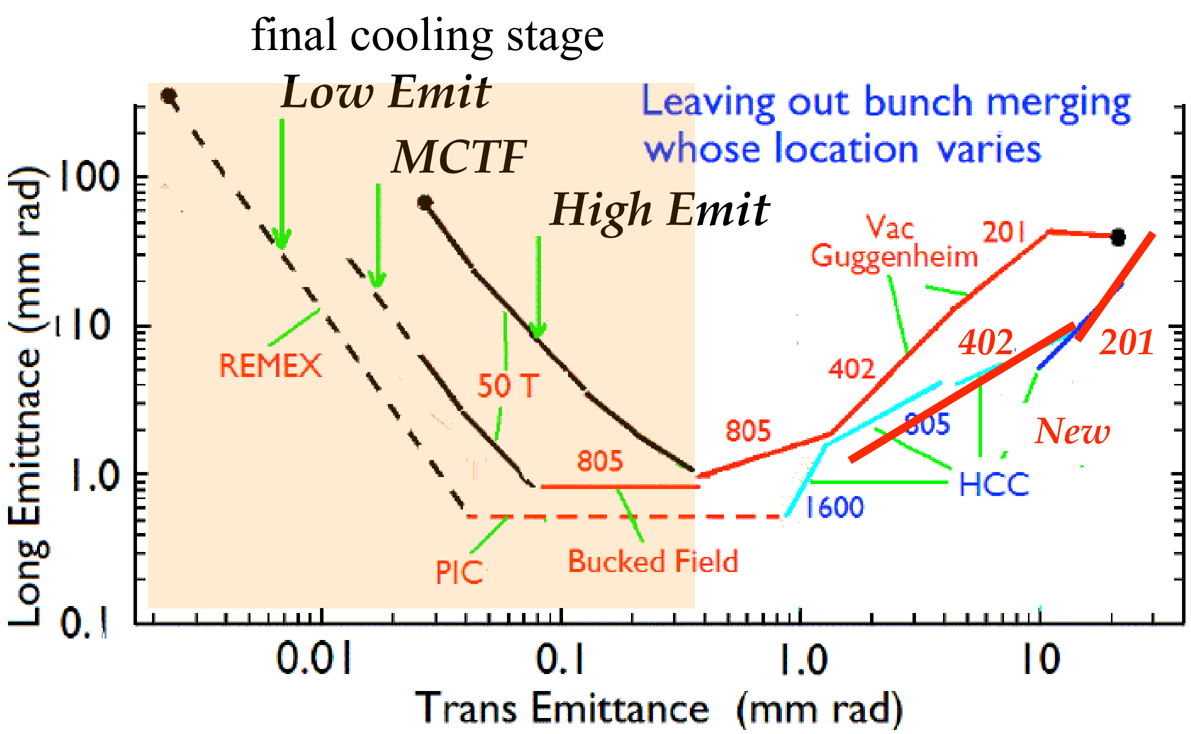
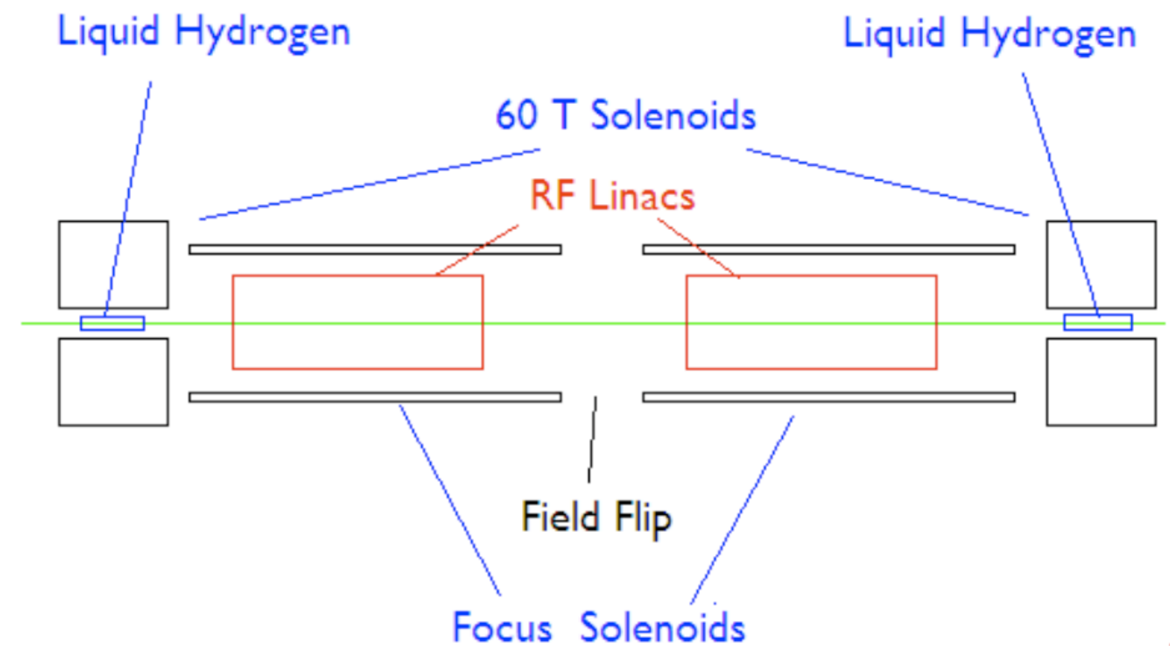
Apply helical cooling channel for extra cooling stage

