# Effect of the Extraction Kickers on the Beam Stability in the CERN SPS

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**Acknowledgements:**
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# Outline

- Introduction and Motivation
- Updated simulations and measurements of the MKE
- The impact of the MKE on the instability threshold in the SPS
- Benchmarking of the impedance model with synchronous phase measurements
- Is it possible to distinguish between the two models of the MKE with beam?

# Is There Impedance Missing From Our Model?

- Performed since 1999 to monitor the evolution of the SPS impedance. Measurements extended in 2016 to scan for the average bunch length
- They were compared to simulations using the SPS impedance model in BLonD
- The scan with bunch length provides more information about the frequency distribution of a potential missing impedance
- This scan hints at a missing resonator with R/Q=3kOhms, Q=1 and f=350 MHz
- One of the possible candidates are the kicker magnets

Full SPS Longitudinal Impedance Model
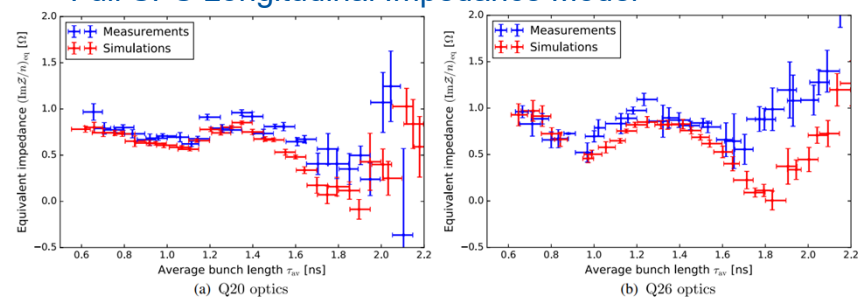


Full SPS Longitudinal Impedance Model with Additional Resonance
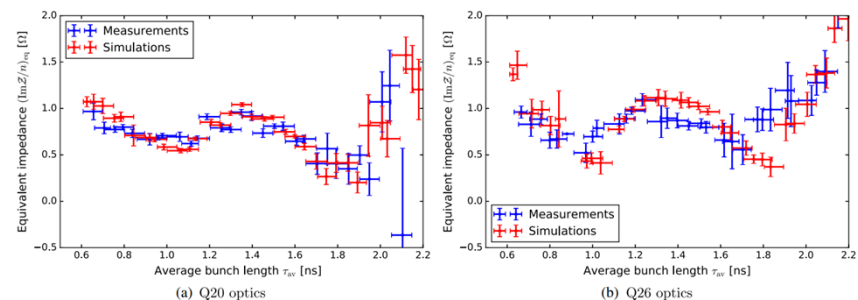


Courtesy of A. Lasheen and E. Shaposhnikova
https://journals.aps.org/prab/pdf/10.1103/PhysRevAccelBeams.20.064401

# SPS Kickers

- The SPS utilizes kickers for: Tune measurements, Beam dumping, Injection and Extraction
- Due to the presence of ferrite materials with a relative permeability of much greater than one, kickers provide a broadband source of impedance
- This is a known source of beam instabilities through causing a loss of Landau damping and hence many have shielding applied
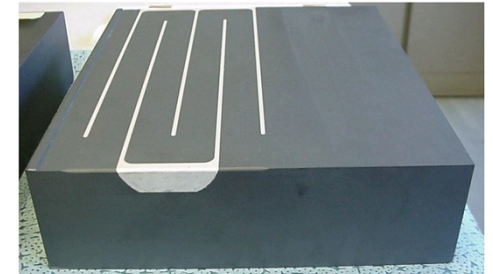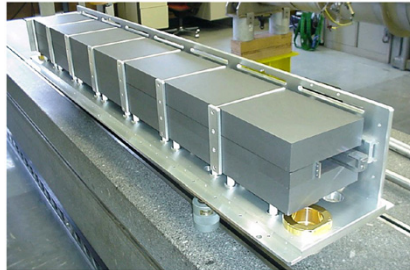


