Beam Dynamics and Commissioning plan for CSNS Linac

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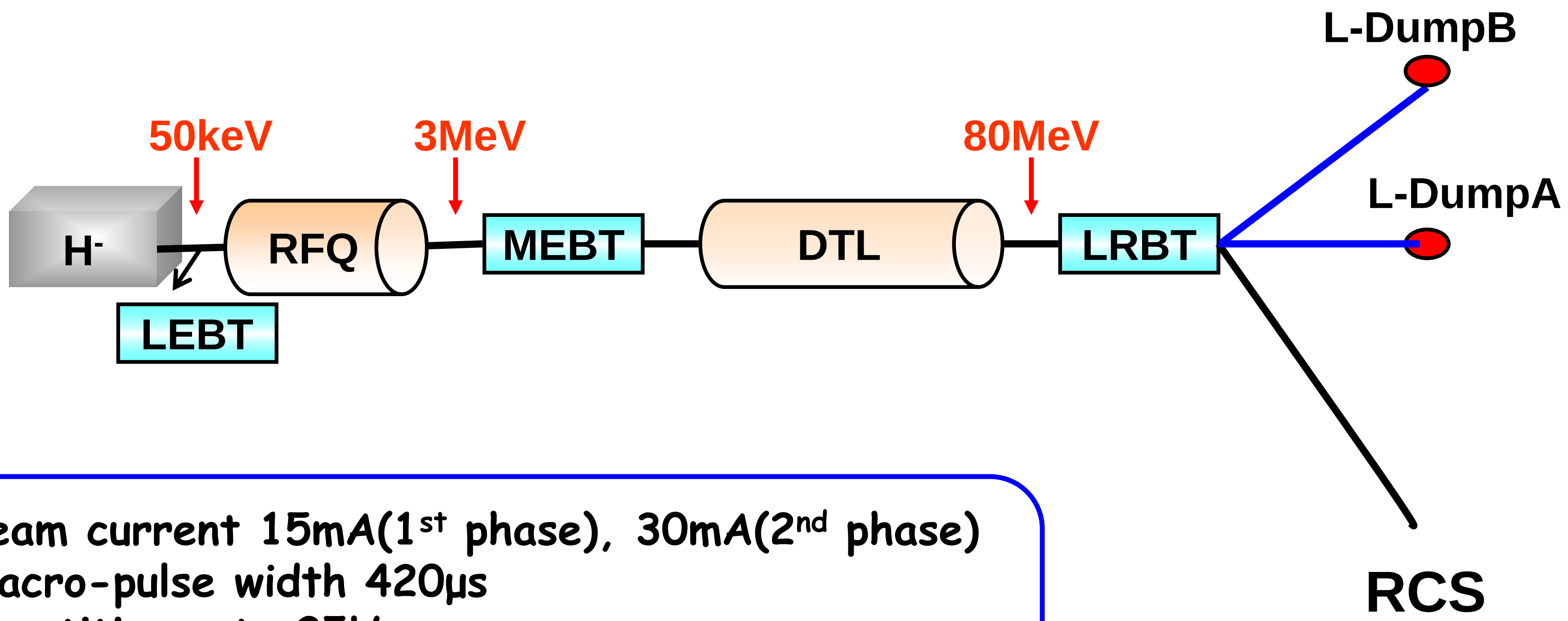
CSNS
CHINESE ACADEMY OF SCIENCES

Outline

- **Beam Dynamics**
- **Commissioning plan**
- **Beam Halo experiment**

Introduction



Beam current 15mA(1st phase), 30mA(2nd phase)
Macro-pulse width 420μs
Repetition rate 25Hz
Duty factor 1.05%
Chopping rate 50%

Test result of the LEBT pre-chopper

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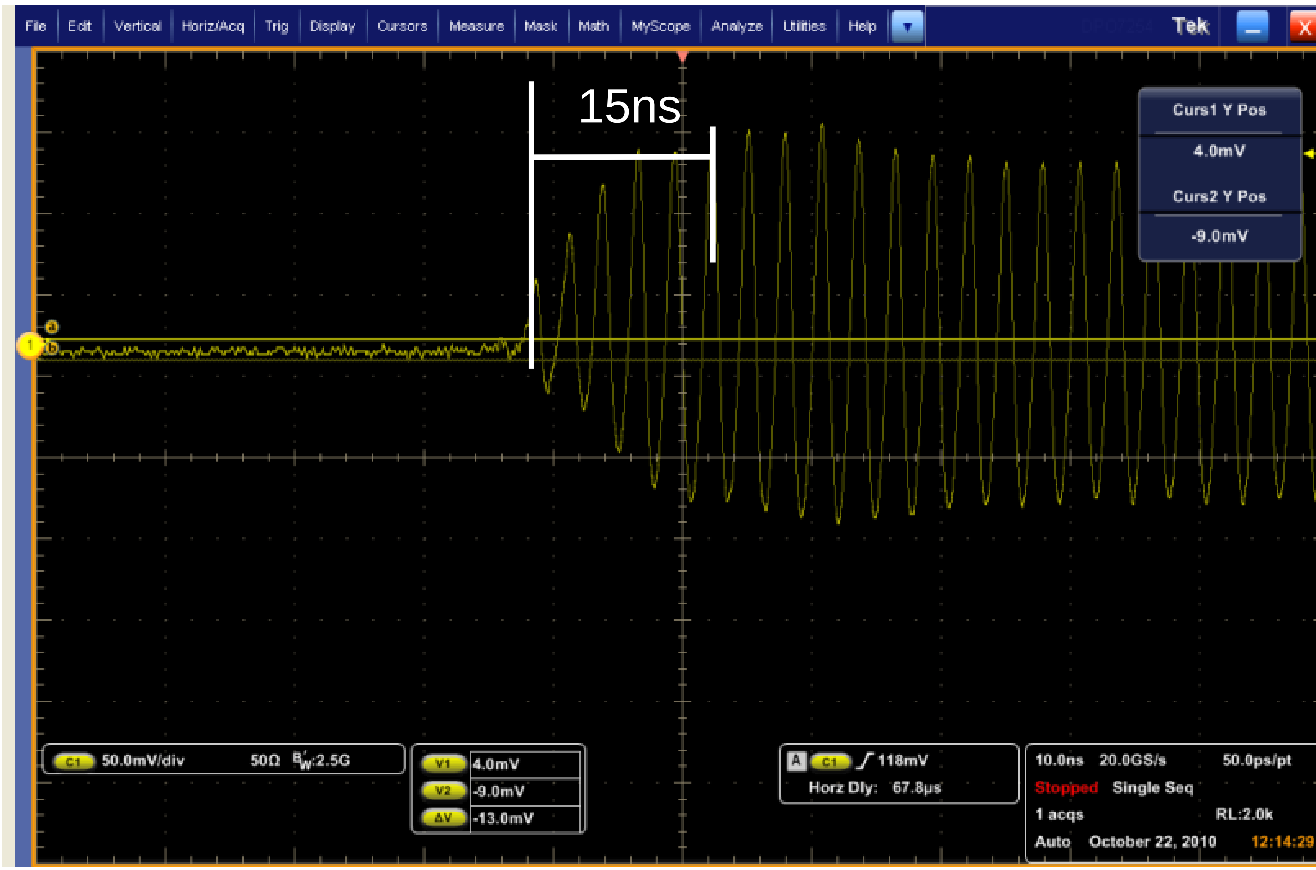
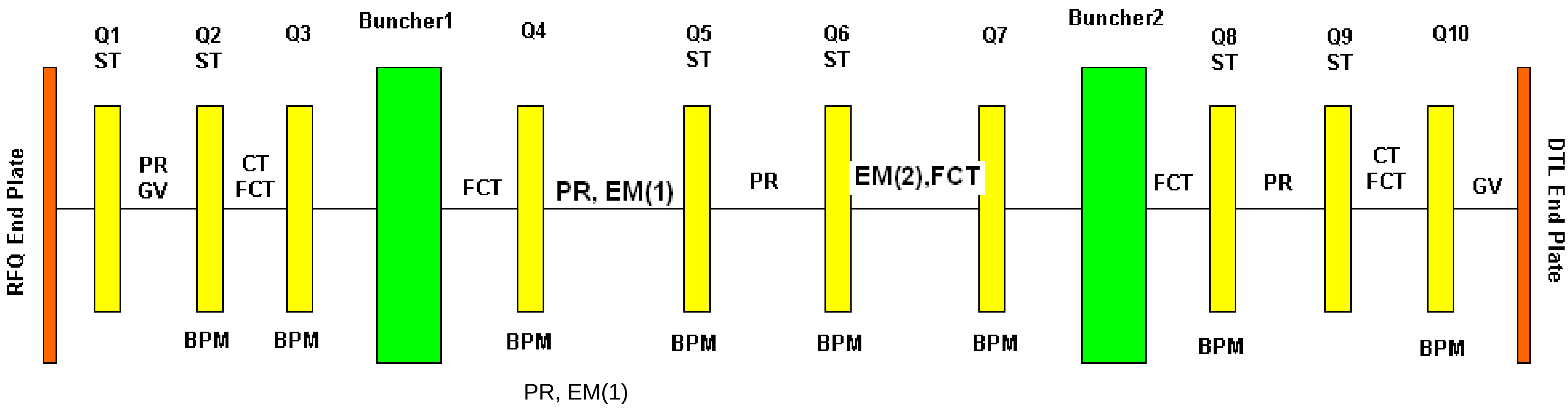
Design and experiment results of the LEBT pre-chopper for CSNS

Huachang Liu *, Huafu Ouyang, Jun Peng, Tao Huang, Keyun Gong, Taoguang Xu, Shinian Fu

By taking advantage of the existing LEBT of the Accelerator Driven Subcritical System (ADS), the beam study of a similar chopper system was successfully performed and the achieved rise/fall time was about 15 ns.



