Energy Recovery Linac (ERL) Science Workshop

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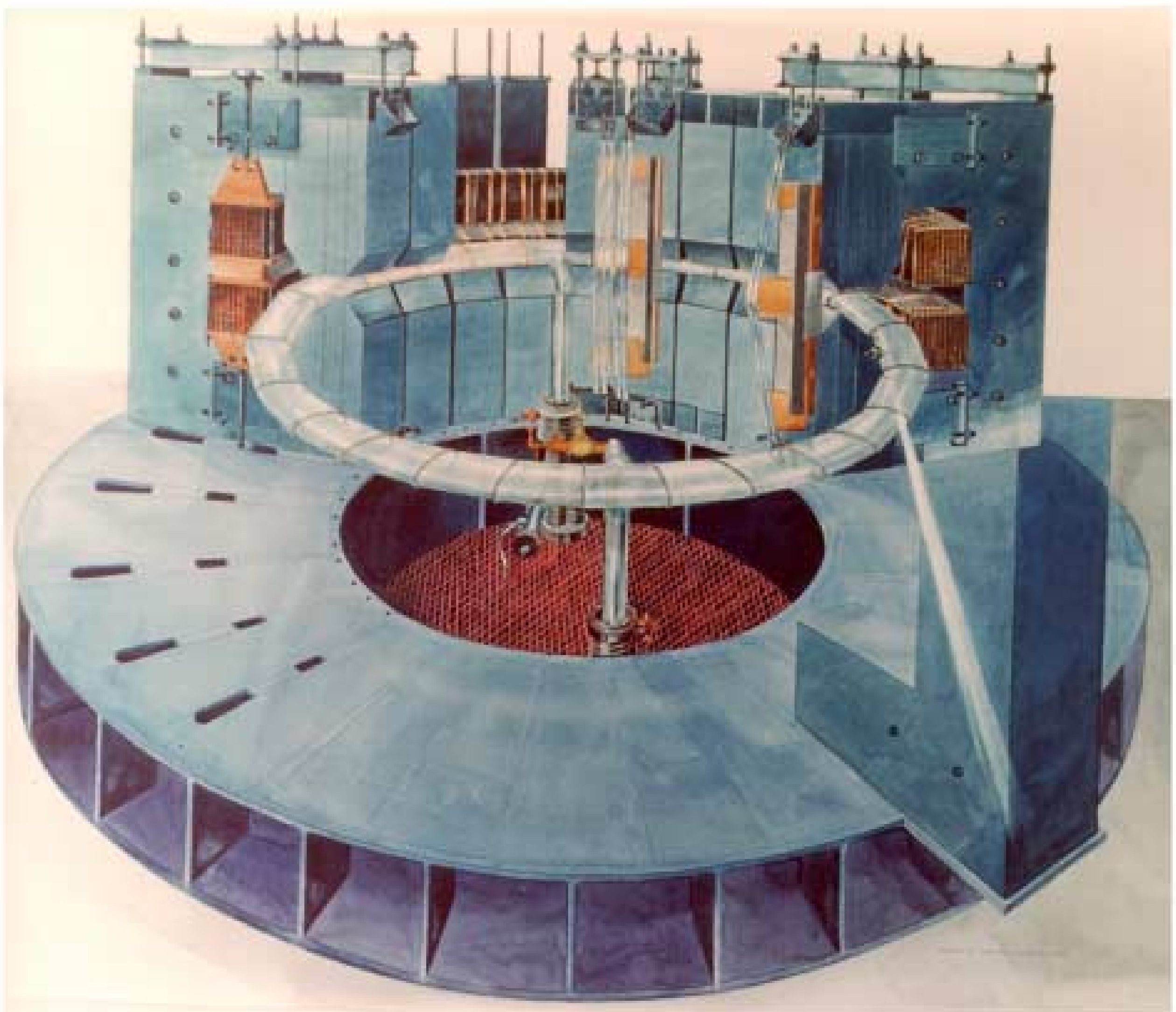
Objective: **Examine science possible with an ERL x-ray source.**

