UT-BATTELLE

Experience from the Spallation Neutron Source Commissioning

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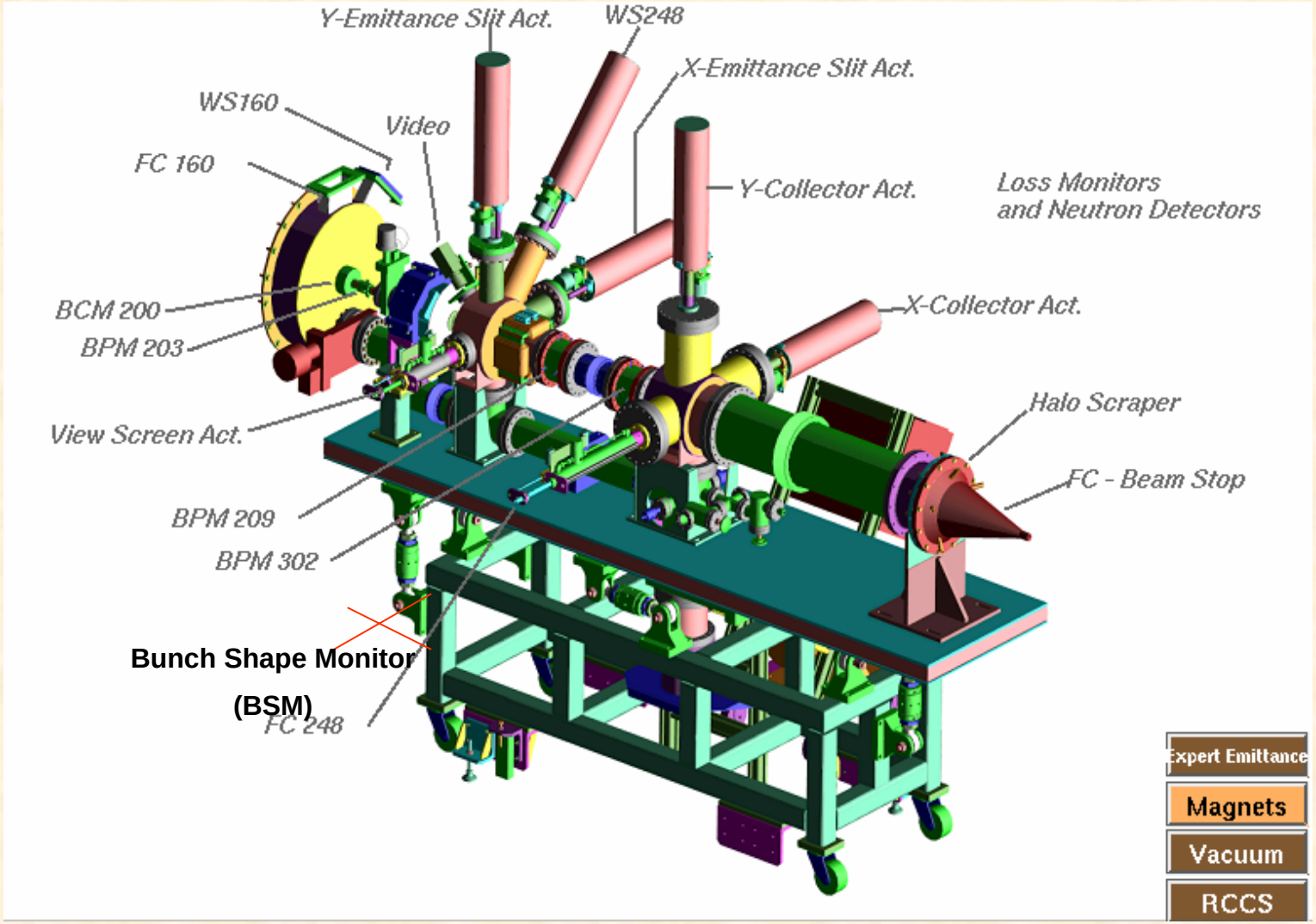
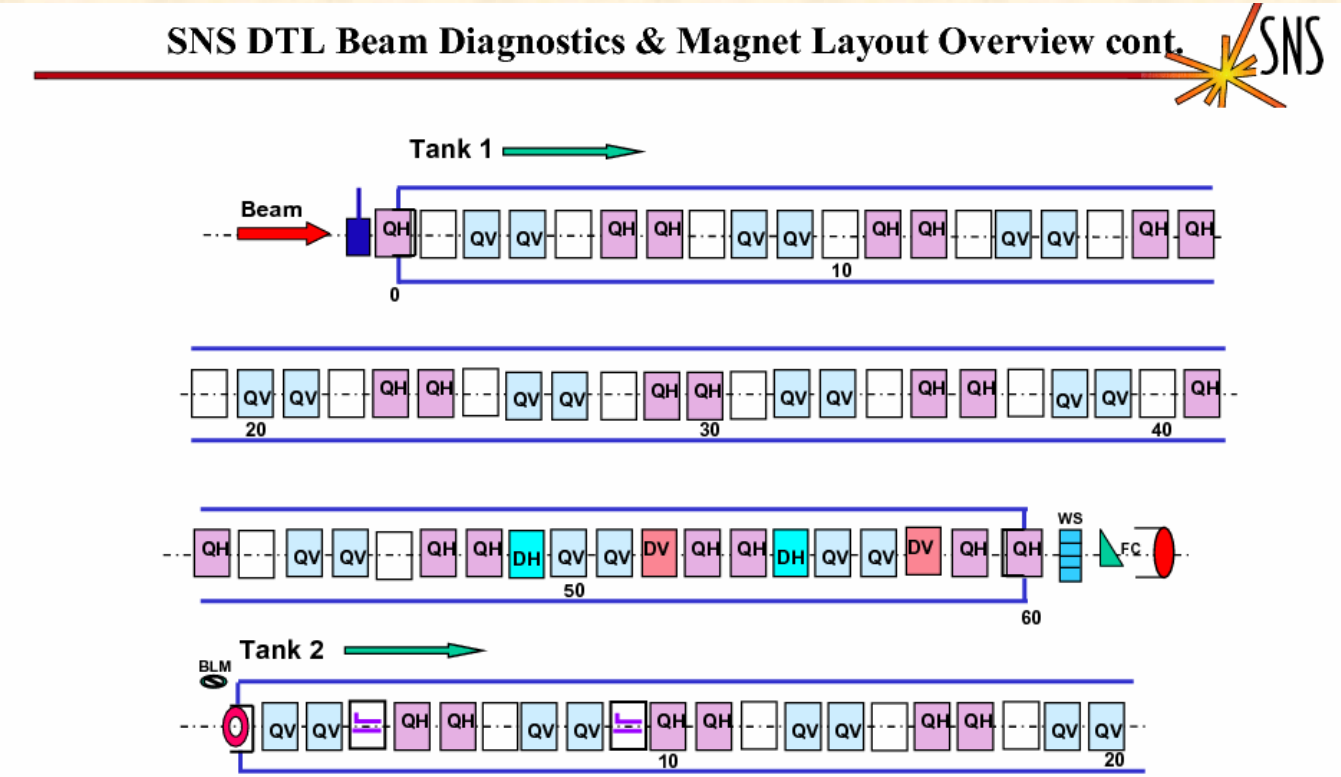
U. S. DEPARTMENT OF ENERGY

Diagnostics on Diagnostics-plate used for commissioning DTL Tank 1



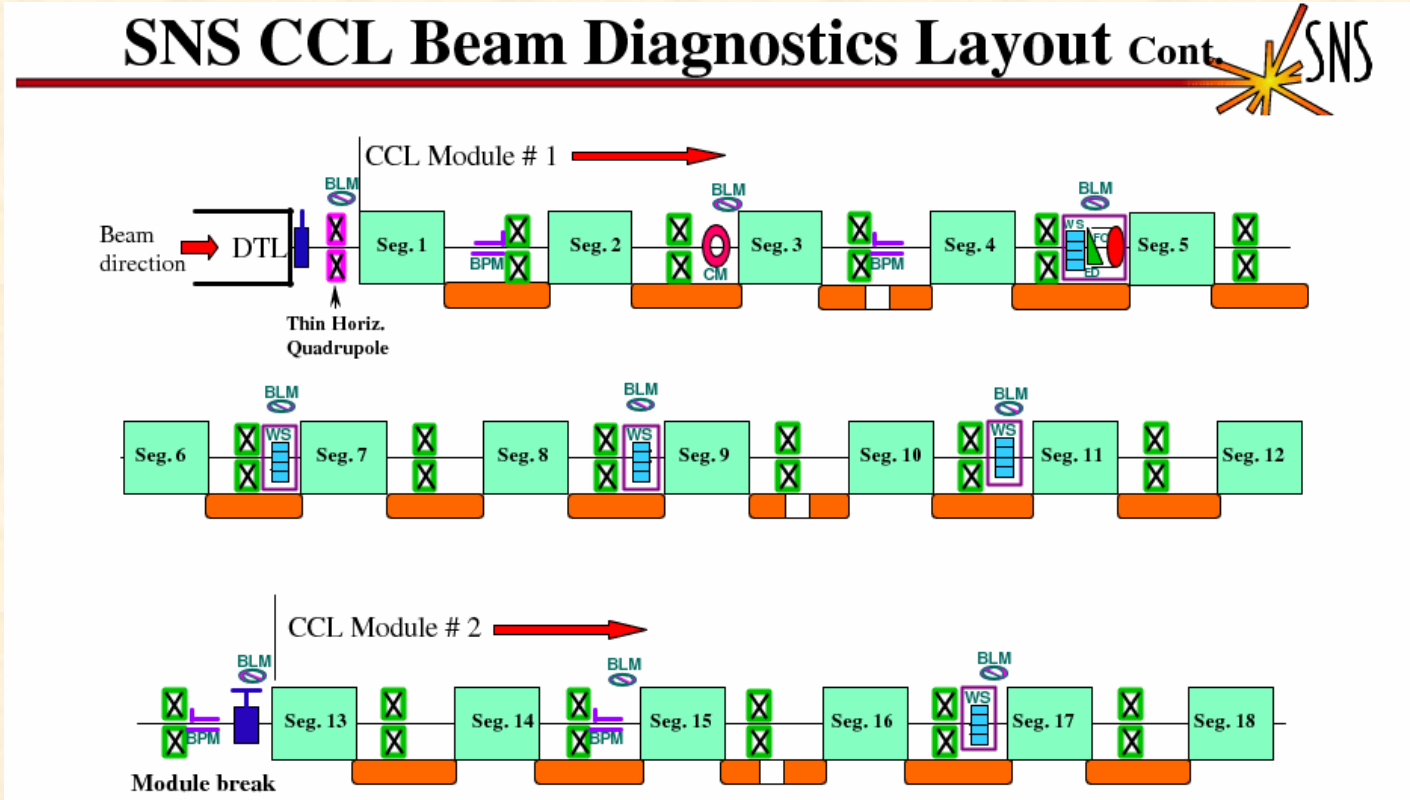
Bunch Shape Monitor installed 50 inches downstream of DTL1

DTL diagnostics devices



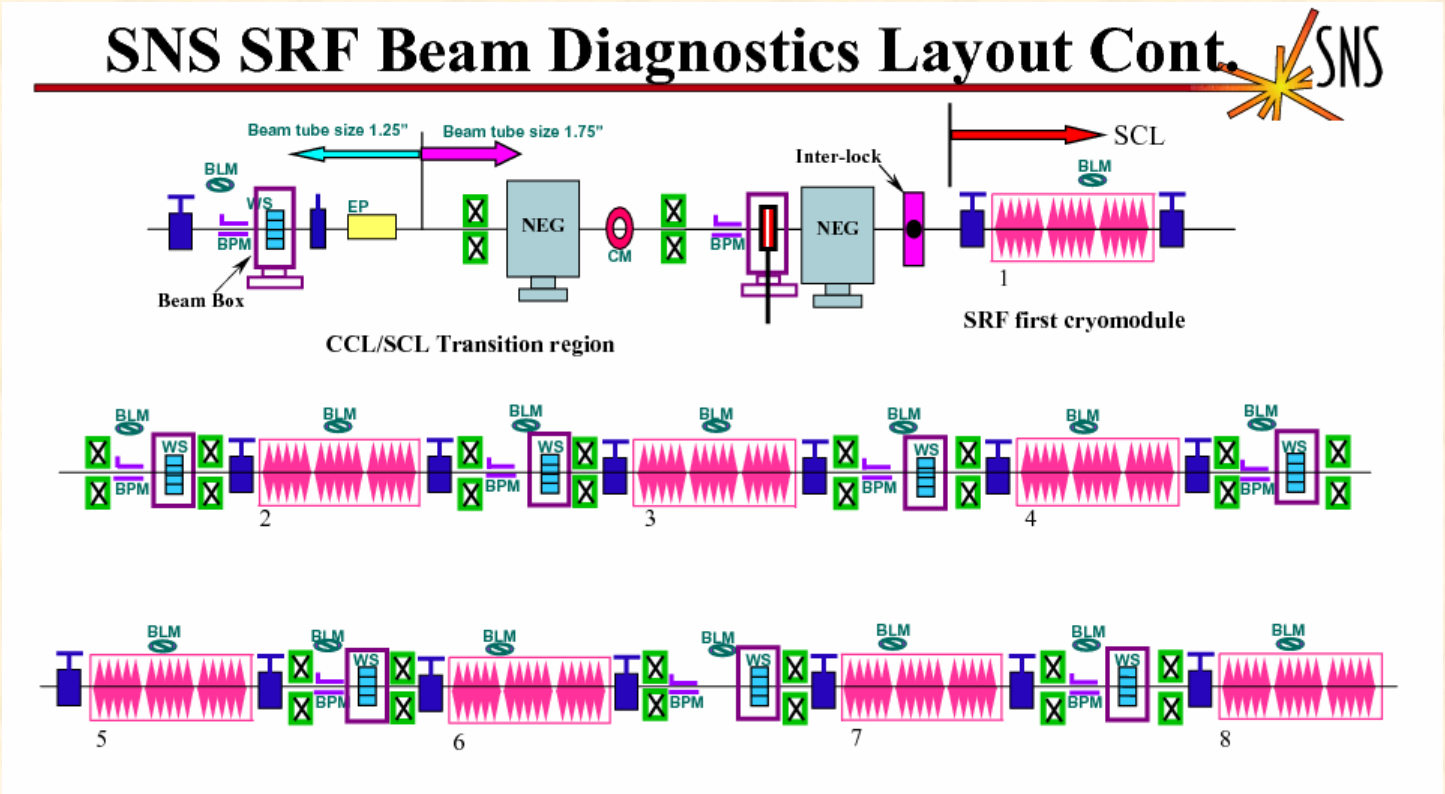
- **Wire-scanners**
- **Beam Position Phase Monitors**
- **Energy Degrader / Faraday Cup**
- **Beam Loss Monitors**
- **Beam Current Monitors**

