The Beam-Halo Experiment at IHEP

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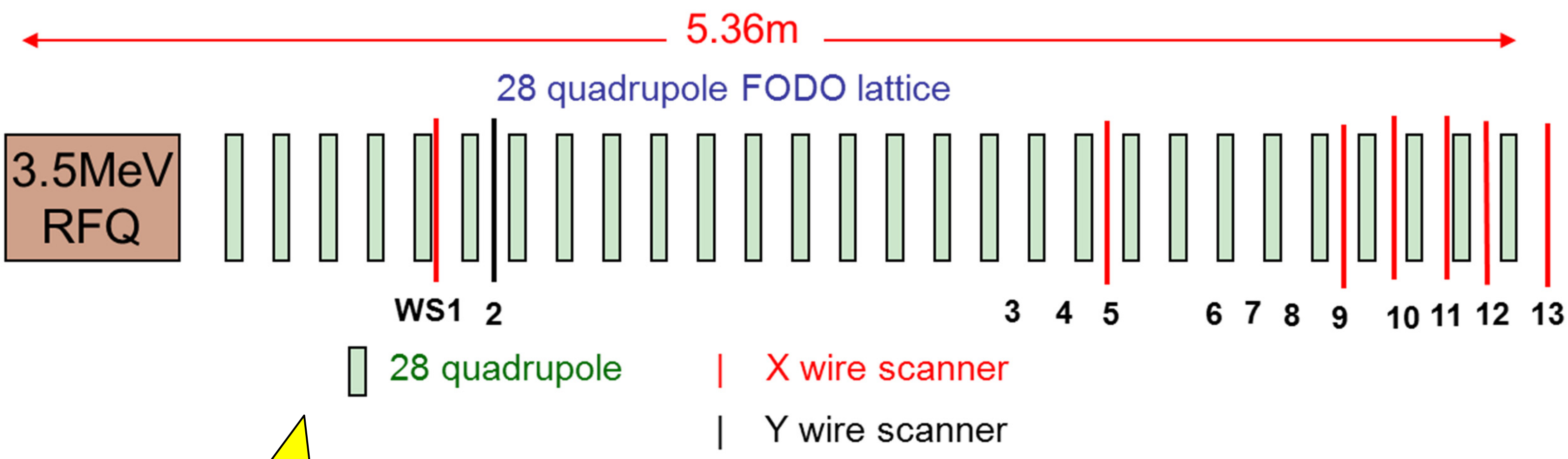
Introduction

Layout of the beam line



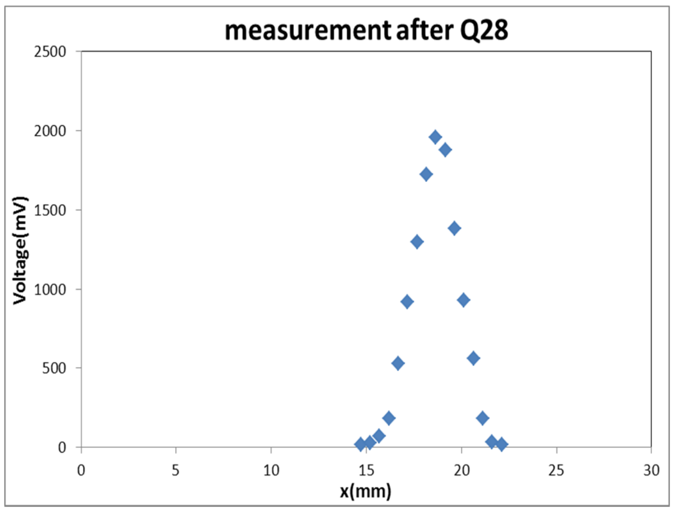
Experiment
I=21mA, 27mA

Phase Ⅰ

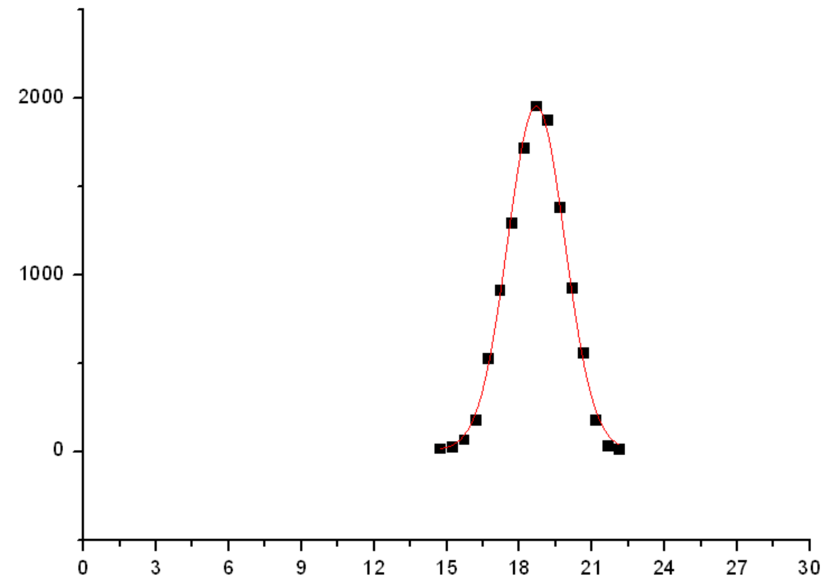
Calculate the initial beam Twiss parameters

Wire Scanner Data

Matched Beam,27mA, WS13x



Guass fitting



σ_{RMS}=1.18mm

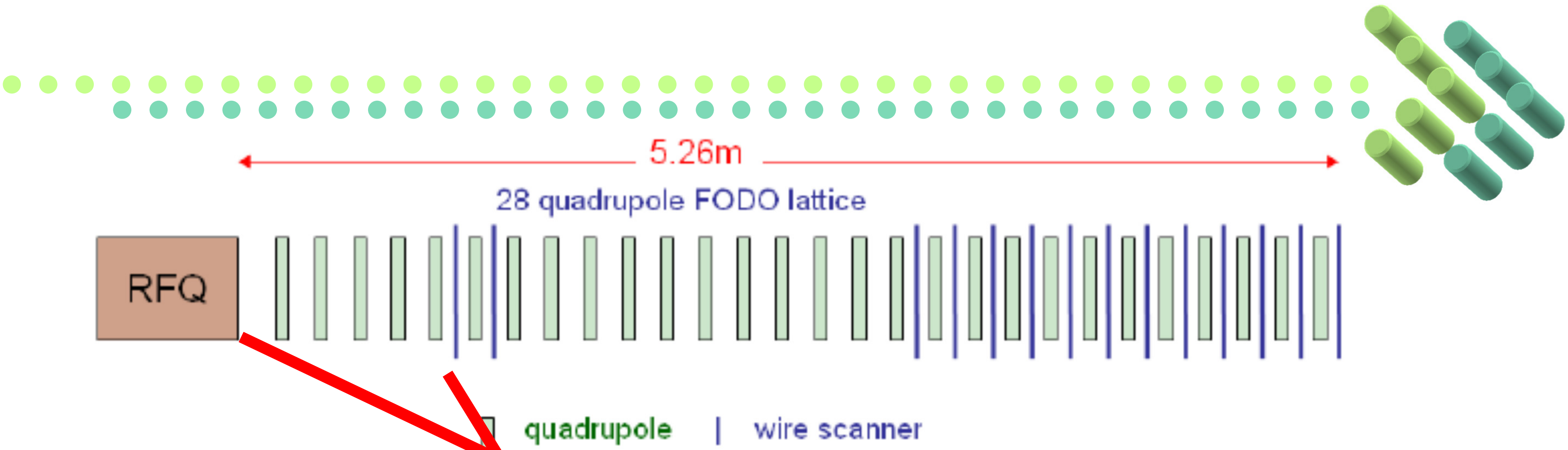


Figure 1 Layout of the beam halo experiment transport line

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

$$\sigma_2 = \begin{pmatrix} \beta_2\varepsilon_2 & -\alpha_2\varepsilon_2 \\ -\alpha_2\varepsilon_2 & \gamma_2\varepsilon_2 \end{pmatrix} = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix} \begin{pmatrix} \beta_1\varepsilon_1 & -\alpha_1\varepsilon_1 \\ -\alpha_1\varepsilon_1 & \gamma_1\varepsilon_1 \end{pmatrix} \begin{pmatrix} R_{11} & R_{21} \\ R_{12} & R_{22} \end{pmatrix} \quad (2)$$

$$\beta_2\varepsilon_2 = R_{11}^2\beta_1\varepsilon_1 - 2R_{11}R_{12}\alpha_1\varepsilon_1 + R_{12}^2\gamma_1\varepsilon_1 \quad (3)$$

