ERL17 Workshop, June 18-23
CERN, Genève, Confédération des Helvètes

ER@CEBAF

A High-Energy, Multiple-Pass, Energy Recovery Experiment at CEBAF

A Collaborative Proposal Between BNL and JLab

On behalf of :

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BIBLIOGRAPHY

◇ **Recent seminar:**
ER@CEBAF: A Test of 5-Pass Energy Recovery at CEBAF,
Todd Satogata, Accelerator Physics Seminar, JLab, Jan 12 2017.

◇ **ER@CEBAF proposal:**
ER@CEBAF: A Test of 5-Pass Energy Recovery at CEBAF,
S.A. Bogacz, et al., eRHIC Tech. Note 54, BNL, June 2016.

◇ **PAC44 report / ER@CEBAF project approval - "C1 Conditional":**
ER@CEBAF: A Test of 5-Pass Energy Recovery at CEBAF, PR12-16-008,
https://www.jlab.org/exp_prog/PACpage/PAC44/PAC44%20Report_FINAL.pdf

◇ **Pre-PAC44 TAC Committee report**
JLab, June 2016, unpublished

◇ **IPAC16 talk:**
ER@CEBAF - A HIGH-ENERGY, MULTIPLE-PASS ENERGY RECOVERY EXPERIMENT AT CEBAF,
F. Meot et al., http://accelconf.web.cern.ch/AccelConf/ipac2016/papers/tuoba02.pdf

◇ **PhD dissertation:**
STUDIES OF ENERGY RECOVERY LINACS AT JEFFERSON LABORATORY,
C. Tennant, http://casa.jlab.org/publications/CASA_PhDs/Tennant_Dissertation.pdf

◇ **JACoW repository (ER 2003, ER@CEBAF)**
and references therein.

◇ **eRHIC R&D presentations and documentation.**

Contents

1 CONTEXT OF THE PROJECT : eRHIC EIC R&D

• EIC : recommended as next high priority large facility, following completion of FRIB, in the 2015 DOE NP Long Range Plan.

• BNL is developing a ring-ring layout, with high luminosity based on large beam currents,

- using existing RHIC ion complex,

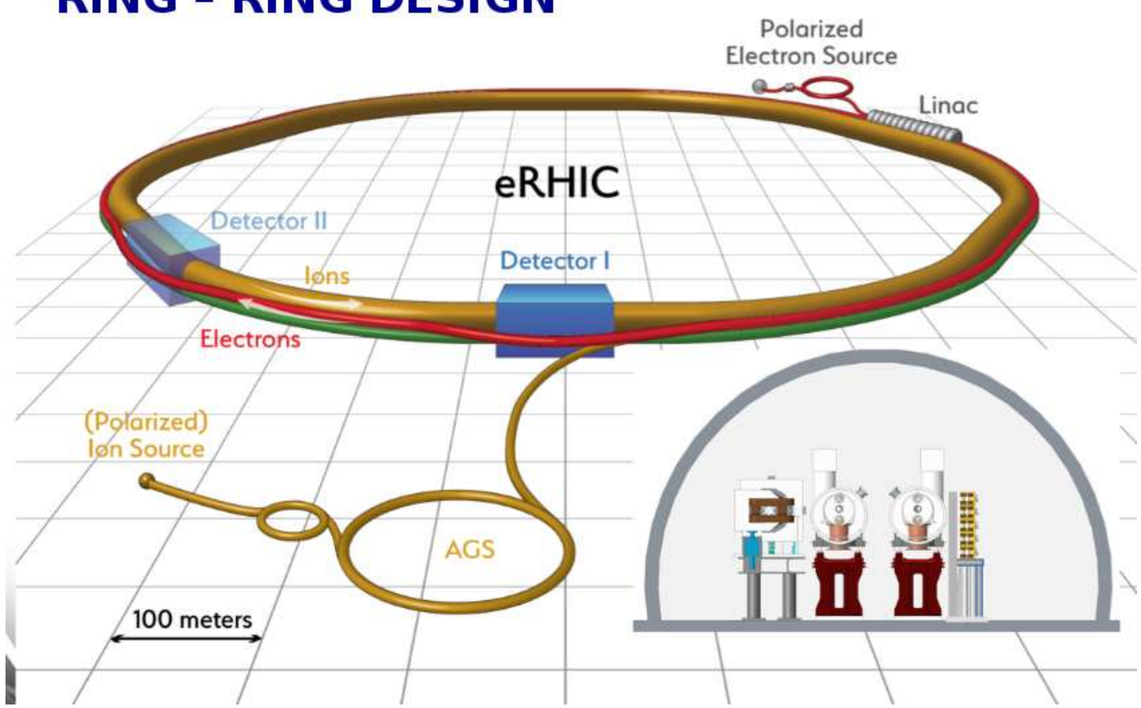
- add a 5∼18 GeV electron storage ring, max. SR power 10 MW,

- add a 3 GeV, CEBAF-like RLA, or an RCS injector.

eRHIC EIC - in short

Luminosity [/cm²/s]	10^{32} – 10^{34}			
Center-of-mass energy [GeV]	20 - 140			
Species	e	p	^{3}He	A
Energy [GeV/u]	5-18	50-275	167	100
Beam current, max. [A]	2.7	0.9		
Nb bunches		330 - 1320		
Polarization [%]	80	70	70	-

RING – RING DESIGN



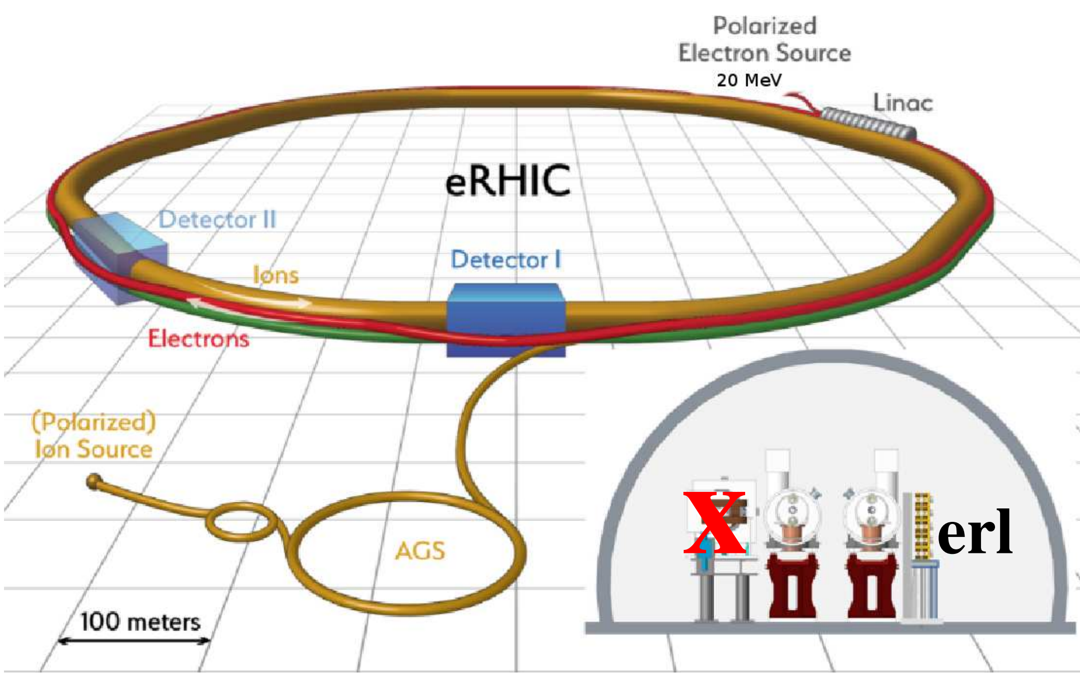
OPPORTUNITIES FOR COST SAVINGS: an ERL based linac-ring scheme

ERL based on 3 GeV linac acceleration

◇ **Electron bunches interact only once with the stored hadron bunches**

◇ **High luminosity stems from extremely small beam size**

◇ **Difficulty : 50 mA, polarized electron gun. Feasibility yet to be demonstrated, this is addressed in an aggressive R&D program.**



"Linac-Ring" eRHIC EIC - in short

Luminosity [/cm^2/s]	10^{32} – 10^{34}			
Center-of-mass energy [GeV]	20 to 140			
Species	e	p	^{3}He	A
Energy, max. [GeV, GeV/u]	20	275	167	100
Beam current, max. [mA]	50	400	200	
Polarization [%]	80	70	70	-

Advantages of ERL method :

◇ **high brightness e-bunches are ER'ed after single collision,**

◇ **enables high beam power with reduced RF drive power,**

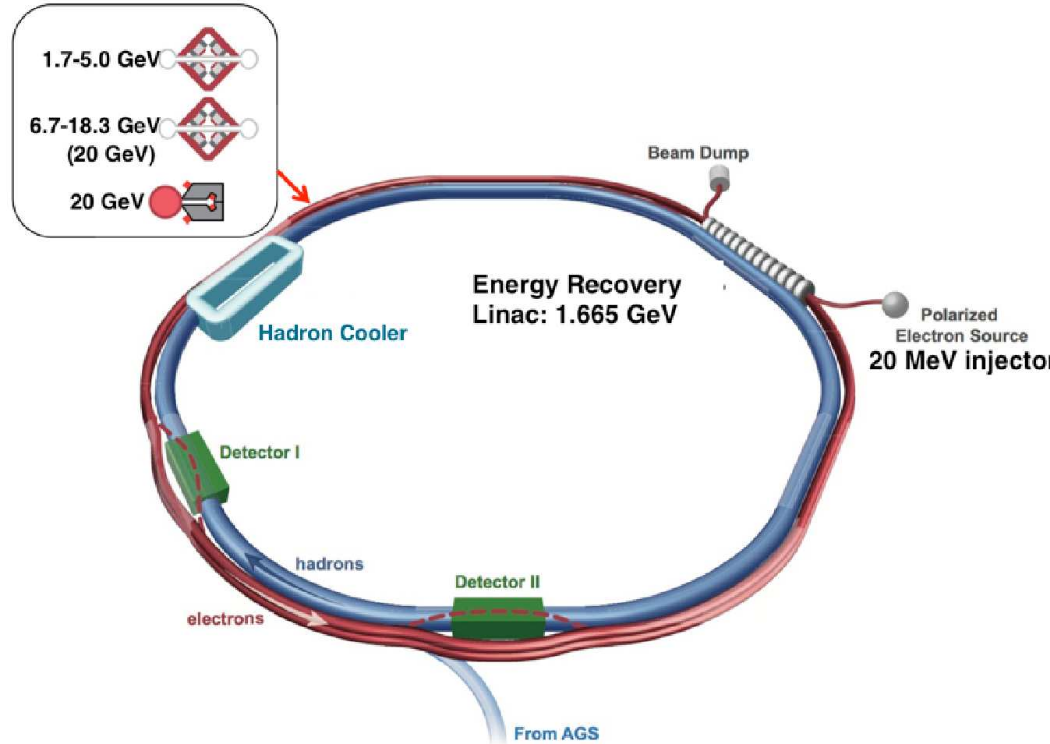
◇ **means low current, 50 mA, thus SR power loss is low as well,**

