Linac Beam Dynamics Progress

Alexander Aleksandrov

Warm Linac Area Manager

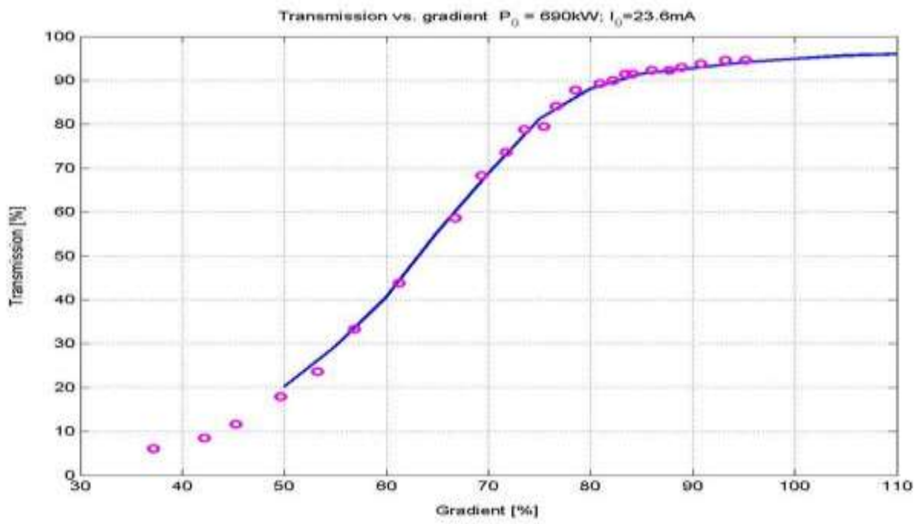
OAK RIDGE
National Laboratory

Outline

- **Systems: RFQ, MEBT, DTL, CCL,SCL**
  - **Tuning algorithms**
  - **CCL losses**
  - **SCL losses**
  - **Model accuracy**

RFQ tuning

- **422 RF cells, strongest space charge**
- **Defines longitudinal and ,in large part, transverse emittances**
- **Only one parameter to set : RF amplitude**
  - **Fit output current vs. RF power curve to PARMTEQ model to find the set point**

