Workshop on Energy Recovery Linacs
Brookhaven National Laboratory

June 2015

Energy Recovery Linacs

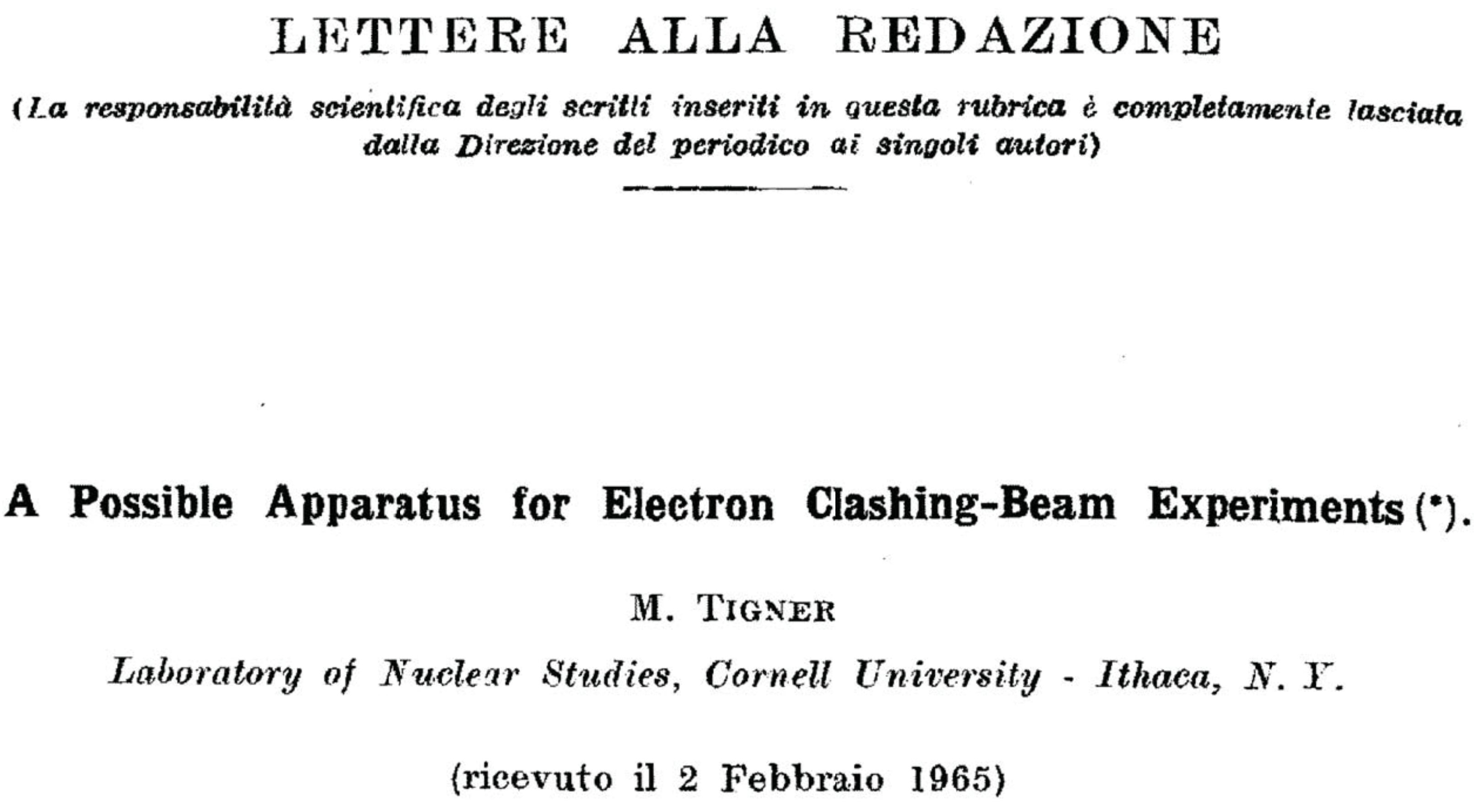
Past... Present... Future...

M. Tigner

Outline

I. Original Concept
II. First Test
III. Currently Operating Machines
IV. Concepts for the Future
V. Challenges to Realization: R&D Needs
VI. Conclusion

I. Original Concept (happy 50th anniversary)


LETTERE ALLA REDAZIONE

(La responsabilità scientifica degli scritti inseriti in questa rubrica è completamente lasciata dalla Direzione del periodico ai singoli autori)

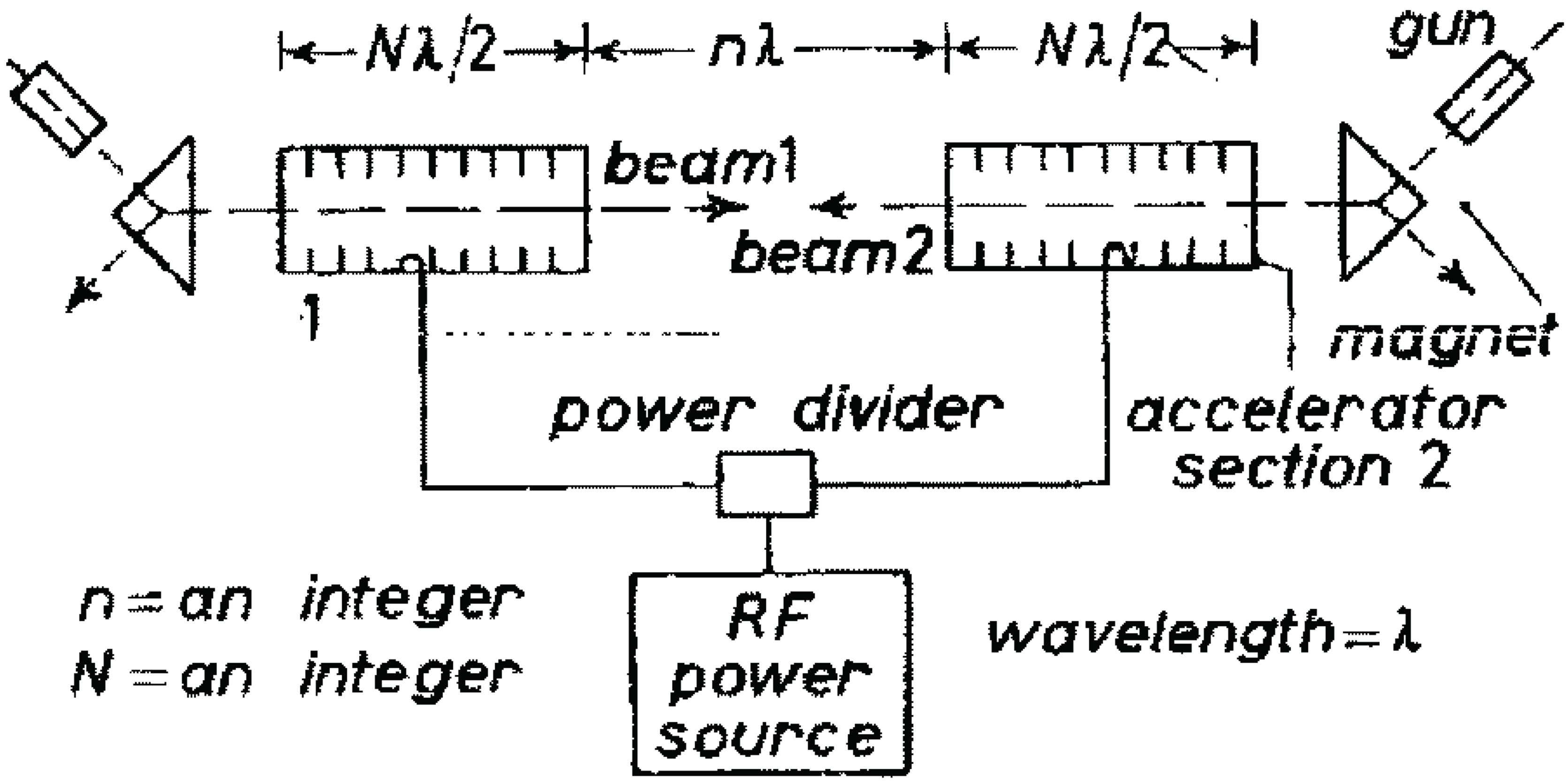
A Possible Apparatus for Electron Clashing-Beam Experiments (*).

