400-MeV Linac Beam

- Linac parameters
- Simulation results

KEK
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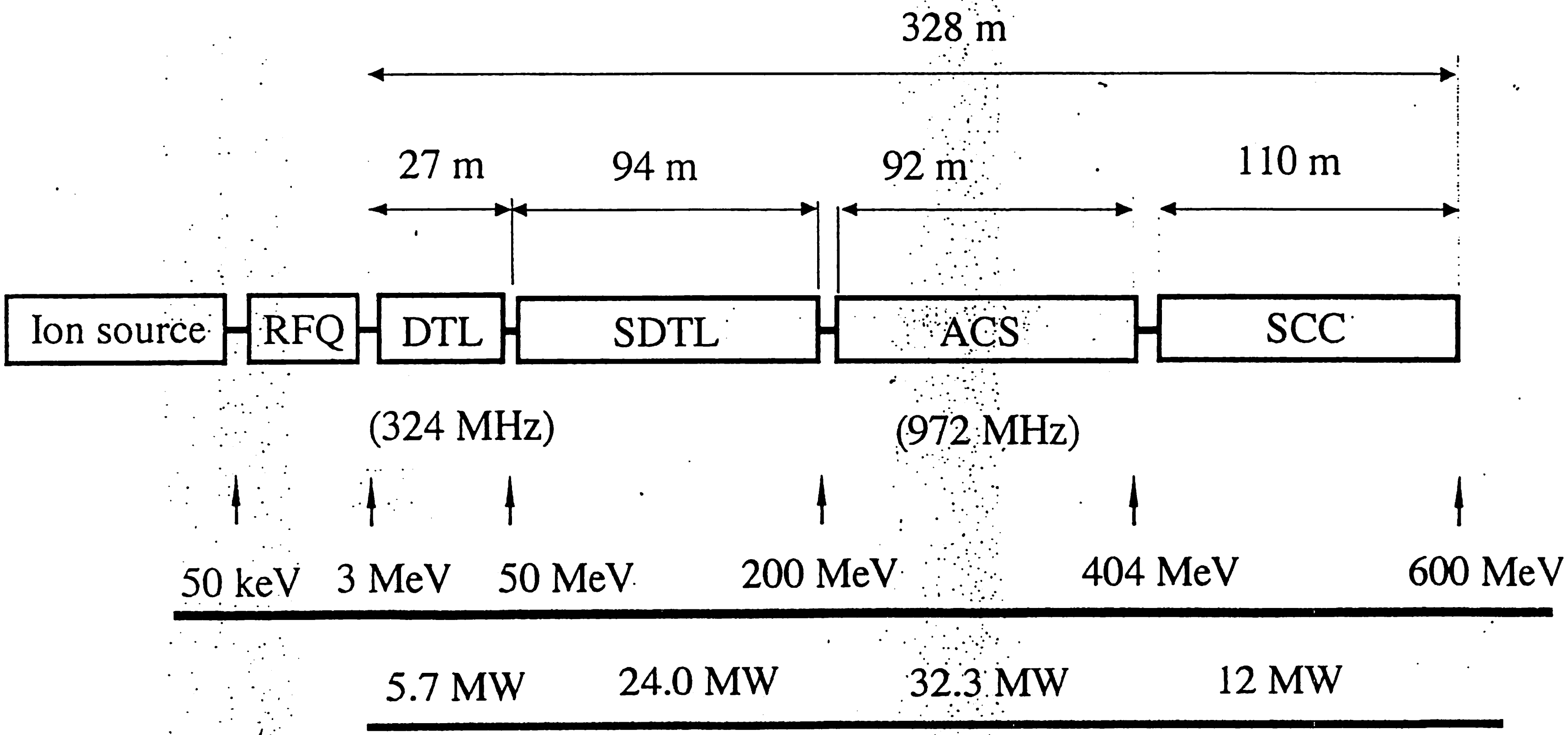
2k0114

JHF-JAERI 600-MeV linac



RFQ, DTL, SDTL,ACS and SCC parameters

	RFQ	DTL	SDTL	ACS	SCC		
Output energy	3	50	200	404	600	MeV	
Frequency	324	324	324	972	972/648	MHz	
Total length	3.1	27.1	98.4	92.1	110	m	
Structure length	3.1	26.7	70.9	63.2	34.1	m	
Number of tank	1	3	34	42	42		
Number of cell		146	170	636	294		
Accelerating field			2.5~2.9	2.5~3.7	4.4~4.8	7.5~8.4	MV/m
Stable phase	-30	-30	-27	-30~ -44		deg	
Vane voltage	82.9(1.8KL)					kV	
Drive power	0.336	3.3	16.5	22.1		MW	
Beam power	0.148	2.4	7.5	10.2	9.8	MW	
Total power	0.484	5.7	24.0	32.3		MW	

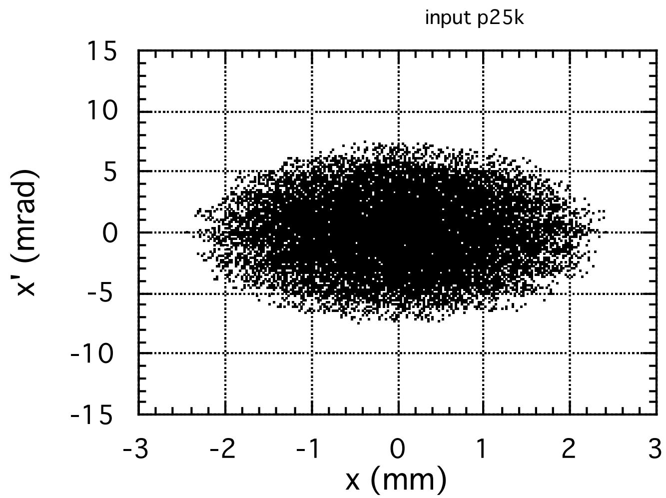
Ipeak=50mA, beam pulse length 500 μsec
Repetition frequency 25/50 Hz
KL=Kilpatrick limit

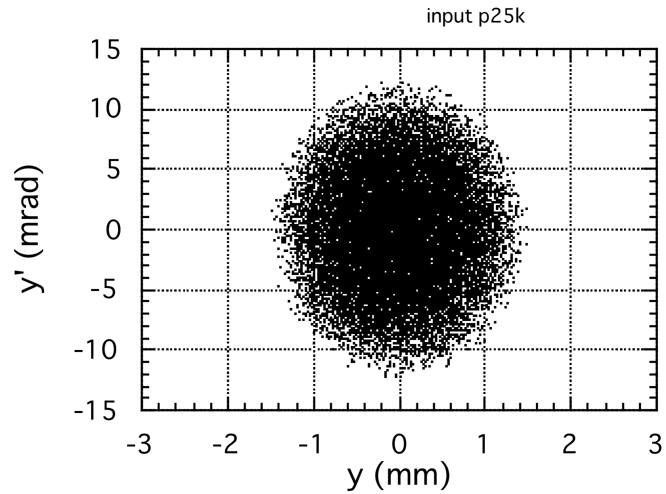
Injection beam into DTL (1)

- Two types of beams: Type-C & RFQ -beam
- Beam parameters for the matched beam

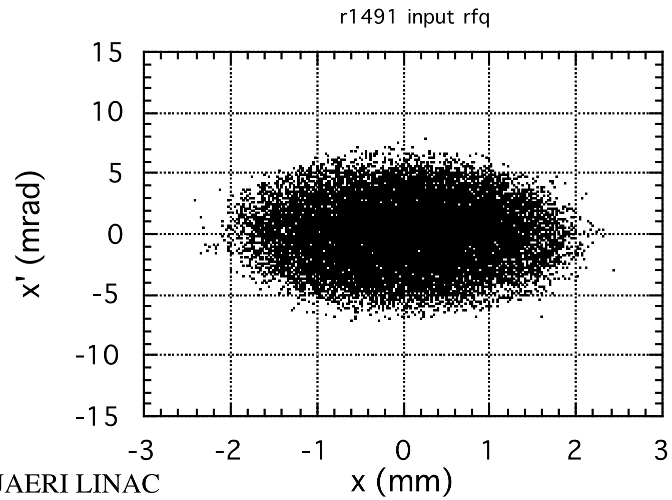
	ε_{xrms} mm-mrad	ε_{zrms} MeV-deg	σ_x/σ_{x0} deg	σ_z/σ_{z0} deg	k_x/k_{x0}	μ_x	k_z/k_{z0}	μ_z
C-30mA	0.2	0.14	42/58	19/31	0.72	0.48	0.61	0.62
C-50mA	0.2	0.15	36/58	15/31	0.62	0.61	0.49	0.76
rfq-30mA	0.16	0.08	38/58	14/31	0.66	0.57	0.44	0.80
rfq-50mA	0.16	0.08	32/58	10/31	0.55	0.70	0.32	0.89

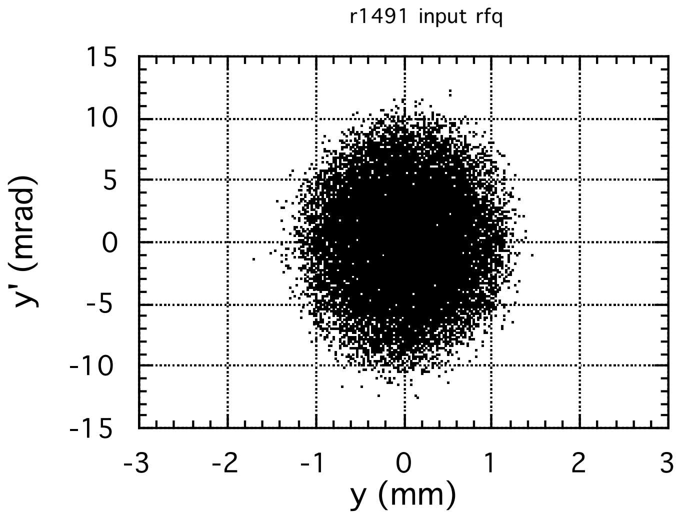
Injection beam into DTL (2)





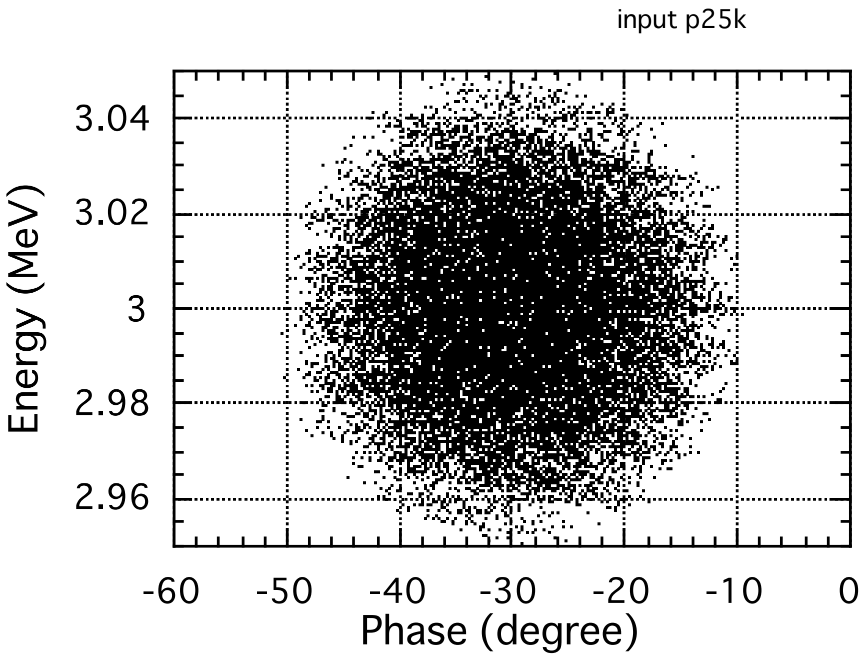
C-type



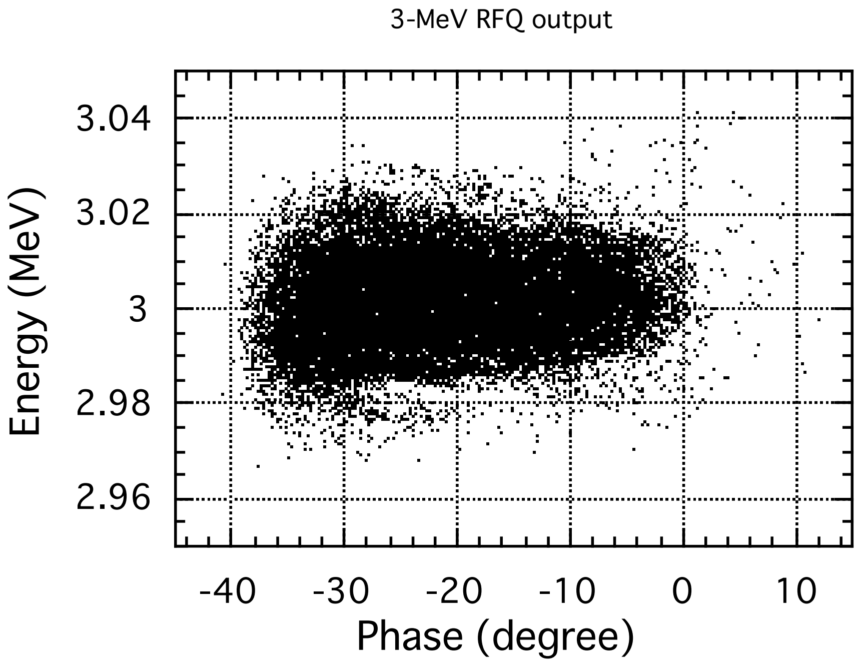


RFQ

Injection beam into DTL (3)

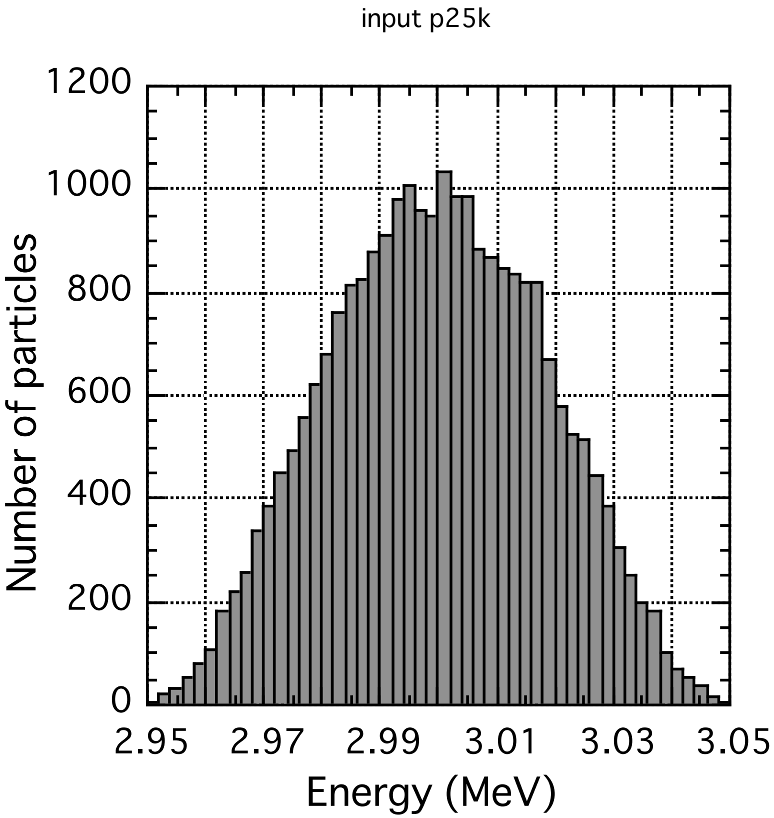


C-type

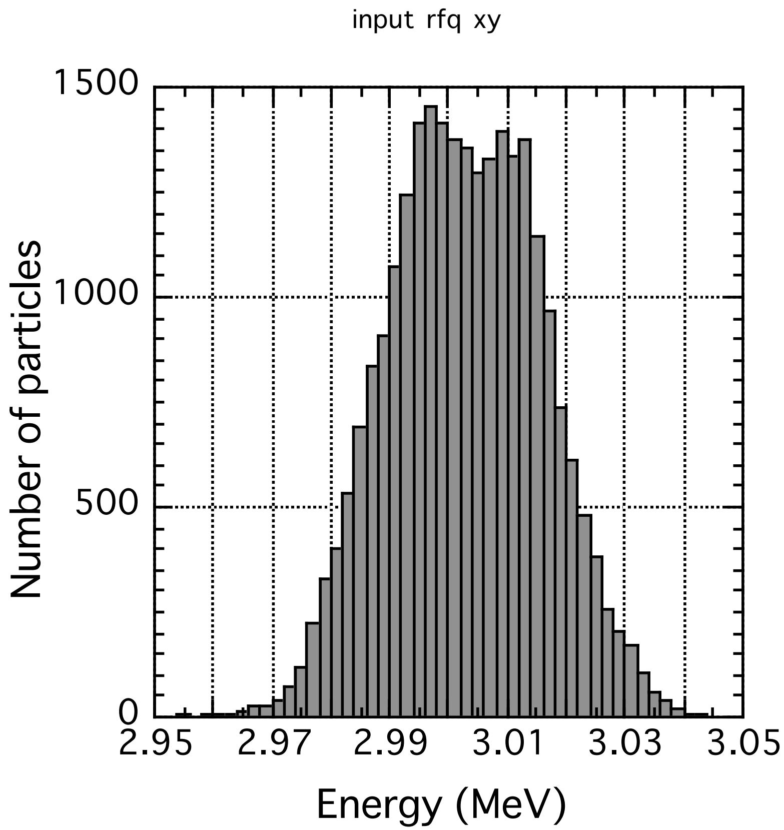


RFQ direct (xy-match)

Injection beam into DTL (4)



