Helical Channels for Longitudinal Compression of Muon Beams

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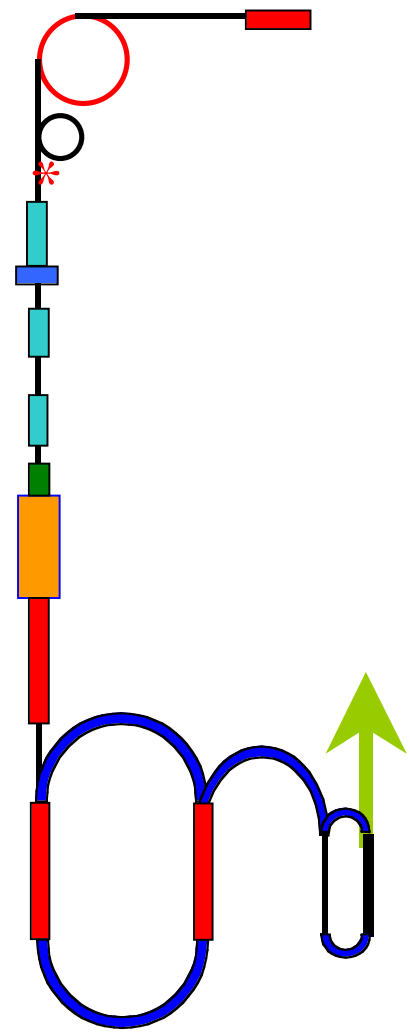
October 8, 2001

LBNL

Neutrino Factory Schematic



proton driver

target

mini-cooling
3.5 m of LH, 10 m drift

bunching 56 m
cooling 108 m

linac 2.5 GeV

ν beam

storage ring 20 GeV

induction linac #1, 100 m
drift 20 m
induction linac #2, 80 m
drift 30 m
induction linac #3, 80 m

Recirculator Linac
2.5 - 20 GeV

6D Phase Space Manipulations

Muon Collaboration

Beams with large transverse emittance show strong coupling between longitudinal and transverse motion;

also, ε_L is constantly increasing during cooling

- need full 6D theory to understand channel performance
- also a tool for designing emittance exchange channels

Must distinguish "true" longitudinal emittance change in presence of large and evolving non-gaussian distribution (correlations).

Especially important between induction linac and cooling channel.

At end of induction linac, roughly equal contributions to energy spread from transverse correlations and truly "stochastic" terms.

Diagnostics in Ecalc9v2 post-processing program:

- "corrected" particle energy; energy dispersion in x,y,radius

Emittance Exchange Schemes

Requiring dispersion and wedges of material

- bent Li lens
- bent solenoid
- ring cooler
- helical wiggler

with optional wedges:

- stopping beam and rapid re-acceleration
- coupling longitudinal and transverse motion, while directly cooling transverse momentum.

Helical Wigglers

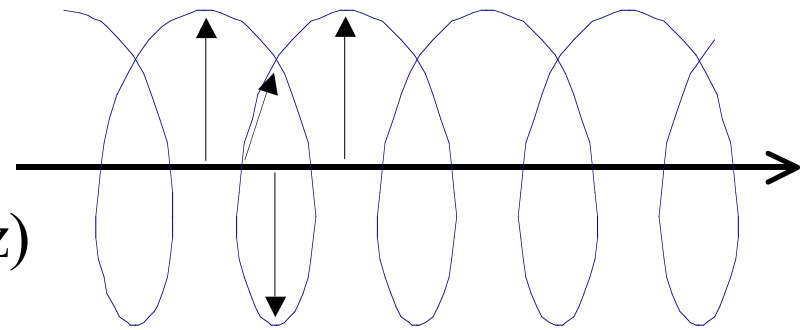
Helical wiggler is solenoid (B_0) plus rotating dipole field (B_W)

Period L_W, $\kappa_W = 2\pi / L_W$

$B_r = 2\, B_W\, I_1'(\kappa_W\, r) \sin(\varphi - \kappa_W\, z)$

$B_\varphi = 2\, B_W\, [I_1(\kappa_W\, r) / \kappa_W\, r] \cos(\varphi - \kappa_W\, z)$

