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Optimization of adiabatic buncher and phase rotator

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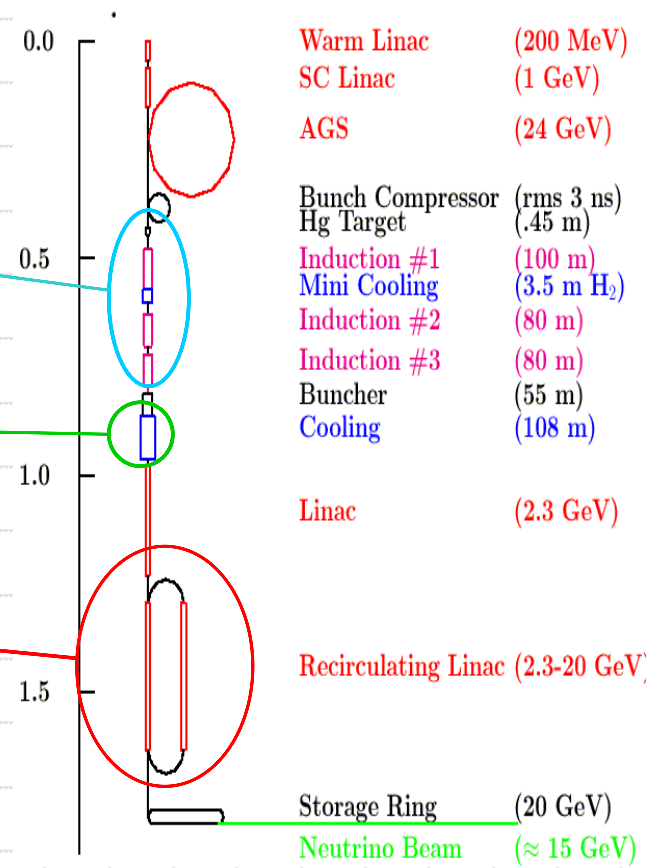
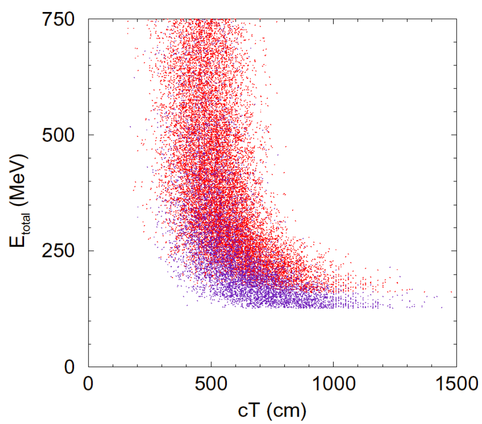
R&D goal: "affordable" ν e, ν μ -Factory

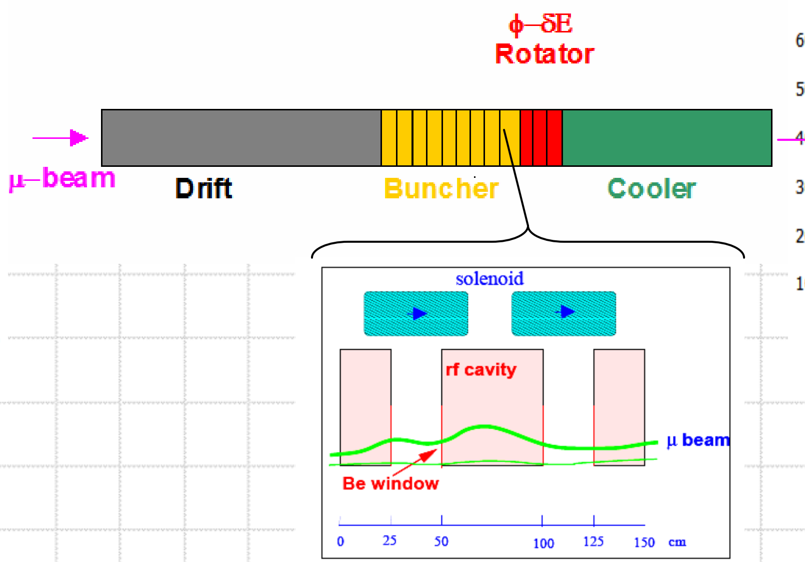
- Improve from baseline:
  - Collection
    - Induction Linac →"high-frequency" buncher
  - Cooling
    - Linear Cooling →Ring Coolers
  - Acceleration
    - RLA → "non-scaling FFAG"

$\mu^- \rightarrow e^- + \bullet_e + \nu_\mu$ and/or $\mu^+ \rightarrow e^+ + \bullet_\mu + \nu_e$

