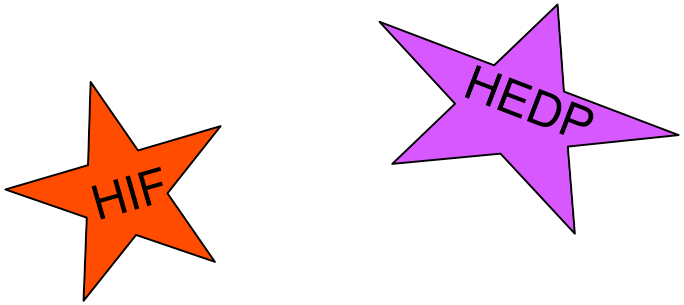
Perspectives on Japanese HIF/HEDP program

Ninth US-Japan Workshop
on
Heavy Ion Fusion and High Energy Density Physics

Masao Ogawa

Tokyo Tech

18 December 2006



1. Beam Physics and HIF Studies by Simulation

2. R&D of Induction Accelerator Technologies

3. HEDP Studies at Tokyo Tech

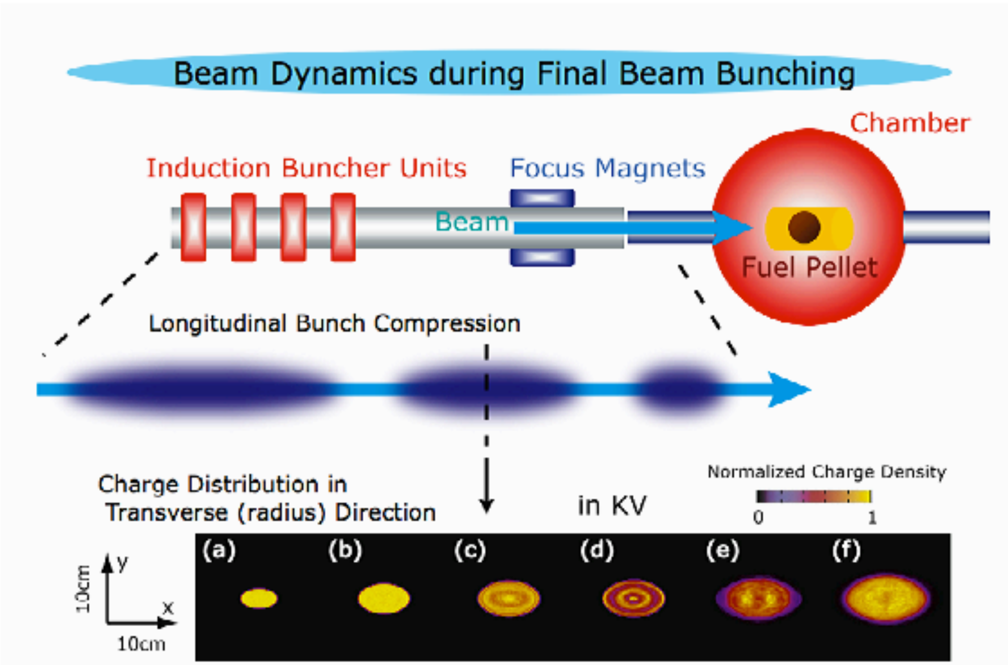
4. HEDP Studies by Laser

5. Soon Commissioning Accelerators in Japan

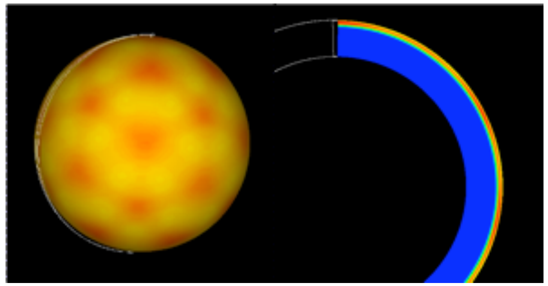
HIF & HEDP Studies at Utsunomiya University

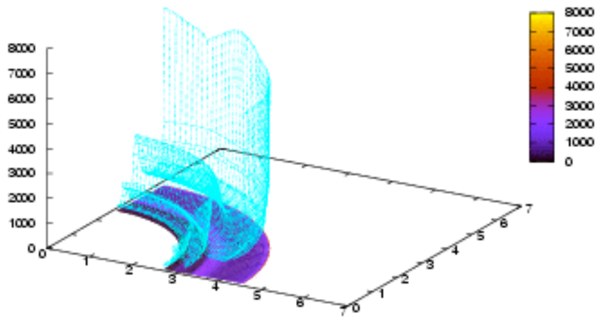
S. Kawata, T. Kikuchi

1) Beam Physics - Final Beam Bunching
2) HIF Implosion & Robust HIB illumination
3) Rayleigh-Taylor Instability Study in HEDP

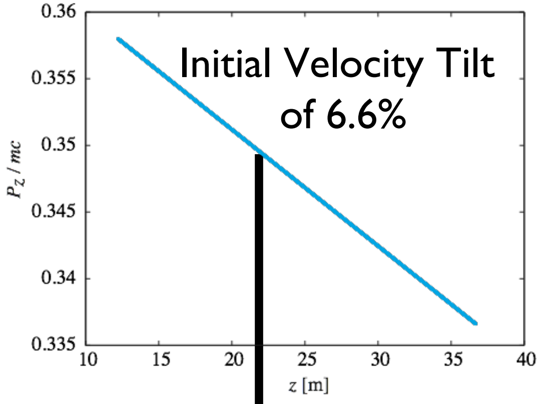


T. Kikuchi, M. Nakajima, K. Horioka, and T. Katayama, Phys. Rev. ST Accel. Beams 7 (2004) 034201.





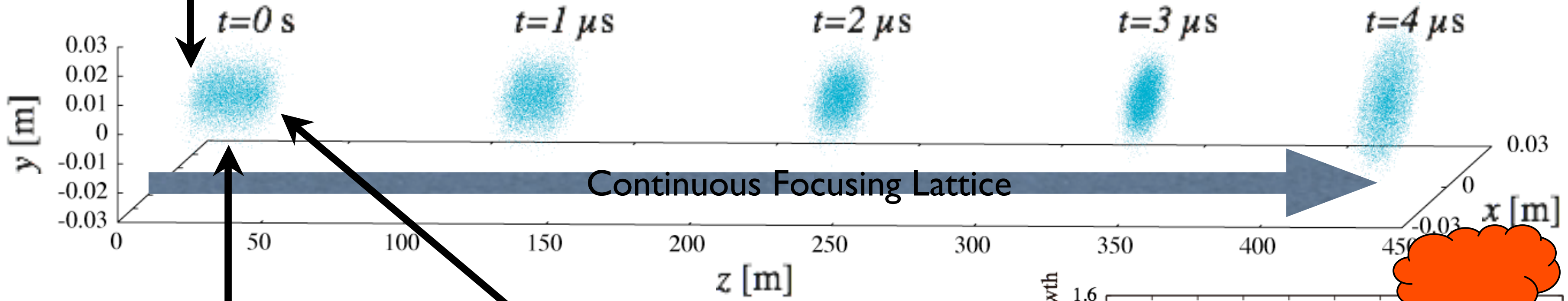
Beam Dynamics Analysis during Bunch Compression

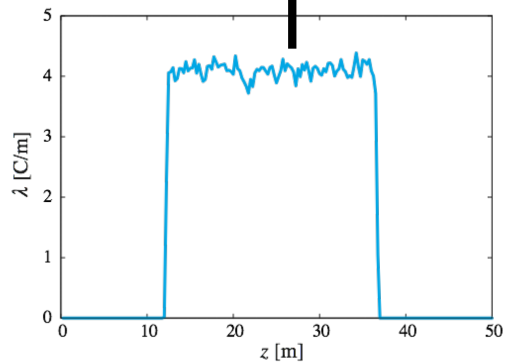


3D Particle Motion & 2D+1D Field Calculations

with Initial Gaussian & Flattop Pulse
& Linear Head-to-Tail Velocity Tilt

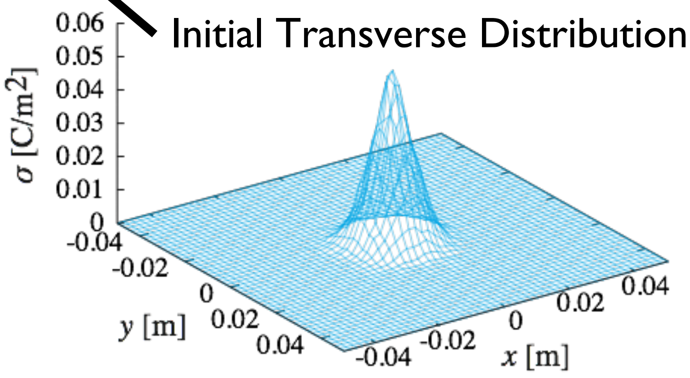
Emittance Growth due to Longitudinal-Transverse Coupling Motions

