Beam Coupling Impedance Localization Technique Validation and Measurements in the CERN machines

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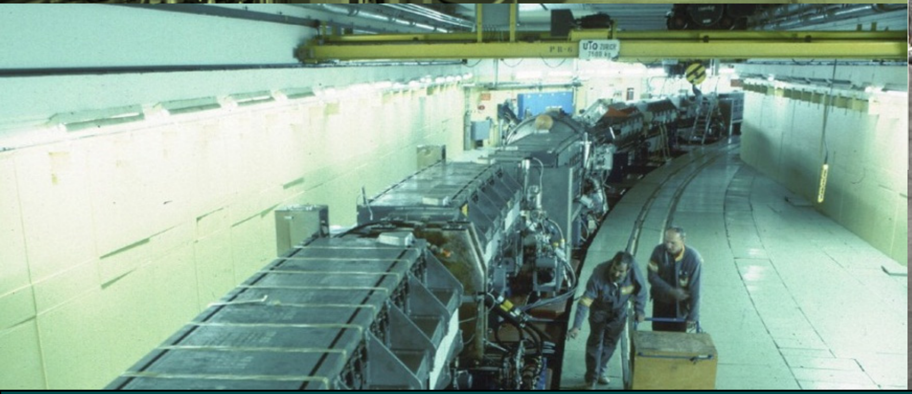

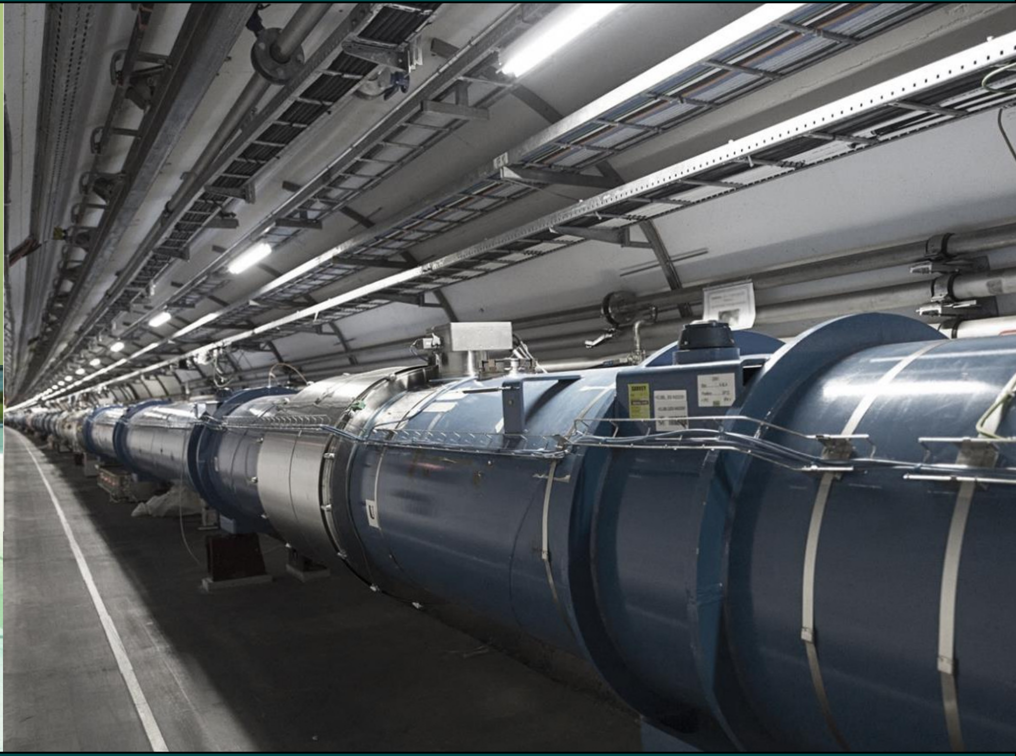

IPAC'13 16-05-2013

THOBB102

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Outline

- **Transverse impedance localization: method description**.
- **Observable: phase advance between BPMs**
  - Accuracy of phase advance variation with intensity.
- **Application to the PS**
  - Measure validation with local quadrupolar errors,
  - Measurements at 2 GeV.
- **Application to the SPS and LHC**
  - Measurements at injection: experience and issues.
- **Conclusion and outlook.**

Method description

Motivation: Increasing the beam intensity, detrimental effects like beam instabilities and beam losses may arise due to the beam coupling impedance. Need impedance quantification!

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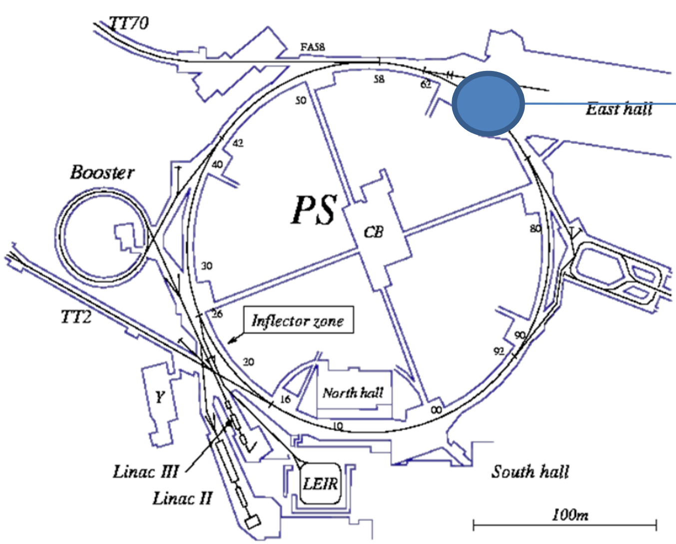
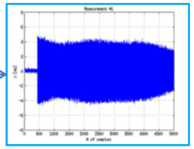
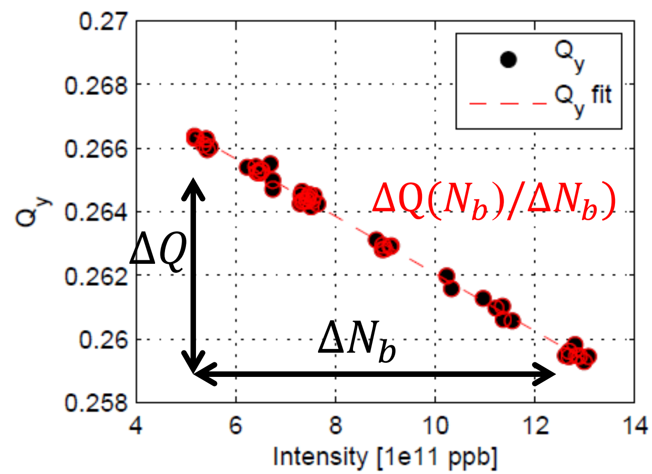
$$\Delta Q(N_b)/\Delta N_b \propto Im(Z^{tot}_{\perp,eff})$$



BPM 1





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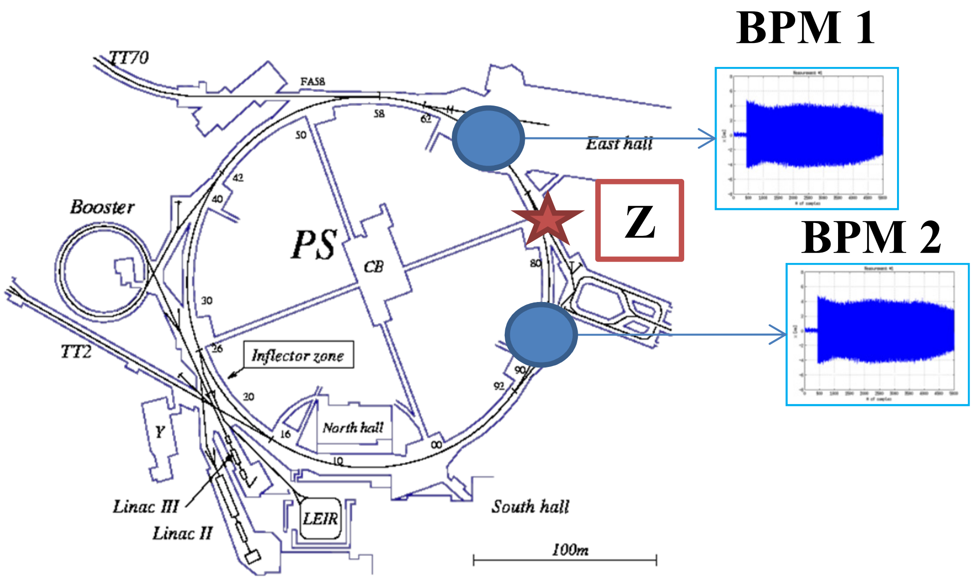
1. Impedance-induced orbit shift with intensity.
2. Impedance-induced phase advance beating with intensity.
3. Others?