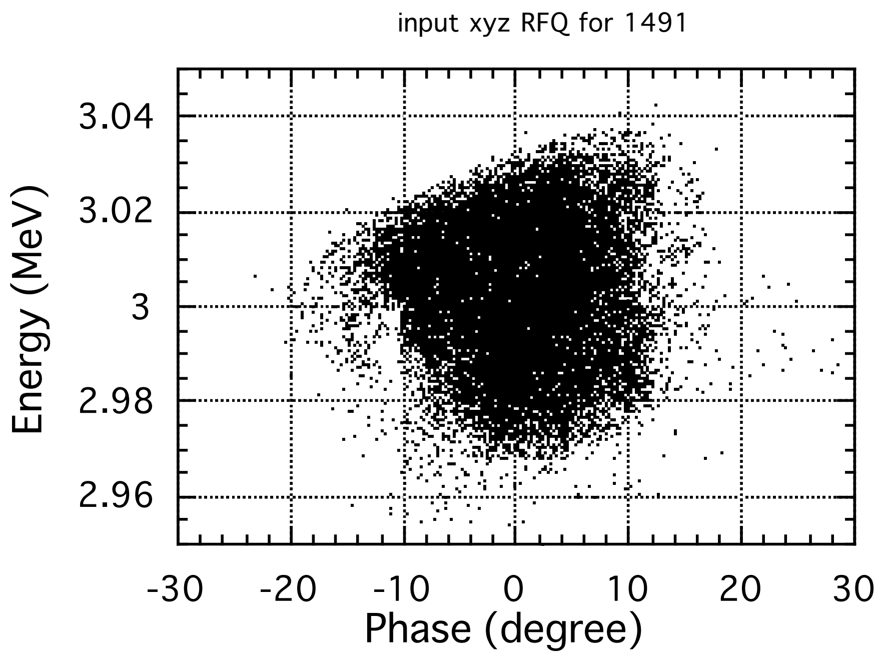
C-type



RFQ

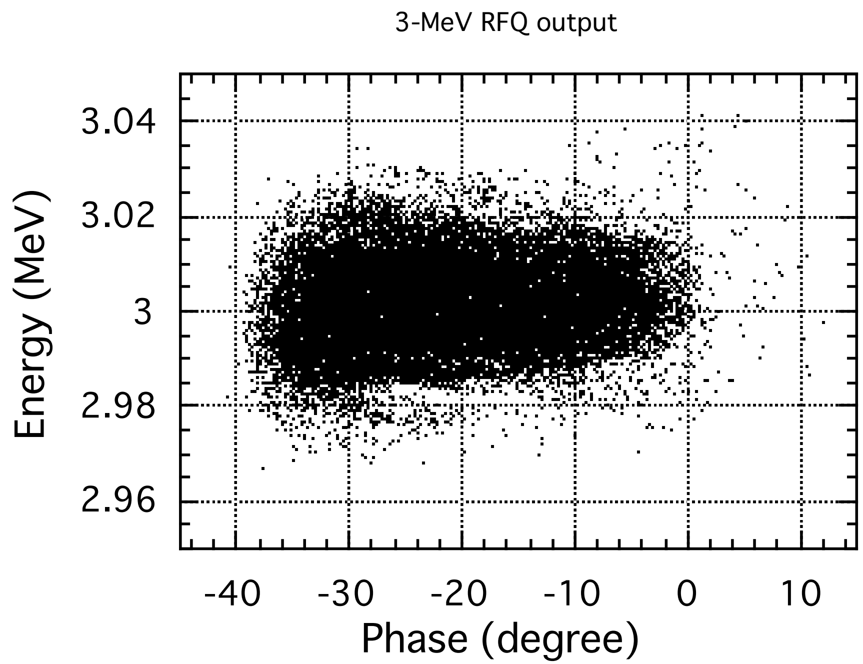
Injection beam: RFQ beam with z -match

with z-match



bz = 550 deg/MeV

without z-match



bz = 500 deg/MeV

Emittances of the input beams

	C-x	RFQ-x	C-y	RFQ-y	C-z	RFQ-z
rms	0.0198	0.0164	0.0198	0.0161	0.140	0.0830
90%	0.0842	0.0703	0.0847	0.0693	0.597	0.348 99% 0.125 0.108

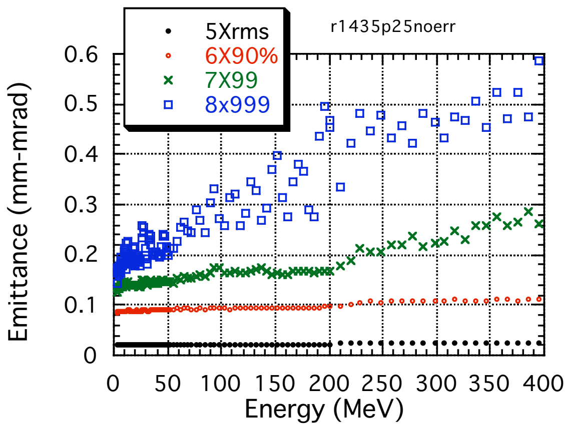
(cm-mrad) (MeV-deg)

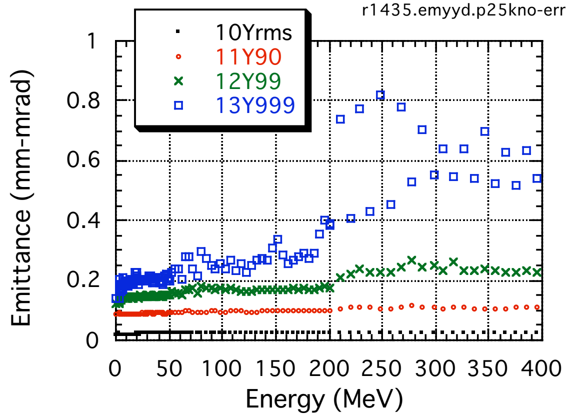
Beam matching

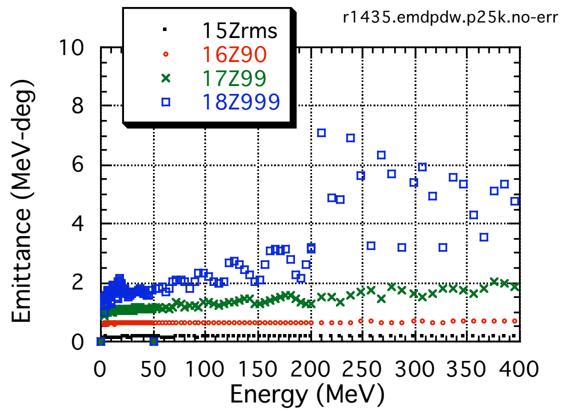
three kinds of solution

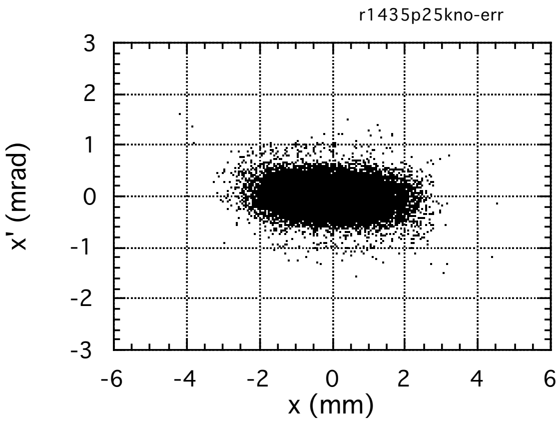
- Matched beam parameters by calculation
- Rms matching by test simulation
- Minimizing rms or 99.9% emittance growth by test simulation

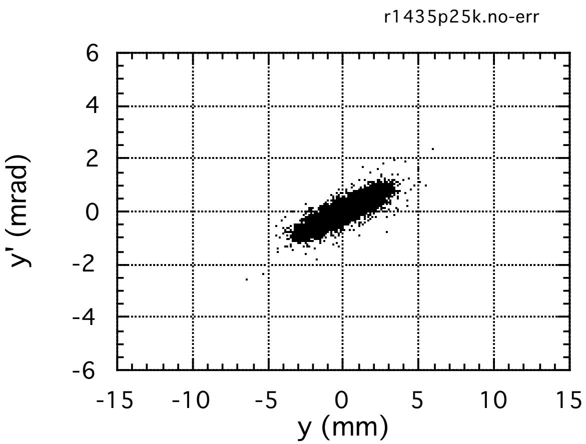
No error simulation: C-type

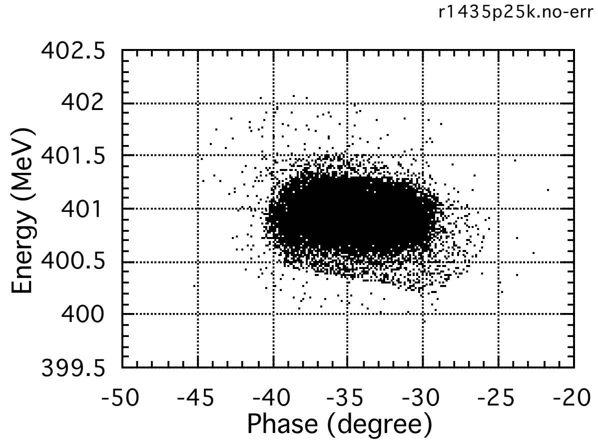




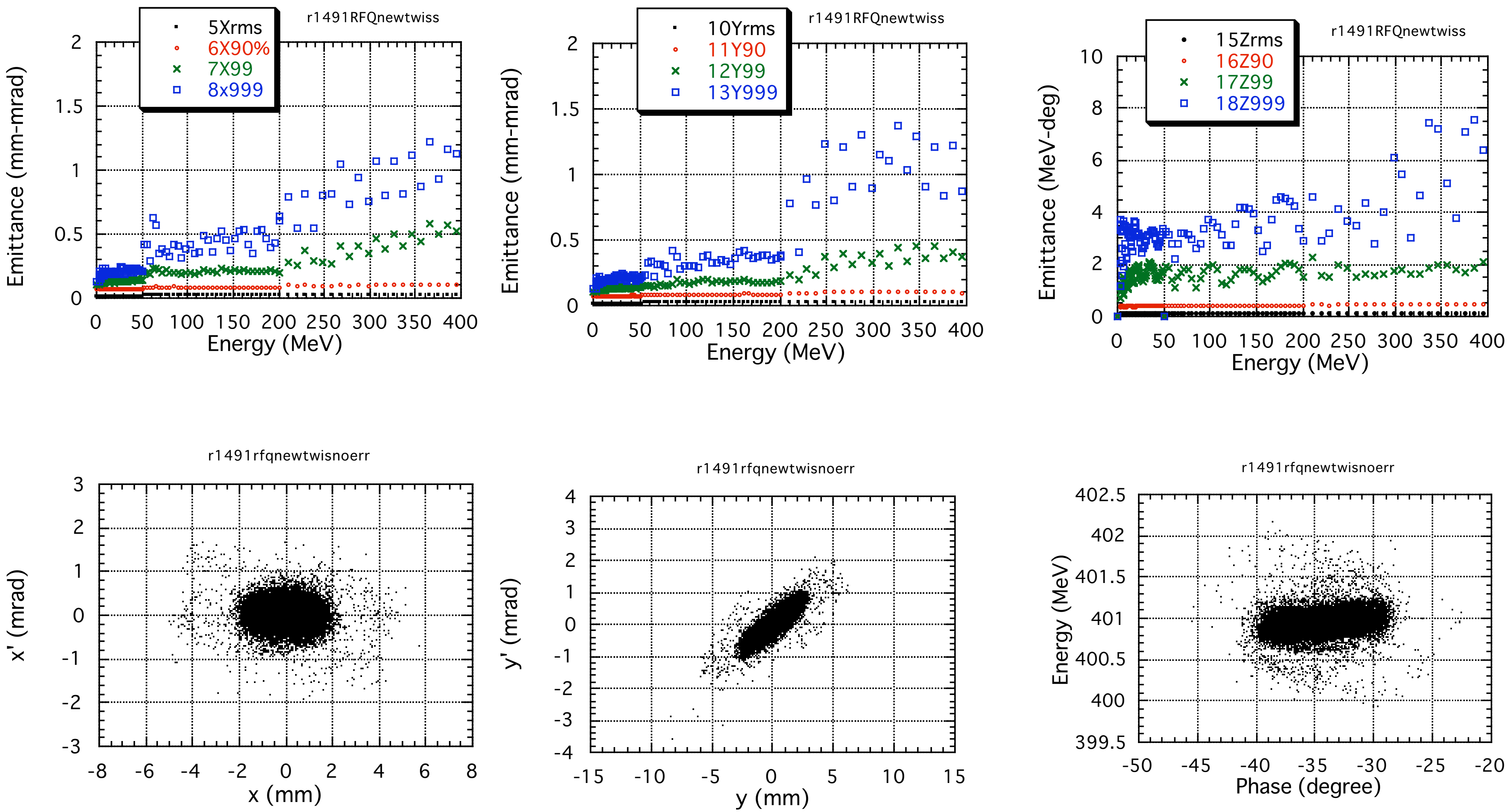




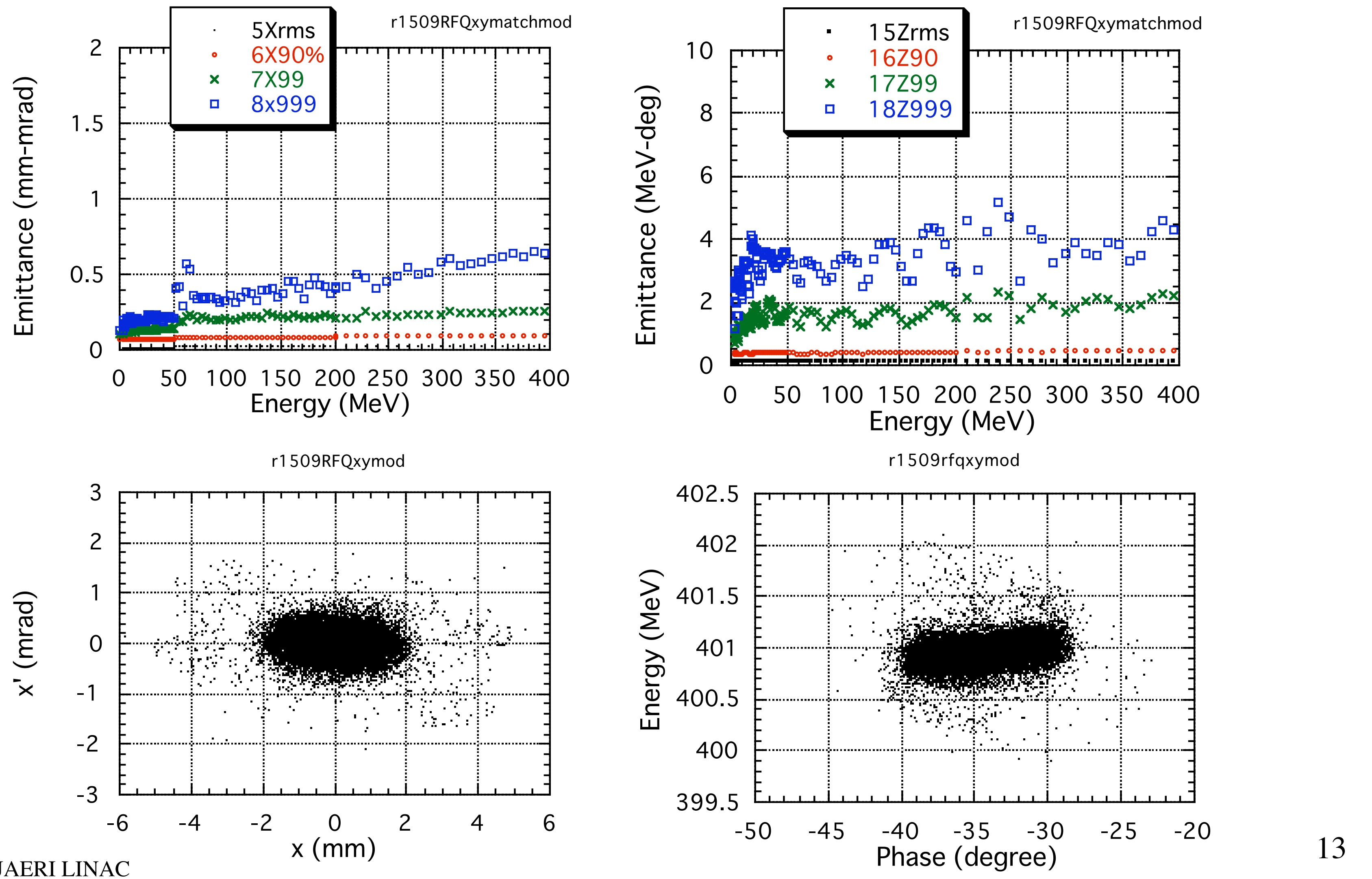




No-error simualtion: RFQ (xyz)



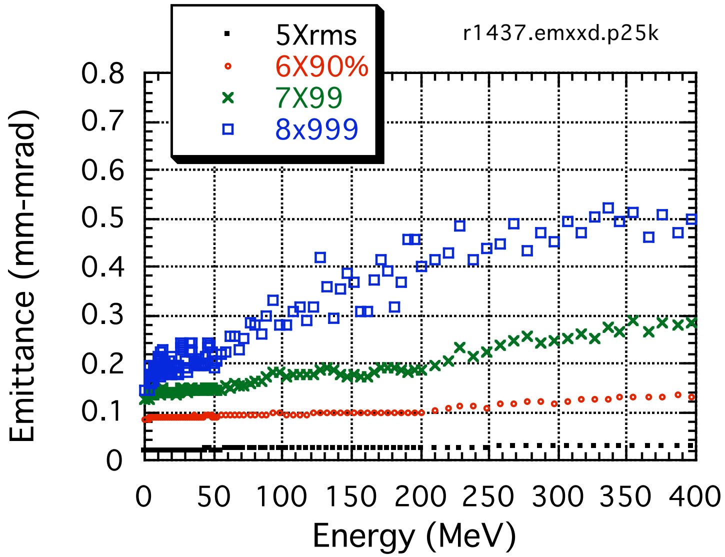
No-error simulation: RFQ (xy)

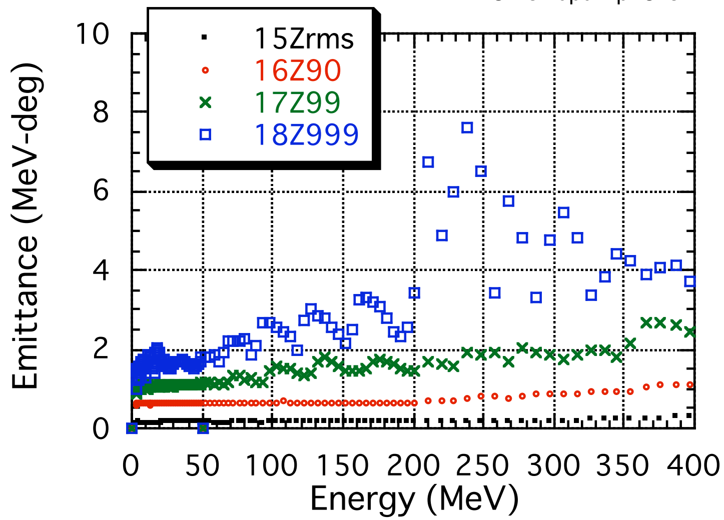


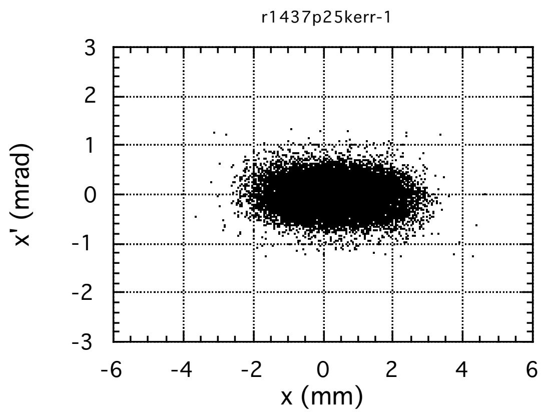
Errors in accelerating parameters

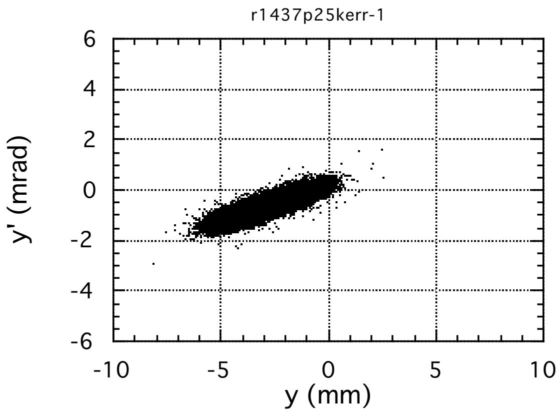
- Error - 1
  - ±1% cell and tank fileds
  - ±1% cell phase and ±3% tank phase
  - Q-magnet displacement ±0.05 mm
- Error - 2
  - ±2% cell and tank fields
  - ±2% cell and ±6% tank phase
  - Q-magnet displacement ±0.1 mm

