Single-Bunch Accumulation Limit Dependence on Impedance at APS

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APS operation modes

- APS operates in 3 fill patterns (total current is always 100mA):
  - 24 equally spaced bunches, 4.2 mA/bunch (16 nC/bunch)
  - 324 equally spaced bunches
  - 1+56 bunches: one 60 nC bunch separated by 1.5 μs from the rest (called hybrid)
- To achieve stable and high-current single bunch, we operate at high chromaticity:
  - Before introducing feedback, we used chromaticity of +7 for 24 bunches pattern and +11 for the hybrid pattern
  - After installing feedback, we lowered chromaticity to +4 and +9
- Increasing chromaticity always works in stabilizing the beam and increasing accumulation limit
  - The downside is lower lifetime

APS Impedance

- APS transverse impedance consists of 3 approximately equal parts[1]:
  - Resistive wall of small-gap ID vacuum chambers
  - Geometrical of the transitions to the ID chambers
  - Geometrical of the rest of the ring
- There are 32 ID chambers installed, 3 ID locations still unoccupied
  - ID chambers are 5-m long, made of aluminum
  - Gaps are 5 mm (1), 7.5 mm (8), and 8 mm (23)
- Every ID chamber is about 2% of total impedance (excluding 5-mm chamber)
- Installing 3 new chambers would add 6% and could have serious effect on accumulation limit

[1]Y.-C. Chae, Proc. of PAC 2007

APS Upgrade

- For the APS Upgrade, lattice changes involve symmetry breaking
  - Three long straight section
  - Short x-ray pulse generation using deflecting cavities
  - One straight section with reduced horizontal beam size (factor of ~3)
- Maintaining a good lifetime with high chromaticity required to provide 16 mA single-bunch will be difficult
- There is also a plan to build new ID vacuum chambers with 7.3-mm gap and use them in place of presently installed ID chambers (10 to 15 new chambers)
  - These chambers will have higher impedance then the present ones
- We expect impedance increase but the lifetime will be lower
  - Will not have a freedom of increasing chromaticity any more
- We need an impedance model that could predict accumulation limit change

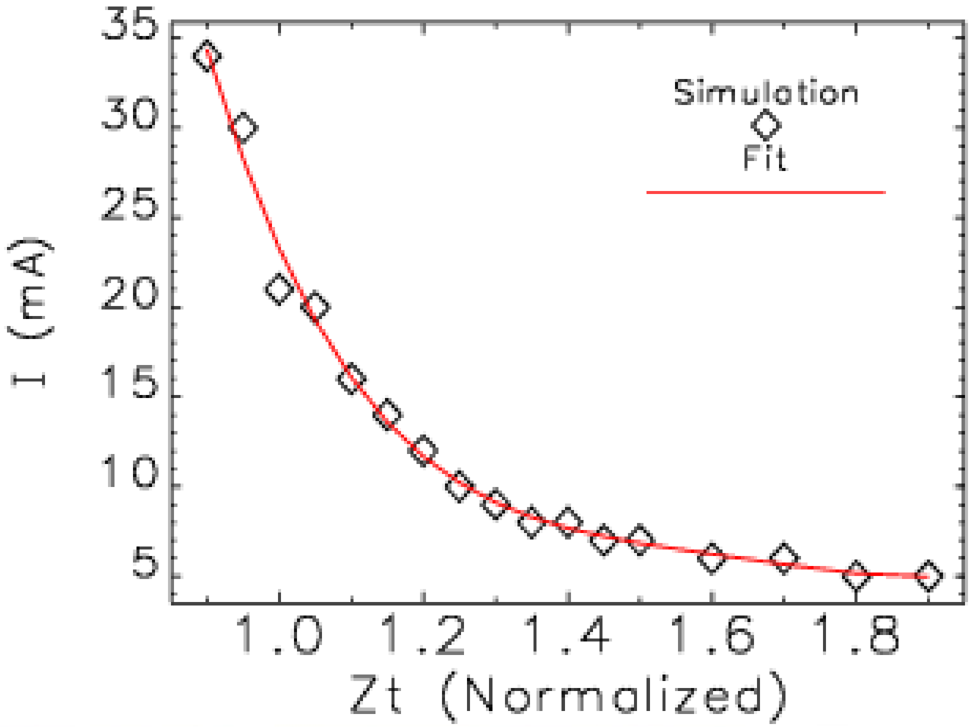
Accumulation limit modeling[1]