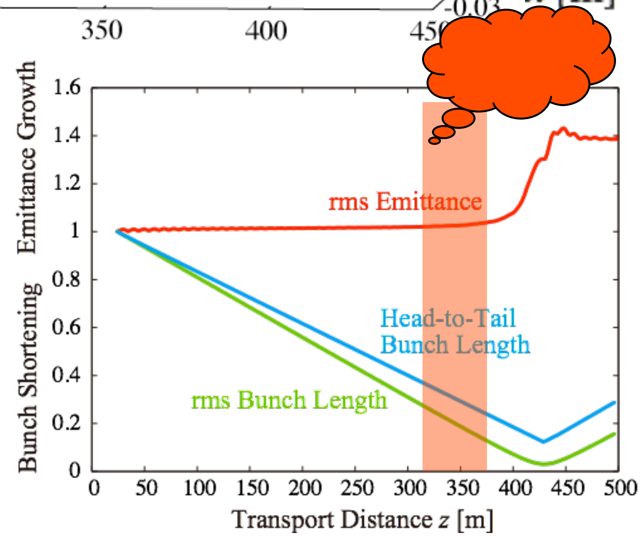




Initial Line Charge Density

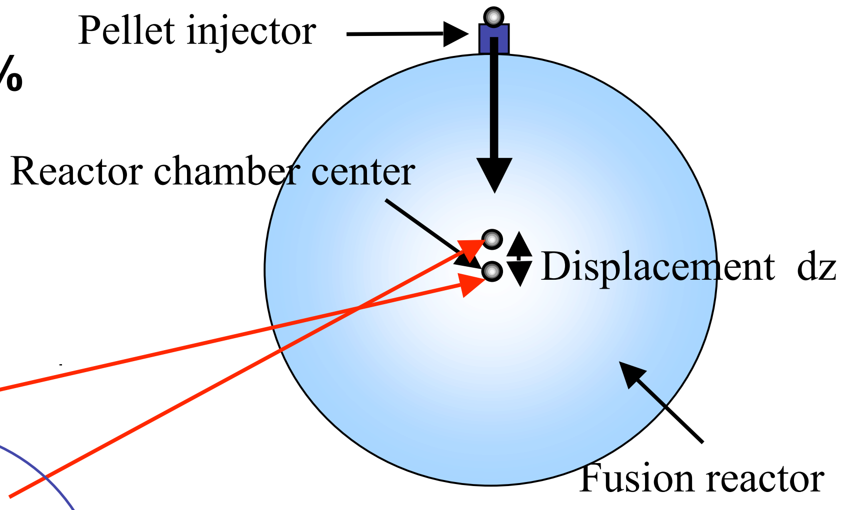
Initial Transverse Distribution

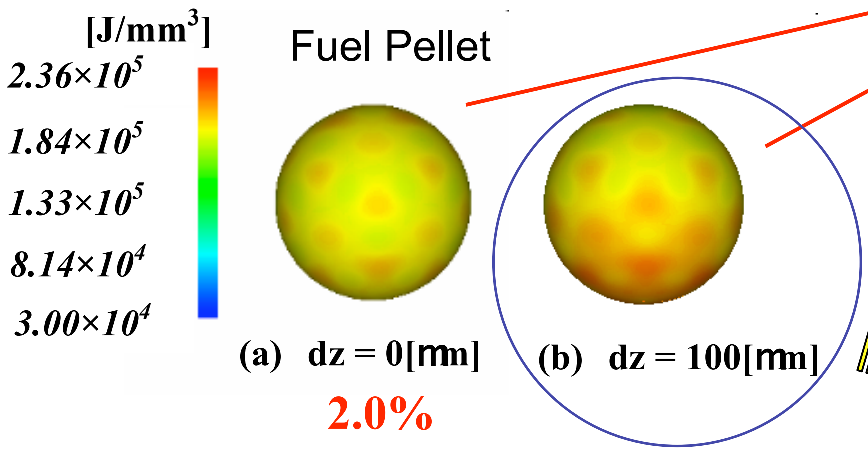




HIB Illumination non-uniformity + Implosion simulation
-> Robust Illumination against dz
-> Direct+Indirect Mixture Implosion Mode

Implosion non-uniformity < a few %
-> HIB illumination non-uniformity should be less than a few %.



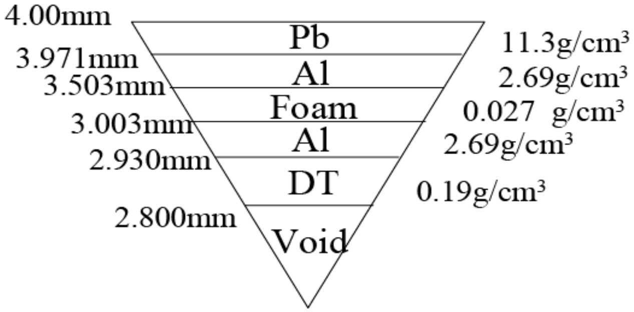


32-HIBs illumination

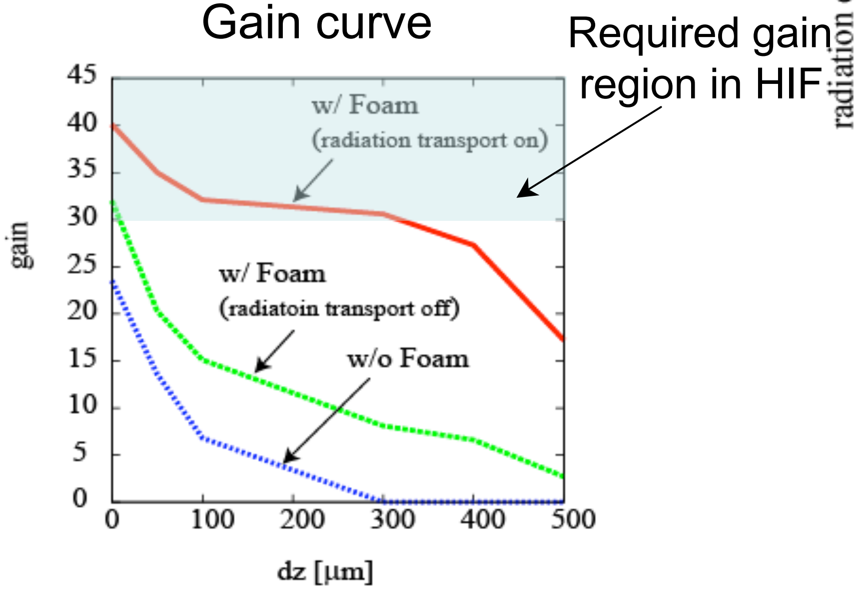
Previous Studies:
dz~20-50μm -> ~4.0%
HIB illumination non-uniformity

If *dz* requirement is relaxed, requirements for HIB control precision, target positioning, & monitoring precision are relaxed.
–> robust HIB illumination scheme & robust target

0.5 mm foam

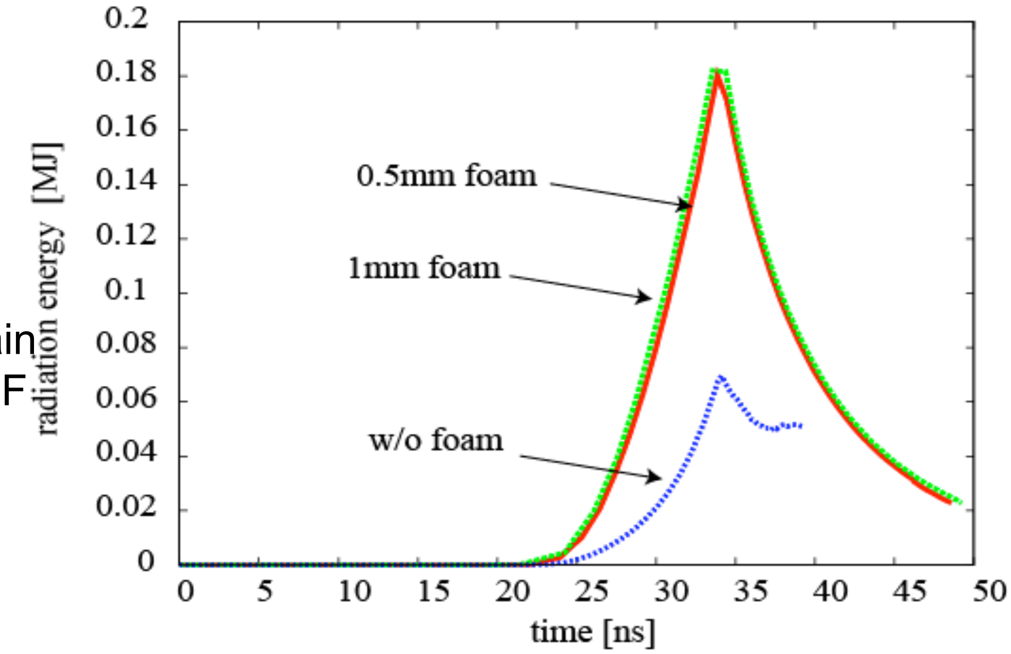


Gain curve



Pellet Gain versus dz

Radiation energy at low density foam region



*Conversion efficiency
(Beam energy to radiation energy)

- 0.5 mm foam : ~ 4.5 %
- w/o foam : ~ 1.5 %

Mixture of direct and indirect mode?

