Muons, Inc.
Innovation in Research

Highlights of Low Emittance Muon Collider Workshop

Fermilab, Feb. 12-16, 2007

David Newsham
Muons, Inc.

Beam Physics Seminar
1 March 2007
Jefferson Lab

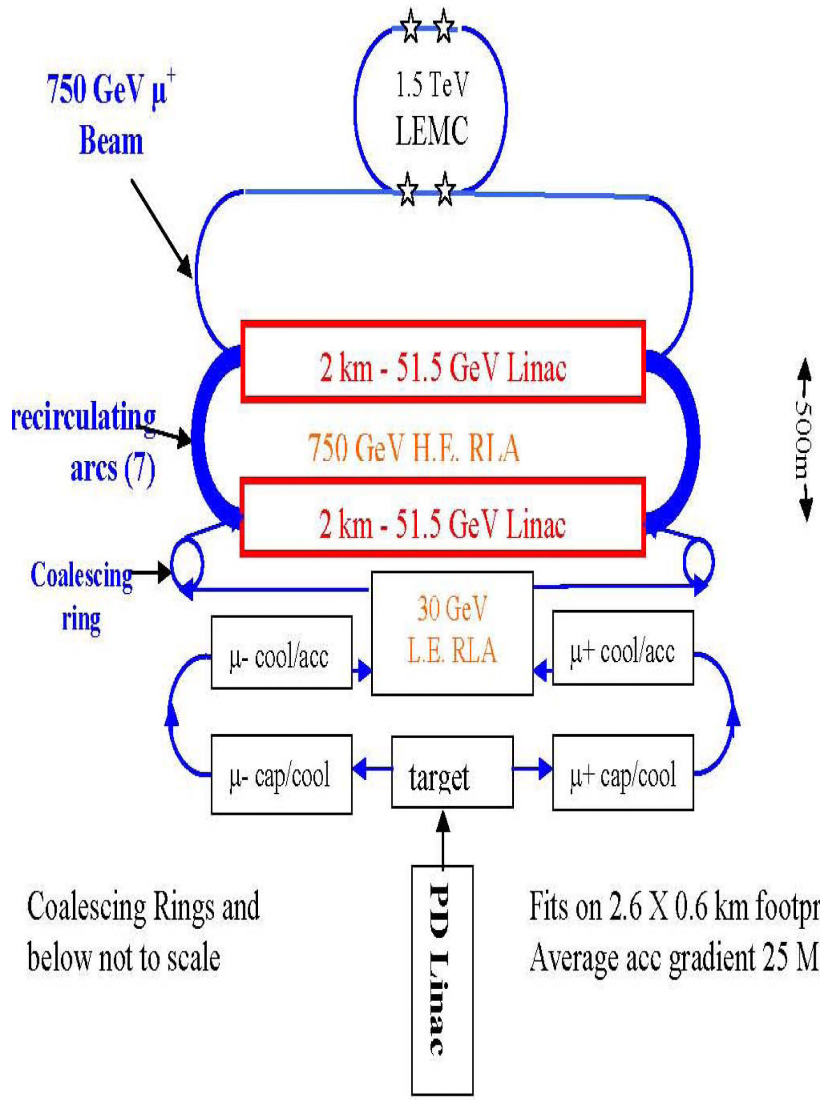
2^{nd} Annual

http://www.muonsinc.com/mcwfeb07/

82 Registared participants 30% more than last year.

Muons, Inc., JLab, FNAL, BNL, LANL, ANL, RAL, CERN, ODU, UCLA, U Miss, Northwestern U, U Mich, IIT, UI Chicago, SAIC

1.5 TeV COM Concept



Coalescing Rings and below not to scale

Fits on 2.6 X 0.6 km footprint
Average acc gradient 25 MeV/m

Workshop Stucture

- Goal: Promote "discussion"
- No "Parallel" sessions
- 5 Working groups
  - Non-exclusive
  - Each given a session thoughout the week
  - Summaries given on last day
- Poster Session
  - Continuously growing
  - 5 – 7pm Mon-Wed

Working Groups

- HEP Theory and Experiment
- Front End (proton source, target, decay, collection)
- μ Cooling
- 6D MANX
- Acceleration, Collider Ring and IR

HEP Theory Starting Point

Mail-order two (2) ACME muon guns

Theory Status

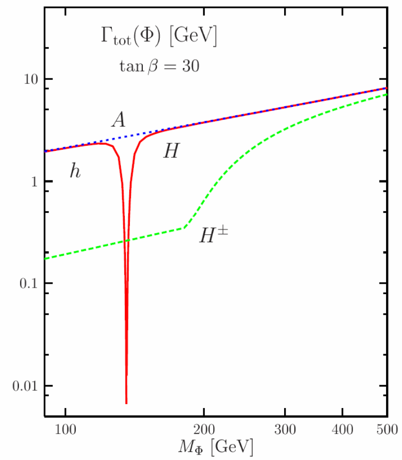
- Standard Model - Great success
- Incomplete: dark matter, GUTS, neutrino masses and mixing.
- The electroweak theory demands new physics at the Fermi scale.
- Many theoretical ideas for new physics: SUSY, ExDim, New Dynamics, ...

Electroweak Theory is incomplete

- It does not account for the fermion spectrum
- masses, quark & lepton mixings
- No explanation for generations
- Right-handed neutrinos are absent
- neutrino mass may have a new origin
- CP-violation is accommodated, not accounted for
- known CPV doesn't readily account for matter excess
- No viable dark-matter candidates
- One really wrong prediction: vacuum energy density too high by $\times 10^{54}$, no candidate explanation for dark energy

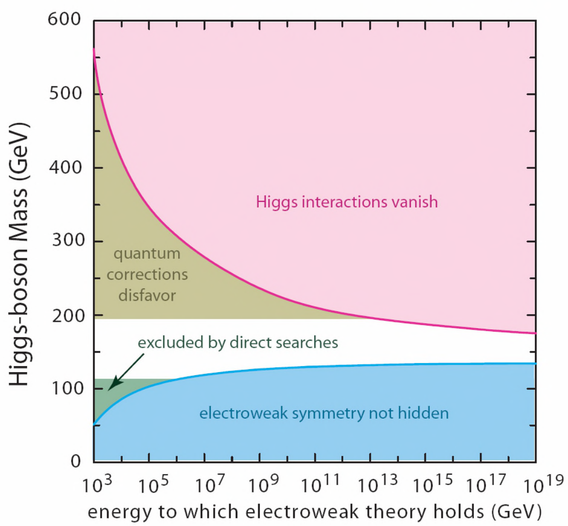
Higgs Boson

Supersymmetric Higgs bosons h, H, A, $H^{\pm}$

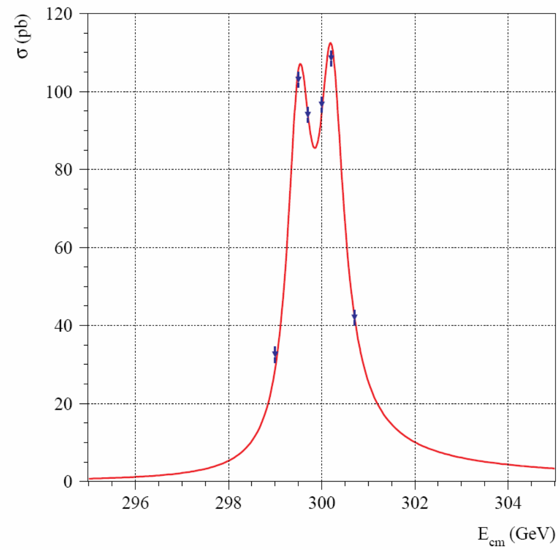


Djouadi, hep-ph/0503173

Incompleteness of the EW theory



Supersymmetric Higgs bosons: $\mu^+\mu^- \to H/A \to b\bar{b}$



$M_A = 300$ GeV, $\tan\beta = 10$, $\delta E/E = 3 \times 10^{-5}$, 25 pb^{-1}/point Janot

Compare to CLIC

- Synergy between CLIC and Muon collider physics studies.
- Look at some oddball possibilities: μP, μe, ...
- Detailed physics studies required. Important parameters need to be identified. Sensitivity quantified.
- Will require detail Monte Carlo simulations.

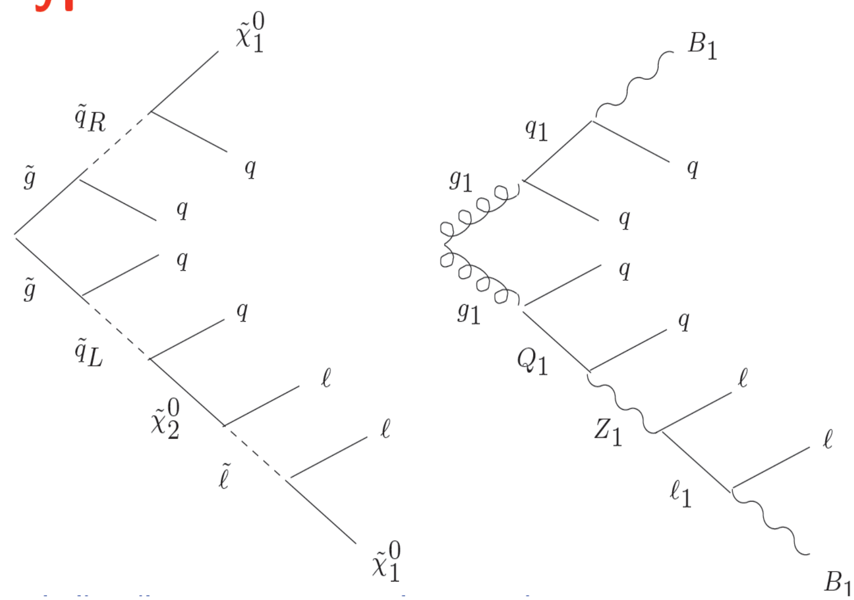
Abridged Parameter List

Machine	1.5-TeV $\mu^+\mu^-$	3.0-TeV $\mu^+\mu^-$	CLIC 3 TeV
$\mathcal{L}_{peak}$ [cm^{-2} s^{-1}]	7×10^{34}	8.2×10^{34}	8×10^{34} tot
$\mathcal{L}_{avg}$ [cm^{-2} s^{-1}]	3.0×10^{34}	3.5×10^{34}	3.1×10^{34} 99%
$\Delta p/p$ [%]	1	1	0.35
$\beta^\star$	0.5 cm	0.5 cm	35 μm
Turns / lifetime	2000	2400	
Rep. rate [Hz]	65	32	
Mean dipole field	10 T	10 T	
Circumference [m]	2272	3842	33.2 km site
Bunch spacing	0.75 μs	1.28 μs	0.67 ns

New Physics

- In UED the lightest KK particle is a dark matter candidate. Mass in the range 500-600 GeV are preferred. Need larger energy than ILC.
- LHC will leave many important issues unresolved.
- Many candidates for new physics have similar signatures at the LHC
- Decay topologies for SUSY and UED can be very similar at the LHC. Critical to know spin information of new particles.
- Difficult at LHC => lepton collider
- CLIC study of these issues very high luminosity and excellent angular coverage - what is required for a muon collider?
- Beamstrahlung much smaller for muon collider

Typical event in SUSY and UED



Detector Considerations

Three sources of backgrounds in a muon collider:

1. **IP backgrounds:** Particles originated from interaction point (IP)
2. **Muon beam decay backgrounds:** Unavoidable bilateral detector irradiation by particle fluxes from the beamline components and accelerator tunnel – **major source in a muon collider**.
3. **Beam halo:** Beam loss at limiting apertures; unavoidable, but is taken care with an appropriate collimation system far upstream of IP.

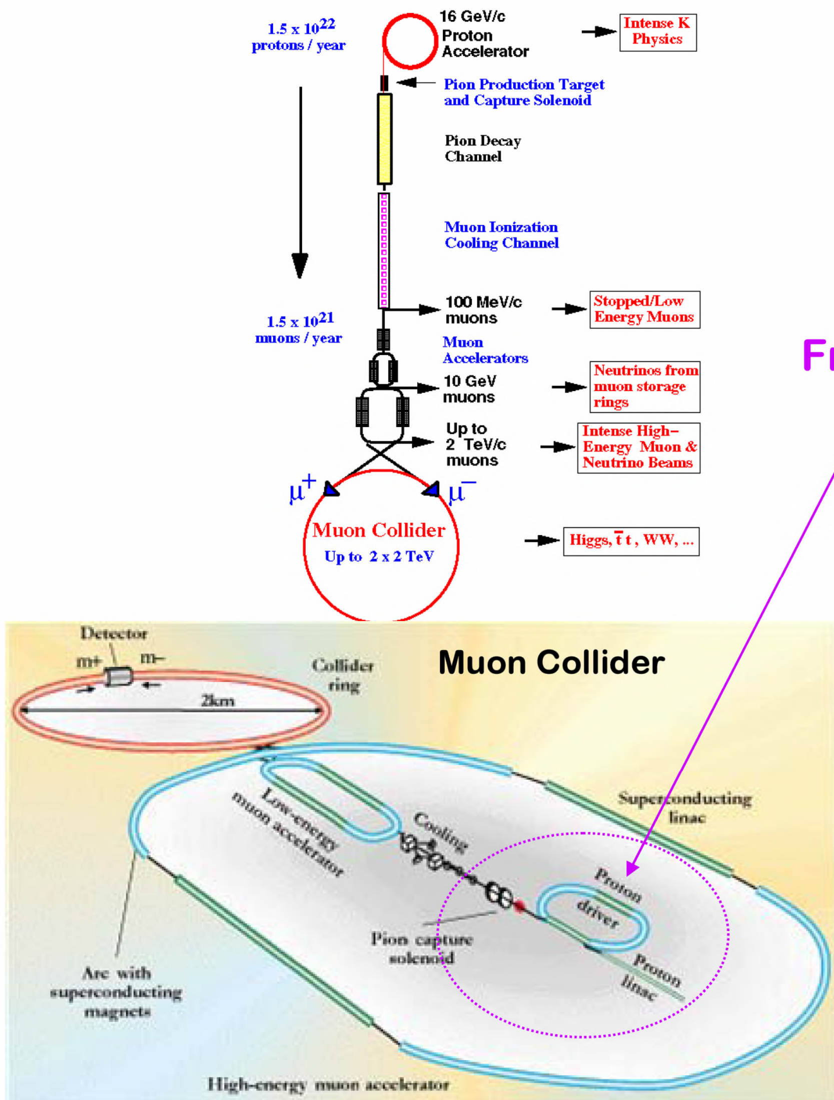
- Muon Collider detectors were studied actively 10 years ago for a 2×2 TeV Collider
- Muon Collider detectors are imagined to be similar in concept to other collider detectors
- Large background from the muon decay electrons must be shielded
  - The shielding strategy must be integral to the final focus design
  - Shielding may limit (eliminate) the detector capabilities in the forward region.

