Transverse machine impedance measurement in AGS and RHIC

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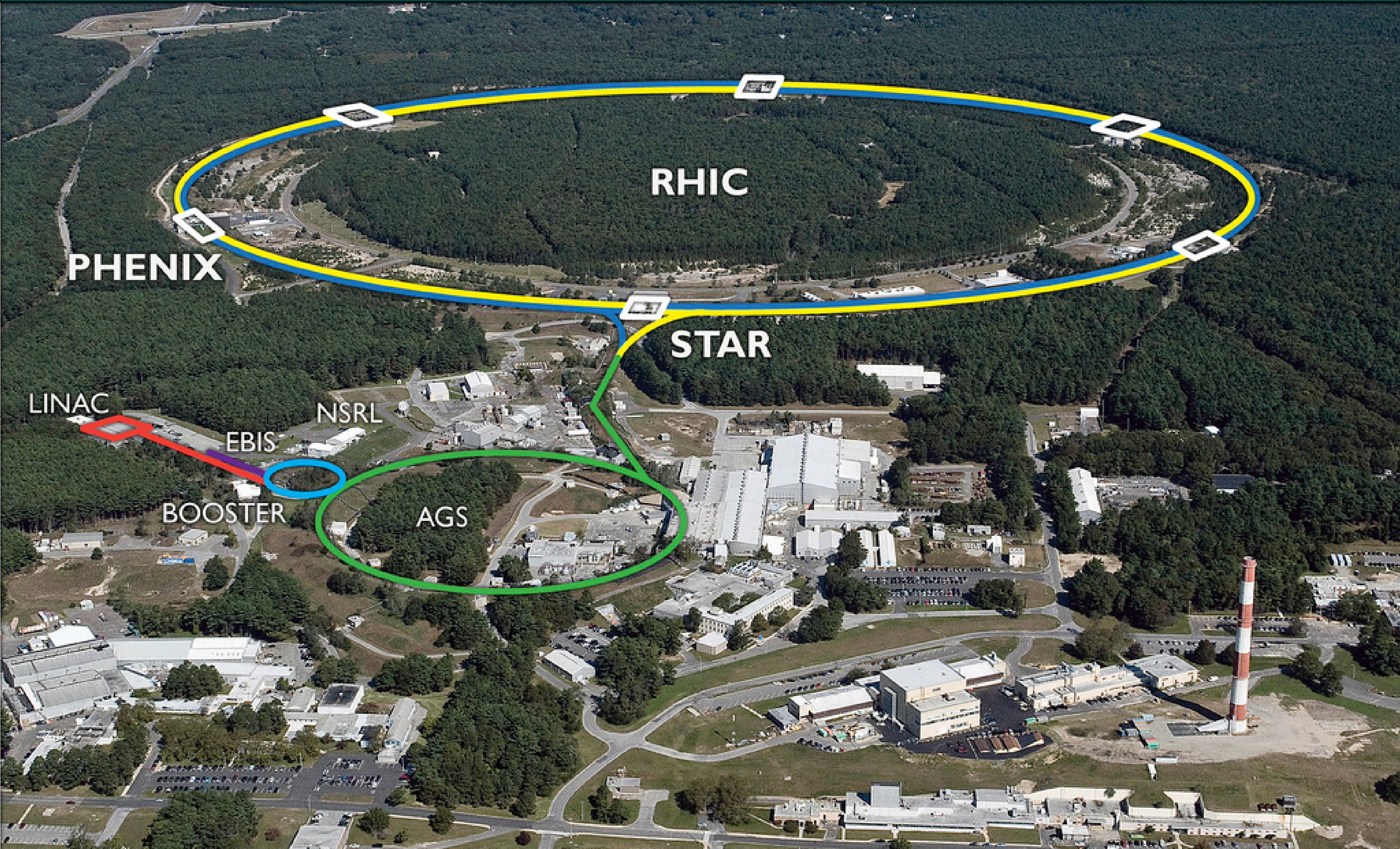
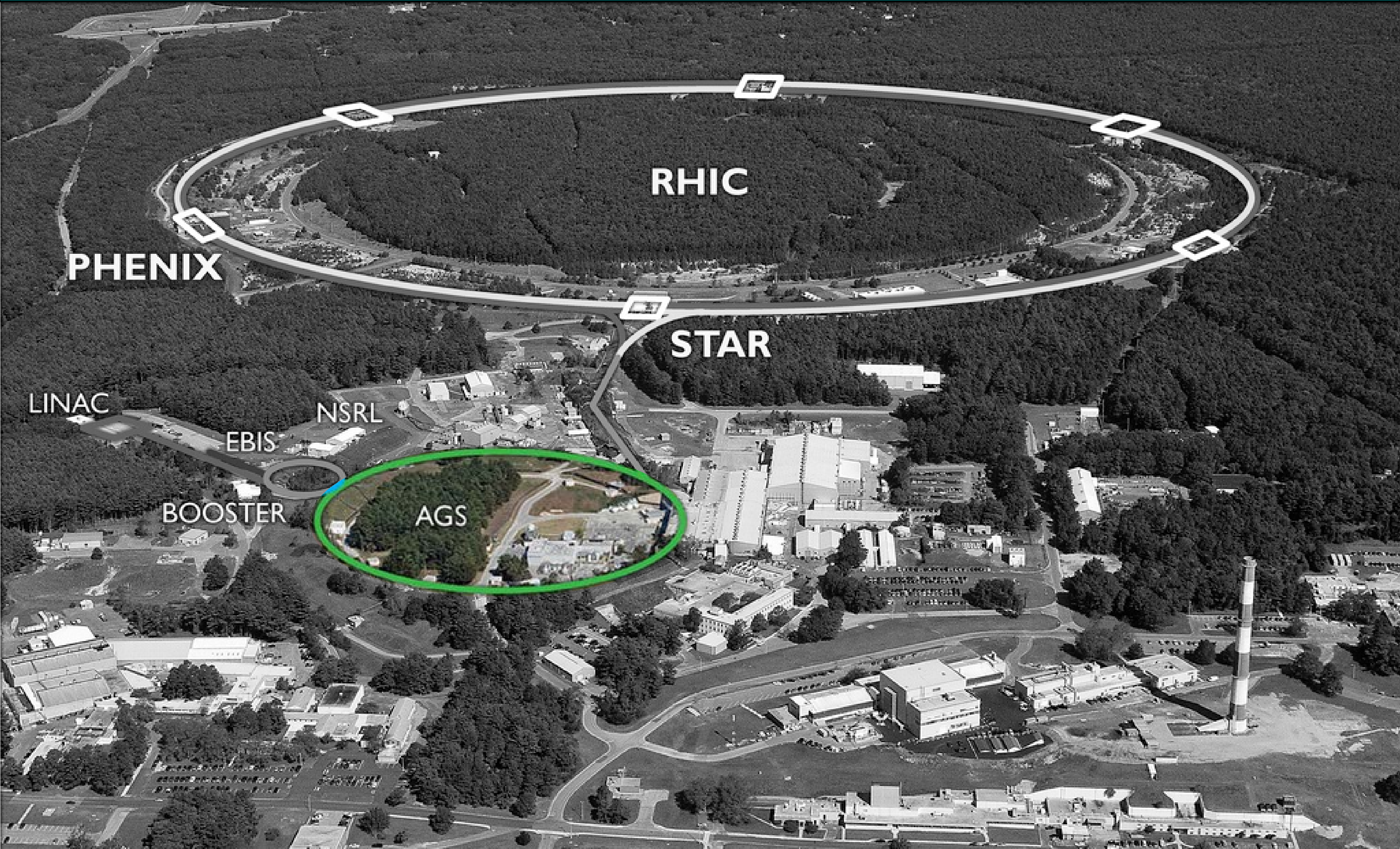