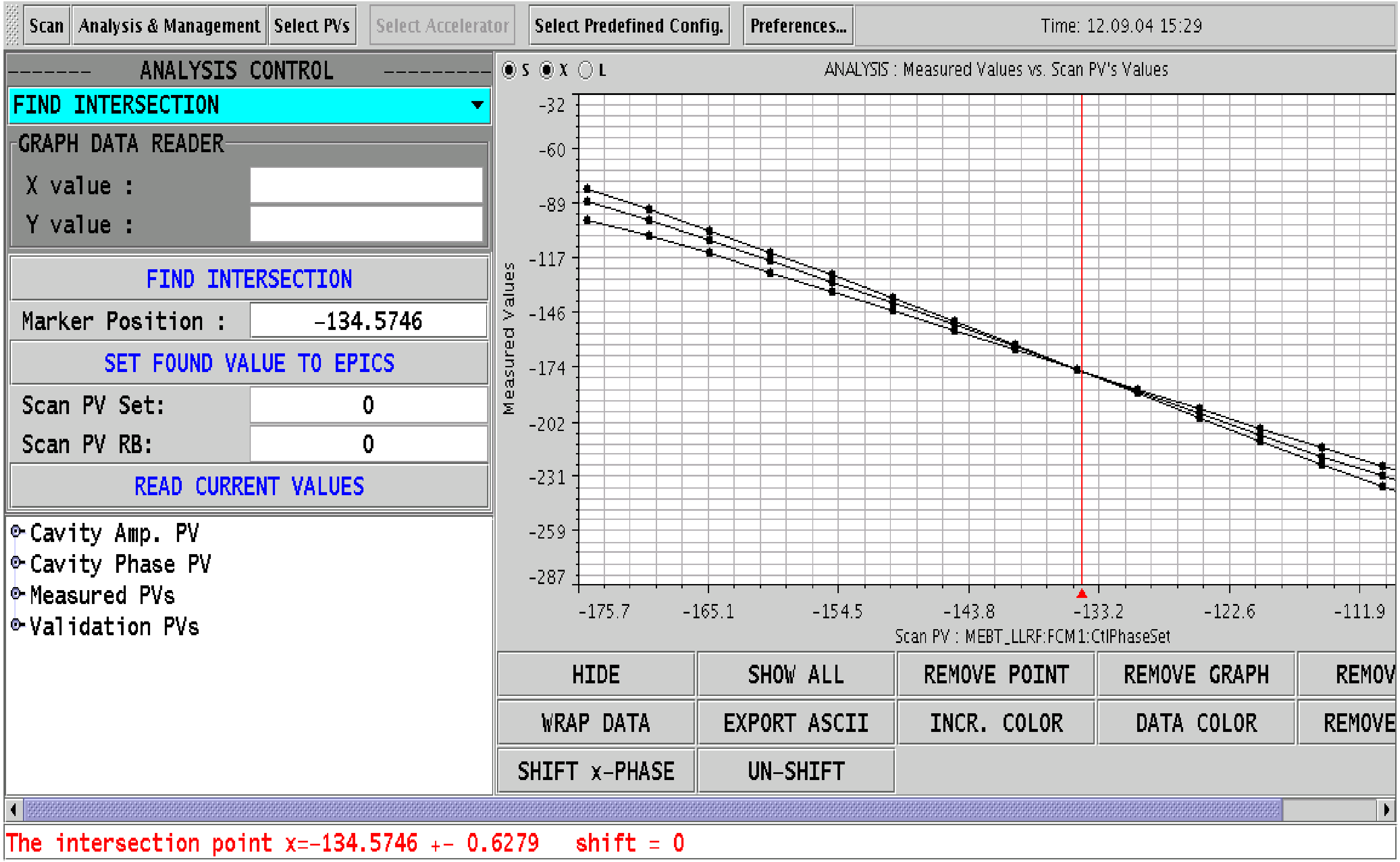


- **No diagnostics to measure absolute transmission**
- **No diagnostics to know what is going on inside**
- **Can characterize resulting beam in the MEBT**

