High Frequency Adiabatic Buncher

(GEANT4 simulation)

V. Daniel Elvira

May 11th, 2002

Motivation

ν factory needs phase rotation after decay channel:

- very low frequency r.f. system or induction linac (Study I, II baseline used induction linac, CERN used low freq r.f.)

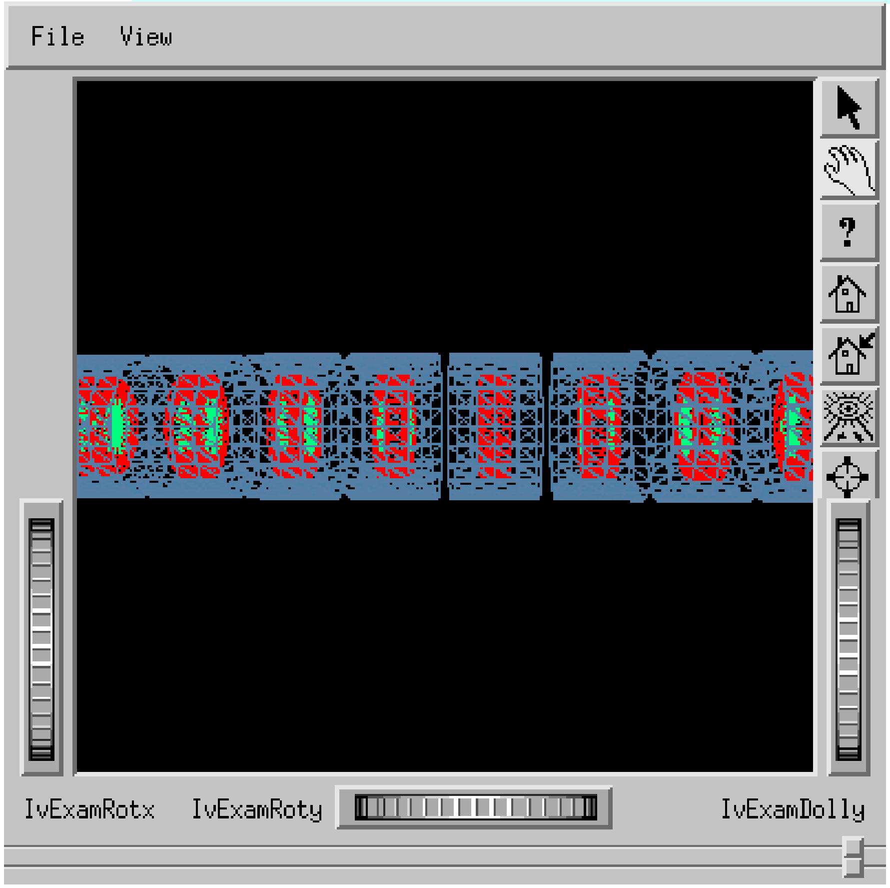
  new development technology, cost…………

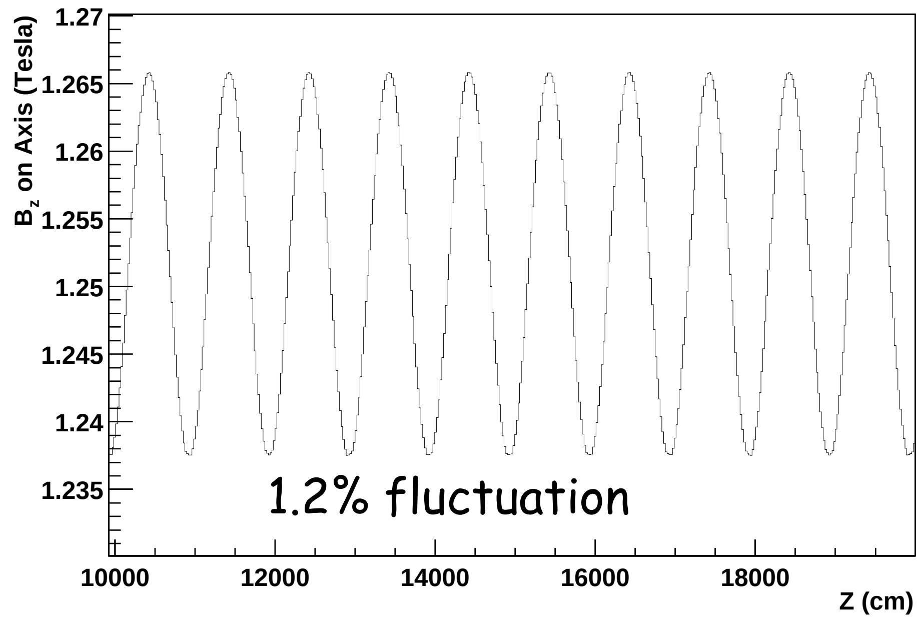
- high frequency bunching and then phase rotation (Neuffer & Van Ginneken)

  established high frequency r.f. systems

Design: 100 m drift section + 60 m adiabatic buncher + 40 m phase rotator + matching section + cooling channel (double flip?)

Lattice Design



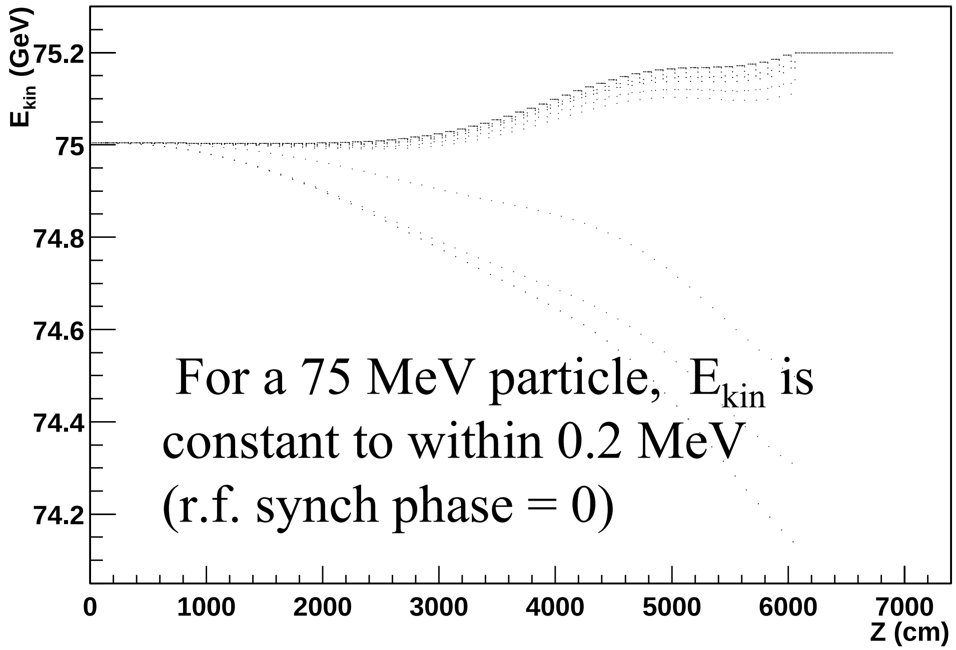


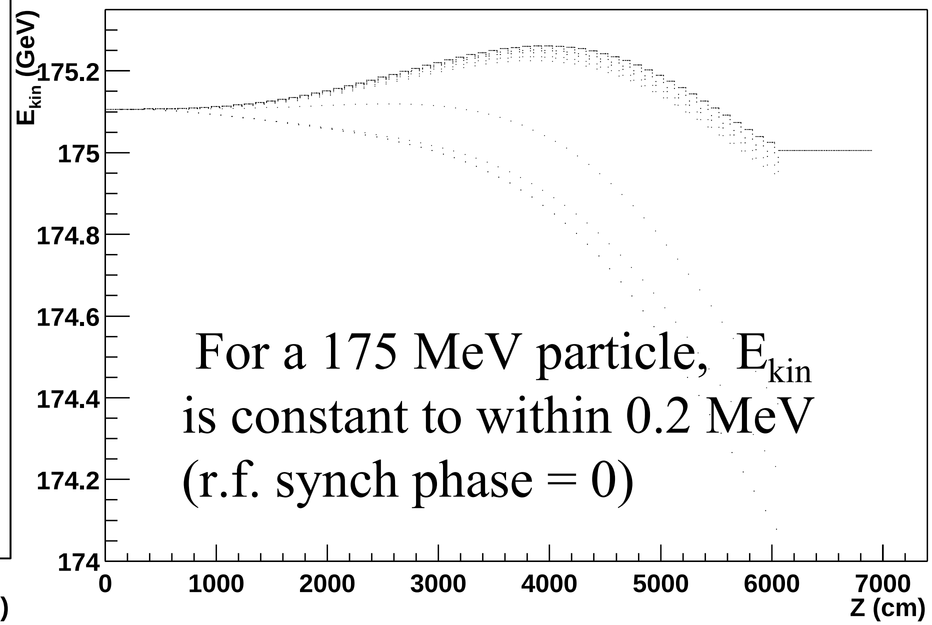
60 cells lattice, unit cell is 1 m long:

Solenoid, 70 cm in radius, 2 cm thick, 85 cm long with 15 cm gaps, B_z=1.25 T on axis

290-180 MHz r.f. system, Pill Box cavities, no windows for now, V_{peak} chosen so that E_{Gain} at 90° would grow quadratically from 0 to 4.8 MeV at the end of the channel (transit time considered), synch. phase is 0°

r.f. Tuning





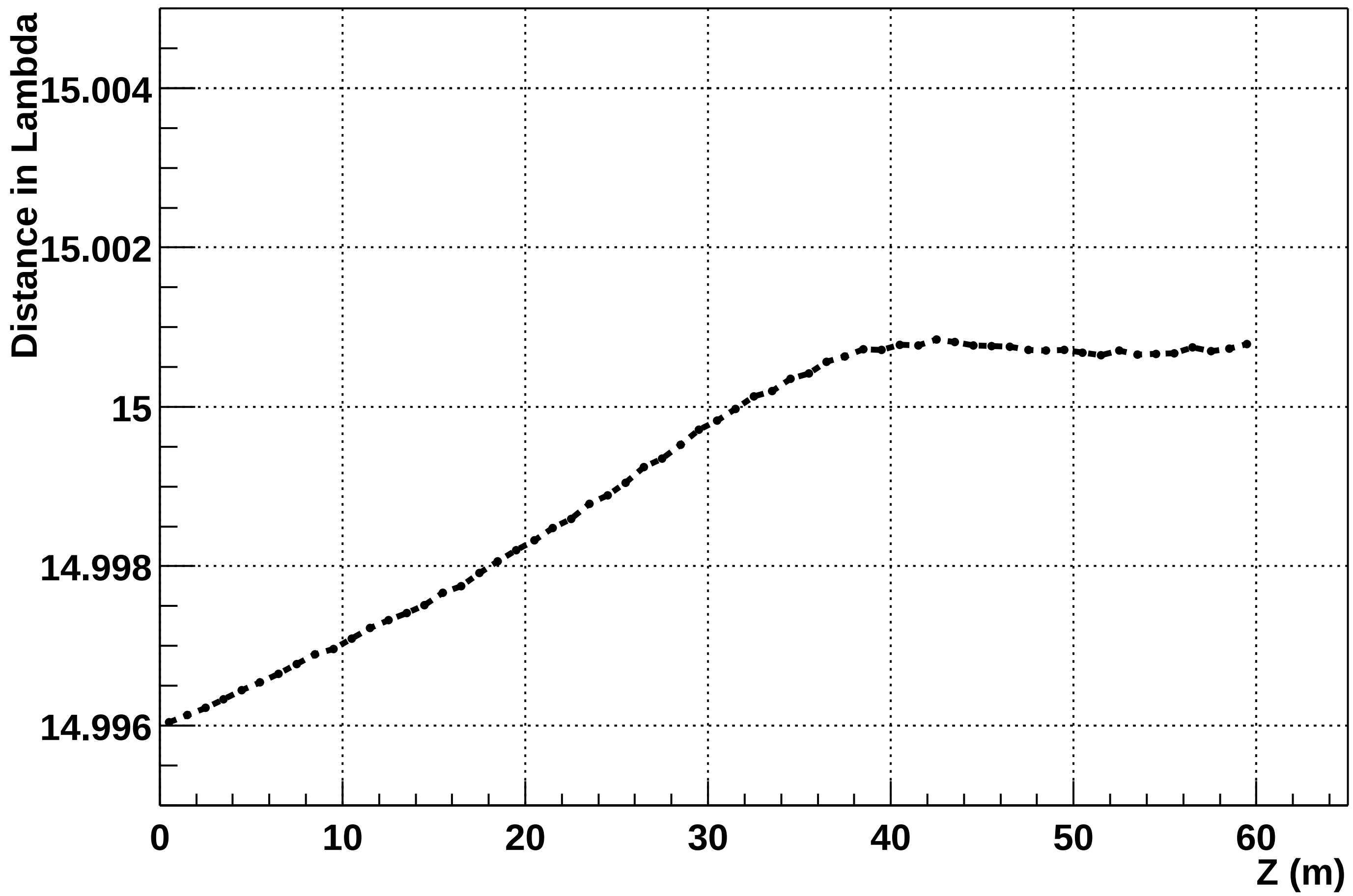
Two reference particles (at the beginning and end of the beam), E_{kin}=75 MeV & E_{kin}=175 MeV, satisfying:

$$\boxed{\Delta t = 15\,T_{r.f.} \Rightarrow \nu_{r.f.} = 15\,\frac{c}{d\left(\frac{1}{\beta_{75}} - \frac{1}{\beta_{175}}\right)}}$$