Ques.: **Why do this?**
Ans.: **Need for more and better SR machines.**

- **World wide, ~70 SR sources built or in works.**
- **Use is still growing in many sectors. Community is large and growing.**
- **All major SR sources based on storage rings, with exception of FELs.**

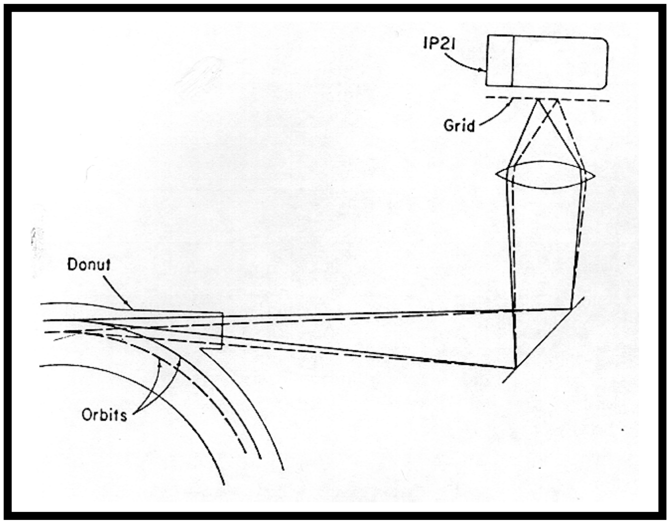
Timely to examine if there are alternatives to storage rings which present advantages.

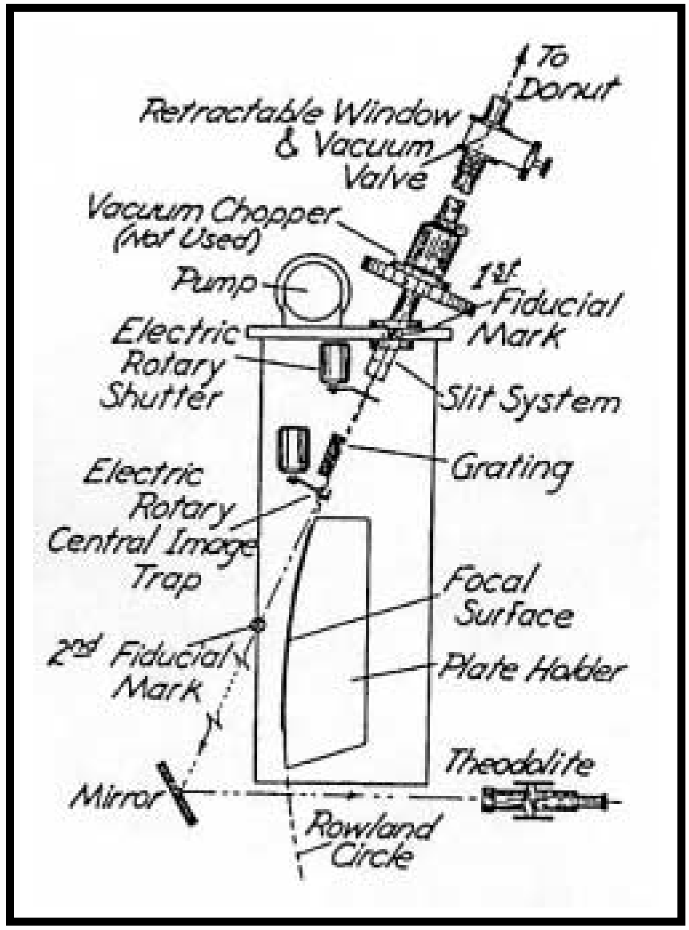
There is a long history of interaction between accelerator physics and synchrotron radiation at Cornell



Cornell 300 MeV Synchrotron (*circa* 1950)
Newman Hall

First SR Beamlines were built on 300 MeV Machine to Characterize SR





Hartman & Tomboulian, Phys Rev, 87 (1952) 33.