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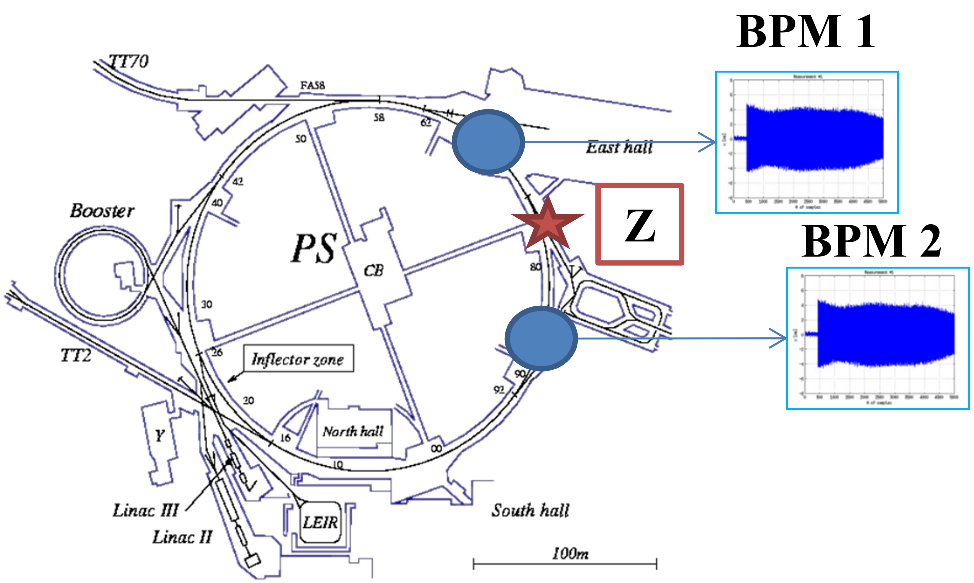

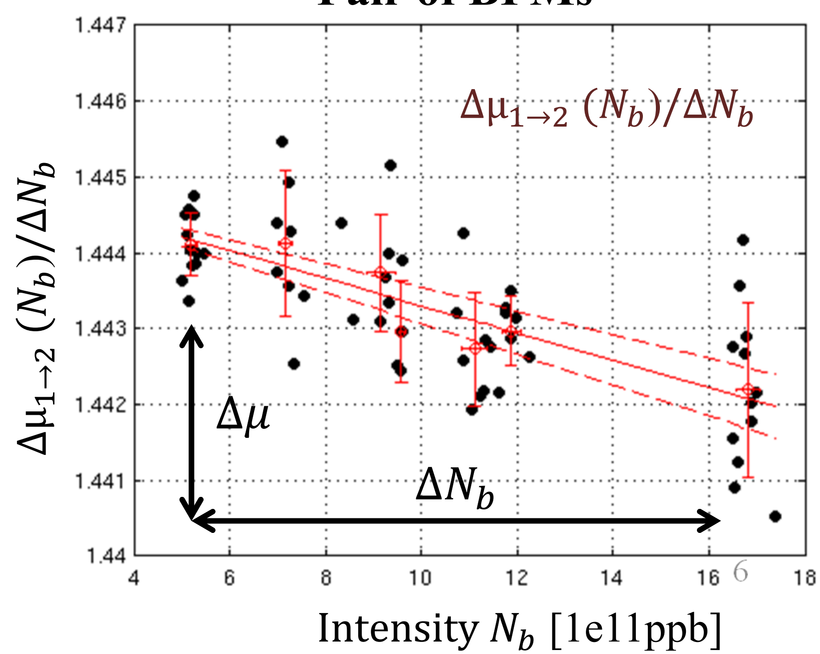

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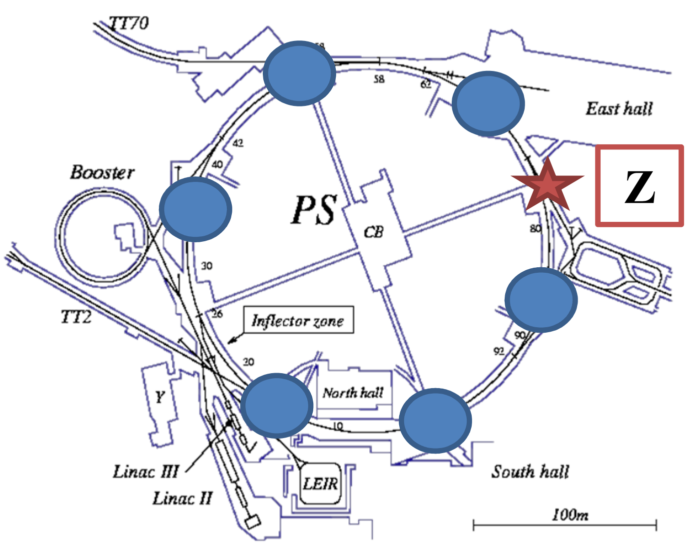
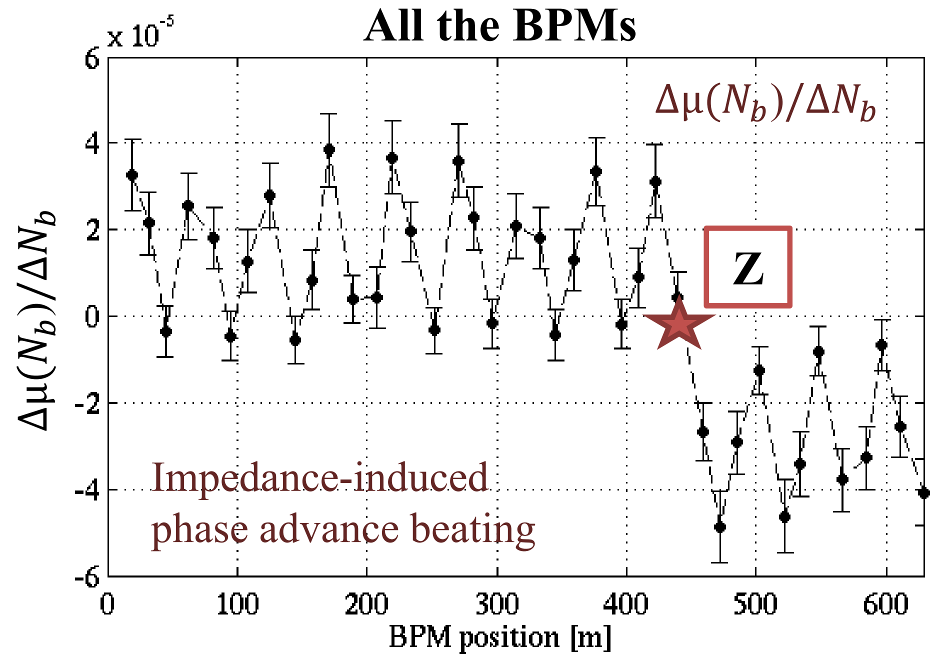
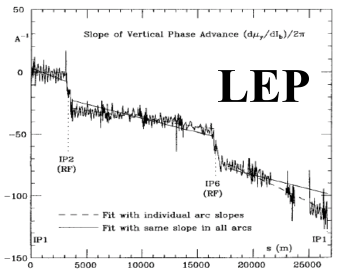


