Design MANX experiment

MANX magnet, Matching, and More

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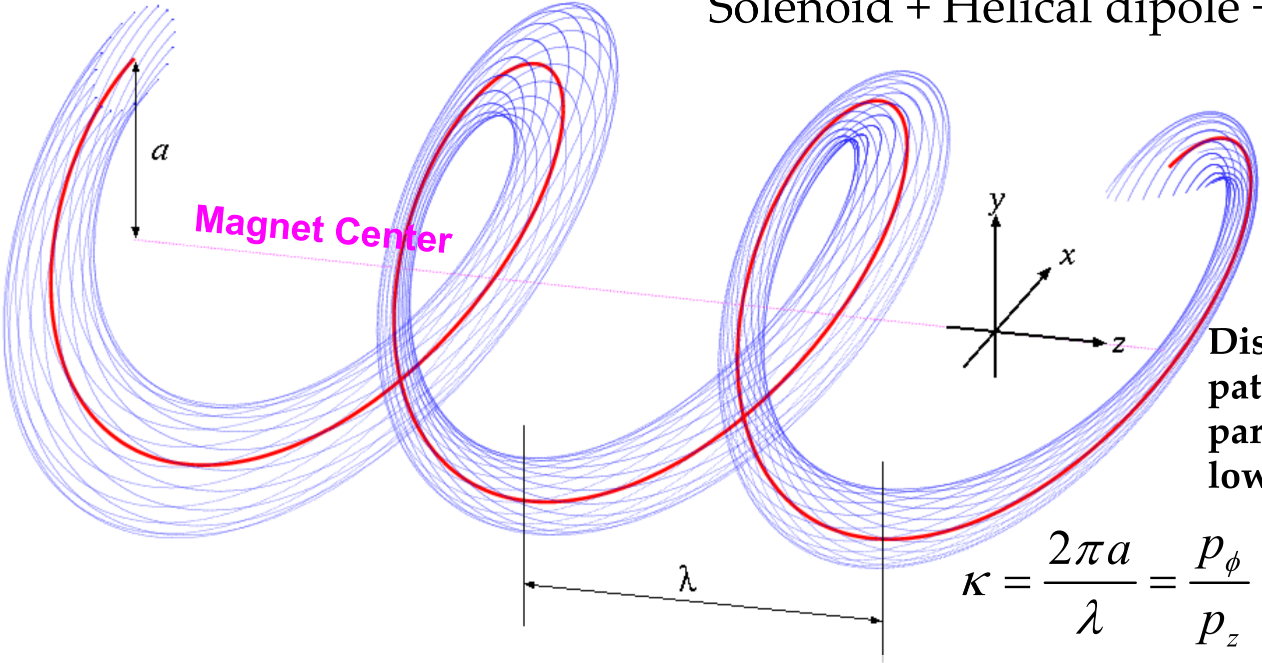
Aim of the MANX experiment

- 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.
  - – Synchrotron motion and transverse and longitudinal coupling with the beta function in HCC.
  - – 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.

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

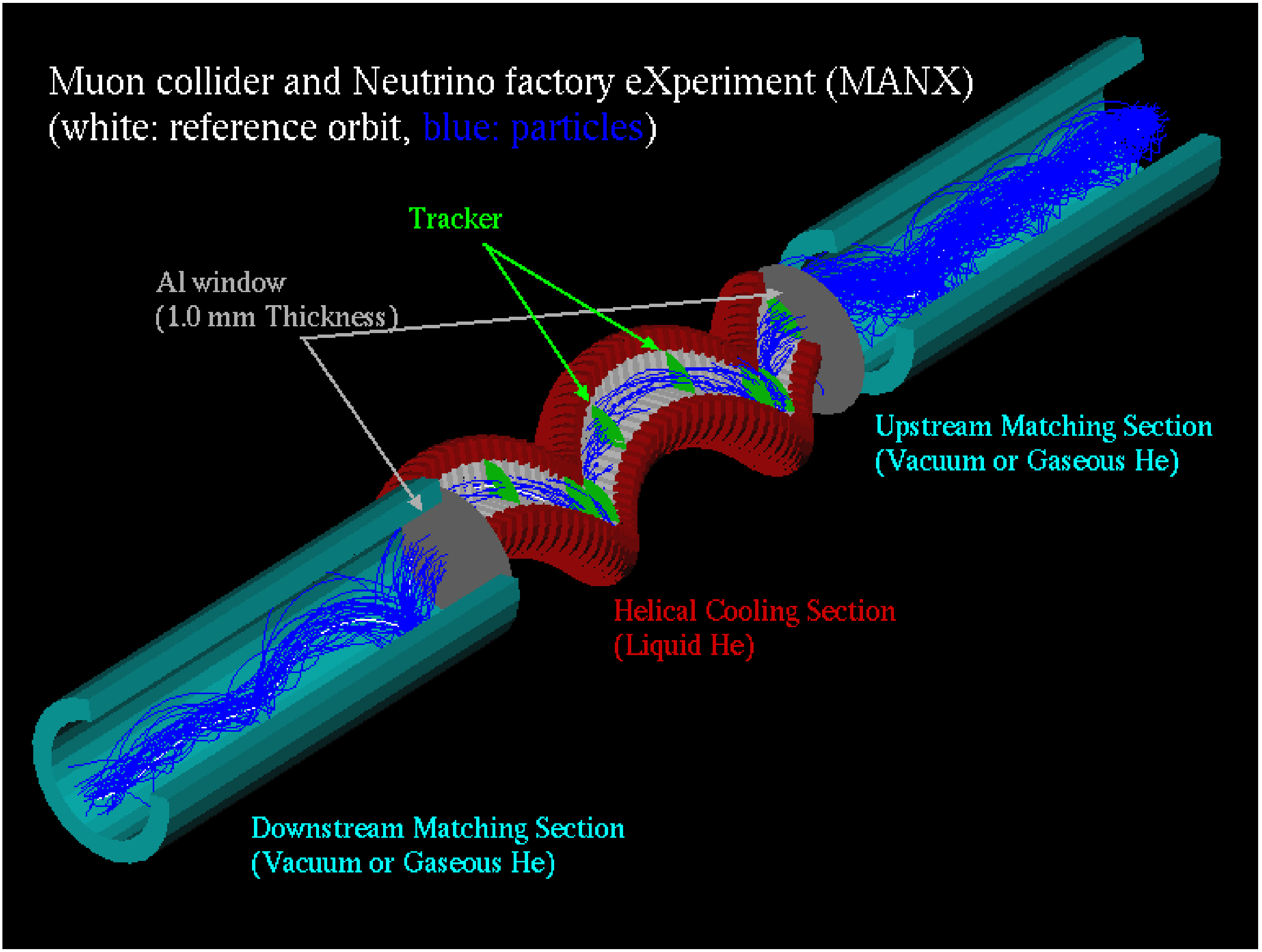
$$f_\uparrow \propto b_\varphi \cdot p_z \quad \text{Repulsive force}$$