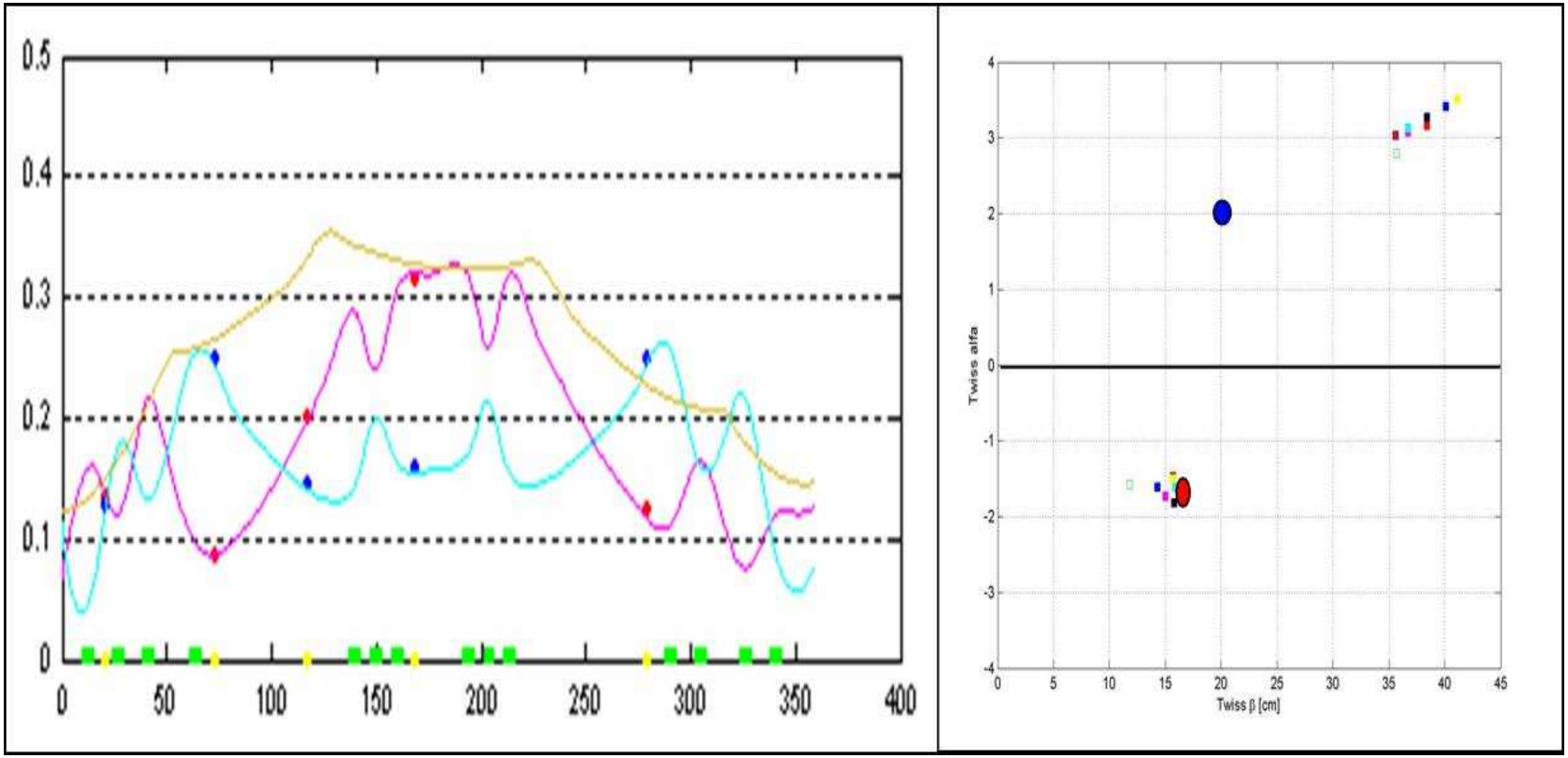
MEBT tuning

- **Set strengths of 14 quadrupole magnets**
  - Establishing proper beam profile for chopper operation
  - Matching beam to DTL
  - Use design quad values usually (~5% accuracy)
  - Verify with wire profile measurements
- **Set strengths of 6 hor. and 6 ver. dipole steerers**
  - for minimum beam centroid offset at 6 BPM locations
- **Set amplitude and phase of 4 rebuncher cavities**
  - Set amplitude to design or max available
  - Set phase to non-accelerating bunching phase using phase scan
  - Verified once in 2004 with laser longitudinal profile scanner

MEBT rebuncher phase scan



Transverse beam profile in MEBT



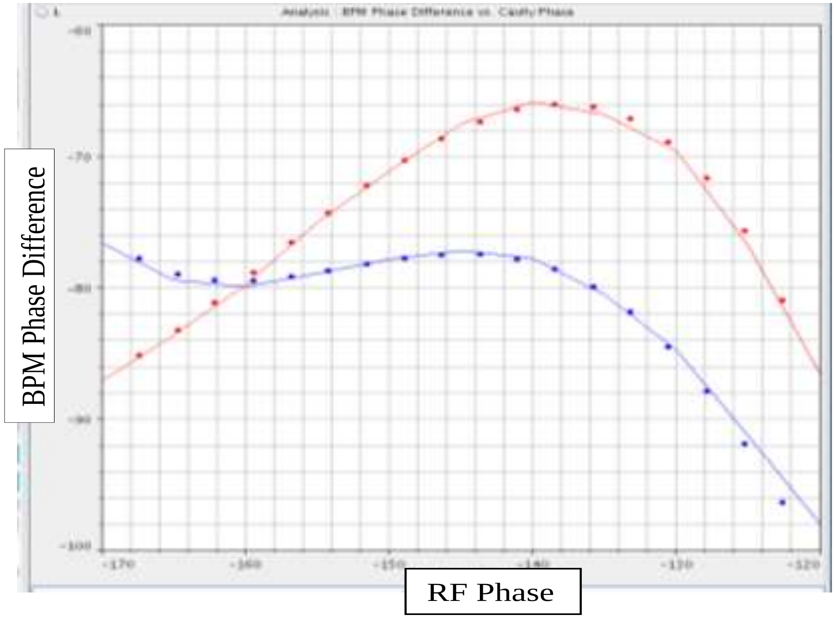
Measure transverse profiles using 5 wire scanners for different quad settings

Solve for input Twiss parameters to best fit model to measured data

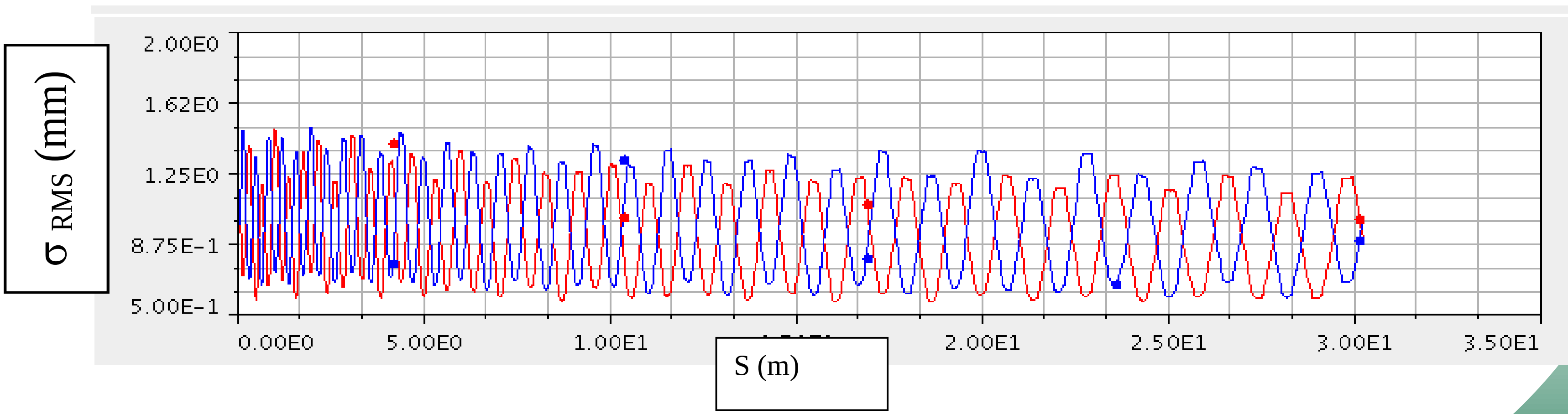
DTL tuning

- **Set RF amplitude and phase for 6 tanks**
  - Derive set points by fitting model to measured beam phase vs. cavity phase and amplitude scan
  - Scan are done consequently one tank at a time with all downstream cavities turned off
- **Set 12 hor and 12 ver dipole steerers**
  - for minimum beam centroid offset at 10 BPM locations
- **Permanent Magnet quadrupoles do not require setting**
  - Verify proper beam sizes with wire profile measurements