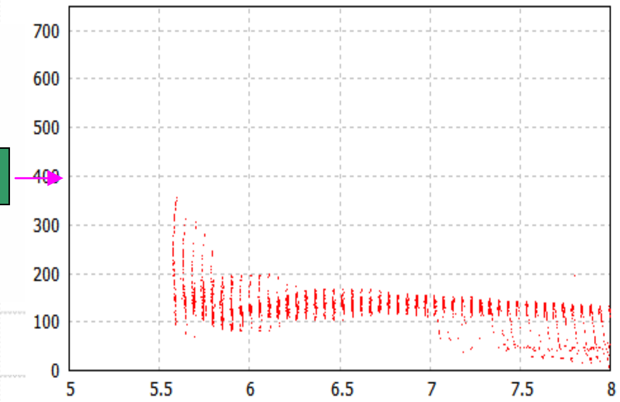


Key Parameters of Buncher and Rotator



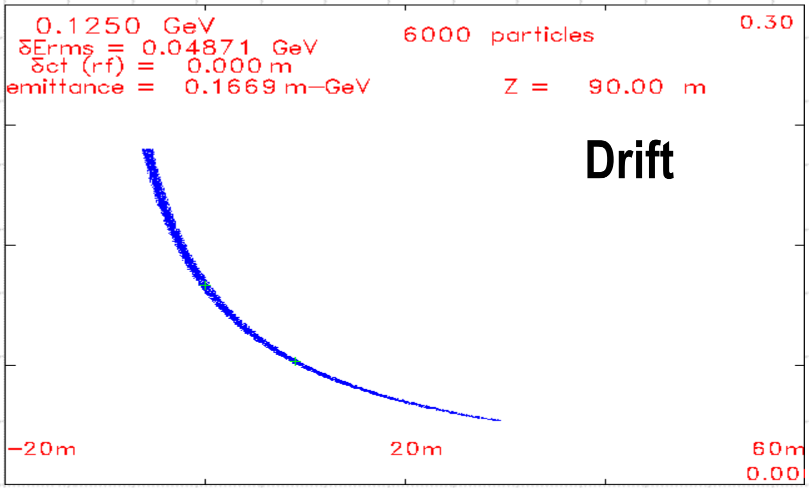


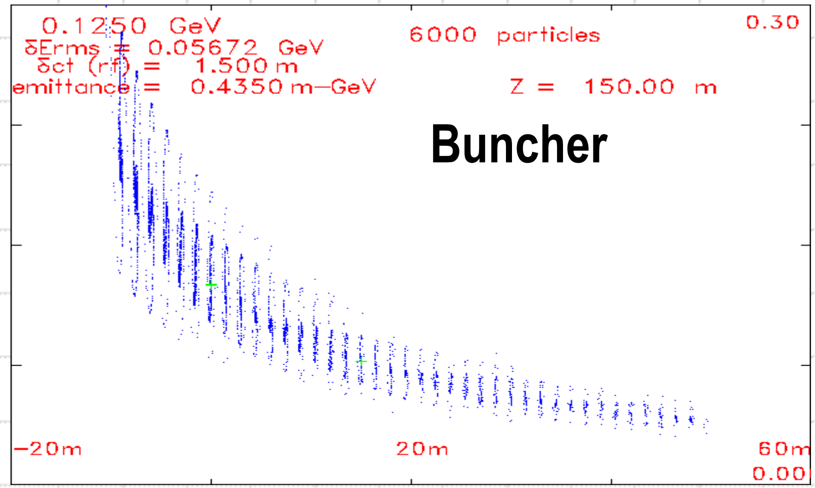
Schematic of two cells of the buncher or phase rotator section.

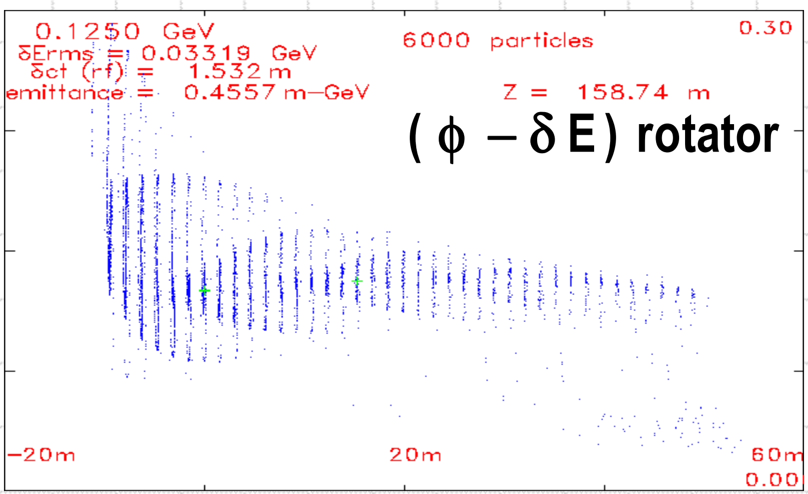


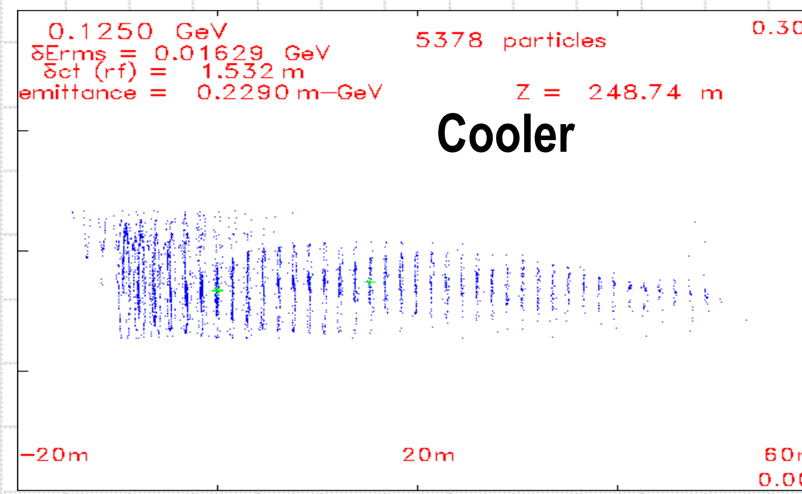
- Drift (Length L_D)
- Buncher (Length L_B, RF Gradients E_B, Final RF frequency λ_{RF})
- Phase Rotator (Length $L_{\phi R}$, Vernier offset, spacing $N_{\phi R}$, δ_V, RF gradients $E_{\phi R}$)

