Japanese Program Overview on HIF and Related Research Activities

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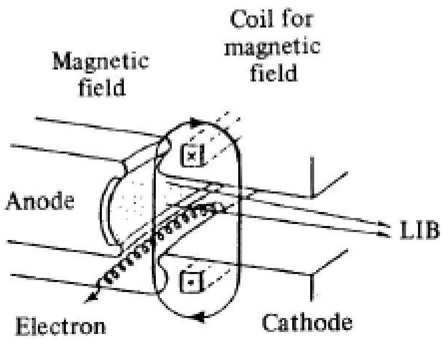
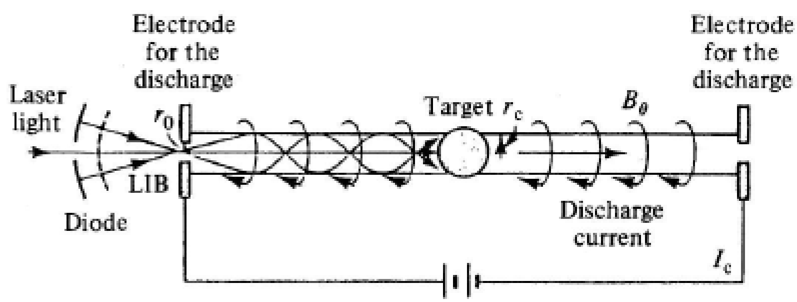
19th International Symposium on Heavy Ion Inertial Fusion (2012)

Origin of Particle Beam Fusion in Japan

Professor Keishiro NIU

- Pioneer of particle beam fusion research in Japan
- Proposed a scheme for light ion fusion reactor based on rotational beams





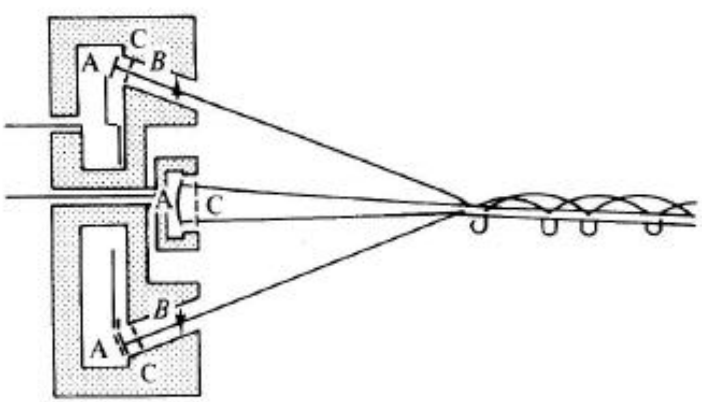
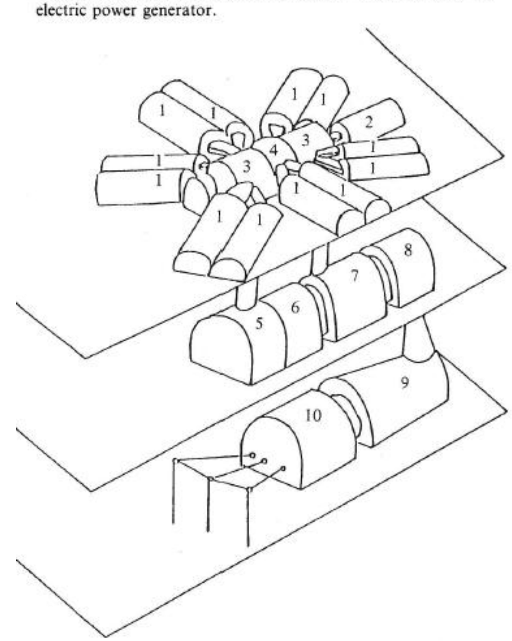


Fig. 4.25. Power plant. **1** Power-supply system of type 1 and 2, **2** power supply system of type 3 for biassing target, **3** reactor cavity, **4** motor to rotate the reactor vessel, **5** D separator from the argon gas and the flibe, **6** T separator of the argon gas and the flibe, **7** heat exchanger from the flibe to NaF–BF_3, **8** heat exchanger from NaF–BF_3 to the water, **9** steam turbine, **10** electric power generator.



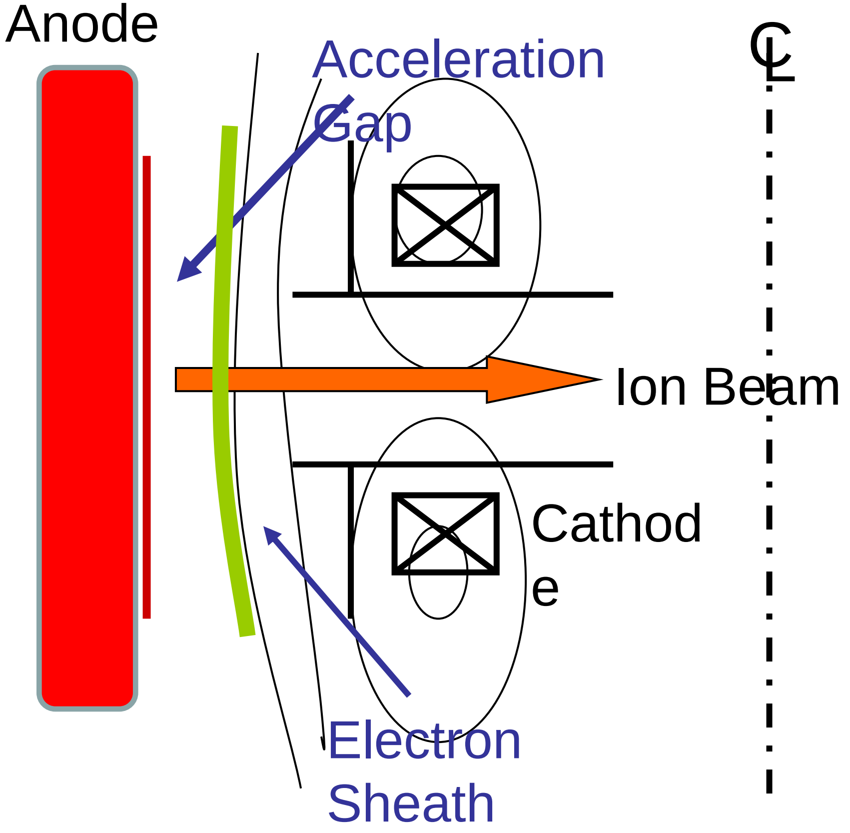
Light Ion Beam is extremely space charge dominated

- Charge neutralization by electron
- Enhancement of ion current
- Bootstrapping effect by electrons and ions
- Impedance collapse
- Unstable electron sheath
- Beam divergence

LIB: 10MeV×10MA (100TW)

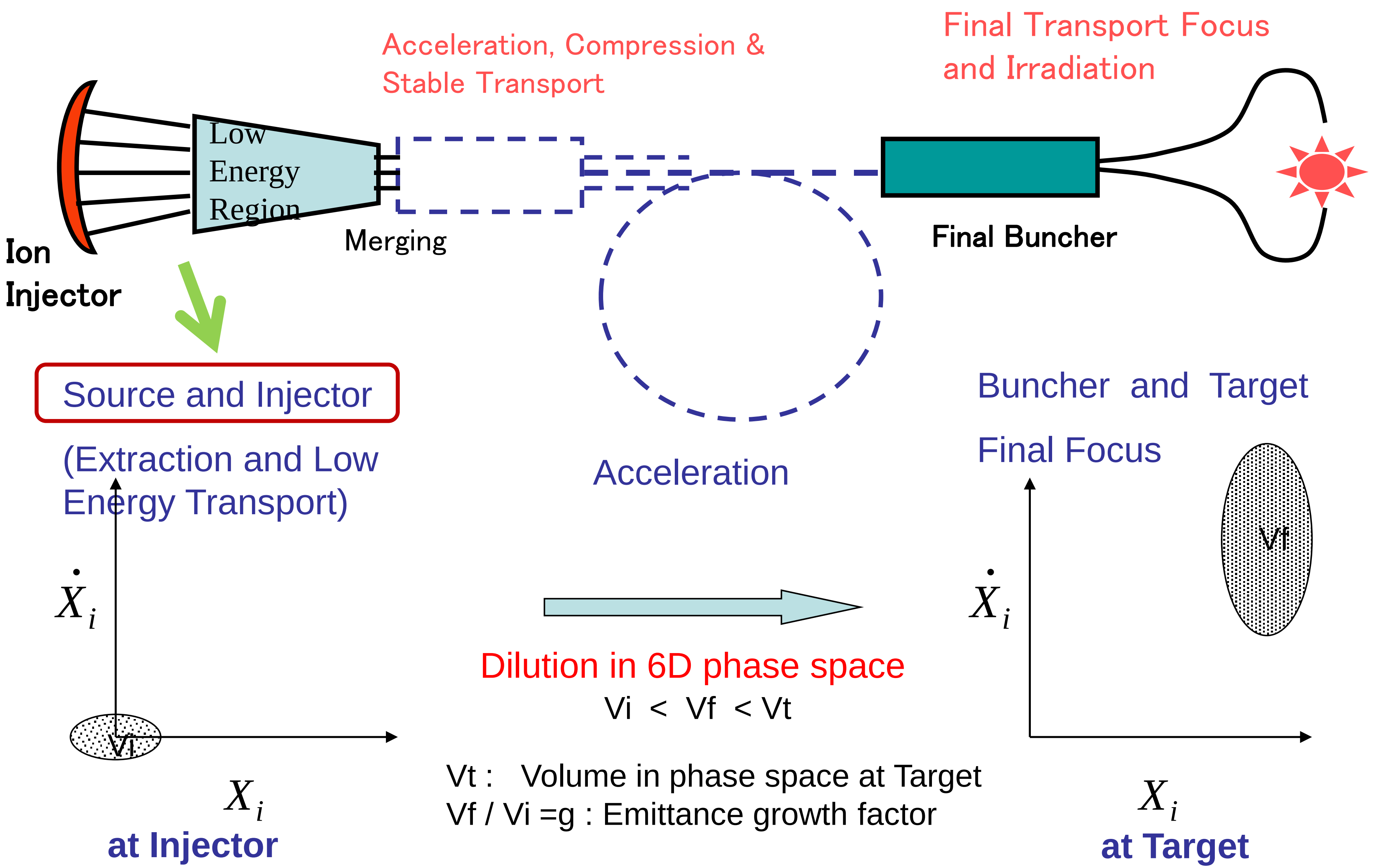
We shifted our efforts to a scheme based on high power ion accelerators