M. TIGNER

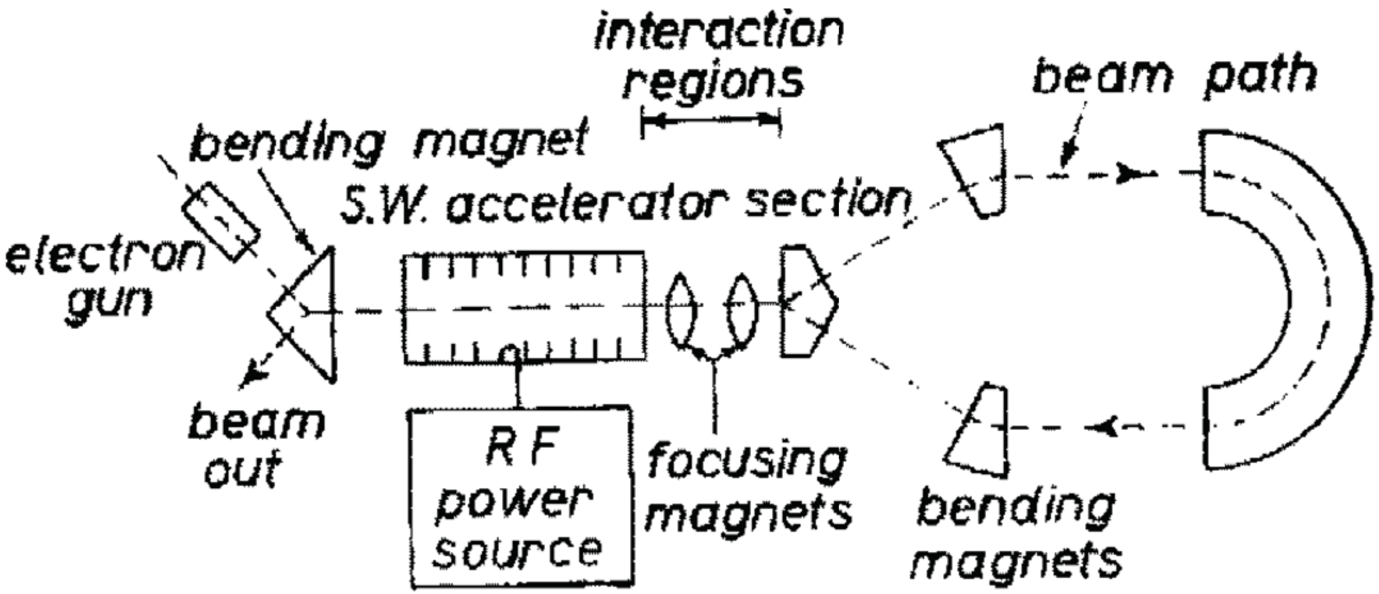
Laboratory of Nuclear Studies, Cornell University - Ithaca, N. Y.

(ricevuto il 2 Febbraio 1965)

