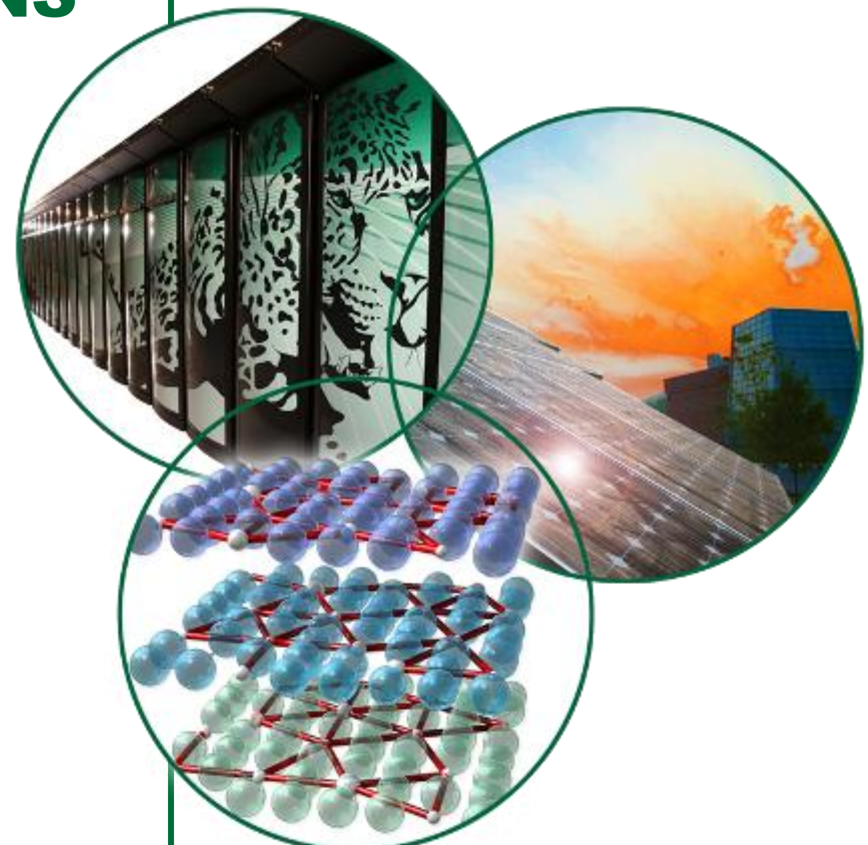
Challenges of Reconciling Theoretical and Measured Beam Parameters at the SNS Accelerator Facility



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Introduction

- The Spallation Neutron Source is running at 1MW and no problems are expected up to the design beam power of 1.4MW
- This success is a confirmation of a general validity of the models used for the accelerator design and tuning.
- Are the same models capable of predicting major beam parameters in the operating SNS accelerator ?
- Are the same models capable of predicting beam loss in the operating SNS accelerator ?
- Do we need to be able to model beam more accurately?
- Do we believe it's possible?
- What are the challenges?

Beam simulation tools for accelerator design stage

- They describe a mathematical abstraction
- Main goal is to verify design stability and establish safety margins
  - End-to-end simulations
  - Various input distributions: water-bag, Gauss, “realistic”….
  - Random deviations of parameters (error study)
- Verification is by comparing with analytical solutions and other codes
- Tend to run large number of particles and require huge computing power
  - 3d space charge calculation
  - Good statistics
- Tend to be universal

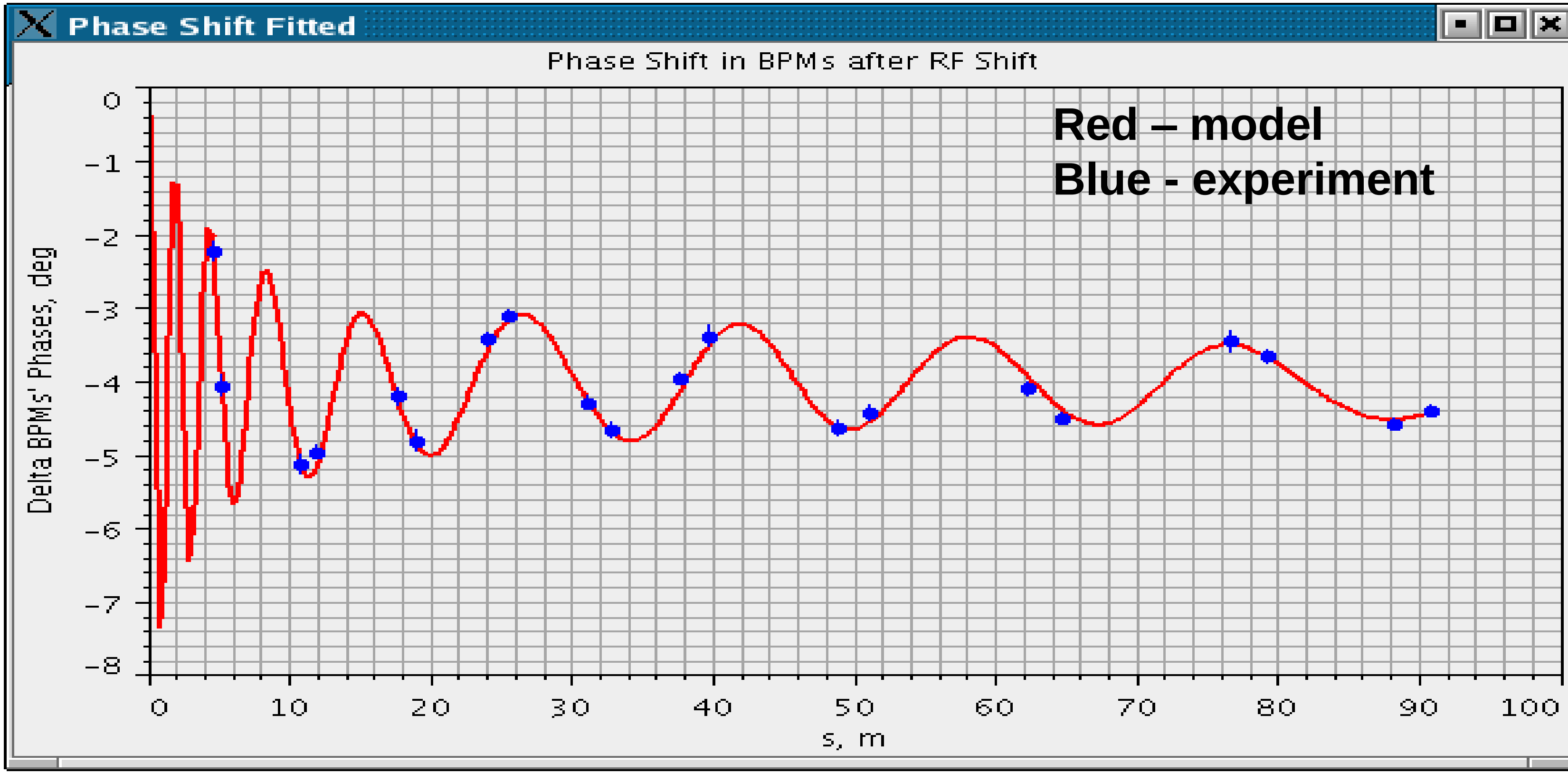
Beam simulation tools for modeling an existing accelerator