- Wake potentials of all elements are computed with 1-mm-long bunch to extend impedance bandwidth
- Wake potentials are separated into dipolar and quadrupolar components
- `elegant` is used for tracking
- Impedance of the whole ring is represented as a single element per each plane
  - ZTRANSVERSE or ZLONGITUDINAL elements in `elegant`, use calculated wake functions
- The ring is represented as linear map of one sector (ILMATRIX) with chromaticity
  - Special elements (cavities, radiation effects, etc) can be inserted between sectors
- The bunch consists of 200k particles
  - Required for correct simulation of longitudinal effects

[1]Y.-C. Chae, AOP-TN-2009-008

Accumulation limit calculation

- Accumulation limit is affected by injection conditions
  - Oscillation of the stored bunch is important
  - Simulation is simplified to a simple kick of the stored bunch
- An agreement with measurement is achieved at 0.3mm vertical kick
- The model is used to calculate the effect of impedance change on the accumulation limit:



Accumulation limit prediction

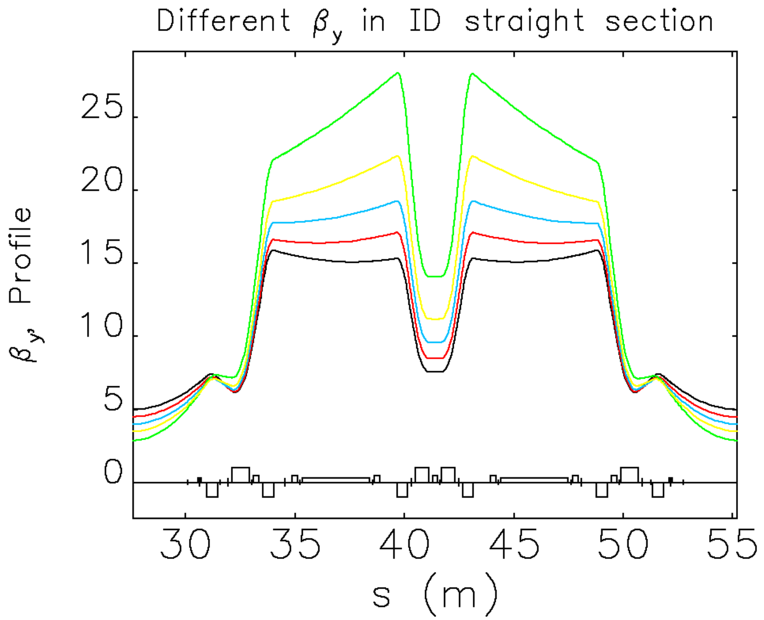
- We developed a simple spreadsheet that allows to estimate accumulation limit using scaling laws obtained from simulation[1]
  - Effect of transitions is scaled as gap in the power of 2.4
  - Resistive wall effect is scaled as gap in the third power
  - Dependence on impedance is taken from the plot from previous slide
- Effect of various vacuum chamber installations on accumulation limit can now be estimated
  - One additional small-gap chamber lowers limit by about 1.5 mA

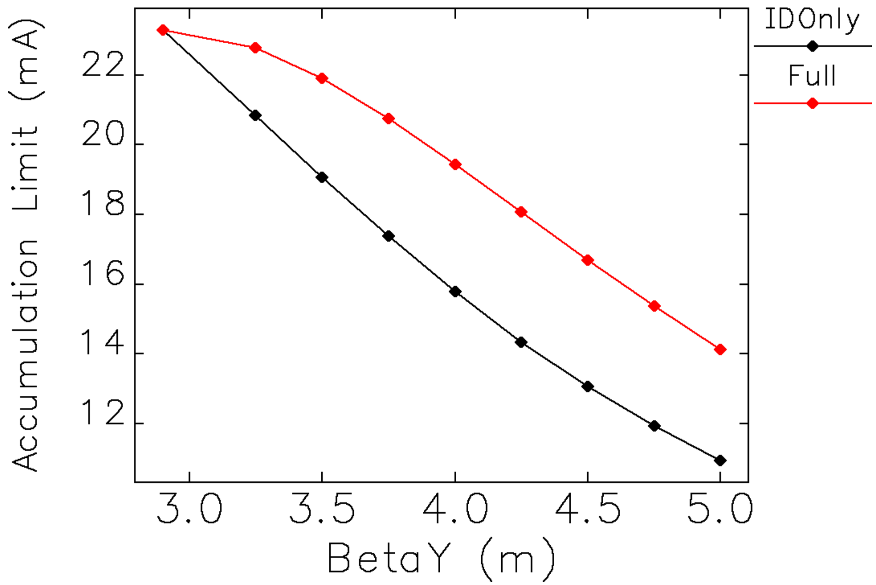
- We now need to verify these calculations
- The easiest way to change the effective impedance of SR is to change beta functions in ID chambers[2]

