FFAG-ADSR Study at KURRI

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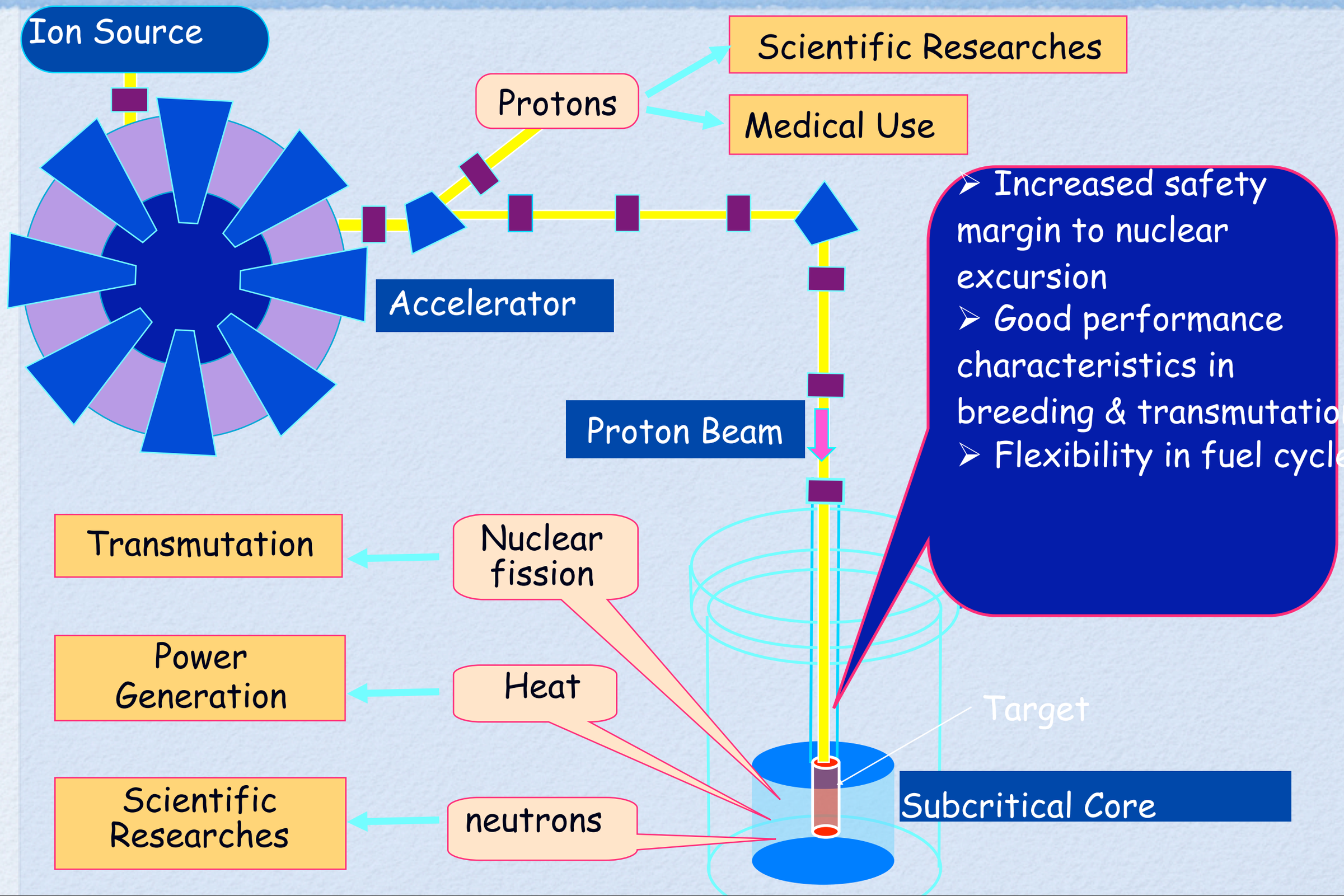
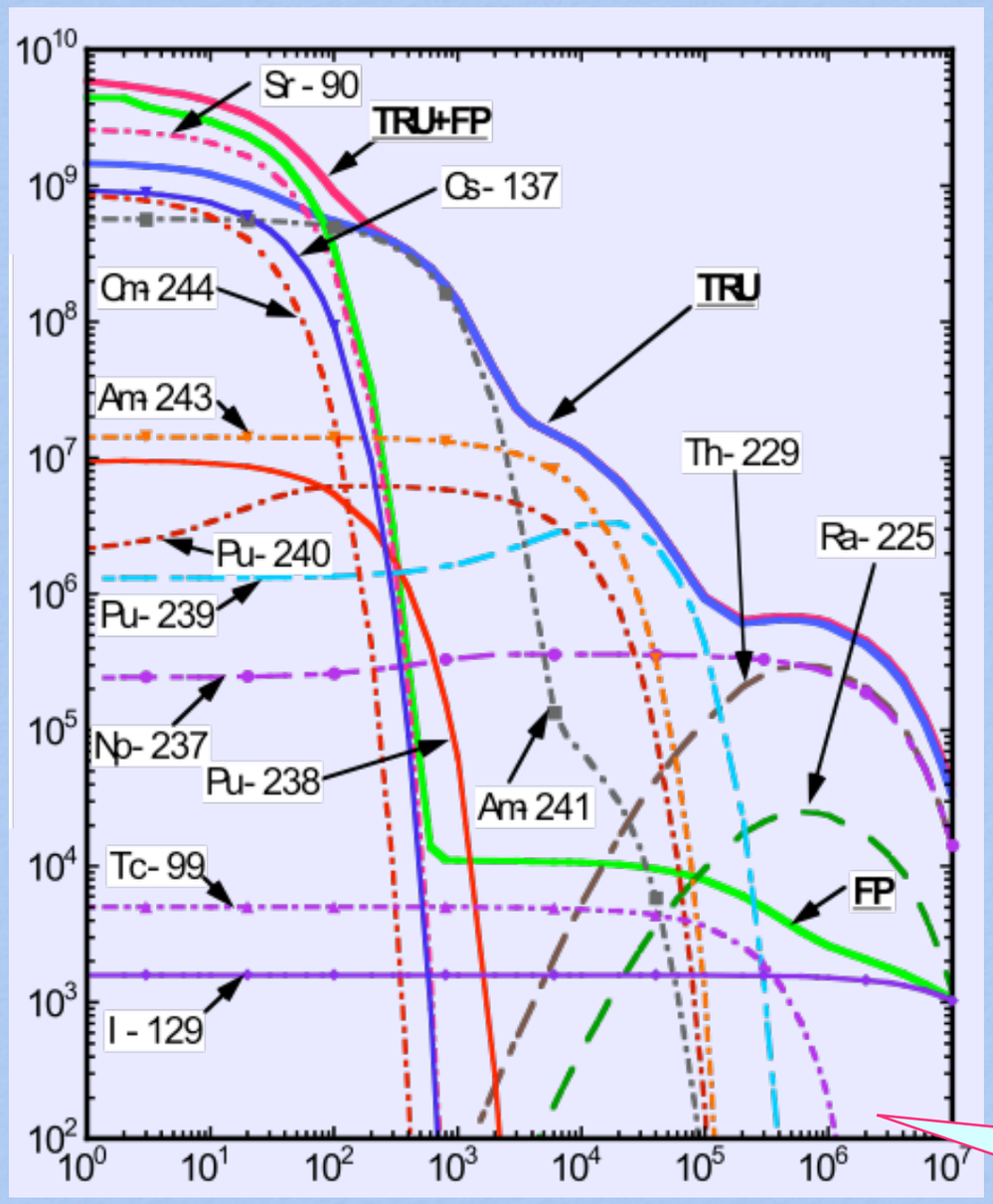
ADSR
(Accelerator Driven Sub-critical Reactor)



Transmutation



- Radiotoxicity : ratio of the mass of nuclide to the permissible limit of annual intake

- Raiotoxicity of FP's is dominant within 100 years after reprocessing, and that of MA's thereafter

Half-lives:

Sr-90	28yrs.
Cs-137	30yrs.
Np-237	2.14 M. yrs.
Am-241	433yrs
Am-243	7370yrs.

Long term risks could be reduced by transmutation of MA's

Why Transmutation??

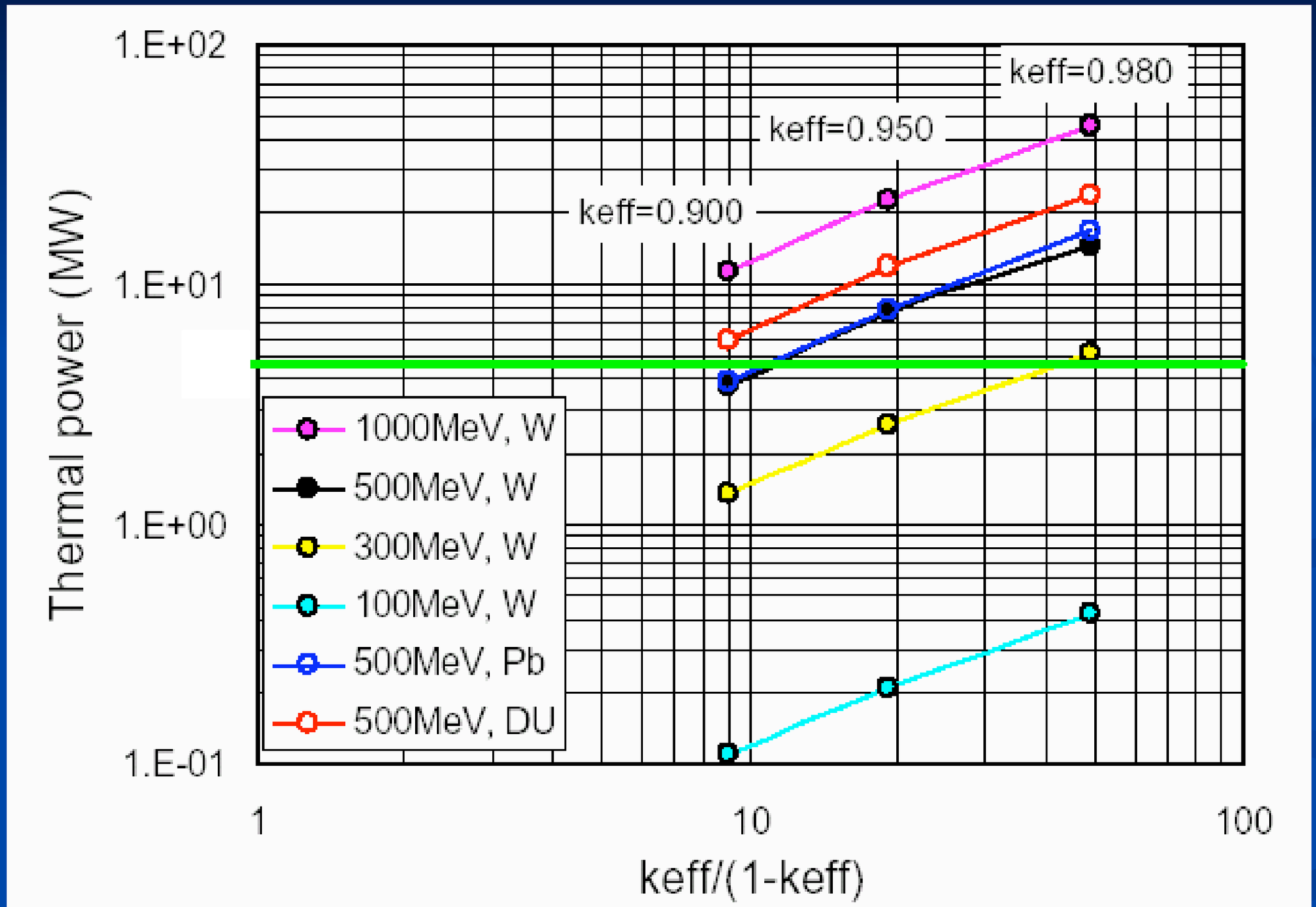
- We need **TRANSMUTATION** and/or BREEDING not because we do not like Geological Repositories but **BECAUSE IT IS THE ONLY WAY TO MAKE NUCLER ENERGY REALLY SUSTAINABLE** and consequently to make it more acceptable