HIB: 10GeV×10kA (100TW)



Schematic of typical LIB diode

There are still space charge issues in high power ion accelerators



We need a breakthrough for HIF injector

High-yield (∼10^{-4} A･sec (10^{15} particles)), and low emittance (Vi < Vt / g))

Laser ablation (Expanding) plasma

- Plasma acceleration and gas-dynamic cooling
- Low temperature and high flux
- Control by axial magnetic field

Achievable beam flux and emittance (High-flux & Phase space density)

$$\frac{dN}{dU_6} = \frac{I}{q\gamma\beta^2 m^3 c^4 \varepsilon_{nx}\varepsilon_{ny}\left(\Delta P_z / P_z\right)} = \frac{qnv_d A}{q\frac{2qV_0}{m} m^3 \left(\frac{kT_s}{m}\right)\left(\Delta P_z / P_z\right)} = \frac{A}{2qkmV_0}\frac{nv_d}{\left(\Delta P_z / P_z\right)T_s} \propto \frac{\left(T_0 - T\right)^{\frac{1}{2}}}{\left(\Delta P_z / P_z\right)T^{\frac{\gamma-2}{\gamma-1}}}$$

$$n \propto cT^{\frac{1}{\gamma-1}}, \quad v_d \propto \left(\frac{\gamma}{\gamma-1}R\left(T_0 - T\right)\right)$$

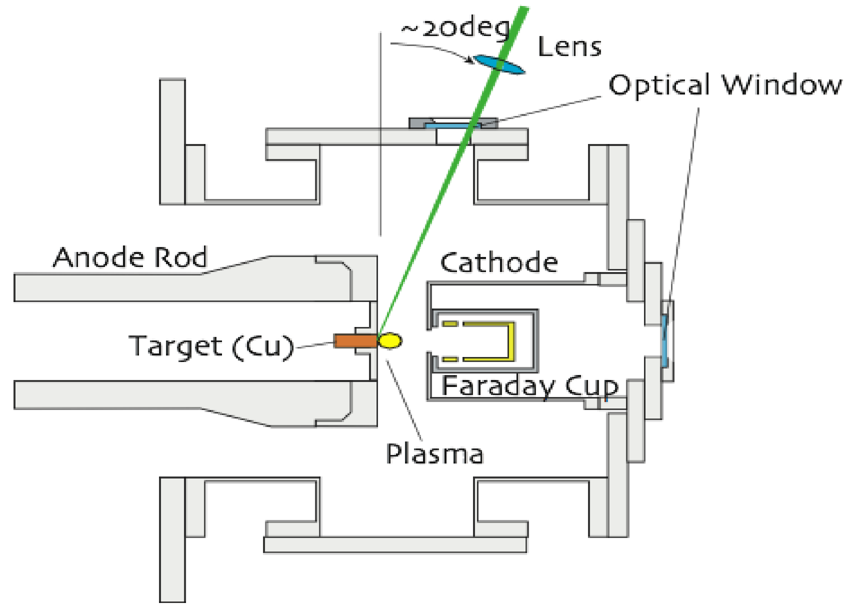
Laser Ion Source may be the Solution for the High Flux Injector

Flux level and current shape of LIS are controllable

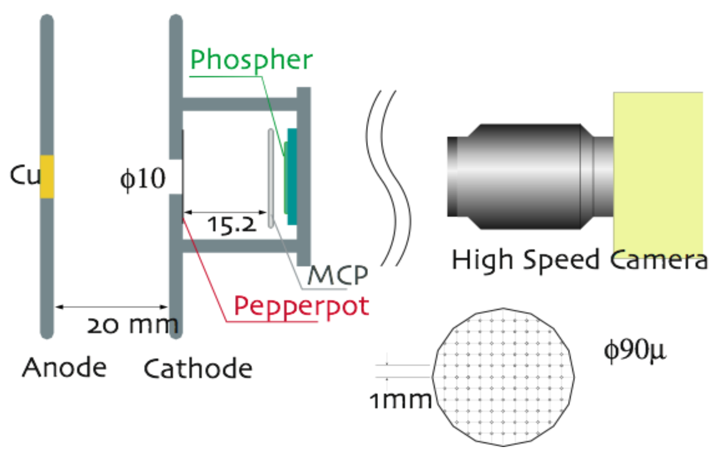
Direct extraction can overcome the Bohm current limit

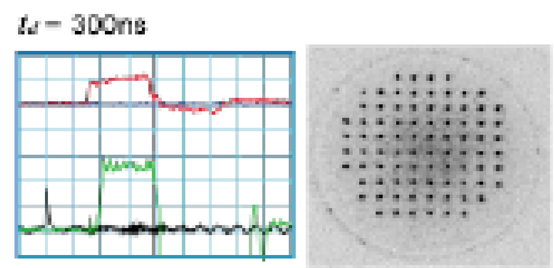
Matching between ion supply and space charge limit of effective gap

Beam bunch of Cu ions with 100mA/cm2 level , emittance of 0.25π mm・mrad and flat-top waveform was obtained



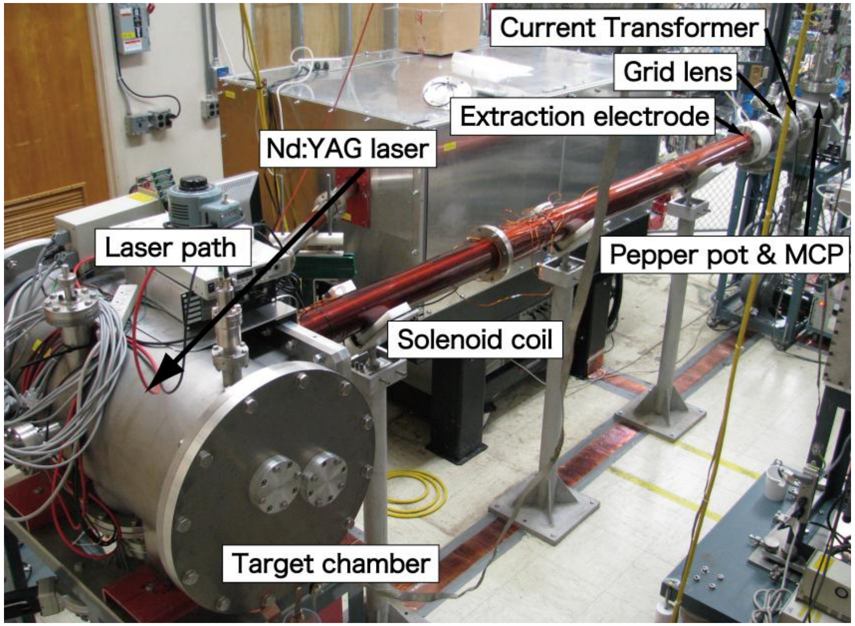
Pepper-pot Emiitance Measurement





M.Nakajima, K.Horioka, et.al., NIFS-Proc. (2004)

