Update of Final Muon Cooling Using Cells With Quadrupole Doublets

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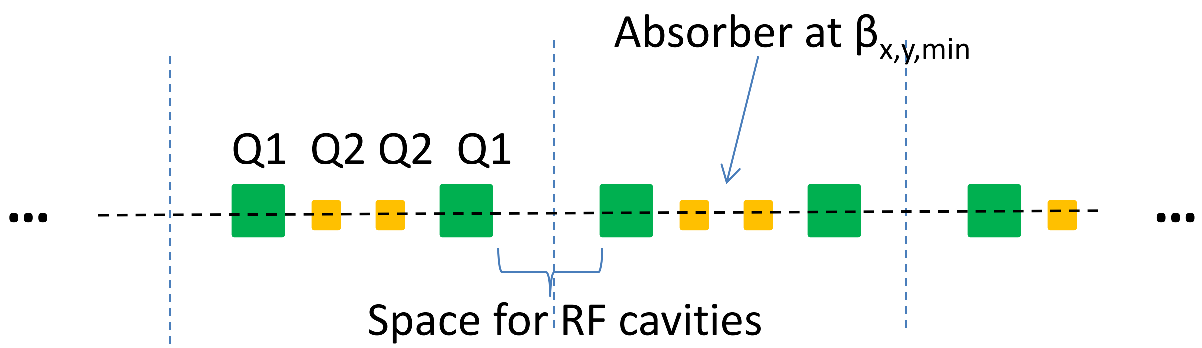
- Overview and motivation
- Simulation of transmission of muon beam through 281 cells of Stage 1 with ICOOL (no RF nor LiH)
  - "Final Muon Emittance Exchange in Vacuum for a Collider", IPAC-2015-TUPWI044
  - http://arxiv.org/pdf/1505.01832.pdf
- Results and future plans



Motivation

- Final cooling for muon collider: manipulation of muon beam emittances from

  $(\varepsilon_{x,N}, \varepsilon_{y,N}, \varepsilon_{L,N}) = (280, 280, 1600)\ \mu\text{m} \rightarrow (25, 25, 72000)\ \mu\text{m}$.

- Includes roughly 3-fold 6D cooling

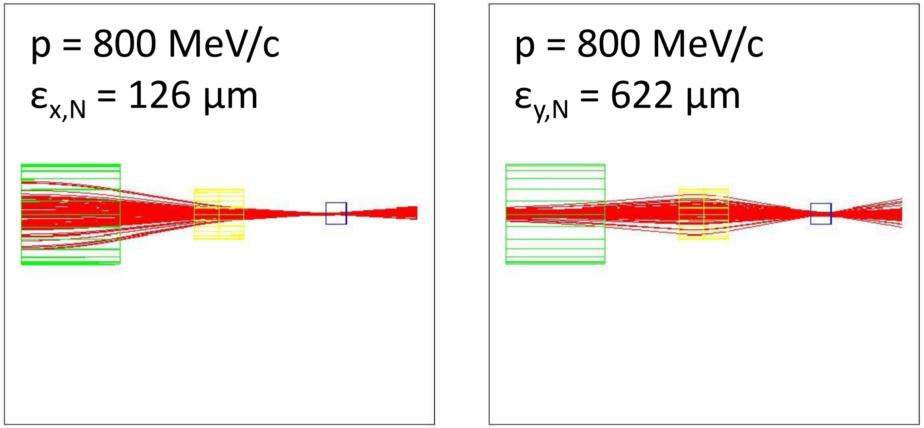
- We're exploring using quadrupole doublet focusing
  - Advantage: Only way so far to get low $\beta_{x,y,min}$ for final cooling

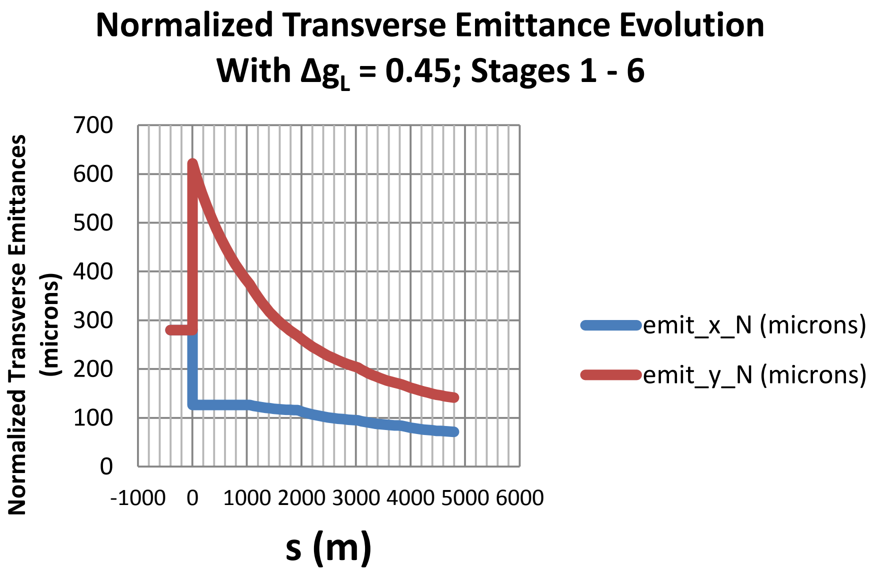
  - Challenges: Need to improve transmission by modest amount