Corson, Phys Rev, 87 (1952) 233.

Hartman & Tomboulian, Phys Rev, 91(1953)1577.

Tomboulian & Hartman, Phys Rev, 102(1956)1423.

Definitions:

***1st generation SR source*: parasitic on HEP, optimized for HEP.**

***2nd generation SR source*: dedicated to SR production. Optimized for flux.**

***3rd generation SR source*: dedicated to SR. Optimized for brilliance and flux.**

***4th generation SR source*: FELs. A whole different animal, especially in hard x-ray. Super-intense peak power , very low duty cycle.**

- ***Flux*: phot /s/ 0.1% bw**
- ***Brightness*: phot /s/ 0.1% bw/ mrad^2**
- ***Brilliance*: phot /s/ 0.1% bw/mrad^2/mm^2**

SR source wish list

1. **Low emittance**

2. **Flexible pulse structure**
   - **complex pulse trains**
   - **pulse lengths: 10 fs to ~100 ps**

3. **Better average**
   - **brilliance**
   - **brightness**
   - **flux**

4. **Very stable beams**

Question: Where do storage ring limitations fundamentally arise from?

Answer: From the dynamical equilibrium which is characteristic of the machine lattice.

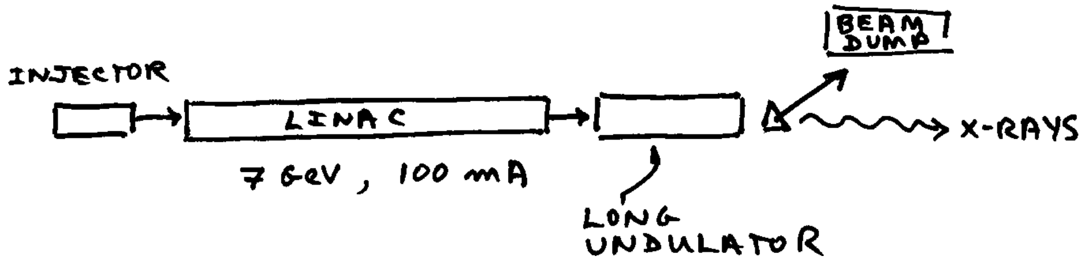
Important Fact: The equilibration times are long, typically thousands of circuits around the ring.

Equilibrium dynamics determine

- **Minimum Emittance**
- **Minimum bunch length**
- **Shape (Gaussian cross-sectional profile) of bunch**
- **Fill decay**

i.e., essentially all the factors of importance for synchrotron radiation!

Let's take a different approach: In principle, injectors can be built with very brilliant e$^-$ beams and linacs can accelerate with very low emittance growth. Why not use this to produce SR?



Advantages:

- **Emittance & pulse length determined by injector**
- **Complete flexibility of pulse structure.**
- **No fill decay**
- **Scrapers allowed to limit pulse profile**

Disadvantage:

You'd go broke!!

(7 GeV) x (100 mA) = 700 MW!!

Solution: Use energy recovery. First proposed by Tigner in 1965.

