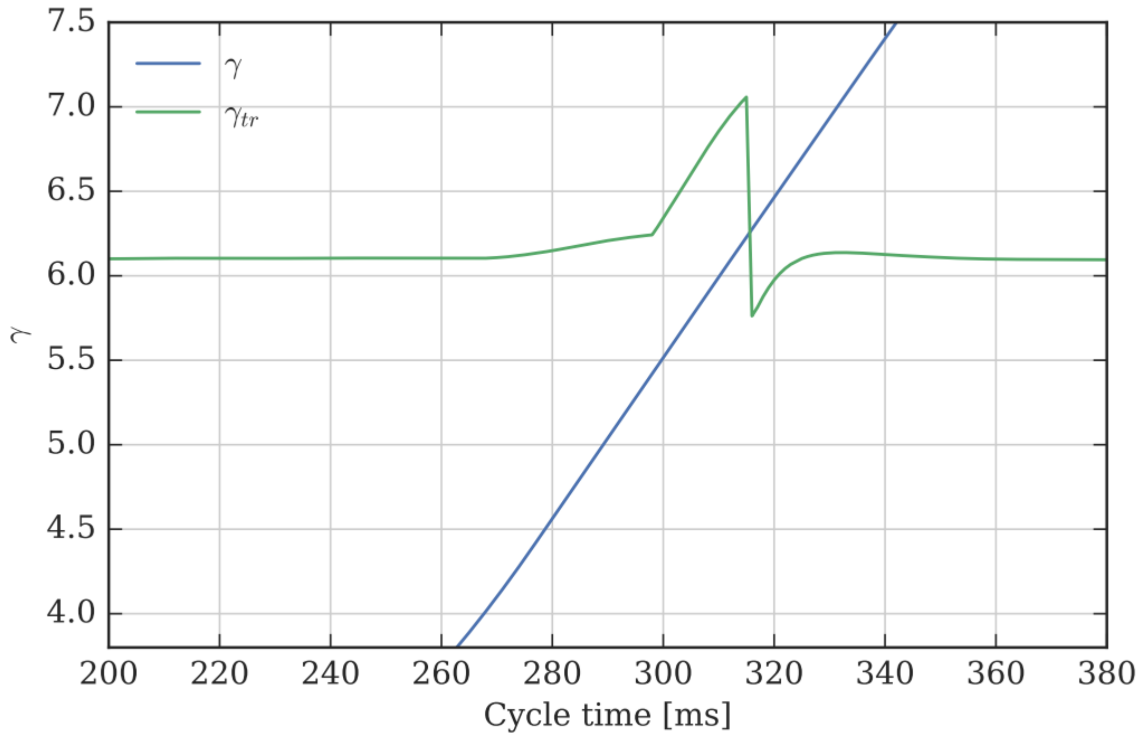
PS instability at transition for nTOF beam

E. Koukovini–Platia
HSC meeting, 5/2/18

Thanks to
S. Aumon, H. Bartosik, N. Biancacci, A. Huschauer, E. Métral, M. Migliorati, A. Oeftiger, S. Persichelli, G. Rumolo, M. Schenk, G. Sterbini, N. Wang

Introduction

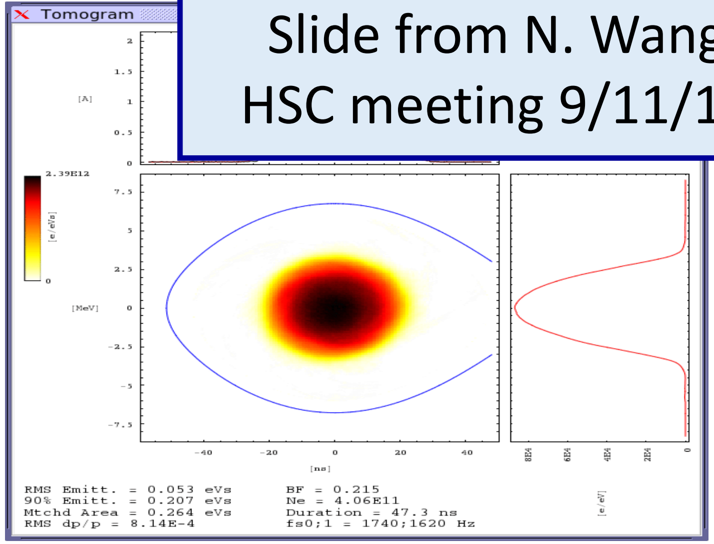
- While PS is crossing transition energy, a fast vertical instability occurs
- The instability threshold is raised by employing a γ-jump scheme

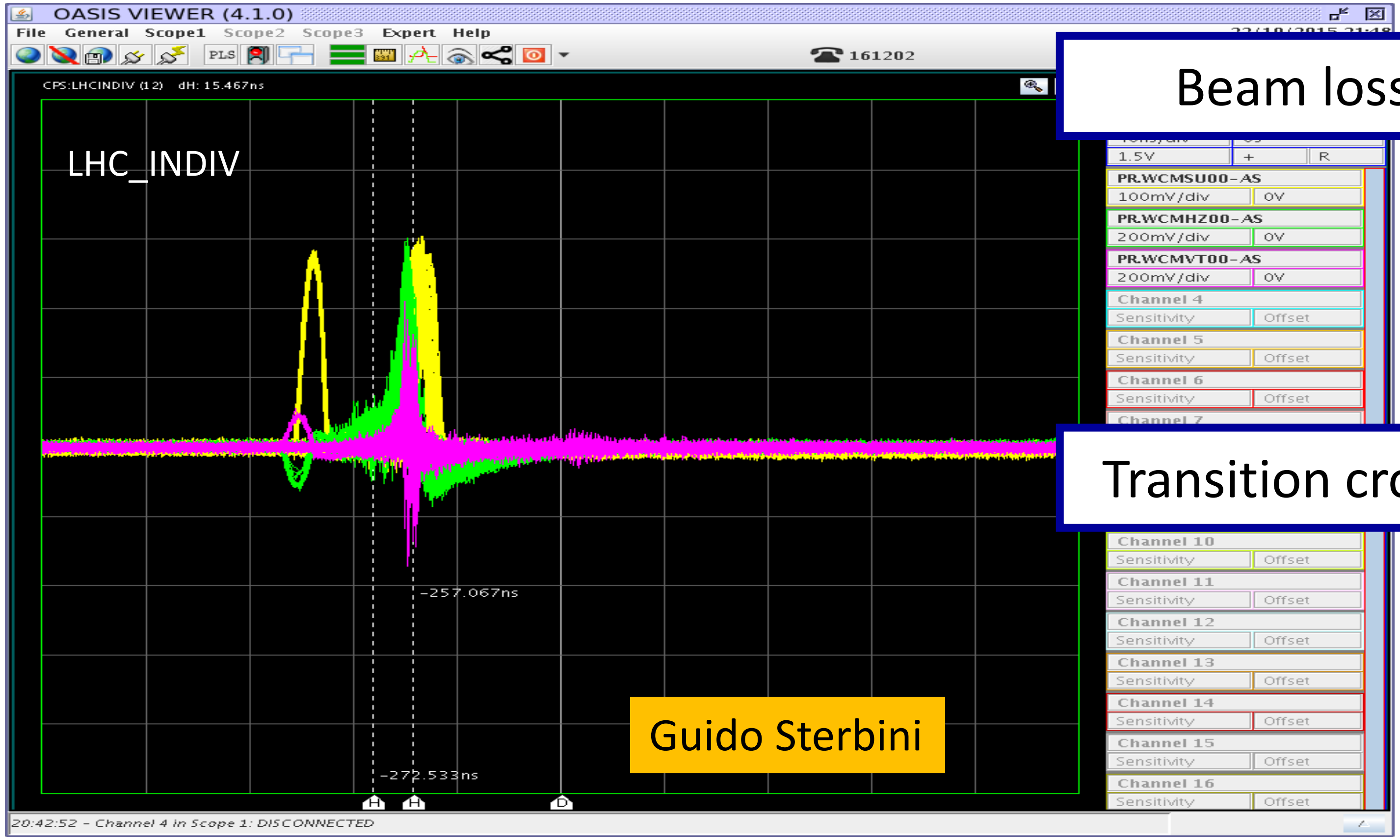


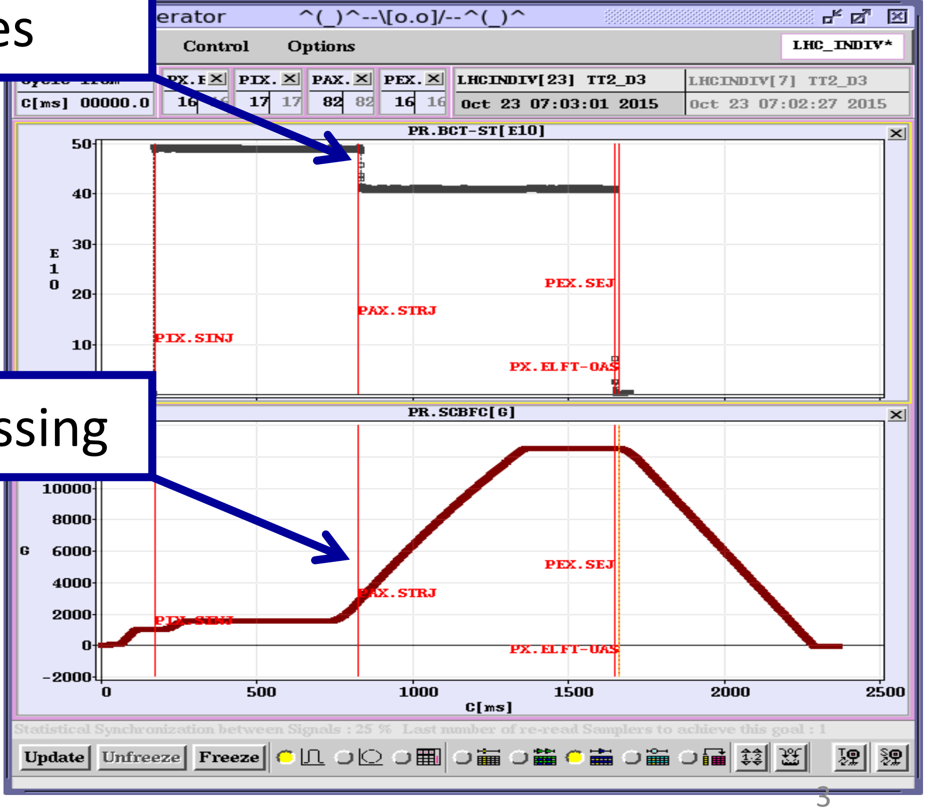
- Even though the threshold is significantly increased with the γ-jump (ex. nTOF: ~180 x 10^{10} ppb → ~800 x 10^{10} ppb), this instability poses an important intensity limitation in case experiments will request higher intensities

Slide from N. Wang
HSC meeting 9/11/15

- Instability observation with LHC-INDIV beam.
  - Beam intensity: 50E10
  - Longitudinal emittance: 0.264eVs
  - Fast vertical instability and beam losses are also observed near transition energy





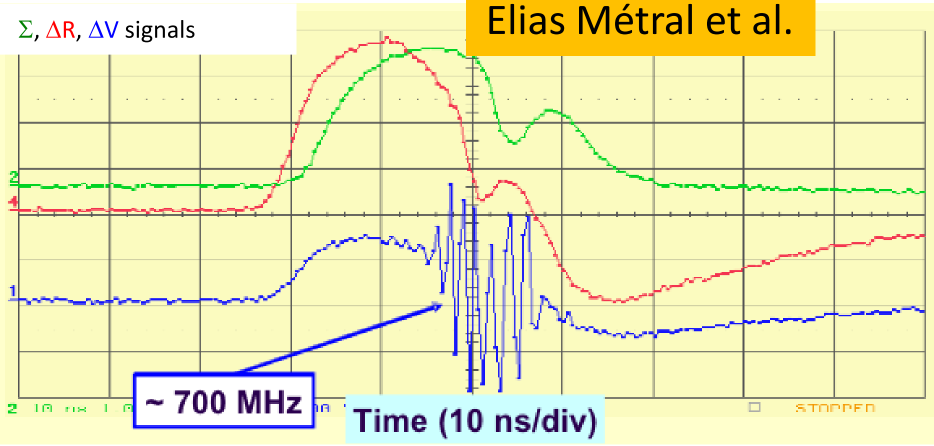


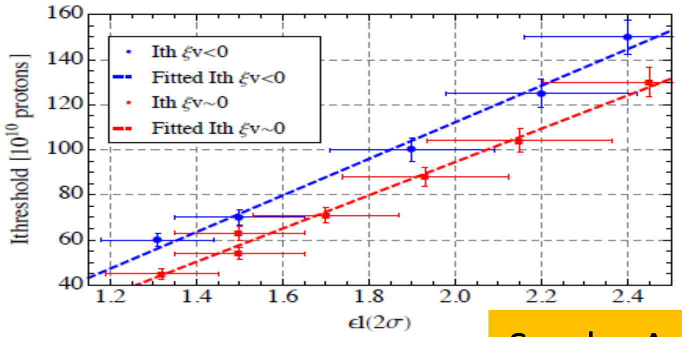
Overview of the vertical instability in PS at transition energy

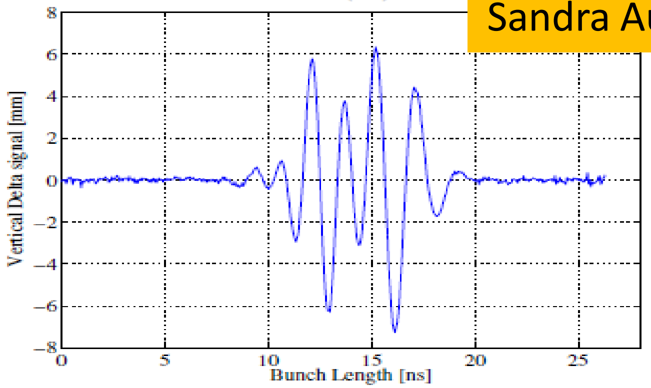
- In the PS, the beam has to cross the transition energy:
  - The synchrotron motion of the particles are frozen
  - The beam is particularly sensitive to perturbations, such as wakefield
- With increasing the beam intensity, a fast ... tical instability was observed near transition energy.
- Many studies have been done wi...
- The instability was re... with simple broadband impedance mod...
- A new i... ...able for instability simulation.

