

Multipass-ER@CEBAF

**high-energy multiple-pass
energy-recovery experiment**

1/ MOTIVATIONS

2/ STATUS OF OUR DISCUSSIONS

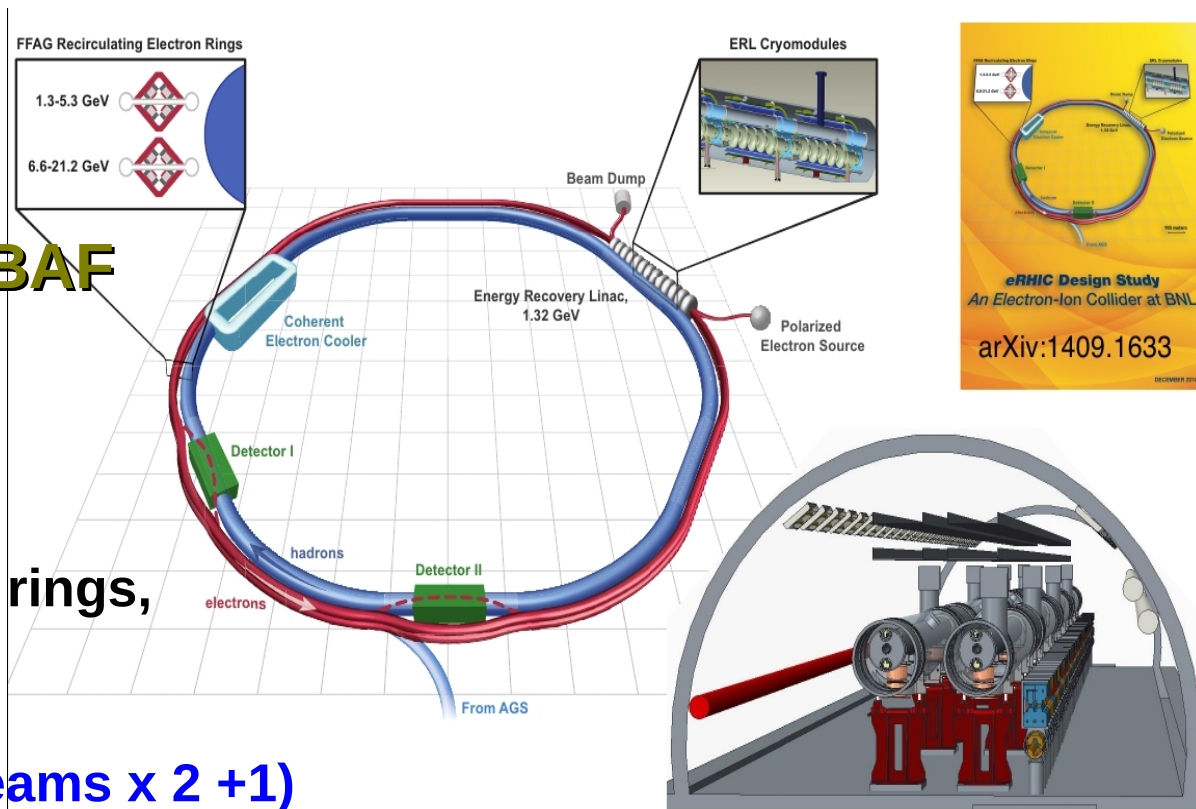
3/ NOTES FROM ERL'2015 SATELLITE MEETING

1/ MOTIVATIONS (1/4)

Multipass ER studies at CEBAF

eRHIC :

- **Double recirculator**, FFAG style rings,
1.3 \rightarrow 5.3 GeV (4 beams x 2)
6.6 \rightarrow 15.9/21.2 GeV (8/11 beams x 2 +1)
- **Average current >10 mA** (>1 nC/b, 9MHz)
- e-nucleon collision luminosity in 10^{33-34} /cm/s, CM energy 20-145 GeV
- Electron bunch undergoes single collision
- **Longitudinally polarized, 80%**
- IR design with 10 mrad crossing angle and crab-crossing
- **Acceleration and 99% energy recovery** by 1.322 GeV/422 MHz CW SCRF linac
- **SR compensation** uses 844 MHz RF, **energy spread control** uses 2.1 GHz RF