◇ **low power beam dump,**

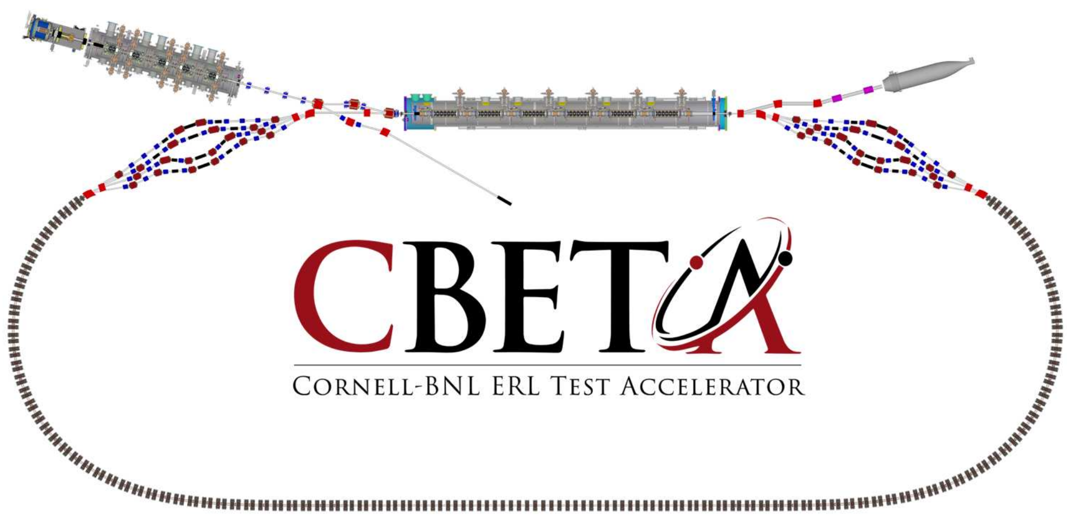
◇ **wall-plug efficiency : a *sine qua non* condition, given 100s of MW e-beam.**

COST-SAVING ERL OPTION : FFAG RETURN ARCS

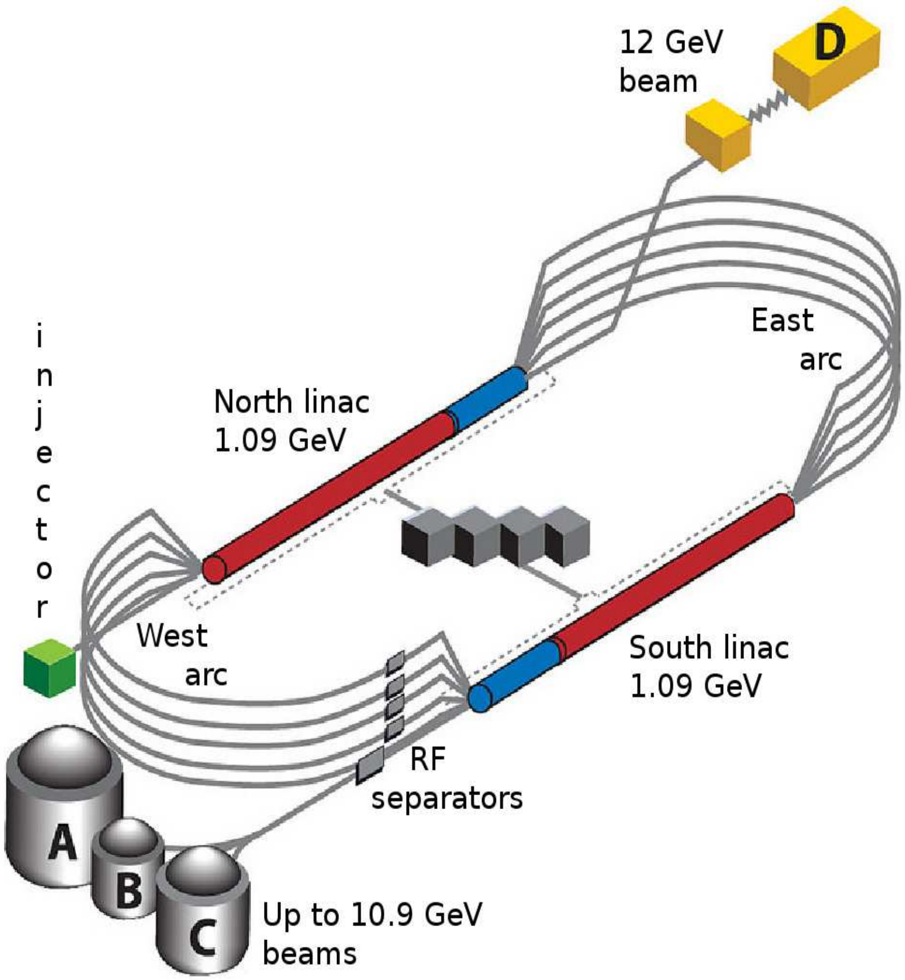
◇ **A Non Scaling FFAG (NS-FFAG) lattice enables multiple passes of the accelerated/decelerated electron beam in a single recirculation loop.**



◇ **This is the motivation for the CBETA project at Cornell**



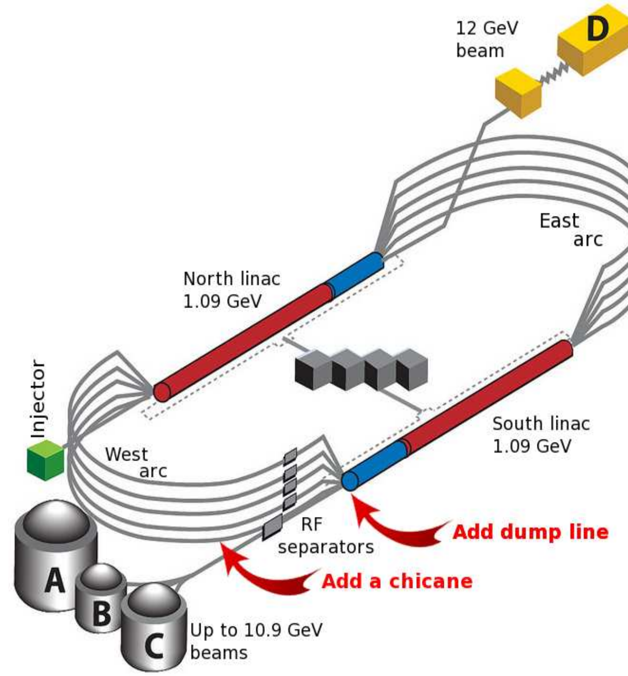
2 CEBAF 12 GeV RLA



Parameters	CEBAF	eRHIC ERL
Energy [GeV]	**12**	**3 - 18**
Beam current [mA]	$\lesssim$**0.1**	**26 - 50**
Beam power [MW]	**1** [(a)]	**up to 400**
SR loss [MW]	**0.005**	**1** [(a)]
Numb. of linacs	**2**	**2**
Linac energy [GeV]	**1.09**	**1.5**
Linac passes	$\leq$**11**	**12up/12down**
Bunch :		
Bunch freq. [MHz]	**31-1497**	**9.4**
ppb, max. $[10^{10}]$	10^{-4}	**1.7 - 3.3**
rms $\epsilon_{x,y,\text{norm.}}$**, inj.** $[\pi\mu\text{m}]$	**3**	**10 - 70**
***rms* length [mm]**	**0.09-0.15**	**3**
rms $\Delta E/E$	$< 10^{-4}$	$< 10^{-3}$
Linac :		
Length [m]	**250**	**198**
RF freq. [MHz]	**1497**	**647**
Numb. of cavities/linac	**200**	**72**
Cavity type	**5- & 7-cell**	**5-cell**
Gradient [MV/m]	**7 - 20**	**18**

(a) Practical limitations

3 ER@CEBAF



• AN EXPANSION OF CEBAF CAPABILITY TO A 5-PASS ERL. With negligible switch over time and negligible impact to the CEBAF physics program.

• MULTIPLE-PASS :

1 linac up + 1 linac down
1 pass up + 1 down
5 pass up + 5 down

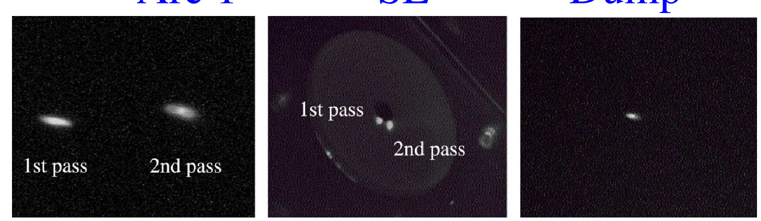
} All three can be done

• HIGH ENERGY ERL : up to 7+ GeV

The limitation is the momentum acceptance in Arc 1, $\frac{\Delta p}{p} \approx 2 - 3 \times 10^{-3}$ ***(beam up and beam down have different energies due to SR loss)***

2003, 1 GeV ER experiment

Arc 1 SL Dump



3.1 Objectives of ER@CEBAF:

- **High-energy ERL experimentation, in relation with EIC R&D**
- **Characterization of CEBAF in ERL mode will include**
  - **initial, intermediate, and final beam emittances**
  - **energy measurements**
  - **evaluation of ISR effects and mitigations**
  - **momentum aperture and tolerances of the longitudinal match**
  - **measurements on the RF system**
  - **halo studies**
  - **BBU studies, including scaling with nb. of recirculations and linac energy**
  - **And beyond, 4-th GLS R&D ? (e.g., transport and ER of large dp/p bunches** *- P. Williams, DL*)
- **All this - in passing - also means commissioning and operation of a large-scale superconducting recirculating linac in energy recovery mode**
- **And these studies will also benefit the existing CEBAF 12 GeV program.**