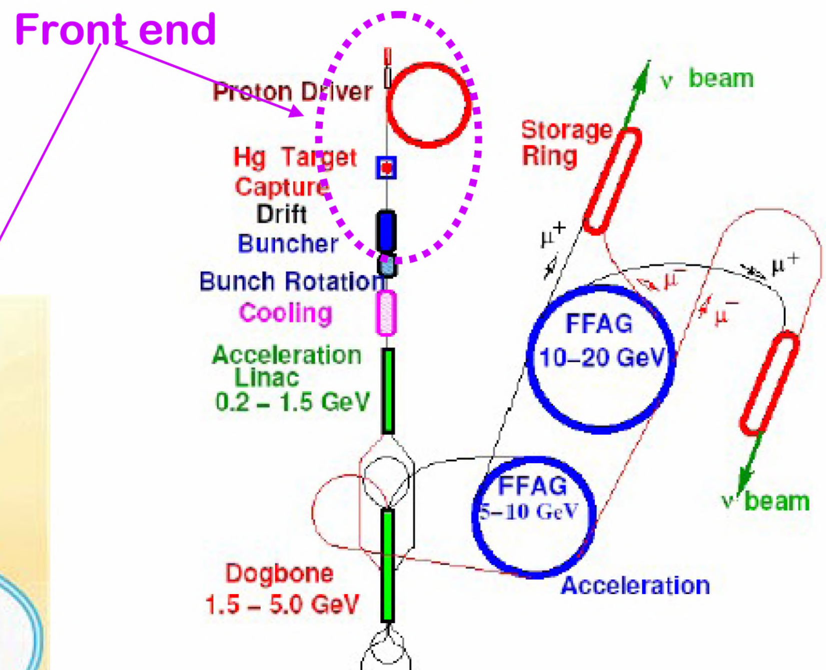
Front End

- Proton Driver - MW sources
  - Fermilab Proton driver
    - 8 GeV SRF proton driver
    - NEEDS BUNCHER RING
- Target and Capture Options
  - Solid or liquid jet target
  - Solenoidal transport?
- • Bunching and φ-E rotation
  - Multibunch scenario (follows ν-Factory)
  - Single (or few) bunch scenarios
- Match into cooling…

Front End

- = Proton source, target, π→μ capture
- Collider and nu-factory have similar front end





ISS nu-factory

Proton Driver Requirements

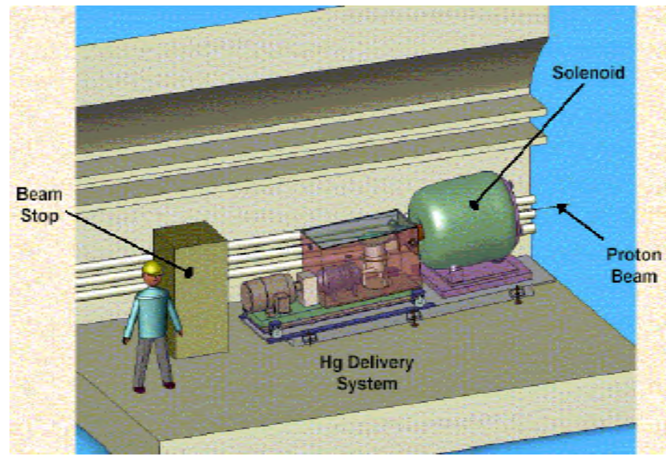
- > ~1MW beam
- E = ~10 GeV to maximize production of ~0.2 GeV μ's
  - 5 to "50" GeV also looked at
- Initial protons in relatively small number of bunches, relatively short bunches (10^{13} p in 1m long bunches?)
- Existing bunched sources (~0.1MW)
- Future MW + sources are planned
  - J-Parc - 50 GeV
  - RAL (design for neutrino factory)
  - Fermilab: SNUMI (125 GeV) or ??
  - SNS: MW but 1-GeV
  - BNL – AGS upgrade "possible"

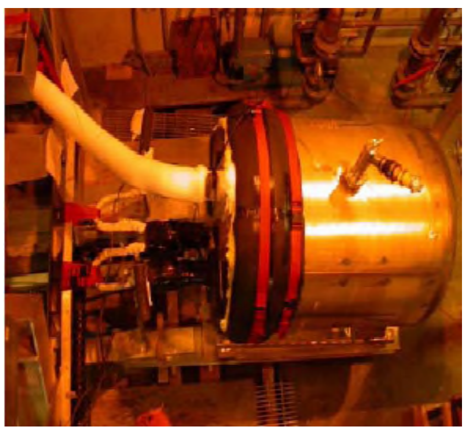
FNAL Option

- Fermilab may develop new proton source to replace “8-GeV” Booster at a multi-MW level
  - Studied at Fermilab but deferred to focus on ILC
  - R&D continues on technology
    - HINS – “High Intensity Neutrino Source” research
- Upgrade options:
  - Extensions of existing complex…
  - 8-GeV SRF proton linac
    - leading high-intensity possibility
    - Requires buncher ring
  - Booster-like rapid-cycling synchrotron
- Discussion conclusion:
  - Fermilab will not have a future without a MW proton driver:
  - Therefore, Fermilab will have a MW proton driver

Targets for π production

- Typical beam: ~10 GeV protons, up to 4 MW
  - 1m long bunches up to 4×1013/bunch, 60Hz
- Solid targets
  - C (graphite targets) (NUMI)
  - Can be used for Muon Collider (1MW ?)
- Liquid Metal targets
  - MERIT – Hg jet in free space
  - Best for 4MW ??



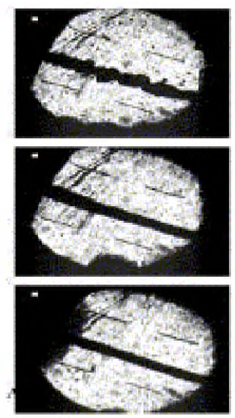


Magnet tested at 15T

O Tesla

1O Tesla

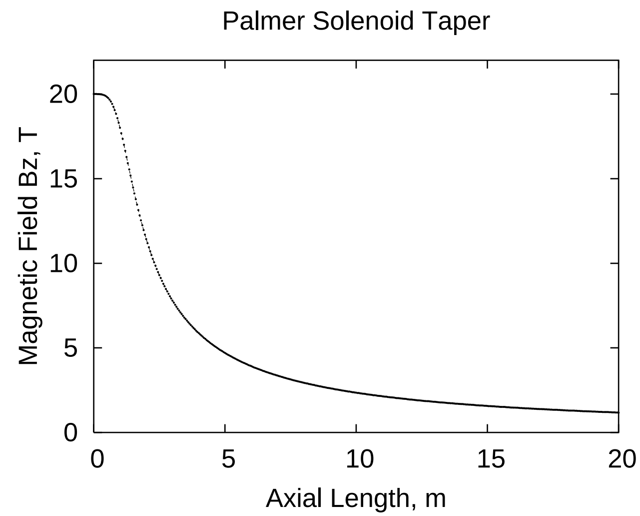
2O Tesla

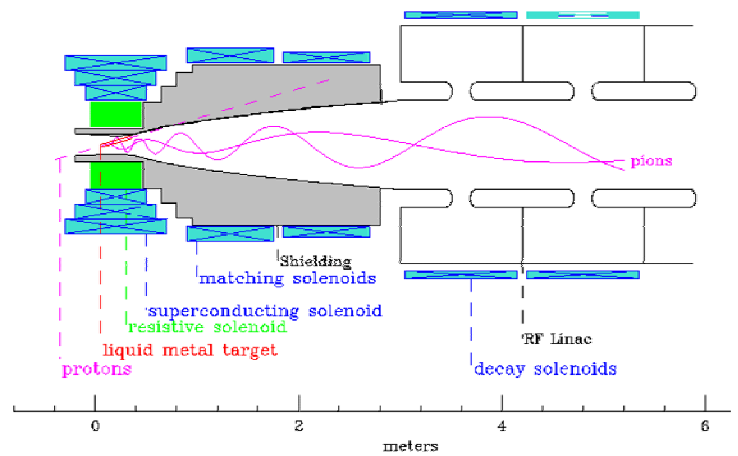


Hg jets

Solenoid transport

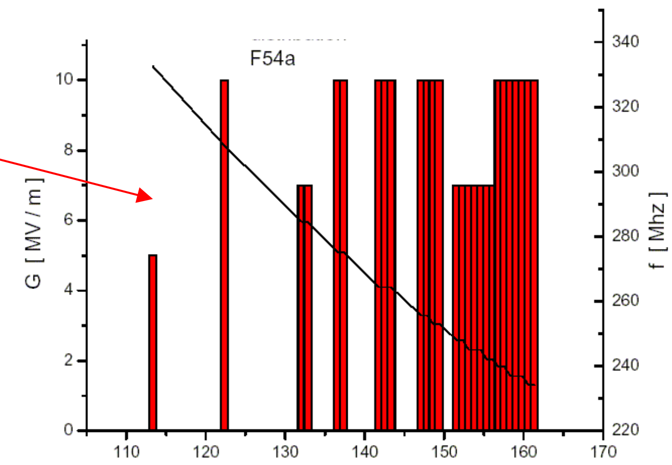
- Magnetic field adiabatically decreases along the transport
- Transverse momentum decreases
  - Busch's theorem: B r_{orbit}^2 is constant
  - B=20T→2T (r=3.75cm →= 12cm)
  - $P_\perp$ = 0.225→0.07GeV/c
- Emittance = ~σ_x σ_{px}/105.66
  - ~8cm×25 MeV/c/105.66≅0.02m
- P remains constant ($P_\parallel$ increases)
- Transport designed to maximize π→μ acceptance

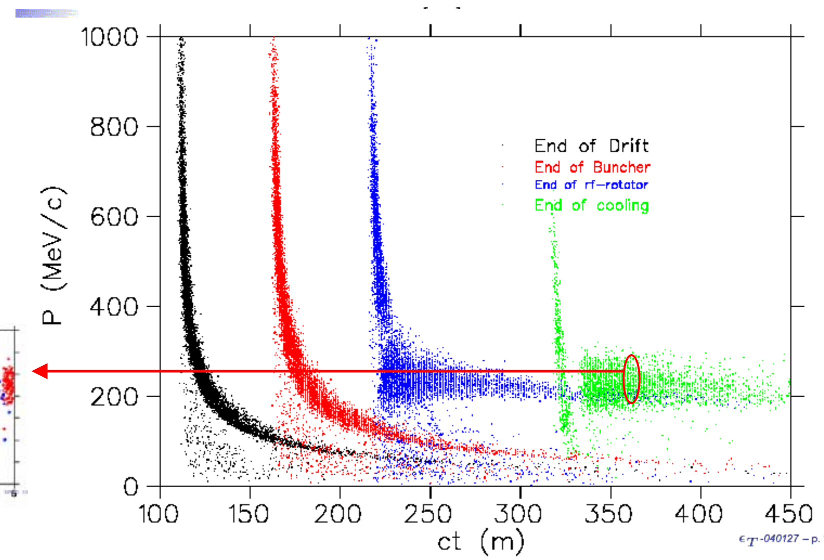


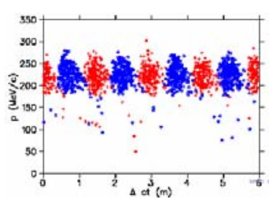


ν–Factory Study2A μ+ and μ- source

- Drift –110.7m
- Bunch –51m
  - Vδ(1/β) =0.0079
  - 12 rf freq., 110MV
  - 330 MHz → 230MHz
- φ–E Rotate – 54m – (416MV total)
  - 15 rf freq. 230→ 202 MHz
  - P_1=280 , P_2=154 δN_V = 18.032
- Match and cool (80m)
  - 0.75 m cells, 0.02m LiH
- “Realistic” fields, components
- Captures both μ+ and μ-

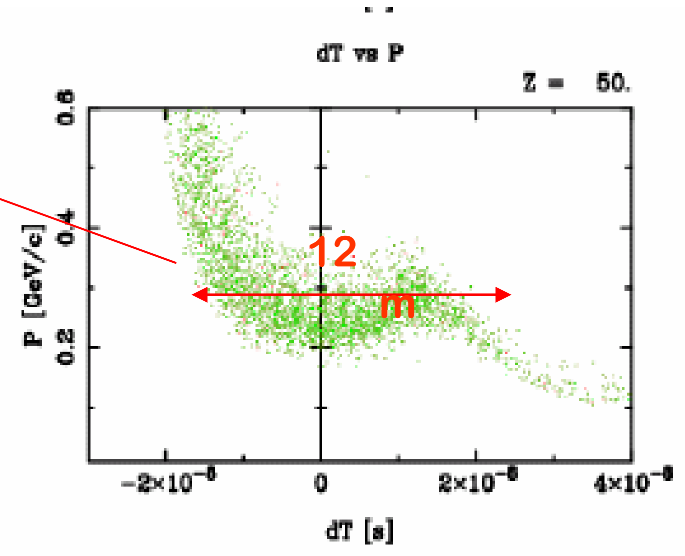


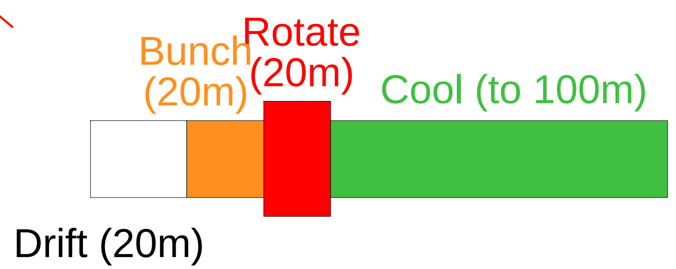




Phase/energy rotation variations

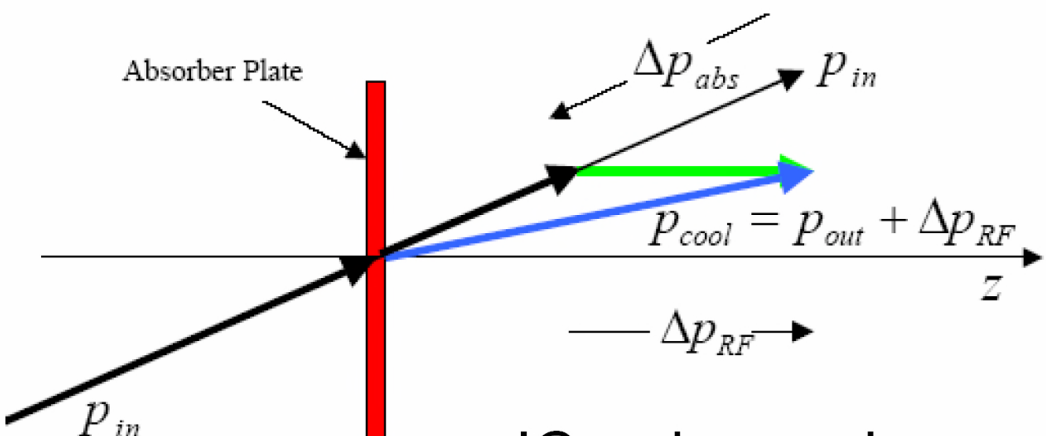
- **Low-frequency rf;** capture into single long bunch
  - But Low-frequency rf is very expensive?)
- **Shorter high-frequency buncher**
  - Shorter bunch train
- **Gas-filled rf cavities**
- **Quad (not solenoid) focusing**
  - Less field in rf, not on axis
  - Less expensive? (B^2L less)
  - "Almost" ready
  - Redo study 2a with quads …
  - A. Poklonskiy assigned to topic





μ Cooling

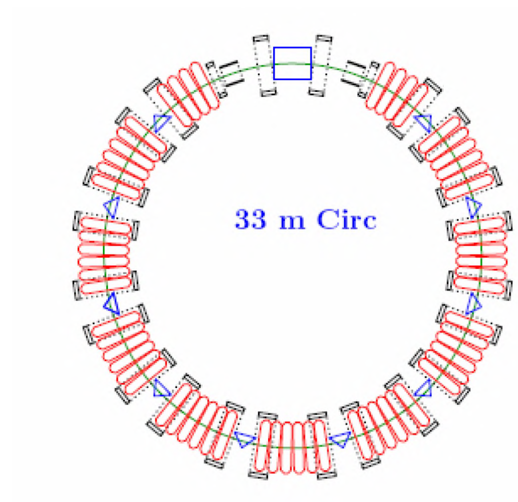
- Cooling is the foundation for the muon collider
- Two collider cooling scenarios presently under investigation
  - Muons Inc.
  - Bob Palmer
- Both of these schemes could be compatible with the NF front end
  - maximizes value of our ongoing R&D programs
  - would enable muon collider to be staged

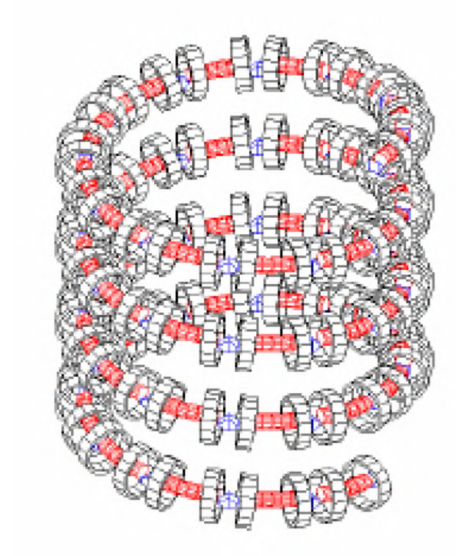


IC reduces x'