Colliding Beam Concept #1



Colliding Beam Concept #2

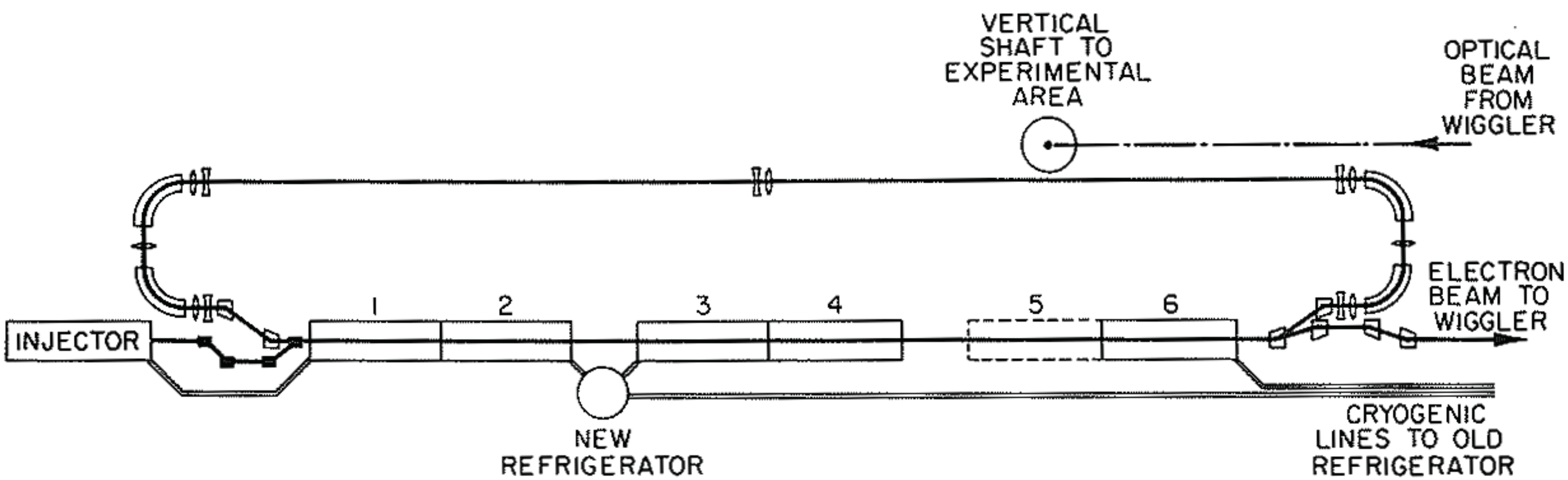


Of course this was not realizable without significant developments in RF Superconductivity – both high Q and relatively high gradients simultaneously. Only recently have we gotten to that stage so that the great advantages of the ERL are ready for prime time.

II. First Test

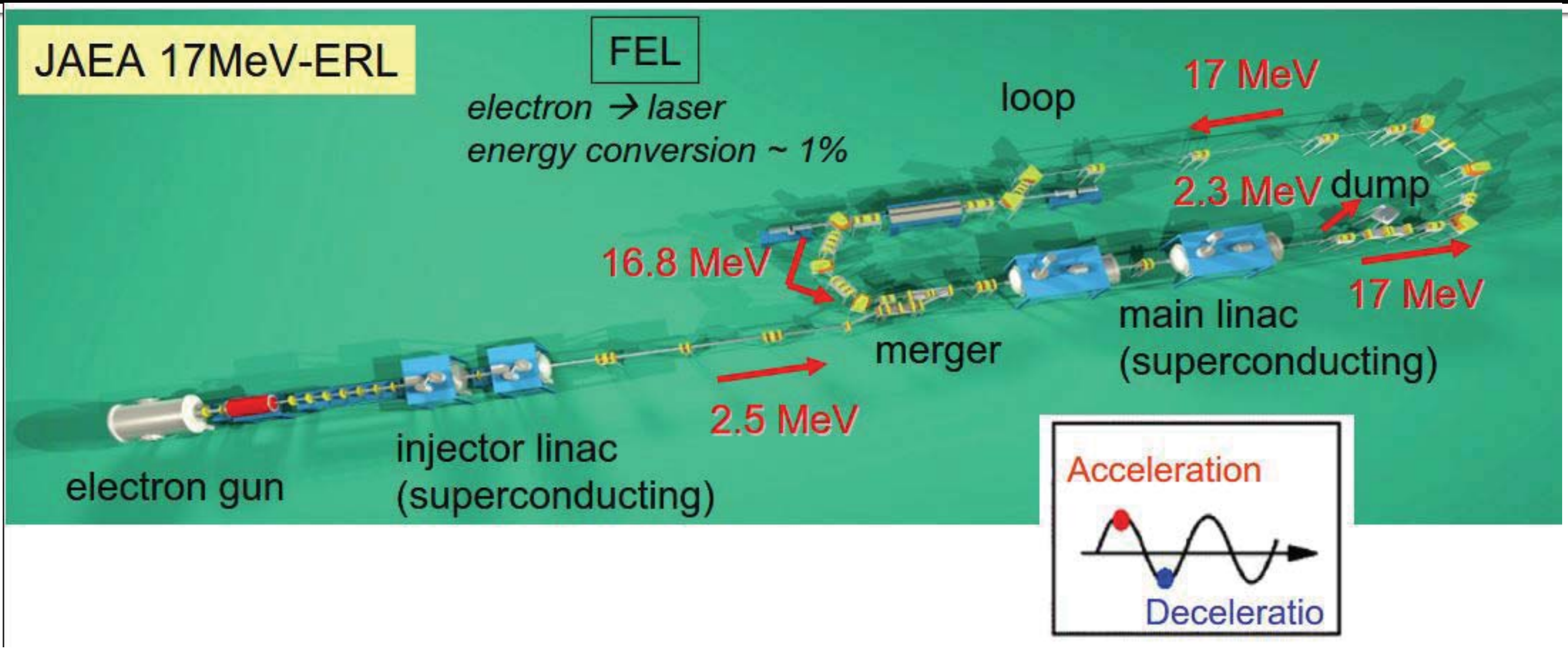
Suggestion in which the same beam is accelerated and decelerated in the same cavity was made in a FEL context: *C.A. Brau et al, in Proc. International Conference on lasers (1979)*

