High brightness Electrons beams at FERMILAB and applications

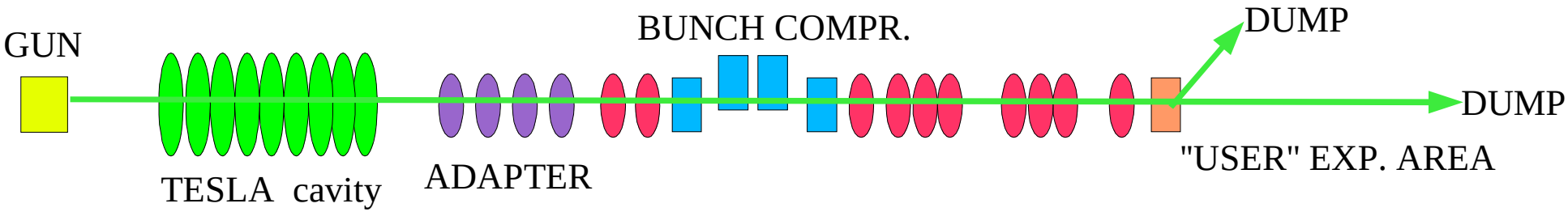
Philippe Piot

- Present activities of A0
- Short term upgrade: R&D for Linear colliders and next generation light sources
- Longer term: HBPI project?
- HBPI as an electron injector for the proposed 8 GeV superconducting booster linac

"Young Session" of the R&D LPR committee
September 3rd, 2003

FERMILAB R&D in e- beam production

- Since mid 90's: Fermilab has designed and operated a high brightness photoinjector producing 15 MeV electron beam
- A0 is dedicated to beam physics and advanced accelerator R&D
- A copy of this injector was built and installed at the Tesla Test Facility. It has driven a high gain single pass free-electron laser in the saturation regime at the shortest wavelength ever achieved (~100 nm) It has served to demonstrate key technological point of TESLA

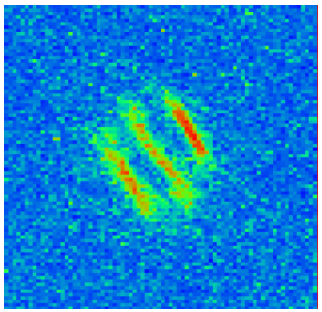


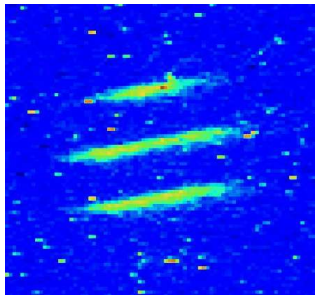
E~15 MeV
Q up to 8 nC

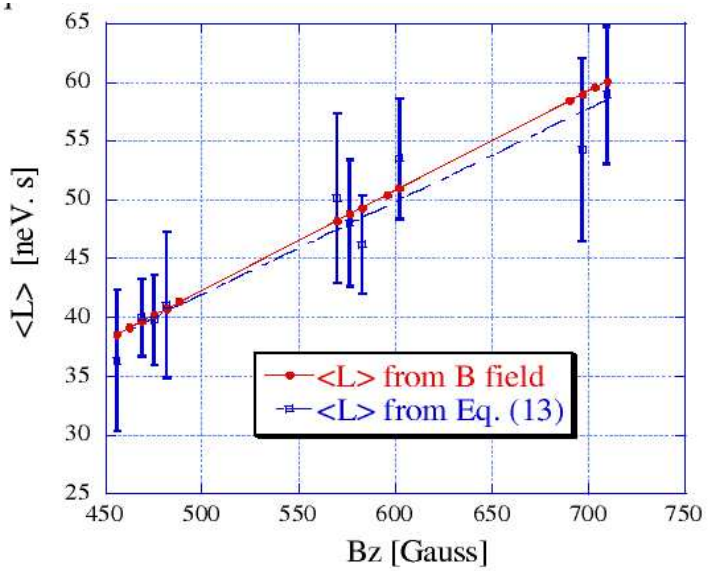
Photo-injector production of flat beam

Flat beams for LCs obtained in damping rings. For electrons, flat beams can be generated out of a photoinjector. Flat beams are also of interest for light source (e.g. Berkeley proposal)