CCL diagnostics devices



- **Wire-scanners**
- **Bunch Shape Monitors (Z-profile)**
- **Beam Position Phase Monitors**
- **Beam Loss Monitors, Neutron Detectors**
- **Beam Current Monitor**

SCL diagnostics devices



- **Laser Profile Monitors**
- **Beam Position Phase Monitors**
- **Beam Loss Monitor, Neutron Detectors**
- **Beam Current Monitor**
- **Bunch Shape Monitor will be installed.**

Emittance scanner is most valuable

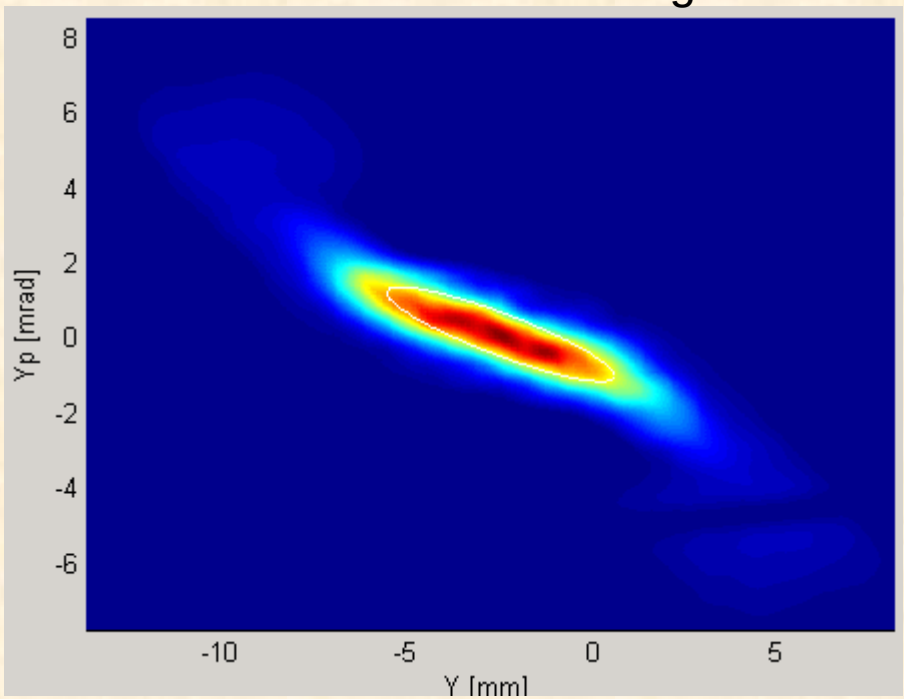
- **Provides direct information about beam quality.**
- **Can perform transverse matching.**
- **Essential for physics studies, providing decisive information of interesting mechanisms.**

Wire-scanners and Laser Profile Monitors

- **Provide information about beam profile.**
- **Limited compared with emittance scanner**
- **Can perform transverse matching.**
- **Laser Profile Monitors commissioned, almost ready…**

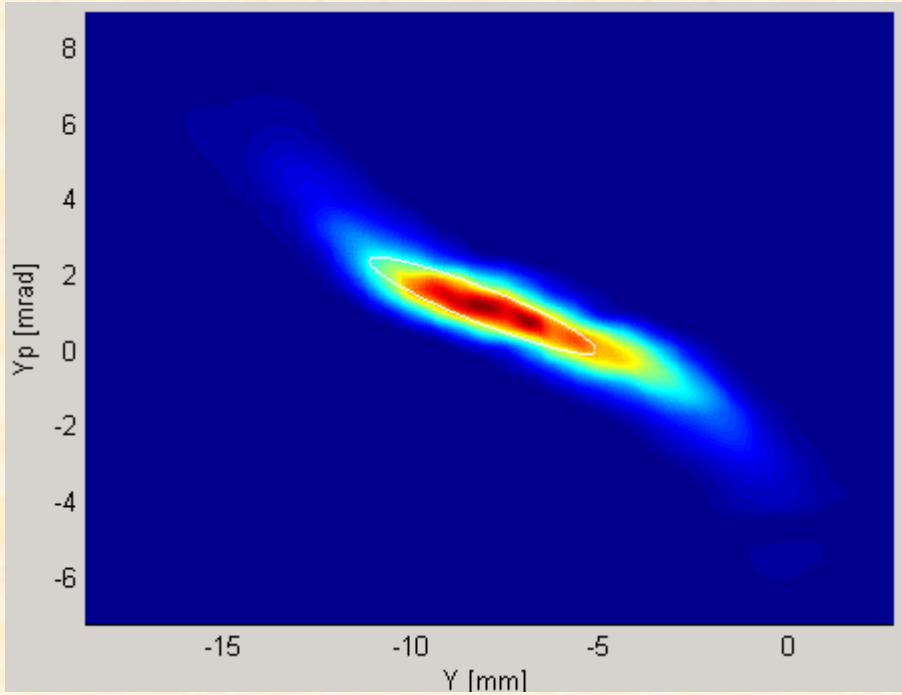
Transverse matching by minimizing rms emittance @ 38mA, nominal optics

Before Matching



- RMS with 1% threshold: 0.42 mm mrad
  0% threshold: 0.50
- Gaussian fit to core: 0.23

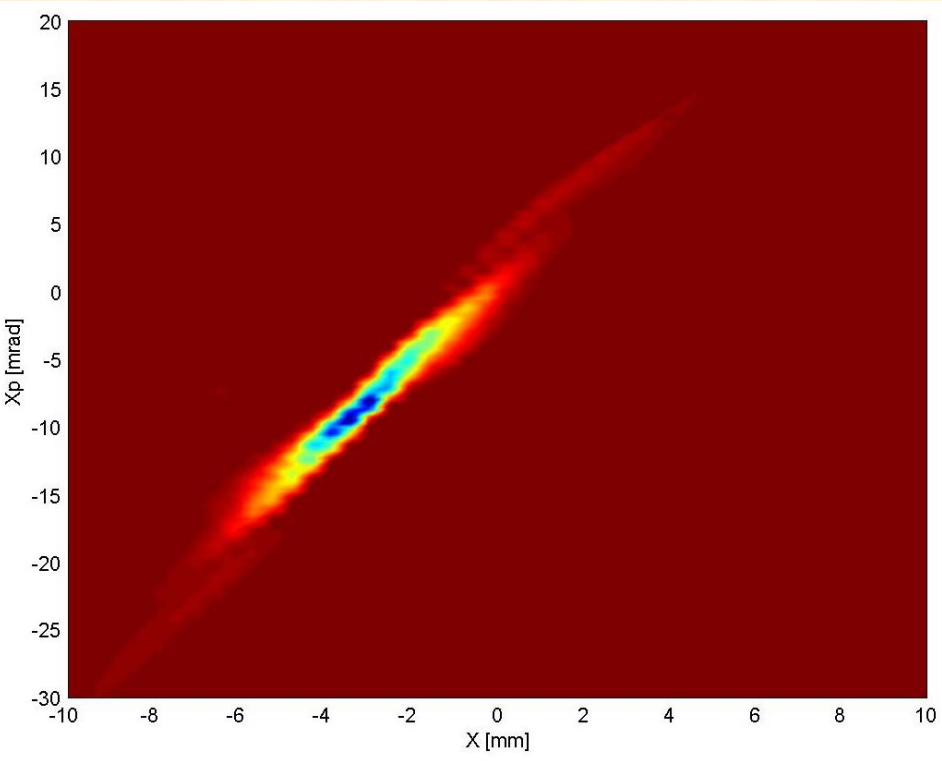
After Matching



- RMS with 1% threshold: 0.31
  0% threshold: 0.39
- Gaussian fit to core: 0.19

	design	before	after
QH12:	-25.96 T/m	-26.12 T/m	-28.31 T/m
QH14:	-18.50 T/m	-17.31 T/m	-16.86 T/m

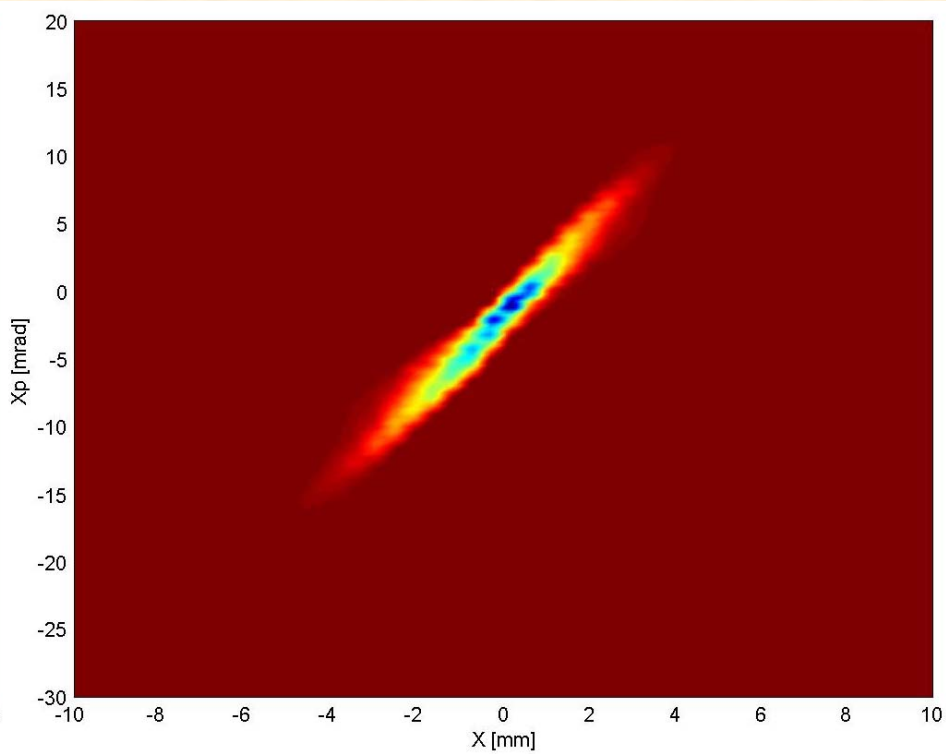
Round Beam Optics improves X beam quality (Emittance Measurement)



Nominal Optics

ε_X= 0.349 mm-mrad (1% threshold)

0.454 mm-mrad (0% threshold)