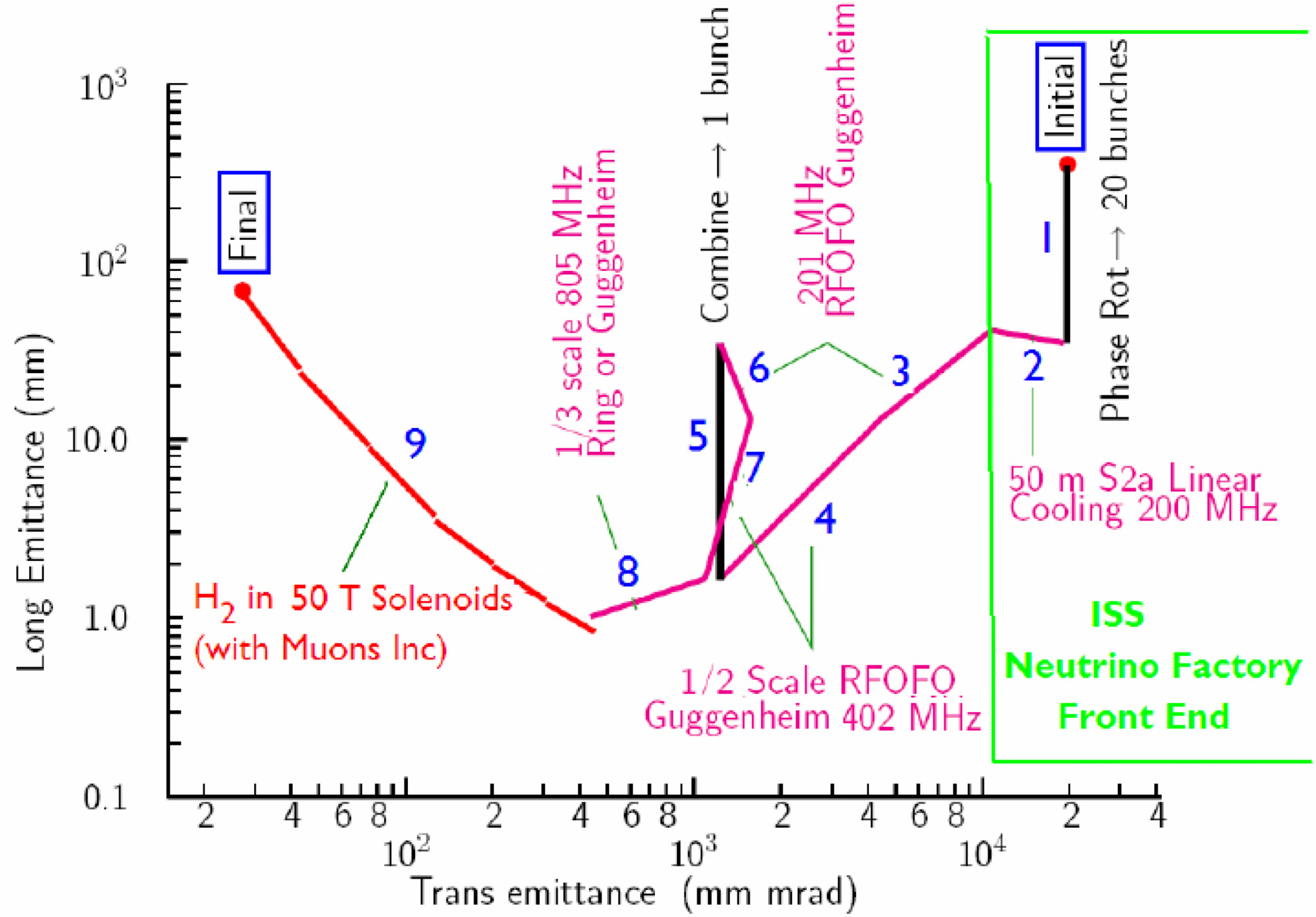
“Palmer” Cooling Rings

- uses three RFOFO rings (maybe, else guggenheim)
  - 201 MHz (extensively simulated)
  - 402 MHZ (scaled)
  - 805 MHz (scaled with new lattice)
- tracking simulations meets specs
- if ring, needs injection/ extraction simulations





Fernow-Neuffer Plot



μ *Muons, Inc.*

700 m muon Production and Cooling (showing approximate lengths of sections)

- 8 GeV Proton storage ring, loaded by Linac
  - 2 T average implies radius=8000/30x20~14m
- Pi/mu Production Target, Capture, Precool sections
  - 100 m (with HP RF, maybe phase rotation)
- 6D HCC cooling, ending with 50 T magnets
  - 200 m (HP GH2 RF or LH2 HCC and SCRF)
- Parametric-resonance Ionization Cooling
  - 100 m
- Reverse Emittance Exchange (1^{st} stage)
  - 100 m
- Acceleration to 2.5 GeV
  - 100 m at 25 MeV/c accelerating gradient
- Reverse Emittance Exchange (2^{nd} stage)
  - 100 m
- Inject into Proton Driver Linac
- Total effect:
  - Initial 40,000 mm-mr reduced to 2 mm-mr in each transverse plane
  - Initial ±25% Δp/p reduced to 2% , then increased
    - exchange for transverse reduction and coalescing
  - about 1/3 of muons lost to decay during this 700 m cooling sequence
- Then recirculate to 23 GeV, inject into racetrack NF storage ring

New Phase II grant

Detailed theory in place, simulations underway.

New Phase II grant

RF cavity to compensate ionization energy loss

Continuous acceleration is more effective.

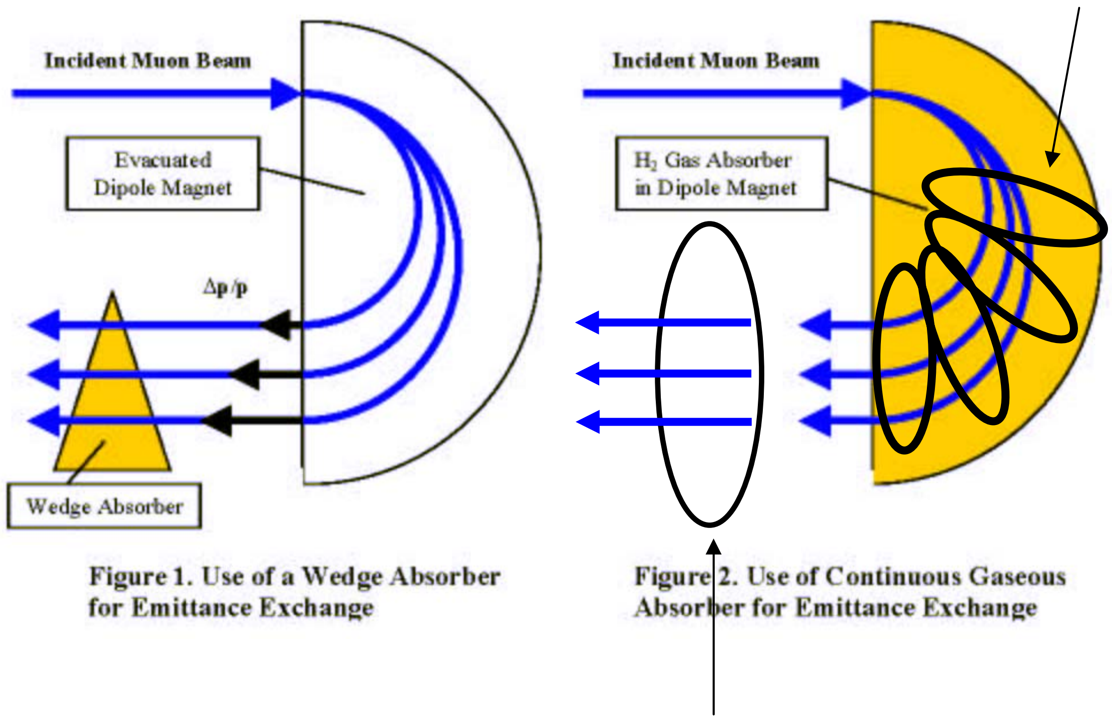


Figure 1. Use of a Wedge Absorber for Emittance Exchange

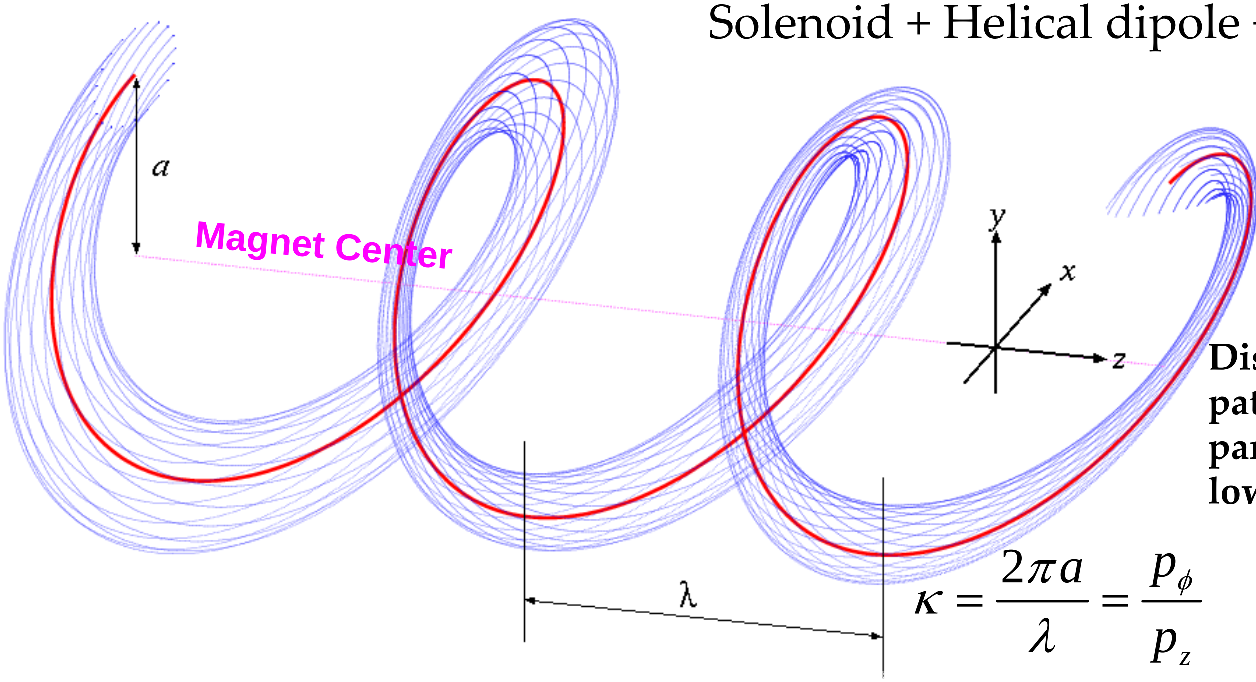
Figure 2. Use of Continuous Gaseous Absorber for Emittance Exchange

RF cavity is needed to compensate ionization energy loss.

Particle Motion in Helical Magnet

Combined function magnet (invisible in this picture)

Solenoid + Helical dipole + Helical Quadrupole



Red: Reference orbit

Blue: Beam envelope

Dispersive component makes longer path length for higher momentum particle and shorter path length for lower momentum particle.

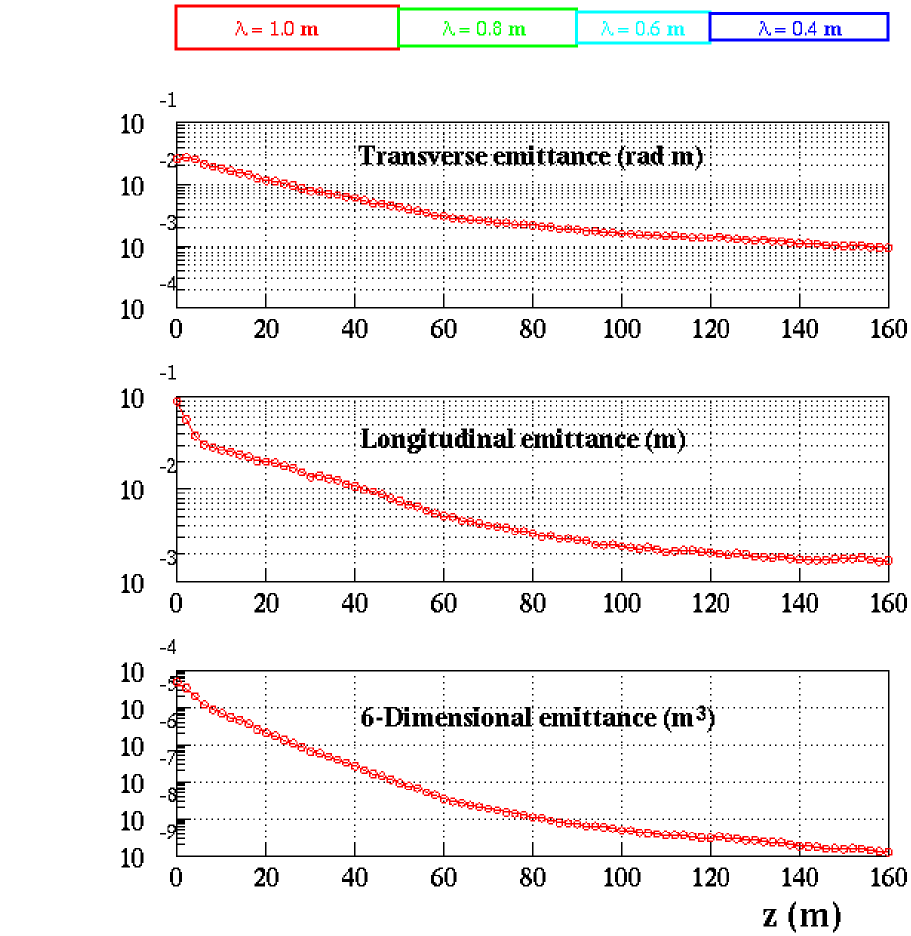
$$\kappa = \frac{2\pi a}{\lambda} = \frac{p_\phi}{p_z}$$

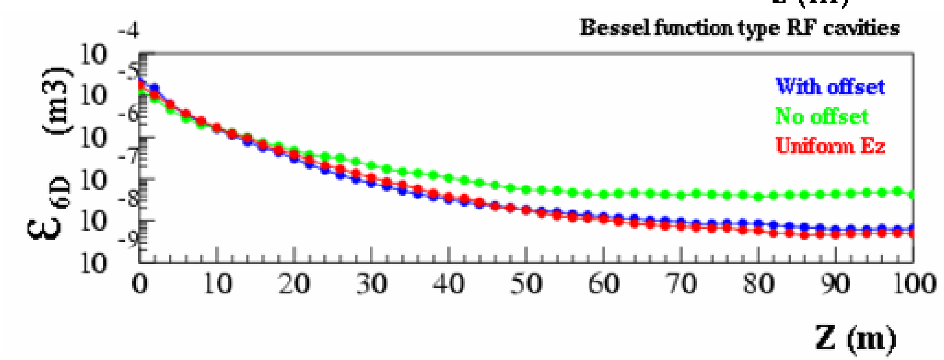
$f_\uparrow \propto b_\varphi \cdot p_z$	Repulsive force
$f_\downarrow \propto -b_z \cdot p_\varphi$	Attractive force

$$f_{central} = \frac{e}{m}(b_\varphi \cdot p_z - b_z \cdot p_\varphi)$$

Both terms have opposite signs.

Emittance in series of HCC

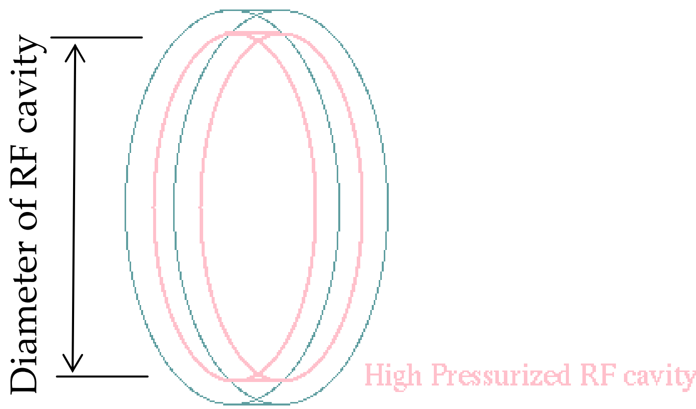




- *Use continuous 200 MHz cavity in a whole channel.*
- *E=31 MV/m in 400 atm GH2.*
- *6D cooling factor in the series of HCC is ~50,000.*
- *The realistic RF field is tested in the single helical cooling channel (bottom plot).*
- *This test is proved the predicted cooling performance in the Slava and Rol's paper.*
- *However, this design is needed to produce the huge magnetic field.*

We need to solve this question.

Incorporate RF cavity in helical solenoid coil



- Use a pillbox cavity (but no window this time).
- RF frequency is determined by the size of helical solenoid coil.

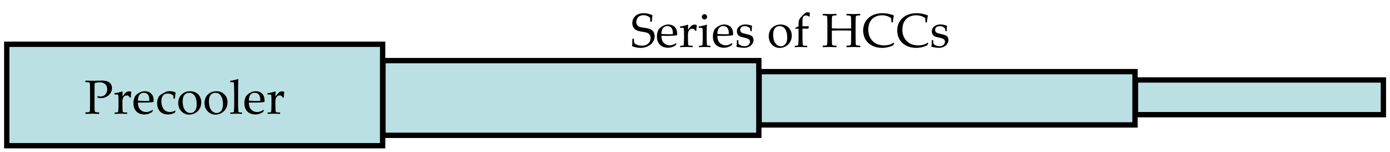
→Diameter of 400 MHz cavity = 50 cm
→Diameter of 800 MHz cavity = 25 cm
→Diameter of 1600 MHz cavity = 12.5 cm

- The pressure of gaseous hydrogen is 200 atm to adjust the RF field gradient to be a practical value.