First done at the SCA, Stanford, 1986: *T.I. Smith et al NIM A 259 (1987)*



E_{max}~93 MeV (N=2); I_{avg}~150μA; I_{pk}~2.5A; Q_{bun}~12.5 pC

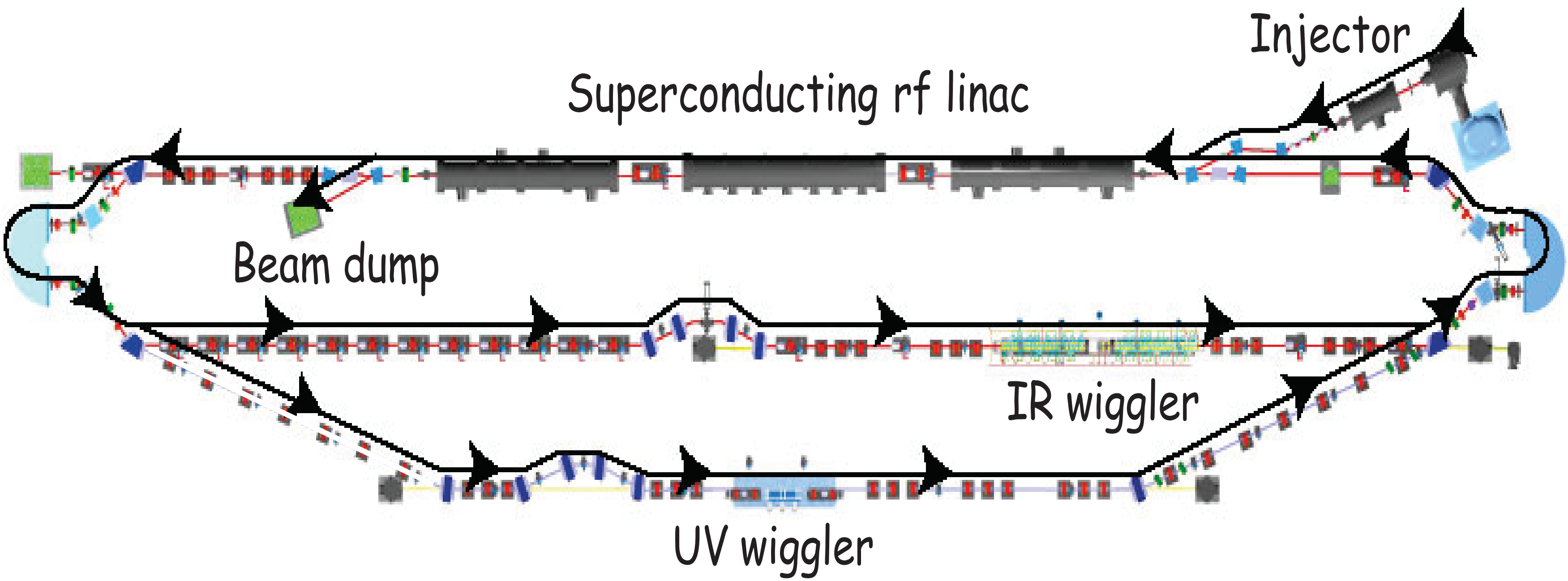
III. Currently Operating Machines



APAC 2007 https://accelconf.web.cern.ch/accelconf/a07/TALKS/MOYMA01_TALK.PDF

The Jefferson Lab IR FEL Upgrade

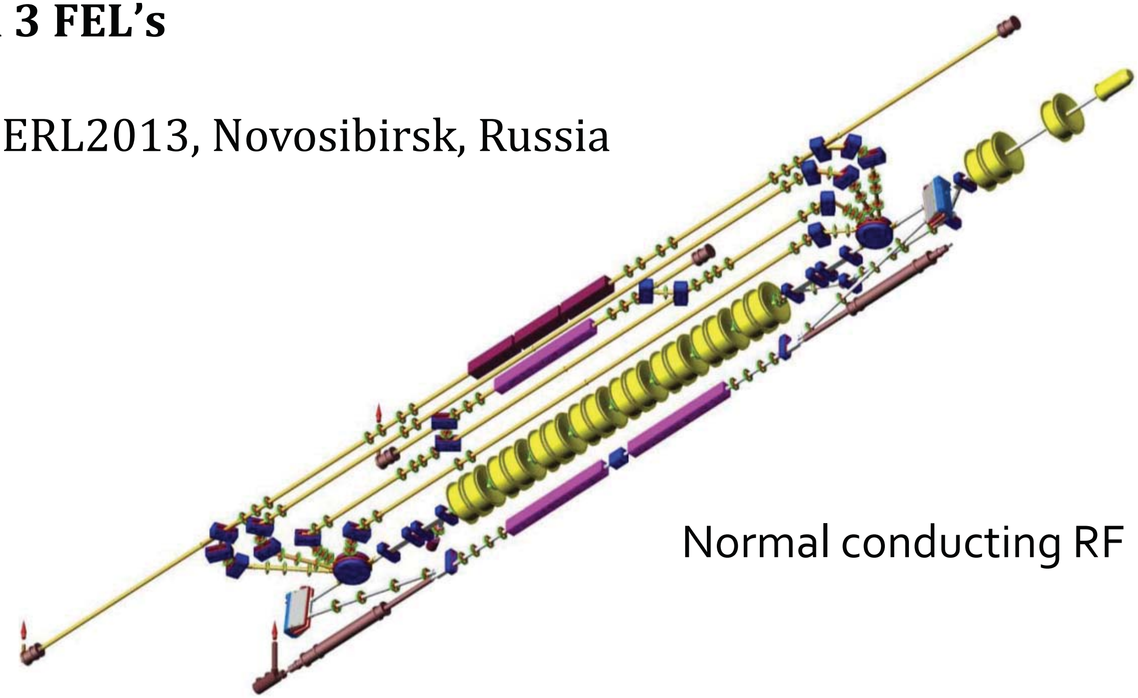
G.R. Neil, et al., Nucl. Instr. & Methods **A557** (2006) 9.



E_{max}=200 MeV; I_{pk}=270A; ε<11 μm; Q_{max}=135 pC; f_{bun}=4.7 – 75 MHz; $P_{beam,\ max}$=2 MW – largest anywhere to date

The Novosibirsk ERL with 3 FEL’s

O. A. Shevchenko et al Proc. ERL2013, Novosibirsk, Russia



Normal conducting RF

E_{inj}=2 MeV; $E_{main\ linac\ gain}$=10 MeV;Q_{bun}=1.5 nC;I_{avg}=5 mA;
ε=20 µm; f_{rf}=180 MHz; f_{bun}=90 MHz; N_{turns}=3 (4th in commissioning)