1. Beam Physics and HIF Studies by Simulation

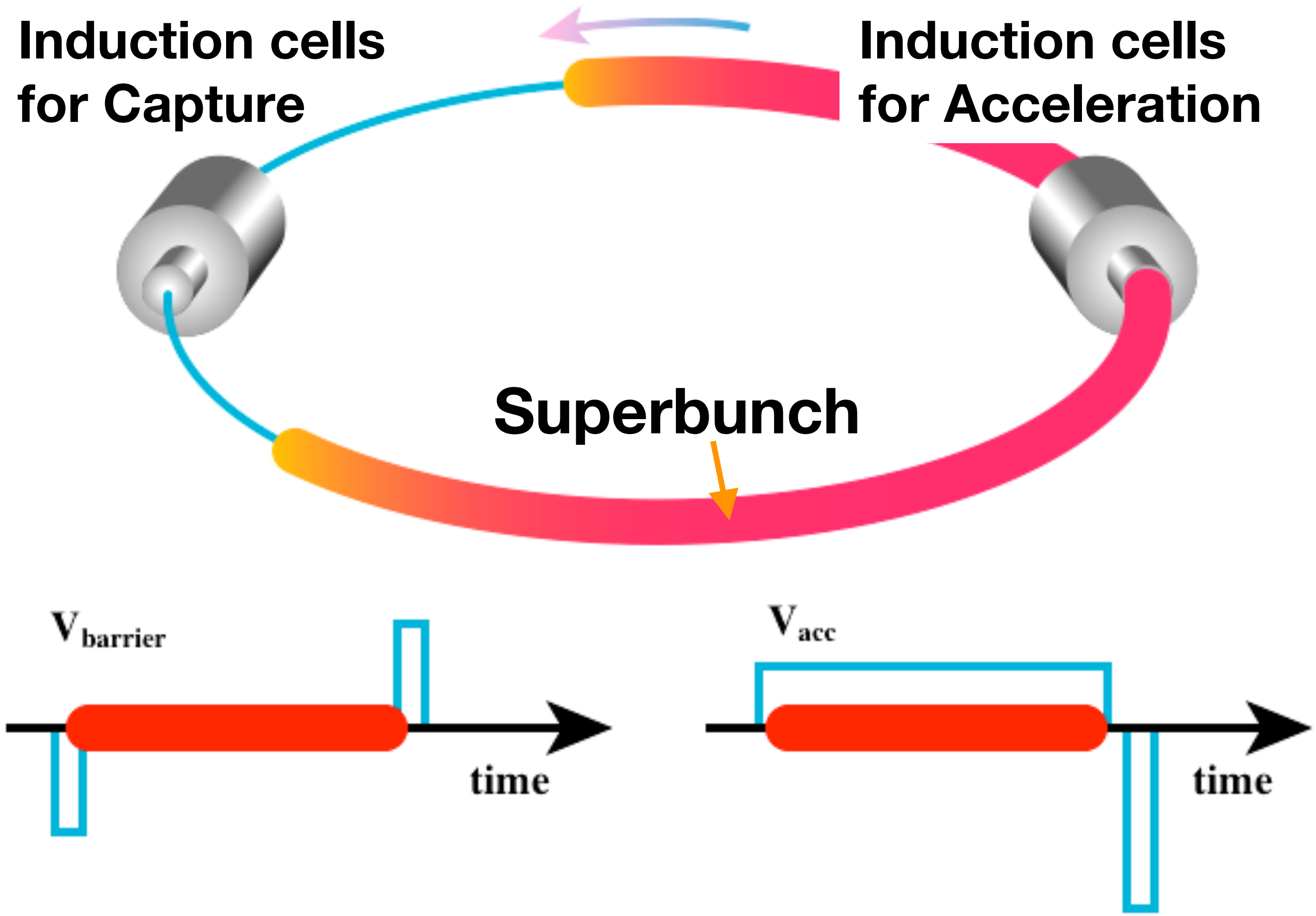
2. R&D of Induction Accelerator Technologies

3. HEDP Studies at Tokyo Tech

4. HEDP Studies by Laser

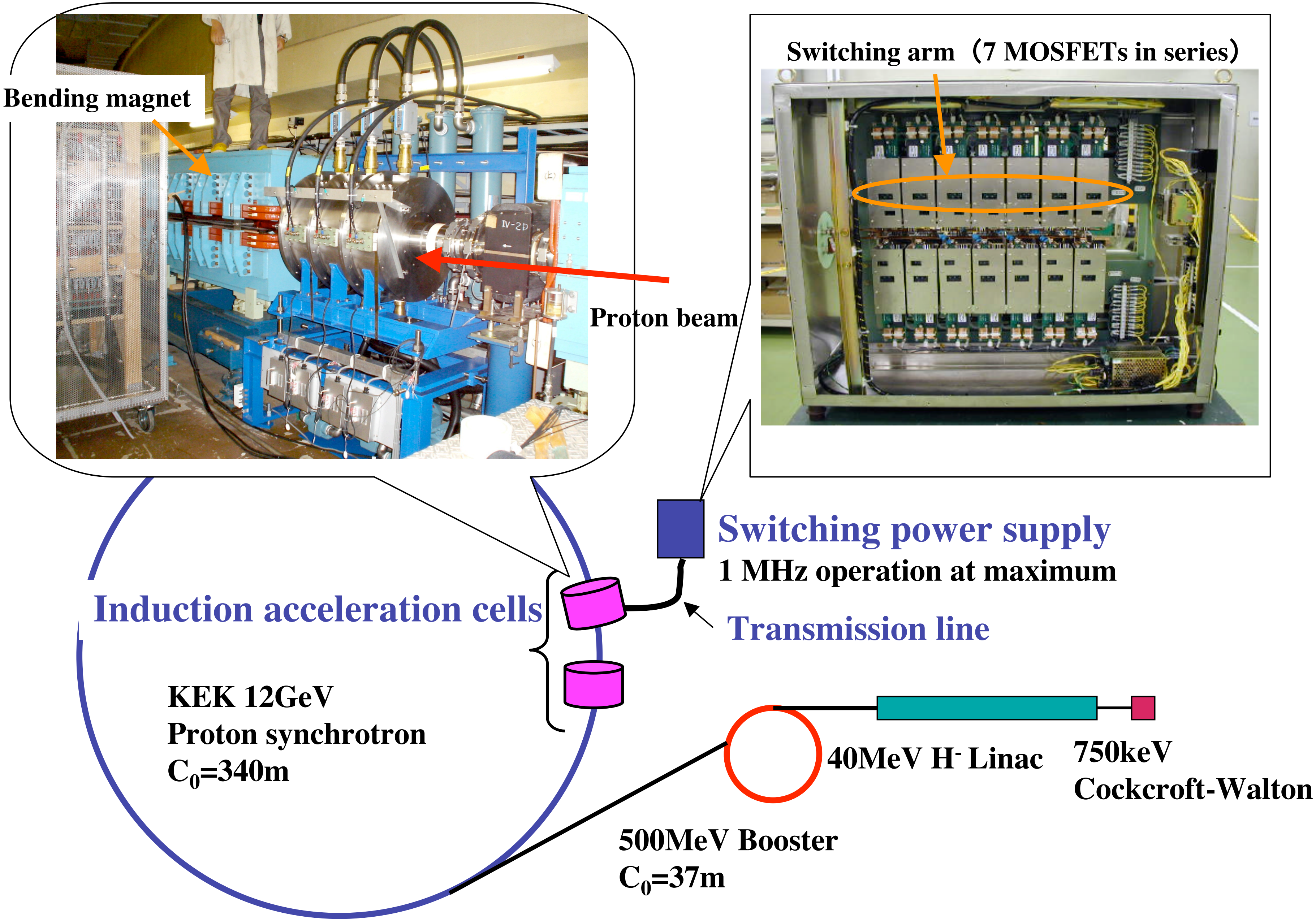
5. Soon Commissioning Accelerators in Japan

Schematic View of the Induction Synchrotron



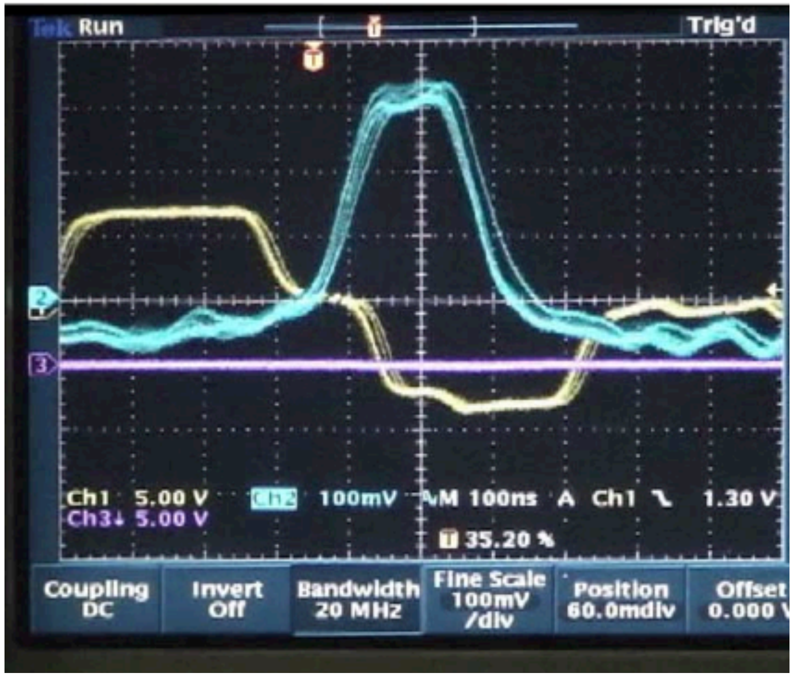
K.Takayama and J.Kishiro, "Induction Synchrotrons", *Nucl. Inst. Meth.* A451, 304-317 (2000)