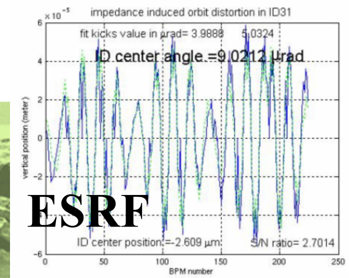


Chronology

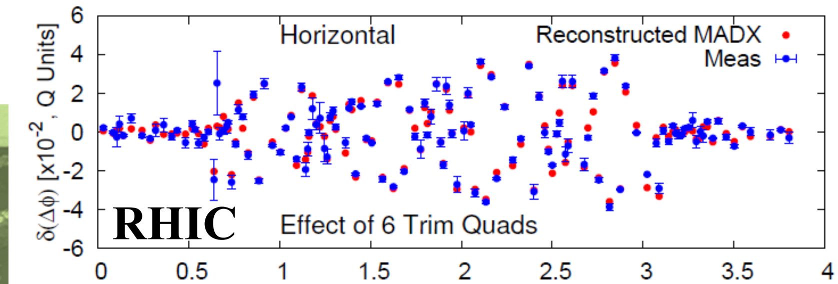
D. Brandt *et al.* proc. of PAC'95



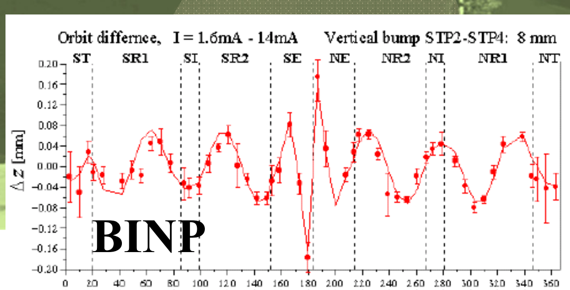
L. Farvacque *et al.* proc. of EPAC'02



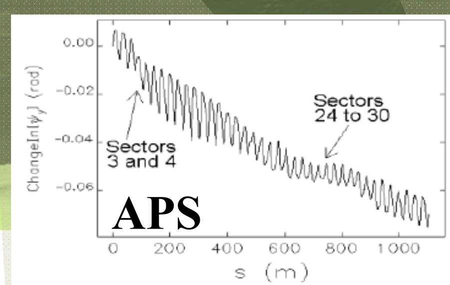
R. Calaga, AB seminar 17-07-2008



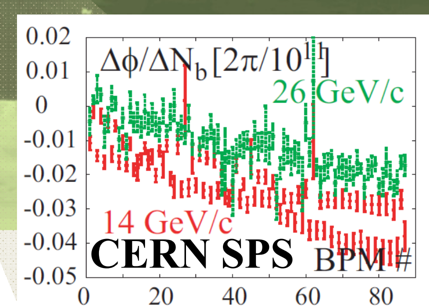
1995	1999	2001	2002	2004..2007	2008	2011..2013
CERN LEP	BINP: VEPP-4M	APS	ESRF	CERN SPS	BNL RHIC	CERN PS/SPS/LHC



V. Kiselev *et al.* proc. of DIPAC'99

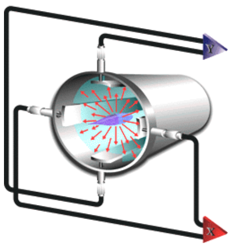


V. Sajaev *et al.* proc. of PAC'03

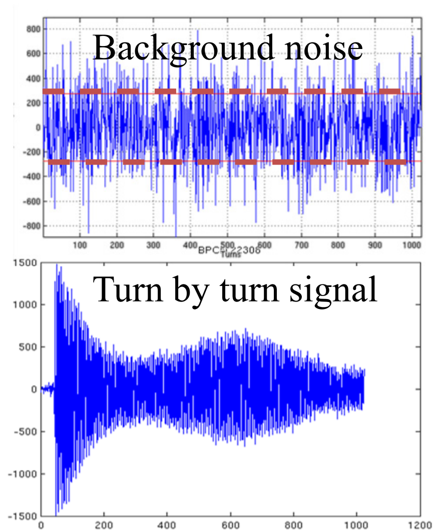


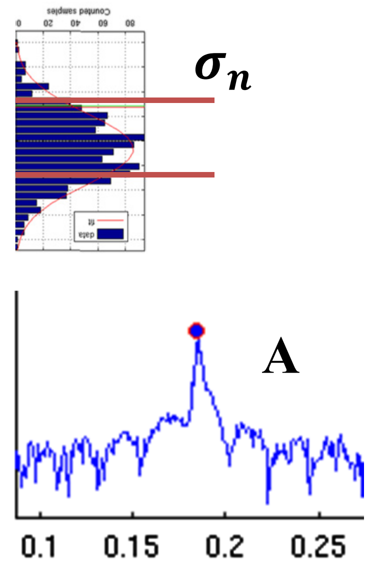
G. Arduini *et al.* proc. of EPAC'04

Accuracy in measurement



BPM system





$$\mathrm{NSR} = \frac{\sigma_n}{A}$$

Noise over Signal Ratio

Accuracy in measurement

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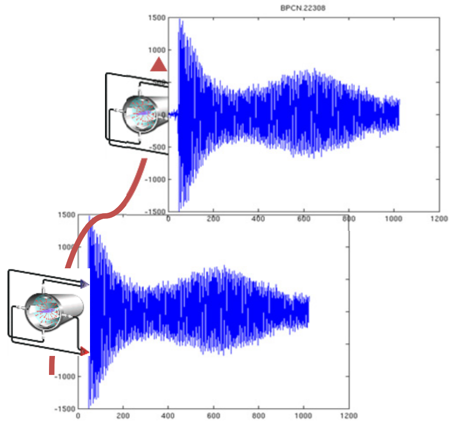
Noise over Signal Ratio

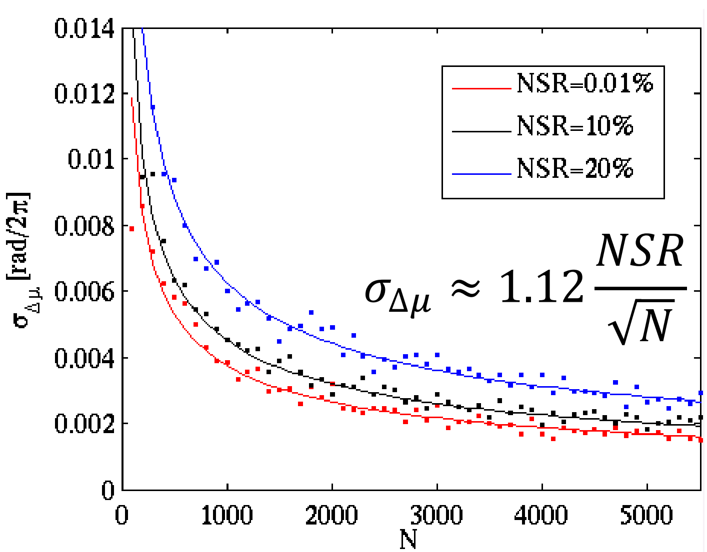


$$\sigma_{\Delta\mu}$$

Phase advance accuracy

Model:

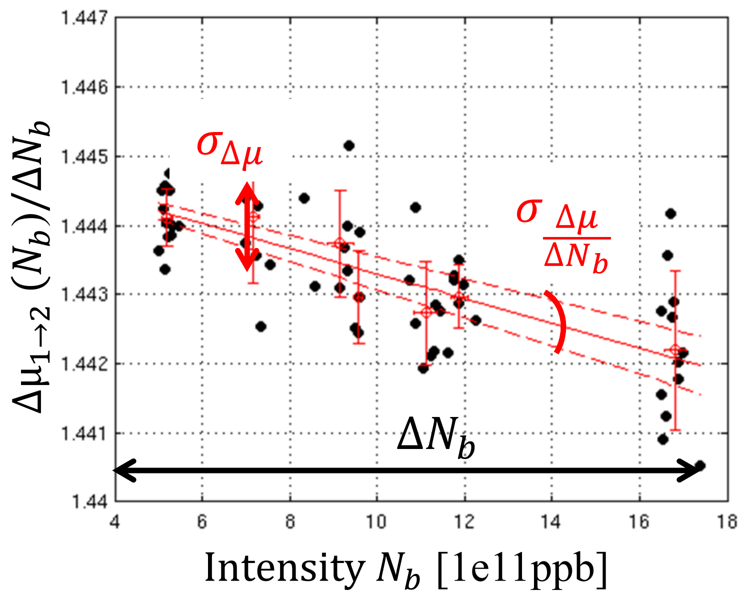
- 2 sinusoidal waves.
- $\boldsymbol{\Delta\mu}$: phase advance.
- Same frequency.
- Additive Gaussian noise of rms $\boldsymbol{\sigma_n}$.
- **N:** number of turns.
- **NSR**: signal to noise ratio.
- NAFF: algorithm for accurate FFT.