Previous Status

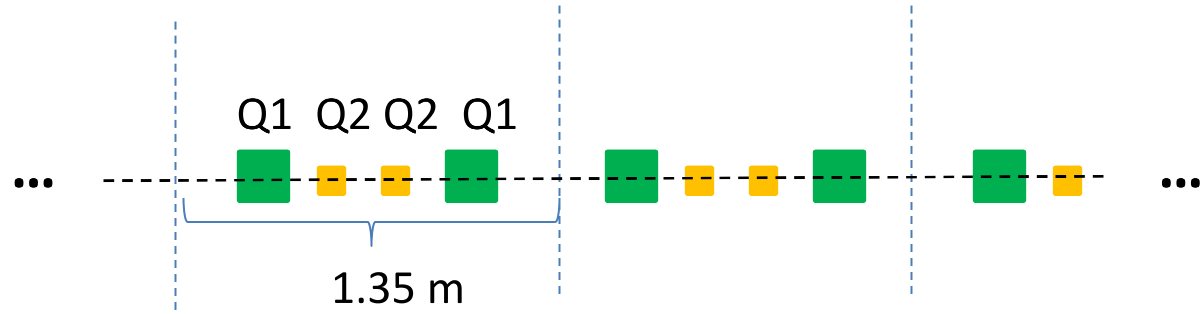
- MAP Workshop talk in May included staged final muon cooling scheme using quadrupole doublets.
- Uses low $\beta_{x,y}$ regions with short, dense low Z absorbers
- 6D muon cooling calculated from standard muon cooling expressions.
- ***No aspect of beam transmission simulated through any full stage.***

G4Beamline Visualization of Stage 1 Half-Cells





ICOOL Simulation of Stage 1



- Full cell with $\beta_{x,y,min}$ = 2 cm midway between Q2 quadrupoles
  - 0.25 m for RF cavities at starts and ends of full cells
  - Space between Q2 magnets increased by 0.1 m

- Input muon beam
  - ***$p_{z,ave}$ = 810 MeV/c optimizes transmission.***
  - $(\varepsilon_{x,N}, \varepsilon_{y,N}, \varepsilon_{L,N})$ = (126, 622, 0 or 1600) μm

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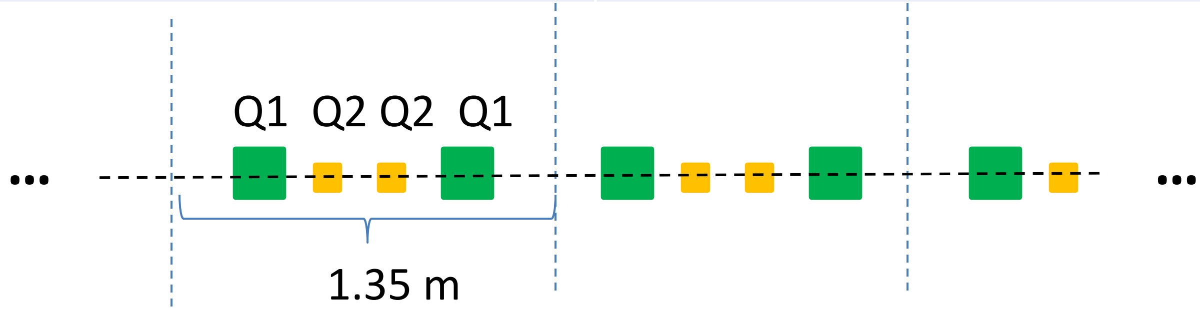
- *Check beam transmission through 281 full cells with/without longitudinal spreads*