MOTIVATIONS (2/4)

- A full-scale multiple-pass ER experiment at CEBAF could study
 - ♦ full cycle bunch acceleration/deceleration : 5 up + 5 down
 - ♦ ER efficiency
 - ♦ response of RF systems
 - ♦ beam dynamics at BBU boundary ?
- Beyond, it could allow studies concerning
 - synchrotron radiation effects (momentum spread, bunch dynamics)
 - transport of polarization to top energy (12 GeV w/o ER)
 - full-scale multiple-beam instrumentation / diagnostics

MOTIVATIONS (3/4)

- **This is pioneering science : a demonstration of general interest to advanced ERL R&D and future EIC projects, light sources, etc.**
- **A collaboration between national labs, on a project which is the future of NP**

MOTIVATIONS (4/4)

- New R&D possibilities
 - *“High energy, multipass ERL using CEBAF”*
- Test ERLs
 - *“CEBAF converted to ERL: high energy, 5 pass, goal is 0.1 mA (1 mA total linac current)”*



2/ PRESENT STATUS OF OUR DISCUSSIONS

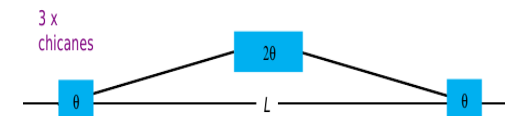
- Discussions about a possible R&D collaboration regarding eRHIC ERL related studies of concern today, have been going on between colleagues from both labs for some time now – started ~ end 2014
- A couple of dedicated joint meetings have taken place already :
 - first meeting was at IPAC 15 (M.Spata, M.Tiefenback, Fulvia, Vadim, FM)
 - a satellite meeting at ERL 2015, Stony Brook, Thu. June 11th
- The project has been discussed in meetings at BNL, including :
 - presentation at eRHIC retreat, May 26-27, BNL
 - last Wednesday at eRHIC meeting, in preparation to the present on
- Echoes, at LHeC workshop at CERN, Wed. June 24 : *“A demonstration of HE multi-pass ER will be high priority for LHeC R&D. Only 1-loop HE ER demonstrated, at CEBAF”*. O. Bruning ready to discuss collaboration to multipass ER@CEBAF experiment.

3/ NOTES, FROM ERL-2015 SATELLITE MEETING (1/3)

* slides can be found here: [indico](#) ; minutes in backup slides *

Thu. 11 June, open, ~25 participants from BNL, JLab, Cornell, CERN, etc.

- Goal of the meeting was : to carry on discussing an ER experiment at CEBAF / discuss its objectives / how to make it happen
- First planned to be closed, it was finally decided to open it, in order to benefit from the participation of experts present at ERL'15.
- Some outcomes, from presentations and discussions :
 - Both parties confirm their interest in this project,
 - BNL for eRHIC studies
 - JLab in view of contributing and of advanced accelerator studies
 - ER with 1GeV/linac, 5 up + 5 down passes, is doable. ER goal 99%.
 - Necessary modifications to the optics are doable – main constraint is constant $E_{\text{max}} / E_{\text{inj}}$
 - Hardware :
 - requires a 3-bump chicane in arc 10, to achieve $\delta l = \lambda/2$
 - a cryomodule has to be removed to place beam dump, at downstream end of South linac, for the duration of the experiment
 - diagnostics have to be developed



Notes, from ERL-2015 satellite meeting (2/3)

- Some outcomes (cont'd) :
 - Cost : to be investigated
 - JLab engineering will work on beam-line and magnet aspects
 - Some components may be available
 - BBU
 - ways to possibly approach BBU have been suggested (inhibit HOM dampers in new CMs; double current; increased current in ER mode ? ...)
 - measurements could include parameter scans as turn dependence
 - see minutes in backup slides
 - Other measurements of interest :
 - emittance effects of orbit+chromaticity on emittance
 - SR effects and compensation
 - diagnostics for multiple-beam
 - ...