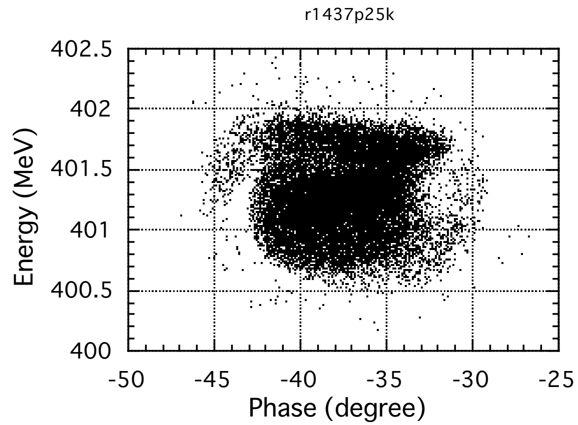
Error - 1 simulation: Type C



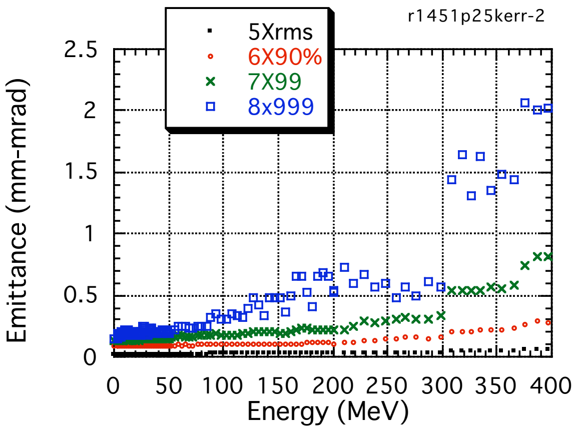


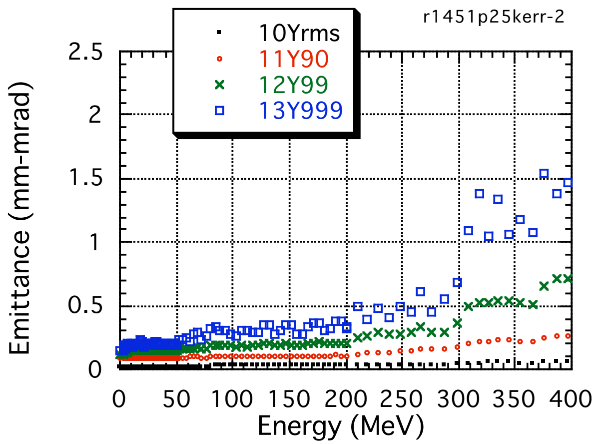


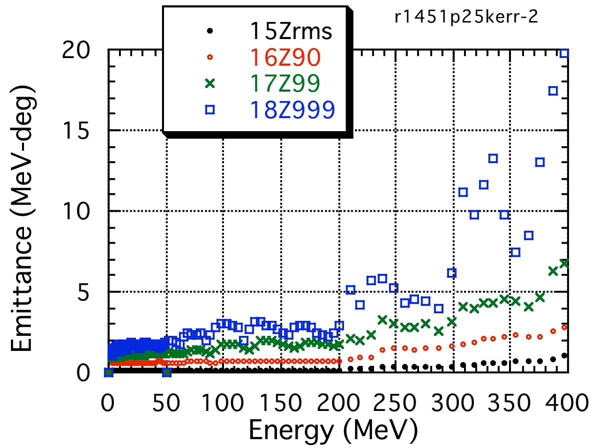


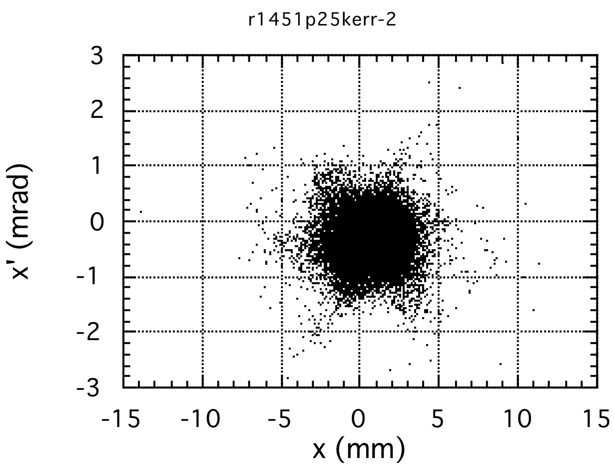


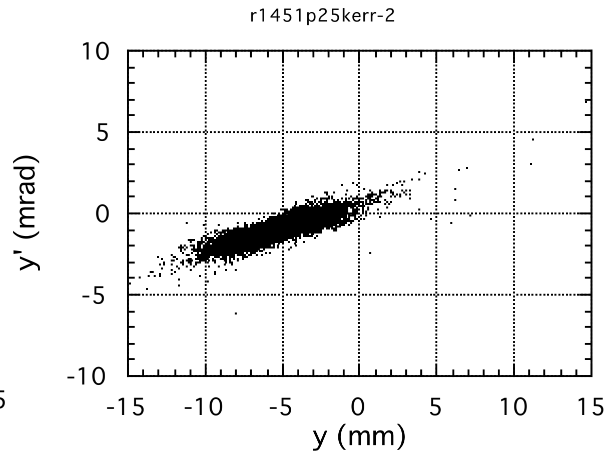
Error - 2 simulation: Type C

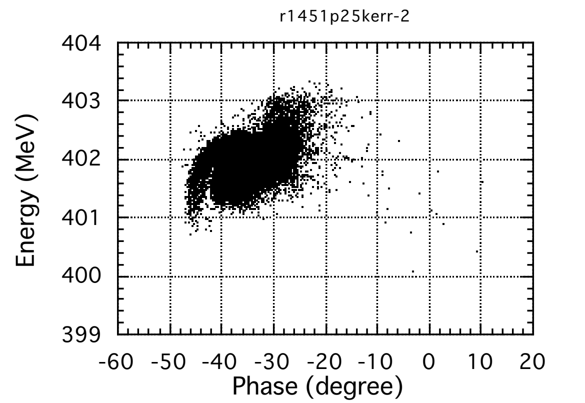




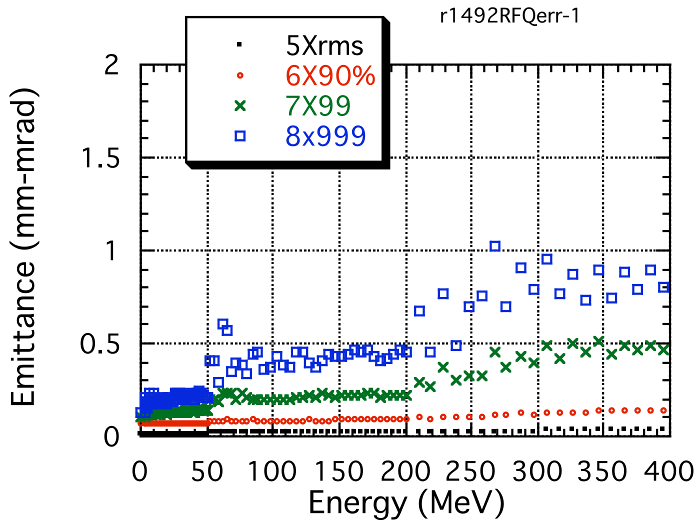


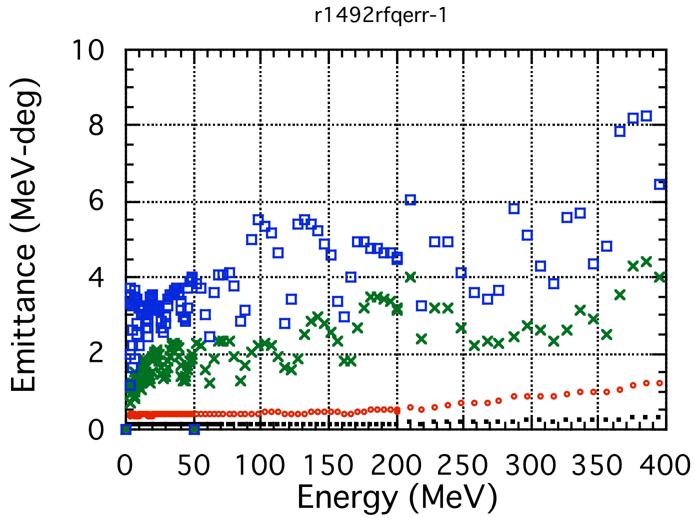


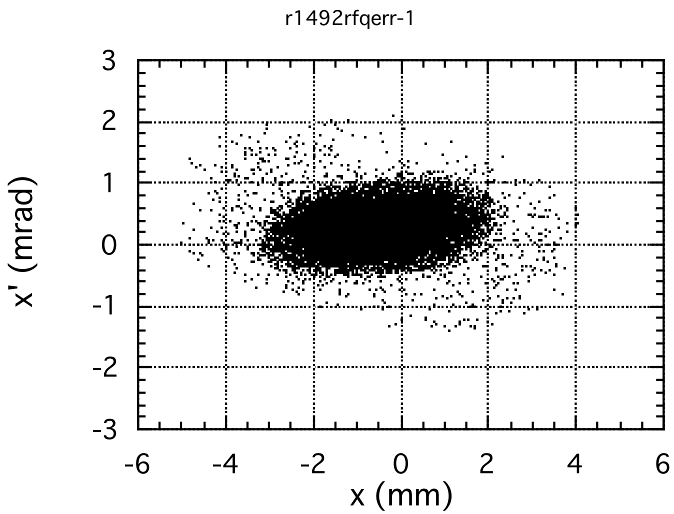


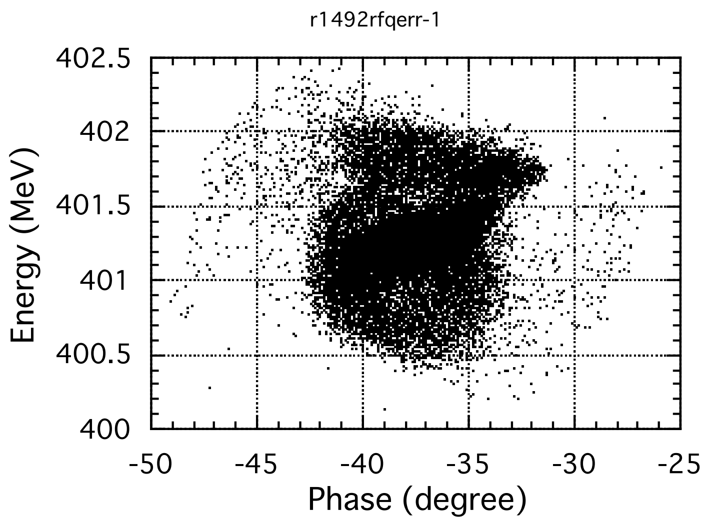


Error - 1 simulation: RFQ xyz-match

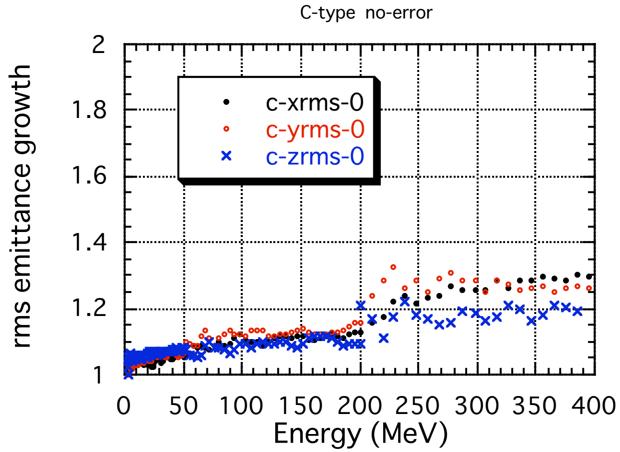


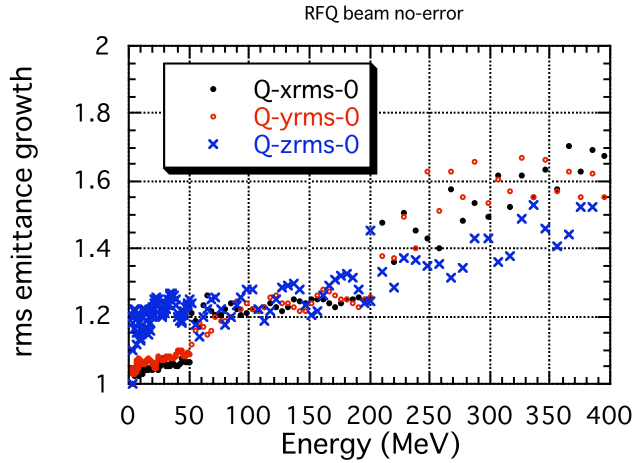




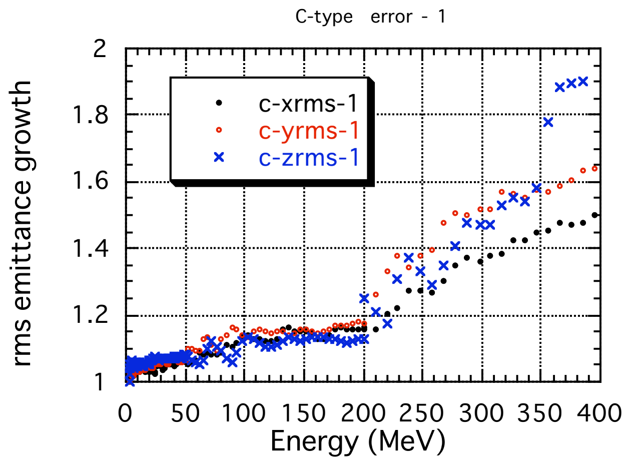


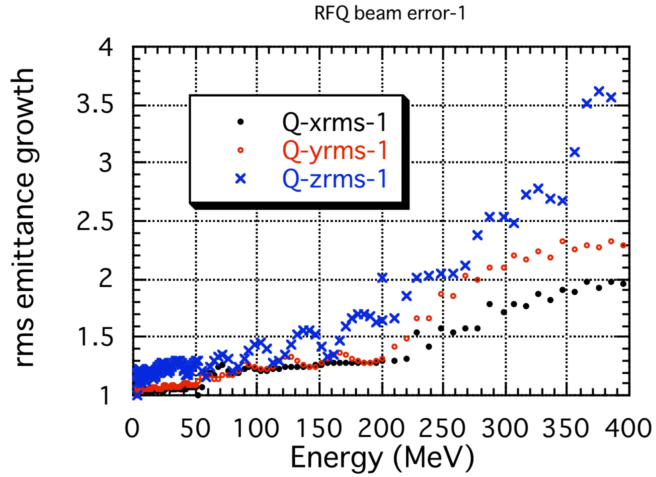
Rms emittance growth





No-error





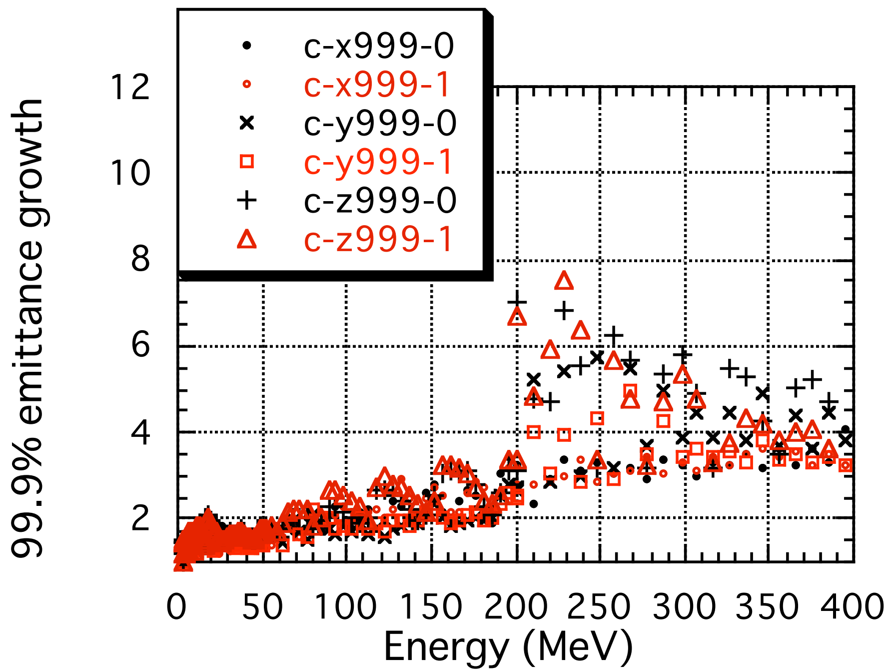
Error-1

C-type

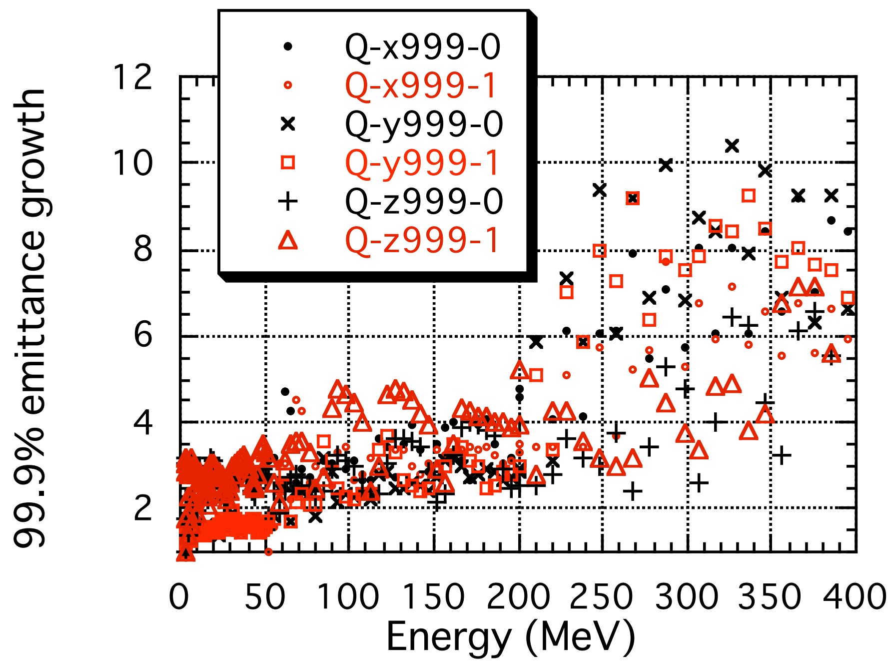
RFQ

99.9% emittance growth

Black = no-error, red = error-1



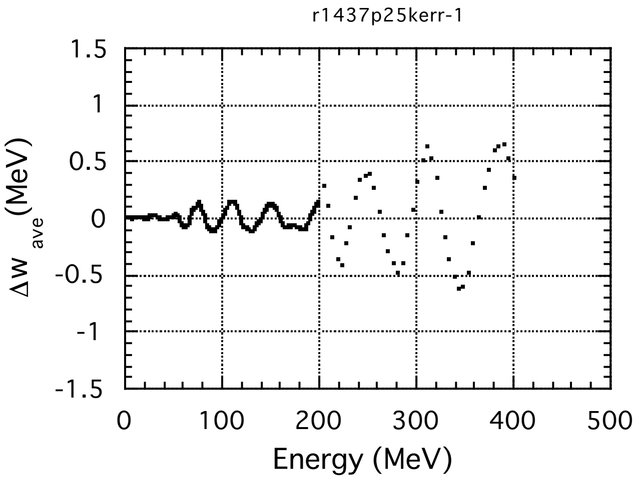
C-type



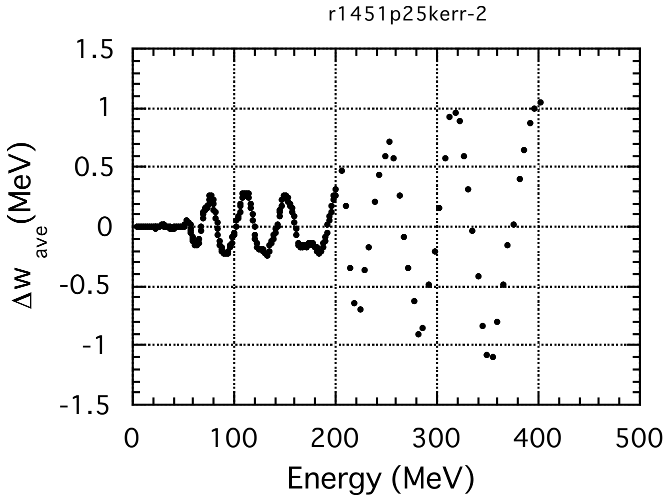
RFQ

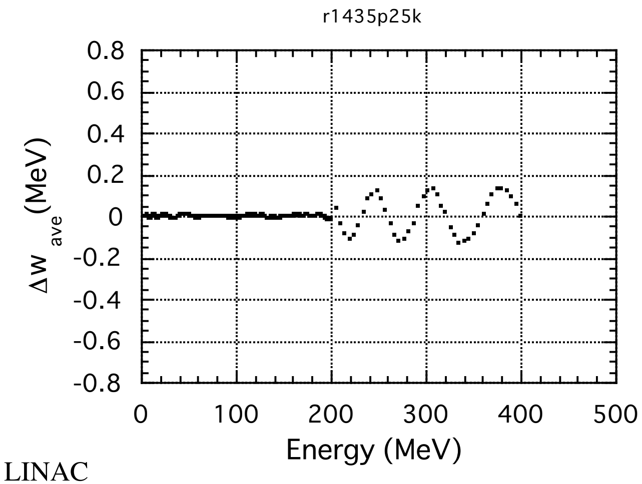
Energy shift

Error - 1



Error - 2

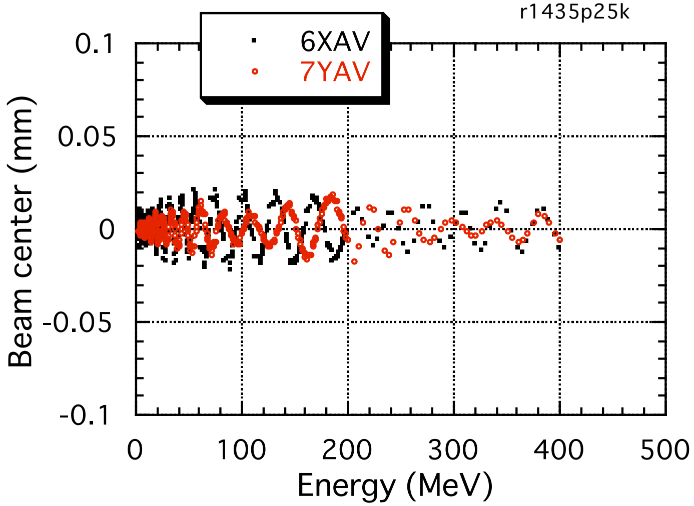


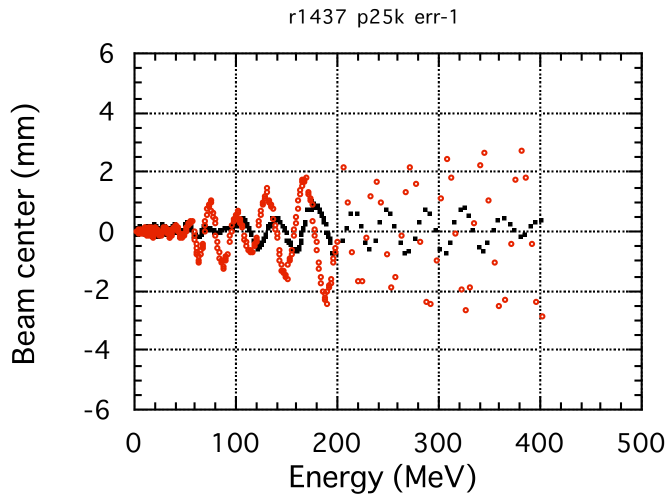


No-error simulation

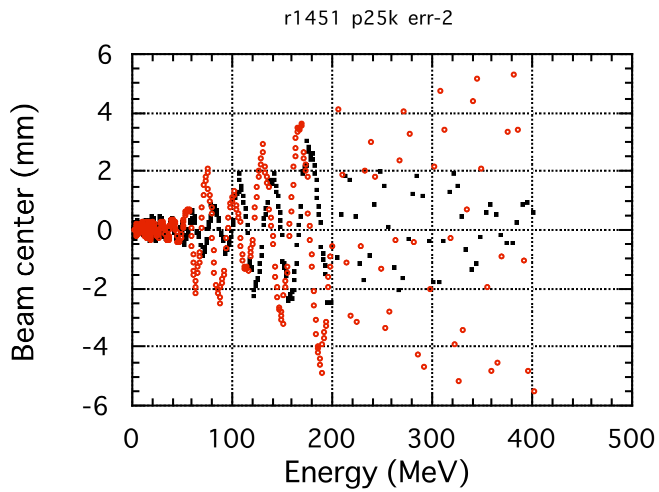
Beam-center shift

No -error