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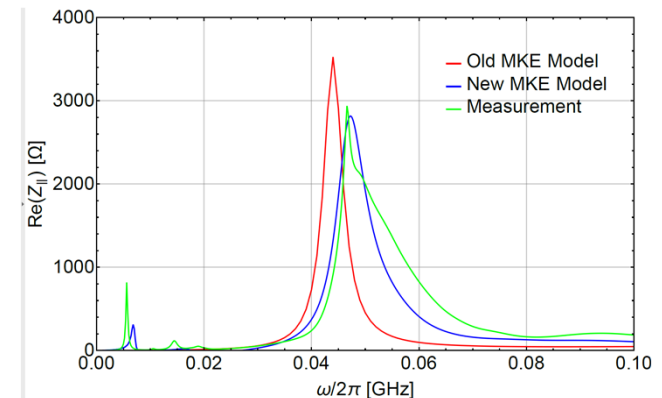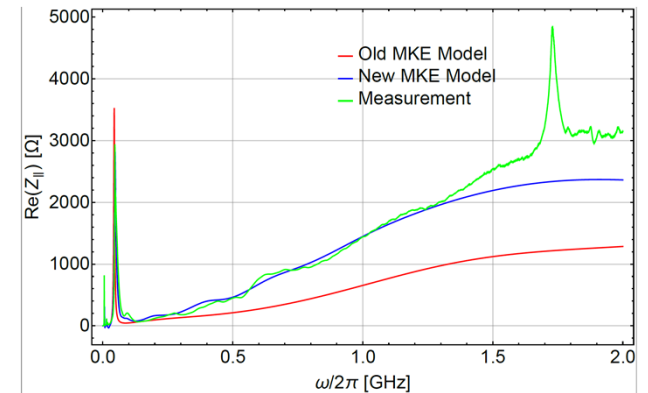
# MKE Kicker Models

- The kickers were first modelled using the Tsutsui model
- Once serigraphy was introduced they were modeled in CST MWS in 2013
- The new model is a more accurate representation of the kicker with changes including:
  1. The introduction of the ground bar
  2. Corrections to the serigraphy layout (Inc. Finger layout & dimensions)
  3. Modelling of the serigraphy as a thin panel material rather than PEC
  4. The relative permittivity is set to 12

The changes in the model are relatively small but have a large impact in particular on the broadband impedance which could be a problem for beam stability
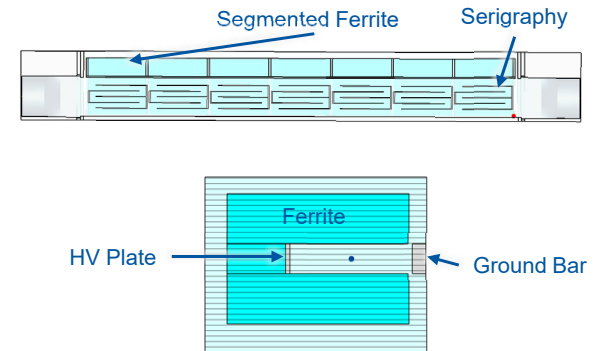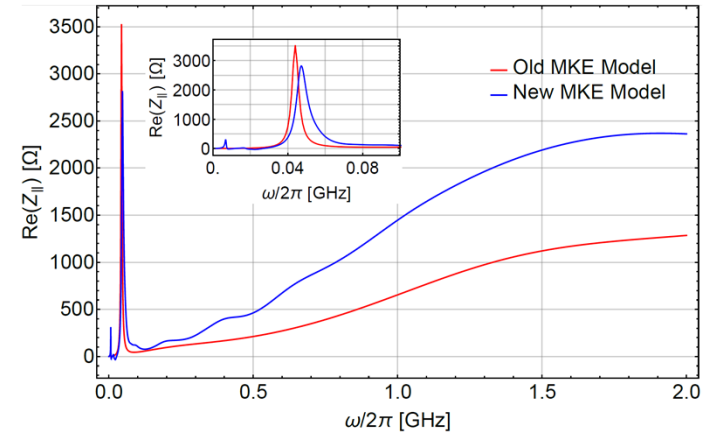
# Measurement of the Kicker