- They describe a real thing
- Main goal is to predict beam parameters and change of beam parameters in response to change of controls
  - Piece-wise simulations are OK
  - Any input beam distribution is OK if it agrees with available experimental data
- Verification is by comparing with experimental data
- Number of particles should be consistent with available experimental data
- Should have powerful tools for data manipulation
  - Data input/output
  - Diagnostics simulation
  - Optimization algorithms
- Does not need to be universal
- Can require huge computing power for some tasks but should be able to run on individual machines as well

Accuracy of beam modeling in different parts of the SNS linac (informal)

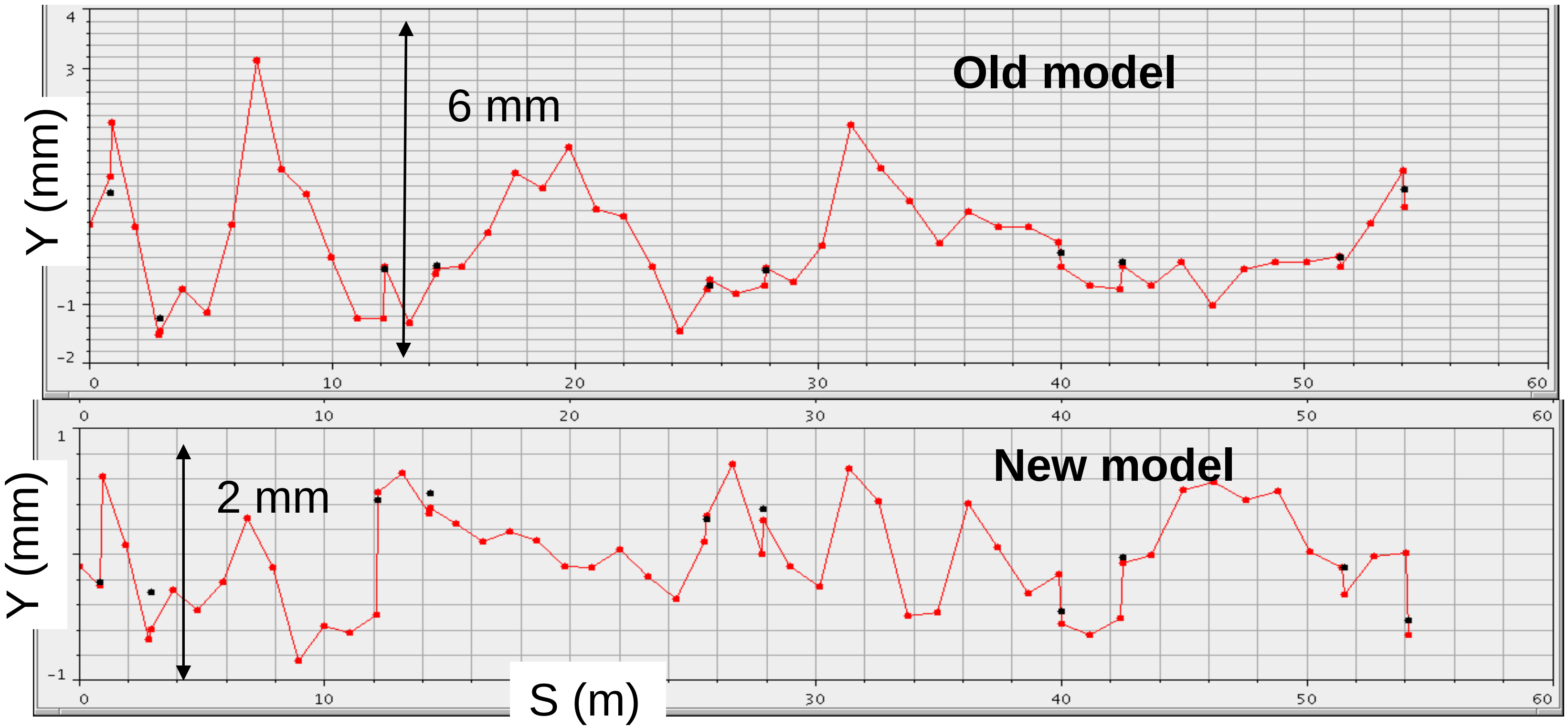
	Transv. centroid	Transv. RMS	Long. centroid	Long. RMS	Halo
RFQ	NA	NA	NA	NA	No clue
MEBT	good	good	not so good	good	No clue
DTL	good	not so good	very good	NA	No clue
CCL	very good	not so good	very good	not so good	No clue
SCL	not so good	not so good	very good	NA	No clue