[1]M. Borland, AOP-TN-2012-034
[2]M. Borland, AOP-TN-2012-028

Lattice development

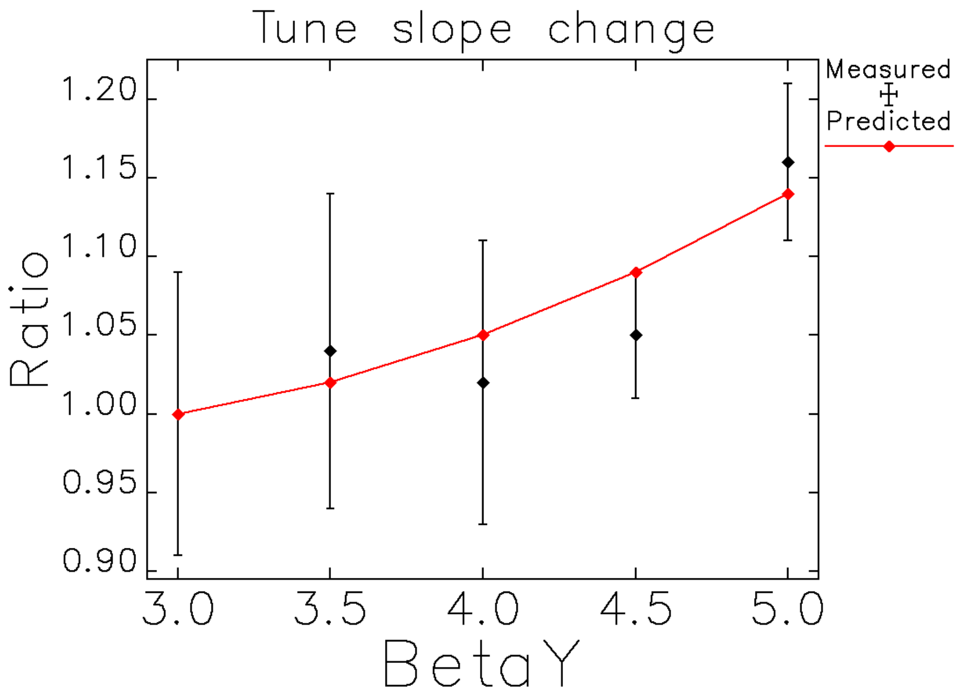
- We can change the effective impedance of an element by changing beta function at its location
- We generated a set of lattices that have different beta functions at ID chamber locations:
  - Five lattices were created with vertical beta function changing from 3 m (nominal) to 5 m
- Requirement of maintaining the betatron tune unchanged reduced total impedance change due to beta function change outside of ID chambers