- To verify which model is correct the MKE was measured
- The measurement was performed using the coaxial wire method The general agreement is very good with the new model
- At high frequency there is a significant discrepancy however this is an artifact of the measurement

# Origin of the Features



Resonance between the conducting strips produce this low frequency peak

This is the broadband contribution reduced due to the serigraphy installed caused by the magnetic permeability

Flanging off the structure to measure causes this peak which is not present in the machine
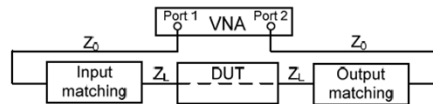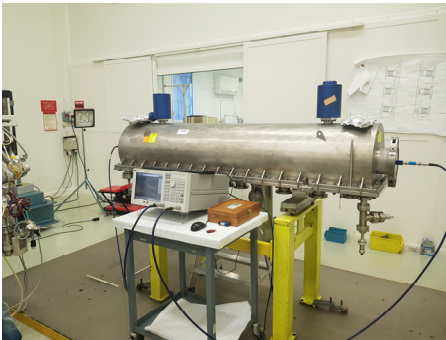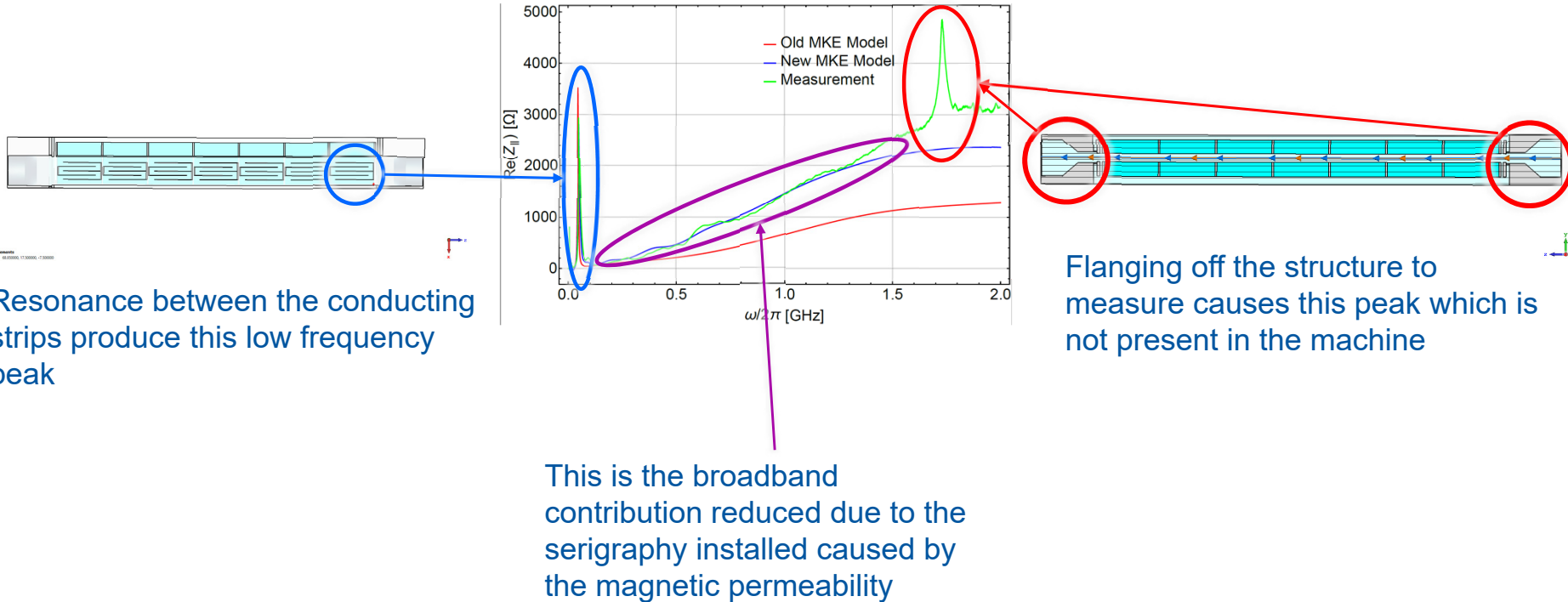
# SPS Impedance Model