Longitudinal Motion (2D simulations)









System would capture both signs (μ^+, μ^-)

Optimization approach formulation

Moving to (T,n) phase space to study motion of the central particles from the buncher and rotator concept we derive formula describing dependence of the final energy of the central particle of each bunch on lattice parameters:

$$T(n,\ldots) = T\left(n, \beta_c, \delta\left(\frac{1}{\beta_c} \right)\right) + m \cdot \Delta T(n, E_{RF}, \delta, n_1, n_2)$$

Problem separation:

- Central particles dynamics
- All beam particles dynamics

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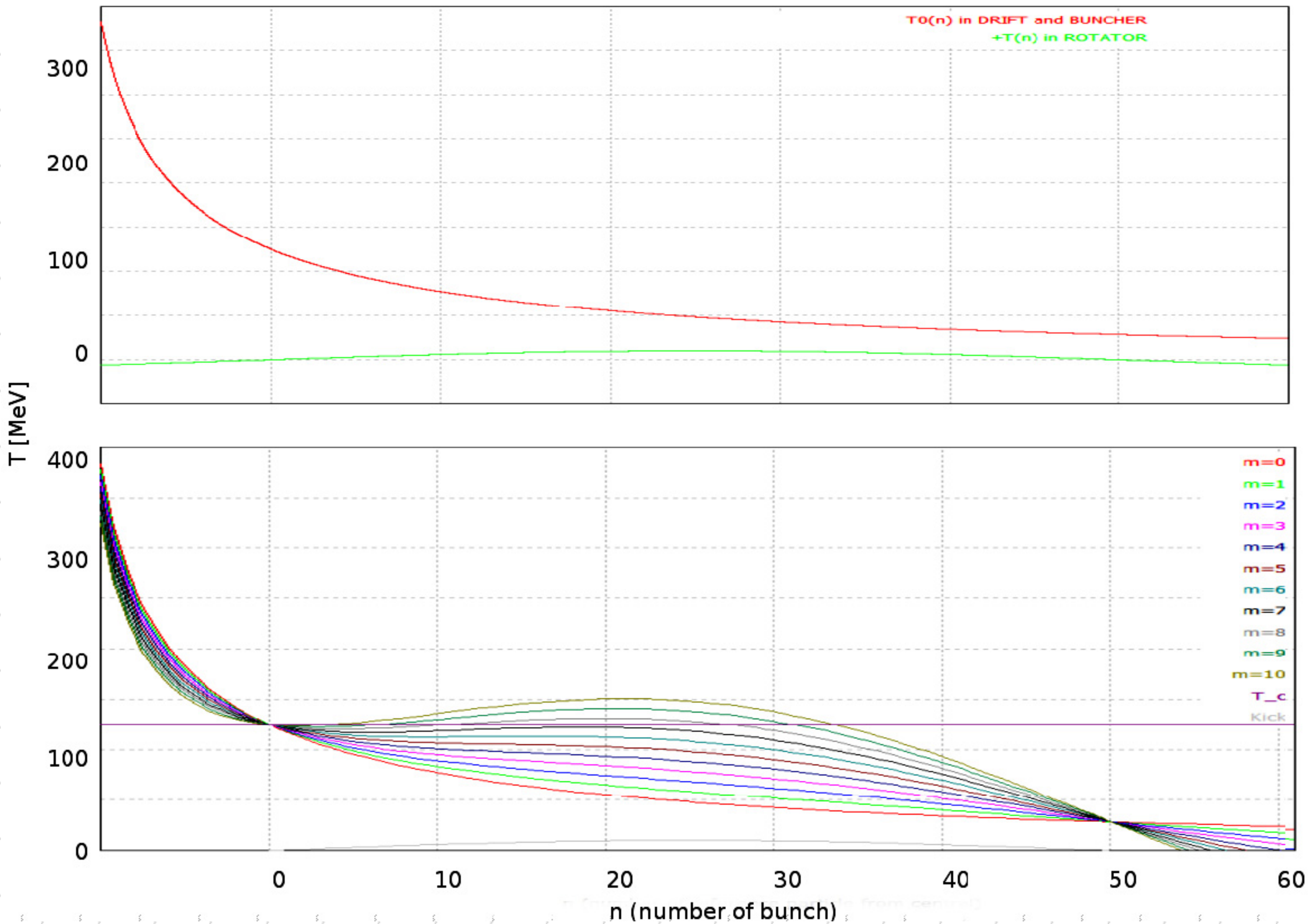
Graphical Illustration