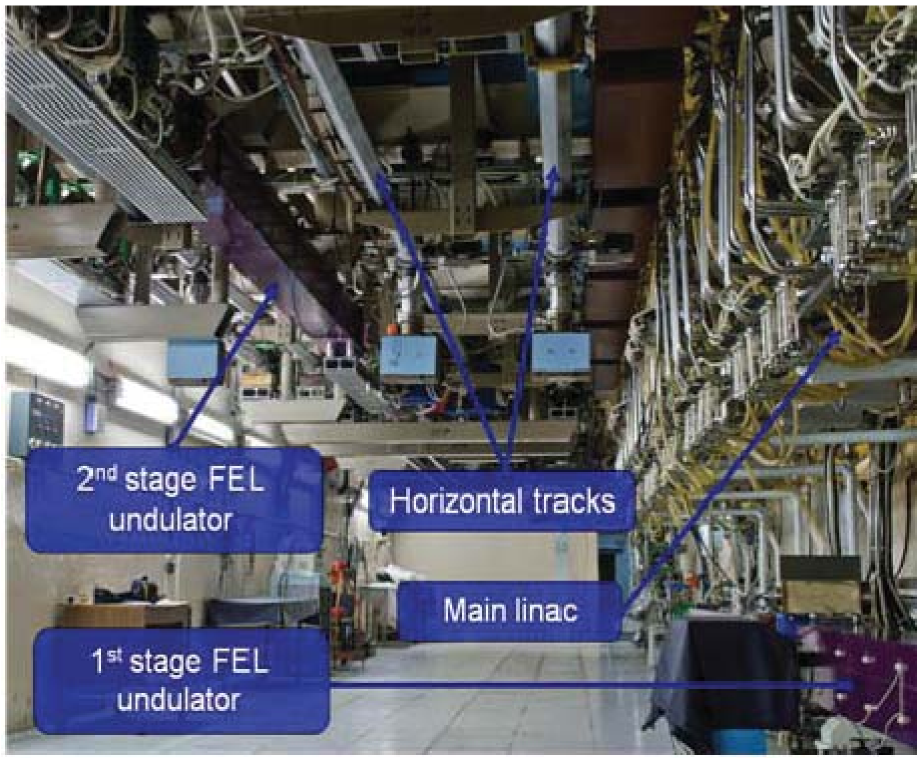
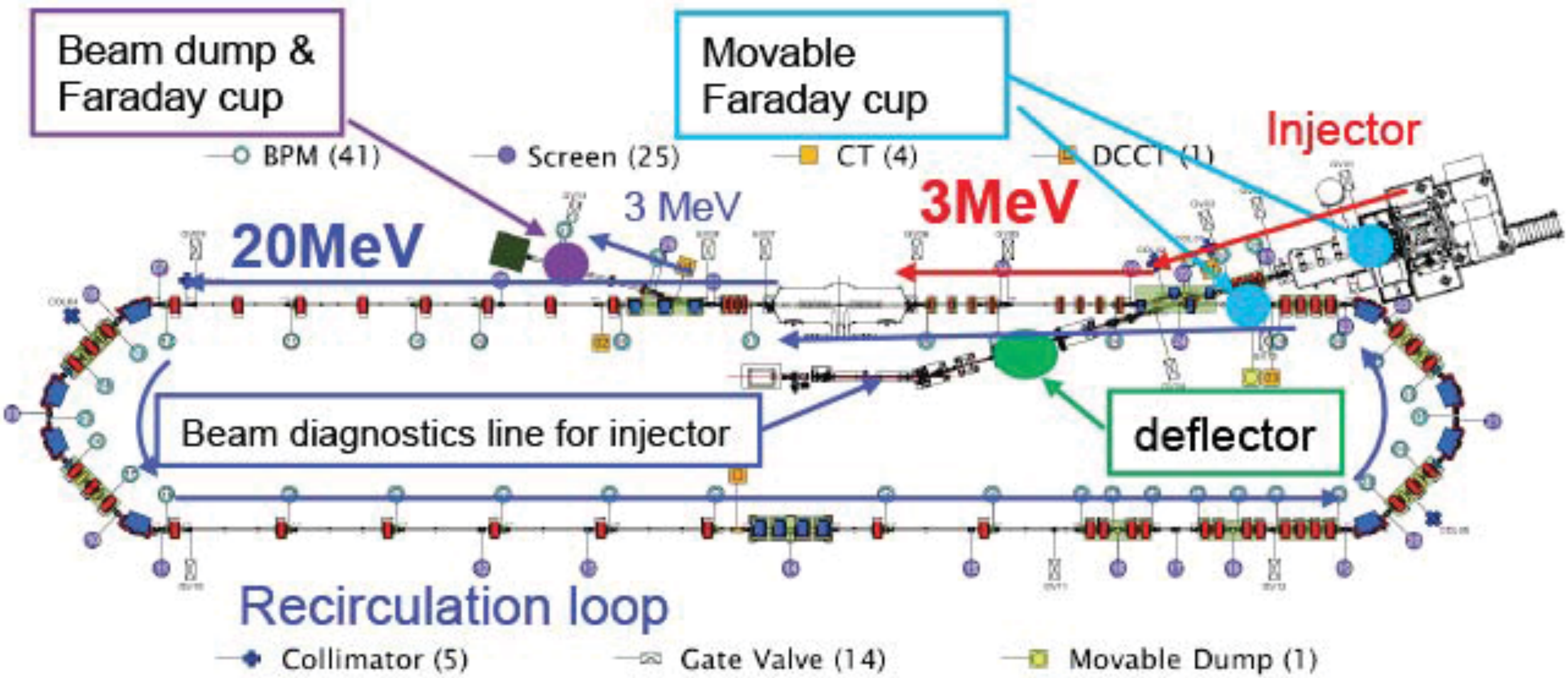


Photo of Novosibirsk 3 pass ERL

cERL at KEK



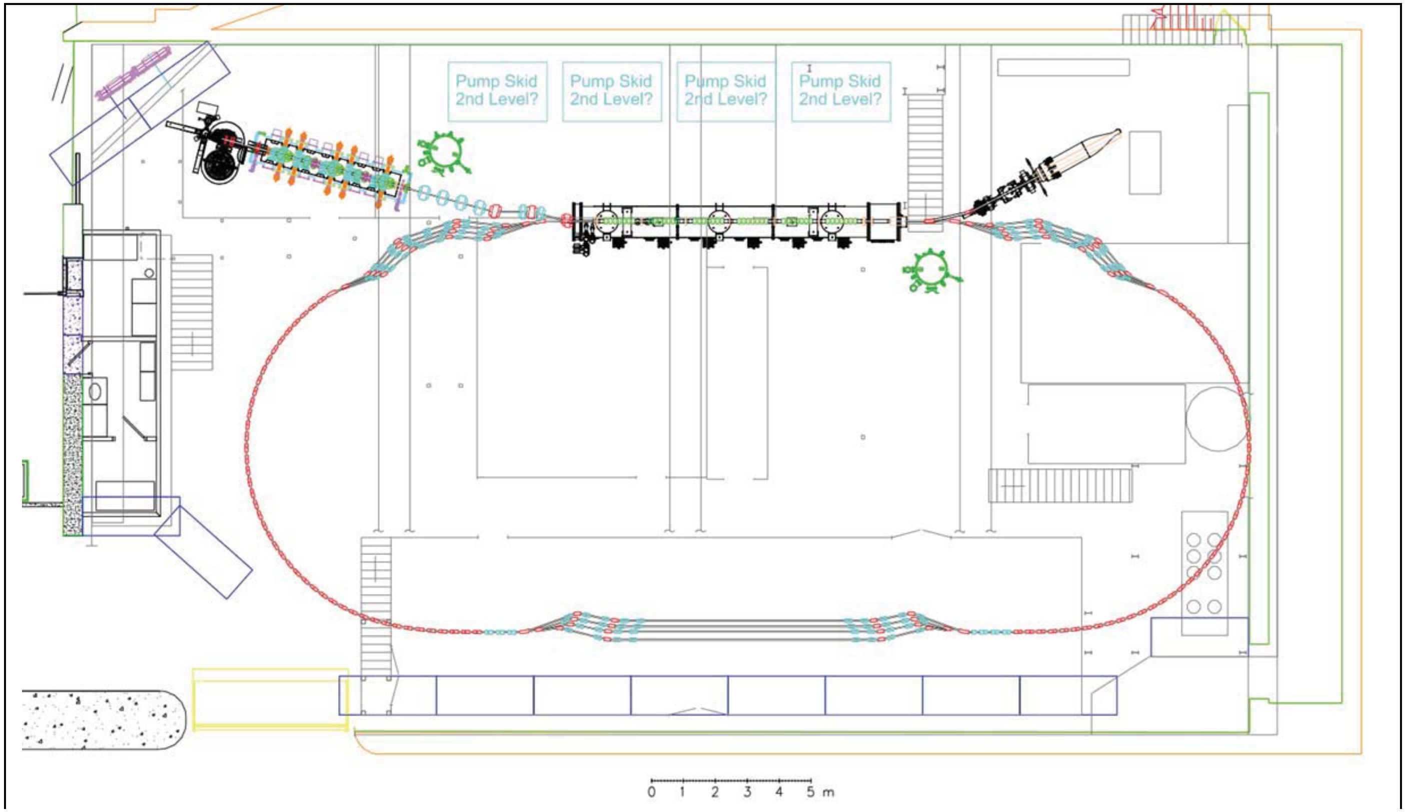
$E_{injgoal}$= 5 MeV; (E_{injopr}=2.9MeV) $E_{maxgoal}$ =35 MeV;