$B_Z = B_0 - \kappa_W\, r\, B_\varphi$



Stable orbit radius varies with energy, yielding radial dispersion.

orbit: $v_\perp \sim B_W/\gamma$, $r \sim B_W/(\kappa_W\gamma)$

Resonance when cyclotron motion in sync with rotating dipole

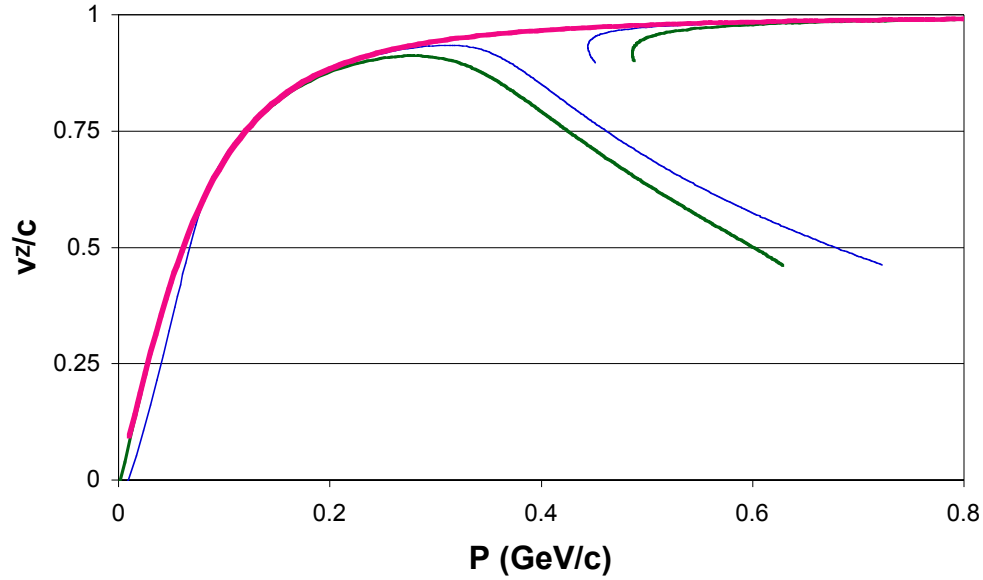
$P_R = eB_0L_W/2\pi$; B_0 is solenoid field, L is wiggler period

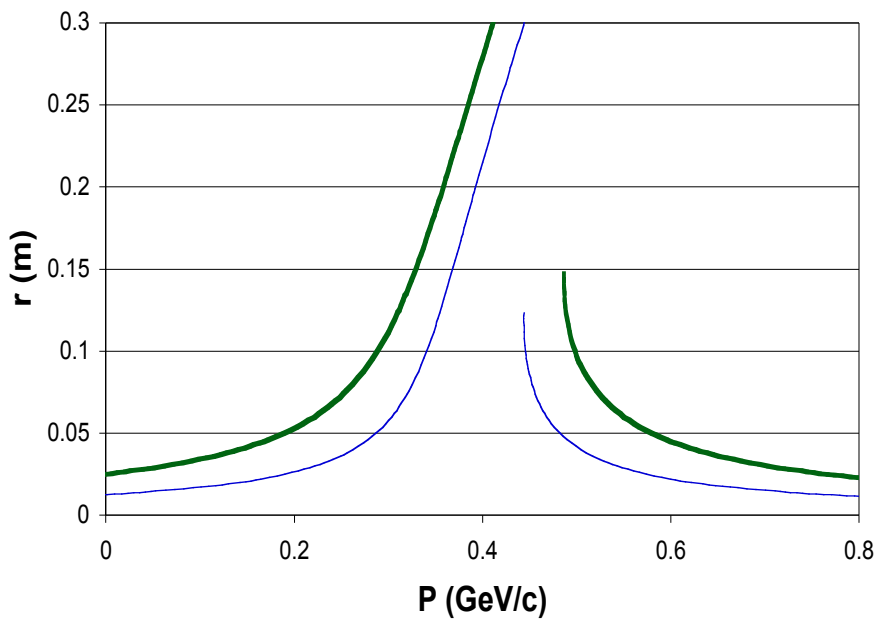
operate at $P < P_R$; dispersion increases as approach resonance