Set-up of the induction synchrotron using the KEK 12GeV PS

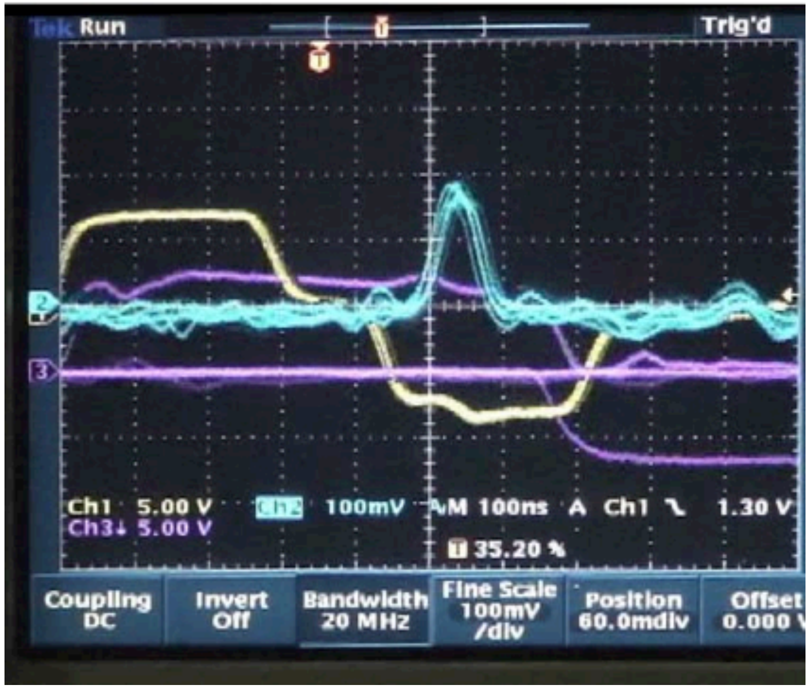


Full Demonstration of the Induction Synchrotron 2

Just before Acceleration



300msec after the beginning of Acceleration



Blue: proton bunch trapped by barrier voltages, Yellow: barrier voltage, Purple: induction acceleration voltage

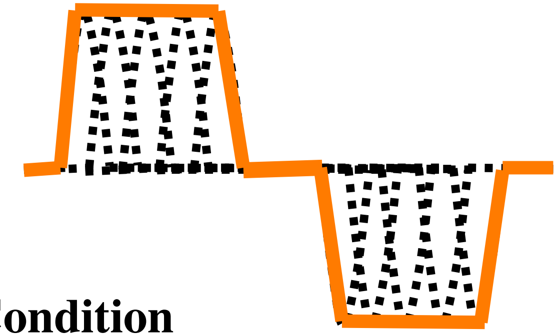
Induction Modulator composed of 5-unit Cells for Waveform Control

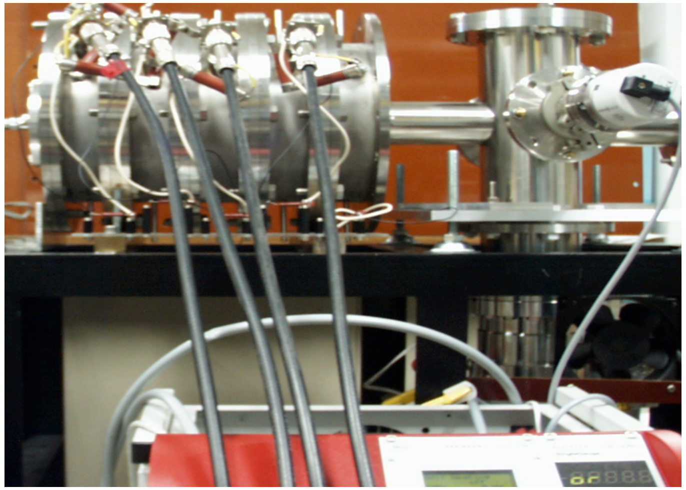
Module Structure

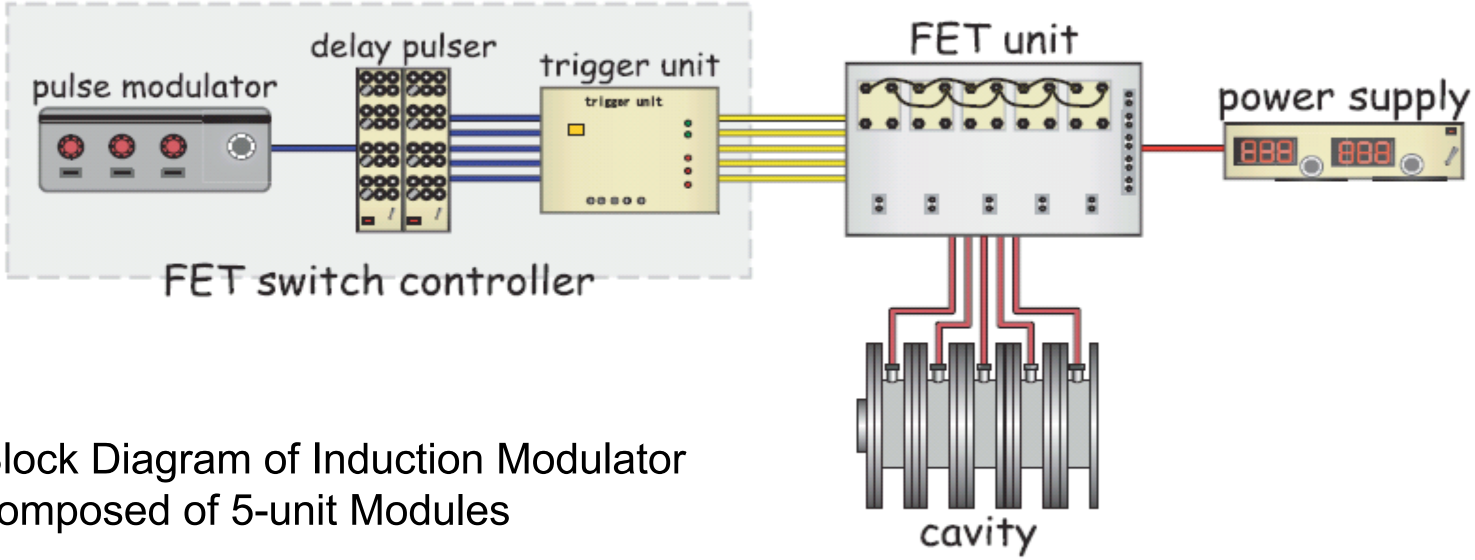
FET-Driver

Waveform Stacking

Robust against Load Condition







Block Diagram of Induction Modulator
composed of 5-unit Modules

1. Beam Physics and HIF Studies by Simulation

2. R&D of Induction Accelerator Technologies

3. HEDP Studies at Tokyo Tech

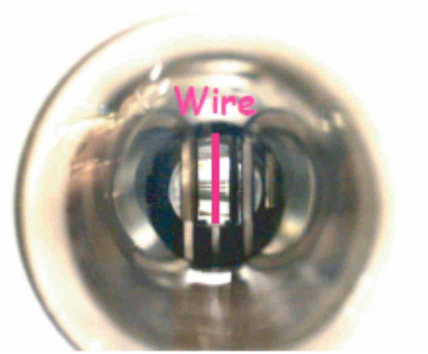
4. HEDP Studies by Laser

5. Soon Commissioning Accelerators in Japan

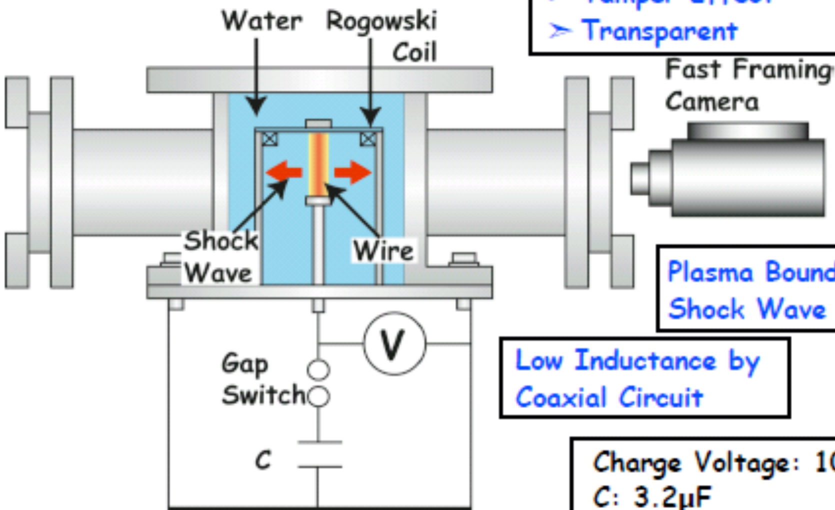
Warm-dense Matter Studies using Pulse-powered Exploding Wire Plasma in Water