- **Longitudinal plane**
  - **Center of mass motion (single particle model)**
    - **MEBT, DTL, CCL**



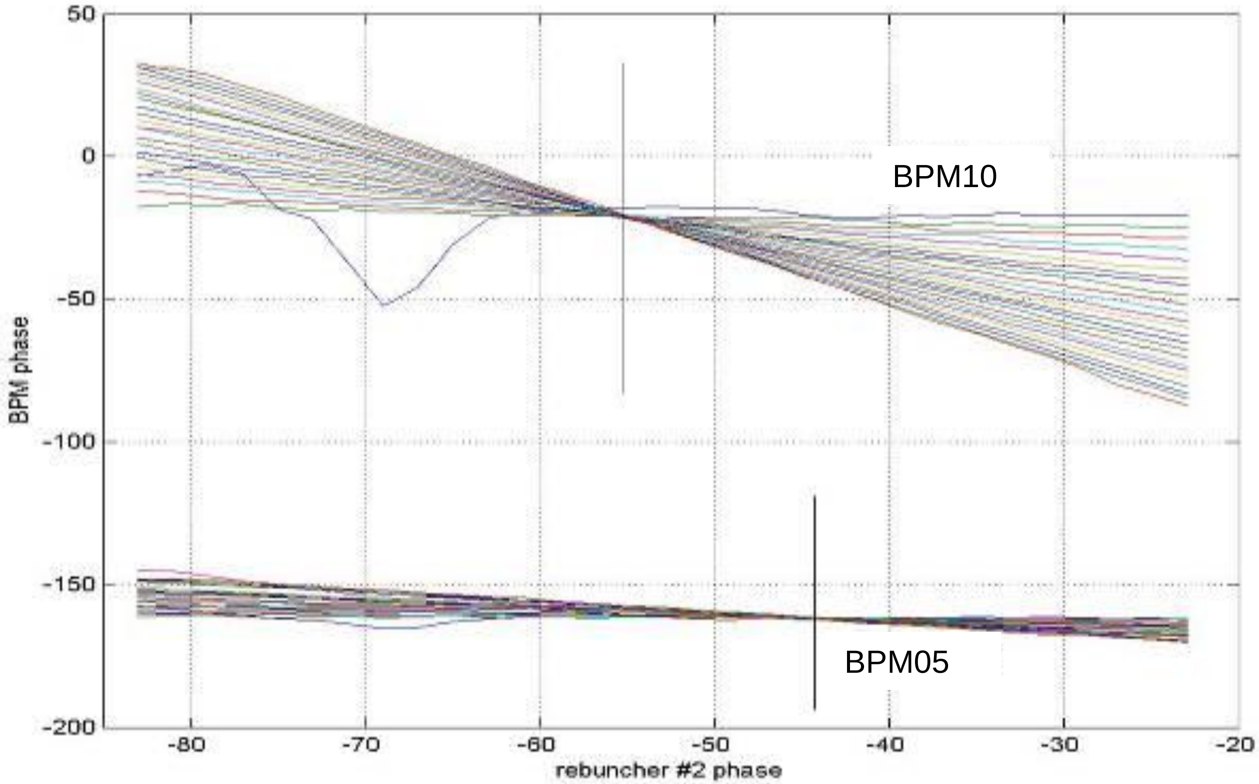
Did not have agreement in XAL on-line model -> achieved good agreement with PARMILA first -> corrected tracking algorithm in XAL on-line model