$$X_{RMS}^2 = R_{11}^2 a + 2R_{11}R_{12}b + R_{12}^2 c \quad (4)$$

Least Squares Method

$$R_{1,11}^2 a + 2R_{1,11}R_{1,12}b + R_{1,12}^2 c = 5X_{1,RMS}^2$$
$$R_{2,11}^2 a + 2R_{2,11}R_{2,12}b + R_{2,12}^2 c = 5X_{2,RMS}^2$$
$$R_{3,11}^2 a + 2R_{3,11}R_{3,12}b + R_{3,12}^2 c = 5X_{3,RMS}^2$$
$$R_{4,11}^2 a + 2R_{4,11}R_{4,12}b + R_{4,12}^2 c = 5X_{4,RMS}^2$$
$$R_{5,11}^2 a + 2R_{5,11}R_{5,12}b + R_{5,12}^2 c = 5X_{5,RMS}^2$$

$$\chi^2 = \sum_{i=1}^{n} (R_{1,11}^2 a + 2R_{1,11}R_{1,12}b + R_{1,12}^2 c - X_{1,RMS}^2)^2$$

$$\begin{cases} \dfrac{d\sum_{i=1}^{5}\left(R_{i,11}^2 a + 2R_{i,11}R_{i,12}b + R_{i,12}^2 c - 5X_{i,RMS}^2\right)^2}{da} = 0 \\ \dfrac{d\sum_{i=1}^{5}\left(R_{i,11}^2 a + 2R_{i,11}R_{i,12}b + R_{i,12}^2 c - 5X_{i,RMS}^2\right)^2}{db} = 0 \\ \dfrac{d\sum_{i=1}^{5}\left(R_{i,11}^2 a + 2R_{i,11}R_{i,12}b + R_{i,12}^2 c - 5X_{i,RMS}^2\right)^2}{dc} = 0 \end{cases}$$

$$\begin{cases} \sum_{i=1}^{5} 2R_{i,11}^4 a + 4R_{i,11}^3 R_{i,12} b + 2R_{i,12}^2 R_{i,11}^2 c - 10X_{i,RMS}^2 R_{i,11}^2 = 0 \\ \sum_{i=1}^{5} 4R_{i,11}^3 R_{1,12} a + 8R_{i,11}^2 R_{i,12}^2 b + 4R_{i,12}^3 R_{i,11} c - 20X_{i,RMS}^2 R_{i,11} R_{i,12} = 0 \\ \sum_{i=1}^{5} 2R_{i,11}^2 R_{i,12}^2 a + 4R_{i,11} R_{i,12}^3 b + 2R_{i,12}^4 c - 10X_{i,RMS}^2 R_{i,12}^2 = 0 \end{cases}$$

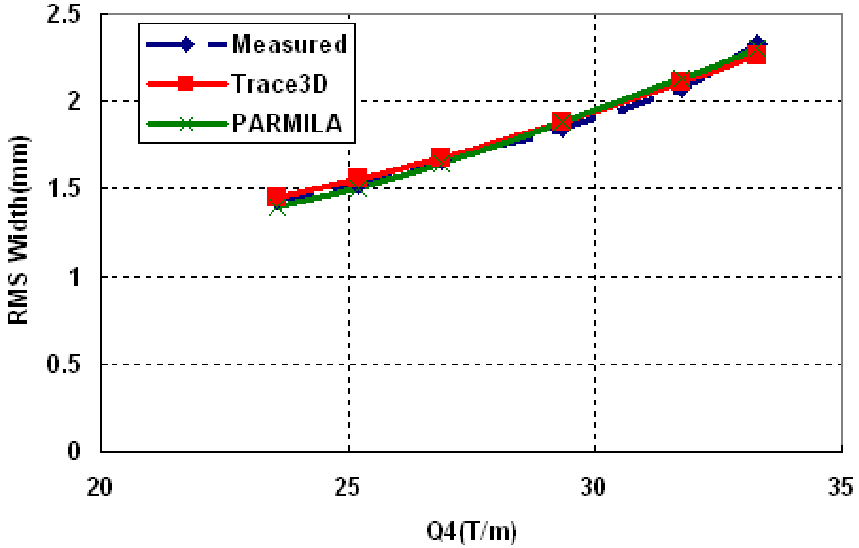
$$\alpha = \pm \frac{1}{\sqrt{\frac{ac}{b^2} - 1}} \qquad \varepsilon = -\frac{b}{\alpha} \qquad \beta = -\frac{a}{\varepsilon}$$

RFQ output beam parameters

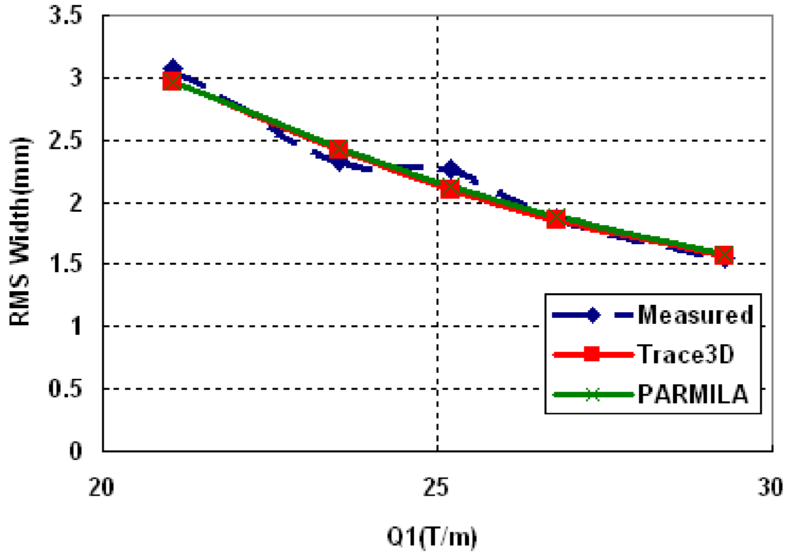
RFQ exit beam	α_x	β_x (mm/mrad)	α_y	β_y (mm/mrad)	ε_x (π.mm.mrad)	ε_y (π.mm.mrad)
PARMTEQM (I=20mA)	**-0.126**	**0.079**	**-0.709**	**0.218**	**0.205**	**0.21**
Experiment-1 Transmission is 70% I=21mA	**3.129**	**0.385**	**-0.546**	**0.112**	**0.344**	**0.327**
Experiment-2 Transmission is 90% I=27mA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