SPS Longitudinal Impedance Model:
- 200 MHz and 800 MHz Cavities Accelerating Mode and HOMs
- Vacuum Flanges
- BPM's, Wire Scanners and other BI equipment
- Injection, Extraction, Tune and Dump Kickers
- Sector Valves, Pumping Ports
- Beam Scrapers
- Electrostatic Septa
- Feedback and Feedforward systems

SPS Impedance Model for the present and future cases
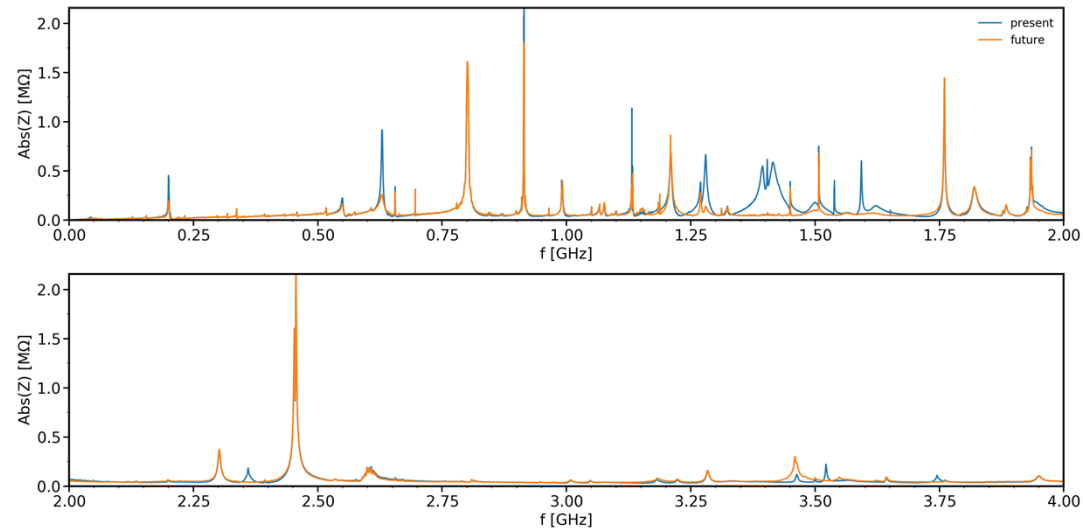


Contributions from J. Varela, B. Salvant, T. Kaltenbacher & C. Zannini

# LIU-SPS Requirements (Protons)

- Ultimate goal is to provide $2.3 \times 10^{11}$ ppb at LHC Flat Bottom (450 GeV)

- This means we need at least $2.4 \times 10^{11}$ ppb with bunch length of 1.65 ns at Flat Top (450 GeV) in the SPS to give overhead for scraping of transverse tails in the SPS and losses in transfer to the LHC

- Selection of what is planned:
  1. This requires doubling the current SPS beam intensities
  2. Requires more than double the RF power (Complete overhaul of the RF System)
  3. An upgrade of the beam dumping and extraction systems
  4. Improved longitudinal and transverse feedback
  5. Impedance reduction
  6. Etc…

# Impact on the Instability Threshold (1/4): Impedance Model

Simulations in BLonD (https://blond.web.cern.ch/):

- 48 Bunches are used as we see no change with 72 bunches and the simulation time is reduced
- $V_{800} = 0.1 \times V_{200}$
- $V_{200} = 7MV$ (Now)
- The full SPS impedance model (slide 8) is included (present/future)
- Feedback, Feedfoward (20 dB reduction in accelerating band)
- 25 ns bunch spacing
- Bunch distribution is binomial as measured in the machine and matched at Flat Top (450 GeV) with intensity effects
- Bunch length oscillations is used to characterize stability (unstable is when a 7% increase in mean bunch length)