Laser ablation plasma was manipulated by magnetic field

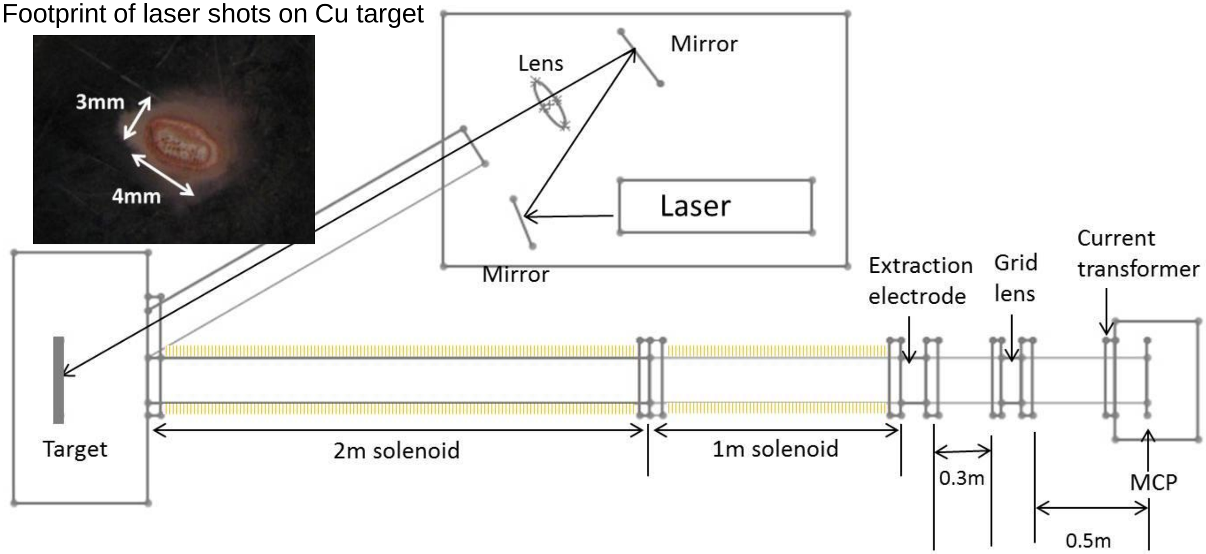


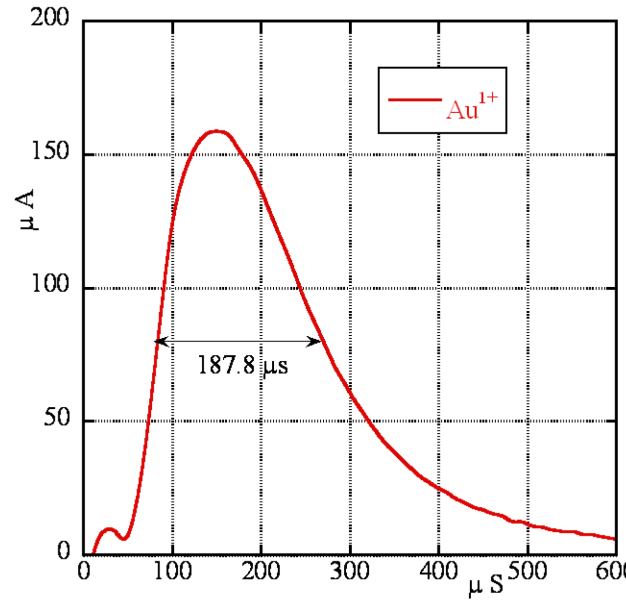
EBIS LIS

(M. Okamura, BNL, this conference)

Laser: Twin Nd-YAG 1064 nm (Brilliant, Quantel)
Pulse length: 6 ns
Energy/pulse: 800 mJ (max)
Power density: 6E8W/cm^2
Repetition rate: 5 Hz
Solenoid length: 3 m, ~100 Gauss
Extraction hole diameter: 15mm
Vacuum: less than 5E-4 Pa