Comparison between Simulation and Measurement

I=21mA, RMS beam radius



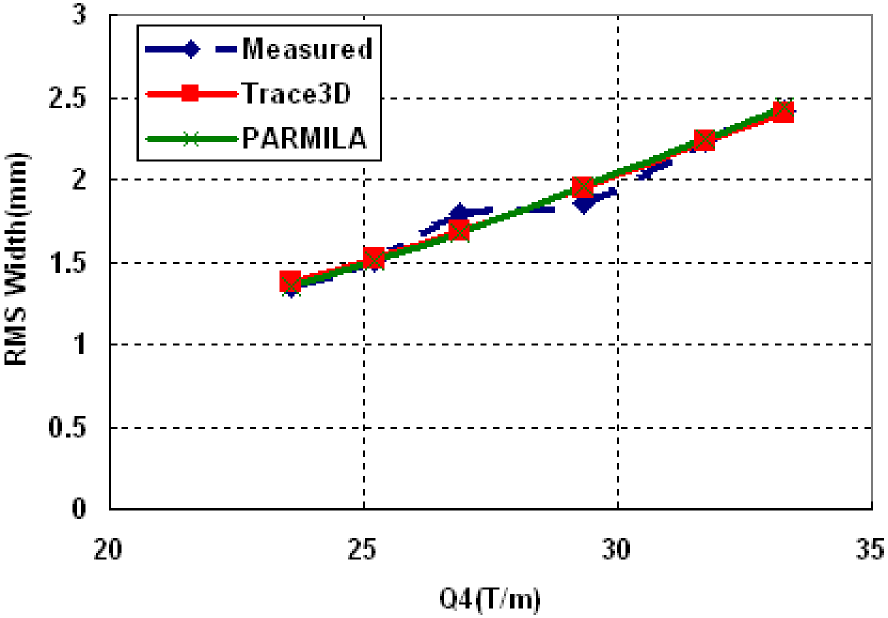
(a) X



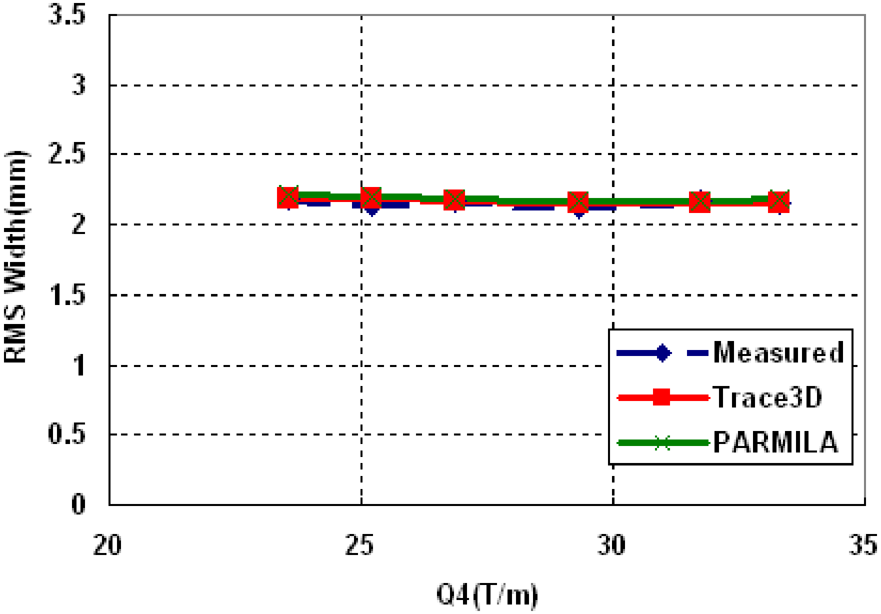
(b) Y

Comparison between Simulation and Measurement

I=27mA, RMS beam radius



(a) X



(b) Y

Phase Ⅱ
Measure the Matched Beam

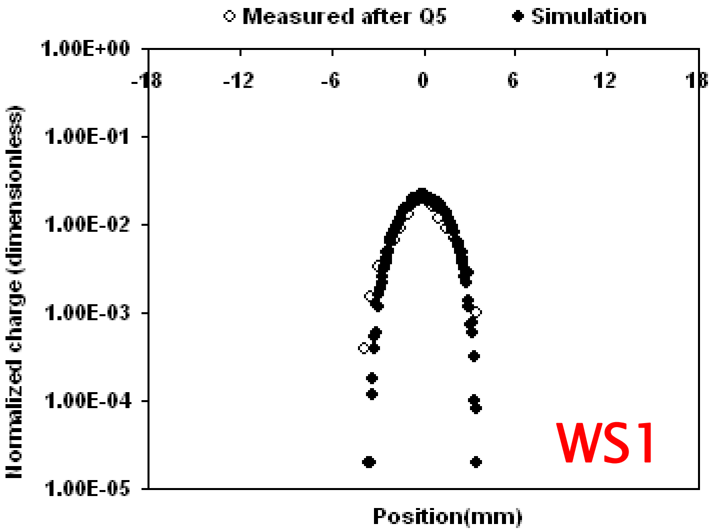
- **FD, 45^o zero current phase advance per period**
- **FD, 60^o zero current phase advance per period**
- **FD, 90^o zero current phase advance per period**

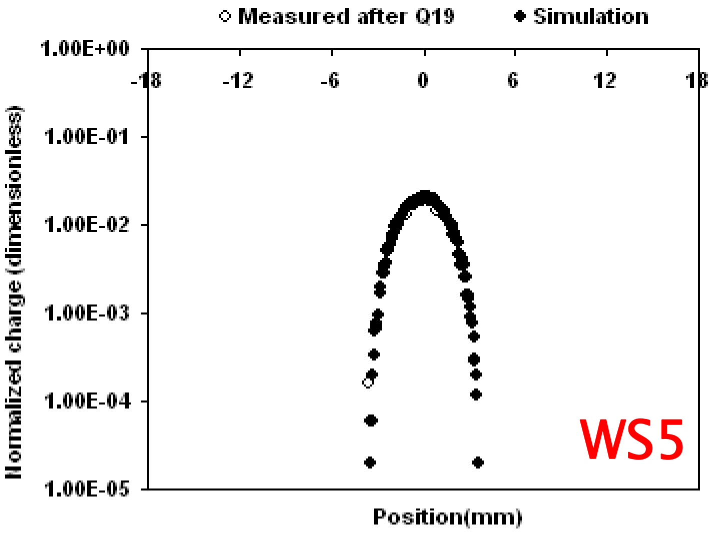
Procedures for Matching

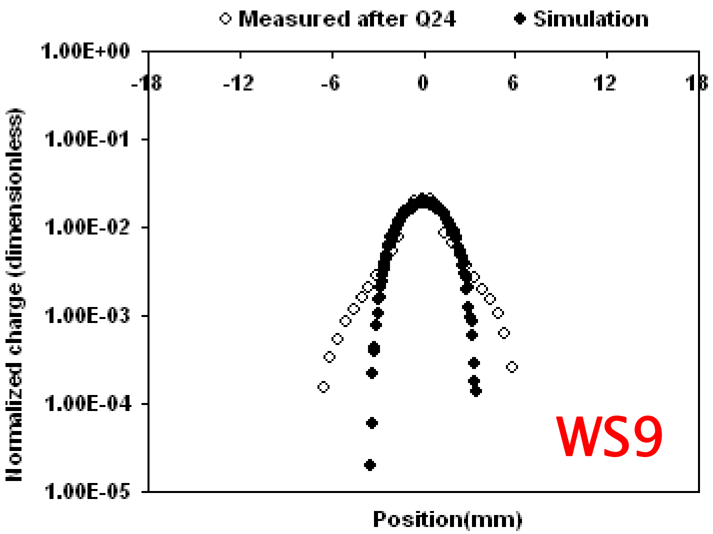
- Initial matched-beam quad settings are determined from TRACE3D
- Quad scans are used to determine partial derivatives of the beam size as functions of the matching quad strengths.
- Determine quad settings that produce equal RMS sizes in x at WS9~13, so the beam is RMS matched