K. Yonehara

NFMCC'09 meeting
01/27/09

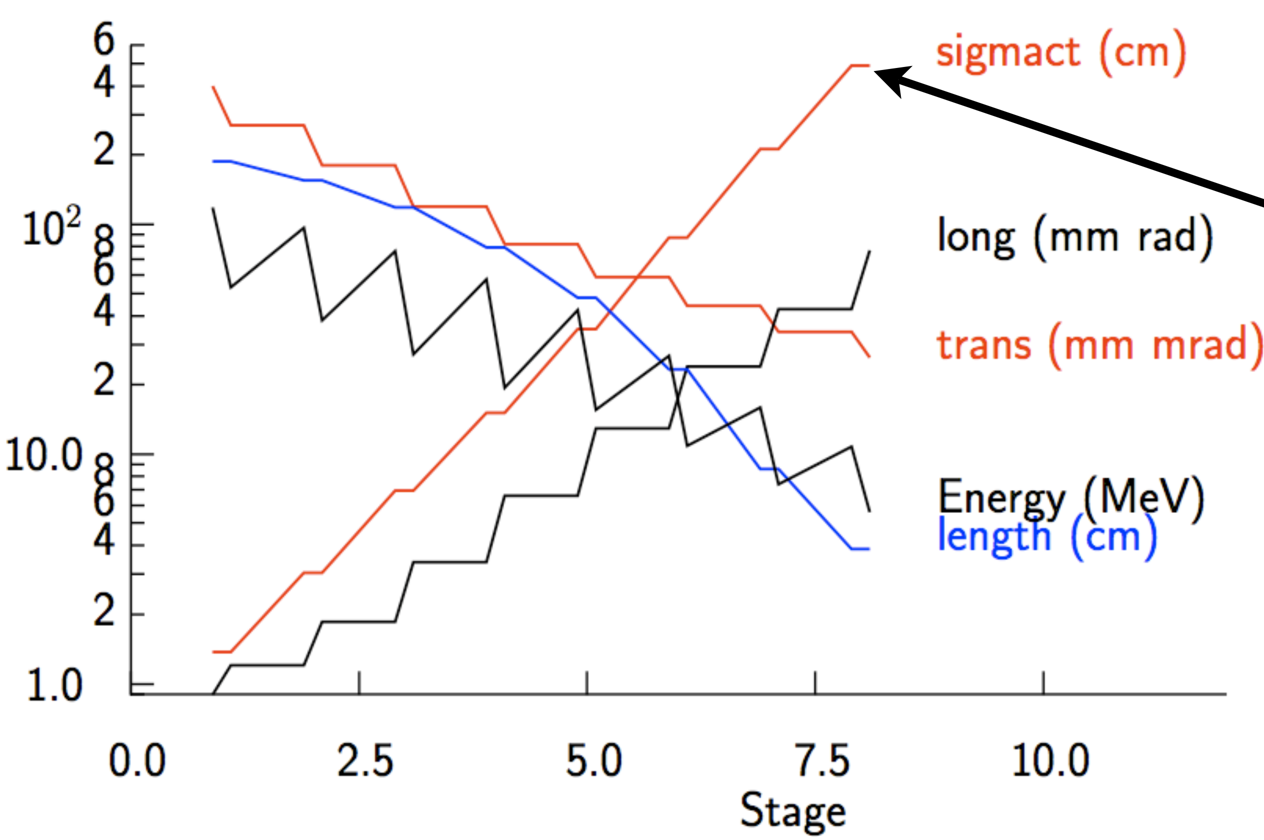
Conventional extra cooling channel





High field cooling channel

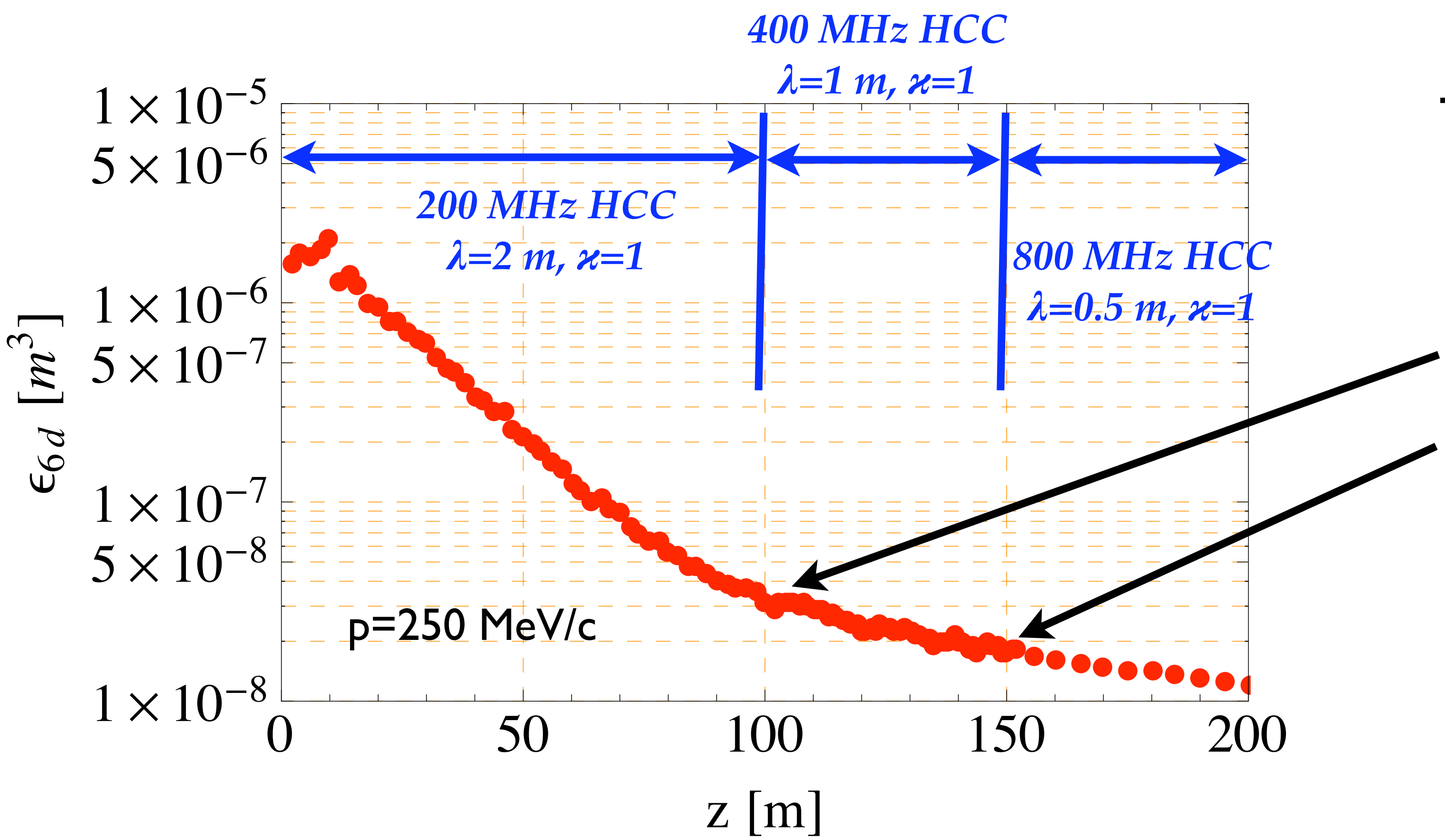
- High field solenoid is proposed to use for a final cooling stage
  → Reverse emittance exchange is taken place
- However, the final bunch length becomes 6 m at the end of channel
- Look for other options