$$f_\downarrow \propto -b_z \cdot p_\varphi \quad \text{Attractive force}$$

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

Both terms have opposite signs.

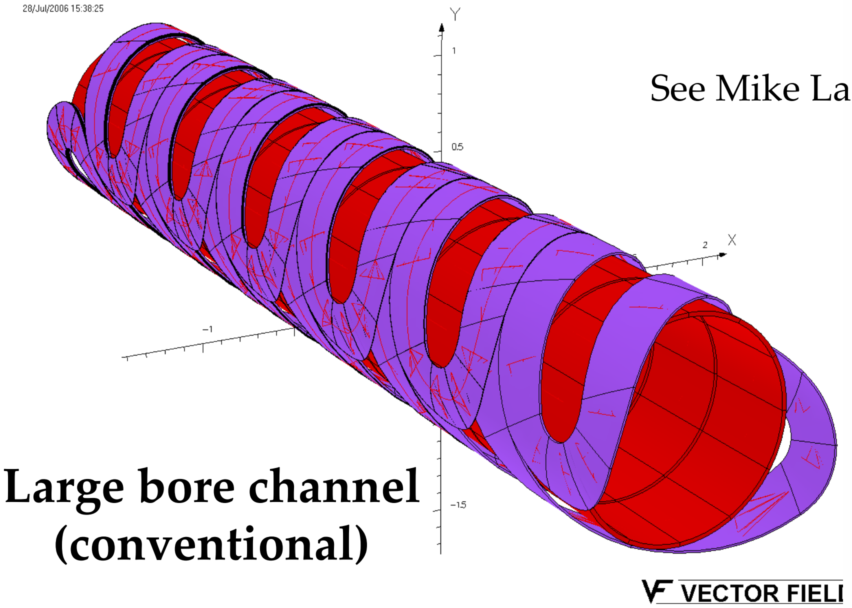
Overview of MANX channel



- 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 %

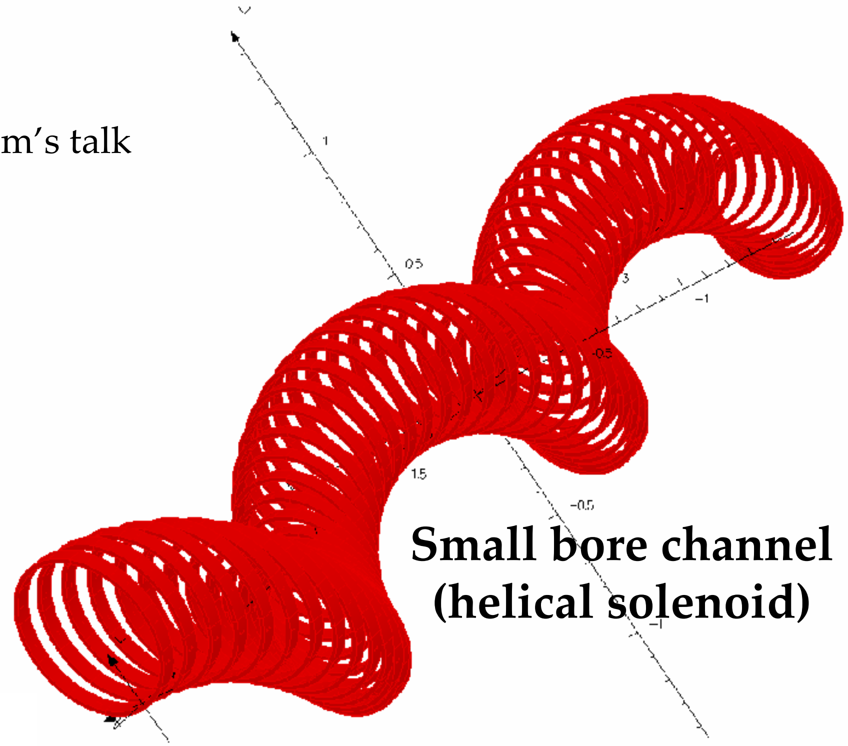
Design practical helical cooling magnet

See Mike Lamm’s talk



Large bore channel (conventional)

- Siberian snake type magnet
- Consists of 4 layers of helix dipole to produce tapered helical dipole fields.
- Maximum field is ~7 T (coil diameter: 1.0 m)