Notes, from ERL-2015 satellite meeting (3/3)

- Principle of a 2-pass FFAG arc experiment was addressed too,
 - 7 + 9 GeV beams, in CEBAF Arc 9 region
 - Permanent magnet technology seems doable – magnet cross section fits
- Plans for future discussed at this satellite meeting :
 - The next CEBAF Physics Advisory Committee will be around April-May 2016.
 - Calls for proposals happen late summer / early fall,
 - Proposals have to be finalized by the end of the year.
 - We plan to submit a proposal through the regular approval process, just like for the 1-loop experiment (2002-2003).
 - Tasks foreseen at the 6th-7th July meeting, amongst others :
 - establish a list of objectives to be achieved in an ER experiment aimed at exploring eRHIC performance parameters
 - make necessary decisions as to writing the proposal, launch the work

To conclude this introduction to our meeting today

- **We are now at BNL C-AD a team of people ready to invest in this project :**
 - **10 people at the moment,**
 - **optics, beam dynamics, magnet, engineering specialists**
- **Ready to contribute in preparing the experiment :**
 - **beam optics, simulations including BBU, SR, polarization**
 - **magnet design, measurements, fabrication**
- **Ready to participate in the experiment**

BACKUP SLIDES

6th-7th MEETING AT JLAB

Monday

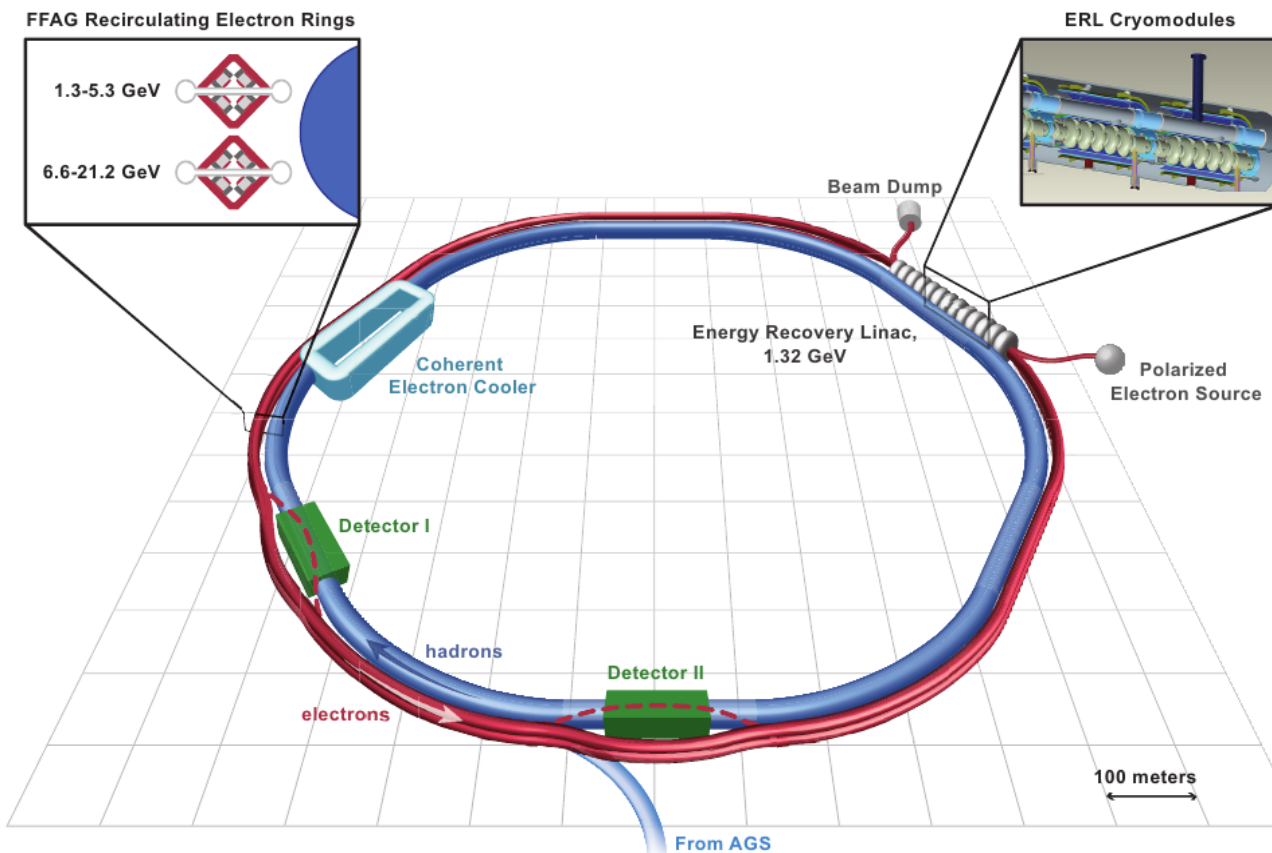
Time	Event	Major Discussion Points	Slides presented by :
0830-1200	Meeting for Discussion	<ul style="list-style-type: none"> • Outline of Overall Proposal • Impact to CEBAF Operations • CEBAF Layout and Limitations <ul style="list-style-type: none"> • Beam Current • Beam Power • Top Energy • Machine Protection • FFAG Transport <ul style="list-style-type: none"> • Energy Requirements • Spreader/Recombiner Layout • Physical Installation • Magnets • Diagnostics • Proposed Measurements • BBU