Accuracy in measurement

$\sigma_{\Delta\mu}$

Phase advance accuracy



$\sigma_{\frac{\Delta\mu}{\Delta N}}$

Phase advance slope accuracy

$$\sigma_{\frac{\Delta\mu}{\Delta N}} = \frac{1.12\ NSR}{\sigma_{\Delta N_b}\sqrt{N}\sqrt{M}}$$

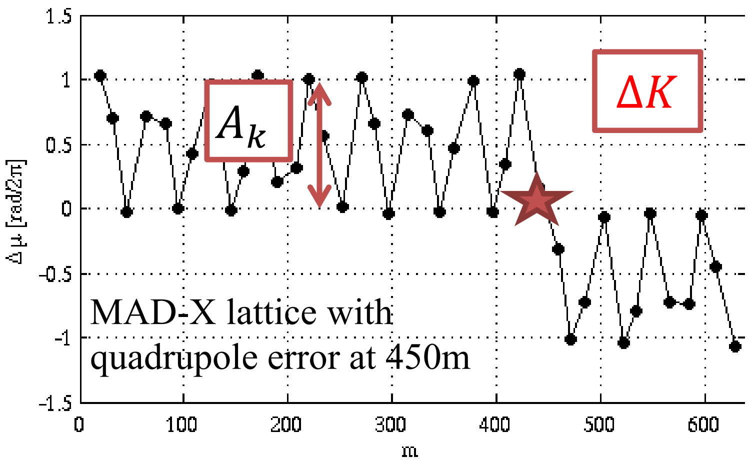
Noise level: To be reduced (kicker strength, BPMs gain, SVD noise reduction, etc…)

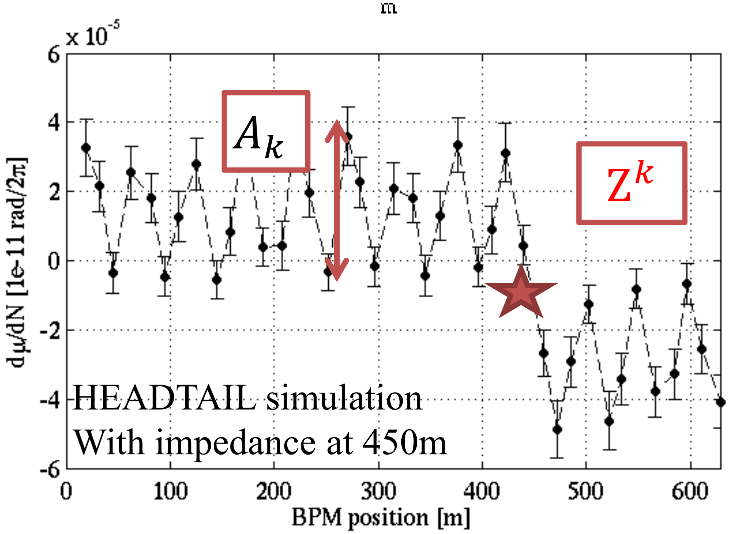
Width of the intensity scan.To be increased (upper threshold can be instability or non-linearities, lower is BPM sensitivity).

N=Number of turns. To be increased (depends on length of coherent oscillation and data transmission from BPM to storage).

M=Number of measurements. To be increased (usually ~100. Limited by machine parameter drift with time).

Reconstruction principle





Theory of lattice imperfection:

$$\Delta Q_k = \frac{1}{4\pi} \beta_k \Delta K$$

Tune shift from a k^{th} quadrupole error.

$$A_k = \frac{\Delta Q_k}{\sin(2\pi Q_0)}$$

phase advance beating amplitude from a k^{th} quadrupole error.

Theory of beam instability:

$$\frac{\Delta Q_k}{\Delta N_b} = \frac{-e^2 T_0}{4\sqrt{\pi}\gamma m_0 (2\pi)^2 Q_0 \sigma_z} \left(\frac{\beta_k}{\bar{\beta}} Im(Z^k_{\perp,eff}) \right)$$

tune shift slope from a k^{th} impedance source Z^k.

$$A_k = \frac{\Delta Q_k / \Delta N_b}{\sin(2\pi Q_0)}$$

phase advance beating amplitude from a k^{th} impedance source Z^k.

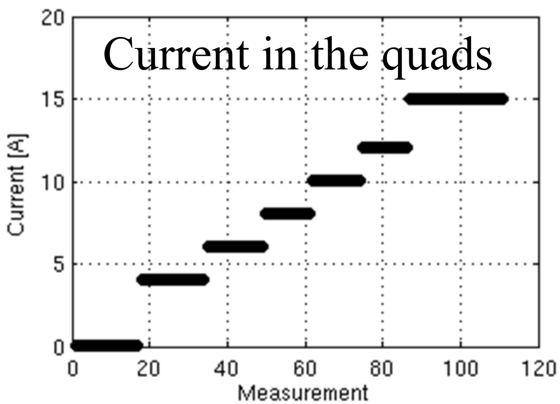
Given the similar behaviour we can reconstruct the measured/simulated phase beating using the MAD-X response matrix to quadrupole errors!

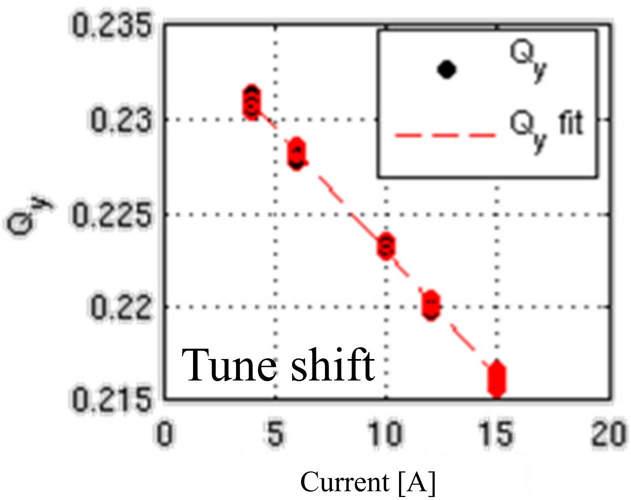
PS

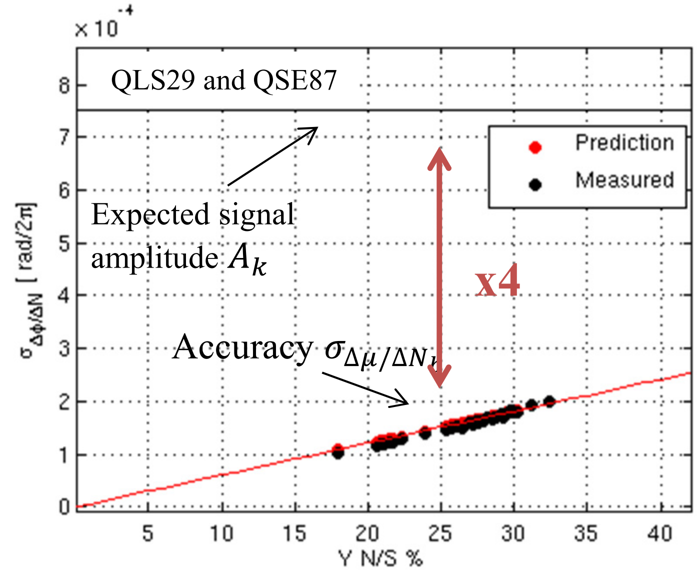
Measurement of local quadrupolar orbit errors

Method validation in the PS:

- We chose two quadrupoles with independent power supply: QLS29 and QSE87.
- We increased their current to provoke a vertical tune shift ΔQ_y~-0.02.
- We tried to localize back the quadrupoles.