Merit Functions

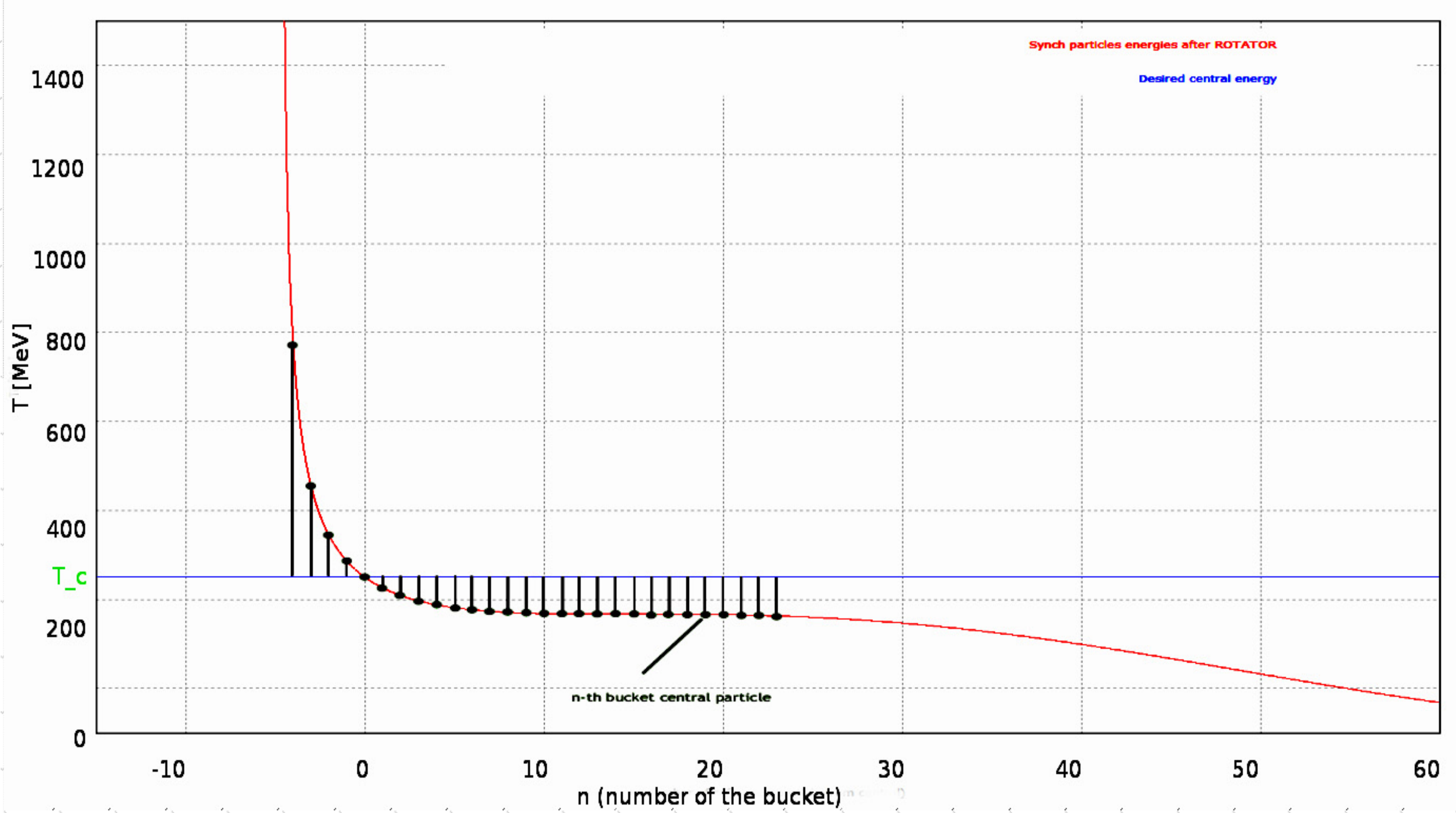
- Purpose of the structure is to reduce overall beam energy spread and to put particles energies close to some central energy. It seems natural to use objective function which has the form:

$$I = \sum c_n \left(T(n, m \ldots) - T_c \right)^2$$

weight coefficients — measure of energy spread

Merit function 1

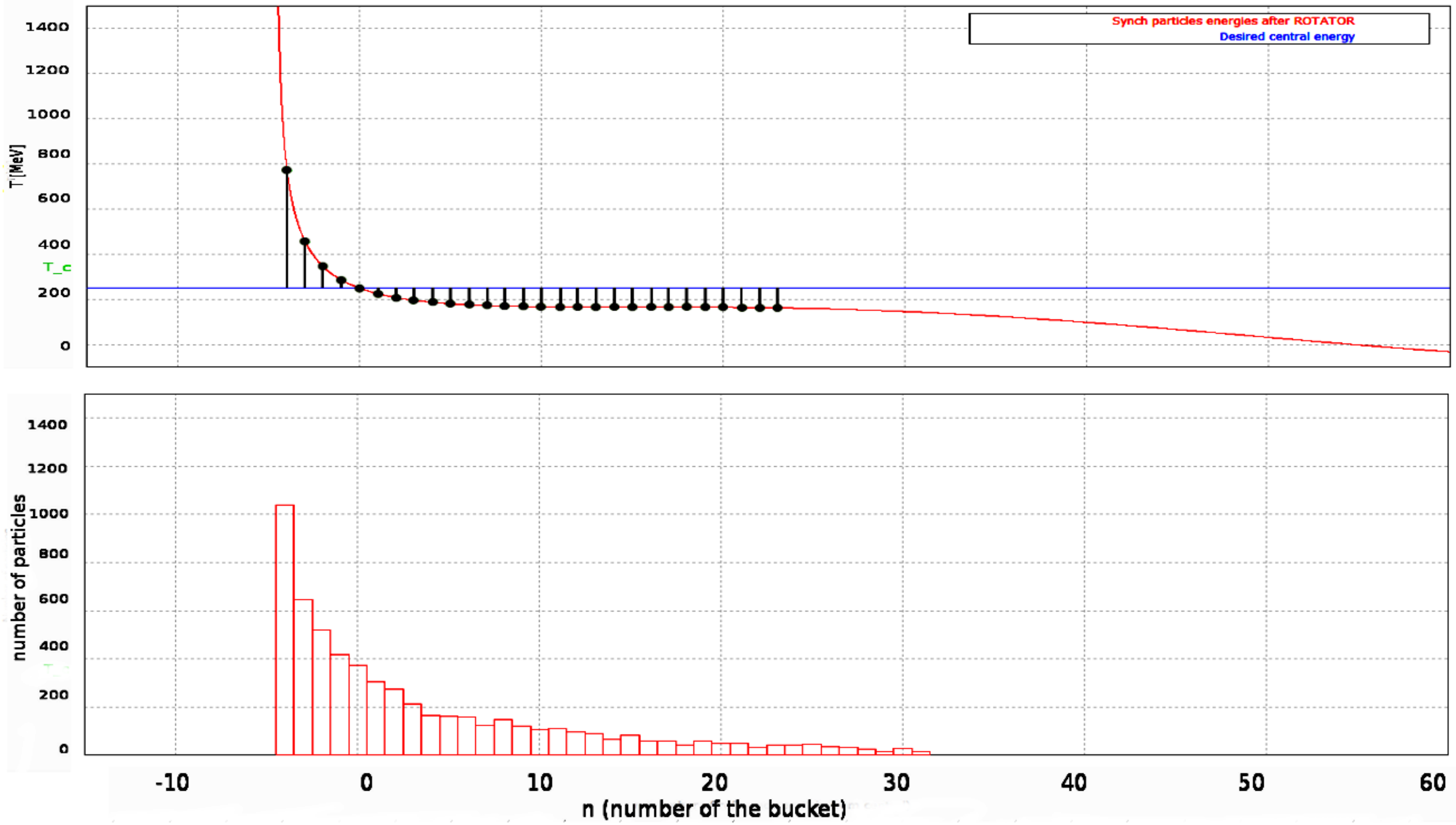
- First, we can set $C_n = 1, \forall n$ and get