MEBT layout



BPM=beam position monitor
PR=profile monitor

FCT=fast current monitor
CT=current monitor

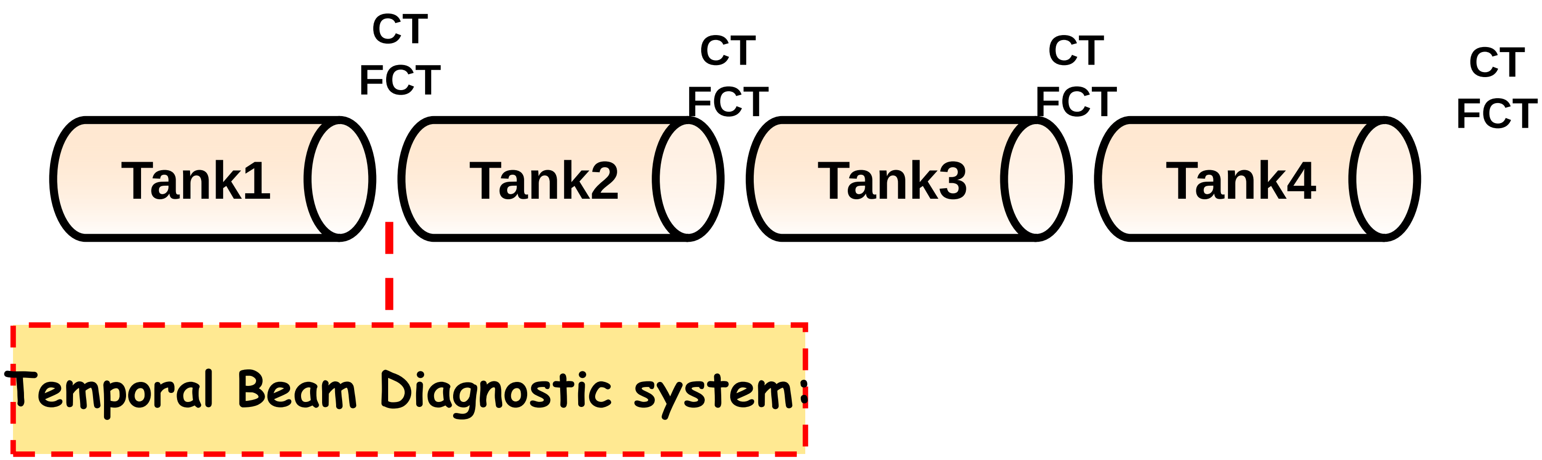
Q=quadrupole magnet
EM=emittance monitor

GV=gate vale
ST=steering magnet

DR=drift space

MEBT is comprised of:
10 electrical megnets, 6 Steeringmagnets, 2 Bunchers
(the MEBT chopper was removed based on the LEBT prechopper test results)

DTL layout

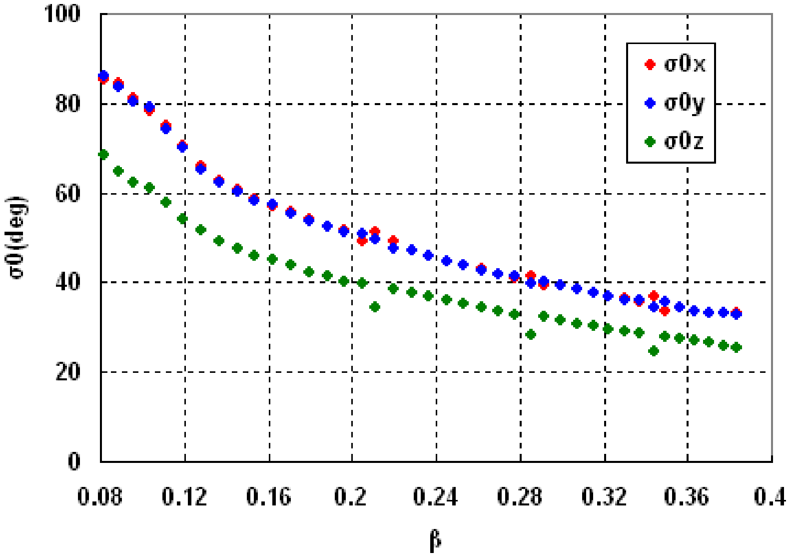


Tank number	1	2	3	4	total
Output energy (MeV)	21.67	41.41	61.07	80.09	80.09
Number of cell	64	37	30	26	157
RF driving power (MW)	1.35	1.32	1.32	1.34	5.33
Total RF power (MW) (I=30mA)	1.91	1.92	1.92	1.93	7.68
Accelerating field (MV/m)	2.86	2.96	2.96	3.0	
Synchronous phase (degree)	-35 to -25	-25	-25	-25	

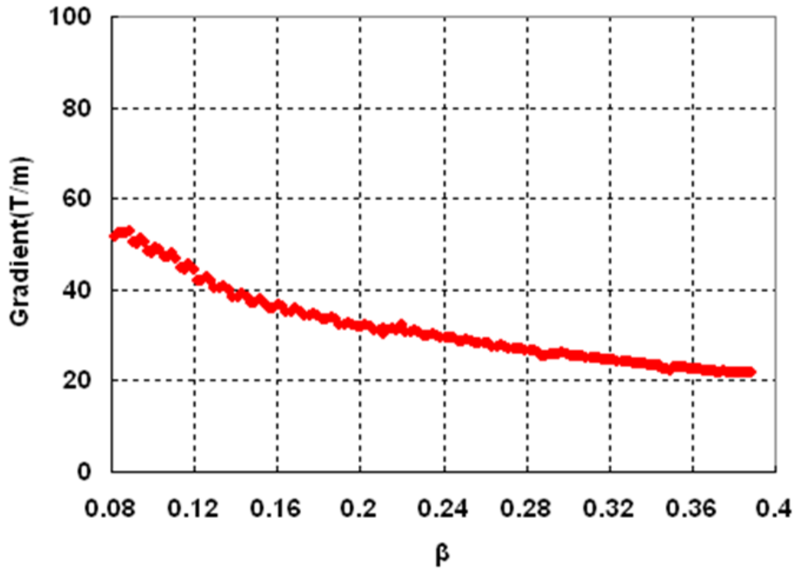
Transverse focusing

- σ_{t0}, σ_{z0}<90^o
- $\sigma_{0t} \neq n\sigma_{0l}/2$,for n=1, 3…
- Equipartitioning require:

$$\frac{k_{t0}}{k_{z0}} = \sqrt{\frac{3}{2}\frac{\varepsilon_{nz}}{\varepsilon_{nt}} - \frac{1}{2}}$$



Zero-Current Phase Advance per Period for FFDD lattice

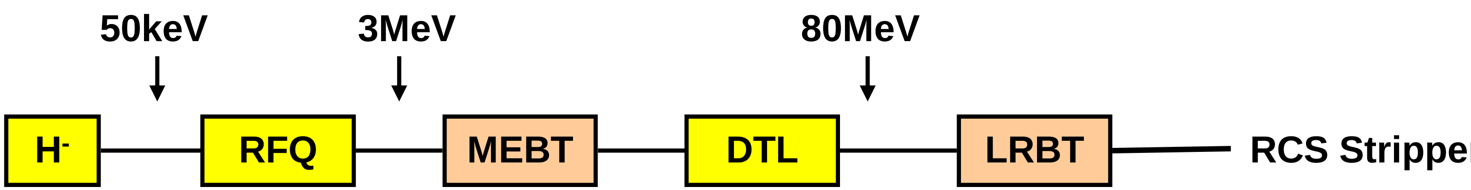


Quad gradient

End to end simulation

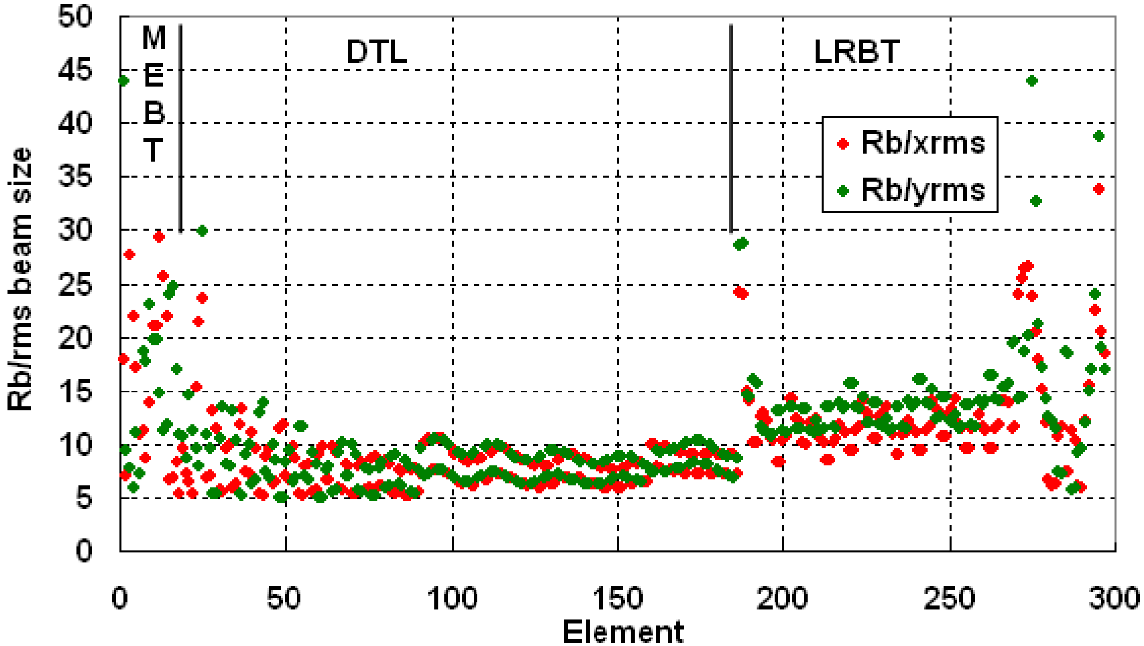
End to End Simulation

Phase Ⅰ:



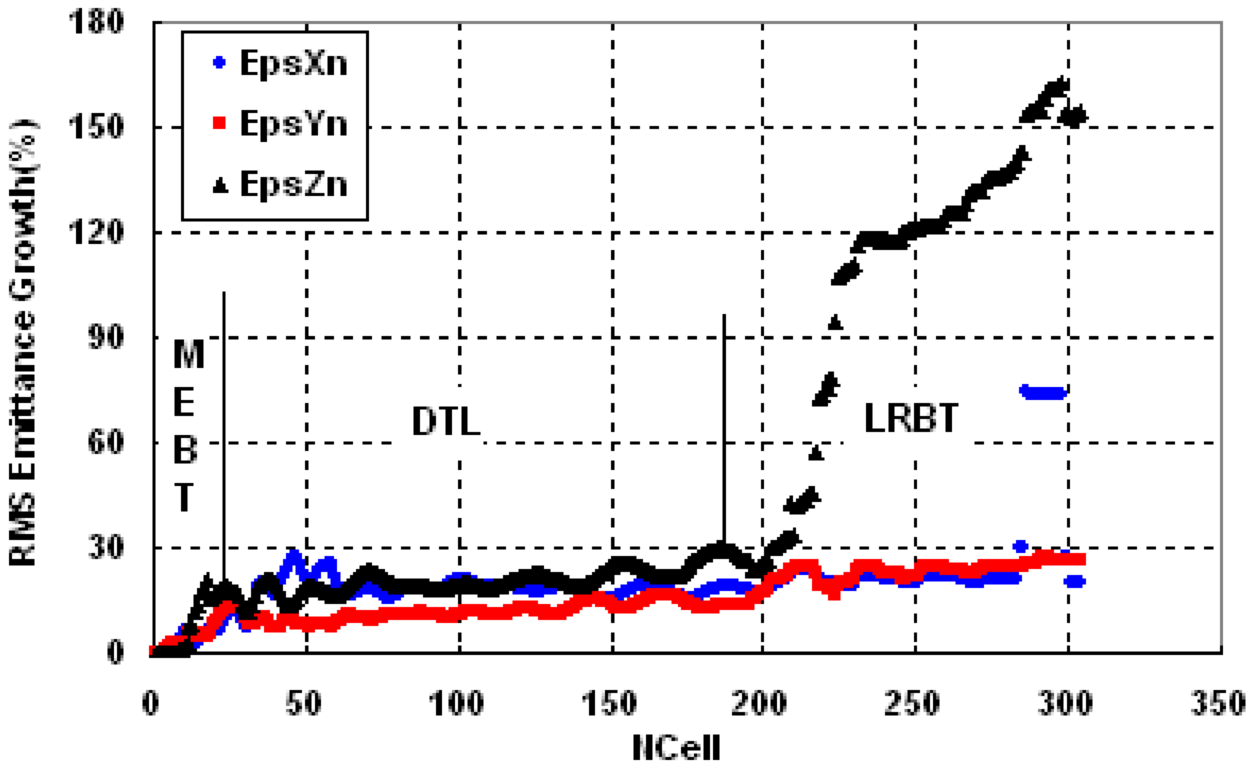
- The initial distribution at the exit of RFQ is obtained with PARMTEQ.
- Simulate MEBT-DTL-LRBT, I_{peak}=15mA
- The number of particles is 50448.
- Trace3D is used for matching, Parmila,TraceWin are used for multi-particle simulation

Beam bore radius/rms beam size



MEBT	DTL	LRBT
ratio>5.2	DTL-1: ratio>5 DTL-2,3,4: ratio>5.8	Ratio>5.7

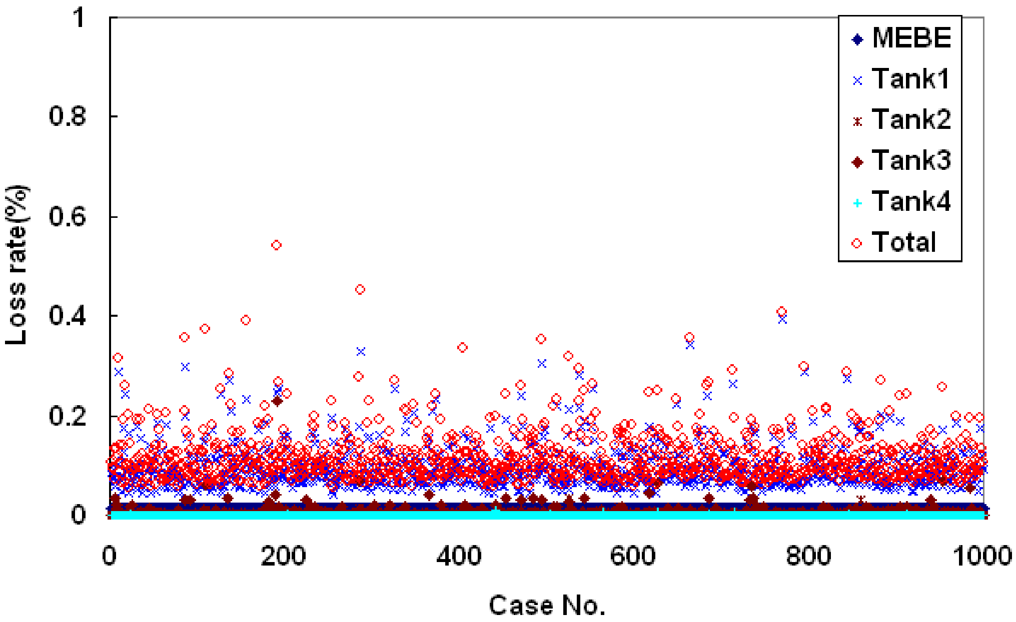
RMS emittance growth along Linac



Error Analysis

For the quadrupoles:
- Transverse displacements≤±0.1mm,
- Rotations≤3mrad,
- Integrated field≤1%,