- Photo-cathode is immersed in a Bz-field
- Solenoid fringe field → beam acquires an angular momentum (fully x-y coupled motion)

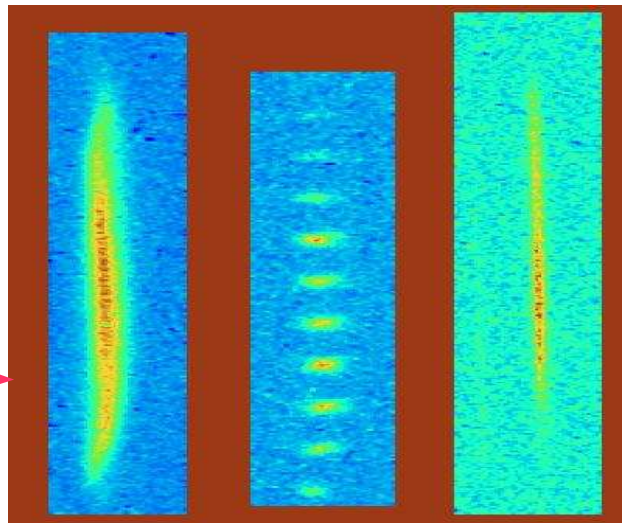






- A skew quad. channel decouples the motion and yields a beam with a high transverse emittance ratio : $\frac{\varepsilon_x}{\varepsilon_y} - 1 \propto B_z^2 \frac{\sigma_r^2}{\sigma_{r'}^2}$
- Status: now working toward emittance ratio of >100

Proof-of-principle experiment done → obtained a ratio of ~40

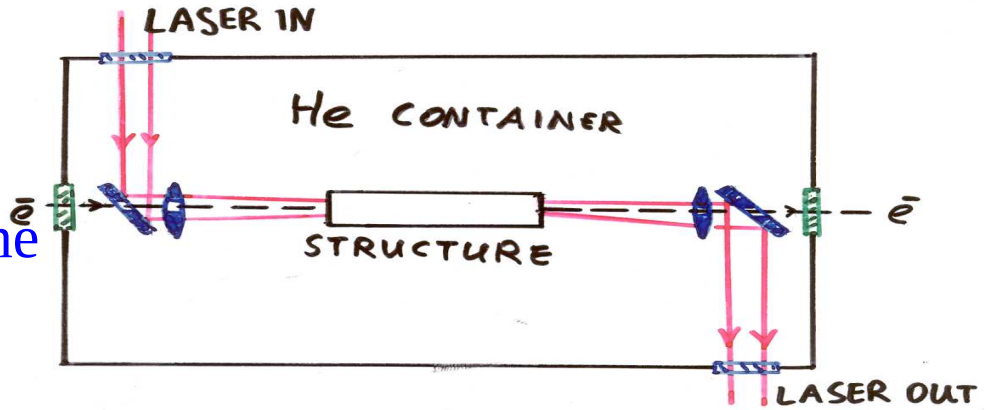


SPOT YMS XMS

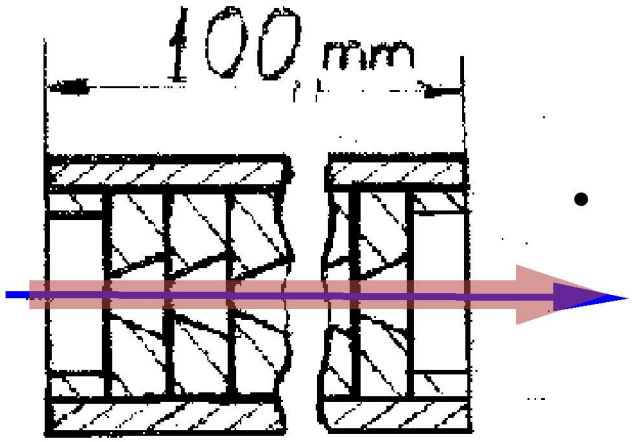
(PhD stud.: Yin-e Sun, U of Chicago)