measurements • Summary of LHeC Workshop • Expanding the Collaboration <ul style="list-style-type: none"> • Cern, Cornell • Funding discussion • Proposal Writing Timeline/Plan 	<p>F. Méot/F. Pilat/V. Ptitsyn</p> <p>M. Spata (TBC)</p> <p>A. Bogacz and/or Y. Roblin</p> <p>Brief eRHIC intro : F. Méot/N. Tsoupas</p> <p>CEBAF : A. Bogacz and/or Y. Roblin</p> <p>C. Tennant (TBC)</p> <p>T. Satogata Intro by Vadim</p> <p>A. Hutton</p> <p>General Discussion</p> <p>M. Spata, A. Freyberger</p> <p>F. Pilat /F. Méot</p>
1200-1300	Lunch	CEBAF Cafeteria	CEBAF Cafeteria
1300-1700	Tour CEBAF/FEL	Injector, North Linac, FEL,SRF	Injector, North Linac, FEL, SRF
1800-2100	Dinner	Offsite Restaurant	Offsite Restaurant

Tuesday

Time	Event	Details
0900-1000	Meeting for Discussion	Continued discussions from previous day or more focused working groups depending on previous days discussions.
1000-1200	Prep for Summaries	Write slides for summary presentations
1200-1300	Lunch	CEBAF Cafeteria
1300-1500	Summary Presentations	TBD

eRHIC parameters

- Hadron species: polarized protons (up to 250 GeV), polarized $^3\text{He}^{+2}$ ions (up to 167 GeV/u), heavy ions (typically $^{197}\text{Au}^{+79}$ or $^{238}\text{U}^{+92}$ ions, up to 100 GeV/u)
- Polarized electrons: in the range from 2 GeV up to 21 GeV
- The luminosity: $10^{33} - 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ in terms of e-nucleon collisions



	e
Energy, GeV	15.9
CM energy, GeV	
Bunch frequency, MHz	9.4
Bunch intensity (nucleons), 10^{11}	0.07
Bunch charge, nC	1.1
Beam current, mA	10
Hadron rms normalized emittance, 10^{-6} m	
Electron rms normalized emittance, 10^{-6} m	
β^*, cm (both planes)	5
Hadron beam-beam parameter	
Electron beam disruption	
Space charge parameter	
rms bunch length, cm	0.4
Polarization, %	80
Peak luminosity, $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$	