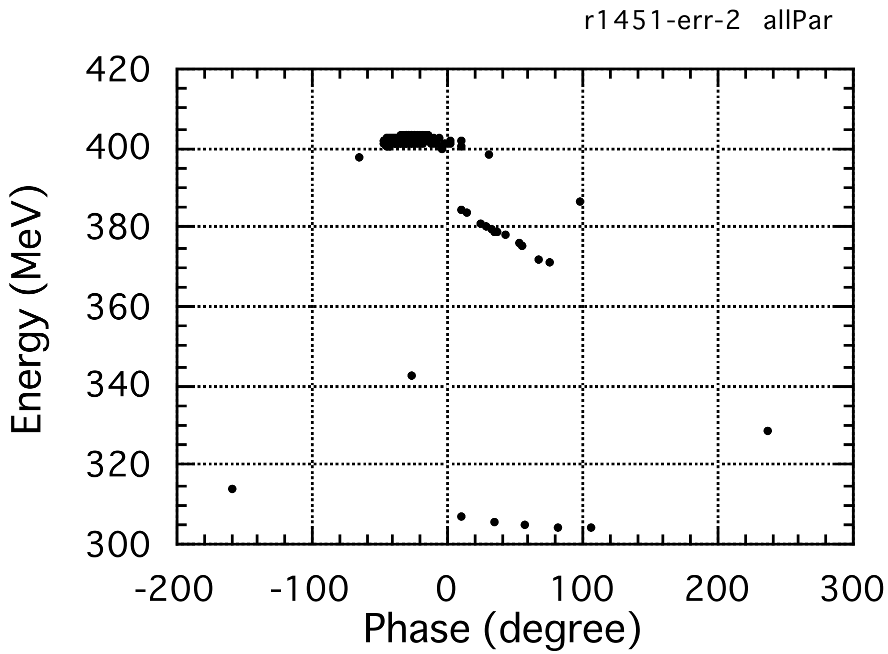


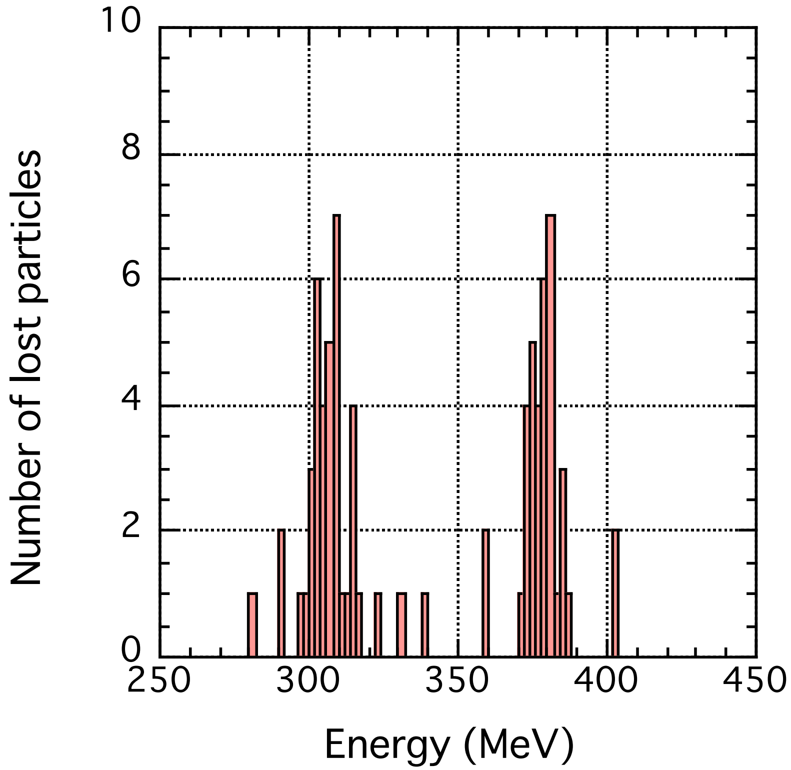
Err-1



Err-2

Lost particles

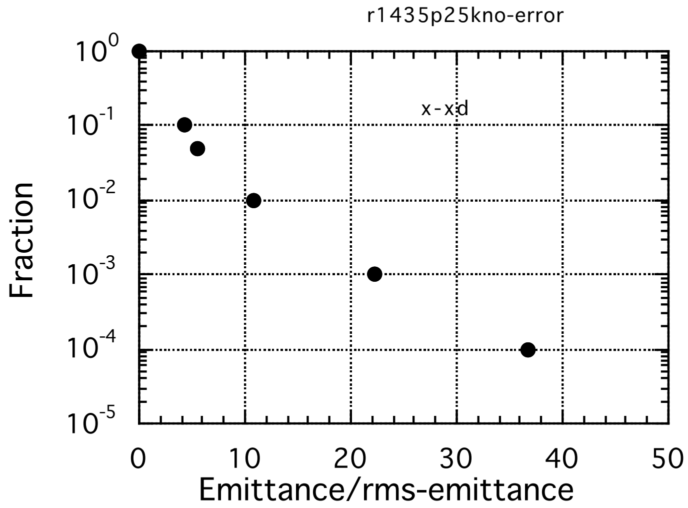




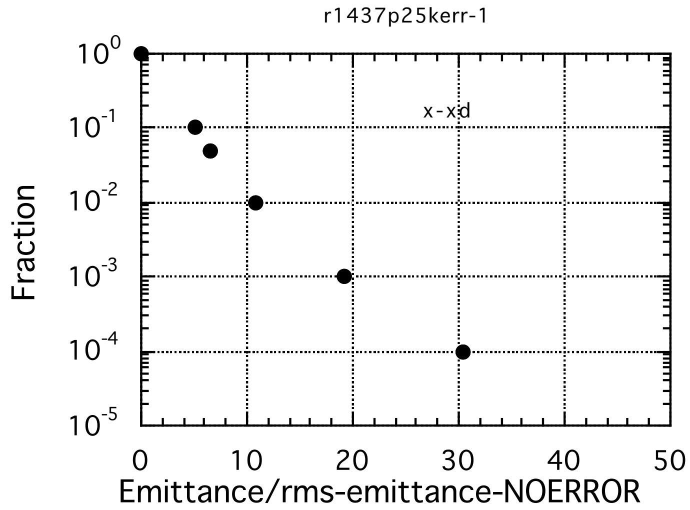
C-type: error-2 0.1% beam loss
RFQ : error-2 0.04% beam loss

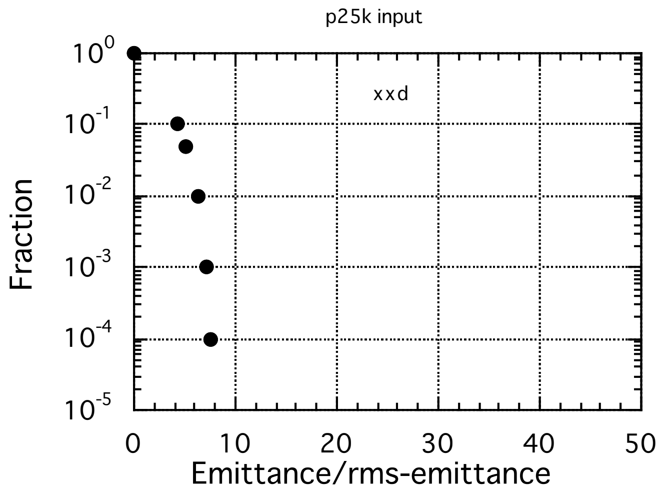
Beam halos - transverse C

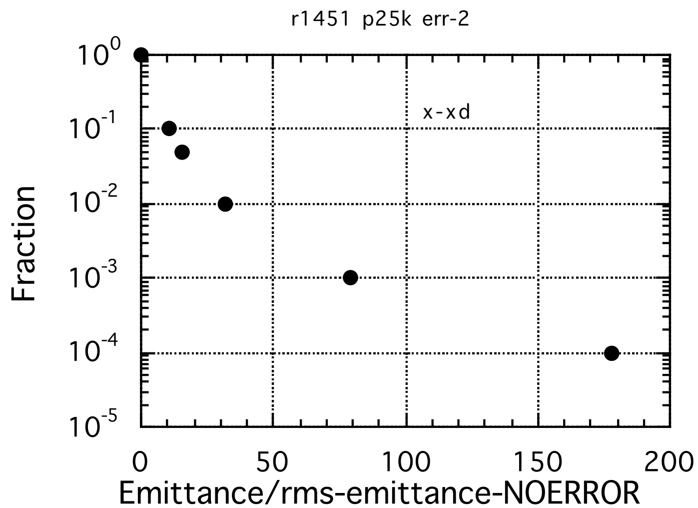
no-error



error-1





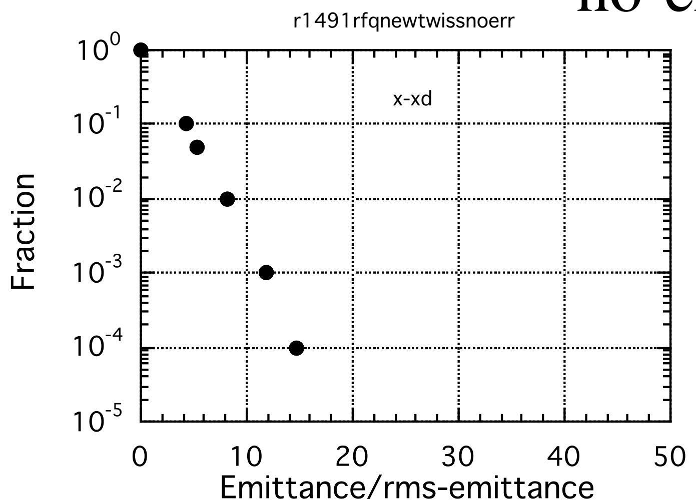


error-2

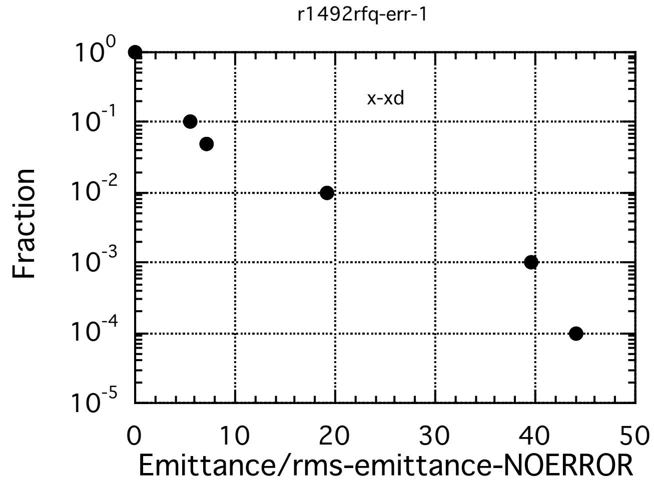
input

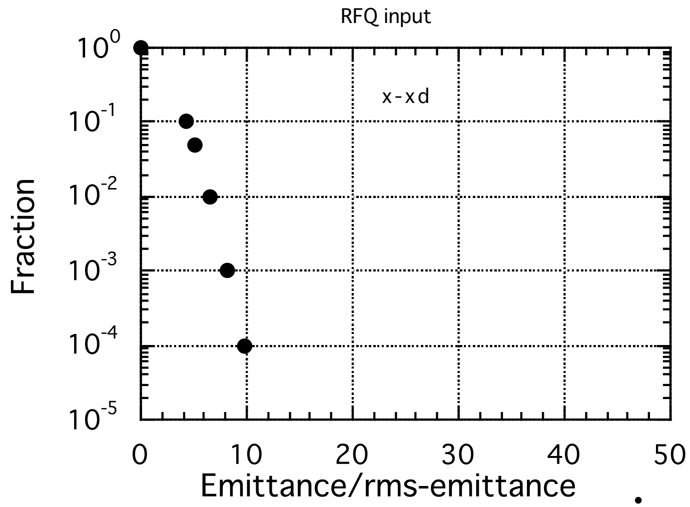
Beam halos - transverse RFQ

no-error

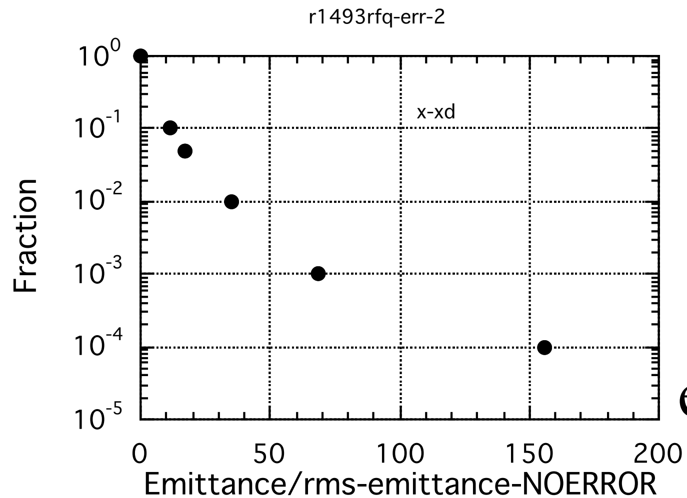


error-1





input



error-2

Output emittance - transverse

x-xd

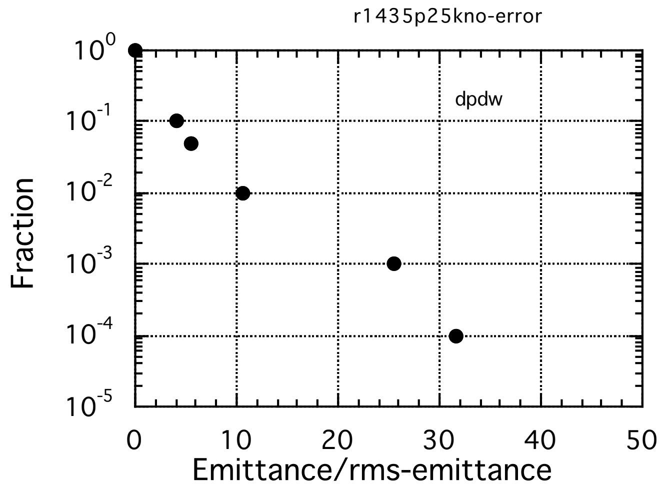
	C-noerr	C-err-1	C-err-2	rfq-noerr	rfq-err-1	rfq-err-2	rfq-xy	
rms	0.0259	0.0299	0.0628	0.0268	0.0339	0.0687	0.0264	0.0225
90%	0.112	0.132	0.283	0.104	0.145	0.306	0.104	0.0962
99%	0.281	0.281	0.826	0.490	0.511	0.950	0.482	0.249
99.9%	0.574	0.497	2.06	1.01	1.06	1.83	1.01	0.623

y-yd

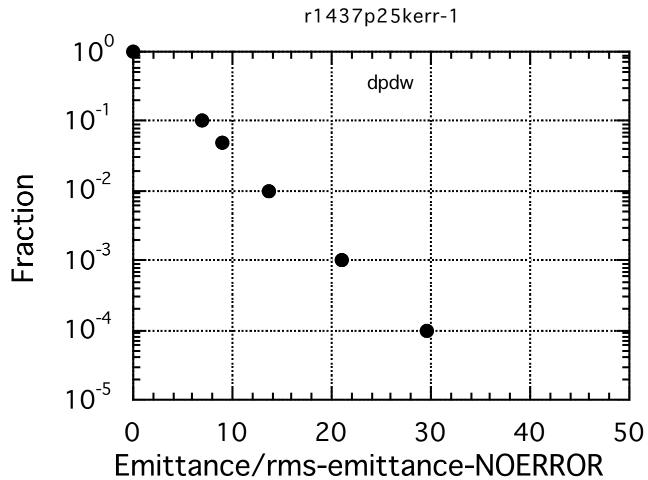
	C-noerr	C-err-1	C-err-2	rfq-noerr	rfq-err-1	rfq-err-2	rfq-xy	
rms	0.0251	0.0326	0.0626	0.0248	0.0371	0.0805	0.0247	0.0223
90%	0.108	0.148	0.271	0.0995	0.166	0.344	0.0988	0.0926
99%	0.228	0.255	0.734	0.360	0.391	1.14	0.362	0.237
99.9%	0.640	0.501	1.37	1.07	1.02	2.02	0.870	0.673