Laser-based acceleration of electrons

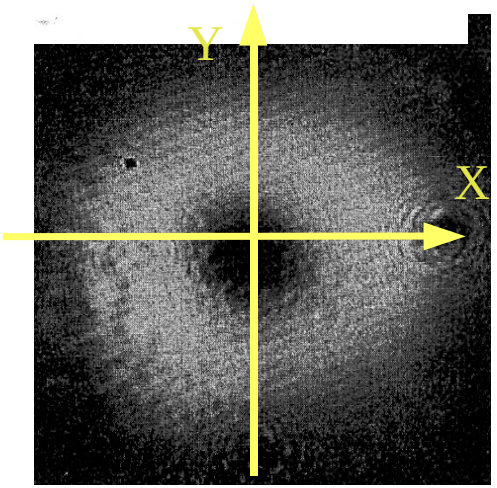
- Laser beam is used to provide longitudinal accelerating E-field



- laser and e- beams are "coupled" in the "open iris structure" (radius>>λ)



- Laser operates in the TEM_{01}* mode, since it provides the largest possible Ez-field.

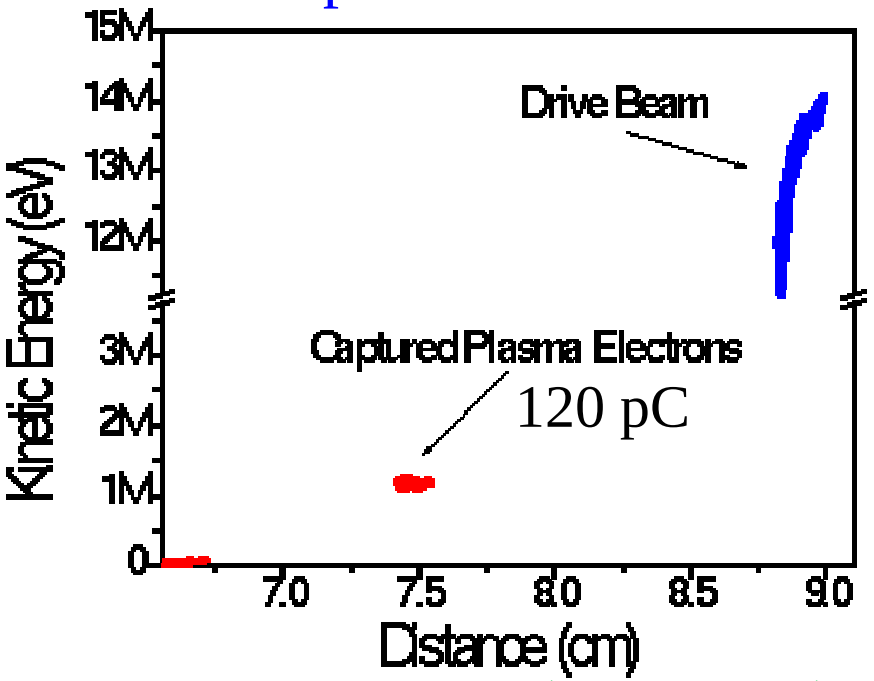


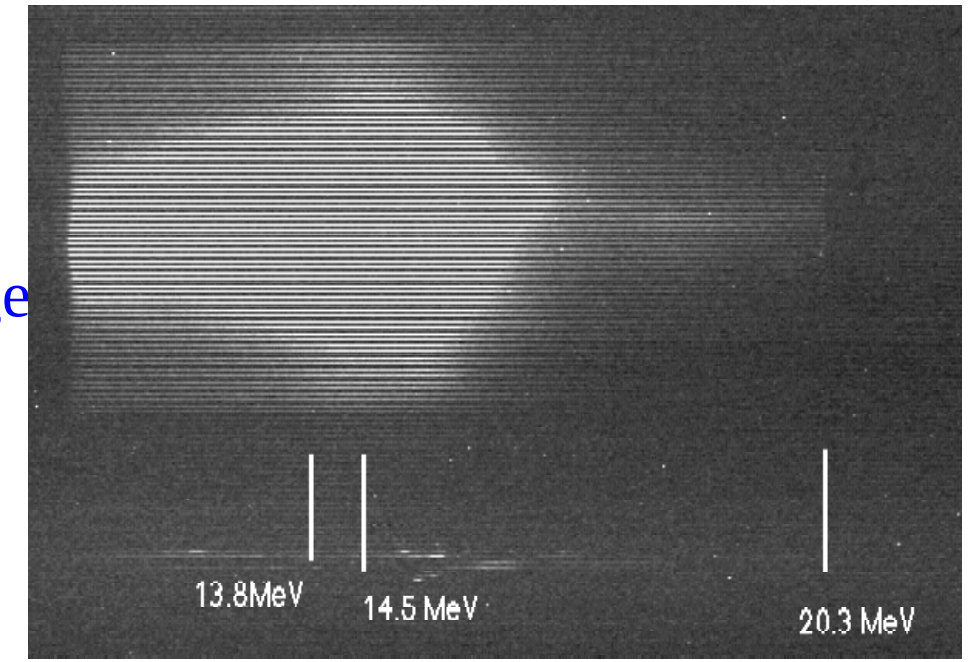
- For a laser peak power of 34 TW → Ea=0.54 GV/m
- With 15 MeV beam, there is problem with phase slippage and large energy gain is not achievable at A0
- Status: laser ready, experiment in preparation (choice of structure,...)

(PhD stud.: Rodion Tikhoplav, Rochester)

Plasma-based generation/acceleration of electrons

- High current e- beam injected in a plasma induces density modulation
- Energy in the bunch is modified according to the induced wake-field.
- Current experiment: have a low charge (test) bunch following the high charge bunch to sample the wake-field