Measurements in AGS



Measurements in AGS

Motivation:
Even if it is not an immediate concern, it is a good practice to keep an impedance model updated for each machine.

How?
Sacherer's theory correlates the imaginary part of the global transverse impedance with the tune shift of mode-0 in the (Gaussian) bunch spectrum [1]:

$$\frac{\Delta Q_0}{\Delta N} = \frac{-e^2 T_0}{4\sqrt{\pi}\gamma m_0 (2\pi)^2 Q_0 \sigma_z} Im\left(Z_{eff}\right)$$

Machine parameters:

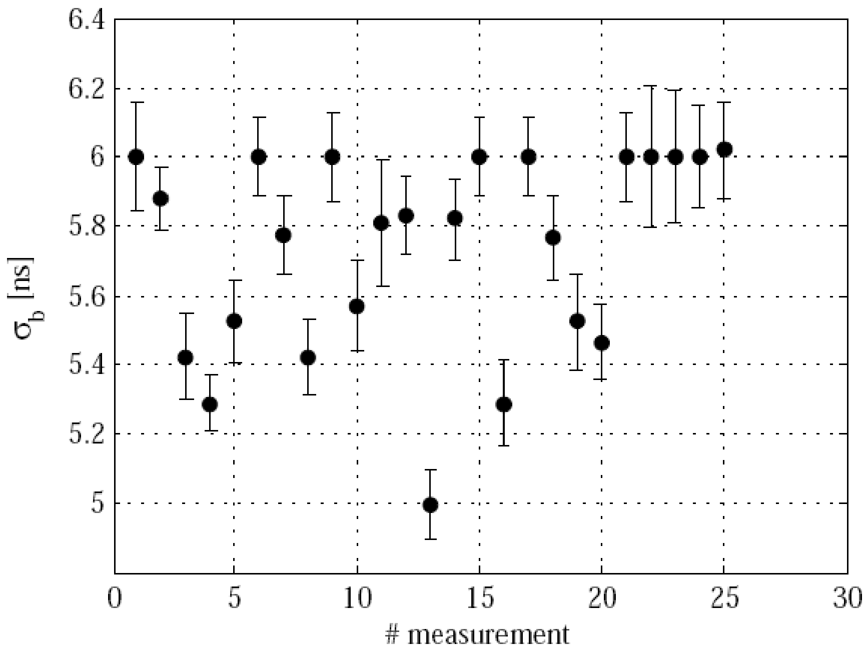
- T_0=2.69 us,
- Average bunch length σ_t= 5.8 ns (1σ-rms),
- Q_0=8.87 in V;
- $\gamma = 25.38$ (@Extraction);
- R=~128.45m → slightly bigger than the PS.

NB: No multi-turn BPM system: only global measurements can be done

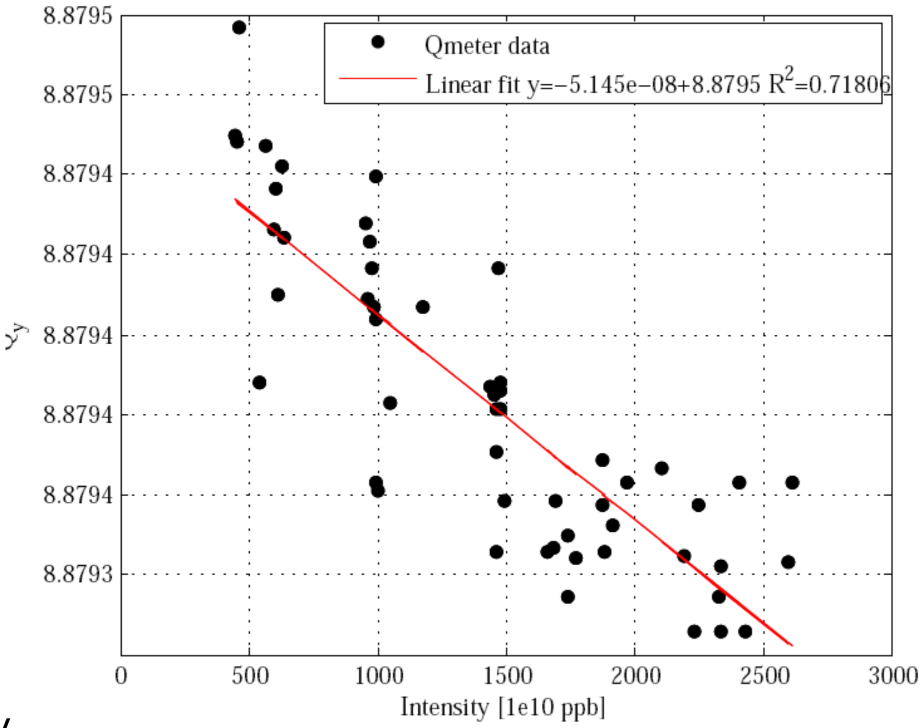
[1] See for example, Elias Métral, USPAS2009 course, Albuquerque, USA, June 22-26, 2009

Measurements in AGS

Bunch length (from Gaussian fit)



Y tune shift with intensity



Y global Impedance: $\boldsymbol{Z_y = 1.3 \pm 0.1\ M\Omega}$**/m**

Y tune shift (per 1e11): **-5.145e-05**.