Example of DTL tuning (J. Galambos)

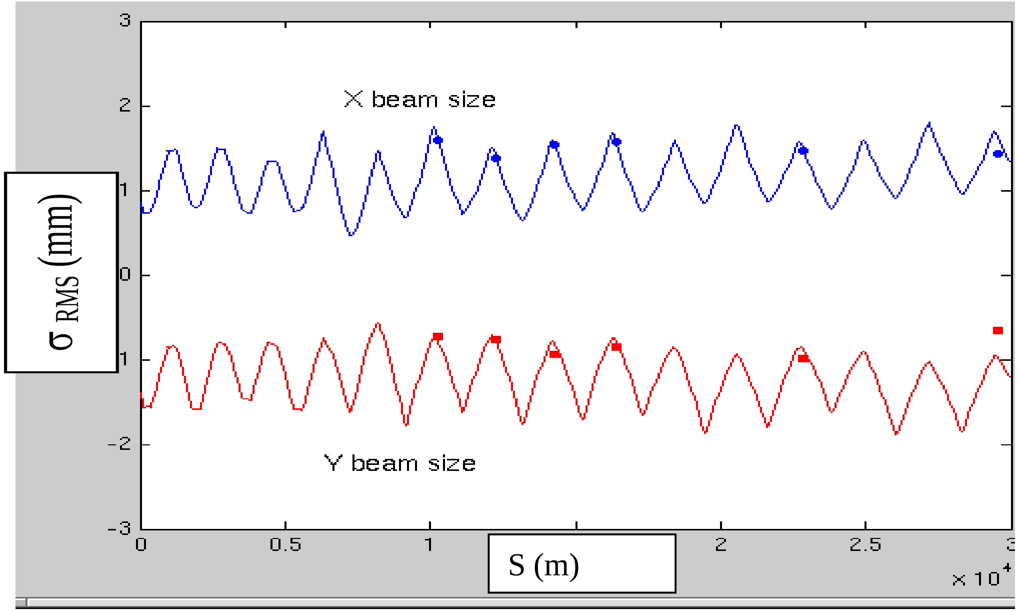


- Scan RF phase for multiple amplitude settings
- Solve for input beam energy, RF amplitude calibration, RF phase offset



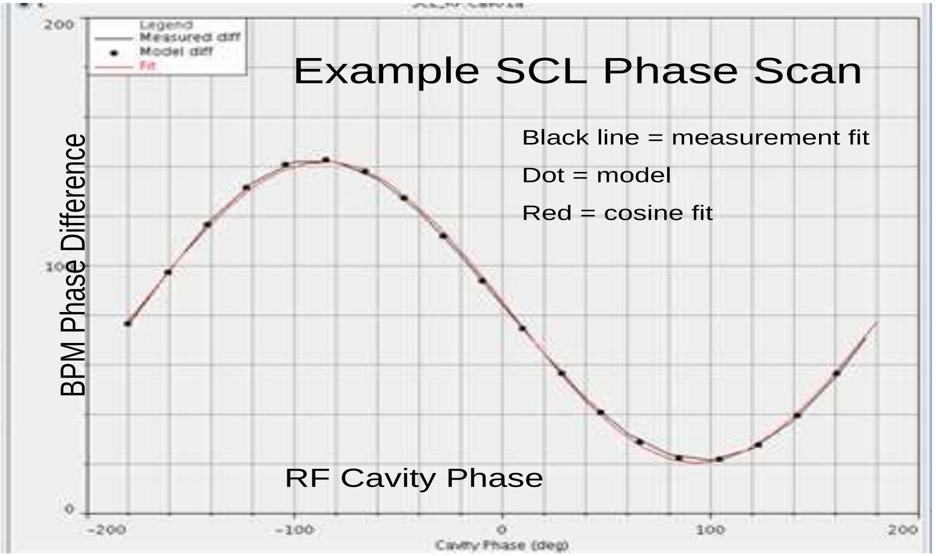
CCL tuning

- Set RF amplitude and phase for 4 moduless
  - Derive set points by fitting model to measured beam phase vs. cavity phase curve
  - Scan are done consequently one module at a time with all downstream cavities turned off
- Set 48 quads strengths
  - Use design values
  - Verify proper beam size
- Set 12 hor and 12 ver dipole steerers
  - for minimum beam centroid offset at 10 BPM locations



