OPTIMIZATION OF H-INJECTION

2013.09.21

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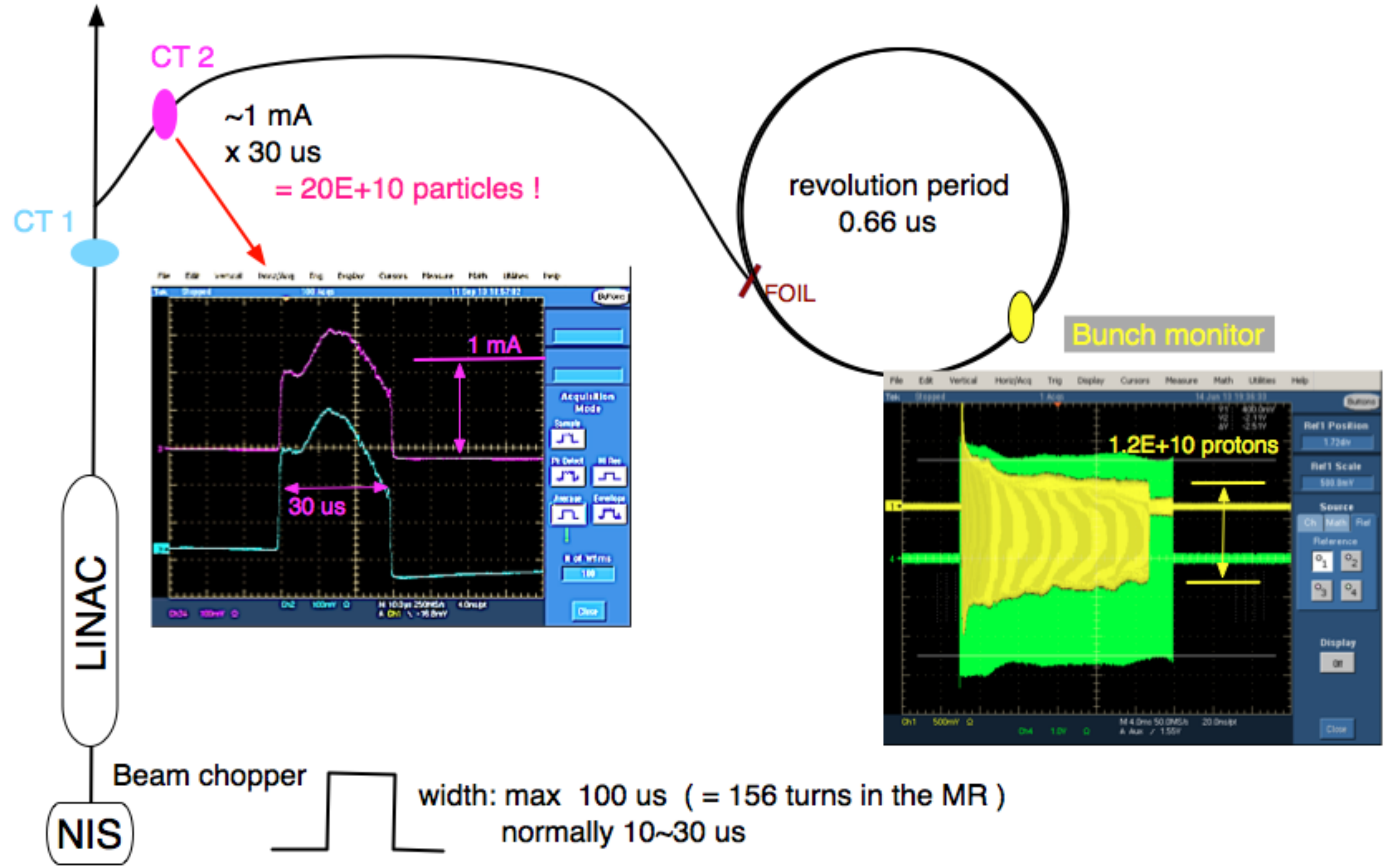
KURRI

====== INTRODUCTION ======

Beam currents in present operation

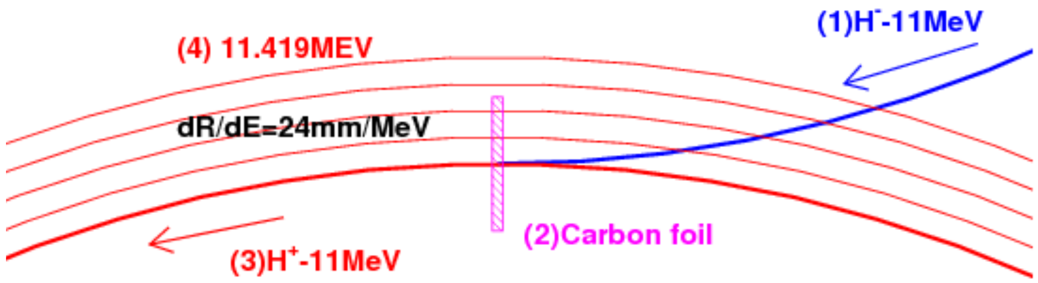


Charge-exchange multi-turn injection without Bump-magnets

The injected beams escape from the foil
by rf acceleration:

$$N\text{turn} = \frac{dE}{dR} \times \frac{\Delta R_{\text{foil}}}{V \sin \phi_s}$$
$$= \frac{1}{24\ \text{mm/MeV}} \times \frac{10\ \text{mm}}{4\ \text{kV} \sin \phi_s}$$

(~ several 100 turns)



Circulating beams hit the foil
many times.

(offset inj)

What is problem ?

Energy loss

$$\Delta E_{\text{loss}} = 760 \text{ eV/turn}$$

Synchronous phase shift

$$V \sin \phi_s = V \sin \phi_a + \Delta E_{\text{loss}}$$

Multiple scattering
(neglected in this study)

Transverse emittance growth
(neglected in this study)

Overheating of the stripping foil
This can give the intensity limit in future

Maximum capture efficiency with
Minimum foil-hitting turn no.