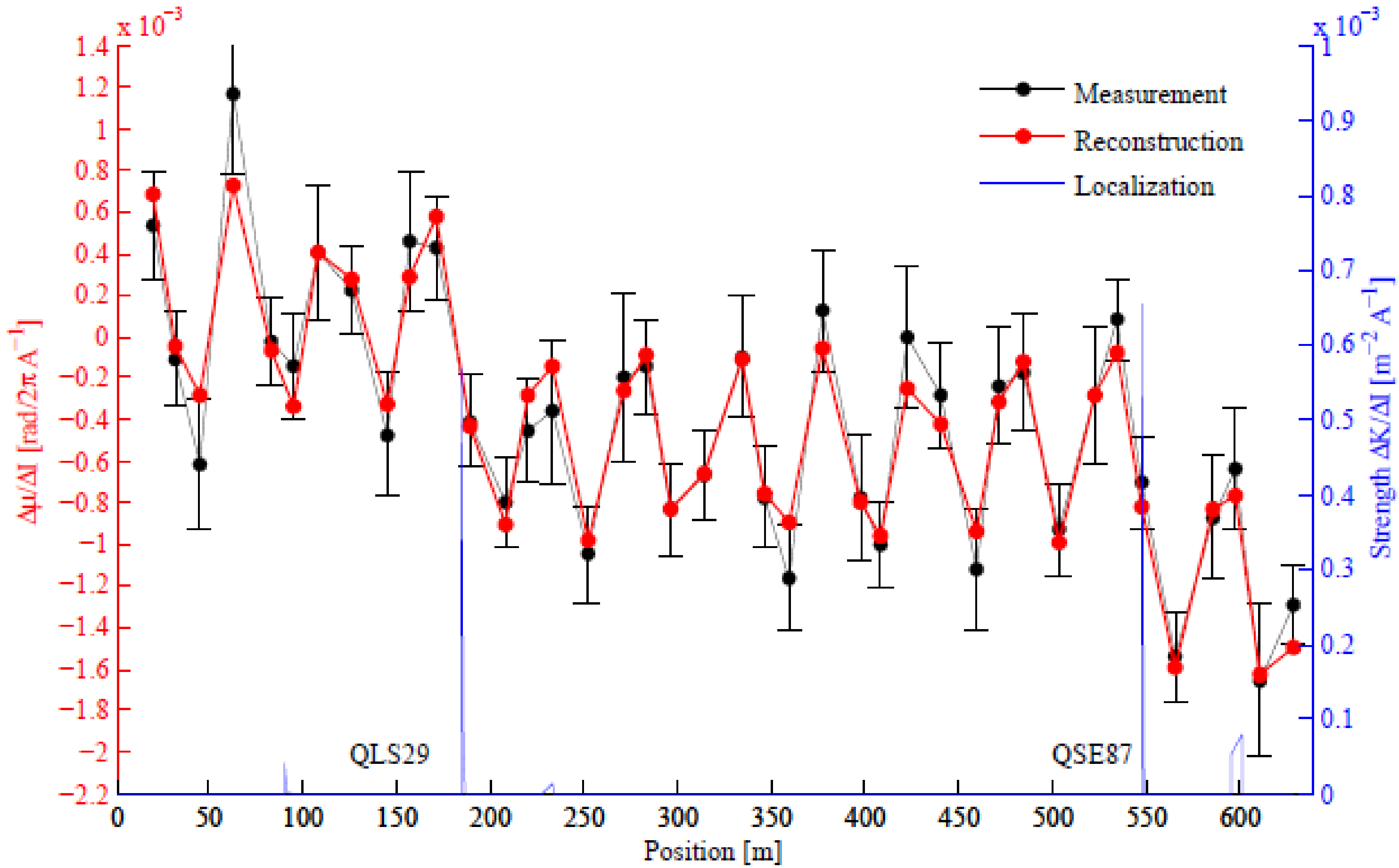




- Beat of amplitude A_k~7.5e-4 expected from the quadrupole strength variation.
- Accuracy limit $\sigma_{\Delta\mu/\Delta N_b}$~2e-4

Enough margin, should be able to localize

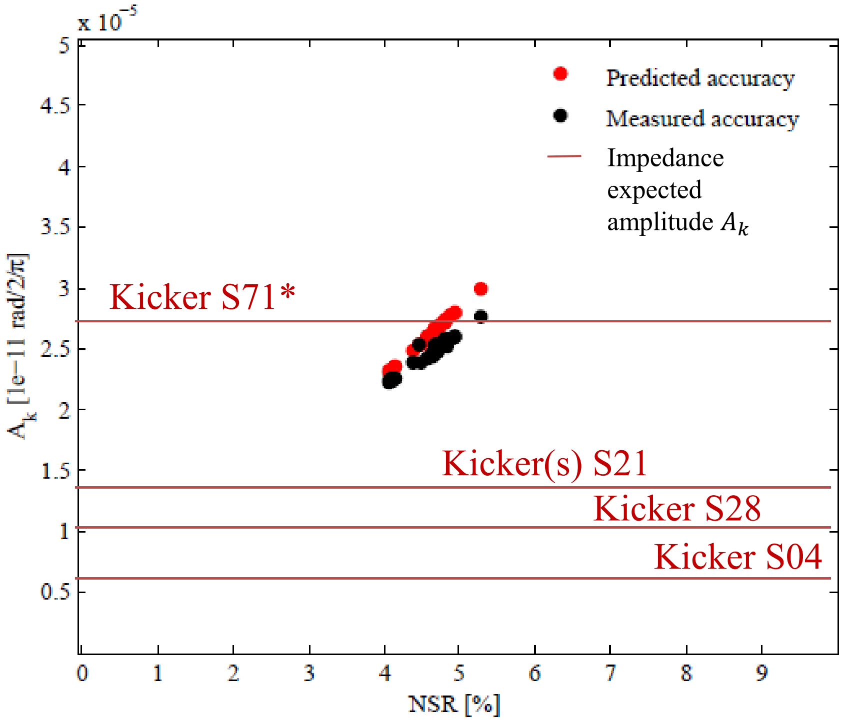
Measurement of local quadrupolar orbit errors

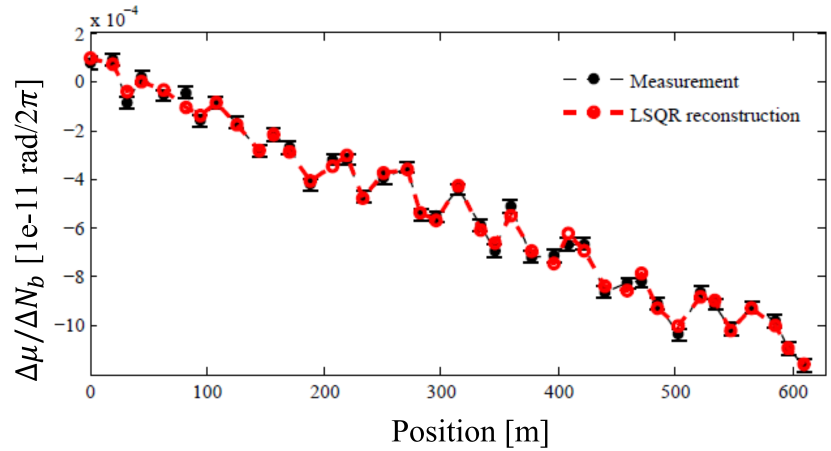


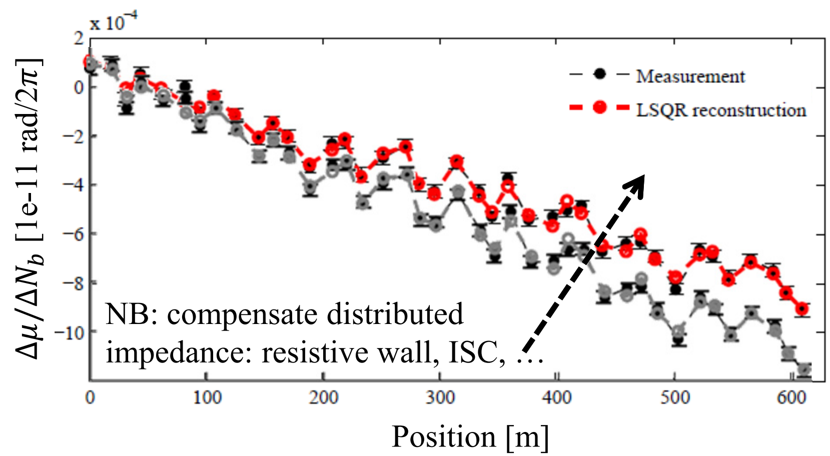
- MAD-X reconstructors: all available quadrupoles in the lattice.
- Good agreement with the real quadrupole positions and strength!

Measurements at 2GeV

- Measurement with single bunch at the energy of 2GeV.
- Intensity scan from 1e12 to 2e12 ppb.
- Transverse feedback (TFB) excitation at tune frequency.







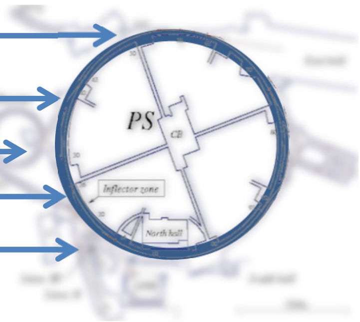
Not much margin.
Some chance to localize kicker S71.

* Estimated with Tsutsui's model

Reconstruction

Before reconstruction:

- We chose as reconstruction points elements that could reasonably be high impedance sources (i.e. not BPMs, vacuum ports, magnets,…).
  - ✓ **Cavities;**
  - ✓ **Kickers;**
  - ✓ **Wirescanners;**
  - ✓ **TFB;**
  - ✓ **Septa;**



MAD-X response matrix:
49 reconstructors x **40** BPMs.