by W.Gudowski

Constraint for ADSR

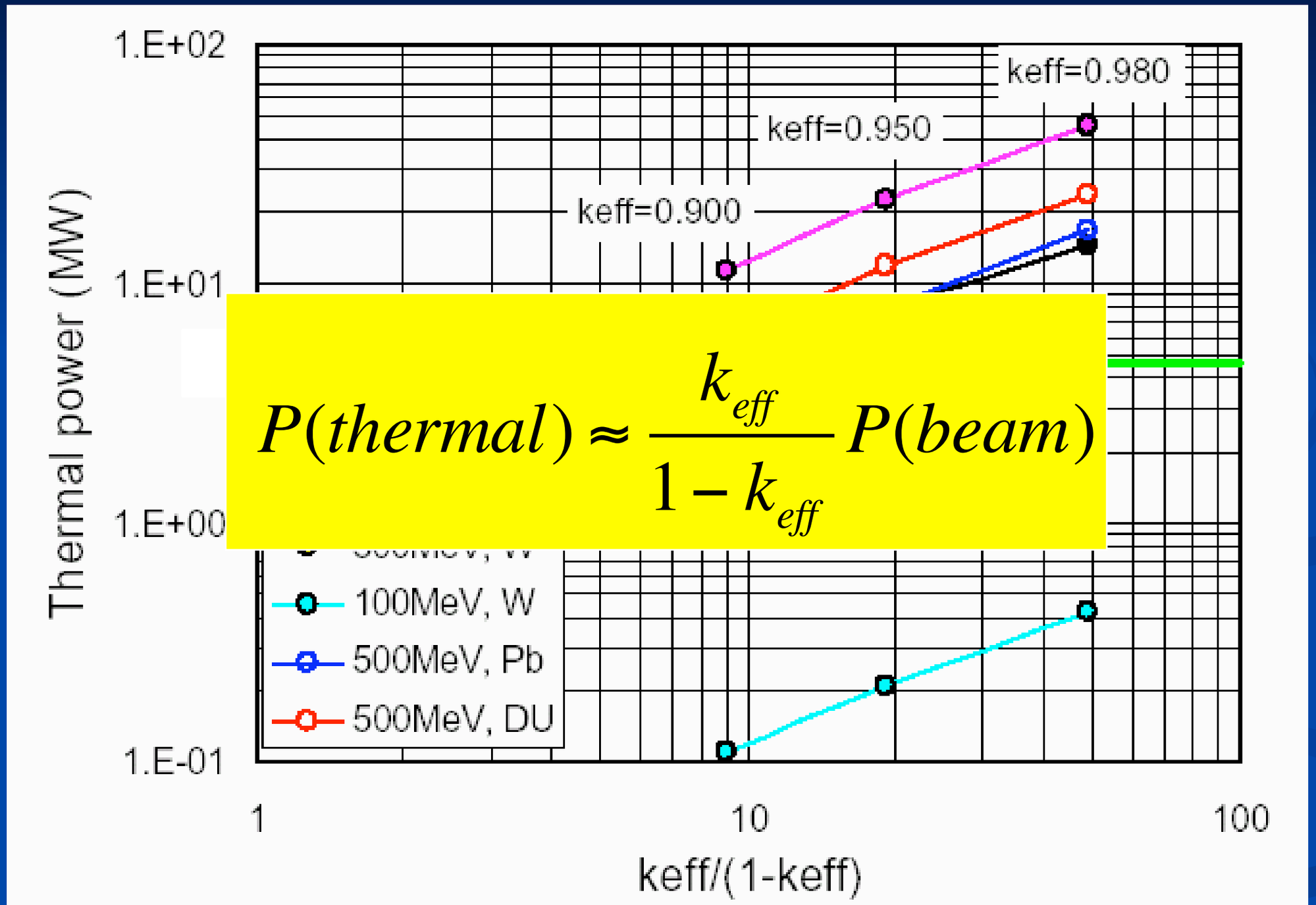
- How much power can ADSR produce?
- Power efficiency sustaining the system.

Calculated Thermal Power of KUR-type ADSR



Thermal power of KUR-type ADSR (proton beam current=1mA) as a function of target material and effective multiplication factor

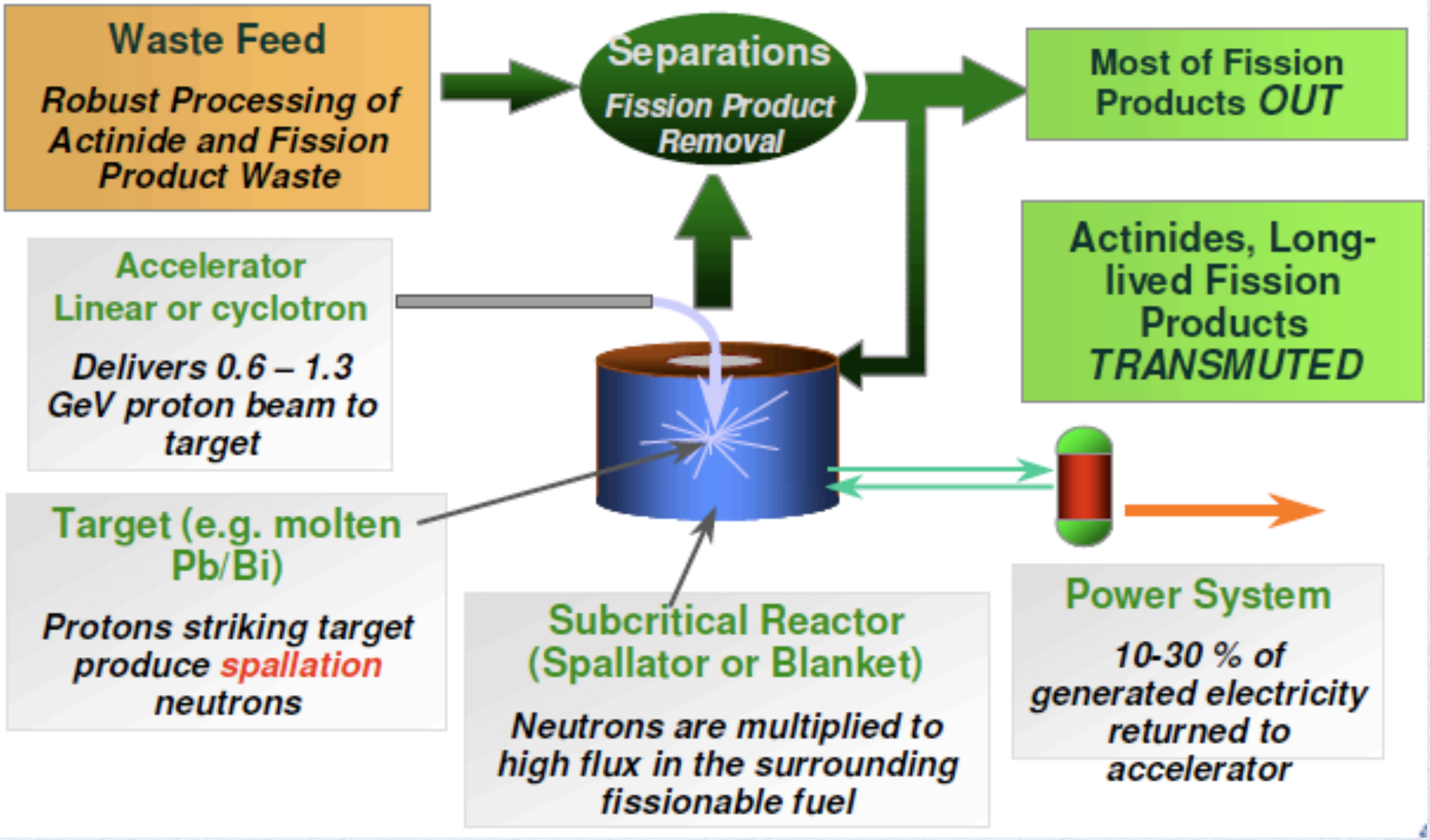
Calculated Thermal Power of KUR-type ADSR



$$P(thermal) \approx \frac{k_{eff}}{1-k_{eff}} P(beam)$$

Thermal power of KUR-type ADSR (proton beam current=1mA) as a function of target material and effective multiplication factor

ADSR transmutation



ADSR transmutation

$$P_{e-power} \approx \varepsilon_{th-e} \times \frac{k_{eff}}{1-k_{eff}} P_{beam} \quad : \varepsilon_{th-e}(\text{thermal to electric})$$

$$\eta_{accelerator} = \frac{P_{beam}}{P_{acceleraotr}} > \frac{P_{beam}}{P_{e-power}} \approx \frac{1-k_{eff}}{\varepsilon_{th-e} \times k_{eff}}$$

$$\eta_{accelerator} \sim 0.25 \quad (\varepsilon_{th-e} = 0.2, k_{eff} = 0.95)$$

Power Efficiency of Accelerator >25%

Power efficiency of accelerator

- SC Linac (JAEA estimates)

  ➡ η~ 25-30%:1.2GeV, 10mA

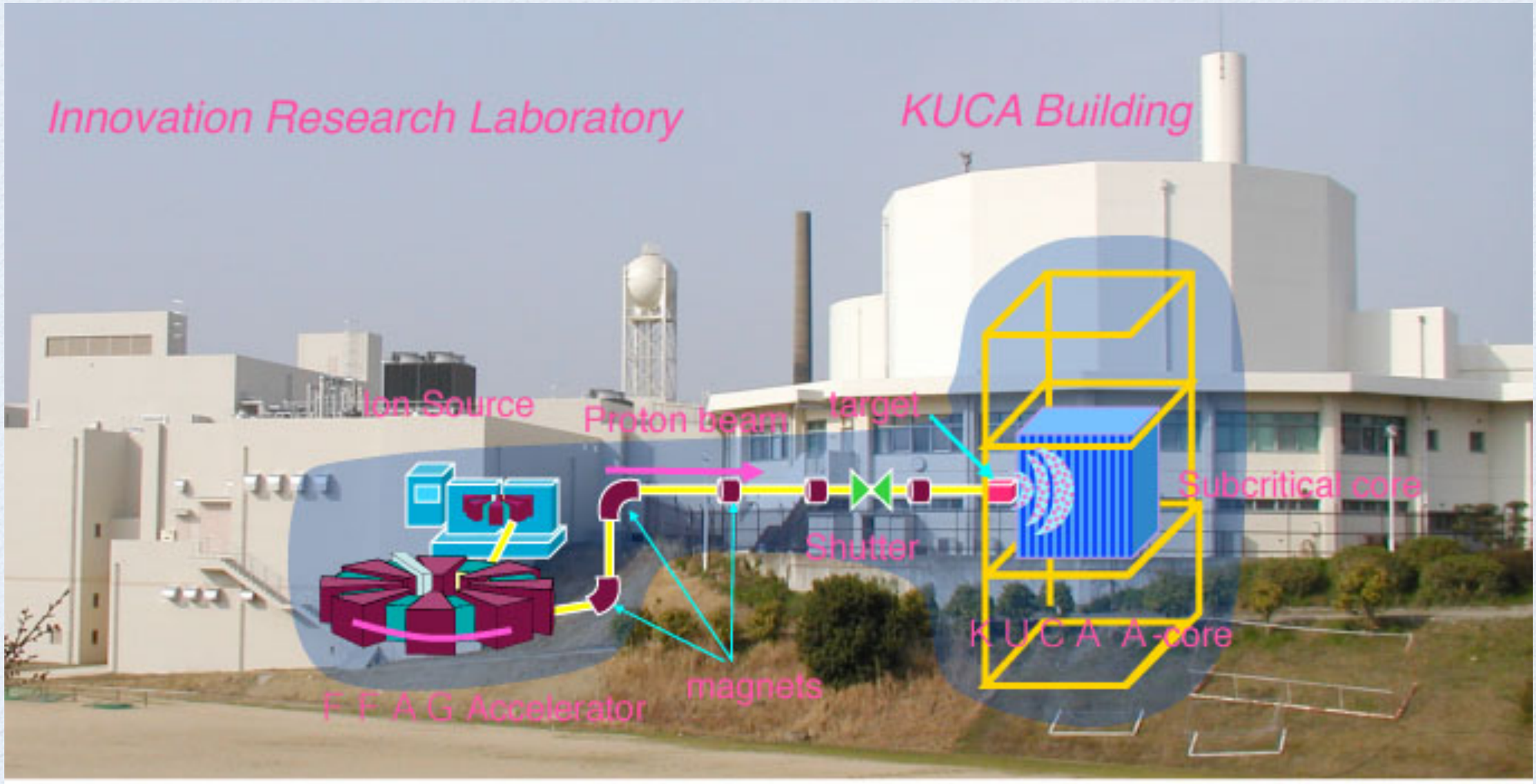
- Ring (FFAG)