(E_{maxopr}=20MeV) I_{bmgoal} = 10 mA; (I_{bmopr}=80μa) $\varepsilon_{goal} = 0.1\mu m$; ($\varepsilon_{opr} = 0.3\mu m$);

7 KeV x-rays by laser Compton scattering

IV. Concepts for the Future

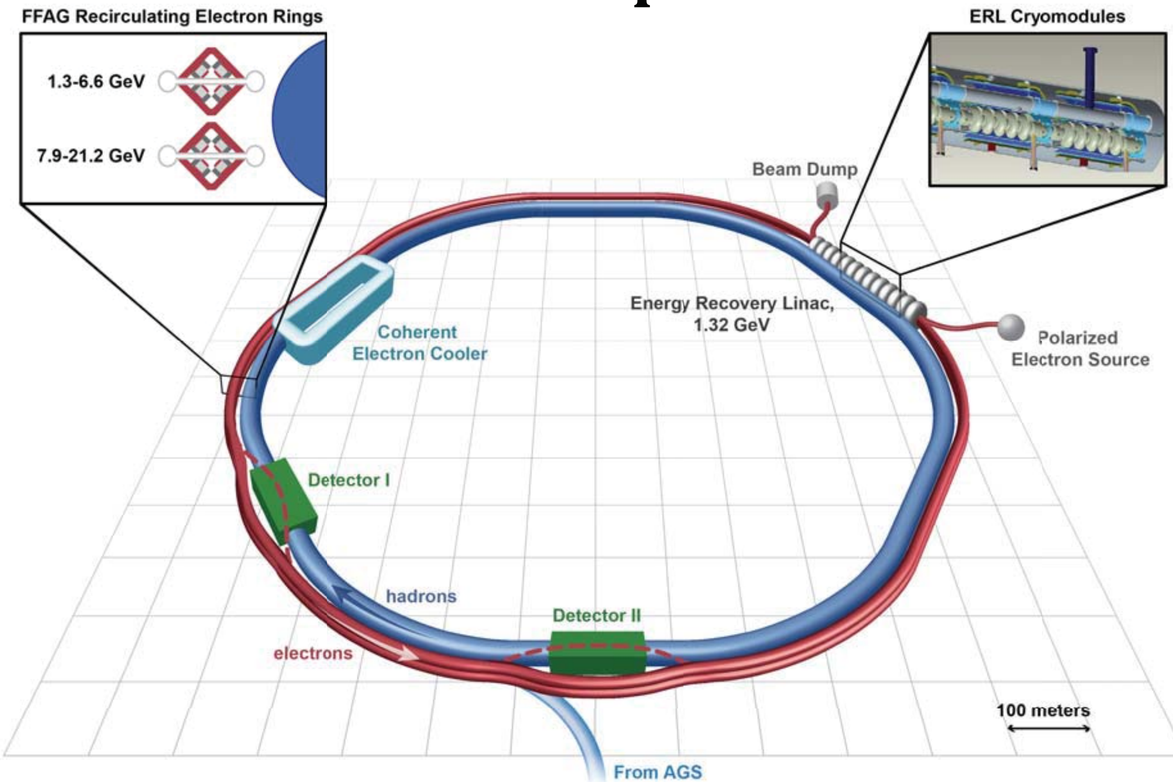
4 pass FFAG R&D loop for eRHIC



E_{inj}= 5 MeV; E_{max} =300 MeV; Q_{max}=80pC; $I_{inj\text{-}max}$ = 100 mA; $\varepsilon=0.3\mu m$

A staged approach is being studied

ERL FFAG Loops for eRHIC



$10 \le E_{max} \le 21.2 Gev$ & $3.7 \le i_b \le 50 mA$ combination limited by 2.4MW synchrotron radiation limit; $23 \le \varepsilon \le 58 \mu m$ depending on species being collided. [eRHIC Design Study - http://arxiv.org/abs/1409.1633]

…more

SRF system for eRHIC: $f = 422MHz$; $n_{cell} = 5$; g=18.5MeV/m;

