Report of the 18th C-AD Machine Advisory Committee meeting

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Zoom Virtual meeting

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Excused:

Overview

The Committee thanks the C-AD management and staff for organizing a well-prepared virtual meeting and all the presenters for their excellent talks and staying within the time limit. The Committee appreciates that the C-AD management responded to all the recommendations from the previous 17th MAC.

The committee would like to congratulate the C-AD management and staff for their exceptional success in completing the RHIC Beam Energy Scan II under the challenging conditions imposed by COVID-19.

The RHIC accelerator complex is a unique and flexible research tool for heavy ion and polarized proton collisions with highest collision rates. The RHIC science program will end in 2025. The focus of the remaining runs will be on polarized protons for STAR (2022) and p+p,p+Au,Au+Au luminosity for sPHENIX (2023-25).

During the transition process from RHIC to EIC, it will be essential to maintain operational skills and to keep the injector complex in ready state.

The RHIC accelerator complex will continue to serve applied physics programs, as for example medical radio-isotope production and radiation effects studies for NASA. There are proposals to substantially extend the application programs at the Linac/Booster/AGS complex over the next decade.

R&D on accelerator technologies in support of the EIC project continues to be a focus at C-AD. Key aspects are R&D towards the demonstration of strong hadron cooling as well as ion sources.

RHIC Performance Update

Findings

The Beam Energy Scan II was successfully completed in Run-21, including Au+Au at 3.85 GeV/nucleon, the lowest ever RHIC energy. LEReC operated reliably and was critical for operation at the lowest energies. Run-21 availability was 90.6%, above the goal of 85%. The operations were successfully adapted for COVID. Run-22 will be polarized protons with refurbished OPPIS source and reliability upgrades for the H- jet polarimeter used to measure polarization. The beam energy will be higher than in recent years. The machine protection system has been improved as detailed in a later presentation. A number of issues have occurred during Run-22 startup, including a short in an AGS partial snake magnet. There has also been an increase in safety incidents, including electrical shock. Studies are planned at 16 days for CeC-X and ~5 days for Accelerator Physics Experiments. Runs 23-25 for sPHENIX as well as STAR are planned with 100 GeV/n beams. The luminosity will be maximized using a 56MHz SRF cavity for increased longitudinal focusing, a small vertex via 2mrad crossing angle with new power supplies to achieve smaller beta*, along with luminosity-leveling. C-AD has a 25-year technical infrastructure upgrade plan to ensure that the hadron injector complex is ready for EIC commissioning while also running for external users. A skew quad scheme to reduce power is progressing with power supply and magnet procurements in progress, and a plan for commissioning in Run-23. The model of the skew quads shows a very flat pole face. The BNL experts state that the large magnet aperture has a good field region sufficient to cover all the beam.

Comments

The continued effort to understand the recent increase in safety incidents may reveal common factors that could be addressed. It would be good to consider whether any of the issues encountered during beam startup this year have implications for running in the EIC era, eg, components reaching end of life. Meeting the availability goal of 85% (increased from 82.5% since Run-20) may be challenging in Run-22 polarized proton mode at higher energy than in recent years.

Recommendation:

Perform an assessment of components and spares needed to continue running in the EIC era

RHIC experiments for EIC

Findings

The EIC hadron beam parameters are advanced as compared with RHIC, including an order of magnitude more bunches, higher beam current, smaller emittances in the vertical plane, and smaller bunch length. The planned studies include:

- Radial shift studies (Run-22) – needed to finalize EIC design parameters
- Spin transparency mode study (Run-22)
- Collimator data for simulation benchmarking (Run-22)
- Decoupling studies and flat beam demonstration (Run-23)

Concerning the radial shift: the hadron orbit circumference will change (dp/p~+/-1%) depending on energy in order to synchronize with the electron beam

- Run-21 studies demonstrated radial shift with good optics control using dipole correctors, but had chromaticity issues and poor lifetime
- Run-22 plan (polarized protons) is to resolve chromaticity control, see how large a shift is possible, demonstrate that there is no effect on the polarization, and see if there is an effect from the Siberian Snakes

Spin transparency allows for control of stable spin direction using weak fields instead of strong field spin rotators

- Would provide an alternative way to create longitudinal polarization as backup to spin rotators
- Run-22 plan is to demonstrate the capability and to accelerate polarized protons without polarization loss

Concerning flat beams and decoupling: EIC HSR design proton H/V emittances are ~10/1 nm at 275GeV

- Goals are to verify RHIC decoupling tools efficiency for EIC requirements, and demonstrate as large as possible an emittance ratio in RHIC
- Run-21 decoupling studies achieved best ever dQmin in RHIC
- Run-23 plan is to use stochastic cooling to reduce vertical emittance

EIC-related beam studies are planned in the Accelerator Physics Experiments (APEX) framework for approval and review. The CeC-X and LEReC studies covered in separate talks are also important for the EIC cooler design.