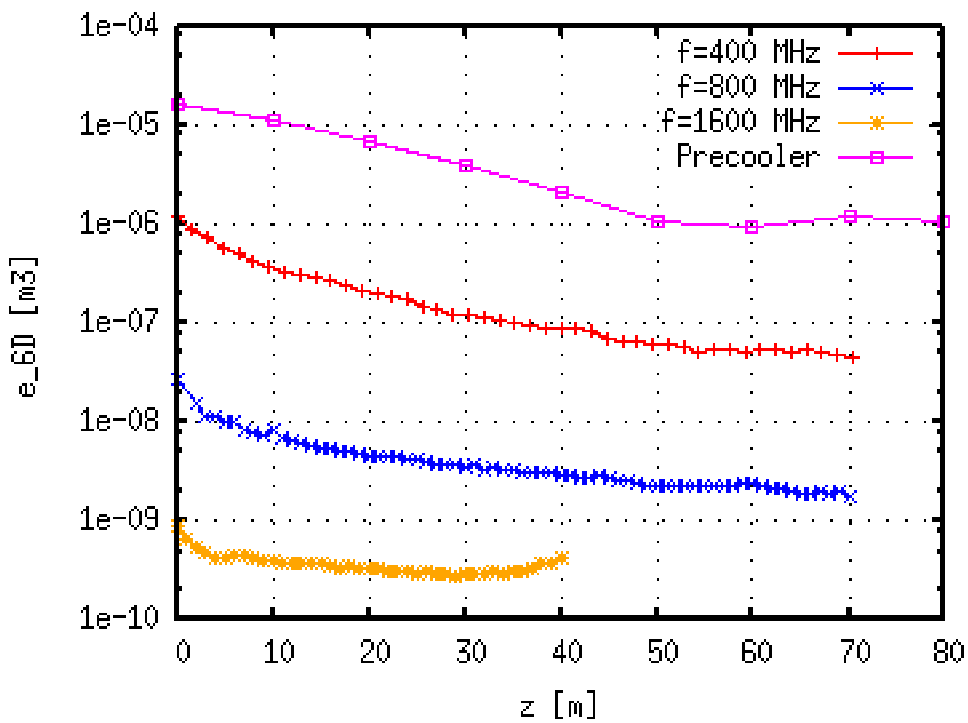
→The field gradient can be increased if the breakdown would be well suppressed by the high pressurized hydrogen gas.

parameters	λ	κ	Bz	bd	bq	bs	f	Inner d of coil	Maximum b	E	rf phase
unit	m		T	T	T/m	T/m2	GHz	cm	Snake | Slinky	MV/m	degree
1st HCC	1.6	1.0	-4.3	1.0	-0.2	0.5	0.4	50.0	12.0 | 6.0	16.0	140.0
2nd HCC	1.0	1.0	-6.8	1.5	-0.3	1.4	0.8	25.0	17.0 | 8.0	16.0	140.0
3rd HCC	0.5	1.0	13.6	3.1	-0.6	3.8	1.6	12.5	34.0 | 17.0	16.0	140.0

Precooler + HCCs

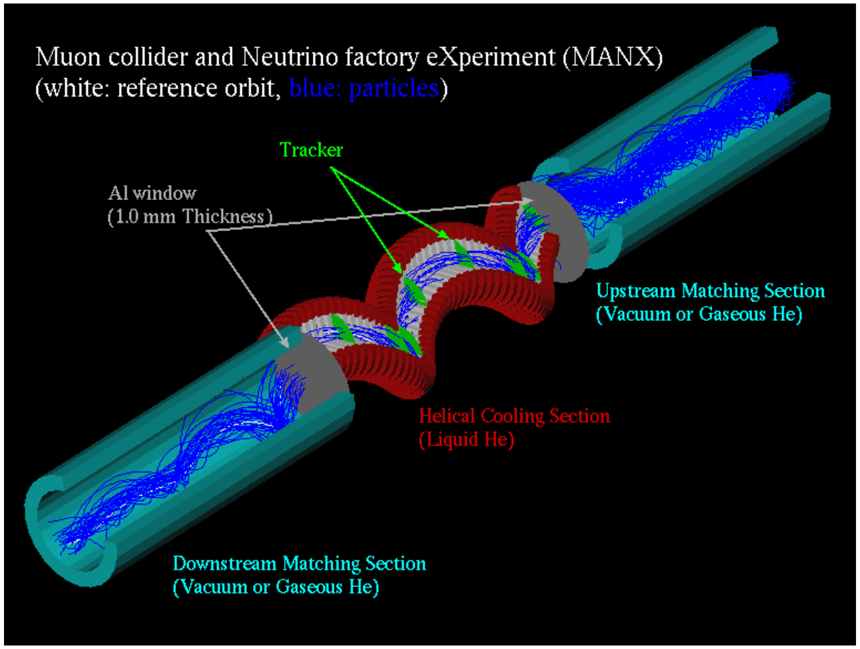


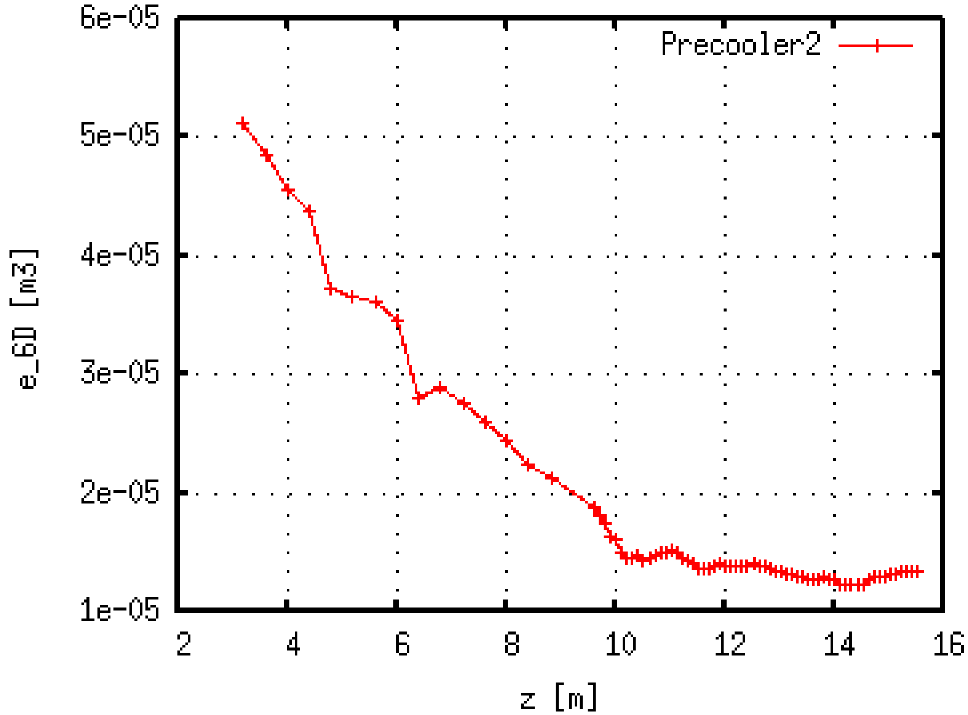
Solenoid + High Pressurized RF



- The acceptance is sufficiently big.
- Transverse emittance can be a quite smaller than longitudinal emittance.
- Emittance grows in the longitudinal direction.

Another Possible Precooler + HCCs





- Use MANX type cooling channel at beginning.
- Install the high pressurized RF cavities after the MANX magnet to compensate the energy loss.
- It works quite well.

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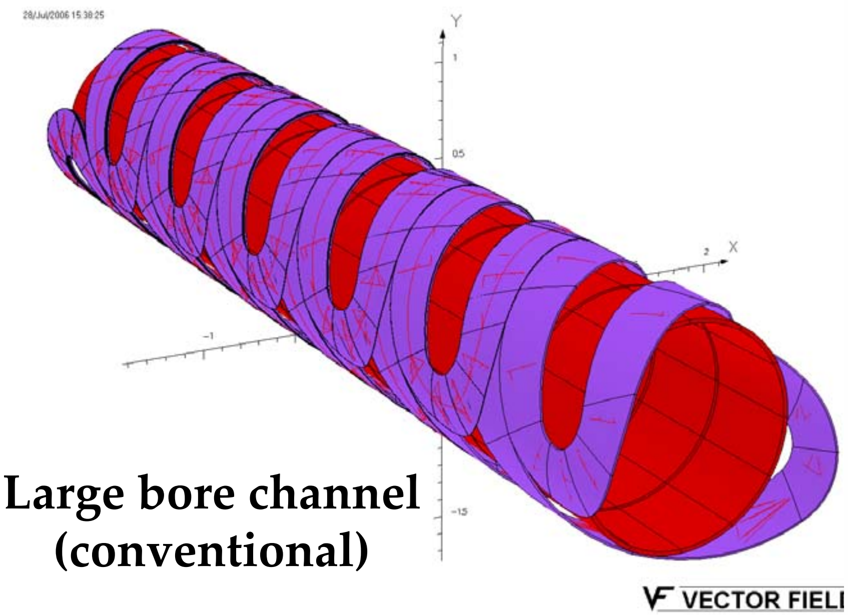
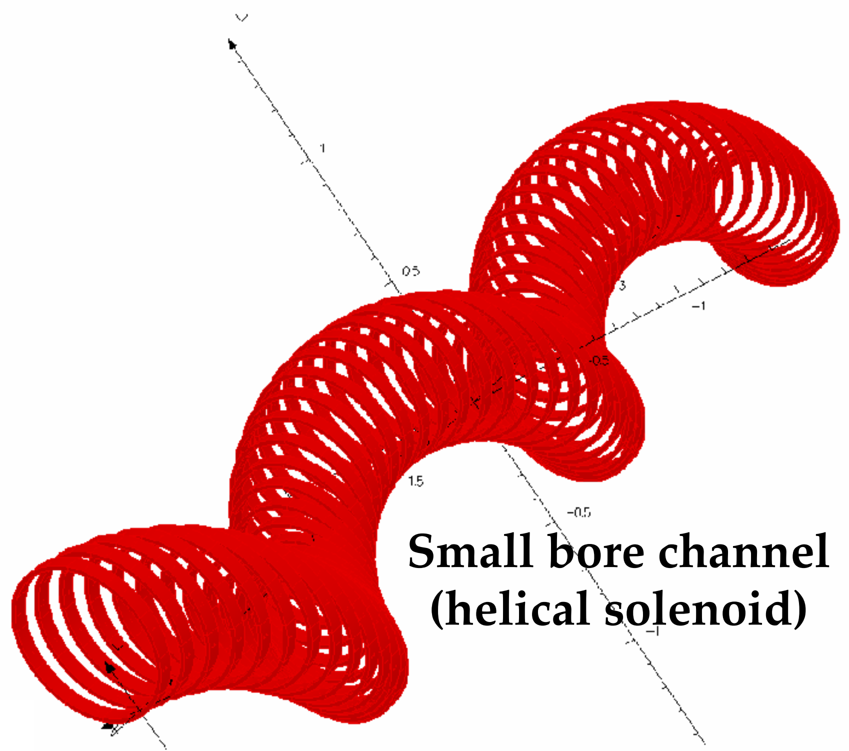
New great innovation!

Fermilab

Two Different Designs of Helical Cooling Magnet



Large bore channel (conventional)



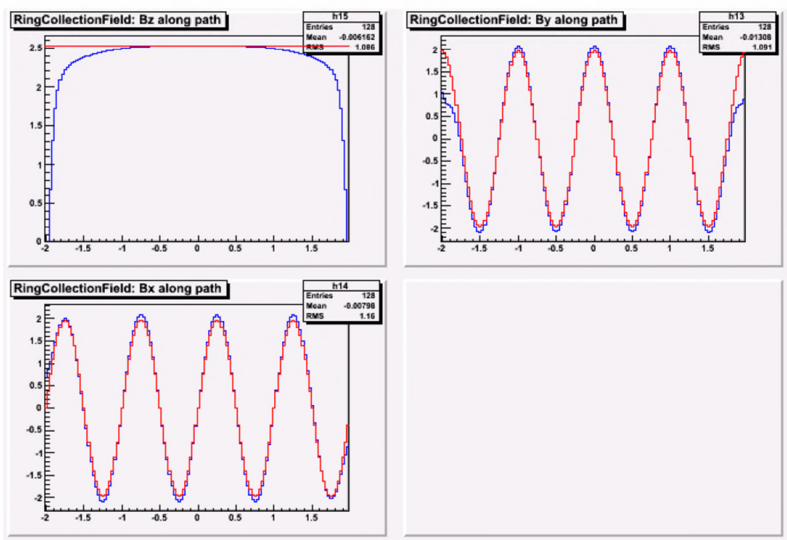
Small bore channel (helical solenoid)

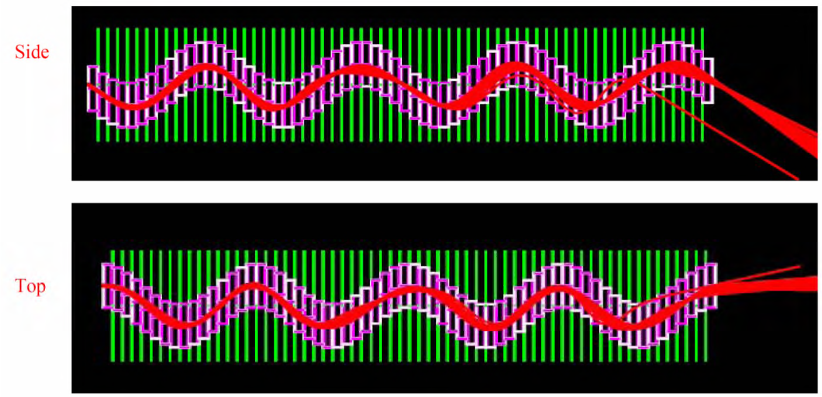
- Siberian snake type magnet
- Consists of 4 layers of helix dipole to produce tapered helical dipole fields.
- Coil diameter is 1.0 m.
- Maximum field is more than 10 T.

- Helical solenoid coil magnet
- Consists of 73 single coils (no tilt).
- Maximum field is 5 T
- Coil diameter is 0.5 m.
- Flexible field by adding a correction coils.

Studies with Larger Gaps-1

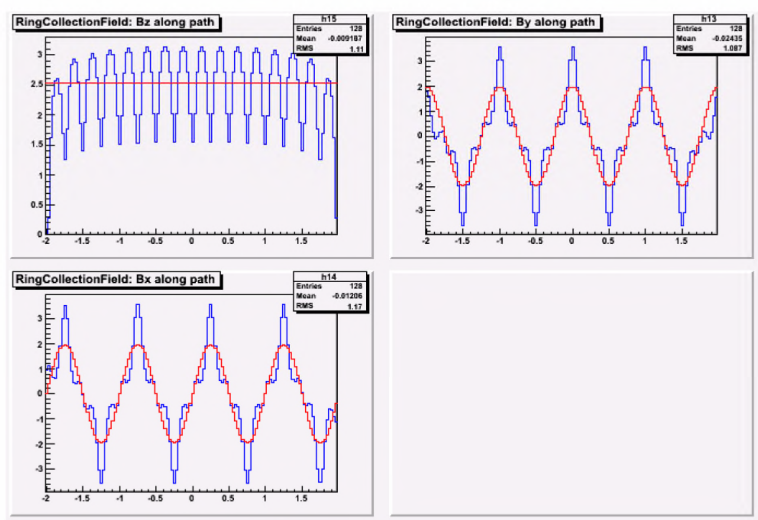
Case 1: 16 Rings/meter with No Gaps

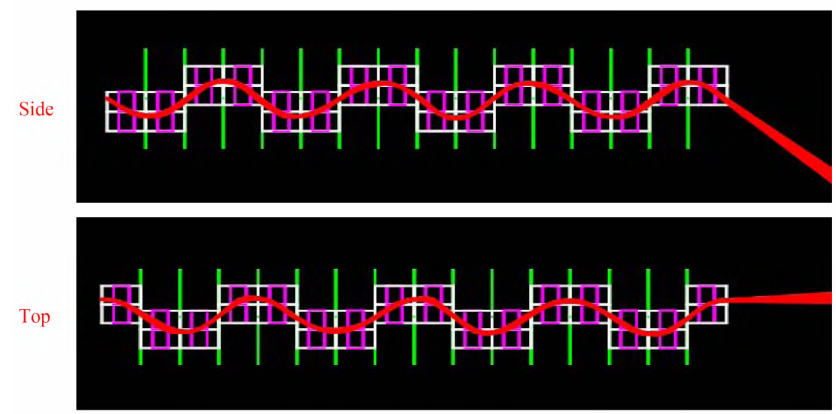




Studies with Larger Gaps-2

Case 3: 4 Rings/meter with 15 cm Gap between rings

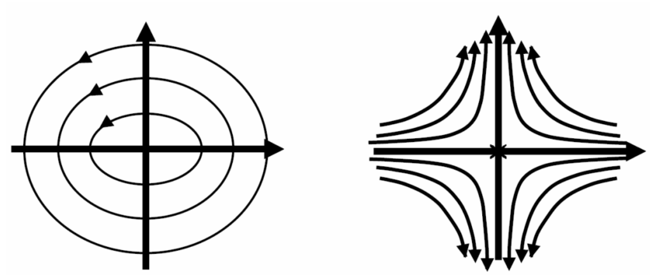




PIC & REMEX

Phase IC

- At equilibrium, IC provides insufficient transverse cooling for high luminosity.
- Excite ½ integer parametric resonance (in Linac or ring)
- Detuning issues being addressed.
- Simulations underway.



Reverse Emittance Exchange

- Cooling at ~100 MeV/c range.
- After acceleration to TeV energies, $\Delta P/P$ is smaller than needed.