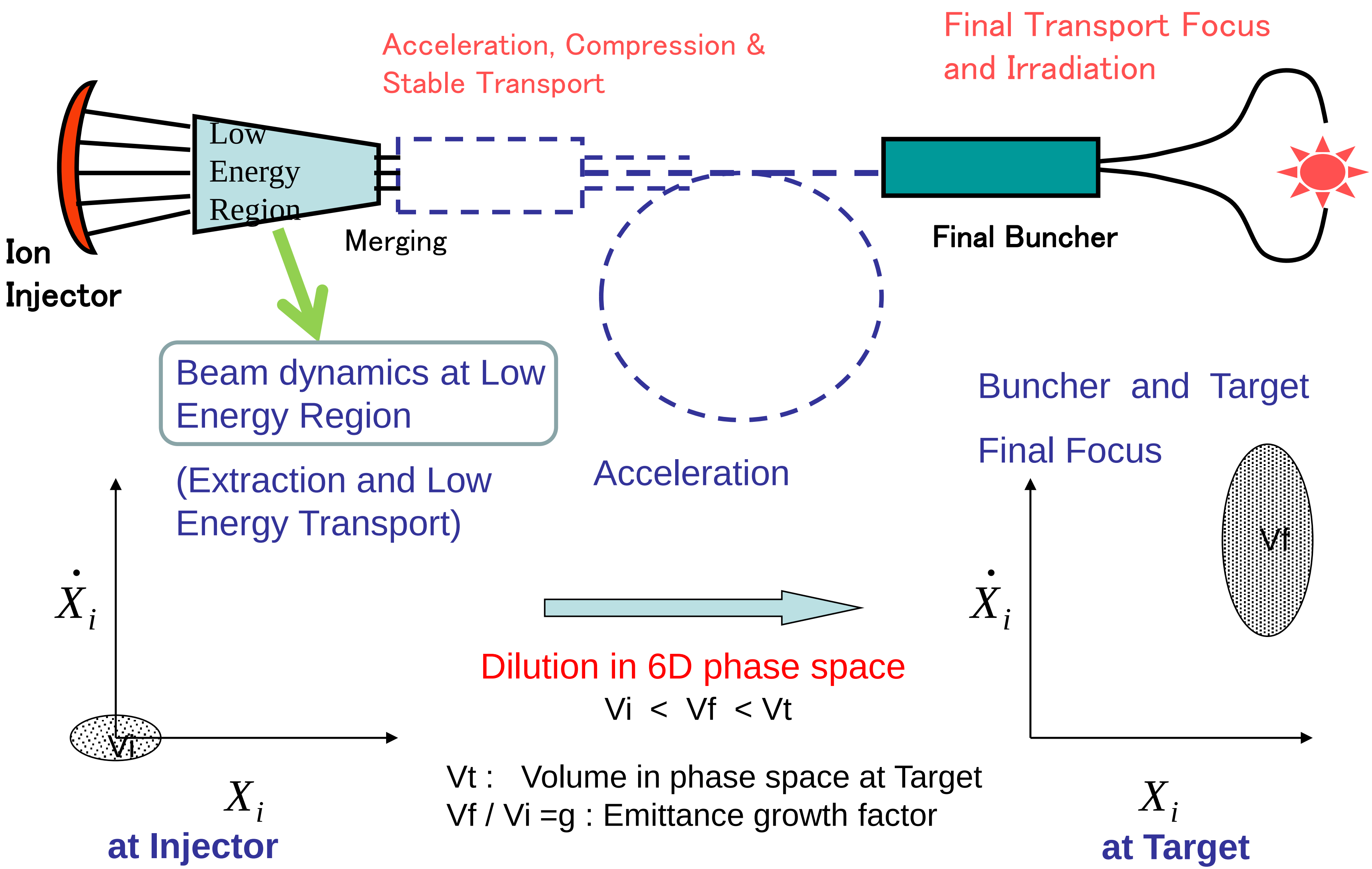
Footprint of laser shots on Cu target





Pulse shape manipulation by 3m solenoidal transport line

There are still space charge issues in high power ion accelerators

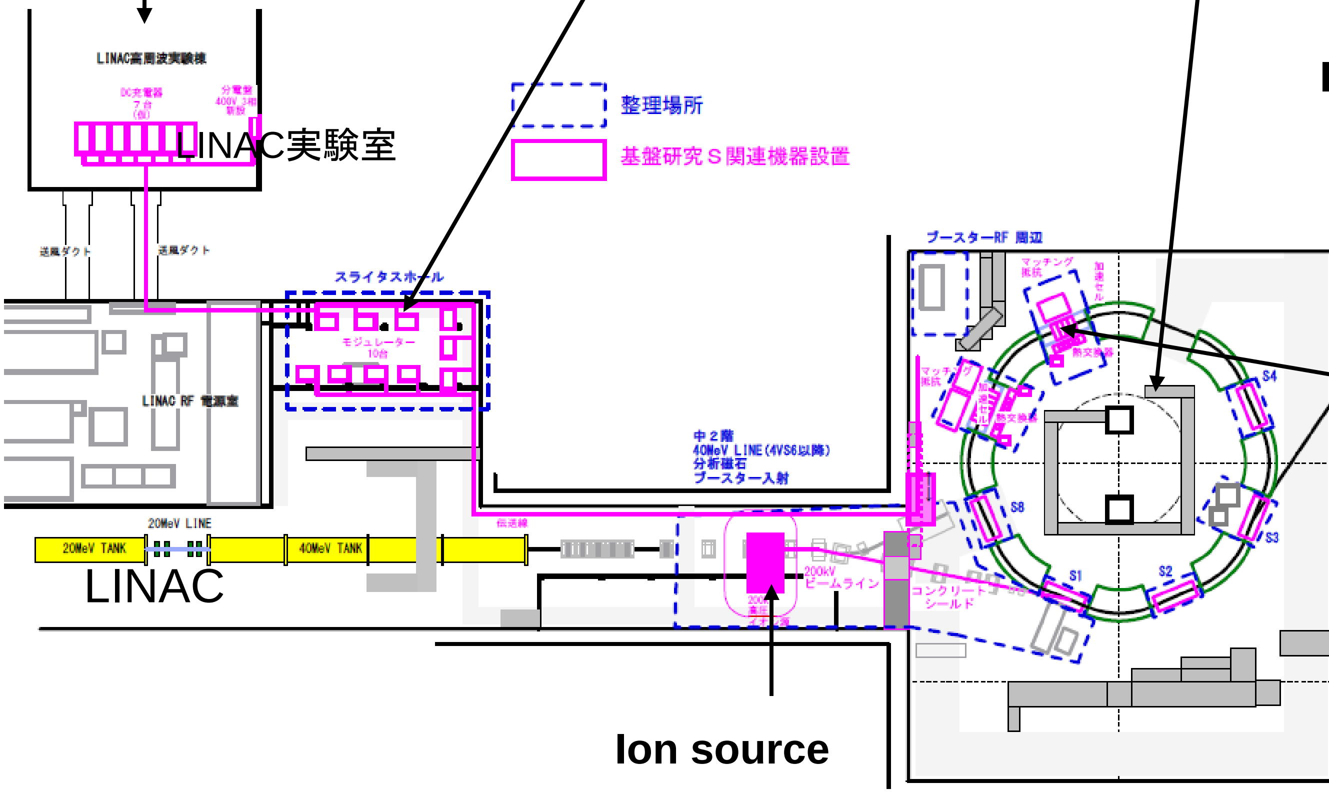


Layout of the KEK Digital Accelerator

DC power supply

Switching power supply

KEK digital accelerator
former 500 MeV Booster PS



Induction acceleration cell

Ion source

Einzel Lens Longitudinal Chopper : Idea, Device, Performance

Why we need a Chopper?

1 turn injection < 10 μsec

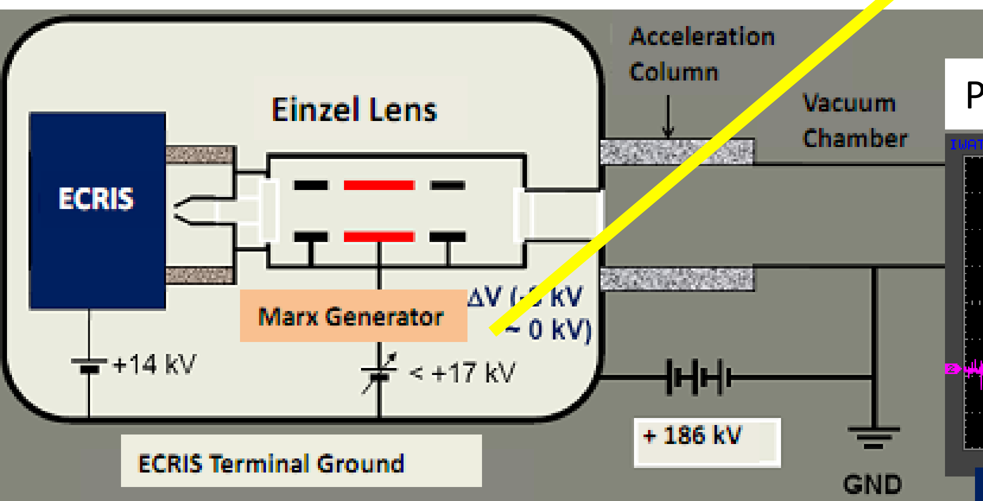
A long pulse from ECRIS ~ 2 - 5 msec

What type is desired?

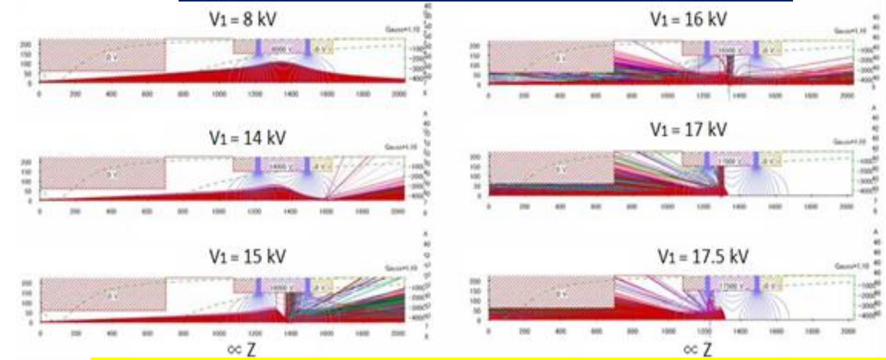
Low energy operation
Low cost (~ $2,500)