<u>Comments</u>

The five days of studies planned by RHIC is expected to be more than sufficient for the highest priority radial shift studies. The spin transparency studies can be done in a later run if necessary. Appropriate priority is given for these and CeC-X/LEReC studies needed for EIC design. Next year the committee would be interested to see results of measurements relevant to collective effects

Recommendation:

<u>Operation with sPHENIX</u>

<u>Findings</u>

The PHENIX detector is located in IR8, upstream of collimators and just one arc downstream from the Abort System of Yellow Ring installed in IR10. Abort System pre-fires happened in the past, causing the beam to hit magnets and leading to damage to the detector. The new sPHENIX detector planned for 2023-2025 operation will have a micro-vertex detector (MVTX) placed very close to the beam. Considering the planned 2mrad crossing angle, pre-fires can create a lot of damage. Pre-fires typically characterized by 1 out of 5 abort kicker modules discharge asynchronously. Considering timing of other modules, over 1300 ns, up to 13 bunches are affected, and some can be lost and cause damage. Pre-fires in the past happened in both rings, about 10 events per year, and typically (90%) with beam. The reason appears to be a combination of high Voltage and radiation on thyratrons. Run 9 to Run 13 had six occurrences that caused damage to both detectors. During Run15, the PHENIX MPC detector was destroyed. Various ways were investigated in the past to protect detectors from pre-fires:

- Masks were added for Run15 with titanium inserts – were not sufficient, primary beam hit produced shower that damage detector
- In Run14 and Run16 protective bumps were added to lose beam in magnets and not in detector, but this caused high radiation doses which damaged diodes

The present plan for pre-fires mitigation is to add mechanical relays (with redundancy) for thyratrons to veto pre-fires. The relays time of action: 30ms to close initially, 6ms after spring load upgrade. The 6 ms time corresponds to 460 turns and is unprecedented in high intensity accelerators. The system was tested in 2018 with 9-11 ms delay at injection and in store, observing no orbit and tune deviation with delayed Quench Switches. A delayed mode of abort triggering (7ms for kickers and 10ms for quench switches) is now used, activated after transition crossing, and deactivated before injecting the beam. For dealing with delayed abort several additional inputs were added to the MPS. Inputs from BPMs were added to MPS, with several tens BPMs monitored at 10kHz, allowing to abort beam milliseconds before seeing BLM losses. The BPM/MPS does not protect from errors that do not affect orbit, for such errors BLMs are the last line of defense. New MPS inputs were also added – correctors of power supply – this can prevent beam loss in case of corrector power supply failure.

New MPS inputs were added for Run22 – monitoring quads PS, as their failure would not affect the orbit. The system will be tested this year. The upgraded MPS with all these additional inputs is still blind to failure modes that blow up the beam faster than 6ms and cause losses without affecting the orbit (instabilities, e-cloud, etc.). A review of all aborts starting from Run19 has been performed to study the adequacy of new MPS. An example of failures are: collimator damage to bearings due to radiation. The SC magnet's bypass diode damage due to radiation was observed, being studied, and monitored now for their evolution. EIC developments related to MPS included studies of radially shifted beams – no orbit restrictions were found. The collimation system for EIC will be new, and is being studied. For EIC more MPS inputs will be added for new systems, like crab cavities. The impact of the delayed abort system for EIC is being studied. Alternatives for delay abort system for EIC are also under investigation

Comments

The team put a lot of effort into solving this problem for sPHENIX operation. The committee heard about redundancy in the mechanical relays, and it was clarified in the discussion that the risk which is addressed is “fails to close” (risk is of a “rebound” reopening the circuit and compromising the kicker discharge), which requires two relays in parallel. Many alternatives were considered, but existing configuration (e.g. no service tunnel like in LHC), limited the options for solving the issues. For the EIC the location of collimators and abort systems can be optimized to mitigate this issue. The compatibility of the MPS upgrade with EIC has just started to be studied, however with significantly higher beam intensity of EIC beam this appears a challenge.