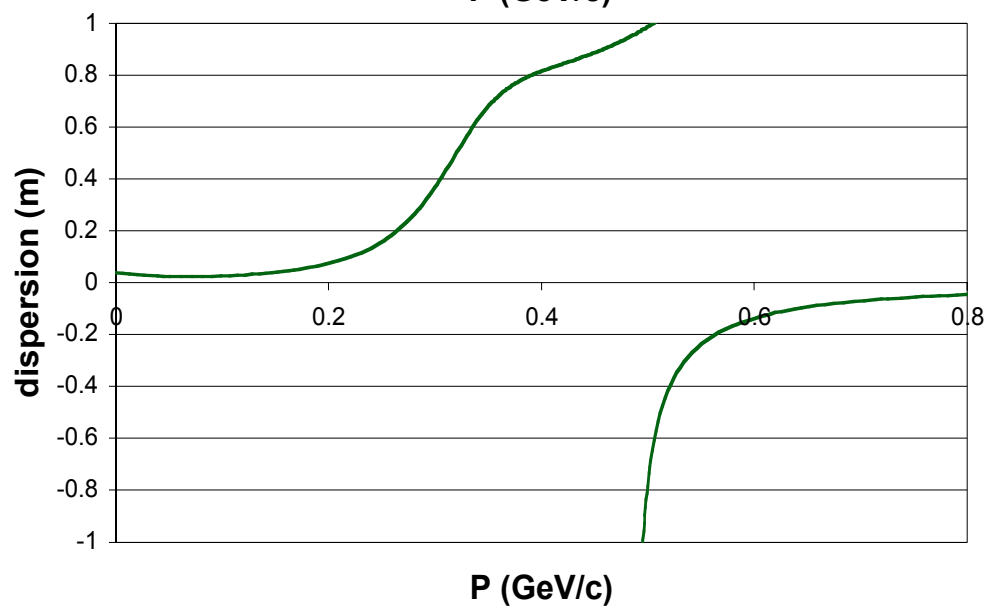
Helical Channel Properties

Constant 3.2 T solenoid field
tanh ramp into helical wiggler
2.5 m period, dipole field 0.2 T
Key:

- Bdipole = 0.2 T
- Bdipole = 0.1 T
- Vz for straight path







Helical Wigglers for Emittance Exchange

Energy dependent radius — especially near resonant momentum.

Leads to large values for dispersion, typically 25-50 cm.

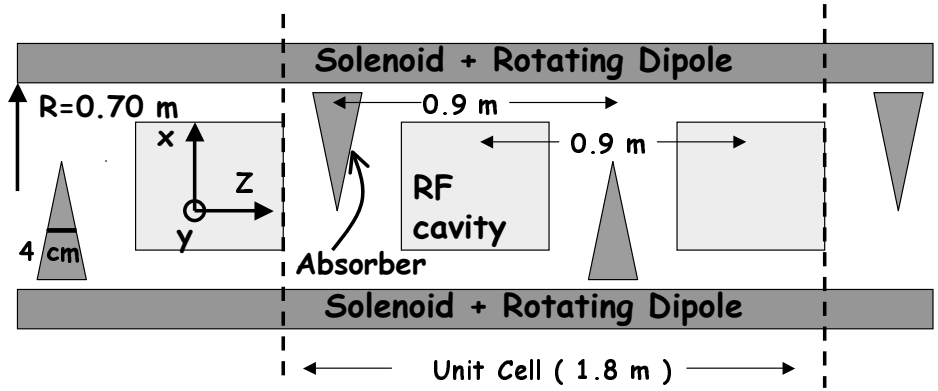
Wedge-shaped absorbers reduce energy spread, increase $\varepsilon_{N.}$

Absorbers can be shaped LH cavities, or Be foils.