For the accelerating field:
- RF amplitude≤1%
- RF phase≤1degree

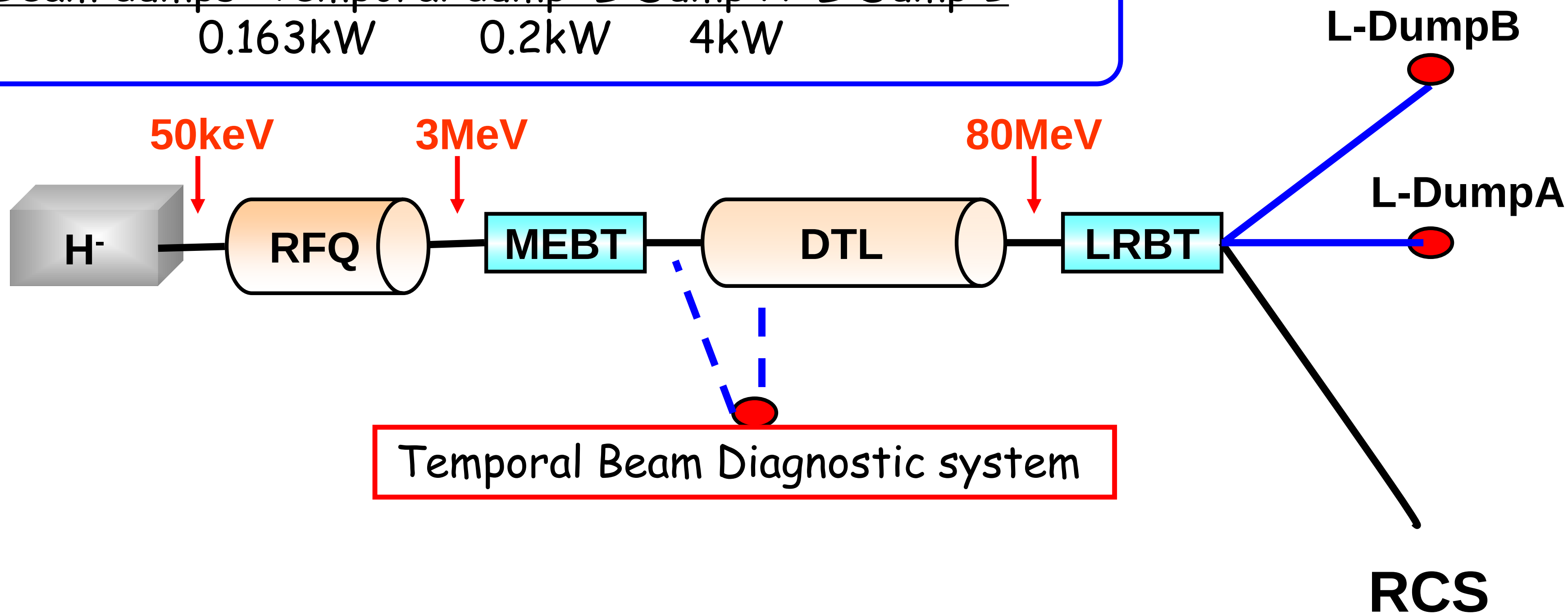


	Tank1	Tank2	Tank3	Tank4
Beam loss <1W/m Probability	98.1%	100%	99.5%	100%

Commissioning plan for Linac

Introduction

Beam dumps:	Temporal dump	L-Dump A	L-Dump B
	0.163kW	0.2kW	4kW



Temporal Beam Diagnostic system

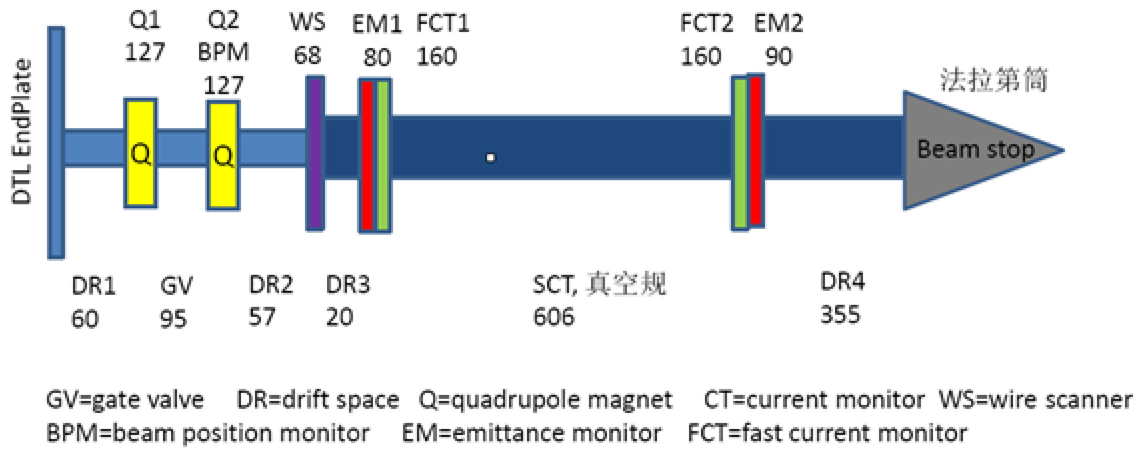


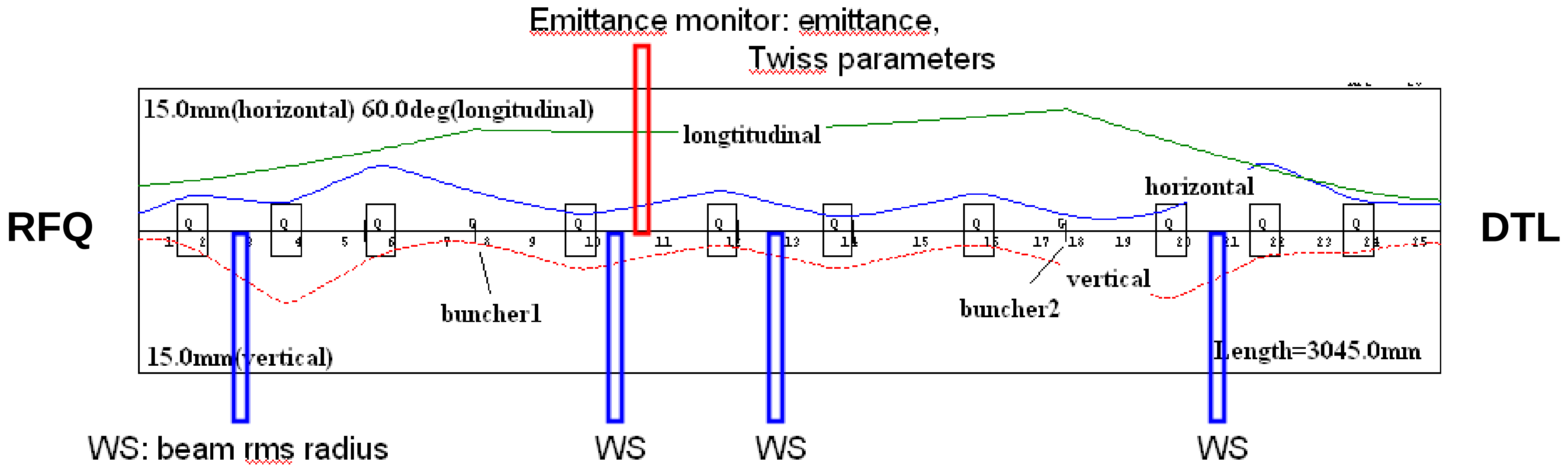
Table 3. DTL 1 measurements with temporal beam diagnostic system

Measurement	Technique	Diagnostic
Profile(transverse)	Validate algorithm	Wire scanner
RF ϕ & amp	time-of-fight phase scan	2 FCT
MEBT matching (transverse)	validate algorithm	Quad & Emittance monitor
MEBT matching (longitudinal)	transmission	CT
steering	validate algorithm	BPM & steering magnet

Transverse matching

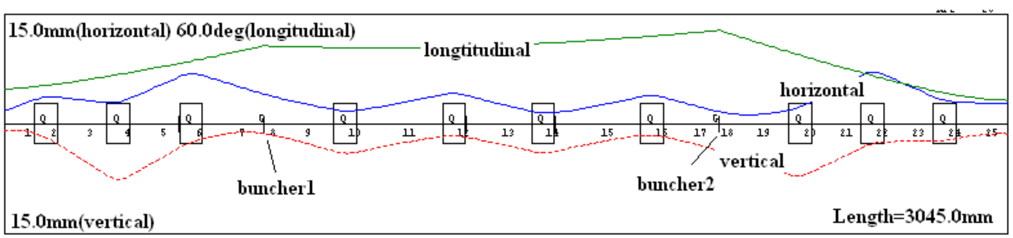
- First step

Based on the values of measured beam parameters, calculate the emittance and Twiss parameters at the exit of RFQ, and then the quadrupole strength is determined based on the calculated emittance and Twiss parameters



➢ Next, do optimization

By varying the four matching quadrupoles of the MEBT, we will minimize the rms emittances measuered from emittance scanners in a temporal diagnostic system at the end of the DTL-1.



MEBT layout

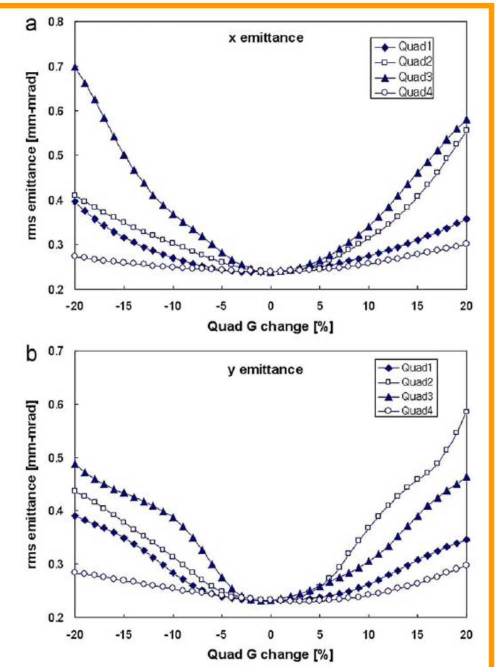
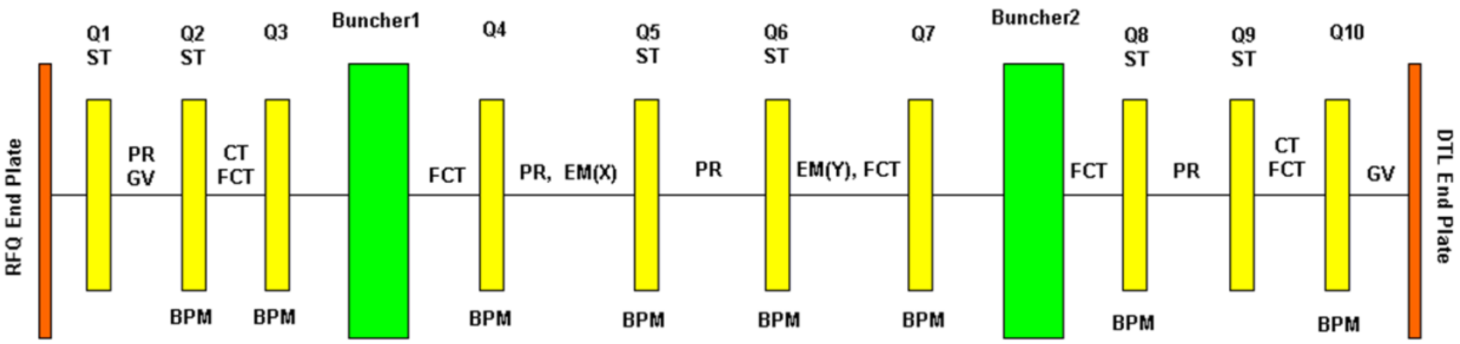


Fig. 2. Plots of the transverse rms emittance values vs. individual gradient changes of the MEBT matching quadrupoles, expressed as percent deviations from their design values, with all other gradients held at their design values.