Condition of charge-stripping inj scheme in KURRI-FFAG MR

* See K. Okabe in this workshop

Injected beam

- Peak intensity : < 5 mA
- Pulse length : < 100 us

Stripping foil

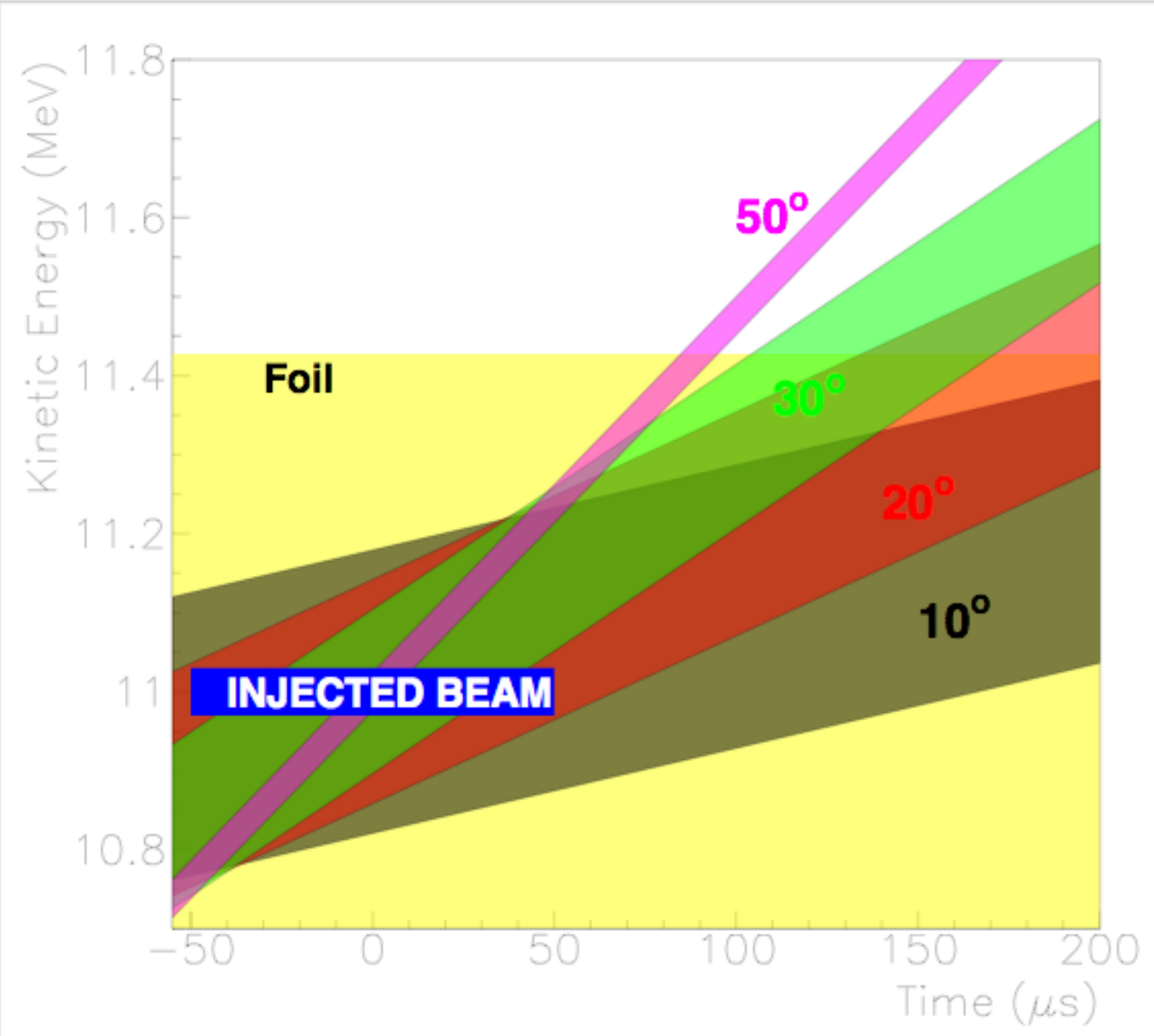
- Thickness : 20 ug/cm^2 (10 ug/cm^2 is under consideration)
- Energy loss : 760 eV/ turn (From Bethe's formula)
- Width : 25 mm

RF system

- Maximum voltage : 4 kV

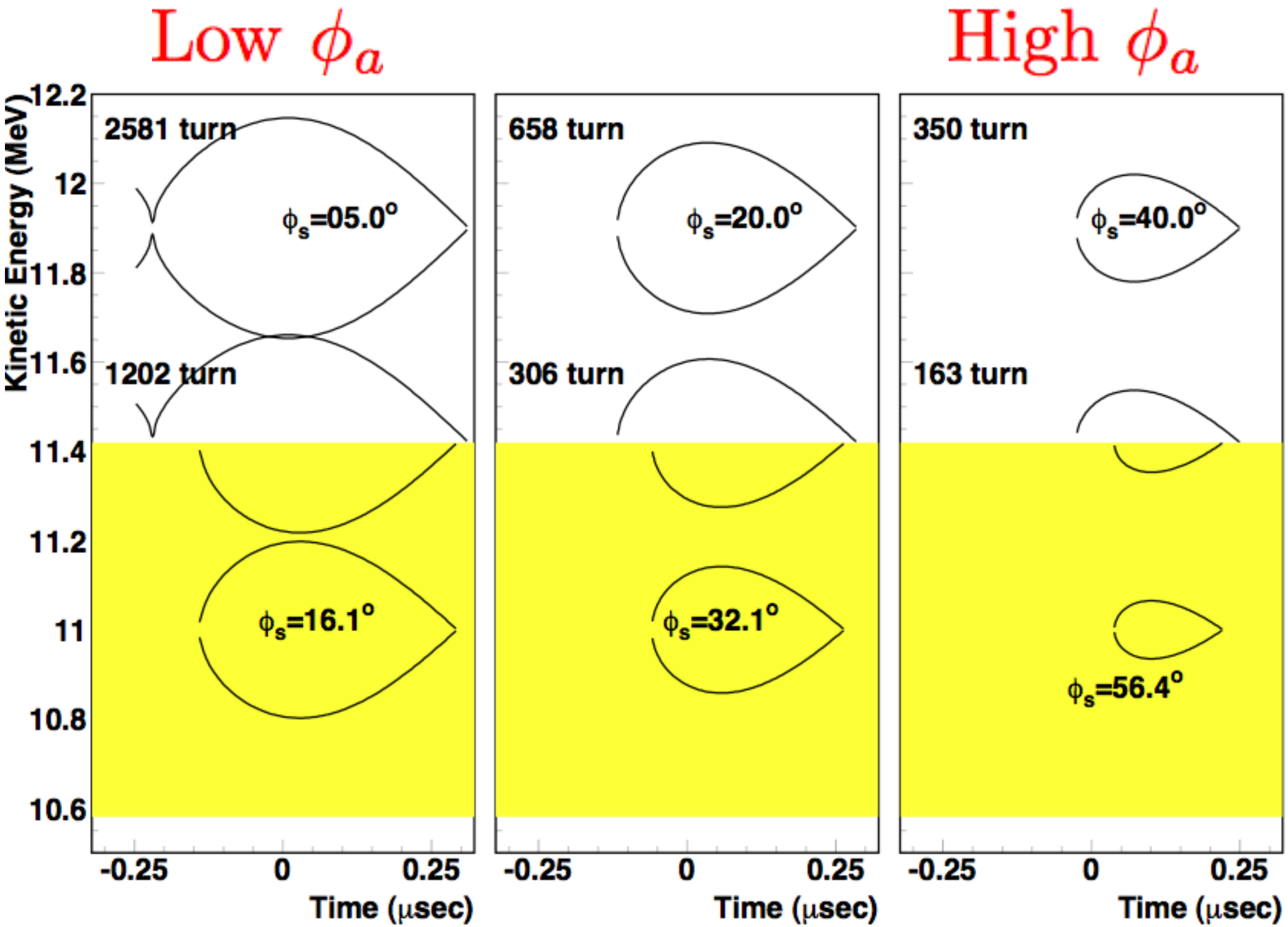
Schematic diagram

Acceleration at constant PHI_a



Bucket areas are plotted here

Choosing acceleration phase



Choosing acceleration phase

Low ϕ_a

- Large bucket area
  . high capture efficiency
- Slow acceleration speed
  . long duration at E_{inj}
  . many foil-hits by particles
  . strong ‘boundary-effect’