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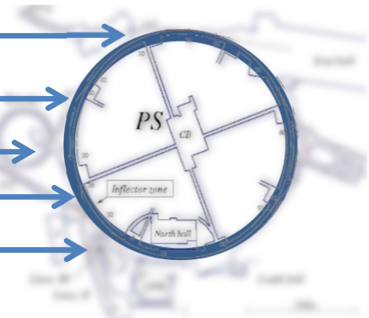

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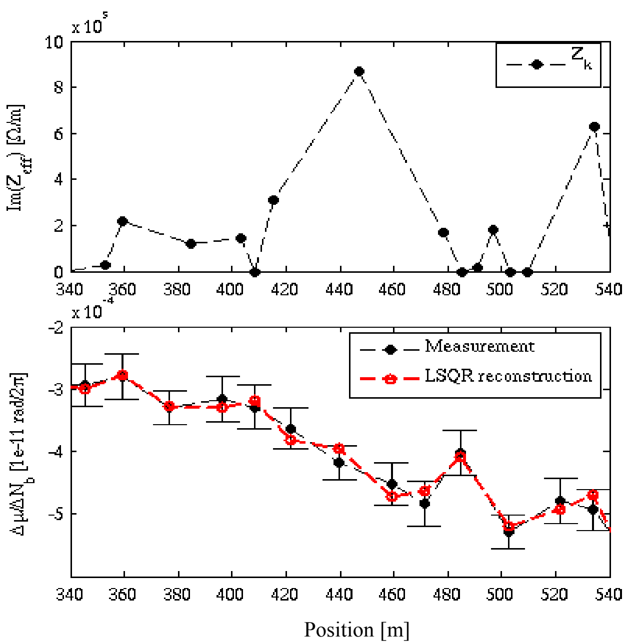
- Refinement on how the measured and reconstructed slope overlap;



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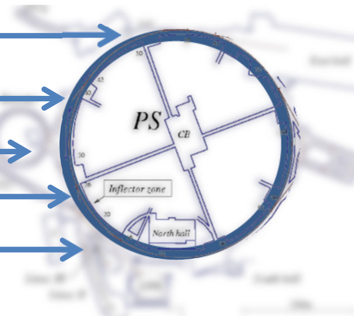
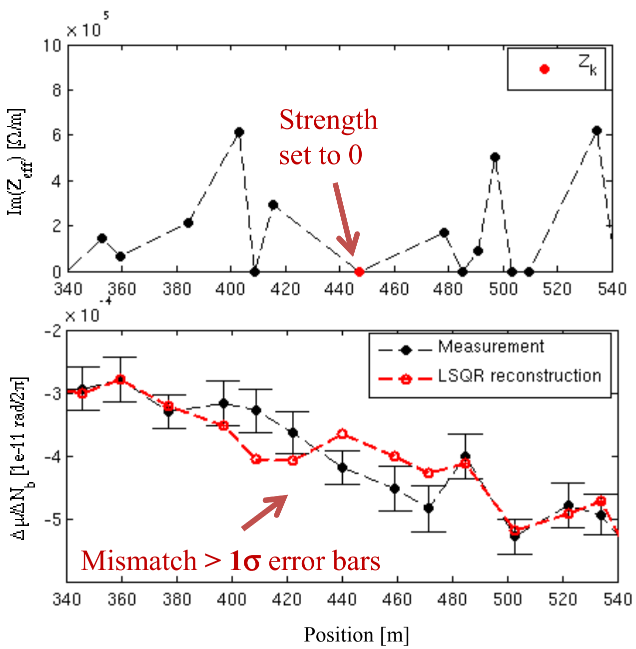


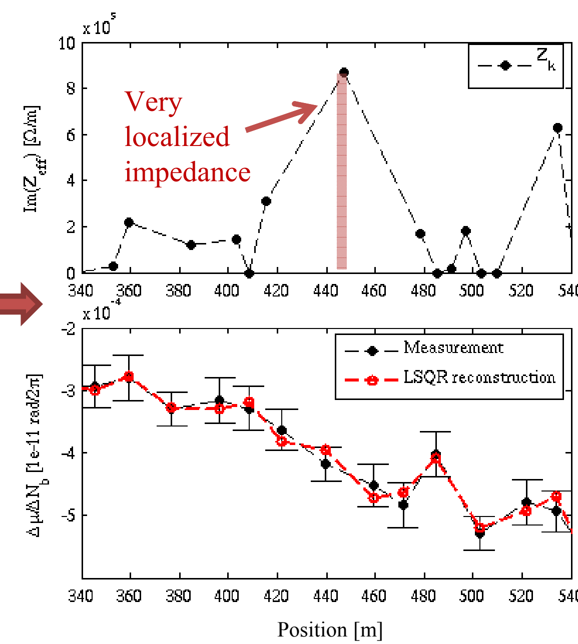
MAD-X response matrix:
49 reconstructors x **40** BPMs.

After reconstruction:

- Refinement on how the measured and reconstructed slope overlap;
- Mismatch if a single or a sequence of reconstructors is switched off .

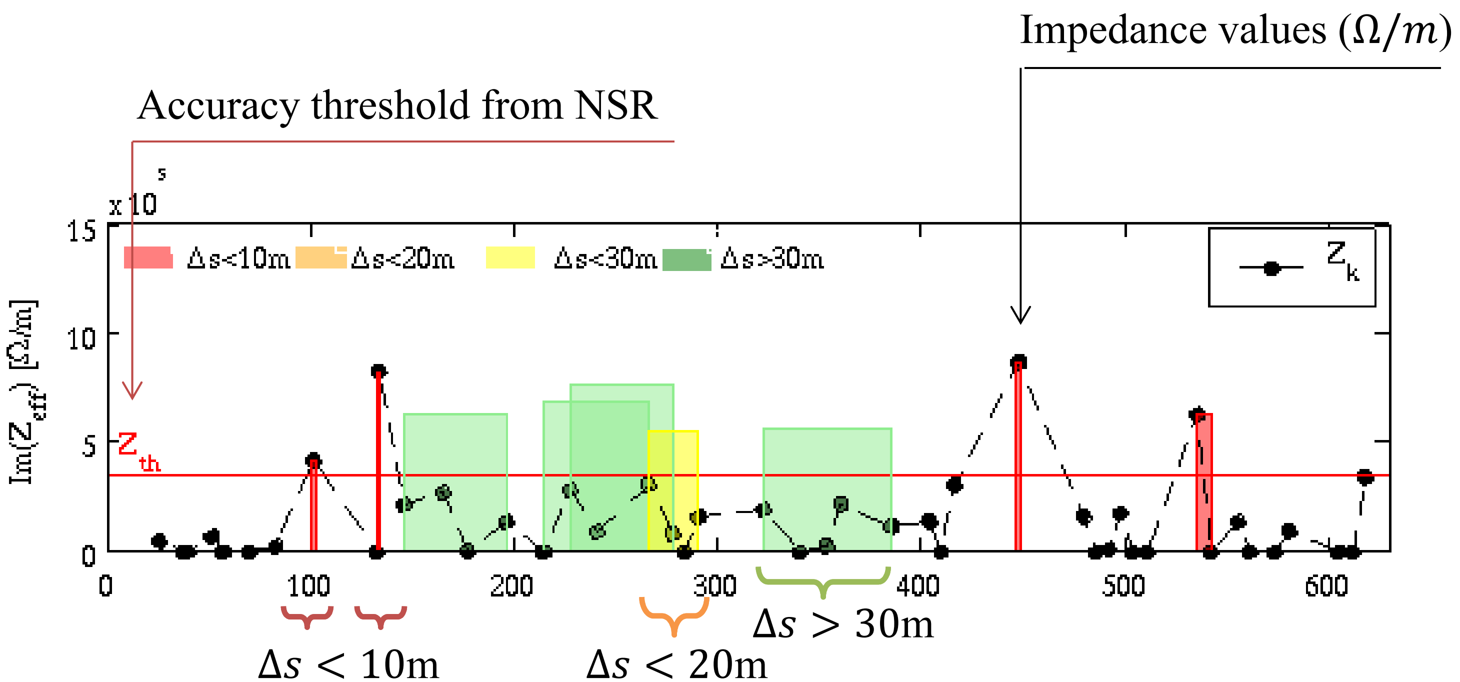
- It reduces the family of selected impedance candidates.
- It gives a spatial uncertainty Δs





Reconstruction

Some reconstruction results:



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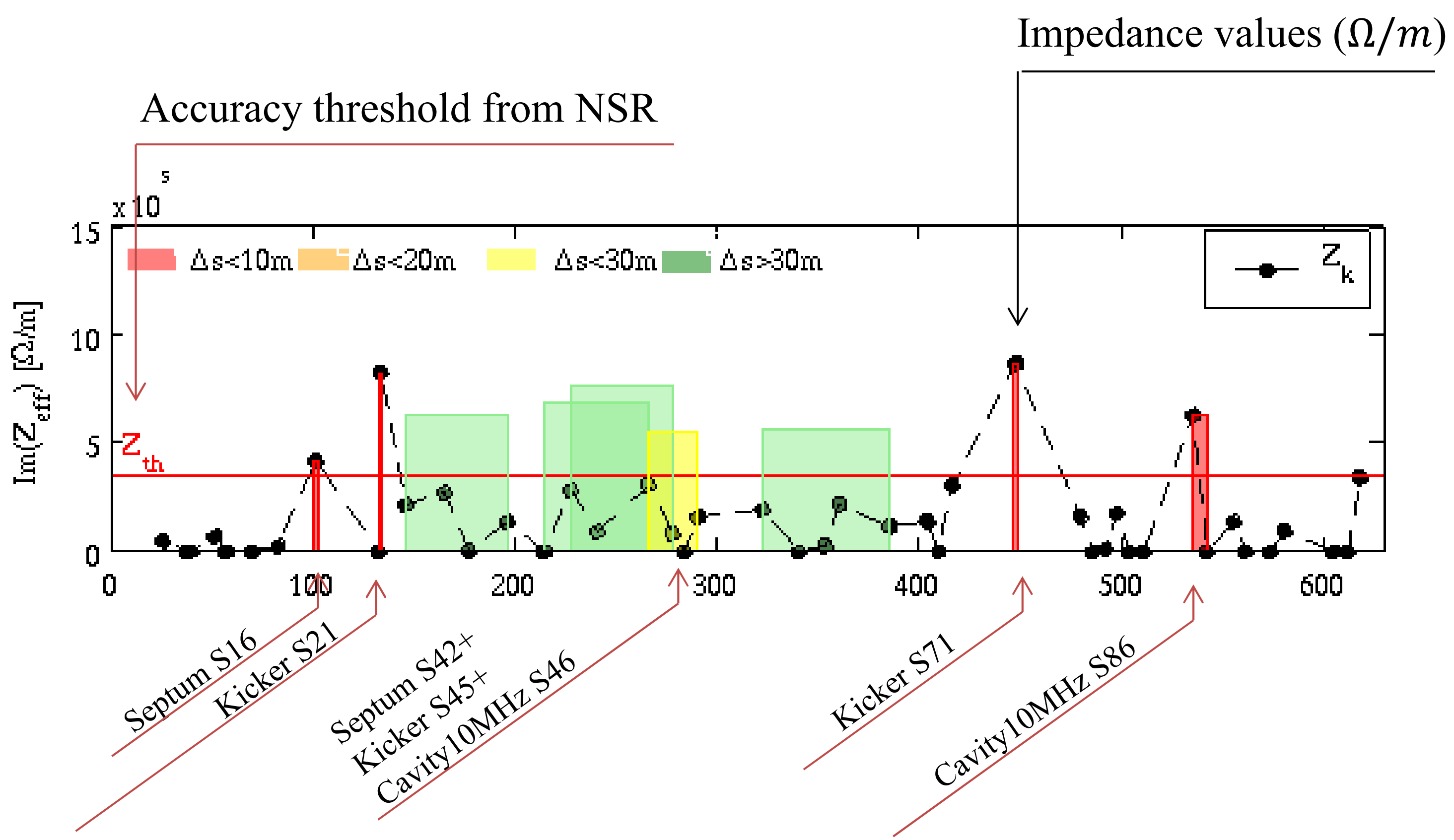

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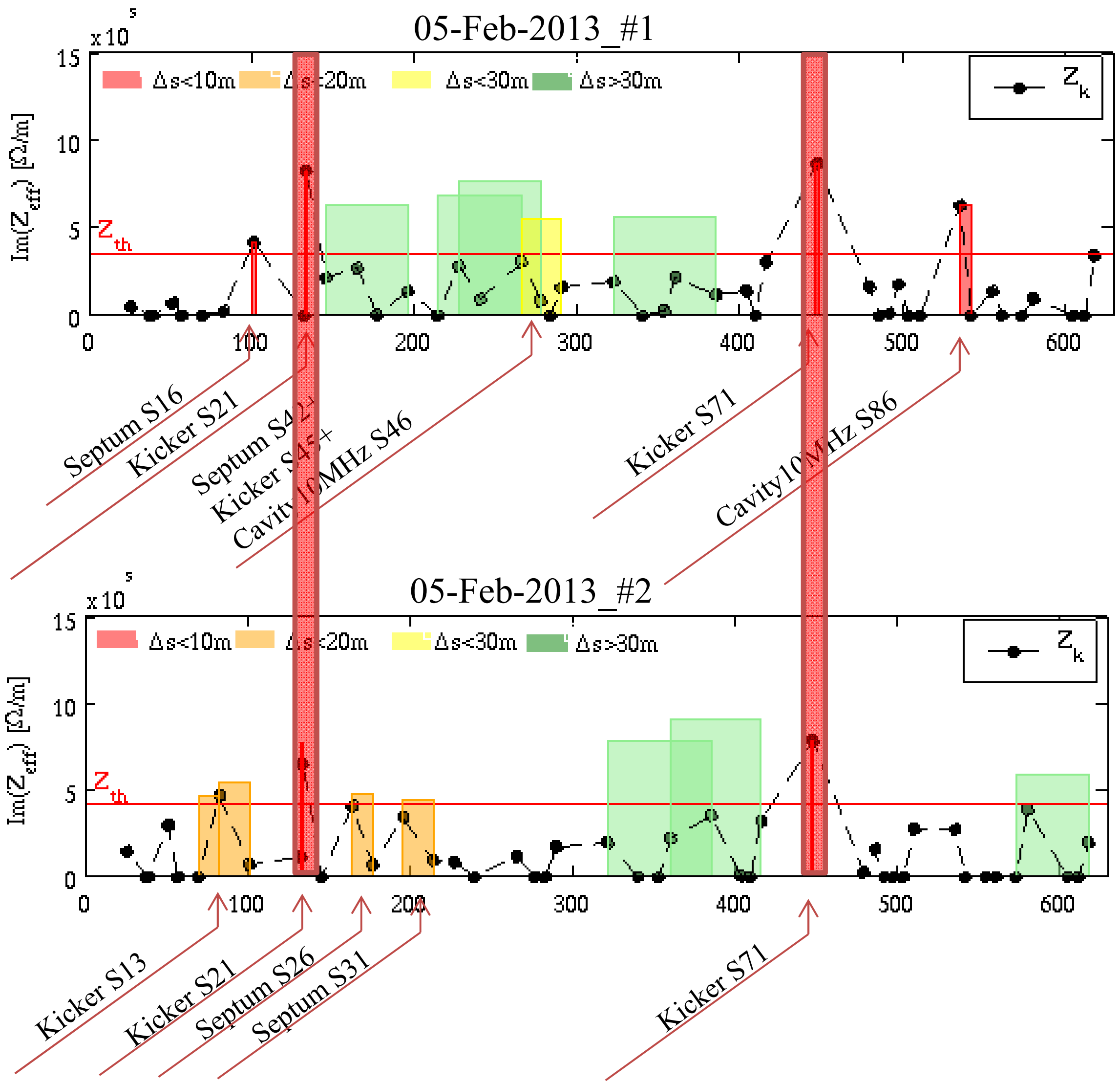
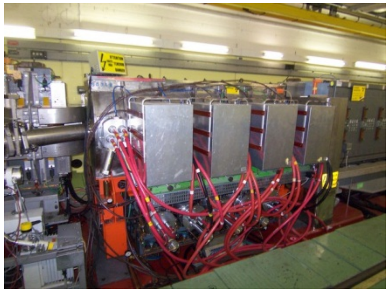
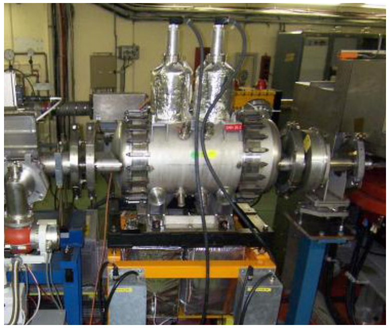