Figure 1. Emittance Exchange

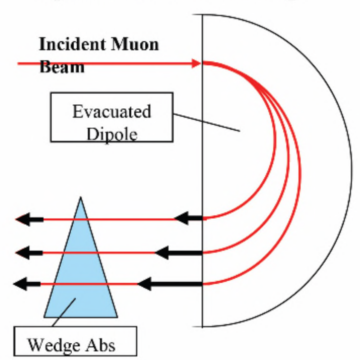
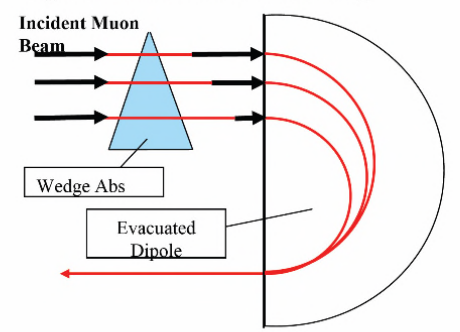


Figure 2. Reverse Emittance Exchange



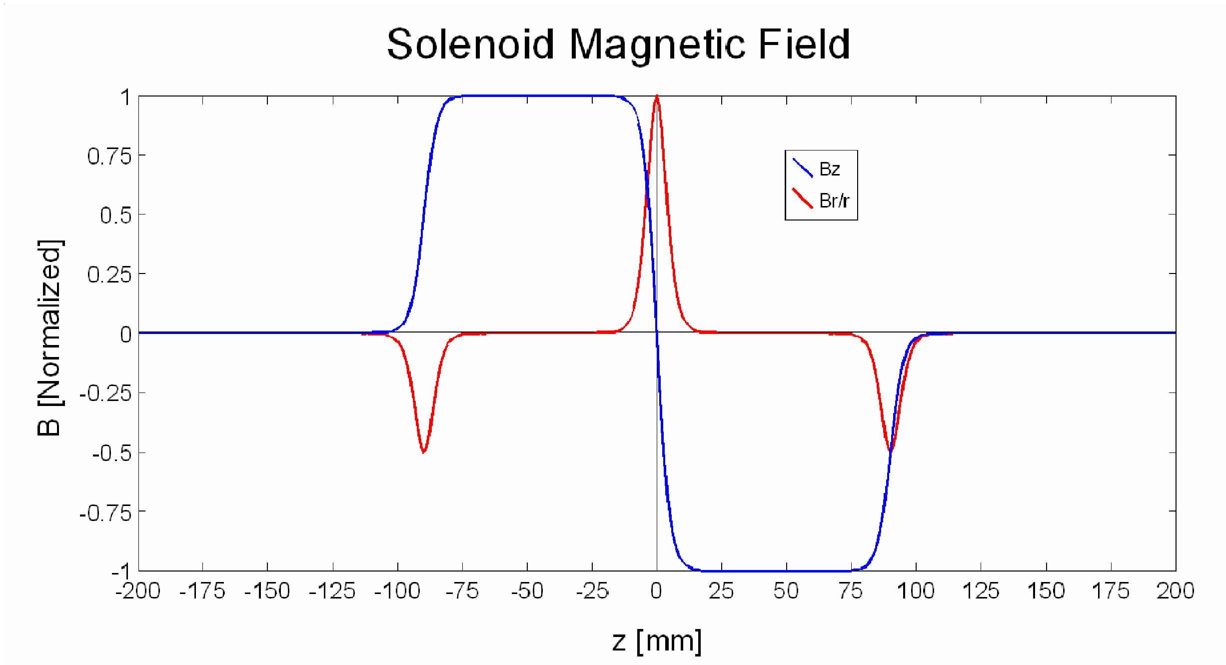
Results of Simulations of Detuned Lattice

Care must be taken in using G4Beamline to simulate channels designed with OptiM:

- Lumped linear elements (transfer matrices) vs. “real” objects
- Accurate injection is required to avoid beam loss
- Linear optics must be understood before adding absorbers
- The effects of fringe fields and end fields must be understood. In the Detuned Lattice, only small-aperture solenoids could be simulated successfully, because of end-field issues.

Latest Simulations

- Used Tanh Bz with no radial dependence, but rapid cutoff.
- Satisfies Maxwell's equations, but corresponds to a small-aperture counter-wound solenoid

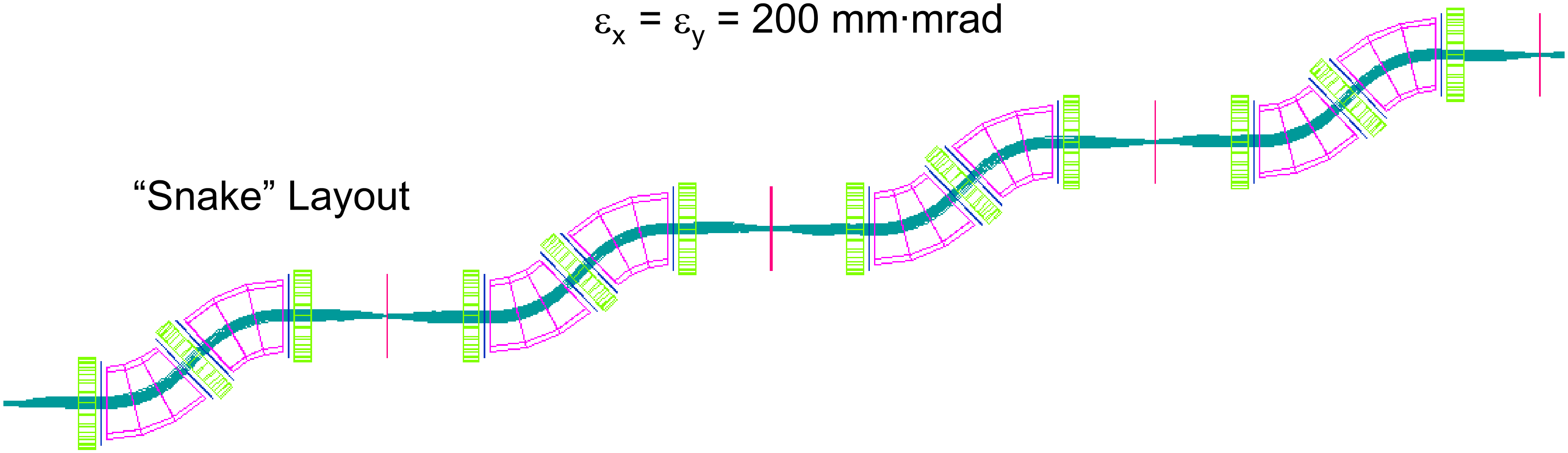


Large Beams are Focused (geometric aberr. only: $\delta = 0$)

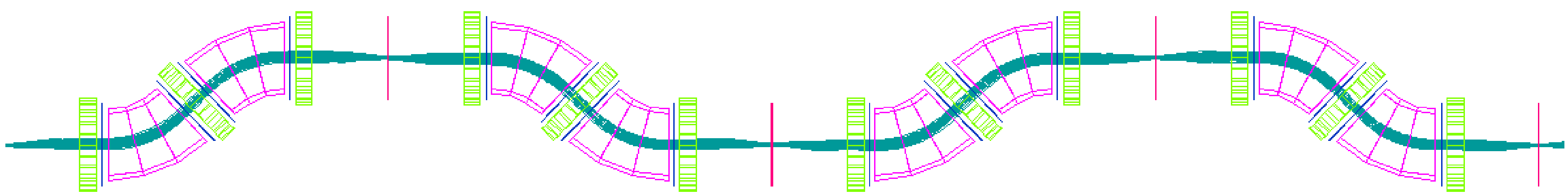
Tuned snake with 1 mm-mr beam (to maintain spot size at absorber planes). Both lattices work well at

$\varepsilon_x = \varepsilon_y = 200$ mm·mrad

“Snake” Layout

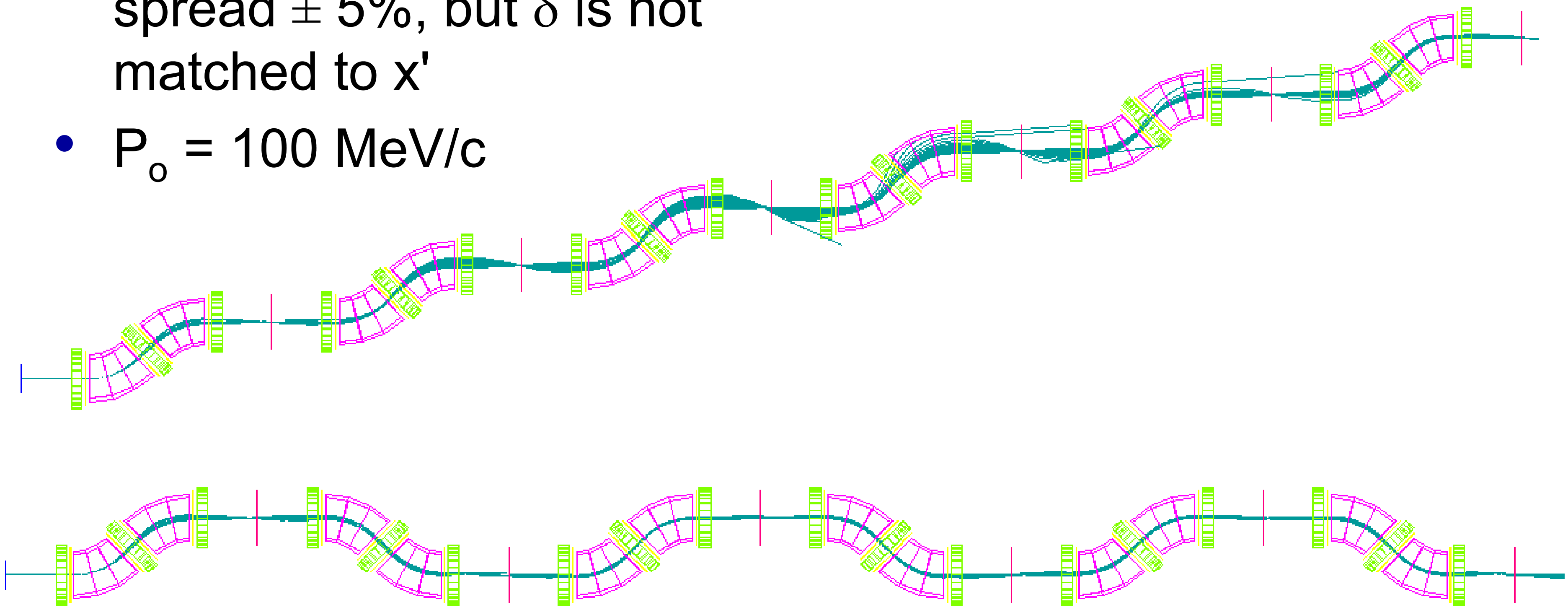


“Chicane” Layout



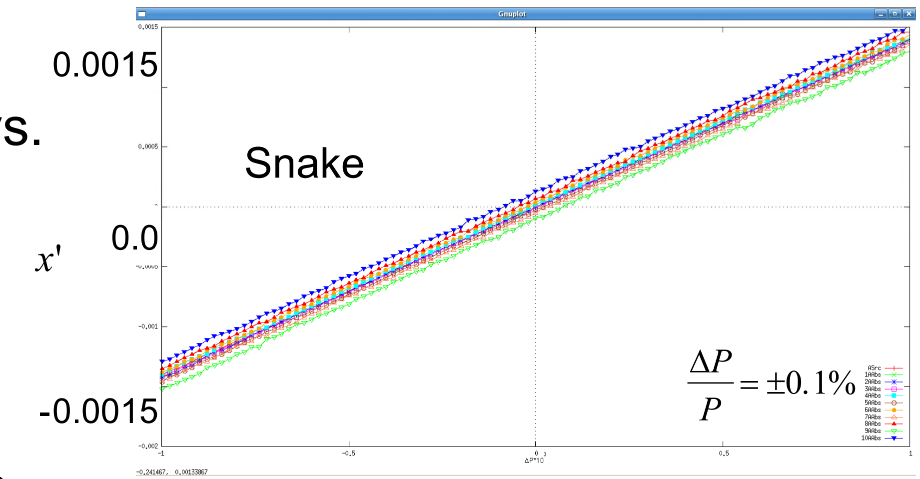
Dispersion Prime

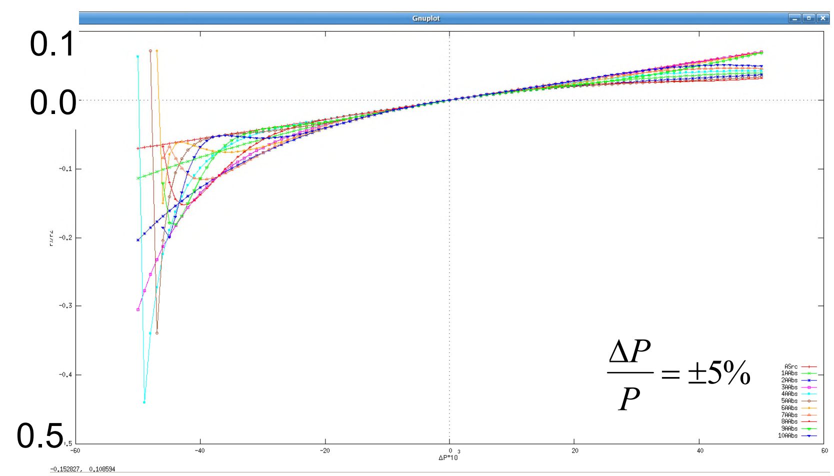
- Initial beam at x = x' = y = y' = 0
- 100 tracks with momentum spread ± 5%, but δ is not matched to x'
- P_o = 100 MeV/c



Matched Dispersion Prime

- <u>Snake lattice</u> studies
  - Match initial values of x’ vs. δ to get best beam behavior along the beamline
  - Study wider momentum spread: chromatic aberrations cause particle loss at low momenta (10 cells)
- <u>Chicane lattice</u> shows very different behavior – unmatched but bound trajectories at the same η’





MANX-The Idea

Muon Collider And Neutrino Factory eXperiment

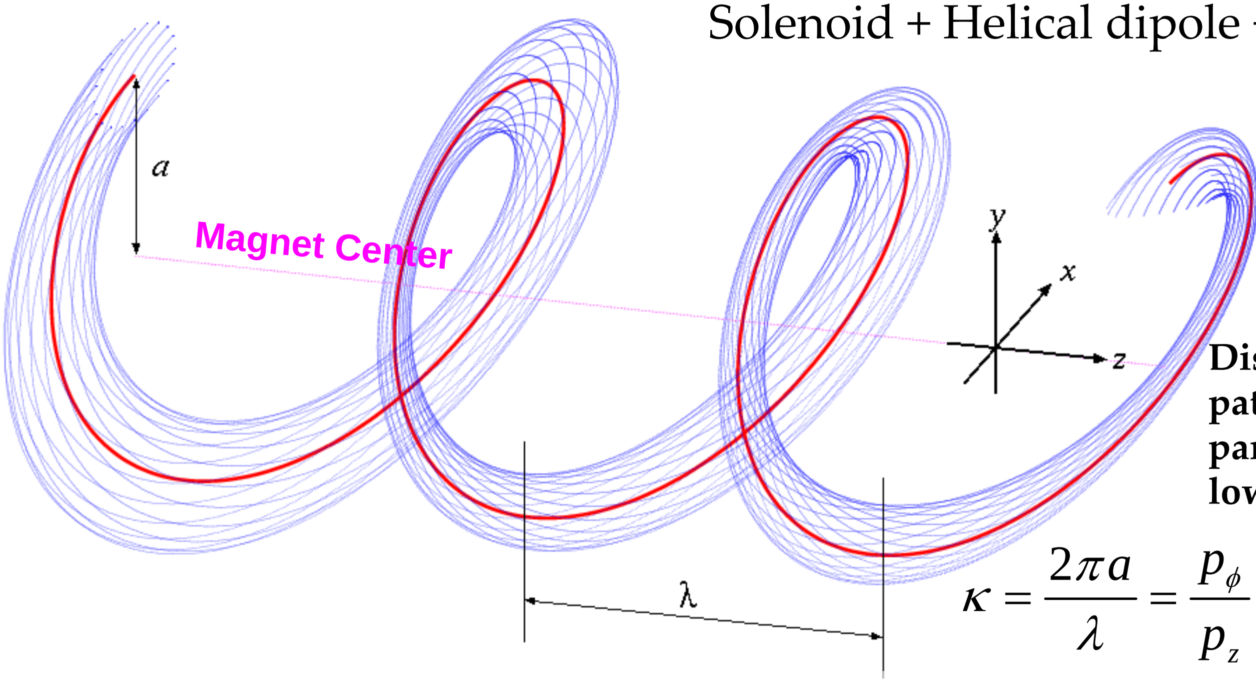
- Test of the HCC concept.
- To Demonstrate
  - Longitudinal cooling
  - 6D cooling in cont. absorber
  - Prototype precooler
  - Helical Cooling Channel
  - Alternate to continuous RF
- Initially intended to follow the Muon Ionization Cooling Experiment (MICE)

MANX-The Experiment (at FNAL)

- MANX is a proof-of-principle experiment.
  - Six dimensional helical cooling theory (ref. PRSTAB 8,041002 (2005)
    - Demonstrate 6D cooling, Continuous emittance exchange, Exceptional cooling performance…
- MANX can be a prototype cooling magnet to R&D of cooling performance for muon colliders
  - MANX can be applied for a short length precooler.
  - Non-linear effects associated with the higher order EM field components and energy loss process.