Refe...

Several colleagues were previously involved in the transition instability studies







[1] E. Métral and D. Mohl, Transition Crossing, CERN-2011-004
[2] S. Aumon, High Intensity Beam Issues in the CERN PS, CERN-THESIS-2012-261
[3] E. Metral, EFFECTS NEAR TRANSITION, CERN Topical CAS on High Intensity Limitations, 2015
[3] S. Persichelli et al., Summary of PS impedance studies, LIU-PS meeting, 2015

nTOF

Protons to nTOF - present:

- **6 - 7 x 10^{12} p^+ per pulse** (PS can deliver ~8.3 x 10^{12} p^+ per pulse)

Protons to nTOF - after LS2:

- Target exchange during LS2. Expected lifetime ~10 y
- Specifications of new lead target: 1.5 x 10^{13} p^+ per pulse
- **Experiments are interested in increasing intensity towards 10^{13} p^+ per pulse**
  - **A 20% increase in intensity is desired after LS2**

Intensity limiting factors in the PS

- **Fast transverse instability at transition crossing**
- For users that need short bunches on target:
  - RF power for bunch rotation before extraction
  - Losses at extraction septum (due to the large dp/p)

PS impedance model

```
elements = {
        'PE.BFA09P_Tsu':'kicker',
        'PE.BFA09S_Tsu':'kicker',
        'PE.BFA21P_Tsu':'kicker',
        'PE.BFA21S_Tsu':'kicker',
        'PE.KFA04_CST_2015_10GHz':'kicker',
        'PE.KFA13_CST_2015_10GHz':'kicker',
        'PE.KFA21_CST_2015_10GHz':'kicker',
        'PE.KFA71_CST_2015_10GHz':'kicker',
        'PE.KFA79_CST_2015_10GHz’':'kicker',
        'PI.KFA28_CST_2015_10GHz’':'kicker',
        'PI.KFA45_CST_2015_10GHz':'kicker',

        'PR.C80.08':'cavities',
        'PR.C80.88':'cavities',
        'PR.C40.77':'cavities',
        'PR.C10.11':'cavities',
        'PR.C10.36':'cavities',
        'PR.C10.46':'cavities',
        'PR.C10.51':'cavities',
        'PR.C10.56':'cavities',
        'PR.C10.66':'cavities',
        'PR.C10.76':'cavities',
        'PR.C10.81':'cavities',
        'PR.C10.86':'cavities',
        'PR.C10.91':'cavities',
        'PR.C10.96':'cavities',

        'PE.SMH16':'others',
        'PR.CWB02':'others',
        'PR.BQL72':'others',

        'rewall_InconelX750':'rewall',
        'rewall_ss316LN':'rewall',
        'Vacuum_ports_10GHz':'vacuum ports',
        'Elliptic_bellows10GHz':'bellows',
        'Valves_10GHz':'valves',
        'Metallic_flange_195':'flanges',
        'Metallic_flange_159':'flanges',
        'Metallic_flange_SPS273':'flanges',
        'Metallic_flange_250':'flanges',
        'Step_10GHz':'steps',
}
```

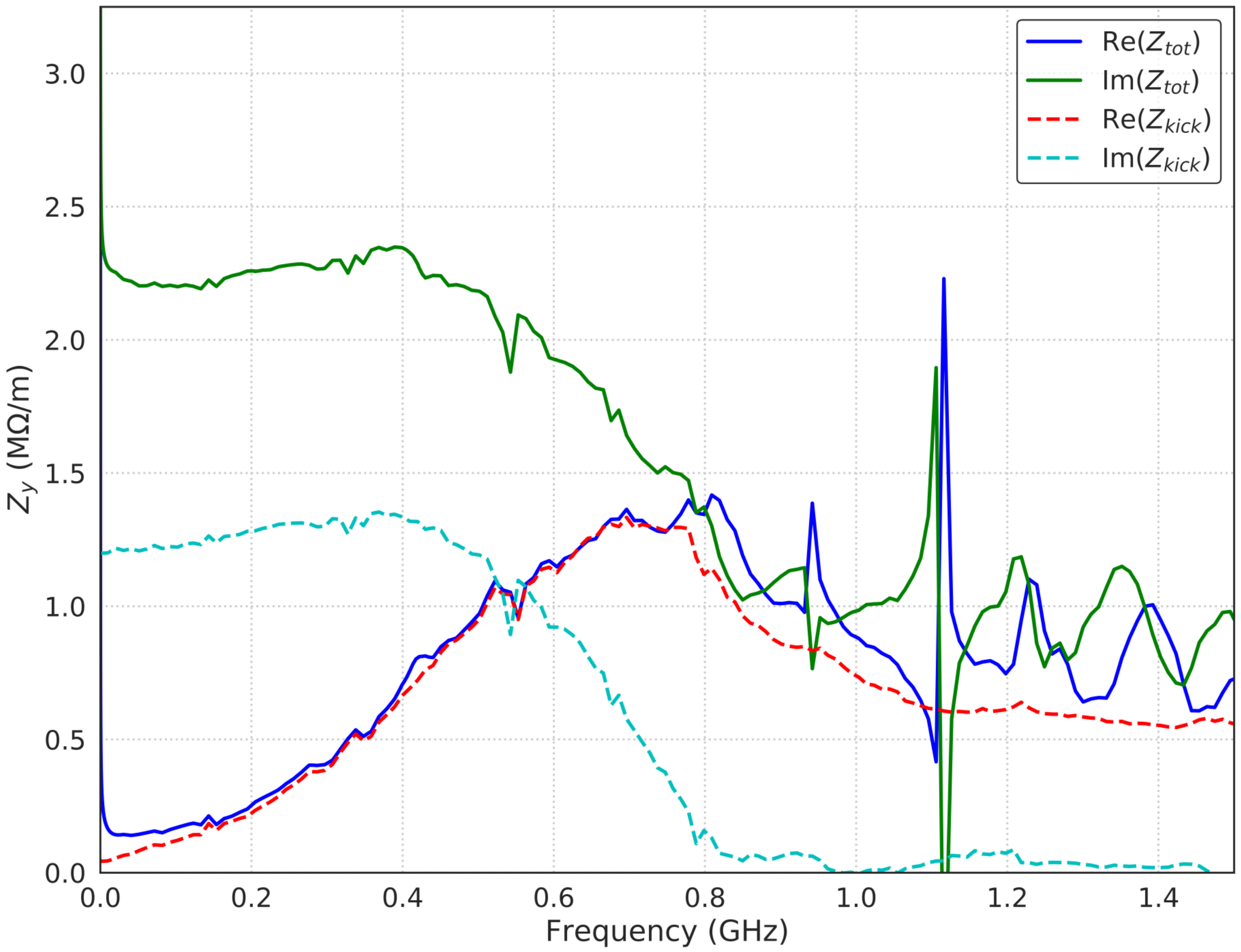
PS impedance model

- resistive wall (35 mm vertical half gap)
- kickers
- cavities
- vacuum ports
- bellows
- flanges
- steps

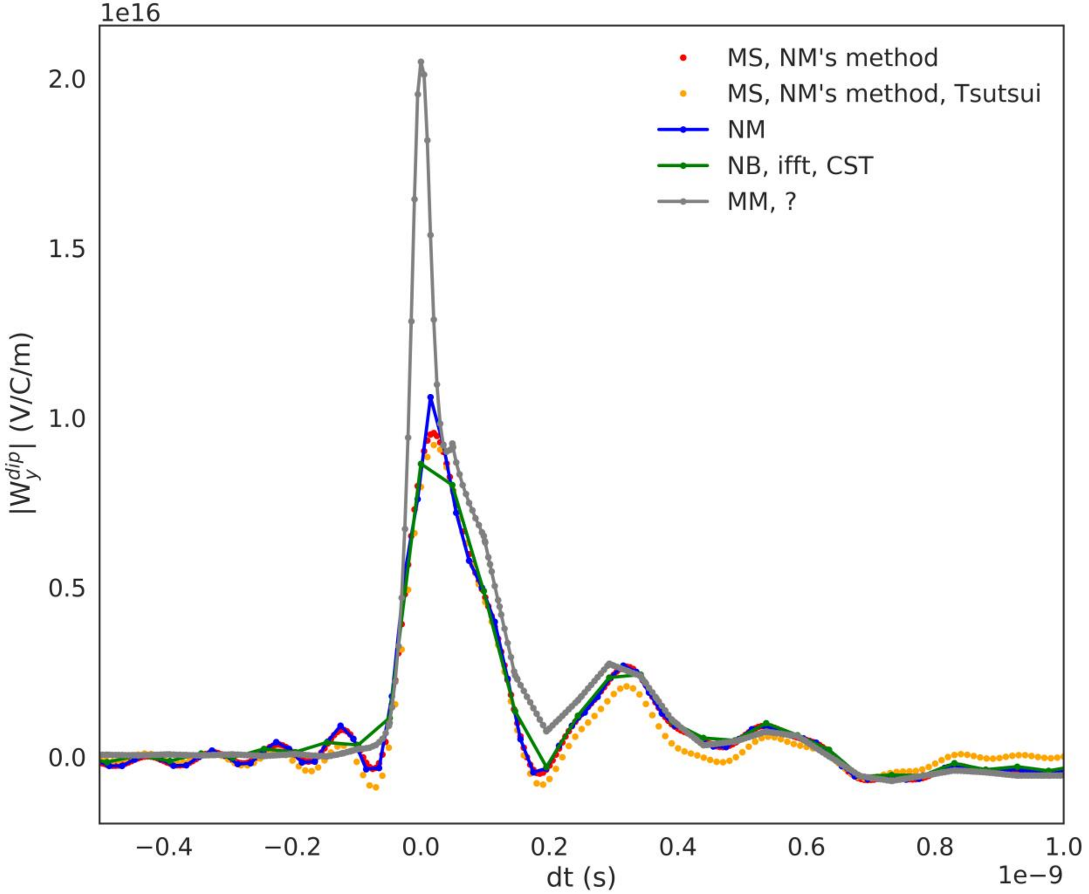
S. Persichelli, E. Mètral, N. Biancacci, B. Salvant: https://impedance.web.cern.ch/impedance/

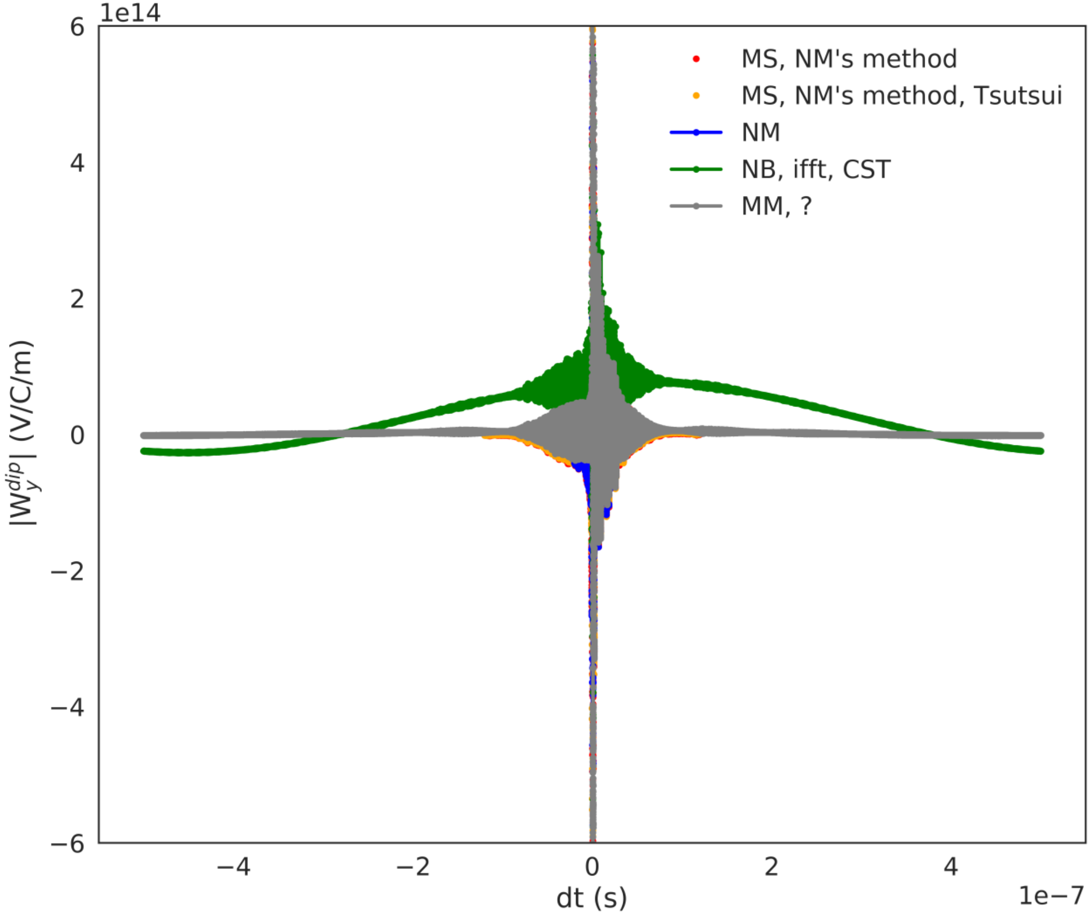
Total vertical PS impedance model

- Some previous studies used a broadband resonator to fit the kickers' impedance
- We are using the full impedance model (shown in the plot)