Design concept of using helical cooling channel (HCC) for extra cooling

- From past MANX (HCC w/o RF structure in the magnet) studies, we observed longitudinal phase space heating as we have seen in the conventional pure solenoid channel
- However, we noticed the heating rate is quite smaller than that in the conventional pure solenoid channel
- In general, very high field strength (40~60 Tesla) is required for the final cooling stage
- High field strength in MANX will be applied relatively easy comparing with a standard homogenous HCC
- Here, I attempted to use MANX for final (or extra) cooling channel

Cooling simulation for normal HCC



Total transmission efficiency = 68 %

Decay loss = ~10 %

Still mismatching between two HCC segments exists:

- Wrong betatron harmonics generates transverse mismatching
- Wrong beta-synchrotron harmonics generates longitudinal mismatching

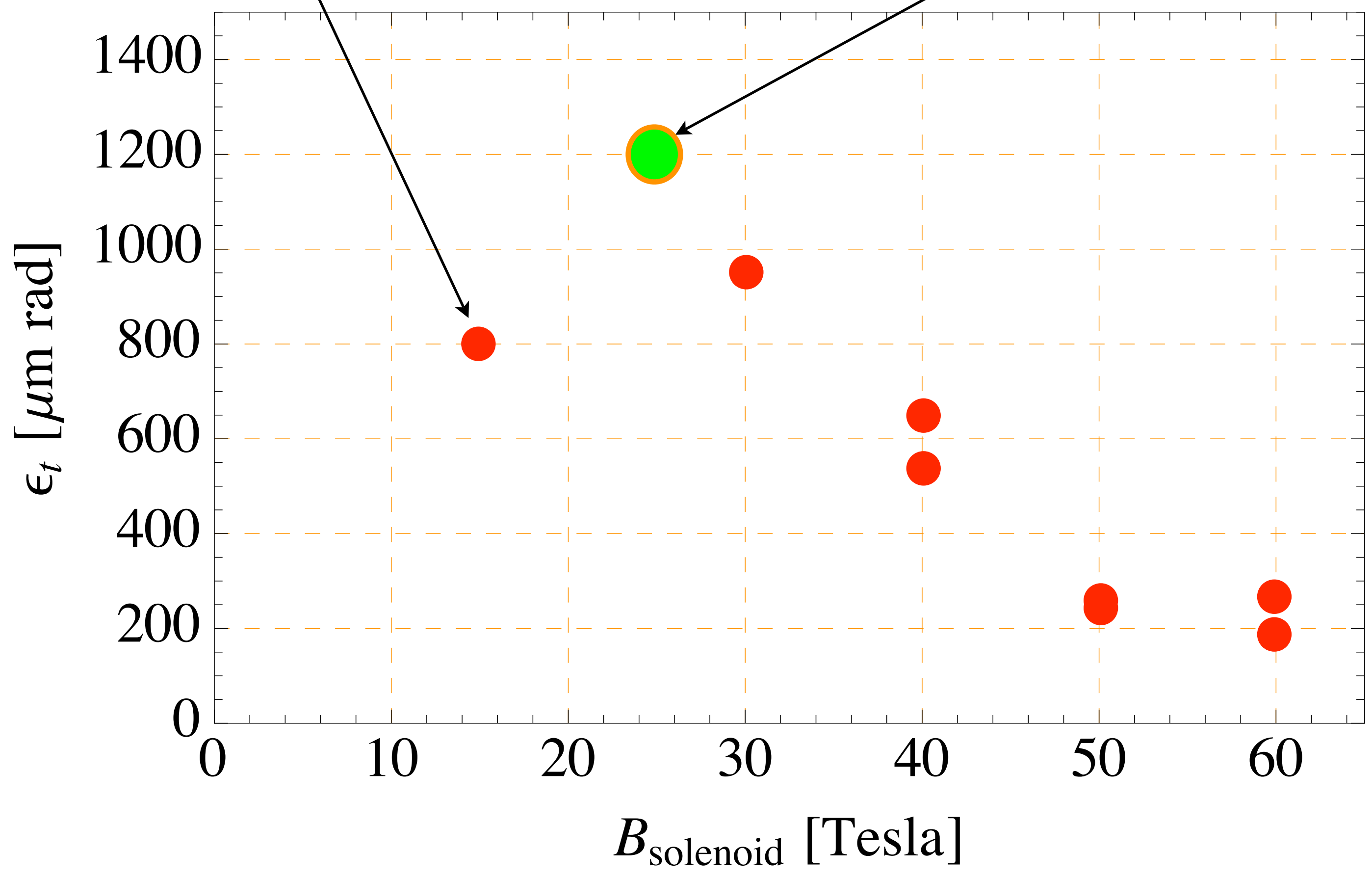
Find the least commom multiple number

Extra cooling in MANX channel

- Eliminate RF structure in HCC
- HCC field must be degraded as a function of the beam path length
- Apply high field solenoid to make extra cooling
  → Assume 60 Tesla is available
- Varying HCC field configuration to achieve lowest transverse emittance
- Just observed the equilibrium emittance in this time

Now study what happens on this point!