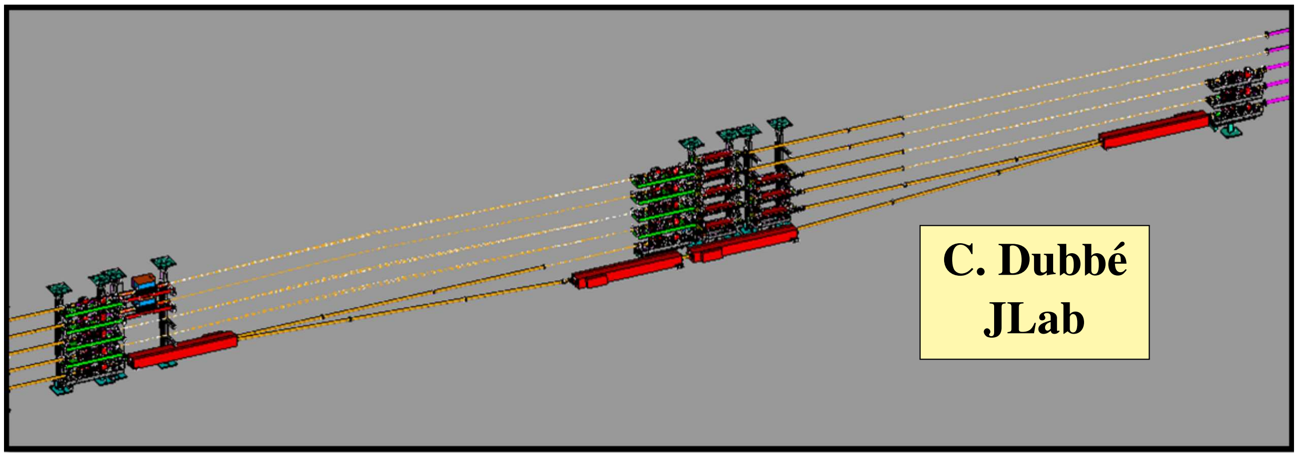
3.2 Hardware modifications to CEBAF

- **(1/3) Phase chicane at entrance of Arc 10 ($\delta l = \frac{\lambda}{2} = 10$ cm)**

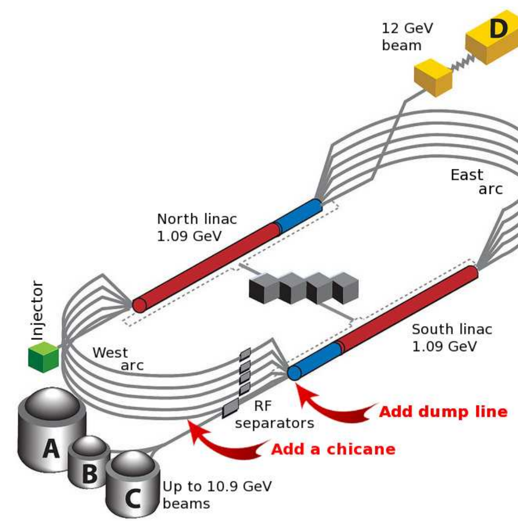
◇ **Uses four standard 3 meter CEBAF MBA, a conservative 5^o deviation per bend.**

◇ **Turned off for regular CEBAF operation**

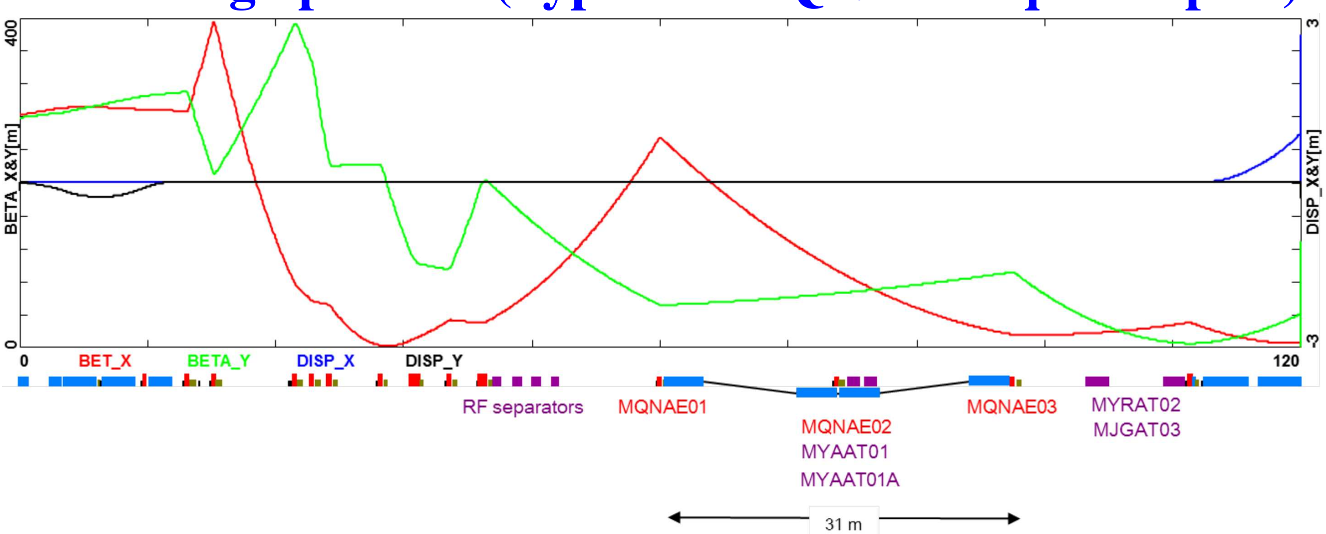
- **Design complete**



C. Dubbé JLab



- **Matching optics ok (bypasses MQNAE02 quadrupole)**



A. Bogacz JLab

• **(1/3) Cont'd - chicane magnets**

◇ **Two spare BA magnets are available on site.**

Can be "stored" in the chicane

◇ **Two spare BA magnet sets worth of coils are available on site**

T. Michalski
JLab

They could be built into two additional BA magnets

◇ **A 425A, 150V, 64 kW box supply is needed**

◇ **We received proposals for magnets (more or less suitable, or potentially reclaimed steel) from**

- *Attilio Milanese, CERN (Aug. 2016)*
- *Davide Tommasini, CERN (July 2016)*
- *C. Johnstone, Fermilab (Aug. 2016)*

Thanks ! We are working on that

Chicane magnets need to be quite flat to fit the installation, in addition to ∼3 m, ∼0.7 T constraints.
Would help if they can serve as spares (coils, cores) 3 m main arc dipoles of CEBAF.
Going away from CEBAF style of magnets raises overall risk, and perhaps offsets some costs from the magnet procurement to magnet maintenance rather than reducing costs.

• **(2/3) Extraction and dump line**

◇ **Switch magnet is a standard injection chicane dipole.**

- Turned off for regular CEBAF operation.

- Failure would only affect ER@CEBAF capability

◇ **ER'ed beam deflected 8^o.**

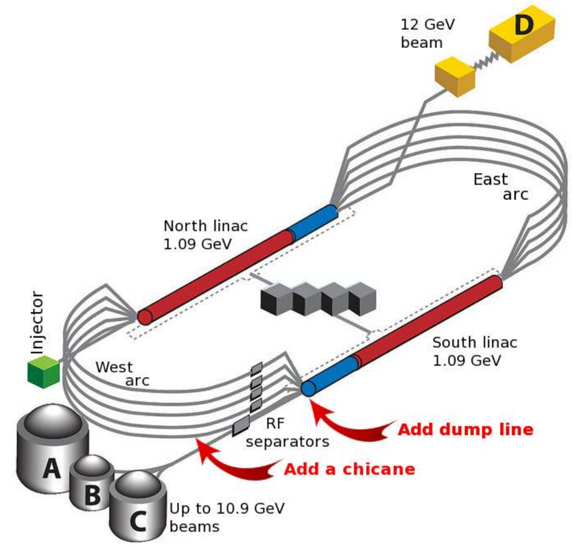
- Other 9 beams (e.g., 1.5 GeV which is next, kicked 6 mrad) are within and corrector capabilities.

◇ **Dump line diagnostics angled away from C100 cone**

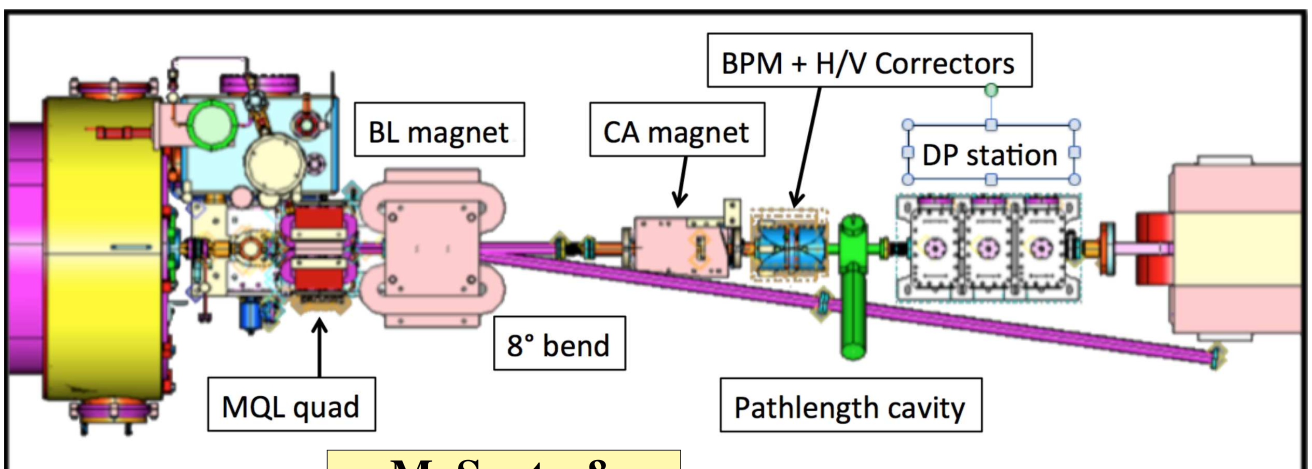
◇ **Existing area has corrector / BPM / quad downstream of 2L27 C100 cryomodule**