Particle motion in Helical Magnet

Combined function magnet (invisible in this picture)
Solenoid + Helical dipole + Helical Quadrupole



Red: Reference orbit
Blue: Beam envelope

Dispersive component makes longer path length for higher momentum particle and shorter path length for lower momentum particle.

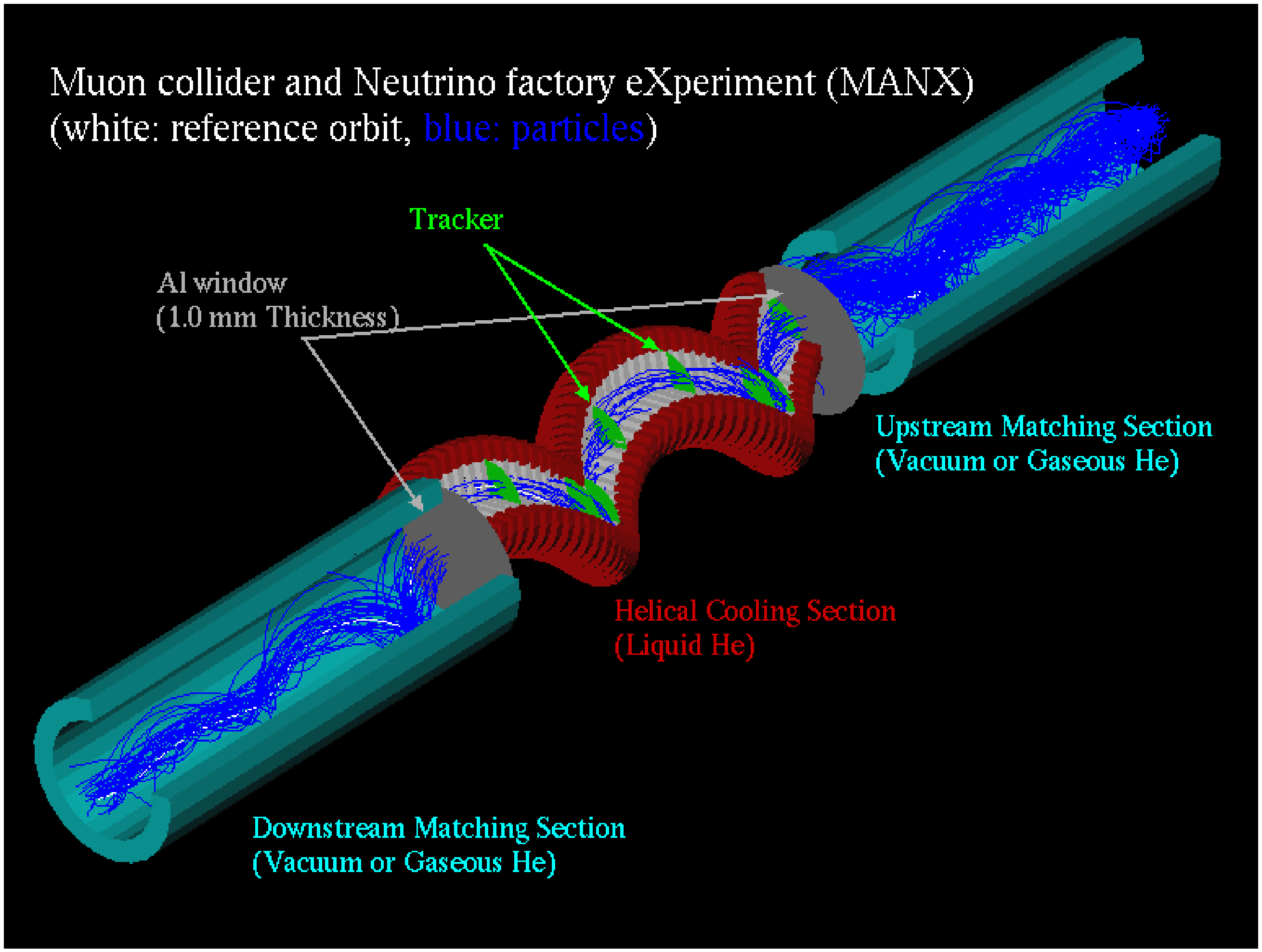
$$\kappa = \frac{2\pi a}{\lambda} = \frac{p_\phi}{p_z}$$

$f_\uparrow \propto b_\varphi \cdot p_z$ Repulsive force
$f_\downarrow \propto -b_z \cdot p_\varphi$ Attractive force

$$f_{central} = \frac{e}{m}(b_\varphi \cdot p_z - b_z \cdot p_\varphi)$$

Both terms have opposite signs.

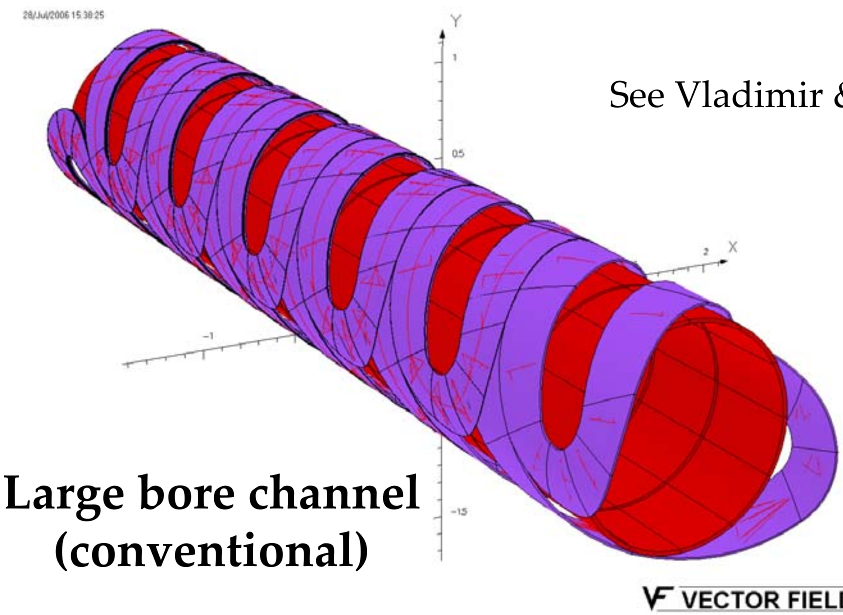
Overview of MANX channel



- Use Liquid He absorber
- No RF cavity
- Length of cooling channel: 3.2 m
- Length of matching section: 2.4 m
- Helical pitch κ: 1.0
- Helical orbit radius: 25 cm
- Helical period: 1.6 m
- Transverse cooling: ~150 %
- Longitudinal cooling: ~120 %
- 6D cooling: ~200 %

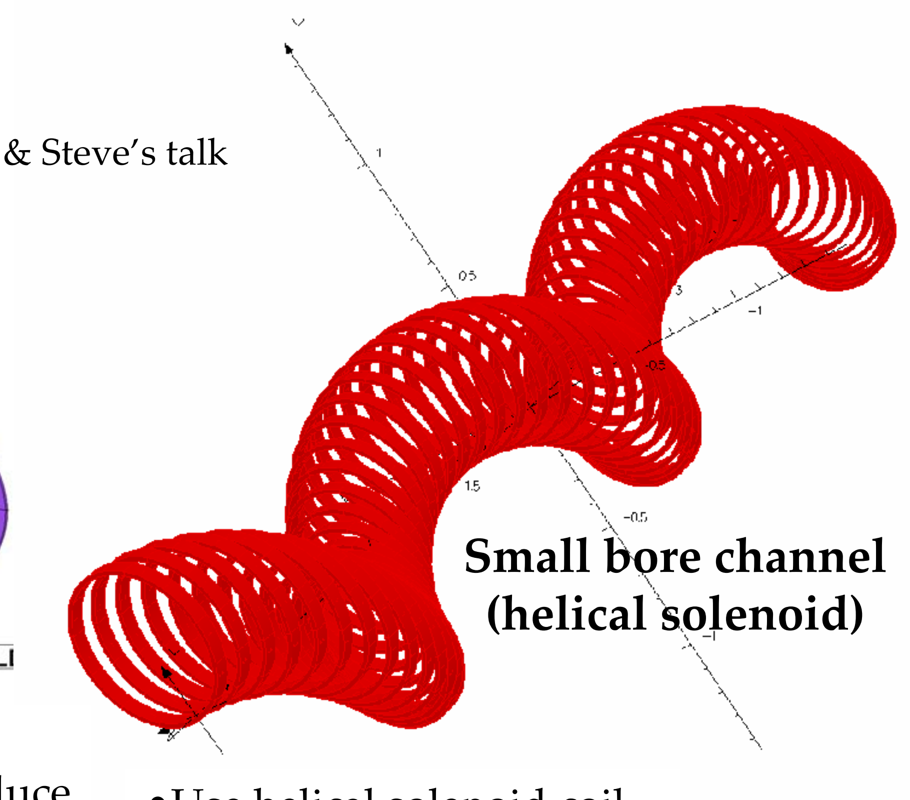
Design practical helical cooling magnet

See Vladimir & Steve's talk



Large bore channel (conventional)

- Siberian snake type magnet
- Consists of 4 layers of helix dipole to produce tapered helical dipole fields.
- Coil diameter: 1.0 m

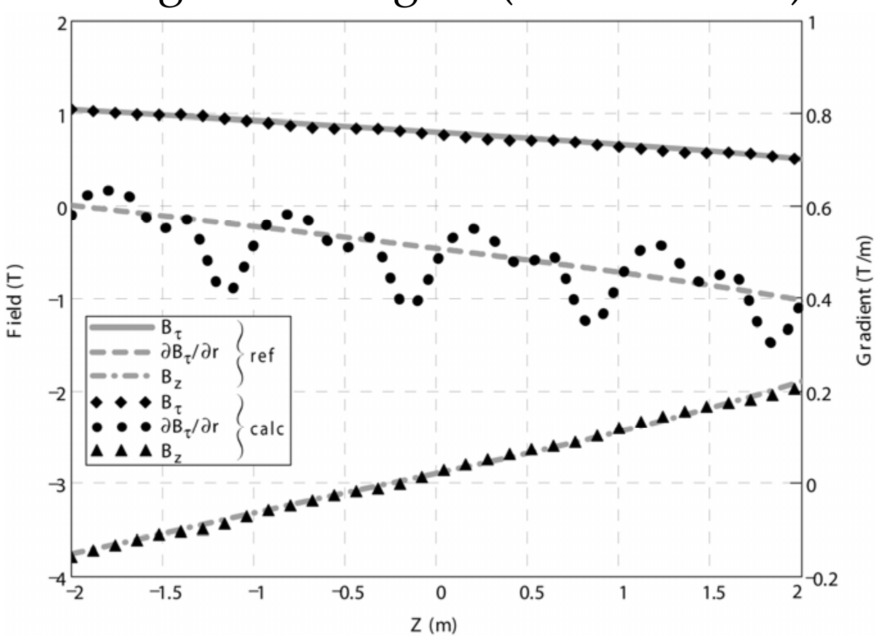


Small bore channel (helical solenoid)

- Use helical solenoid coil
- Consists of 73 single coils.
- Coil diameter: 0.5 m

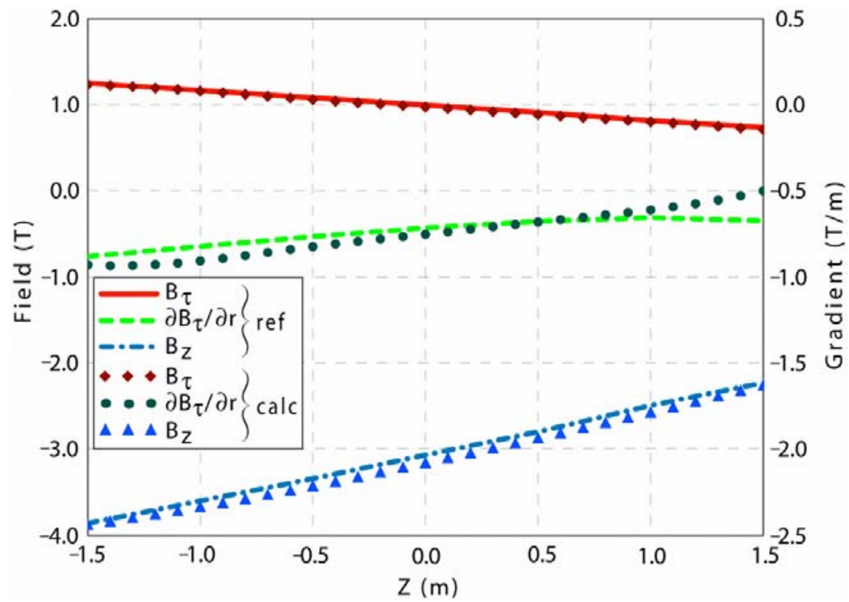
Helical field maps in TOSCA

Large bore magnet (conventional)



- Design with $\lambda = 2.0$ m and $\kappa = 0.8$

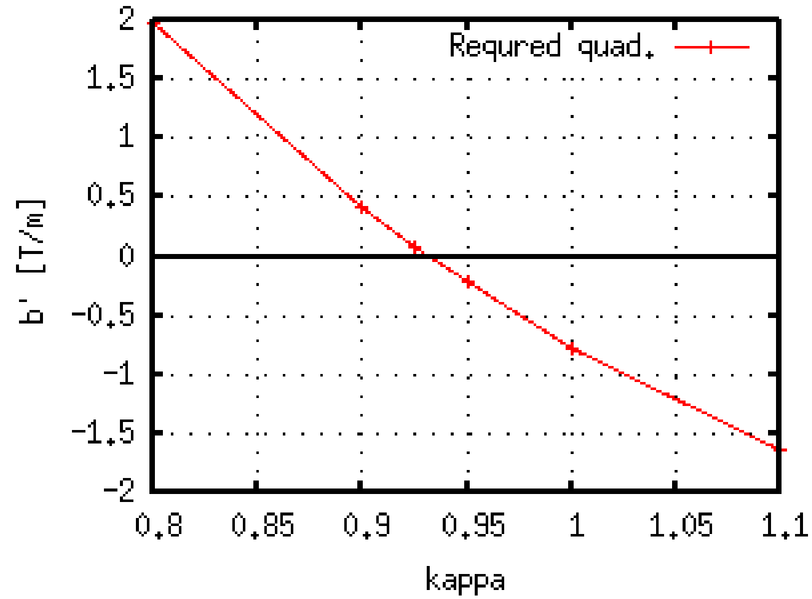
Small bore magnet (helical solenoid)



- Design with $\lambda = 1.6$ m and $\kappa = 1.0$.

Natural quadrupole component in small bore magnet system (helical solenoid)

- Negative field gradient is produced in helical solenoid coils.
- The required helical quadrupole component is changed by κ (helical pitch).
- The strength of the quadrupole component can be adjusted by the solenoid coil diameter.