Some issues: which wake for PyHEADTAIL simulations

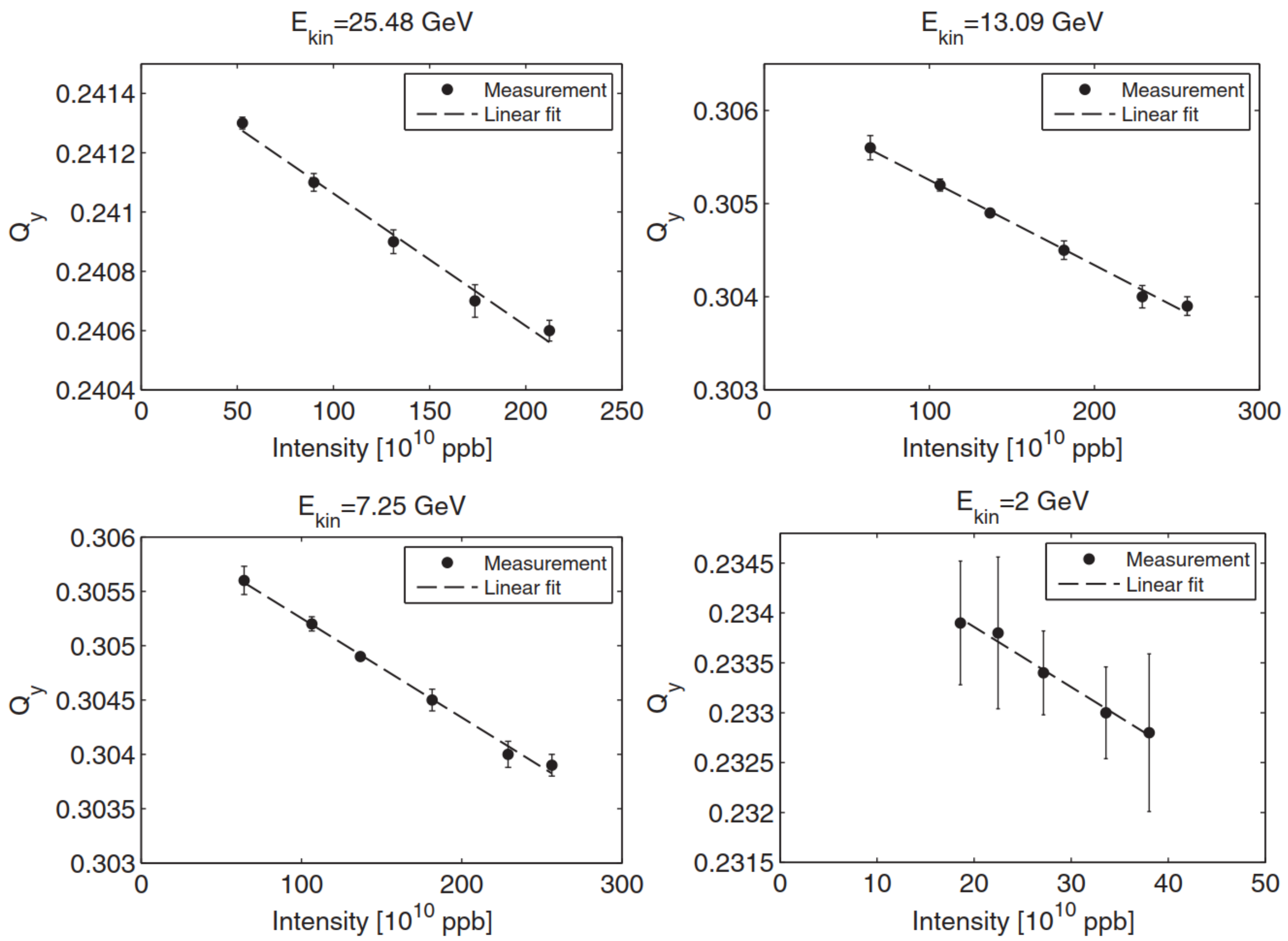




- Some differences on the impedance model used before and now
- Some differences depending on the method to obtain the wake
- I use the wake obtained with N. Mounet’s method

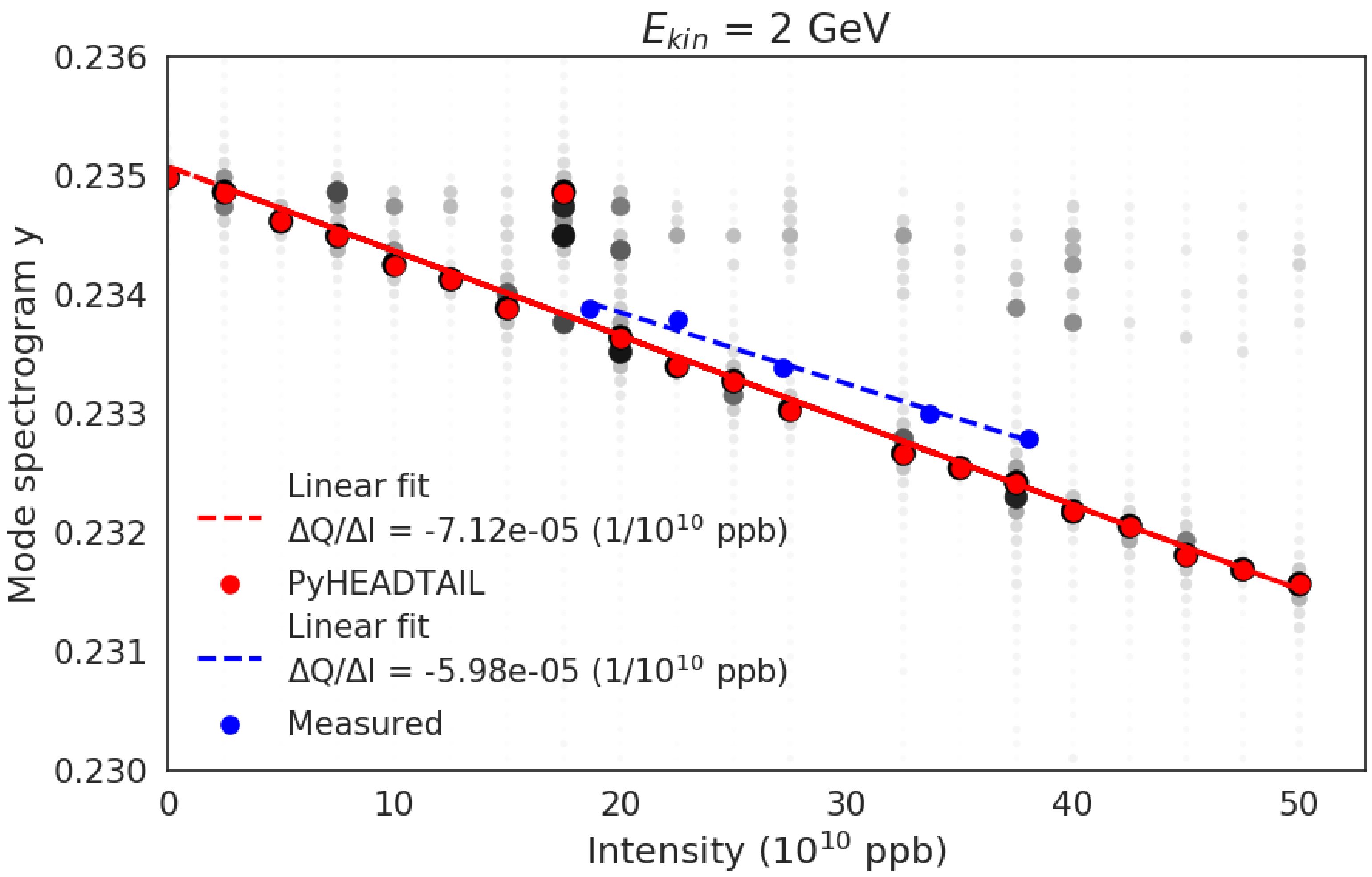
Benchmark of PS impedance model: Comparison of measured and simulated tune shift