HL-LHC/LIU Goal: $2.4 \times 10^{11}$ ppb with bunch length of 1.65 ns

Aaron Farricker (CERN)
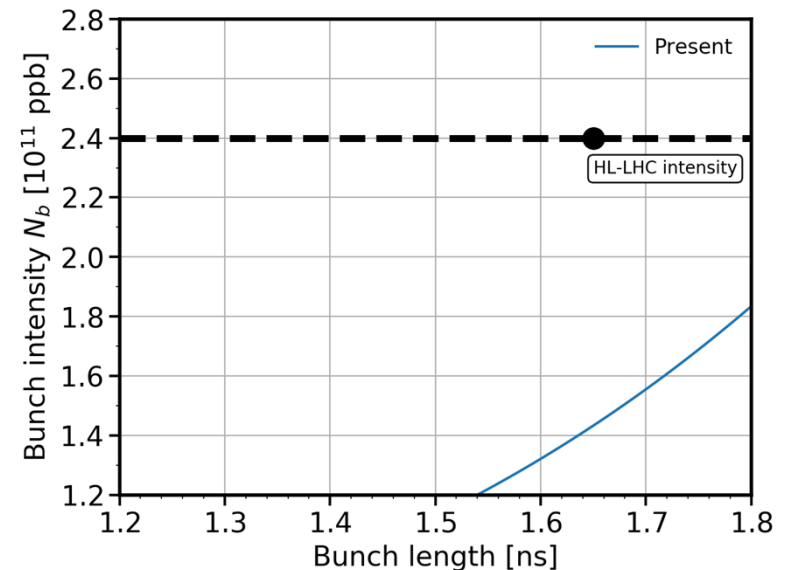
# Impact on the Instability Threshold (2/4): Post-LS2

Changes Post-LS2:

- Improved Feedback on the 200 MHz cavities (26 dB)
- Reduction in the 630 MHz HOM in the 200 MHz cavity by a factor of 3
- Shielding of the QF type flanges in short straight sections
- Shielding of BPH/QF flanges
- Increase in VVSA/B type sector valves number
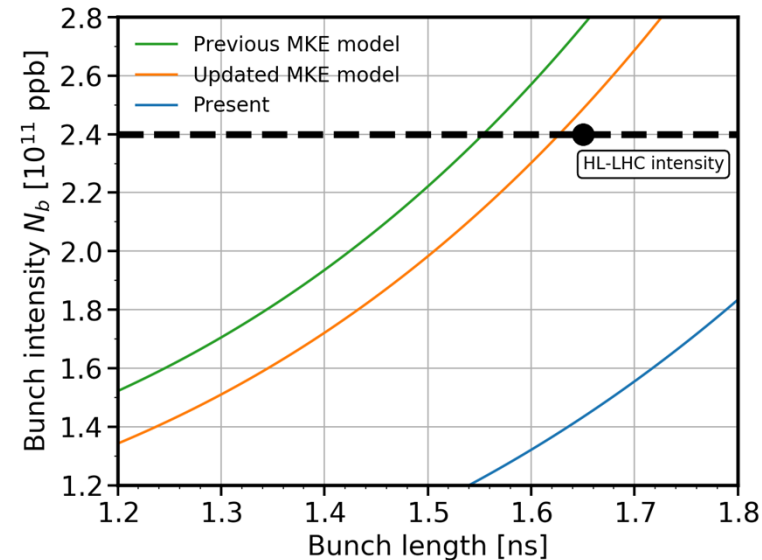- Increase in RF power to give 10 MV acceleration at HL-LHC intensities
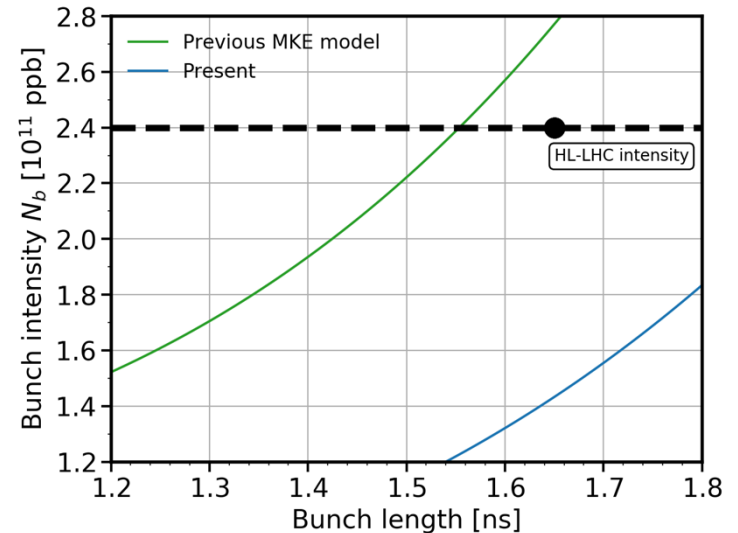