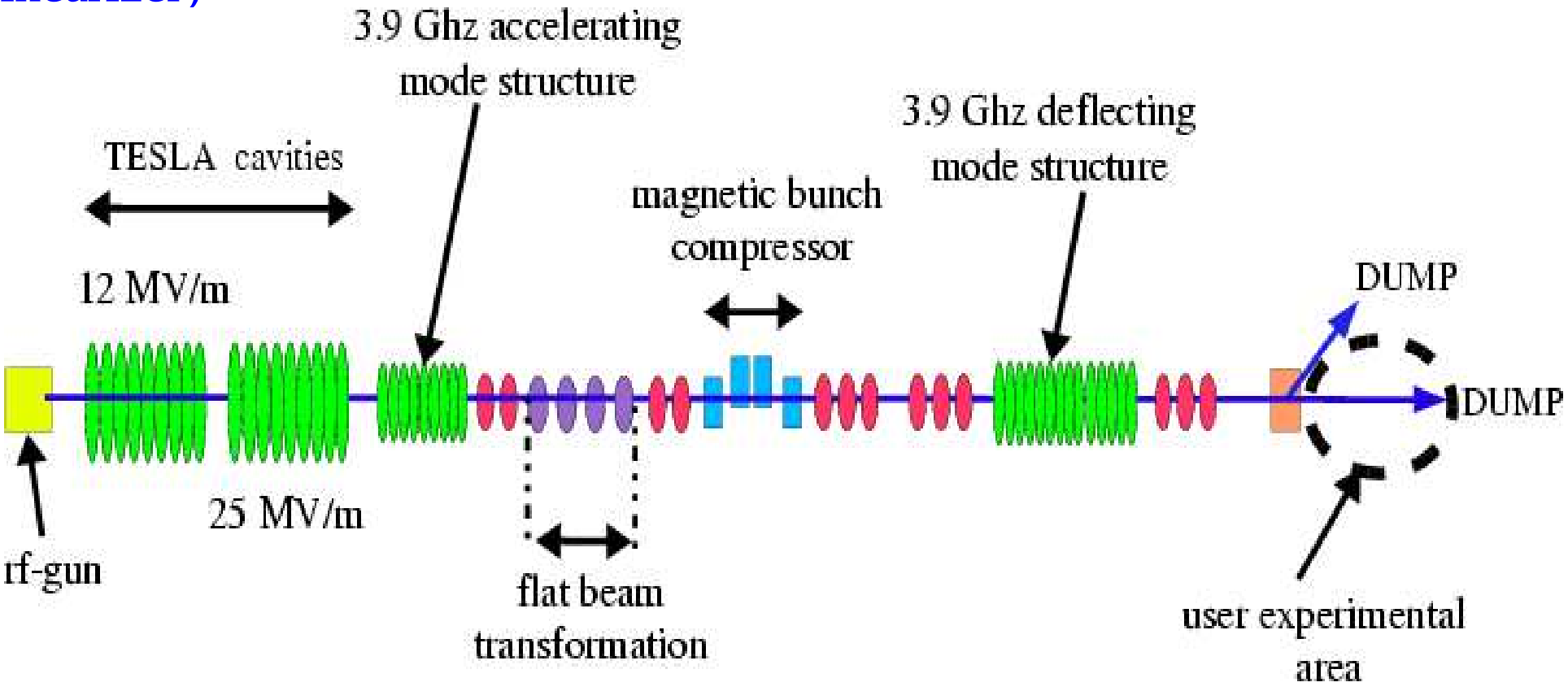


- Plasma-based electron source: use a sharp density transition to rephase the plasma wake so to accelerate plasma electron (that are at rest)

(N. Barov (NIU) + PhD stud.: Matt Thompson, UCLA)

A0 short term upgrade (a year from now ?)

- A0 energy is currently 15 MeV, the beam is then space charge dominated (for ~1-8 nC charge/bunch)
- DESY has offered to give a TESLA cavity (Grad.>25 MV/m)
- The new design would also incorporate the CKM deflector (3.9 GHz deflecting cavity) and the 3.9 Ghz accelerating mode cavity (so-called linearizer)