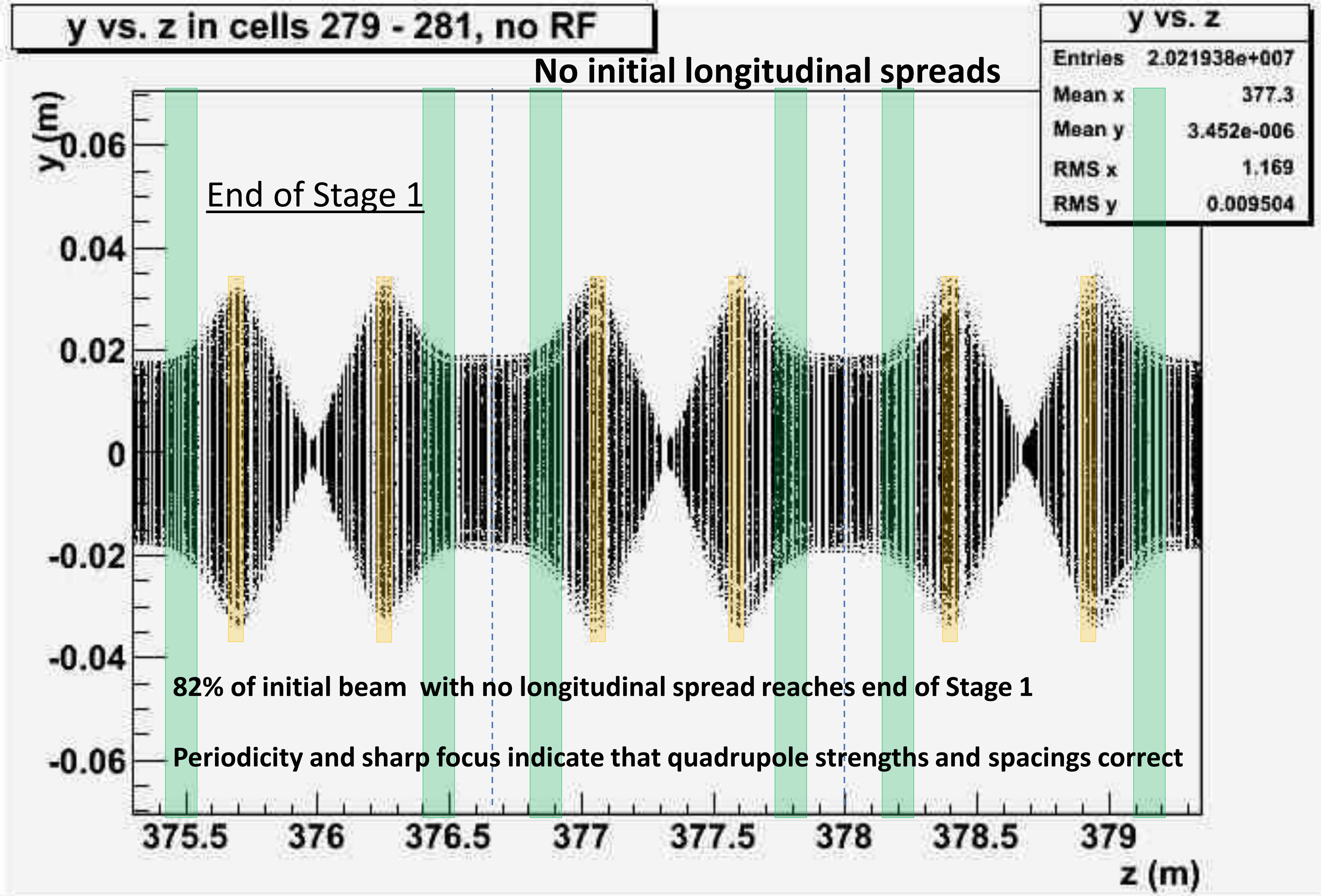
Beam Transmission Through 281 Full Cells (379.35 m Total Length)

	Fraction of initial beam through 281 full cells
$(\varepsilon_{x,N}, \varepsilon_{y,N}, \varepsilon_{L,N}) = (126, 622, 0)$ µm	**0.820** (need to increase transmission)
$(\varepsilon_{x,N}, \varepsilon_{y,N}, \varepsilon_{L,N}) = (126, 622, 1600)$ µm with $\sigma_{p_z} = 5$ MeV/c	**0.730** (need to add sextupoles)