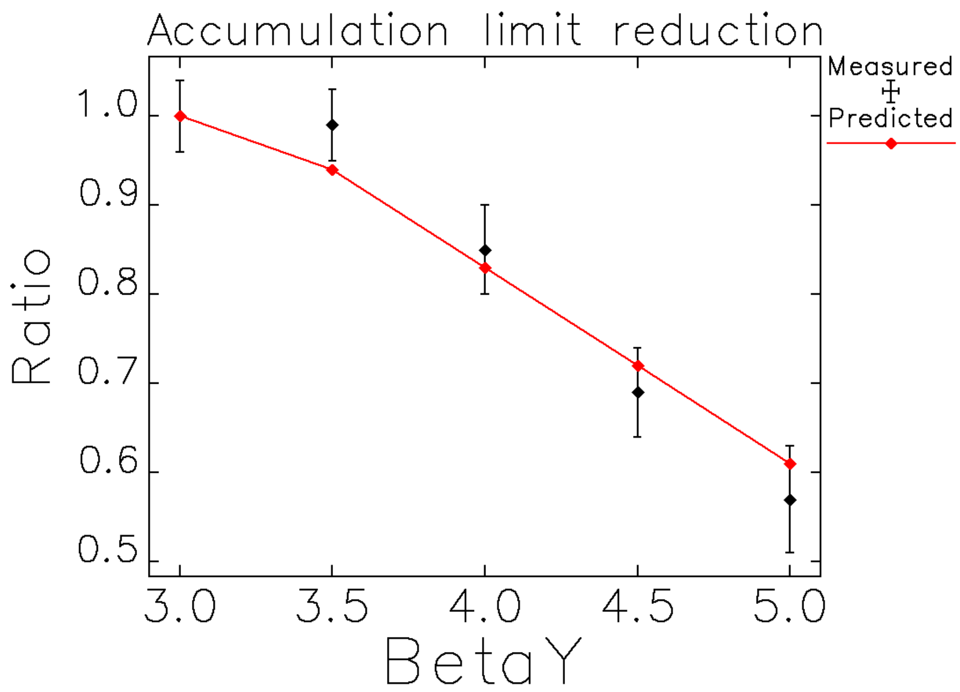
Tune slope measurements

- All five lattices were implemented
- To characterize the effective impedance increase, we first measured tune slope with current
  - As expected, we don't have enough accuracy to show ~5% change
  - Large tune spread within the bunch is main reason for low accuracy of the measurement



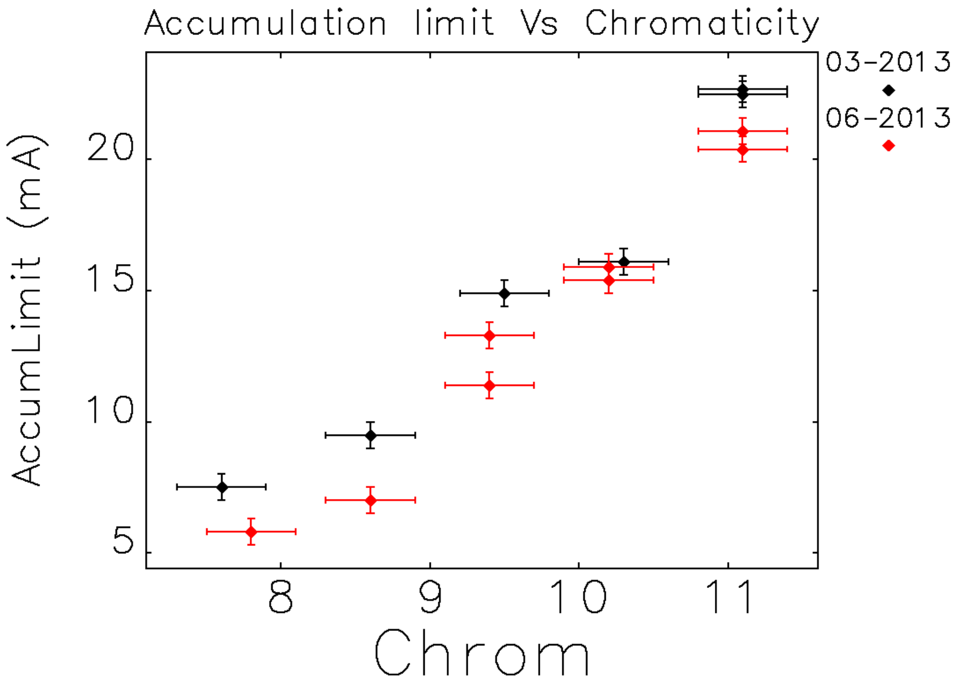
Accumulation limit measurements

- To improve accuracy of the AL measurement, we followed a procedure of AL optimization that was repeated for all lattices
  - Lattice correction: beta function correction, coupling minimization, chromaticity correction
  - Injection optimization on closed bump
- We found a good agreement with our predictions



Installation of two small-gap chambers

- To further validate our impedance model, two spare small-gap chambers were installed in two free sectors in May 2013
  - Expected increase of vertical impedance is 4%
  - Expected reduction of AL is ~3mA
- Same procedure of AL optimization was followed to compare measurement before and after installation
- A reduction by 2 mA was measured (20.5 mA vs 22.5 mA)