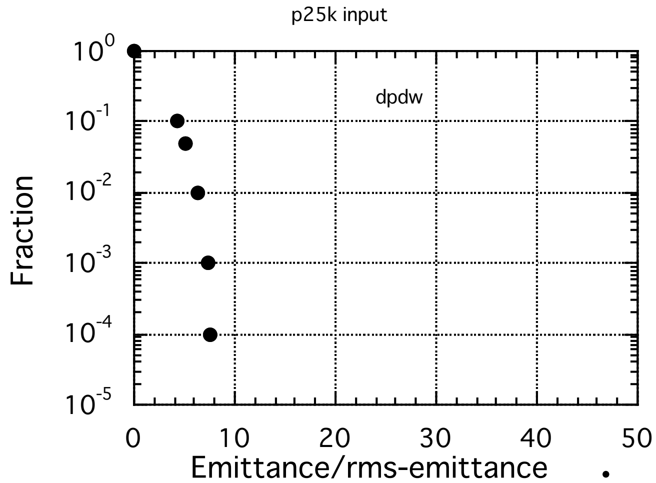
Beam halos - longitudinal C

no-error

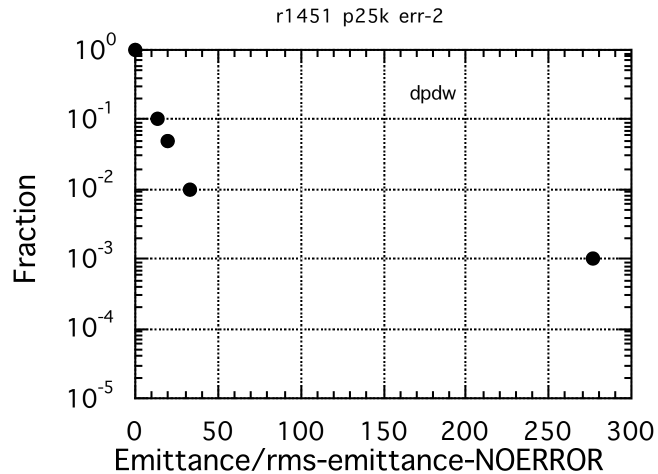


error-1





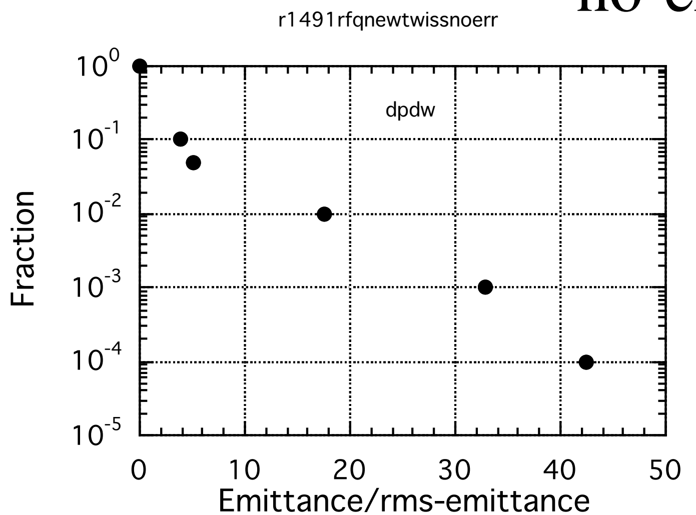
input



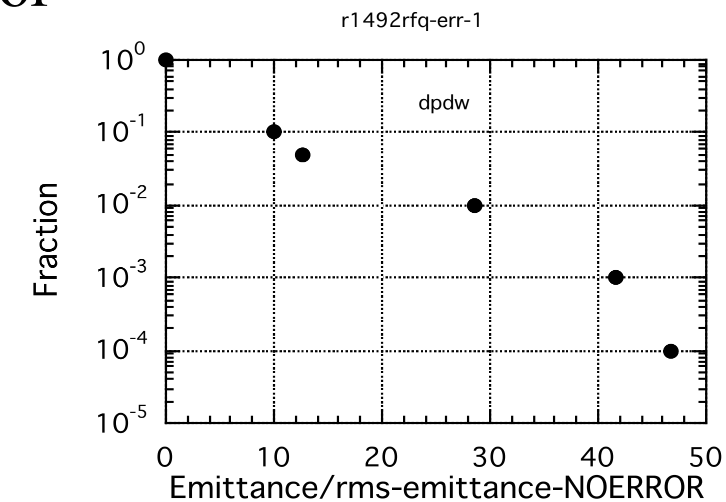
error-2

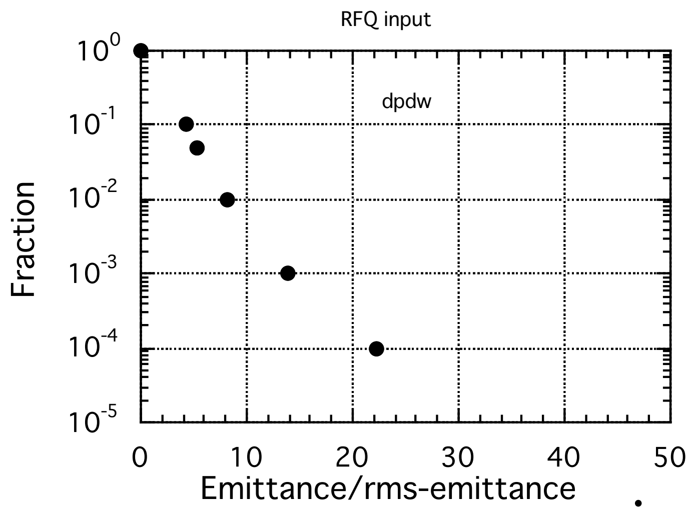
Beam halos - longitudinal RFQ

no-error

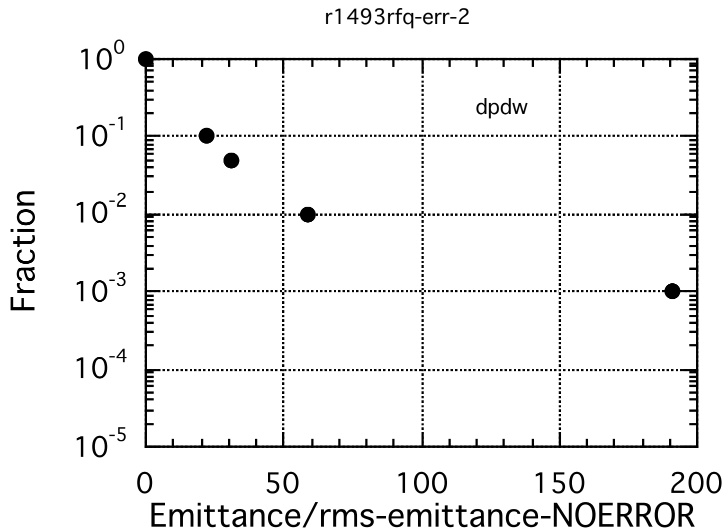


error-1





input



error-2

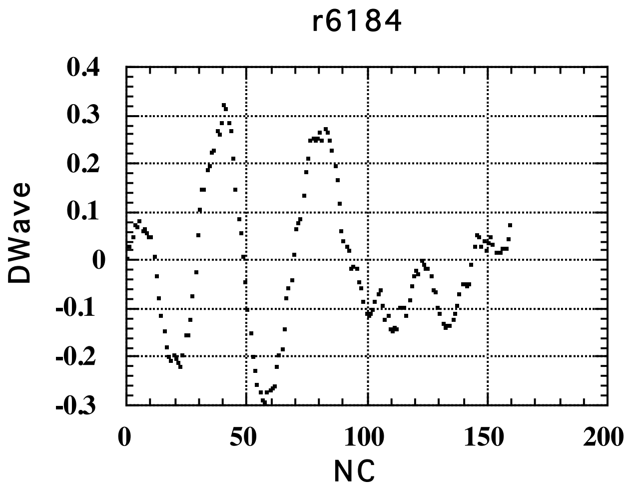
Output emittance dpdw

	C-noerr	C -err-1	C -err-2	rfq-noerr	rfq-err-1	rfq-err-2	rfq-xy	
rms	0.494	0.793	3.23	0.374	0.871	3.60	0.361	0.354
90%	2.04	3.44	8.77	1.44	3.74	10.3	1.40	1.40
99%	5.26	6.80	19.2	6.39	10.7	25.7	5.90	6.35
99.9%	12.6	10.4	66.1	17.2	15.6	75.5	19.1	12.3

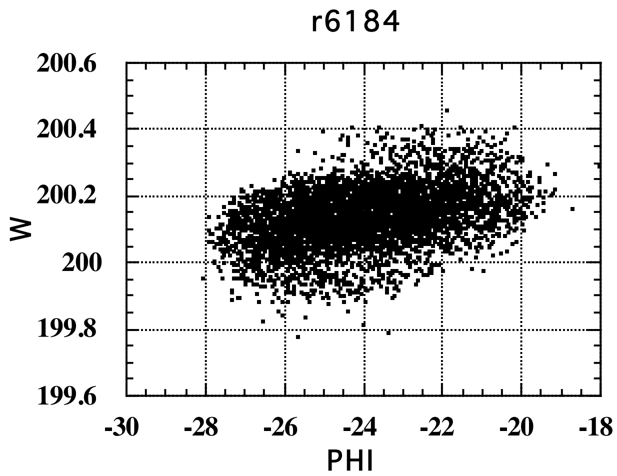
Longitudinal tuning

- 各タンクの電場と位相とが独立に決められる事
- 精度目標 ±1%、1 degree
    - 電場のエラーは位相補償で相殺できる?
        - 出来るが程度により副作用をともなう

$$\Delta W_{\tan k} = \overline{E}\,\overline{T}\cos\overline{\phi}L = \overline{E}_c\overline{T}\cos\overline{\phi}_c L$$



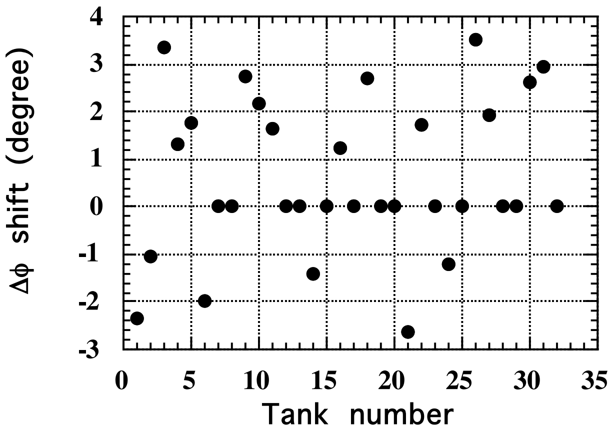
Error simulation in SDTL



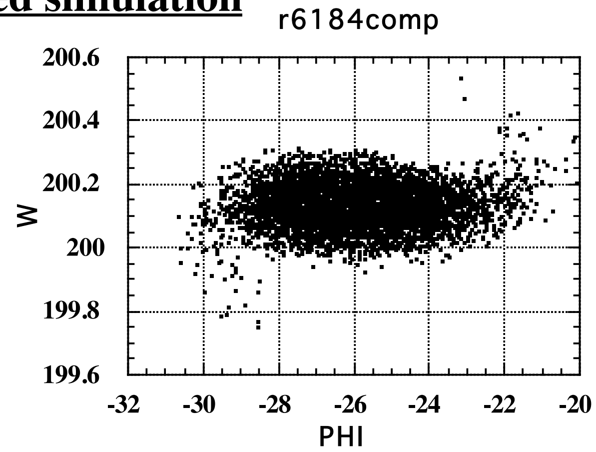
ep error 32-21

Phase compensation in SDTL

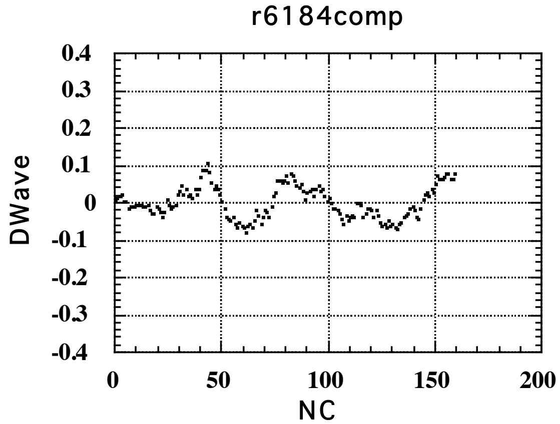
Phase-compensated simulation



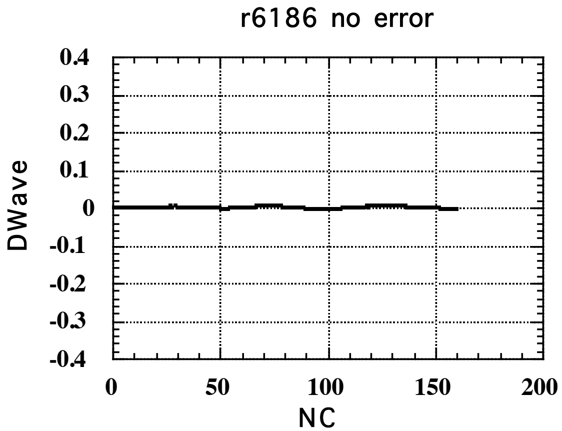
Compensation phase in each tank

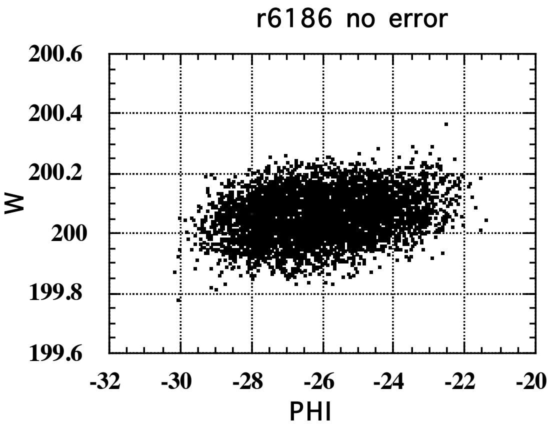


Output emittnace

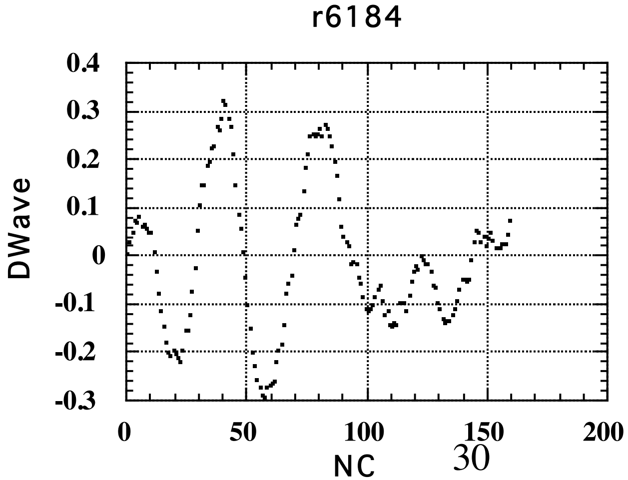


Deviation of average energy





No-error simulation



With errors

Output energy width

	c-noerr	c-err-1	c-err-2	rfq-noerr	rfq-err-1	rfq-err-2	rfq-xy	
Rms	0.193	0.304	0.343	0.146	0.348	0.381	0.140	MeV
Full	2.13	2.26	3.24	2.25	2.36	4.94	2.10	Mev
Loss	0	0	0.1	0	0	0.04	0	%

Debuncher operation

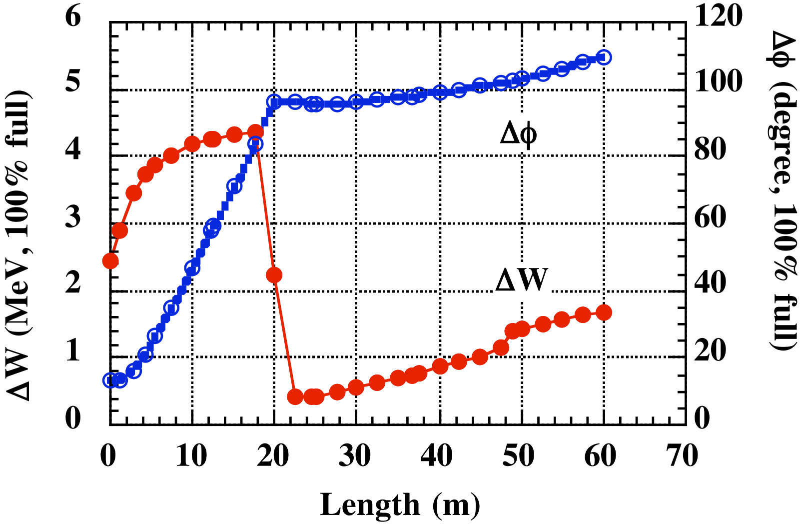


Fig. 4.35 Variation of spreads of phase (in terms of 972 MHz) and energy along the 400-MeV beam-transport line. A debuncher of 2.1 MV is placed at a position of 20 m from the entrance of the beam-transport line. The peak current of 180 mA is assumed. The number of particles is 3200.