  ➡η can(may) be 50% with SC magnet

FFAG-ADSR project

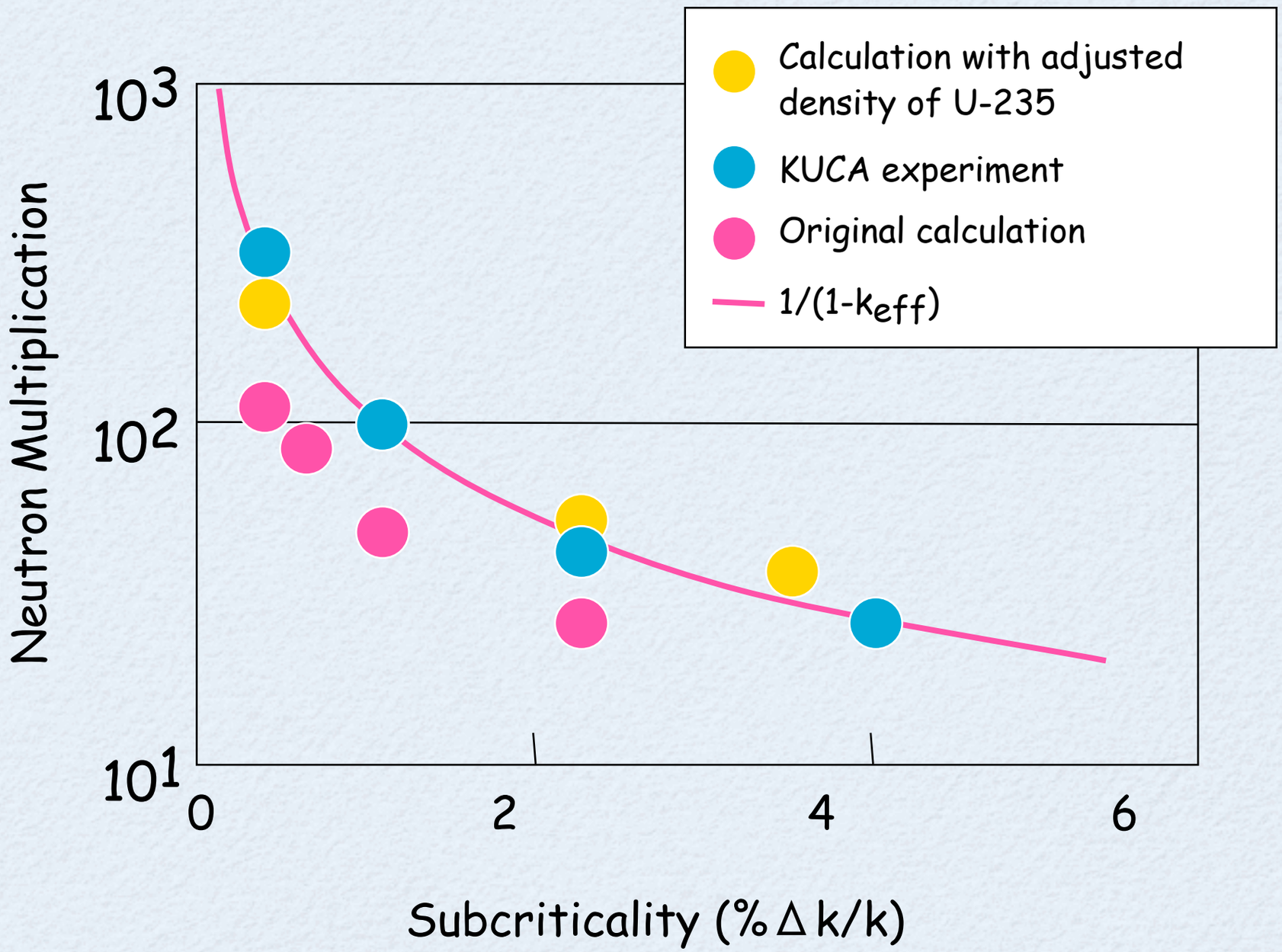
- Purpose of the proejct
  - Basic study for ADSR(Accelerator Driven Sub-critical Reactor) with FFAG accelerator and KUCA(Kyoto University Critical Assembly)
- KUCA
  - Output power ~10W
  - Neutron amplification : $\alpha=1/(1-k_{eff})$. If $k_{eff}=0.99$, $\alpha=100$
  - Beam power requirement not exceed < 0.1W!!
    - cf. For 100MeV proton beam, I<1nA

FFAG-ADSR project



ADSR STUDY WITH FFAG

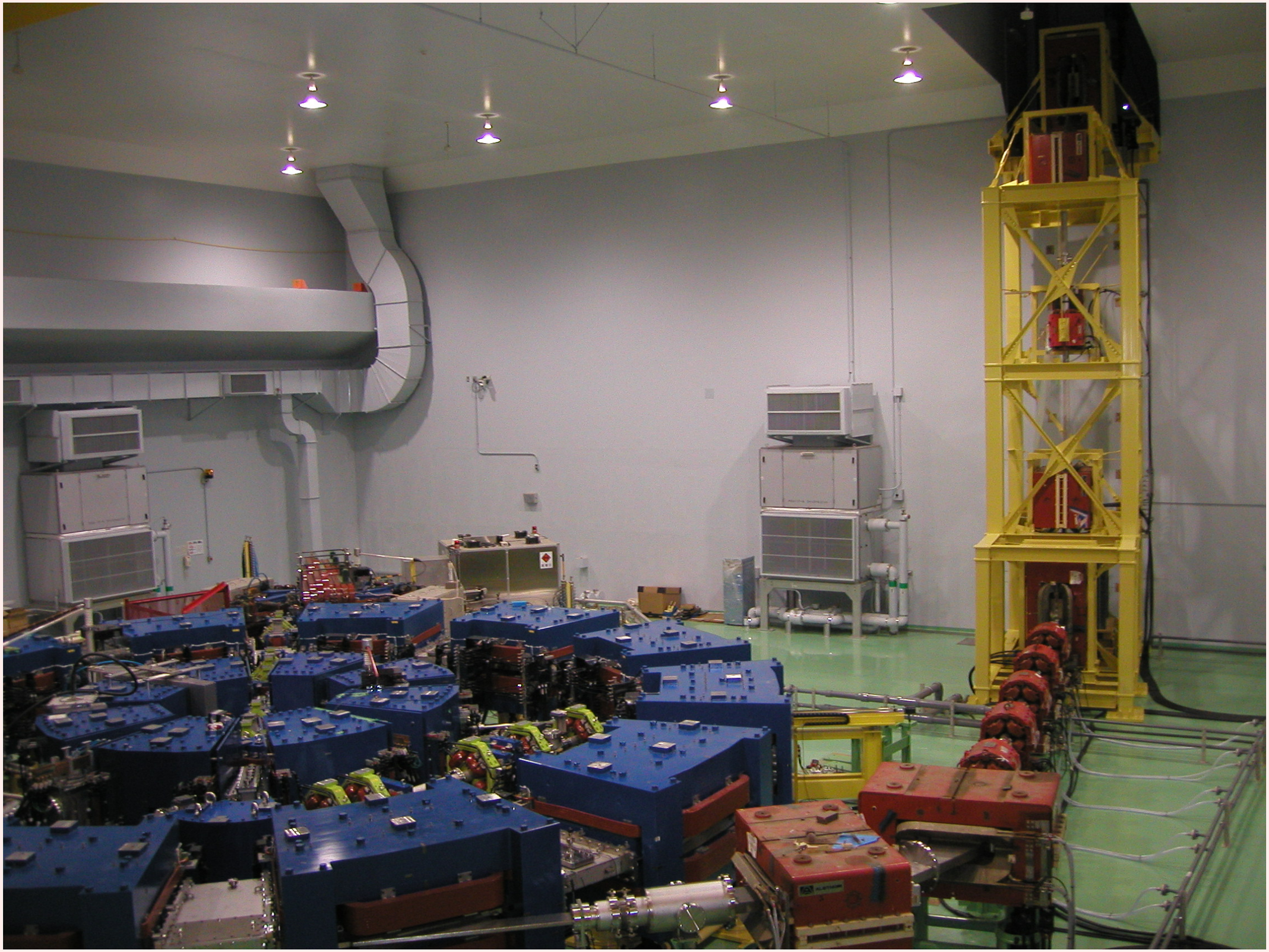
- Neutron multiplication for sub-criticality
- Effective critical factor for spectrum index (neutron portion of less than 1eV)



BASIC PARAMETERS FOR ADSR EXPERIMENT @KURRI

- Reactor output power ~10W
- Neutron multiplication <100(max.)
- Beam power of FFAG <0.1W
- Beam energy of FFAG 100-150MeV
- Beam current of FFAG <1nA

FFAG complex for ADS study

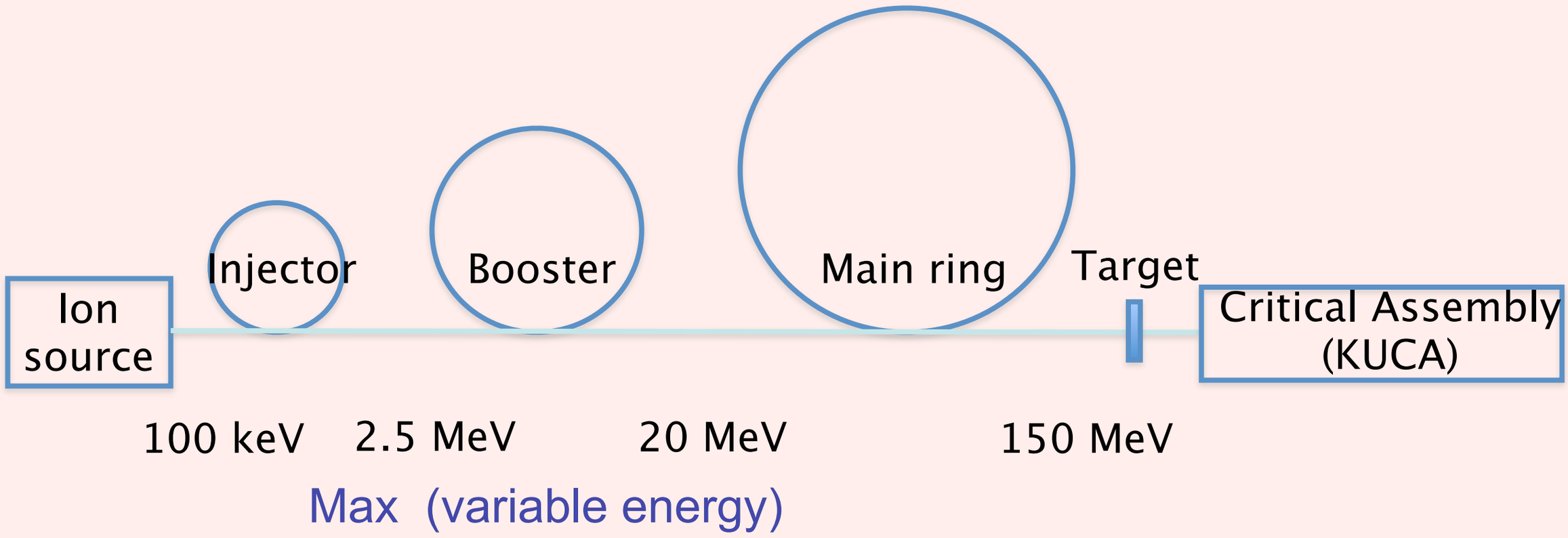


FFAG-ADS Project

To study

Accelerator Driven Sub-critical Reactor (ADS)

- Narrow energy spectrum of n beam
- Energy and Flux of the n beam
  can be easily controlled.



Accelerators for ADS

	Injector	Booster	Main Ring
Focusing	Spiral, 8 cells	Radial, 8 cells	Radial, 12 cells
Acceleration	Induction	RF	RF
Field index, *k*	2.5*	4.5	7.5
Energy (max)	0.1-2.5 MeV*	2.5-20 MeV	20-150 MeV
P_{ext}/P_{inj}	5.00(Max)	2.84	2.83
Average orbit radii	0.60 - 0.99 m	1.42 - 1.71 m	4.54 - 5.12 m