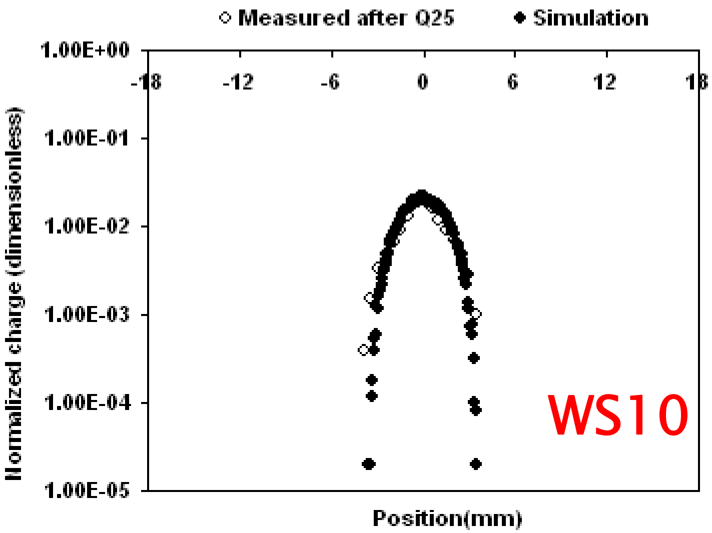
Beam Profile

FD, 60° phase advance, matched beam

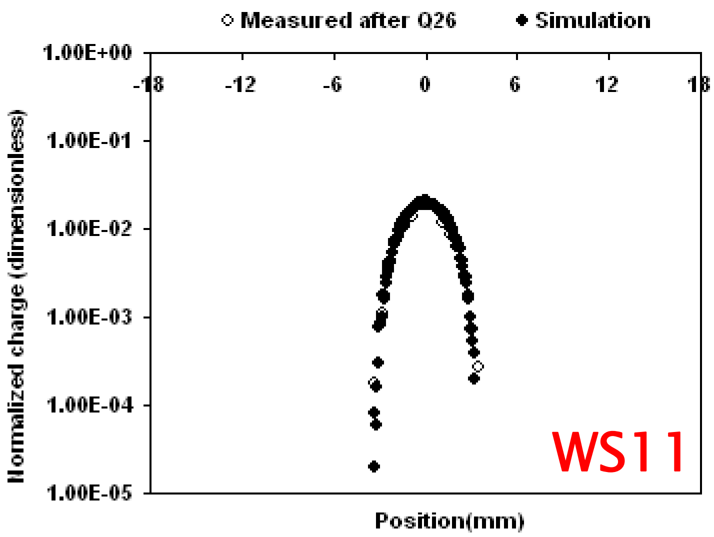


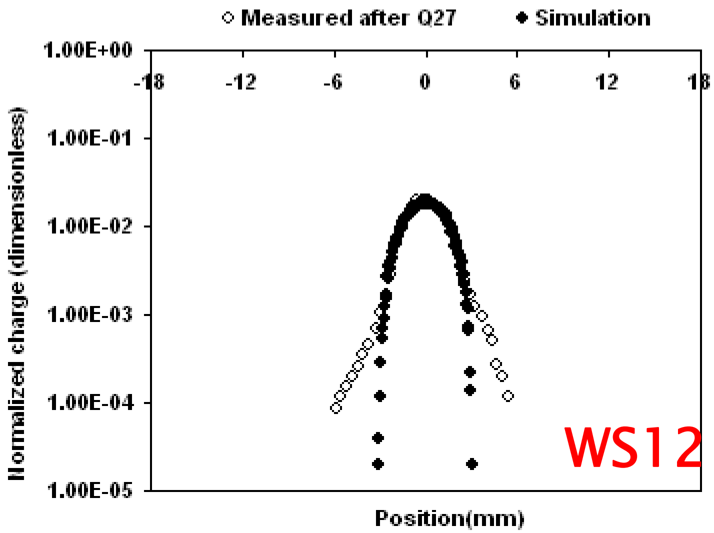


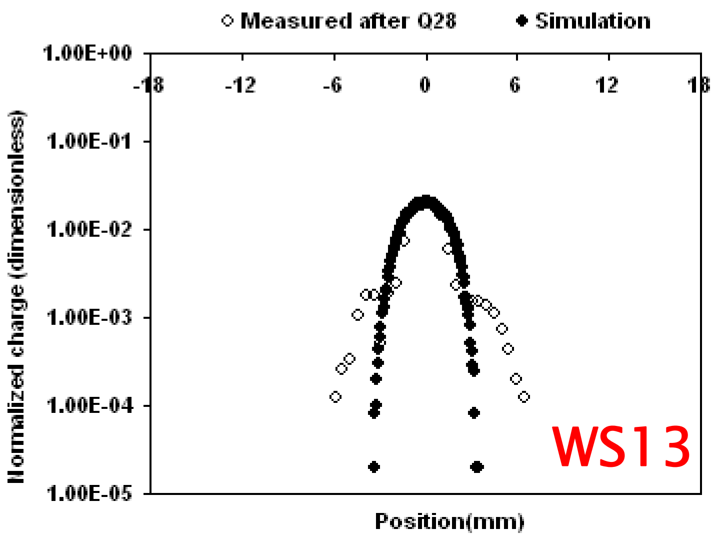




FD, 60° phase advance, matched beam

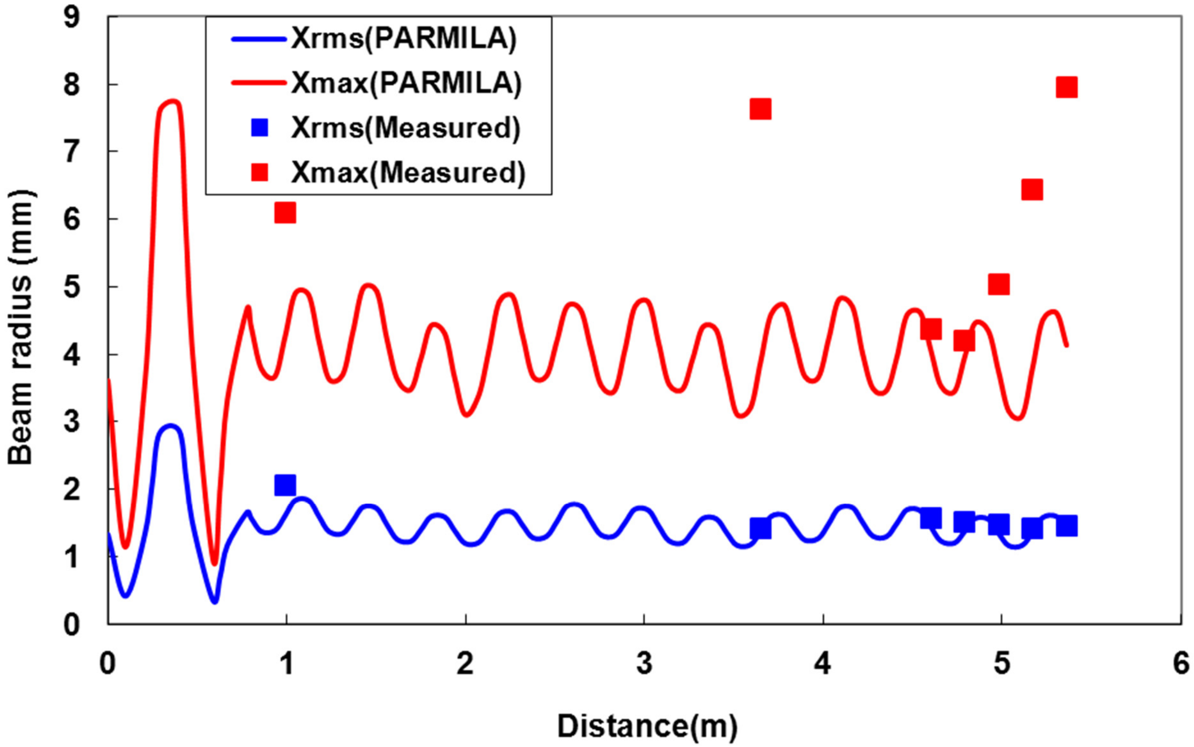






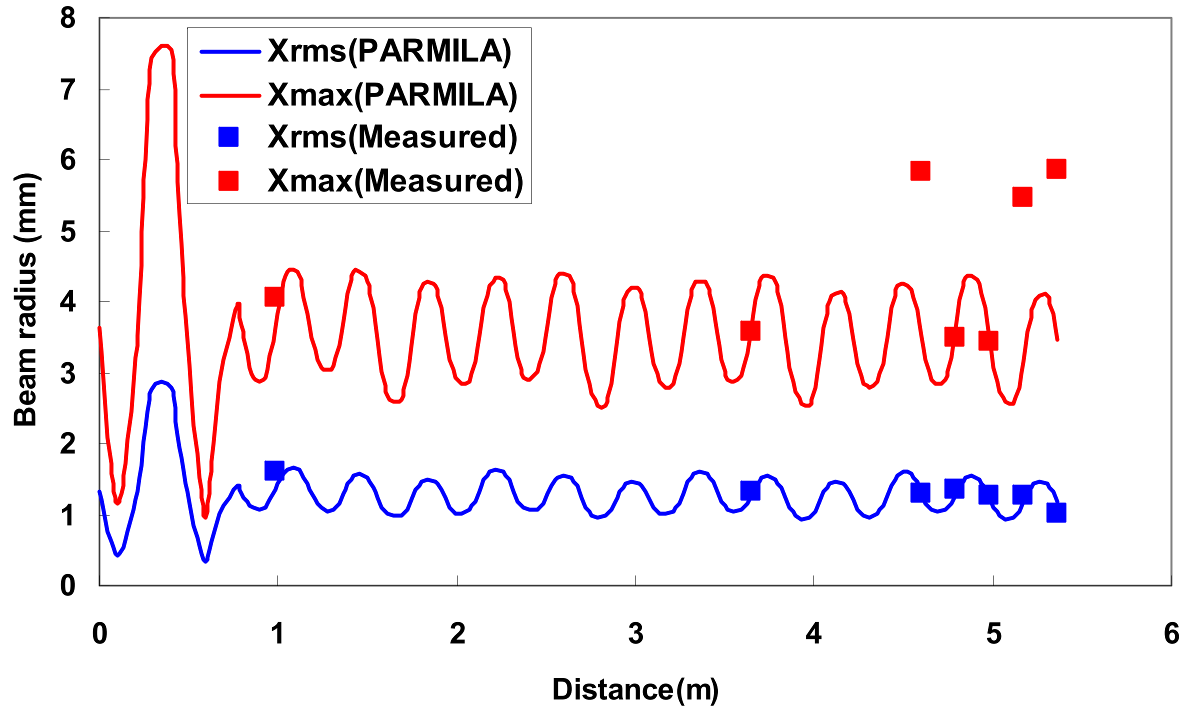
Comparison between Simulation and Measurement