$\nu_{r.f.}$ =
290-180 MHz

d: dist. to origin

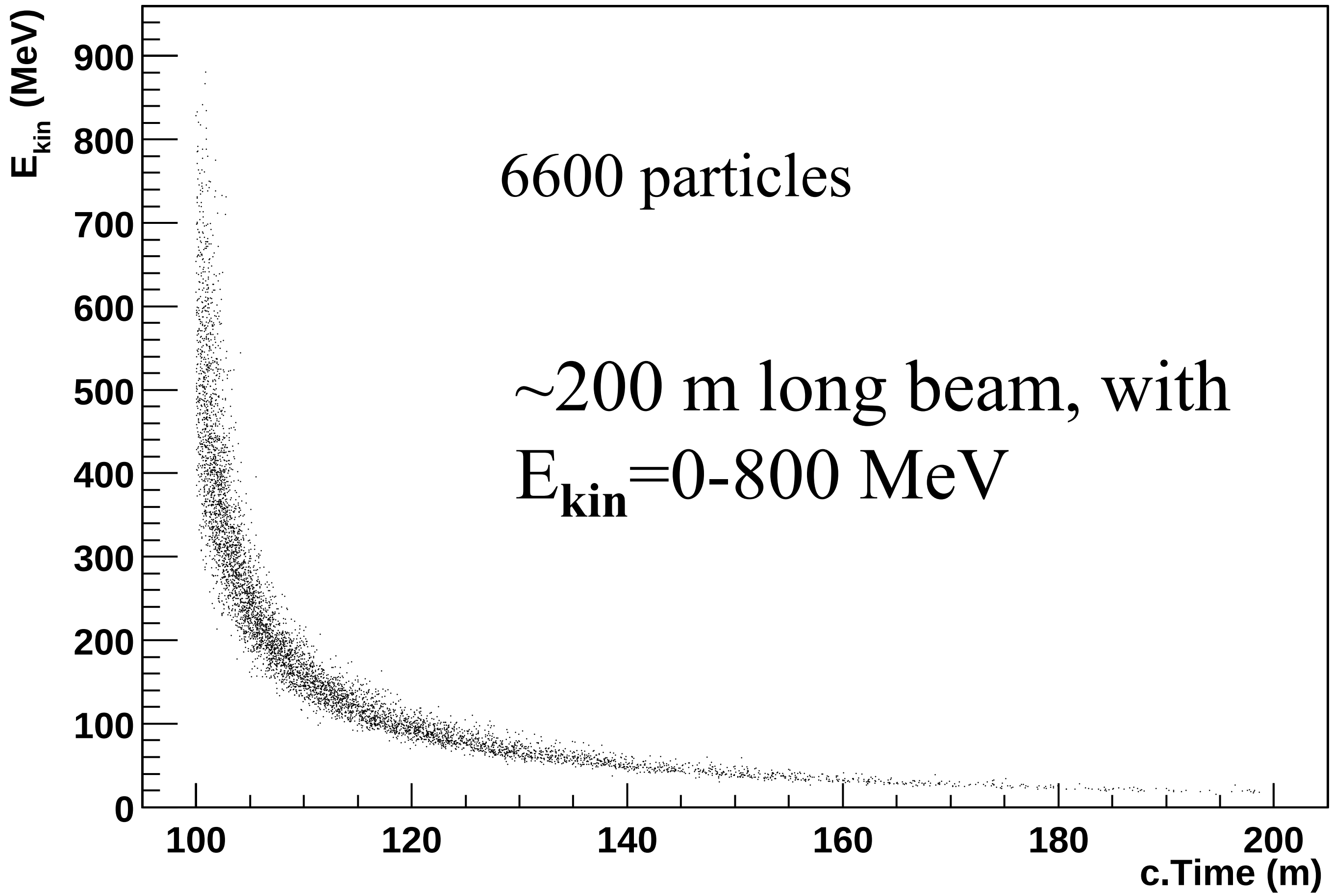
r.f Tuning (cont)



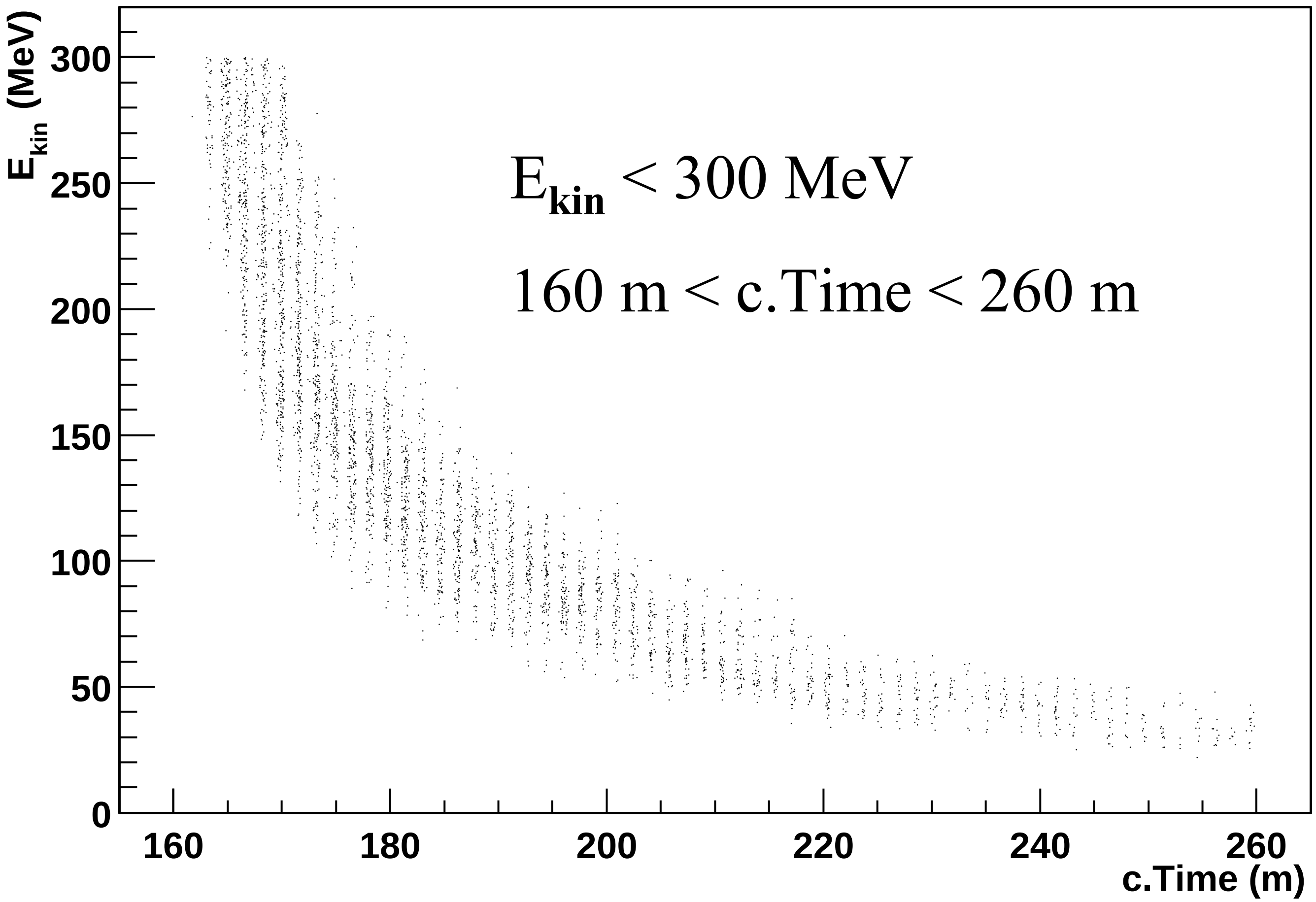
Distance between reference particles is 15 r.f. wave-lengths to within 0.02%

Results

Initial beam for the buncher: Study II beam (Hg target, 20 T capture solenoid, 99 m drift



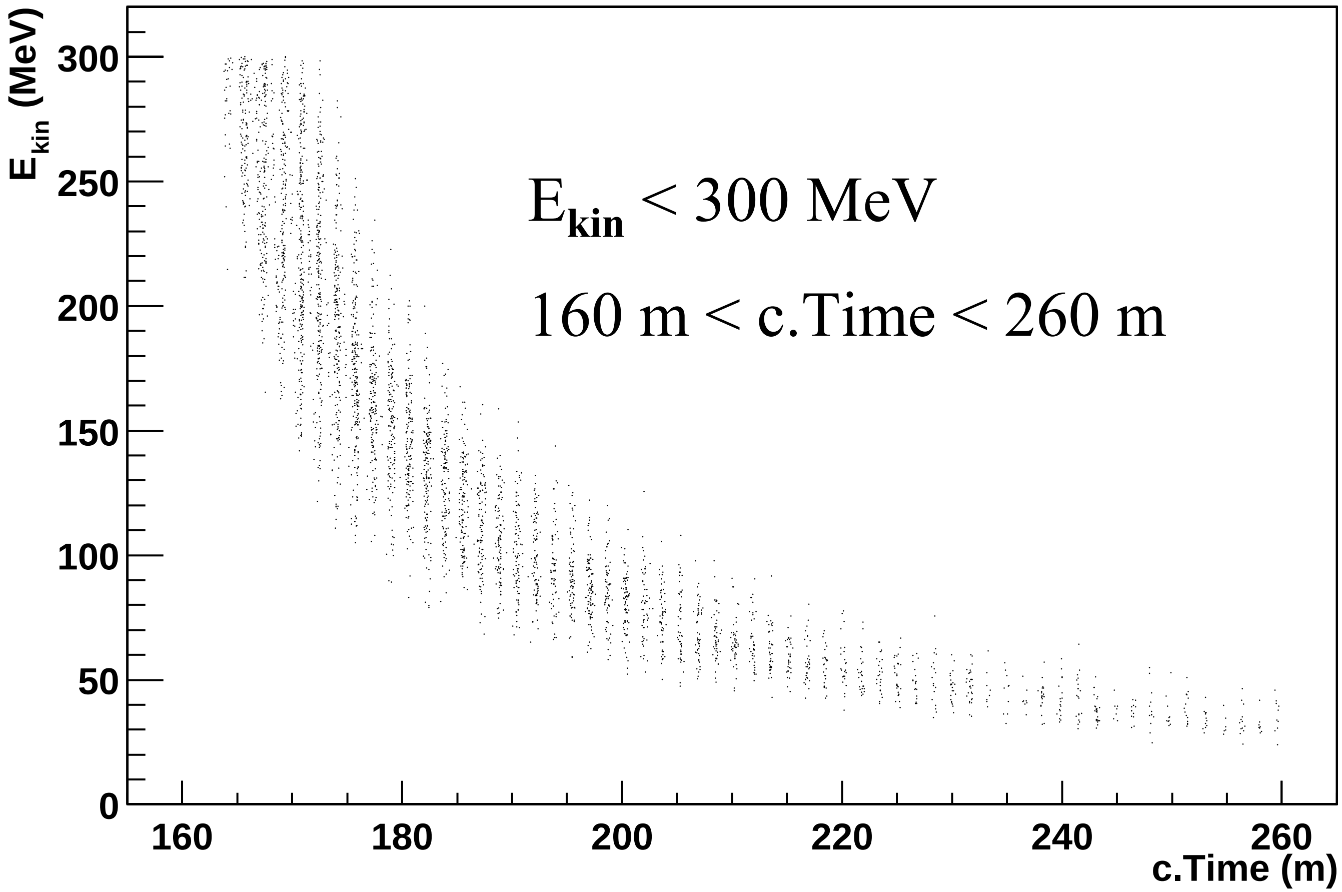
Results: case (i)



64.6% of the particles survive at the end of the buncher within the E_{kin}, c.Time interval. The bunch structure is apparent.