Variation of orbit with energy can also modify energy-amplitude correlations, or lead to isochronous channels.

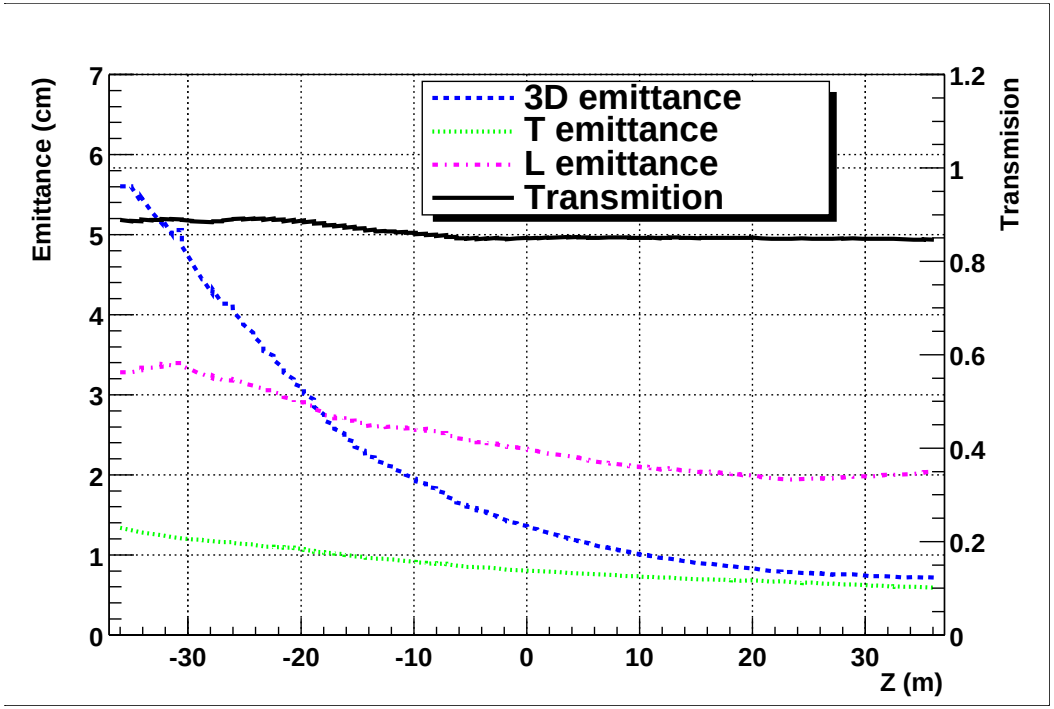
Potential to operate RF cavities at crest for maximal acceleration.