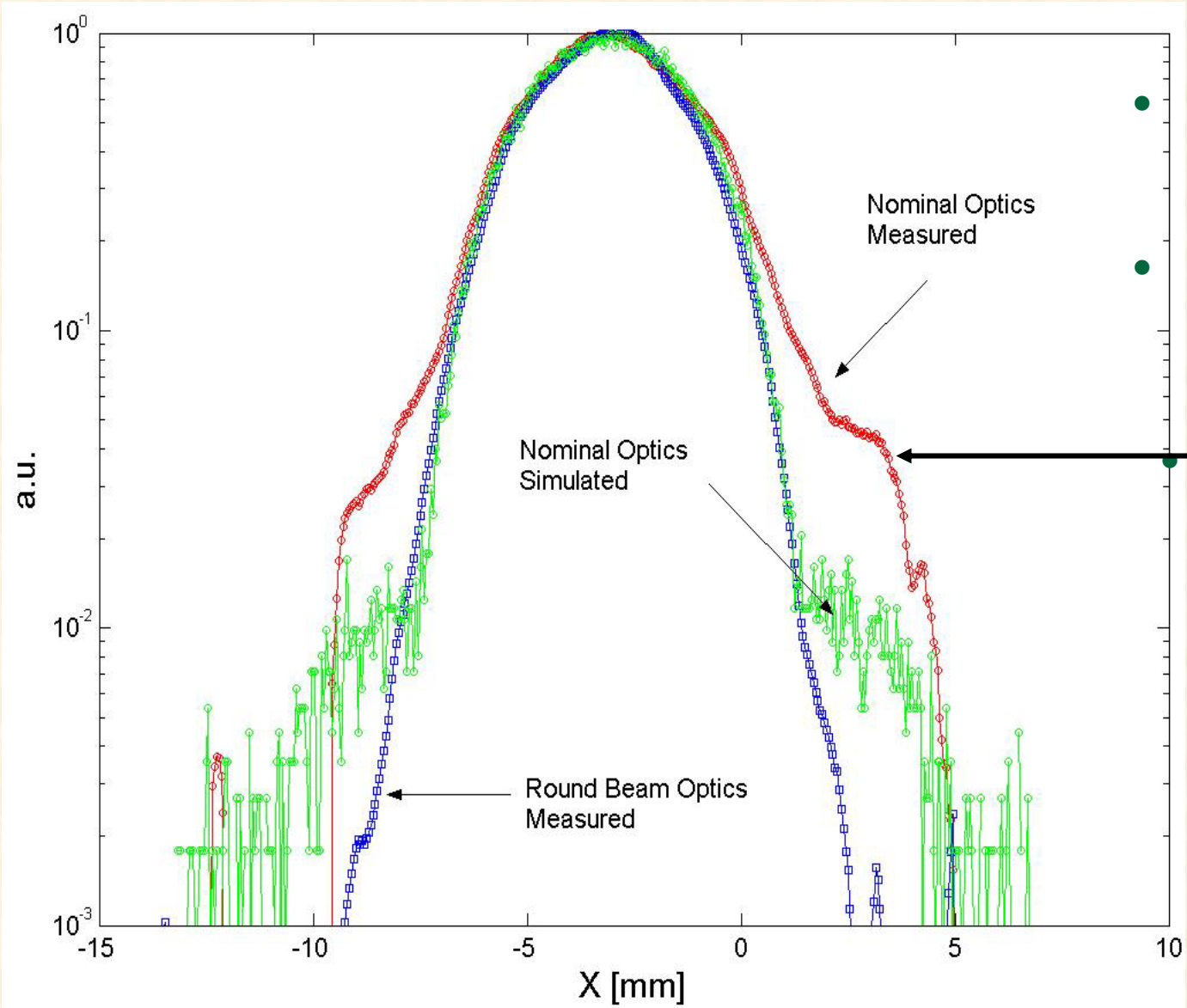
Round Beam Optics

ε_X= 0.231 mm-mrad (1% threshold)

0.289 mm-mrad (0% threshold)

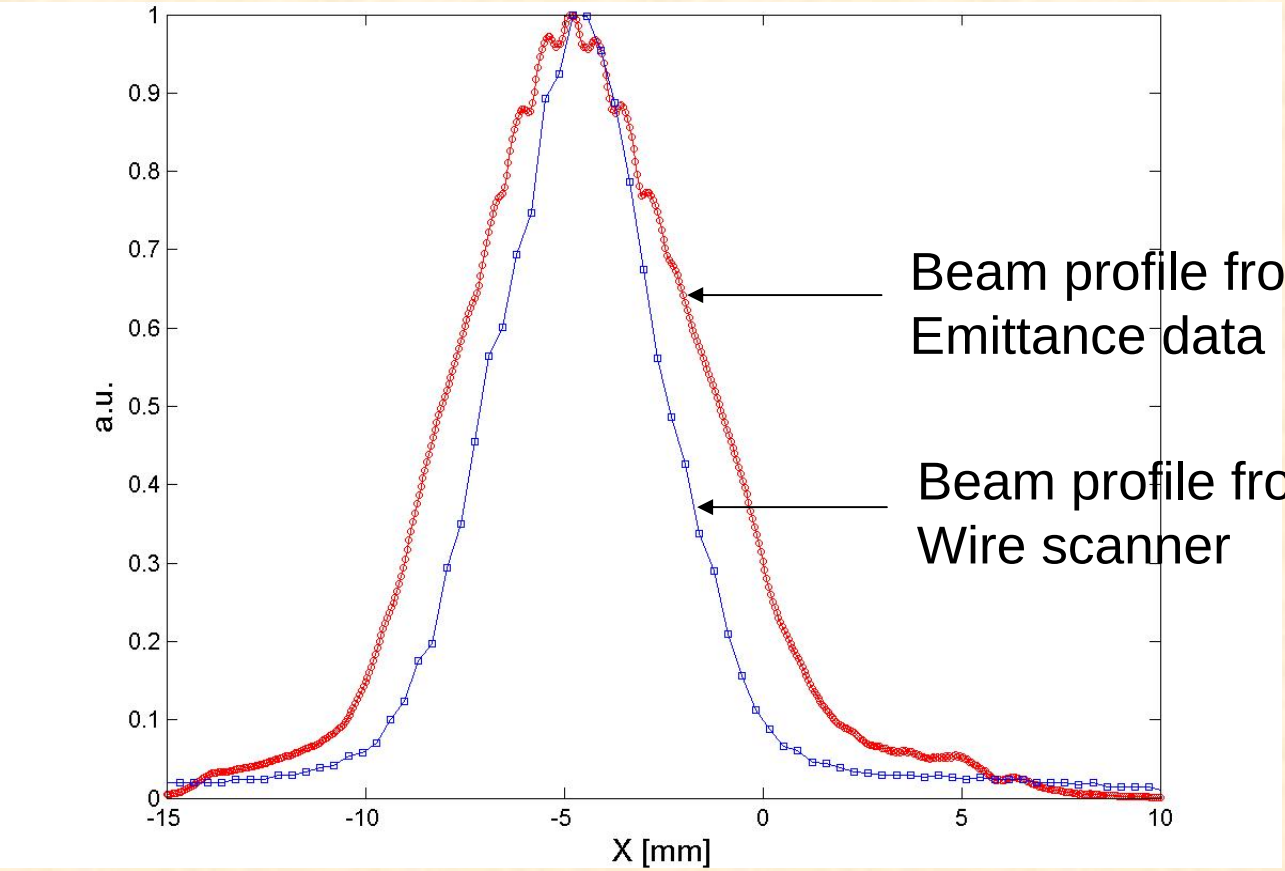
- **Round Beam Optics reduces halo and rms emittance in X significantly**

Tail is significantly reduced in X plane for Round Beam Optics



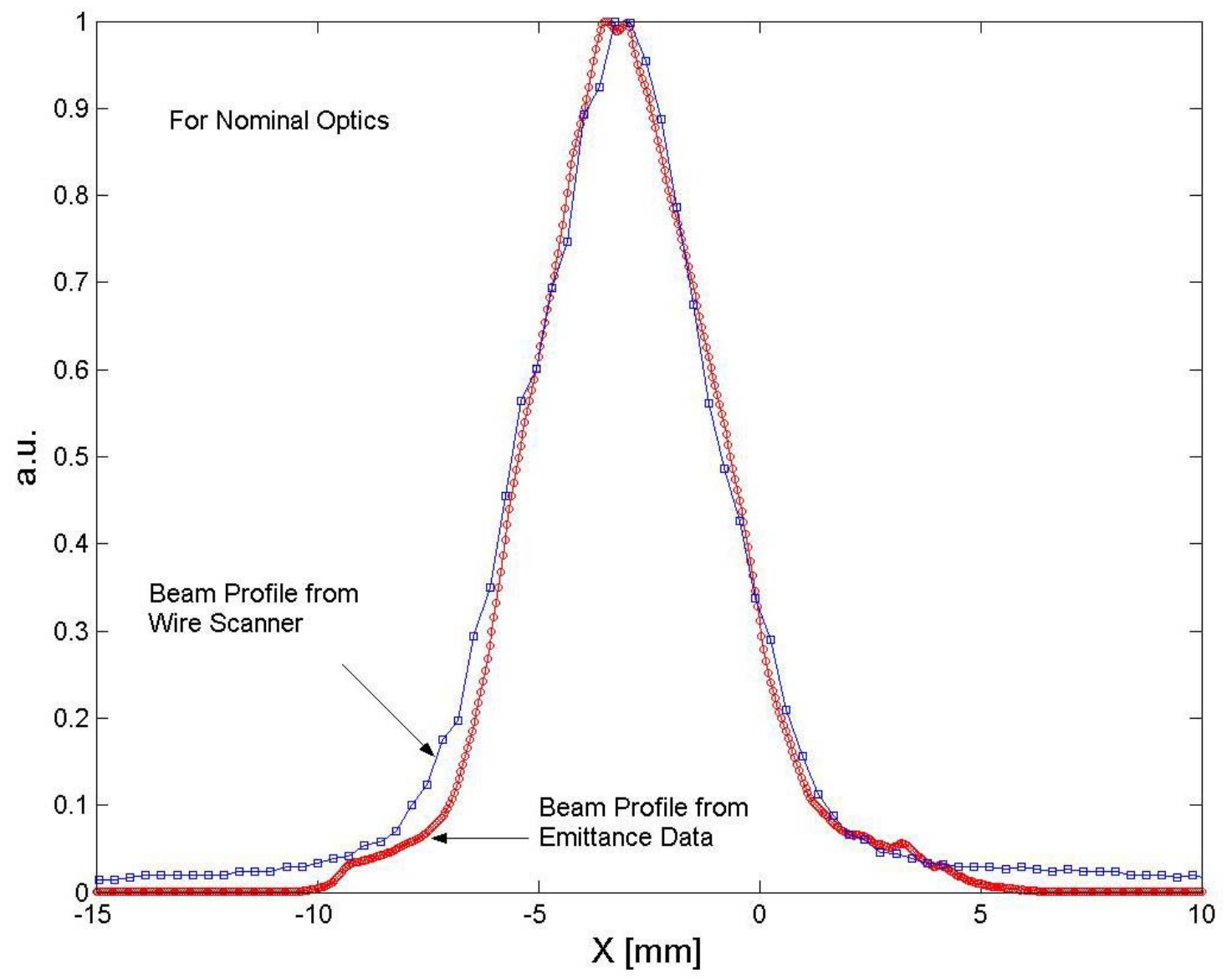
- **Round Beam Optics reduces beam tail visibly**
- **Rare measurement data with no tail!**
- **Tail is the source of beam loss**

Redundant diagnostics matters
emittance data and wire-scanner

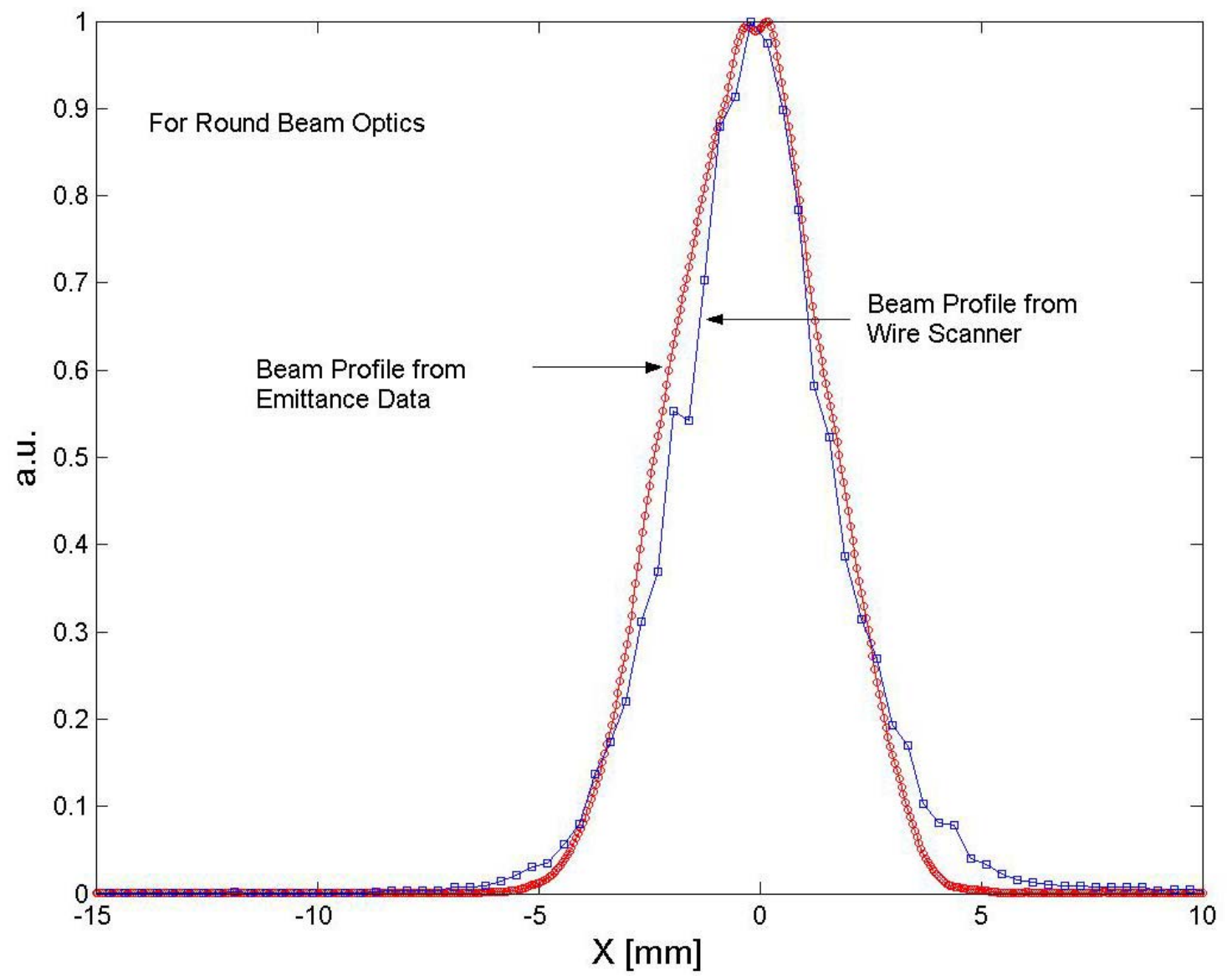


- **X beam size from emittance data is ~1.5 times bigger than that from wire scanner data.**
- **Y beam size from emittance is consistent with that from wire scanner data.**