Results: D. Neuffer's

1D simulation using uniform magnetic field and thin cavities

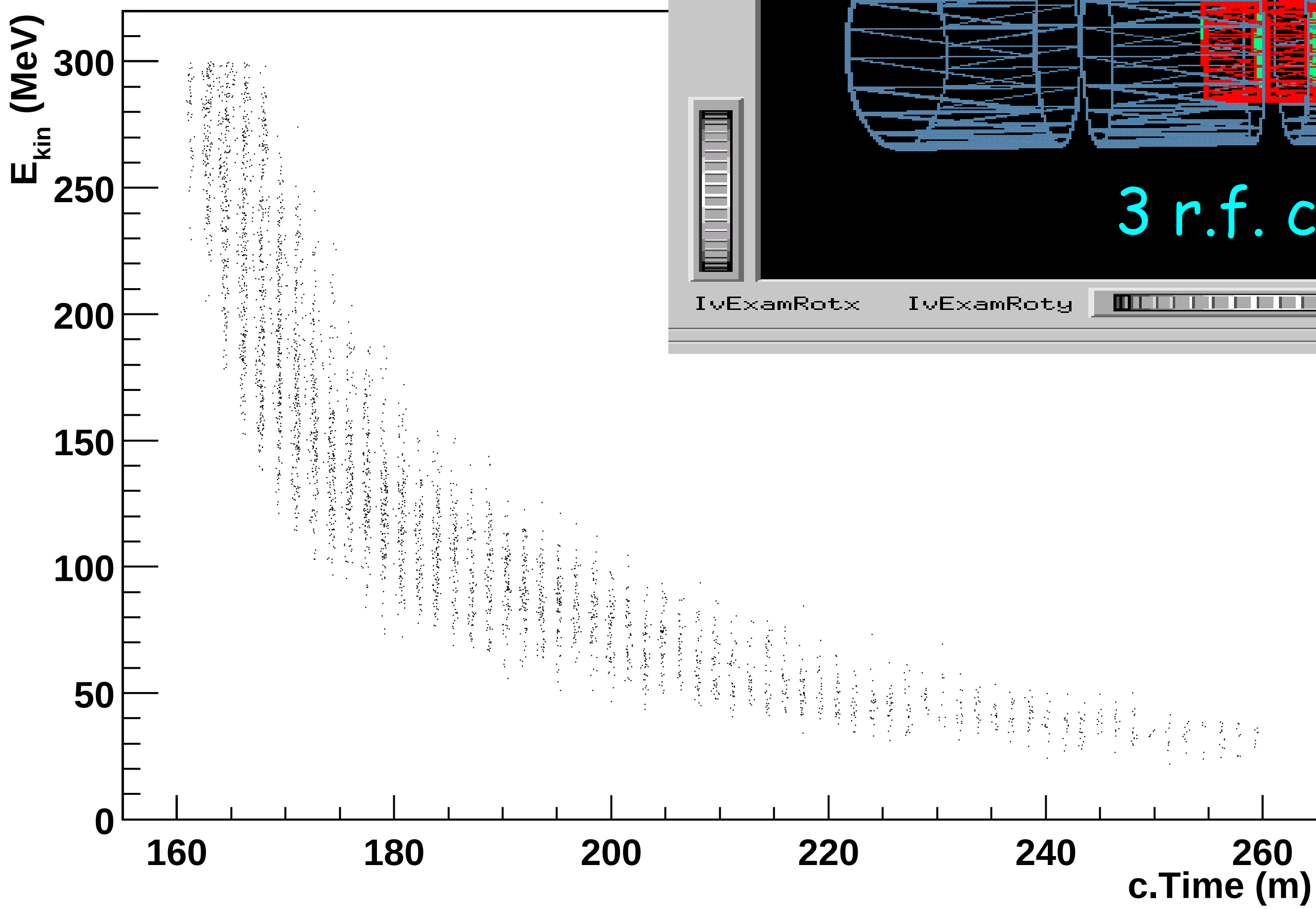


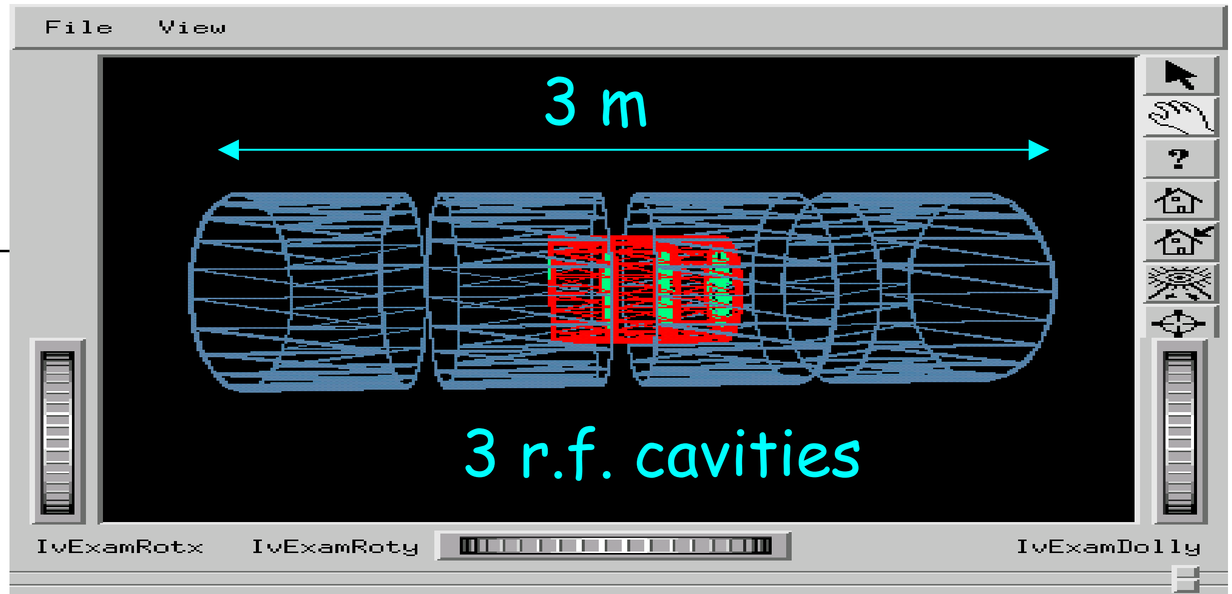
62.3 % of the particles survive at the end of the buncher

Results: case (ii)

$E_{kin} < 300$ MeV

160 m < c.Time < 260 m





Only 20 frequencies and voltages.

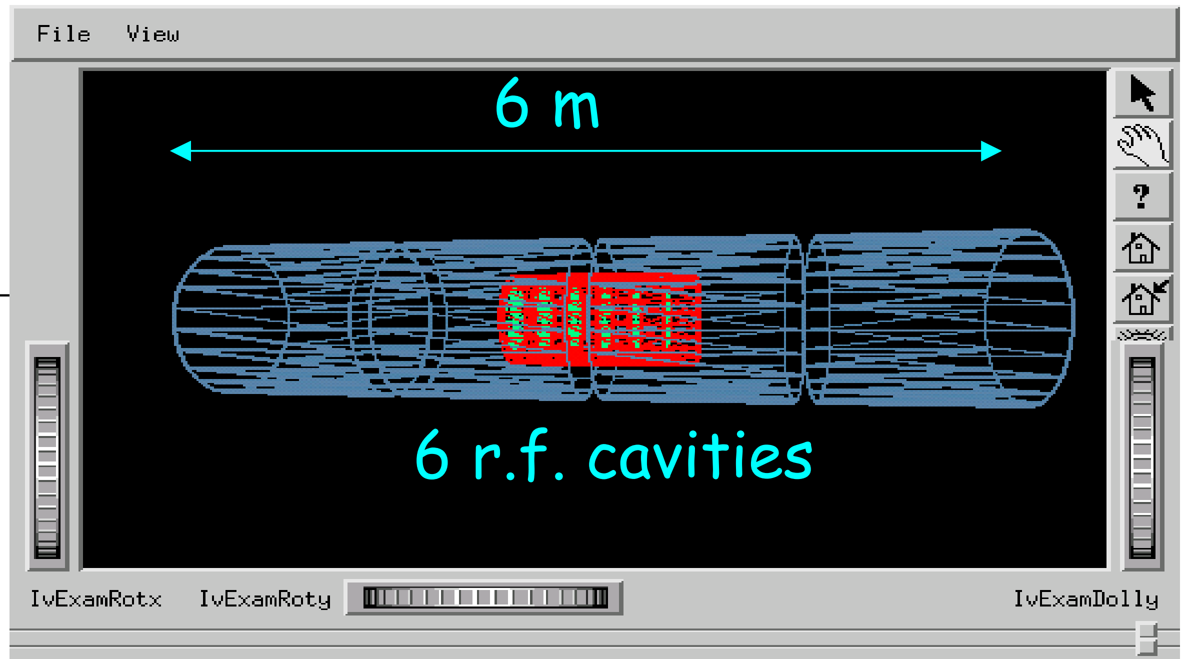
(20 equidistant linacs made of 3 cells)

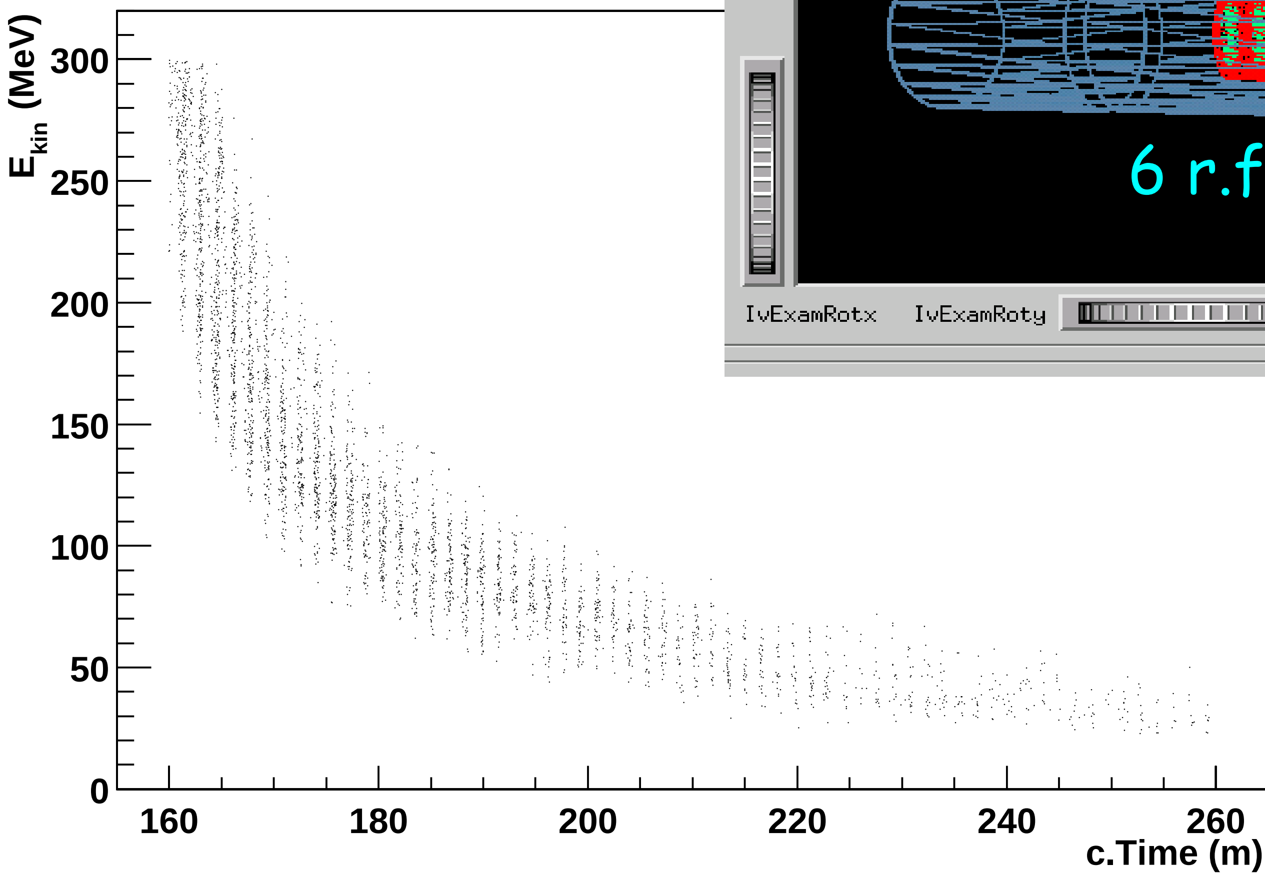
64.9 % of the particles survive at the end of the buncher

Results: case (iii)