The picture is from D.Jeon et al, “Parctical transverse matching of the high-intensity SNS Linac”

Orbit correction

Using the BPM’s and steering magnets, make the orbit deviations<1mm。



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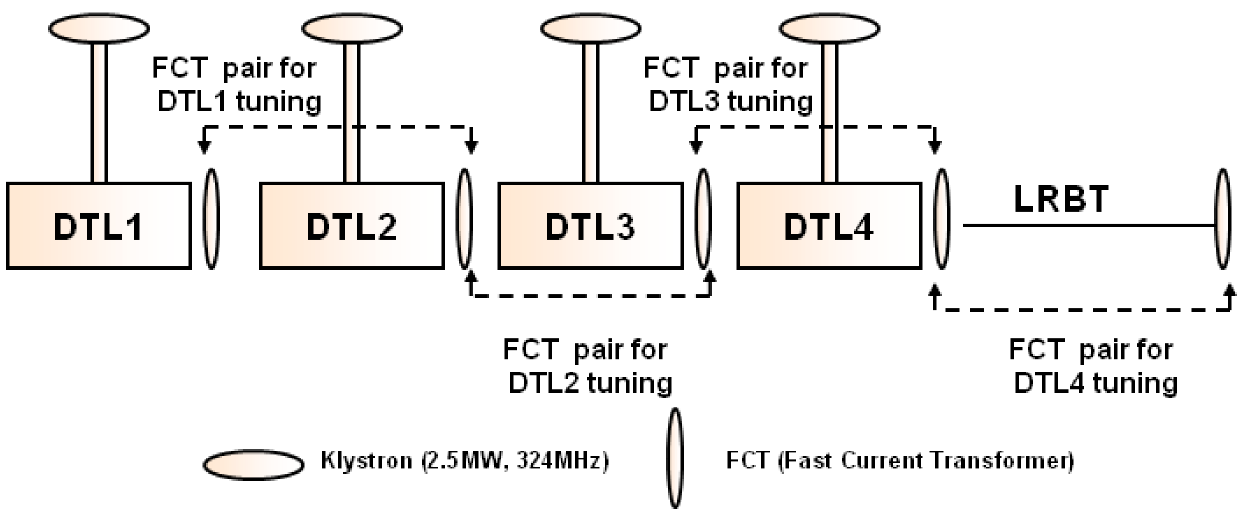
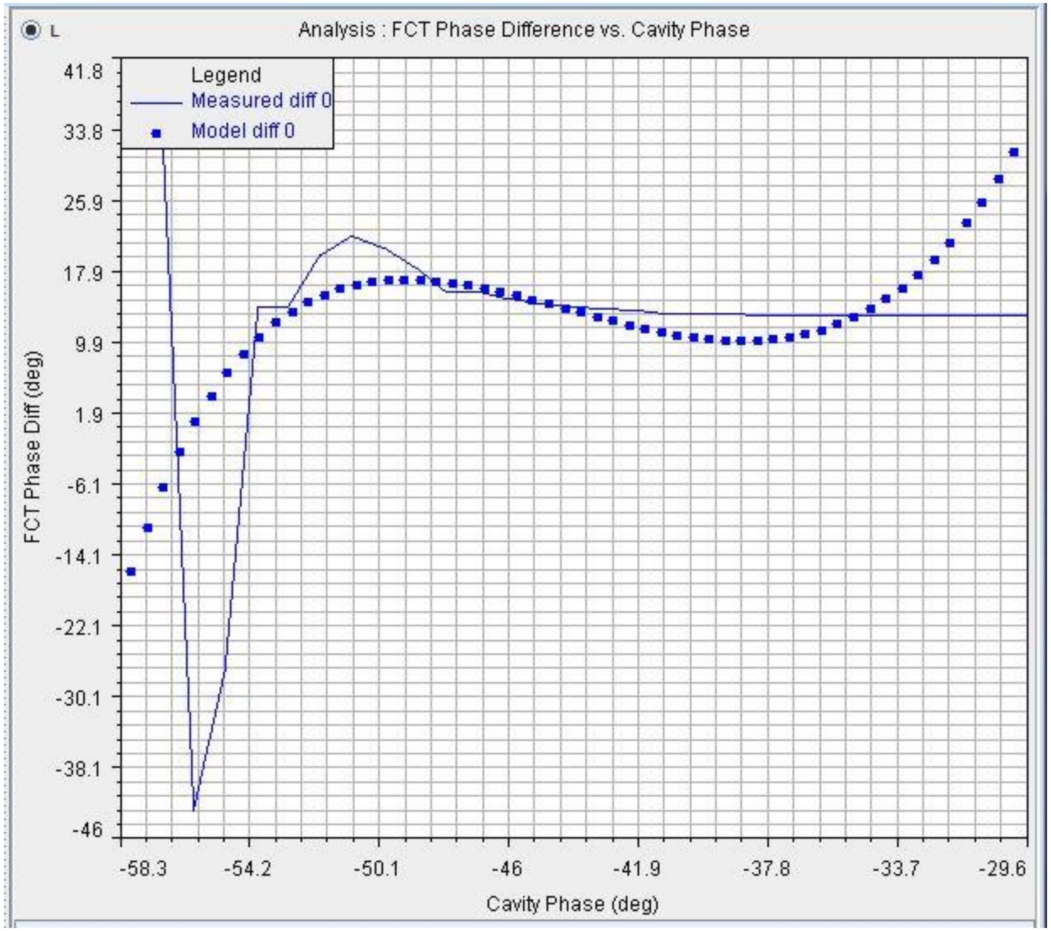
Longitudinal RF set-up

- Find the RF set point of DTL1 with a **phase scan method.** The tuning goal of the RF set point is **1deg** in phase and **1%** in amplitude.



XAL, Pasta (an RF phase scan and tuning application)



Examples of the phase scan signature-matching technique for the DTL-1 at the CSNS

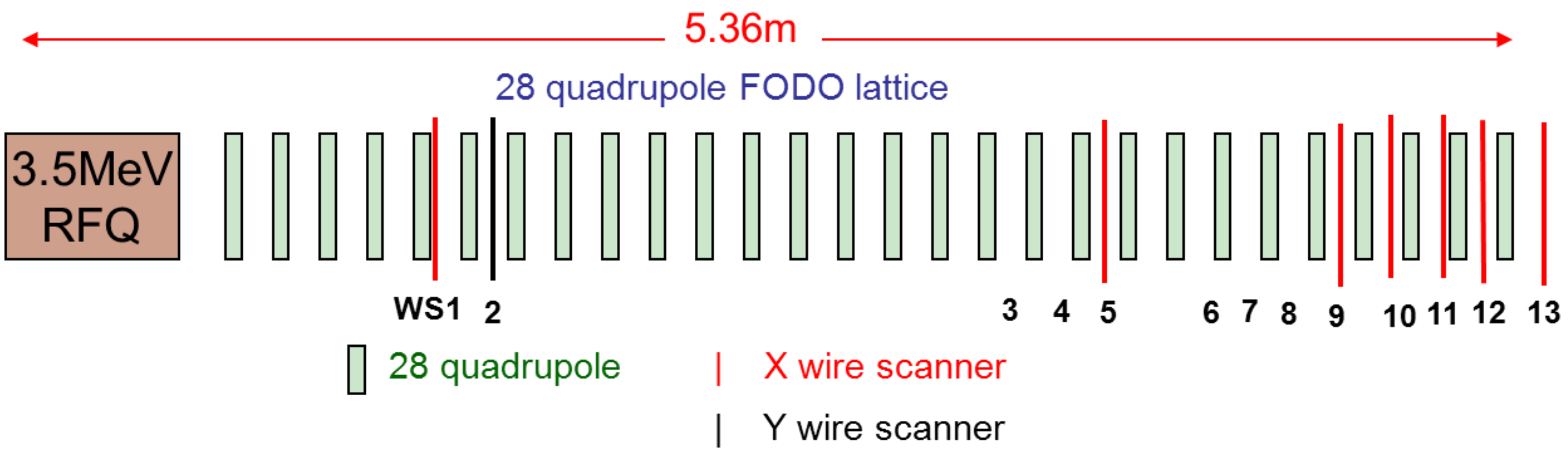
Signature matching

$$\Delta\varphi = \varphi_{FCT2} - \varphi_{FCT1}$$

$$\chi^2 = \frac{\sum_{j=1}^{n} (\Delta\varphi_{Measured} - \Delta\varphi_{Model})^2}{n}$$