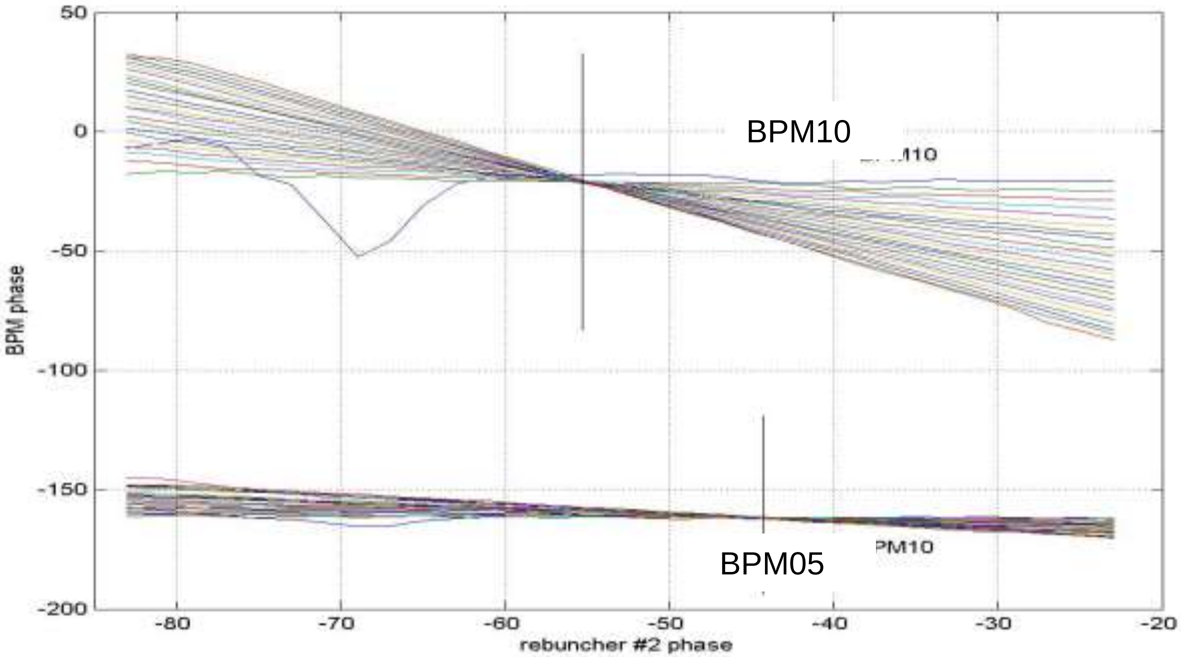
SCL

- **Set RF amplitude and phase for 81 cavities**
  - **Derive set points by fitting model to measured beam phase vs. cavity phase scan**
  - **Scan are done consequently one cavity at a time with all downstream cavities turned off**
- **Set 31 quad doublets strengths**
  - **Use design values**
  - **Beam size diagnostics is not available**
- **Set dipole steerers**
  - **for minimum beam centroid offset at BPM locations**



Ambiguities during the set up

- MEBT rebunchers phase
  - Resulting set point depends on BPMs selected for scan
  - (5º - 10º uncertainty)
- DTL, CCL phase and amplitude
  - Resulting set point depends on scan range and pair of BPMs selected for scan (<5º phase, <5% amplitude uncertainty)



Set up described above resulted in (I)

- Significant losses in CCL
  - Large trajectory deviation due to small number of BPMs per betatron period (<2) and unfortunate choice of phase advance between BPMs (~360º)
  - Used beam based method (“quad shaker”) to find beam transverse position in every quad
    - Effective but slow
  - Based on above information calculated quads and BPMs displacements, field calibration errors by fitting model to measured data
  - Use improved model for trajectory correction in CCL
    - Significantly reduced losses
    - Excellent agreement between model and BPMs

Set up described above resulted in (II)

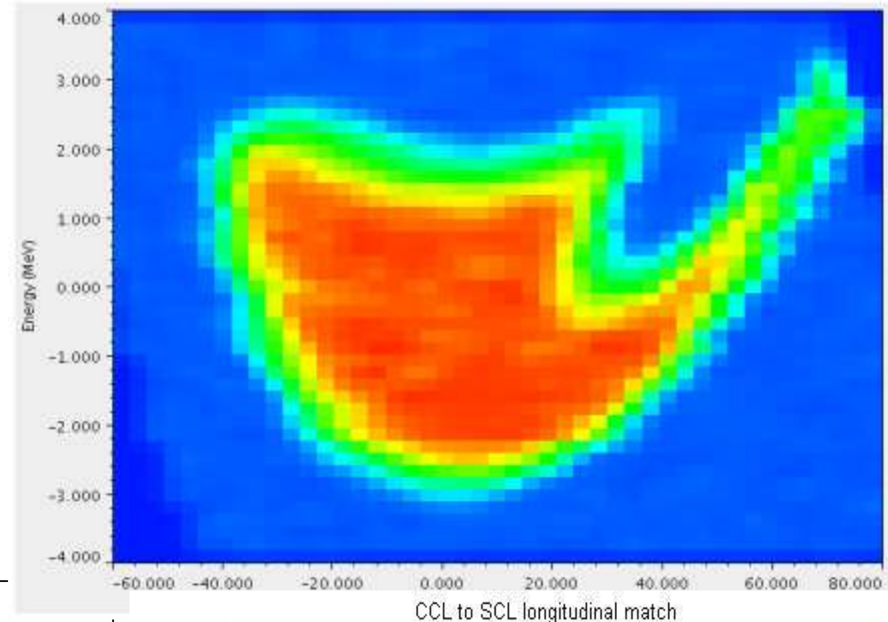
- Significant losses in SCL
- Not consistent with transverse losses
  - Almost independent on large trajectory variations
  - Weak dependence on quad settings
- Consistent with longitudinal losses
  - Strong dependence on SCL “phase law”
    - Have not found “right” “phase law” yet. Different variants produce about same loss results with proper tweaking
  - Strong dependence on warm linac phases
    - DTL6 shift of -6º from “nominal” provides spectacular reduction in SCL losses
- Unexpected and unexplained yet
- Prompted new look at longitudinal beam dynamics in the linac
- Lost beam fraction is at 1e-4 level
  - Below of reach of almost all linac diagnostics

