Document Title:	Requirements for Collector Ring Design
Project Name:	Collector Ring
Description:	Required vacuum crosses and decapole corrector
Division/Organization:	NUSTAR / ILIMA
Field of application:	FAIR

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It is the purpose of this document to specify the way in which certain parts in the CR should be built so that experiments can be done properly by the ILIMA collaboration.

Document History:

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V 1.0	Helmut Weick	07.12.2016	08.12.2016	

1. Crosses for vacuum connections

Particle detectors inside of pockets are an approved part for experiments in the CR. Even though most experiments with silicon detectors inside the pockets were once foreseen to be done in the NESR, some experiments can also be done in the CR. The observation of neutron emission delayed by a preceding beta decay is one of the key cases. A spontaneous decay can happen anywhere in the ring, but ions changing charge in the straight sections will all follow the same dispersion curve and can be efficiently collected on a detector in the arc. A test for this detection method was done in the ESR, and showed the ions located in a peak [1].

It is important that the detectors are placed at positions with enough dispersion to separate circulating beam and ions with changed charge after beta decay. But on the way to the detector the dispersion must also not be larger, or otherwise only poor transmission to the detector can be reached. The analysis has shown that a position after two dipoles is well suited for detection of charge change in the region around Z=50 and after four dipoles for Z around 82. Usually, this will happen after bunch rotation and stochastic cooling, with small beam envelopes. The beam positions and widths can be calculated from the optics parameters of the also shown in Figure 1.

Therefore, we ask to build the vacuum tubes at these positions not as simple tubes but as crosses, as shown in Figure 2. At all other similar positions simple tubes are sufficient. The detector pockets will then be mounted on CF150 flanges left or right to the beam. When not in use the CF150 ports can be blind flanged. The pockets themselves along with drives and a support will be delivered by the ILIMA collaboration. They belong to the experiment part of FAIR with PSP 1.2.6.6.

The names of the exact locations in the CR are: CR01EX3SZ, CR01EX4SZ, CR03EX3SZ, and CR03EX4SZ. In some places the detector positions are the same as foreseen for Schottky pickups also from ILIMA. In this case the cross has to be exchanged with a pickup later. It is not planned to use them at the same time.

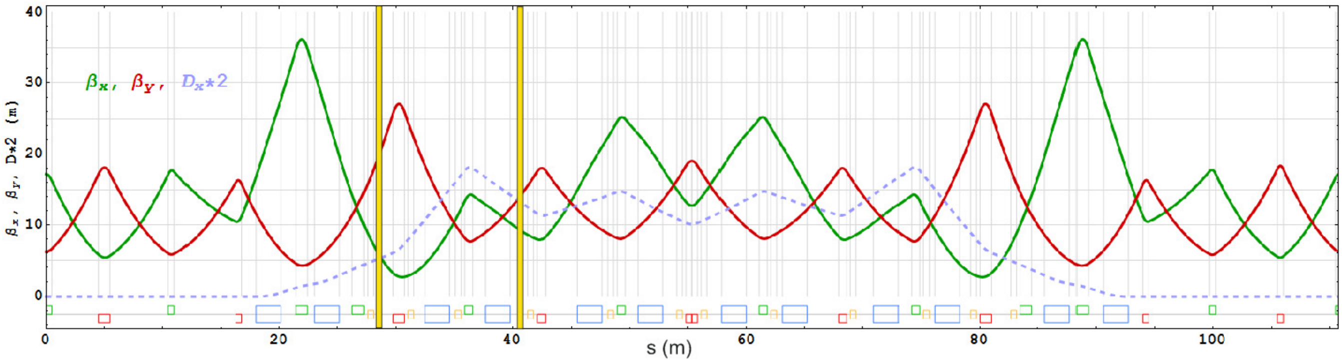

Figure 1: Dispersion and beta functions in RIB mode of CR, from the CR-TDR Annex1 [3] (Fig.2.5-10). The positions for detector pockets are indicated by the yellow lines.

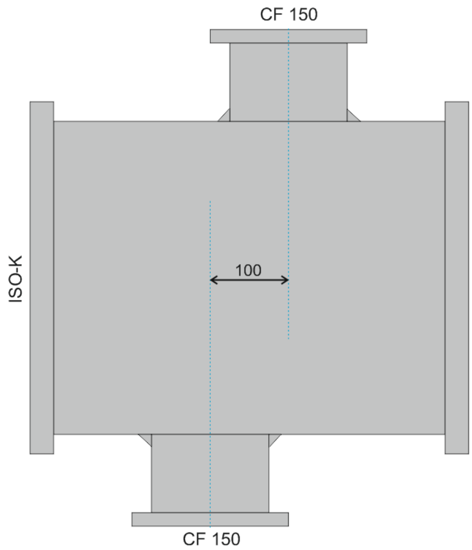

Figure 2: Scheme of vacuum cross, with CF150 ports to the sides and ISO-K flanges along the ring. The two side ports should be shifted by 100mm.