FD lattice, zero current phase advance per period=**45°**, matched beam envelope



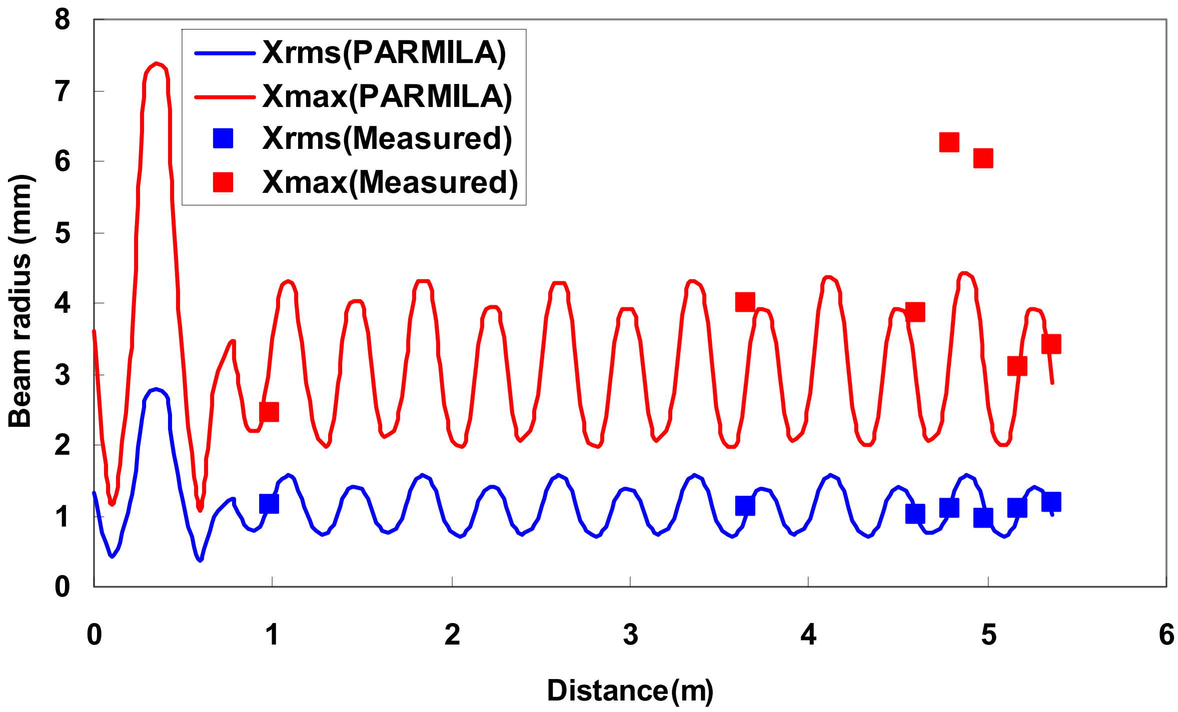
Comparison between Simulation and Measurement

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



Comparison between Simulation and Measurement

FD lattice, zero current phase advance per period=**90º**, matched beam envelope



Summary

- Measurements have been made at 45^o,60^o,90^o phase advance.
- For matched beam, measurements are in good agreement with multi-particle simulations. The measured envelope is about 1~1.5 times of the simulated envelope.

Phase Ⅲ
Measure the Mismatched Beam

- **Comparison among different phase advances**
- **Comparison between different beam transmissions**
- **Comparison among different mismatch factors**

Mismatch factor μ is defined as:

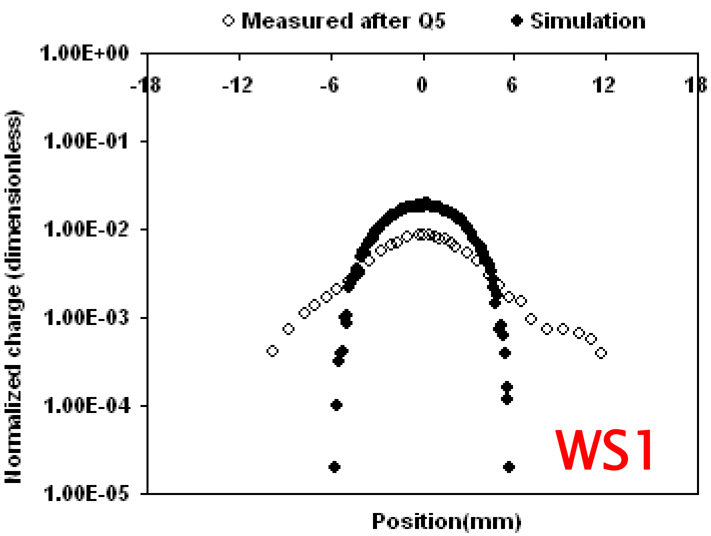
$$\mu^2 = \frac{\alpha}{\alpha_m}$$

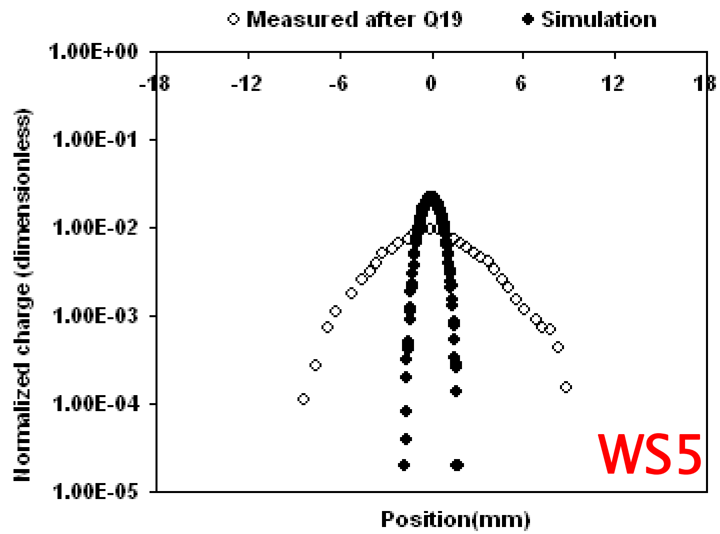
$$\mu^2 = \frac{\beta}{\beta_m}$$

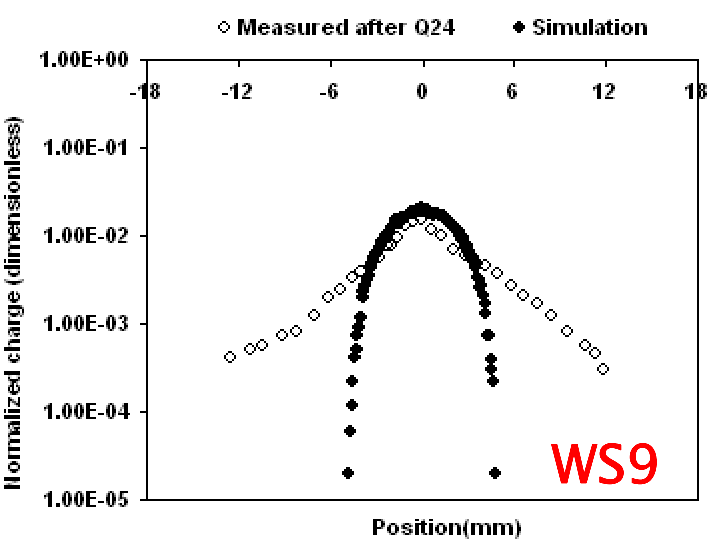
Here, α_m, β_m is the matched twiss parameters,
α, β is the mismatched twiss parameters