◇ **Maintains vacuum isolation**

◇ **Design complete**



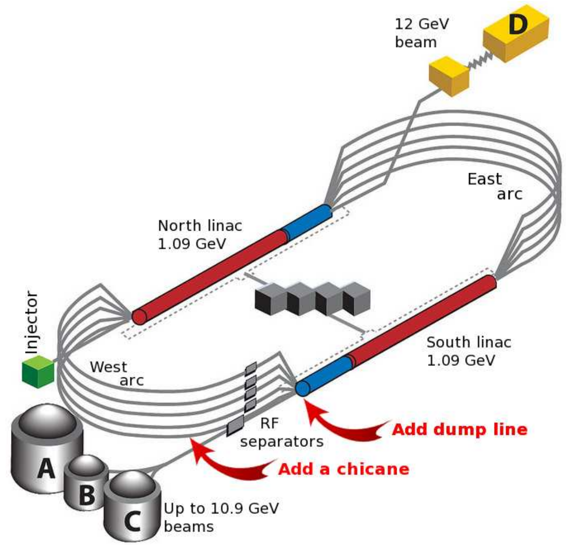
SOUTH LINAC →



→ **SPREADER**

M. Spata & C. Dubbé - JLab

• **(2/3) Cont'd - Extraction and dump line**



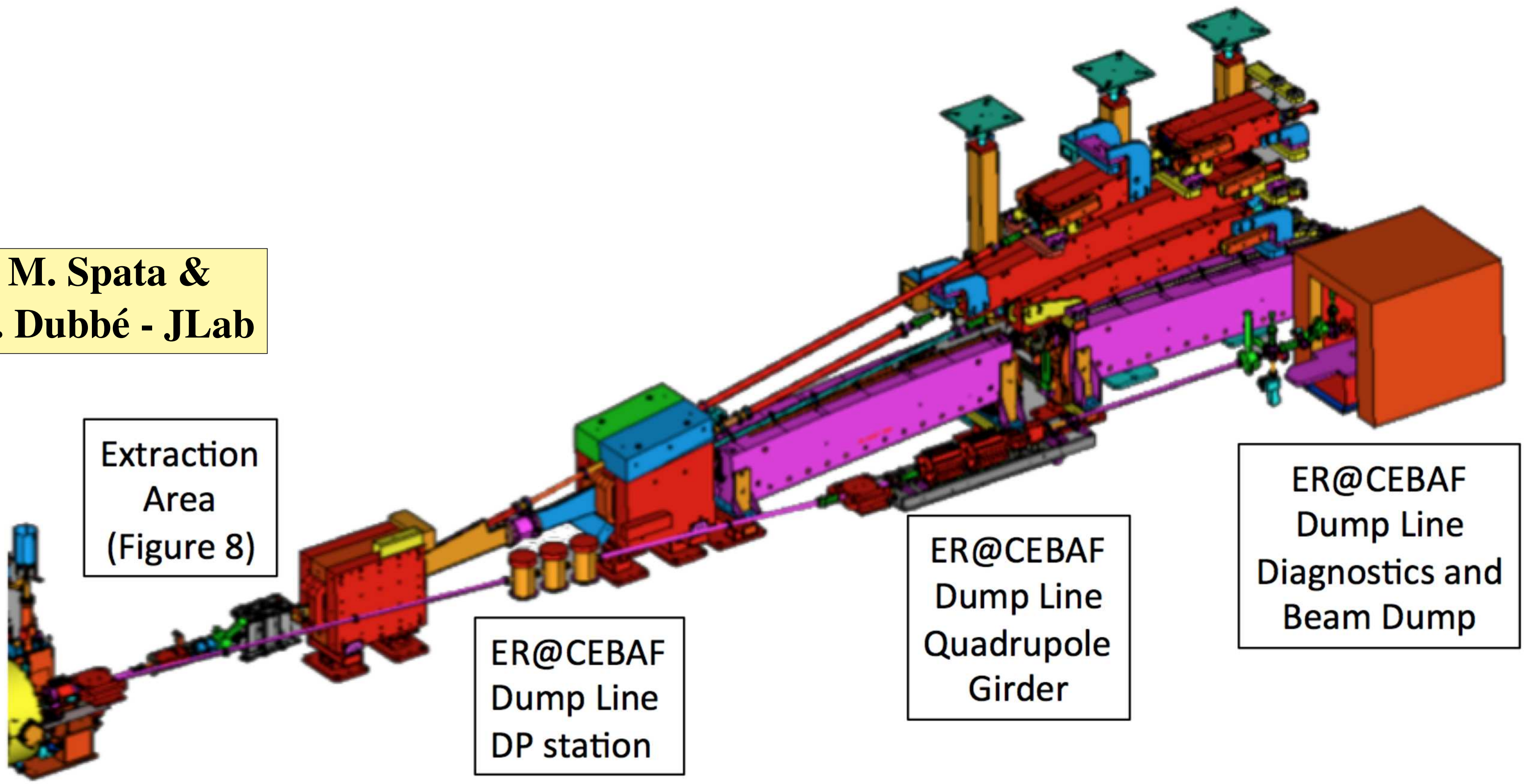
◇ **Dump line maintains clearance for magnet carriage clearance**

- Cryomodule carriage clearance not required in this area

- ER@CEBAF would not interfere with expected tunnel traffic

◇ **Design complete**

M. Spata & C. Dubbé - JLab



● (3/3) Beam instrumentation

A minimal list, sufficient for successful demonstration of ER capability :

◇ **Calibrated diagnostics at energy recovery dump (3 BPMs for steering, 2 quadrupoles for emittance, spectrometer dipole, BCM for current, viewer for images of dump beam)**

◇ **Extension of CEBAF linac "SEE BPMs" ("Switched Electrode Electronics")**

- very useful in the 2003 ER demonstration,

- current linac SEE BPMs temporally multiplex 5-6 passes of beam

- for ER@CEBAF, *enable temporal resolution of 10 passes***, based on software and beam pulse structure modifications**

◇ **Calibration of the the time of flight monitor (relative RF phase monitor at 1497 MHz) at the end of the NL, for full 360 degree relative phase**

◇ **Installation of 3 GHz BPMs (modified SEE BPMs) and/or OTR foils, at (minimally) 3 locations in each of Arc 1 and Arc 9**

- used in establishing accelerating/decelerating energy ratios

◇ **Existing viewers and harps discriminate multiple pass beams**

◇ **Beam measurements in experimental Hall lines:**

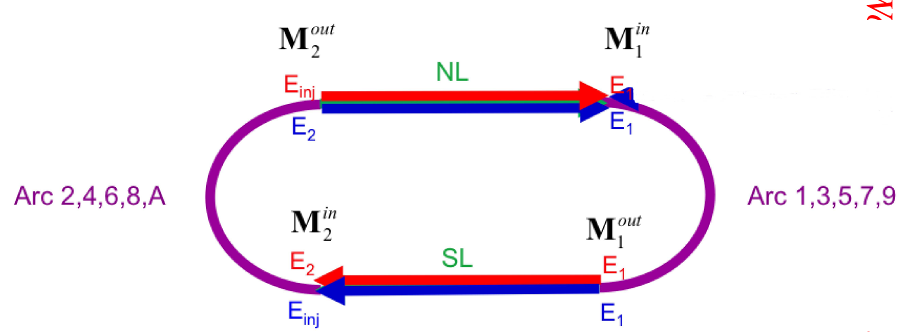
- enable RF separation in 8E/6E/4E/2E selectively to divert decelerating beam into Hall B line for detailed phase space diagnostics.

- well-calibrated Hall A dipole system

- existing diagnostic in the 2C line can be used for terminal diagnostics of extracted beams on intermediate passes for comparison of properties between accelerated and decelerated beams.

3.3 Dedicated optics

- **(1/3) Linacs**

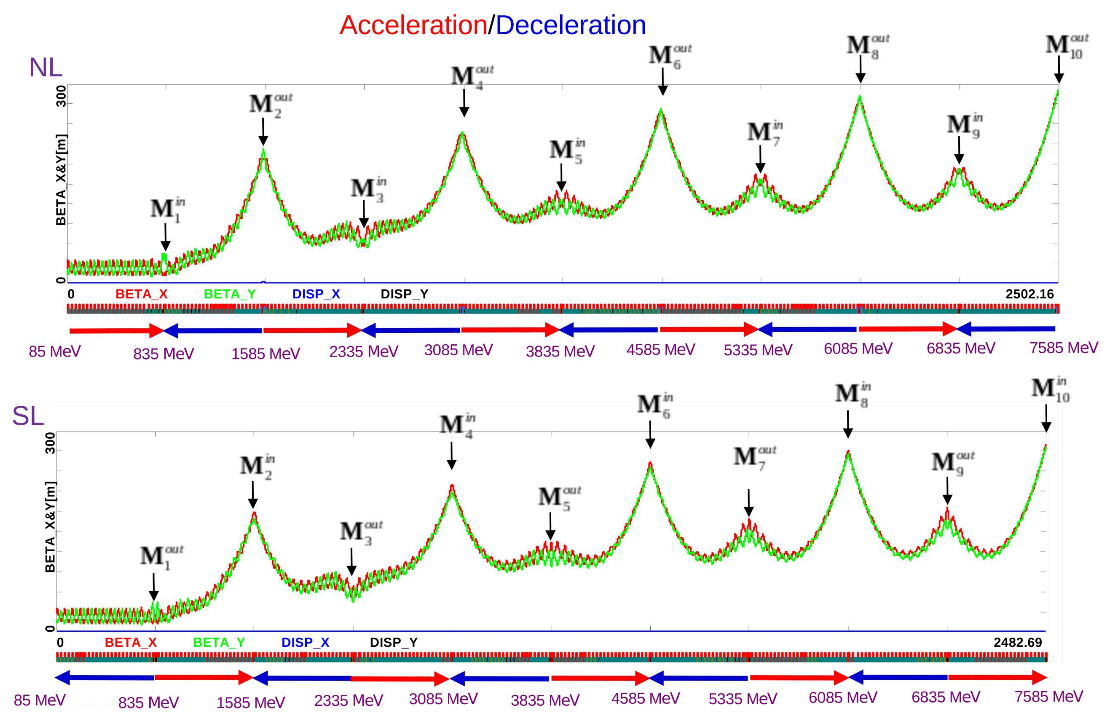


o Constraints :

- max beta ≈ 300 m (reached at max energy)

- minimize $< \frac{\beta}{E} >_{\text{linac}} = \frac{1}{L}\int \frac{\beta}{E}\, ds)$

o Optimal (out of drift-to-120^o investigation) : 60^o FODO-like on first up pass/last down pass



◇ Complete multi-pass optics in NL and SL

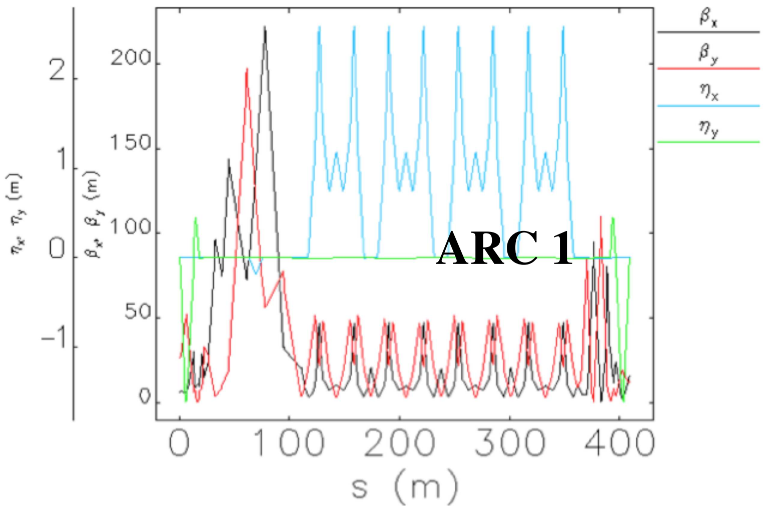
◇ In this representation, linac direction is reversed for decelerated passes