HL-LHC/LIU Goal: $2.4 \times 10^{11}$ ppb with bunch length of 1.65 ns

# Impact on the Instability Threshold (3/4): New MKE Model

Changes Post-LS2:

- Improved Feedback on the 200 MHz cavities (26 dB)
- Reduction in the 630 MHz HOM in the 200 MHz cavity by a factor of 3
- Shielding of the QF type flanges in short straight sections
- Shielding of BPH/QF flanges increase in VVSA/B number
- Increase in RF power to give 10 MV acceleration at HL-LHC intensities
- Additionally introduce the more recent kicker model

1. The introduction of the updated impedance model of the MKE results in a decreased threshold prediction.
2. The error bar on the lines are significant – We may not meet all of our impedance goals
3. We may unearth a source of instability which is not in the current model (currently in the shadow of something else)
4. The identification and reduction of the contribution of elements to the impedance spectrum is now more crucial
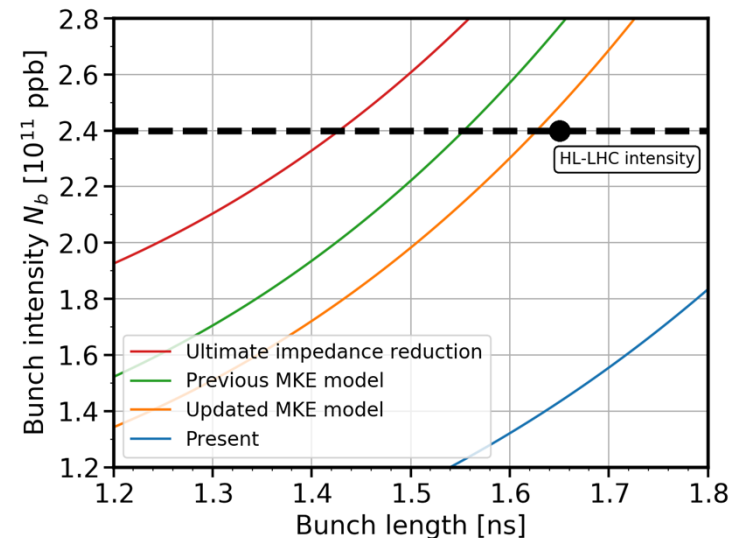
HL-LHC/LIU Goal: $2.4 \times 10^{11}$ ppb with bunch length of 1.65 ns

# Impact on the Instability Threshold (4/4): Possible Mitigation

Possible methods to increase the threshold:

- RF shielding of all non-shielded pumping ports (at least 25)
- Systematic check for shielding non-conformities (Not in the Model)
- Shielding of the MKP (Non-Trivial)
- Shielding of VVSA and VVSB type sector valves

1. Currently the only one which will be partially implemented is the shielding of pumping ports (15/25)
2. Shielding of the valves is possible but has significant costs
3. Shielding of the MKP basically means new kickers and studies are ongoing



HL-LHC/LIU Goal: 2.4 x 10$^{11}$ ppb with bunch length of 1.65 ns

# Synchronous Phase Shift

- In a storage ring parasitic energy loss is inevitable
- This is caused by the resistive impedances and results in a shift in the synchronous phase
- The phase shift is related directly to the energy loss and hence impedance
- The synchronous phase shift can be used to test the SPS impedance model
- It may also be possible to measure the phase shift due to the MKE impedance