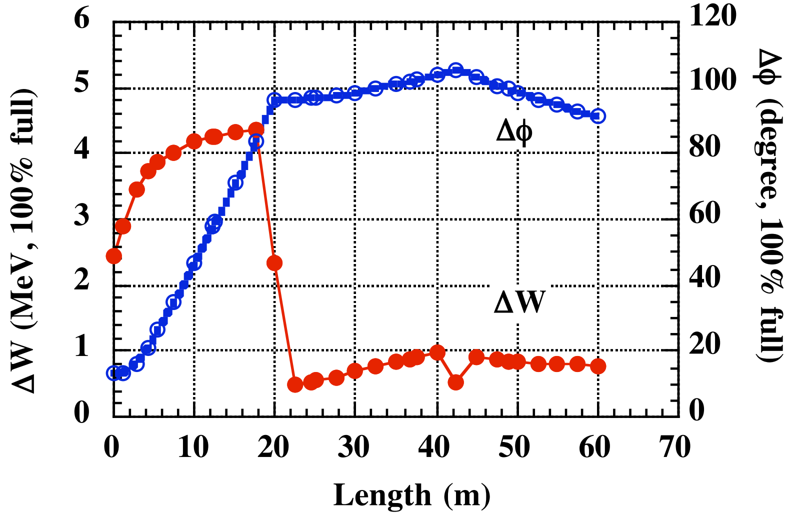


Fig. 4.36 Variation of spreads of phase (in terms of 972 MHz) and energy along the 400-MeV beam-transport line. Two debuncher are used. The voltages are 2.1 and 0.6 MV. They are placed at a position of 20 and 42.5 m from the entrance of the beam-transport line. The peak current of 180 mA is assumed. The number of particles is 3200.

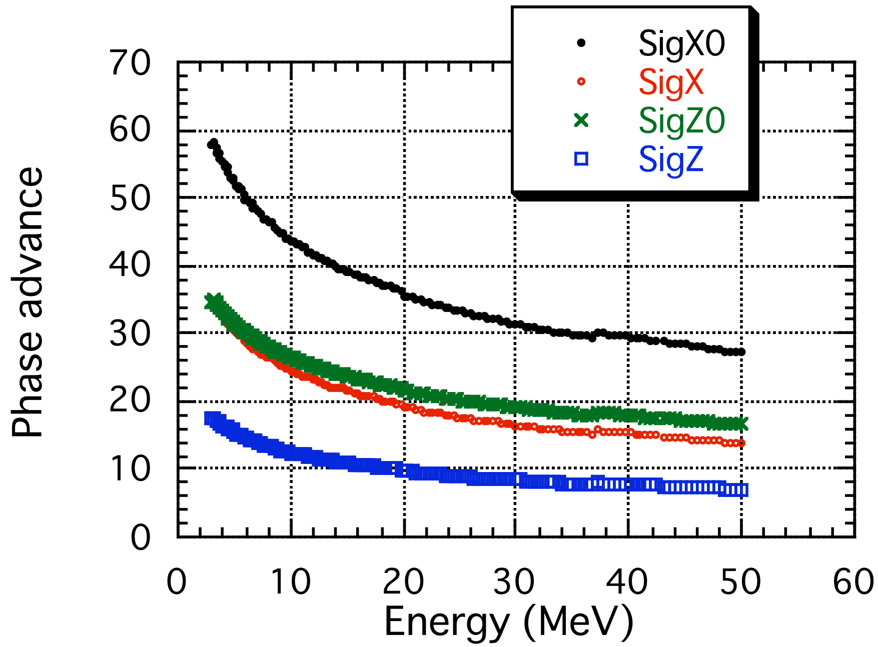
Compensation for errors

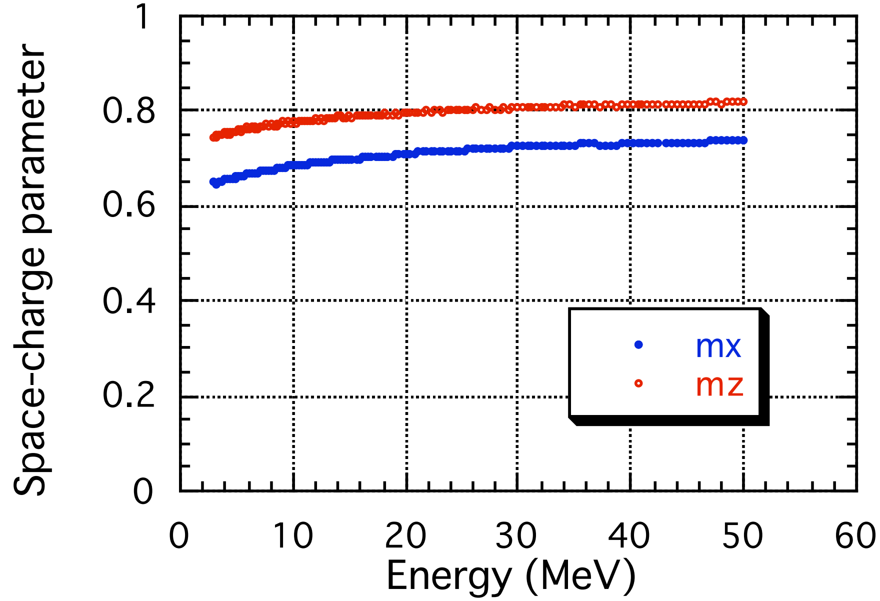
- **Bunch phase measurement at each-tank exit**
  - **Minimizing energy deviation by adjusting rf phase**
- **Bunch profile/center measurement**
  - **Minimizing beam-center deviation by steering**
  - **Correction of Q-magnet alignment if necessary**
- **Energy-width compression by debuncher**
- **Energy compensation by a low-Q cavity if necessary**

Future improvements

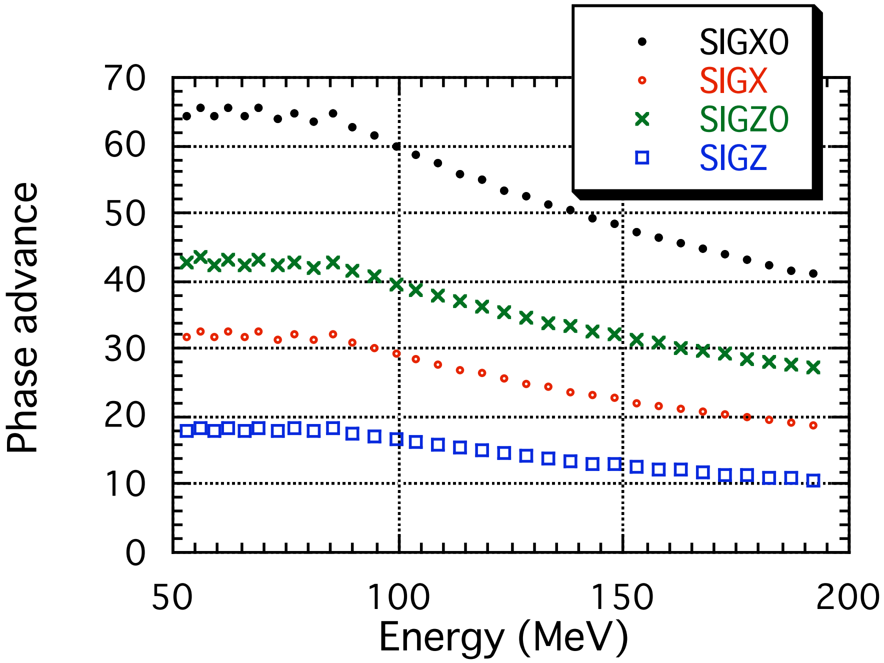
- ACS
- Beam transport to the rings
- Matching methods
- Supercomputer of 10 times ability (March)
- Survey of transverse focusing parameters
- Link to the beam measurements
- Easy access to simulation system

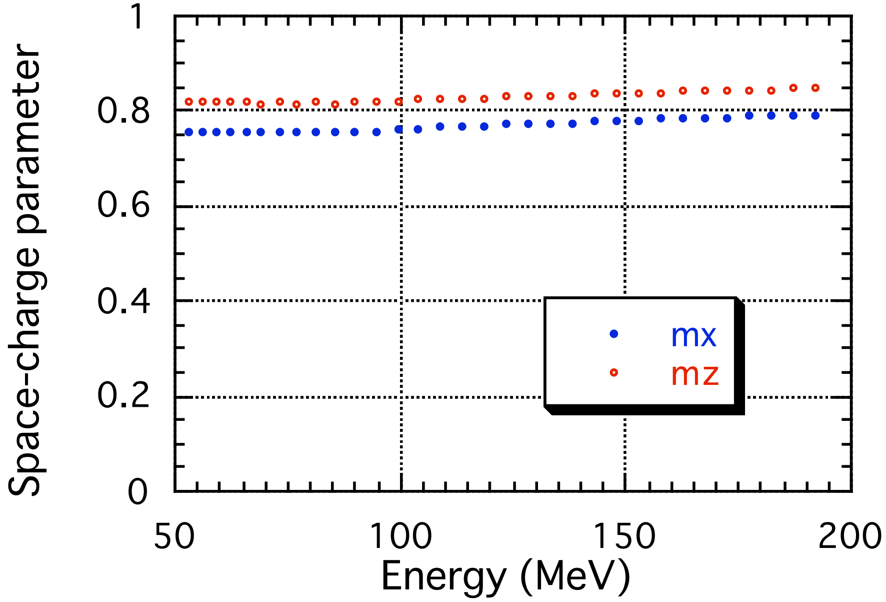
Focusing parameters: DTL





Focusing parameters: SDTL

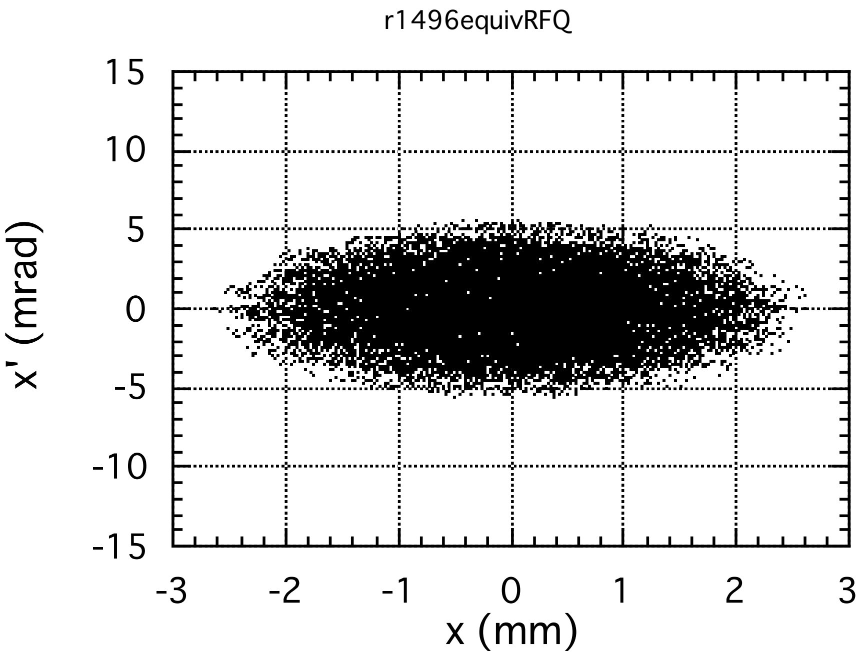


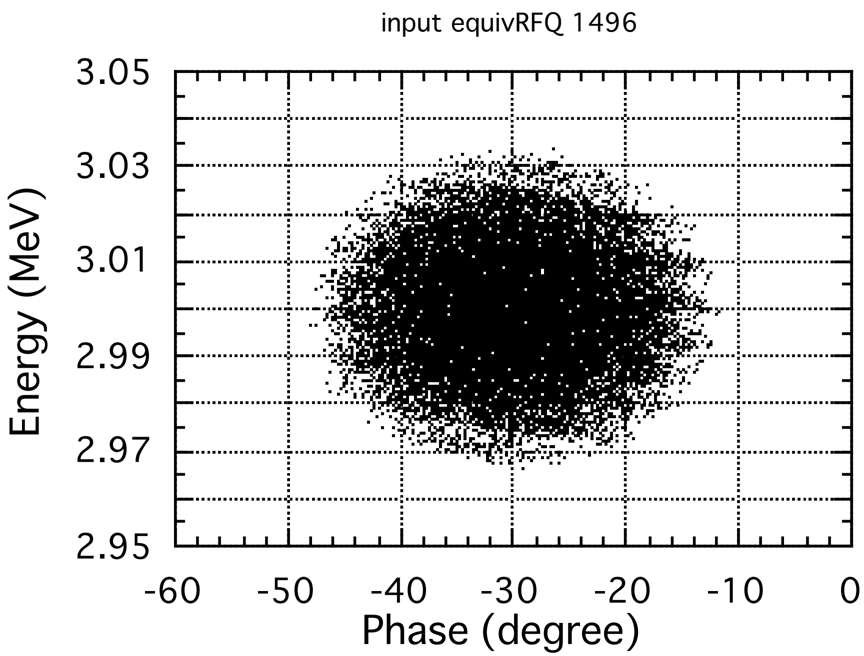


Focusing parameters for 50-mA RFQ beam

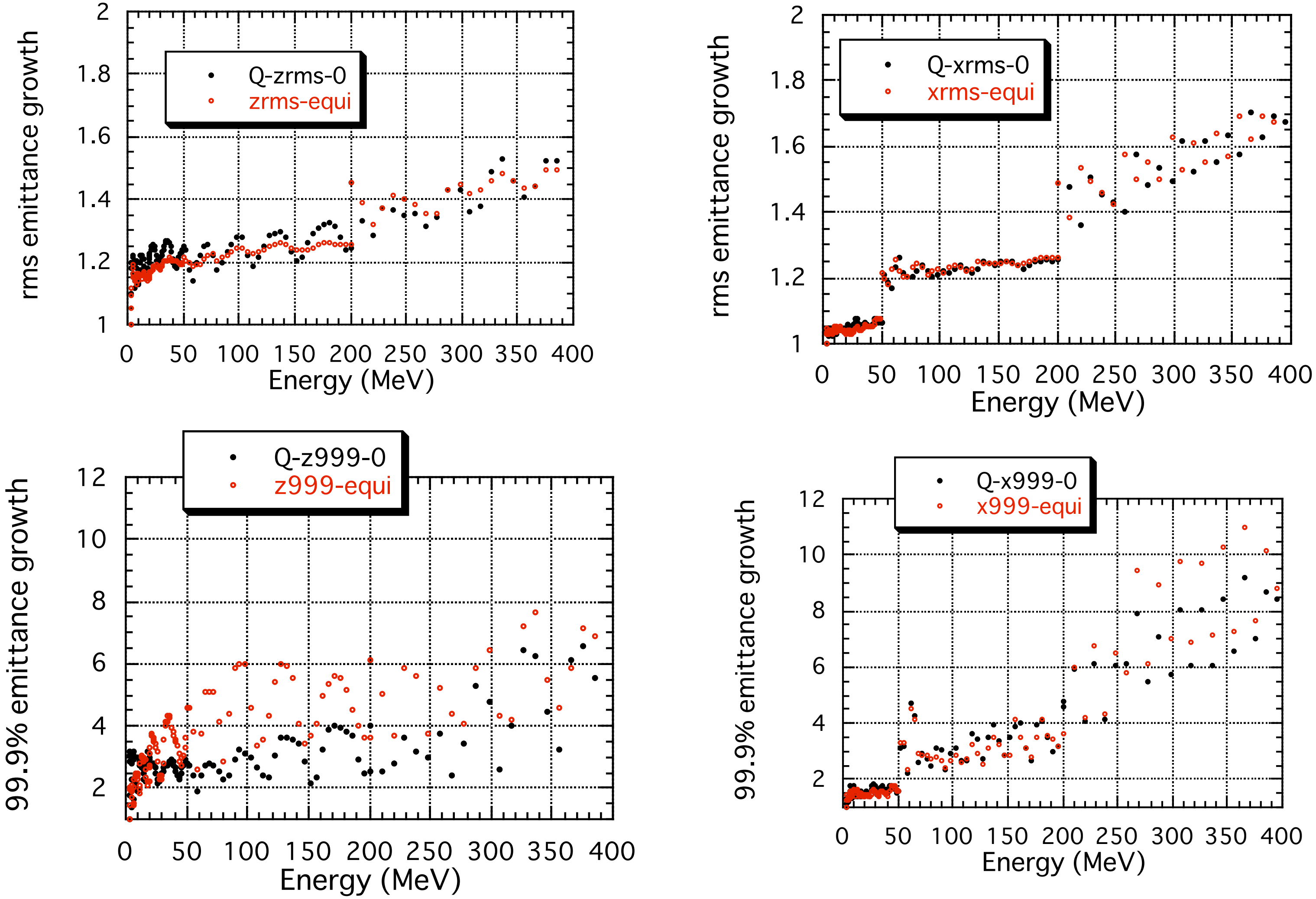
	Energy	μx	μz
DTL	3	0.69	0.90
SDTL	50	0.75	0.90
ACS	200	0.77	0.81
ACS	395	0.57	0.87