2. Decapole Corrector

The detailed calculations of the CR in isochronous mode [2] have shown that inhomogeneities of the dipole magnets cause time-of-flight deviations of almost the same relative magnitude. The goal for mass measurements must be $\Delta T/T \sim 10^{-6}$. But the dipole magnets can at best be built to a level of $\Delta B/B(x) \sim 2\times10^{-4}$, see Figure 3. This will also vary for different magnetic rigidity of the beam.

It is not necessary to have each magnet homogenous to such a high level like the goal for $\Delta T/T$. Averaging over the ring helps and instead only the integral must be compensated over a full revolution in the CR. Nevertheless this goal will require a careful tuning of the magnet setting.

Most critical are the deviations for particles of different momentum defined as an average over the used aperture. The effect of different multipole distributions at different height in the dipole magnet will average out by the vertical betatron oscillations. But with a closed dispersion line (at least to first order) the purely longitudinal contributions will not average out and they are the largest contributions. This means that the integral of a multipole component over one full turn must be corrected to high accuracy.

Sextupole and octupole correctors are already foreseen in the CR. But a typical field distribution in an H-type magnet also is characterized by a stronger decapole component as it can be seen in Figure 3. This cannot be computed before to the required precision, and it changes with the excitation of the magnet. Therefore, an adjustable decapole corrector is required in the CR. Otherwise the required level of isochronicity cannot be achieved. This is demonstrated in Figure 4. On the other hand including a decapole corrector as shown in Figure 5 (from [2]) it can be achieved.

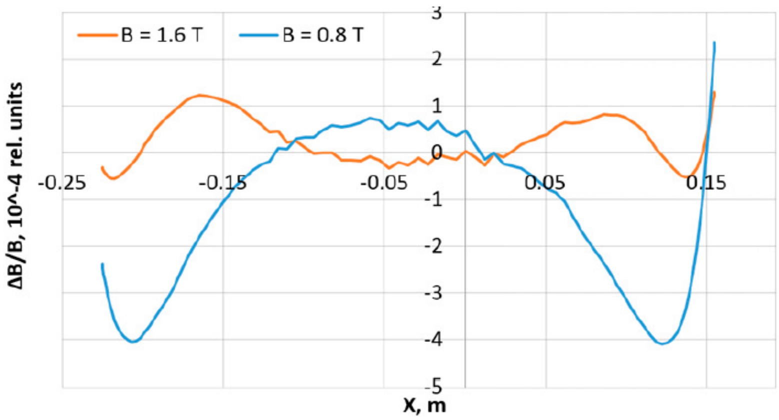

Figure 3: Homogeneity of the dipole magnets along the border of the elliptical aperture for different strength of a CR dipole, from CR-TDR Annex1 [3] (Fig.2.5-19).

Based on the first design of the dipole magnets with the results shown above in Figure 3 the required strength of the decapole correctors can be calculated. To the calculated curves presented in the TDR (Annex-1), we added an additional safety factor of two to include also the other magnets in the ring. This then corresponds to a design that is able to correct for a decapole component of b4 = $8x10^{-4}$ in the dipoles. In the calculated CR68 this can for example be achieved with a superimposed decapole component of B = $5.9x10^{-3}$ T at a radius of 0.168m over the 1m length of the two central quadrupoles CR01QS11 and CR03QS11, (numbers are given for the maximum Bρ of 13Tm) The effectiveness scales with the dispersion at the position of the corrector, in CR68 (γ_t=1.67) mode it was D= 29.8 cm/%. Based on the isochronous modes presented in the TDR (Annex-1, Fig 2.5-17) about 10% more is needed in the γ_t=1.84 mode. In total one can say the variable decapole strength over the full ring should be B''''L = ± 400 T/m^3 and close to the middle of the arcs.

Even though the calculated shapes so far all show the same sign, the power supply should be bipolar. Whether symmetry regarding the positions in the ring is required for such a weak corrector should be checked. For the isochronous mass measurement itself which aims at short lived nuclei it is not required, for longer lifetimes it could be.