Final emittance in standard HCC



ToF in HCC and pure solenoid

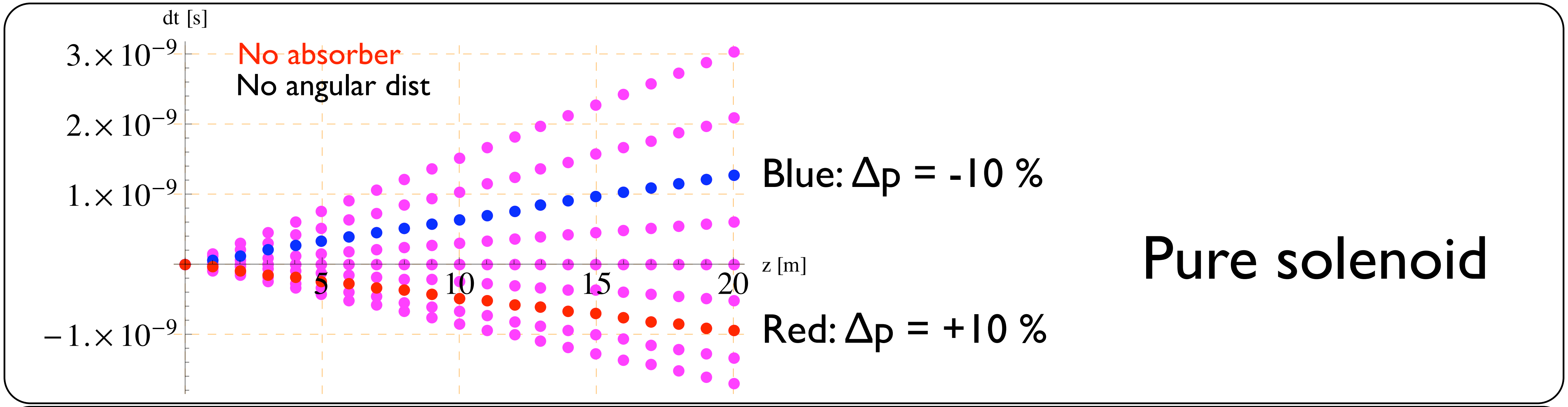
- In a pure solenoid channel, a ToF of slow (fast) particle takes more (less) time to reach the other end of channel
- This picture is opposite in HCC (opposite phase slip factor)
- Phase slip factor can be tuned by adjusting the dispersion

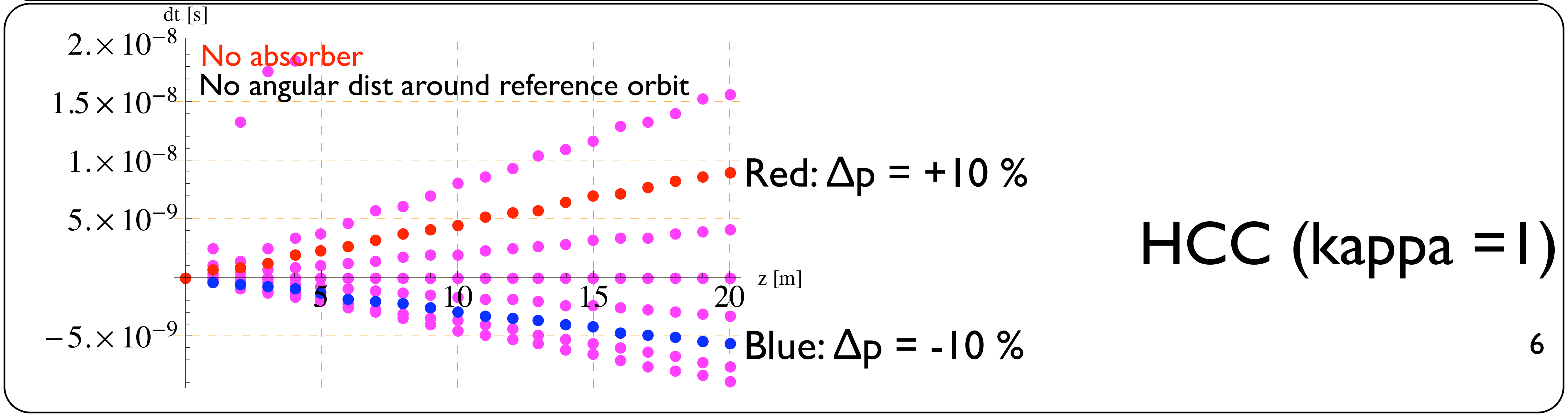
→ Even isochronous condition can be realized in HCC