High ϕ_a

- Small bucket area
  . low capture efficiency
- Fast acceleration speed
  . short duration at E_{inj}
  . few foil-hits by particles
  . weak ‘boundary-effect’

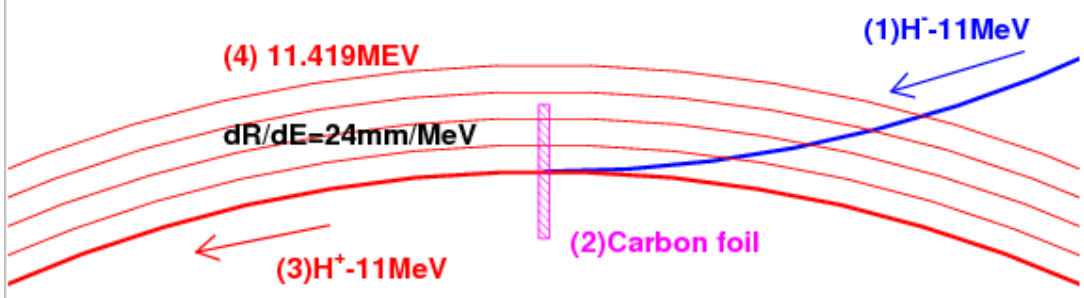
trade-off

--> Simulation studies are necessary !!

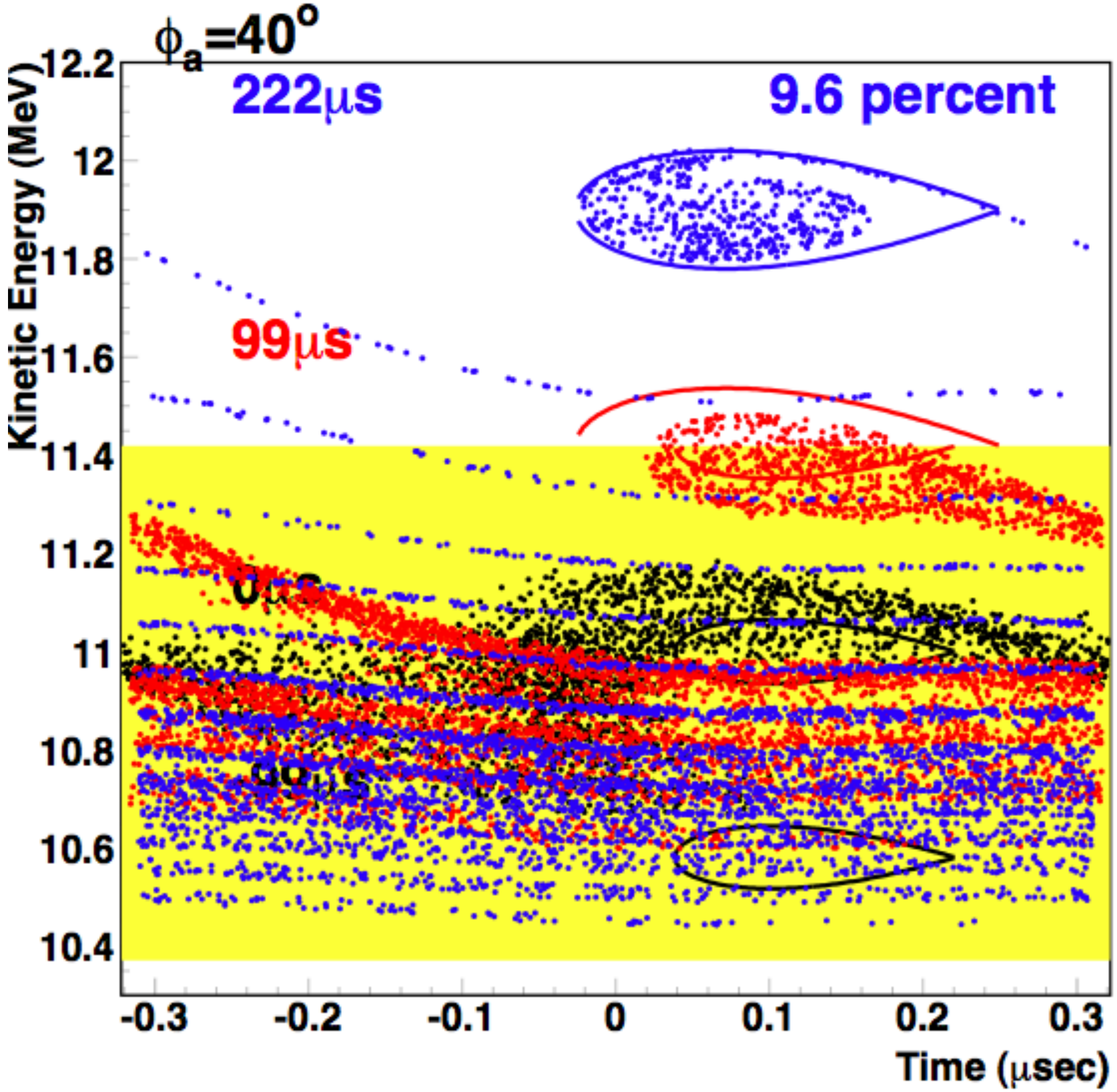
====== SIMULATIONS ======

Simulation model

- Simple kick-drift algorithm_
- Particles are injected during first 100us.
- Uniform energy loss 760 eV each turn,
  for particles whose energy is less than threshold.
- The threshold corresponds to the foil edge.
- Transverse motions are neglected.
  Offset injection is not adopted.

