



THE UNIVERSITY OF
TENNESSEE
KNOXVILLE

Muon Beam Dynamics in HFQFO Part of Muon Cooling

Daisy Kalra

March 20, 2026

RF phase investigation

- Our goal is to determine and correct the RF cavity timing so that particles experience the appropriate accelerating phase when traversing the cavities.
- Idea is to look at the field map to evaluate the "true" or "actual" RF phase at particular z location and compare this phase to particle RF phase to obtain the time offsets.
 - Use these time offsets to tune the cavities.

```
param beamtime=-0.671
param toffs0=$beamtime-$beamstart/275.79-0.07 t
param toffs1=$toffs0-.061-.0026+.0115+.006 # ti
param toffs2=$toffs1-.064+.149-.0052-.0029|
param toffs3=$toffs2
param toffs4=$toffs3
param toffs5=$toffs4-.008
param toffs6=$toffs5
```

RF phase calculation

1) Field map $E_z(t)$ is sampled at different z positions

○ $Z_{\text{start}} = -425$ mm $z_{\text{end}} = 5 \cdot 4200$ mm; step size = 25 mm

○ $T_{\text{start}} = 300$ $t_{\text{end}} = 600$; step size = 0.001 ns)

RF phase calculated from field map at a particular z

The image shows a handwritten derivation on lined paper. It starts with the text 'Field map' followed by an arrow pointing to the expression $E_z(z, t)$. Below this, the electric field is given as $E_z = E_0 \sin(\omega t + \phi)$. The next line shows the derivative of E_z with respect to time: $\frac{dE_z}{dt} = E_0 \omega \cos(\omega t + \phi)$. The following line shows the ratio of the field to its derivative: $\frac{E_z}{dE_z/dt} = \frac{1}{\omega} \tan(\omega t + \phi)$. The final line shows the inverse tangent of this ratio: $\tan^{-1} \left[\frac{\omega \cdot E_z}{dE_z/dt} \right] = \underline{(\omega t + \phi)}$. An arrow points from the underlined expression to the word 'phase' written above it.

$$\text{Field map} \rightarrow E_z(z, t)$$
$$E_z = E_0 \sin(\omega t + \phi)$$
$$\frac{dE_z}{dt} = E_0 \omega \cos(\omega t + \phi)$$
$$\frac{E_z}{dE_z/dt} = \frac{1}{\omega} \tan(\omega t + \phi)$$
$$\tan^{-1} \left[\frac{\omega \cdot E_z}{dE_z/dt} \right] = \underline{(\omega t + \phi)} \rightarrow \text{phase}$$

RF phase & time offsets

- 1) Compute E_z and its derivative for each cavity from the fieldmap.
- 2) Compute actual phase using definition on previous slide (`phase_field`) : wrap to 0-360 deg
- 3) Compute particle RF phase (`phase_particle`) using `ztuple` output (using nominal G4bl input card): wrap to 0-360 deg
- 4) Convert phases to radian and compute time offset =
$$\text{phase_field_rad} - \text{phase_particle_rad} / 2 * \pi * 0.325$$

RF phase & time offsets

=== OFFSETS vs Z ===

	z	delta_t
0	-425	-1.207234
1	-400	-1.207234
2	-375	-1.207234
3	-350	-1.207234
4	-325	-1.207234
..
853	20900	1.296946
854	20925	1.296946
855	20950	1.296946
856	20975	1.296946
857	21000	1.296936

```
place RFC0 z=-425. timeOffset=$toffs0-0.77123842
place RFC0 z=-175. timeOffset=$toffs0+0.13491993
place RFC0 z=75. timeOffset=$toffs0+1.0410783
place RFC0 z=325. timeOffset=$toffs0+1.9472366
place RFC0 z=575. timeOffset=$toffs0+2.853395
place RFC z=1075 timeOffset=$toffs1+4.6712809
place RFC z=1325 timeOffset=$toffs1+5.5805068
```

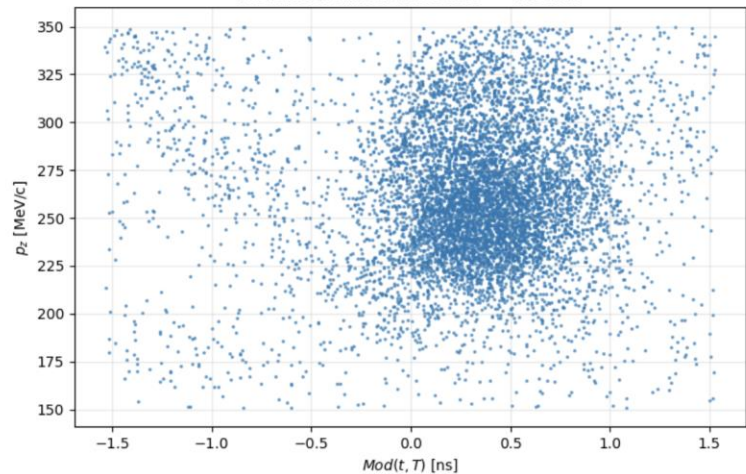
```
groups = {
  "toffs0": (-425, 576),
  "toffs1": (1000, 6300),
  "toffs2": (6300, 42000),
  "toffs3": (42000, 84000),
  "toffs4": (84000, 126000),
  "toffs5": (126000, 170000)
}
```