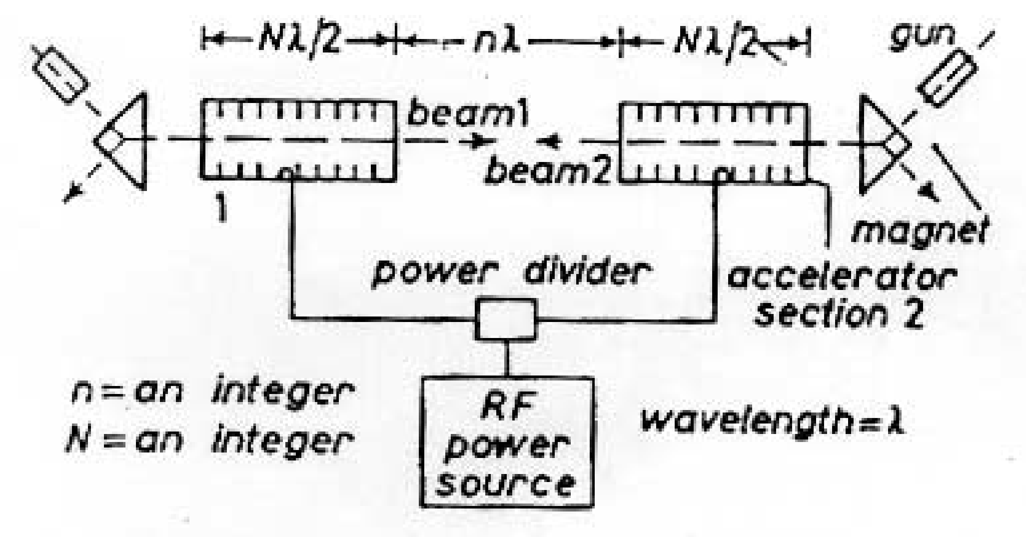


Fig. 2.

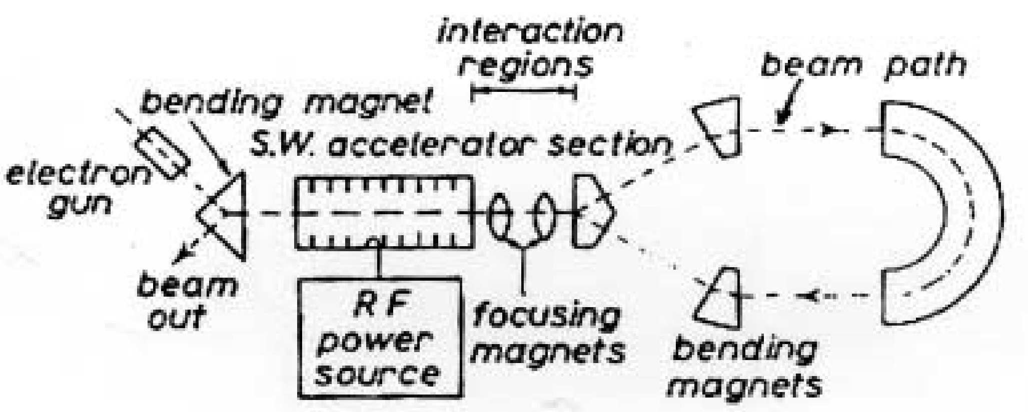
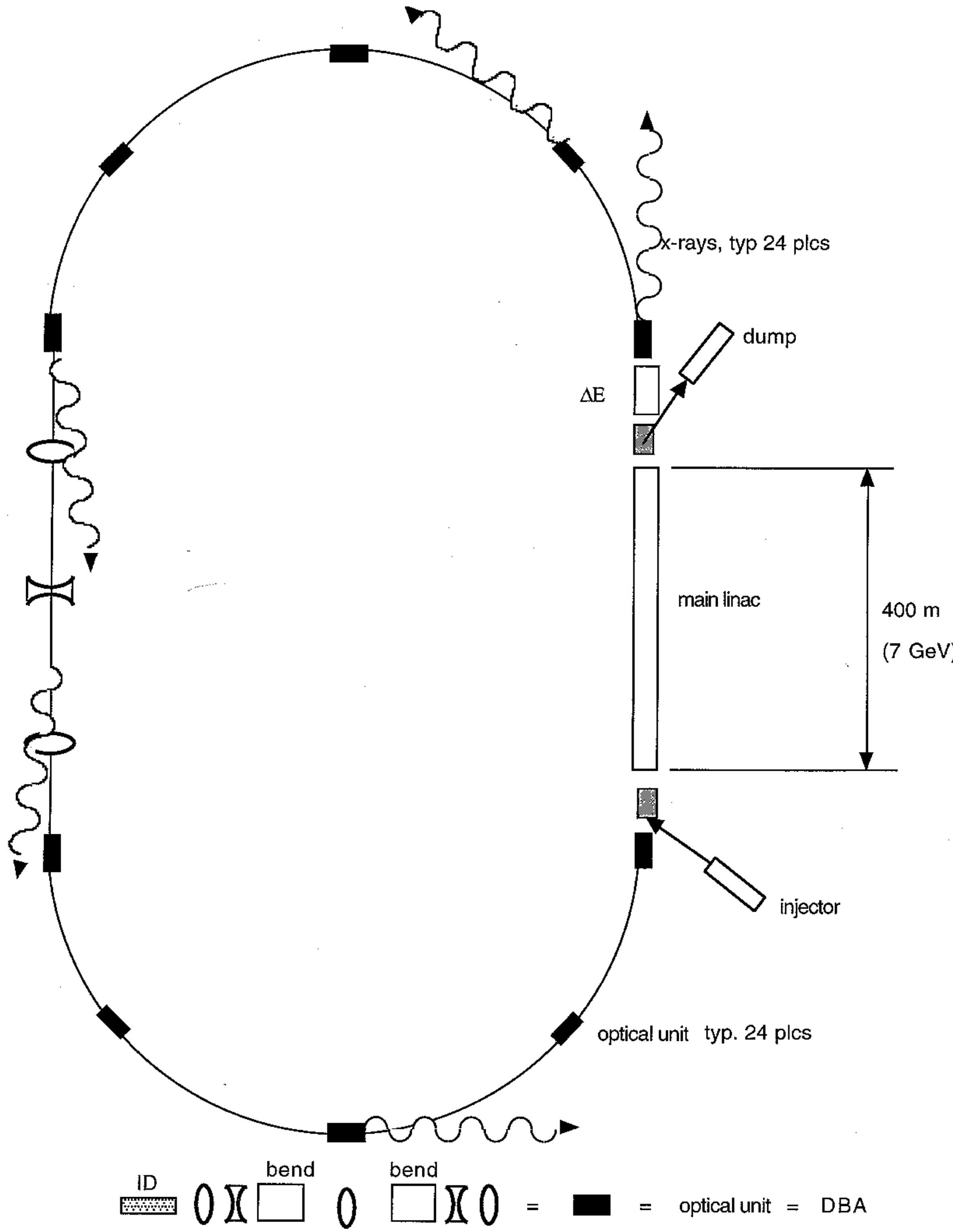