**Beam power at 15.9 GeV:
160 MW and beyond
→ ER is necessary**

Linac parameters

Energy gain	1.32 GeV
Bunch length	4 mm rms
Bunch repetition frequency	9.38 MHz
Number of RF buckets per RHIC revolution	120
Number of RF buckets filled	111
RF frequency	422.3 MHz
Number of SRF cavities	42
Linac fill factor	0.60
Cavity type	elliptical, 5-cell
Accelerating gradient	18.4 MV/m
Operating temperature	1.9 K
Cavity intrinsic Q factor at operating gradient	$5 \cdot 10^{10}$
Peak resonant frequency detuning due to microphonic noise	6 Hz
Q_{ext} of FPC	$3.5 \cdot 10^7$
Peak RF power per cavity	30 kW
Total heat load at 1.9 K	2 kW
Maximum HOM power per cavity	7.8 kW

Table 3-4: Parameters of the main SRF linac.

Additional SRF :

SR loss : 844 MHz (h=2)

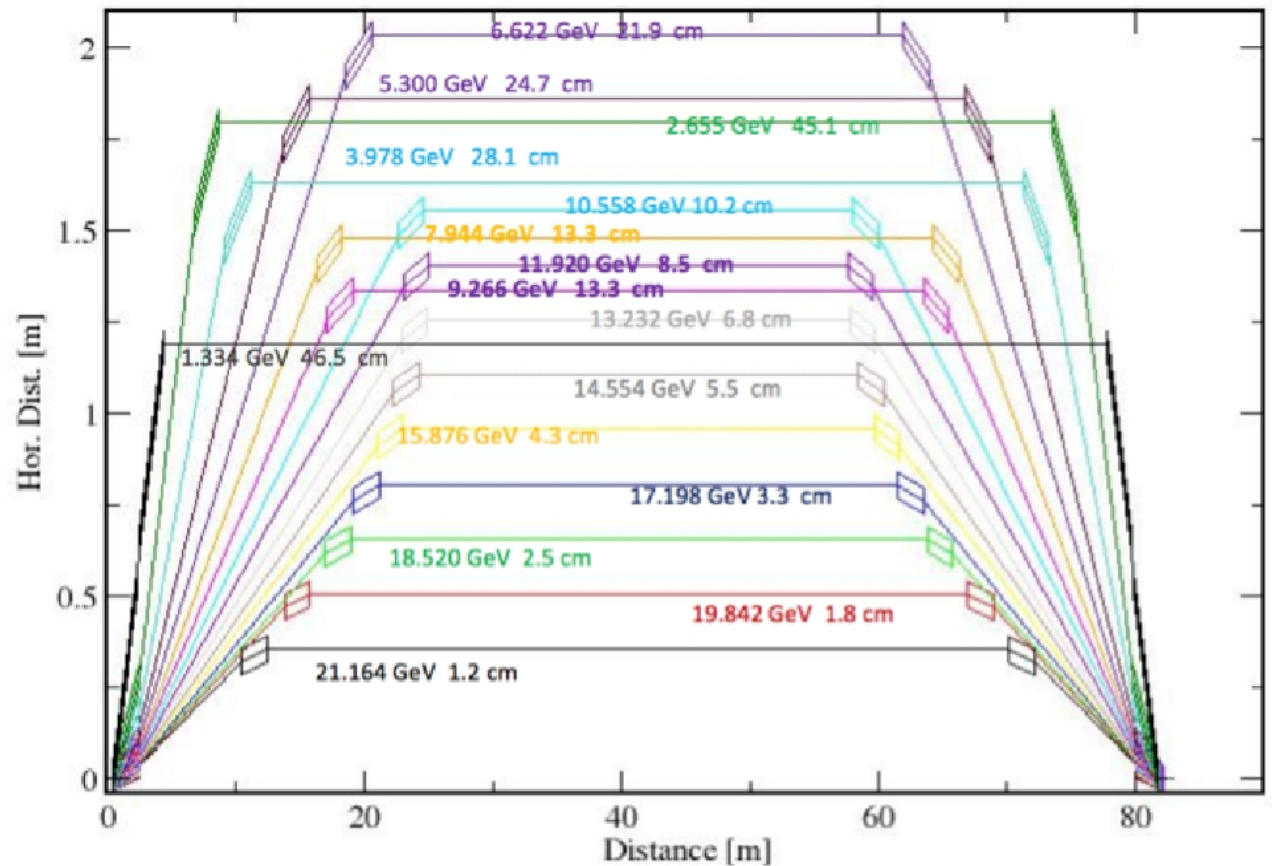
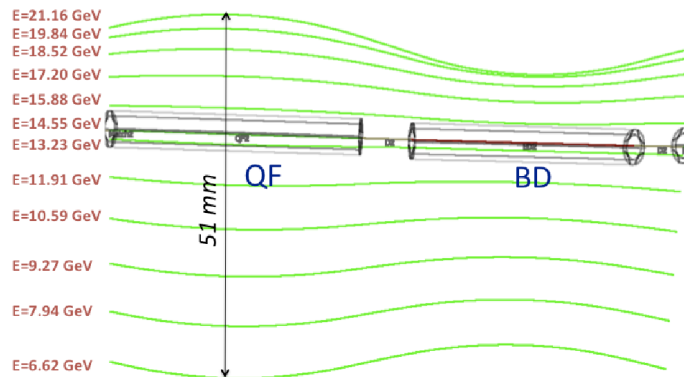
Energy spread (polarization) : 2.1 GHz (h=5)