* Output energy of the injector is variable

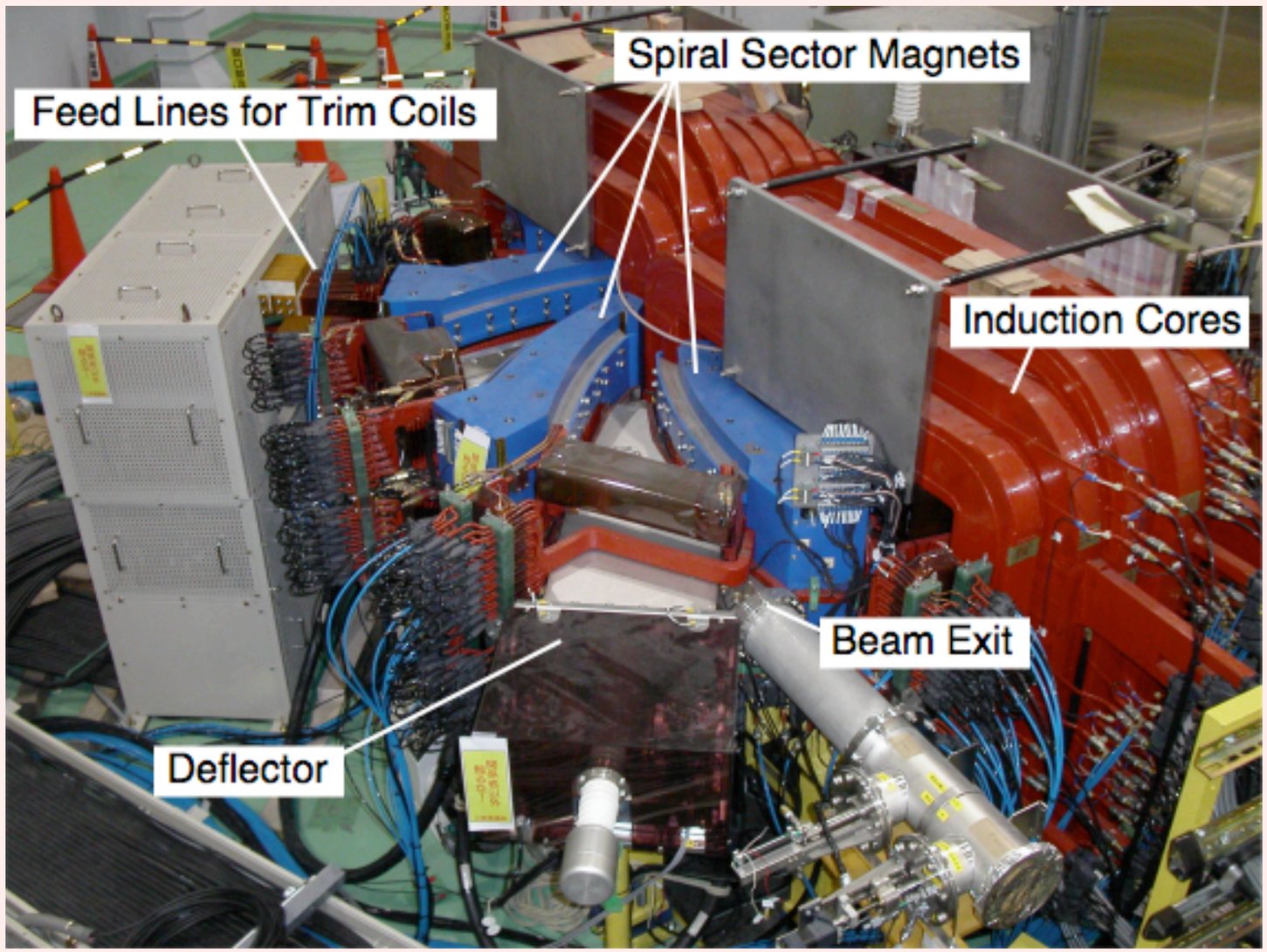
Injector

	Design	operation
E_{inj}	0.1MeV	0.12MeV
E_{ext}	2.5MeV	1.5MeV
Curr.	10nA	10nA
Rep.	120 Hz	120 Hz

Spiral sector magnets
spiral angle = 42 deg

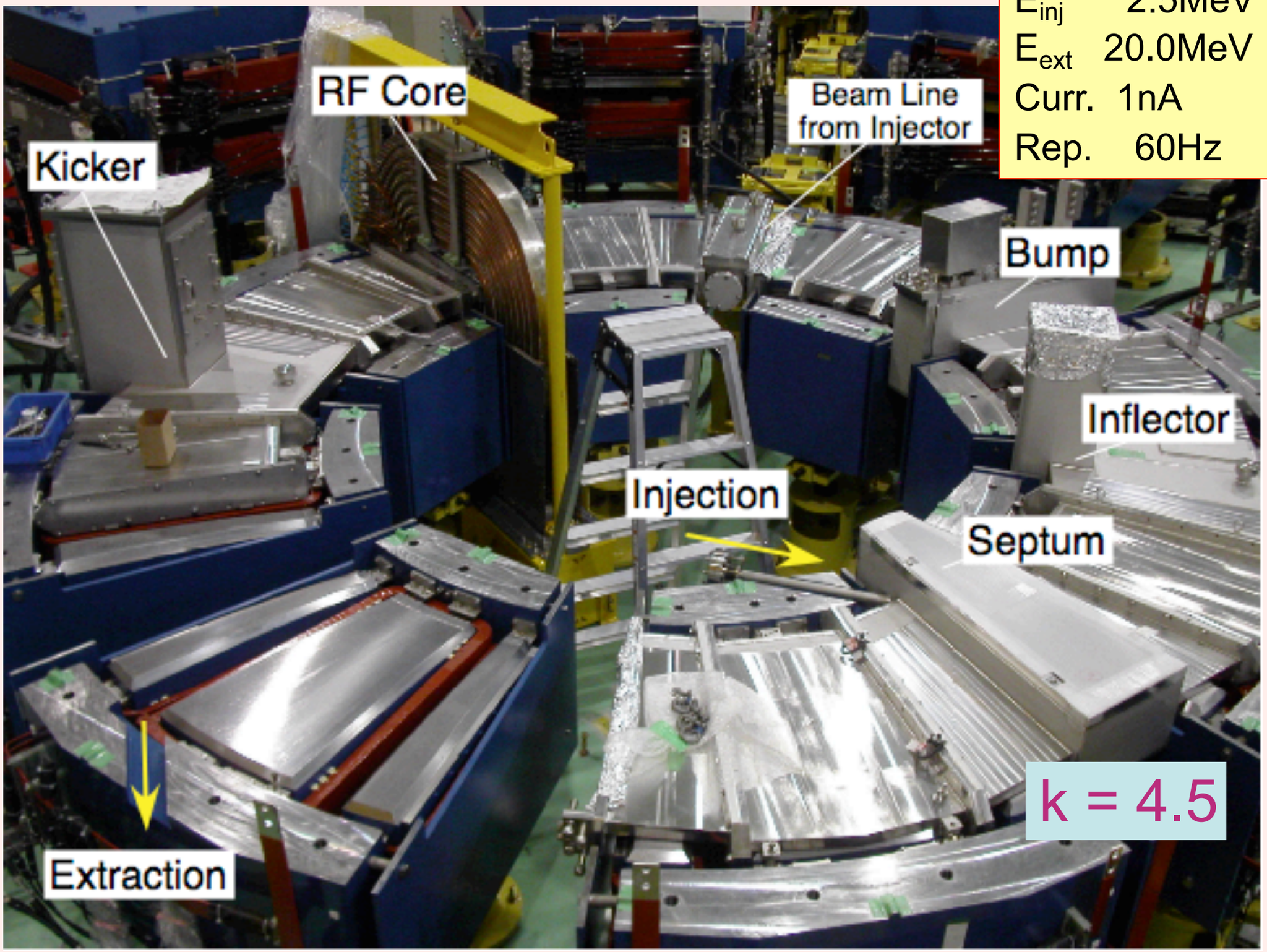
Induction acceleration
500 V/turn

Variable field-index k,
by means of trim-coils

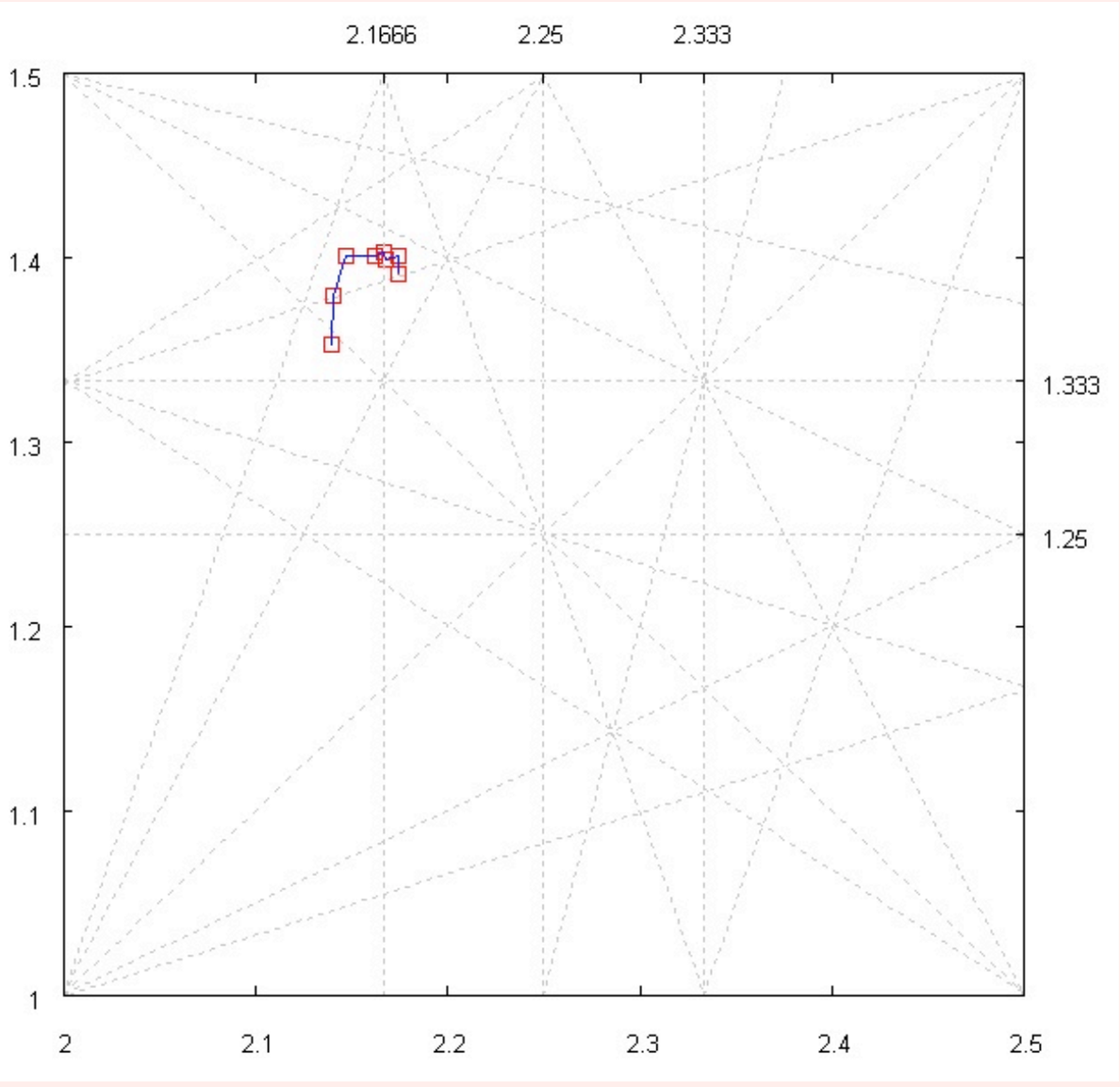


Booster

	Design	Operation
E_{inj}	2.5MeV	1.5MeV
E_{ext}	20.0MeV	11.6MeV
Curr.	1nA	5nA
Rep.	60Hz	60 Hz



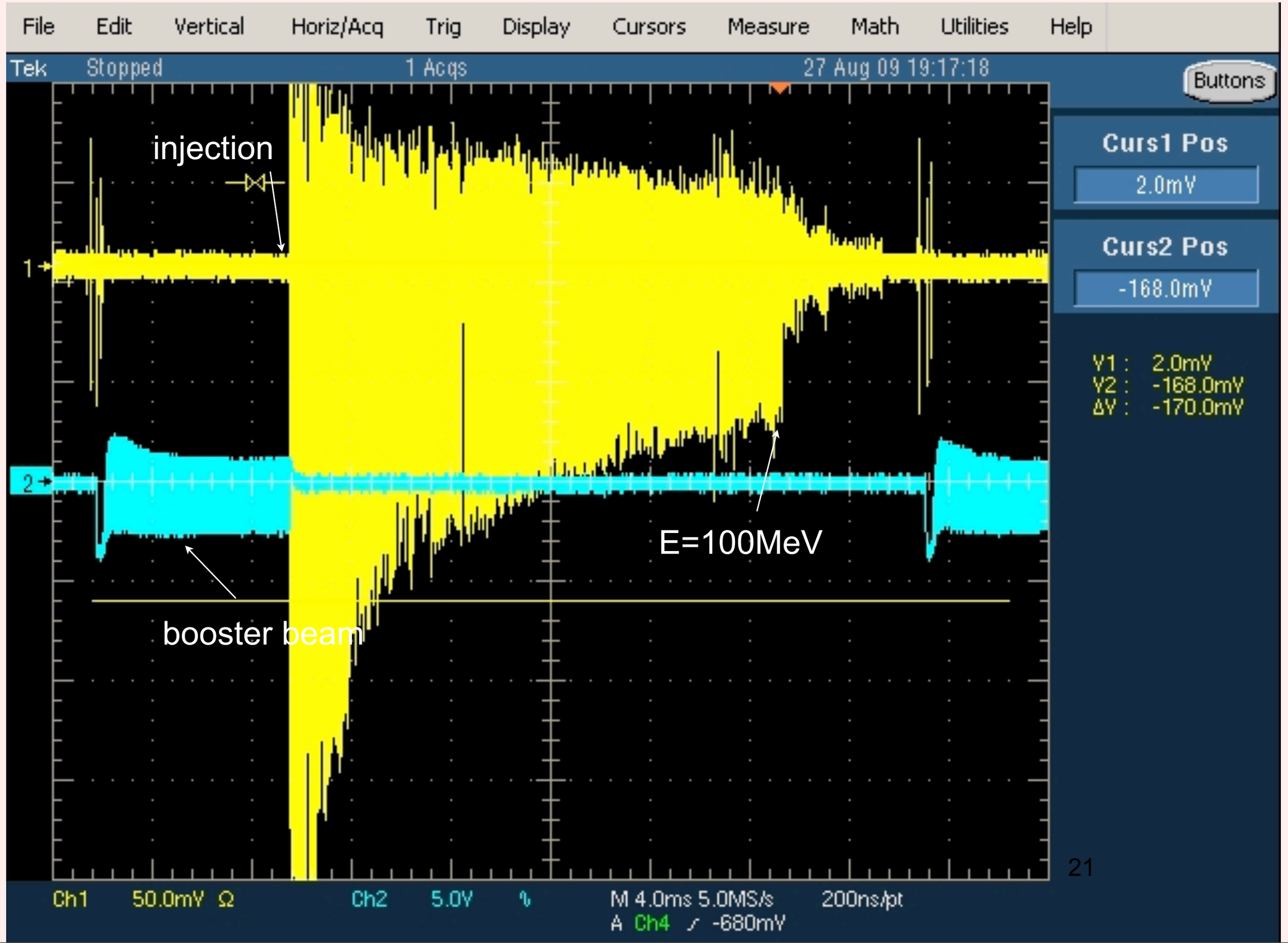
Tunes measured at booster



Perturbation was applied by ..