Fig. 3.

M. Tigner, Nuovo Cimento 37 (1965)1228.


x-rays, typ 24 plcs
dump
ΔE
main linac
400 m
(7 GeV)
injector
optical unit typ. 24 plcs
ID
bend
bend
= = optical unit = DBA

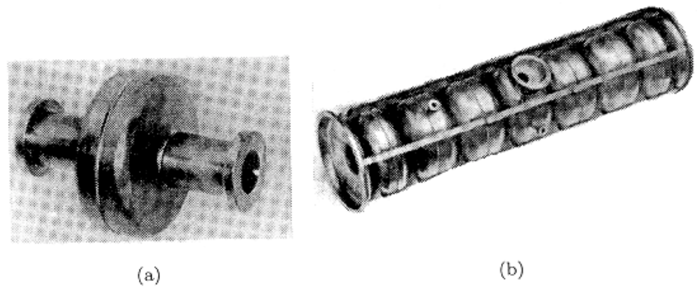


Figure 1.6: (a) Single-cell HEPL niobium cavity, resonant frequency 1.3 GHz, active cell length 11.5 cm. (b) HEPL 7-cell subsection. The niobium cavities were fabricated by sheet metal forming and electron beam welding. (Courtesy of Stanford University.)

The devil is always in the details. Can an ERL be made suitable as a brilliant, high intensity SR source?

Some Key Dates in Superconducting (SC) Technology Leading to an ERL

1965	**Tigner proposes ERL idea**
1965	**Stanford SC resonator**
1975	**Cornell SC synchrotron tests**
1977	**Stanford SC recircul. linac tests**
1982	**First storage ring SC tests (CESR)**
1984	**CEBAF cavities tested at CESR**
1994	**CEBAF experimental beams**
1998	**Jlab ERL-FEL**

See Padamsee et al., RF Superconductivity for Accelerators (John Wiley, NY, 1998) for history.