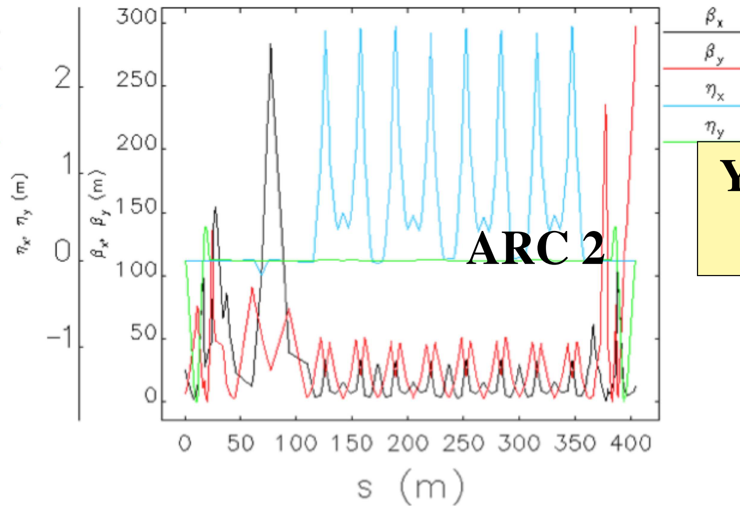
A. Bogacz
JLab

- **(2/3) Arc optics**

◇ **ARC1 and ARC2 are modified for ER@CEBAF, by just changing quadrupole setpoints:**
  - **from standard high dispersion optics, 8 and 6 meters peak respectively,**
  - **to low dispersion like other arcs in nominal 12 GeV CEBAF, for larger dp/p acceptance**

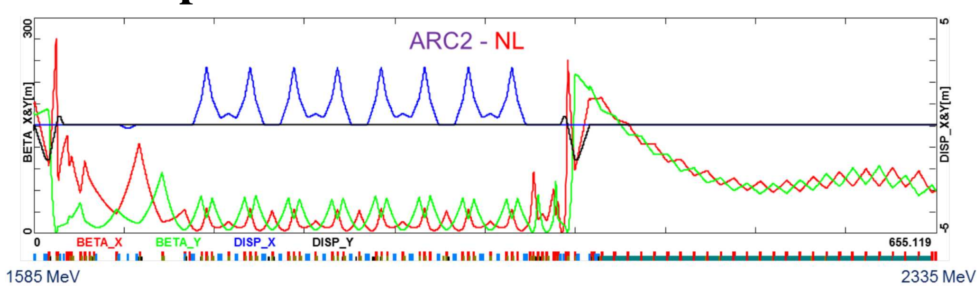
◇ **this determines a maximum feasible 700∼750 MeV/linac**

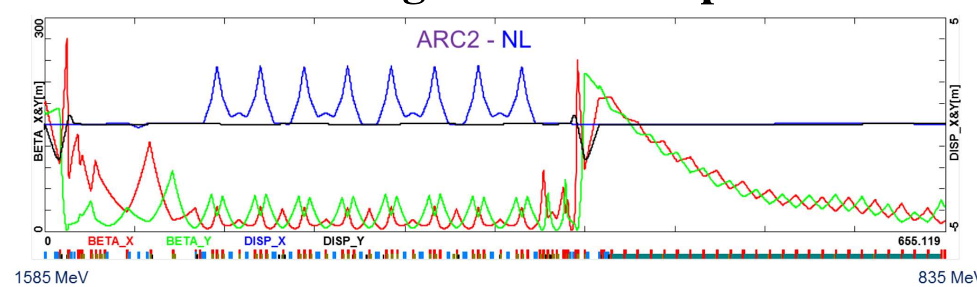


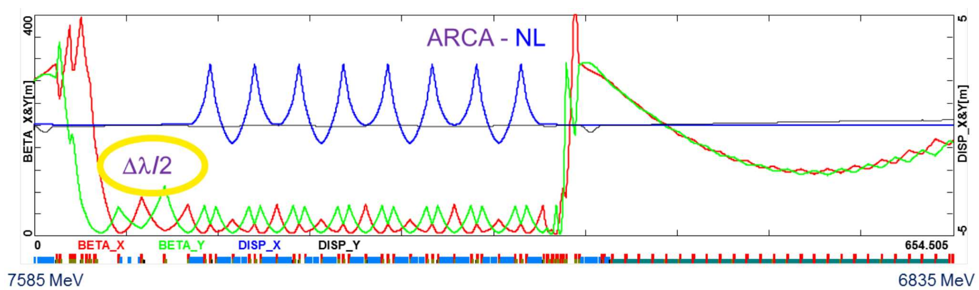


Y. Roblin
JLab

- **All spreader/recombiner sections are re-designed for arc matching to 60^o linac optics :**







• (3/3) Longitudinal optics

D. Douglas
JLab

• ISR will degrade the beam energy spread and cause energy loss;

- this must be allowed for by the longitudinal match

- phases and momentum compactions must be adjusted to insure that the beam stays within the machine momentum aperture during recovery:

⋄ energies must be matched during transport through corresponding recirculation arcs

⋄ energy spread must be compressed

• CEBAF transport system provides phase (path length) and compaction (M_{56} trim) knobs

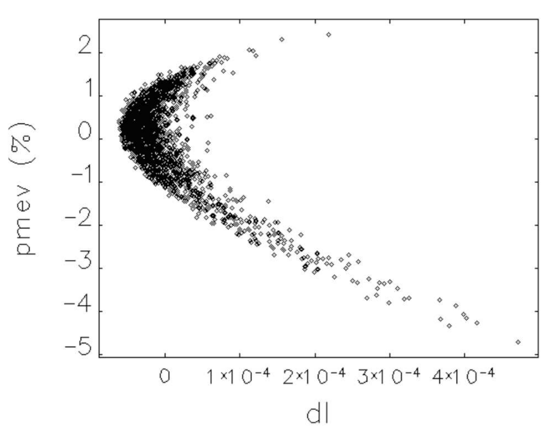
• A tentative solution for a 700 MeV/linac setup (injection at 79 MeV/c), starting point for further optimizations :

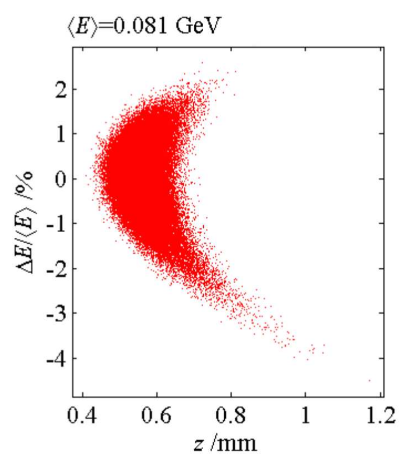
- north and south linacs accelerate at 92.2^o (2.2^o from crest)

- and decelerate at 266^o (-4^o from crest)

This yields a beam energy recovered at 86 MeV/c with an energy spread of 2-3% at the ER dump.

Phase space at the ER@CEBAF dump, from elegant (left) and LiTrack (right) :





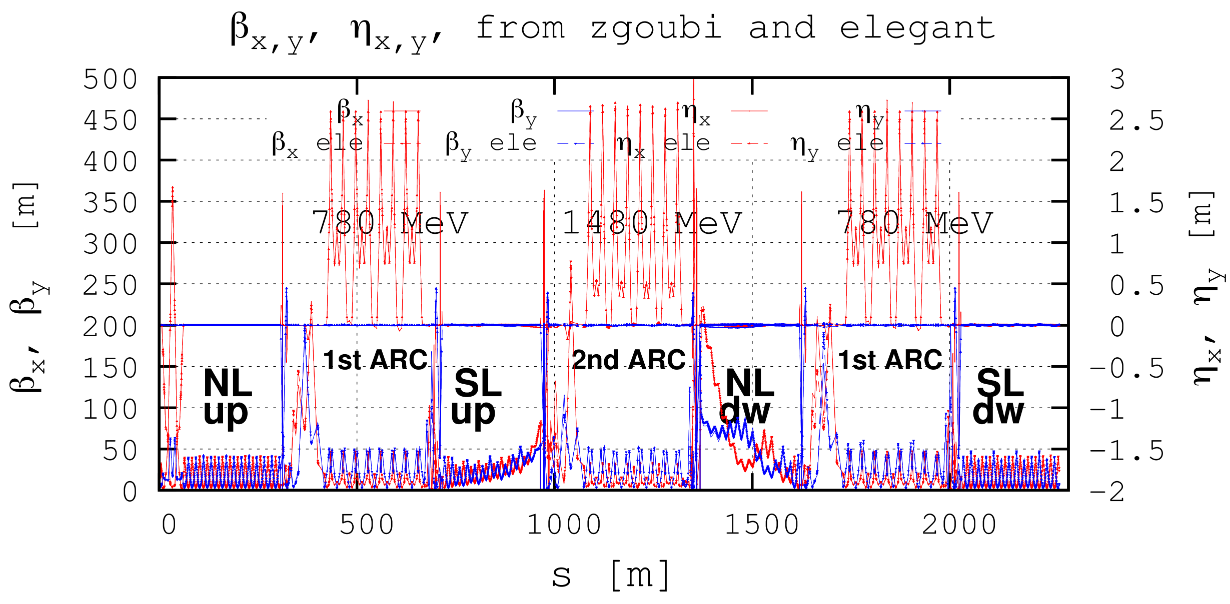
3.4 Code developments and cross-checks

• ER@CEBAF is under installation in a stepwise ray-tracing spectrometer code. This provides
- highest accuracy representation of CEBAF TOF spectrometer,
- high order transverse optics,
- accurate computation of energy spread, etc.

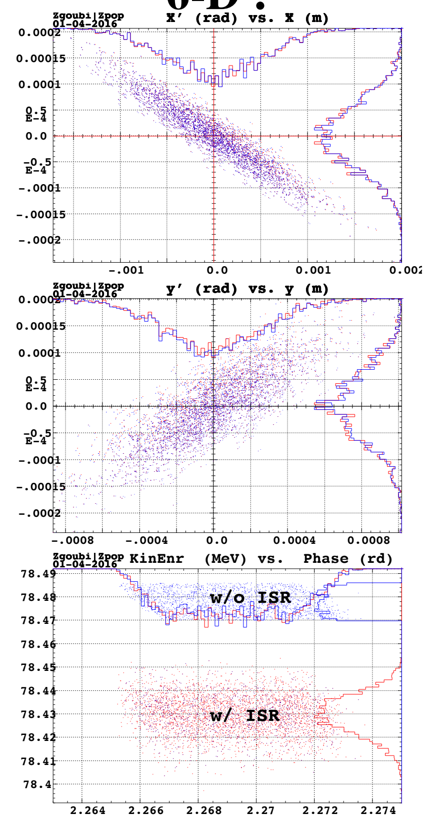
• This is an advantage when optimizing the (different energy) accelerating and decelerating beams in Arcs 1-9

• These developments also benefit CEBAF spin program.