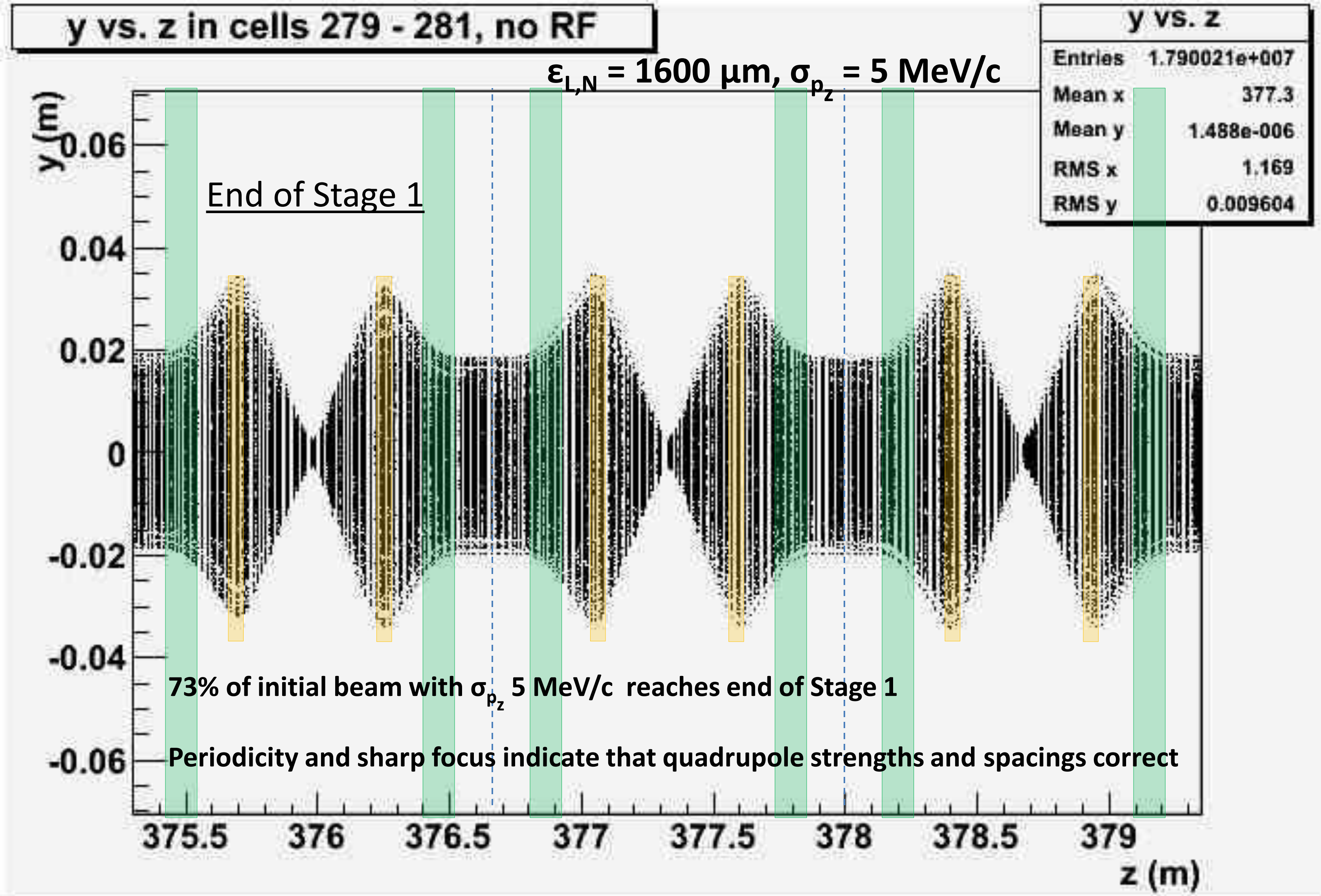


- No LiH absorber, no RF cavities
- $\varepsilon_{L,N} = 1600$ µm and $\sigma_{p_z} = 5$ MeV/c fits in RF bucket with f = 650 MHz
  - $\lambda_{RF}/4 = 0.115$ m
  - $\sigma_z = 0.0338$ m corresponding to about 3.3 σ longitudinal coverage