Low energy x-ray
Reduced out-gassing
Reduced secondary e⁻

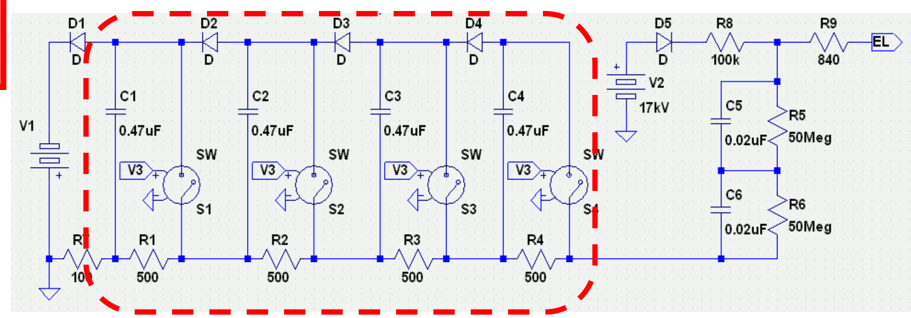
Einzel lens longitudinal chopper



Longitudinal gate study by IGUN

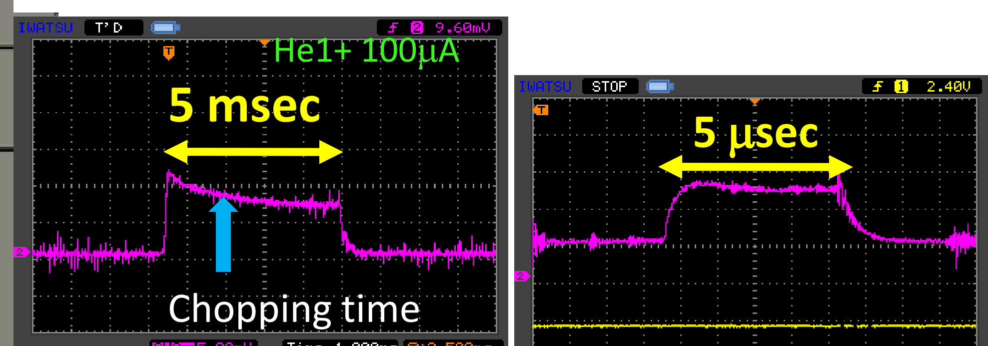


FET switch driven 4 stages Marx generator



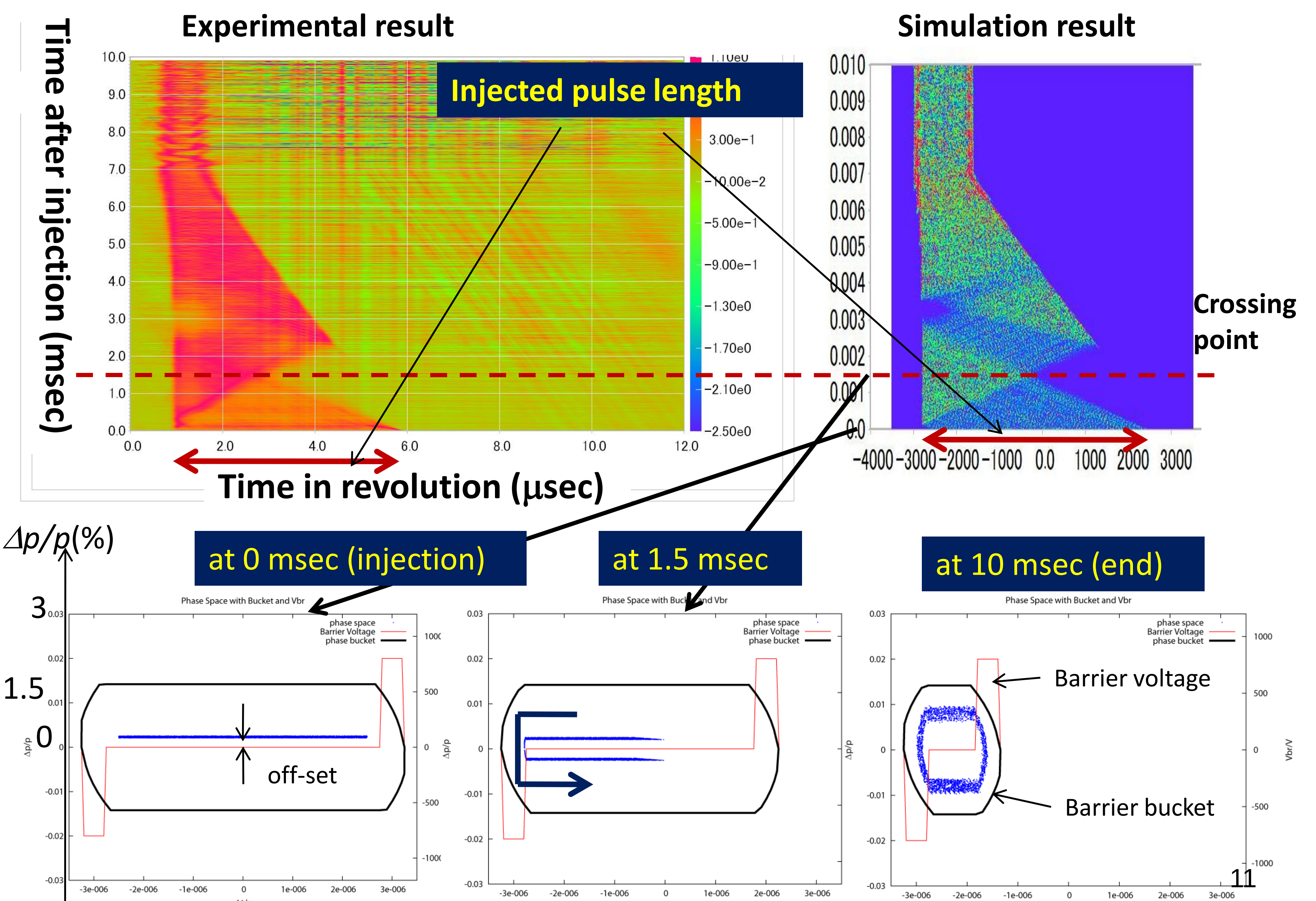
Pulsed beam from ECRIS

Chopped beam



T.Adachi, K.W.Leo *et al.*, *Rev. Sci. Inst.* 82, 083305 (2011)

Longitudinal Beam Handling in the KEK-DA by Barrier Voltages

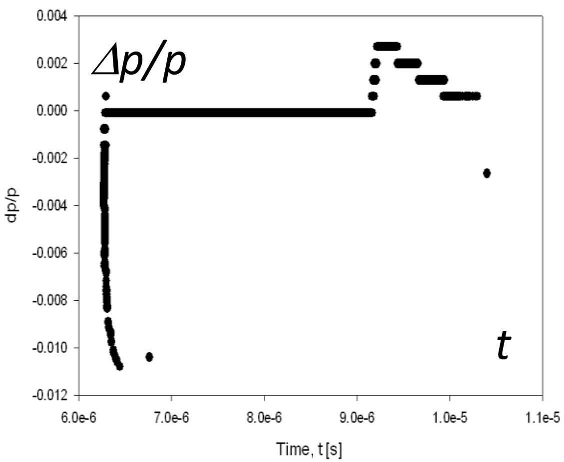


momentum spread=0.025%, off-set=0.23% (optimized so that **crossing point** is reproduced)

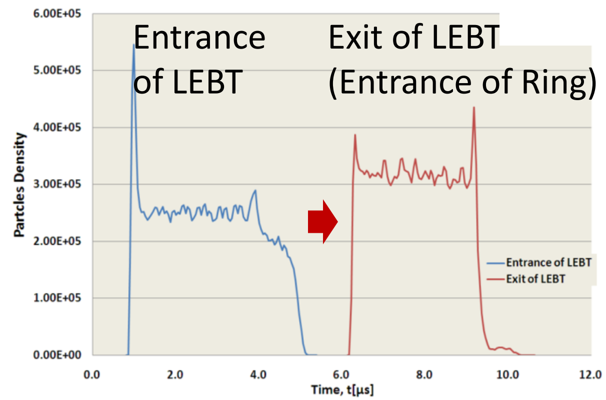
Longitudinal Space-charge Effects over Long Drift in the KEK-DA (without Acce./Confinement)

Notable facts in LEBT:

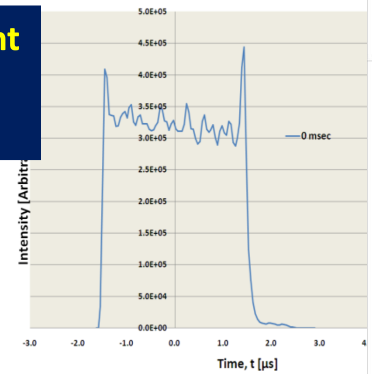
- Modulation in the momentum space caused by the transient fields of the chopper
- Drift compression