Example :
start-to-end, 700 MeV/linac,
1-pass up /1-pass down



Beam at the dump,
6-D :

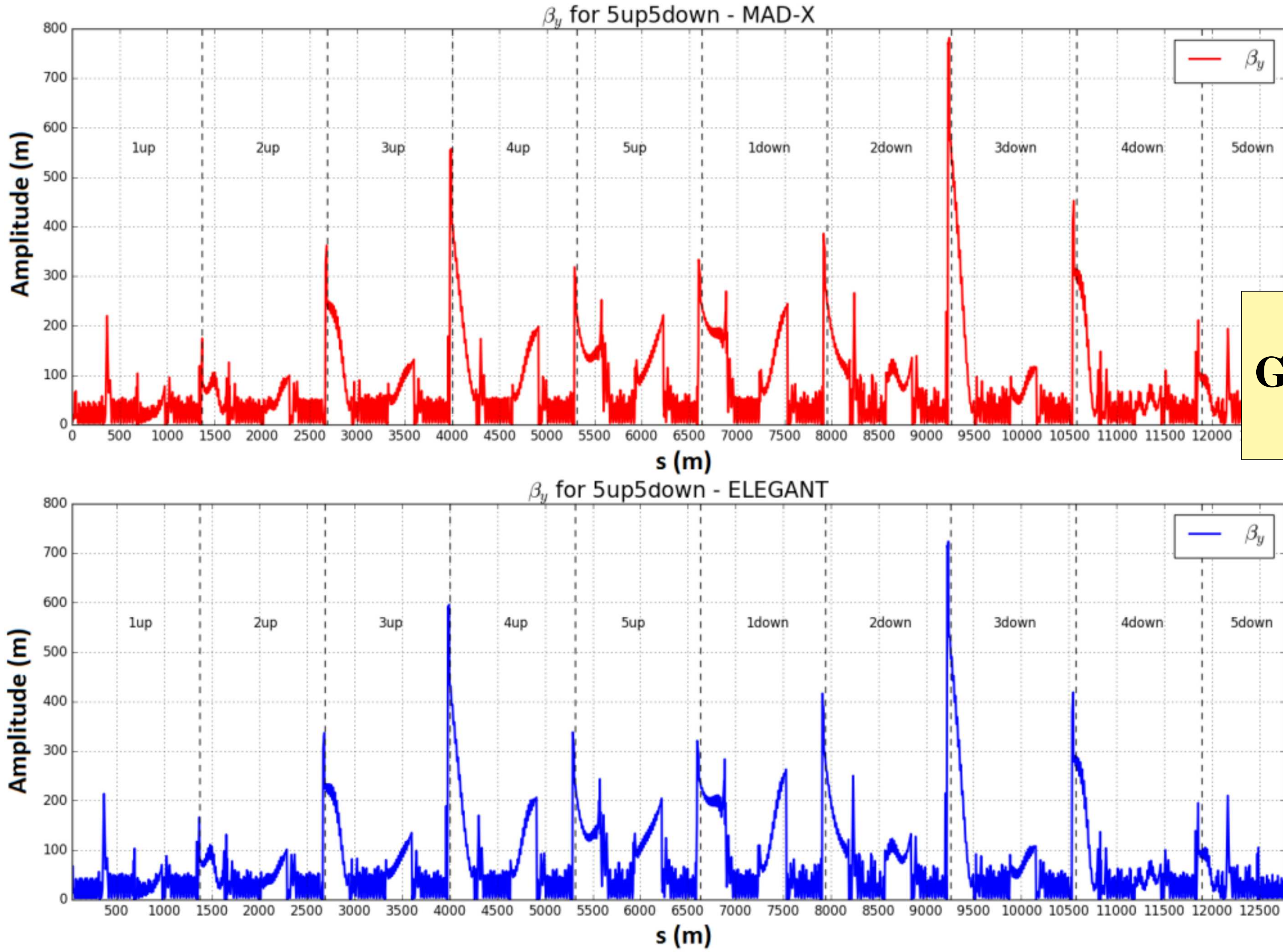


- **ER@CEBAF lattice has also been installed in MADX-PTC**

- **Ready for lattice and defect studies, tracking simulations, code comparisons**

5 pass up / 5 pass down

Vertical betatron functions, from MADX and from ELEGANT



P. Korysko
G. Robert-Demolaize
BNL

3.5 Parameter list

T. Satogata - JLab

MACHINE/LATTICE

f_{RF}	1497	MHz	Standard CEBAF RF frequency
λ_{RF}	20	cm	Standard CEBAF RF wavelength
E_{linac}	700	MeV	Energy gain per linac pass (baseline)
E_{inj}	79	MeV	From injector (= $E_{\mathrm{linac}} \times 123/1090$)
N passes	1, 3, 5		Number of $\left\{ \begin{array}{l} \text{accelerated} \\ \text{decelerated} \end{array} \right.$ passes
ϕ_{FODO}	60	deg	Phase advance per cell at first NL/last SL pass
M_{56} (Arc A)	80-90	cm	M56 compression of Arc A
M_{56} (other arcs)	0	cm	M56 compression of other arcs
Extraction angle	8	deg	Angle to dump line
Dump power	20	kW	Max. ER'ed beam power
$\Delta\phi_{\mathrm{tol}}$	0.25	deg	Required path-length control tolerance$^{(*)}$

(*) A Master Oscillator MODulation (MOMOD) feedback system provides pathlength/phase control for main RF. Allows 0.1 degree with new electronics.

BEAM

f_{beam}, CW	31 - 499	MHz	Bunch rep. freq. (standard is 249.5 MHz)
f_{beam}, tune $^{(1)}$	7.485	MHz	Bunch repetition frequency in tune mode
I_{beam}, max. CW	100	μA	Maximum CW beam current
q_{bunch}, max. CW	0.2	pC	Bunch charge at 100 μA CW
σ_l	90 - 150	μm	Bunch length at high energy
σ_t	300 - 500	fs	
σ_ϕ	0.16 - 0.27	^{o}	
$\epsilon_{\mathrm{x,y}}$ geom., inj.	$\sim 10^{-8}$	m	Transverse rms, at injection
dp/p$_{\mathrm{inj}}$	$< 10^{-4}$		Energy spread at injection
$\epsilon_{\mathrm{x,y}}$ geom., extr.	$\mathcal{O}(10^{-8})$	m	Extracted bunch, after 5 pass up/down
dp/p$_{\mathrm{extr}}$	2-3%	$10^{-??}$	ER@CEBAF, energy spread at extraction

1. Tune mode beam: {250 μs macro-pulse filled, 100 μs off, 4 μs macro-pulse filled, then off} repeating at 60 Hz (16.67 ms).
The 4 μs trailing pulse is used for linac orbit BPMs and linac arrival time cavities.

3.6 Cost and schedule

- **ER@CEBAF Procurement and Installation Costs (including 20% overheads).**

◇ **BNL/C-AD has provisionally agreed to take responsibility for pathlength chicane costs**

	Procurement (k$)	Labor (k$)	
Extraction region	96	20	
Dump line	169	125	
Pathlength chicane	290	46	(4×(core+assembly) + PS + 2shunts)
3 GHz BPMs	56	23	
Total	611	214+17	

- **ER@CEBAF installation schedule from start of access to funding.**

3.7 Hardware commissioning

1 linac up/ 1 down: NL accelerating, SL decelerating - *1-2 days*

- Commission dump line extraction, diagnostics
- Compare injection and dump line; beam characterization

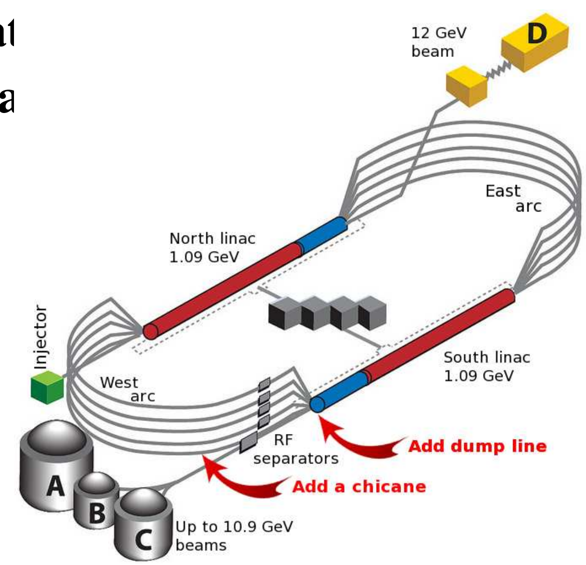
1 pass up/ 1 down: reproduce 2003 ER experiment results - *3-4 days (took 1.5 days in 2003)*

- Does not require changes to Arc optics
- Commission pathlength chicane, Arc 1 3 GHz BPMs
- Demonstrate intermediary beam diagnostics
- Evaluate MOMOD pathlength control tolerances
- Preferably Einj = 56 MeV (same as 2003), Elinac=500 MeV

5 pass up/ 5 down: (linac up to 750 MeV) - *14 days of tuning and characterization*

- Away from ISR difficulties in a first stage, with 400∼500 MeV/linac (and away from coupling, using C100 CMs)
- Commission new arc optics, longitudinal beam manipulat
- Commission 3 GHz BPMs in Arc 9, 10-beam BPM softwa
- Further demonstrate intermediary beam diagnostics
- Use 500 MHz separators at start of west arcs
- Perform tuning tolerance studies
- Demonstrate full decelerating beam transport
- Perform RF tuning studies

- Demonstrate CW energy recovery



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4 CONCLUSION

• A multiple-pass, high energy Energy Recovery Linac experiment at the JLab CEBAF will be instrumental in providing necessary information and technology testing for a number of possible future applications and facilities such as

- Linac-Ring based colliders, which have been designed at BNL (eRHIC) and CERN (LHeC),

- and also drivers for high-power FELs.

• ER@CEBAF has been approved by JLab Program Advisory Committee (PAC44), July 2016.

• Since it was launched 2+ years ago, the project has progressed in defining the experimental goals, including ER efficiency, multiple-beam instrumentation, BBU, in defining the necessary modifications to CEBAF lattice, numerical simulations and software tool developments, etc.

• The next objective in demonstrating readiness is a technical review by a dedicated committee, as mandated by PAC 44. We are working on that.

THANK YOU FOR YOUR ATTENTION

BACKUP SLIDES

ENVISIONED eRHIC TIME LINE

- **April 2017 Design Choice Validation Review**
- **2017/18: Work out a pre-conceptual design report**
- **2018: eRHIC Design Review**
- **2019: Mission need acknowledged by DOE, critical decision zero (CD-0)**
- **2019-2021: Conceptual design incl Evaluation of alternates**
- **2021: CD1: site decision**
- **2021-2022: preliminary design project baseline in scope cost, and schedule scope**
- **2022: CD2**
- **2022-2023- Engineering design (final design)**
- **2023: CD-3 Start Construction**
- **2028 CD-4 Completion**

• **CEBAF is the only installation that allows multiple-pass, multi-GeV ER.**

• **Other installations are limited**

- in energy

- or in the number of passes

Operated ERLs, in short :

Facilities	CEBAF -ER	JLab FEL IR+	JLab FEL UV	BINP	KEK
Linac E [MeV]	1000	165	135	10	17
Numb. passes	1	1	1	4	1
ER'ed curr. [mA]	0.08	9	2.5	30	0.1

• **JLab has a long expertise in design, commissioning, operation of multiple ERLs:**

- CEBAF Front-End Test (*1992*, 42.8 MeV, 31 μA CW beam, 100% ER'ed)

- CEBAF-ER experiment (*2003*, 1 GeV, 80 μA, CW)

- JLab FEL, *since 1997* : IR Demo, IR Upgrade, UV FEL, Darklight

MULTIPASS-ER@CEBAF
BBU studies

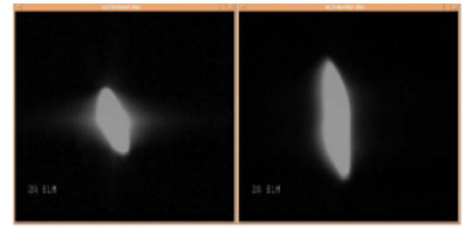


Figure 2: Beam spot well below BBU limit (left) and very close to BBU limit (right) on the SLM.