Equivalent RFQ beam

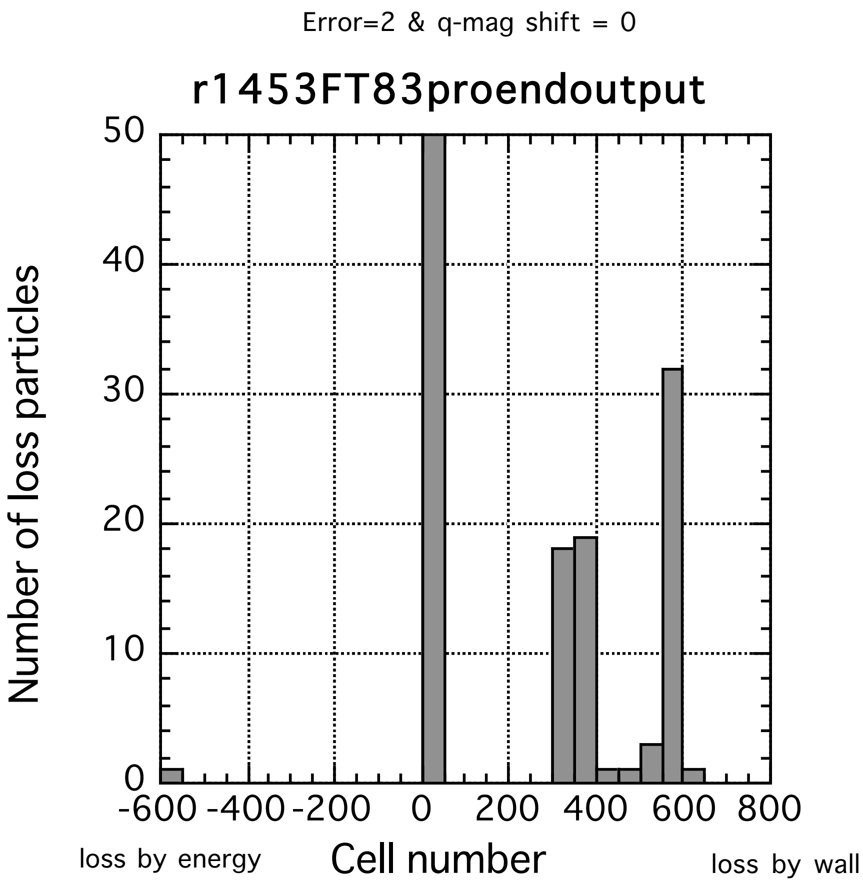




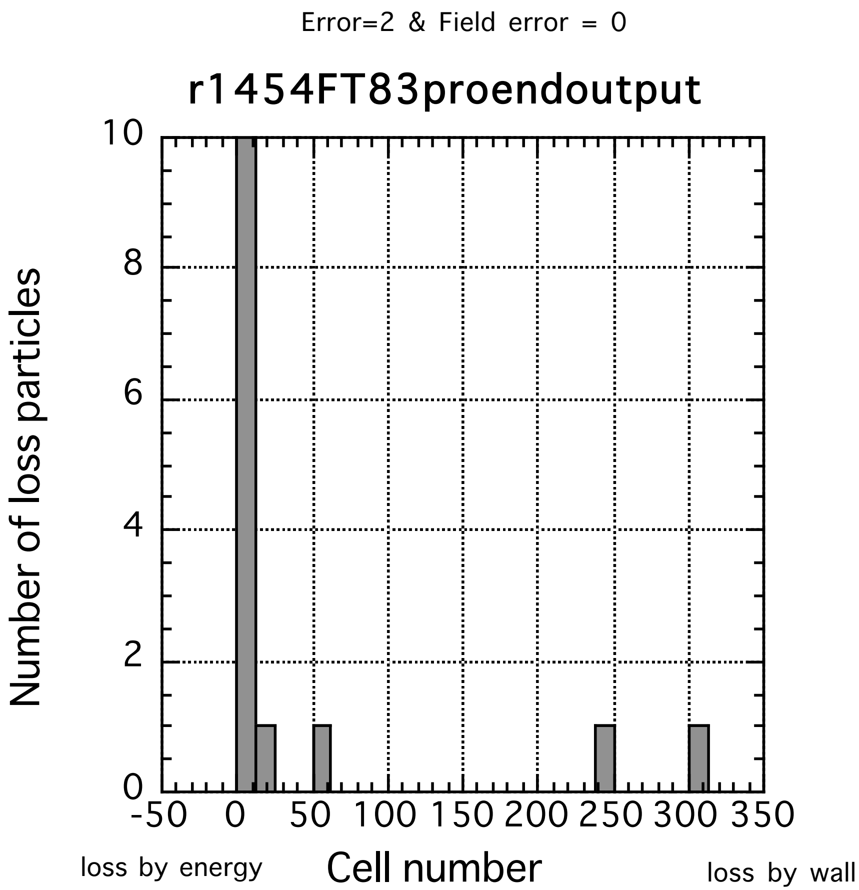
Em-growth of equivalent RFQ beam



Two kinds of error-2

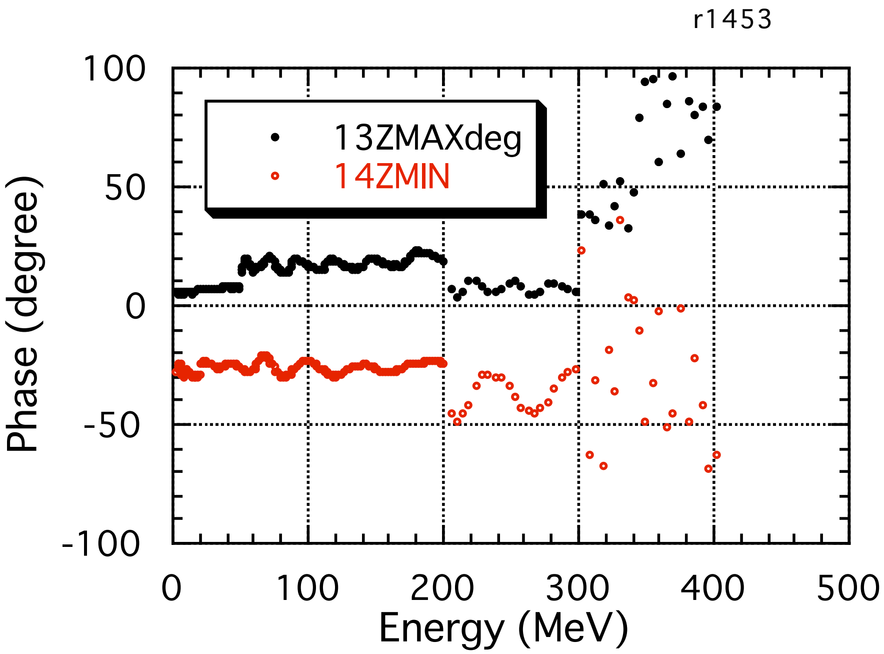


Field error

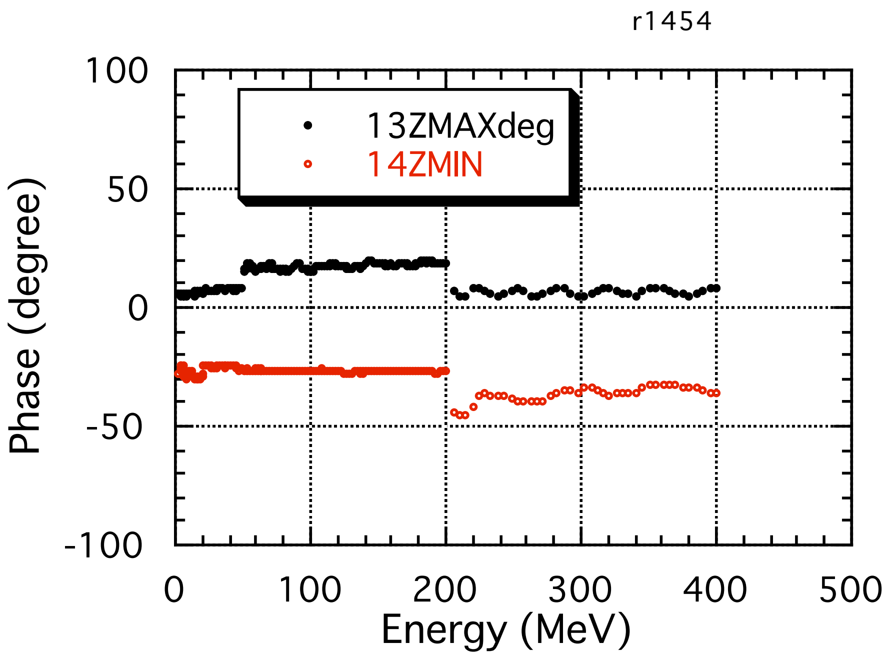


Q-mag error

Max & Mini. Phase

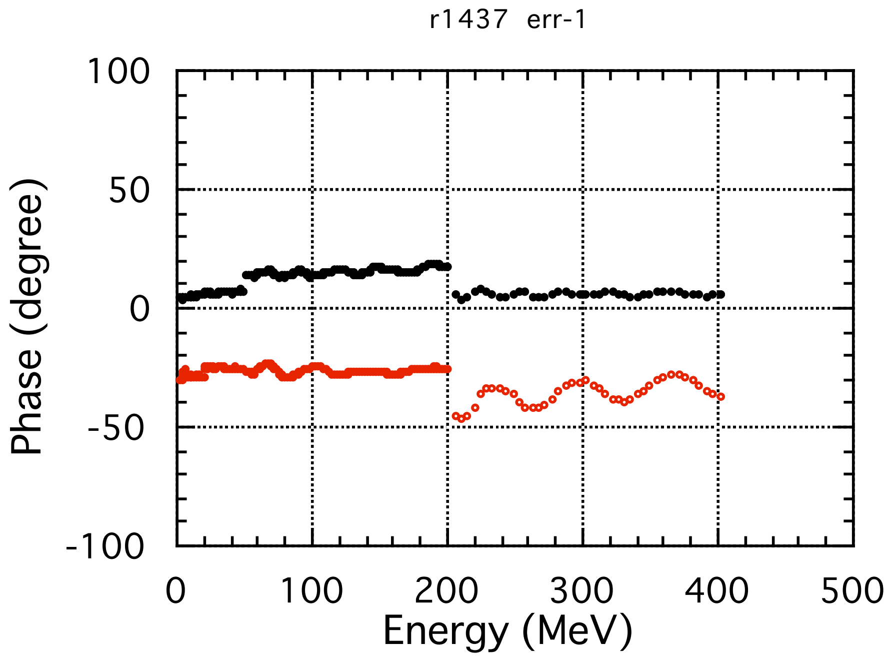


Field error

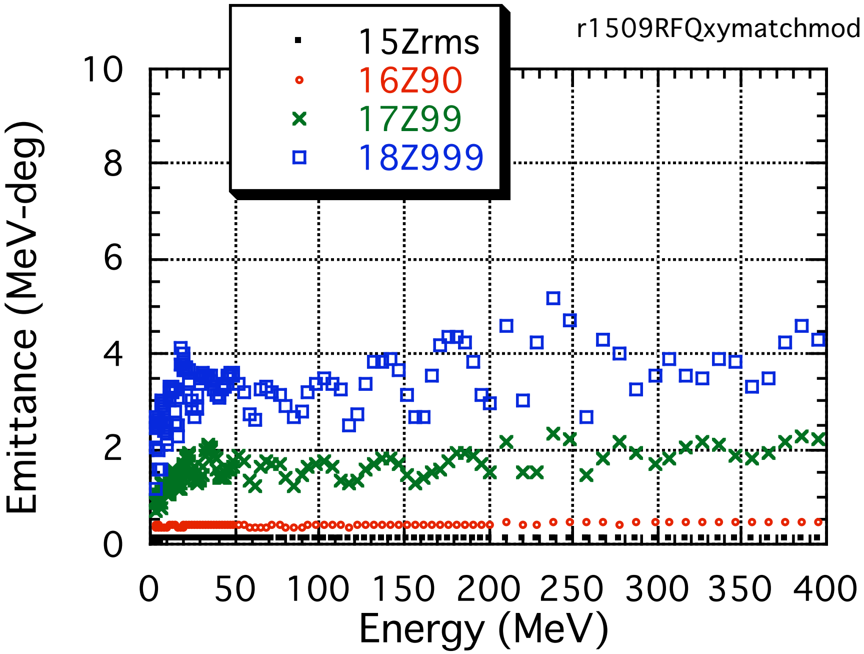


Q-mag error

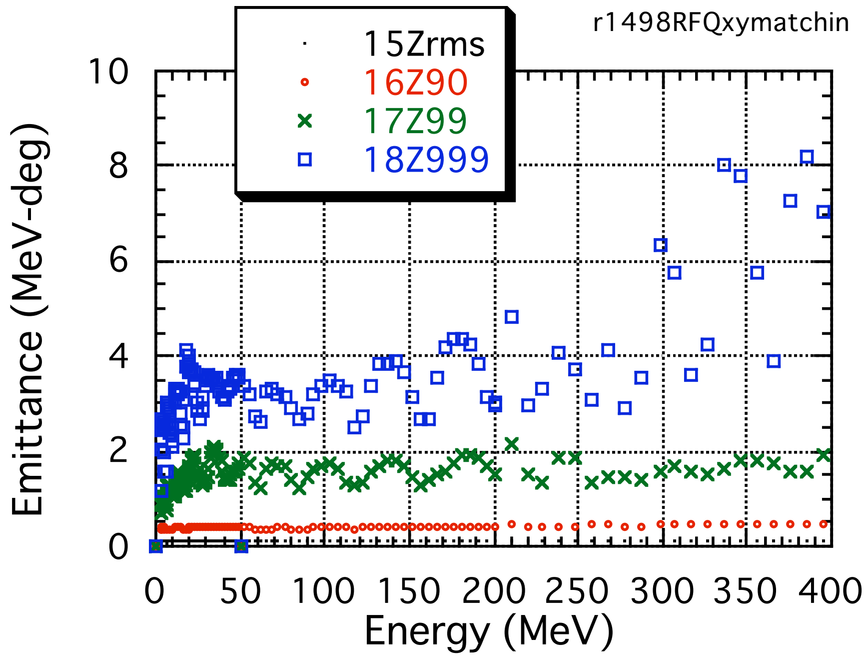
Max & Mini. Phase error-1



Tuning of ACS injection

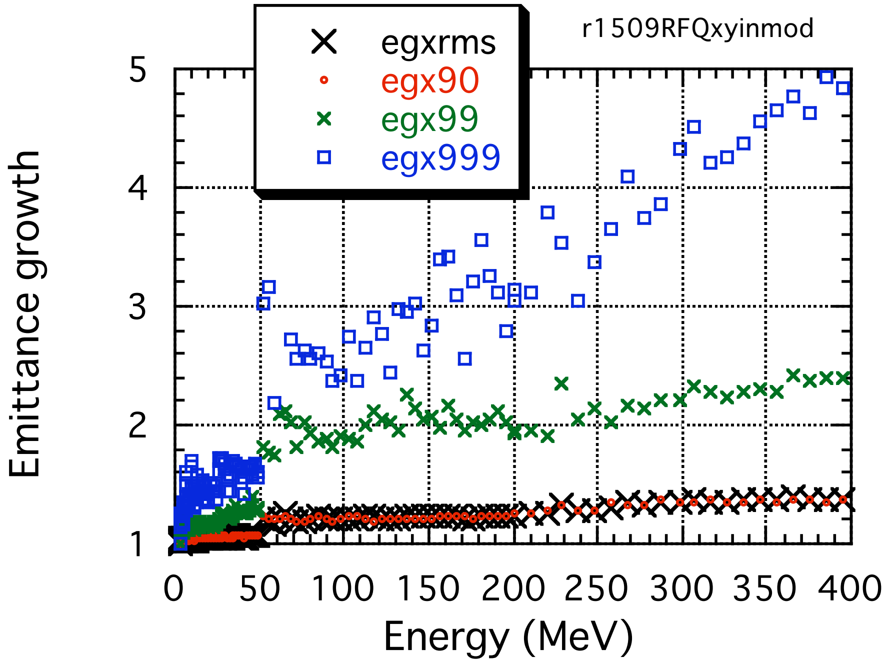


bz=26

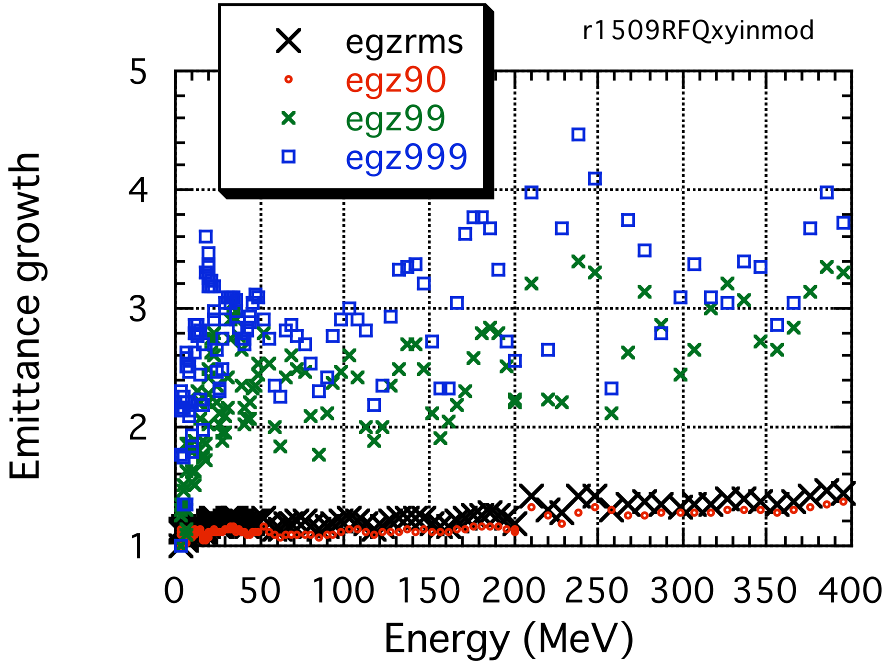


bz=18

Emittance growth: RFQ-beam xy-match injection

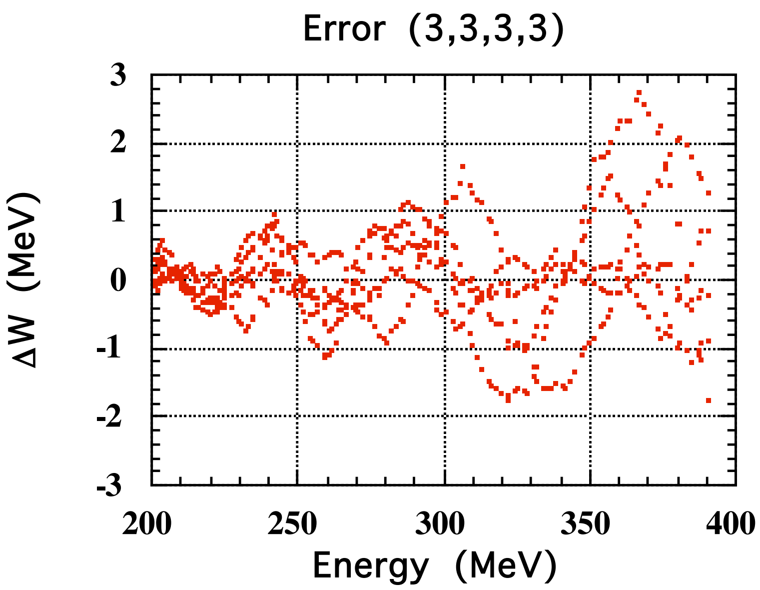


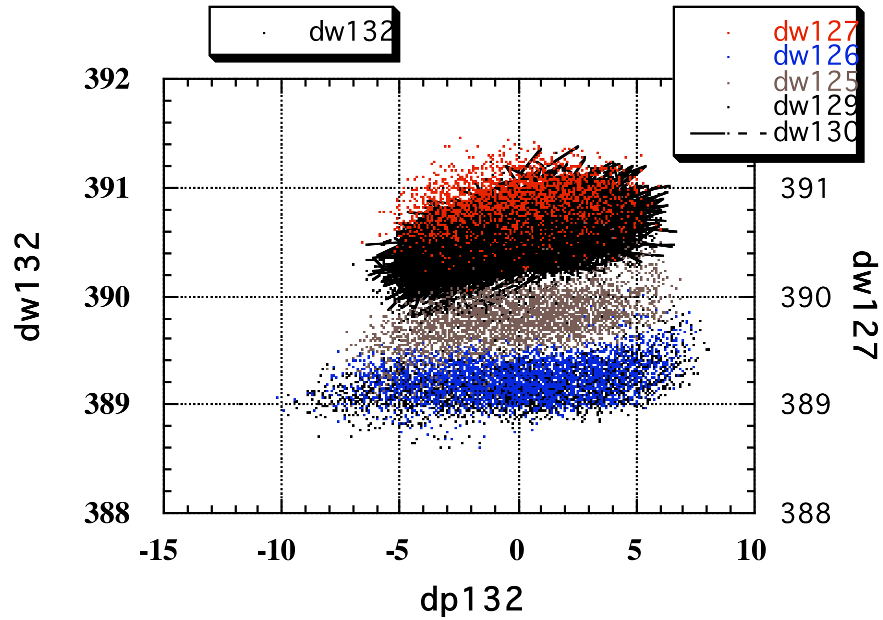
x-xd



dpdw

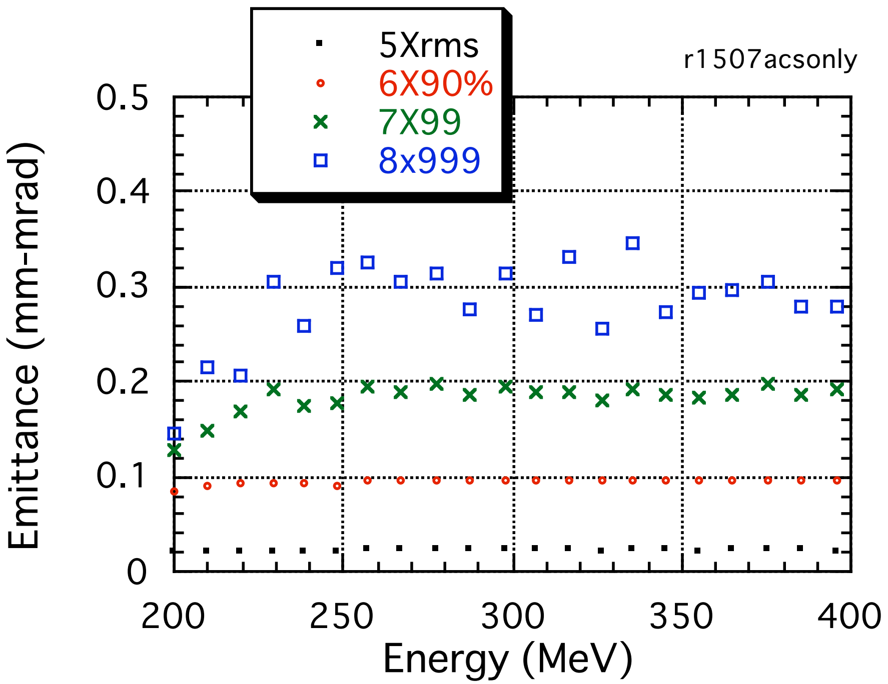
Energy deviation



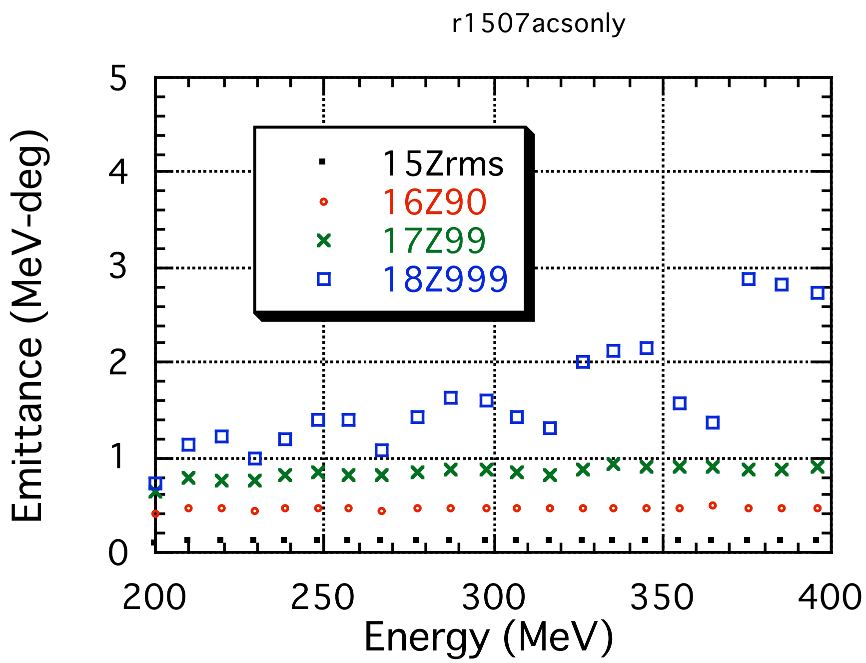


電場強度エラー(セル及びタンク双方に±3%)と位相エラー(セル及びタンク双方に± 3度)の5種類のエラー分布に対する平均エネルギーの変化。

Injection generated in ACS code



x-xd



dpdw

Injection beam

	ε_{xrms} mm-mrad	ε_{zrms} MeV-deg	σ_x/σ_{x0} deg	σ_z/σ_{z0} deg	k_x/k_{x0}	μ_x	k_z/k_{z0}	μ_z
C-30mA	0.2	0.14	42/58	19/31	0.72	0.48	0.61	0.62
C-50mA	0.2	0.15	36/58	15/31	0.62	0.61	0.49	0.76
rfq-30mA	0.16	0.08	38/58	14/31	0.66	0.57	0.44	0.80
rfq-50mA	0.16	0.08	32/58	10/31	0.55	0.70	0.32	0.89

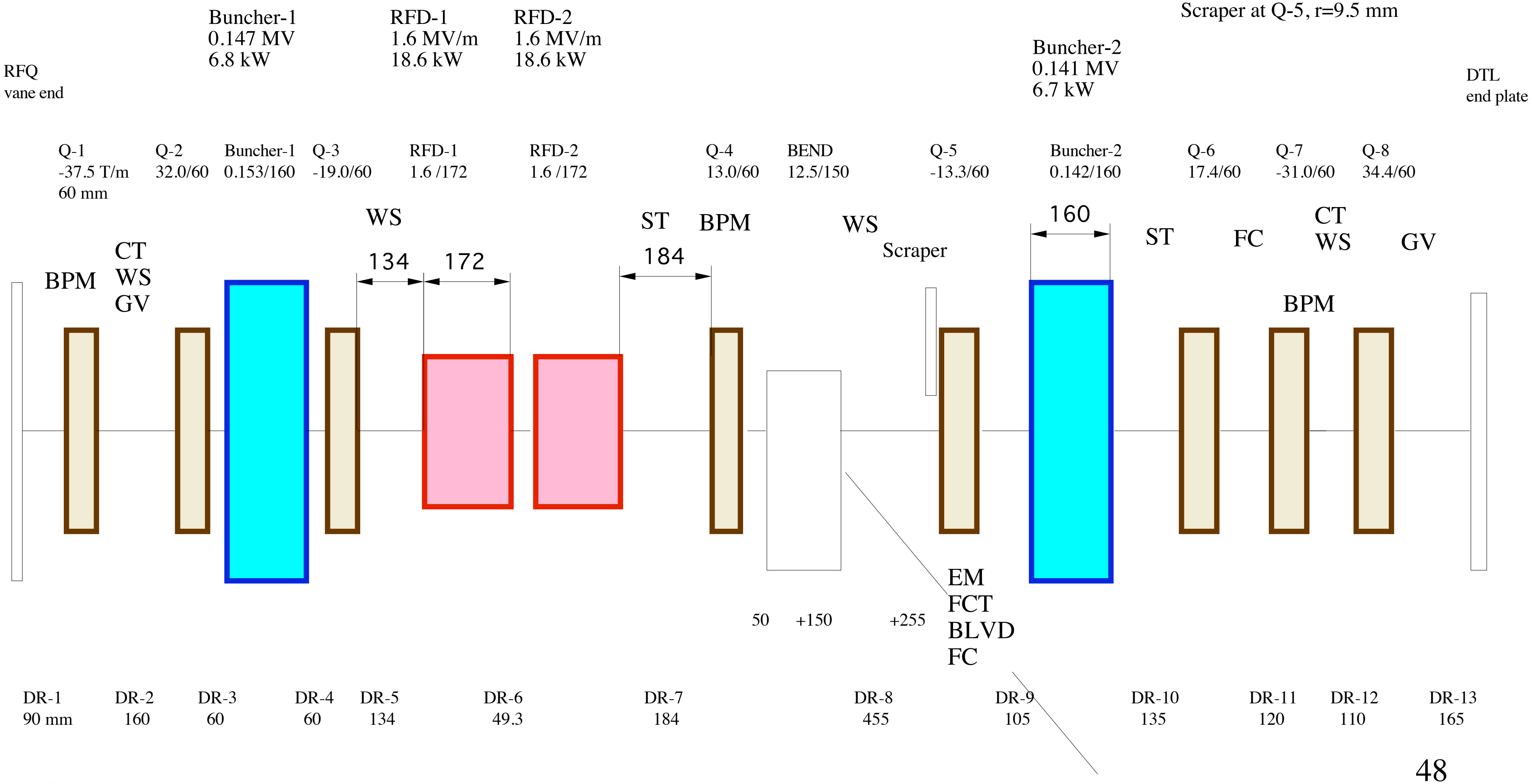
Table 5 Two kinds of injection beams used for the simulations.

	Type A	Type B	
rms transverse emittance	0.187	0.375	pmm.mrad
rms longitudinal emittance	0.133	0.266	pMeV.deg