Balbekov: with Cooling

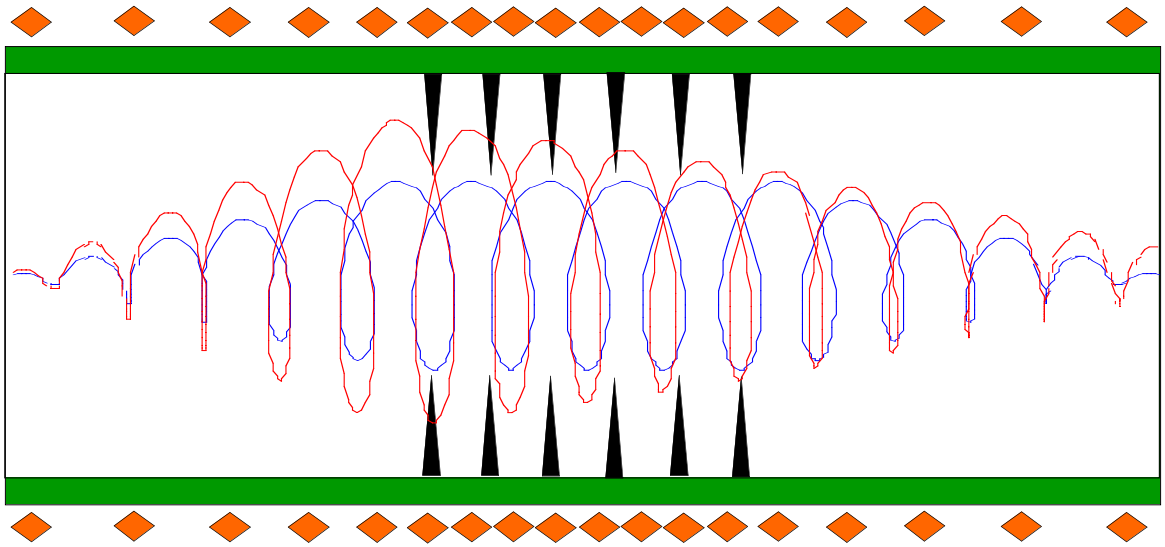


See muon collider notes,
#146, V. Balbekov
#193, V.D.Elvira, P.Lebrun, P.Spentzouris
http://www-mucool.fnal.gov/

	initial	final	
avg Pz	240	240	MeV/c
ε⊥	15	5.9	mm
εL	46	20	mm
ε6D	10350	710	mm^3
losses		15%	