E_{kin} < 300 MeV

160 m < c.Time < 260 m





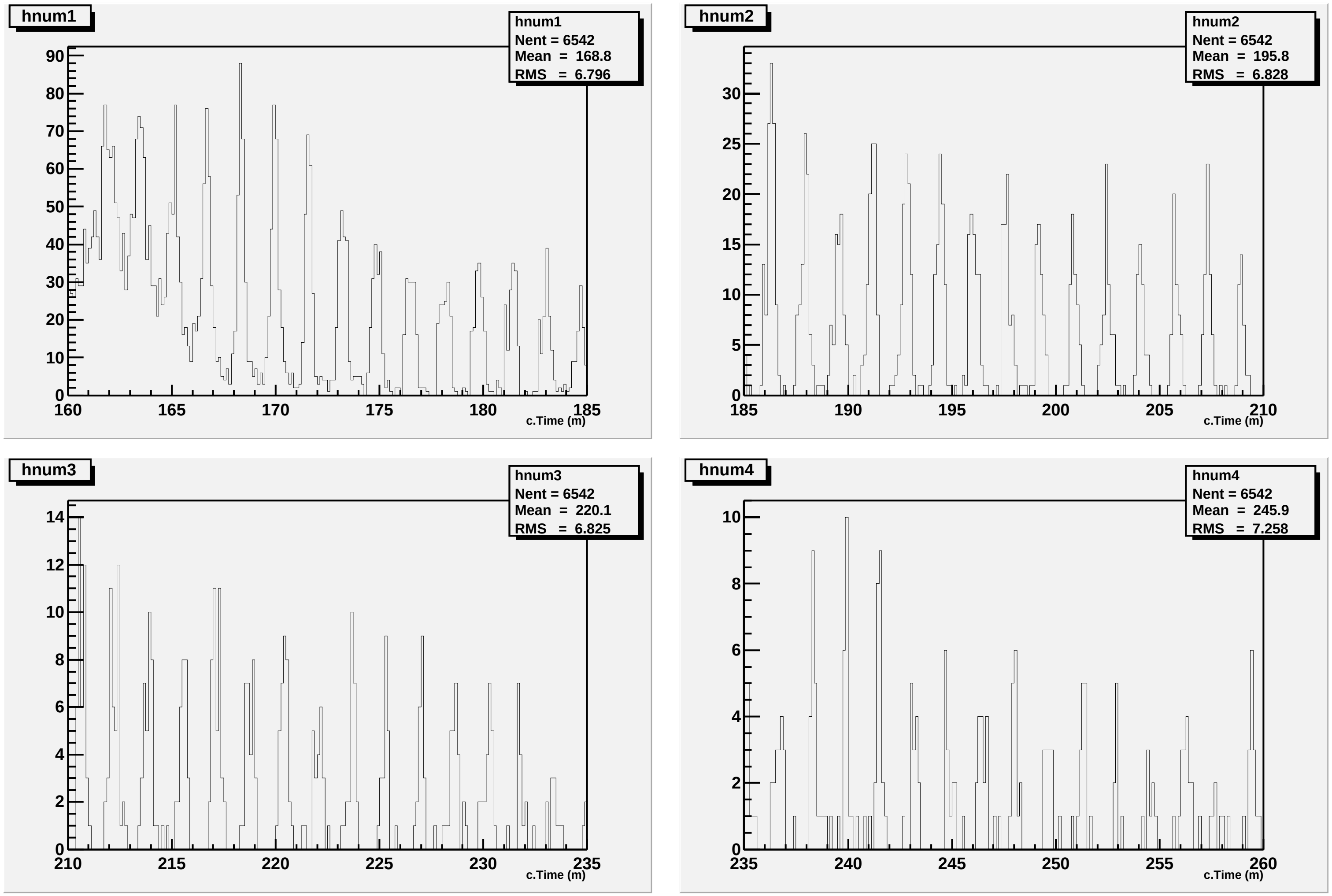
Only 10 frequencies and voltages.

(10 equidistant linacs made of 6 cells)

62.2 % of the particles survive at the end of the buncher.

Results: case (i)

Number of particles versus c.Time

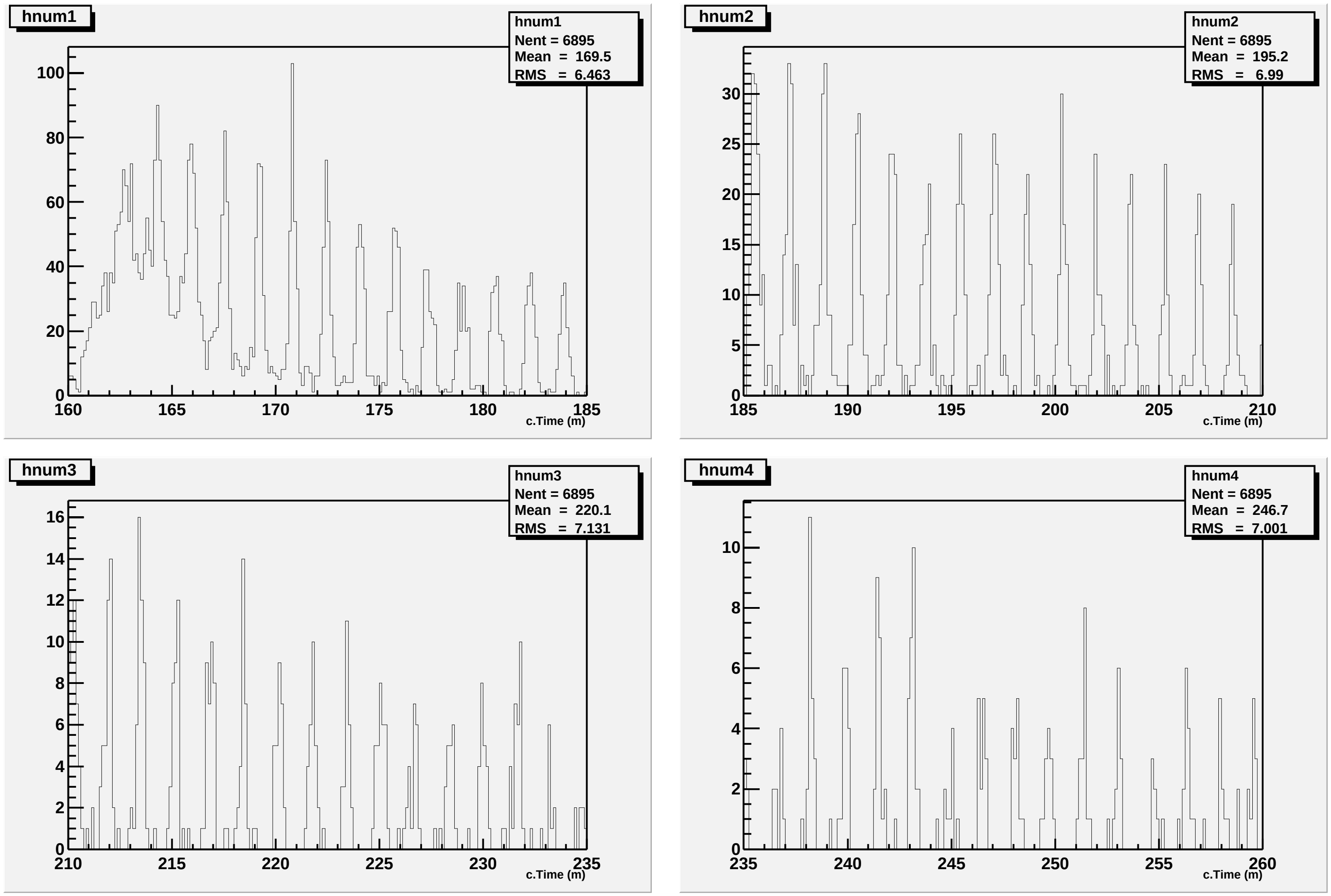


100 m of well defined bunches

Time delay between bunches is $c.\Delta t \sim 1.63$ m

Results: Neuffer's

Number of particles versus c.Time

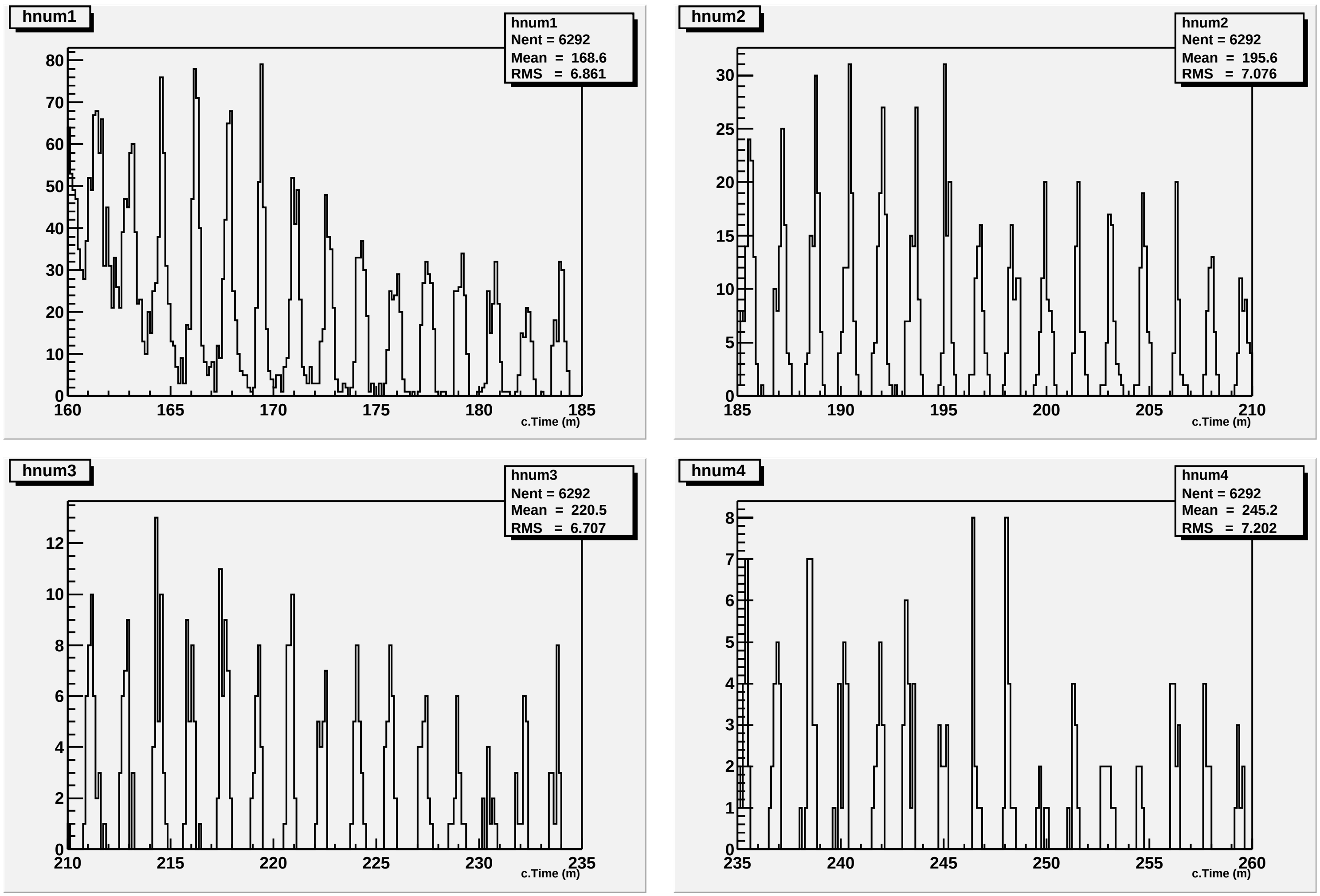


Excellent qualitative agreement with (i)

Bunches separated approximately 1.64 m

Results: case (ii)

Number of particles versus c.Time



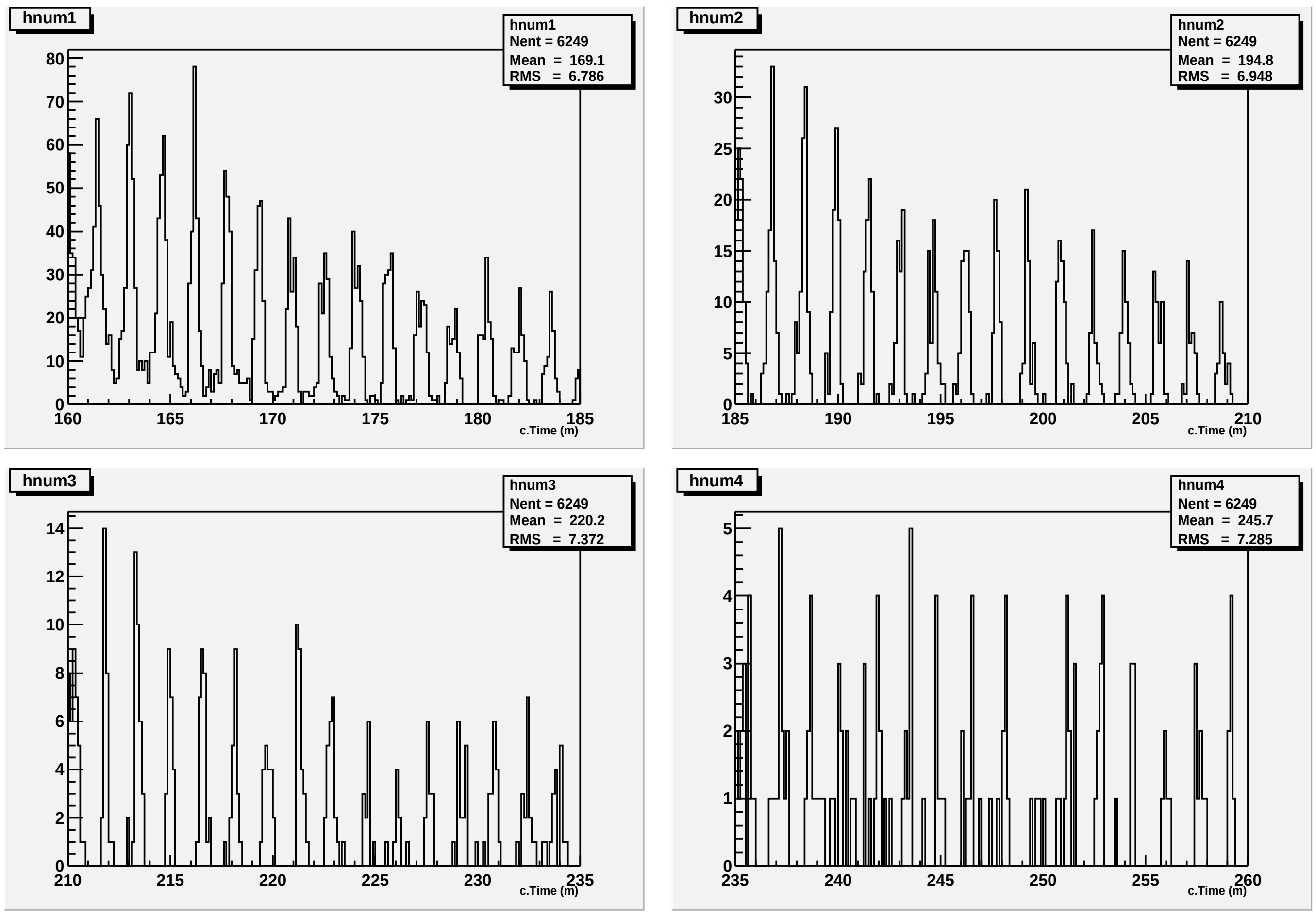
Better bunch structure at high energies,