Measured tune shifts with zero chromaticity at flat top for a TOF-like beam



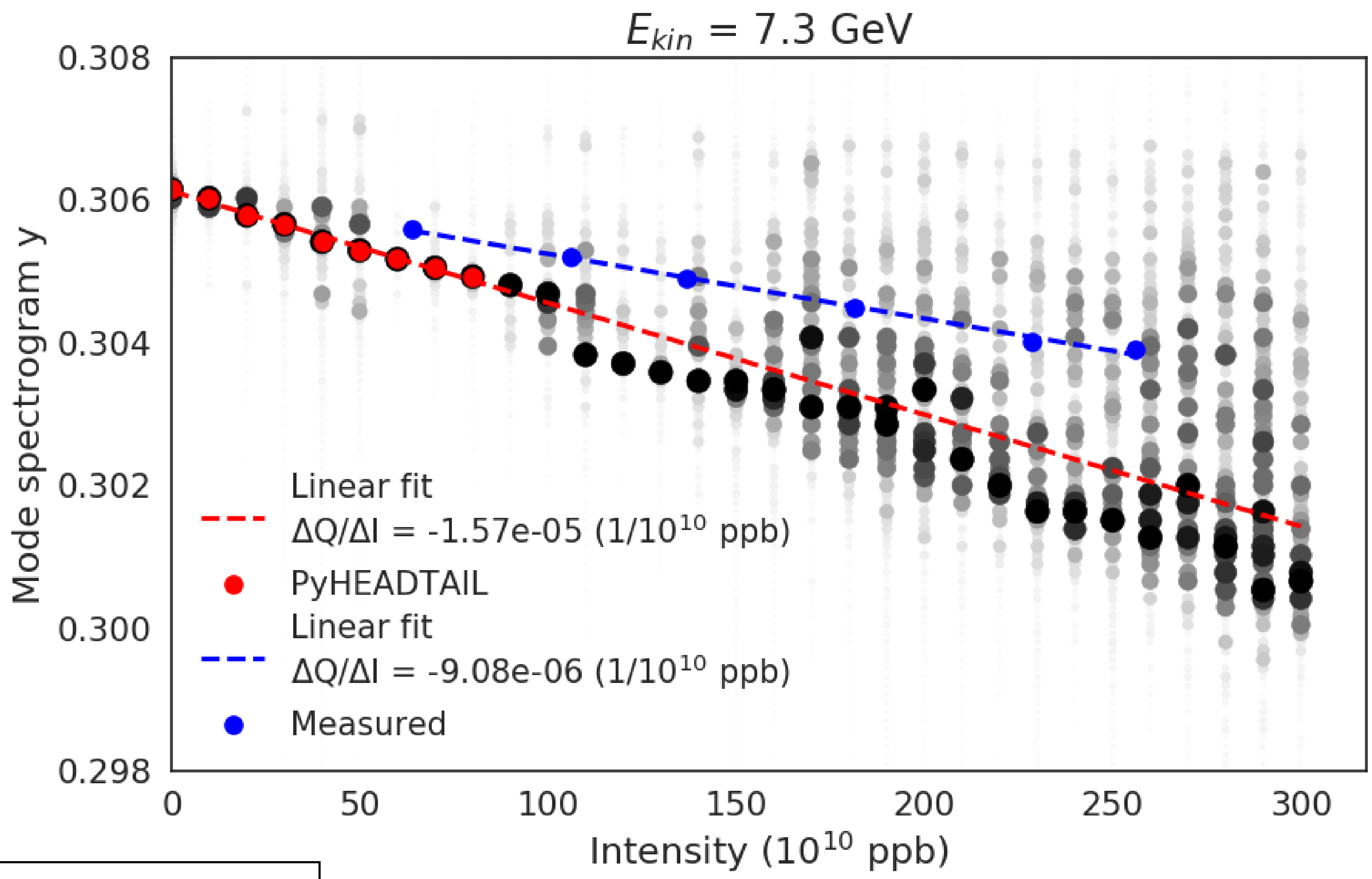
S. Persichelli et al. PRAB 19, 041001

E_{kin} = 2 GeV: PyHEADTAIL vs. measurements



17% difference in the slopes

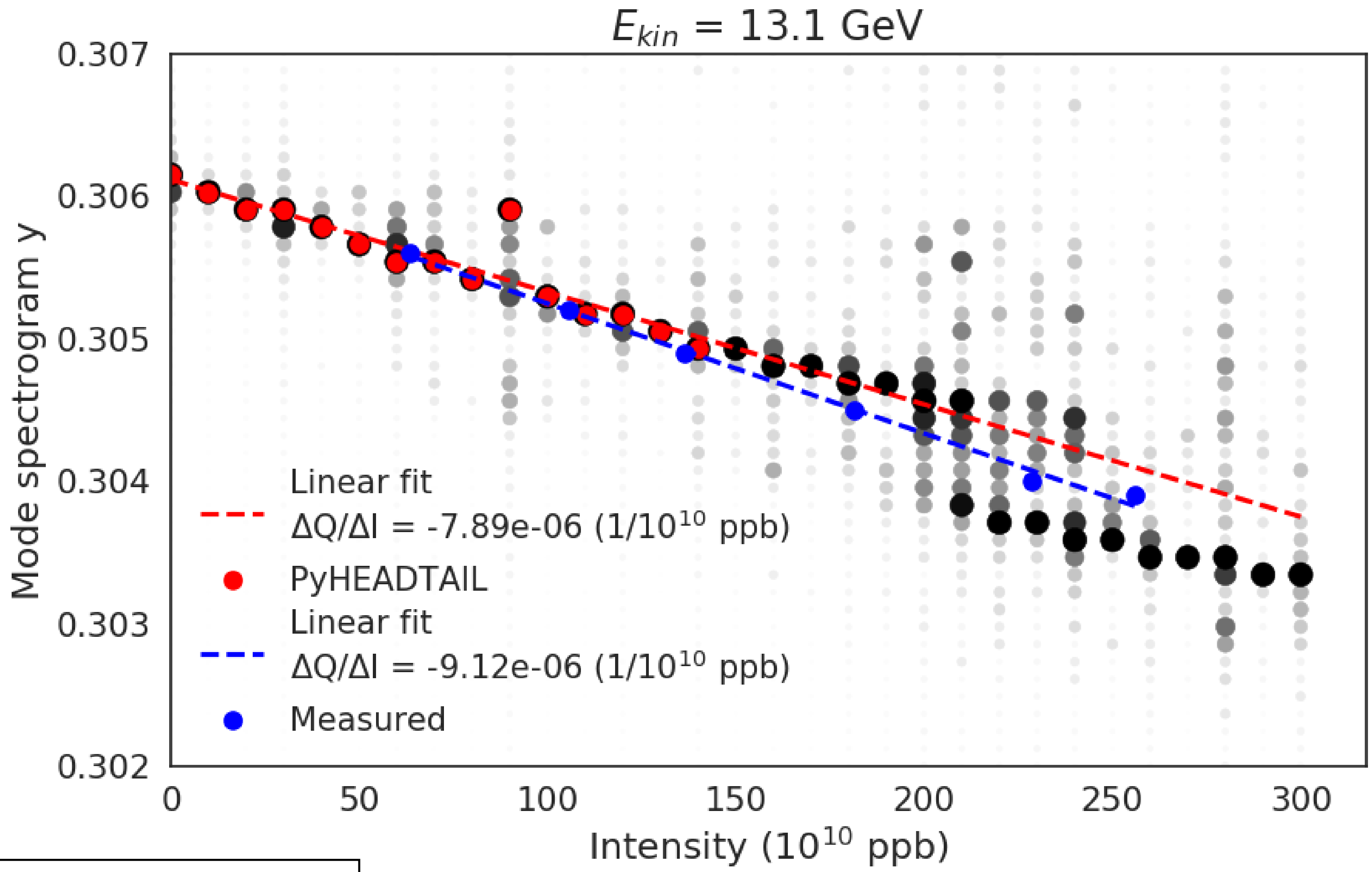
E_{kin} = 7.3 GeV: PyHEADTAIL vs. measurements



*M.M.: some doubts on the validity of these measurements. To be repeated in 2018.

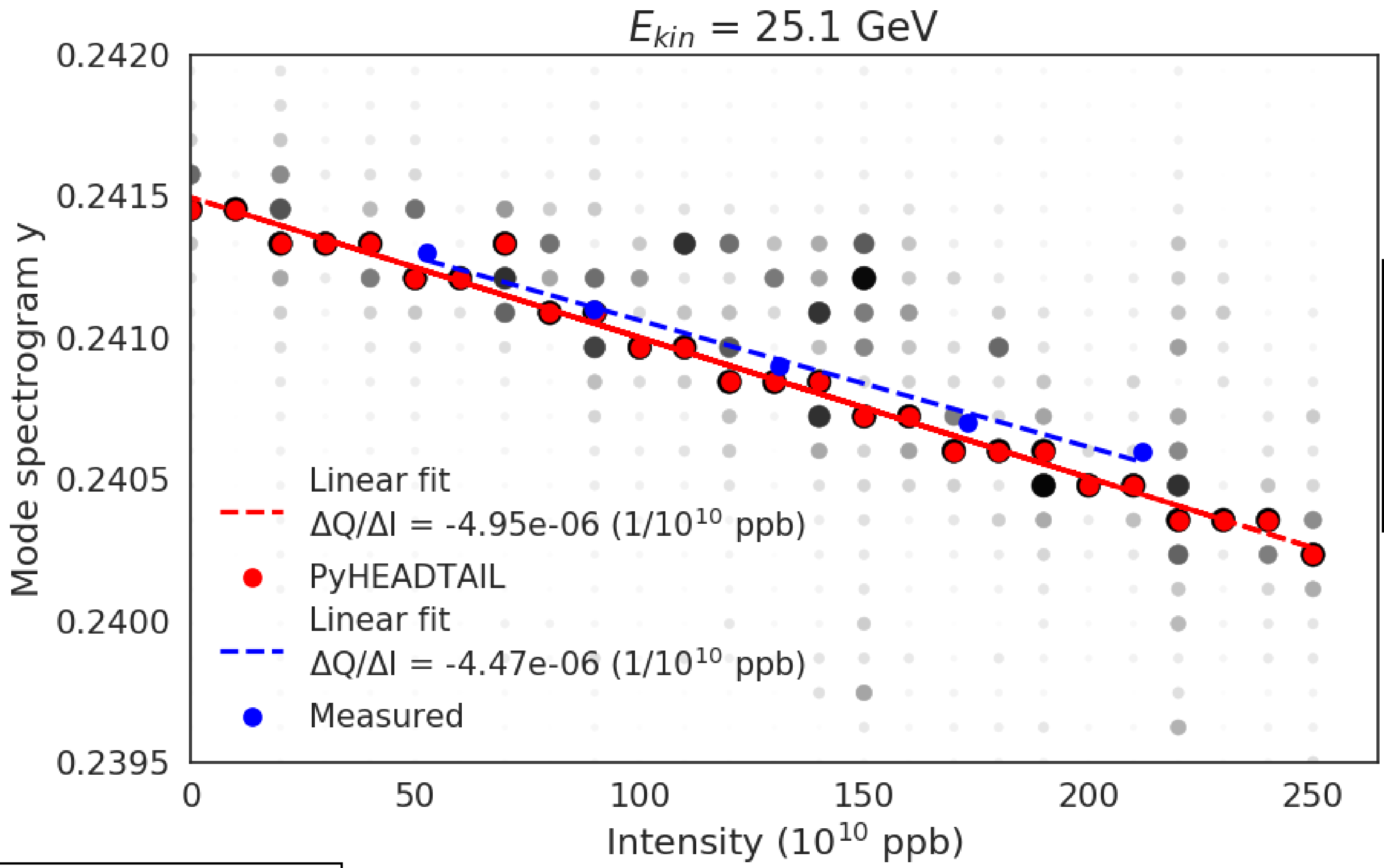
53% difference in the slopes

E_{kin} = 13 GeV: PyHEADTAIL vs. measurements



14% difference in the slopes

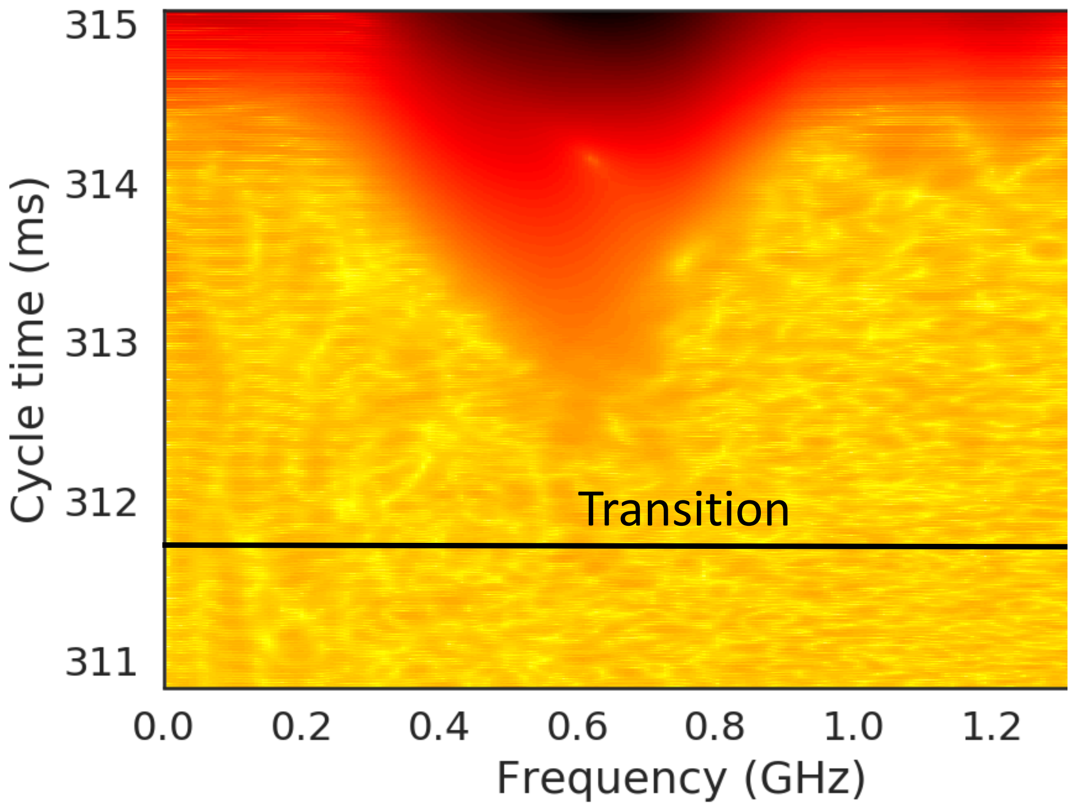
E_{kin} = 25 GeV: PyHEADTAIL vs. measurements

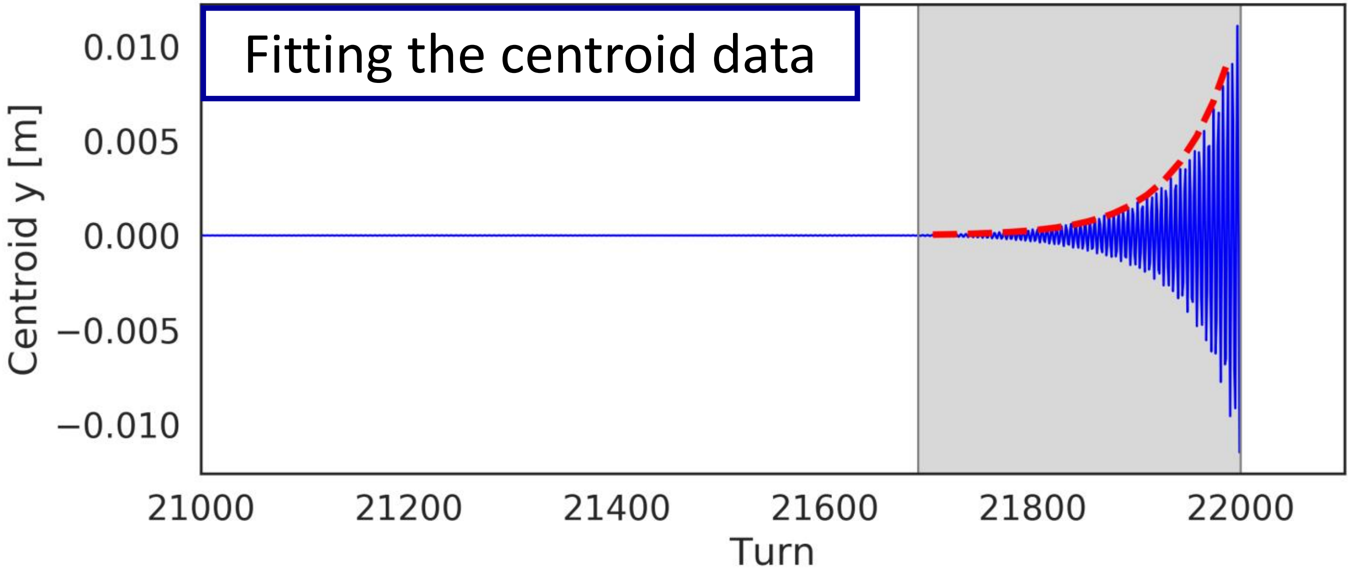


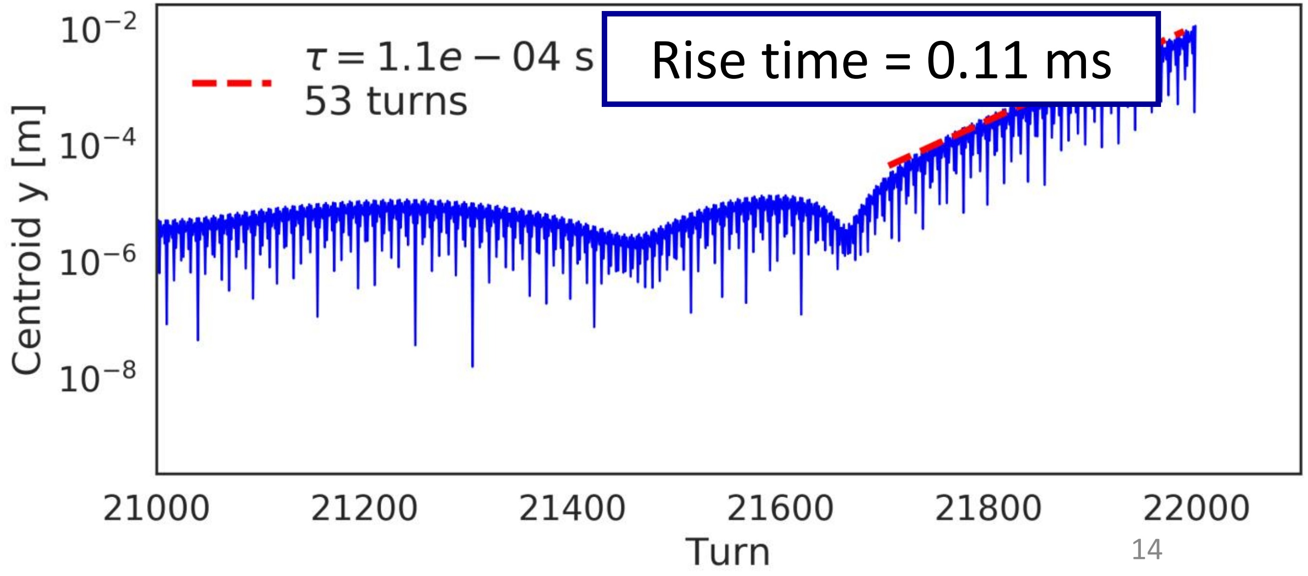
Satisfactory agreement between PyHEADTAIL and measurements in most cases