Working theory of the day

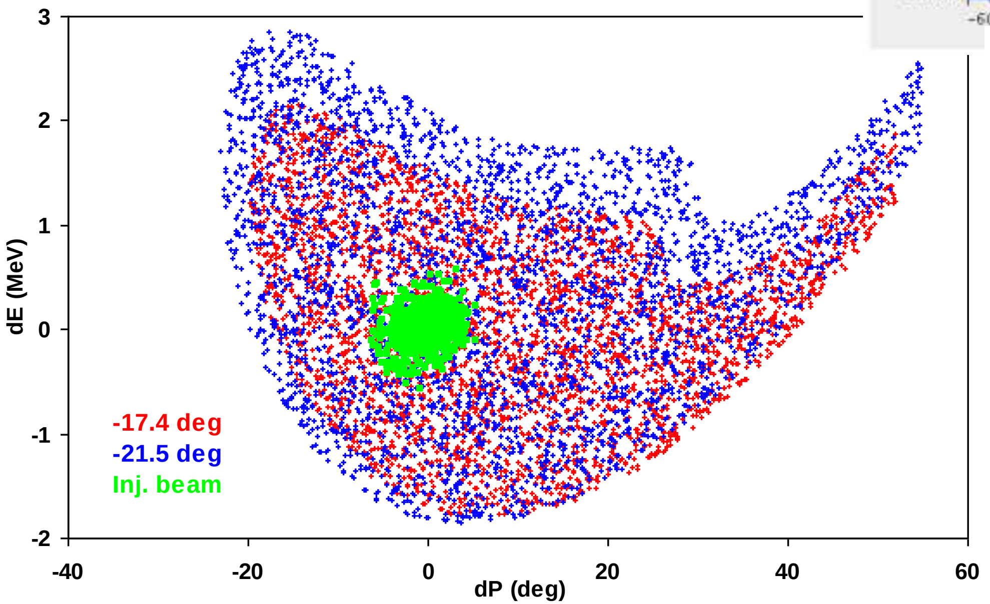
- Bunch coming out from warm linac has low level extended tails (halo) in longitudinal phase space
  - Originates in RFQ ???
  - Created in warm linac ???
- Distribution tail does not fit into SCL longitudinal acceptance
  - Acceptance is not large enough
  - Acceptance shape doesn't match incoming halo shape
- DTL6 phase shift effect
  - Moving CCL output distribution on phase-energy plane at SCL entrance to maximize overlap with SCL acceptance
- Mitigation possibilities
  - Reducing the halo
    - Verify validity of warm linac set points
    - Locate halo source ???
  - Increase SCL acceptance size
    - By good choice of "phase law"
    - By adjusting transverse focusing strength
- May be the remaining losses are due to stripping on residual gas and nothing can be done about it.

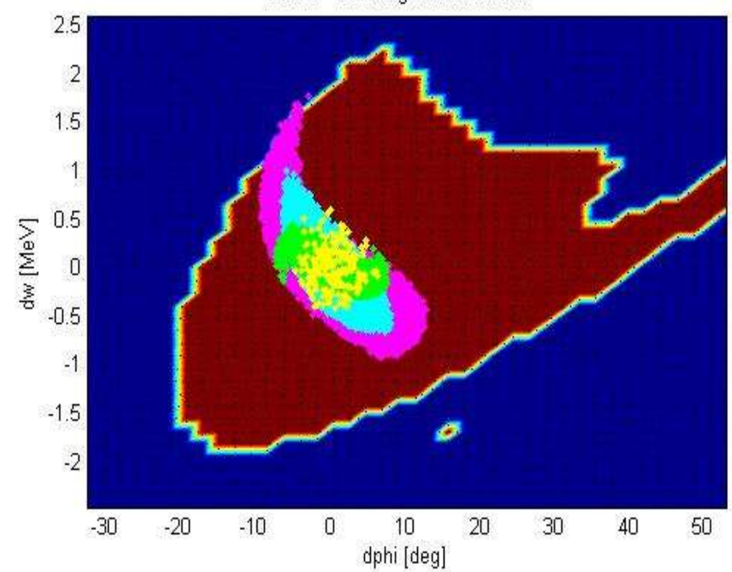
SCL acceptance (Y. Zhang)