- ToF wrt momentum is directly correlated with path length
- ToF is used to optimize the HCC field

$$\frac{\delta s}{s} = \frac{\delta v}{v} + \frac{\delta t}{t}$$

$\delta v = 0$ in no RF, no abs



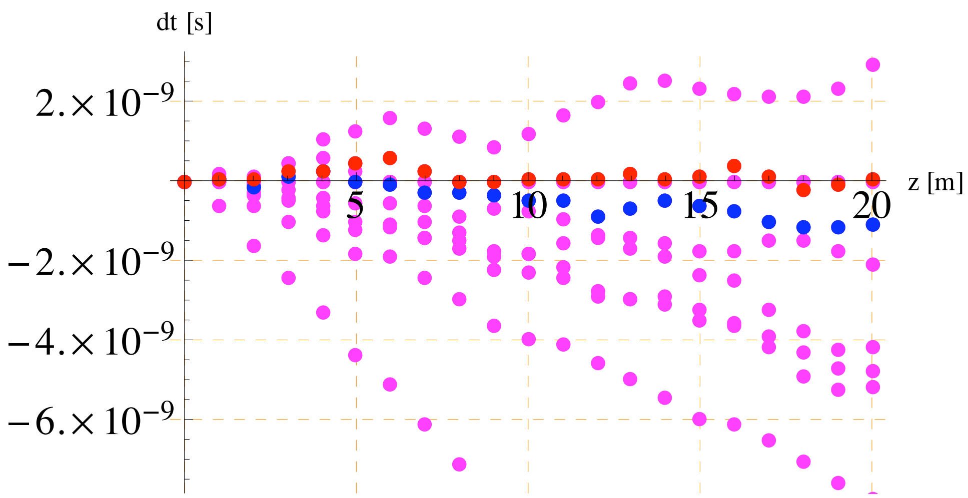


Challenge to use low kappa HCC for final cooling

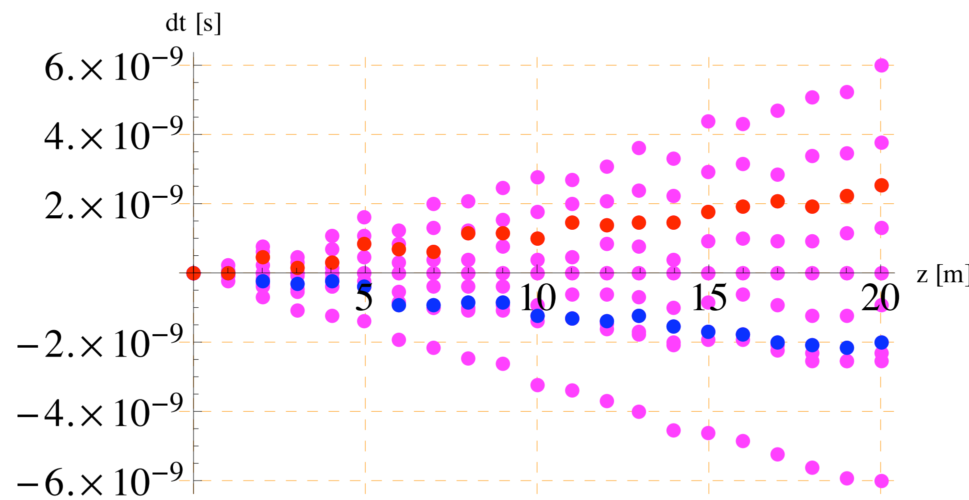
- HCC can reduce the longitudinal heating effect which has be issued in pure solenoid
- Low kappa HCC design would be easy to put the energy loss compensation RF
- Putting wedge absorber in low kappa HCC will be effective for emittance exchange (not studied yet)

