RF capture of KURRI FFAG Main Ring

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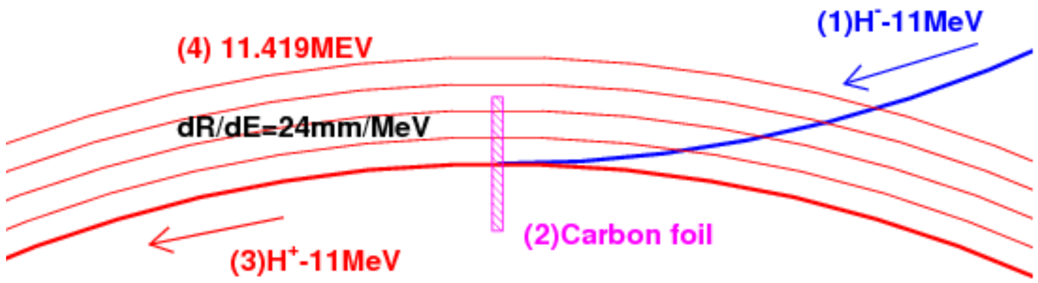
=== Introduction ===

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

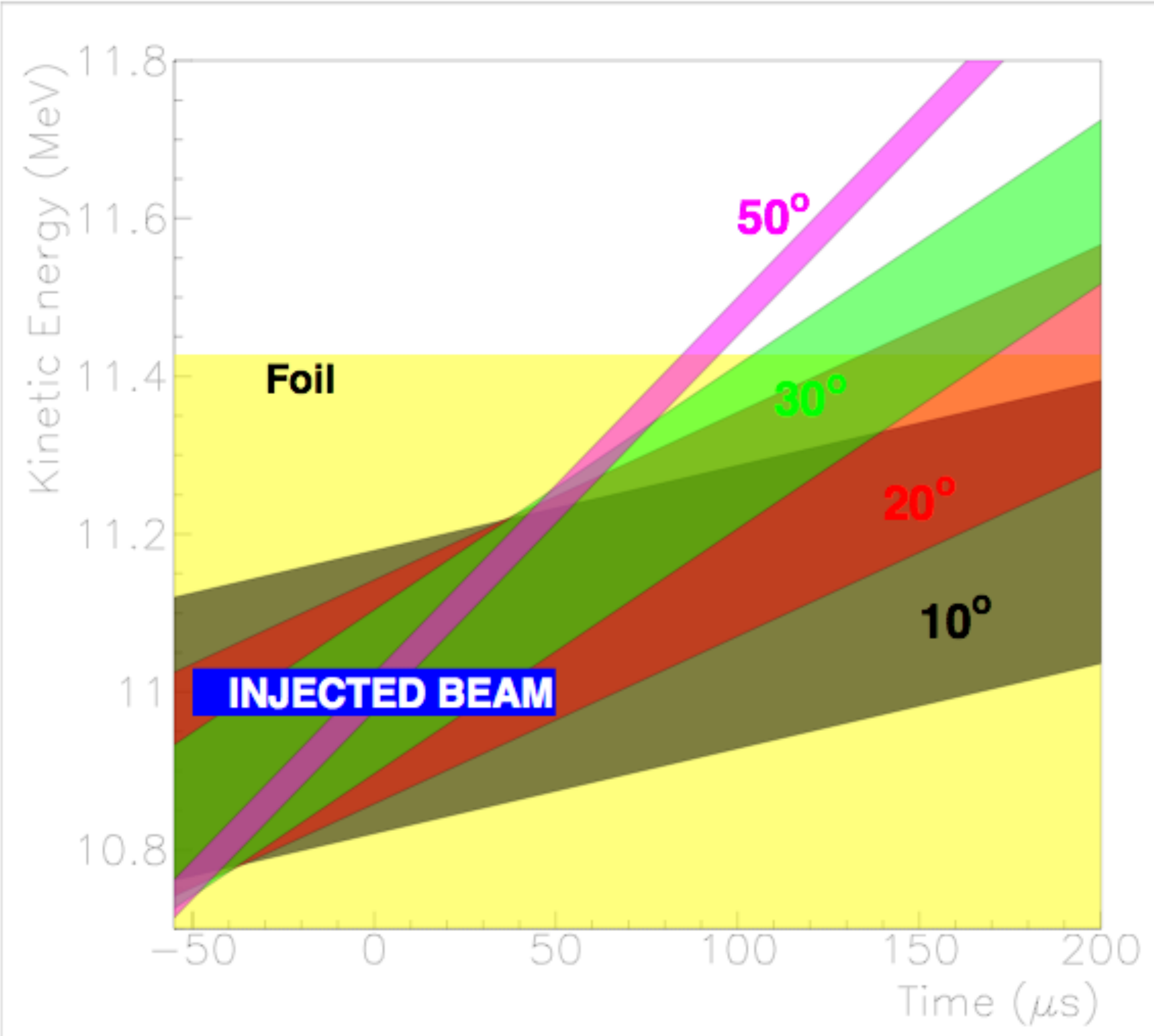
- Thickness : 20 ug/cm^2 (10 ug/cm^2 is under consideration)
- Energy loss : 760 eV/ turn (From Bethe's formula)
- Width : 25 mm