Experimental Setup

Experimental Set-up



Picture of Load Section



Experimental Arrangement

Load Section Filled with Water
- Tamper Effect
- Transparent

Plasma Boundary
Shock Wave Behavior

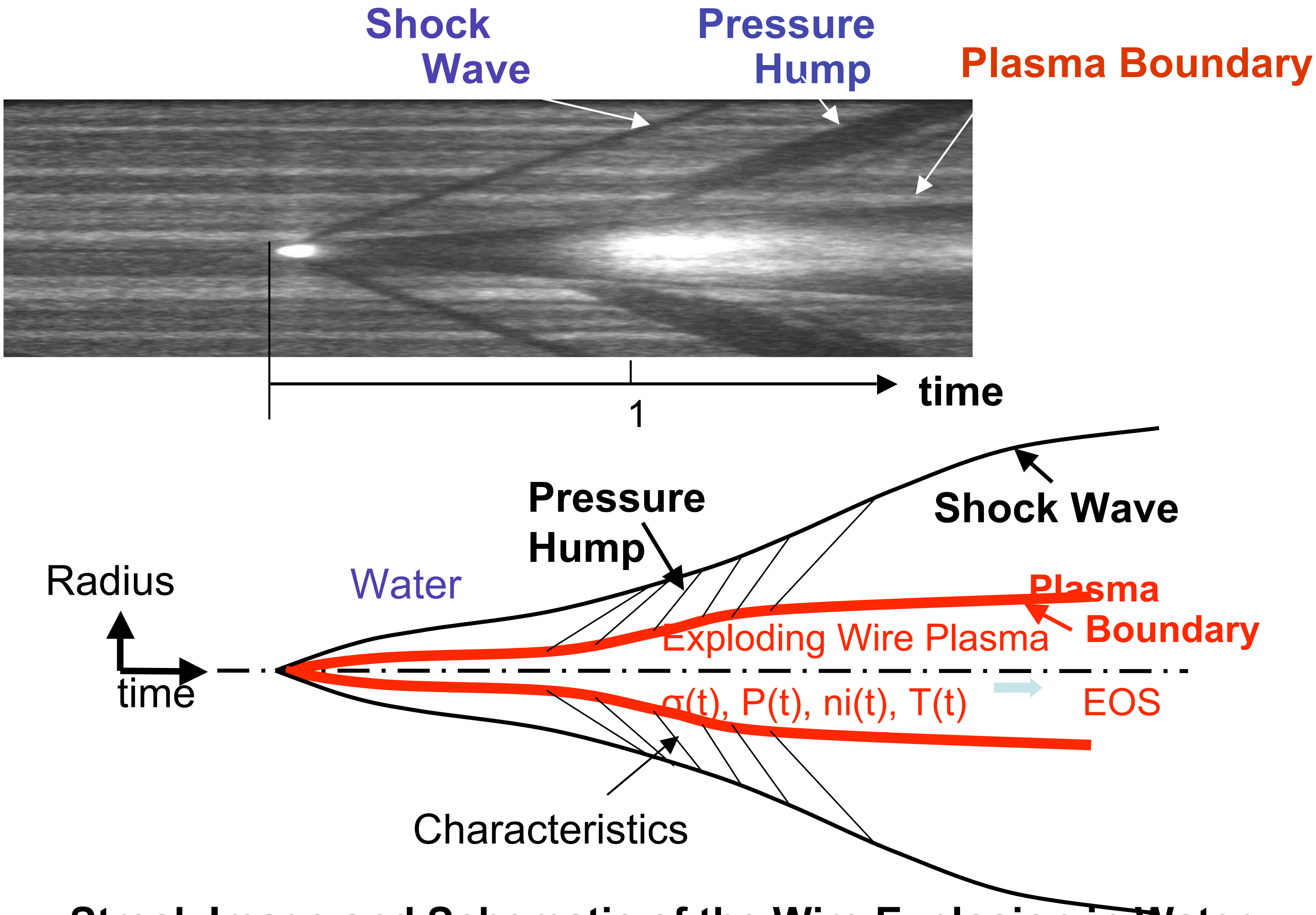
Low Inductance by
Coaxial Circuit

Charge Voltage: 10kV
C: 3.2μF
Circuit Inductance: 112nH
Load: Al, Cu and W Wire

Advantages of This Scheme

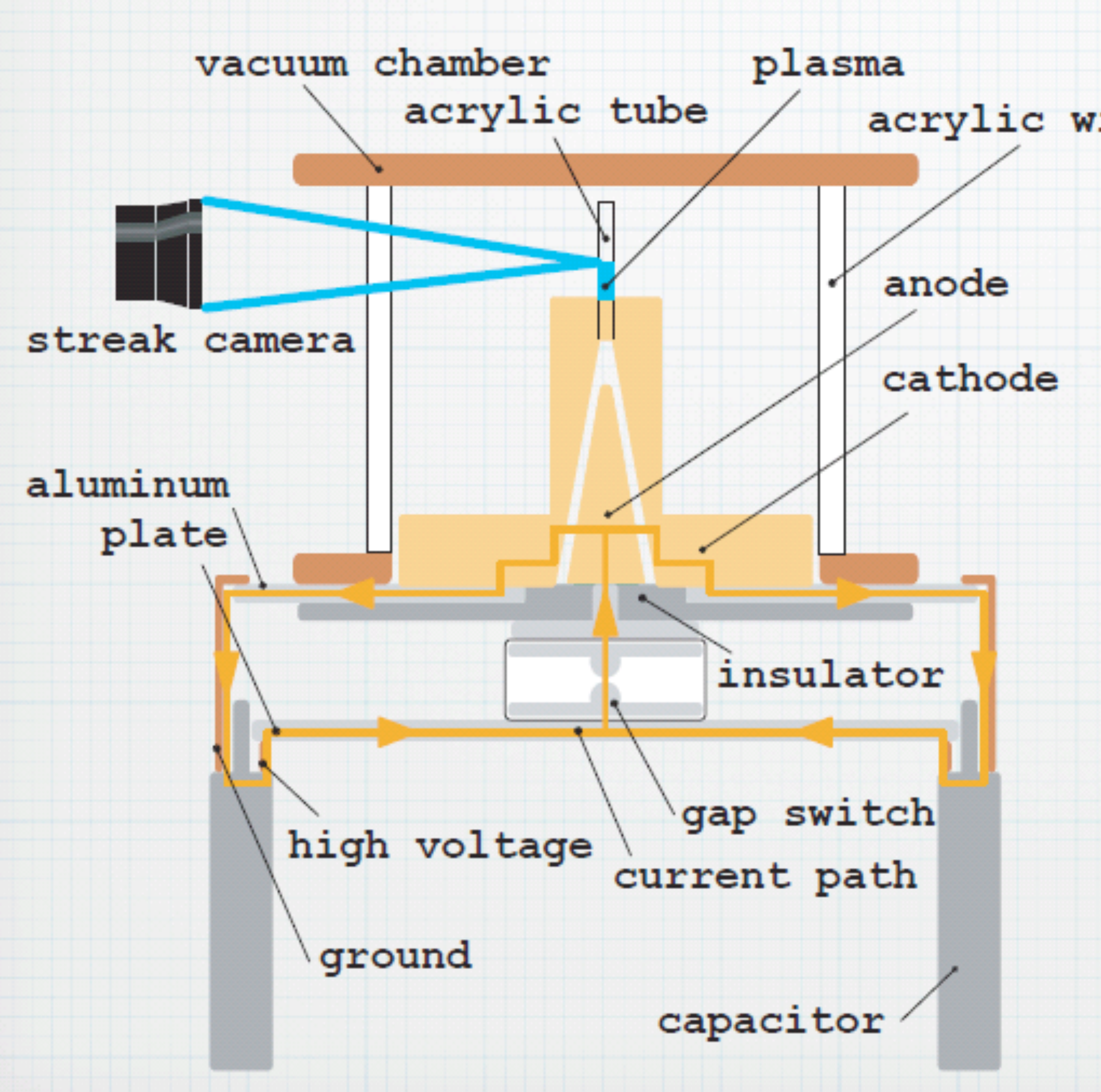
(1) Electrical conductivity is directly measured by wire voltage and current.
(2) Density is measured by evolution of wire radius.
(3) Pressure history can be measured by shock wave trajecties in water.

Semi-empirical fitting of hydrodynamic behavior brings us EOS modeling



Streak Image and Schematic of the Wire Explosion in Water

Experimental Arrangement for the Formation of E-M driven 1-D Strong Shock Wave



Gases : Xe, Ar

Initial pressure

: 50 ~ 8000 mtorr

1. Beam Physics and HIF Implosion Simulation
   at Utsunomiya University

2. Induction Synchrotron at KEK

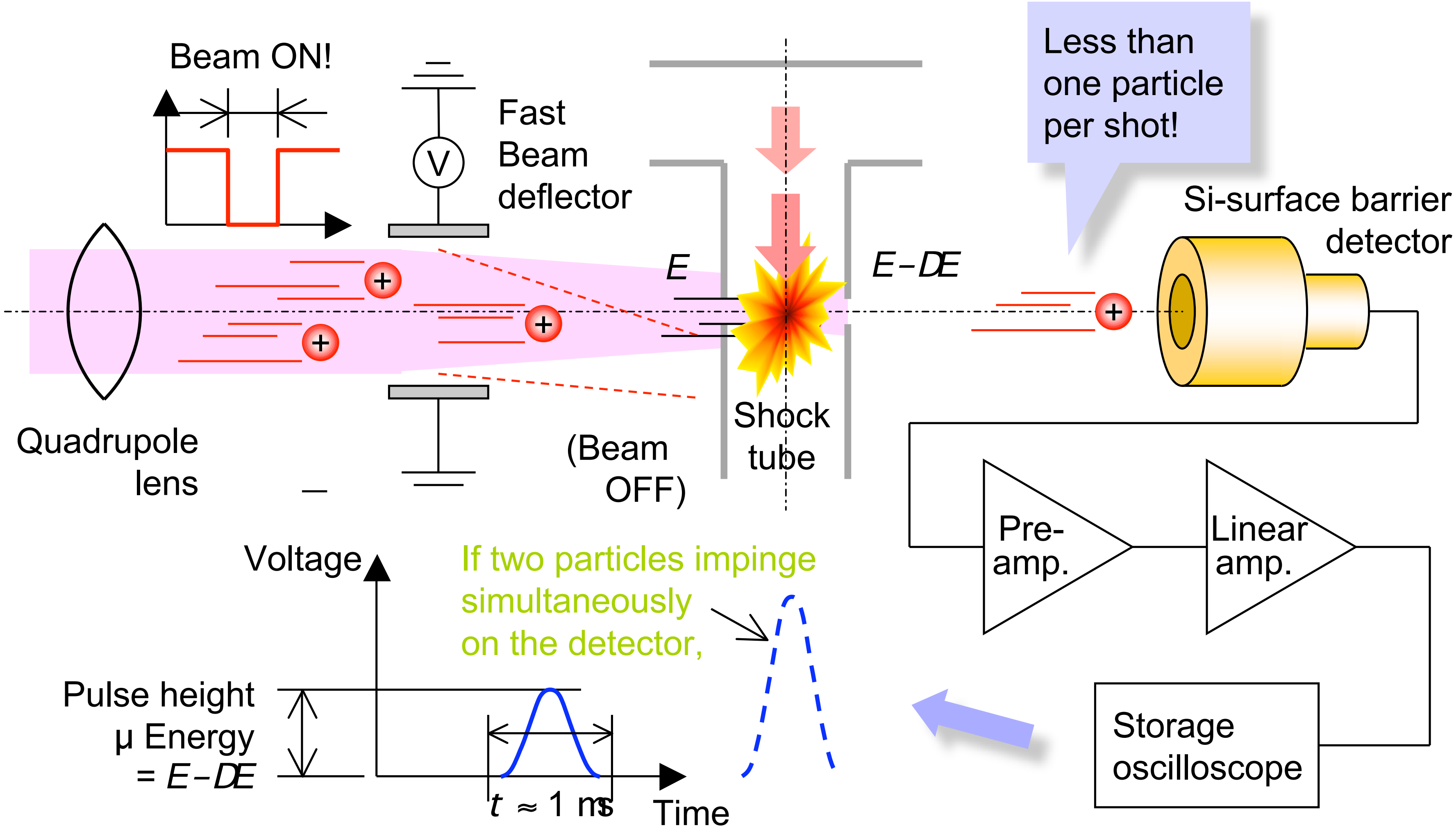
3. HEDP Studies at Tokyo Tech
   dE/dX Experiment in HED Target