Very stable machine! → Measurements of very small tune shift possible!

Measurements in AGS

Y global impedance: $\boldsymbol{Z_y = 1.3 \pm 0.1\ M\Omega/\mathrm{m}}$
Y tune shift (per 1e11): **-5.145e-05**.

In the past it was measured $Z_{\parallel}(n)/n \sim 10\Omega$.

$$Z_{//}^{RW0}(\omega) = (1+j)\frac{L}{2\pi b}\sqrt{\frac{\omega Z_0}{2c\sigma}}$$

$$Z_{\perp}^{RW1}(\omega) = (1+j)\frac{L Z_0}{\pi b^3}\frac{1}{\sqrt{2\mu_0\sigma\omega}}$$

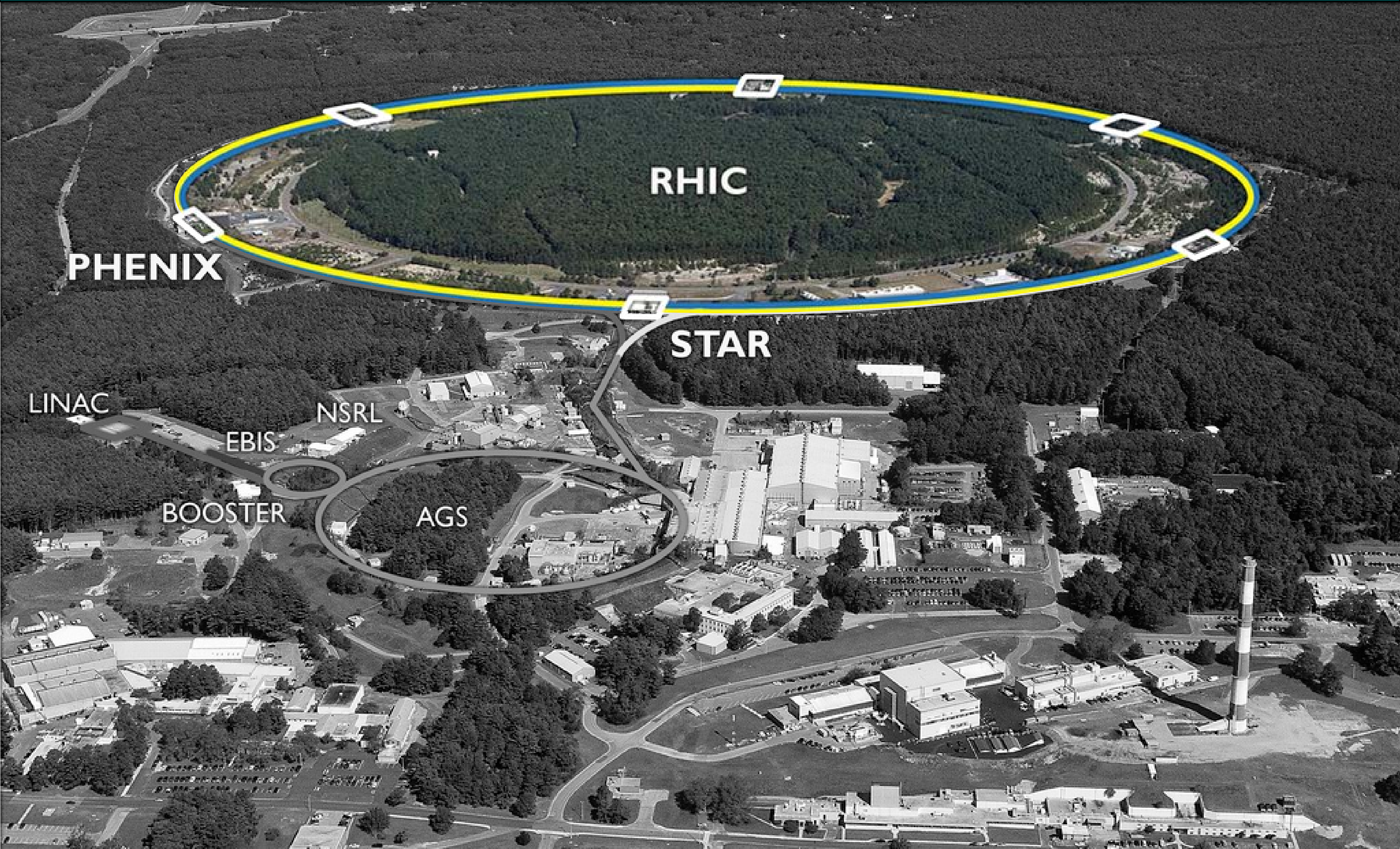
Assuming that the longitudinal impedance is mainly due to the resistive wall part, the transverse impedance can be estimated as:

$$Z_y \cong 2R/b^2 Z_{\parallel} = \boldsymbol{1M\Omega/m}.$$

Beam pipe radius b ≅ 5cm

<u>The longitudinal and transverse measurements are consistent!</u>

Measurements in RHIC



Measurements in RHIC

Estimations:

- Estimation of localization accuracy.
- Estimation of L shape collimator impedance with NM code.

Measurements:

24-04-2013 (when I was there…)

- Chromaticity and BPMs set up in Blue.
- Few problems from power supply.
- 15’ of (fast!) measurements at injection in Blue ring.

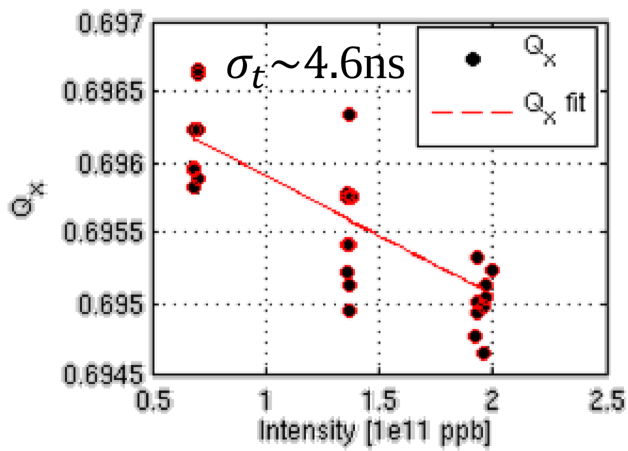
01-05-2013 (operated by S.White and colleagues, thanks!)