Comparison of beam profile from emittance data and wire-scanner

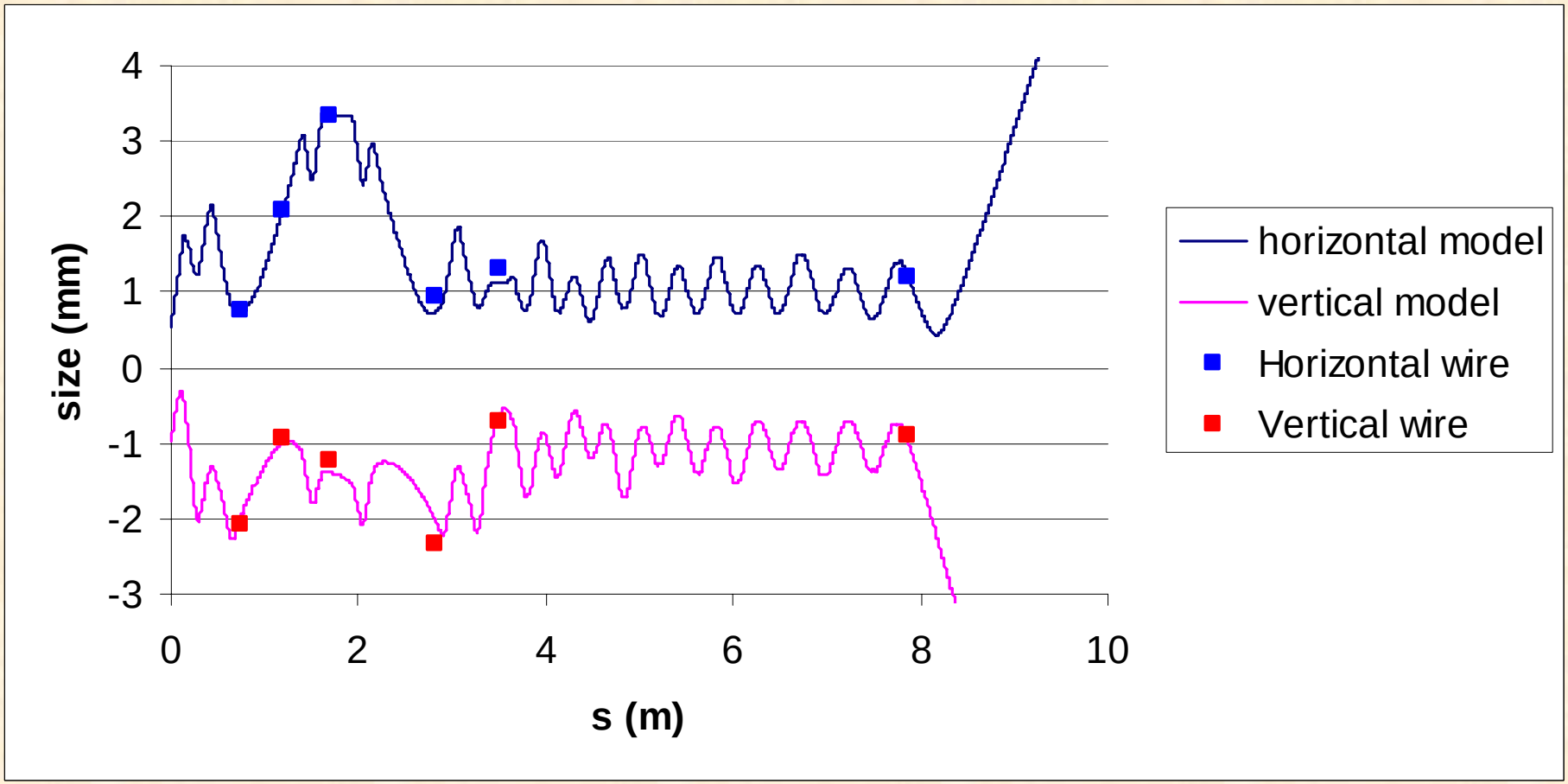


Comparison of beam profile from emittance data and wire-scanner



Comparison of Measured Beam Profiles with Model

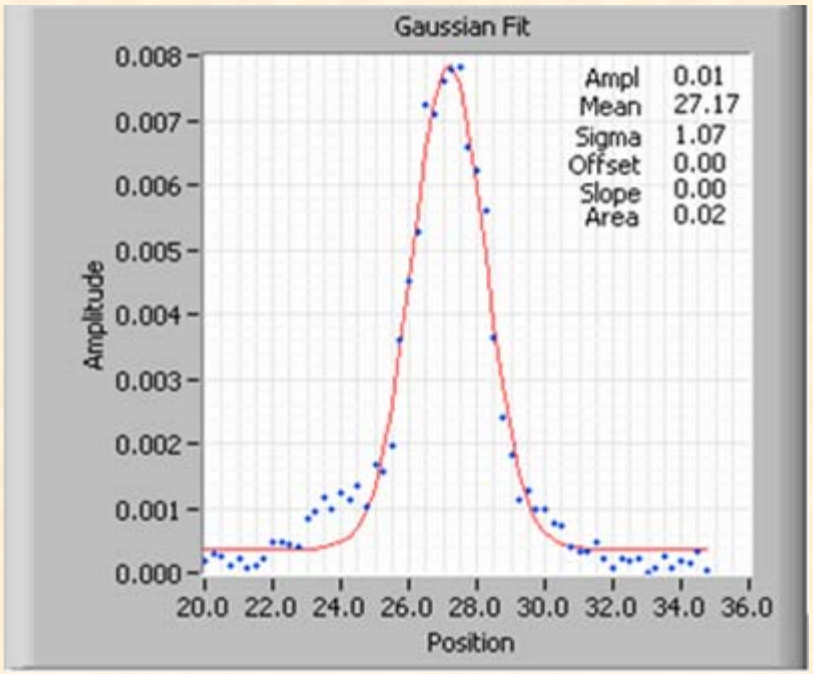
- Fit of starting twiss to beam profiles using online model delivers matched beam in DTL



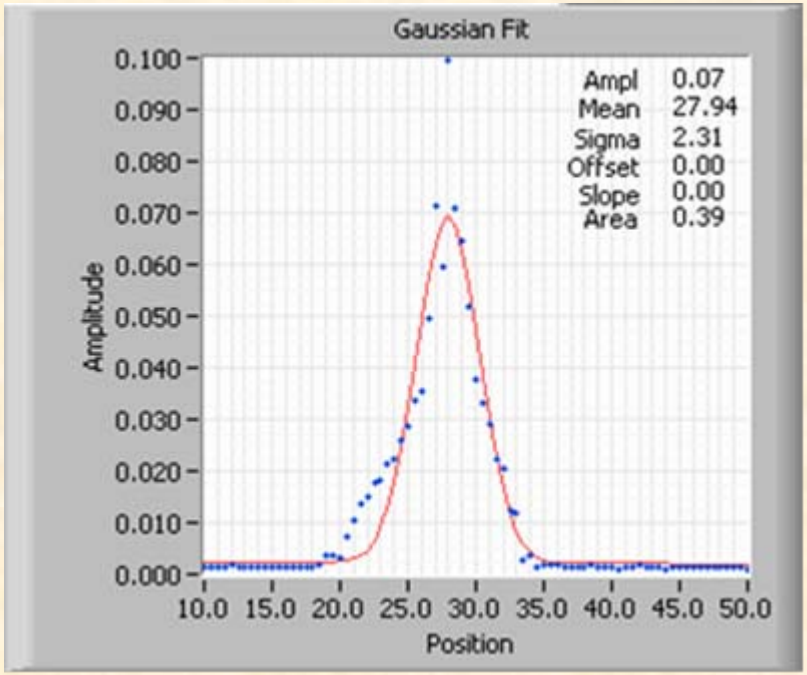
Laser Profile Monitor

Courtesy of S. Assadi et al

- **This is a new way of diagnosing the transverse profile of an H- beam.**
- **R&D, implementation, and commissioning at the same time!!**



LW04 Hor. 30 steps at 0.5mm each. analysis: average. time: 10:58

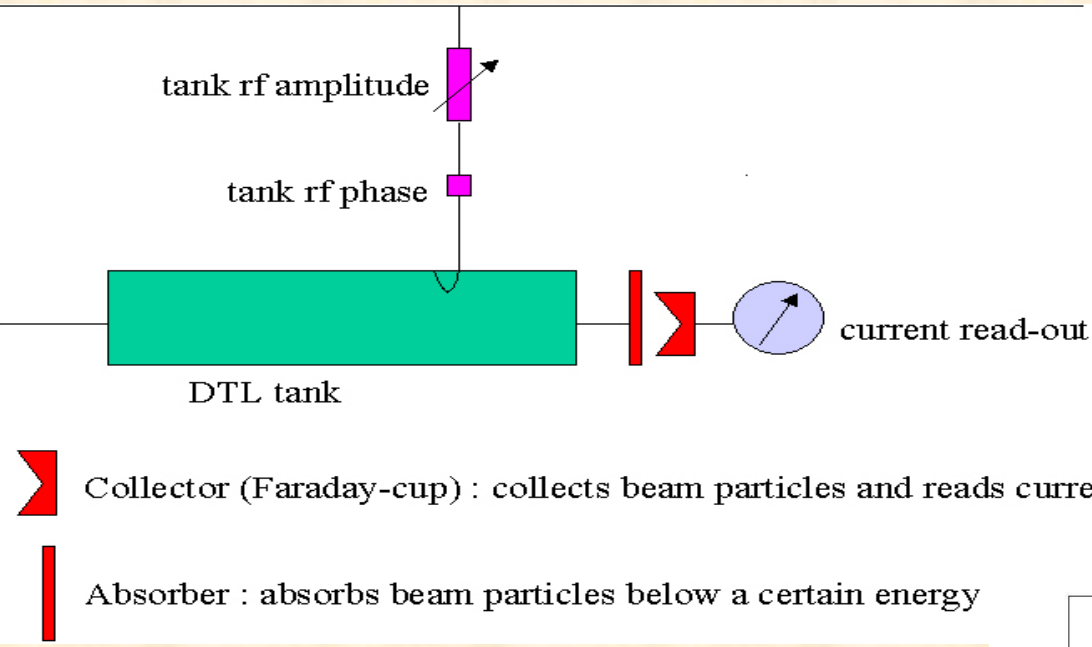


LW04, vertical, quads at nominal setting

Beam Phase Monitors and Energy Degrade/Faraday Cup

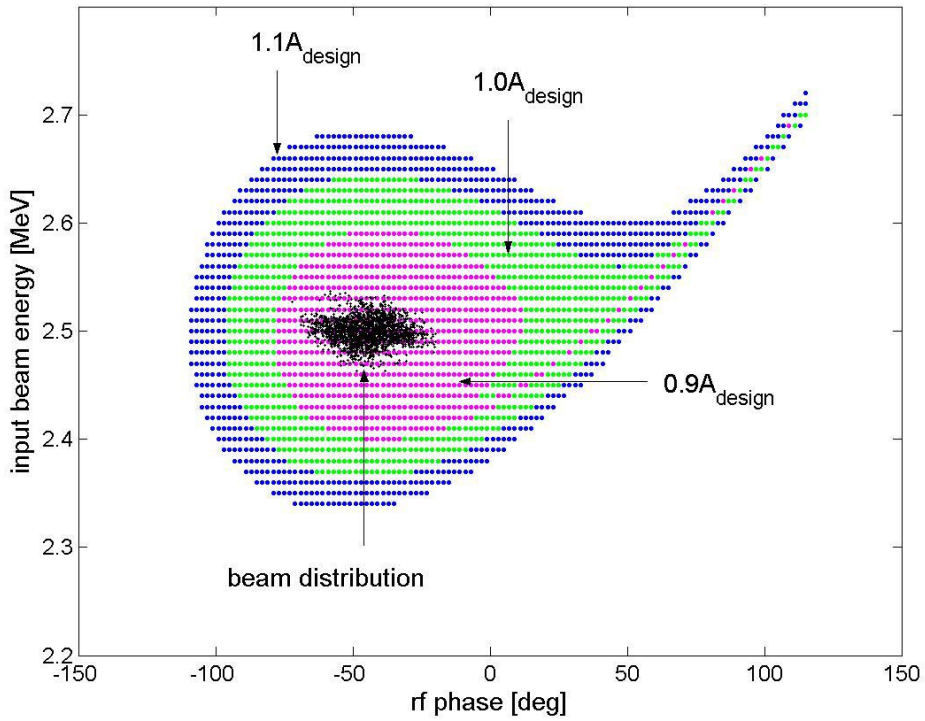
- **Beam Phase Monitors can provide information about tank rf amplitude, phase (A, ϕ) and incoming beam energy deviation ΔE**
- **ED/FC generally can not determine ΔE**
- **ED/FC gives information of longitudinal beam profile.**