Merit Function 2

We can use particle energies distribution to get weights

$$I_2 = \sum c_n (T(n,m) - T_c)^2$$



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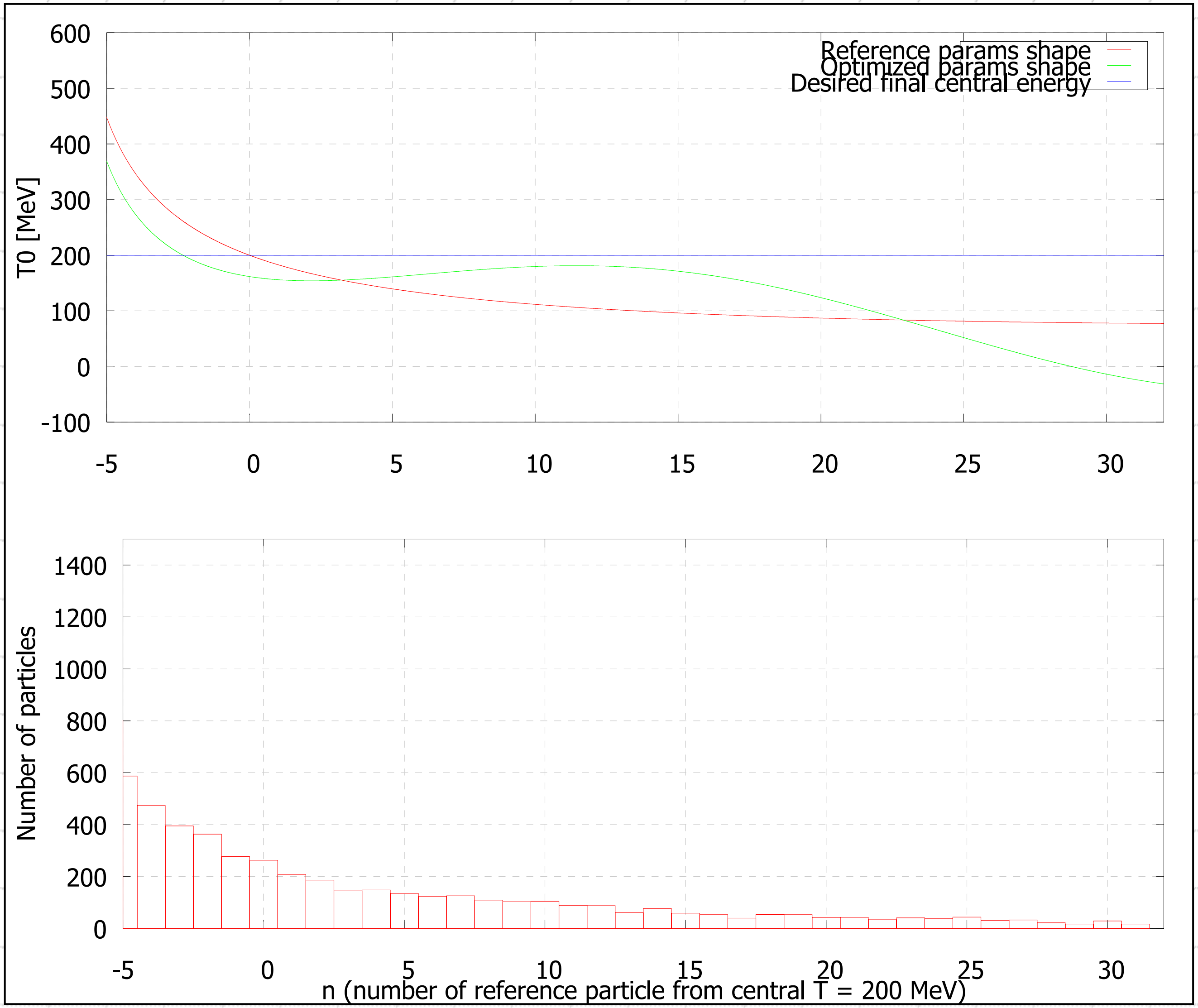
Optimization with OBJ1