Halo experiment

Beam line layout



- To study beam halo
- To prepare for the upcoming commissioning of CSNS linac

Obtain the RFQ output beam parameters

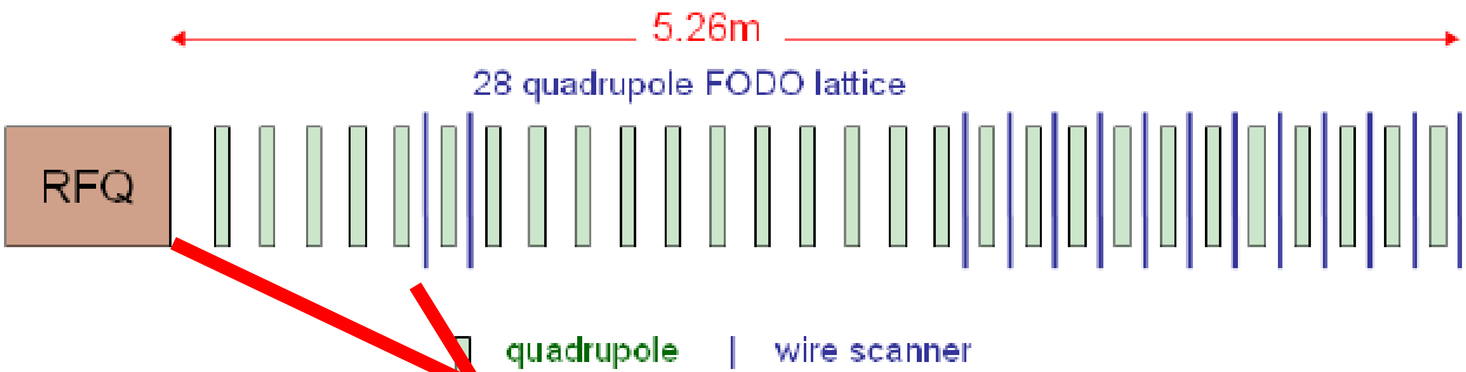


Figure 1 Layout of the beam halo experiment transport line

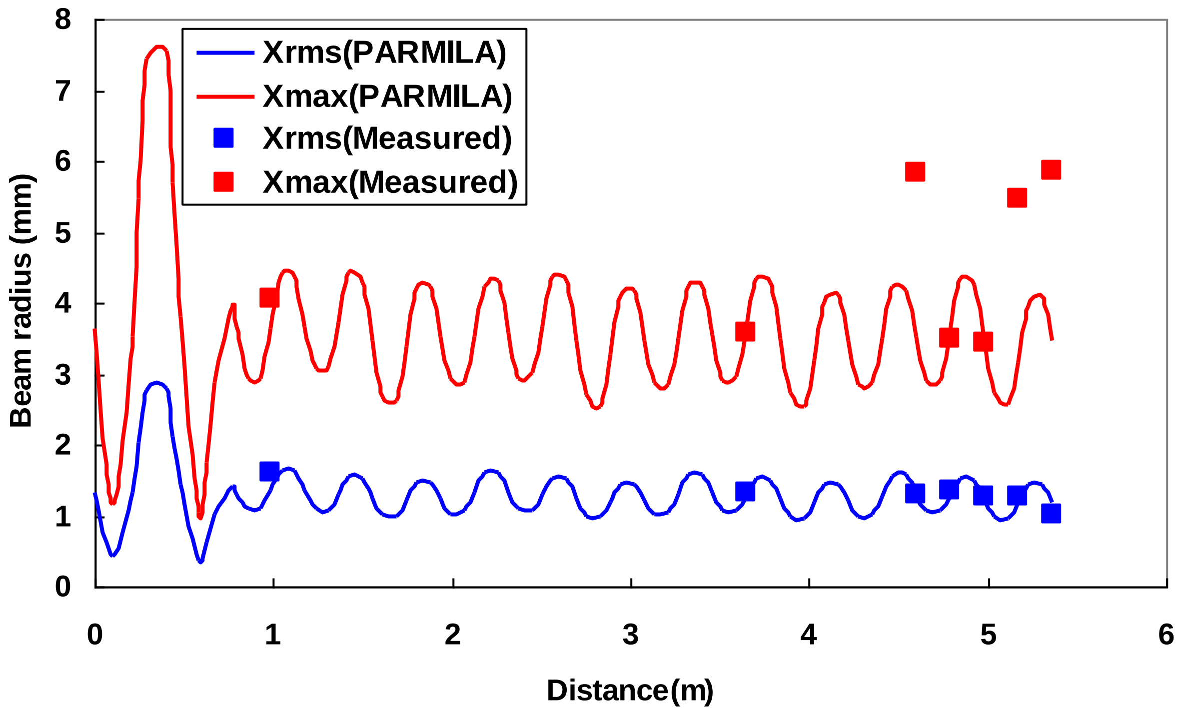
Vary quadrupole gradients: $$\sigma_2 = R\sigma_1 R^T \quad (1)$$

RFQ output beam parameters

RFQ exit beam	α_x	β_x (mm/mrad)	α_y	β_y (mm/mrad)	ε_x (π.mm.mrad)	ε_y (π.mm.mrad)
PARMTEQM (I=20mA)	-0.126	0.079	-0.709	0.218	0.205	0.21
Experiment-1 Transmission is 70% I=21mA	3.129	0.385	-0.546	0.112	0.344	0.327
Experiment-2 Transmission is 90% I=27mA	3.753	0.461	-0.611	0.113	0.333	0.33

Measure matched beam

Comparison between Simulation and Measurement



FD lattice, zero current phase advance per period=**60º**, matched beam envelope

Measure mismatched beam

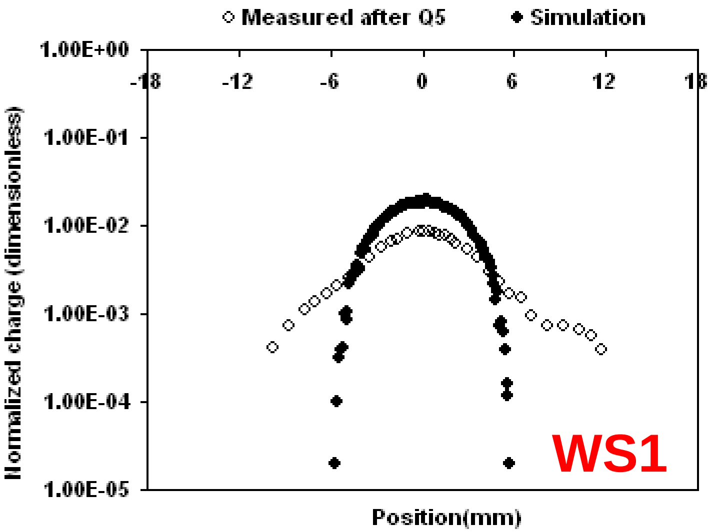
Mismatch parameter μ is defined as:

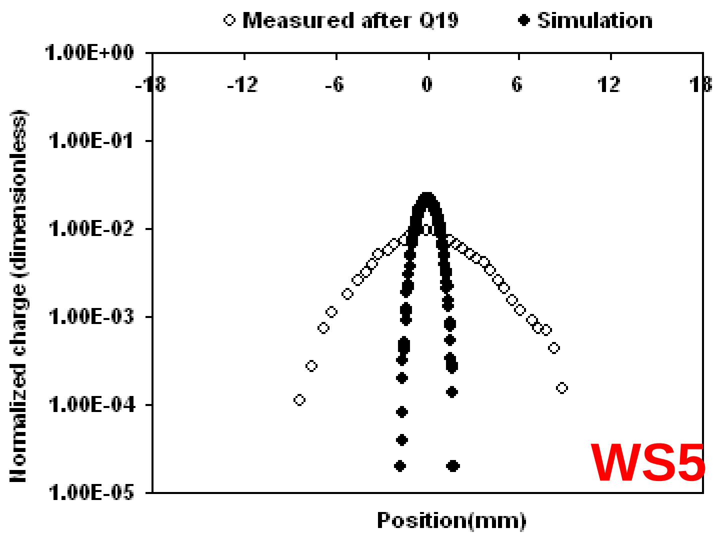
$$\alpha = \mu^2 \alpha_m$$

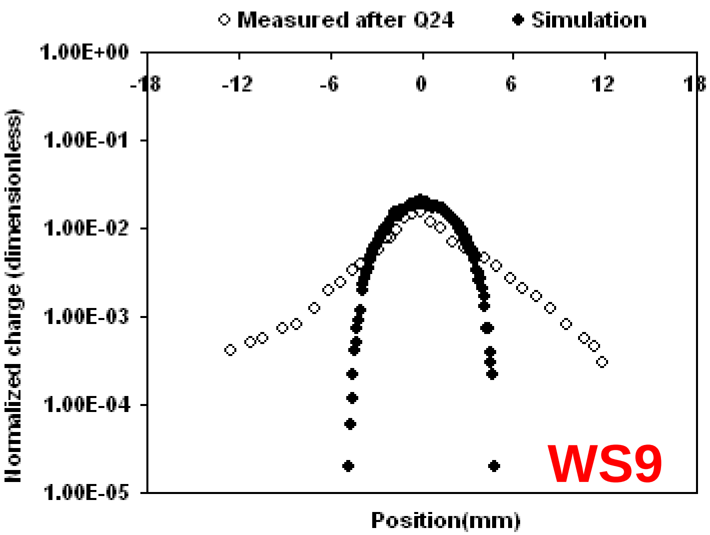
$$\beta = \mu^2 \beta_m$$

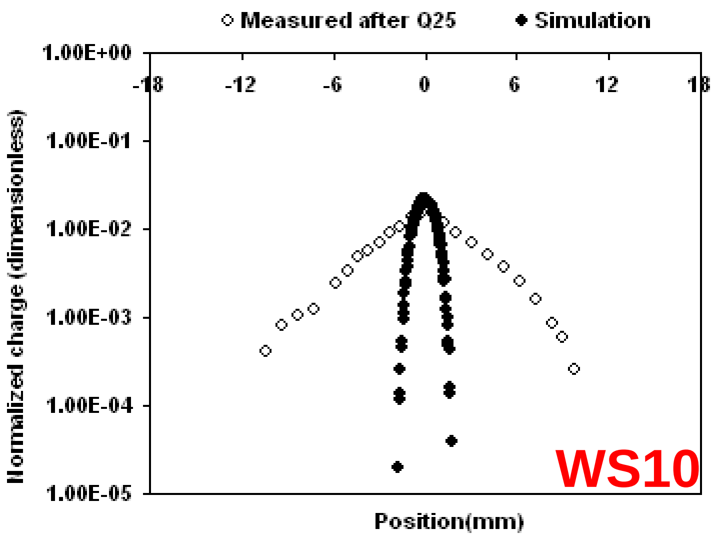
Here, α_m, β_m is the matched parameters,
α, β is the mismatched parameters