Helical Wiggler

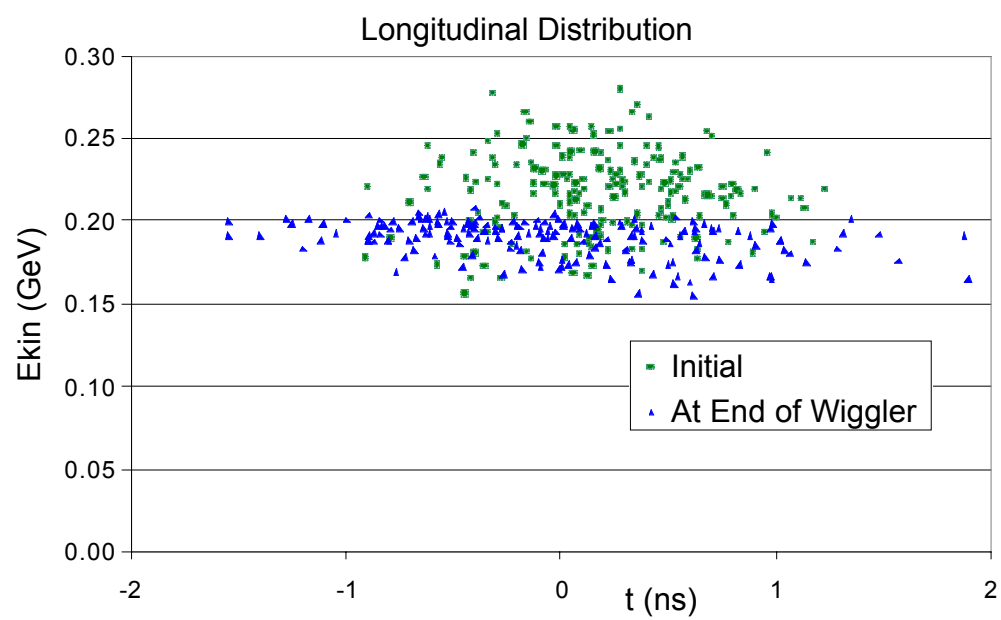


solenoid

particle trace:
high energy
low energy

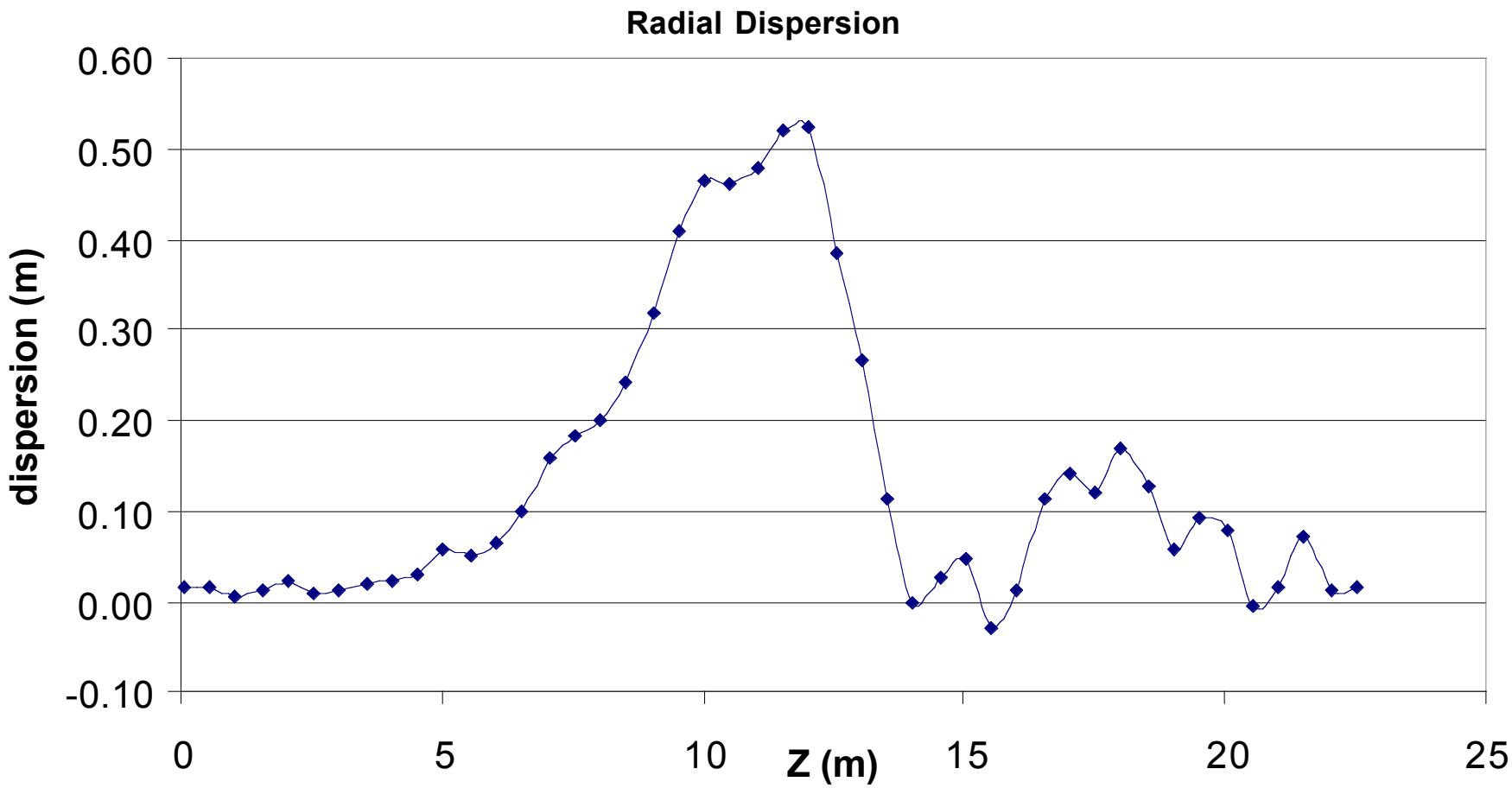
rotating
dipole coils

	initial	final	
avg Pz	300	270	MeV/c
ε⊥	2.1	4.6	mm
εL	28	18	mm
ε6D	120	380	mm^3
losses		5%	



Helical Wiggler Results

Beam parameters from end of cooling, with momentum at 300 MeV/c;
Be wedges to reduce energy spread, at Z between 6 and 16 m