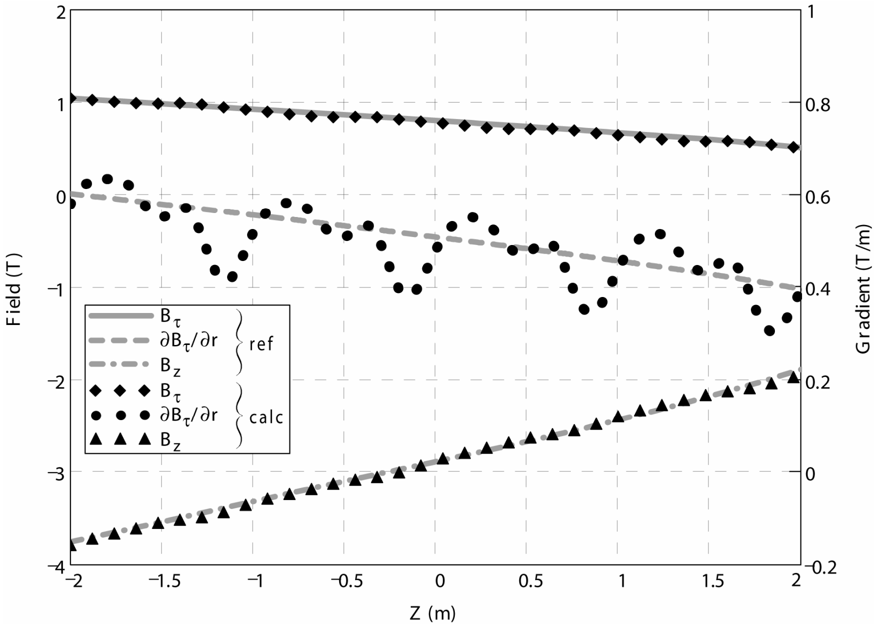


Small bore channel (helical solenoid)

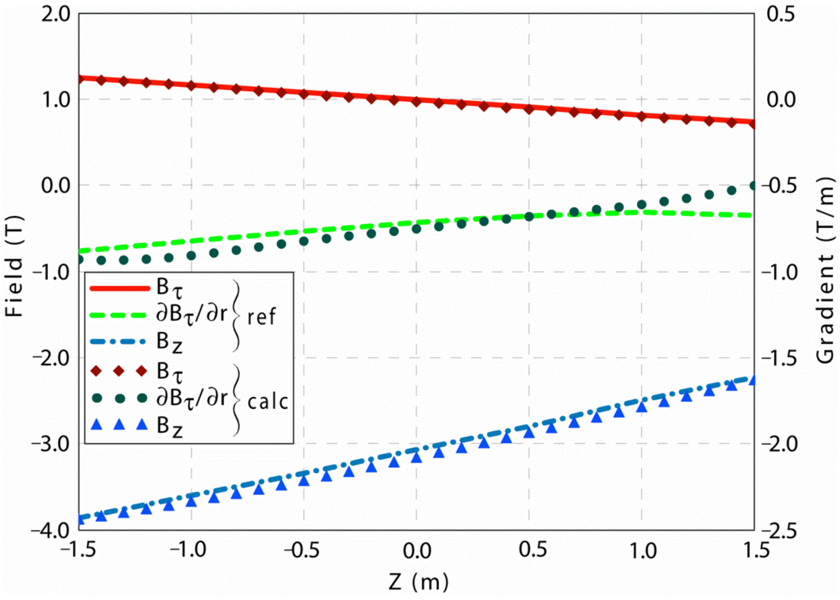
- Use helical solenoid coil
- Consists of 73 single coils (no tilt).
- Maximum field is ~5 T (coil diameter: 0.5 m)
- Flexible field configuration

Helical field maps in TOSCA

Large bore magnet (conventional)



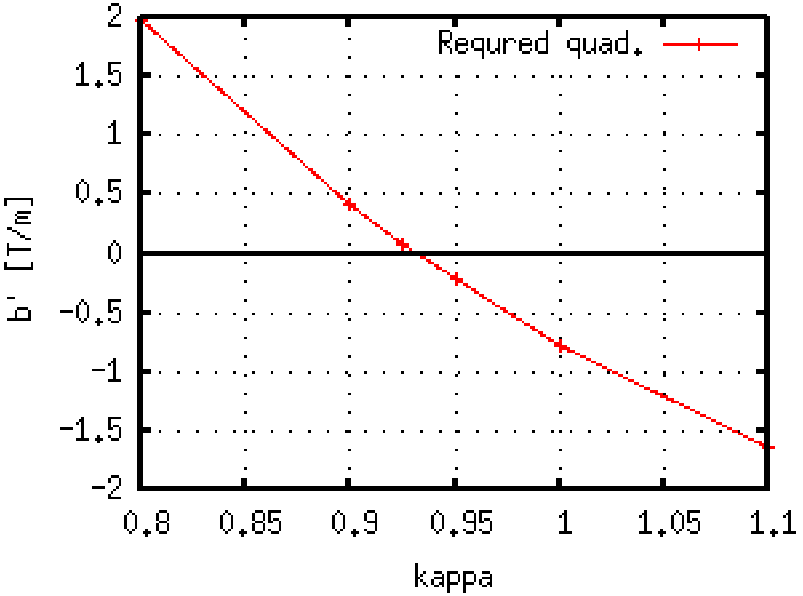
Small bore magnet (helical solenoid)



- Design with $\lambda = 2.0$ m and $\kappa = 0.8$
- Design with $\lambda = 1.6$ m and $\kappa = 1.0$.

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

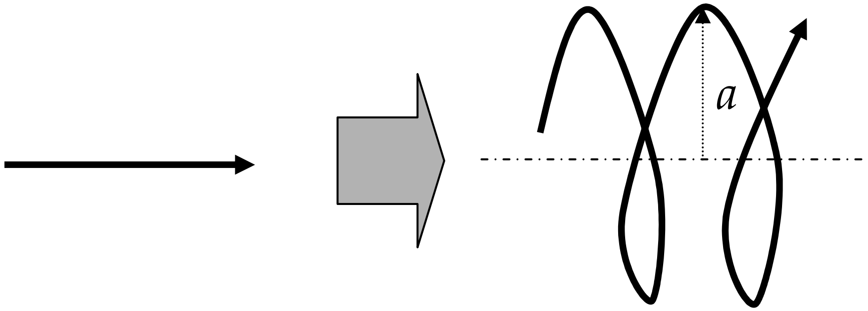
- Negative field gradient is produced in helical solenoid coils.
- The required helical quadrupole component is changed by κ (helical pitch).
- The strength of the quadrupole component can be adjusted by the solenoid coil diameter.