Jlab ERL FEL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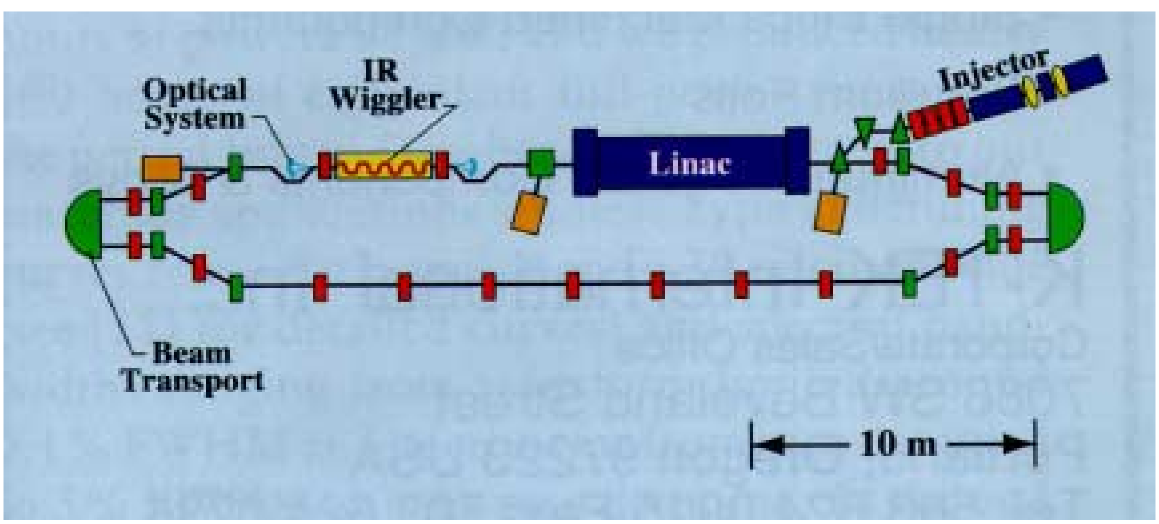
Optical System
IR Wiggler
Injector
Linac
Beam Transport
10 m

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ERL Machine Physics Workshop Cornell University, 11-12 Aug 2000

(see http://www.chess.cornell.edu/ERL/Papers/Papers.htm)

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Workshop Participants

- **Jlab experts**
  Charlie Sinclair, Lia Merminga & Geoff Krafft.

- **LNS accelerator types**
  Special thanks to Gerry Dugan, Joe Rogers, Richard Talman, Ivan Bazarov (LNS & CHESS)

- **CHESS x-ray types**
  Special thanks to Ken Finkelstein

- **Cornell laser types**

Primary Conclusions of Machine Workshop

- **High current, very brilliant ERL has never been built, but seems feasible.**

- **Challenges arise from high current & brilliance.**

Areas in particular need of R&D:

- **Injectors**
- **Energy budget**
- **Linac optics**

In all cases, however, likely solutions exist. Will require R&D, but do not foresee killer problems.

ERL SR source opens new science opportunities stemming from

- **Low emittance, in *both* x & y**
- **Unprecedented brilliance**
- **Ultra-short bunches**
- **Flexible bunch structure**
- **Control of bunch cross-section**
- **Stable beams**
- **Flux**
- **Extreme flexibility**

Charge to workshop

1. **What are the best science opportunities?**
2. **What machine parameters should be optimized to realize the science?**

Experiment	**Microdiffraction w/3 - 30 nm probe size** **highly demagnify ERL source size by x100 to x1000**
Important machine parameters	**Small source size in ERL of 3 - 10 microns** **Stable beams**
Undulator needs	**Small beta ~ 1 m** **Short period , ID length of ~ 2 m**
Special concerns	**Low floor vibrations**