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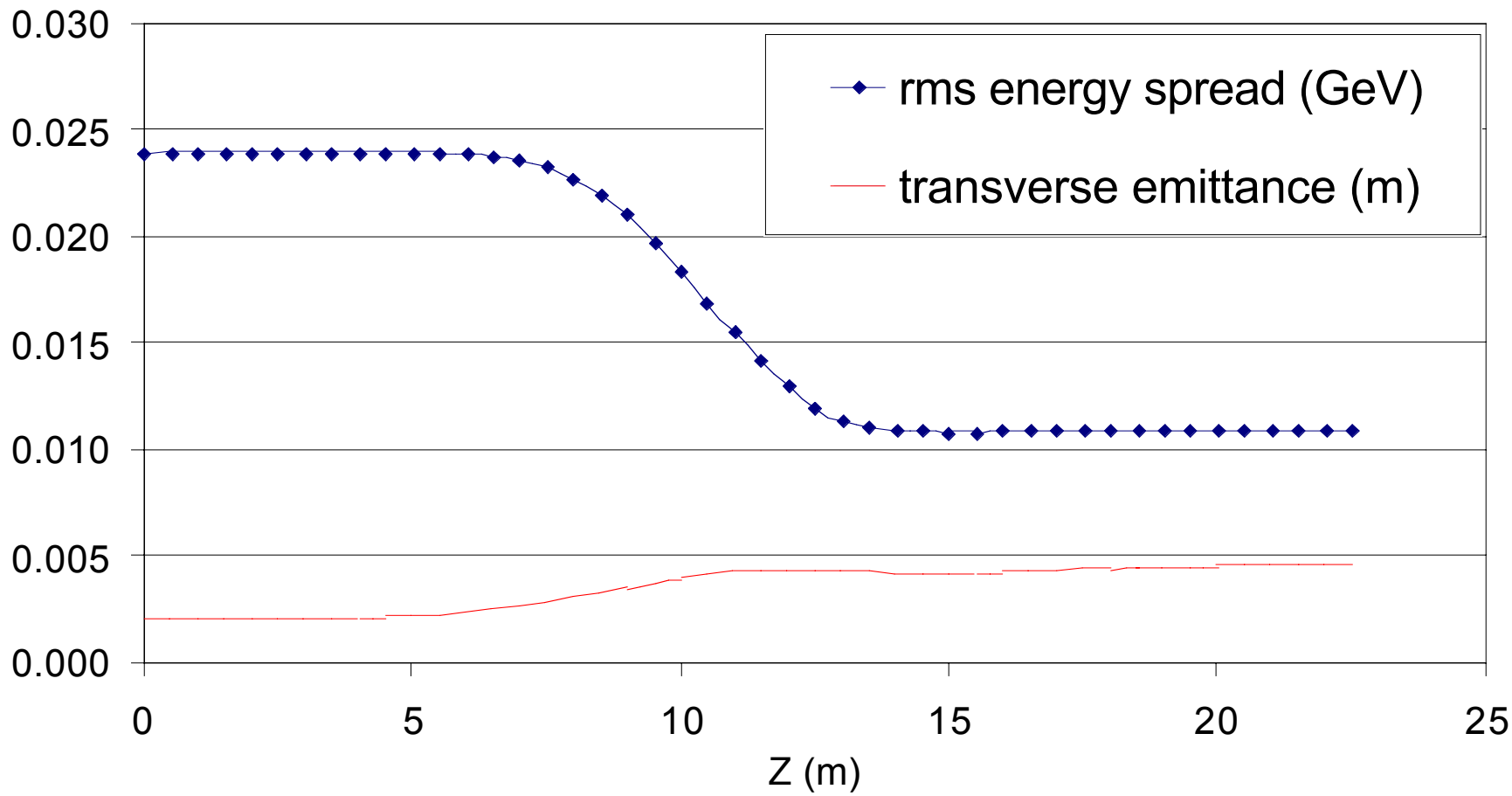