$\lambda = 1.0$ m, p = 300 MeV/c

Possible beam line in Fermilab site

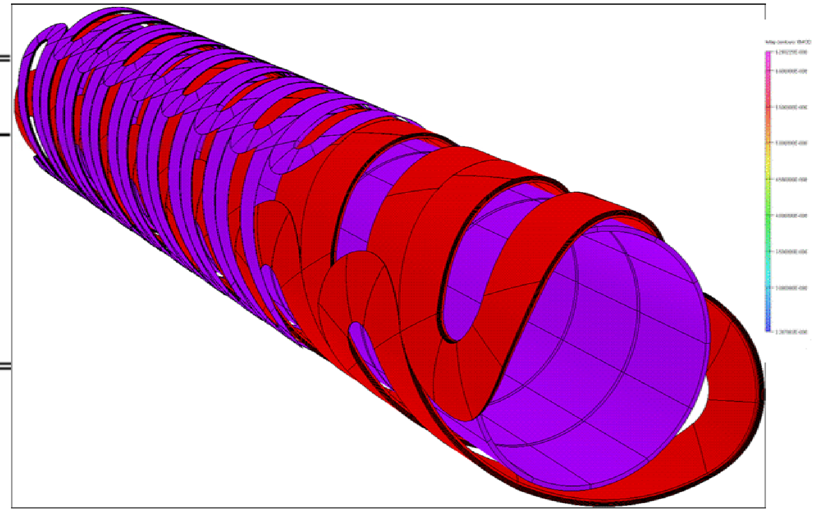
- Candidates
  - Linac (0.4 GeV proton) See Andreas & Dan's talk.
    - Low yield, narrow space
  - Meson Test area (120 GeV proton) Ask B. Abrams.
    - Need energy absorber to reduce momentum.
    - Parasitic design with the ILC detector group
  - pbar accumulator ring (8 GeV)
    - Obtain good quality beam, sufficiently high intensity
    - One of the most preferable place
  - MiniBooNe (8 GeV)
    - Need muon capturing element

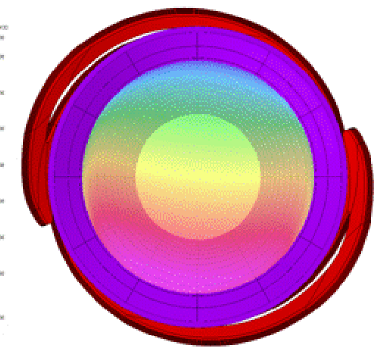
Large Bore Superconducting System

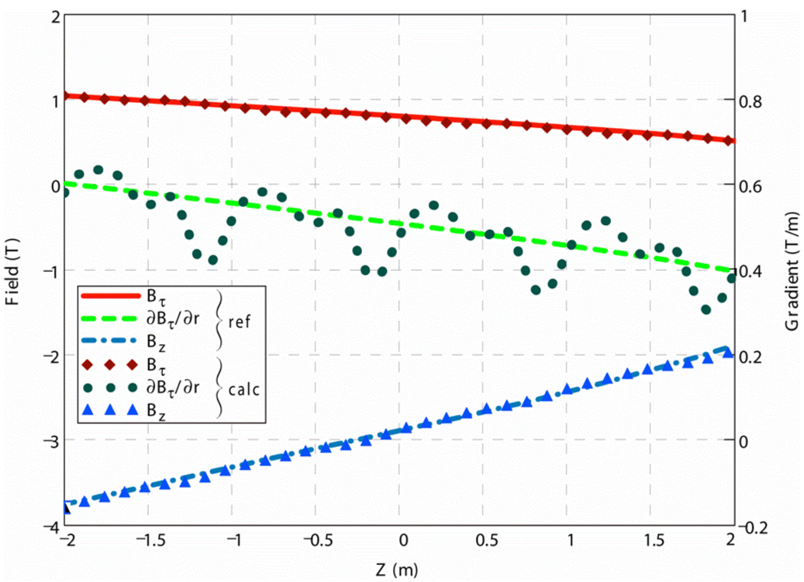
Parameters of Large Bore Cooling Channel

Parameter	Unit	Dipole	Quad	Solen
Inner radius	m	0.55	0.58	0.50
Radial thickness: innermost layer	mm	10.00	1.00	20.00
Radial thickness: all other layers	mm	2.72	1.00	-
Radial space between layers	mm	1.00	1.00	-
Operating current density†	A/mm^2	174.3	61.3	253.6
Operating peak field	T	6.41	2.49	7.60
Quench peak field‡ at 4.2 K	T	8.56	3.66	8.37
Operating stored energy	MJ		31.84	

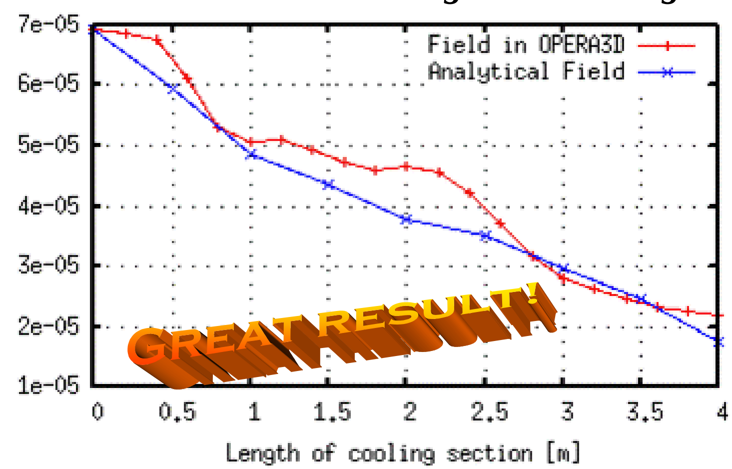
†Calculated as the total current over the total conductor cross-section.
‡Calculated in assumption that the non-Cu fraction of superconductor spans 30% of the total conductor area and the current density in other coils remains at the operating value.







6D emittance evolution in the large bore cooling channel



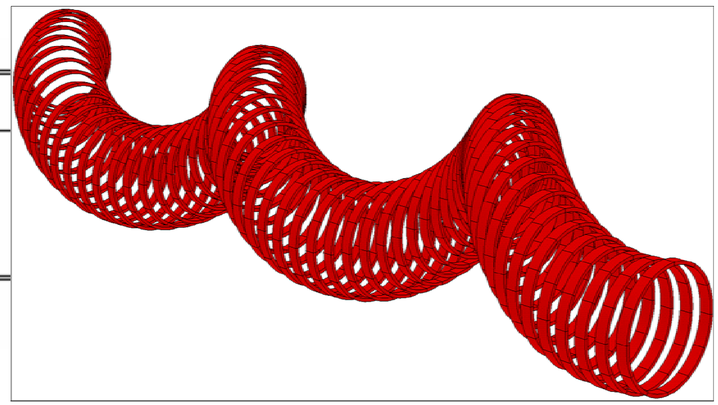
Helical Solenoid

Another novel approach is to use a helical solenoid to generate the needed fields. The solenoid consists of a number of ring coils shifted in the transverse plane such that the coil centers follow the helical beam orbit. The current in the rings changes along the channel to obtain the longitudinal field gradients. Apart from the large bore system, where the longitudinal and transverse field components are controlled by independent windings, the small bore system has a fixed relation between all components for a given set of geometrical constraints. Thus, to obtain the necessary cooling effect, the coil should be optimized together with the beam parameters.

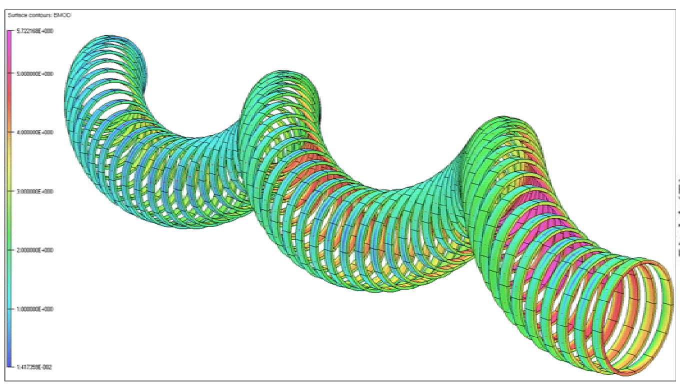
Parameters of Small Bore Cooling Channel

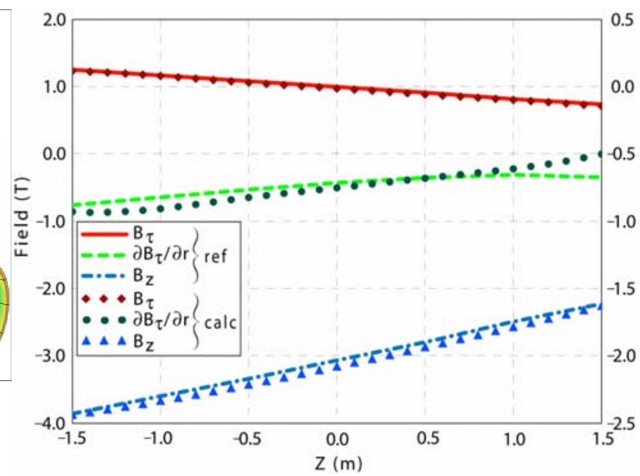
Parameter	Unit	Value
Inner radius	m	0.28
Radial thickness	mm	15.00
Operating current density†	A/mm^2	346.4
Operating peak field	T	5.72
Quench peak field‡ at 4.2 K	T	7.38
Operating stored energy	MJ	4.42

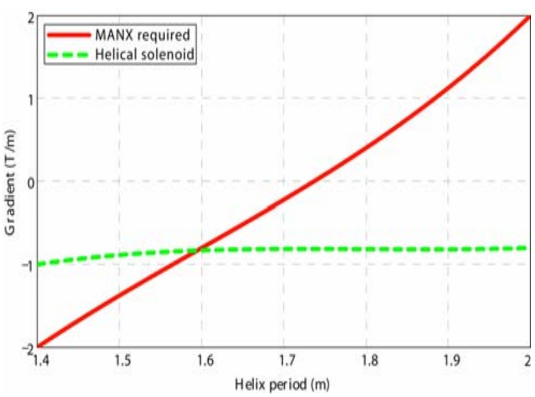
†Calculated as the total current over the total conductor cross-section.
‡Calculated assuming that the non-Cu fraction of superconductor spans 30% of the total conductor area.



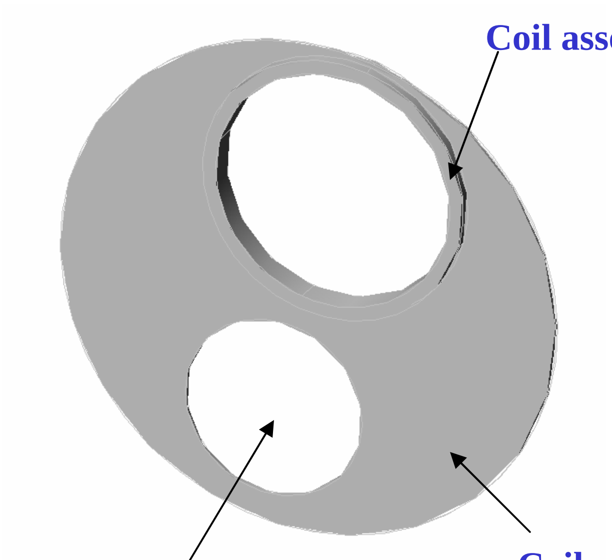
One can see that the optimum gradient for the helical solenoid is -0.8 T/m, corresponding to a period of 1.6 m. Besides that, the system has other variables, one of which is the inner coil radius. For example, 0.2 m radius increase corresponds to -1 T/m change in the transverse field gradient. At the same time, it has a small influence on the dipole and longitudinal field components which provides another effective way to optimize a transverse gradient.







Single Coil Structure



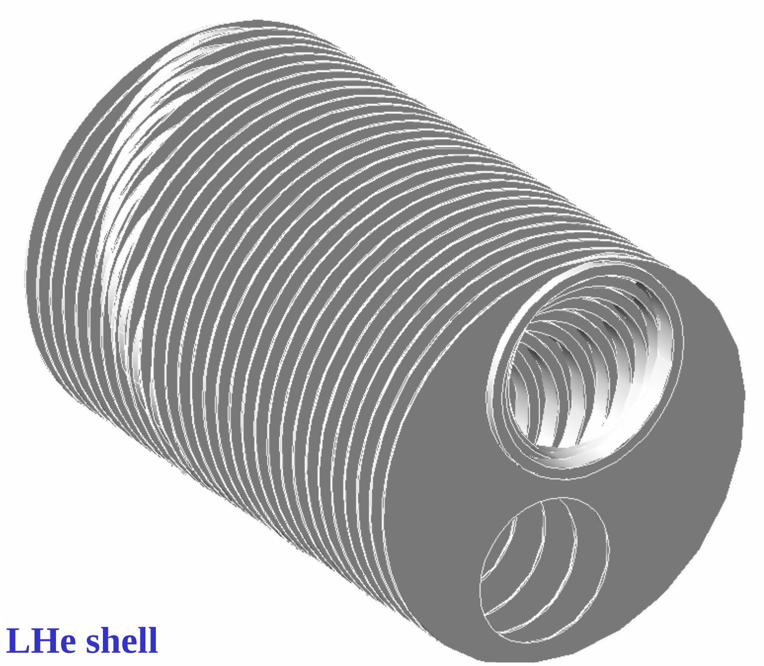
Coil structure

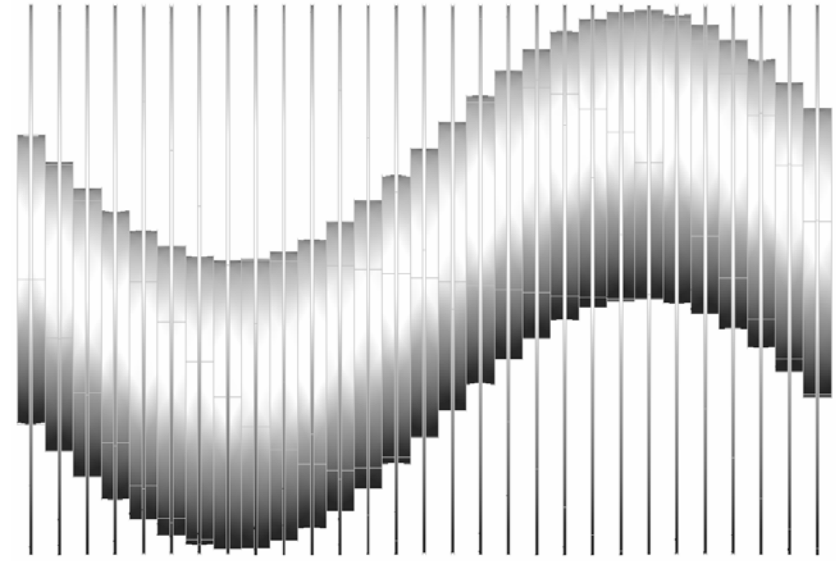
Reserved LHC Cable for MANX

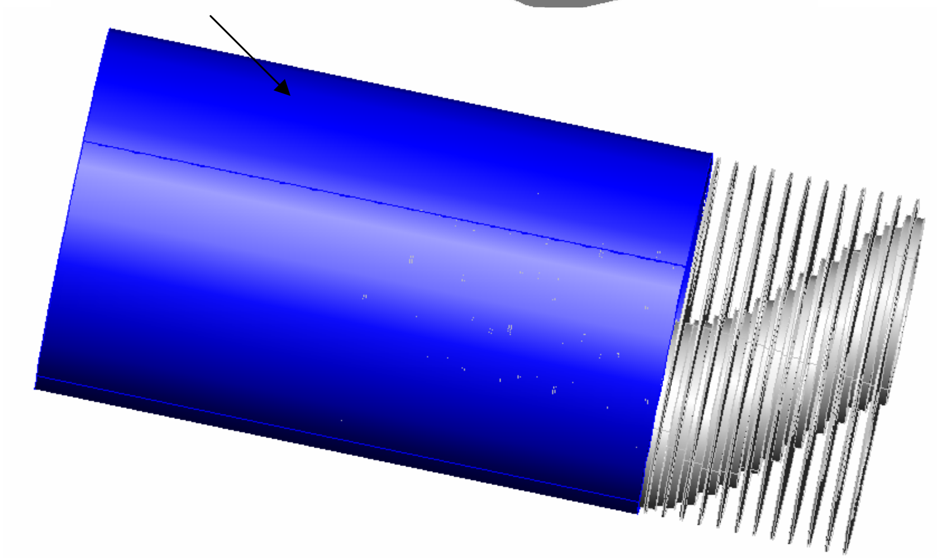
Each coil has one layer and wound from NbTi Rutherford type cable
Cable has Kapton electrical insulation (LHC HGQ type)
After winding coil cured to provide solid mechanical structure
Coil has outer bandage ring to intersept hoop stresses
Coil assembly fixed in radial direction by the coil support
Structure.