Acceptance Scan for DTL

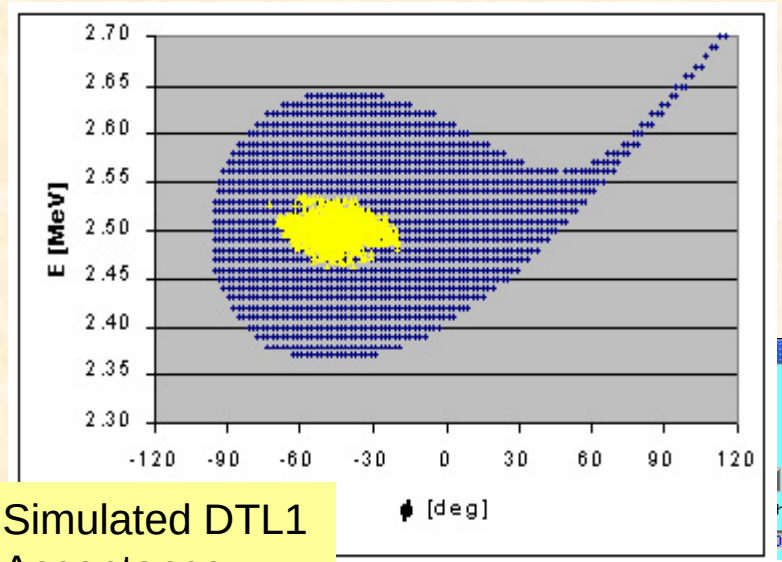


- **Results depend on incoming beam energy ΔE**
- **Acceptance Scan technique generally can not determine ΔE**

Acceptance of DTL Tank 1

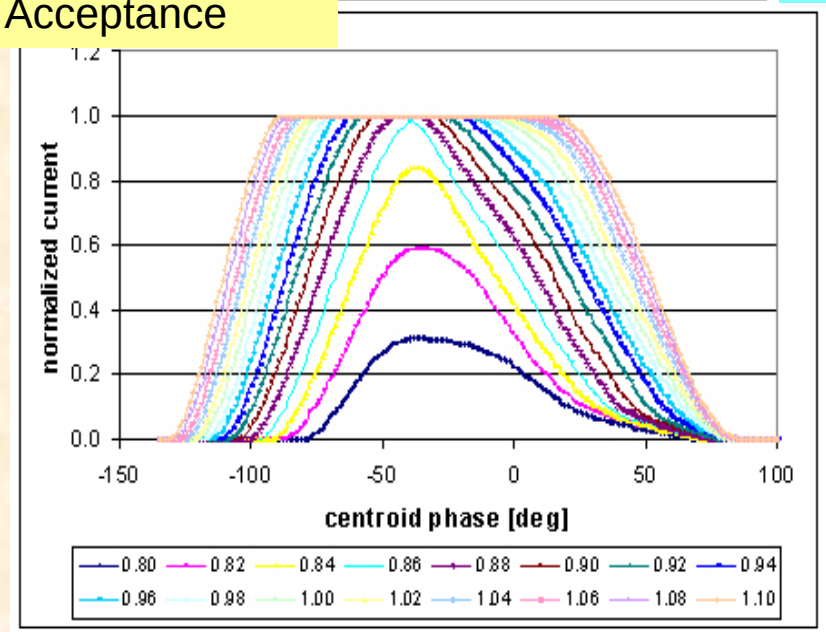


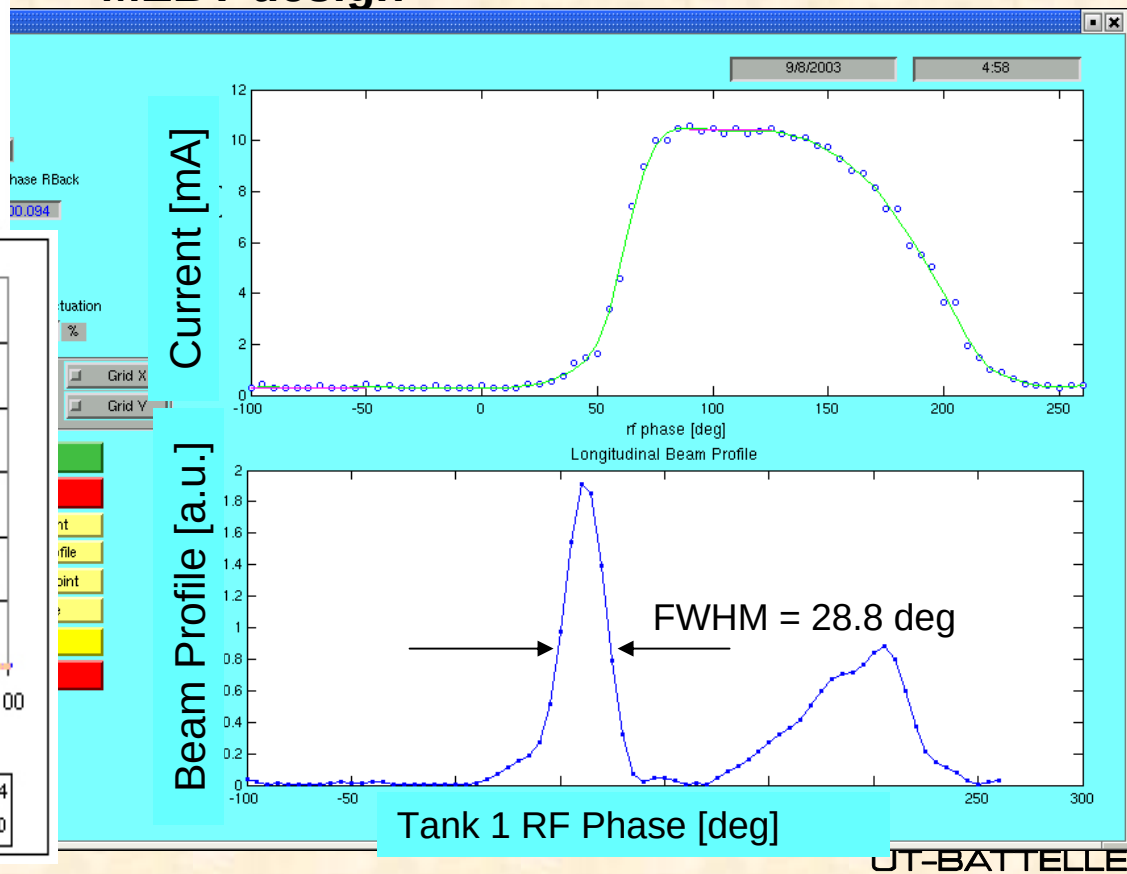
DTL tanks rf set-point by Acceptance Scan with Absorber/Collector



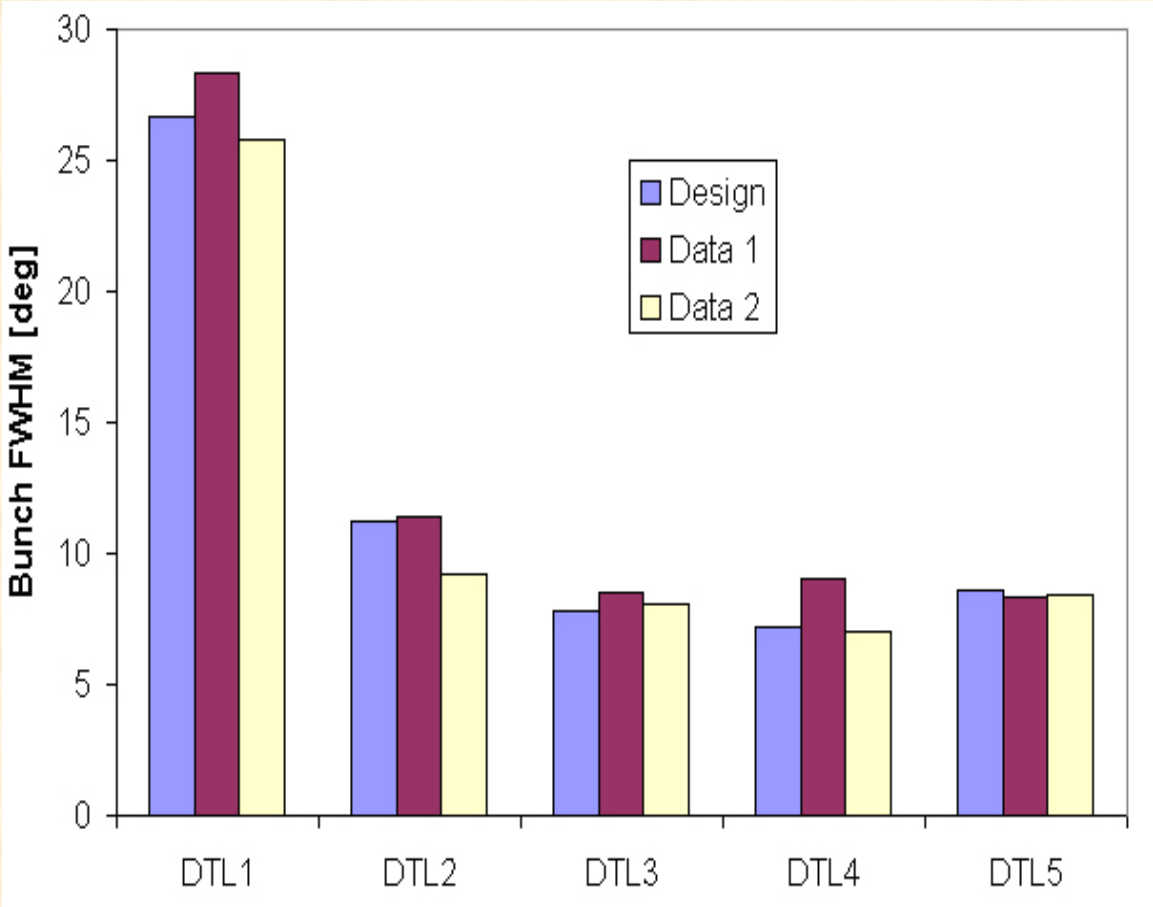
Simulated DTL1 Acceptance

- **Measurements consistent with simulations**
- **Used to establish proper amplitude and phase setpoints**
- **Measured bunch width consistent with MEBT design**