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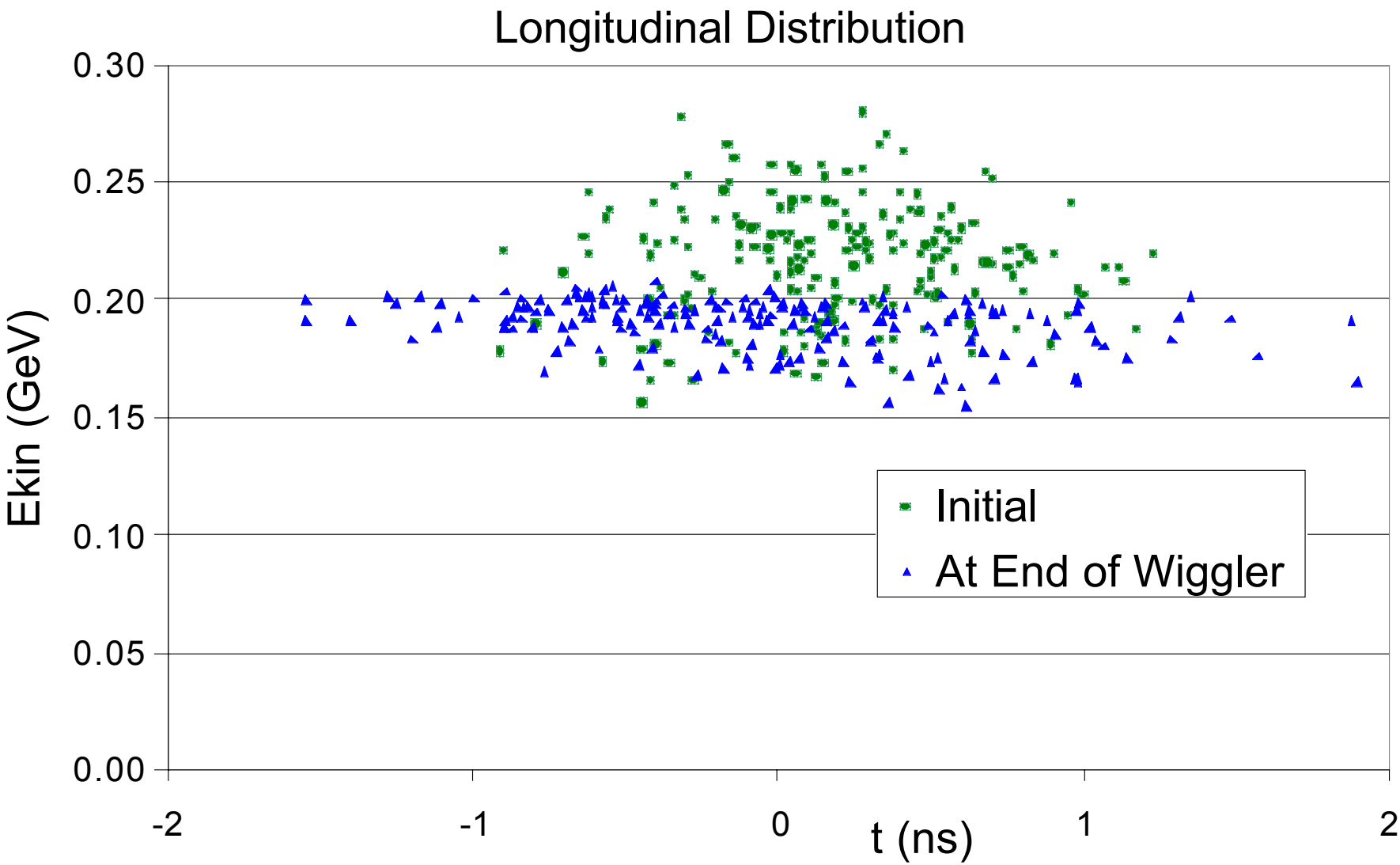

Summary

Helical channels are promising for controlling energy spread of beams and improving front-end performance. Theory of generating dispersion and reducing energy spread is well understood. Applications to a muon collider are under study.

Reduction in longitudinal emittance has been demonstrated; however, need to push parameters farther in order to see improvement in muon throughput.

Specialized diagnostics developed and in use (Ecalc9, v2)

- calculating particles within downstream acceptance
- dispersion for emittance exchange

For further work: integrated simulations, emittance exchange within context of muon beam front-end.