- Tightest aperture is in Q2 where radius is 2.2 $\sigma_{y,max}$.
  - Working on optimized long straights for RF cavities
  - Lattice optimization may improve apertures.

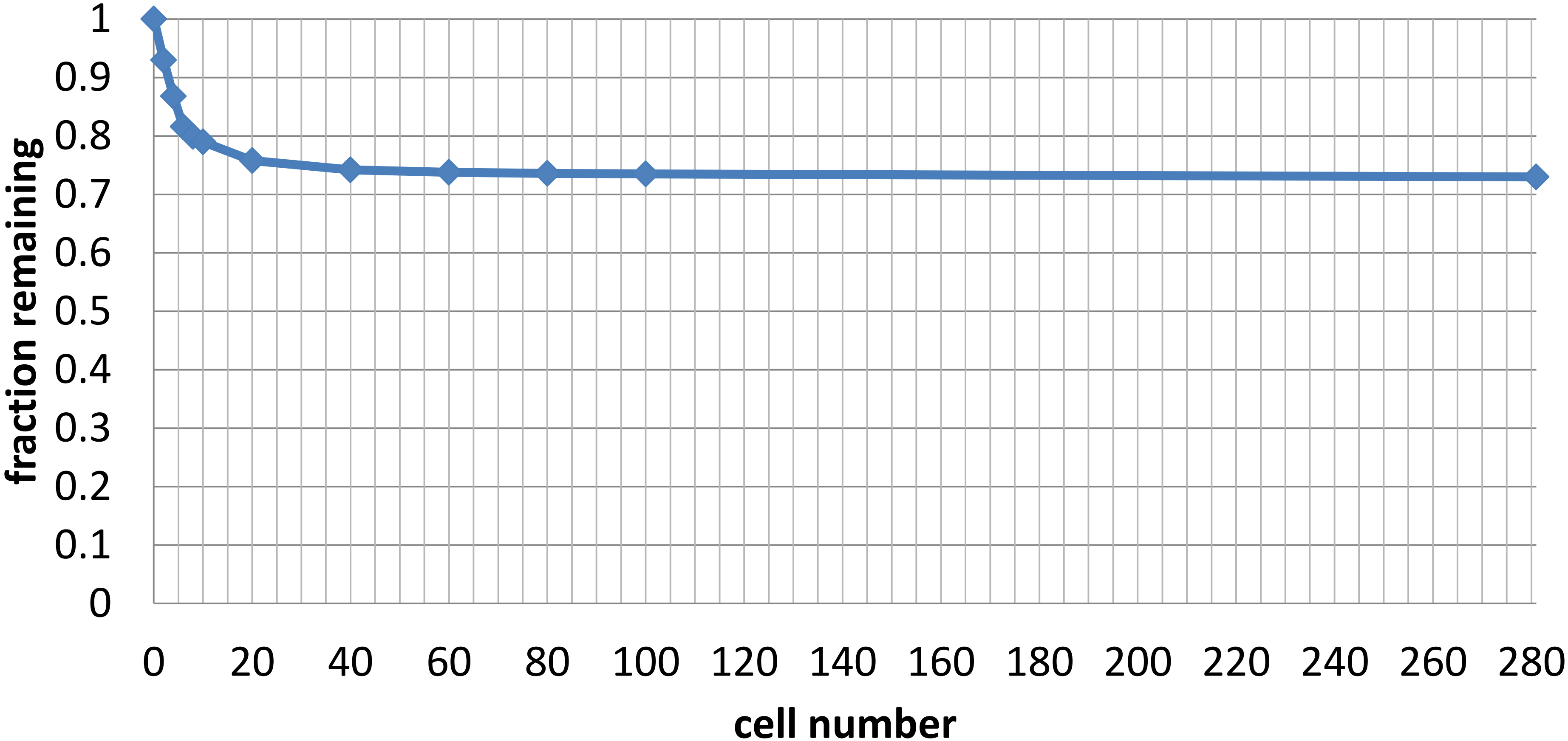
82% Transmission of Initial $(\varepsilon_{x,N}, \varepsilon_{y,N}, \varepsilon_{L,N}) = (126, 622, 0)$ μm Beam