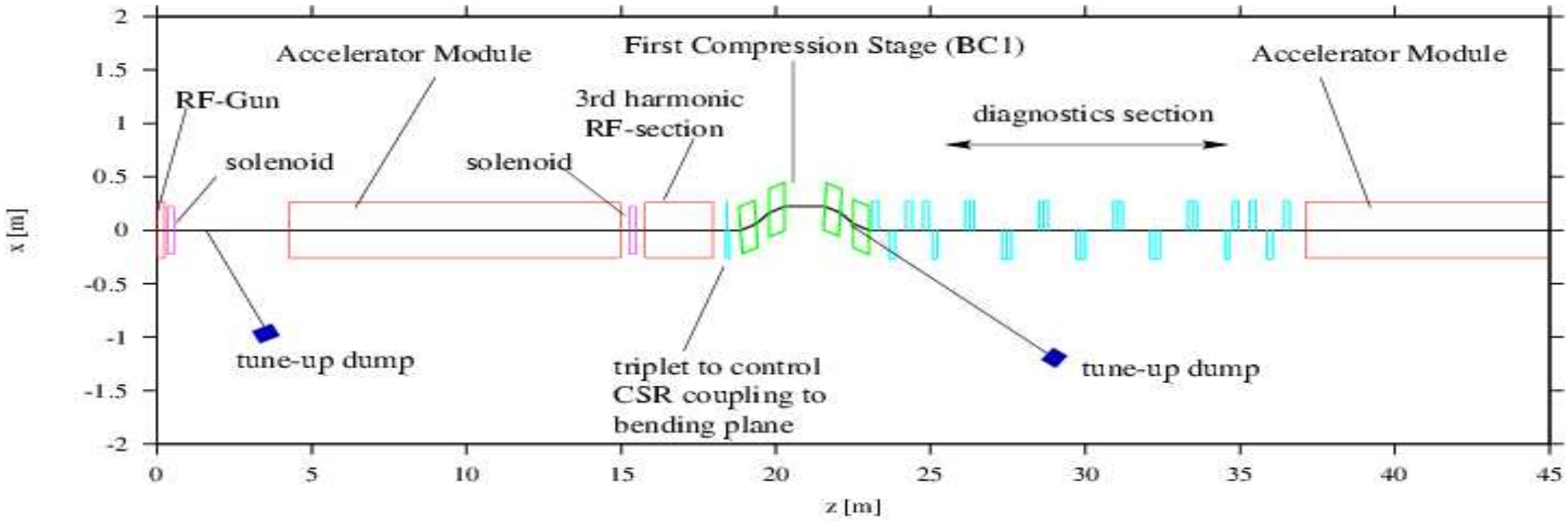


A0 short term upgrade: Scientific case

- **Test and optimization of the longitudinal phase space linearization** scheme (using the 3.9 Ghz accelerating section) to increase the peak current downstream of a bunch compressor
- **Longitudinal phase space measurement** (using the CKM cavity) and direct measurement of "slices parameters" along the bunch
- **Production and compression of flat beams:** such type of beam could be use to test the generation of Smith-Purcell radiation based on the image-charge undulator (discussion with JLab)
- Full **test of a high gradient TESLA superconducting cavity**
- **Characterization of the CKM experiment rf-deflector**: measurement with beam of the cavity performance
- **Better set-up for Laser-based acceleration**
- **1 microns SASE-FEL**: preliminary simulations indicate substantial gain could be achieved with the A0-upgraded parameter
- ...

Still: 50 MeV is not a full scale injector...