Recirculations

ERL \leftrightarrow FFAG orbits splitter/combiners

Low energy ring : 4

High energy ring,
15.9 GeV : 8
21.2 GeV : 12



Path compensation in splitter/combiners is ensured at higher energies by H and V chicanes.

F. Méot, BNL, 12 June 2015

A multiple-pass energy-recovery experiment at CEBAF

Thu. 11 June 2015

ERL 2015 Workshop satellite meeting

Minutes

Introduction

A 1hr45 satellite meeting was held during ERL 2015 workshop in Stony Brook University (on Thursday 11 June, 0900-1045am), a joint BNL-JLab initiative, as a follow on of earlier e-mail exchanges, and of a dedicated joint meeting that took place during IPAC 15. The goal of this ERL'15 meeting was to carry on the discussion regarding a multiple-pass ER experiment using CEBAF, in particular regarding the objectives of such an experiment, and the way to make it happen.

It was at the origin planned to hold a closed meeting, however, it was eventually decided to open it, in order to benefit from the participation of experts present at ERL'15. The meeting so gathered about 25 participants, from BNL (V. Ptitsyn, N. Tsoupas, Berg, FM, etc.), JLab (F. Pilat – on video, M. Spata, A. Bogacz), CERN (at least 2), Cornell (at least 4) and other labs.

An introduction, by V. Ptitsyn followed by F. Pilat, started the meeting, this introduction emphasized the interest of both parties, BNL for eRHIC project purposes, JLab in view of contributing and of advanced accelerator studies. Then followed the three planned presentations by FM, A. Bogacz and N. Tsoupas, slides available [here](#). The talks essentially addressed the general motivations for such experiment (FM), and preliminary approaches of ways to technically achieve it (AB, NT). The question of an FFAG arc was also addressed in a similar manner, yet shortly, by both parties, BNL and JLab.