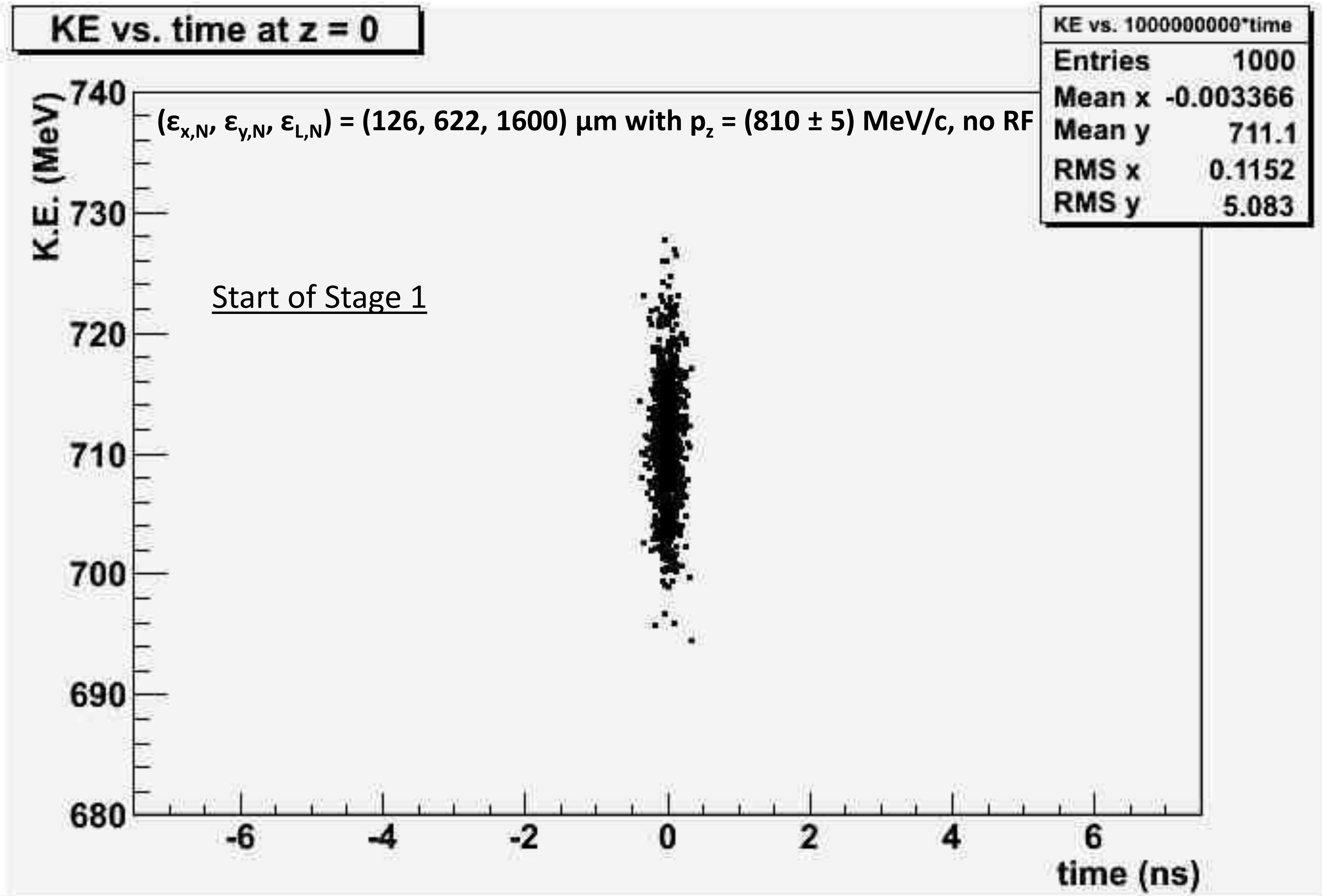


73% Transmission of Initial ($\varepsilon_{x,N}$, $\varepsilon_{y,N}$, $\varepsilon_{L,N}$) = (126, 622, 1600) μm Beam