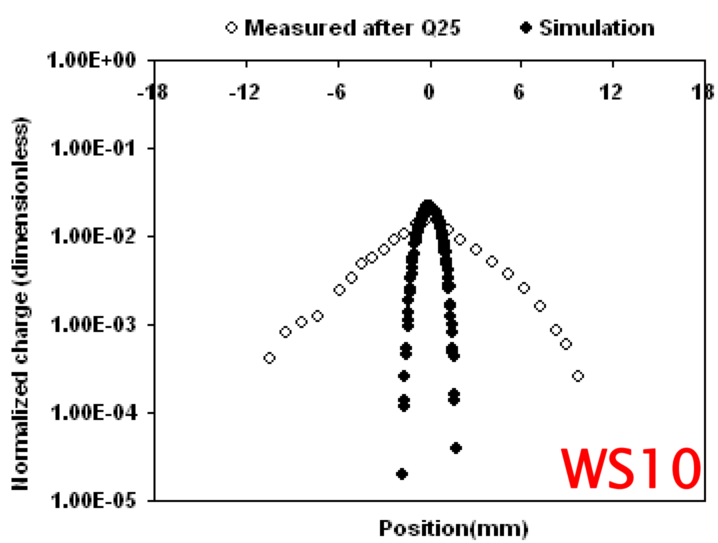
Different phase advance

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

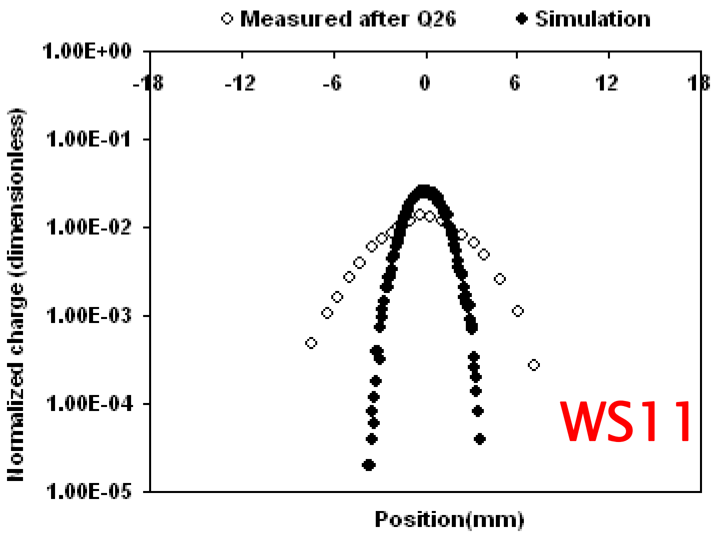


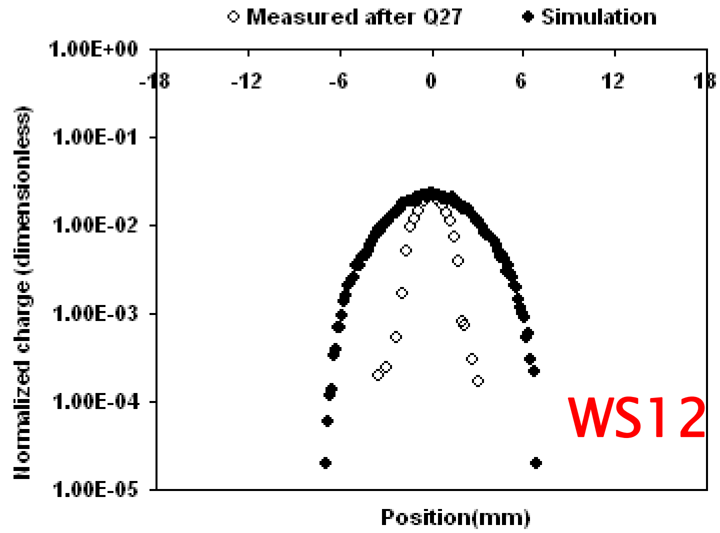


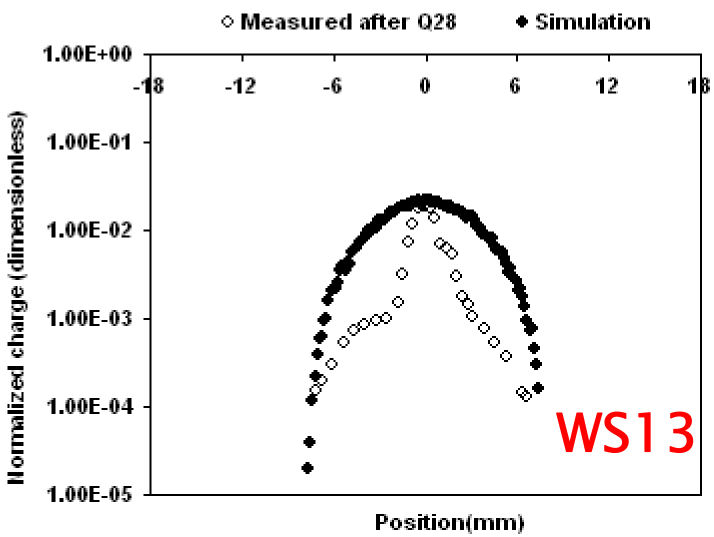




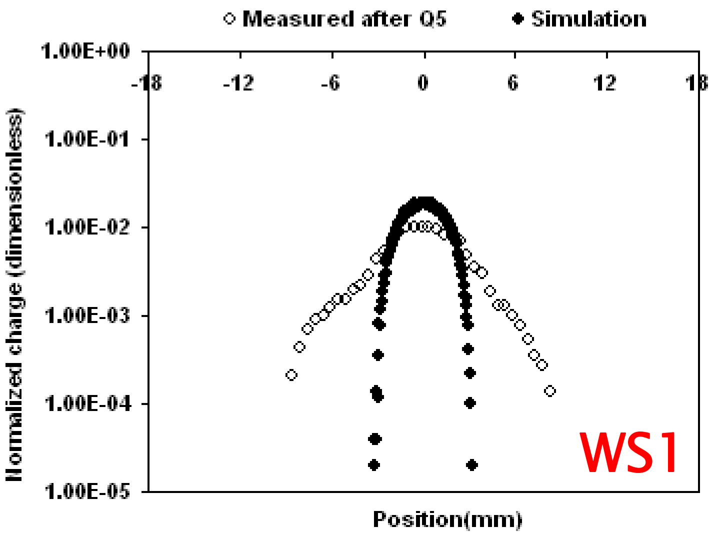
FD, 60° phase advance, mismatched beam, μ=2