Measured

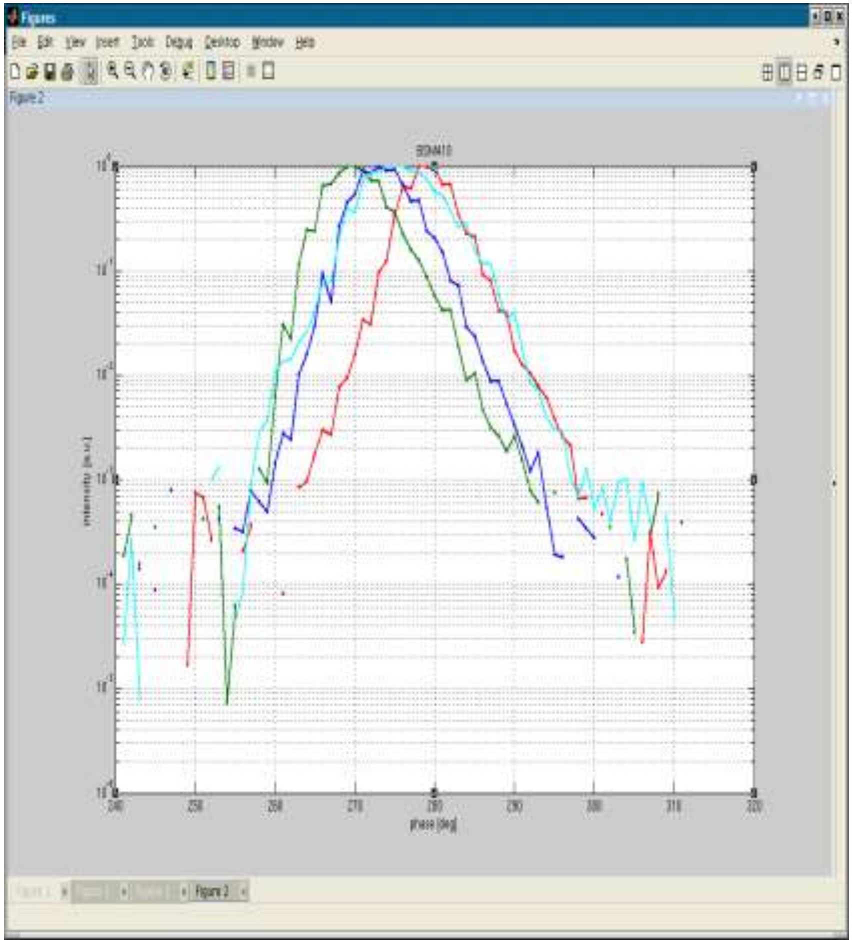


Simulated
two different "phase laws"