4. PW Laser at ILE Osaka

5. Soon Commissioning Accelerators in Japan

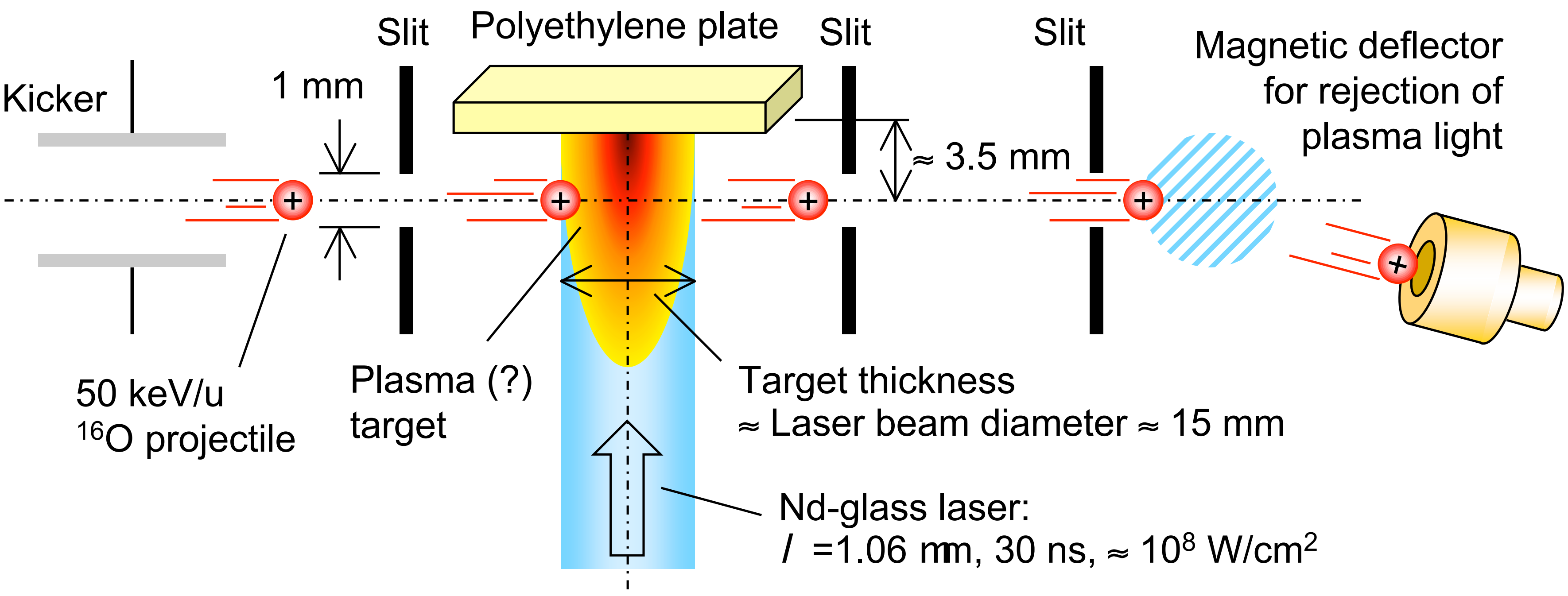
For time-resolved measurements, the SSD has to be used in combination with a fast beam deflector.

- Many shots are needed to detect one particle:



To test the timing performance of the system, projectile energy loss in a laser-plasma target was measured.

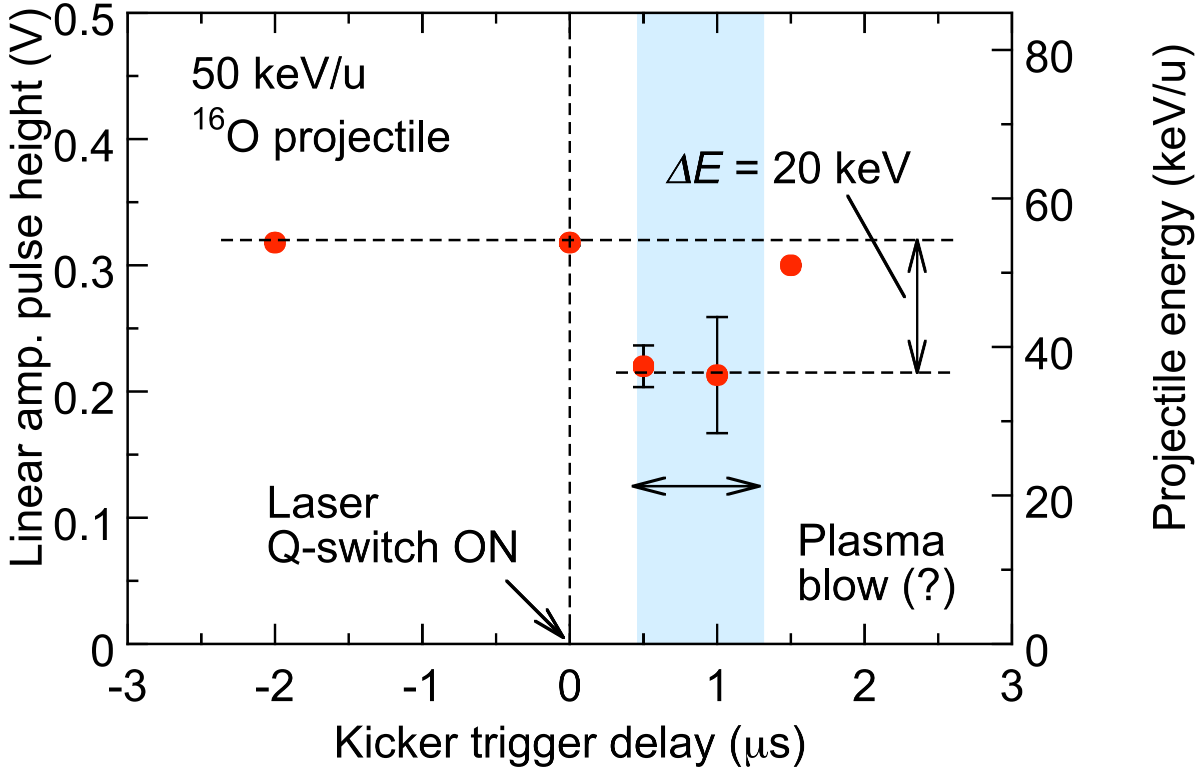
- The shock-driven plasma target and the differential pumping system is NOT YET installed in the beam line!
- As a substitute, a laser-plasma target was prepared as a short-lived target:
  - A polyethylene plate was irradiated with a pulsed laser to produce a plasma blow.
  - Diagnostic measurement of the plasma was not performed.



Temporal dependence was observed for the projectile energy loss in the plasma blow.

- Preliminary result on the time-resolved energy loss measurement:
  - Energy loss *DE* ≈ 20 keV
  - Target thickness *Dx* ≈ 15 mm
  - *dE/dx*(cold $(CH_2)_n$) ≈ 6 MeV/(mg/cm²)

  → Target atomic density ~ 10^{18} cm^{-3} (?)