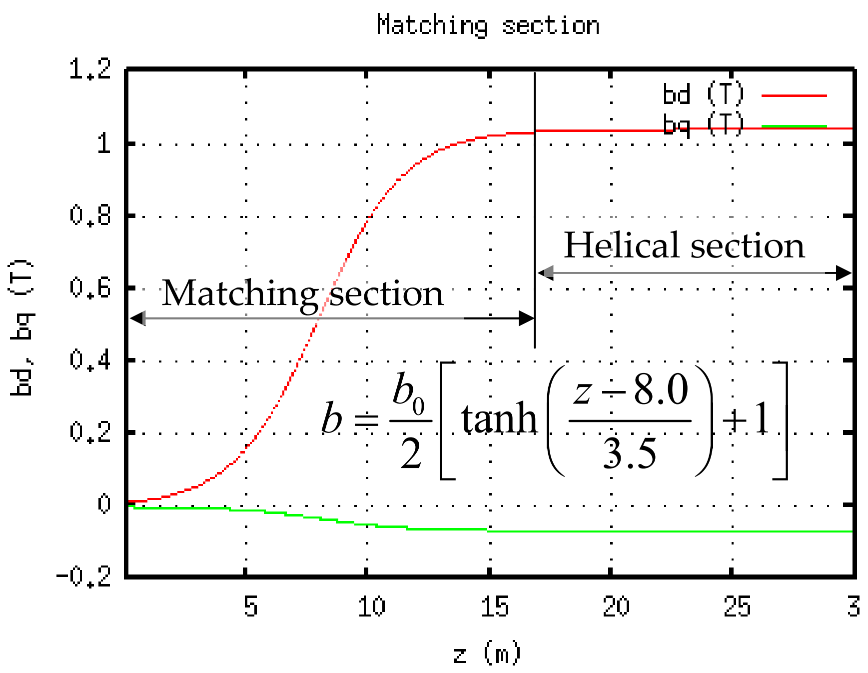
λ = 1.0 m, p = 300 MeV/c

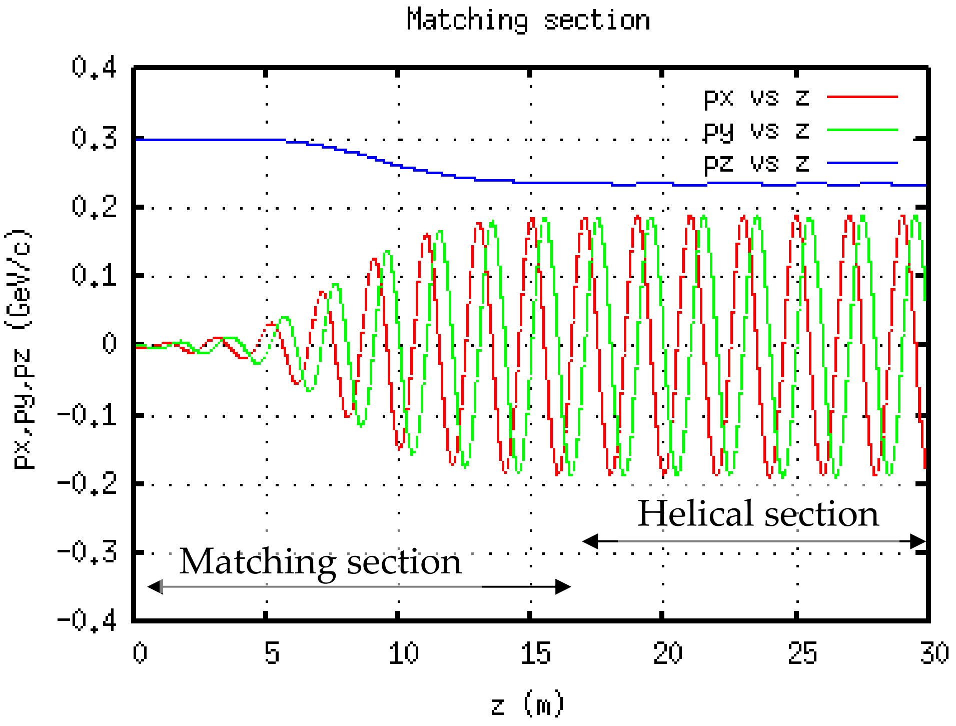
Matching design

- Connect the straight beam section to the helical beam section.
  - Need to induce
    - Helical pitch κ (=pϕ/pz)
    - Helical radius *a*



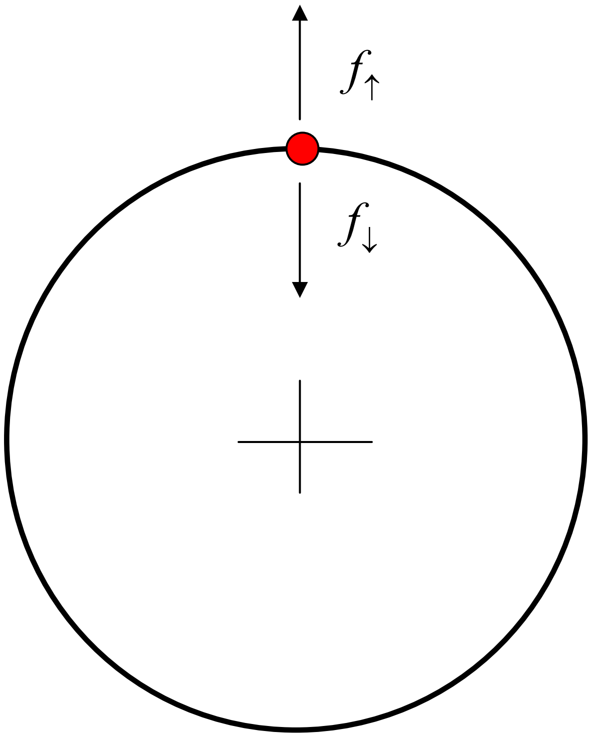
Adiabatic method





- Use atan to make smooth tapered field.
- Clearly see a smooth tracking.
- This channel is needed 10~15 meters.