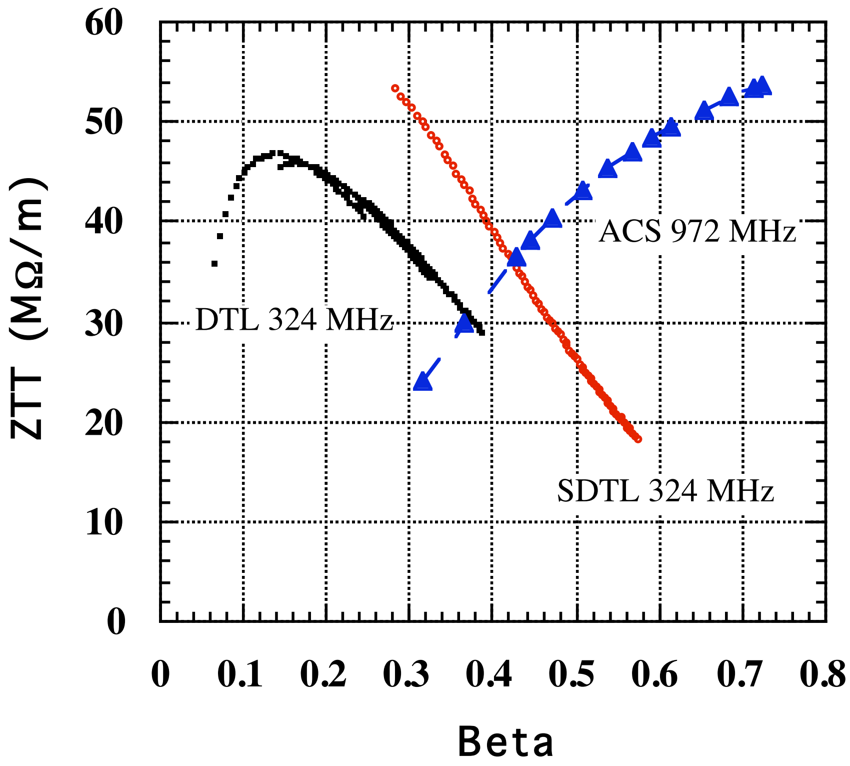
MEBT

Matching, chopping and measurements

negative charge
Total length 2989.9 mm
Normal beam size < 10 mm
Deflected < 26 mm
Scraper at Q-5, r=9.5 mm



ZTT

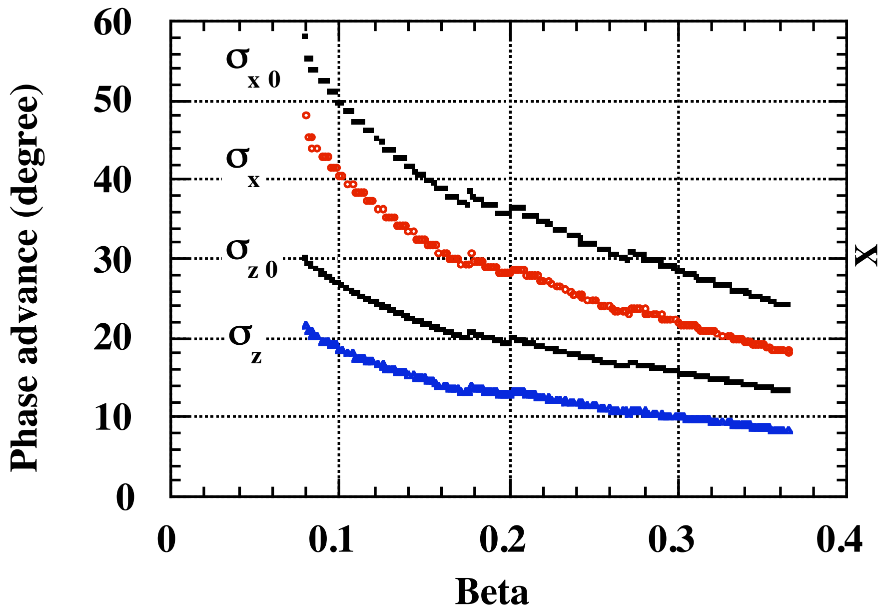


60
50
40
30
20
10
0
ZTT (MΩ/m)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Beta
ACS 972 MHz
DTL 324 MHz
SDTL 324 MHz

収束法

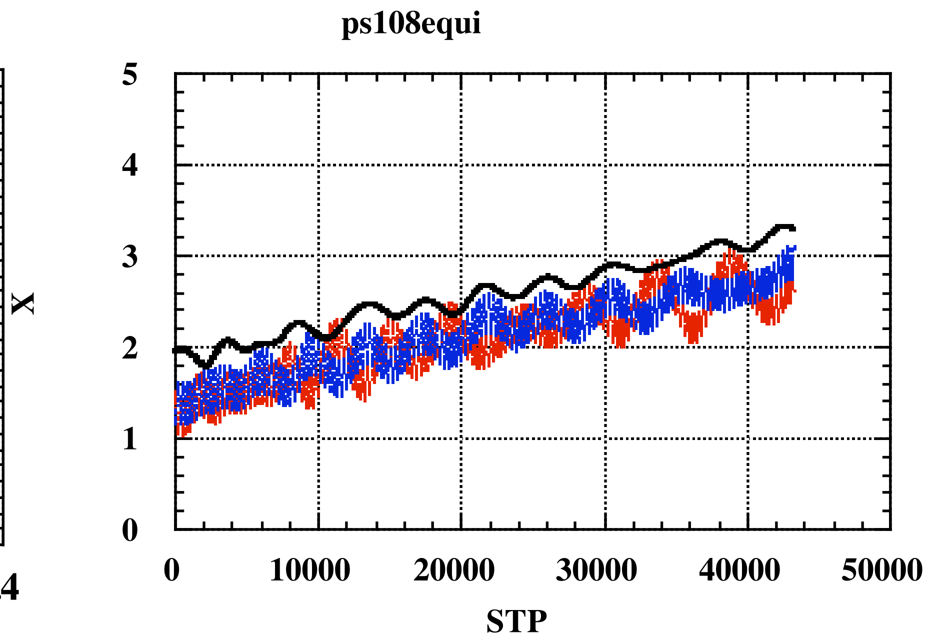
Equipartitioning focusing

$$\frac{k_{x0}}{k_{z0}} \propto \text{const}$$



Constant phase advance

$$\frac{k_{x0}}{k_{z0}} \propto \beta_0^{1/2}\gamma_0^{3/2}$$



Simulation 予測はいろいろある。
実機にて最適加速を与える横収束法を求める

Equipartitioning

$$\gamma_0 \frac{\varepsilon_{nx}}{\varepsilon_{nz}} \frac{z_m}{a} = 1 \qquad \frac{k_x \varepsilon_{nx}}{k_z \varepsilon_{nz}} = 1 \qquad \varepsilon_{nx}\sigma_x = \varepsilon_{nz}\sigma_z$$

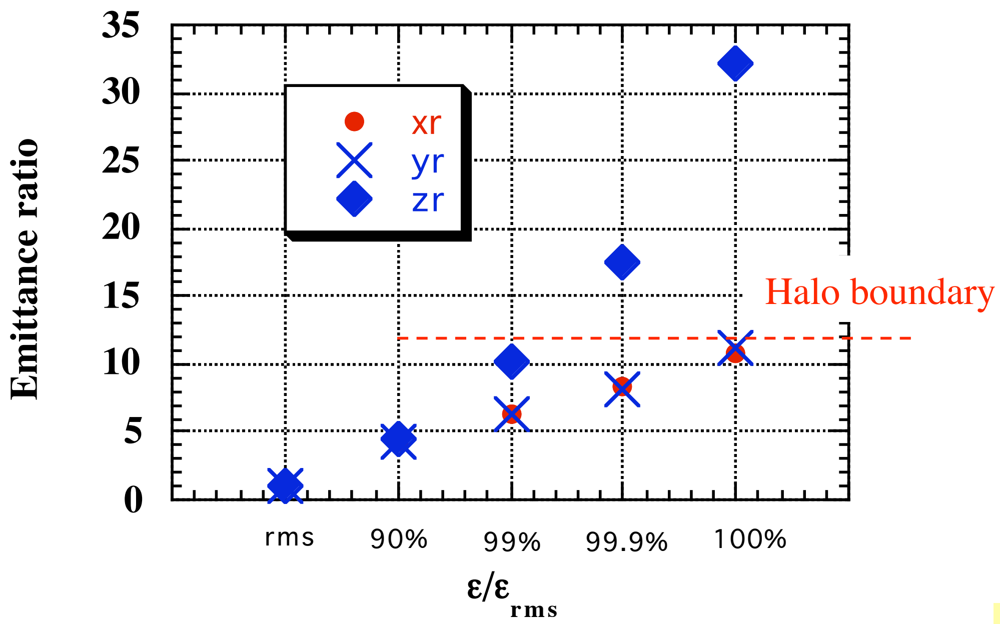
$$T_\perp = T_\parallel$$

$$\frac{k_{x0}}{k_{z0}} = \left(\frac{3}{2}\frac{\varepsilon_{nz}}{\varepsilon_{nx}} - \frac{1}{2} \right)^{1/2}$$

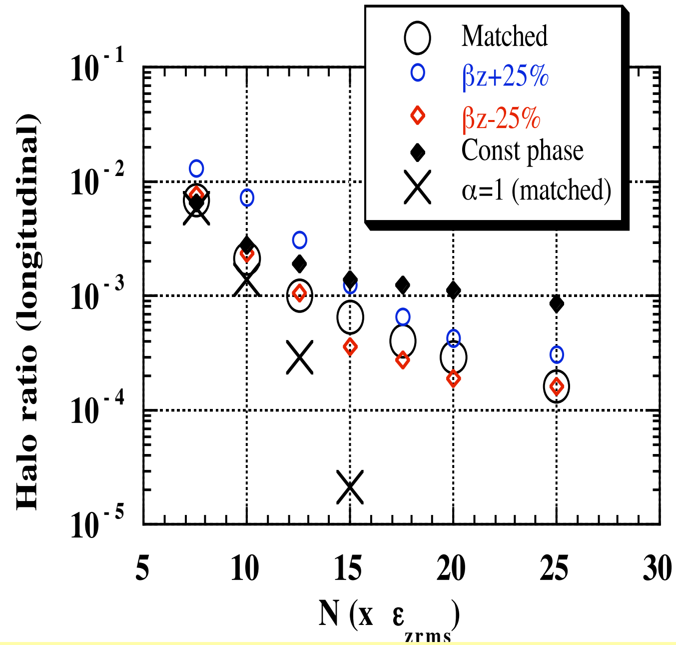
$$\tilde{\varepsilon}_{nx} = \tilde{x}\left(\frac{\gamma_0 k_B T_\perp}{mc^2}\right)^{1/2} \qquad \tilde{\varepsilon}_{nz} = \tilde{z}\left(\frac{\gamma_0^3 k_B T_\parallel}{mc^2}\right)^{1/2}$$

Beam halos in RFQ beam

RFQ calculated beam



LINSAC DTL results



Here, halo-like particles are defined by those in the outside of 12.5 times the longitudinal output rms emittance.

400-MeV linac