[compared with (i)]

Bunches separated approximately 1.61 m

Results: case (iii)

Number of particles versus c.Time



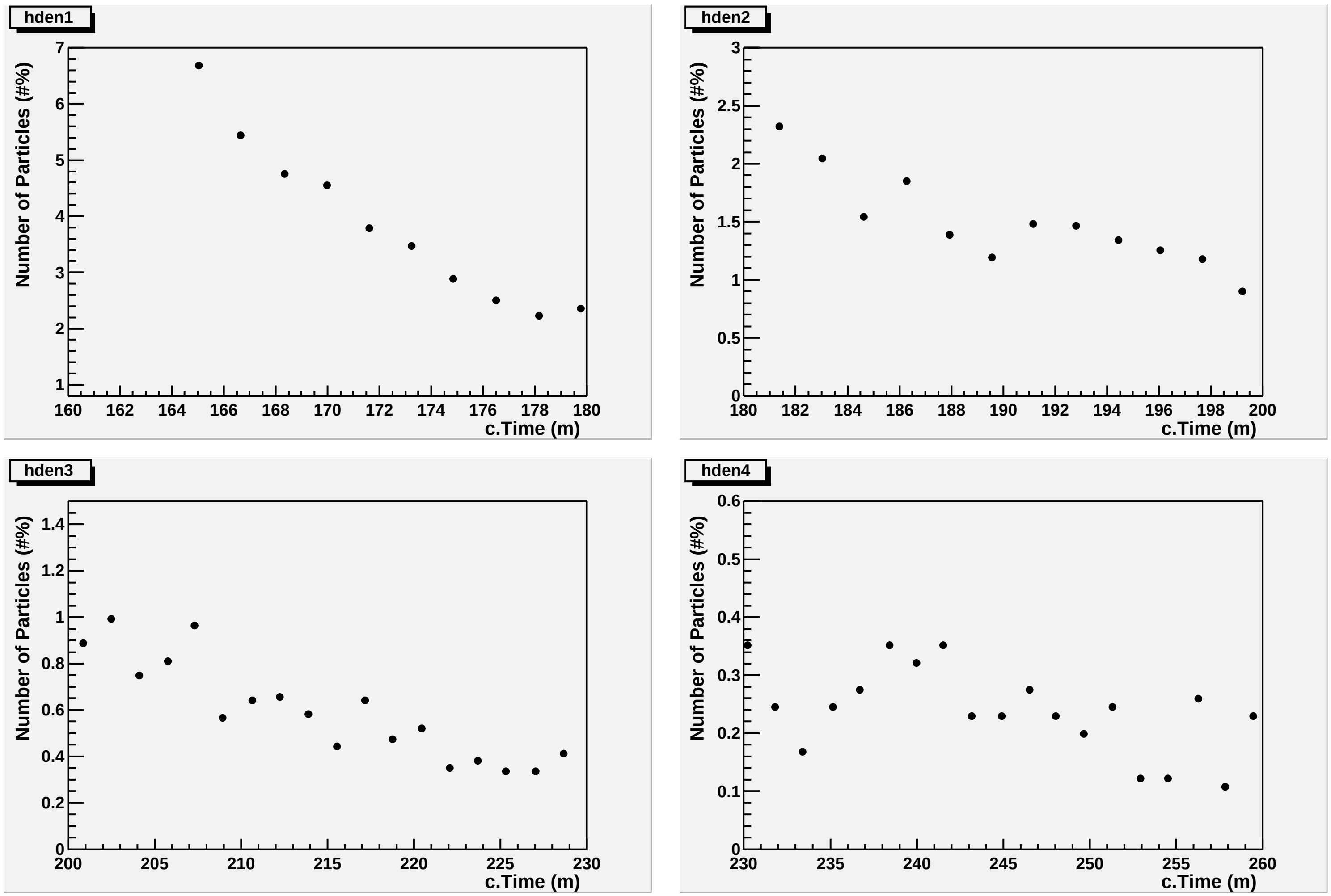
Bunch structure at low energy is fading

Still good performance (most particles are in the high energy range)

Bunches separated approximately 1.58 m

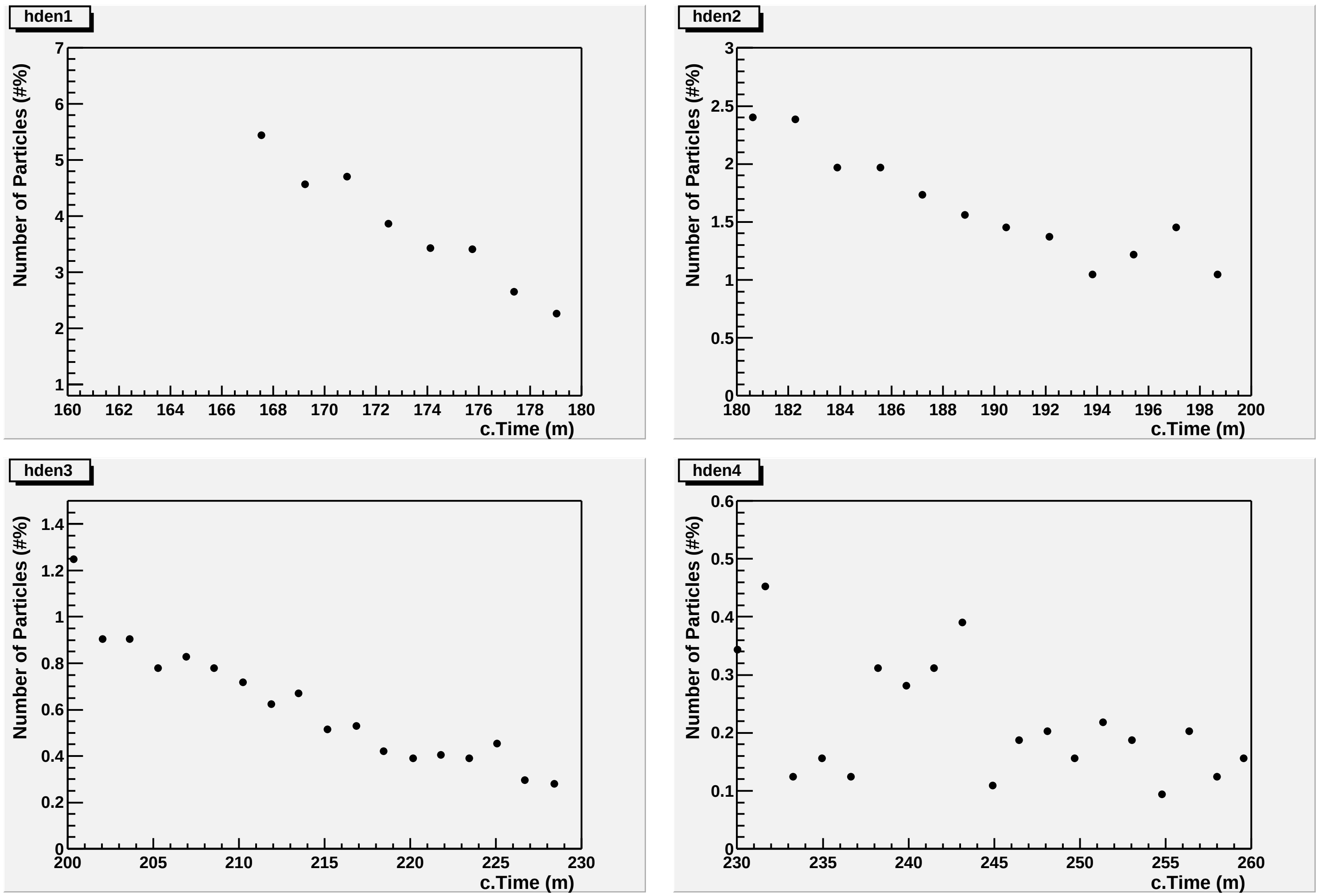
Results: case (i)

Fraction of particles in each bunch between 6% for bunch at 166 m and 0.1-0.25% at 260 m



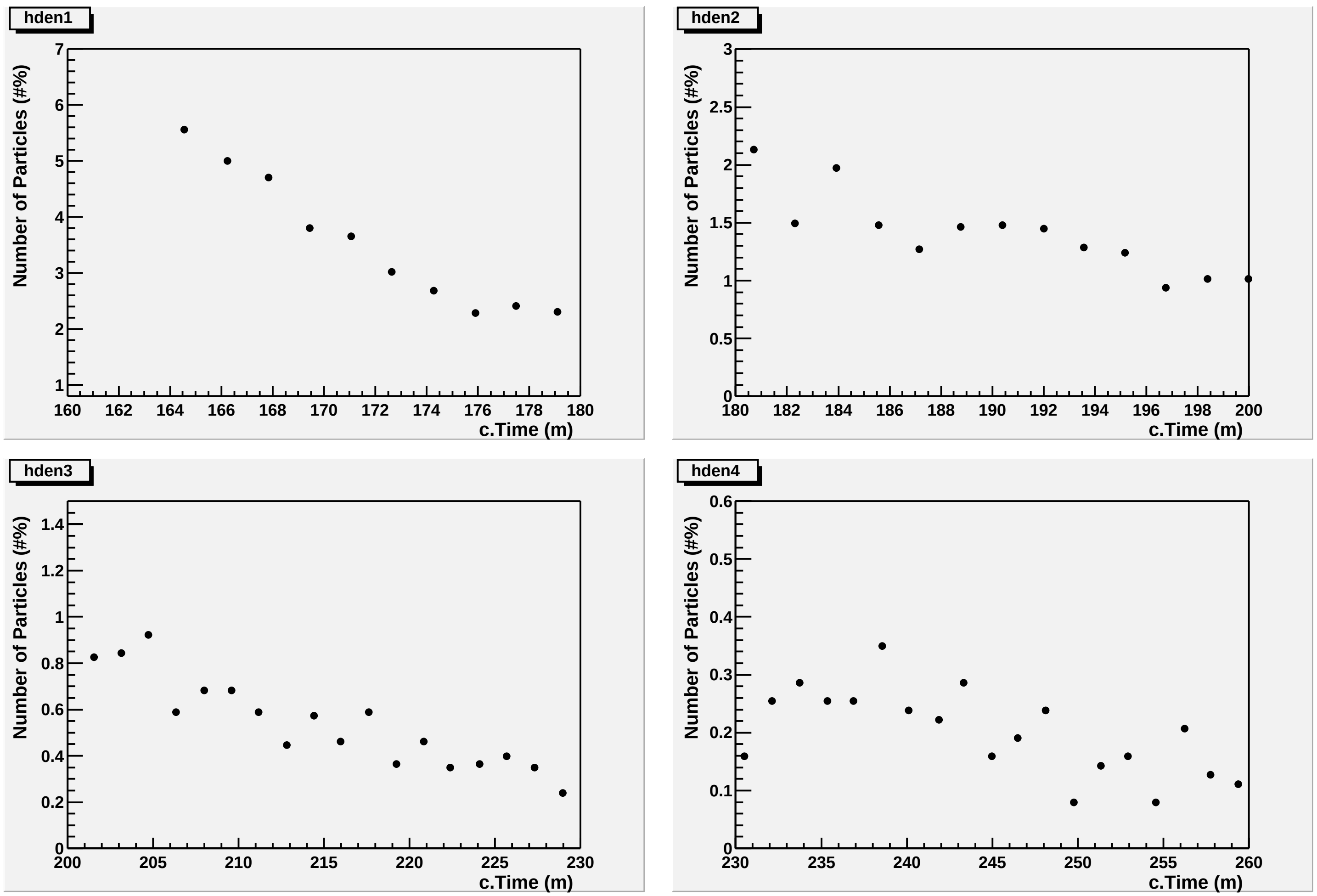
Results: Neuffer's

Fraction of particles in each bunch basically identical to (i).