Can we make a shorter matching section?



Equilibrium orbit (ref orbit)

$$\boxed{f_\uparrow \propto b_\varphi \cdot p_z \quad \text{Repulsive central force}}$$

$$\boxed{f_\downarrow \propto -b_z \cdot p_\varphi \quad \text{Attractive central force}}$$

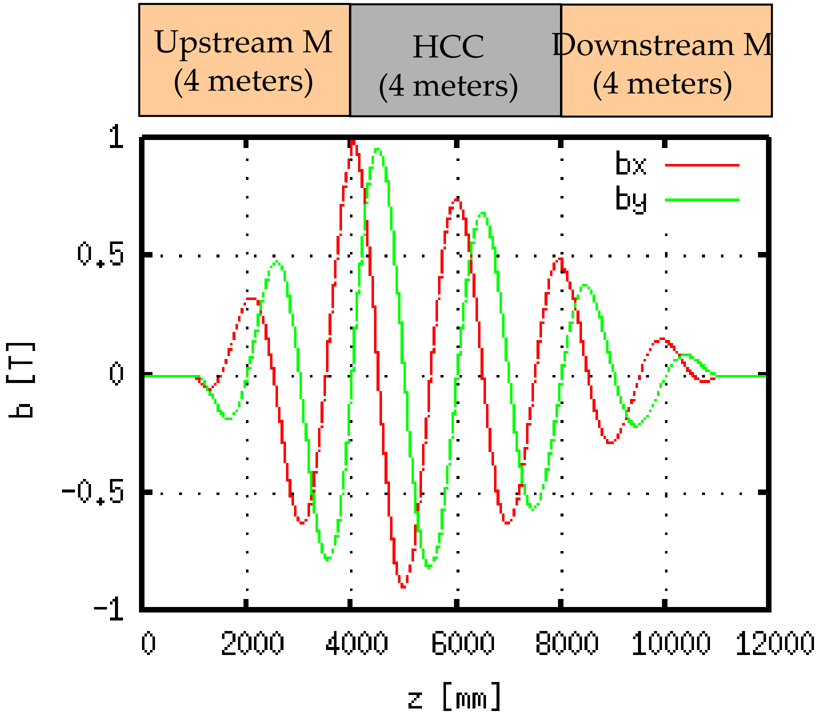
$$f_{central} = \frac{e}{m}\left(b_\varphi \cdot p_z - b_z \cdot p_\varphi\right)$$

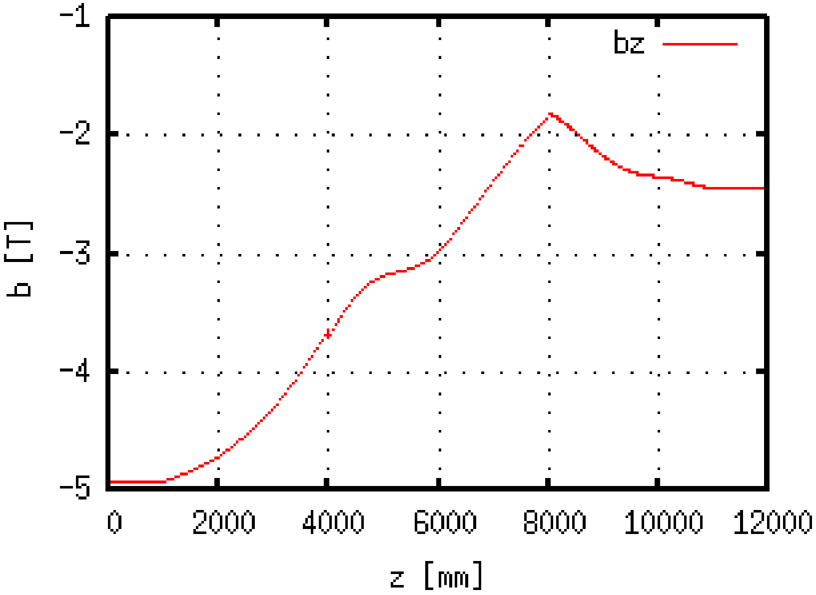
$$\longrightarrow \quad \frac{\partial p_\varphi}{\partial a} = \alpha b_\varphi + \beta b_{solenoid} + \delta \frac{\partial b_\varphi}{\partial a} + \varepsilon \frac{\partial b_{solenoid}}{\partial a}$$

- Transverse bφ field produces transverse p kick.
- Solenoid bz field stabilizes orbit.

α, β, δ, and ε are the coefficients.

Shorter matching and HCC field map





Use linear function for first trial

$$b_{matching} = \alpha b_0 z$$

b_0: Amplitude of initial helical dipole magnet

α: Ramping rate

Adjust solenoid strength to connect to a proper helical orbit.

