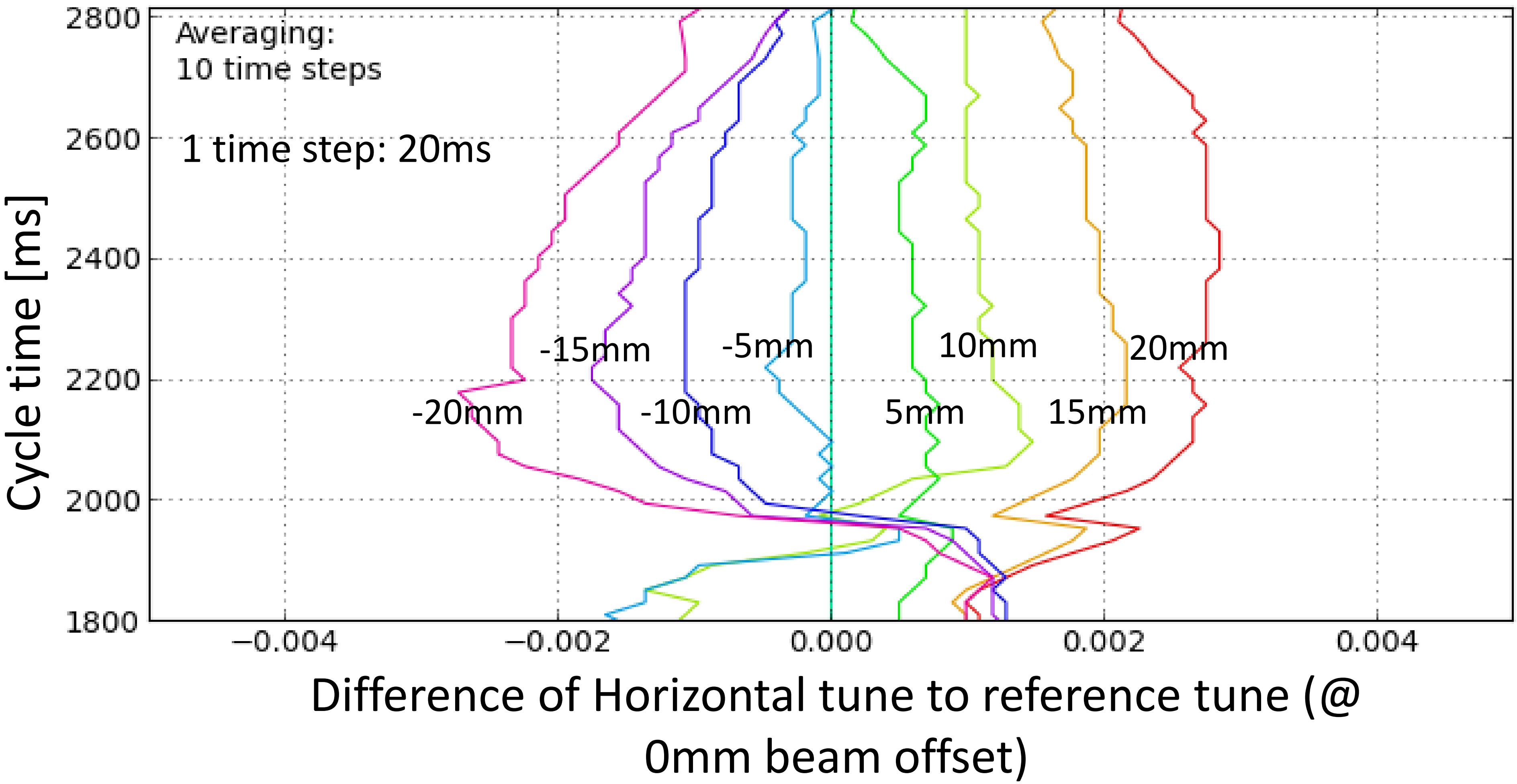
0.02
0.01
0
Iterations
0 5 10 15 20
6.33E9
[e/eVs]
0
[MeV]
60
40
20
0
-20
-40
-60
-150 -100 -50 0 50 100 150
[ns]
7E2 6E2 5E2 4E2 3E2 2E2 1E2 0
[e/eV]
RMS Emitt. = 1.52 eVs
90% Emitt. = 6.17 eVs
Mtchd Area = 8.13 eVs
RMS dp/p = 4.41E-4
BF = 0.292
Ne = 2.73E10
Duration = 177 ns
fs0;1 = 1530;1290 Hz