=== GROUP OFFSETS ===

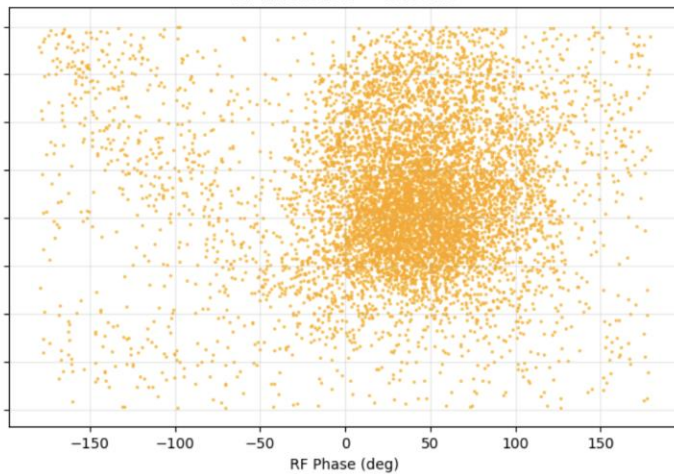
```
toffs0 = -0.53376 ns
toffs1 = -0.00888 ns
toffs2 = -0.12755 ns
```

```
param toffs0=$beamtime-$beamstart/275.79-0.07-0.53376
param toffs1=$toffs0-.061-.0026+.0115+.006-0.00888 # t
param toffs2=$toffs1-.064+.149-.0052-.0029-0.12755
param toffs3=$toffs2
param toffs4=$toffs3
param toffs5=$toffs4-.008
param toffs6=$toffs5
```

Modulated Arrival Time at z = -425 mm

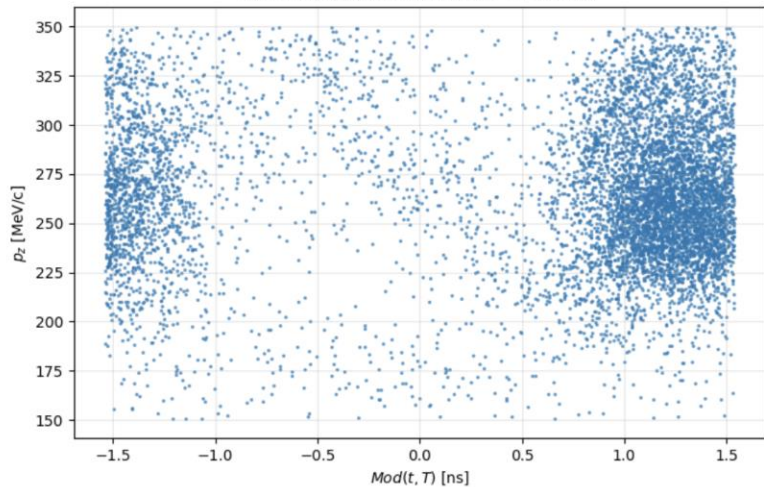


RF Phase at z = -425 mm

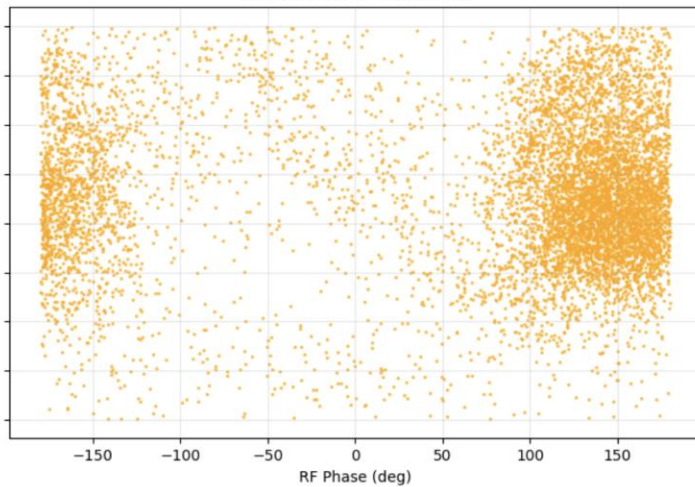


```
place RFC0 z=-425.  
place RFC0 z=-175.  
place RFC0 z=75. ti  
place RFC0 z=325. t  
place RFC0 z=575. t  
place RFC z=1075 ti  
place RFC z=1325 ti
```

Modulated Arrival Time at z = -175 mm



RF Phase at z = -175 mm



Doesn't seem to work earlier in matching section
next slide has plots in cooling channel

Next steps

- Think, and think more
- Is this method to get time offsets correct?
- Are we missing anything here?