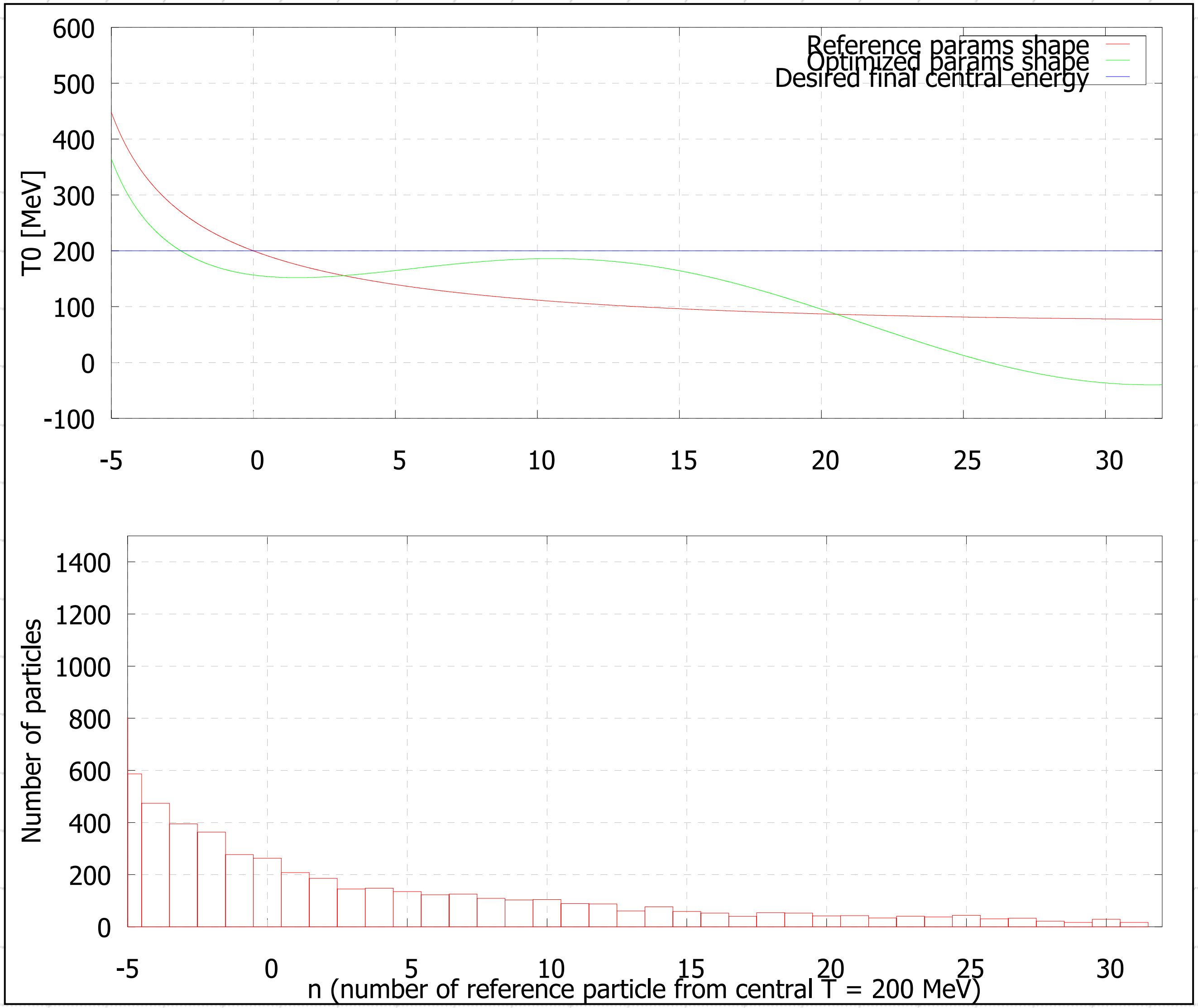


Fixed params:
  Desired central kinetic energy (T_c) = 200.0000000000000
  T_0 in buncher (T_0) = 200.0000000000000
  Drift+Buncher length (L_buncher) = 150.0000000000000
  Final frequency (final_freq) = 200000000.0000000

Varied params:
  1st lever particle (n1) : 0 ==> 3.000000000000000
  2nd lever particle (n2) : 18 ==> 6.000000000000000
  Vernier parameter (vernier) : 0.032 ==> 0.08
  RF gradient (V_RF) : 8 ==> 9.000000000000000
  Number of RFs in rotator (m) : 10 ==> 10.00000000000000

Objective functions:
  619593.7642709546 ==> 522561.7532899606 = - 97032.01098099403
!! 750907264.4334378 ==> 615875434.3135488 = - 135031830.1198890
  -1066.685941047459 ==> - 869.7924497231580 = 196.8934913243012
  749769445.5366095 ==> 615118895.4079534 = - 134650550.1286561

Optimization with OBJ2



Fixed params:
Desired central kinetic energy (T_c) = 200.0000000000000
T_0 in buncher (T_0) = 200.0000000000000
Drift+Buncher length (L_buncher) = 150.0000000000000
Final frequency (final_freq) = 200000000.0000000