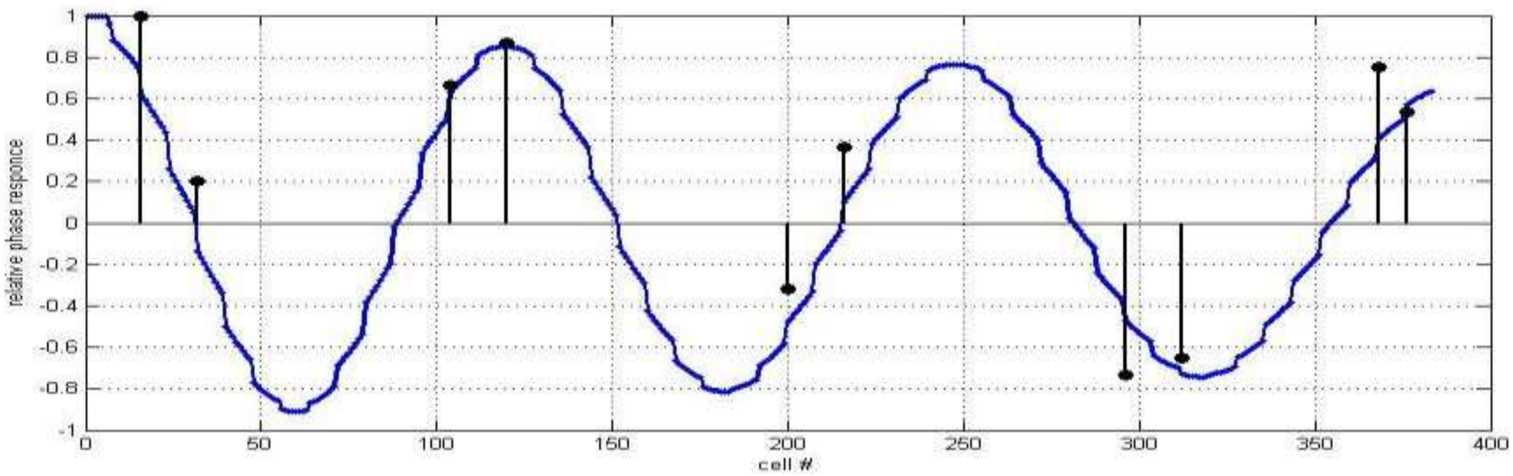


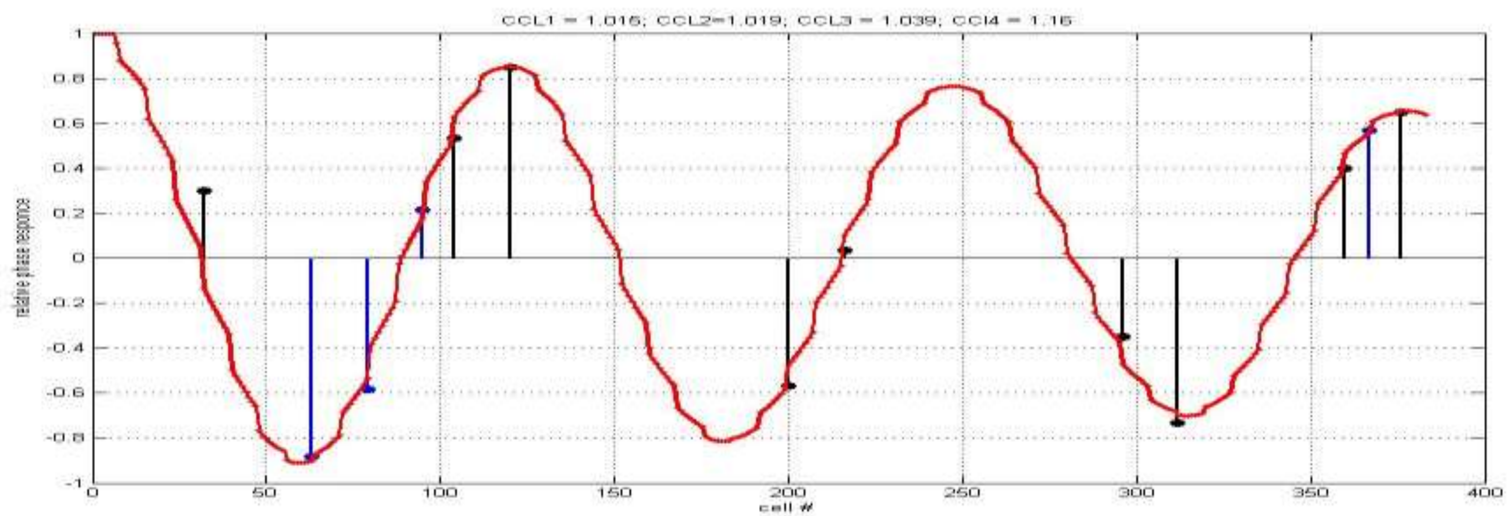


Longitudinal measurements at CCL exit



Measured vs. simulated bunch phase in CCL





Do we understand beam dynamic in our linac well enough?

- Requirements to good model:
  - Good agreement with measured RMS beam sizes
  - Can predict bunch centroid response on known transverse (dipole steerer) and longitudinal (phase shift) excitation
  - Can predict change of RMS size of bunch core in response to change of focusing element strength
  - Accuracy of agreement should be well within RMS size
- Accuracy of model and diagnostics both contribute
- Side note: problem of appropriate software. PARMILA is loosing support. There is no obvious replacement

Understanding of beam dynamics in different parts of the linac

	Transv. centroid	Transv. RMS	Long. centroid	Long. RMS
RFQ	?	not so good	?	?
MEBT	good	good	not so good	not so good
DTL	good	not so good	?	?
CCL	very good	not so good	not so good	not so good
SCL	not so good	?	very good	?

Do we understand halo?

- Expected in transverse plane – do not observe
  - Not running at nominal peak current yet
  - DTL serves as a collimator?
    - Do not have reliable information on losses inside DTL
- Did not expect in longitudinal plane
  - Very low level
  - Have only limited direct diagnostics tools in CCL
- Problem of initial distribution for simulations
  - “reference” distribution used at design stage is not adequate

Conclusions

- We have a very well operating linac
- We have tuning algorithms producing accurate RF set points (in case of SCL) or close enough (in case of warm linac)
  - Healthy margin for errors is manifestation of good linac design
- We have been able to reduce losses by combination of conscious decisions and blind tweaking to very low levels close to design requirements
- We do not have precise understanding of beam dynamics in whole linac but have good understanding in some parts and continuously improving in others
  - Our priority is minimizing losses during production
- The highest priority for the nearest future is longitudinal dynamics study in CCL – SCL area
  - Why CCL RF set points are not very accurate
  - What is source of longitudinal halo
  - How to maximize SCL acceptance
- There is a long list of study to do
  - Need beam time