- Transverse planes
- Center of mass motion (single particle model)
- CCL



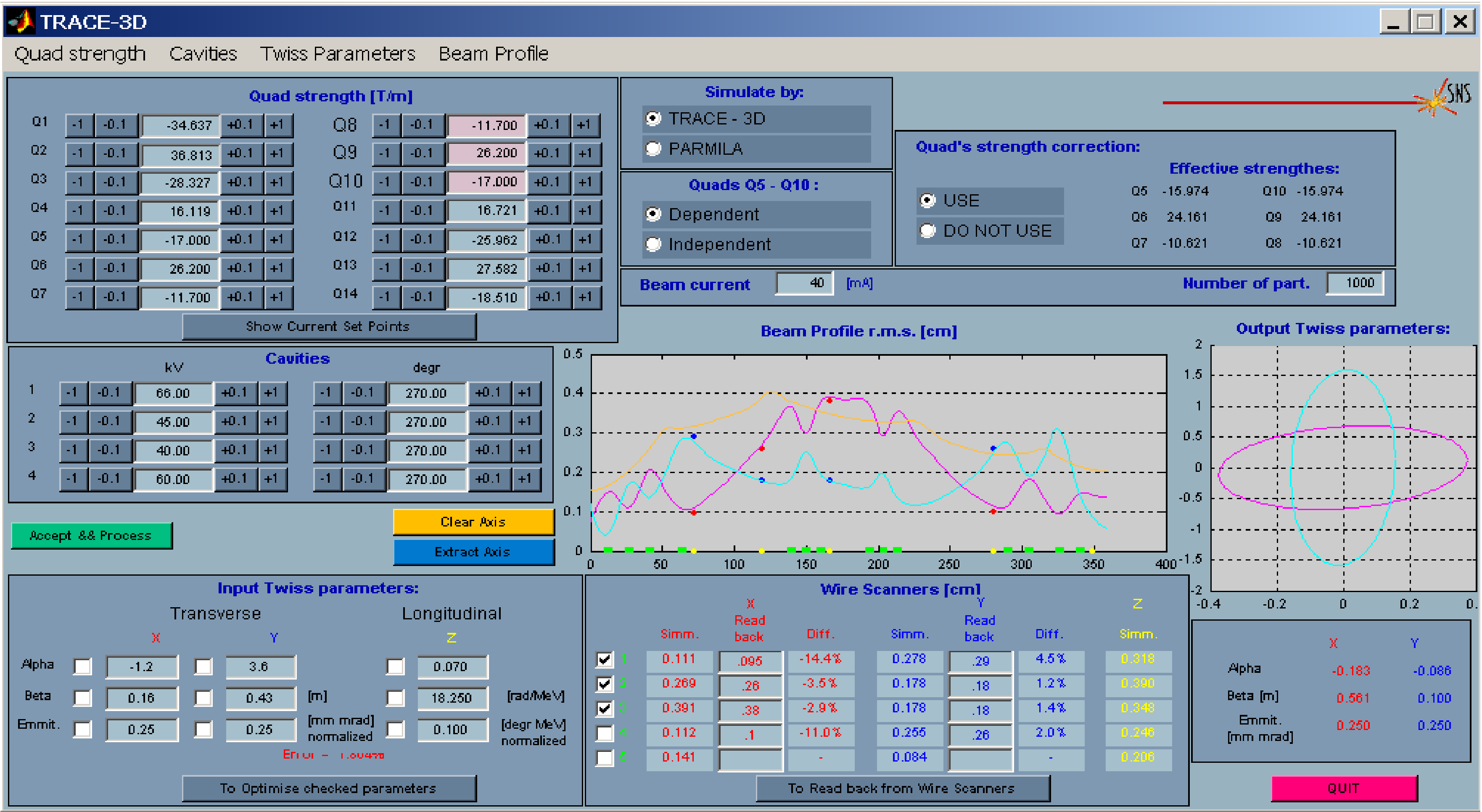
- **Small number of BPMs**
- **Beam based alignment**
- **Good agreement if add quads offsets to the model**
    - **unrealistic but works**
- **Stand-alone script using some XAL capabilities. It is still not part of XAL on-line model**

Example of center of mass model limitations ???



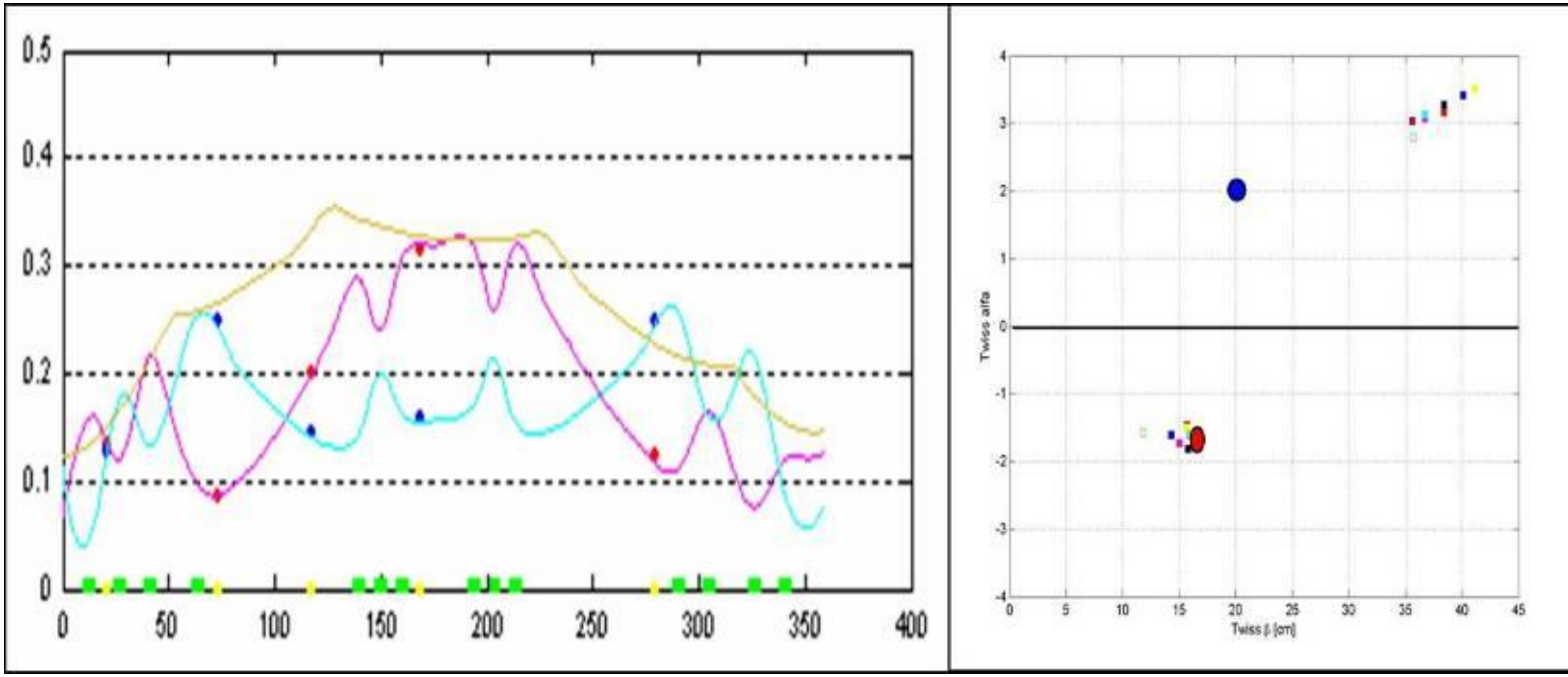
- **MEBT rebuncher phase scan can produce different results with different BPMs**
  - **5º - 10º uncertainty**
  - **Have not been reproduced in a model. We suspect asymmetric longitudinal distribution**