Horizontal; RF knockout
Vertical ; Vertical exciter (J.B. Lagrange)

Beam Intensity

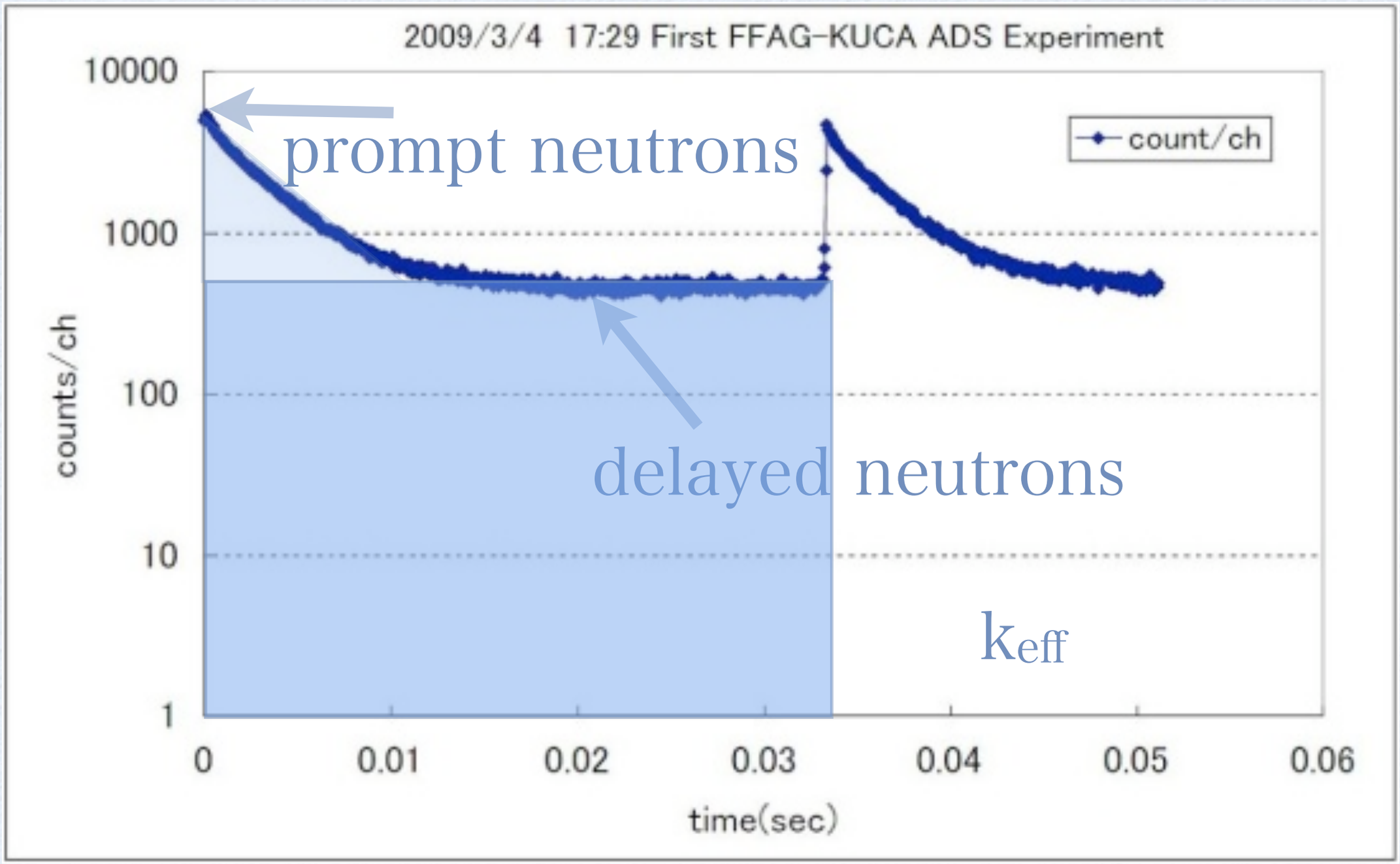


Let's drink

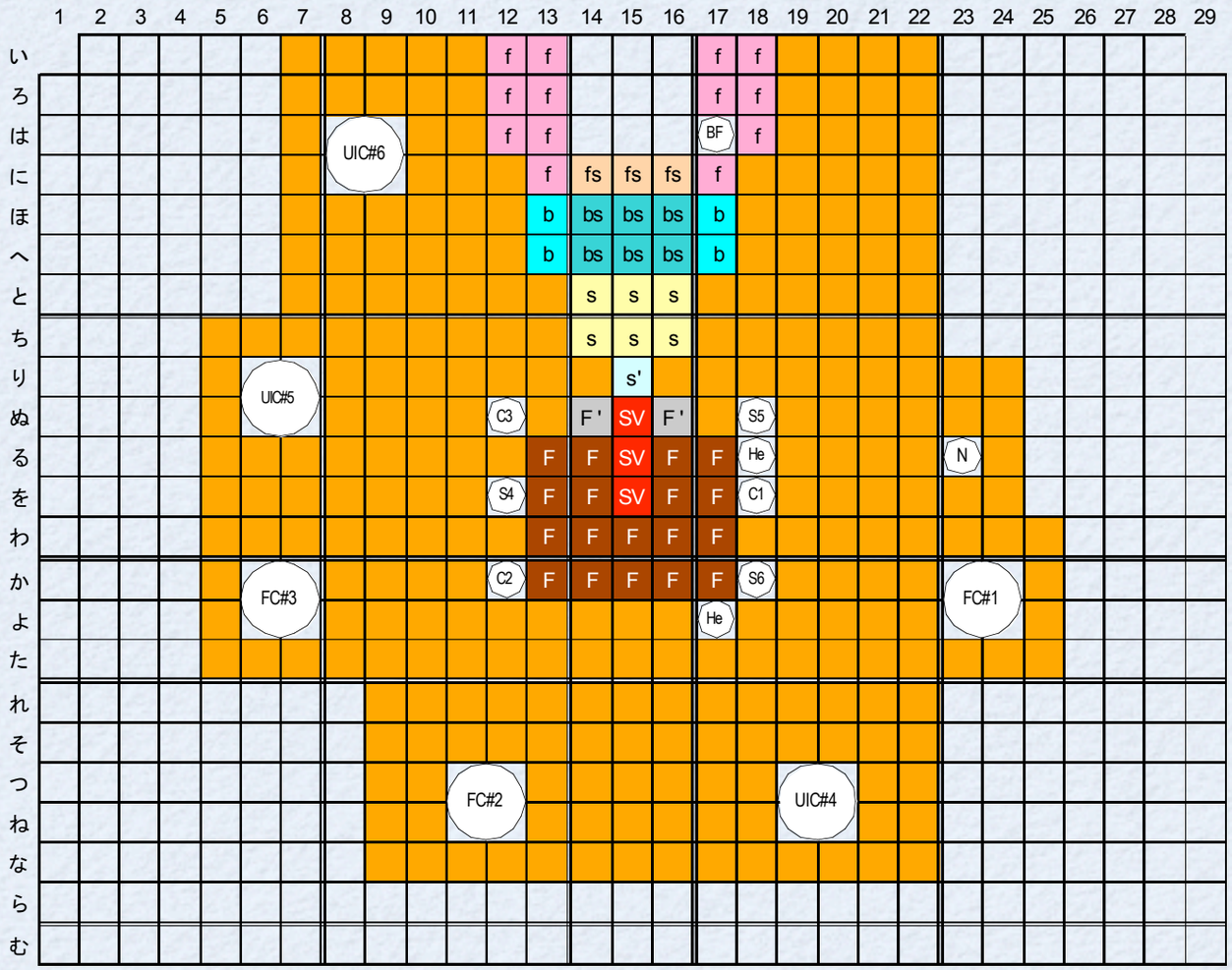
First ADSR experiment

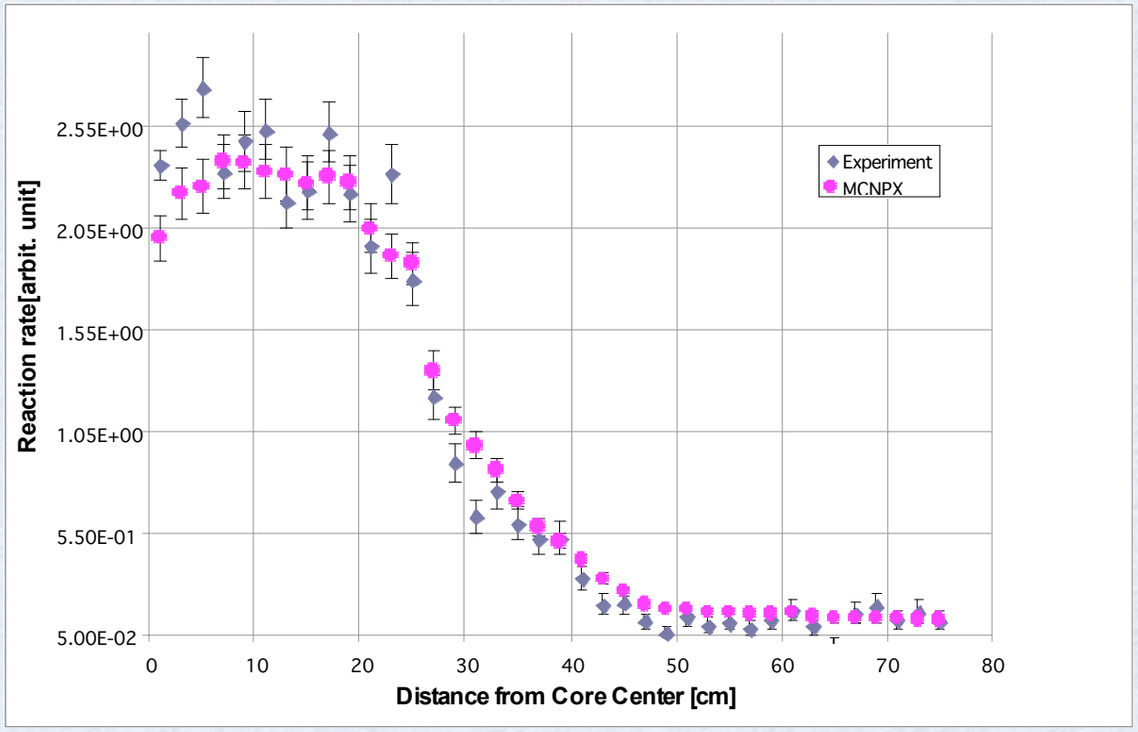
- March 4, 2009　The first beam from FFAG was delivered to KUCA.