1. Beam Physics and HIF Studies by Simulation

2. R&D of Induction Accelerator Technologies

3. HEDP Studies at Tokyo Tech

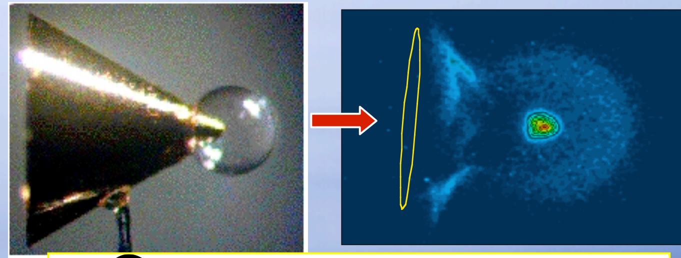
4. HEDP Studies by Laser
   ILE Osaka

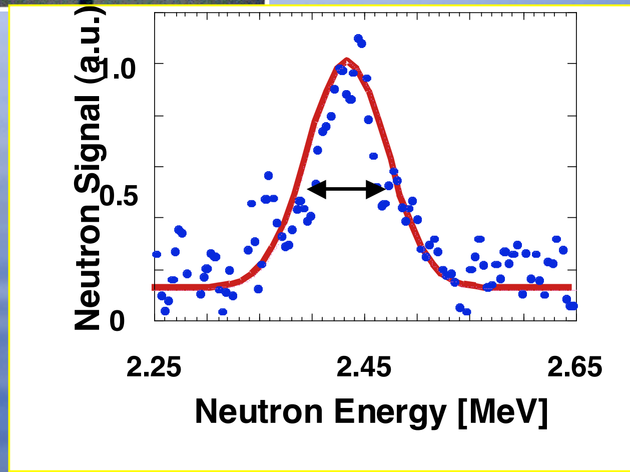
5. Soon Commissioning Accelerators in Japan

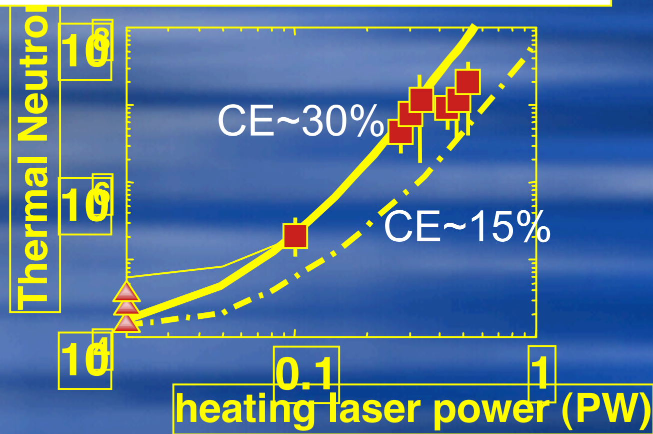
Fast ignition works with gold cone guiding

- The exist of the cone does not reduce the core plasma density much (~80%)
- Laser to core plasma thermal energy coupling conversion efficiency 20%~30%
- Core plasma temperature 1keV at 50-70g/cc due to enforced heating
- Thermal neutron yields increased from 10^4 to 10^7
- Cone may focus the heating laser light and hot electrons from the cone wall to the cone inner tip

R.Kodama *et al.* Nature **412** 798-802 (2001); **418**, 933 (2002)

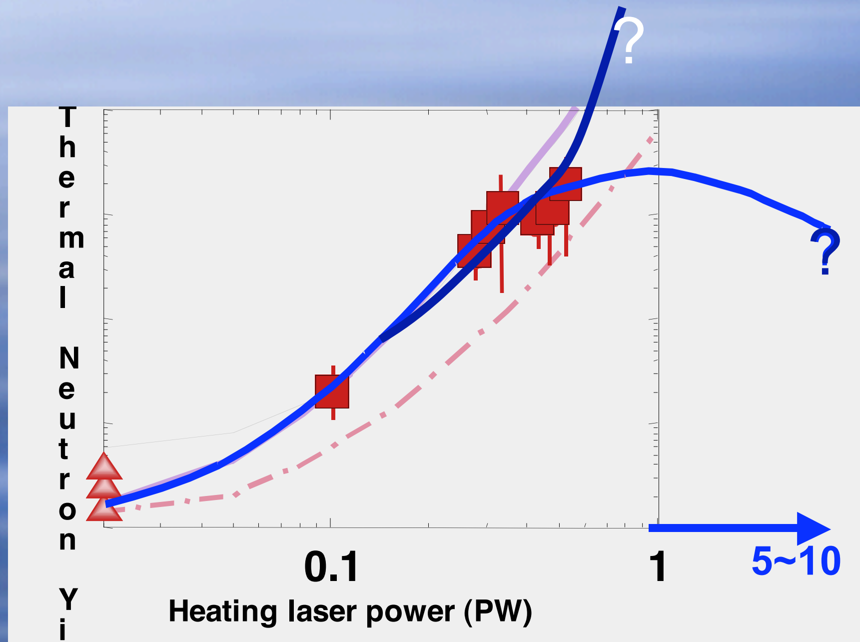






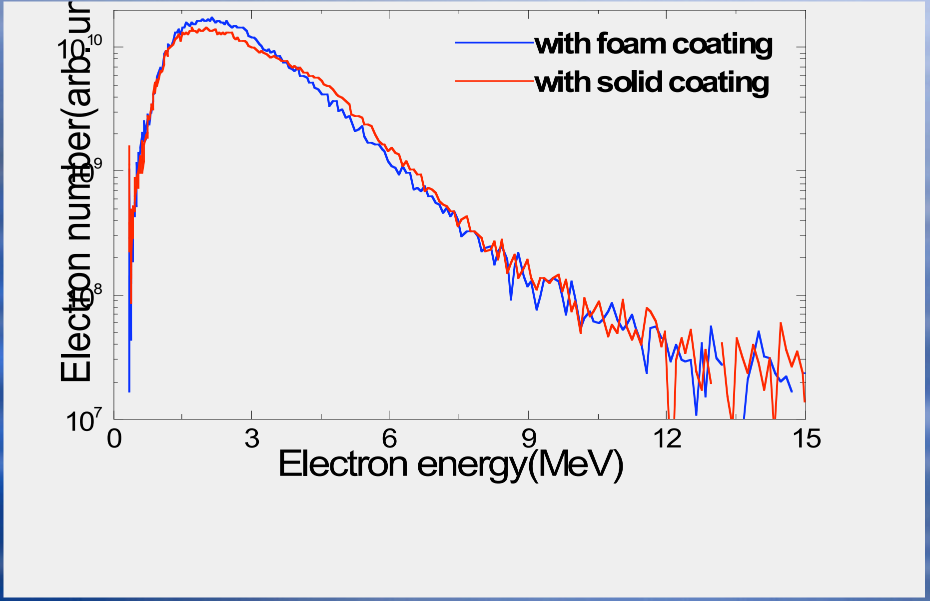
Advanced fast ignition with physical cone guiding

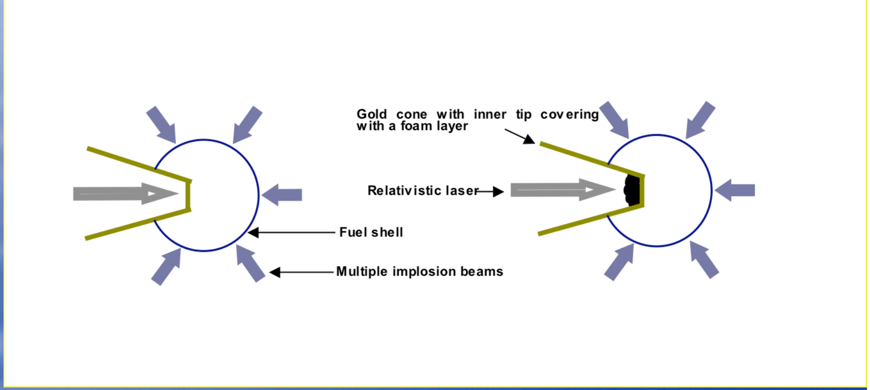
- **Some issues on heating efficiency need to be answered.**
  - What is the heating laser power at ignition level? PW or higher or lower?
  - How the laser-core energy coupling efficiency changes at ignition level? Further increasing or decreasing?
  - The reason for CE reduction is attributed to high -e temperature. At ignition level, temperature would be even higher.



Au foam coating does not change the hot – electron energy spectral characteristics

- Hot -e energy spectra are very similar for solid gold coated and gold foam coated targets, showing a temperature ~1.5 MeV, a typical value for solid aluminum targets





- There is a question: why there is no comparable increase in the amount of hot electrons observed with Au foam coated target?

  In vacuum electrons escaping from the target is fully limited by the static potential.

  [T. Yabu-uchi et al., submitted to Phys. Rev. E.]