- Transverse planes
- Profiles (envelope and PIC models)
- MEBT



Need to have initial distribution for the model

Characterizing RFQ output beam using MEBT wire scanners

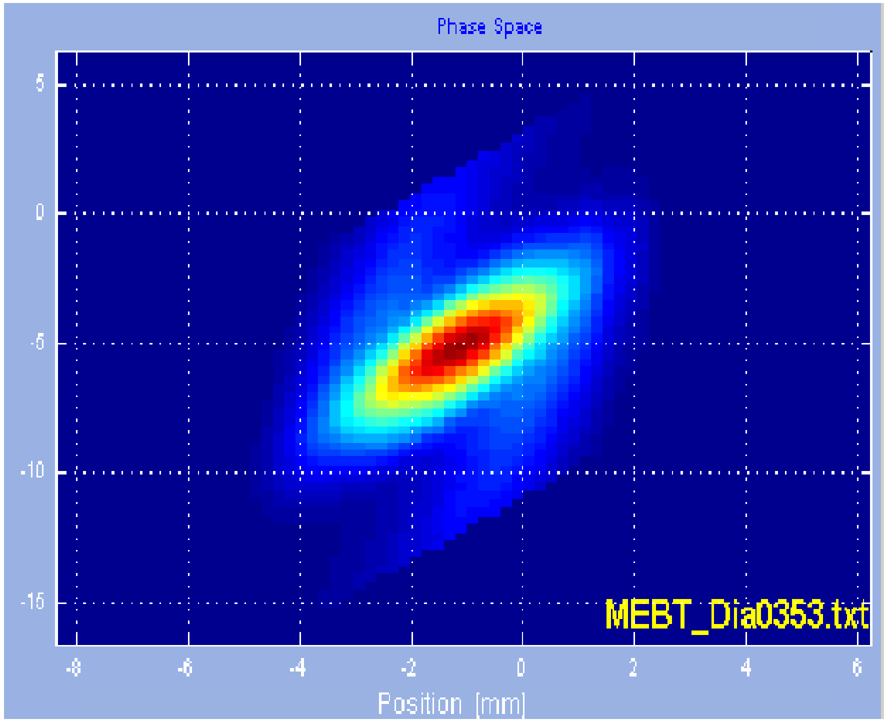


Measure transverse profiles using 5 wire scanners -> Search for input Twiss parameters to best fit model to measured data -> Repeat several times with different quad settings

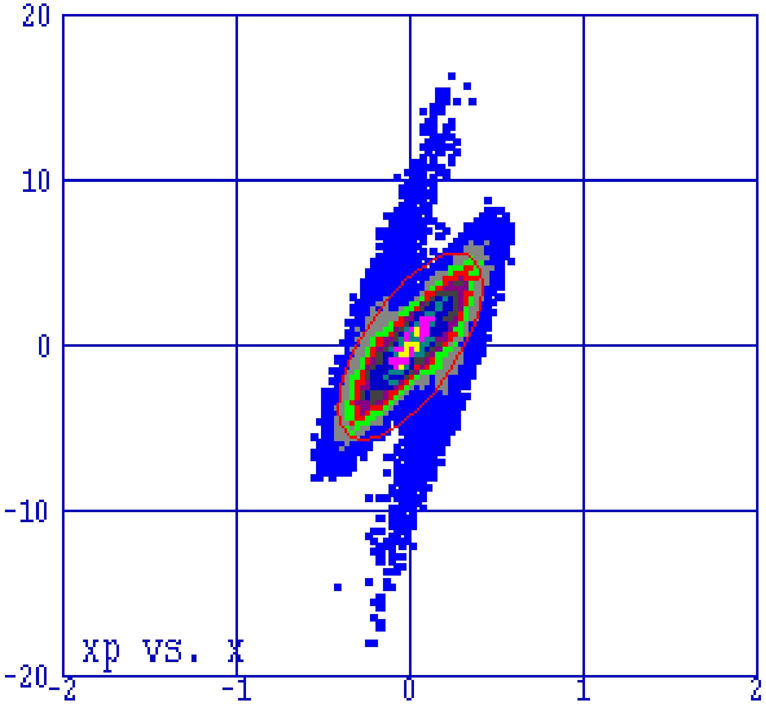
Disagreement with PARMTEQ design in vertical plain