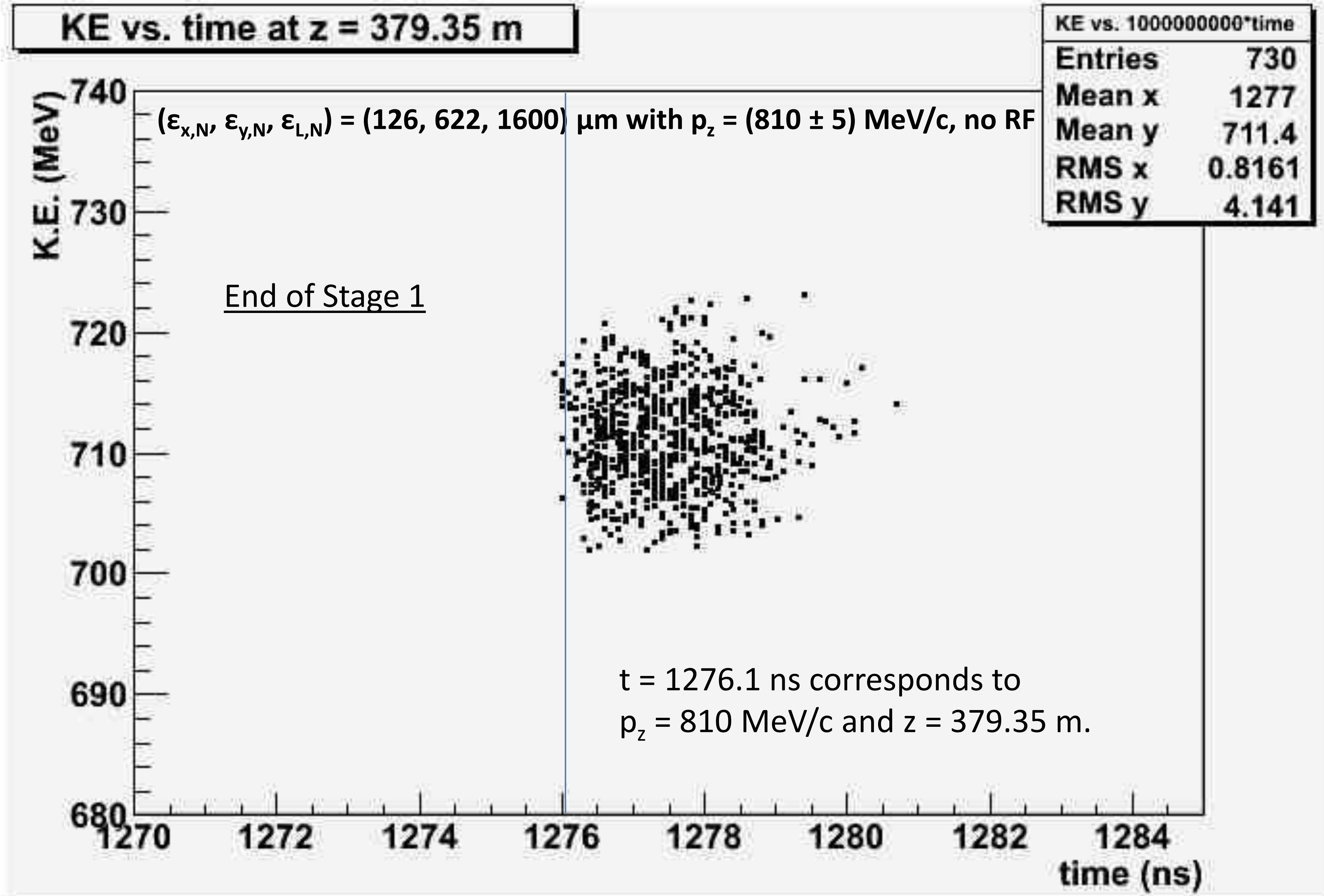


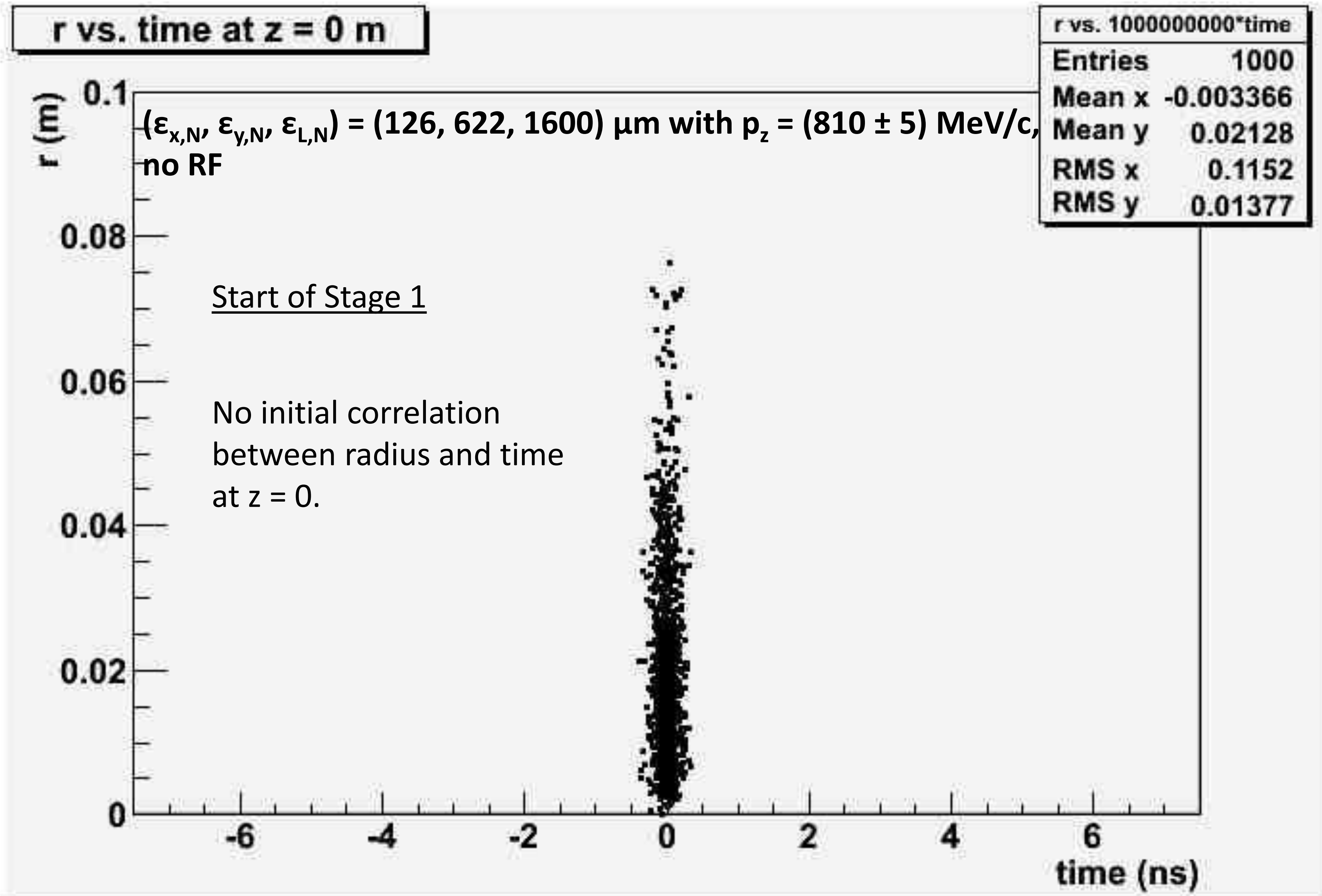
6D Beam Fraction Remaining vs. Cell Number; No RF, No LiH $(\varepsilon_{x,N}, \varepsilon_{y,N}, \varepsilon_{L,N}) = (126, 622, 1600)$ μm, $p_{z,ave} = 810$ MeV/c, $\sigma_{p_z} = 5$ MeV/c