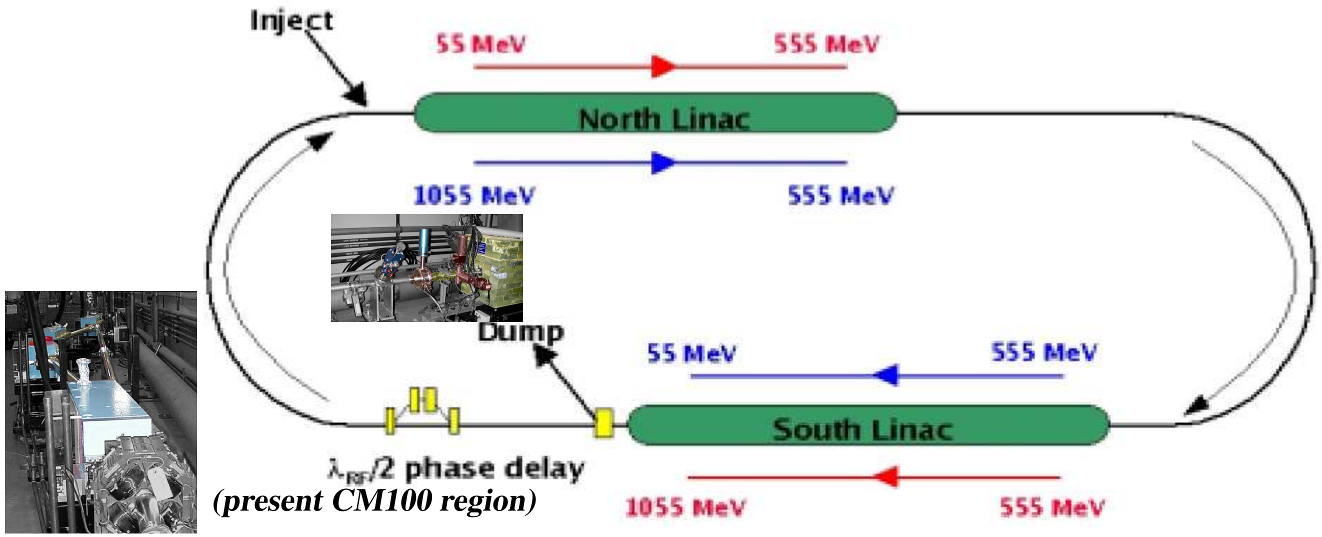
- BBU was studied in 2007 with multi-pass recirculated beam : a shorted, HOM Q damper caused 40μA threshold
- BBU studies were part of the 12GeV upgrade
- Feasibility of exciting BBU in a multiple-pass ER experiment ?
  - A 5up + 5down experiment means twice as much current
  - Amongst various possibilities to be investigated :
    - lower E, increase I, for larger transverse kick
    - unscrew filters and remeasure HOM Qs to see if things are reachable
    - upgrade a gun
    - increase bunch charge
    - run in a mode where ER has sufficient efficiency for large-current while limiting power at beam dumps
    - "intensity-doubling" coasting, based on a λ/4 phase chicane

REFERENCES

- R. Kazimi et al., "Observation and Mitigation of Multipass BBU in CEBAF, Procs EPAC 2008
- Ilkyoung Shin, "Multipass Beam Breakup Study at Jefferson Lab for the 12 GeV CEBAF Upgrade", Ph.D dissertation. University of Connecticut, 2013.
- Doubling the intensity of an ERL based light source, Andrew Hutton, Jefferson Lab, Newport News, VA23693

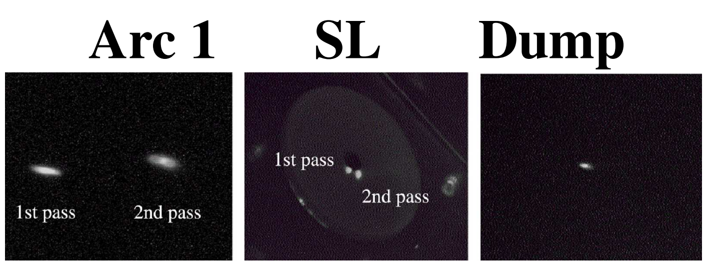
CEBAF-ER experiment, 2003

- **It demonstrated 1-pass up/1-pass down, 1 GeV energy recovery, CW beam,**

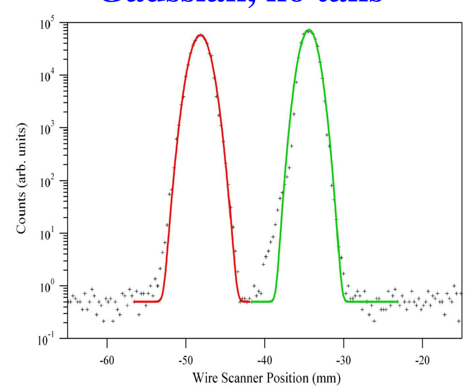


- **Measurements included (at injector, arcs, dump) transverse emittances, momentum spread, halo. Included RF system response to ER.**

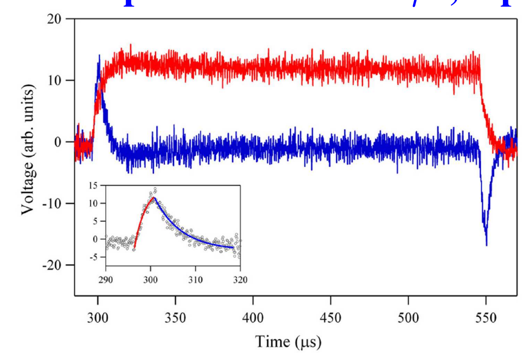
[Details : C. Tennant, Studies of ERLs at Jefferson Laboratory, PhD Dissertation, JLab, 2006.]



V / H beam profiles at dump
Gaussian, no tails



LLRF signal w/o ER and w/ ER.
Transient power draw is 4.3μs, 1-pass.

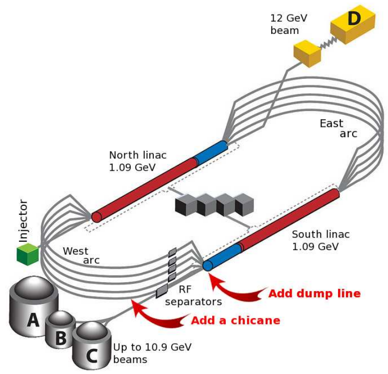


Measurements foreseen

- **The ultimate goal of the measurements is :**

characterizing the bunch at all steps in the ER process all the way from injection to dump line - similar to 2003's CEBAF-ER, in many more locations

- **In particular, transverse emittances can be characterized at all energies (up, down) by extraction to Hall lines**



- **Dump line includes full diagnostics suite : three BPMs for steering; two quadrupoles for focus/emittance measurements; BCM for total beam transmission; viewer for dump beam images**

- **Will study RF system response to ER regime**

- **A host of open topics :**

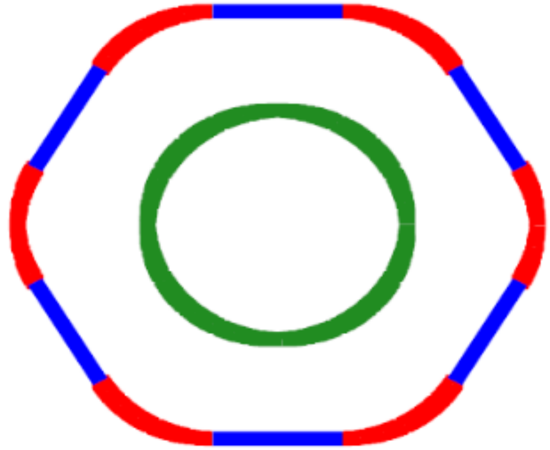
  - Increase beam current beyond 0.1 mA.

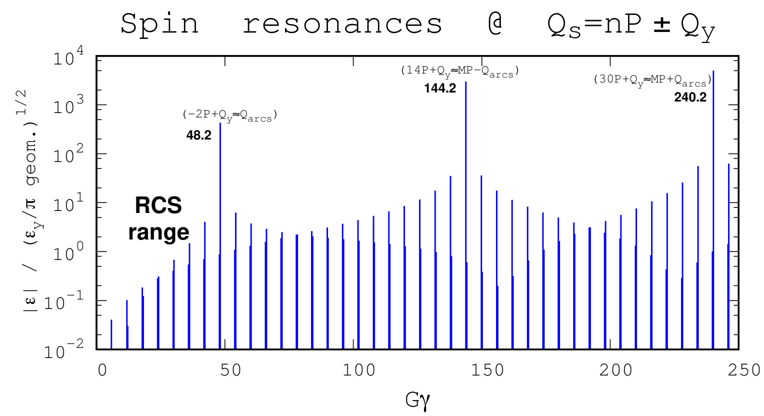
How far / what limitations ?

  - 6D tomography at the dump

  ...

