ELENA Project Review Closeout

Review Committee

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General Comments

- The review committee would like to support the construction of low energy antiproton ring ELENA
- We find it greatly supportive for the CERN program with low energy antiprotons as well as an interesting project in the accelerator physics
- We would like to thank all presenters for good and coherent presentations
- Comments, findings and recommendations follow below

Optics, Optics correction, Longitudinal and transverse dynamics

Findings

- Choice of the working point and optics is based on incomplete knowledge of the machine magnetic elements (stray fields, e-cooler elements, B-field from other sources)
- Not complete collection of possible dangerous resonances around the working point
  - Fourth order resonance is only 0.05 away!
- Seems that no-collective effects, excluding space charge, can have a deleterious influence on the beam

Comments

- Lattice design seems to be appropriate
  - Machine tunability is quite small
  - Optics design difficult due to many constraints

Recommendations

- Revise the working point to avoid forth order resonances with and without large Laslett tune shifts.
- 6D tracking and resonance driving term evaluation should be done including field-maps and e-cooler magnets (toroids and compensation solenoids) to evaluate resonances and phase space distortion.
- Dynamic aperture should be studied including e-cooler magnets and fields from measurements or simulations (including fringe field multipoles).
  - Effect of the lattice sextupoles and e-cooler needs to be characterized.
- Even there are no concerns for collective instabilities, evaluation of impedances of every element and, prior-installation, if possible, measurements of impedances should be done
- Estimate a reduction of transverse space charge effects due to use of double harmonics at extraction energy.

Orbit correction and Optics measurements

Findings

- Remnant field of correctors complicates optics/BTF measurements. Degaussing cycle risks to require too long time.
- Systematic study of orbit distortions effect on the machine optics was not done
- Difficult steering of the injection line with only two GEM detectors and MTV screen which cannot be used simultaneously.
- Cycling of AD magnetic field can produce not-negligible effect on the orbit.
- Supercycle operation could be difficult due to remnant fields.

Comments

- The committee believes that the number of correctors and pickup installed in the ring is sufficient for machine operation and optics measurements

Recommendations

- Orbit/optics distortion studies with random errors should be done to have better estimation of the closed orbit and their effect on optics and required level of orbit correction.
- Effect of supercycle operation on the machine reproducibility due to changing remnant fields within each cycle need to be analyzed
- Micro-wire detectors could be deployed in the injection line for steering
- Measurement of the AD B-field at the Elena location during AD operation should be done
  - The results have to be included in the optics and orbit simulations.
  - Effect of grounding of the ELENA elements on the surrounding magnetic fields have to be evaluated

Electron cooling, IBS and Equilibrium Sizes

Findings

- BETACOOL was used to find the equilibrium antiproton emittances
  - However AD experience shows an about order of magnitude discrepancy between the measurements and the predictions
- Ion clearing electrodes were not shown in the cooler design. They have to be present in the real machine

Comments

- We do not expect that cooling of a 100 keV anti-proton beam should be a problem.
  - Electron cooling measurements done in TSR with a single charge phosphor beam $^{31}P^{+}$ at ß=0.014 shows the 1/e cooling time of 13.5 s. Because the cooling time scales with the ion mass A the anti-proton 1/e cooling time should be below 0.5 s @ at 100 keV
- Although the cooling proposal looks good at the conceptual level there are a number of things which need to be done
  - In particular, no details were presented on the electron collector, ion clearing electrodes, and relative antiprotons-to-electrons

beam position measurements in the cooler

- To measure relative positions and angles of the antiproton and electron beams two horizontal and two vertical pick-ups can be used. They have to be integrated in the cooling solenoid. A residual gas monitor can present another way to measure the relative alignment. It also can see distortions in the electron beam profile related to the cathode poisoning and other reasons. Exclusively positive experience was obtained in TSR.

- Electron beam size is twice larger than the maximum size of antiproton beam. It results in 4 times larger beam current and positive voltage on the 1-st anode. It creates a possibility for ion trapping in the gun
- Details of the cooler magnetic design are well behind of what was done for the ring magnets
  - No clear plan for design and manufacturing were presented

Recommendations

- A proof of accuracy of BETACOOL should be done.
  - Comparison with the AD and TSR measurements can be used
- Study of the toroidal field effect on the dynamic aperture need to be performed
  - There are many ways to mitigate it if the study will show the problem
- Investigate use of residual gas profile monitor for antiproton beam
  - Our estimate shows that considerable signal (10 s^{-1} at channel-plate ∅=4 cm) will be observed even at the design vacuum ($5 \cdot 10^{-12}$ Torr)
- Pickups at the cooling section beginning and the end are extremely desirable to assure relative positions of the beams
  - Pickups can be also used for control of ion storage in the electron beam

Injection and Extraction

Findings

- The ELENA ring will be equipped with a "standard" injection system and two similar electrostatic extraction systems to deliver the beam to two different experimental branches. Kickers allow extraction of one or more bunches out of 4 (switching times 1 μs).
- The extraction lines are entirely equipped with electrostatic elements (fast switchers, deflectors, quads and correctors).
- The aperture of all extraction line elements is based on a maximum momentum spread of $\Delta p/p = 2.5 \cdot 10^{-3}$.
- An H^-/proton source is foreseen for the commissioning phase.