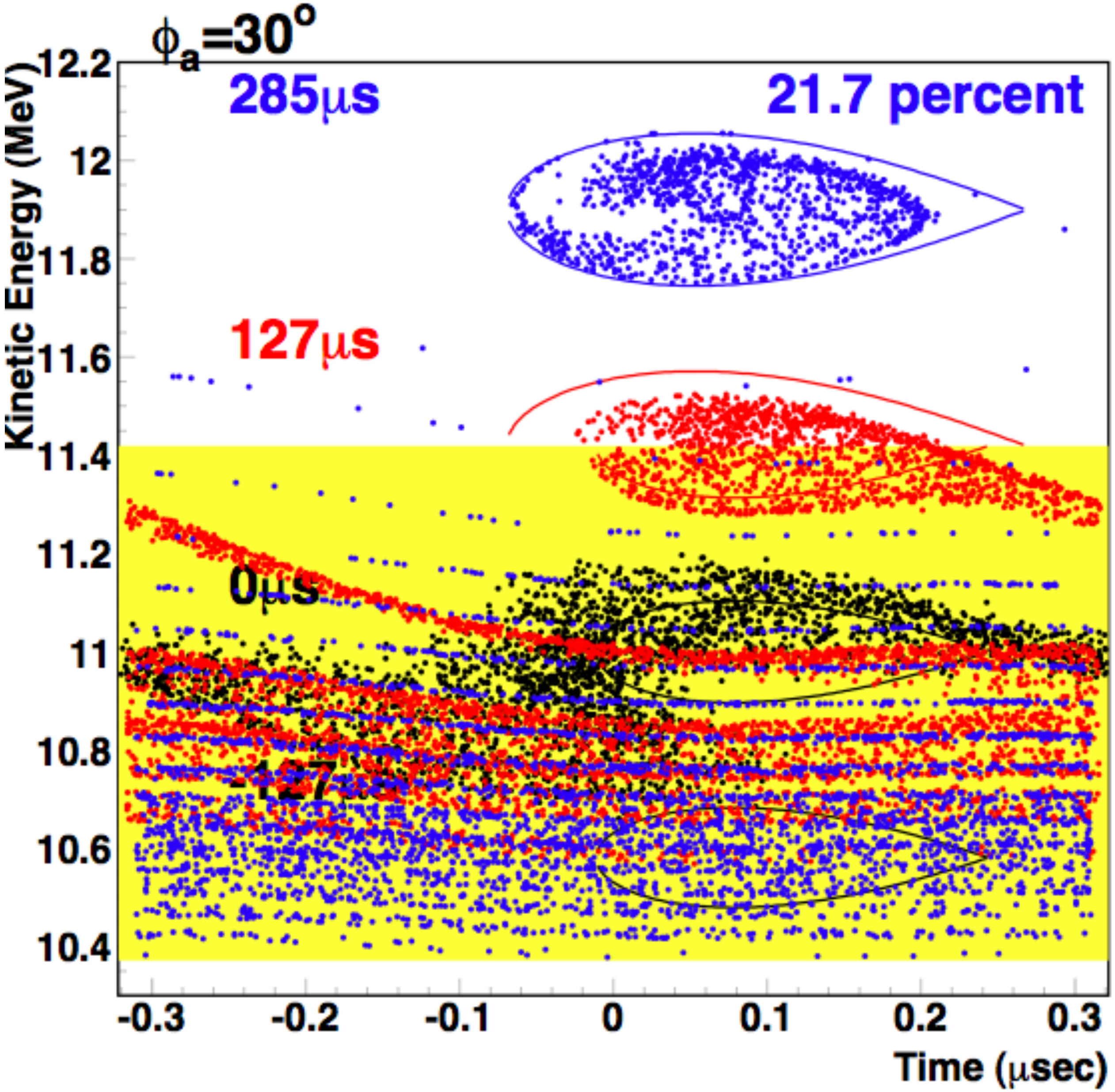


Example (1) Fast acceleration



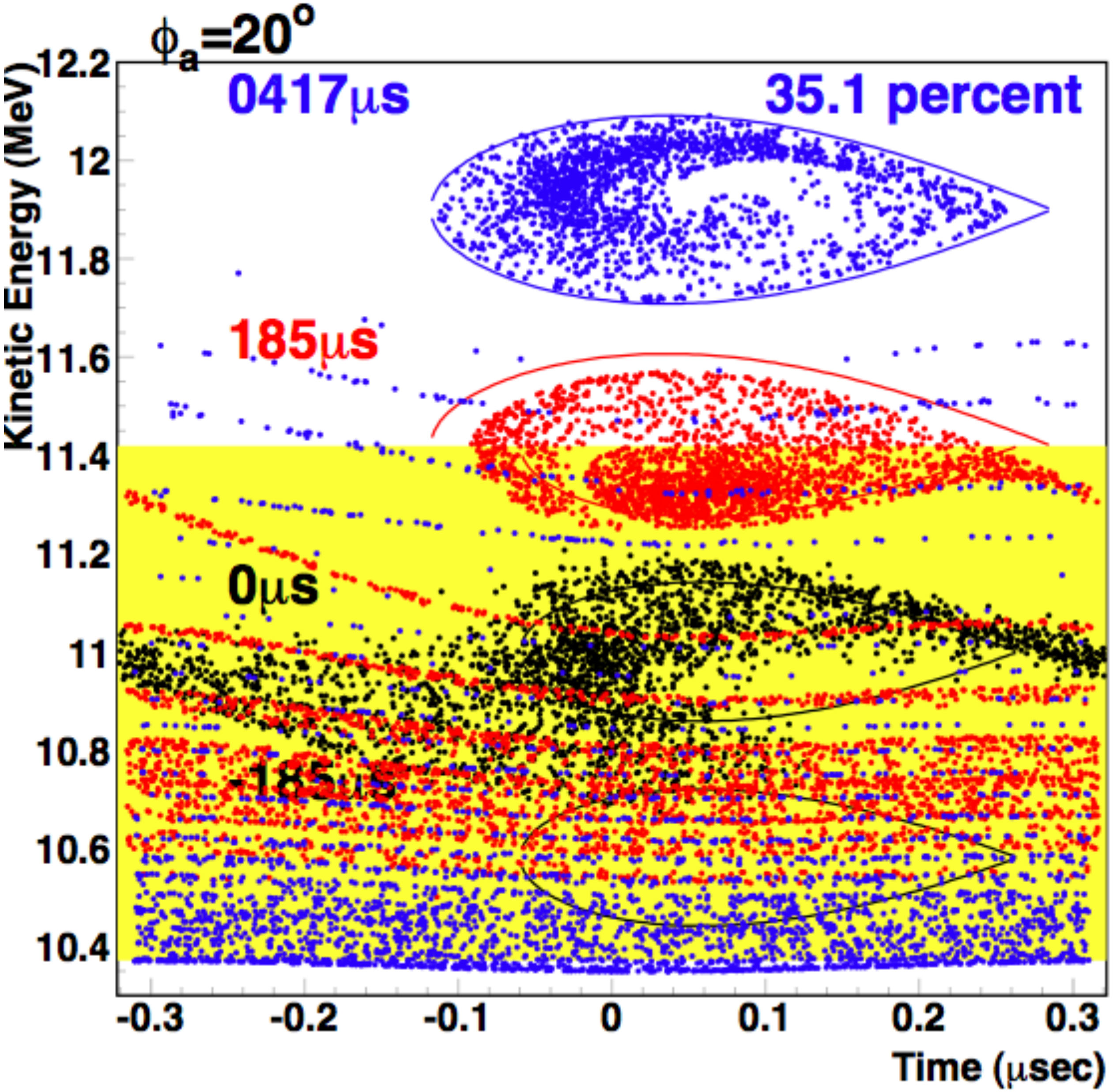
$\phi_a = 40^o$

Example (2) Present operation



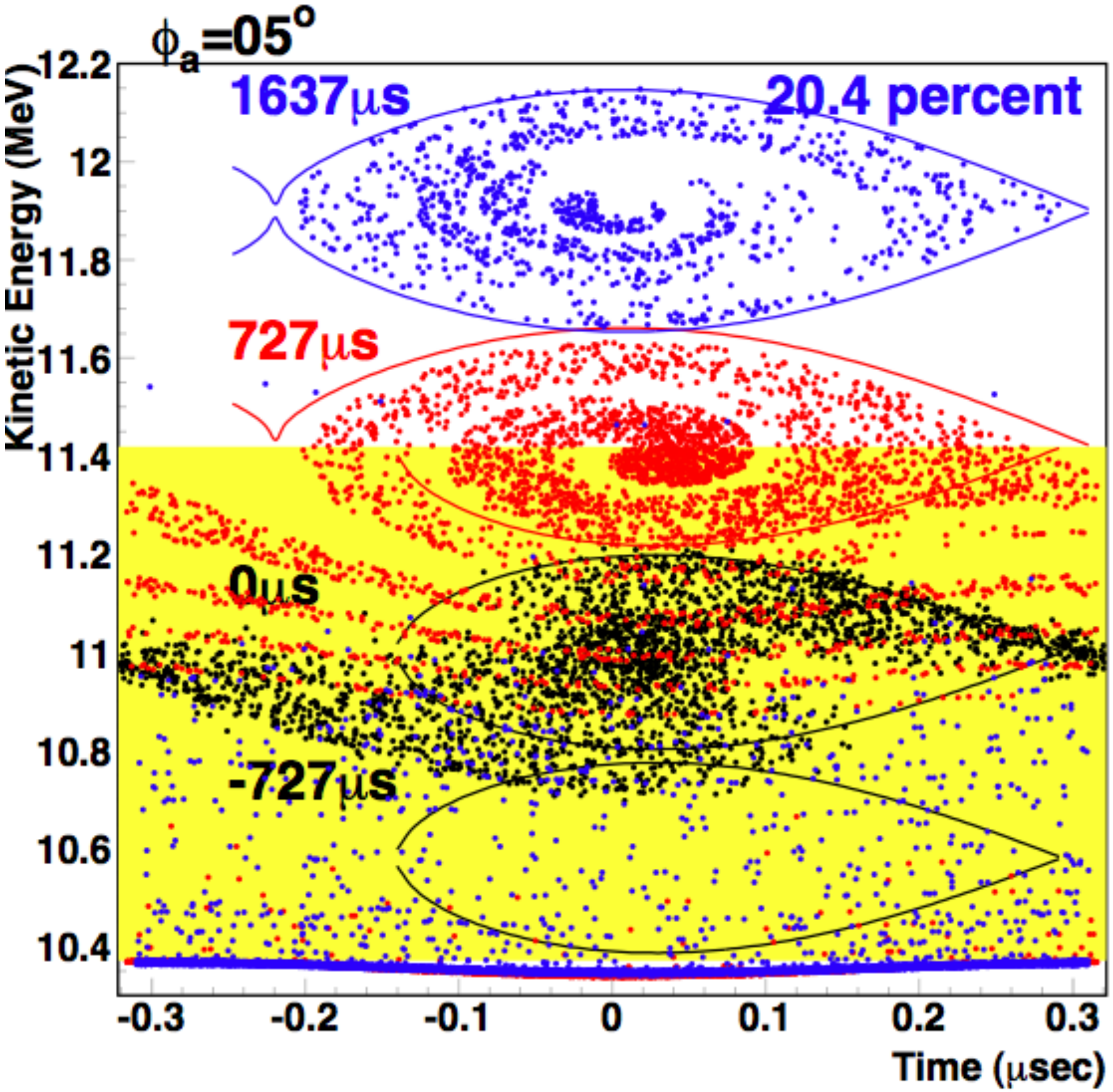