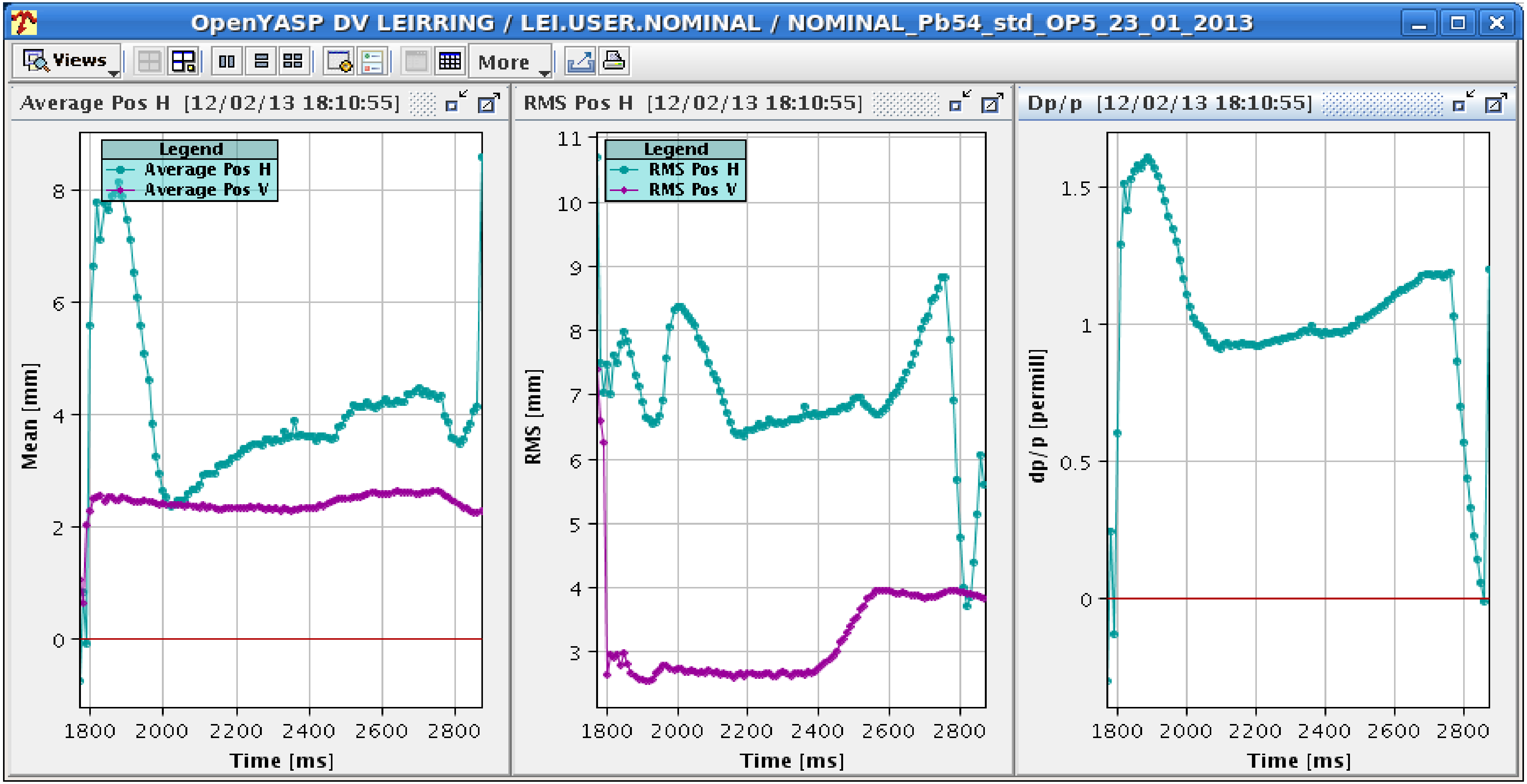
Restricted maxima search



ΔQ for **programmed** radial offset from -20mm to +20mm

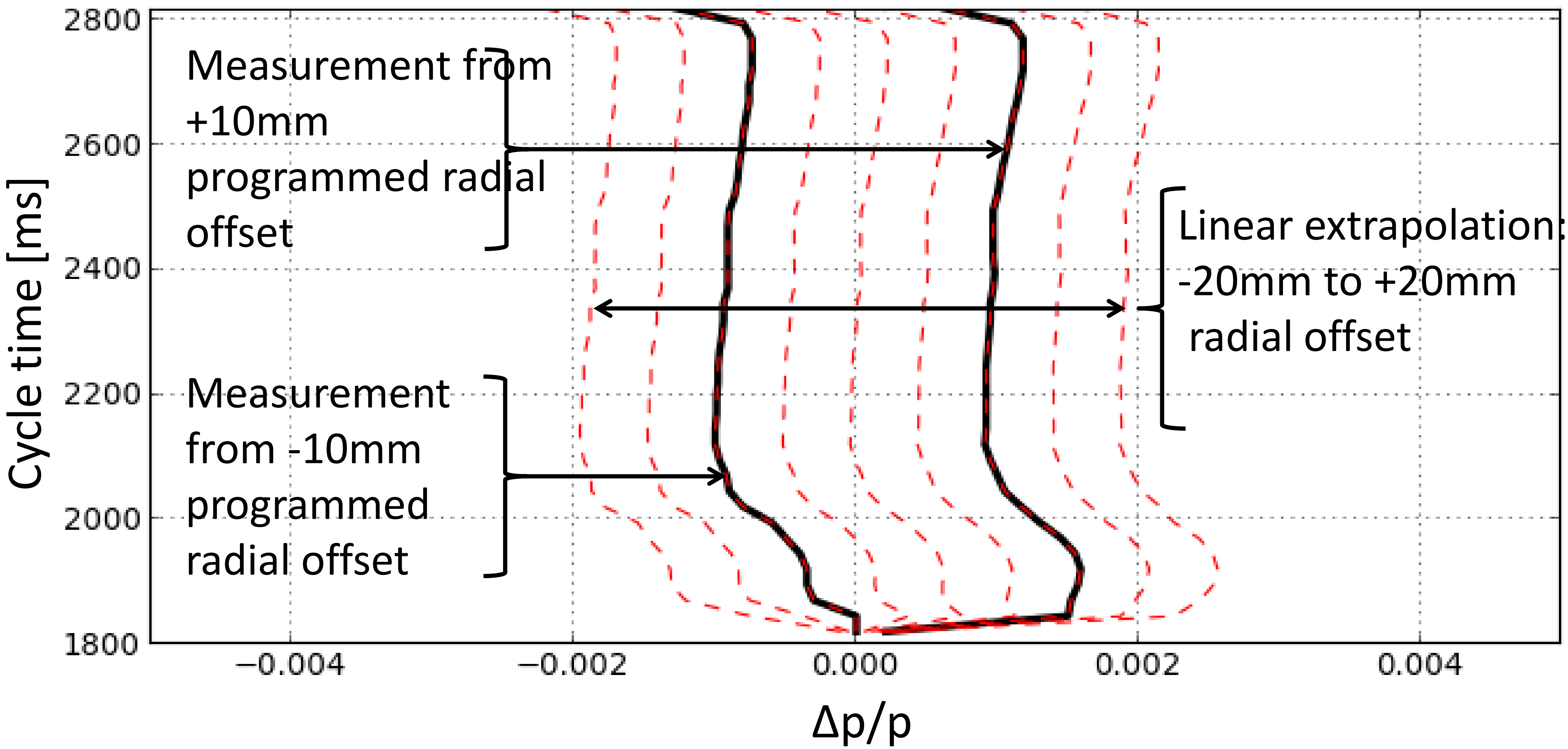


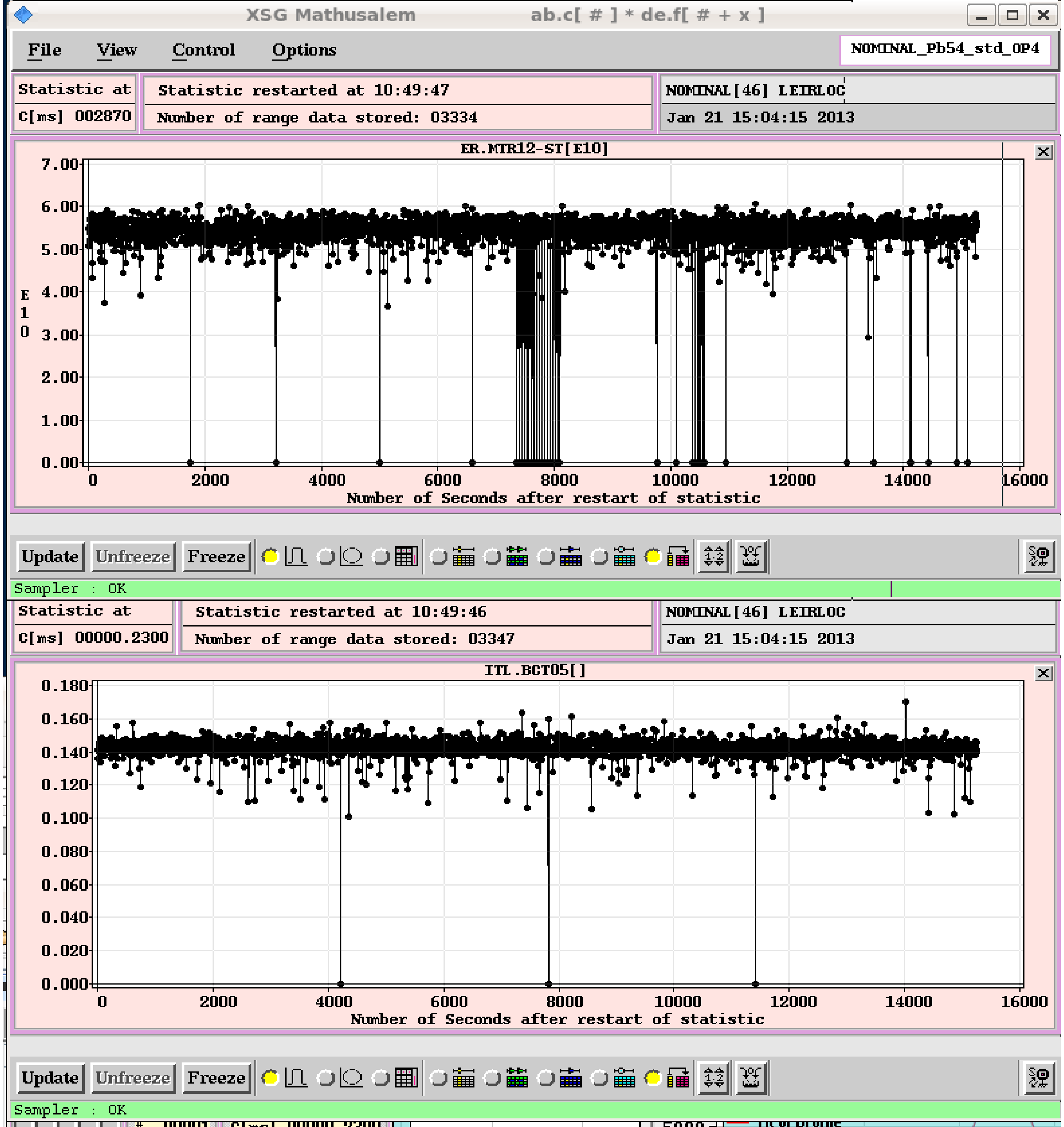
YASP output



OpenYASP DV LEIRRING / LEI.USER.NOMINAL / NOMINAL_Pb54_std_OP5_23_01_2013
Views
More
Average Pos H [12/02/13 18:10:55]
Legend
Average Pos H
Average Pos V
Mean [mm]
Time [ms]
RMS Pos H [12/02/13 18:10:55]
Legend
RMS Pos H
RMS Pos V
RMS [mm]
Time [ms]
Dp/p [12/02/13 18:10:55]
dp/p [permill]
Time [ms]

Linear extrapolation of Δp/p





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Statistic restarted at 10:49:47
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NOMINAL[46] LEIRLOC
Jan 21 15:04:15 2013
ER.MTR12-ST[E10]
E10
Number of Seconds after restart of statistic
Update Unfreeze Freeze
Sampler : OK
Statistic at
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Jan 21 15:04:15 2013
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