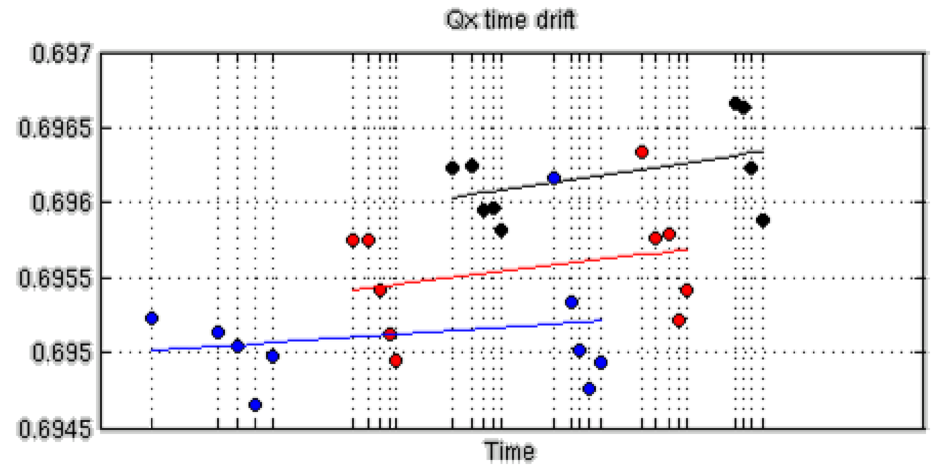
- Chromaticity and BPMs set up in Yellow.
- Measurements at injection in Yellow ring.

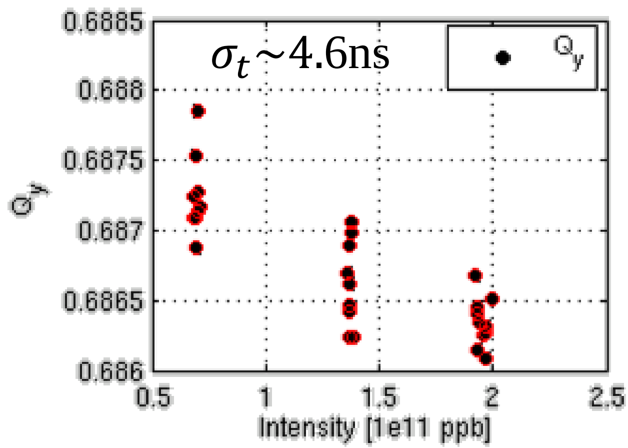
15-05-2013 (operated by S.White and colleagues, thanks!)

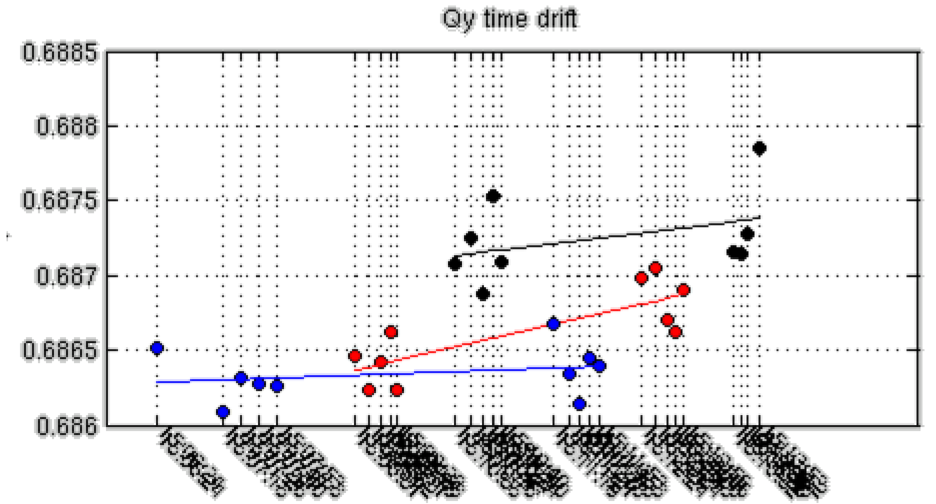
- Chromaticity and BPMs set up in Blue.
- Measurements at injection in Blue ring to crosscheck the first results.

Blue - Tune shifts









Zx = 12.5+/-2.0 MΩ/m
Slope in X = -8.4e-4+/-1.4e-4

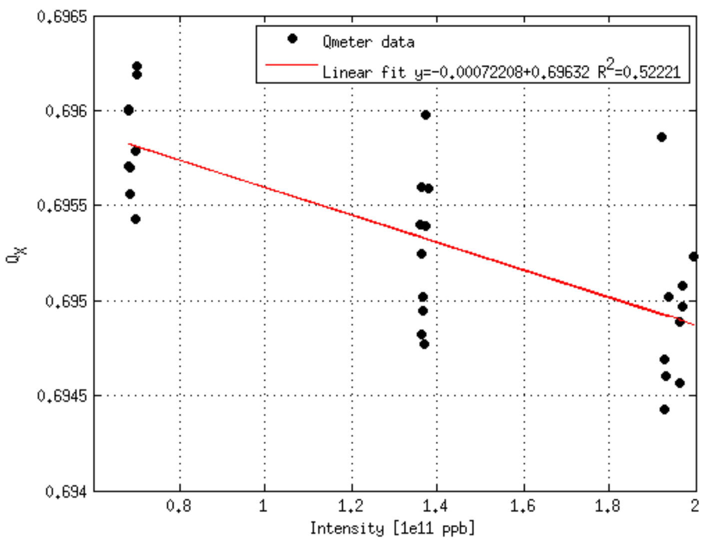
Zy = 11.1+/-1.5 MΩ /m
Slope in Y = -7.2e-4+/-0.9e-4