$\phi_a = 30^o$

Example (3) etc…



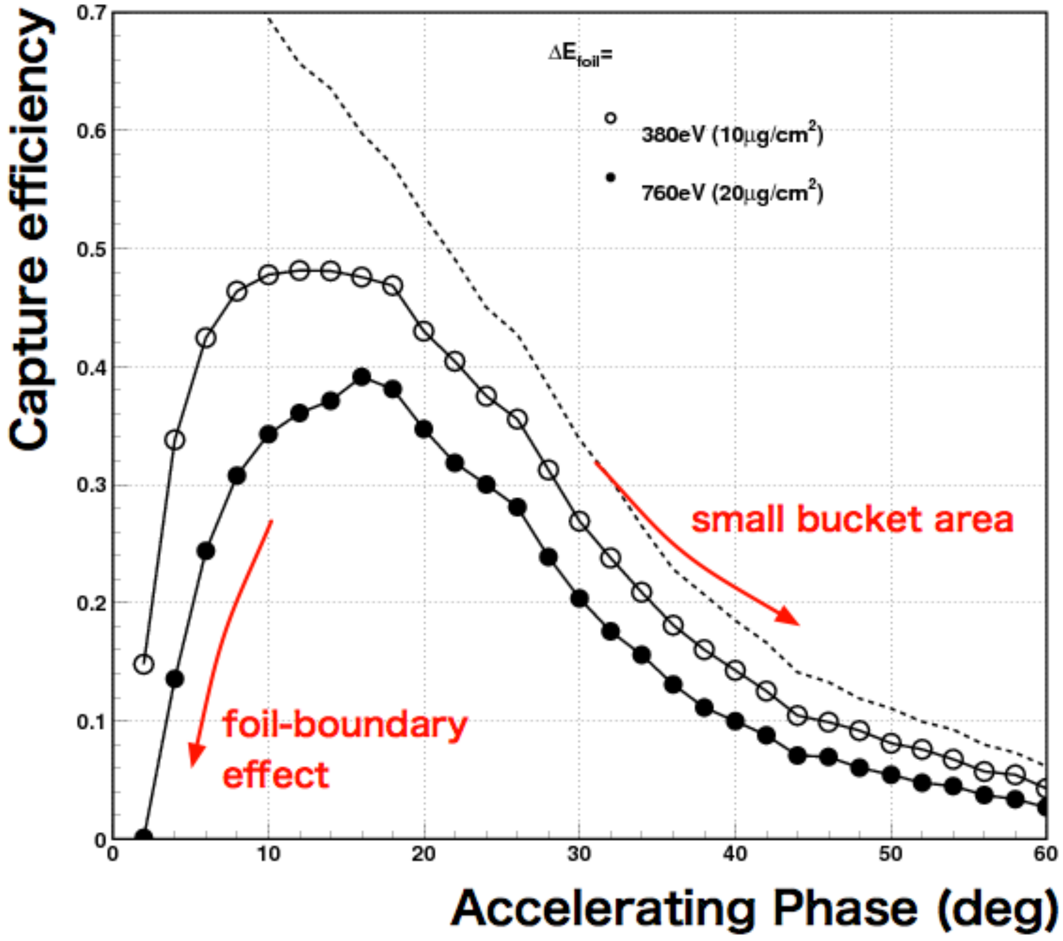
$\phi_a = 20^o$

Example (4) Large bucket



$$\phi_a = 5^o$$

Capture efficiency depending on ϕ_a .