V. Kashikhin

Helical Solenoid Cold Mass

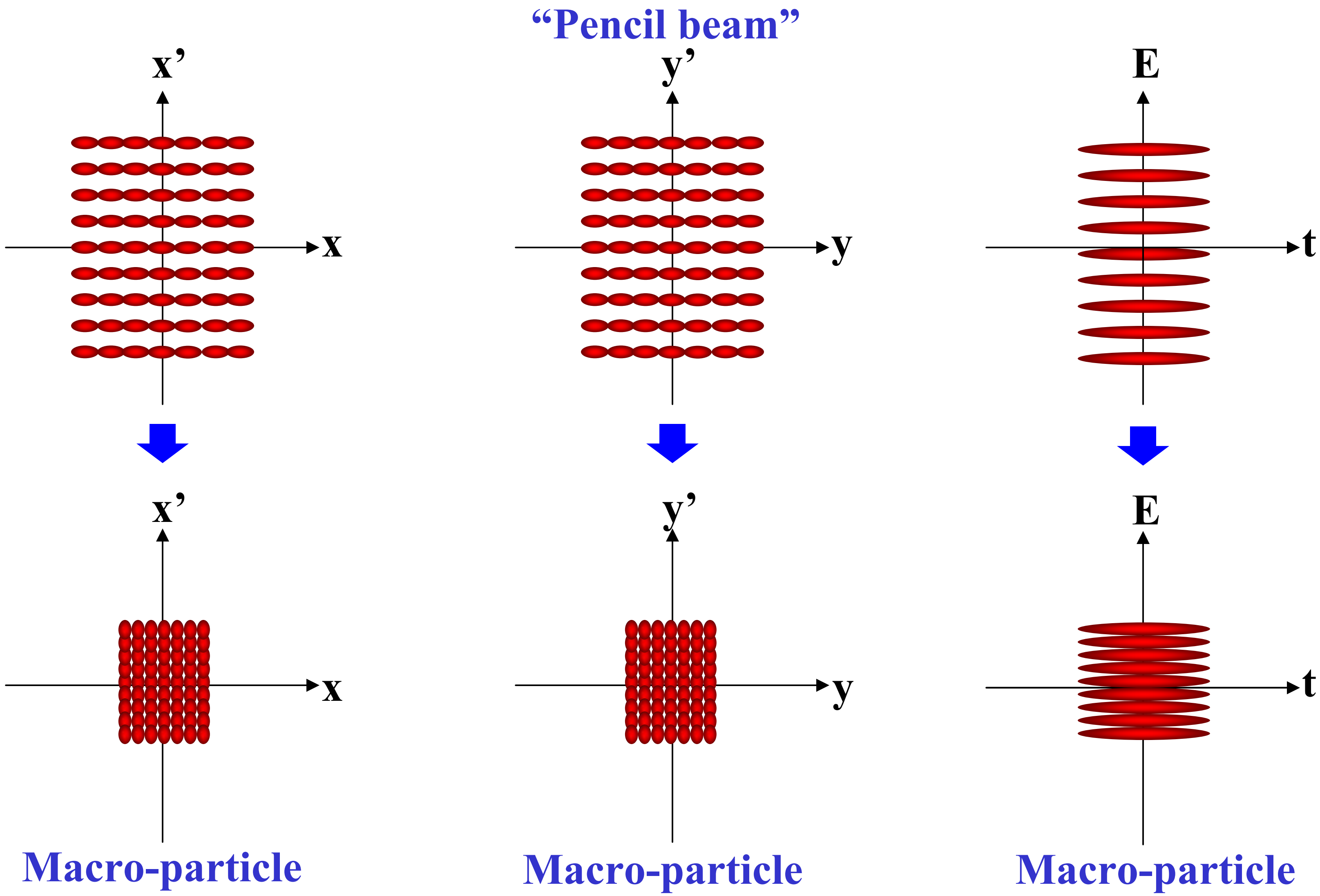






1. The cold mass assembled by 12.4° rotation of each coil assembly around axis Z
2. Technological holes used to splice cables of neigboring coil sections
3. 29 coils form 1.6 m period
4. LHe vessel has longitudinal keys with angular step 12.4 ° to protect coils from rotation under Lorentz forces torques

5D Raster Scan



Muons, Inc.
Innovation in Research

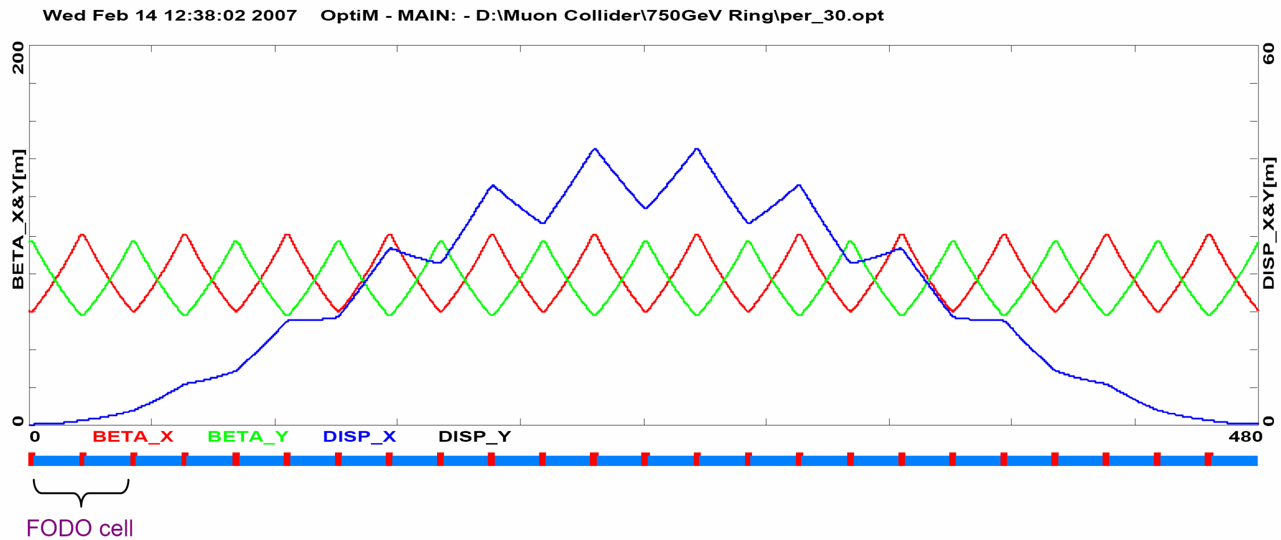
Acceleration, Collider Ring and IR

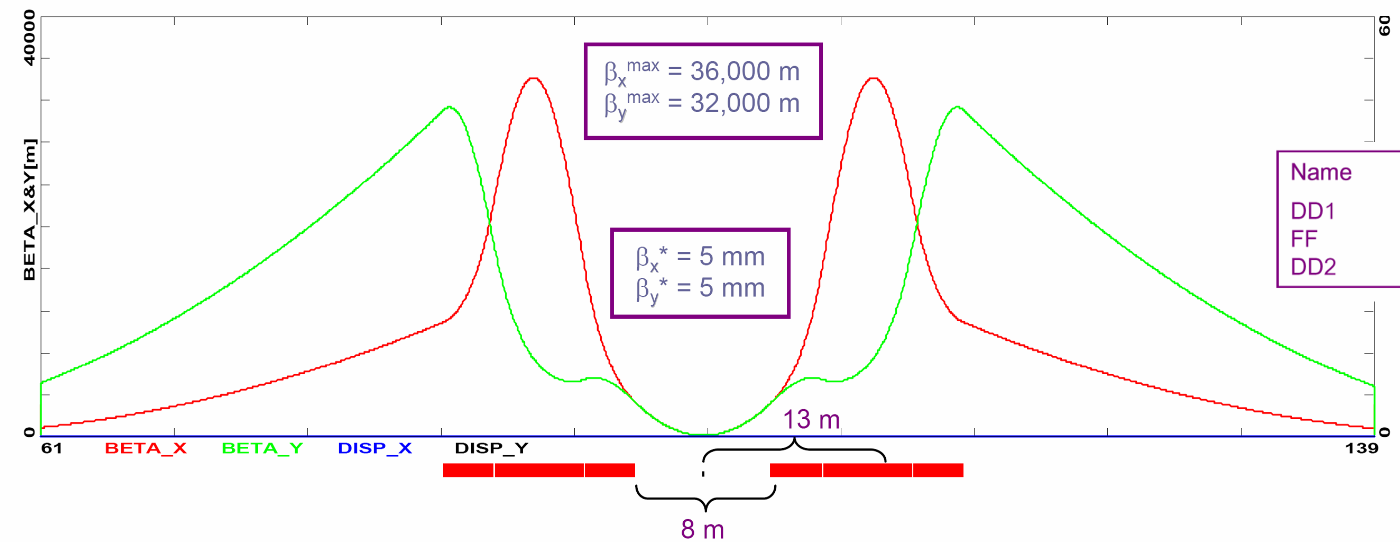
- IR designs and dynamics have been studied for 3-4, 0.5, and 0.1 TeV CoM Muon Colliders and now 1.5 TeV for the Fermilab site.
- Studies are now in progress on how to achieve the required 10^{34} luminosity and what parameters will optimize collider performance for a 1.5 TeV collider

Collider Lattice Design

- β*=3 mm (3 – 4 TeV CoM)
  - A. Garren and C. Johnstone
- β*=1 cm (1.5 TeV, CoM, Fermilab site)
  - Fermilab MCTF (E. Gianfelice and Y. Alexin)
  - Jefferson Lab (A. Bogacz)
  - NFMCC (C. Johnstone, M. Berz, P. Snopok)
- β*= 4 and 14 cm (0.1 TeV CoM)
  - NFMCC (M. Berz, A. Garren, C. Johnstone, P. Snopok, W. Weishi

Lattice and IR





Name	L[cm]	G[kG/cm]
DD1	290	-21.8
FF	510	18.6
DD2	290	-18.2

Rules of Thumb

- IR length scales inversely with β*
- Peak beta and linear chromaticity also scale inversely with β*
- Momentum acceptance scales with β*
- Momentum acceptance is ultimately limited by the chromatic correction
- High-order chromatic correction can be devastating on transverse acceptance
- Even in cm β* lattices we do not see momentum acceptances on the order of 1%

Steps for simultaneously increasing Momentum Acceptance and DA

- Decrease spacing from IP to 1st quad.
- Increase IR quad strength until quad length does not contribute significantly to focal length of triplet - ignore feasibility
- backtrack to get apertures based on magnet shielding requirements,what transverse emittance can be accepted, and what poletips can be achieved..
- Combine transverse + longitudinal optimization studies
- Explore asymmetric emittances – flat beam + doublet IR

Muon Acceleration to 750 GeV in the Fermilab Tevatron Tunnel

D. J. Summers
Univ. of Mississippi - Oxford

Modify the 400 GeV Main Ring

- 70 → 750 GeV in 68 orbits (1.4 ms).
  10 GeV of 1.3 GHz, 30 MV/m SRF.
  Muon Survival = 79%.   r = 1000 m.

Q F	$\mp$1.8T Dipole	+8T Dip.	$\mp$1.8T Dipole	+8T Dip.	$\mp$1.8T Dipole	Q D

3.2 m, 8 Tesla Superconducting Dipoles.
5.7 m, 360 Hz, $\mp$1.8 Tesla Dipoles.

3.3 m, 160 Hz, 30 T/m Quadrupoles.

Eddy Currents: Thin copper wire and .28mm grain oriented Si steel laminations.

Two Ring Option to Reduce Path Length Difference

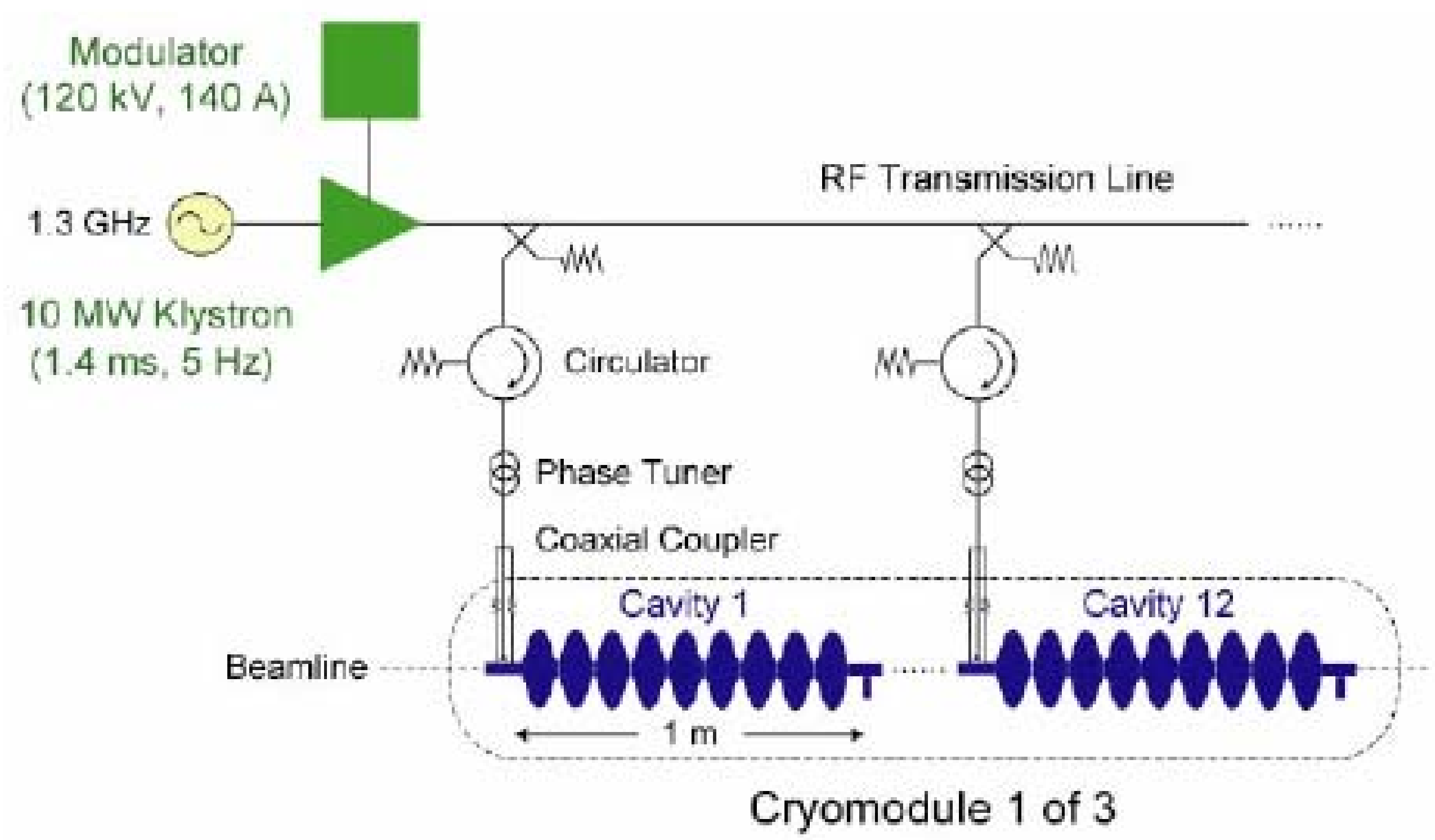
- $20 \rightarrow 400$ GeV in 38 orbits (0.8 ms).
  No superconducting magnets, just Si-iron.
  10 GeV of 1.3 GHz, 30 MV/m SRF.

- $400 \rightarrow 900$ GeV in 50 orbits (1.1 ms).
  Hybrid magnet system with larger superconducting magnet fraction.

Enabling Technology: Grain Oriented Silicon Steel

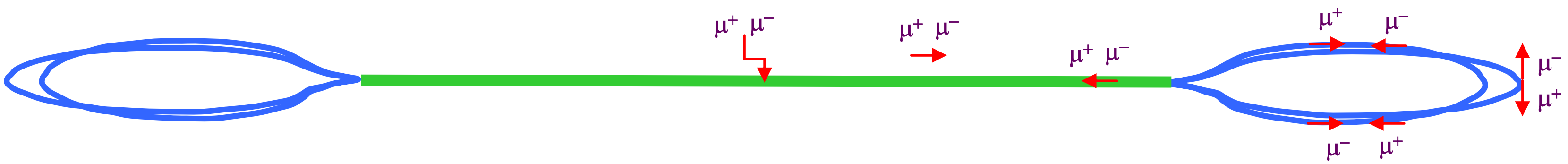
Much less $E = B^2/2\mu$ in Si-steel at 1.8T.

- Energy of Ten 10MW Klystrons in 1.4ms.
  140 000 Joules.
- Options to get enough energy.
  Twenty Klystrons, Two couplers per cavity.



Muon Acceleration in 'Dogbone' RLA
Alex Bogacz, Jefferson Lab

Simultaneous acceleration both μ^+ and μ^- species



better orbit separation at linac's end ~ energy difference between consecutive passes (2ΔE)

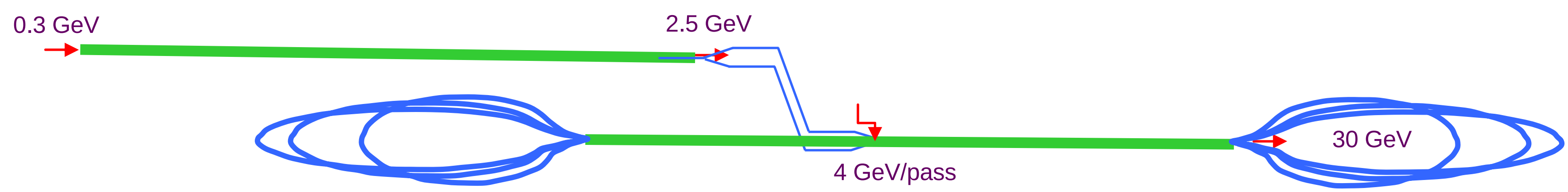
Two-step-RLA Acceleration Scenario

- L.E. RLA (2.5 GeV to 30 GeV)
  - 7.5-pass 'Dogbone' RLA: Linac (160 m, 4 GeV/pass) + 7 droplette Arcs
  - SRF: 400 MHz, 25 MeV/m
  - Top-to-injected energy ratio = 12
- H.E. RLA (30 GeV to 750 GeV)
  - 7-pass 'Dogbone' RLA: Linac (4114 m, 103 GeV/pass) + 7 droplette Arcs
  - SRF: 1300 MHz, 25 MeV/m
  - Top-to-injected energy ratio =25

30 GeV Dogbone RLA (7.5 pass)

energy ratio:

$$\frac{E_f}{E_0} = 12$$



Conclusions