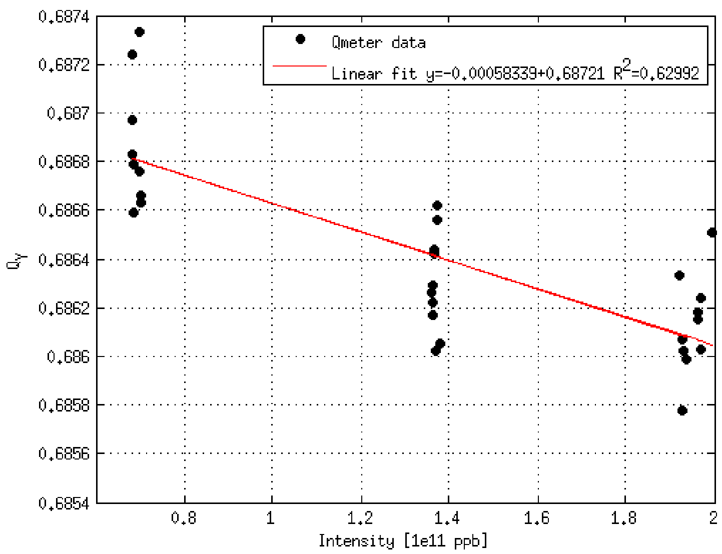
But…

The tune drifts with time: it can be taken into account measuring at the same intensity after some time.

Blue - Tune shifts

After compensating…





Zx=(10.7+/-1.9) MΩ /m
Slope in X is: (-7.2+/-1.3)*1e-4

Zy= (8.98 +/- 1.32) MΩ/m
Slope in Y is: (-5.8 +/- 0.8)*1e-4

Crosschecked also on 15-05-2013:

Zx=(8.33+/-1.77) MΩ /m
Slope in X is: (-5.50+/-1.17)*1e-4

Zy= (8.77 +/- 1.49) MΩ/m
Slope in Y is: (-5.62 +/- 0.95)*1e-4

Measurements consistent with the uncertainty

Blue - Accuracy of phase advance slope

Given a set of **M** measurements of $\boldsymbol{\Delta\varphi}$ with equal error bars $\boldsymbol{\sigma_{\Delta\varphi}}$, obtained along an intensity scan **X** , we can calculate $\boldsymbol{\sigma_{\frac{\Delta\varphi}{\Delta N}}}$ using a standard straight line least square formula*:

$$\sigma_{\frac{\Delta\varphi}{\Delta N}} = \frac{\sigma_{\Delta\varphi}}{\sigma_X\sqrt{M}}$$

with σ_X standard deviation of the intensity scan X.

Comparing with the previous formula one has:

$$\sigma_{\frac{\Delta\varphi}{\Delta N}} = \frac{1.12\ NSR}{\sigma_X\sqrt{N}\sqrt{M}}$$

$NSR = \sigma_n/A$: to be reduced.
(reduce noise level σ_n,
increase betatron amplitude A,
check BPMs gains, ...)

To be increased: M= number of measurements.
Usually a 100 points it's the case.

To be increased: It is the width of the scan of intensity. Upper threshold can be TMCI. Lower is BPM sensitivity.

To be increased: N=Number of turns.
Depends on ability on hardware and data trasmission from BPM to storage.

*see IPAC13 - THOBB10

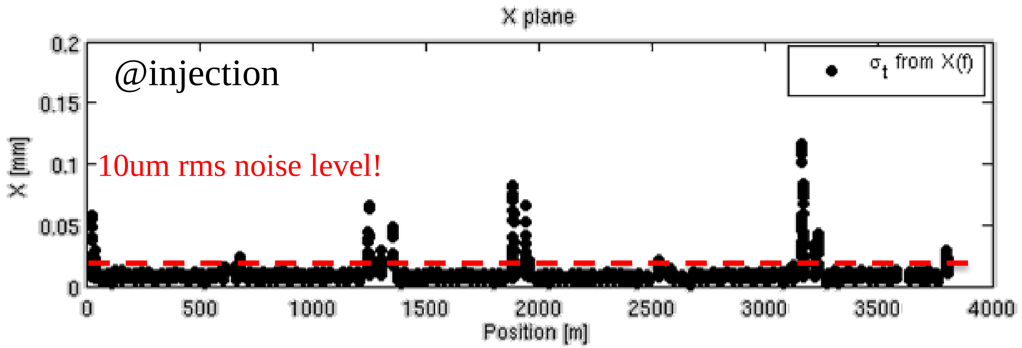
Blue - Accuracy of phase advance slope

$$\sigma_{\frac{\Delta\varphi}{\Delta N}} = \frac{1.12\, NSR}{\sigma_X \sqrt{N}\sqrt{M}}$$

Best performance
I~5e10→2e11
M~100
N~1000
NSR*~0.7%

$$\sigma_{\frac{\Delta\varphi}{\Delta N}} \sim 6 \cdot 10^{-5} [\text{rad}/2\pi \text{ 1e-11}]$$

*Calculated for an amplitude A~2mm for full N turns coherent oscillation, and σ_n~10 um rms noise from the BPM system.



Blue - Accuracy of phase advance slope

$$\sigma_{\frac{\Delta\varphi}{\Delta N}} = \frac{1.12\ NSR}{\sigma_X \sqrt{N}\sqrt{M}}$$