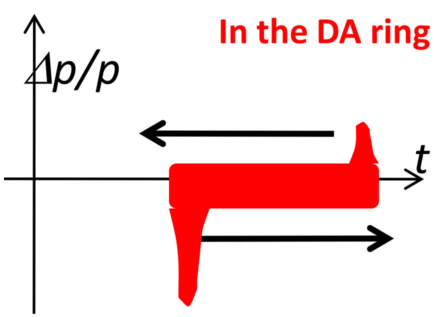
simulation



Measurement at 1 turn in the ring



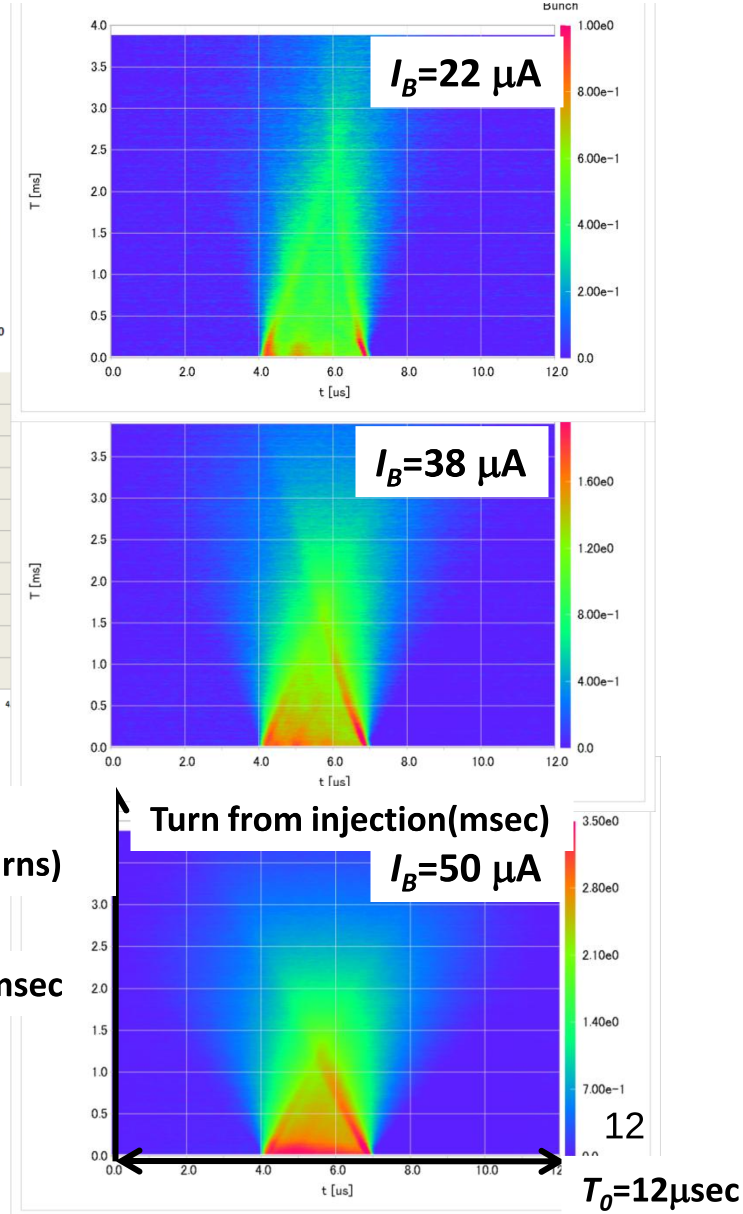
In the DA ring



Slippage factor: $\eta = \frac{1}{\gamma_T^2} - \frac{1}{\gamma^2} \prec 0$

$\Delta t \propto \eta \cdot \frac{\Delta p}{p}$

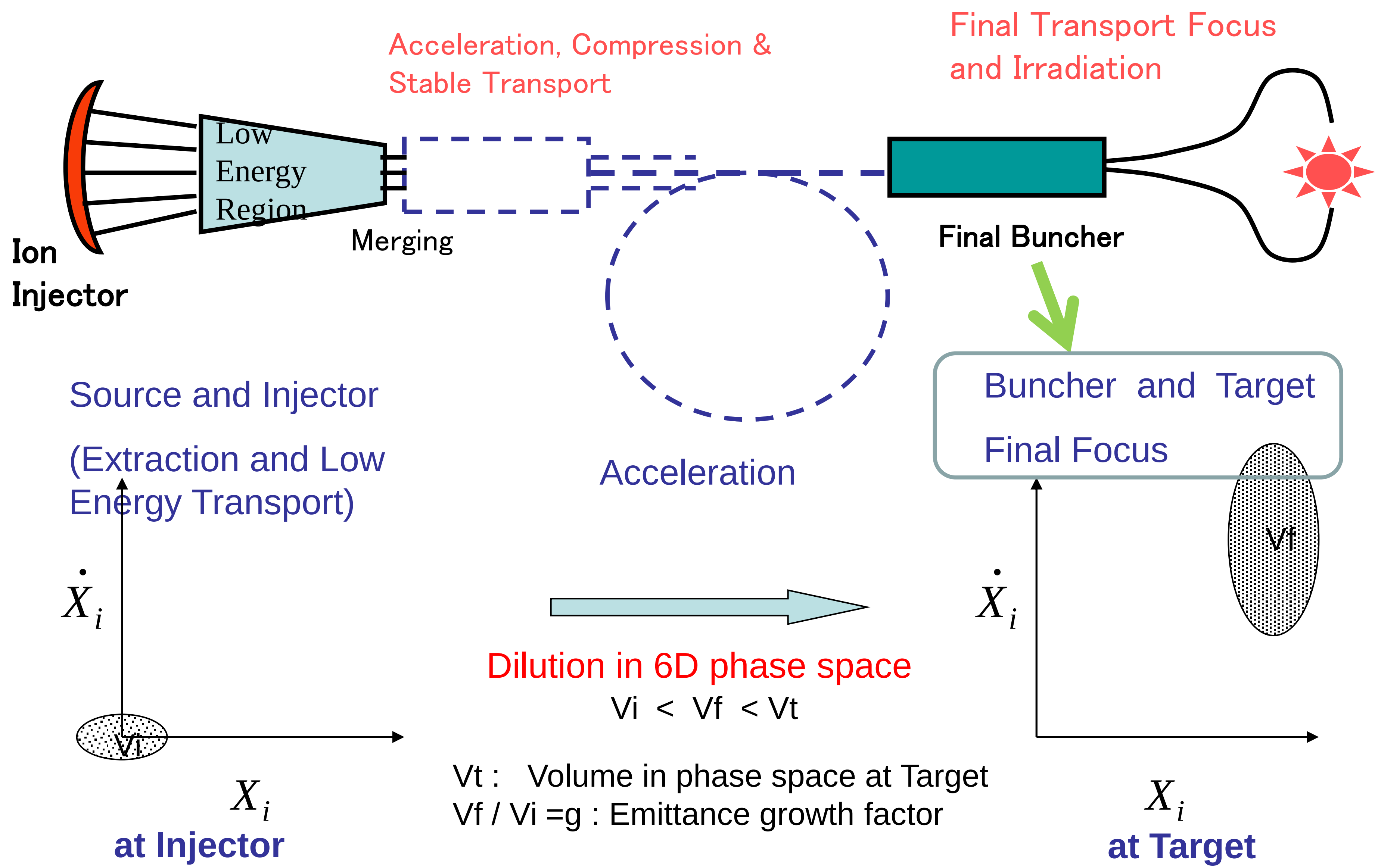
Projection of Bunch Signal Mountain view (3D) In Ring



Notable facts:

- Some spread in the momentum space
- Diffusion and further compression depends on beam intensity

There are still space charge issues in high power ion accelerators

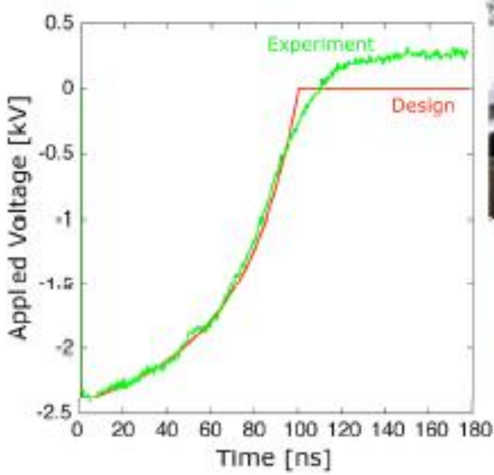


Compact beam simulator was developed for bunching dynamics study

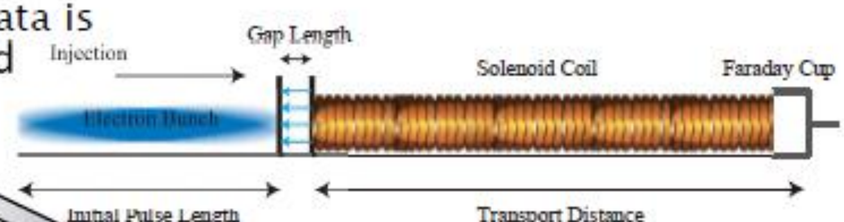
Extreme Bunch Compression Study : 1D PIC Calculation with Experiment

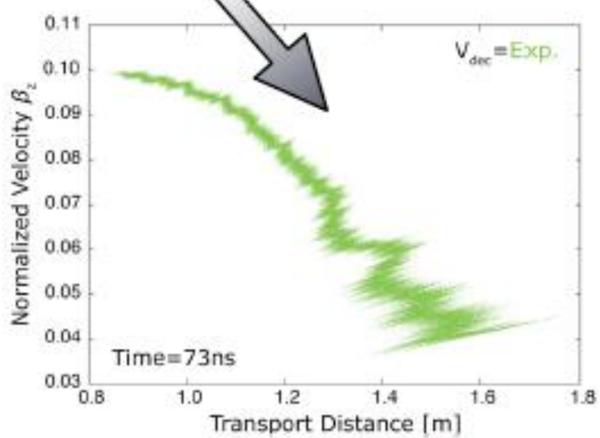
Experimental Setup in TIT

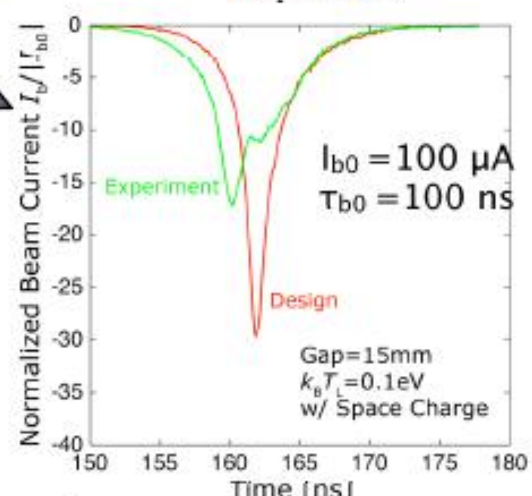
Y. Sakai, et. al.,
in this conference.



Experimental data is used for applied Voltage to PIC simulation.