10% difference in the slopes

PyHEADTAIL simulation
I = 1.4 x 10^{12}, ε_z = 2.25 eVs





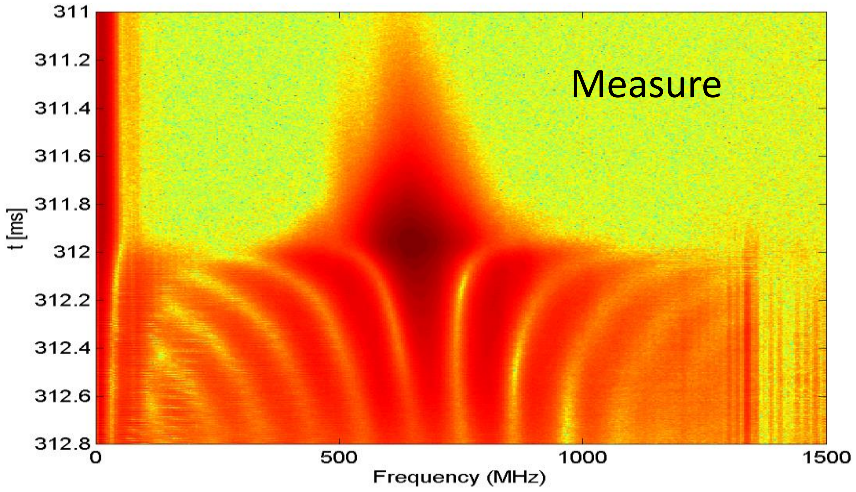


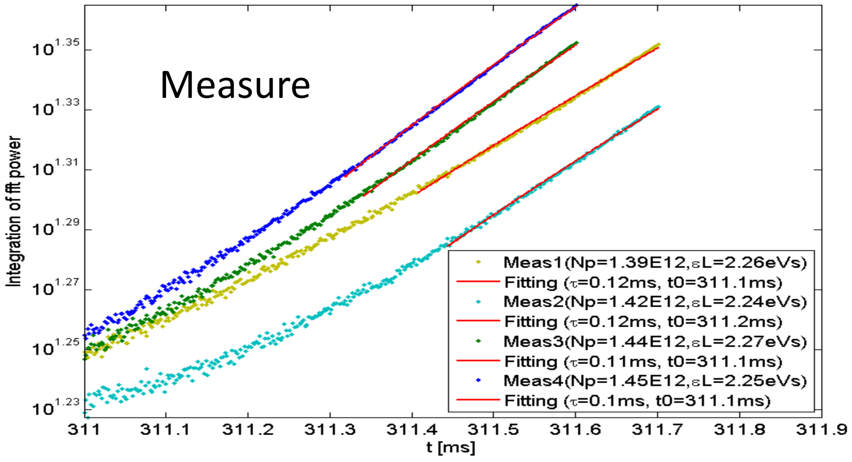
Instability is stronger at ~600-700 MHz

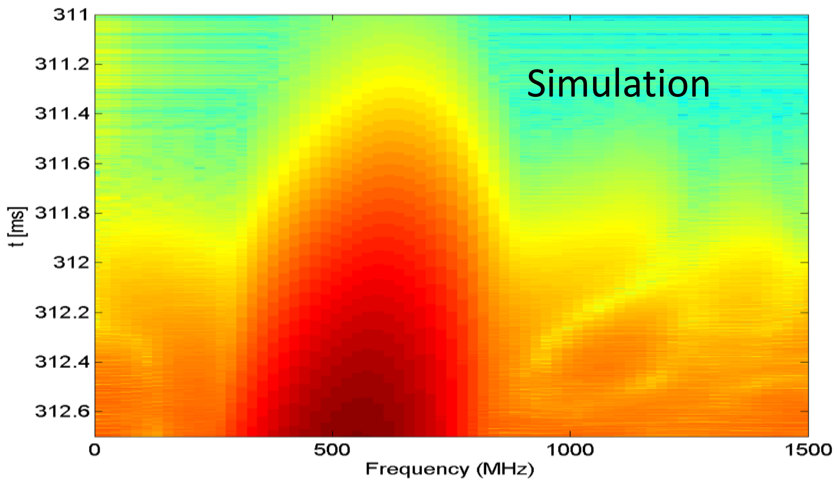
Previous studies

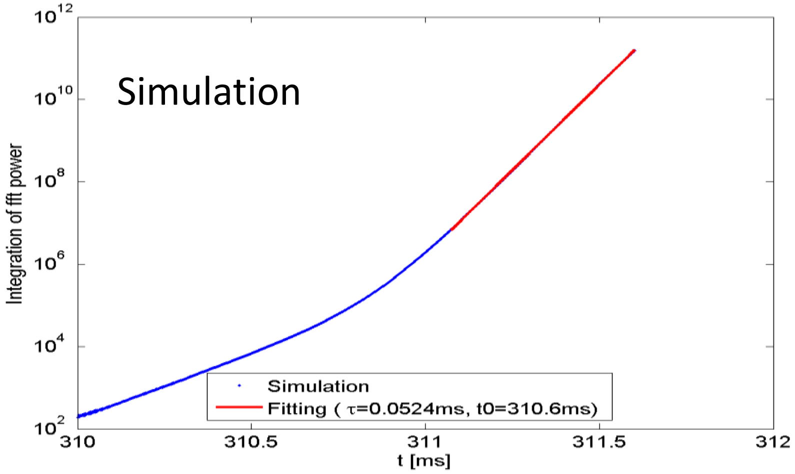
- Np=1.4E12, εL=2.25eVs
- **Measurement**
  - fr: ~600-700 MHz
  - **growth time 0.1-0.12 ms**
- **Simulation**
  - fr: 600~700MHz
  - **growth time 0.05ms**

The integration of fft spectral **power** was used
(leads to factor 2 faster rise time compared to fit of centroid)





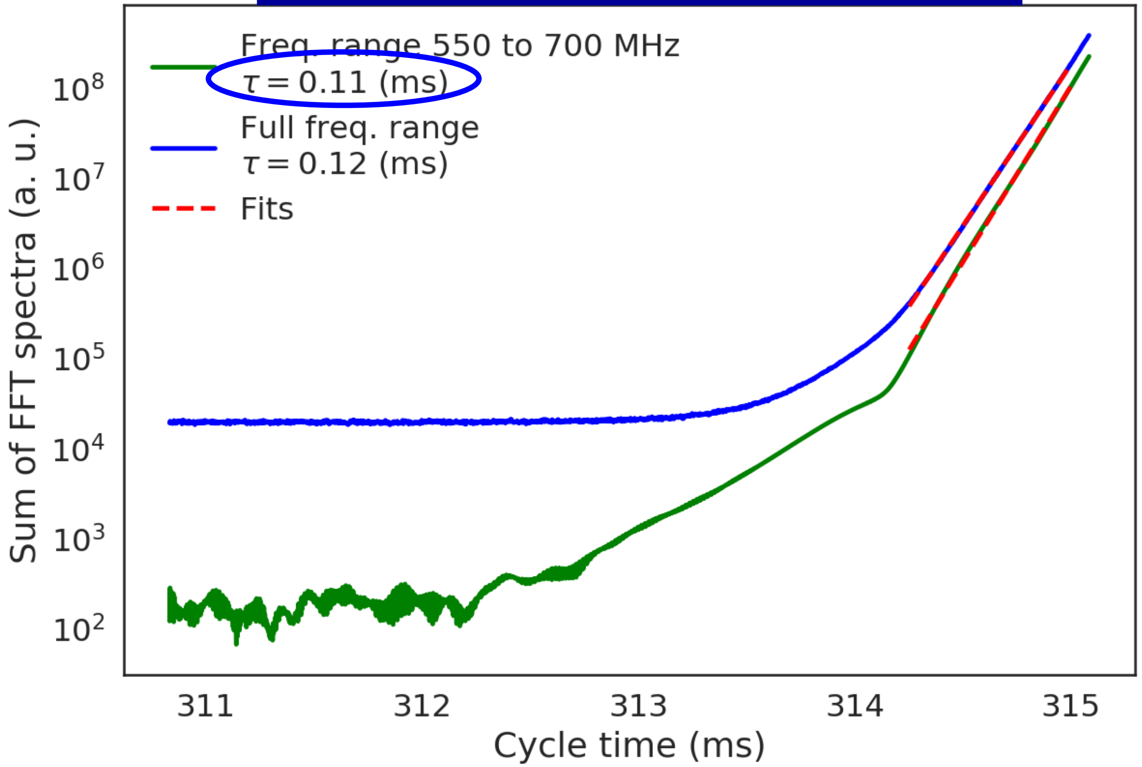




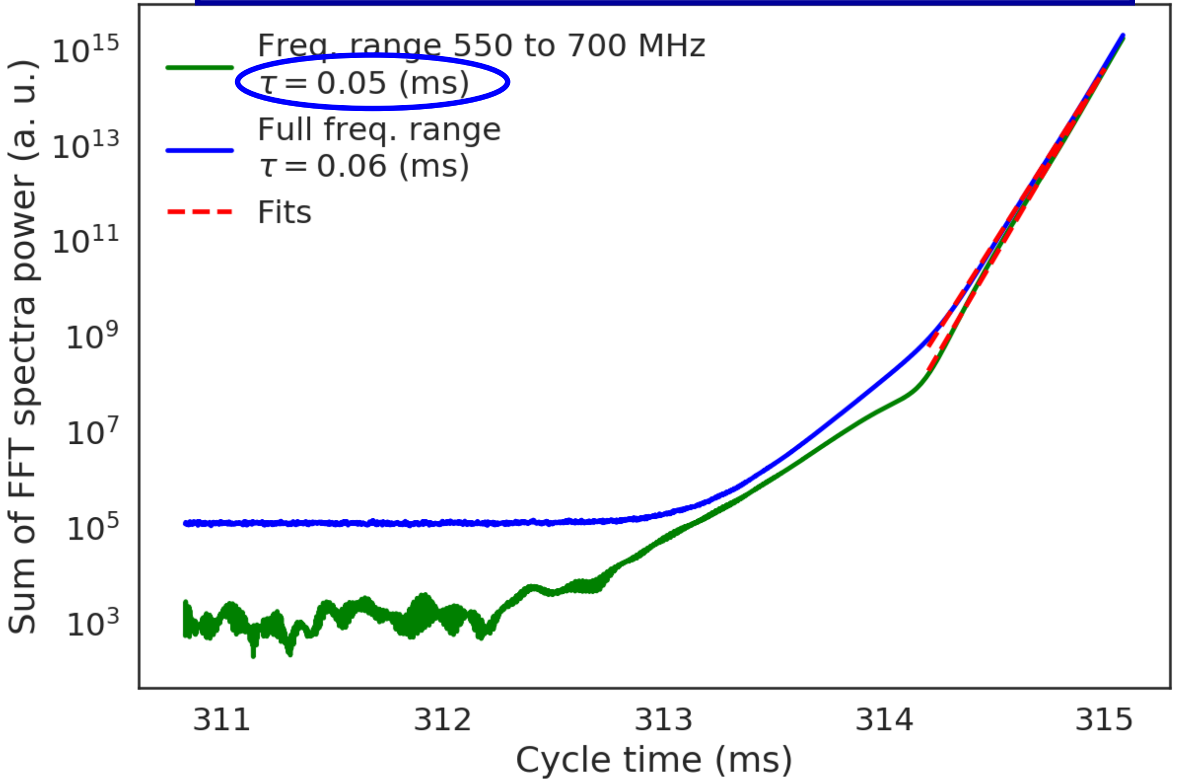
Slide from N. Wang
HSC meeting 9/11/15

PyHEADTAIL simulation
$I = 1.4 \times 10^{12}$, ε_z = 2.25 eVs

Fitting the FFT spectra
(same rise time as when fitting centroid)