Beam Profile

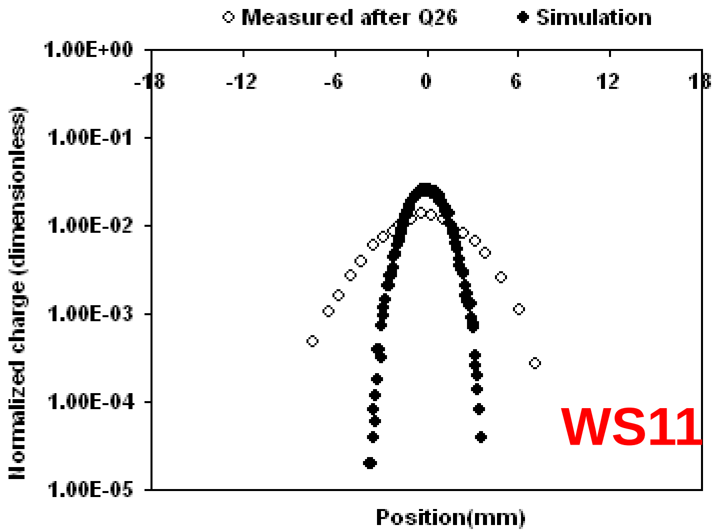


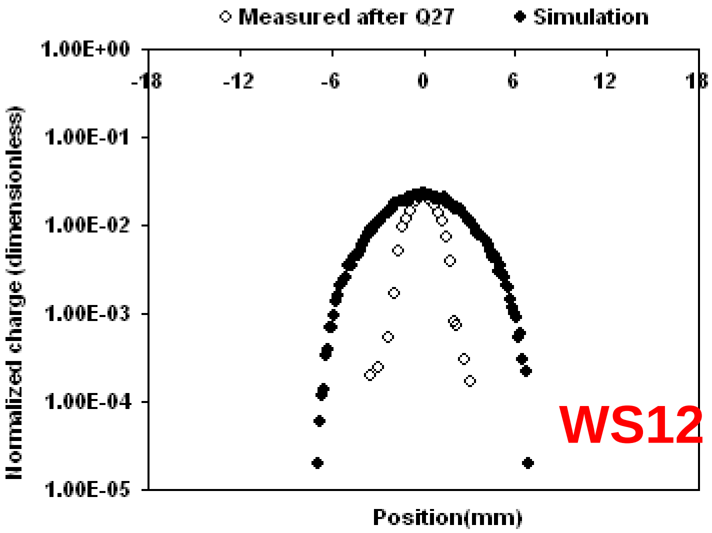


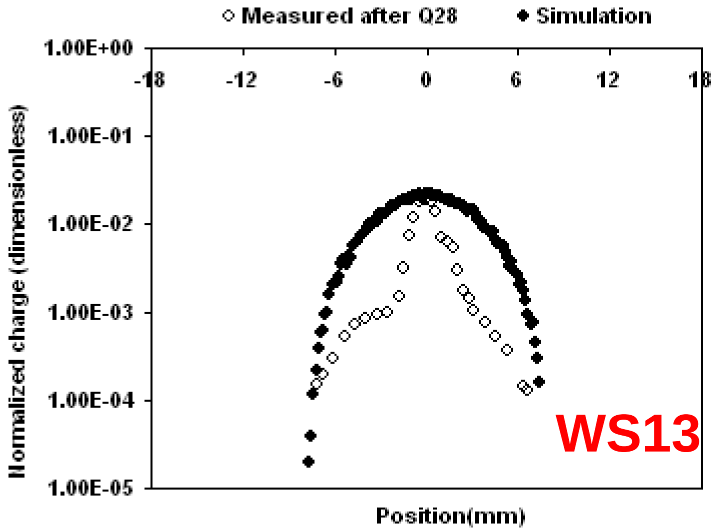




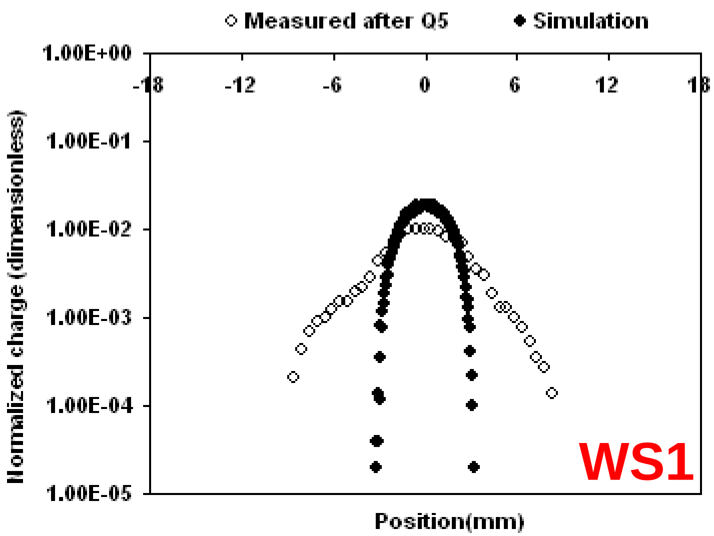
FD, 60^{o} phase advance, mismatched beam, $\mu=2$