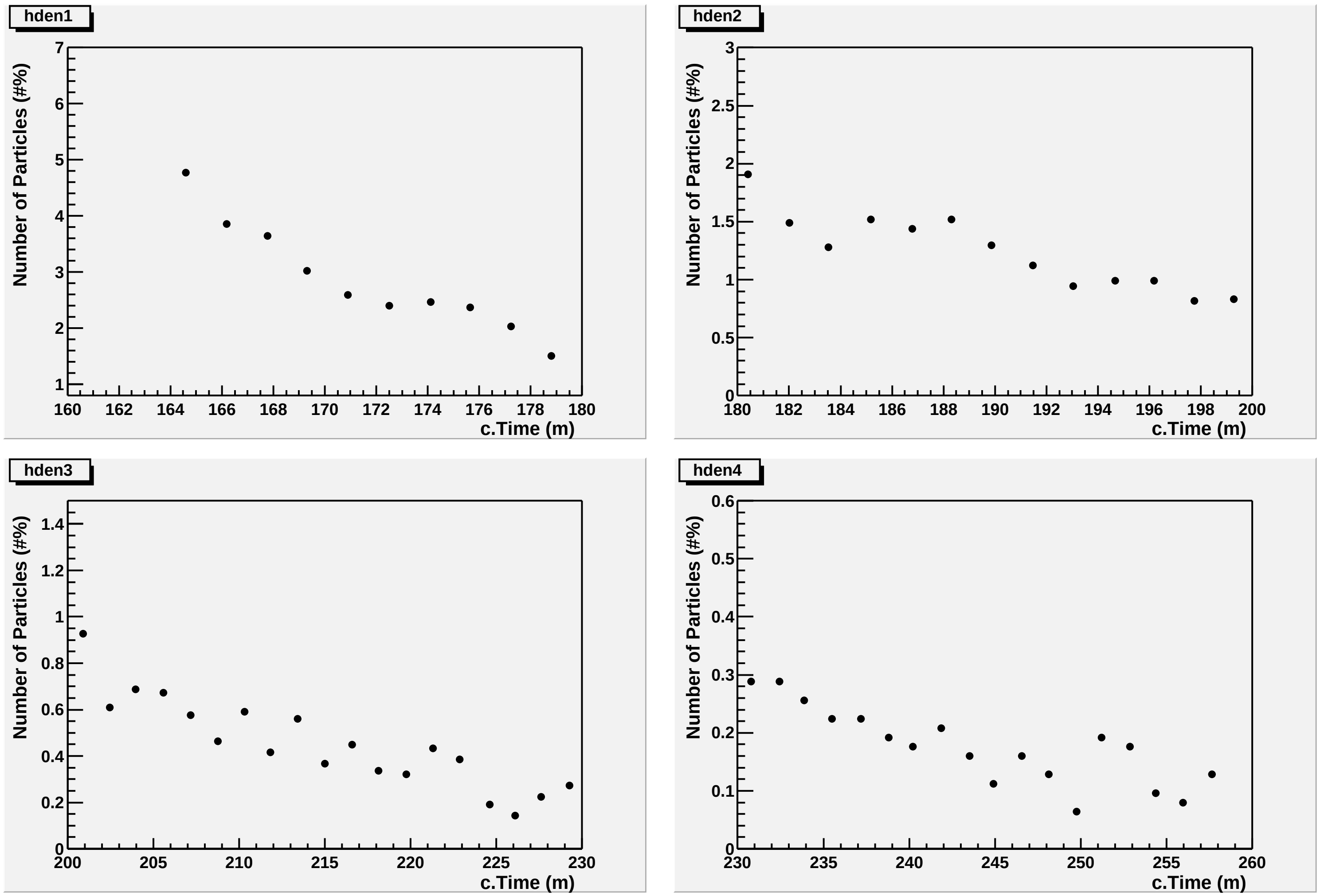
Results: case (ii)

Fraction of particles in each bunch. Better bunch structure at higher energies than for (i), 5% for bunch at 166 m



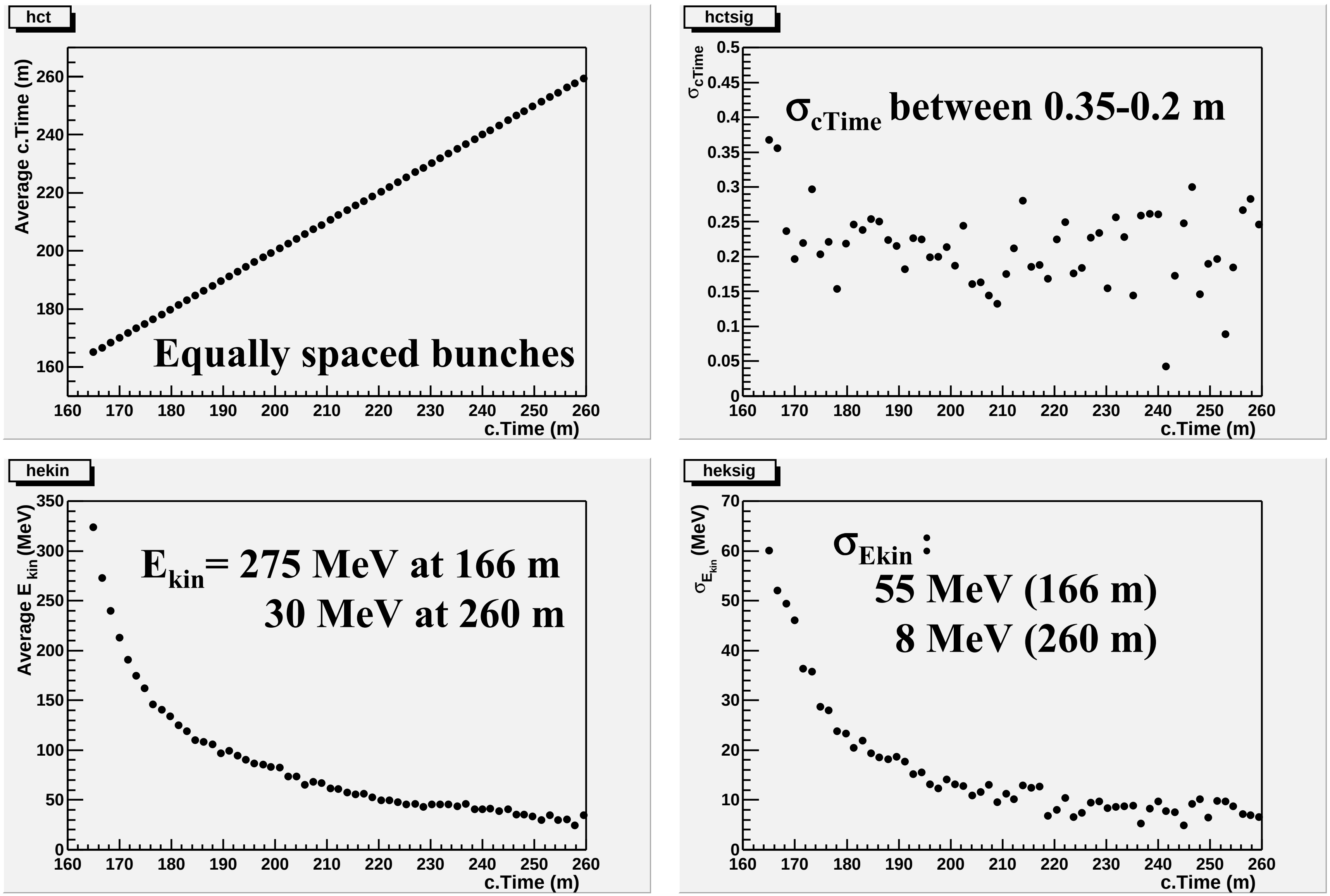
Results: case (iii)

Fraction of particles in each bunch. Lower density: 4.8 % for bunch at 166 m, 0.1% at 260 m. Bunch structure good at high energies but fading away at low energies.

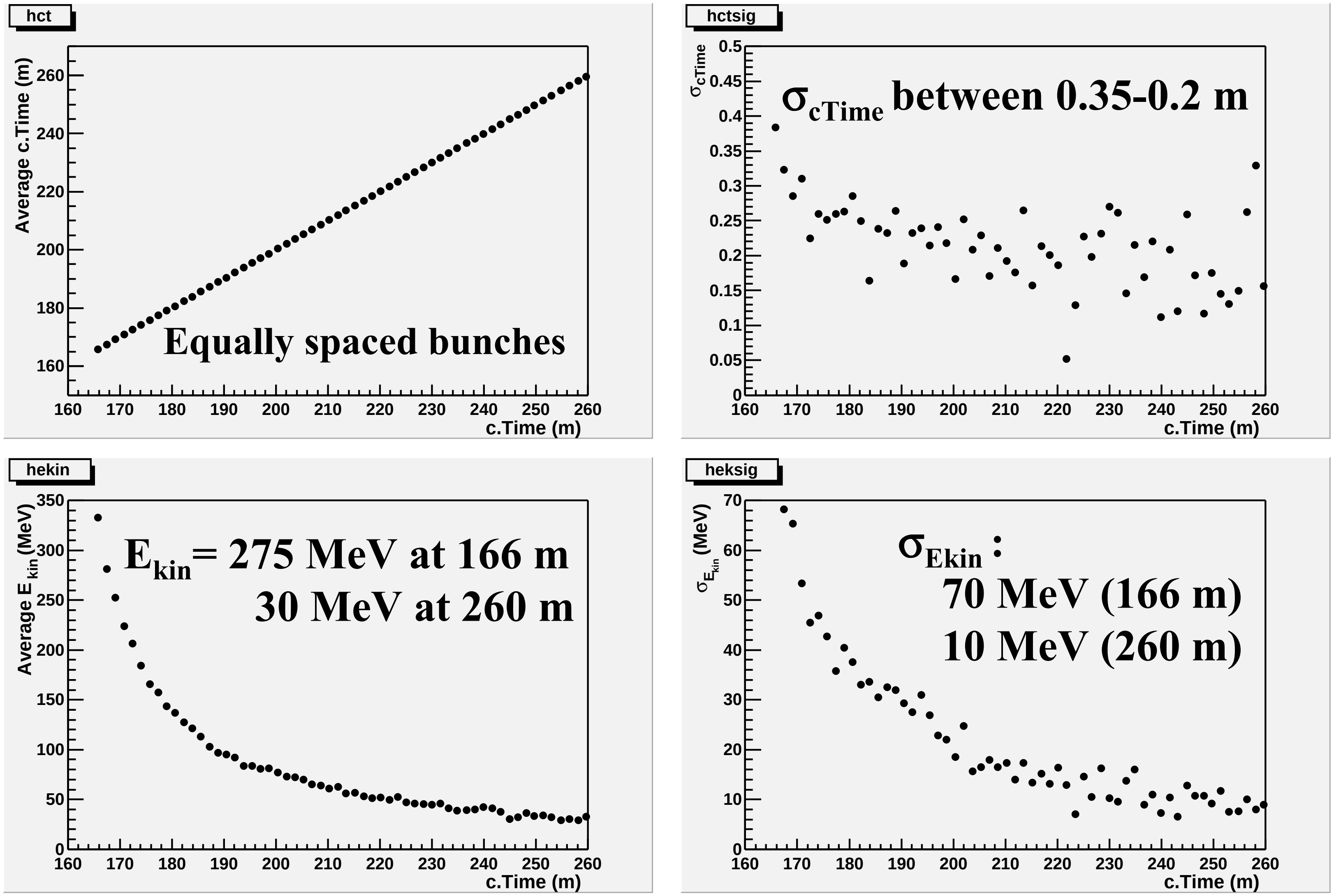


Results: case (i)

Averages (E_{kin}), and sigmas (σ_{cTime}, σ_{Ekin})