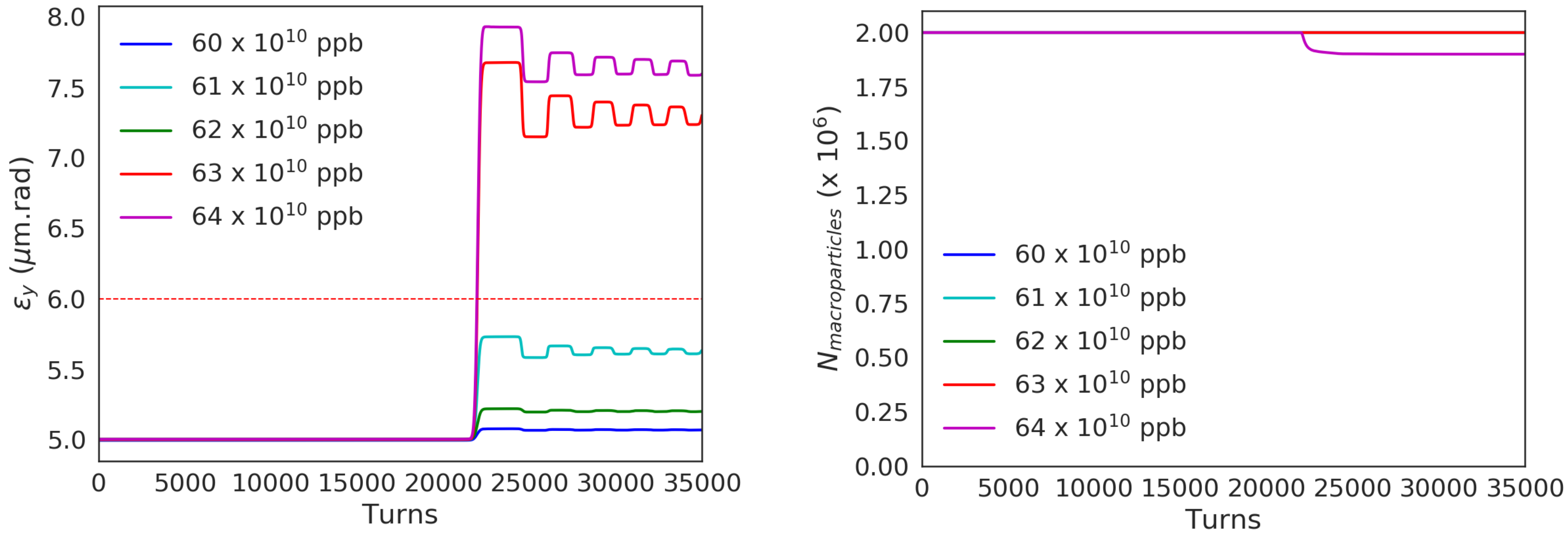
Fitting the FFT spectra power
(as expected leads to factor 2 faster rise time)



Action: look at experimental data from the past and make sure we are comparing the same things

Predicted threshold with PyHEADTAIL
N_p = 2 x 10^6, $\varepsilon_{z,rms}$ = 0.44 eVs

- Simulations include a physical vertical aperture

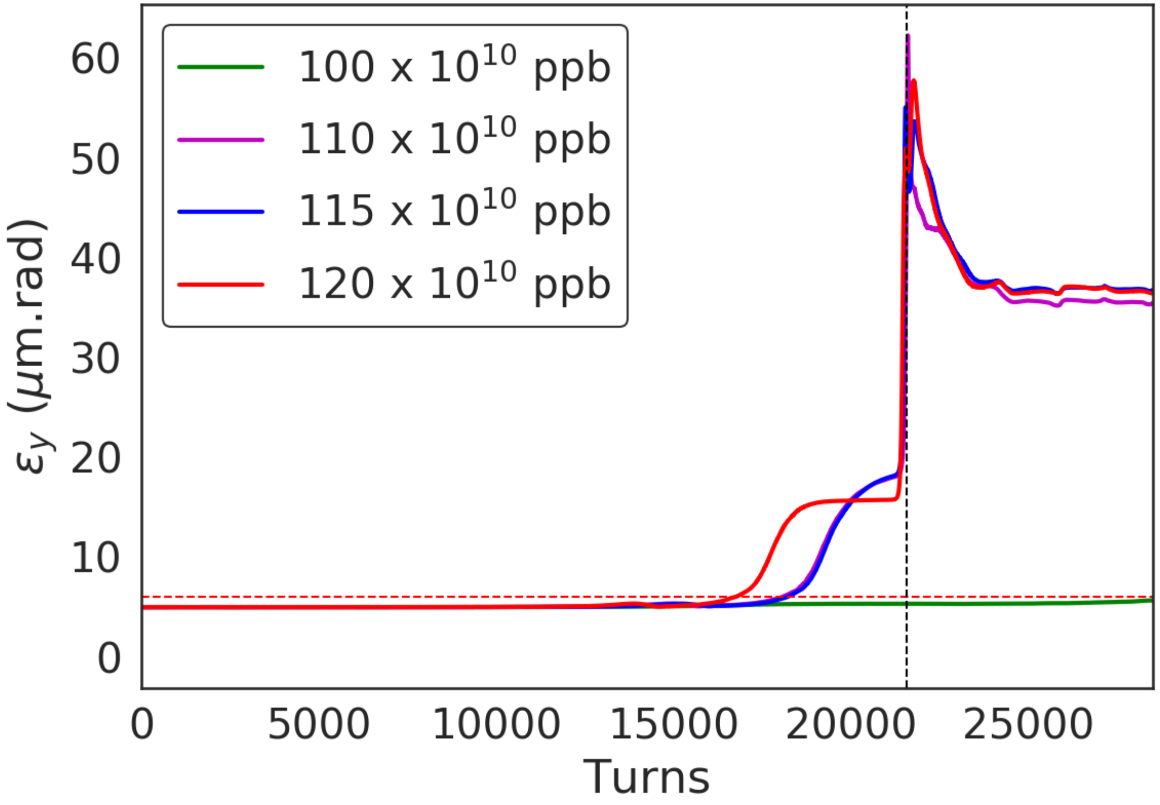


Criterion: 20% emittance increase (red dashed line) resp. particle losses due to aperture of 35 mm.
Simulated threshold is ~**63-64 x 10^{10} ppb** (measured is ~180 x 10^{10} ppb)

Which stabilizing mechanism(s) is missing in the simulations?

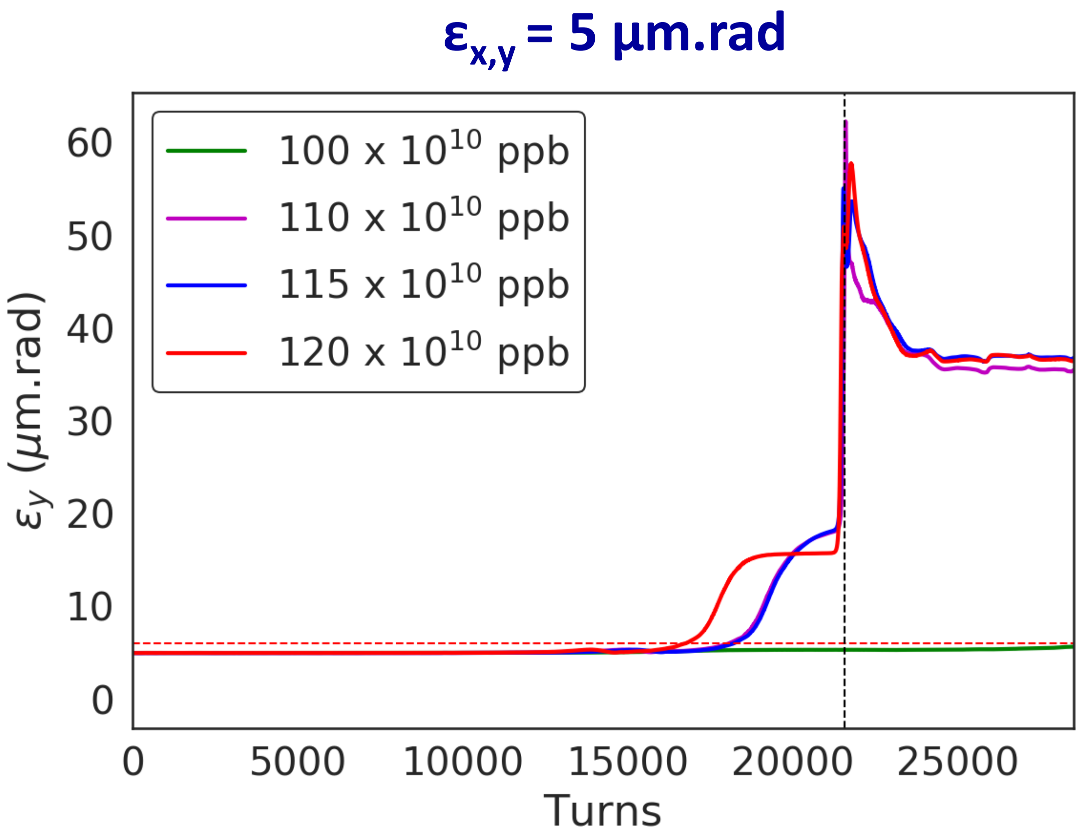
Predicted threshold with PyHEADTAIL including PIC space charge module (2.5D)

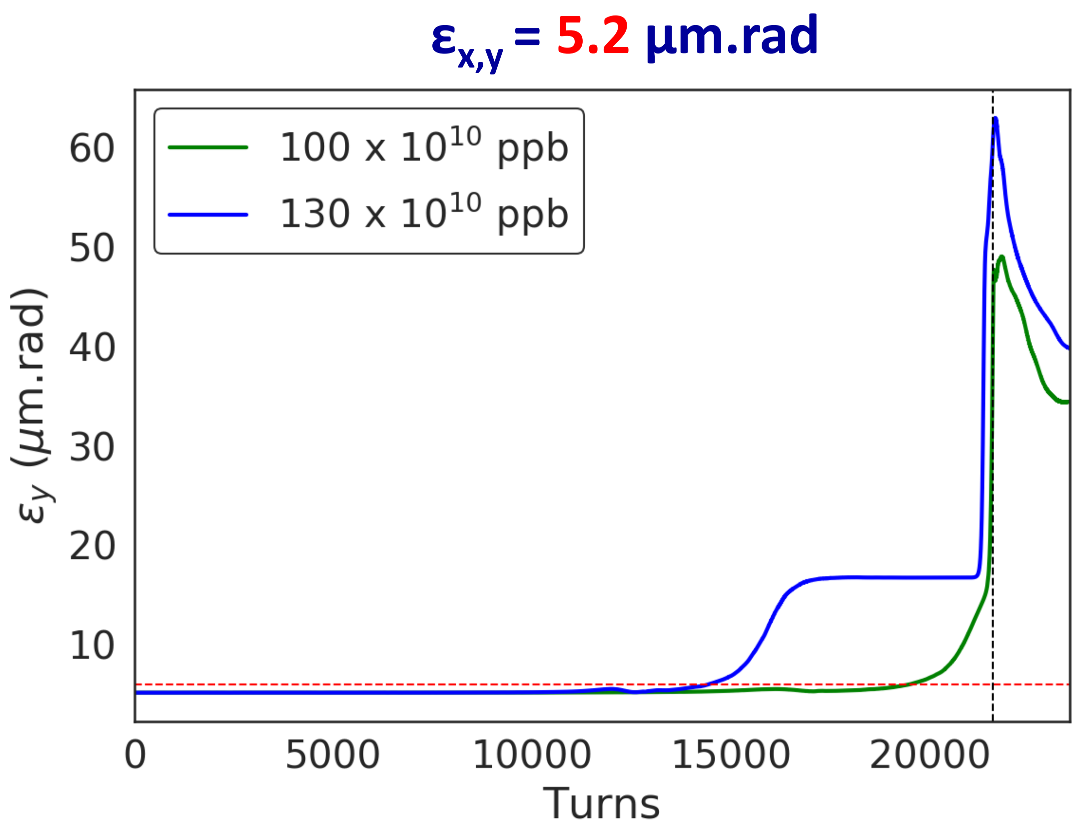
- $\varepsilon_{z,rms}$ = 0.44 eVs, $\varepsilon_{x,y}$ = 5 µm.rad, 2 x 10^6 macroparticles and (64,64,32) space charge grid
- Using the LIU-PS computer with 4 GPUs



- Simulated threshold is increased to ~105-110 x 10^{10} ppb
- Still there is something missing to explain the measured threshold of ~180 x 10^{10} ppb
- How sensitive is the threshold on the transverse emittance?