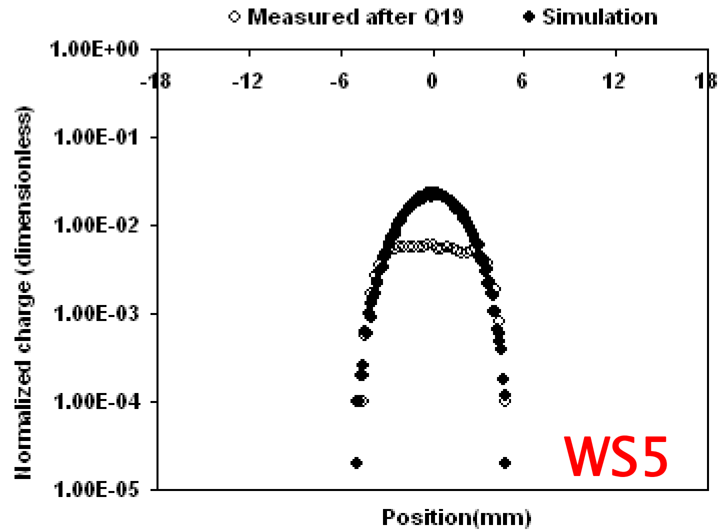


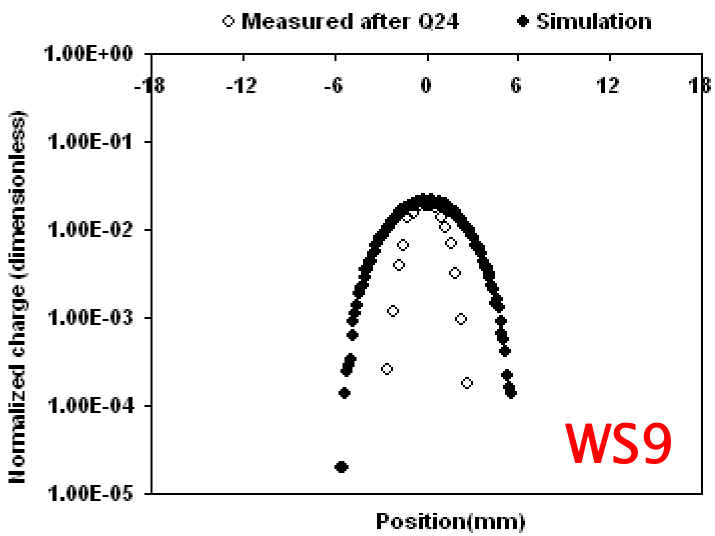


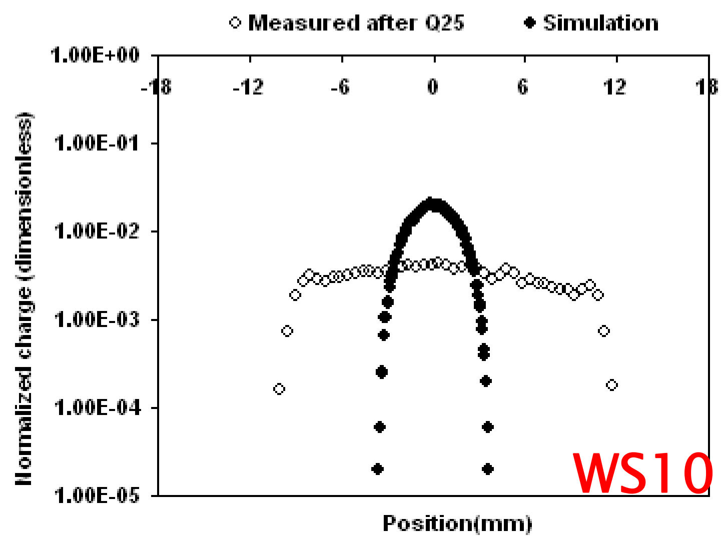


FD, 90° phase advance, mismatched beam, μ=2

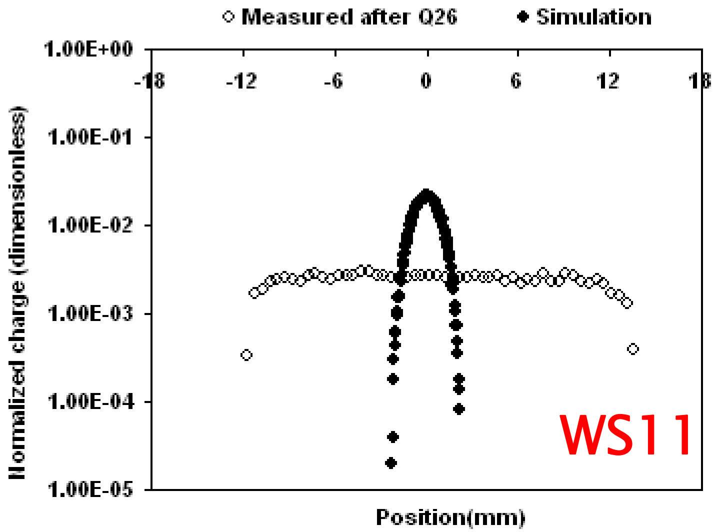


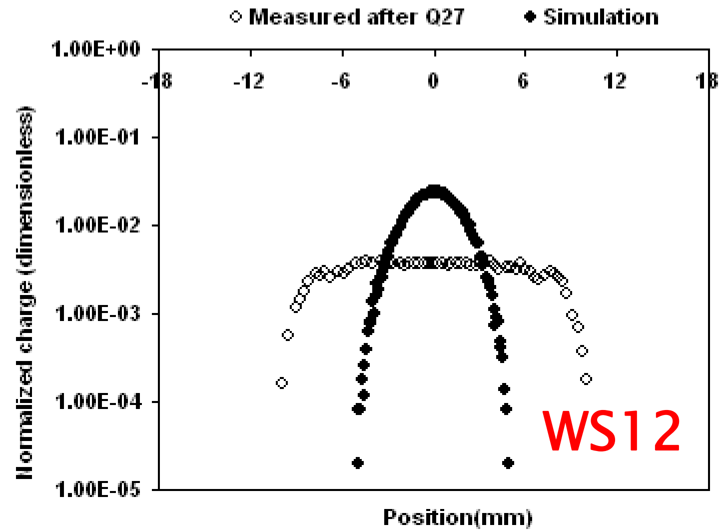


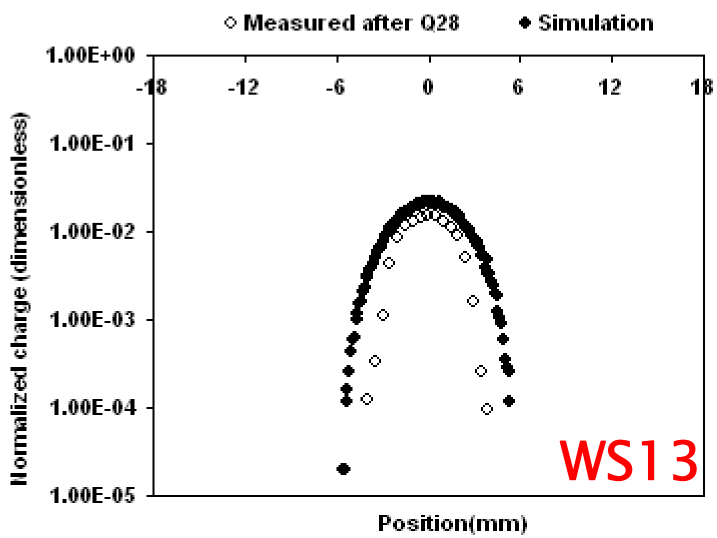




FD, 90° phase advance, mismatched beam, μ=2

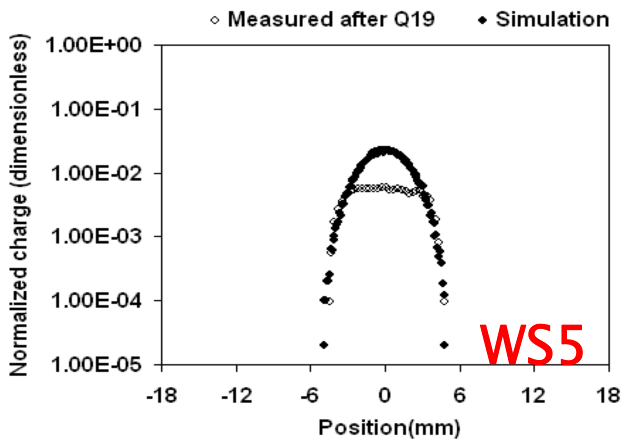


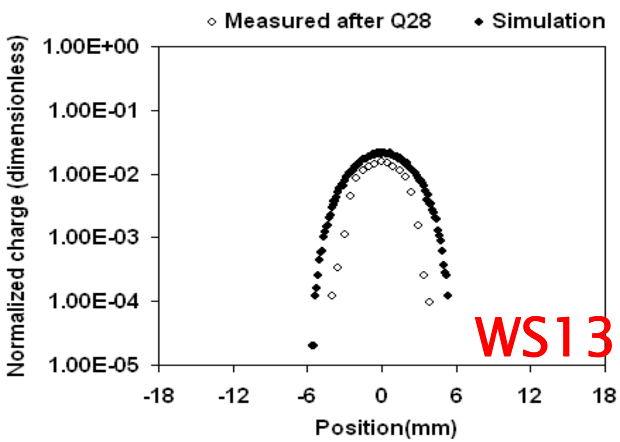




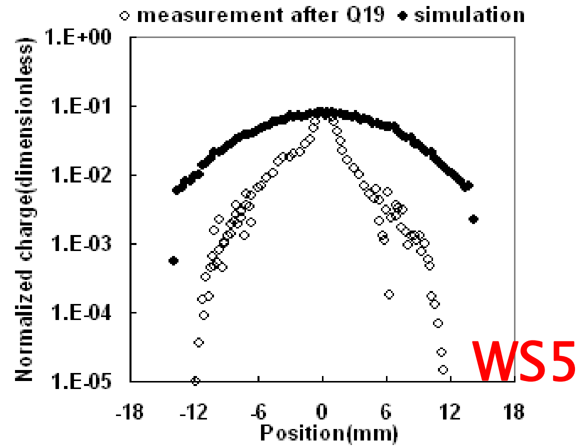
Different Beam Transmission for the RFQ

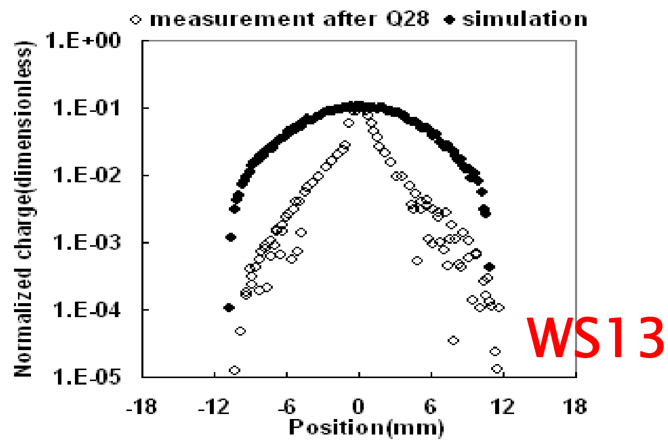
FD, 90º phase advance, mismatched beam，μ=2