Transverse phase space measurements in MEBT

- **S-shape formation observed in measurements**

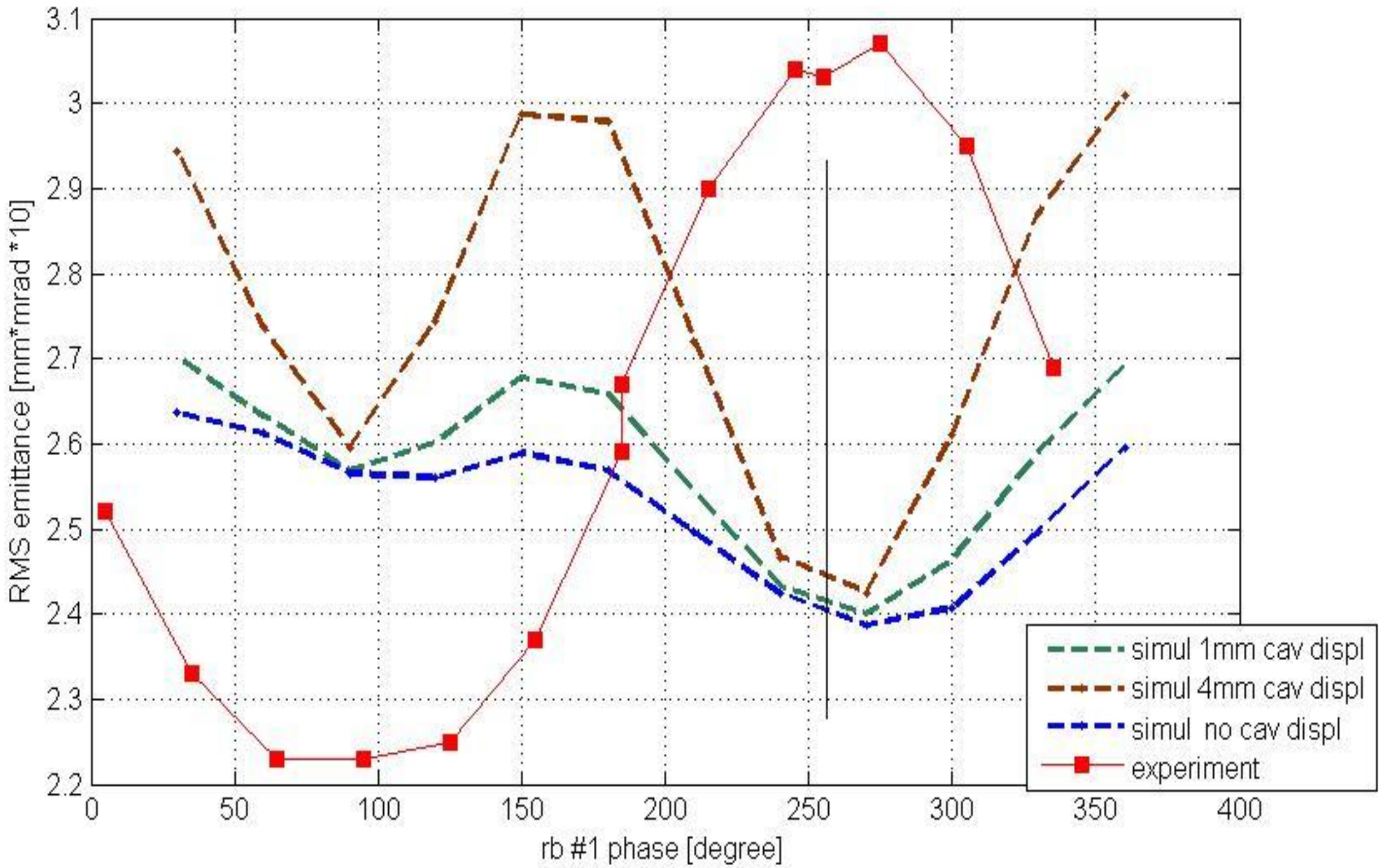


- **S-shape formation observed in simulation**

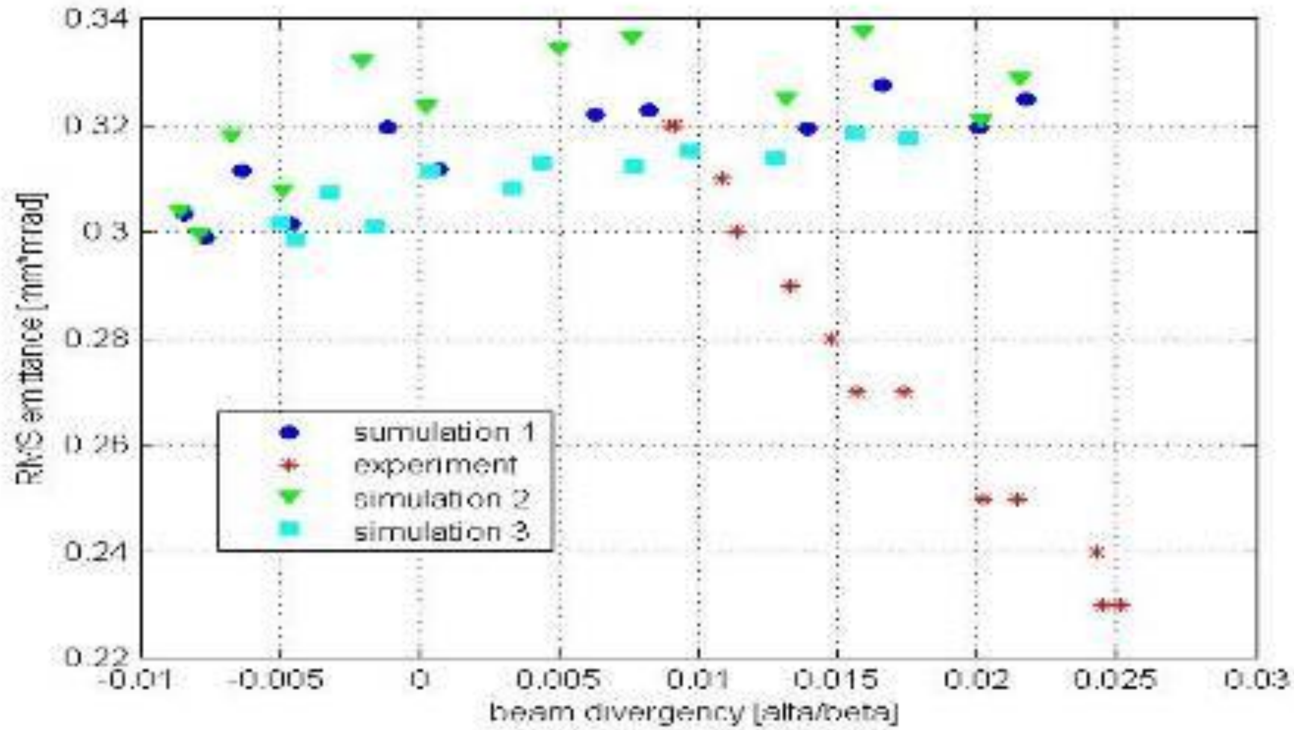


What about quantitative analysis ?