Varied params:
1st lever particle (n1) : 0 ==> 3.000000000000000
2nd lever particle (n2) : 18 ==> 6.000000000000000
Vernier parameter (vernier) : 0.032 ==> 0.07
RF gradient (V_RF) : 8 ==> 9.000000000000000
Number of RFs in rotator (m) : 10 ==> 10.00000000000000

Objective functions:
619593.7642709546 ==> 522561.7532899606 = - 97032.01098099403
!! 750907264.4334378 ==> 615875434.3135488 = - 135031830.1198890
-1066.685941047459 ==> - 869.7924497231580 = 196.8934913243012
749769445.5366095 ==> 615118895.4079534 = - 134650550.1286561

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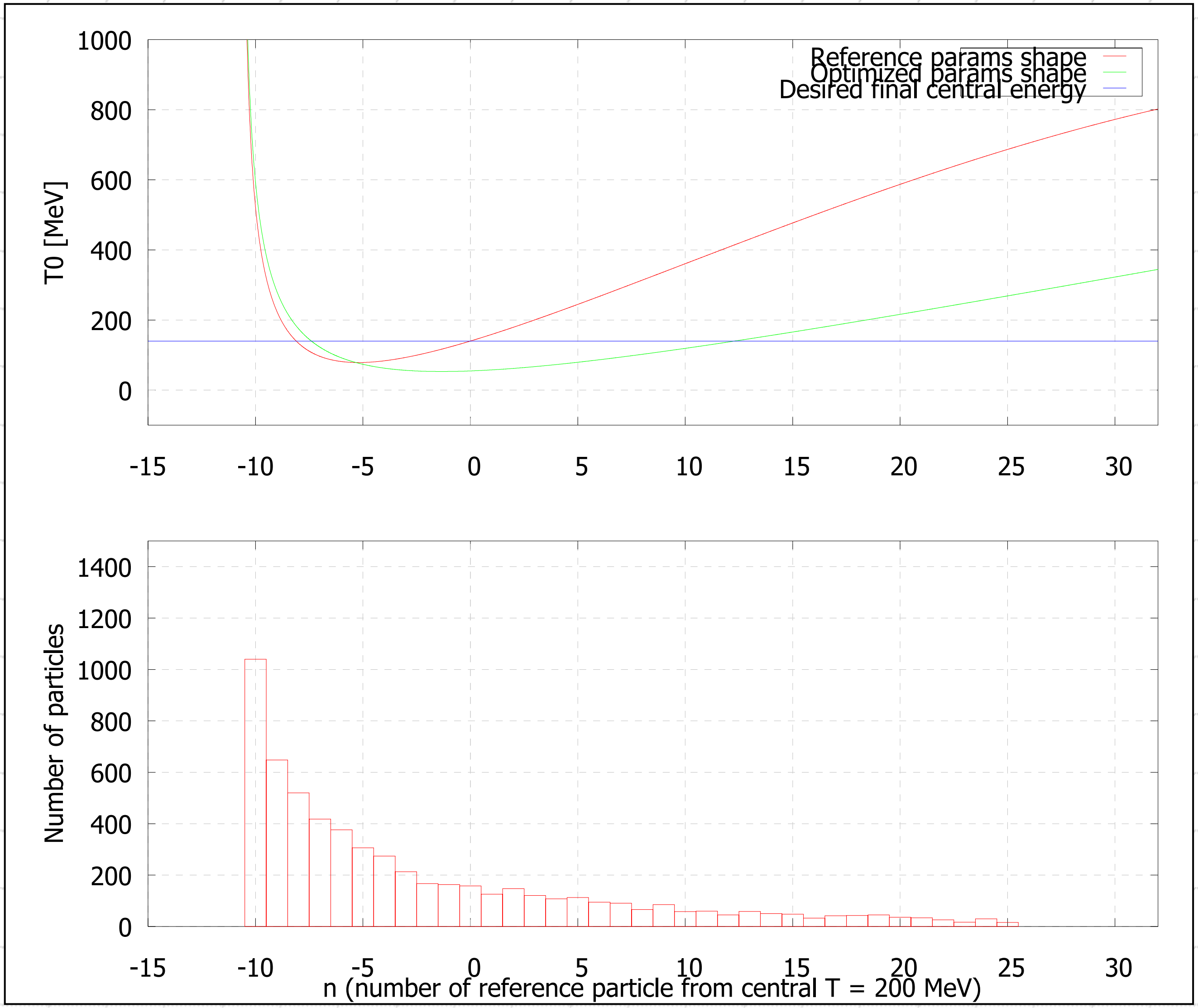
Optimization with Study 2b params



Fixed params:
  Desired central kinetic energy (T_c) = 140.0000000000000
  T_0 in buncher (T_0) = 140.0000000000000
  Drift+Buncher length (L_buncher) = 150.0000000000000
  Final frequency (final_freq) = 200000000.0000000

Varied params:
  1st lever particle (n1) : ==> 7.000000000000000
  2nd lever particle (n2) : ==> 14.00000000000000
  Vernier parameter (vernier) : ==> 0.1000000000000000E-01
  RF gradient (V_RF) : ==> 14.00000000000000
  Number of RFs in rotator (m) : ==> 97.00000000000000

Objective functions:
!!   485808.1248155629 ==> 316581.0365864867 = - 169227.0882290762
  589204203.9100170 ==> 312400472.6813000 = - 276803731.2287170
  -860.6933665745339 ==> - 1008.554979752263 = - 147.8616131777286
  588463410.8387516 ==> 311383289.5341169 = - 277080121.3046346