FIREX laser specification

Energy	12 kJ/4 beams (chirped pulse) 10 kJ/4 beams (compressed pulse)
Wavelength	1053 nm
Pulse shape	1-20 ps (FWHM) Rise time ≈ 1-2 ps
Beam synchronization	0.1 ps (timing jitter) $\leq \lambda/5$ (phase)
Focusability	20-μm diameter (50% efficiency) F/6 (4 beam cone)
Pulse contrast	$< 10^{-8}$

0.6 - 10 PW

One beam by March 2007
Full PW laser available in 2008

1. Beam Physics and HIF Studies by Simulation

2. R&D of Induction Accelerator Technologies

3. HEDP Studies at Tokyo Tech

4. HEDP Studies by Laser
   Laser and Ion Experiments at UEC

5. Soon Commissioning Accelerators in Japan

1. Beam Physics and HIF Implosion Simulation
   at Utsunomiya University

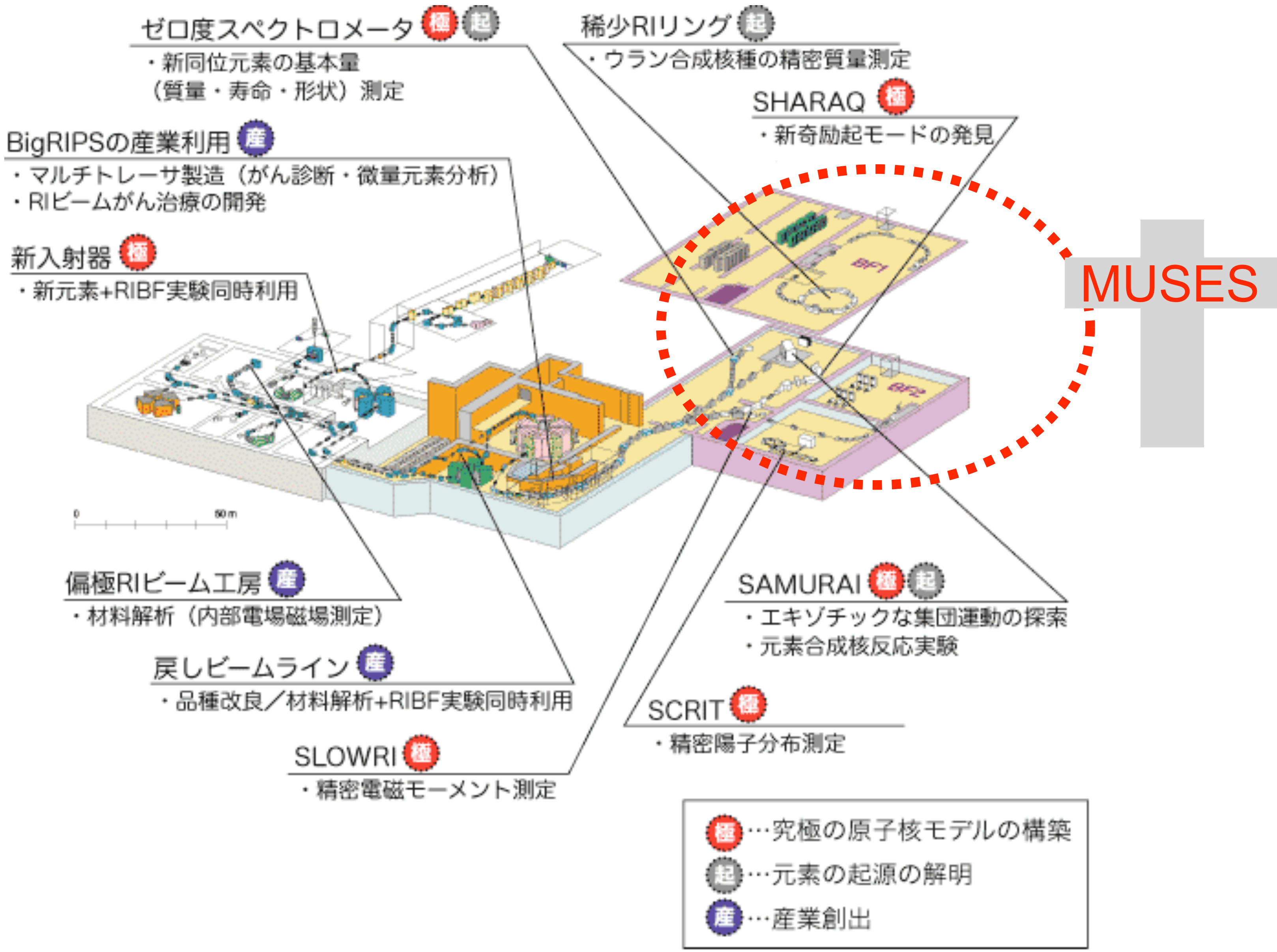
2. Induction Synchrotron at KEK

3. HEDP Studies at Tokyo Tech

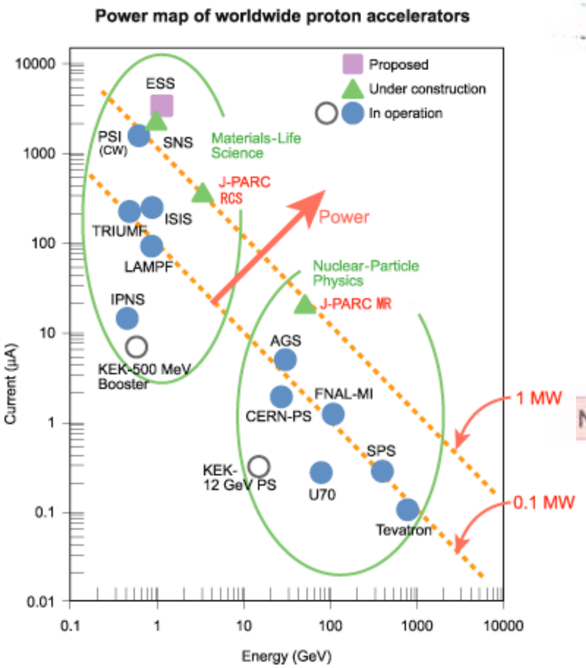
4. PW Laser at ILE Osaka

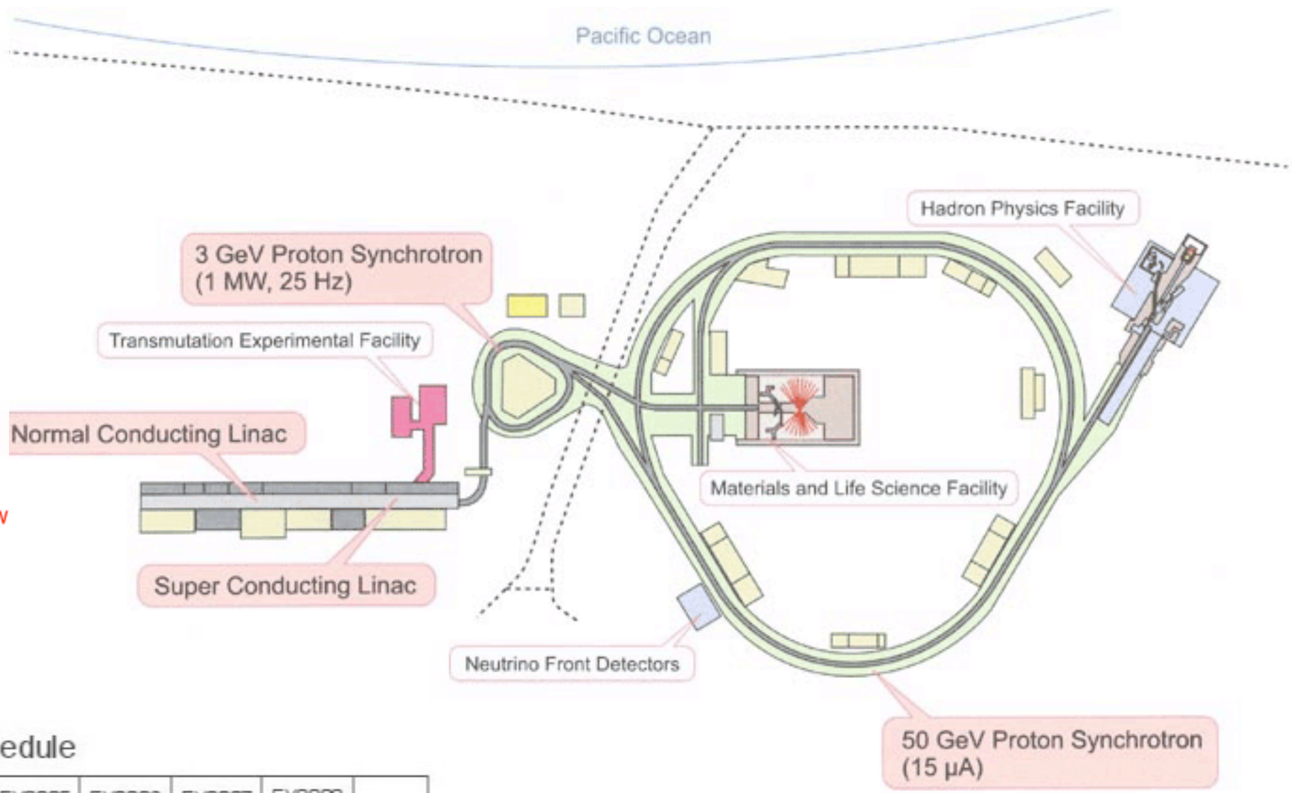
5. Soon Commissioning Accelerators in Japan

RIBF at RIKEN

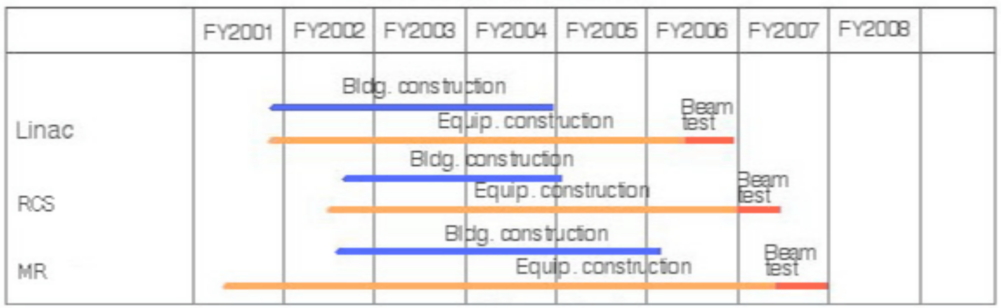


J-PARC





Construction Schedule



Summary

1. HIB
   - Induction Synchrotron
   - Induction Modulator for Waveform Control
   - Beam Physics via Simulation

2. HEDP
   - HEDP Based on Pulse Power
   - dE/dX Experiment toward HED Target
   - Up-grade of PW Laser