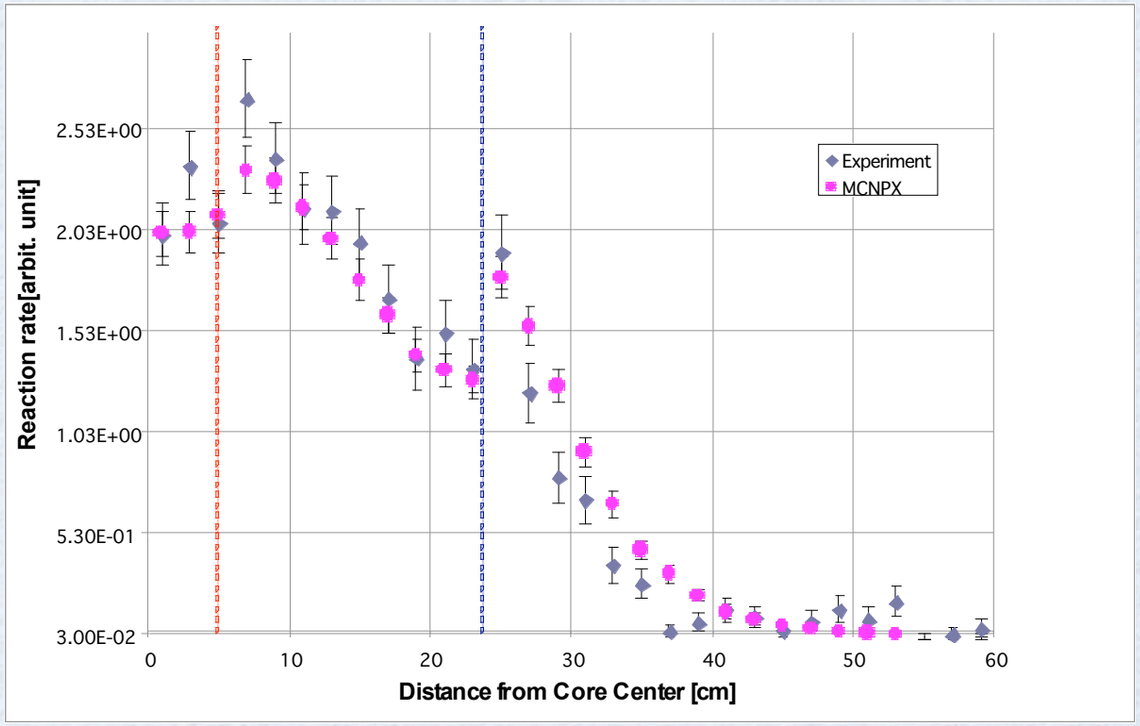
First data of ADSR



Neutron distribution

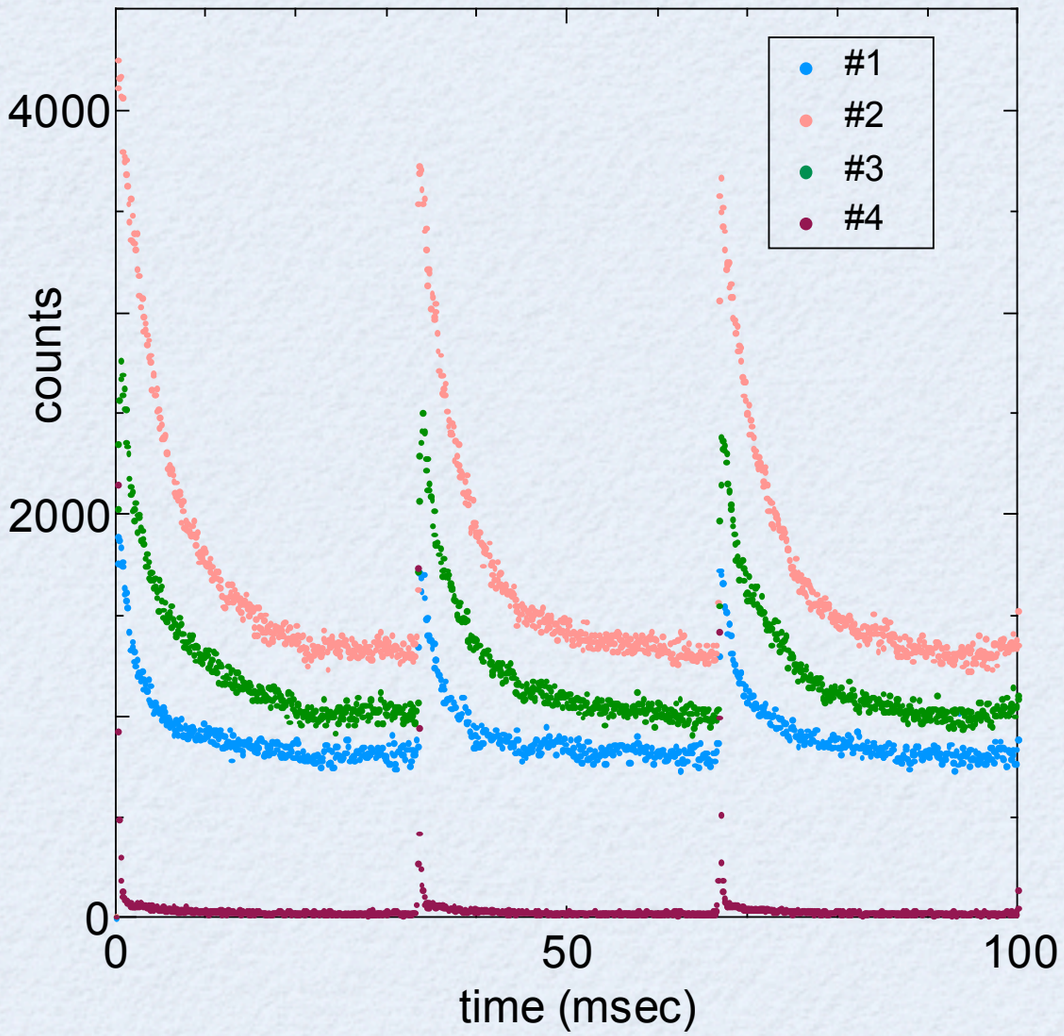


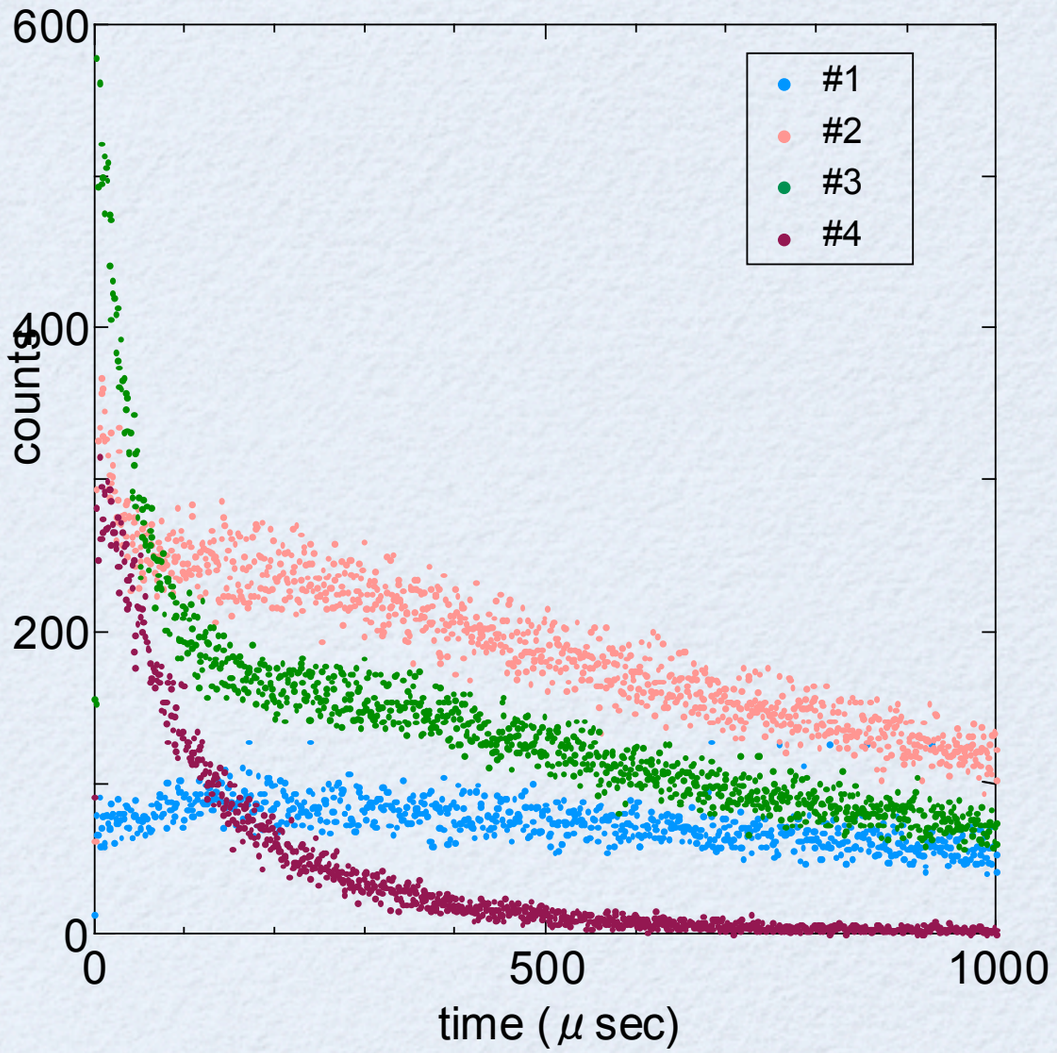




Neutron time sturucture

At various positions in the reactor





Increase of beam intensity >1μA

(under development)

- Beam intensity capability of Main Ring

  ➡Space charge limit ~20μA (@10MeV injection)

  ➡Many protons should be injected!

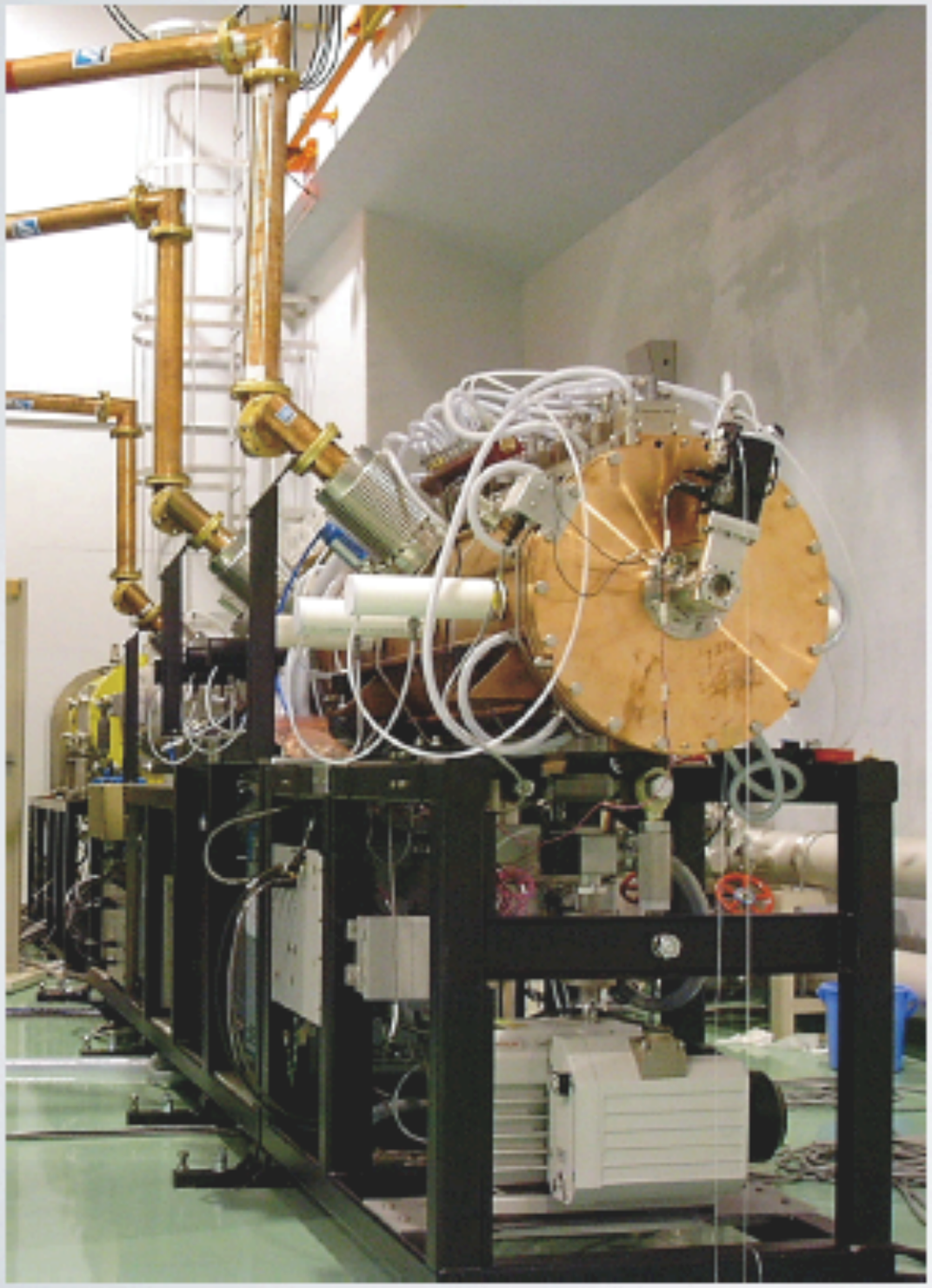
- Charge-exchange injection with H^- beam

  ➡Multi-turn injection (>100turns)

  ➡Need high corrent H- injector

  ➡We have 11MeV H- Linac for FFAG-ERIT.