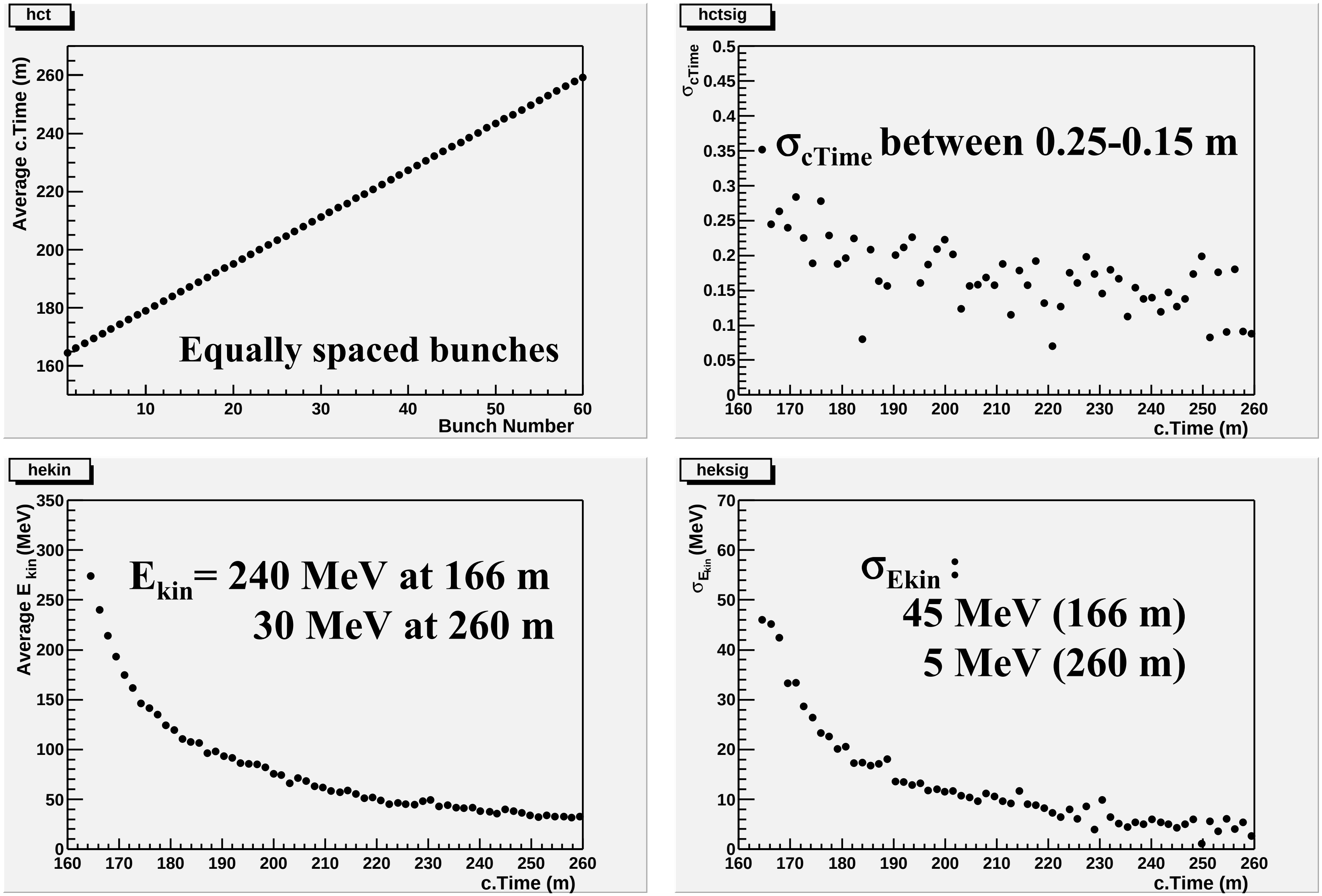


Results: Neuffer's



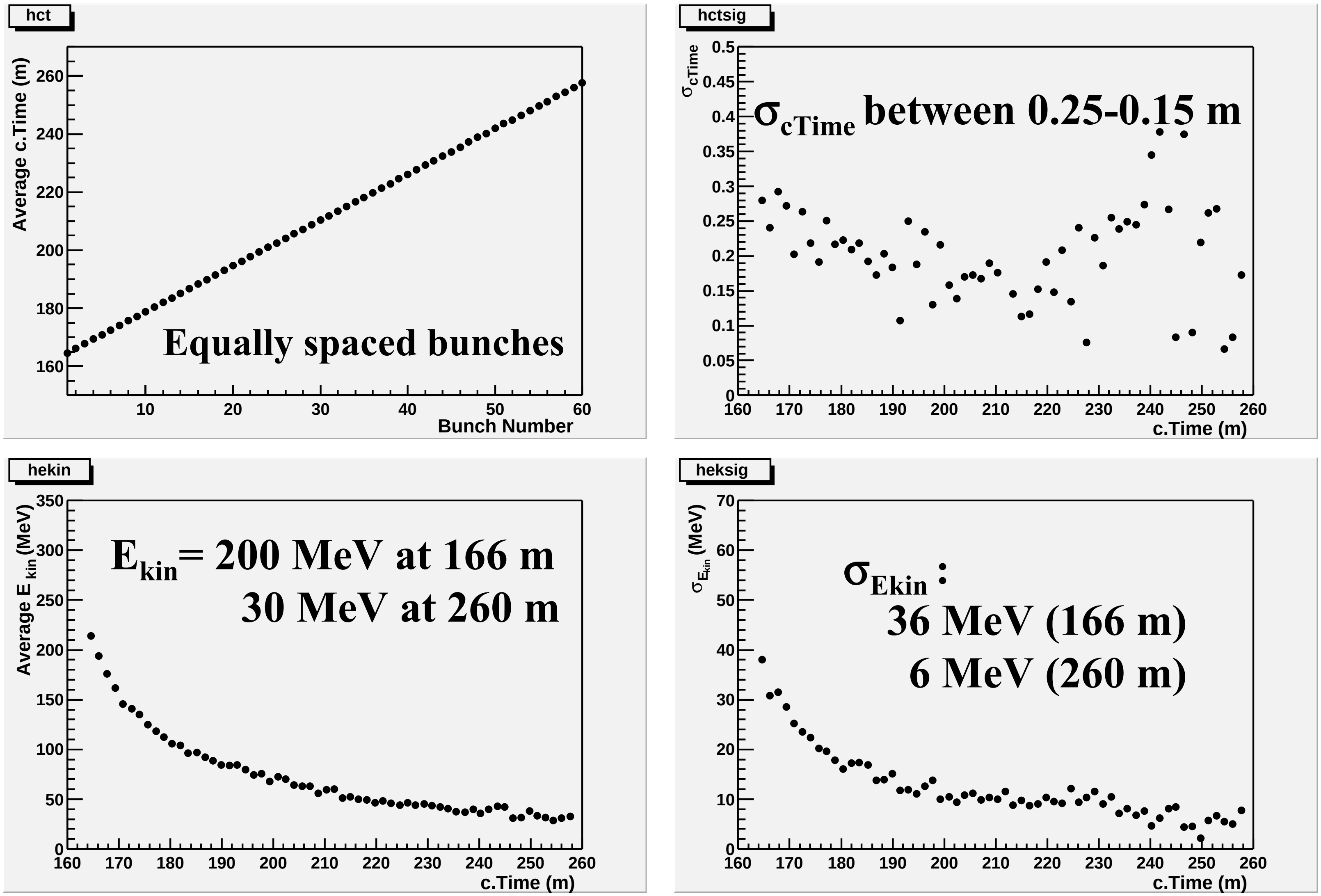
Averages (E_{kin}), and sigmas (σ_{cTime}, σ_{Ekin})

Results: case (ii)



Averages (E_{kin}), and sigmas (σ_{cTime}, σ_{Ekin})

Results: case (iii)

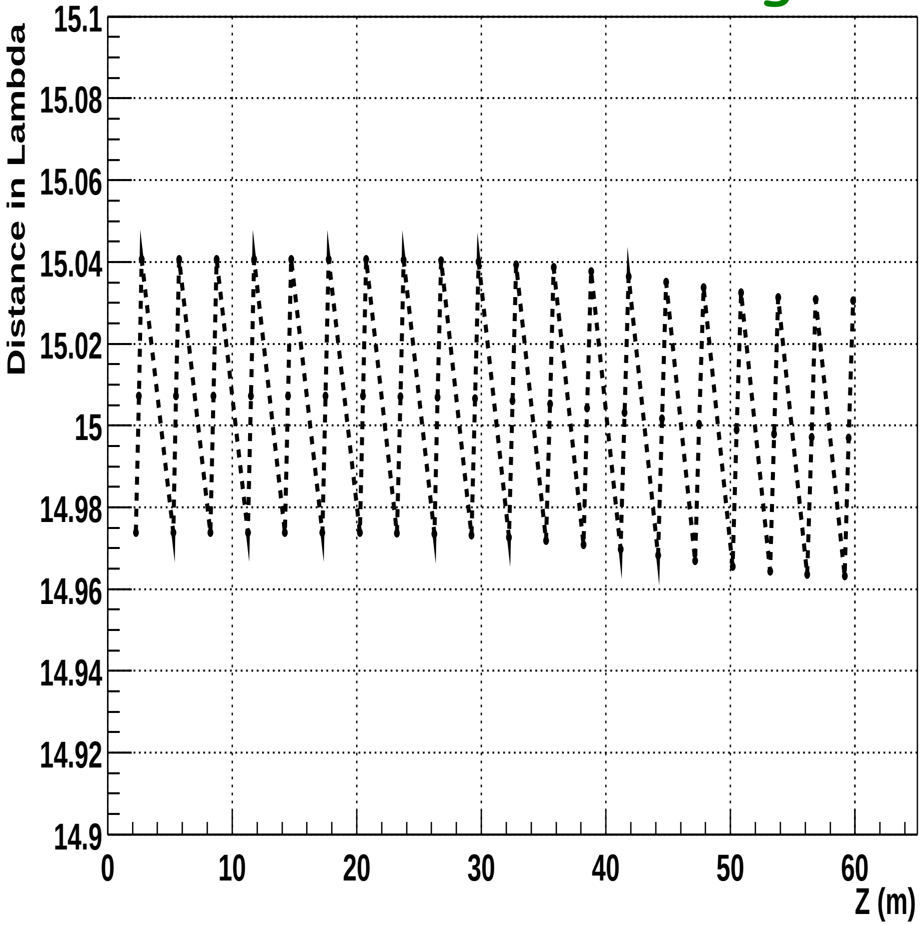


Averages (E_{kin}), and sigmas (σ_{cTime}, σ_{Ekin})

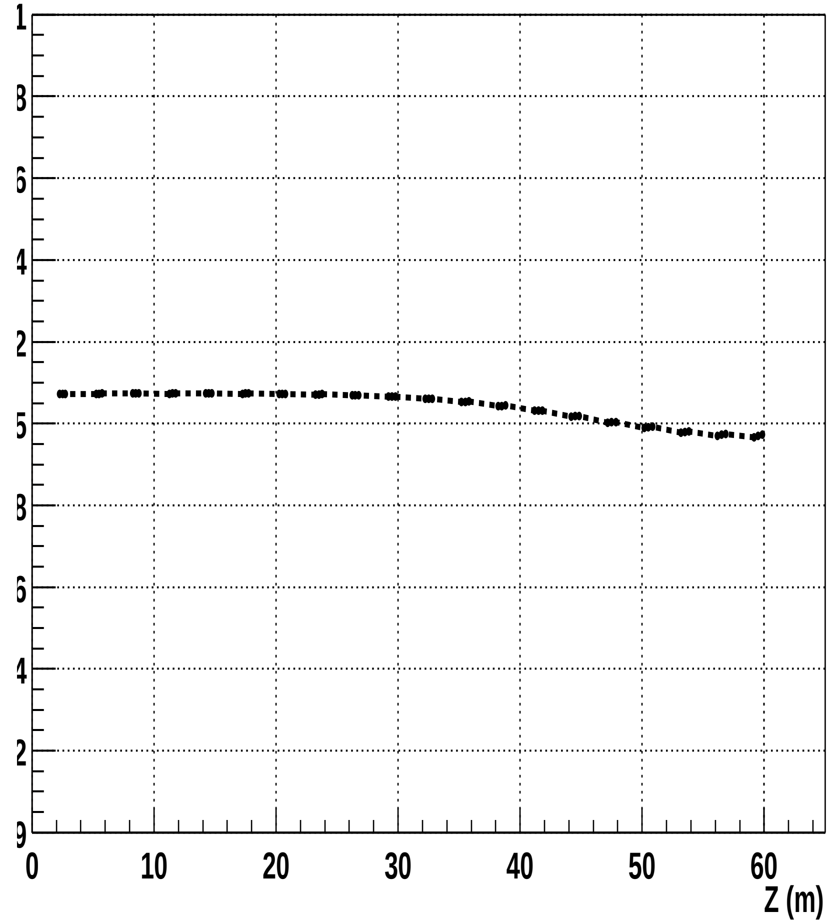
Results: case (ii)

r.f tuning : distance between the two reference particles (75 & 175 MeV)

units of Linac wavelength



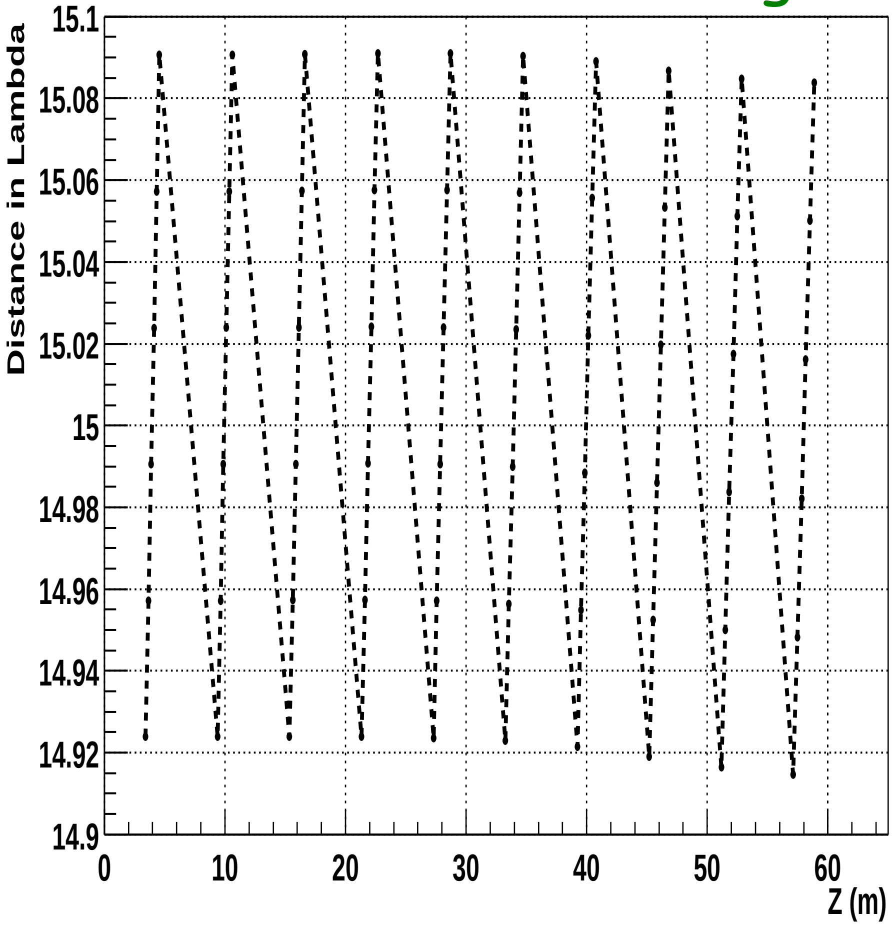
units of $\nu_{\mathrm{r.f.}} = f(d, \beta_{75}, \beta_{175})$