Find optimum field configuration in low kappa HCC

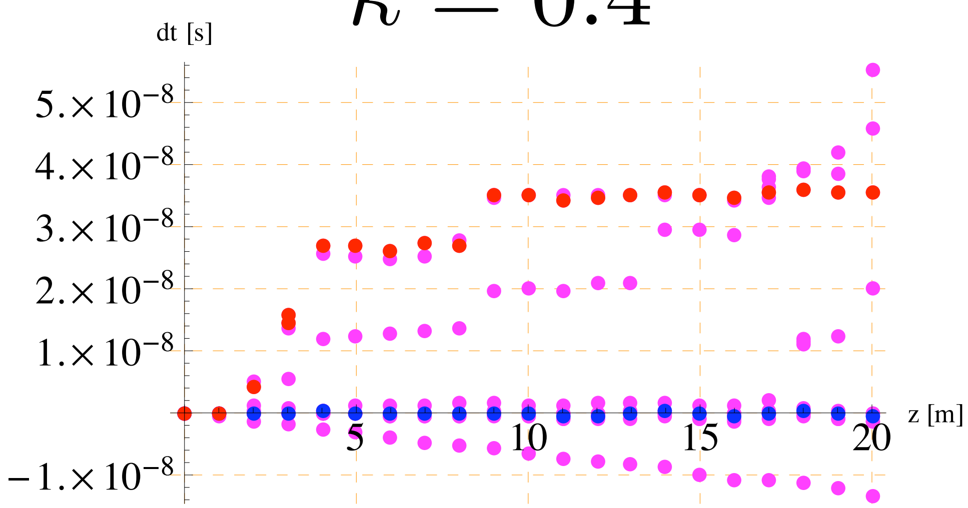
$\kappa = 0.2$



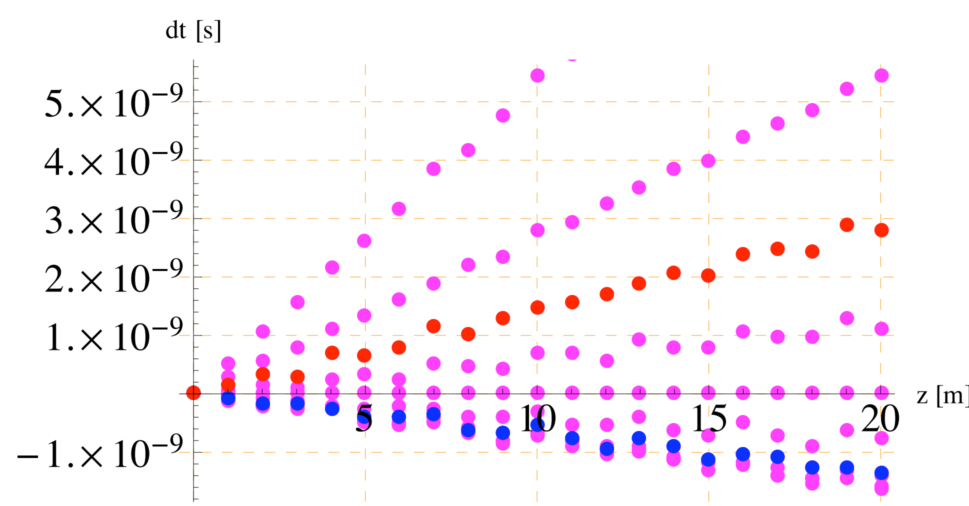
$\kappa = 0.6$



$\kappa = 0.4$



$\kappa = 0.8$



Proper condition can be seen from kappa = 0.4

Study Balbekov HCC

HCC simulation with wedge absorbers

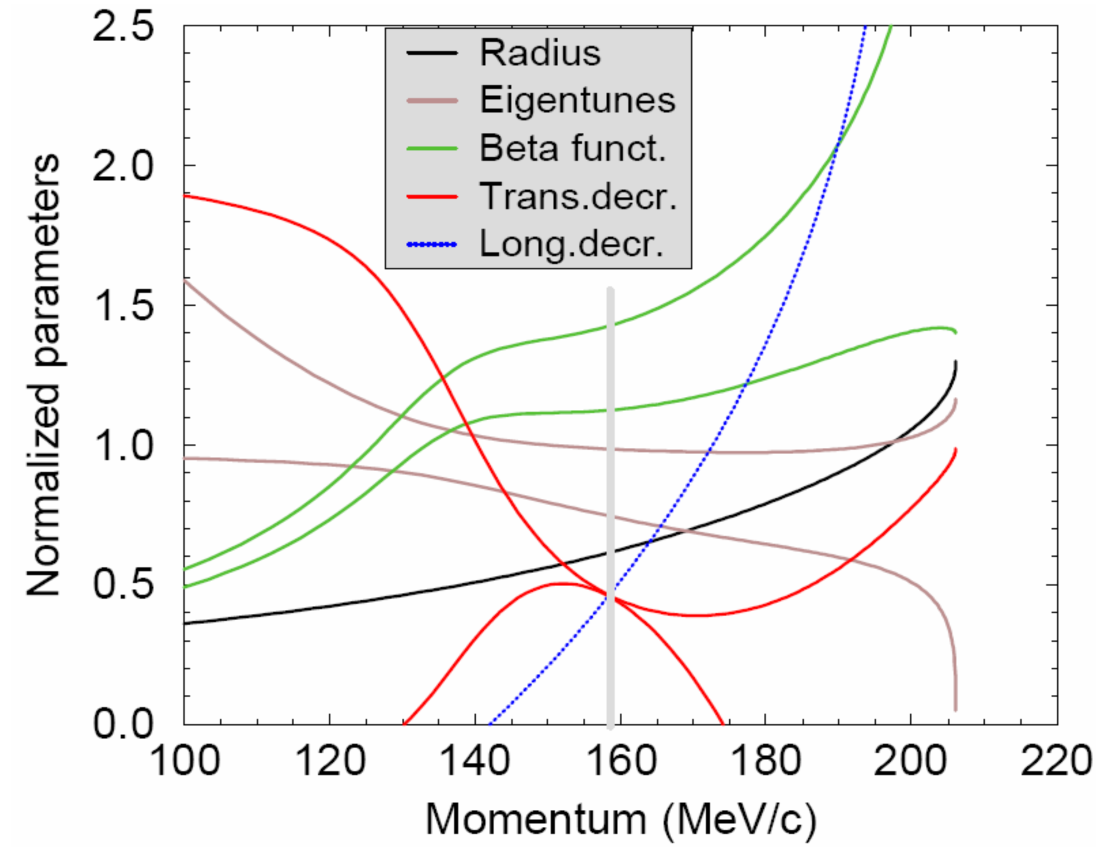
V.Balbekov, 10/09/08

WA allows to reduce reference momentum

Normalized parameters

F'=-0.196, F"=0

$X_0 = \kappa = 0.62$ Wedge = 0.57



For simulation

Period length	*1 m*
Reference radius	*10 cm*
Reference momentum	*159 MeV/c*
Solenoid field	*5.23 T*
Dipole field at centre	*-1.02 T*
Accelerating gradient	*29.4 MV/m*
Reference energy loss	*14.7 MV/m*

Field expressions in Balbekov HCC design

$$b_\psi = 2b_d I_1(\kappa) + b_q I_2(2\kappa) + \ldots$$

$$k\frac{\partial b_\psi}{\partial \kappa} = b'_\psi = 2b_d I'_1(\kappa) + b_q I'_2(2\kappa) + \ldots$$

omit higher order expression

Use 1st order of Taylor expansion in Balbekov HCC design

$$b_\psi = 2b_d I_1(\kappa)$$