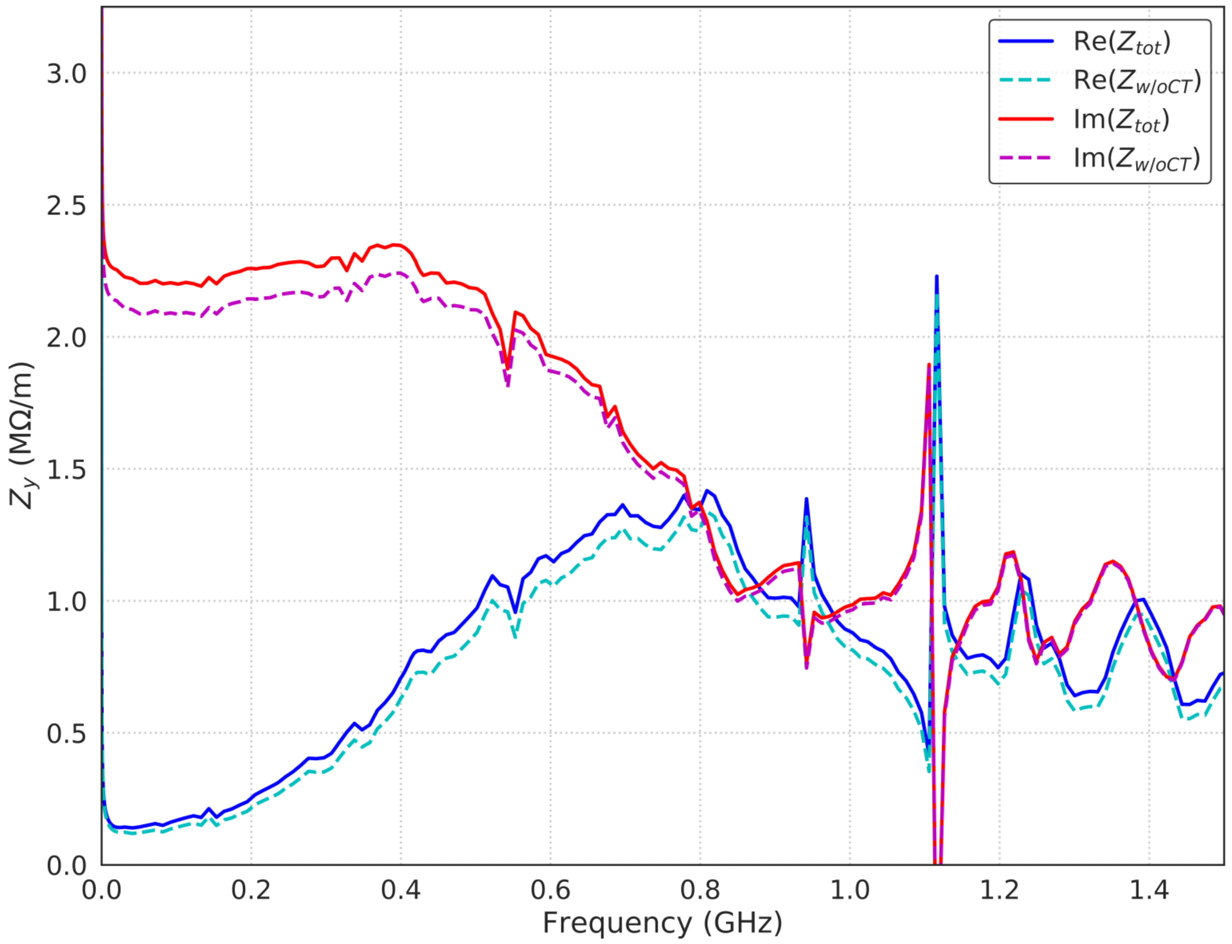
Predicted threshold with PyHEADTAIL including PIC space charge module (2.5D)





- A slightly larger transverse emittance weakens the stabilizing effect of space charge (now with 100 x 10^{10} ppb the beam is unstable)
- Running now on the GPUs: transverse emittance of 4.8 μm.rad

Threshold prediction without CT equipment

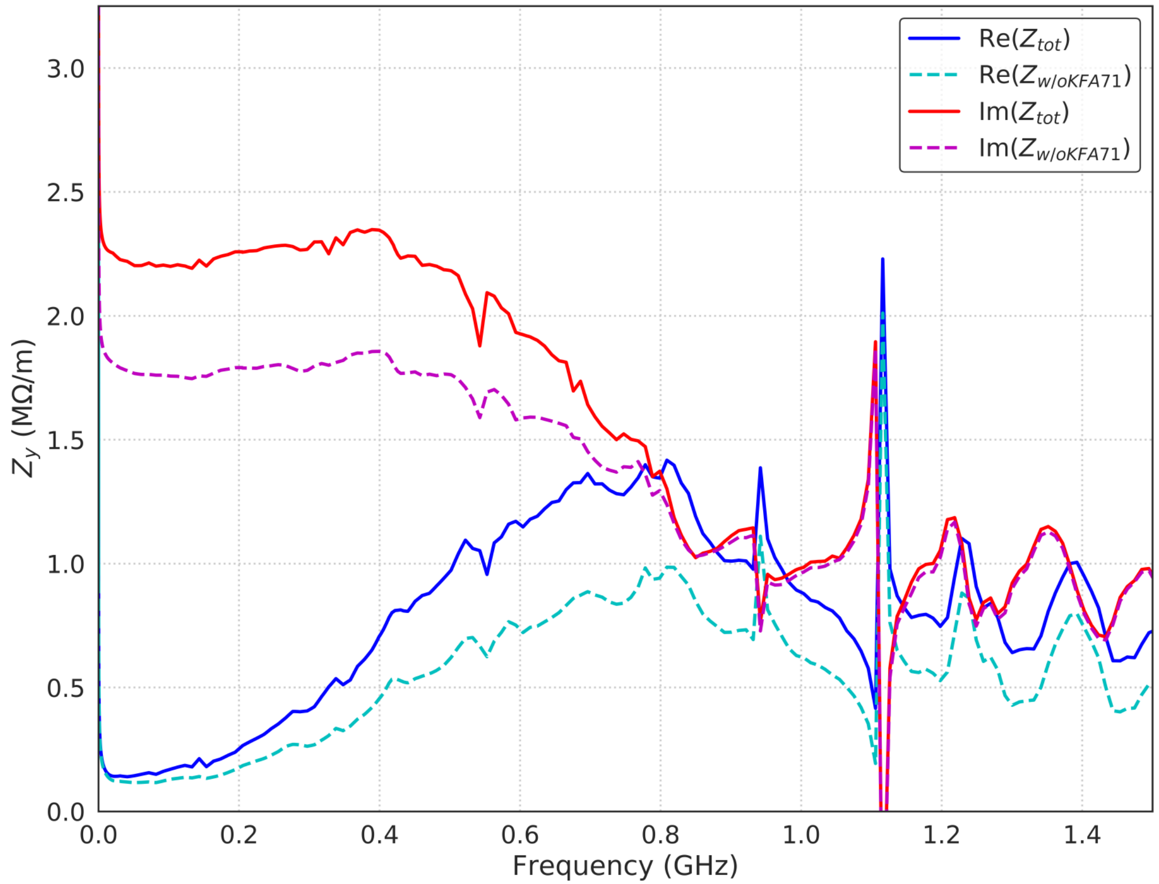


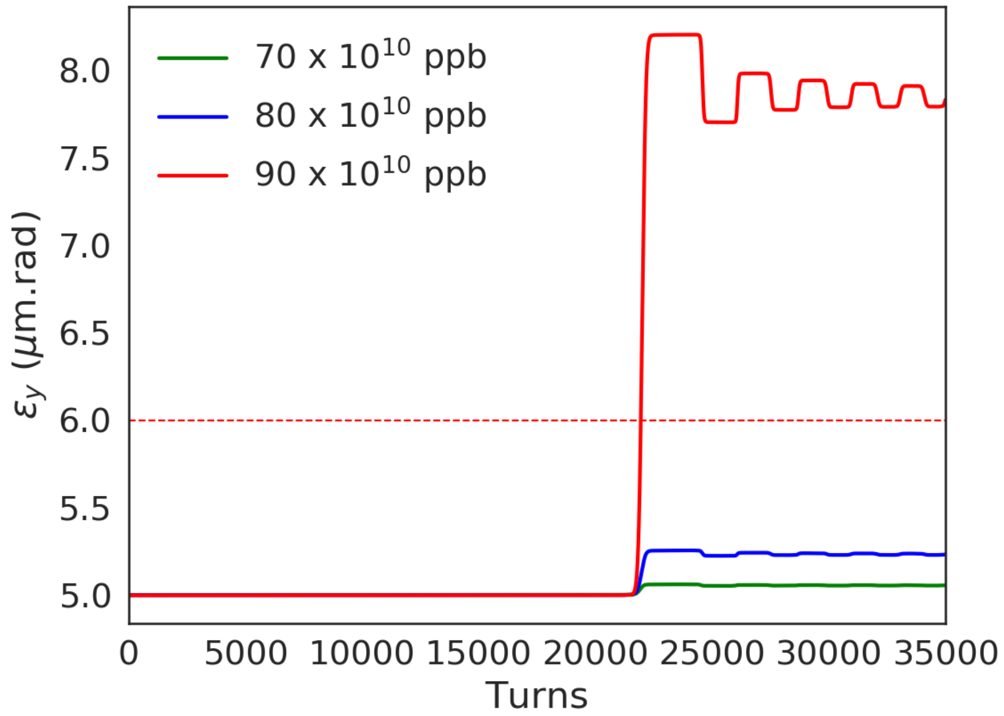
Obsolete equipment that was used for the Continuous Transfer (CT) extraction was decided to be removed during LS2.

Threshold ~64 x 10^{10} ppb after removing it. Not expected to raise the instability threshold in a noticeable way.

Impedance contribution of KFA71 kicker

- Remove the KFA71 extraction kicker from the impedance model and investigate its contribution to the instability threshold





Threshold increases from 63 x 10^{10} ppb to ~90 x 10^{10} ppb. Reduce the vertical impedance of the kicker?

Summary (1/2)

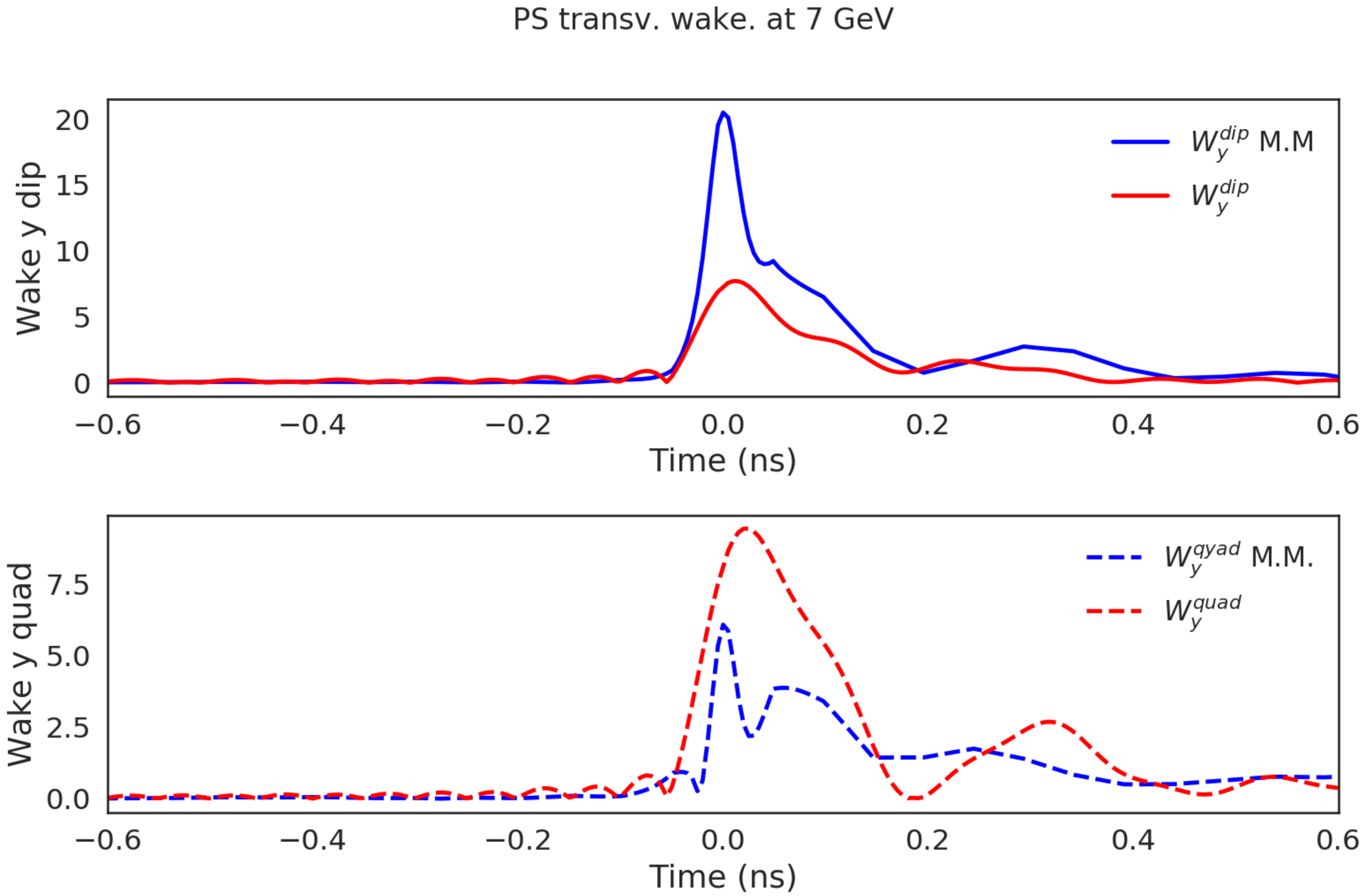
- Repeating the steps from scratch (which impedance model, how to obtain the wake function, building the analysis scripts etc.), it was possible to simulate and reproduce the characteristics of the transition instability in terms of frequency
- Some differences with previous studies found
  - Wake difference is attributed to the slightly different impedance model and also the method used to obtain the wake from the impedance
  - The wake used now follows N. Mounet's method and uses the full PS impedance model and wherever available uses the impedances from CST computations rather than Tsutsui model
  - For the rise time prediction, older experimental data will be checked to ensure that the fits are done according to the same method
- The effect of transverse space charge on the predicted threshold was studied using a 2.5D PIC module in PyHEADTAIL
- Transverse space charge helped to increase the predicted threshold by almost a factor 2
- Still there is a discrepancy between measured and predicted threshold
  - Study of threshold sensitivity on the transverse emittance is underway
  - What is the effect of the longitudinal space charge? Not included at the moment
  - Effect of slightly positive chromaticity