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

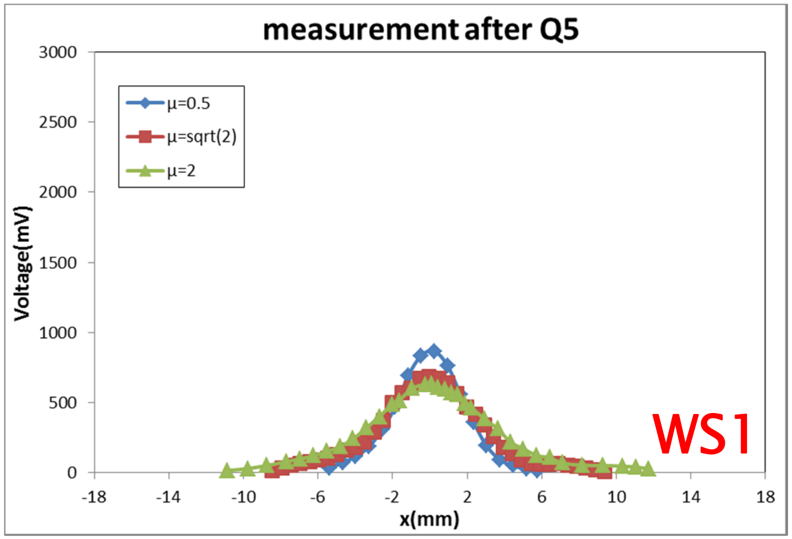


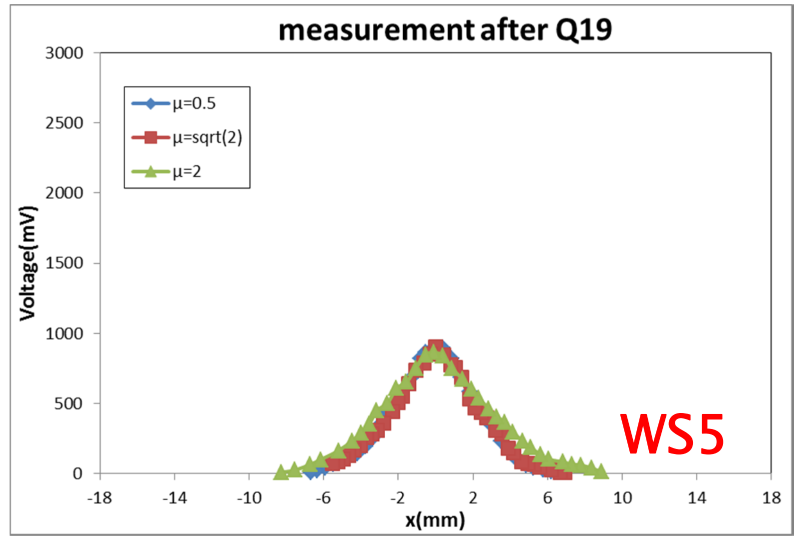


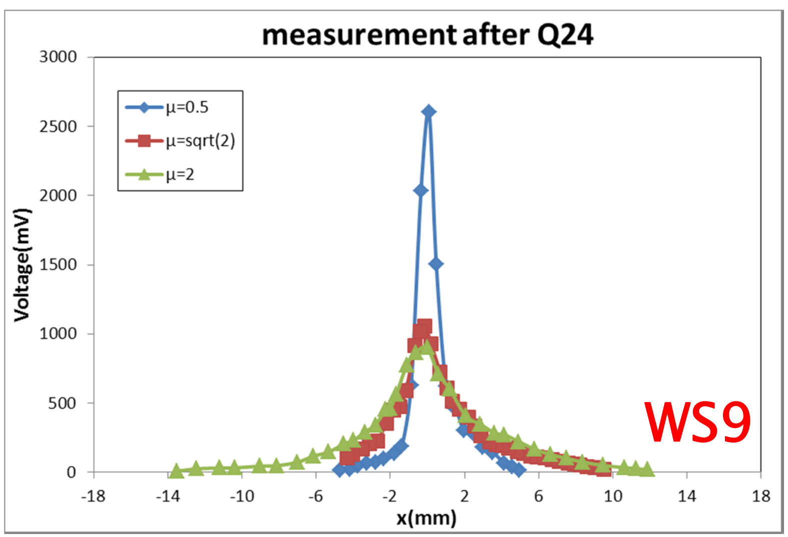
(b)Transmission is 70% , beam current is 21mA

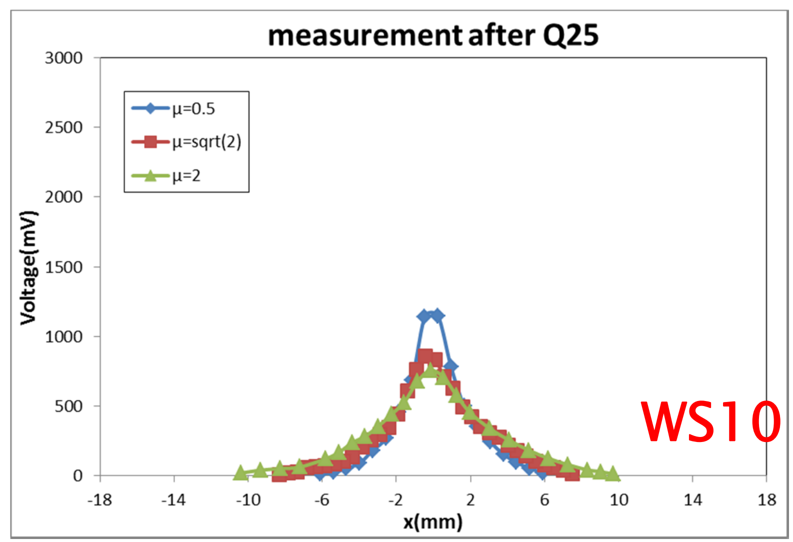
Different mismatch factor μ

FD, 60° phase advance, mismatched beam, μ=0.5, sqrt(2), 2

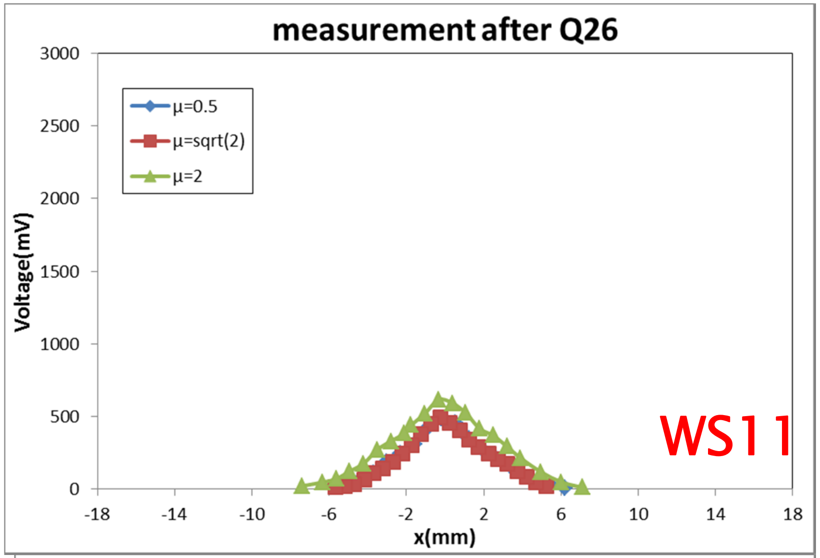


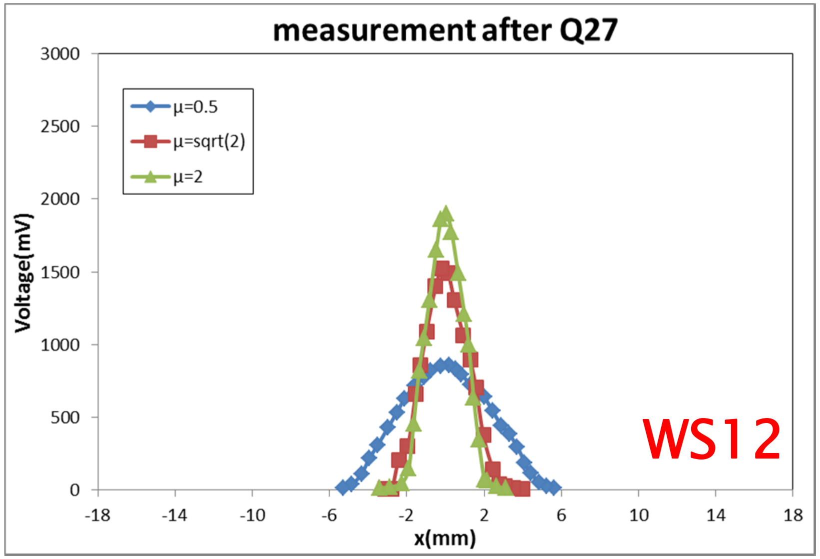


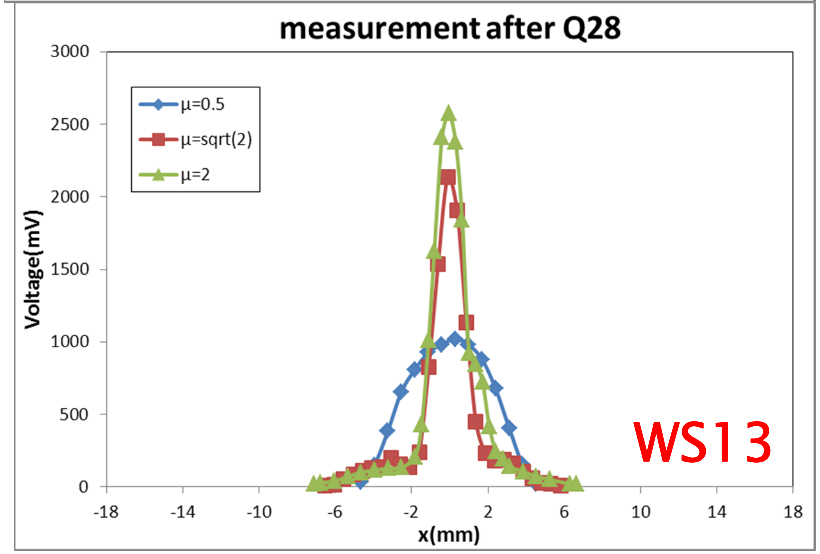




FD, 60° phase advance, mismatched beam, μ=0.5, sqrt(2), 2







Summary

- For mismatched beam, simulation can't predict the beam profiles, the actual beam size are about 2~3 times of the simulated ones.
- Many factors may affect mismatched beam profile and halo formation, such as phase advance, mismatch factor and initial distribution. There will form long period oscillation in mismatched beam. The bigger the mismatch factor is, the bigger the oscillation amplitude is. However, the oscillation period is only determined by the focusing period.

Thank you !