$$b'_\psi = b_d\left(-\frac{4\pi I_1(\kappa)}{\kappa^2\lambda} + \frac{2\pi(I_0(\kappa) + I_2(\kappa))}{\kappa\lambda}\right)$$

$$p = 0.159 \quad \text{GeV/c}$$

$$\lambda = 1.0 \text{ m}$$

$$a = 0.1 \text{ m}$$

$$\kappa = \frac{2\pi a}{\lambda} = 0.628$$

Balbekov field parameters		Derbenev & Johnson field parameters
$b_\psi = 0.673$ T	mismatching ⟷	$b_\psi = -0.863$ T
$b'_\psi = -1.04$ T/m	mismatching ⟷	$b'_\psi = -3.77$ T/m
$b_s = 5.23$ T	mismatching ⟷	$b_s = 4.74$ T

- I concluded that Balbekov HCC design concept is completely different from Slava & Rol's HCC model

Reference: NFMCC-doc-146,147,185,187,193,284

Summary

- Studied extra cooling MANX channel
- Lowest transverse emittance is 240 μm rad @ 50 Tesla and 190 μm rad @ 60 Tesla in transverse planes
  - 800 μm rad (RF frequency=1600 MHz) in longitudinal plane (not shown in this presentation)
- Challenge to use low kappa HCC for final cooling stage
- Looked at Balbekov HCC model and realized that it is based on different design concept from Slava & Rol's HCC