Summary (2/2)

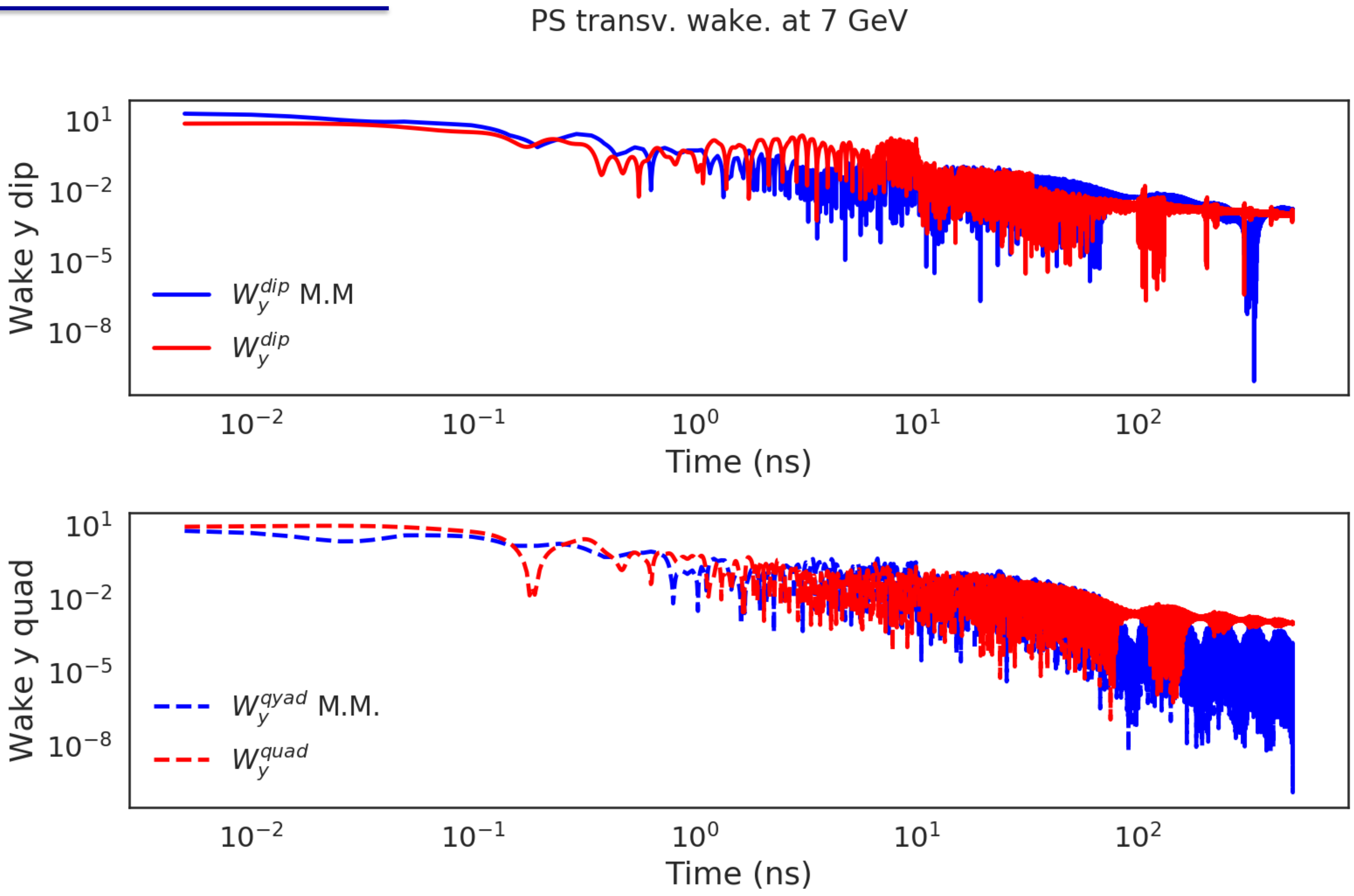
- The effect of the CT equipment on the threshold was studied and was found to be negligible
- On the other hand, reducing the impedance of the PS kickers would help significantly to raise the threshold

Backup slides

PS wakes comparison

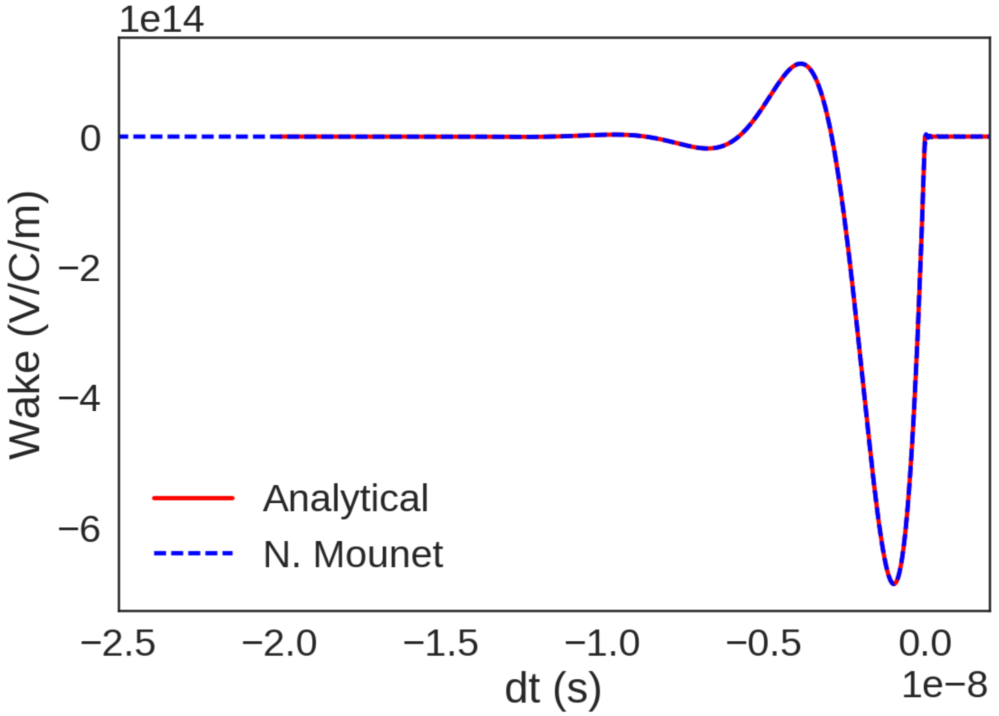


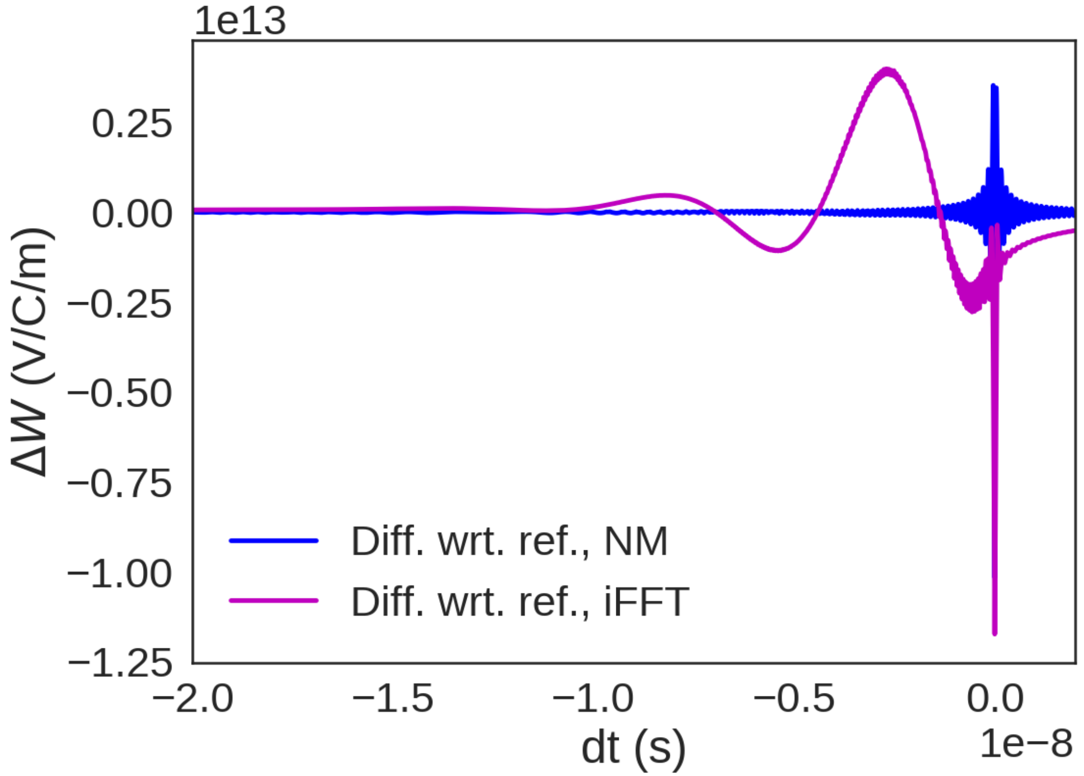
PS wakes comparison



Comparison of N. Mounet method vs. FFT vs. analytical

Broadband resonator used for the comparison: R_s = 1 MΩ/m, f_r = 200 MHz, Q=1





N. Mounet method vs. FFT

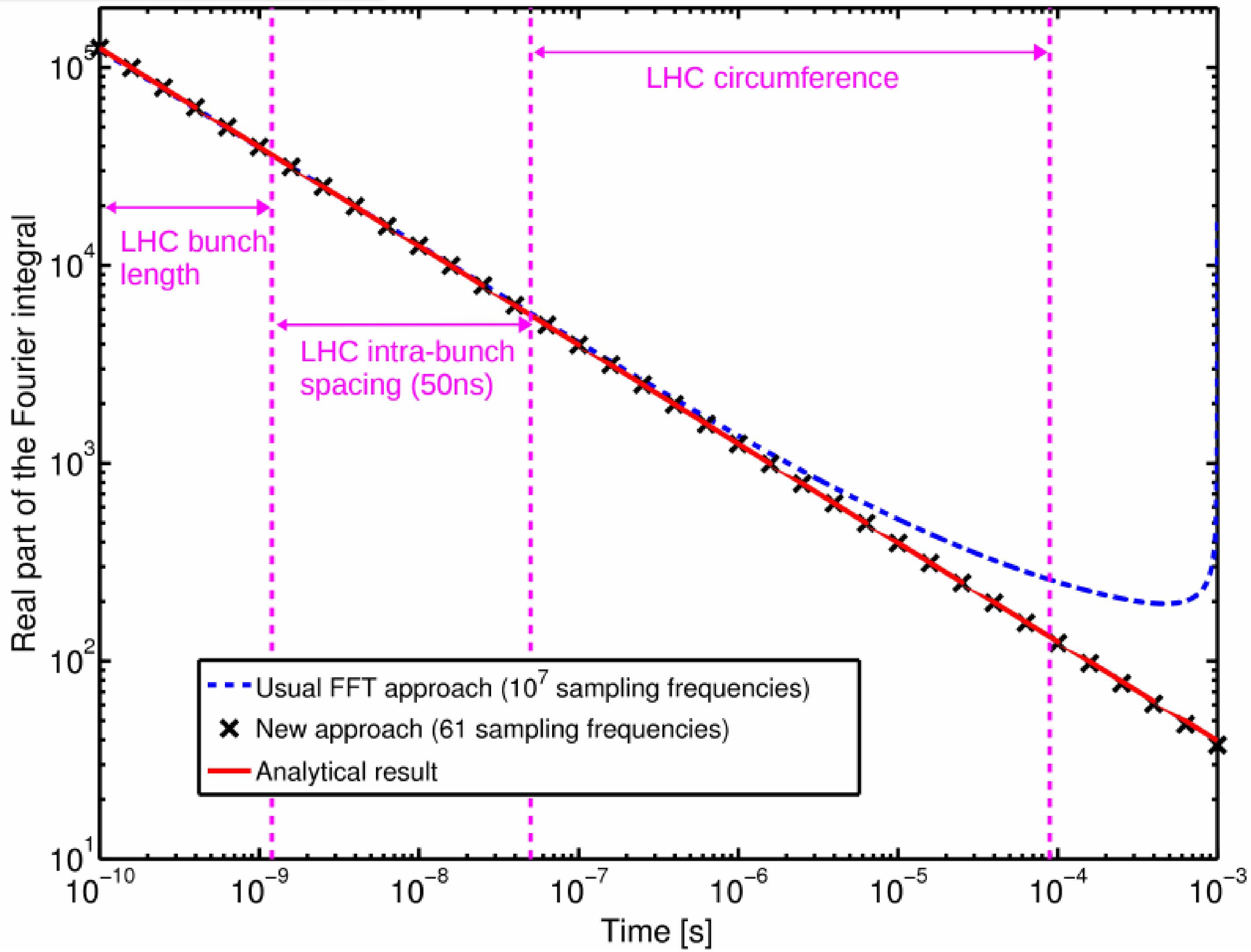


Figure 1.5: Real part of the Fourier integral from 0 to ∞ of $f(\omega) = \frac{1}{\sqrt{\omega}}$, obtained using the usual FFT method, the new general method proposed in this work, and the analytical formula.

N. Mounet
CERN-THESIS-2012-055