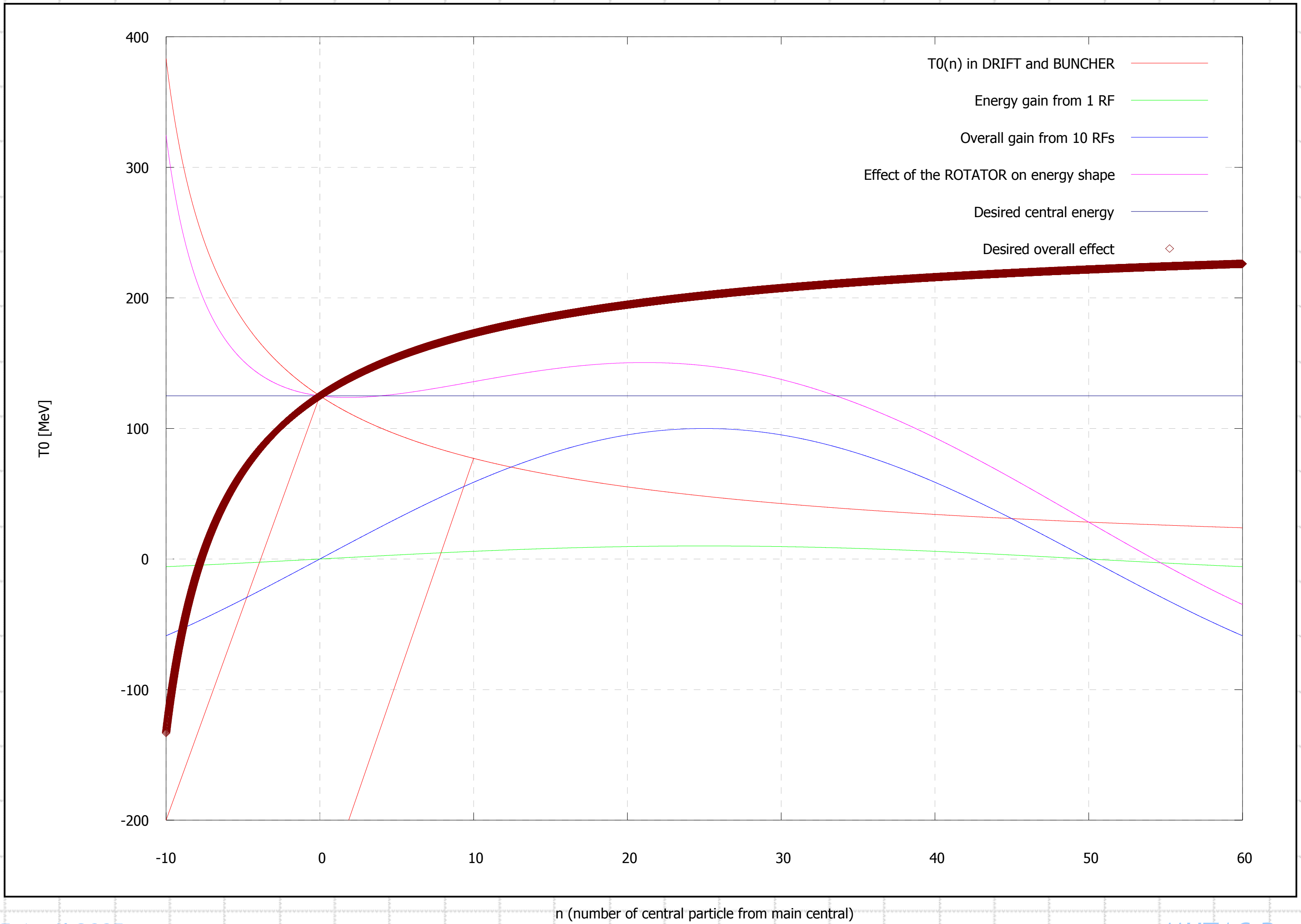
To do

- Check optimized parameters for the whole beam distribution (COSY, ICOOL). Is it better for all particles? 6D-dynamics.
- Different merit functions? Other parameters to incorporate (bucket capture, cost, etc…). Playing with the model.
- Tuning overall rf field effect?
- Develop different optimal sets of parameters (on cost, number of muons survived, captured, final frequency, etc. or combinations). Verify by simulations.

Summary

- ✓ An approach for optimization of bunch central energies in buncher and phase rotator is proposed.
- ✓ The algorithm is implemented in COSY Infinity. It enables optimization on any set of supported parameters (length of the buncher and rotator, final frequency, central energy, E field gradient, phases).
- ✓ Optimization runs are presented.
- ✓ Future plans are discussed.

Overall RFs Effect



Central Kinetic Energies after Buncher

- Moving to (T,n) phase space to study motion of the central particles from the buncher concept we derive following relation:

$$T\left(n,\beta_c,\delta\left(1/\beta_c\right)\right)=W_0\left(\frac{1}{\sqrt{1-\left(\frac{\beta_c}{1+n\beta_c\delta\left(1/\beta_c\right)}\right)^2}}-1\right)$$

Puts limits on n_min and n_max => n_bunches!

Energy Gain in Rotator and Final Central Kinetic Energies

- From the rotator concept we derive amount of energy gained by n-th central particle in each RF (kept const in ROTATOR)

$$\Delta T(n, E_{RF}, \delta, n_1, n_2) = E_{RF} \sin\left(2\pi \cdot \delta \frac{n - n_1}{n_2 - n_1} \right)$$

- So final energy n-th central particle has after the BUNCHER+ROTATOR is a function of n,m,…

$$T(n, m, \ldots) = T(n, \ldots) + m \cdot \Delta T(n, \ldots)$$