The High Brightness Photo-Injector (HBPI) proposal

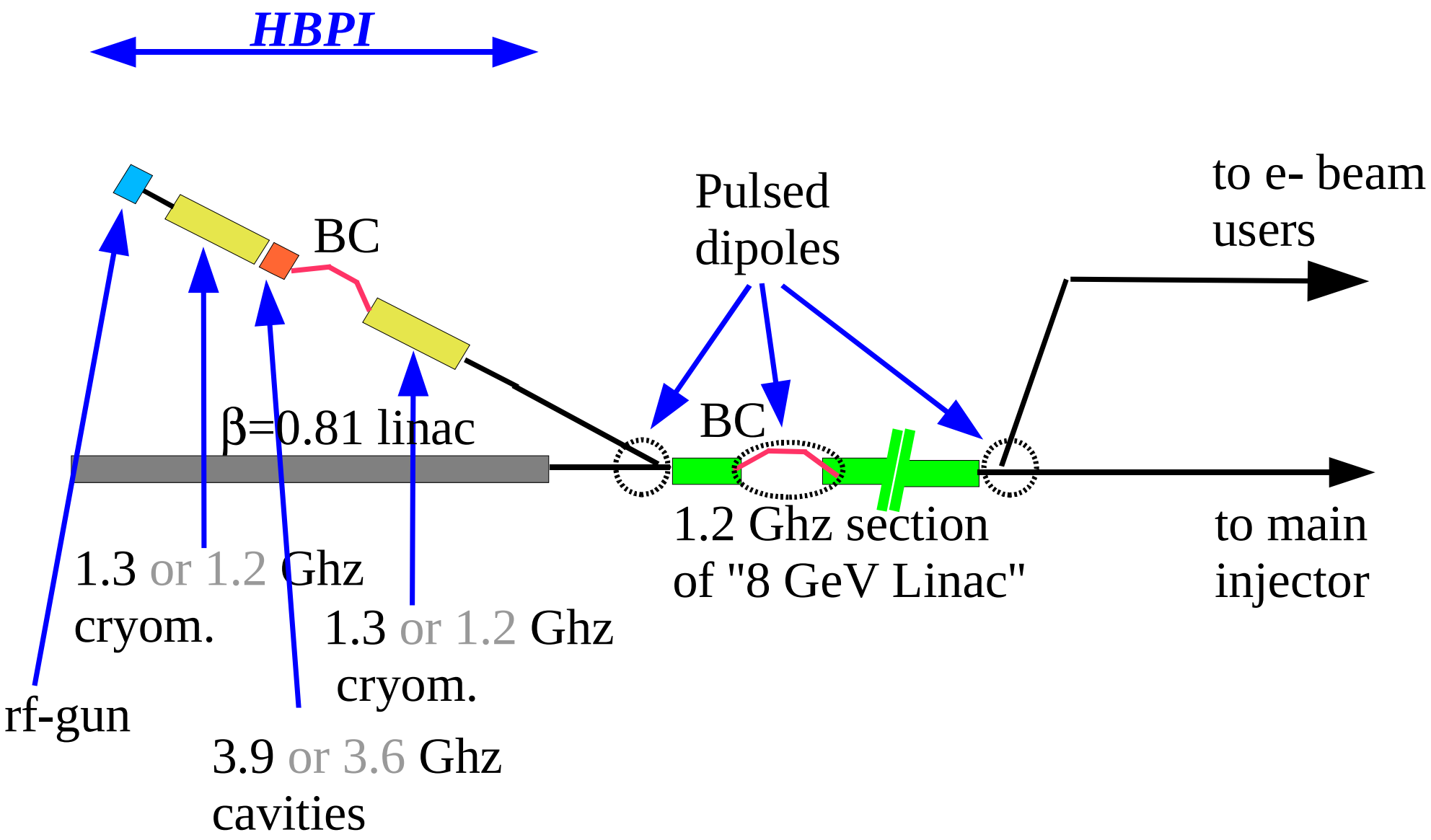


- Full scale photo-injector (hereabove a copy of the TESLA X-FEL's) also should incorporate the learning of A0
- It allows a full test + understanding of optimization mechanism (emittance compensation, longitudinal phase space corrections)
- Such a facility could also serve users (~200 MeV) for a wide range of applications

HBPI as an e- injector for the proposed 8 GeV superconducting booster linac

- One of the candidate for the Tevatron complex upgrade is a 8 GeV TESLA-like linac (however the beta=1 section is 1.2075 and not 1.3 GHz)