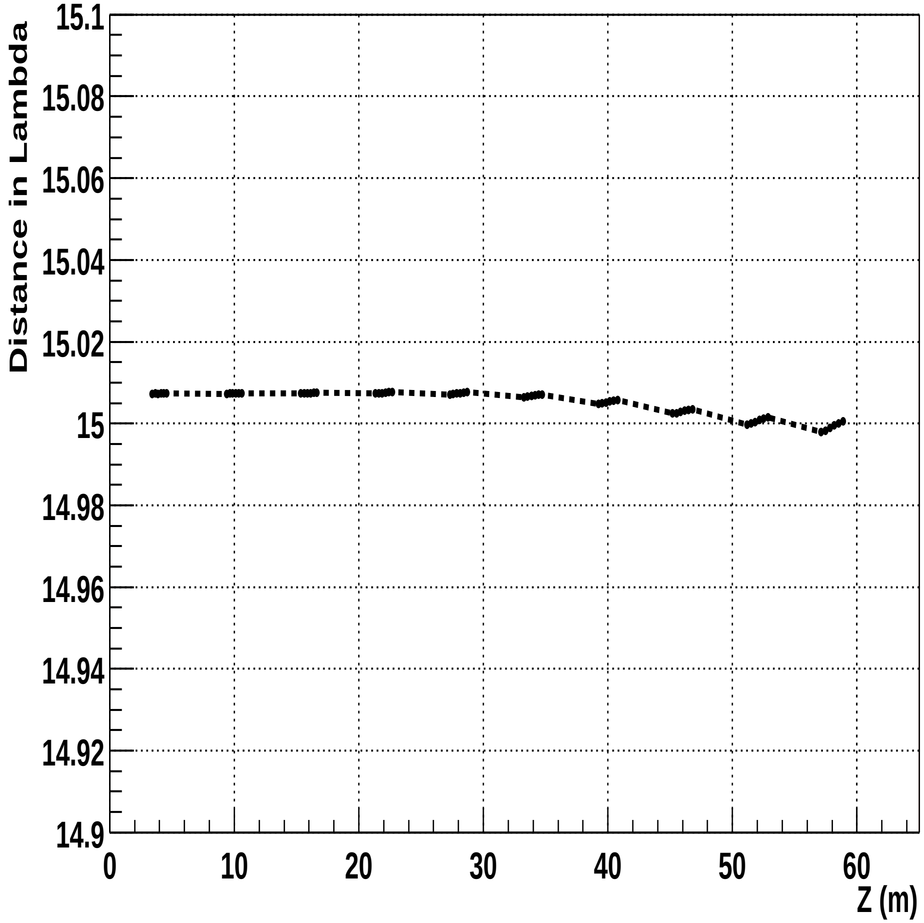
Results: case (iii)

r.f tuning : distance between the two reference particles (75 & 175 MeV)

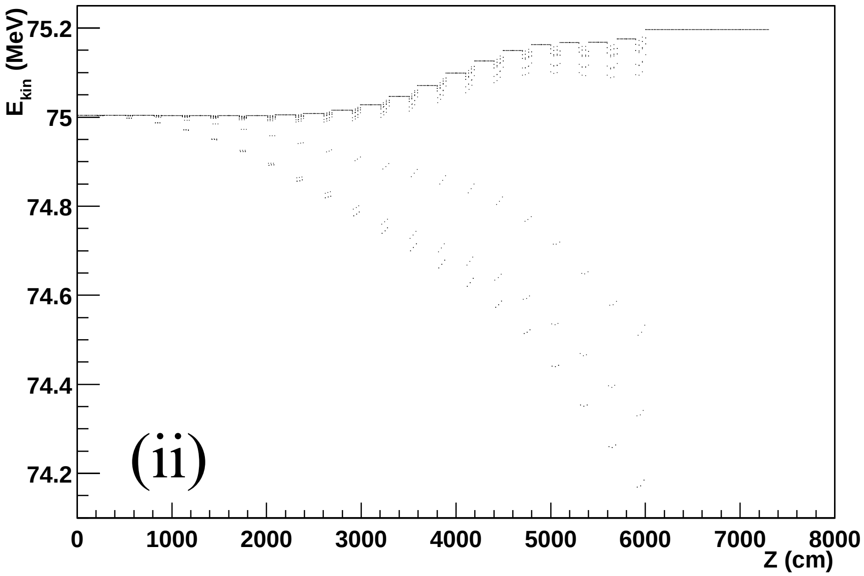
units of Linac wavelength

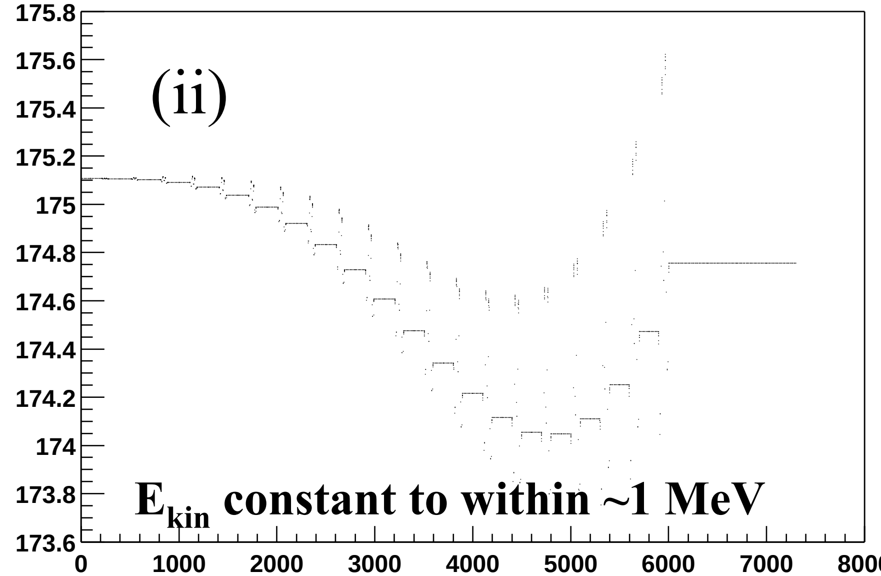


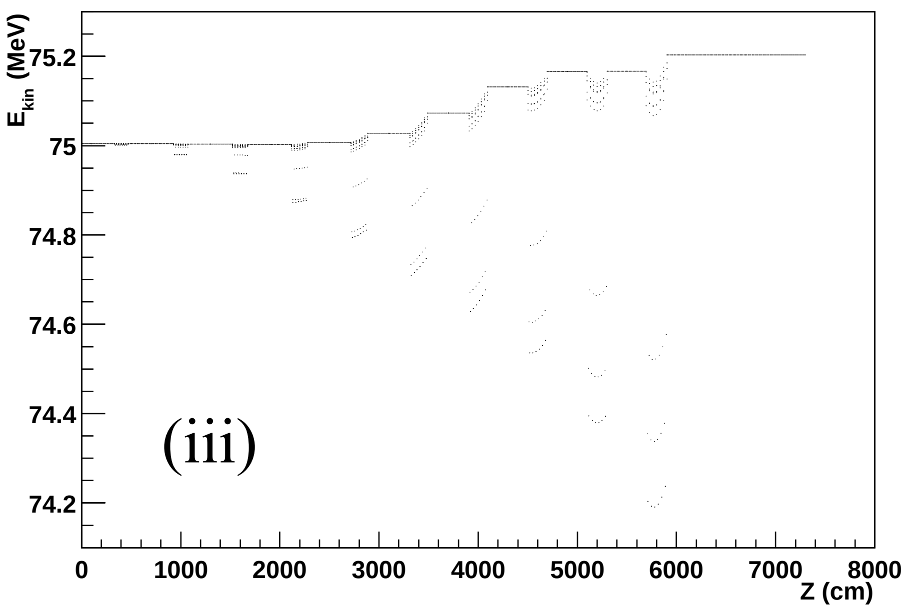
units of $\nu_{\text{r.f.}} = f(d, \beta_{75}, \beta_{175})$

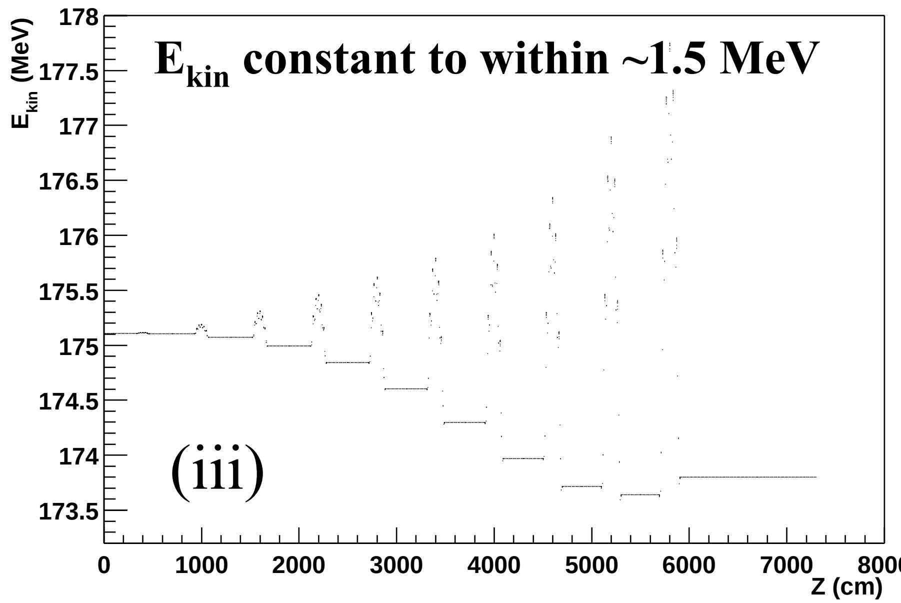


Cases (ii) & (iii): Reference particles









Cases (ii) & (iii): r.f. Tuning Improvement

Currently using same gradient, synchronous phase (zero) in all cavities of each linac.

- Make voltage a function of distance, different for each cavity of a Linac.
- Use a more accurate rule to determine different synch. phases for each cavity of every linac.

Case of 3 cavity linacs:

$$V_1 \sin\theta_1 + V_2 \sin\theta_2 + V_3 \sin\theta_3 = 0$$ **for a 175 MeV particle**

$$V_1 \sin\theta'_1 + V_2 \sin\theta'_2 + V_3 \sin\theta'_3 = 0$$ **for a 75 MeV particle**

If θ_2=0 & V_1=V_3:

$$\boxed{\theta_1 = -\theta_3 = \arcsin \sqrt{\frac{1}{1+\left(\frac{\gamma-\alpha}{\beta+\gamma}\right)^2}}}$$

with $\alpha=\cos(2\pi\nu\Delta t_1)$
$\beta=\sin(2\pi\nu\Delta t_1)$
$\gamma=\cos(2\pi\nu\Delta t_3)$
$\delta=\sin(2\pi\nu\Delta t_3)$

Conclusions

- Excellent quantitative agreement between G4 realistic simulation and 1D simulation from D.Neuffer (60 frequencies)
- The 20 frequencies design gives the best performance (& cheaper!).
- The 10 frequencies design performance is also good (& even cheaper!)

Plans:

- Extend simulation to phase rotation section & parameter optimization
- Match the buncher-phase rotation result to a cooling channel