- **Attempted using emittance measurements to find rebuncher cavity offset**
- **Found strong disagreement between measurements and model**



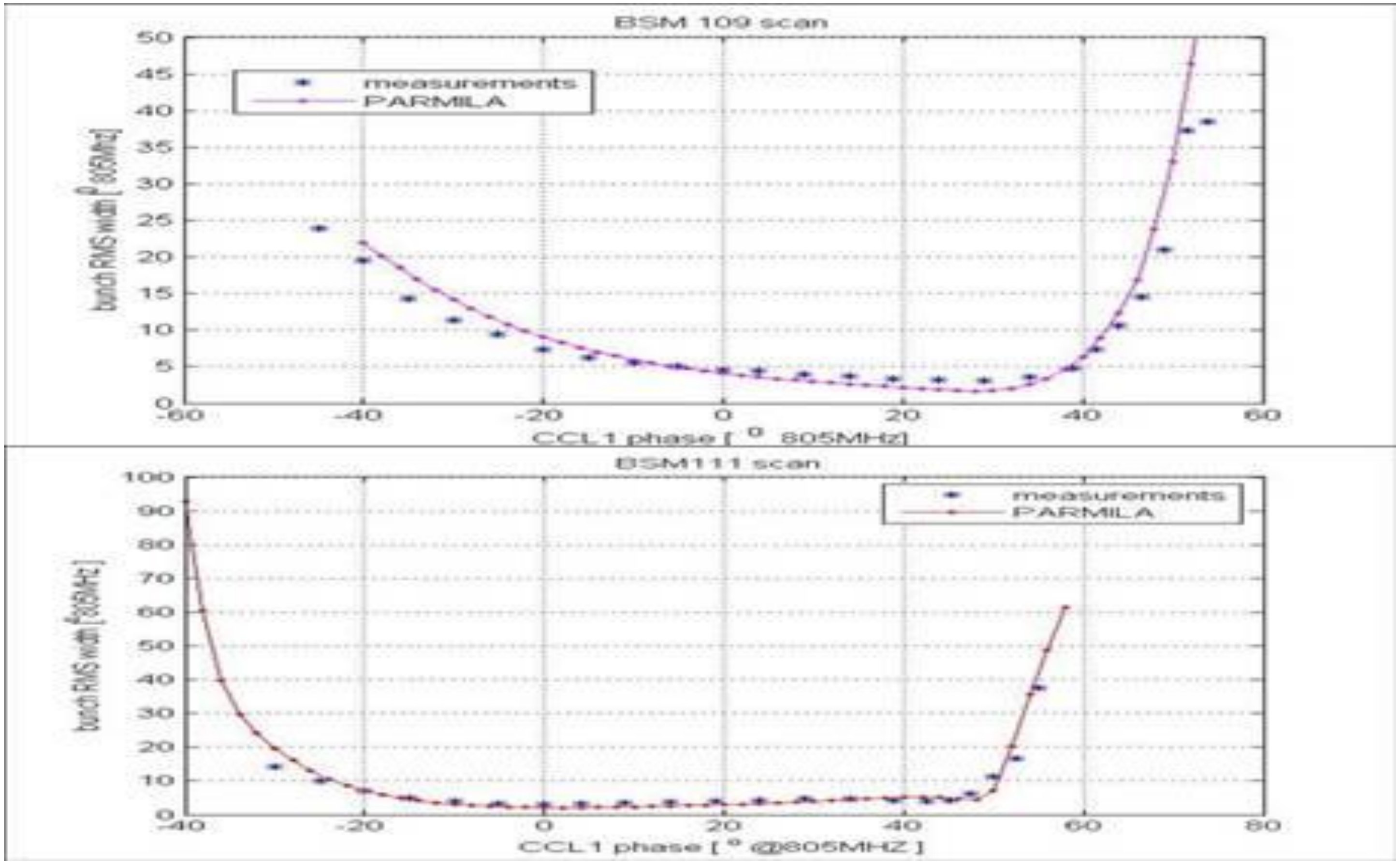
Validity and accuracy of measured data has to be questioned and proved