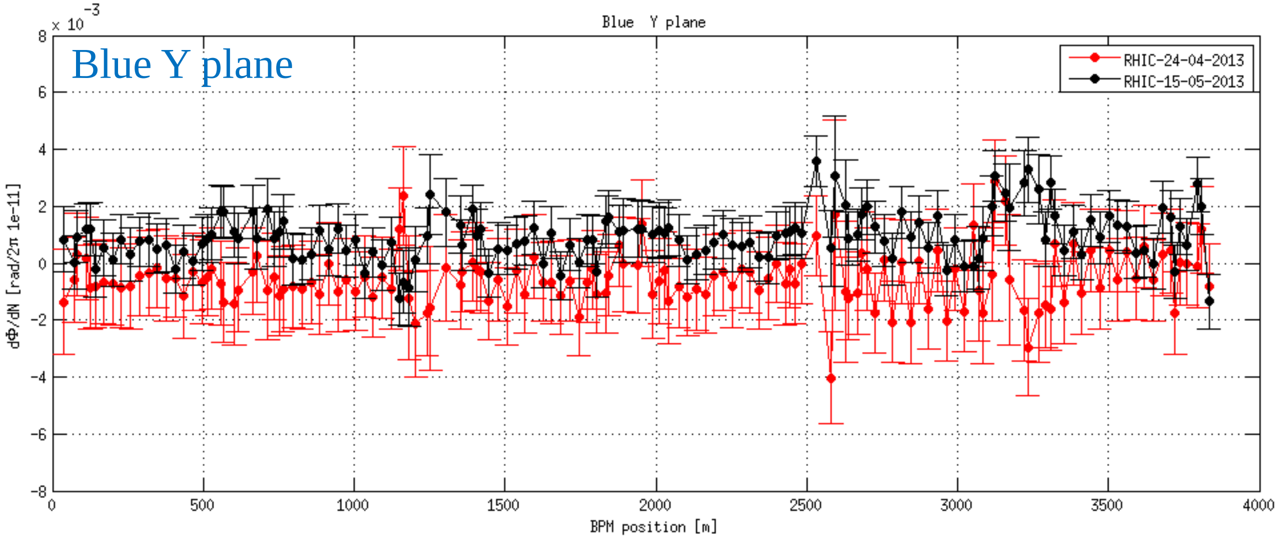
Best performance	**24-04-2013**	**15-05-2013**
I~5e10→2e11 M~100 N~1000 NSR~0.75% $\sigma_{\frac{\Delta\varphi}{\Delta N}} \sim 6 \cdot 10^{-5}$	I~6e10→2e11 M~29 N~380 NSR~9% $\sigma_{\frac{\Delta\varphi}{\Delta N}} \sim 1.5 \cdot 10^{-3}$	I~7e10→1.7e11 M~60 N~400 NSR~7% $\sigma_{\frac{\Delta\varphi}{\Delta N}} \sim 10^{-3}$

The loss of accuracy in the measurement is mainly due to:

- Short coherent time (<500turns)
- High NSR.

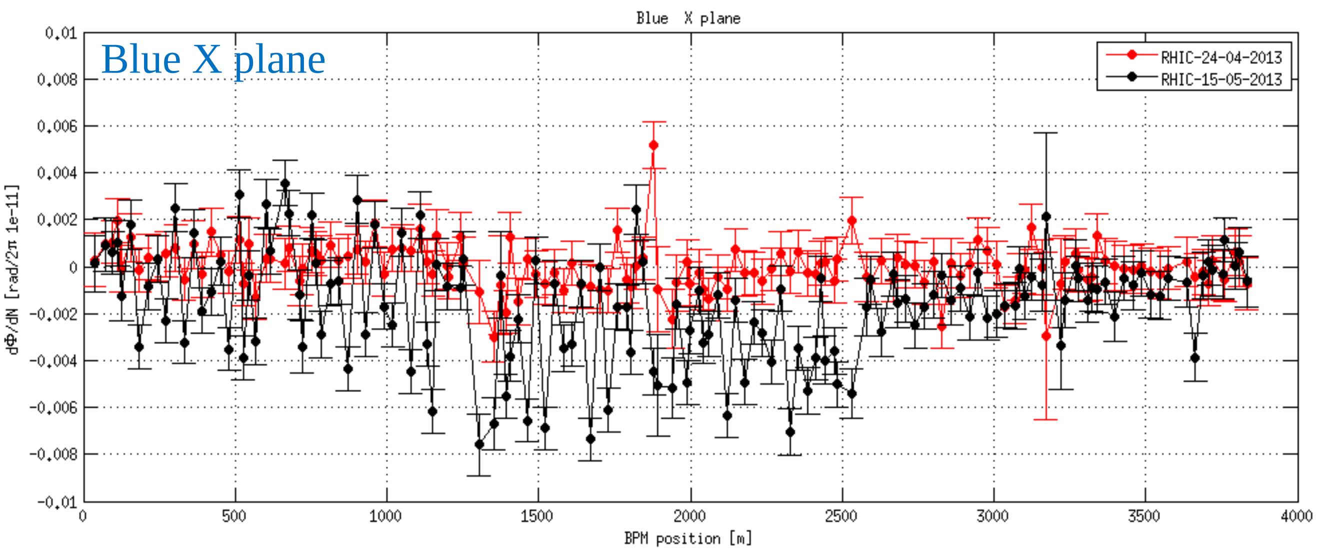
By itself knowing the accuracy is not enough, we need an impedance amplitude to compare with, but it is good to keep it in mind.

Blue - phase advance slope



Blue Y plane

- Very noisy,
- Systematic offset?

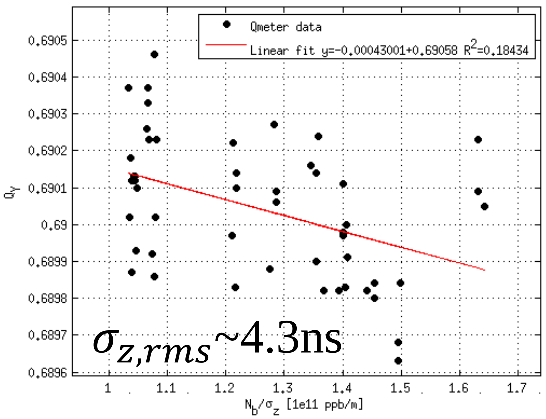


Blue X plane

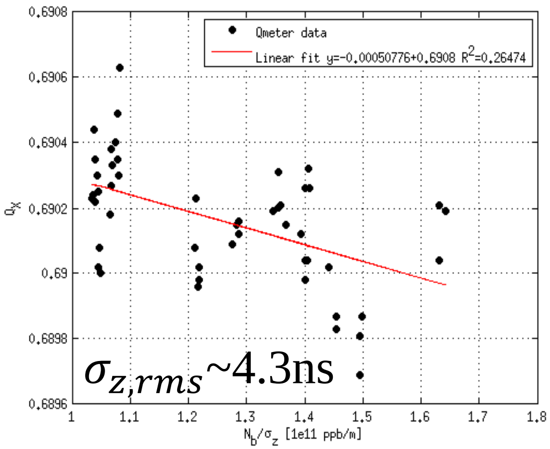
- Present oscillation on 15th, not on 24th. What was changed?