Recommendation:

Further evaluate the possible beam loss mechanisms that are caused by instabilities or other phenomena which occur faster than the present reaction time and for which the upgraded MPS is presently blind

Continue studies of compatibility of the MPS upgrade for EIC operations and make a detailed presentation at the next MAC, together with possible alternatives

Charge question (sPHENIX)

> **Are the technical goals realistic and is the progress appropriate to meet the stated goals?**
>
> Yes, the Committee believes that the technical goals are realistic and the progress is appropriate.
>
> **Are there any technical issues that were missed and/or need additional attention by the team?**
>
> The Committee is suggesting to further review the modes of beam loss that can be caused by instabilities or fast loss effects.
>
> **Is the accelerator R&D effort well executed and future work well planned?**
>
> Yes. The Committee is supporting the team’s efforts to evaluate compatibility of the developed MPS upgrade with future EIC operations.

<u>CeC results in Run-21, plan for Run-22</u>

<u>Findings</u>

CeC will be essential to reach the EIC design luminosities. The proof of principle experiment, CeC X, is therefore of highest priority. Since 2019 the focus is on the Plasma Cascade Amplification (PCA). The first goal of CeC X is to demonstrate longitudinal cooling, based on PCA. The theoretical foundations of this novel amplification mechanism are described in a recently submitted publication.

During Run 20 the presence of the ion imprint in the electron beam was observed. During Run 21 substantial progress towards CeC X has been made. A diagnostics beam line has been commissioned. This allowed for more accurate measurements of the beam parameters. The recombination of electrons with Au ions led to more precise measurements of the beam alignment and the energy offset. The seed laser was identified as the source of bunch-by-bunch jitter and has been replaced. Possibly there has been a first indication of CeC, with a cooling rate of about 16h.

The conceptual scheme of PCA-based EIC strong cooler, requested for this MAC, was presented only partially in the HomeWork - based on periodic 4-cell PCA and 3-path ERL. The PCA gain is 3-5 times larger than of CBA, and PCA bandwidth (500 THz) significantly exceeds that of CBA (30 THz), which was reported to allow eliminating the need for pre-cooler in case of PCA-based strong cooler. However, the feasibility of electron beam parameters (beam emittance, bunch length) compatible with 3-pass ERL injector was not described.

<u>Comments</u>

With the new seed laser, improved beam control and diagnostics CeC X should be ready for Run 22 and the first demonstration of longitudinal CeC. This would allow the team to validate their simulation models and to make more accurate predictions for the EIC requirements. Run 23 would then be dedicated to 3D cooling, which is required for luminosity improvements.

Recommendation:

Focus on CeC X with the goal of longitudinal cooling demonstration. From the experiment, extrapolate parameters and requirements of PCA based CeC for EIC

Present the concept of PCA-based EIC cooler at the next MAC, including discussion of the feasibility of e-beam from 3-pass ERL

Charge question (CeC)

> **Are the technical goals realistic and is the progress appropriate to meet the stated goals?**

Yes, for the demonstration experiment.

Are there any technical issues that were missed and/or need additional attention by the team?

No. Also see the recommendations above.

Is the accelerator R&D effort well executed and future work well planned?

Yes. Also see the recommendations above.

LEReC operational performance summary

Findings

LEReC is the first non-magnetized RF-linac based electron cooler that was successfully used for improving luminosity in colliders. The team addressed previous MAC recommendations, in particular further optimizing luminosity during run, and supporting dedicated R&D. The Phase II is presently not planned, so no resource loaded schedule for it was developed. LEReC was used in operation, providing stable cooling in 2020 and 2021. Various feedbacks were implemented, cooling was optimized vs heating effects, the optimal e-current was 15-20mA for 4.6GeV/n Au in 2020 and 8-20mA for 3.85 GeV/n Au in 2021. Robust K2CsSb photocathodes with QE of 8-9% required cathode exchange only every 2 weeks. Typical available average laser power is 25W with 8.5W on the cathode, point stability achieved with feedback. Cooling optimization for luminosity included many knobs: longer stores with cooling, dynamic squeeze of ion beam beta functions at IP (transverse size squeezed about 10%), reducing RF voltage (to about half - from 180kV to 90kV) resulting in smaller ion momentum spread and better lifetime, etc. The team is also evaluating the EIC precooler of LEReC type, as well as strong cooler alternatives such as a wiggler filled storage ring with 150 MeV electron beam that can cool protons at full energy. The team also performed a number of cooling experiments to better understand the effects relevant for EIC (described in the next talk). The team is also making use of the LEReC gun, which is capable of higher current (30-50mA and above) than used for LEReC, for studies towards the 100 mA source which is needed for EIC. Gun voltage limitations and operations at 400-425-450kV will be explored, as well as operations with different laser spot sizes on the cathode, etc.