Kickers in S21 - S71



Septa

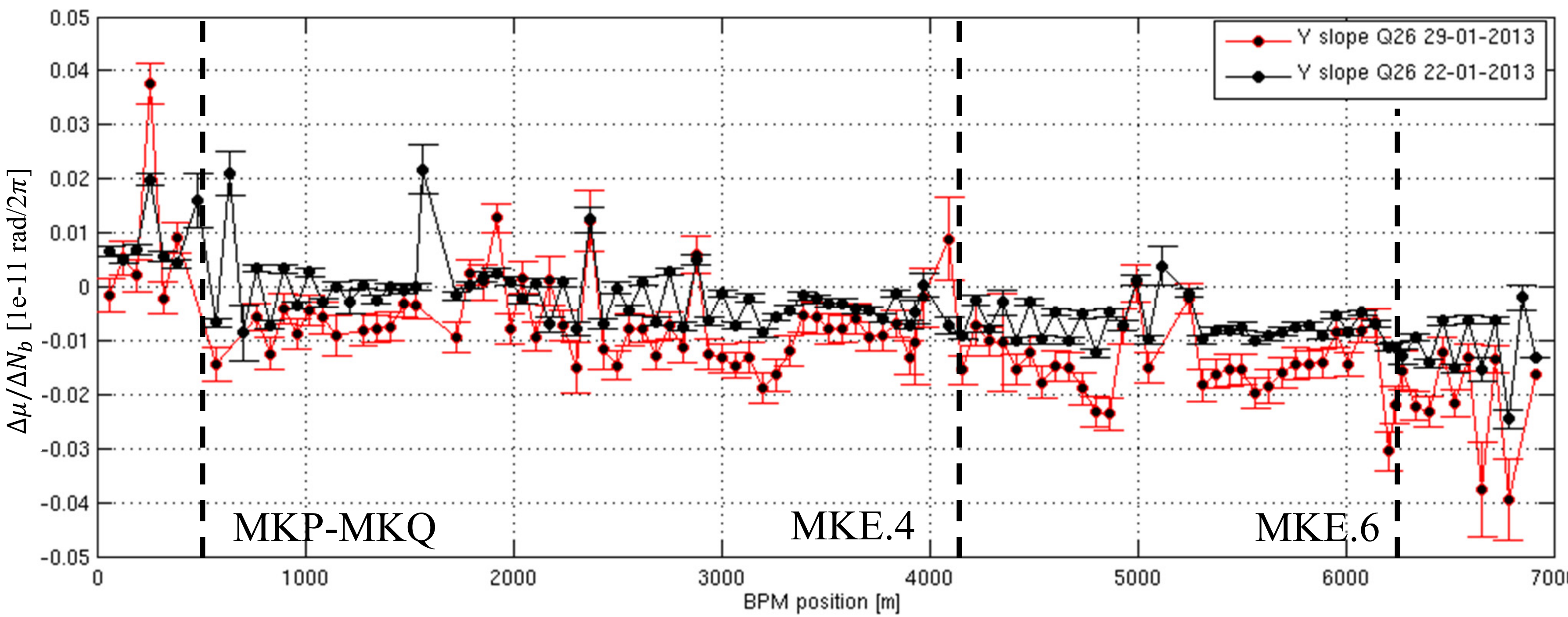
10MHz Cavity

SPS & LHC

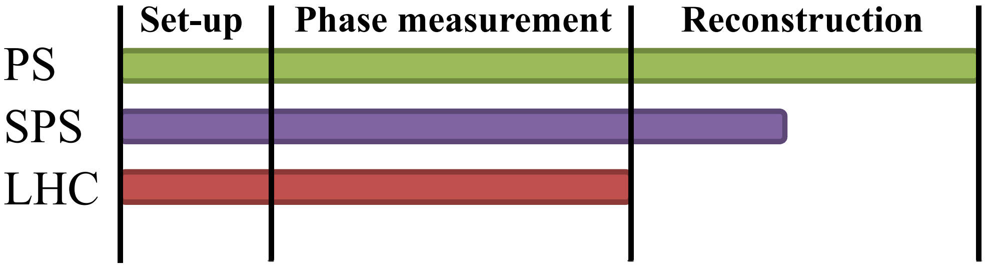
SPS

- Measurements NSR acceptable.
- Scarce reproducibility on investigation.
- Analysis with response matrix on-going.

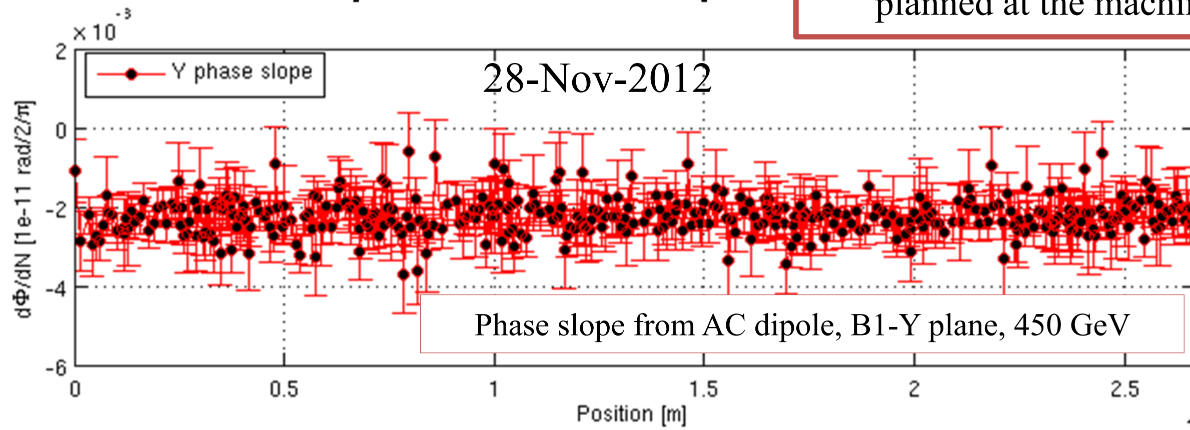
Measurements of 22-Jan-2013 and 29-Jan-2013

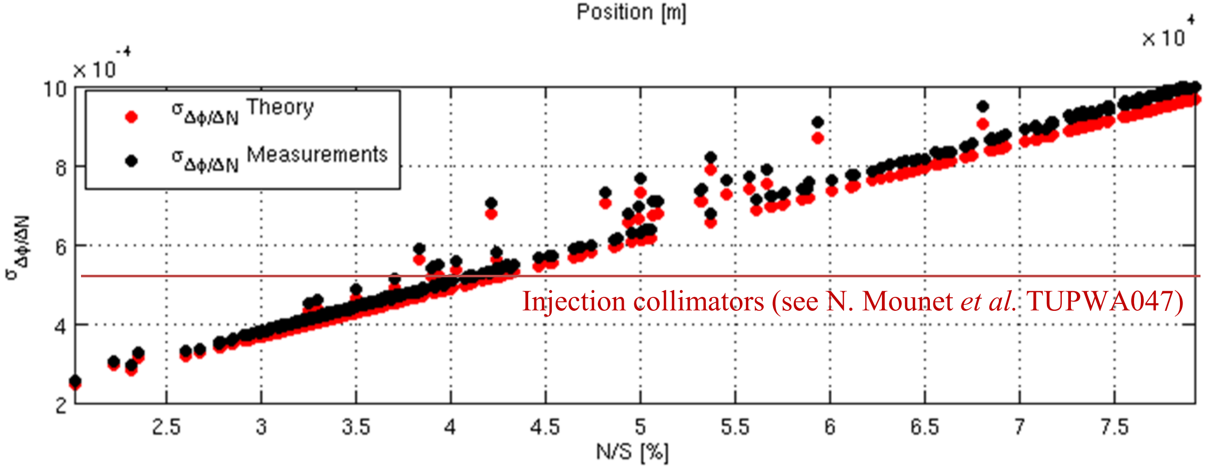


LHC



- Good agreement for accuracy expectation and measurements.
- Signal from known impedances expected at the level of noise.
- Difficult to reconstruct… new measurements planned at the machine restart.





Conclusion

Method:

- ✓ A better understanding of the major constraints and parameter interplay in the impedance localization measurement has been achieved.
- ✓ The accuracy in the measurements has been studied and benchmarked with measurements (and simulations).
- ✓ A reconstruction algorithm has been studied in order to include reasonable impedance positions, resistive wall + indirect space charge contribution and spatial accuracy.

Measurements in PS:

- ✓ The measurements with current dependent quadrupole errors proved the feasibility in the simplest case.
- ✓ The measurements with beam showed good reproducibility and reconstruction.
- ✓ Found high impedance sources for *kickers* in section 21 and 71 with occurrence of septa and 10 MHz cavities.

Measurements in SPS & LHC:

- ✓ SPS: Measured impedance-induced phase advance beating. Work is on-going to reconstruct the impedance position.
- ✓ LHC: First localisation measurement was attempted. Accuracy limits may be overcome decreasing NSR with a careful measurement set-up within new measurements planned at the machine restart.

In the meantime: RHIC….
but that's an other story!

Many people behind this work!

PS, SPS, LHC operators,
LHC collimation team,
J.Albertone,
C.Boccard,
S.Jackson,
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H.Damerau,
M.Giovannozzi,
C.Hernalsteens,
J.E.Muller,
G.Rumolo,
G.Papotti,
S.White,
C.Zannini,
F.Zimmermann.

Thank you!

謝 謝 !!

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