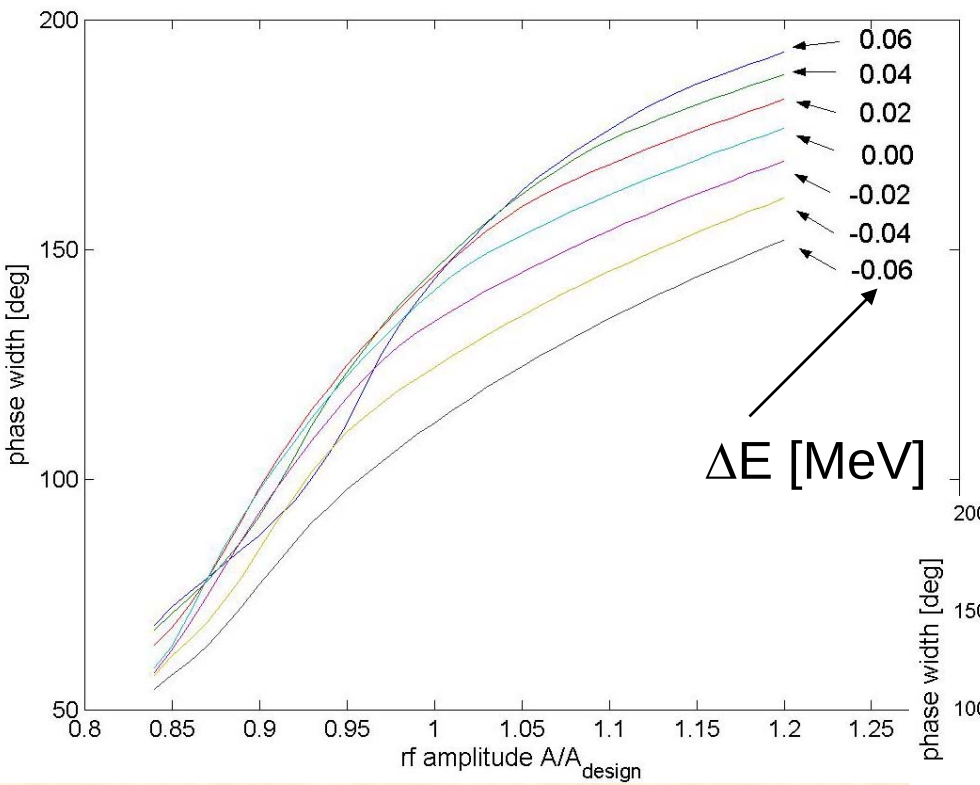


Beam bunch length at the entrance of DTL tanks obtained from Acceptance Scans

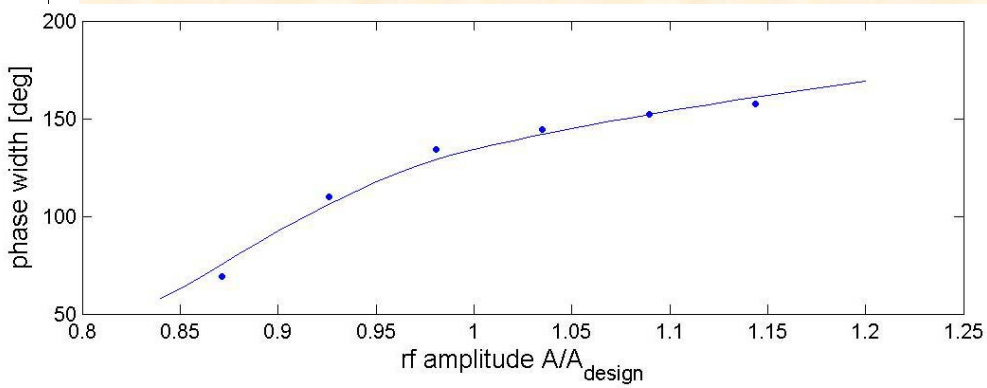


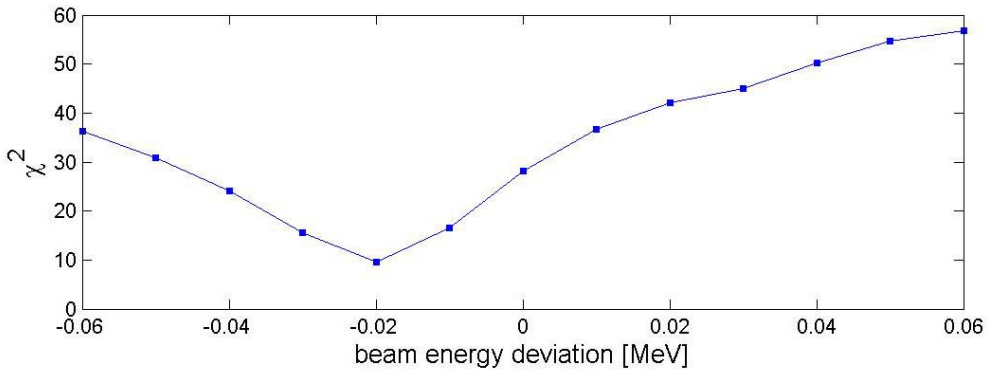
- **Z beam size @ DTL 1 entrance is consistent with model 28.8 deg vs. 26.7 deg FWHM.**
- **Z beam size remains consistent with the model beam distribution we used.**

Acceptance Scan generally can not determine ΔE

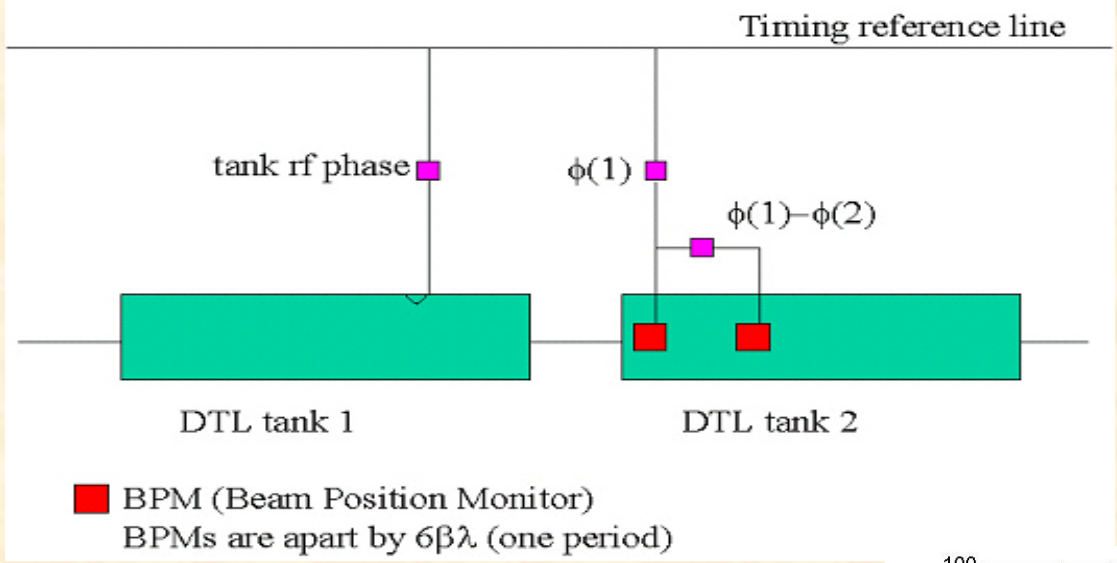


- **Only DTL Tank 1 shows variations enough to detect the incoming beam energy deviation ΔE**
- **Data noisy!**





Multiparticle Phase Scan for DTL

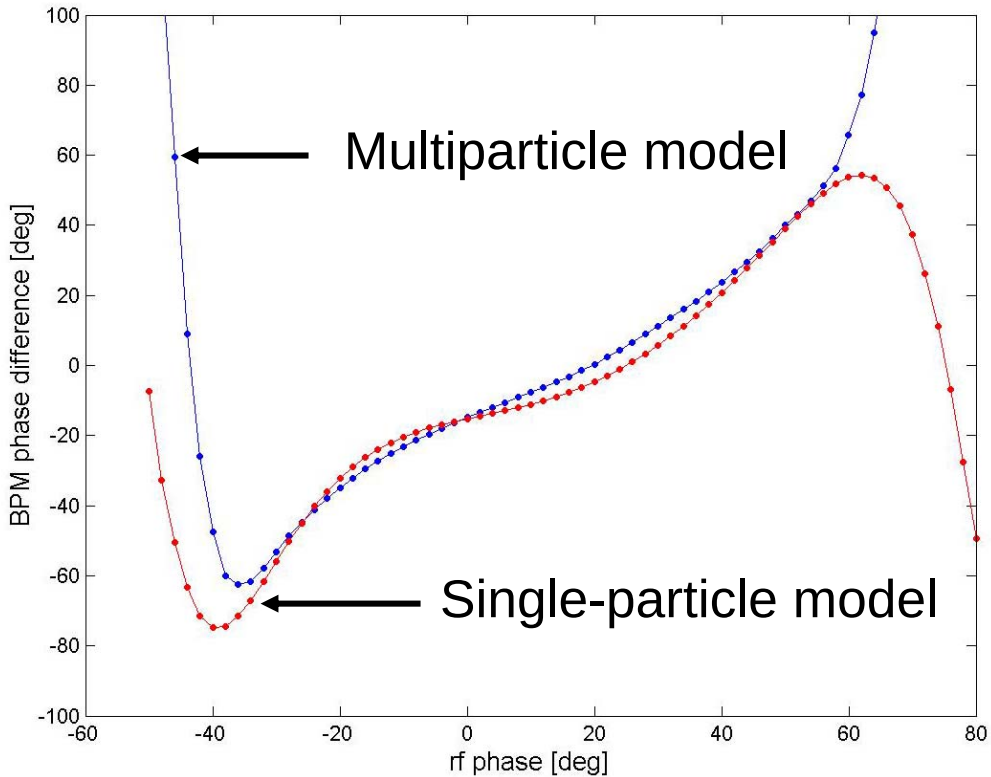


Schematic drawing

Why Multiparticle Phase Scan?

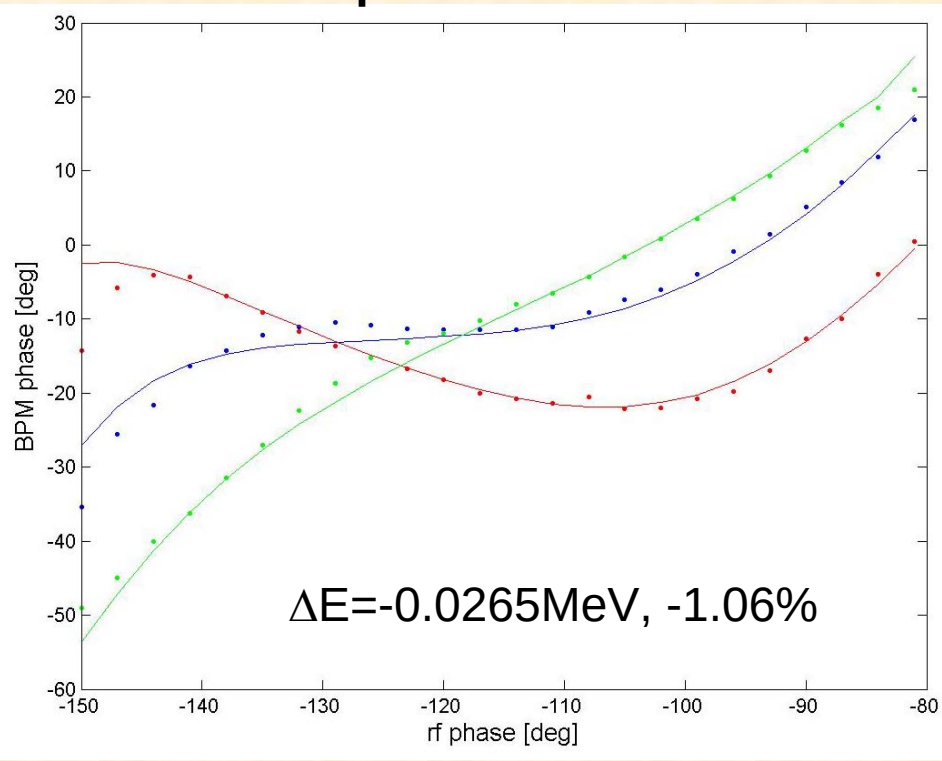
When beam bunch is long,

Single particle tracking is not accurate enough.



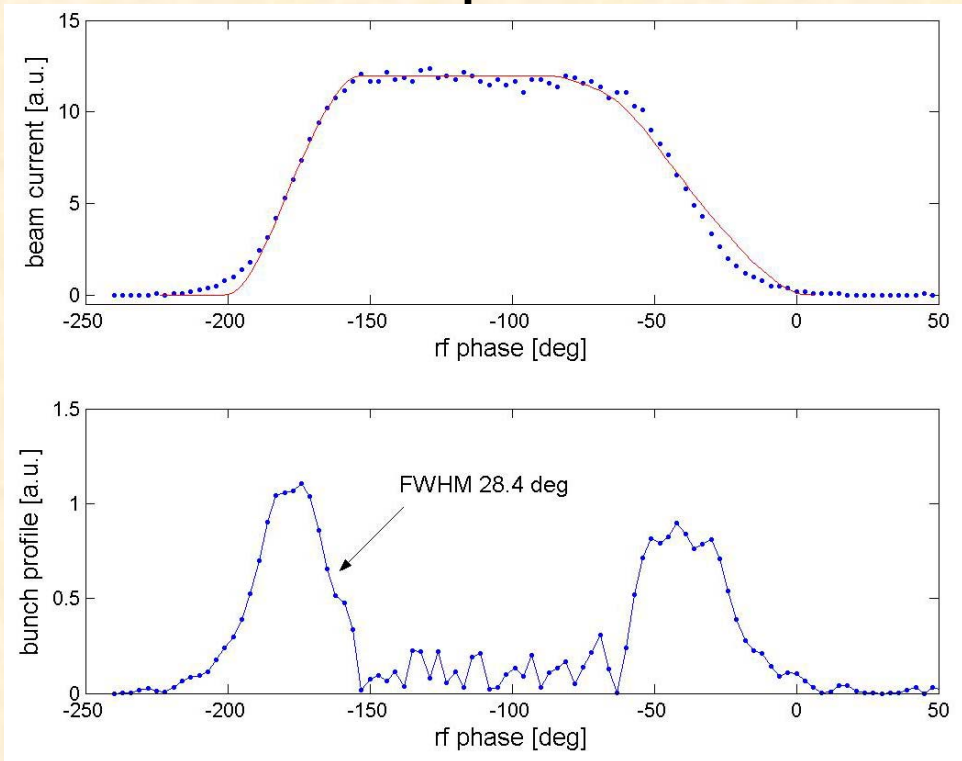
Multiparticle Phase Scan vs Acceptance Scan

DTL 1 Multiparticle Phase Scan



(A, ϕ)=(0.179, -125.5°)

DTL 1 Acceptance Scan

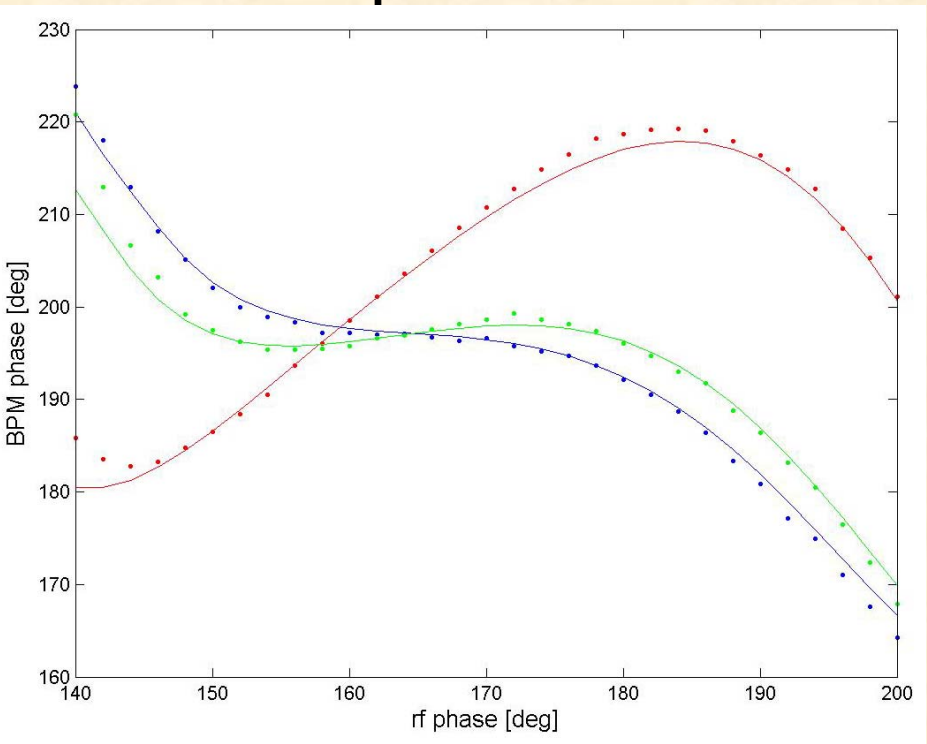


(A, ϕ)=(0.176, -124.6°)