Comments

The team is congratulated on successfully using LEReC for RHIC operations and luminosity improvements. Experimental studies at LEReC are unique and very important for optimization of EIC pre-cooler. High voltage and high current studies of the gun have a probability to damage the gun, and should be optimally scheduled, so as not to impact other LEReC studies.

Recommendation:

Since the time for cooling experiments in 2022 and 2023 may be limited, prioritize the variety of planned cooling experiments based on the needs of the EIC precooler and high-energy cooler designs, while aiming to avoid possible loss of time due to potential gun damage in high current studies.

LEReC experiments, past and future

Findings

LEReC represents a unique facility for studies of EIC precooler studies. It is the first RF based cooler and first to use non-magnetized beam – making it scalable to high energy applications. Completed studies include: coherent excitation in cooled ion bunches, recombination, ML for cooling optimization. Ongoing studies include: the mechanism of electron-ion heating, redistribution of cooling decrements, cooling of short bunches, impact on ions' lifetime, and high current studies.

The results of coherent excitation study have shown that coherent excitation in longitudinal and transverse direction must be avoided. This translates to the requirement for EIC that the path length of e-i needs to be controlled to be better than 1.3 micrometres, (and also translates to 4e-4 energy stability for electrons and 3e-4 energy stability for protons, which is not so bad).

The recombination study confirmed that textbook formulas work, no recombination enhancement was observed. Studies of recombination also created the way to match relativistic factors of beams with 0.2% accuracy. The ML testing to improve e-beam trajectory was successful and resulted in a paper submitted to PRAB.

The electron-ion heating is one of ongoing studies, where a certain invariant in dependence of heating on parameters (heating rate times the 4^{th} power of size of ion beam is constant) was experimentally observed, but not yet explained theoretically. This effect may not be limiting for RHIC but may be for EIC. Further studies are planned, including dependence on the working point, studies at higher energy, etc.

Redistribution of cooling decrements is another ongoing study, which involves creating e-dispersion and offsetting e-beam. About 20% longitudinal to transverse redistribution was observed. Studies will continue with e-dispersion larger than 2.7m.

Cooling with short electron bunches is also ongoing. The plan is to measure cooling with shorter e-pulses, which will require modification of the laser system.

Studies of ion lifetime in the presence of the electron beam, and of the elevated ion losses, is yet another ongoing study critical for EIC, and they will continue, including the dependencies on e-beam size, current, density and RHIC tunes. Future studies also include high current study as described in the previous talk. These studies will use the potential capability of the LEReC gun designed by Cornell, which at Cornell achieved 65 mA, while LEReC used 30mA.

Comments

The electron-ion heating is not yet understood theoretically, but may be important for EIC. Other effects planned for studies at LEReC are also critical for EIC. Recombination of protons will also happen in EIC cooler and needs to be studied. It was noted in the discussion that the e-p binding energy is very low, and e- can be stripped from e-p in bending magnets right away, producing local beam losses. In comparison, Au recombined in LEReC can circle a few turns in RHIC. Recombination of e-p needs to be studied for EIC. The committee is supportive of the LEReC group's efforts for continuously discussing the obtained observations and possible theoretical explanations with experts at BNL and at other laboratories.
Committee is pleased to see strong connection with the EIC design team and with a wider team of design and theoretical experts that helps for timely discussion of experimental observations, and for possible proactive adjustments of experimental plans of studies that are critical for EIC.

Recommendation:

Consider lowering the priority of high voltage high current gun studies, as these studies can presumably be done elsewhere or later, while the window of opportunity for LEReC cooling study is limited.

Polarized He-3 source

Findings

The production of polarized ^{3}He is proposed to use an Electron Beam Ion Source, based on the solenoid design of the present RHIC EBIS, as well as the electron gun.