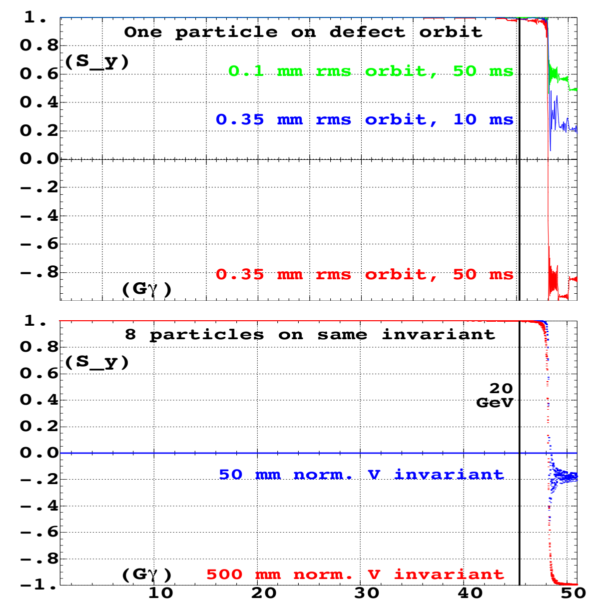
RCS INJECTOR





- A ring injector, accelerates polarized bunches to store energy 5 ∼ 18 GeV, 10∼50 ms ramp
  - ⋄ 6-periodic footprint is that of RHIC,
  - ⋄ a spin transparent lattice : $Q_s = a\gamma < Q_y$, always

Amongst many effects investigated
- very preliminary results -
0.34 mm rms orbit, large vertical betatron motion,
10 ms (25MV, 800 turns) and 50 ms (5MV, 4000) ramp :



- A polarized bunch RCS, launching a bunch through a forest of depolarizing resonances, this has never been done

- In addition to extensive simulations,

⋄ we have plans to test polarization transport at Cornell RCS (10 GeV, 60 Hz, injector to CESR)

• **Relevance to LHeC**

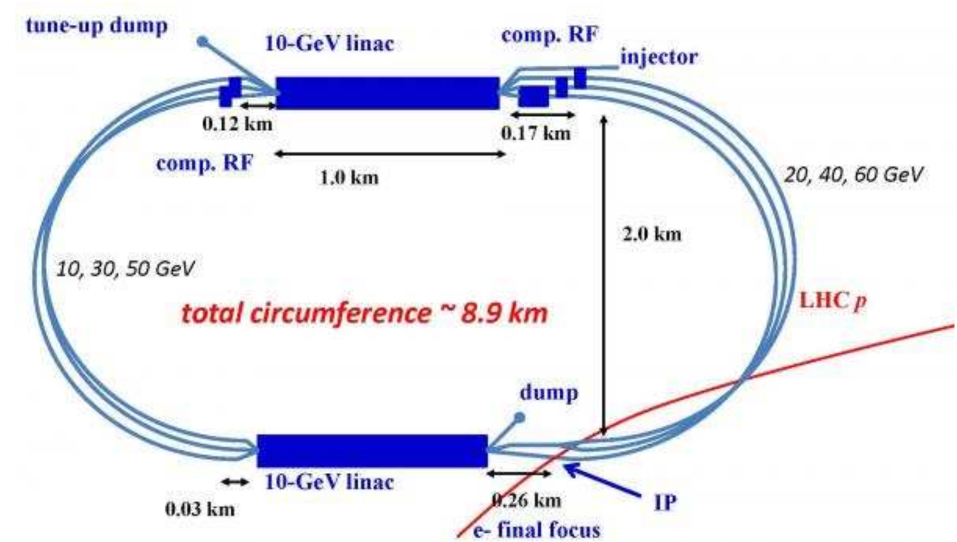
In a similar way to eRHIC in the principle, a linac-ring LHeC EIC is based on an ERL:

- a similar layout to CEBAF

- yet with parameters in much higher range,

- the LHeC ERL faces even greater challenges towards efficient beam handling and energy recovery.

The ER@CEBAF project offers a unique opportunity of early exploration of multiple-pass, multi-GeV parameter range towards these goals.



July 2016 PAC44

PR12-16-008

Scientific Rating: Pass

Recommendation: C1

Title: ER@CEBAF: A Test of 5-Pass Energy Recovery at CEBAF

Spokespersons: T. Satogata and F. Meot

Motivation: This proposal aims to explore Energy Recovery LINAC technology at high energy and in 5-pass operation. This is an important proof of principle for proposed future electron-ion colliders including eRHIC and LHeC as well as possible FELs, electron cooling devices and synchrotron radiation sources. CEBAF is a unique facility for this experiment as it provides high enough energy to test the effects of synchrotron radiation and multiple pass behavior. However, this experiment cannot test high-current capabilities.

Measurement and Feasibility: Two permanent pieces of equipment would be added to CEBAF, a new path-length chicane in the west arc (after the south linac) and a new low energy beam dump at the end of the south linac. New accelerator optics would be developed and new beam diagnostic equipment would be installed. The measurement would proceed in three phases: half-pass, one-pass and then five-pass acceleration and deceleration. The measurement seems well planned and the goal achievable.

Issues: The four-month installation period may be significantly underestimated. The 2003 single-pass ERL measurement took two weeks and was not complete enough to be published, although a PhD thesis did result. Therefore, 18 days of beam time to do both 1-pass and 5-pass ERL may be insufficient to achieve the definitive demonstration of multi-pass ERL proposed. We note that this measurement would operate in single-user-mode and thus have three times the impact on the rest of the JLab program.

Summary: Because of the potential for major impact on proposed EIC designs, the PAC is very interested in seeing this experiment performed, but lacks the accelerator expertise to make a detailed judgment on technical details of the proposal. We recommend conditional approval with a panel of accelerator physics experts convened to review the proposal to validate the methods and to identify the appropriate resources (accelerator time and equipment costs). The PAC strongly encourages JLab management to identify additional resources that will minimize the negative impact on the JLab nuclear physics program.

June 2016 TAC

Proposal Number: PR12-16-008
Hall: Accelerator
Title: ER@CEBAF: A Test of 5-pass Energy Recovery at CEBAF
Contact person: Todd Satogata (JLAB)
Beam time request: Days requested for approval: 12
Spectrometers: CEBAF Arcs
Special requirements/requests:
1. CEBAF in single-user mode, no other experiments can run simultaneously with this experiment.
2. Modifications to CEBAF, adding a pathlength chicane, energy recovered dump, and diagnostics.

Technical Comments:

1. PR12-16-008, ER@CEBAF: A Test of 5-pass Energy Recovery at CEBAF,is a proposal to use CEBAF to demonstrate 5-pass energy recovery (ER). CEBAF successfully demonstrated one-pass energy recovery in March 2003, and this test remains the highest ever energy recovery demonstration with superconducting RF structures. The 2003 ER demonstration consumed about 10 days of the CEBAF operations, which were solely dedicated to the ER experiment during that time. PR12-16-008, this proposal, requests 12 days for commissioning, and suggests that weekly beam studies time can be used to complete the demonstration. There are several things that make this not appropriate. First, PAC approved experimental time on the floor are charged as "Research Hours" not beam studies. Second, the unique energy (700 -750 MeV/linac) required for multi-pass ER is not consistent with the majority of the 12 GeV program which is dominated (¿85will be required for multi-pass ER, which is not something that can be fit in an eight hour beam studies period. Third, the proposal uses unique optics in Arc1, Arc2, Linacs and matching sections, again this represents a big perturbation to CEBAF and will be highly disruptive to the end-station experiments. The collaboration should make a formal request for the time needed to perform this experiment. Using the 1-pass 2003 demonstration (approved with 12 PAC days) as guidance and a request at least 25 PAC days seems more appropriate, and ask for this time in two pieces. The end-stations will not receive beam for experiments during this time, CEBAF will be operated in "single user mode". As a gauge for how long it takes to commission new accelerator configurations, the recent, Nov/Dec 2015, successful commissioning of 12 GeV CEBAF at design energy required a bit more than 4-weeks (28 days) to complete the successful setup. Dividing the time into two periods with a gap that spans at least one accelerator down period will provide time to make changes to the hardware if they are required.

2. The proposal does require a modification to CEBAF. The proposed addition of a chicane and dump are well thought out and once installed can remain in-place with modest impact to CEBAF operations and maintenance. The installation time is estimated at 4-months. This installation will likely have to span multiple accelerator shutdowns as it is hoped that

future weeks of operations are sufficiently robust that the accelerator maintenance periods are shorter than 4- months. With that said the proposal suggests a schedule that is too aggressive. Scheduling is not a PAC concern and this issue should be left to the JLab Nuclear Physics Schedule Committee (NPES) to resolve (if approved).

3. The new energy recovered dump line is located at the end of the South linac, just after the new 12 GeV C100 cryomodules. These cryomodules are a significant source of field emitted electrons which reach energies high enough to activate material (E ¿ 10 MeV). The proposed low energy extraction magnet is likely to accept a fair amount of these field emitted electrons. The impact of this background on the planned diagnostics should be evaluated as well as the impact on the lifetime of the proposed components.

4. The optics changes are well motivated and appropriate for the proposed experiment. However the modeling of CEBAF in ER mode for this proposal appears to be a very idealized model. The model should be used to explore the expected range of transport errors (magnets and RF related) and demonstrate that the adjustments required by the CEBAF transport for 5-pass ER are within the range of the CEBAF system. 5. There was not any technical discussion in the proposal addressing the open issues from the 2003 1-pass ER demo. The 2003 ER demonstration found large emittance growth (Tennant page 49) which was attributed to coupling in the SRF cavities.

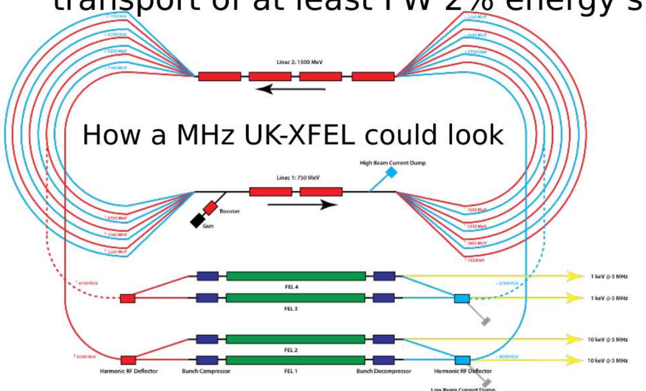
6. The cavity phase and pathlength requirements require CEBAF tools (online Krest and MOMOD) that remain to be commissioned.

7. The beam position monitor modification to resolve all ten beams in the linac monitors will require substantial software development.

8. It is stated that the collaboration will fund and construct two new permanent non- invasive additions to the CEBAF 12 GeV accelerator. Detailed information on the resources required is given in the proposal. However, it is unclear where these resources are considered to come from. The call for proposals states that the proposing scientists and institutions must state clearly their intention to participate in and contribute to the construction of the new apparatus, but also include summary statements identifying the resources that will be requested from JLab as part of the construction effort.

R&D In Support of a UK-XFEL

- STFC has initiated a four year R&D phase for an X-ray free electron laser facility for the UK
- Part of this effort is investigating possibilities for a high-repetition rate (> 1MHz) design
- A promising solution is based on a **multipass recirculating SC linac with energy recovery** with FELs driven by 9 GeV beam
- Such a solution requires the demonstration of GeV-scale transport through turn-around arcs of beams with relative energy spread of a few percent - this can be done as part of the planned **CEBAF-ER experiment** - initial calculations suggest transport of at least FW 2% energy spread is possible with just arc optics retuning



JLAB-TN-17-011
15 March 2017

How To (At Least) Double CEBAF Arc Momentum Acceptance

D. Douglas (JLab) and *Peter Williams* (ASTeC)

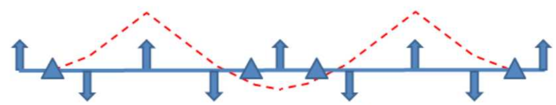


Figure 1: Focusing and dispersion pattern in generic CEBAF isochronous arc superperiod

Figure 2: Notional superperiod retune to reduce peak dispersion

Peter Williams, Daresbury Laboratory