Synchronous Phase

$$\sin \phi_s = \frac{U}{eV}$$

Energy Loss

$$U_b = -e^2 N k = -e^2 N \sum_n k_n(\sigma)$$

Modal Loss Factor  (Gaussian Bunch)

$$k_n(\sigma) = \frac{\omega_0}{\pi} \sum_{p=0}^{\infty} \mathfrak{R}[Z_n(p\omega_0)] \exp[-(p\omega_0\sigma)^2]$$

# Synchronous Phase Shift - Calculated

- The synchronous phase shift according to the SPS impedance model is computed in BLonD
- This allows the bunch intensities, bunch lengths and cavity voltages to be varied easily
- The clear linear dependence on the intensity is seen at fixed bunch length
- The slope is directly related to the energy loss U (small angle approximation):

$$\phi_s = \frac{U}{eV},$$

- We can see a relatively small but clear difference between the synchronous phase shifts with the different MKE models

- Computations are carried out for Flat Bottom (26 GeV) with Q20 optics in single RF
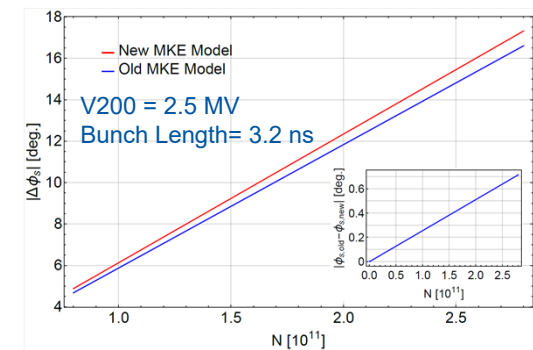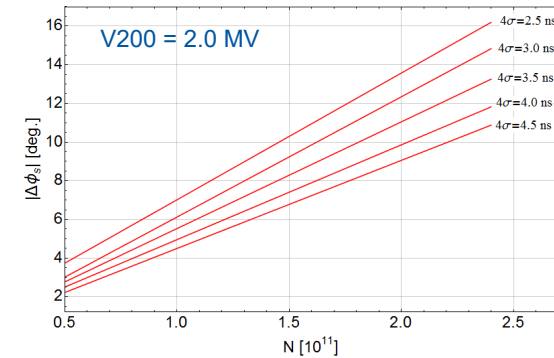
# Synchronous Phase Shift – Measurement Technique

- In order to measure the synchronous phase shift a reference phase must be identified
- Earlier measurements used the signal sent to the Amplifiers
- In this measurement two bunches of equal bunch length will be used
- The reference with low intensity and the test bunch with a higher variable intensity
- By sampling the bunch profiles on a 40 GS/s oscilloscope simultaneously the relative phase is trivial to calculate.
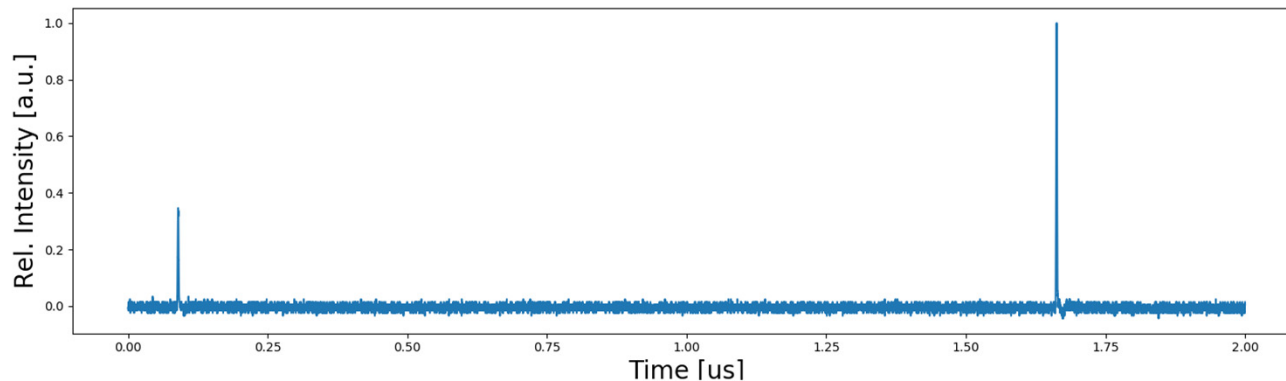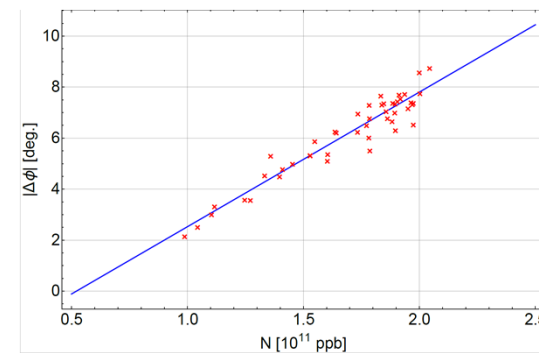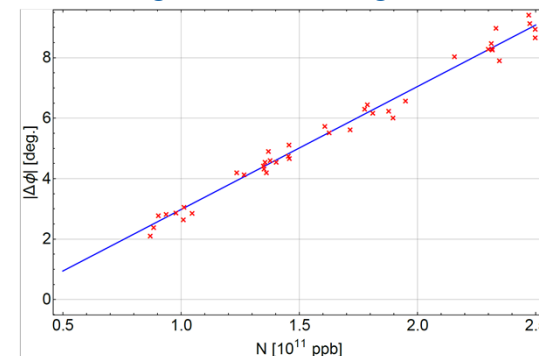
# Synchronous Phase Shift – Measurement Results