Comments

- Choice of electrostatic elements for extraction lines is well adapted to the beam energy and justified in terms of operational flexibility, spare part policy, cost and technology aspects.
- The design of the electrostatic elements is well advanced.
- It was noted that all electrostatic elements except the fast switches operate in a quasi-DC mode, which requires all elements in combined parts of the extraction lines to have identical settings for all experiments. Change of that concept would require a different power converter design.
- The concept of using an H^-/proton source for the commissioning of ELENA is considered very beneficial and expected to significantly ease and speed-up commissioning.

Recommendations

- Modelling of electrostatic devices is important
  - It is proposed to perform tracking studies through the complete lines up to the focal points.
- The sensitivity of the optics and beam transport to various error sources should be analysed.
- Momentum acceptance of extraction line elements should be reviewed with respect to the characteristics of the extracted beam (for various machine performance scenarios) and also requirements from experiments.
- A suitable shielding concept for beam perturbation by stray magnetic fields has to be devised and tested to protect the beam against these perturbations.
- Attention needs to be given to vacuum and outgassing aspects of the electrostatic elements.

Instrumentation, RF and Longitudinal Diagnostics

Findings

- An instrumentation suite has been prepared for ELENA based on the diagnostics devices used at the AD, which as is well-known has similar particle numbers per cycle. In addition, some new and improved performance instruments are foreseen.
  - It is proposed to use the so-called GEM screens further downstream the line towards ELENA in addition to the already used Al_2O_3 scintillating screens at the AD extraction line. These monitors supply beam profiles and positions. A concern is the measurement speed with the long cycle of the ELENA machine.
  - A total of 20 new BPM systems will be built. Their design is based on the experience obtained at the AD.
  - A new base-band tune system is being built for the AD, and it will be copied for ELENA too.
  - A conventional beam profile detector based on scrapers is planned for ELENA.
    - Additionally, a profile monitor for the low-energy proton

beam based on recombination in the electron cooler is proposed. The choice of the detection system is still to be made.

- In the experimental lines, it is proposed to use the well-functioning micro-wire monitor developed by ASACUSA.

- The RF programs were presented including the longitudinal dynamics. It seems that bunched-beam cooling is needed for the expected longitudinal emittance to provide the required energy spread and bunch length. This should be studied more (see also section on the electron cooling).
- HLRF, LLRF
  - A Finemet broadband unturned cavity is proposed for ELENA. Such a system is expected to provide the needed performance.
  - The hardware and software for the LLRF will be copied from the present consolidation project of the other machines at the Meyrin site (PS Booster).

- Longitudinal diagnostics
  - The longitudinal beam diagnostics systems will be based on an already developed high-sensitivity magnetic pickup system providing longitudinal parameters of both continuous and bunched beams.

Comments

- Could the ASACUSA micro-wire detector be useful in the ELENA ring also, *e.g.* for destructive profile measurements by kicking the beam?

Recommendations

- A profile monitor for observation of the low-energy neutral beam (after recombination) is recommended.
- Experience from the AD with all the above monitors has shown their feasibility, but a complete listing of their expected performances needs to be assembled.
- Improve the analysis on RF noise.

Vacuum

Findings

- The vacuum design is well advanced and suggested options are good.
- It could be useful to install a few Ti sublimation pumps around the ring for long term operation
- More experience has to be taken from LEIR kickers for the design of the injection kicker, as the chosen option is a copy of an existing hardware
  - We believe that the titanium sublimation pumps on large surface present good solution.
- Fast vacuum valves were not presented on the review. Their locations and number need to be discussed.
- A presence of quadrupole mass spectrometer was not presented. Its necessity needs to be discussed.

Recommendations

- Electron cooler: the completion of the vacuum design is urgent. The committee insists on installation of efficient differential pumping just after the gun and just before the collector.
- It seems to the review committee that vacuum valves need to be installed on both sides of the injection kicker by reducing the length of the BTV tank. This could have an effect on the global sectorisation.

MAGNETS

Findings

- The design of the magnets is in a good shape. The chosen magnetic material is good to minimize the remnant field.
- Details of how B field measurements in the reference magnet are going to be used were not presented.

Comments

- The low pole field requires laminations dilution in all magnets, not just in dipoles. The machine operation and the reproducibility will be greatly improved.
- The magnets have a short length compared to their aperture. That requires a good knowledge of the end fields.
  - In particular, the influence of the surrounding magnetic material (other magnets, supports....) needs to be considered. These effects have to be correctly accounted in the machine model.

- The correcting dipoles have $6 \cdot 10^{-3}$Tm integrated field which makes ~20 mrad deflection at 100MeV/c.
  - 1/4 of this strength is sufficient
  - Dilution of 3 or more is desirable to reduce the remnant field effects at low energy.
    - The target for maximum magnetic field in the steel should be in the range 1 – 1.4 T.

Electrostatic elements

Findings

- It seems that the transfer lines layout is well advanced. The choice of electrostatic elements is well adapted to the beam energy.

Comments

- Our main concern is the modeling of these elements. Tracking from the beginning to the end looks as the most appropriate choice.
- A suitable system has to be devised and designed to shield the beam from the magnetic fields present in the transfer lines vicinity.

Power supplies

Comments

- All power supplies suggested for ELENA seem to fit the CERN rules and specifications. A number of selections remain to be finalized.
- A careful analysis of power supply noise, including the main power supply, and the control in vicinity of zero current should be done. The latter has primary importance for the correctors and the lattice sextupoles.