Efficiency takes maximum around

$$\phi_a = 10^o \sim 20^o$$

But, how about the number-of-foil-hit? -->

====== EXPERIMENTS ======

With fully injected beam

1. Dependence on Capture-rf phase

- to find the best rf-phase for capture
    - too fast --> narrow bucket area.
    - too slow --> many foil-hit and emit. growth.

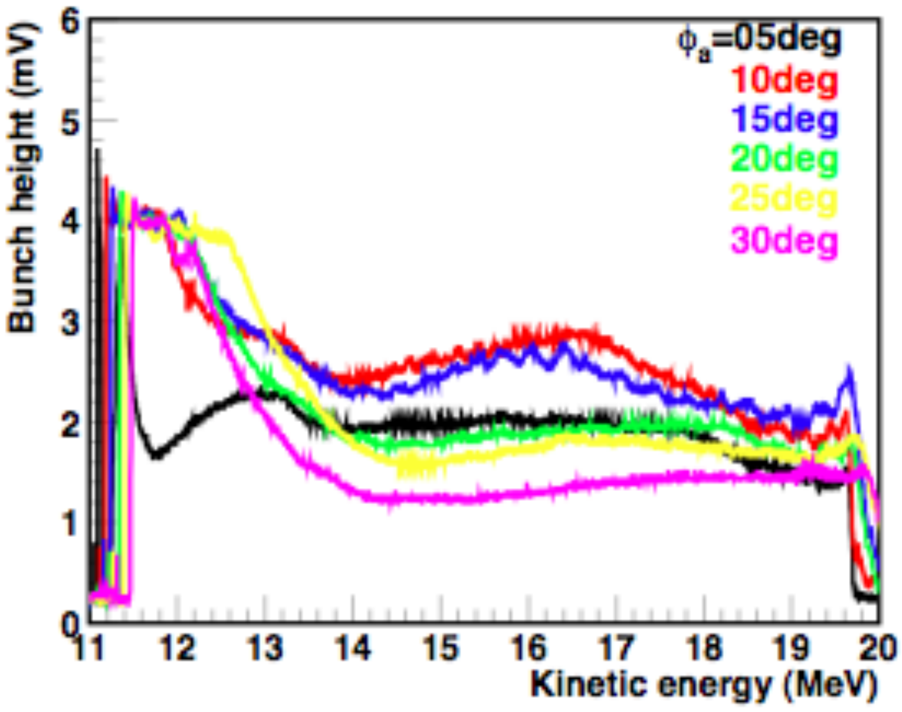
- Acc phase of 5, 10, 15, 20, 25, 30deg were tested

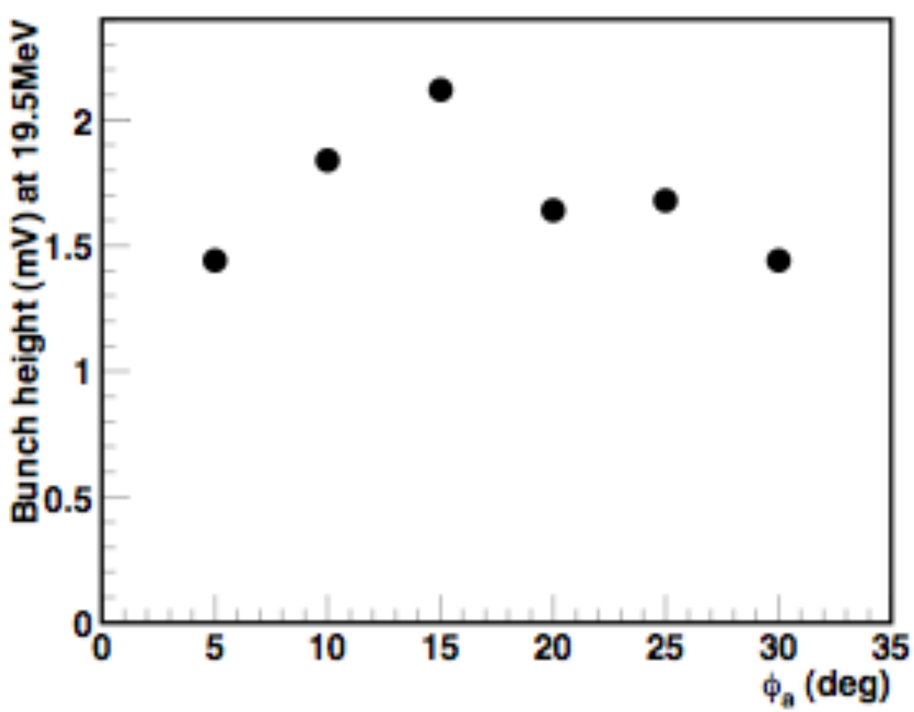
- Acceleration up to 20 MeV was enough to escape from the foil.

- Long-beam was injected.
  Bunching time, synchrotron oscillation at very beginning of injection

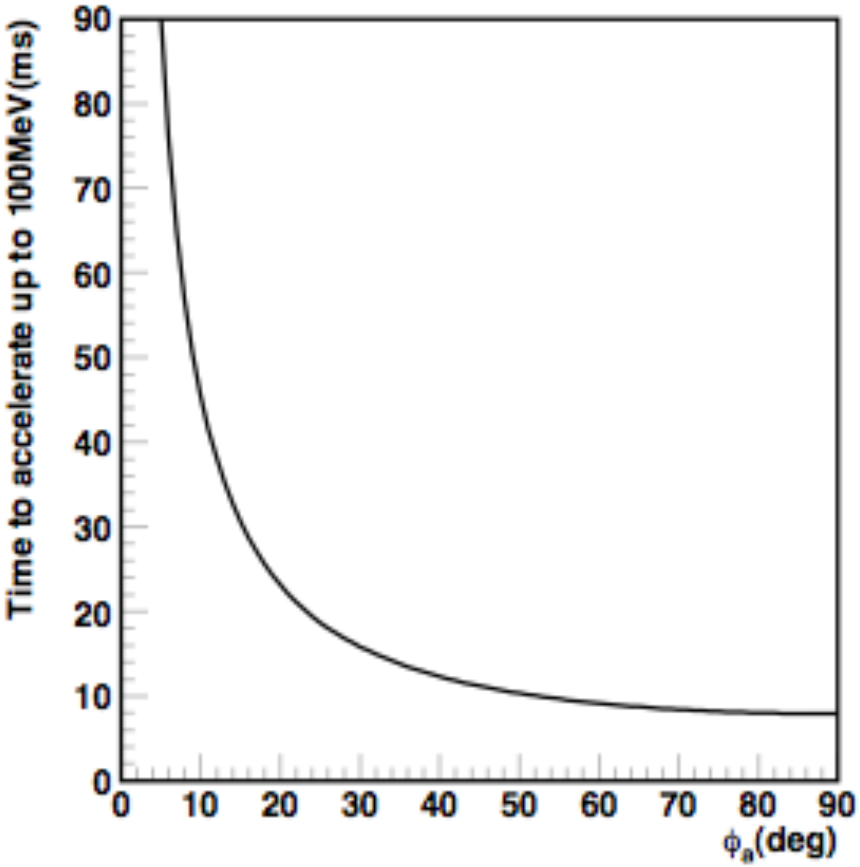
Results 06.12

PHIa of 10~20deg seems the best.
This is consistent with the simulation.