LINAC



Linac beam para.

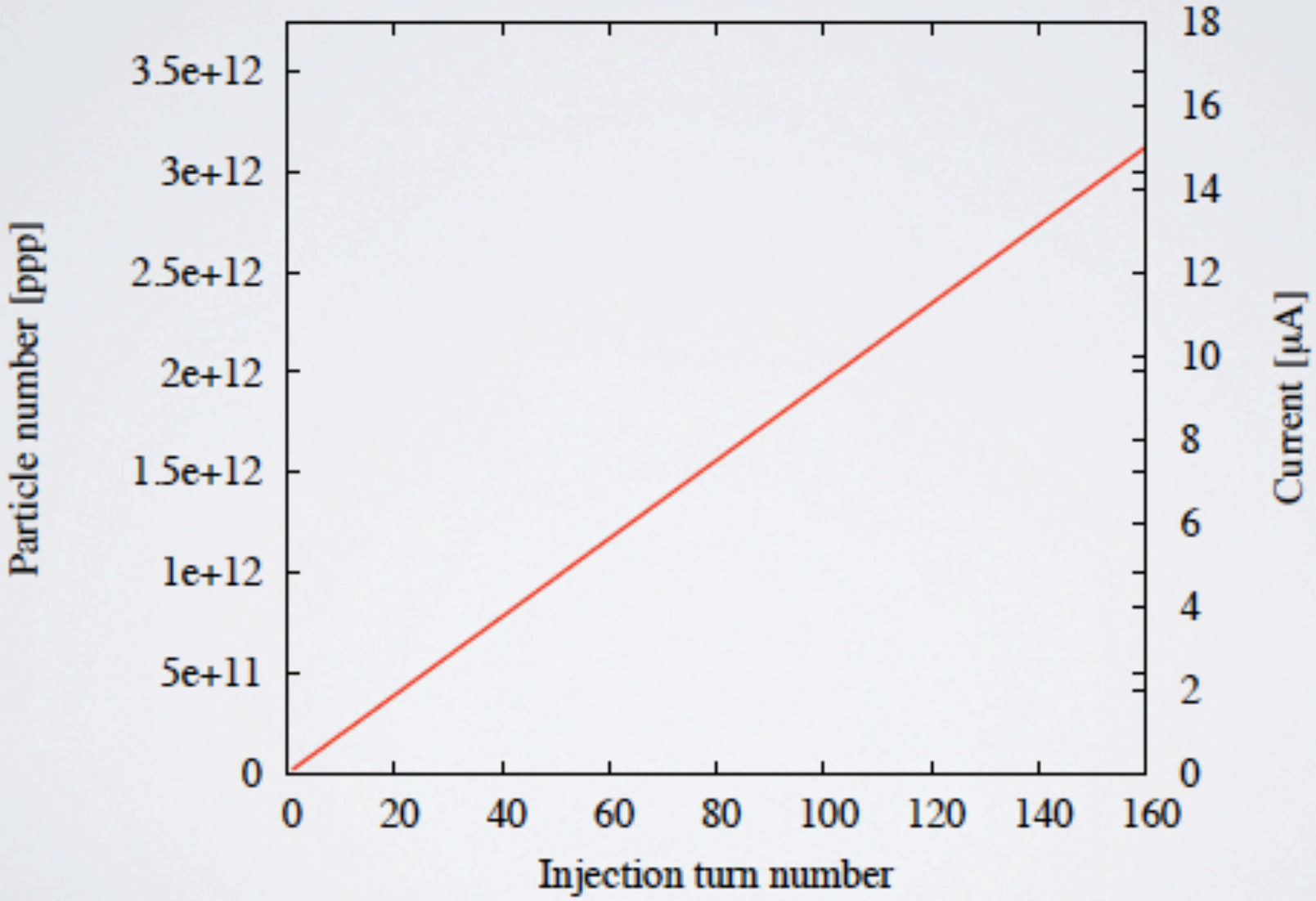
- ion : H^-
- E_{ext} : 11MeV
- Beam Pulse width(MAX) : 100 μsec
- Peak Curr.(MAX) : ~5 mA
  :$3.12*10^{12}$ [ppp]
- rep. rate : 1Hz ~ 200Hz
- unnorm. rms emittance
  Hori. : 0.896 mm mrad
  Vert. : 0.830 mm mrad

Charge-exchange injection

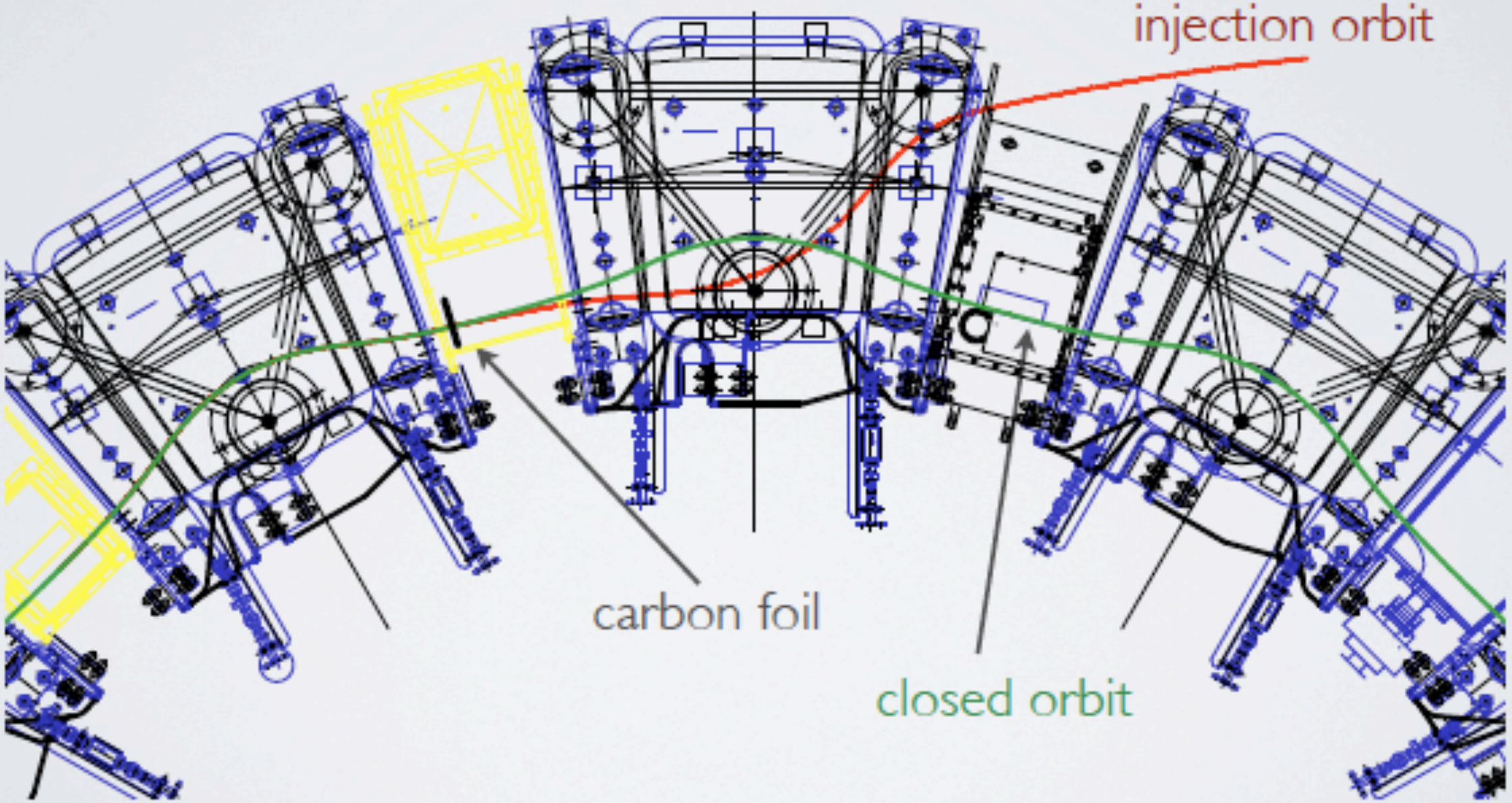
- Low energy (11MeV) cf. 600eV for 20μg/cm^2 C-foil
  - ➡large energy loss
  - ➡large emittance growth
- Energy loss
  - ➡rf re-acceleration as ionization cooling
- Emittance growth
  - ➡Reduction of hitting probability
    - Off-center injection in horizontal direction
    - Moving orbit by rf acceleration (FFAG)

Injection efficiency

MIAN-RING@11MeV rev. freq : 1.582 MHz, (632nsec)
MAX ~160 turn injection(linac-beam pulse: ~100μsec)