- **For low energy DTL tanks, beam bunch length is relatively long and it is important to do multiparticle tracking to accurately simulate the phase scan.**
- **Agreement between measurement and simulation is excellent.**
- **Agreement between multiparticle phase scan and acceptance scan is excellent.**

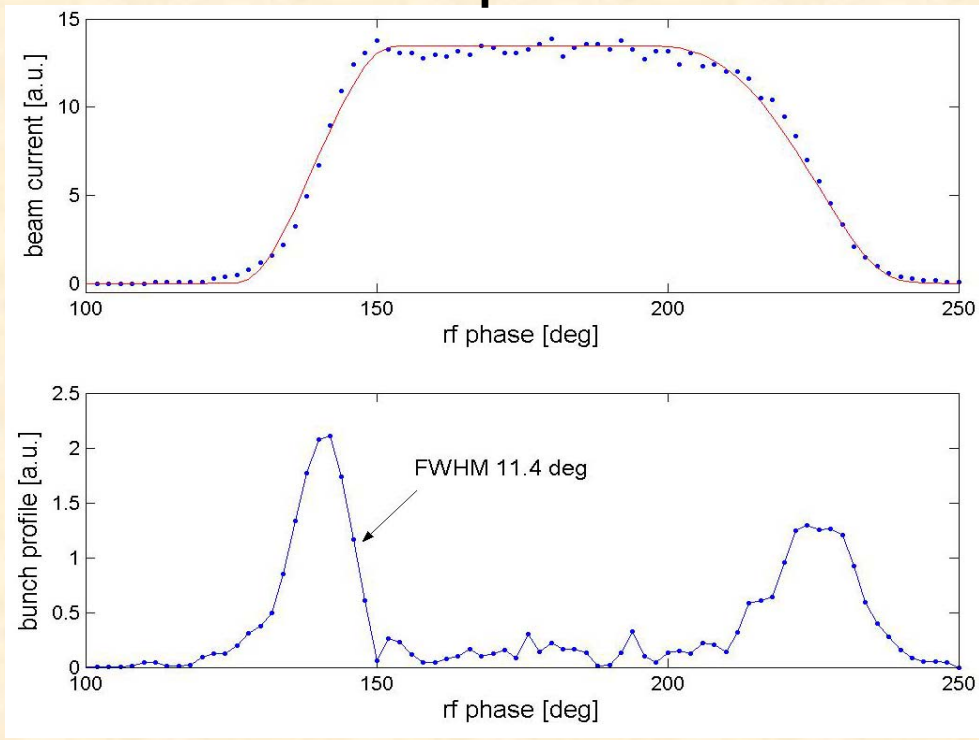
Multiparticle Phase Scan vs Acceptance Scan

DTL 2 Multiparticle Phase Scan



(A, ϕ)=(0.483, 166.5°) ΔE=-0.314%

DTL 2 Acceptance Scan

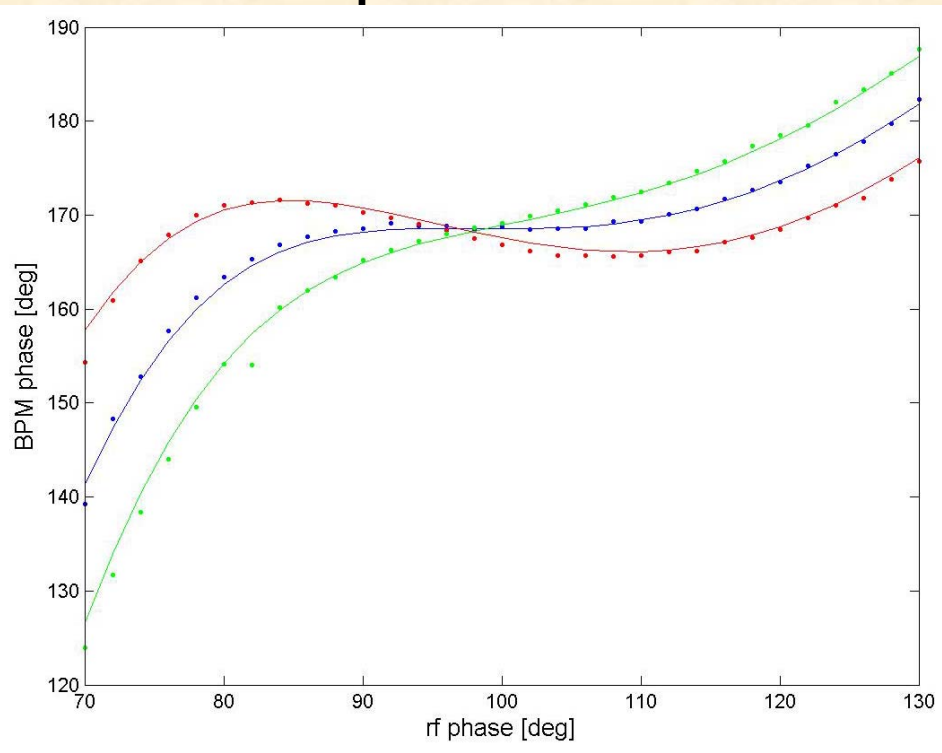


(A, ϕ)=(0.484, 168.0°)

- **Agreement between measurement and simulation is excellent.**
- **Agreement between multiparticle phase scan and acceptance scan is excellent.**

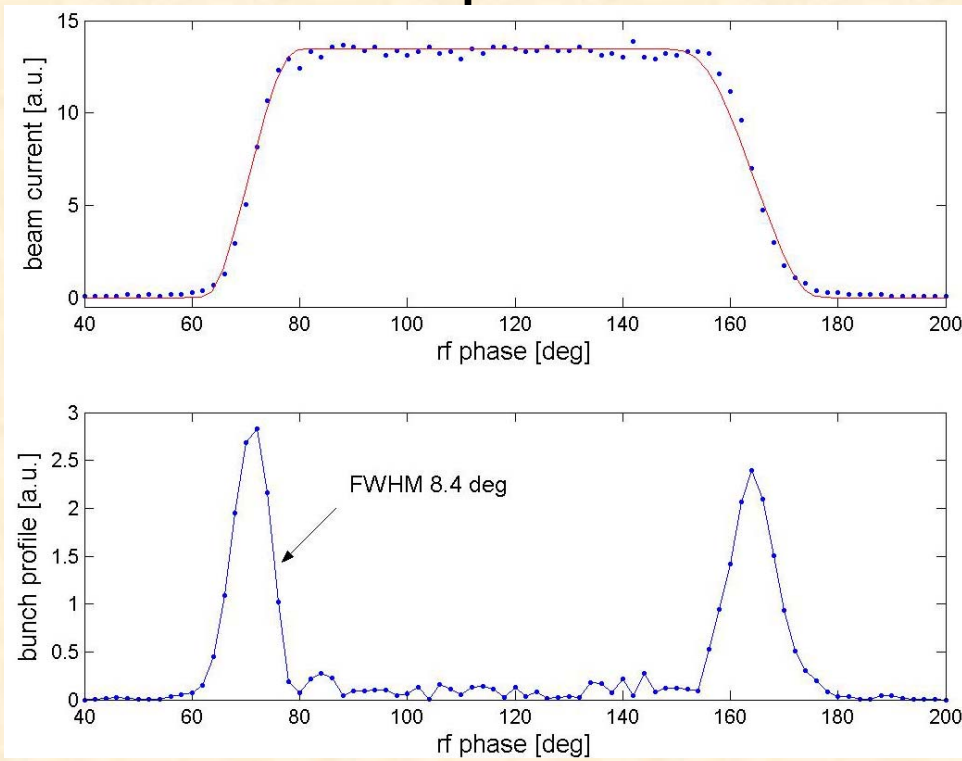
Multiparticle Phase Scan vs Acceptance Scan

DTL 3 Multiparticle Phase Scan



(A, ϕ)=(0.490, 105.0°) ΔE=0.254%

DTL 3 Acceptance Scan



(A, ϕ)=(0.494, 104.7°)

- **Set-points from the phase scan and acceptance scan are consistent with each other within ±2% and ±2º.**

Multiparticle Phase Scan vs Acceptance Scan Summary

	Phase Scan	Acceptance Scan
DTL 1	(0.179, -125.5°)	(0.176, -124.6°)
DTL 2	(0.483, 166.5°)	(0.484, 168.0°)
DTL 3	(0.490, 105.0°)	(0.494, 104.7°)
DTL 4	(0.599, 181.6°)	(0.585, 180.0°)
DTL 5	(0.576, 116.6°)	(0.547, 112.0°)

- **Set-points from the phase scan and acceptance scan are consistent with each other within ±2% and ±2º, except Tank 5.**

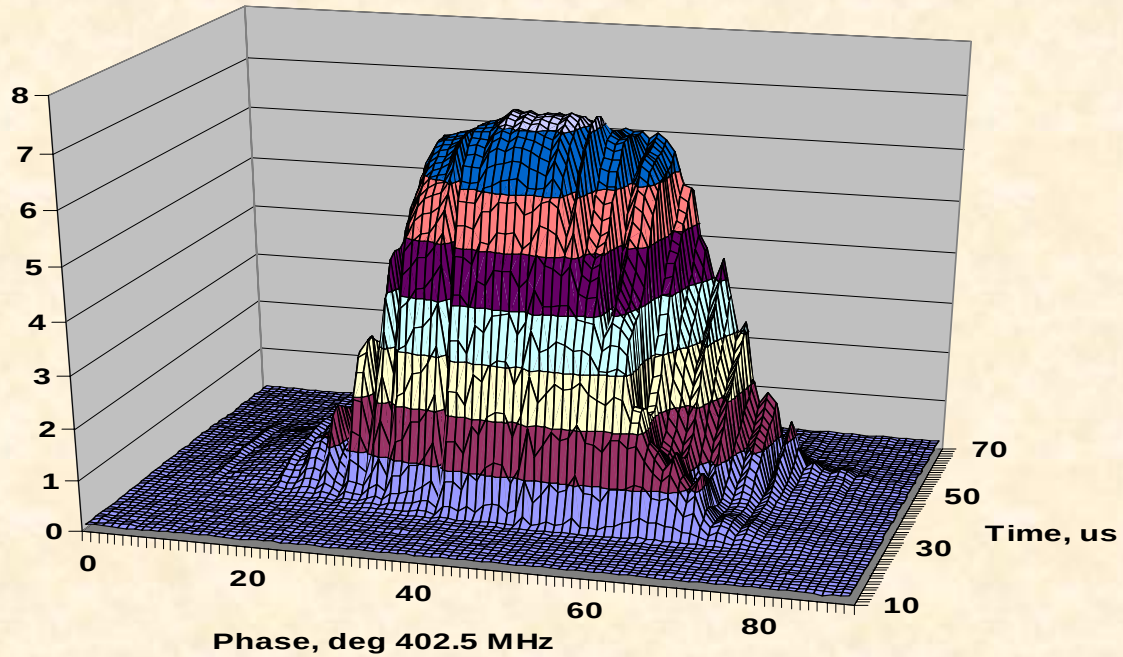
- **Noisy Acceptance Scan data for DTL Tank 5 is an issue**

Longitudinal beam profile

- **Bunch Shape Monitors (INR)**
- **Mode locked Laser Profile monitor**
- **Energy Degrader/Faraday Cup**