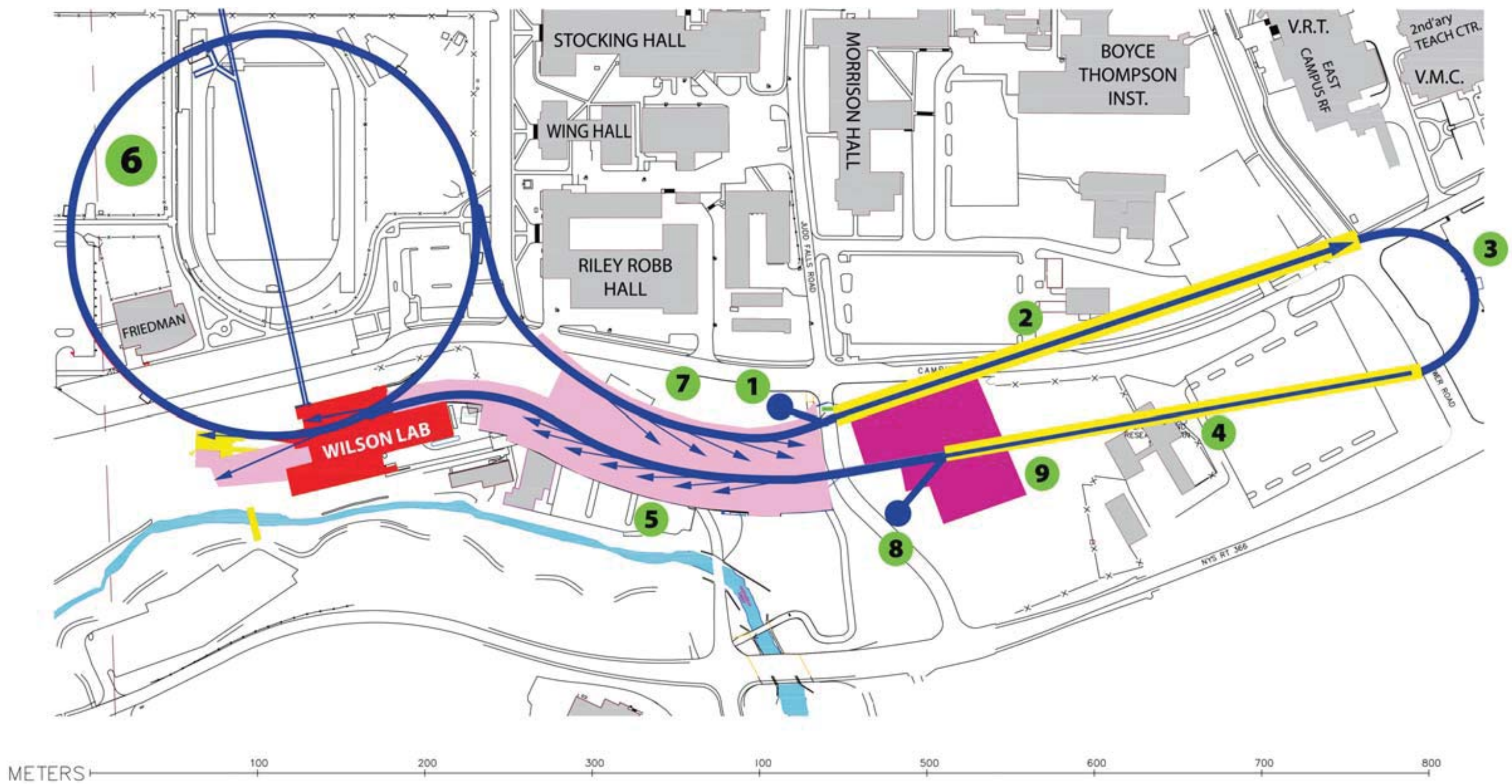
SR power compensated by separate, second harmonic system with energy spread compensation by a fifth harmonic system.

There will be SRF crab cavities at the IR’s using a BNL design

AND

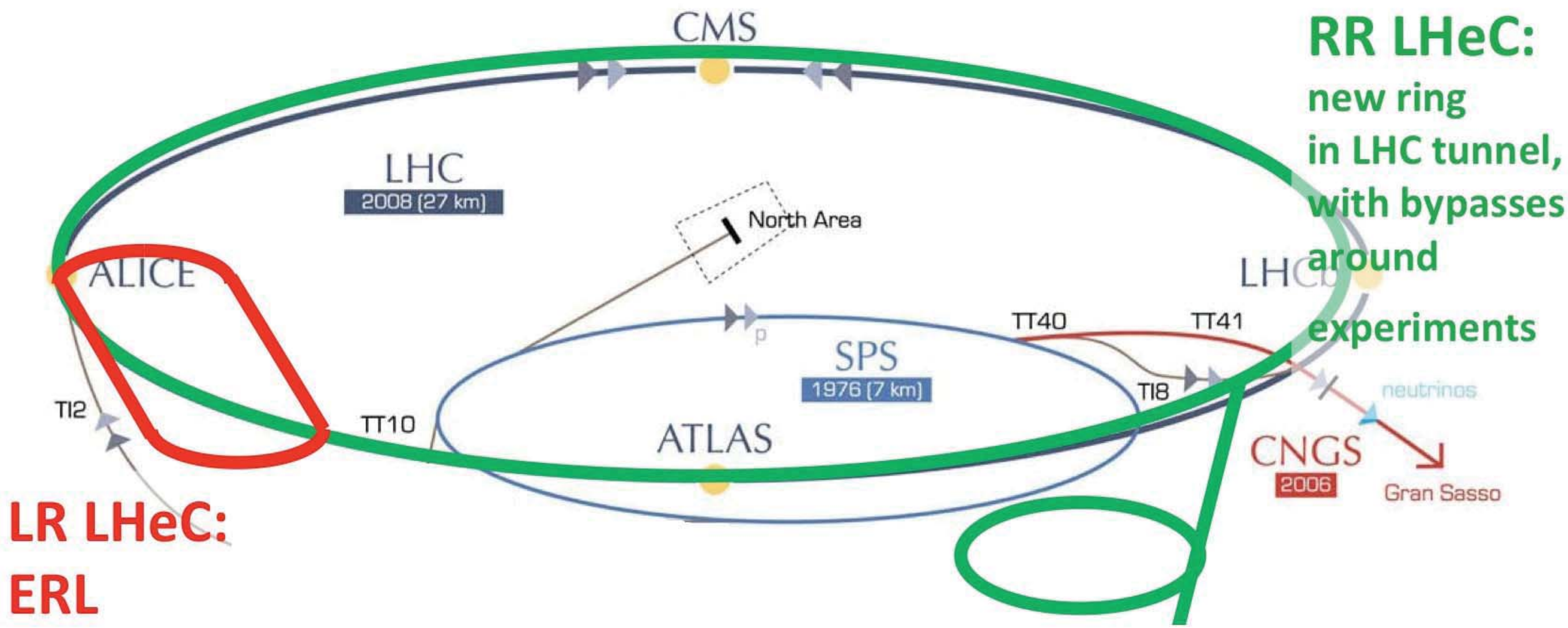
There will be another ERL to provide the electron beam for the Coherent electron Cooling system for the ions!!