The system will be heavily modified to use two solenoids, the first solenoid with a new trap layout that is optimized to allow the injected polarized ^{3}He gas to be quickly pumped away without entering the second solenoid. In that case the performance of the EBIS for the externally injected ions should not be compromised, and actually more trapping volume will be available which is of benefit to the heavy ion program.

The ^{3}He is to be polarized in a dedicated cell also inside the first EBIS solenoid with 1083nm light delivered through a fiber, with a pulse valve to deliver polarized atoms into the EBIS ionization region on demand. Very positive results of the gas polarization on a test solenoid were presented at the previous committee. There is still development work to perform, which will make use of the large bore RhicEBIS solenoid. This work is performed in collaboration with MIT.

The number of ^{3}He ions that can be produced is based on the EBIS trap capacity which is well established for EBIS.

One of the few unknowns is that sufficient ^{3}He atoms are ionized before their polarization is lost.

Presently the double solenoid configuration has been set up on the test stand and has already been used with high electron currents to create He, Ar and H ions. The system is now being assembled with the final vacuum system.

The system will be moved to the Linac in the second half of 2022. After this time the ^{3}He (unpolarized) can be set up and potentially delivered to the polarimeter set-up. However, the ^{3}He polarization system will become available for installation in 2023, with its full commissioning at the end of 2023.

Mention was made that the extended-EBIS could provide 5-10x10^{11} protons per pulse (unpolarized), which could be sufficient for the needs of NSRL. This could avoid some periods of operation of the 200MeV linac just for NSRL.

Comments

Overall, the R&D and plans for polarized ^{3}He are excellent and technically well thought out, and are at the cutting edge of science. The committee cannot see any further issues and are interested to see the next results.
It should be verified that the proton production from the extended EBIS would be compatible with the NSRL needs (given the lower Linac energy).

Recommendation:

The resources required for completing the R&D should be confirmed and made available.

High-current SRF gun update

Findings

The CeC SRF gun showed excellent performance by 2020 in charge per bunch, transverse emittance, and lifetime of high QE photocathode. Following the results, the new research project to upgrade the SRF has been funded and launched in 2021. Tasks in the project are divided into three tracks. Track1 focuses the research direction of high current SRF electron gun to increase average current of unpolarized beam to 1 mA (3mA in ultimate goal) in Phase I, the first two years, and to 30 mA (100 mA in ultimate goal) in Phase II. Track2 is new direction in polarized SRF electron gun R&D. Track3 is development of performance restoration techniques for SRF guns.

Modifications of CeC accelerator is continuing in order to prepare for the gun operation with 1-3 mA. A new solenoid and a DCCT were installed in the diagnostic beamline and in place of the second 500 MHz cavity which was removed, respectively. Adjustment of MPS to allow use of buncher cavity and 5-cell SRF linac is in progress. High beam transmission from the SRF gun to the diagnostic beam dump was successfully demonstrated in Run 21. The maximum bunch charge of ~8 nC was limited by MPS, which will be updated in Run 22, in the demonstration.
Upgrade of the laser system is in progress. New seed laser with 5 psec rms time jitter is installed to improve electron beam energy stability and now operational. Beam dynamics studies for high current gun operation in Run 22 are nearing completion. The ultimate goal of 3-mA operation is expected to be achieved by the following two scenarios: (1) operational repetition rate of 0.837 MHz, charge/bunch of 3.58 nC with the linac and buncher, (2) 2.974 MHz, 1.01 nC without the linac and buncher. The high current study toward 1-3 mA beam current is pursued in Run 22 working in parallel with the regular CeC operation.

Upgrade of the cathode deposition and transport system for GaAs has been completed. In the new vacuum cathode system, load lock and cathode transfer chambers achieved 10^{-12} Torr range. The CeC cathodes system is upgraded to accommodate multiple clustered alkali sources, and to introduce 2 D mapping system of quantum efficiency, and new cathode magazine for 4 cathodes, etc.

In February of 2021, the CeC SRF gun showed performance degradation owing to damage on the RF spring finger of cathode end effector. The damage caused significant contamination of the SRF cavity. However, the cavity in CW and pulsed modes with He conditioning demonstrated performance restoration of the SRF gun.

<u>Comments</u>

The steady progress was made on SRF gun R&D of high beam current operation and polarized source. The scenarios to achieve the beam operation with 1-3 mA are well studied and seem to be realistic to reach the goal within 2022 as planned. Good progress is shown also on preparation of the polarized SRF gun.