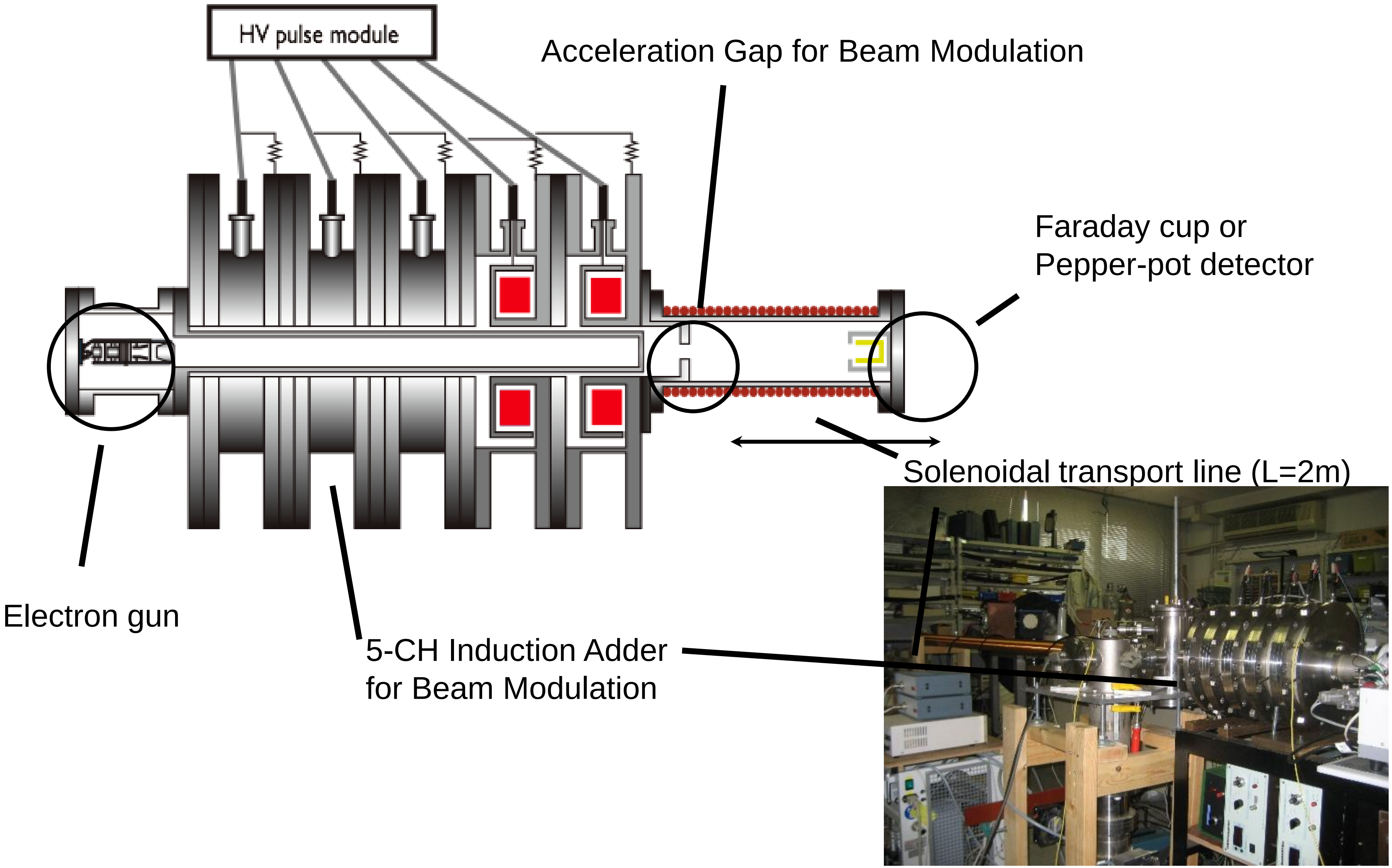






T. Kikuchi, et. al., in this conference.

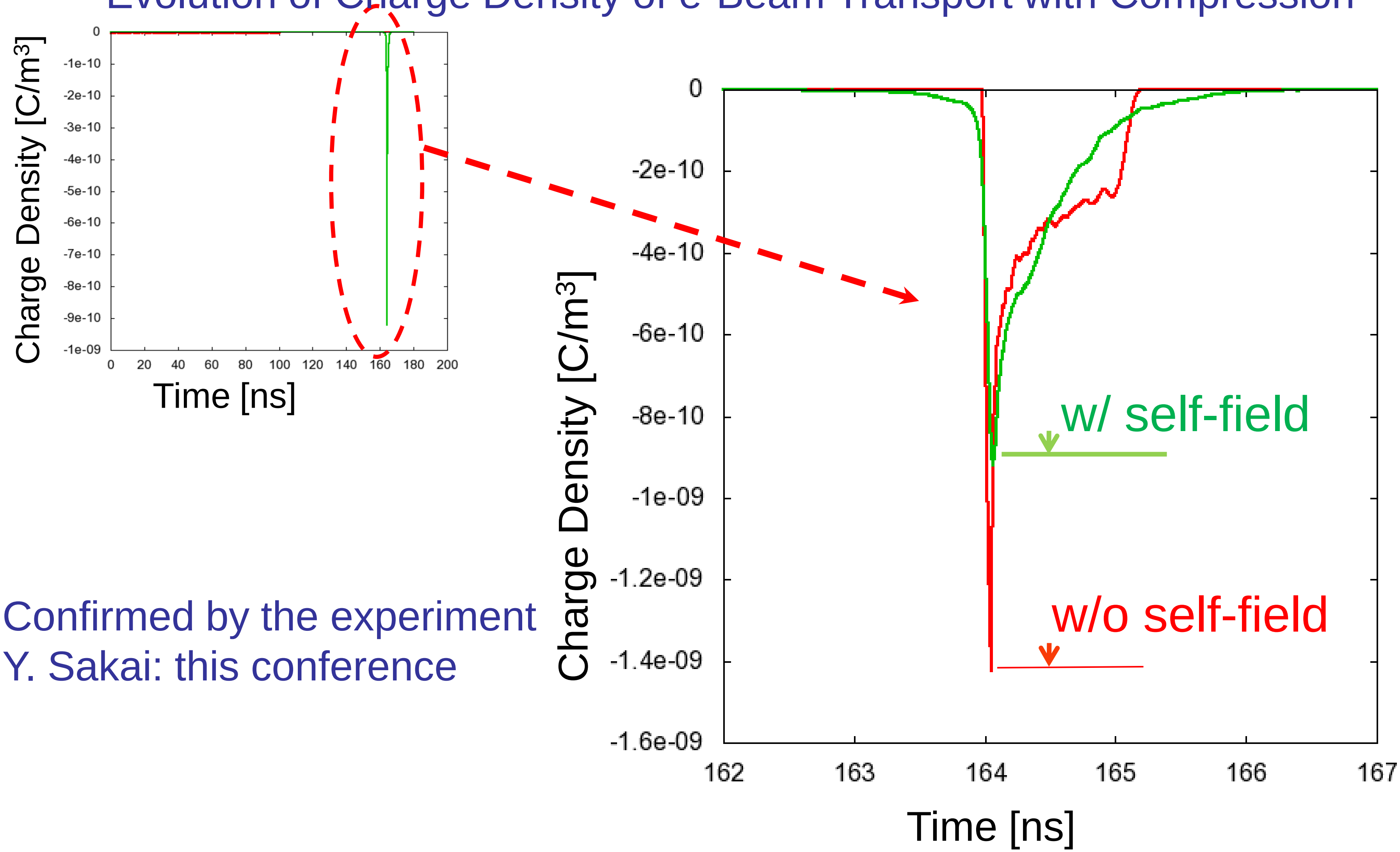
Arrangement for Bunch Compression Experiments



- Discuss the Beam Dynamics during Beam Manipulation in the Final Buncher with Laboratory-scale devices

PIC Simulation indicates an effect of space charge field

Evolution of Charge Density of e-Beam Transport with Compression

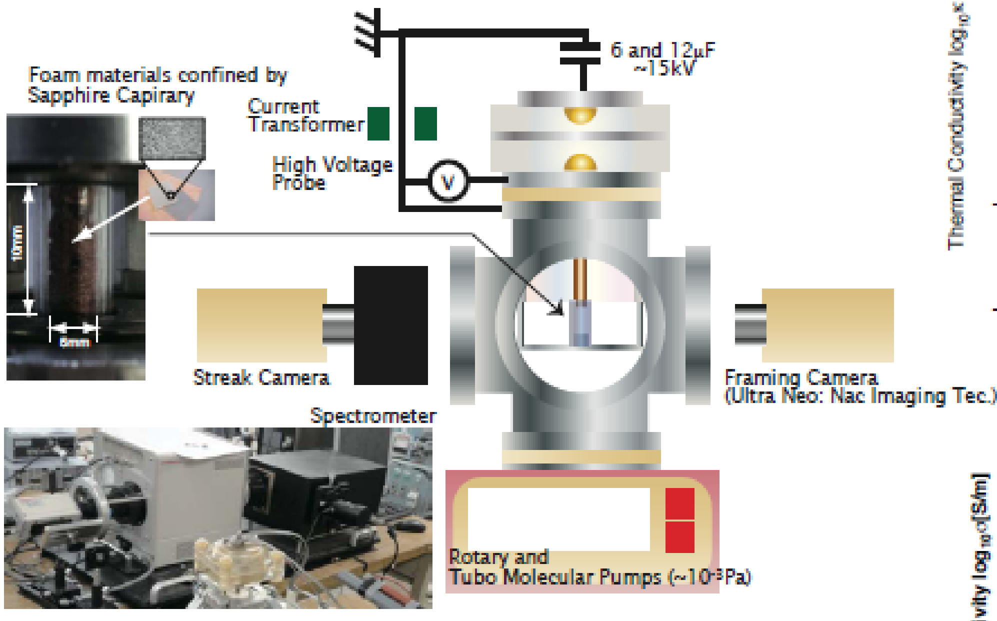


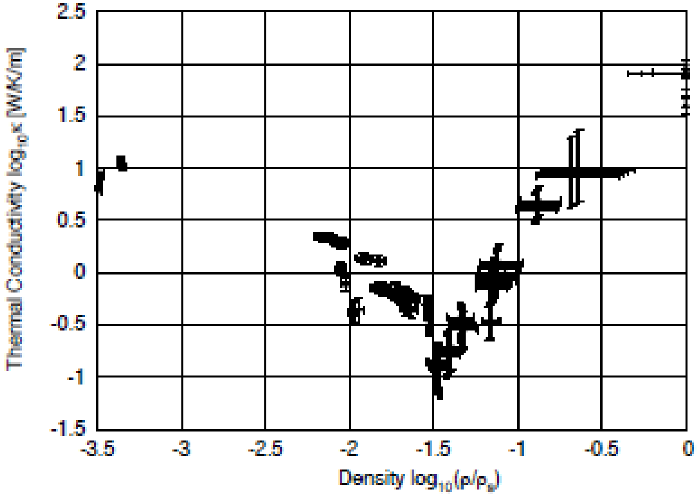
Confirmed by the experiment
Y. Sakai: this conference

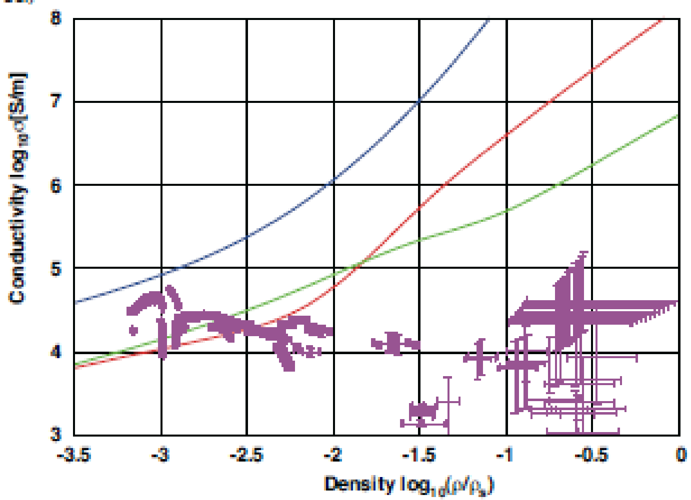
by T. Kikuchi, Nagaoka University of Technology,

WDM study using pulse power device (NUT)

Electrical conductivity and Thermal conductivity were measured using form heating in Saphire







> T. Sasaki, et. al., submitted to IEEE Plasma Sci.
> Y. Amano, et. al., to be published in RSI, 83 (2012)
> Y. Miki, et. al., in this conference.