Yellow - Tune shifts

#1

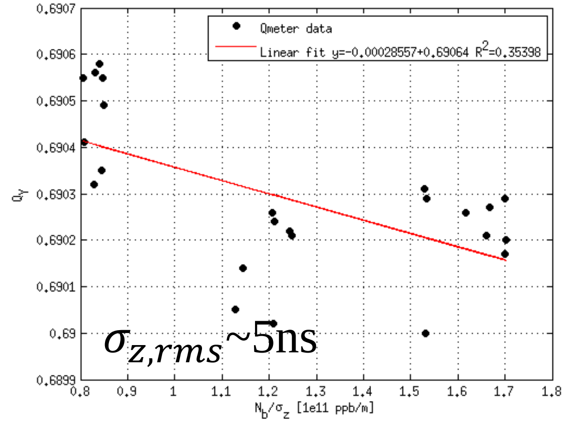


ZeffY: (4.7299+/-1.4513) MOhm/m
dQY/dN: (-4.3001+/-1.3194).1e-4

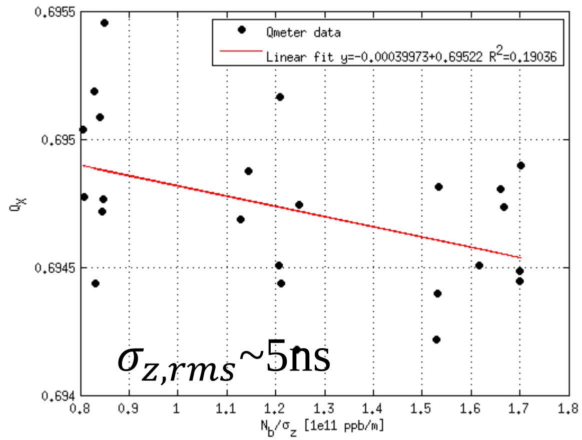


ZeffX: (5.3969+/-1.3119) MOhm/m
dQX/dN: (-5.0776+/-1.2343).1e-4

#2

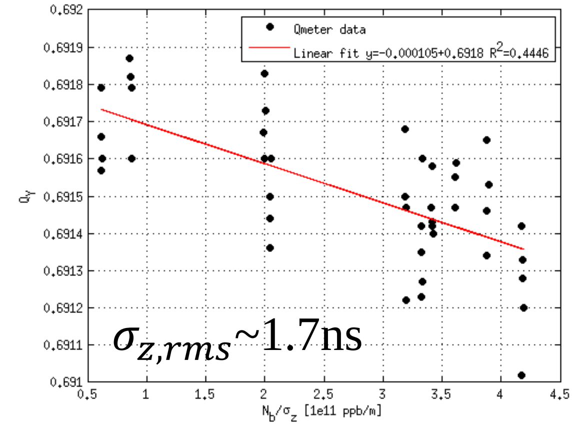


ZeffY: (3.1411+/-0.90468) MOhm/m
dQY/dN: (-2.8557+/-0.82248).1e-4

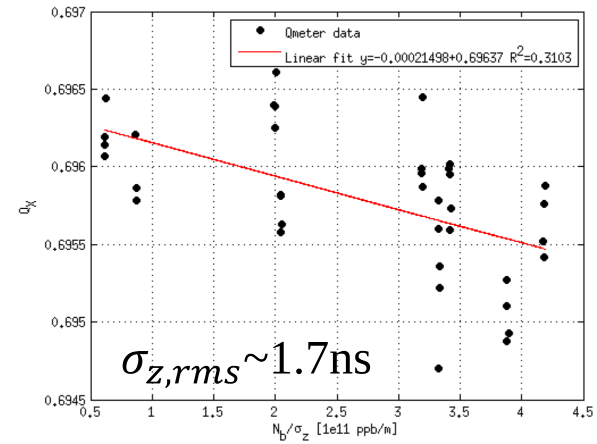


ZeffX: (4.2487+/-1.8681) MOhm/m
dQX/dN: (-3.9973+/-1.7576).1e-4

#3



ZeffY: (1.1549+/-0.2041) MOhm/m
dQY/dN: (-1.05+/-0.18555).1e-4



ZeffX: (2.285+/-0.57582) MOhm/m
dQX/dN: (-2.1498+/-0.54176).1e-4

Yellow – Accuracy of phase advance slope

$$\sigma_{\frac{\Delta\varphi}{\Delta N}} = \frac{1.12\ NSR}{\sigma_X \sqrt{N}\sqrt{M}}$$

Best performance	**01-05-2013_#1**	**01-05-2013_#2**	**01-05-2013_#3**
I~5e10→2e11	I~11e10→2.4e11	I~9e10→2.7e11	I~4e10→2e11
M~100	M~50	M~16	M~40
N~1000	N~880	N~900	N~1000
NSR~0.75%	NSR~6%	NSR~4%	NSR~10%
$\sigma_{\frac{\Delta\varphi}{\Delta N}} \sim 6 \cdot 10^{-5}$	$\sigma_{\frac{\Delta\varphi}{\Delta N}} \sim 1 \cdot 10^{-3}$	$\sigma_{\frac{\Delta\varphi}{\Delta N}} \sim 4 \cdot 10^{-4}$	$\sigma_{\frac{\Delta\varphi}{\Delta N}} \sim 1 \cdot 10^{-3}$

Phase advance slope studies are still on going…

Conclusions and Outlook

Conclusions:

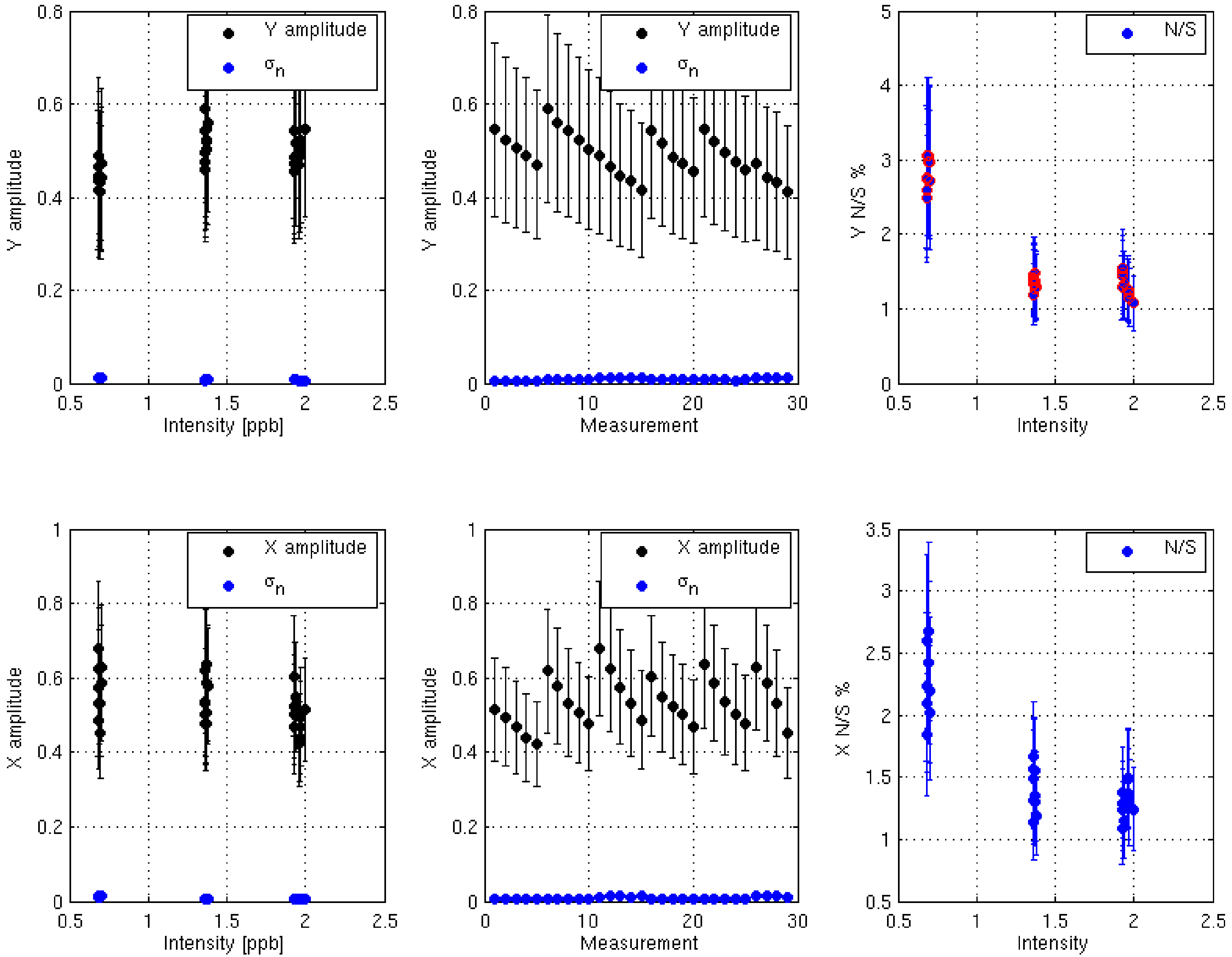
- **AGS:** The vertical impedance has been measured: $Z_y = 1.3 \pm 0.1\ M\Omega/\text{m}$. this is in good agreement with old measurements for the longitudinal impedance in the resistive wall approximation.
- **RHIC - Blue:** Tune shift and impedance measured: Z_x = 9.5+/-1.8 MΩ/m, Z_y = 8.8+/-1.4 MΩ /m. For the impedance localization: accuracy could be enough, at least for the horizontal plane, but the measurements appear to be very noisy.
- **RHIC – Yellow:** Tune shift and impedance measured: Z_x = 3.9+/-1.3 MΩ/m, Z_y = 3.0+/-0.8 MΩ /m. The impedance appears to be much less than Blue! Conclusions similar to the Blue hold for the localization.

Outlook:

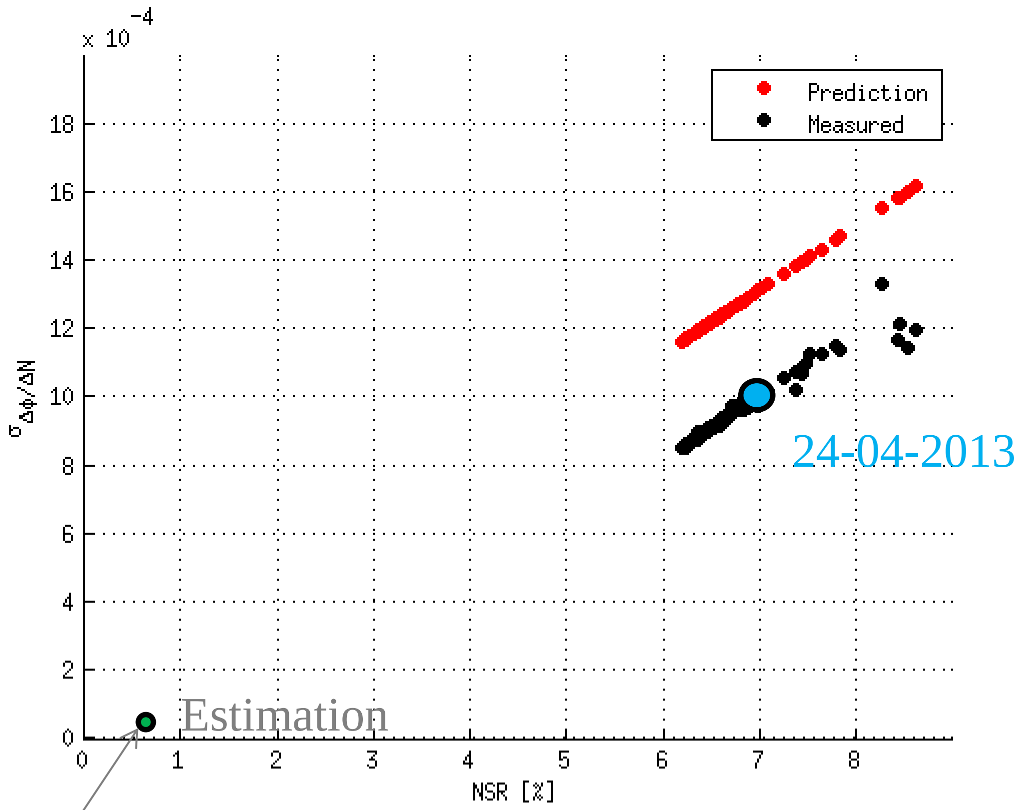
- **AGS:** Horizontal plane will be measured as well (expected less impedance).
- **RHIC:** An estimation of some (big) impedance source could help understanding what impedance signal we want to localize. The resolution could be achieved by the good BPM system spending more energies on adjusting chromaticity.

BACKUP

24-04-2013 Amplitude and Noise



24-04-2013 Accuracy



(0.7% ; 6e-5)

24-04-2013 Y phase advance