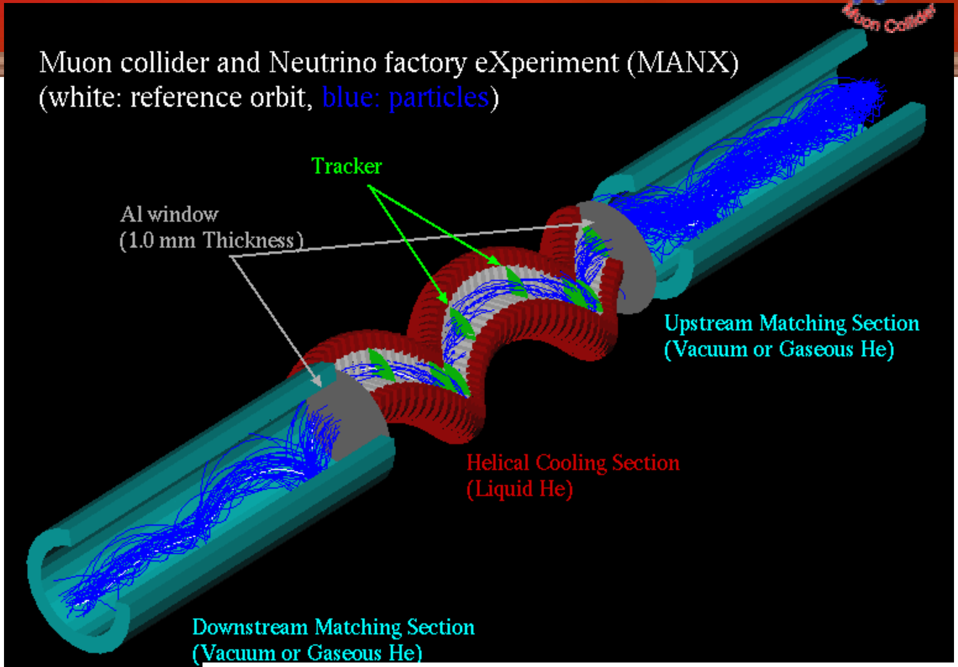
Simulation study

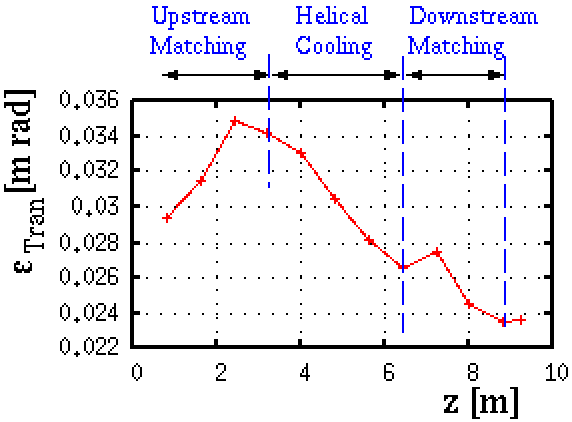
Initial beam profile

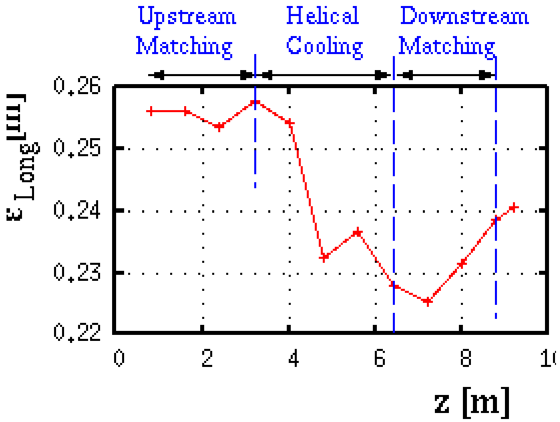
- Beam size (rms): ± 60 mm
- $\Delta p/p$ (rms): ± 40/300 MeV/c
- x′ and y′ (rms): ± 0.4

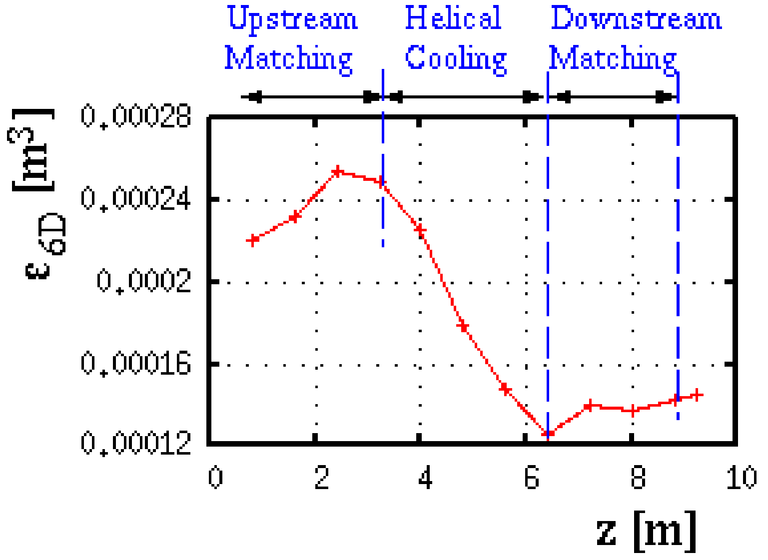
(Acceptance study has not been done yet.)

- Obtained cooling factor: ~200%


Muon collider and Neutrino factory eXperiment (MANX)
(white: reference orbit, blue: particles)