Excerpts from the presentations and discussion :

- ER with 1GeV per linac and 5 pass (10.1 GeV beam) is doable. A 100:1 ratio at 100 MeV injection energy. ER goal is 99%.
- Main aspects of the modifications to be done to the optics have already been investigated, they can be done.
- Main constraint is to maintain E_{max}/E_{inj}

- A conservative 3-chicane string (θ - 2θ - θ chicanes, 2m long 2θ dipole) can be installed in the new arc 10, to achieve $\delta l = \lambda/2$. It is not possible to achieve that if based on sole orbit deformation (aperture would only allow $\sim 30\%$).
- A cryomodule has to be removed to place the beam dump, upstream of arc 10, at the downstream end of the South linac. The CM will be put back in place after the experiment.
- Costing of an ER experiment (cf. also slide #8 in FM's presentation) : Mike Spata will engage JLab engineering on the beam-line and magnets aspects. Besides, various components may be available, TBC, that might reduce costs compared to slide #8 data.
- BBU has been subject to substantial discussion, many ideas/points have been discussed/addressed, amongst which (see also slide #7, FM pres.) :
 - possibilities of increased current, limit of beam dump is 20kW, so allowing 200 μ A ER-ed beam
 - BBU studies at low I/high E at CEBAF compared to high I/low E R&D projects
 - Intensity upgrade on the injector front
 - at constant beam power the lower rep.-rate limit is 31MHz (limit is space charge in the injector). No such constraint if power is not maintained.
 - possibilities of exciting BBU, including removal of HOM dampers in the upgrade CMs (in the number of 5 per linac) for which HOM ports are out of the CM
 - question of the equivalence low Int./strong HOMs \leftrightarrow high Int./weak HOMs
 - parameter scan, as turn dependence, etc.
- SR loss can be a limitation in power increase. SR loss is 105 MeV for the nominal 12 GeV lattice.
- Chroma effects (typical of eRHIC FFAG lattice) could be studied using CEBAF sextupoles
- Possibilities to study SR effects, compensation (based on RF phase, off-crest tuning).
- Plans for ad hoc diagnostics for such multiple-pass ER experiment
- It was argued that iron trapping might be more a problem than BBU
- Feasibility of parasitic operation of the experiment during physics run
- Extending CEBAF run, a matter of ~ 2 weeks, for an ER experiment. Requires dedicated funds
- RF and klystrons : seems doable to increase Int. in ER mode since no additional power draw from RF. How far ?

The FFAG arc discussion has addressed the following points :

- It is possible to insert a two-beam arc, 7GeV+9GeV, between CEBAF arcs 7 and 9. Clearance is 50cm, fits with eRHIC permanent magnet cross section. Beam steering into the arc is doable.
- Lower energy arc/lower cost/lower synchrotron radiation versus high E/higher cost/eRHIC level SR for SR studies
- Using RF kickers (frequency in range up to e.g. $\sim 400\text{MHz}$) in place of regular spreader-combiner, for simplicity and flexibility

Other FFAG R&D plans were brought up, besides CEBAF ones : CEBAF ERL is available, the interest is there for possible multiple-pass ER and FFAG arc R&D. It was suggested to add an appendix with such a proposal in a bid to JLab PAC.

Plans for future

The next CEBAF Physics Advisory Committee will be around April-May 2016. Calls for proposals happen late summer / early fall, proposals to be finalized by the end of the year. We BNL/JLab group plan to submit a proposal through the regular approval process, just like the 1-loop experiment.

We plan to meet in very close future to, amongst others,

- establish a list of objectives to be achieved in an ER experiment aimed at exploring eRHIC performance parameters
- establish a list of tasks to be undertaken, and names to go with
- make necessary decision as to the proposal and its writing

In a very first step, we plan to meet at JLab by early July to visit CEBAF tunnel, and establish the necessary collaborations with machine designers in preparation to that proposal.