- This linac (as already suggested) could be used to accelerate electron bunches
- HBPI could be used as an injector for this linac (then only single bunch acceleration within an rf-macropulse is possible)
- A scaled version of HBPI to 1.207 Ghz could be used for multi-bunch injection/acceleration (in the following I scaled TESLA X-ray FEL injector to 1.207 Ghz for a "feasibilty study")

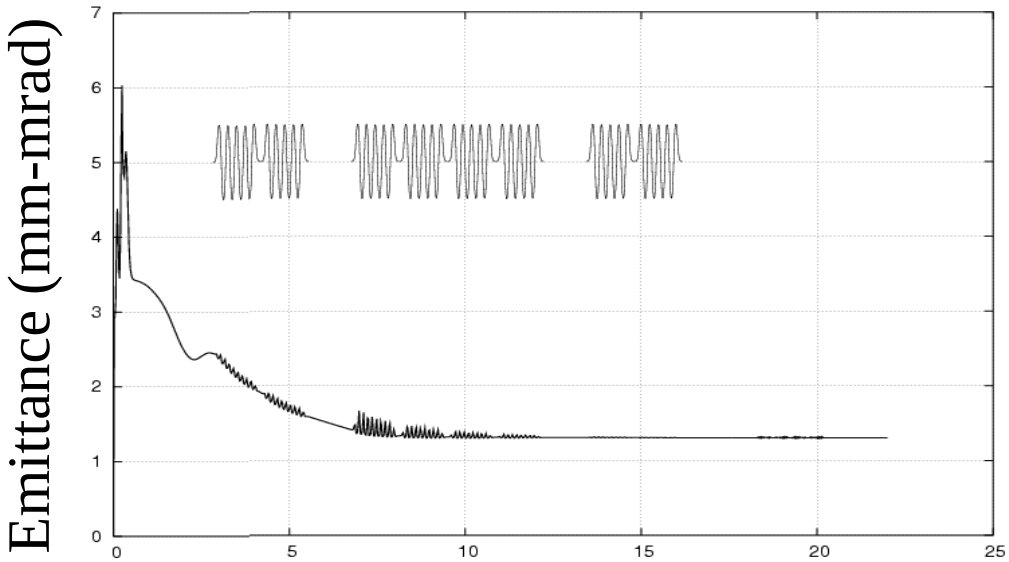
HBPI as an e- injector for the proposed 8 GeV superconducting booster linac