Discussion of simulation result

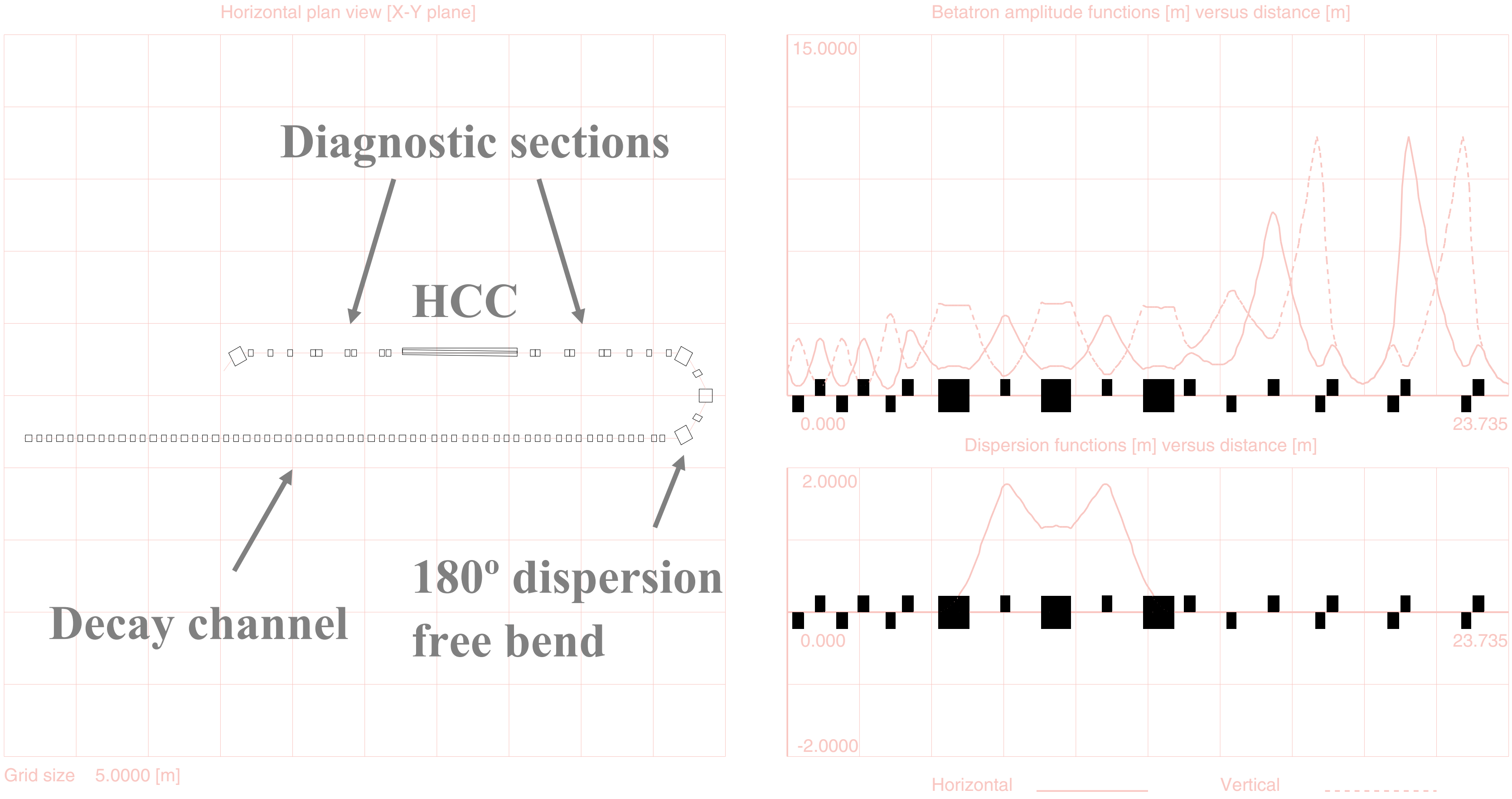
- Good cooling performance is preserved in the helical solenoid coil magnet.
- Longitudinal betatron oscillation makes complicated emittance evolutions.
- Optimize matching magnet
  - Fine tune Twiss parameters
- Optimize MANX magnet
  - Obtain the best cooling performance.

Possible beam line in Fermilab site

- Candidates
  - Linac (0.4 GeV proton) See Andreas Jansson'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

Preliminary optics design in MTA

See Andreas Jansson’s talk



Diagnostic sections

HCC

Decay channel

180° dispersion free bend

Uses BNL D2 quads **“Almost” fits in MTA**

Spectrometer design

- 6D phase space (or emittance exchange) measurements at HCC entrance/exit are the minimum requirement to verify the cooling theory.
- Single particle tracking measurement vs beam measurement
  - Cost, reliability, precision, beam transport, etc…
  - Fermilab AD now consider rastering a pencil beam.
- The hardest part of the spectrometer design is how to determine the longitudinal phase space.
  - Time structure measurement?
  - HCC is a kind of spectrometer itself. Therefore, we can determine the momentum by tracking the particle in HCC.
  - Other interesting parameter is the feature of isochronous. This can be done by measuring ToF between upstream and downstream spectrometers.
  - PID?

Conclusions

- Big inflation in magnet design
- Found the simple solution for matching
- Need fine tuning
- Beam line design in progress
- Spectrometer design in progress

Collaborators list

Muons, Inc.

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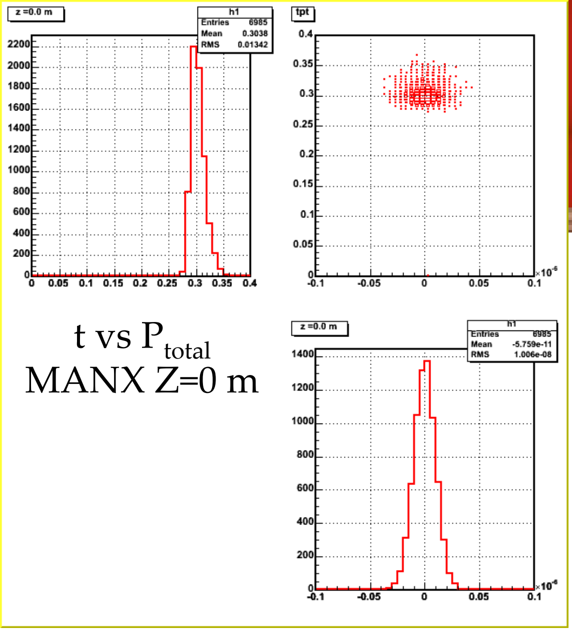
Fermilab Accelerator Division

C. Ankenbrandt, D. Broemmelsiek, M. Hu, A. Jansson, M. Popovic, V. Shiltzsev

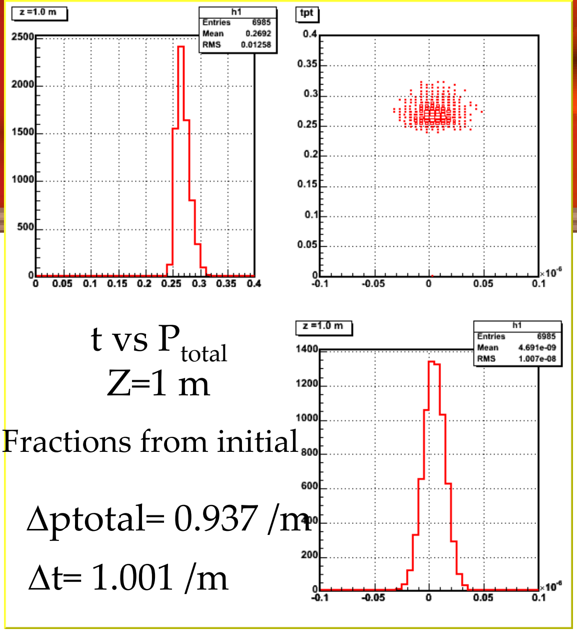
And many useful comments & suggestions from Muon Collider Task Force people