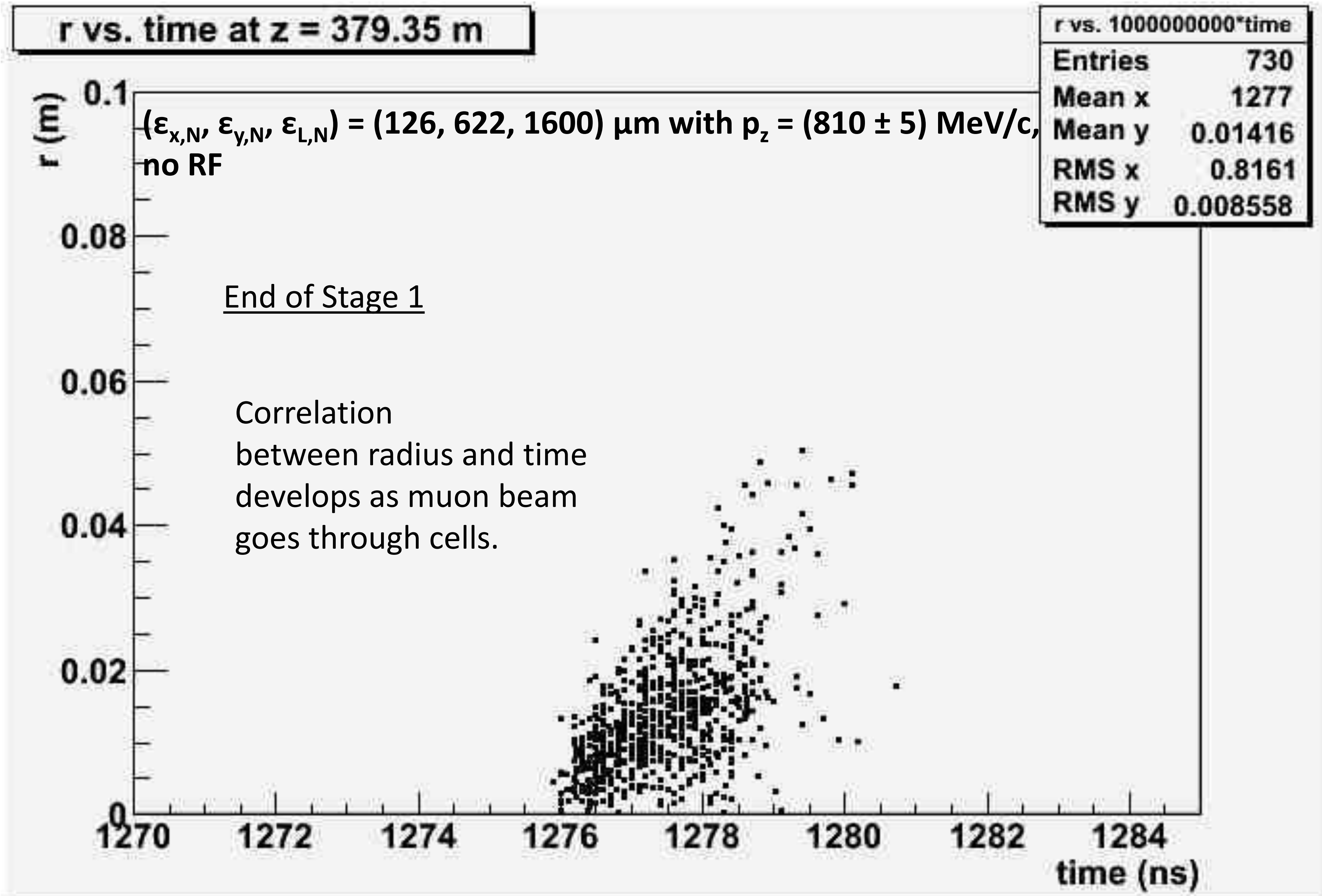




KE vs. time at z = 0
KE vs. 1000000000*time
Entries 1000
Mean x -0.003366
Mean y 711.1
RMS x 0.1152
RMS y 5.083
(εx,N, εy,N, εL,N) = (126, 622, 1600) μm with pz = (810 ± 5) MeV/c, no RF
Start of Stage 1
K.E. (MeV)
740
730
720
710
700
690
680
-6
-4
-2
0
2
4
6
time (ns)


KE vs. time at z = 379.35 m
KE vs. 1000000000*time
Entries 730
Mean x 1277
Mean y 711.4
RMS x 0.8161
RMS y 4.141
K.E. (MeV)
740
730
720
710
700
690
680
1270
1272
1274
1276
1278
1280
1282
1284
time (ns)
$(\varepsilon_{x,N}, \varepsilon_{y,N}, \varepsilon_{L,N})$ = (126, 622, 1600) μm with p_z = (810 ± 5) MeV/c, no RF
End of Stage 1
t = 1276.1 ns corresponds to
p_z = 810 MeV/c and z = 379.35 m.


r vs. time at z = 0 m
r vs. 1000000000*time
Entries 1000
Mean x -0.003366
Mean y 0.02128
RMS x 0.1152
RMS y 0.01377
r (m)
0.1
0.08
0.06
0.04
0.02
0
-6
-4
-2
0
2
4
6
time (ns)
($\varepsilon_{x,N}$, $\varepsilon_{y,N}$, $\varepsilon_{L,N}$) = (126, 622, 1600) μm with p_z = (810 ± 5) MeV/c,
no RF
Start of Stage 1
No initial correlation
between radius and time
at z = 0.


r vs. time at z = 379.35 m
r vs. 1000000000*time
Entries 730
Mean x 1277
Mean y 0.01416
RMS x 0.8161
RMS y 0.008558
(ε_{x,N}, ε_{y,N}, ε_{L,N}) = (126, 622, 1600) μm with p_z = (810 ± 5) MeV/c, no RF
End of Stage 1
Correlation
between radius and time
develops as muon beam
goes through cells.
r (m)
0.1
0.08
0.06
0.04
0.02
0
1270
1272
1274
1276
1278
1280
1282
1284
time (ns)

Further Work

- Learn to control path length differences so that RF is phase matched.
- Investigate a 200 MeV/c beam with the same normalized emittances to see if initial radius-energy correlations can improve phase matching to RF.
- Investigate how to improve quadrupole emittances.
- Add RF cavities, LiH absorber, and stochastic processes (decay losses, scattering, energy straggling)
- Investigate how much RF can control longitudinal dynamics.
- Add dispersion and wedge absorbers for suitable emittance exchange.