To us the best way seems to include the decapole correctors by extra coils in the quadrupole or sextupole magnets. The critical gap in the dipoles will probably not allow mounting extra surface coils as it was done for example in the ESR for the same type of flexible multipole correctors used for isochronicity correction. If all of this is not possible, then we would have to look for separate magnets. However, in this case the positions in the arc for Schottky pickups should not be used as the pick-up are intended for the isochronous mode and must be used at the same time.

It is clear to the ILIMA collaboration that additional coils in magnets and extra power supplies will also cause additional costs. The collaboration is willing to contribute to these. So far this sum is not foreseen in the intended spending, but should be introduced as part of the work package 1.2.6.1. ILIMA will also rearrange already foreseen money in this case. Experiments need an approved TDR before money can be spent or asked for. The material for this TDR must then be a magnet design which we can also hand in to FAIR as an ILIMA TDR for a decapole corrector.

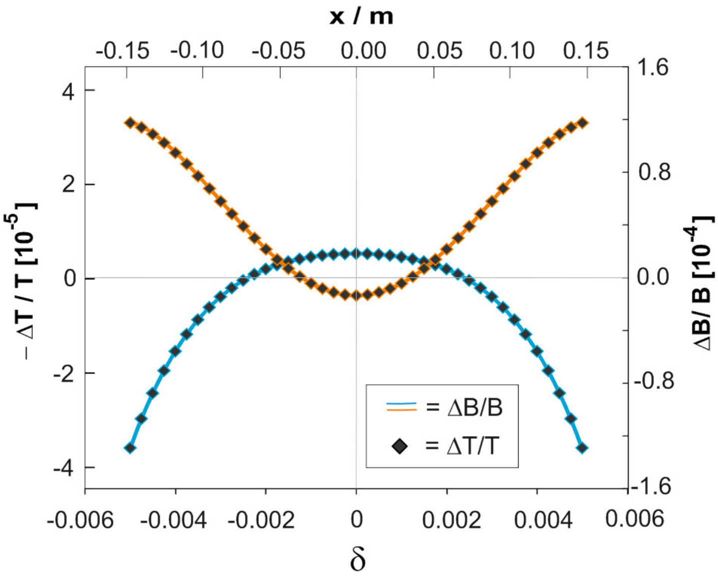

Figure 4: Correlation between magnet homogeneity and time-of-flight deviation in the CR (version 68) for field distributions roughly corresponding to Figure 3. On the right and top axis the relative deviation in flux density along the horizontal axis (x) is plotted and on the left and bottoms axis the resulting time-of-flight deviation as function the relative momentum deviation of an ion to the reference orbit. All dipoles were assumed to have exactly the same field distribution.

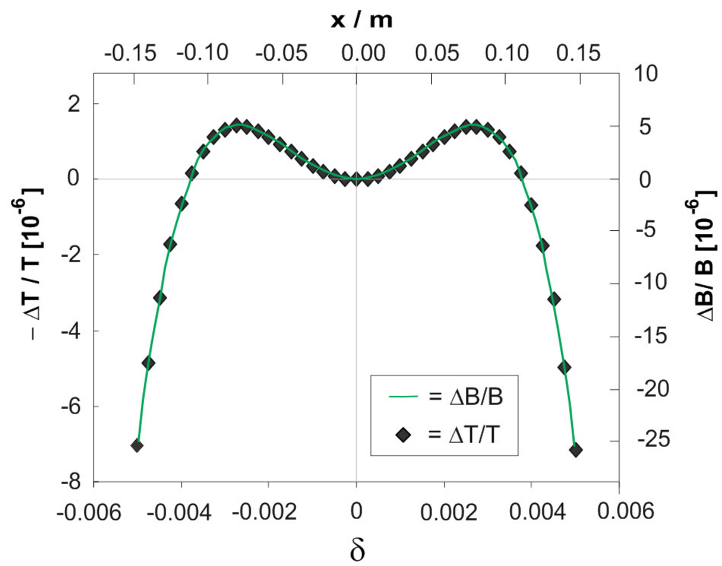

Figure 5: Same calculation as above but in addition to sextupole, octupole correctors also a decapole magnet was used. The magnet homogeneity corresponds to an integral over the whole ring. The picture was taken from ref. [2].

[1] A. Najafi et al., Nuclear Instruments and Methods in Physics Research A 836 (2016) 1.

[2] S. Litvinov, D. Toprek, H. Weick, A. Dolinskii,
Nuclear Instruments and Methods in Physics Research A 724 (2013) 20.

[3] CR TDR-Annex 1 v7.6.1 June.2016 by BINP Novosibirsk.