Appendix

- Show isochronous feature in HCC



t vs P_{total}
MANX Z=0 m

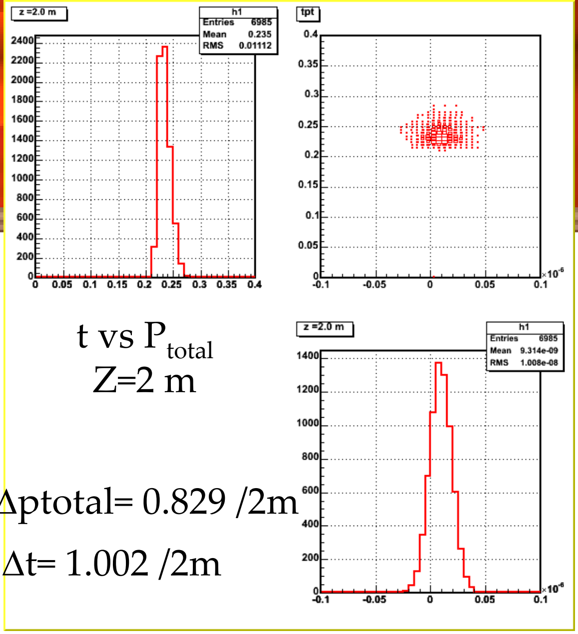


t vs P_{total}
Z=1 m

Fractions from initial

Δptotal= 0.937 /m

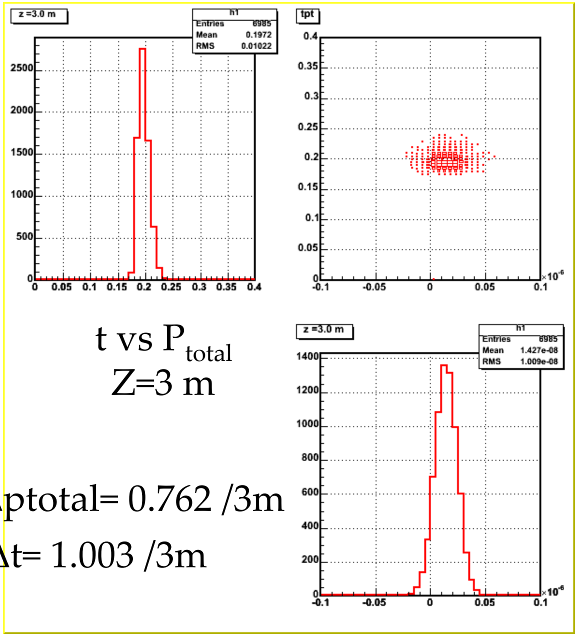
Δt= 1.001 /m



t vs P_{total}
Z=2 m

Δptotal= 0.829 /2m

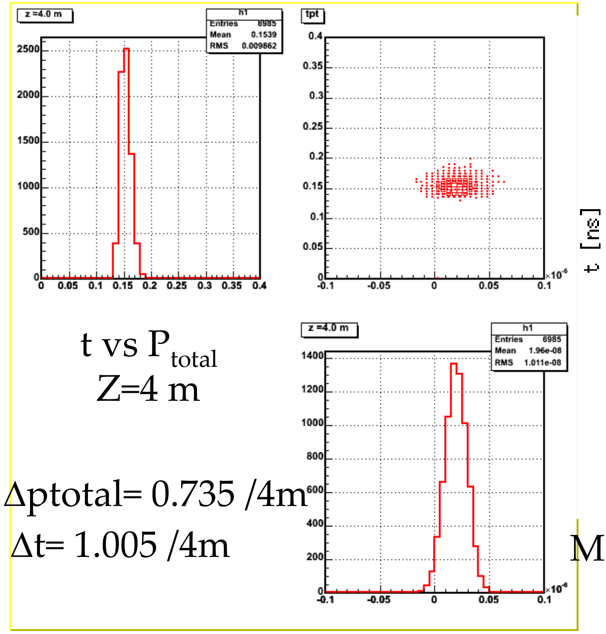
Δt= 1.002 /2m



t vs P_{total}
Z=3 m

Δptotal= 0.762 /3m

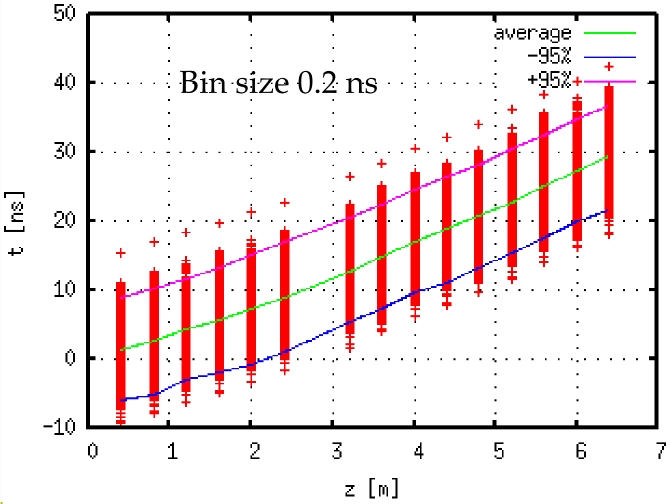
Δt= 1.003 /3m



t vs P_{total}
Z=4 m

Δptotal= 0.735 /4m

Δt= 1.005 /4m



Bin size 0.2 ns

Momentum compaction factor $\eta = 0.34$

$\gamma_t^{-2} = 0.72$