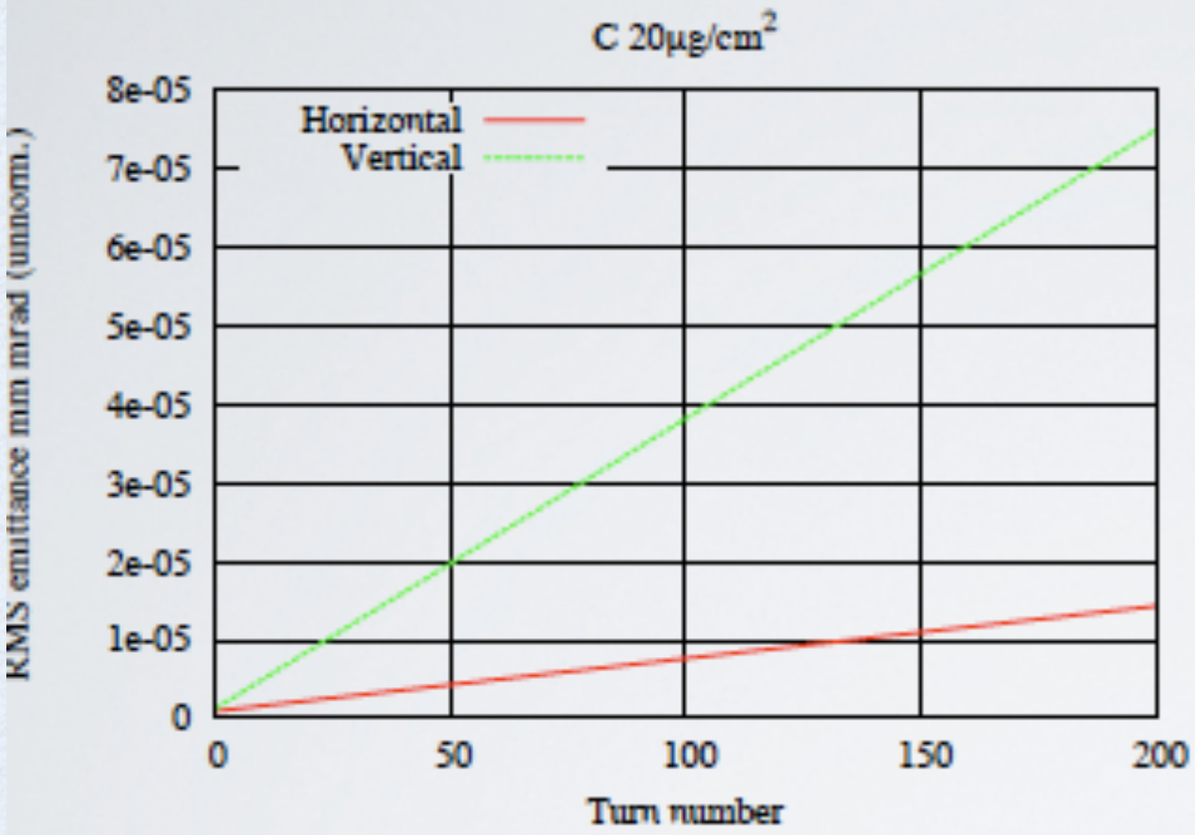


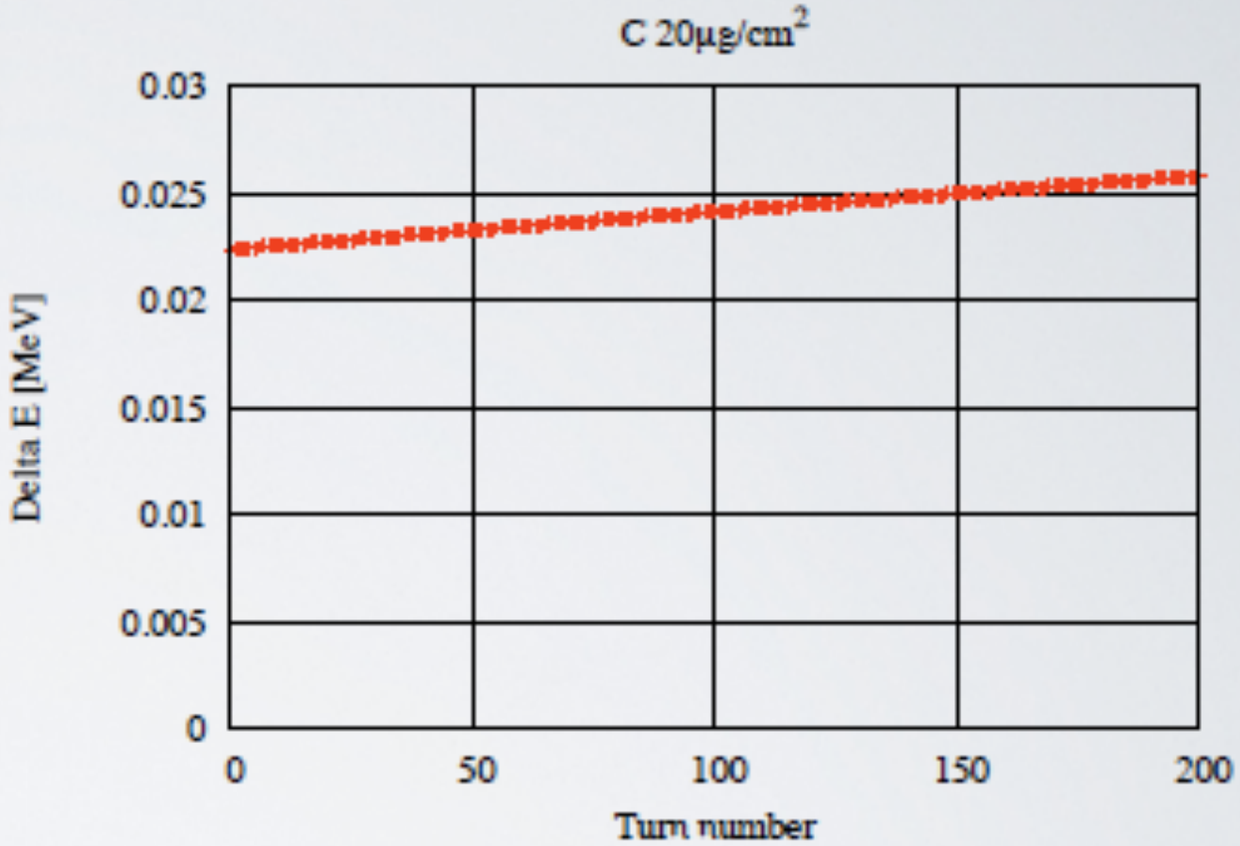
Injetion scheme



Emittance growth

- Vertical emittance ~5 x horizontal emittance
- Longitudinal emittance ~ negligible



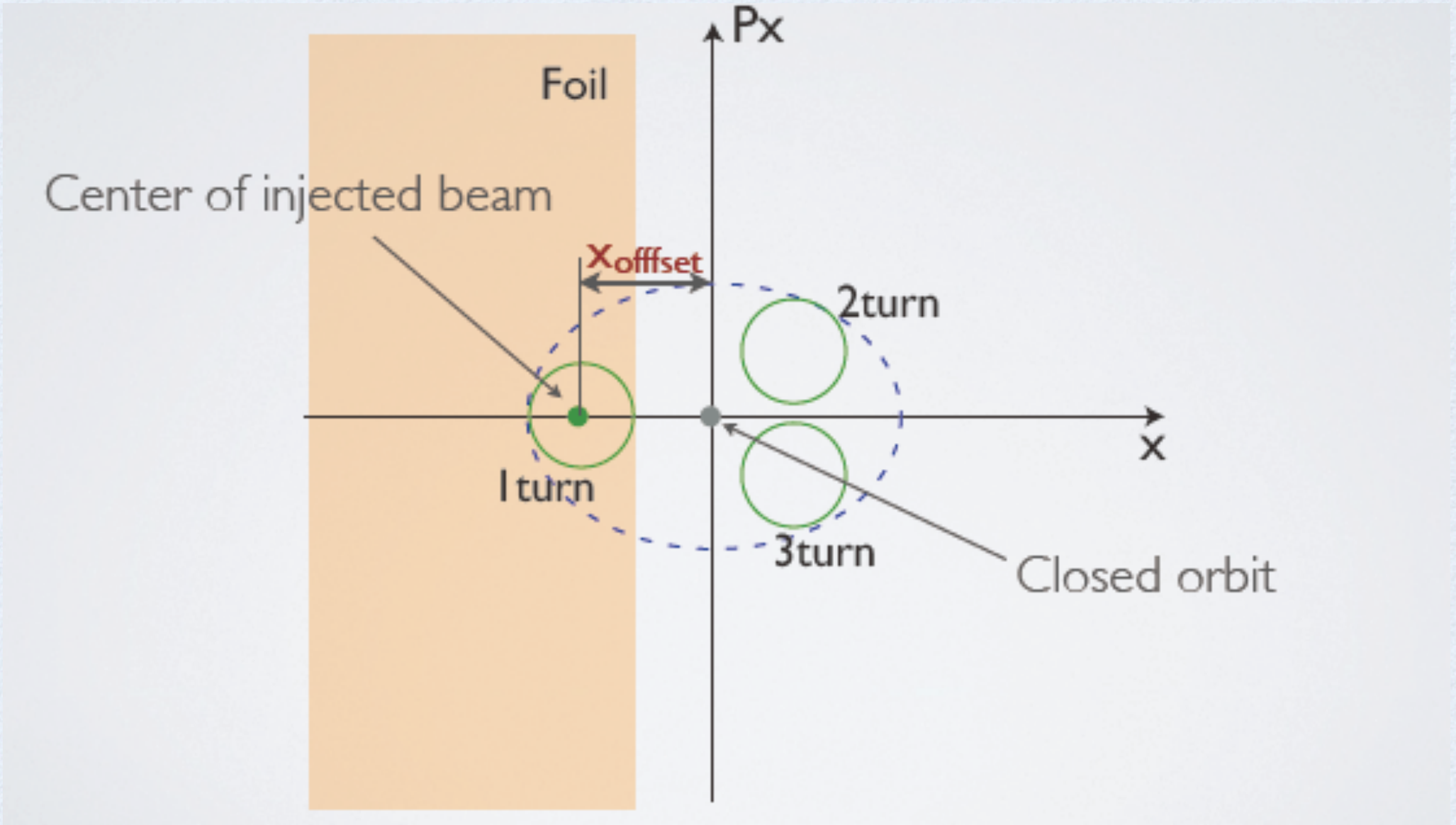


foil : 20 µg/cm^2

Reduction of emittance growth

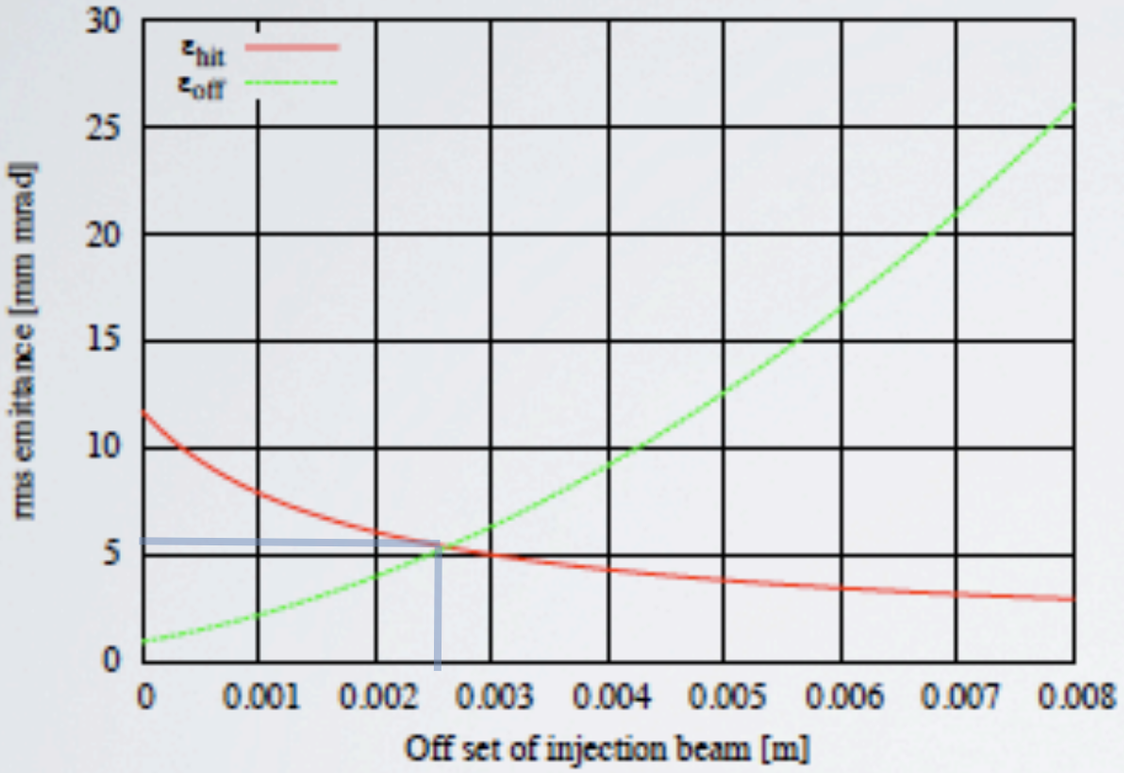
- Hitting probability

➡Off-center (hor.) injection →betatron mismatch

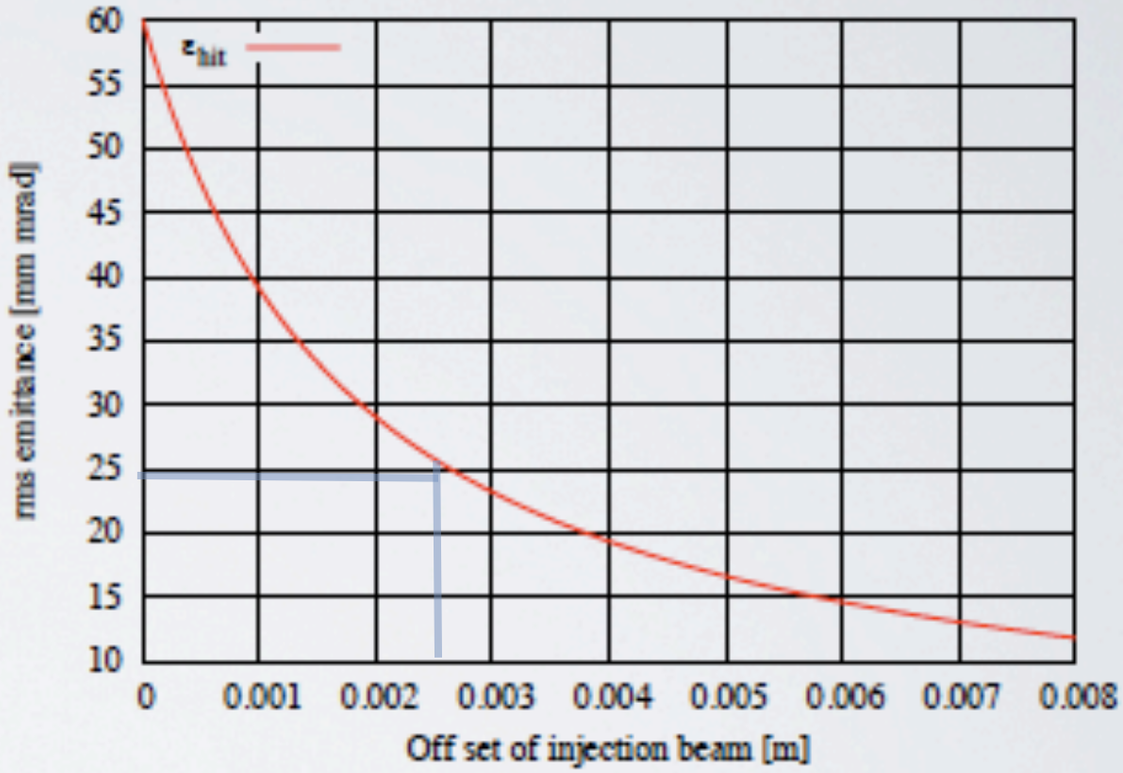


Reduction of emittance growth

Horizontal



Vertical



off set ~2.6mm

$\varepsilon_x \sim 7.7$ mm mrad

$\varepsilon_y \sim 25$ mm mrad

$(\varepsilon_{total}^2 \sim \varepsilon_{off}^2 + \varepsilon_{hit}^2)$

Summary

- First ADSR experimental study with FFAG proton accelerator was successfully carried out.