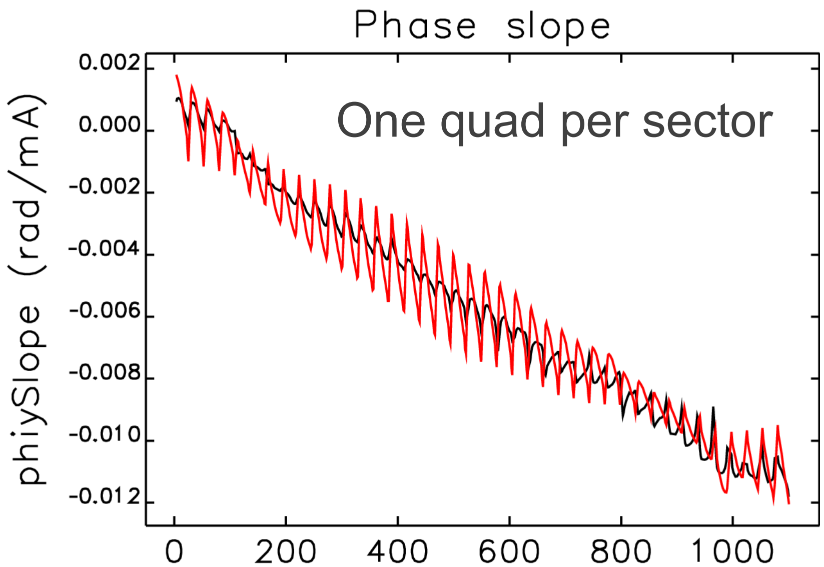


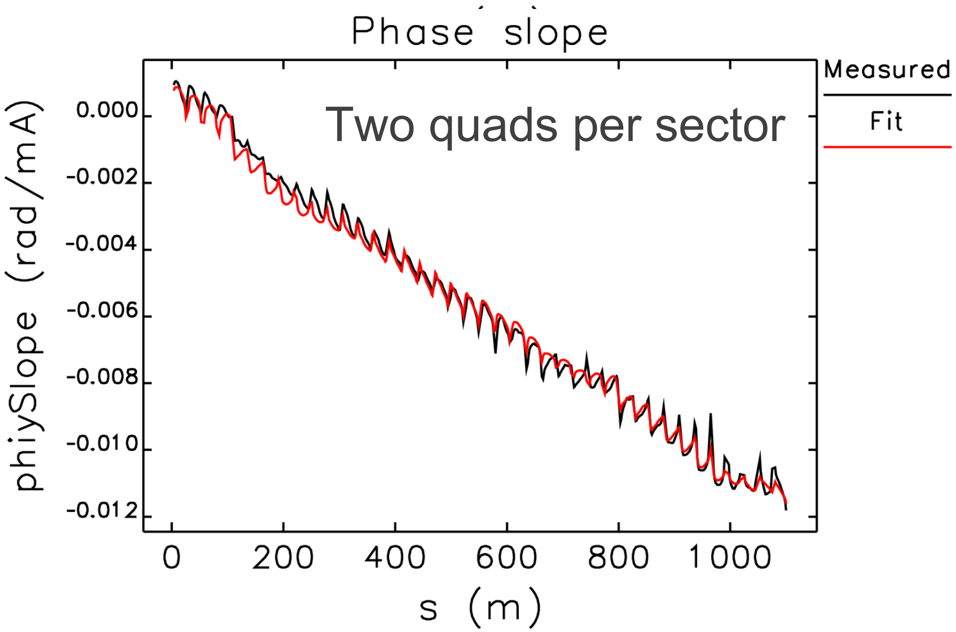
Local impedance measurement[1]

- Transverse impedance of a component can be represented as defocusing element whose strength depends on beam current
  - Lattice measurements at different current can provide information on local impedance
- Due to quadrupole ambiguity of the RM fit, we cannot just use differences in quadrupole solution
- The procedure is the following
  - Measure and fit response matrix for different single bunch currents
    - The result is a set of beta function files
  - For every ring element (for example, BPMs), take betatron phase advance from every file and calculate phase slope with current
    - The result is phase slope with current as a function of s
  - A small set of quads is used to match the phase slope with current
    - This quad set represents local impedance