Smoothly Connecting to higher PHIs after capture



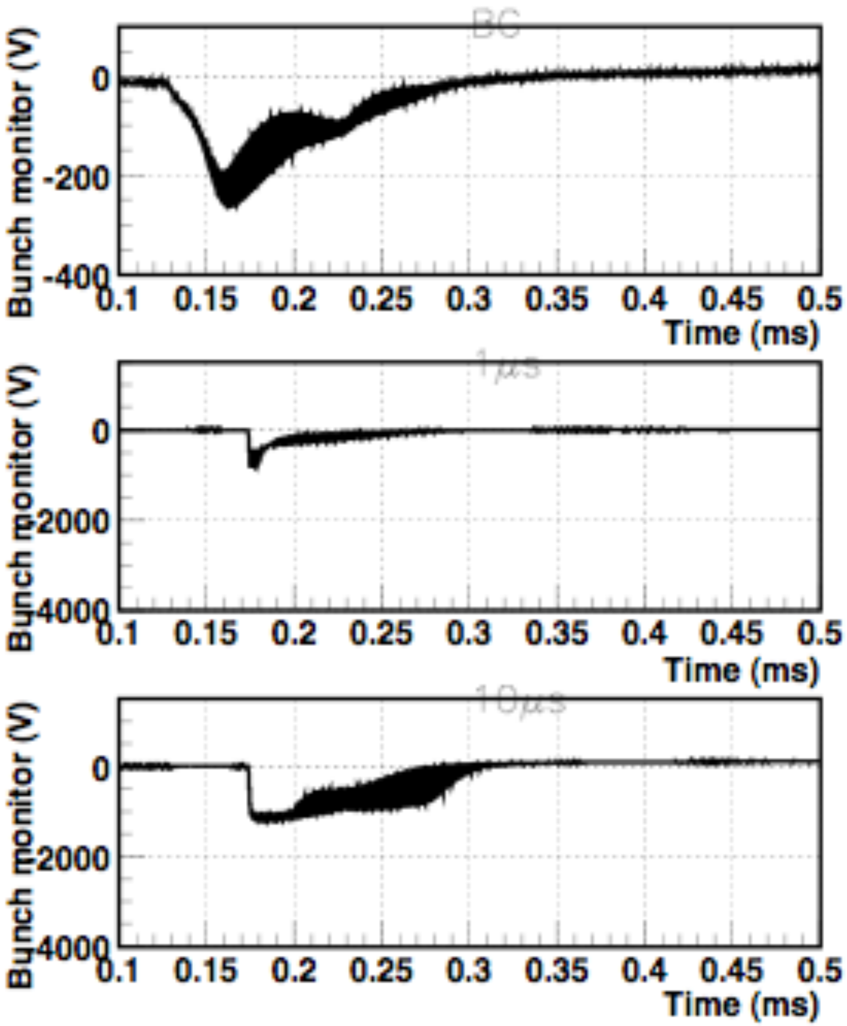
With PHIs = 10 deg
it takes 40ms to accelerate
up to 100MeV.

In order to increase the repetition cycle, PHIs should be Increased smoothly.

=== EXP with Chopped Beam ===

It turned out that most of the data are useless,
because the chopper did not work very well.