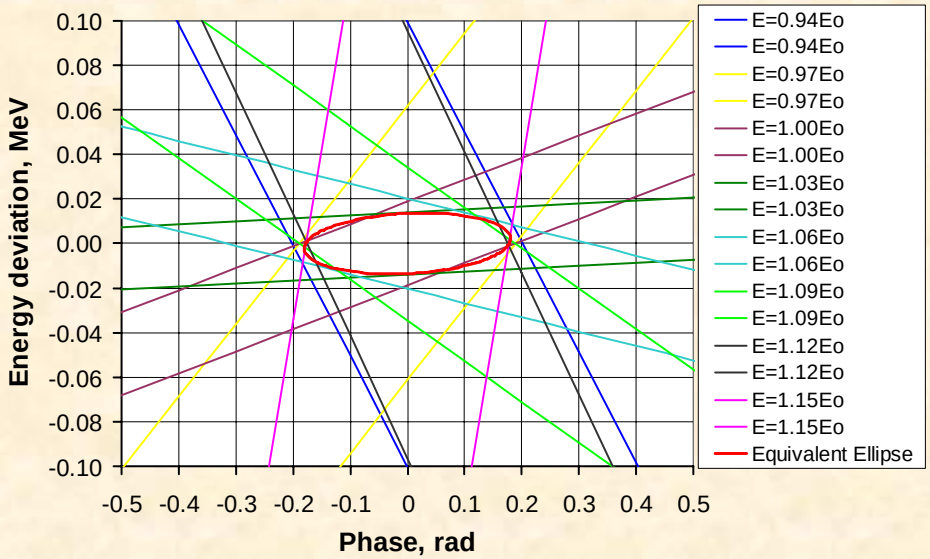
Bunch Shape Monitor (BSM) Measurements

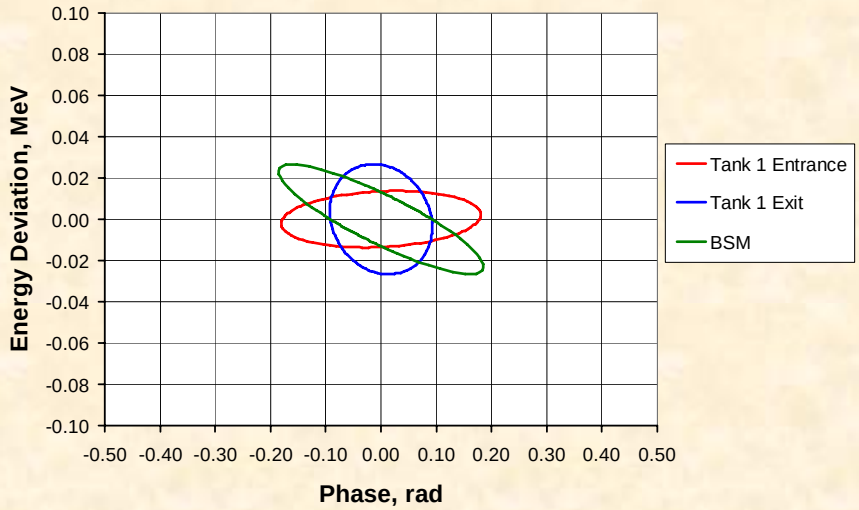
- INR Collaborators produced Bunch Shape Monitor (Feschenko, Jeon, Blokland et al.)
- Early BSM measurements indicated poor phase stability
- Tracked to MEBT Rebuncher RF System



Longitudinal Emittance at DTL1 Input Estimated Using the BSM

Feschenko, Jeon et al. (INR)





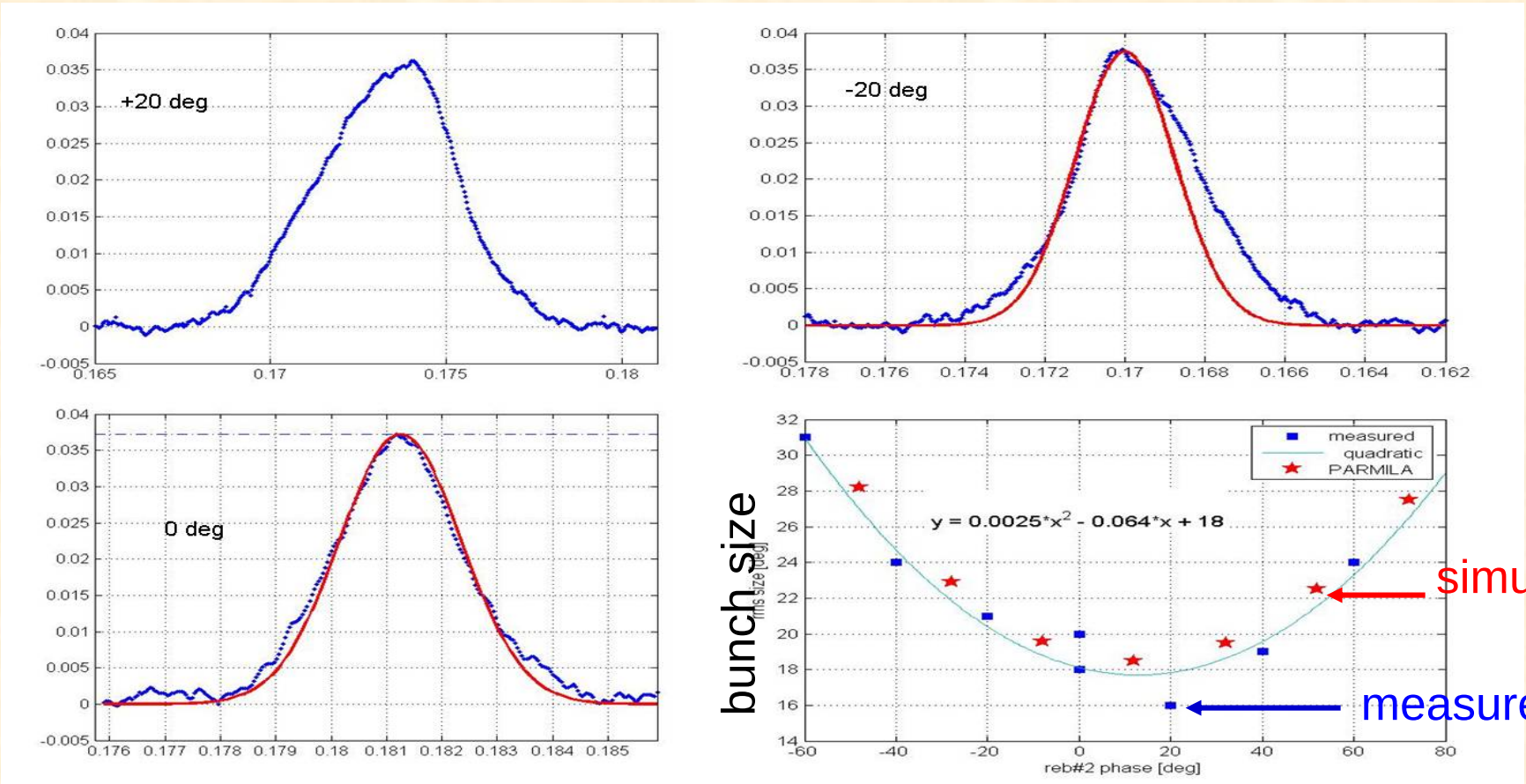
Parameter list: 0.13 pi MeV-deg (RMS) for 38 mA

Estimated longitudinal emittance: 0.14 pi MeV-deg for 15 mA

Longitudinal laser bunch profile monitor in MEBT

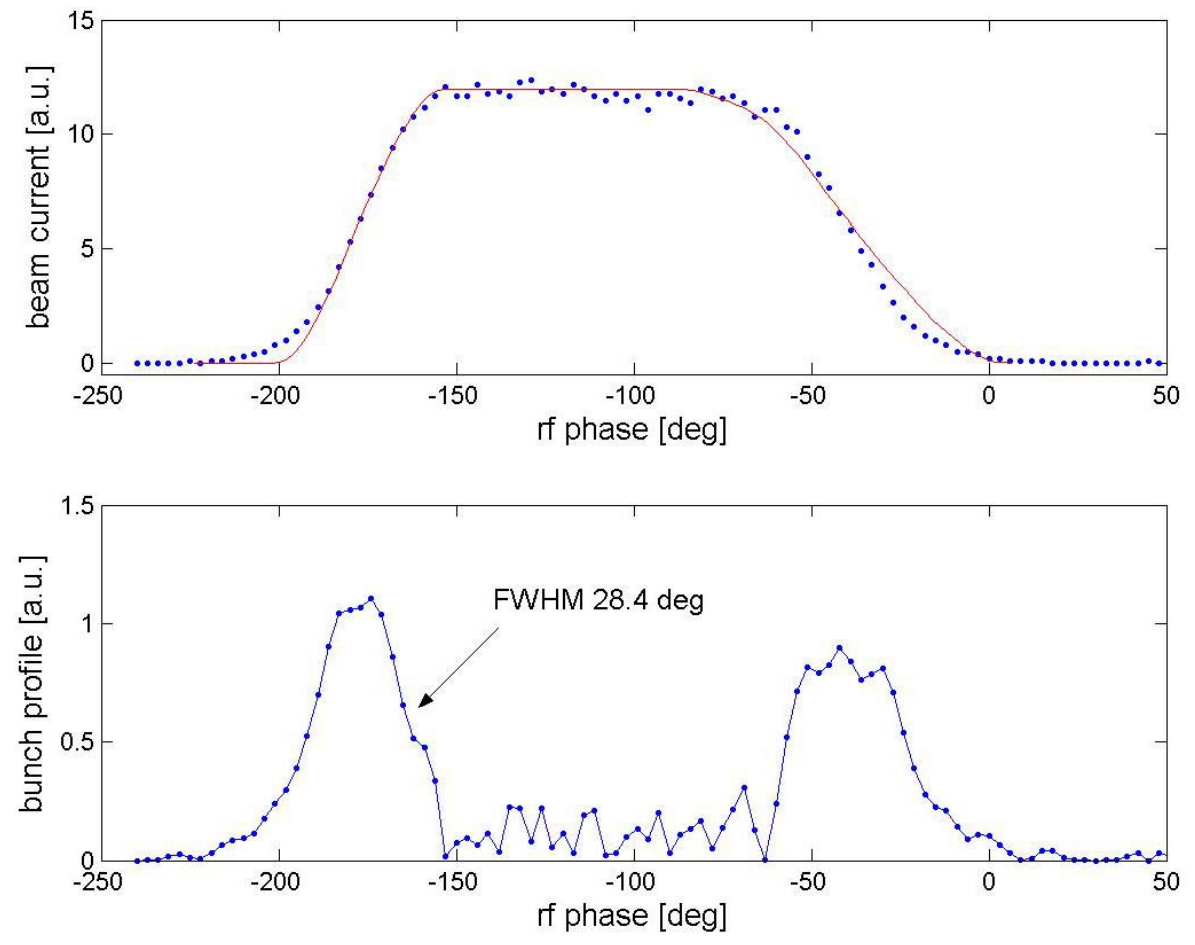
Courtesy of A. Aleksandrov et al

Now have mode-locked laser diagnostics for 3-dimensional profile measurement in MEBT (only longitudinal has been commissioned)



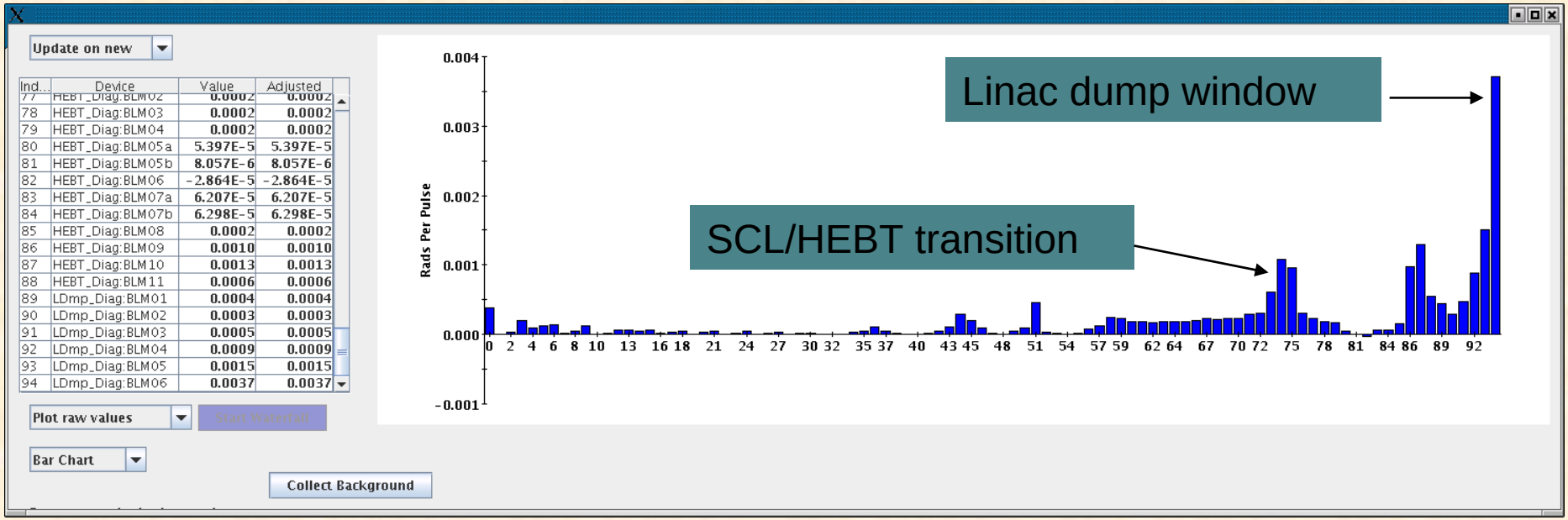
Longitudinal bunch profile (blue dots) and Gaussian fit (red line).

Longitudinal beam profile from Acceptance Scan



- **Comparable quality to Mode-locked Laser Profile Monitor measurement**

Beam Loss Monitors



500 μsec, peak = 0.004

Loss units in Rads/pulse

From loss studies calibrations, the peak loss (next to the linac dump window) ~ 2 W/m at 1 Hz

Conclusions

- **Emittance scanners are very valuable for commissioning and future beam physics studies. SNS used to have once and gone!**
- **Redundant diagnostics devices can play an important role … cross checking, backup.**
- **Preplanning and testing of diagnostics are crucial … otherwise one might end up using the commissioning period in commissioning diagnostics devices.**
- **LINAC4 … Uniquely positioned to carry out many valuable physics studies.**