- Measurement setup:
  1. Feedback, Feedforward and longitudinal damper were off
  2. 800 MHz cavities off (but impedance is still present)
  3. 200 MHz voltage at capture of 4.5 MV→ Dropped to 2.5 MV for measurement

- Bunch lengths and intensities are changed by modifying parameters in the PSB (CERN-ATS-Note-2013-040 MD)
- Several bunch intensities are set and the natural spread is used to populate the space
- The energy loss is calculated from the gradient of the fit to the data

Average Bunch Length = 3.2 ns



Average Bunch Length = 3.6 ns

# Synchronous Phase Shift – Measurement Comparison

- At the moment we do not have the data to draw firm conclusions
- However it looks like our model is in the same ball park as the beam measurement
- This is suggestive that the current impedance model is accurate
- The data is not currently good enough to discern the difference between the differing impacts of the two MKE models
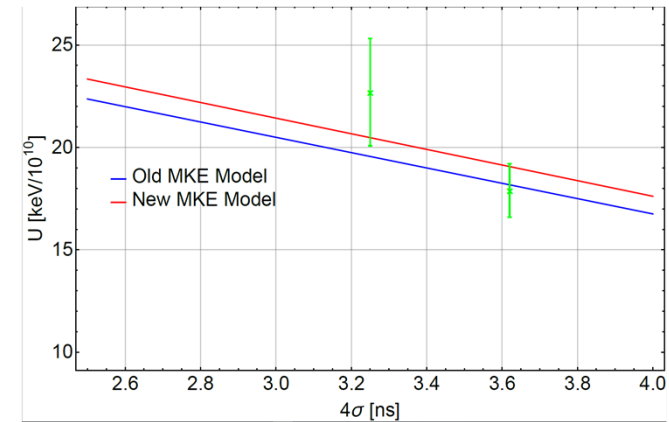
# Where to go from here?

Threshold Limitations:
- Have options in place which can be implemented in the event the threshold is not met (ie VVSA/B shielding, MKP shielding)
- Identify additional sources which may reduce the threshold further through expanding the impedance model

Measurements:
- Currently we plan to improve the measurements by taking samples over an increased range of bunch lengths, intensities and cavity voltages
- This may require some extra work in the PSB and PS as well
- In addition it may be possible to use the 800 MHz cavity to help capture bunches with smaller bunch lengths

# Summary

- Simulations and measurements confirming the MKE impedance in the SPS is much larger than originally estimated
- The impact on the stability threshold is significant and poses problem for the LIU goals
- Several options to compensate for this were suggested
- Simulations and preliminary measurements benchmarking the SPS impedance model were given which show promising results
- The possibility to identify the difference between the two MKE models in beam measurements was also examined

# Thank you for your attention