Chopper did not work well



Leak output beam from linac

2. Measurement of Transverse Emittance Growth in the Foil

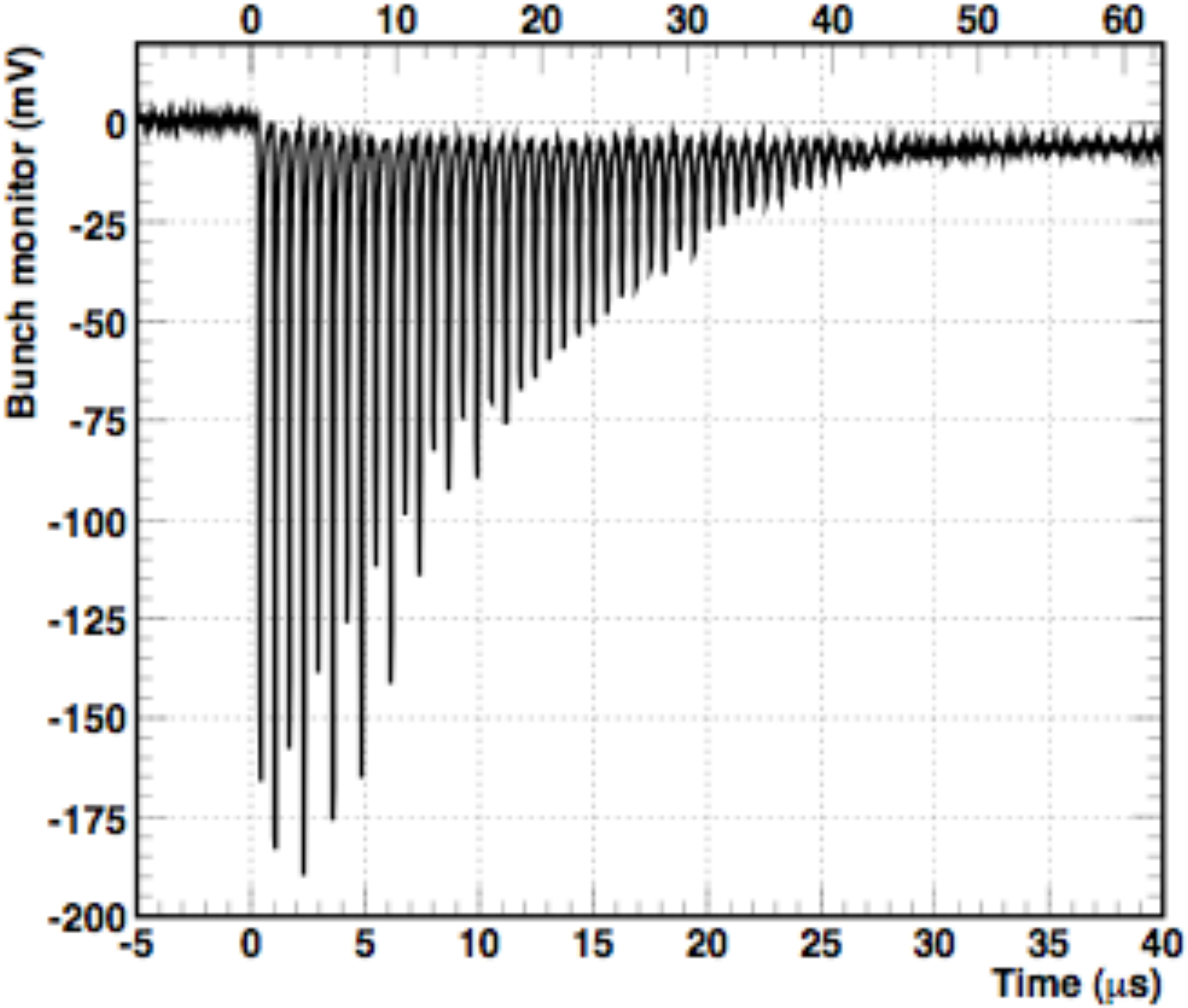
Just plan

- Constant rf frequency
  ---- no emittance growth due to acceleration

- Injection beam is chopped and matched with rf bucket
  ---- so that the longitudinal motion get equilibrium very fast

- Restrict vertical aperture by a probe and measure the beam-loss time vs aperture height

Preliminary results



Aperture = 25mm
Chopper width 0.2us (~Trf/3)

Knob;

1. Frf 1563-1578kHz
2. Rf phase 0-180deg

3. How many turns of beam can be injected from the linac?

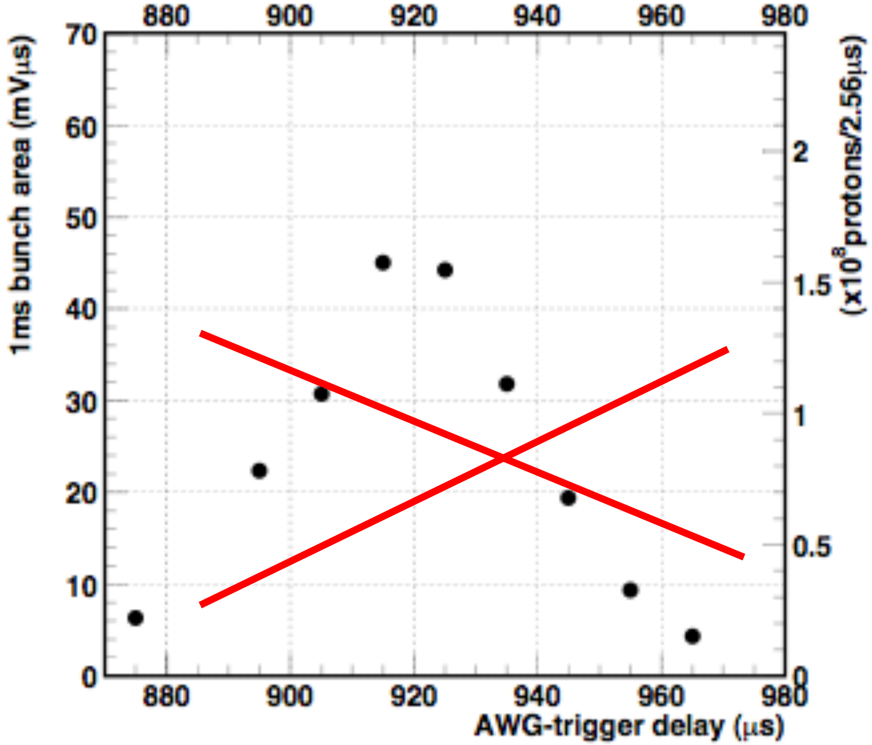
- Does the MR rf accept the beam of 100us wide?

- chopped beam (2.56us; =~4Trev) was injected to see the time dependence of injection efficiency.

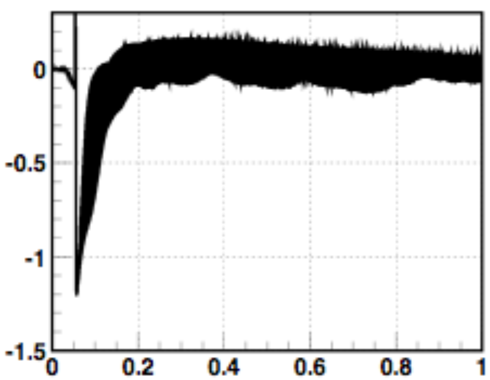
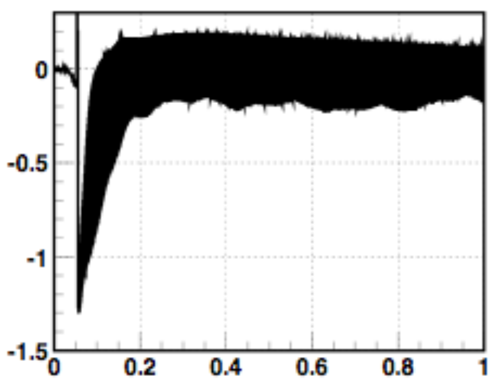
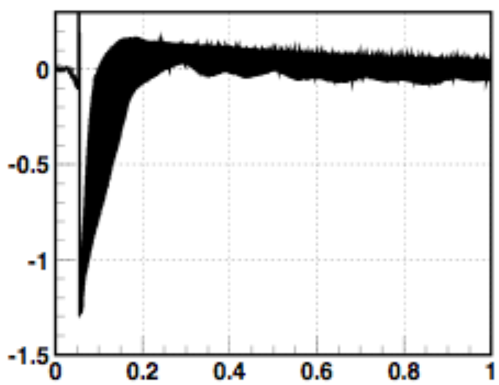
- AWG timing was changed, instead of the chopper timing, in order to elclude the time structure of linac output beam.

- Capture efficiency was evaluated from the bunch-area, not from bunch height, because the bunching factor might depend on the position where the beam is injected in phase space.

~~Results (0725)~~



1. There is a global structure
2. Integrated particle number is ~~~0.3e10.~~

Improvements under Cosideration

Against emittance growth in the foil

-Thinner foil

to decrease the emittance growth.

20μg/cm^2 ---> 10μg/cm^2 ?

- Higher vertical aperture of foil frame

20mm ---> 30mm ?

- Fast acceleration after capture

Limited by the rf voltage

Half integer resonance at injection energy

- COD corrector installed at rf cavity
is replaced by wide-aperture one.

SUMMARY

There is a very big beam loss at injection in KURRI FFAG. We just started experimental studies of rf-capture of charge-stripped H- beam, in order to minimize this beam loss.

The optimum capture-rf phase was 10~20degree, which is consistent with a simple 1d simuation.   Smoothly raising rf phase after capture is necessary.