[1]V. Sajaev, Proc. of PAC 2003; V. Sajaev, AOP-TN-2012-046

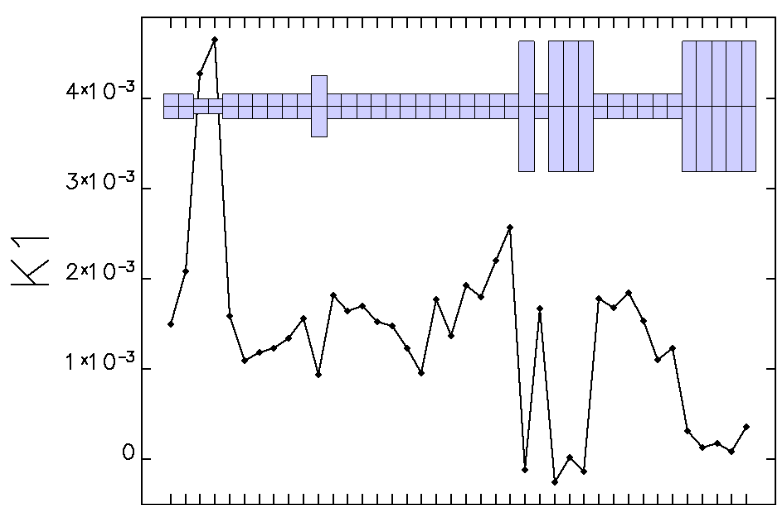
Phase slope fit





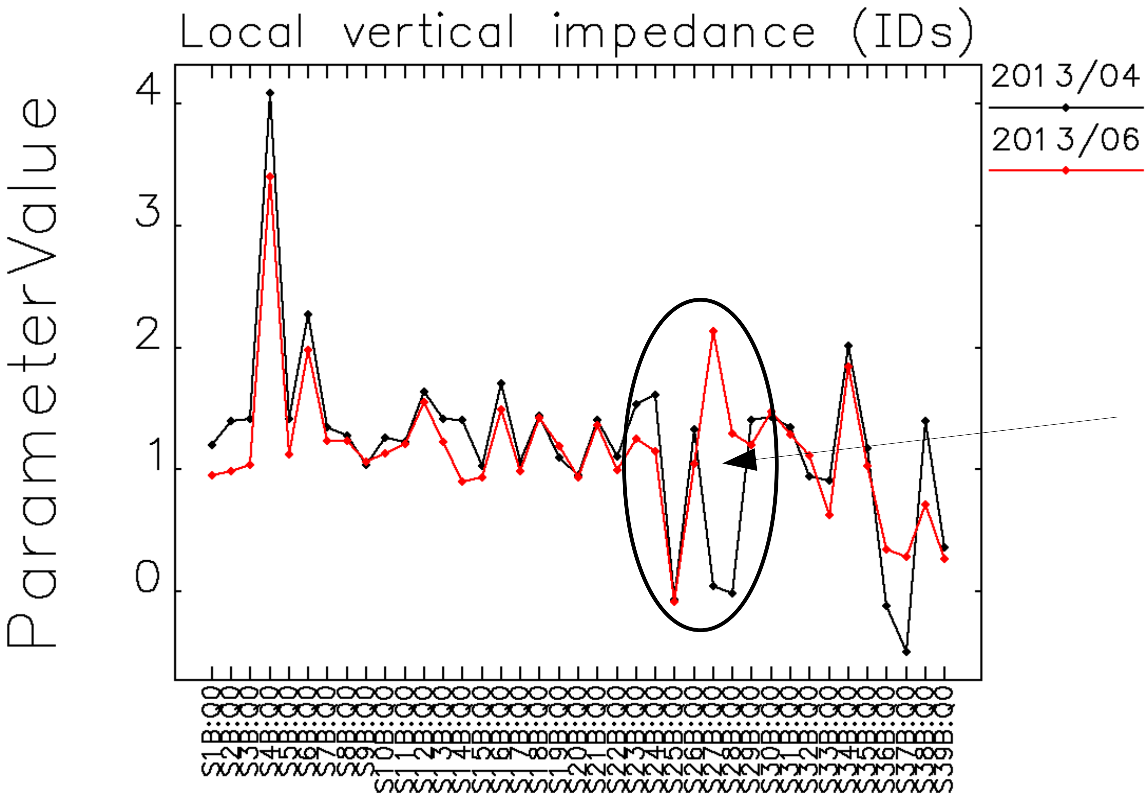
- Minimal quad set that fits the phase slope satisfactory is two quads per sector: one in the middle of ID, and second in the middle of the arc
- No reason to increase number of quads beyond that – the phase slope curve is too noisy

Quad strength in the ID



Local impedance comparison

- We measured local impedance before and after installation of 2 new vacuum chambers
  - Clear differences at location of new chambers
- Variation between two measurements is accuracy



Two vacuum chambers installed here.

Conclusions

- We have simulated accumulation limit at APS
  - We have achieved a good agreement with measurements
- We have developed a model that predicts how the AL would change due to new vacuum chamber installations
- We have verified the predictions by measuring the AL in lattices with increased effective impedance due to higher beta functions
- We have also verified the predictions by installing 2 new small-gap chambers and measuring the AL before and after installation

- We have realized the necessity to reduce the impedance of new vacuum chambers
  - New transitions are being developed