The high current CW SRF proposal funded from 2021 is collaboration effort of BNL, Fermilab, JLab and SBU. The committee heard about study plan of the first two years in the last C-AD MAC meeting. However, it would be necessary to clarify the overall plan which includes whole schedule and final goals of the SRF high current and polarized beam R&D for the EIC project.

Recommendation:

Develop the overall plan, including schedule and goals for the high current and polarized beam R&D project.

Center for Linac Isotope Production (CLIP) proposal, p-accelerator

Findings

A draft proposal (CLIP) to extend the existing medical isotope production facility (BLIP) has been prepared. Besides a factor 2 gain in average current from the existing linac, the idea is to boost the present proton beam energy of 200 MeV (33 kW, at present) to 600 MeV (120kW) or even higher. This would result in a similar cross section for Ac-225 production but would allow for thicker targets and higher production yields. In addition, higher energy will allow increased production of faster spallation neutrons that can be used, for example, for radiation damage studies. Motivation for the project is well defined.

In addition, a light ion accelerator for up to 60 MeV/u (80 kW) is considered.

Different options to accommodate the booster linac, the ion linac and the new target sections are under consideration. Some of them require a new tunnel and/or new buildings for RF gallery and targets. Four options have been considered. Comparison of these options has been presented; however, cost analysis of each option hasn't been included.

The booster linac should rely on room temperature structures (Fermilab CCL) and its length would be about 120 m. First beam dynamics studies were presented. The details/requirements of the target stations have not been presented.

Comments

Beam losses in the existing linac are well understood and controlled. The increase of the average current by a factor 2 should be straightforward and should lead to a corresponding increase in isotope production rates. It would be useful to summarize the limitations for further proton intensity upgrades with the existing linac.

The proposed booster linac will rely on proven technology. However, the proposed CLIP facility will be a major undertaking in terms of the various linac structures and required building infrastructure, with possible additional radiation protection measures, also at

the targets. Upgrade of the parts of the 50 years old linac (such as RF systems, controls, etc.) will be required.
As isotope production does not require very good beam quality and usually benefits from continuous beams, it would be interesting to understand how a stand-alone cyclotron facility would compare. More detailed beam parameter requirements on target by the isotope program would be important to know, in order to understand the optimum design choices for such a new facility.

Recommendation:

Continue working on the separate proposals for the proton and ion parts.

Clarify beam requirements by the isotope program.

Analyze the presentated options including approximate cost analysis and select the most feasible.

Center for Linac Isotope Production (CLIP) light ion accelerator

Findings

A proposal is being put forward for a 60MeV/u Linac cable to deliver p, He and Li ions with 2ms pulses at 100Hz at 2mA intensity, to be used for isotope production, in particular for alpha emitters as well as nuclear cross-section measurements.
The presentation concerned the Linac part, but the full project would also consist of targetry. Low and medium energy transport have been presented. Unique existing super conductive RF cavities have been described.
No schedule was shown as this is in the conceptual phase, one will become necessary for discussion with the isotope production community so the expectations are clear.

Comments

The project is very ambitious in general given the high intensities (for Li), high rep-rates and likely use of superconducting cavities.
Although there are certainly many possibilities for optimization of the frequency, cavity types etc, at this stage it is important to put together a feasible and coherent design such that any highly critical R&D and/or show-stoppers can be identified.
The lithium ion source is a challenge, and was presented in the next talk. The criticality of Li ions for the application should be assessed.

Recommendation:

Complete the conceptual design, concentrating more on feasibility than optimization.

Identify stages for the project and develop a schedule and budget for each phase.

Lithium ECRIS

Findings

For a light ion Linac for isotope production, p, D, He and Li beams are proposed. Li beams at high intensity and millisecond pulse regime are not currently available at any known source.

The production of multiply charged ions is the domain of EBIS, MEVVA, Laser Ion and ECR sources. The ECR source has been considered at present. The increase in intensity that is needed is approximately ten times higher than previously produced in ECRs.

The team is presently at the stage of investigation of the issues that are pertinent to using an ECR for Li production.

The team has already identified difficulties from the reactivity of Li which will limit the possible materials in the source. Three possible mechanisms for injecting lithium were outlined

ECR sources used with metal vapor ions suffer from stability issues, which should not be underestimated. The coating of the chamber with Li changes the parameters during a conditioning period. The team have already identified that it might be necessary to control the plasma chamber wall temperature to control this, but they noted high temperatures on the wall must be compatible with radial magnetic field if it is provided by a permanent magnet. Additionally, the use of a buffer gas can contribute to the removal of that layer due to sputtering. Oxygen buffer gas typically improves performance but that may not be the case with Li, so other buffer gasses would have to be tried.