High Brightness X-ray Light Source as CESR Upgrade



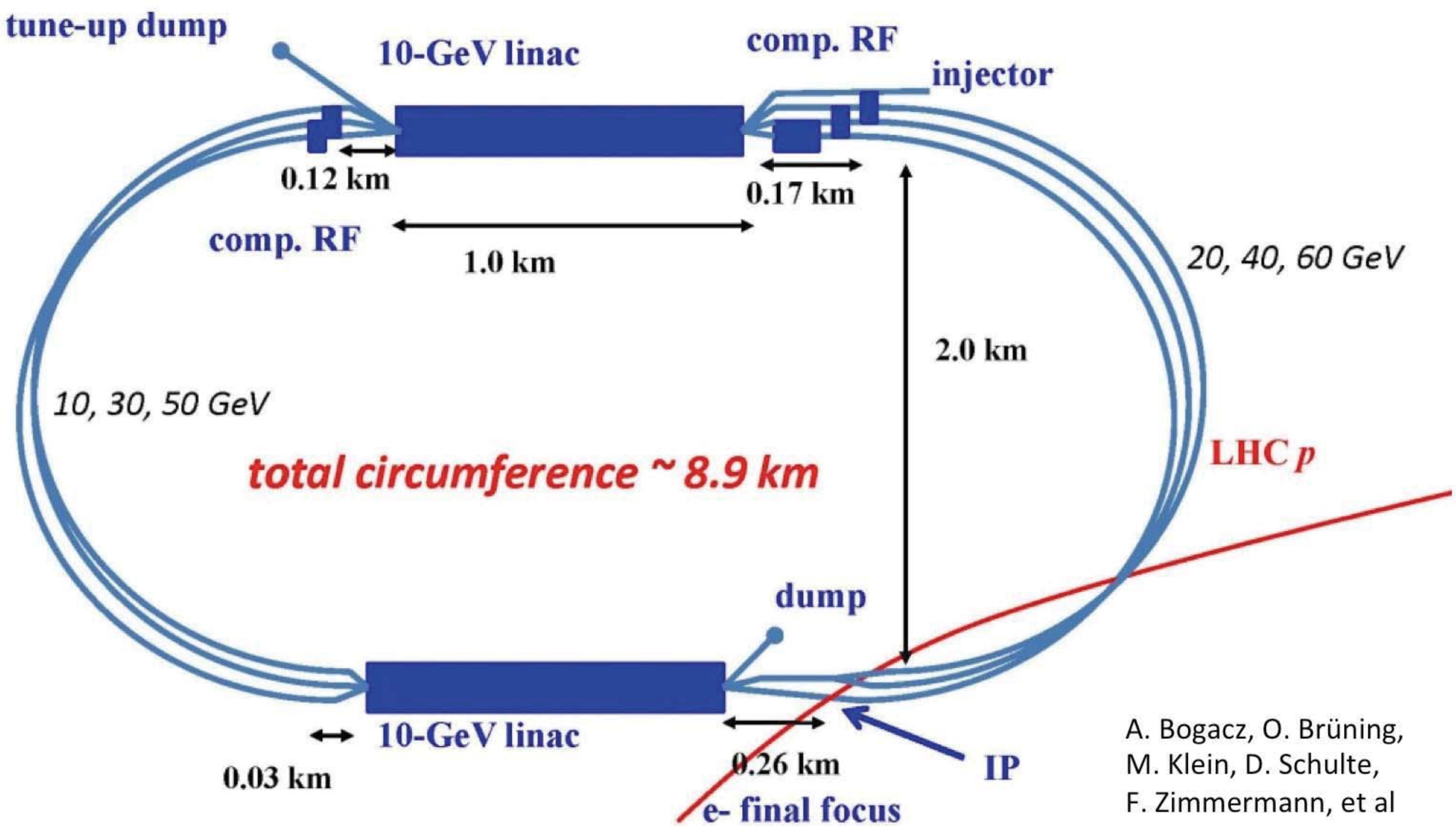
1 injector 100mA; 2,4 srf linac; 3 turnaround arc; 5,7 5GeV x-ray beamlines;
6 CESR arc return loop; 8 beam stop; 9 cryoplant. [http://www.classe.cornell.edu/Research/ERL/PDDR.html]

Large Hadron electron Collider



two 10-GeV SC linacs, 3-pass up, 3-pass down;
6.4 mA, 60 Gev e-'s collide w. LHC protons/ions

LHeC Linac-Ring ERL layout



[https://indico.cern.ch/event/278903/timetable/#all.detailed]

V. Challenges to Realization: R&D Needs

- Many of the projects require large scale-up w.r.t. existing machines e.g. ERL using FFAG
- Very precise phase and amplitude control required over large spatial extent with varying ground vibration conditions
- Unprecedented beam currents in SRF linacs (BBU, halo)
- Beam dynamics of unprecedented numbers of spatially superposed bunches in the SRF linacs
- High power of high energy x-rays to be protected against

R&D for mitigation

•Large scale-up risks need mitigation by excellent, full scale, machine modeling including realistic error distributions derived from real hardware prototypes and putative specifications

•Phase and amplitude control challenges are multidimensional here we mention only one i.e. vibration induced detuning of the very high Q cavities. Successful mitigation will require great attention to the vibration source(s) and design of the cryomodules for favorable transfer functions - source to cavity. Enough prototypes needed to assure robustness of design. RF and beam measurements in R&D loop can both help.

More…

•Advanced evaluation of ion effects and Touschek scattering and halos caused by intra-beam scattering and disruption of e-beam at the IP's with mitigation designs as needed

•Assurance of high enough BBU threshold requires advanced cavity design with realistic error distributions to determine the conservative number of cells per cavity allowed and a concomitant QC program of manufacturing.

•Radiation checks of prototype magnets using simulated distribution of radiation power and spectrum – look for asymmetric demagnetization

An example...

A multipass FFAG test loop such as indicated in slide 11 could illuminate key issues:

1. multiturn BBU thresholds for proof of possible cavity designs (theory test) and manufacturing quality control
2. halo caused by dark current, gas scattering, Touschek scattering, laser reflections…….. and their mitigations
3. multiturn FFAG magnetic multipole control
4. beam-ion effects
5. operational challenges including instrumentation and stability for multiturn beams

VI. Conclusion

Currently there are proposals and suggestions for several important applications of the ERL principle. As many of the suggested machines are at scales much larger than supported by our experience, great attention needs to be given to detailed simulations. Required *error tolerances* and *instrumentation* as determined from detailed simulations need to be practical as shown by prototypes and small-scale models of the loops where possible.

THANK YOU!