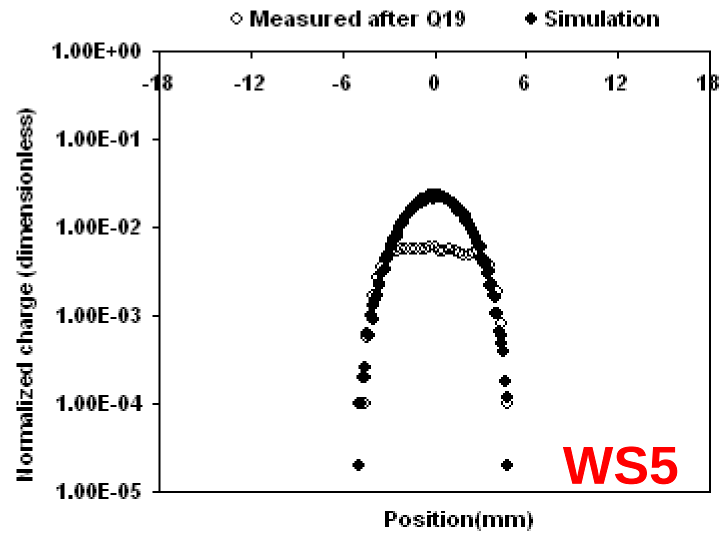


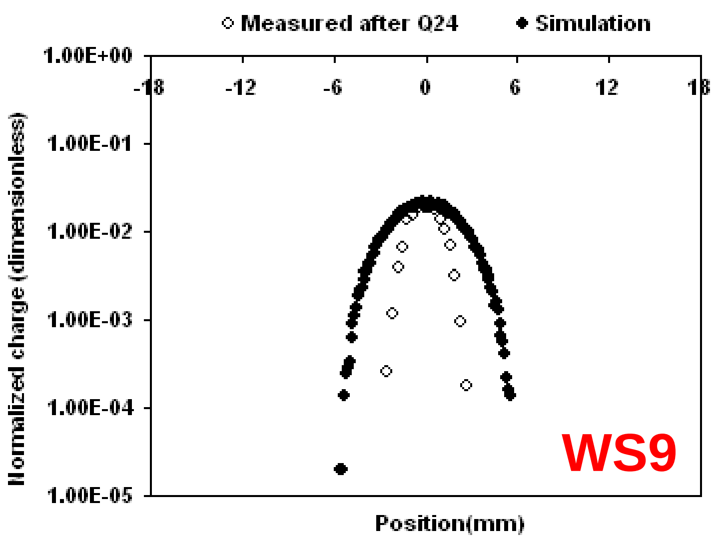


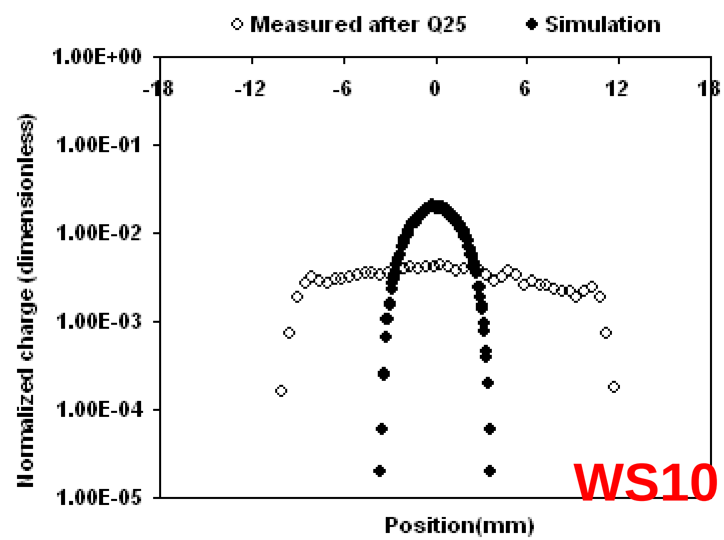


FD, 60º phase advance, mismatched beam, μ=2

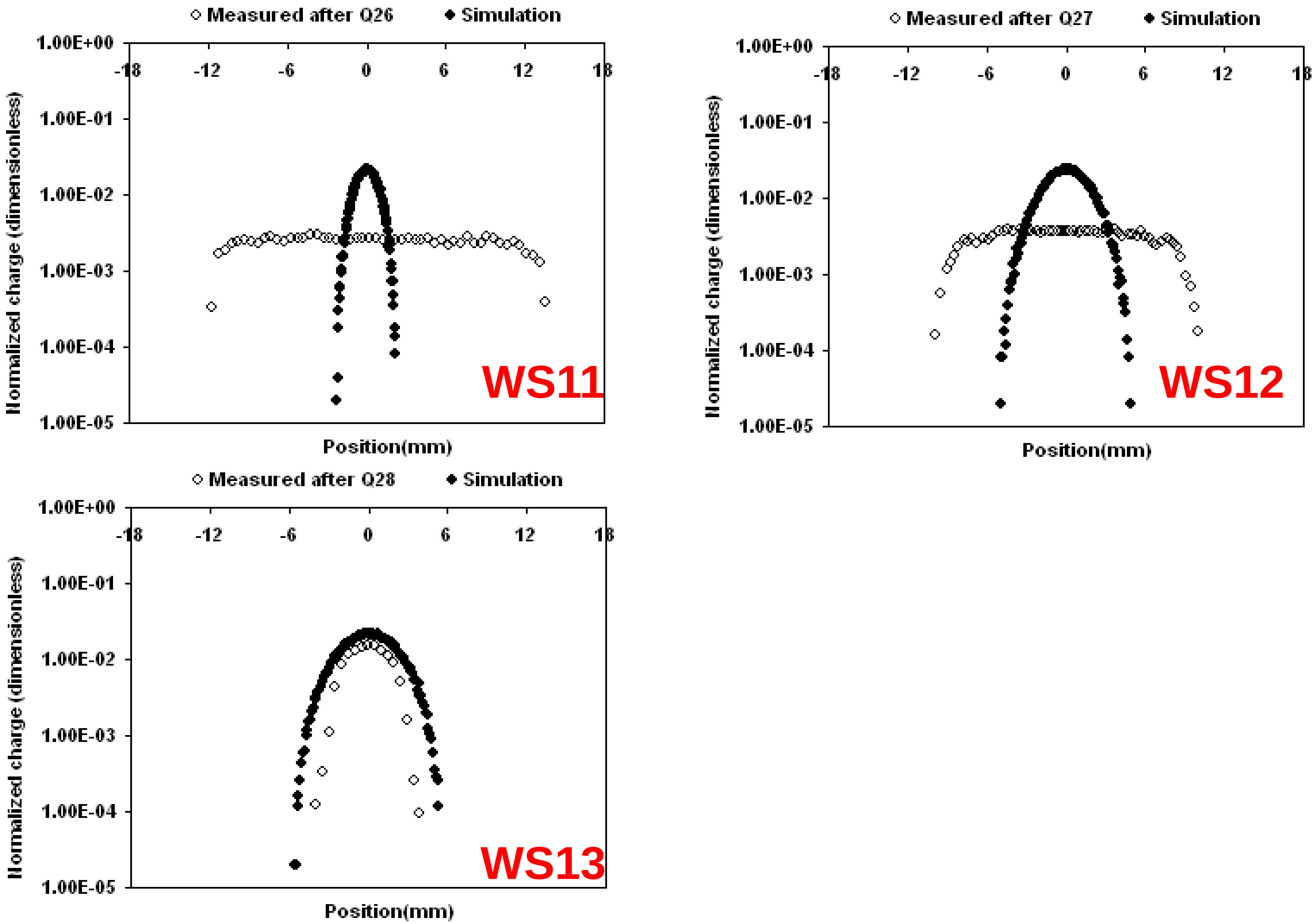






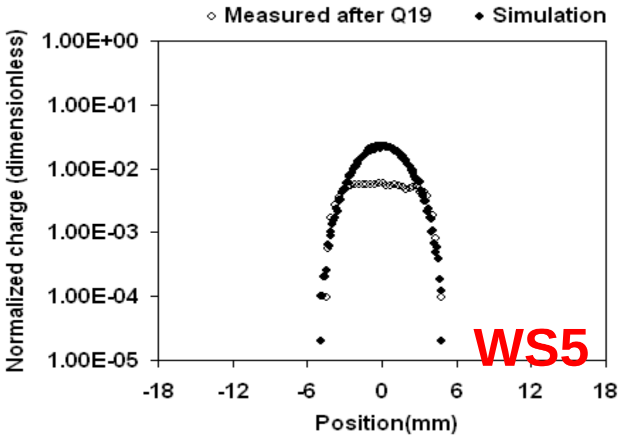


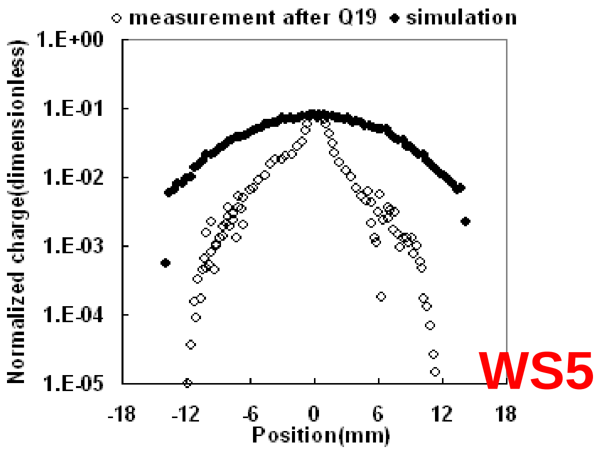
FD, 90^o phase advance, mismatched beam, μ=2

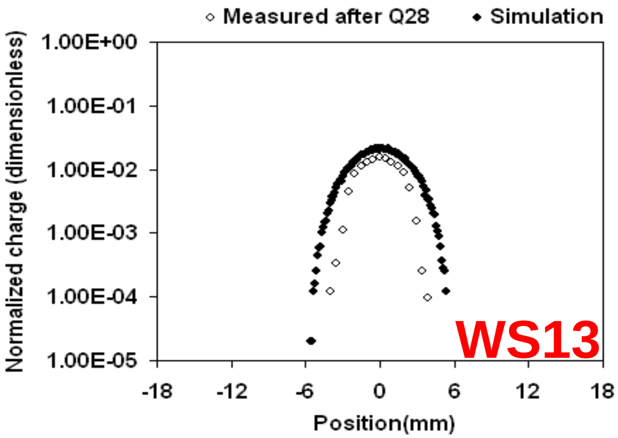


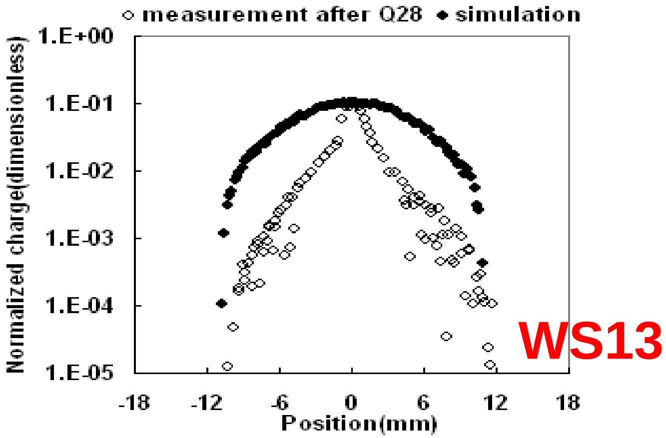
FD, 90º phase advance, mismatched beam, μ=2

Different RFQ Transmission









(a)Transmission is 90% , beam current is 27mA

(b)Transmission is 70% , beam current is 21mA

FD, 90º phase advance, mismatched beam

Summary

- End to end simulation for CSNS LINAC has shown that the beam loss, emittance growth rate and the ratio of bore radius to rms beam size were acceptable.
- The LINAC beam commissioning is scheduled to start at the end of 2014. The phase scan method will be used in the DTL commissioning .
- A beam halo experiment was performed for better understanding the halo characteristics, It is also considered to be very helpful for the upcoming beam commissioning. The results show that measurements are in good agreement with multi-particles simulations for matched beam. For mismatched beam, the measured beam profiles is different and the maximum amplitudes are much bigger.

Thank you!