Afterglow and pulsed mode operation of the ECR should be considered as one way to increase the intensity by approximately a factor 2. This would need experimental verification as the effect is not as well studied for light ions.

Comments

Although calculation and simulation are important for the engineering of sources, iterative development is still a very important part of development for beam production.

Starting development of an ECR source is a potentially long process, and as much as possible a good candidate source should be taken as a base for the design. If possible a partner lab should be identified where tests with Li can be made.

It was noted that the field quoted was typically the ECR resonance field in the source, it should be clarified that ECR source typically work with peak fields longitudinal and radial approximately 2x the resonance field.

Recommendation:

Clarify the timeline for development of a source and the resources needed.

Clarify the criticality of a Li beam to the CLIP program, and if low intensities are of use in a staged development.

Charge question (CLIP)

Are the technical goals realistic and is the progress appropriate to meet the stated goals?

Given the conceptual stage of the project, there are limited physical technical results and it is too early to assess the progress.

Are there any technical issues that were missed and/or need additional attention by the team?

No

Is the accelerator R&D effort well executed and future work well planned?

No long-term schedule for R&D was presented. The development on the Li source will be significant and should not be under-estimated.

High-Energy Effects Test Facility (HEET) proposal

Findings

This is a new proposal which addresses a national need to heavy ion single event effects (SEE) test facilities for increasing test time and reaching higher energies to simulate the radiation environment in space, which is now only available at NASA Space Radiation

Laboratory (NSRL).
The new facility, High Energy Effect Testing Facility (HEET) is designed to utilize the AGS. It has some significant capabilities, such as a large range of beam energy (for example, 40-2000 MeV/n for Fe21+ ions), large number of available ion species from hydrogen to uranium (and more), fast energy and ion species change in minutes. The broad energy range extends the available fraction of galaxy cosmic ray spectrum simulation from 60 % at NSRL to ~75 % at HEET in maximum.
Beams will be extracted from the AGS using a third-integer resonant extraction method. A significant challenge in the beam extraction is improving spill structure. Harmonics of 60 Hz power line should be reduced by tuning parameters of power supplies, and adopting active ripple filters. In addition, study of high frequency correction quadrupole(s) system, which is introduced for feedback operation using measured field harmonics, is now in progress.
In the operation plan, the total number of weeks available in a year is 44, and approximately 5000 hours per year is expected. The facility availability is supposed to be 80 %. The remaining 20 % is for down time due to failures and for use of the AGS for beam injection into RHIC today and EIC in the future. The present situation of concurrent operation with RHIC (EIC in the future), NSRL and BLIP is assumed. NSRL and HEET run concurrently with taking different ion species.
Construction funded by DoD to be finished in 3-4 years. Commissioning cost are part of construction funding. The first year of operations supported by DoD. Funds after the second years will be collected based on proposal review process.

Comments

The AGS HEET is a project to meet growing demand for high energy SEE testing and fit to the strategic initiative of the BNL. The committee strongly supports the proposal.
The project uses existing building and shielding, and requires no civil construction. It basically only needs to build a beamline and user facility.
The team has world class expertise to be required for design and construction of the facility, and also has rich experience of advanced beam control including slow extraction.
Technically, the improvement of spill structure is a challenge. Although the proposed measures, parameter tuning of PS's and introducing active filters, have proven their effectiveness in the past AGS operation, the other approach, such as the feedback system using fast response quadrupole magnets should be continued to pursue with a high priority. In the feedback system, using a measured signal of the extracted spill structure may be effective to improve intensity uniformity, as established in J-PARC.

The committee agrees that keeping AGS operation for the HEET during the construction period of EIC is beneficial for the quick start of the EIC operation with high reliability in the future.

Recommendation:

Continue to pursue effective methods to improve the spill structure for slow extraction of low intensity beams.

Charge question (HEET)

> **Are the technical goals realistic and is the progress appropriate to meet the stated goals?**
>
> Yes
>
> **Are there any technical issues that were missed and/or need additional attention by the team?**
>
> No
>
> **Is the accelerator R&D effort well executed and future work well planned?**
>
> Yes, and please see the recommendation above.