Wobblers and Rayleigh-Taylor Instability Mitigation in HIF Target Implosion

S. Kawata[1], T. Kurosaki[1], K. Noguchi[1], T. Suzuki[1], S. Koseki[1], Y. Hisatomi[1], D. Barada[1], Y.Y. Ma[1], A. I. Ogoyski[2],
J. J. Barnard[3], B. G. Logan[3]

[1]*Utsunomiya University, Japan*
[2]*Technical University of Varna, Bulgaria*
[3] *LBNL, HIF-VNL*

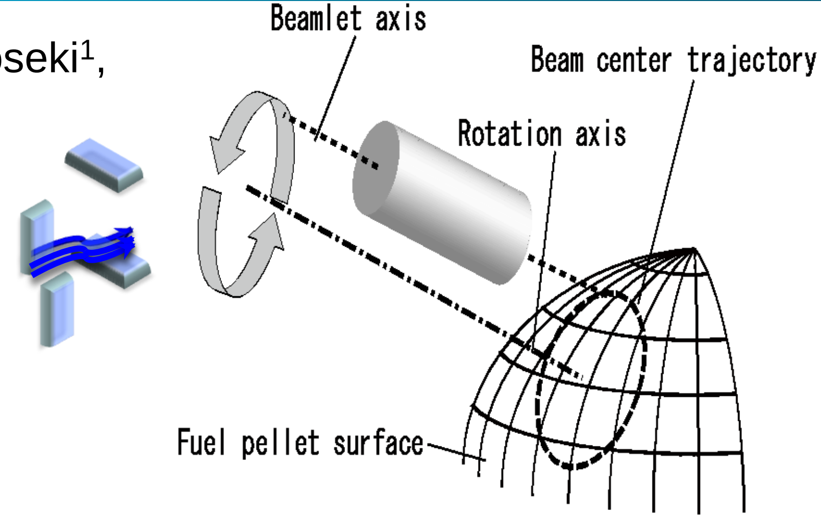


Image of Wobbling Heavy Ion Beam

Background

Precisely controllable HIB: pulse shape, particle energy, beam axis, etc.

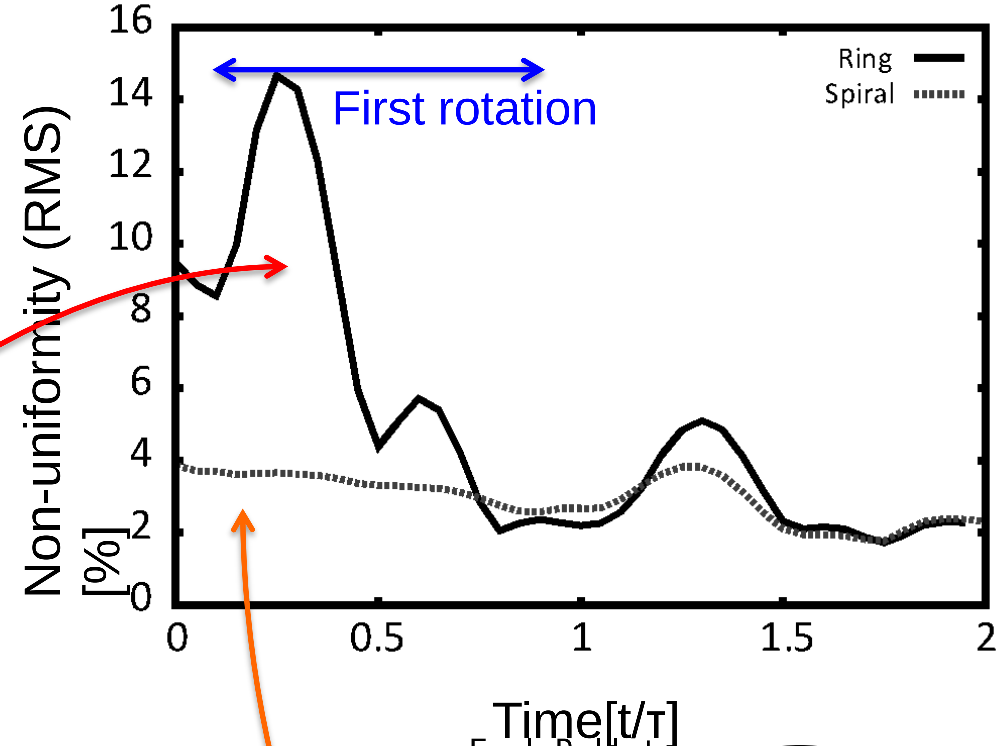
Wobbling HIBs were proposed to smooth HIB illumination nonuniformity & R-T growth reduction. <- /M. Basko, et al., /S.Kawata, et al., /J. Lunge, et al., /H. Qing, /A. Friedman, etc.

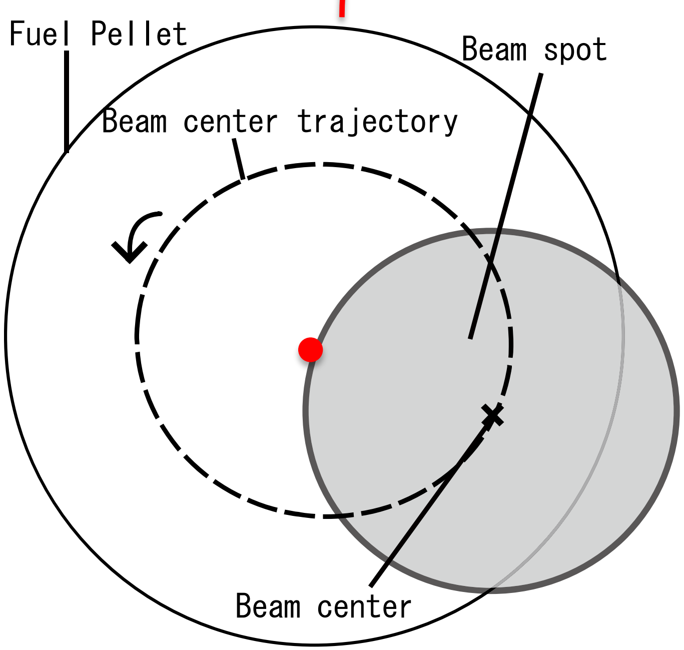
J. Lunge & G. Logan found a very-good uniformity of wobbling HIBs illumination for time-averaged HIBs on a target.

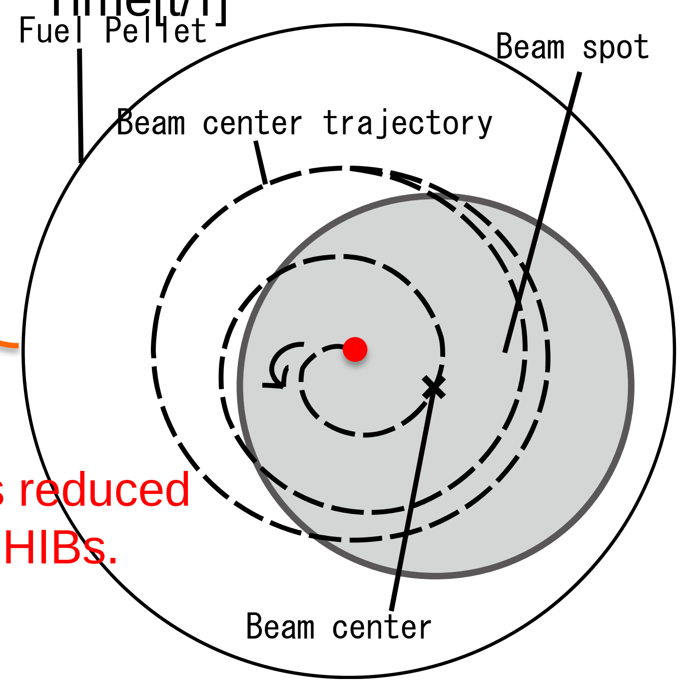
-> A large Initial imprint ~ 15% -> The initial imprint is reduced by Spiraling HIBs.

Initial imprint was huge.

<- Spiral HIBs reduce Imprint.







The initial imprint is reduced much by Spiraling HIBs.

Summary

- Feasibility of laser ablation plasma was discussed for high-flux and/or high yield ion source (BNL-RIKEN-KEK-TIT)

- Beam experiments with KEK digital accelerator has started successfully (KEK-TIT)

- Compact beam simulator was developed for study on bunching beam dynamics (TIT-NUT)

- Target physics was made progress (ILE, NUT), in particular, spiraling HIBs were proposed for uniform irradiation (UU-VNL)

- Japanese HIF group is weakly coupled, but their research activities extend from ion source to target physics through the beam dynamics