Strong correlation between beam divergence and measured emittance Indicated a systematic measurement error

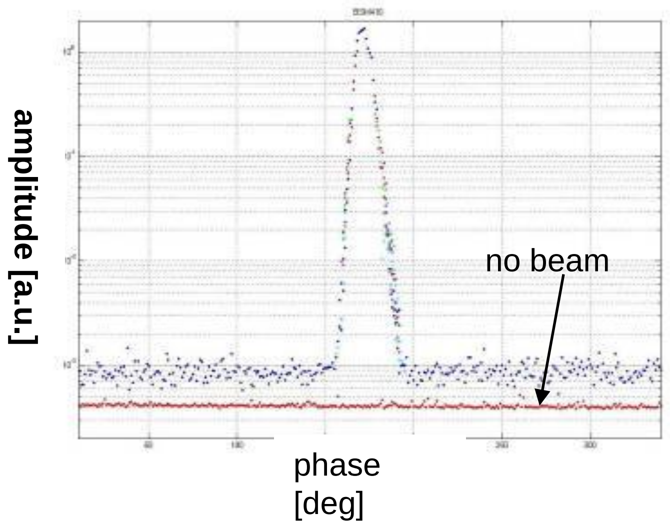
Emittance measurements accuracy has been improved significantly after 3 years of concentrated efforts

- **Longitudinal plane**
  - **Profiles (envelope, PIC models)**
    - **CCL**

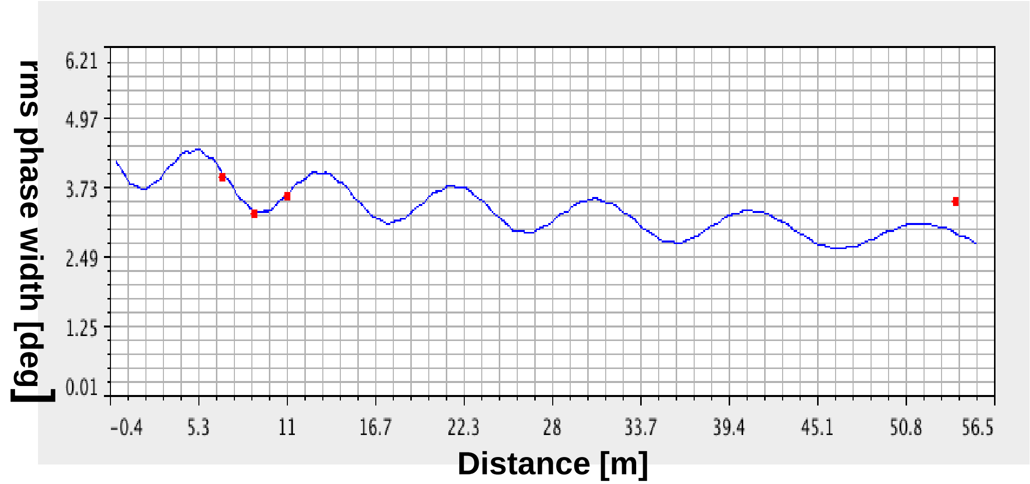


Reasonable agreement with model for each device separately with proper choice of input parameters

- **Longitudinal plane**
  - **Profiles (envelope, PIC models)**
    - **CCL**



Typical longitudinal bunch profile



Measured longitudinal bunch size vs. model

Struggle to reconcile measurements with model for all 4 BSMs simultaneously

Have to find ways to confirm BSM resolution and accuracy in absence of a reliable model

Challenges

- Diagnostics requirements
  - Dynamic range
  - Time resolution
  - Data validation
- Limited beam study time
  - Non-interceptive diagnostics
- Limited man power
  - Powerful data analysis tools (reconstruction, optimization, …)
  - Friendly and powerful simulation tools
  - External participants (collaborations, visitors, students ….)

SNS Beam Instrumentation Group nearest plans (2-3 years)

- Diagnostics improvements and additions
  - Wire scanners dynamic range increase to at least 10^4 everywhere
  - New HEBT laser emittance station
  - Resurrect longitudinal bunch profile diagnostic in MEBT
  - BSM resolution improvement/verification to <1º
  - Electron scanner energy and aperture increase
  - DTL high-spatial-resolution loss monitors

- New experimental techniques
  - Betatron phase advance measurements using emittance device and scrapers, wires
  -

- Goals to aim for
  - RFQ output distribution reconstruction using all available MEBT diagnostics

Phase advance measurements in MEBT