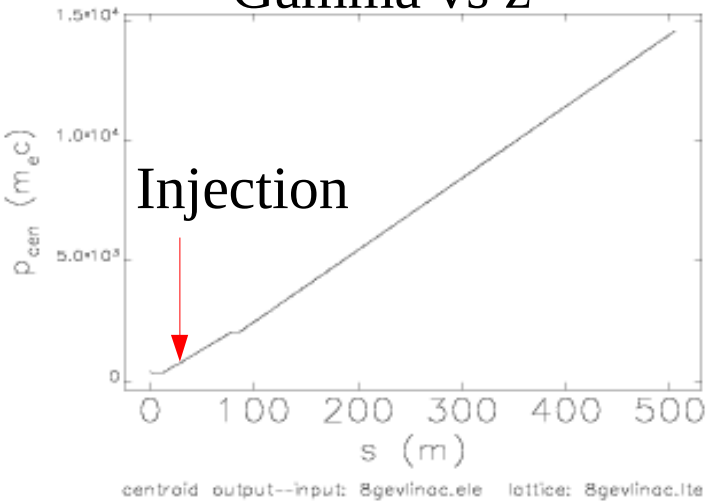
HBPI as an e- injector for 8 GeV linac

Injector:

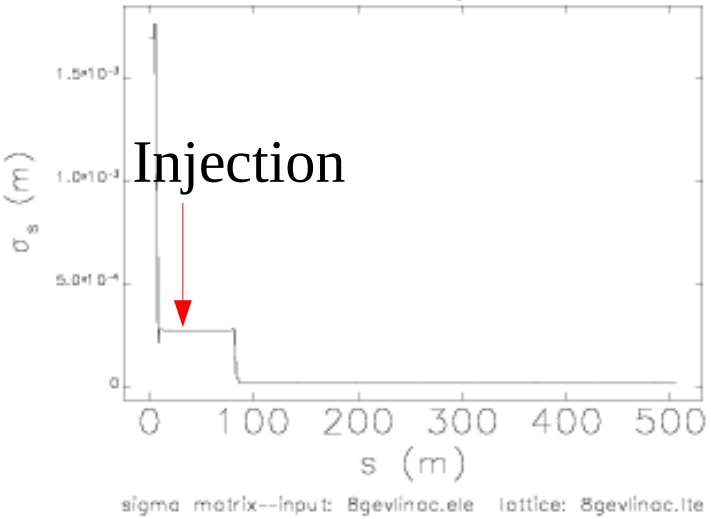
- scaled TESLA X-FEL to 1.2075 GHz
- Q=1nC, emittance achieved=1.2 mm-mrad



Gamma vs z



Bunch length vs z



Main linac:

- assumed SNS type module
- 25 MeV accelerating voltage/cavity
- did not yet optimized transverse dynamics
- with proper compression scheme, rms bunch length can reach 50 microns easily

HBPI as an e- injector for the proposed 8 GeV superconducting booster linac

- Injecting e- into the beta=1 part of the proposed 8 GeV linac could produce ~7 GeV electron beam
- With a proper bunch compression scheme, 100's fs electrons bunches can be obtained
- Compared to other designs of high brighness electron linac (e.g. TESLA X-ray FEL or LCLS) there is no much difference and thus transverse emittance of ~2 mm-mrad is probably achievable (though the study should be done)
- Naively scaling TTF2 design (1 GeV) to 7 GeV, would mean that a "few Angstrom FEL" could be driven by such a linac
- ...

Summary

- FNAL has been involved in e- production since a decade and made a significant contribution to the field
- Proposed energy upgrade of A0 injector will contribute in an improved understanding of phase space structure out of photo-injector and provide a better quality beam for "user experiments"
- A full scale facility (with E~200 MeV) should be considered
- Such an injector could eventually be included in the 8 GeV booster linac and serve to accelerate electron up to ~7 GeV. Such electrons could be used for advanced accelerator physics, novel radiation sources (e.g. X-ray SASE-based FELs, or X-ray Smith-Purcell FELs if a conclusive proof-of-principle experiment is performed at A0)
- ***Comment:*** R&D on high brighness electron beams and their applications **involve R&D on laser beams** and effort should be made to develop a laser group