RF system

- Maximum voltage : 4 kV

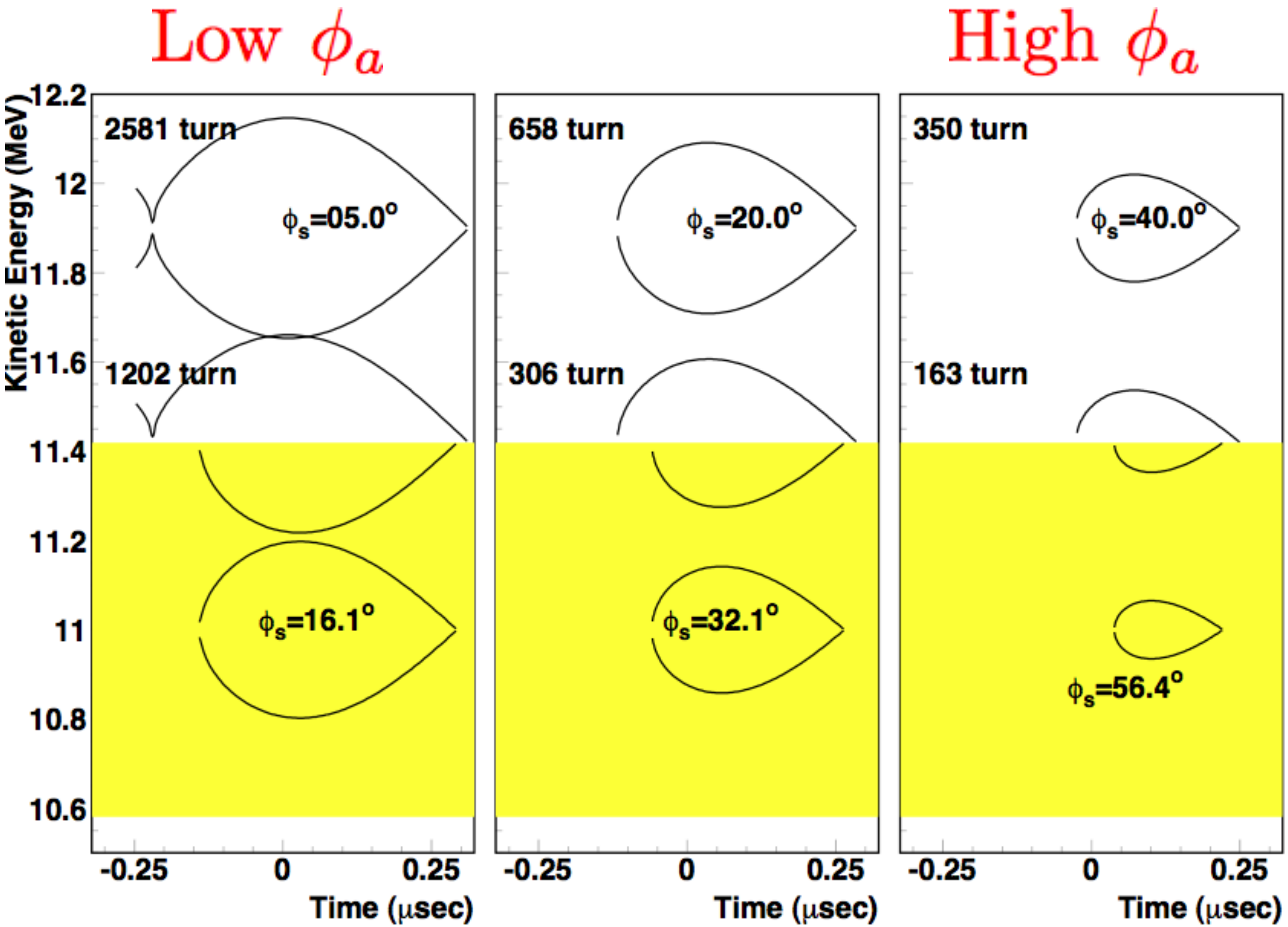
Schematic diagram

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’

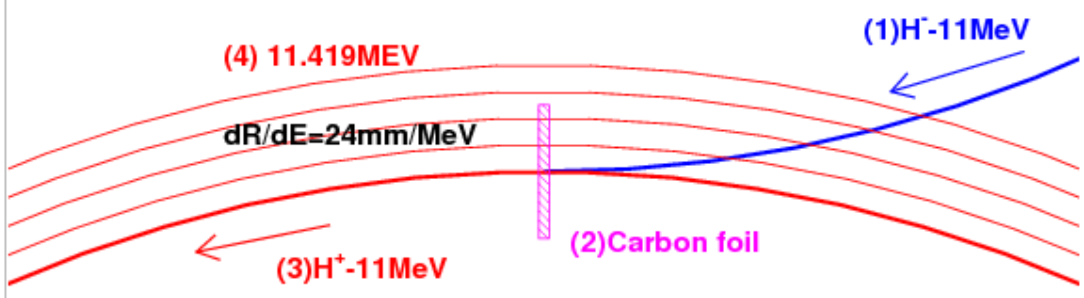
trade-off

--> Simulation studies are necessary !!

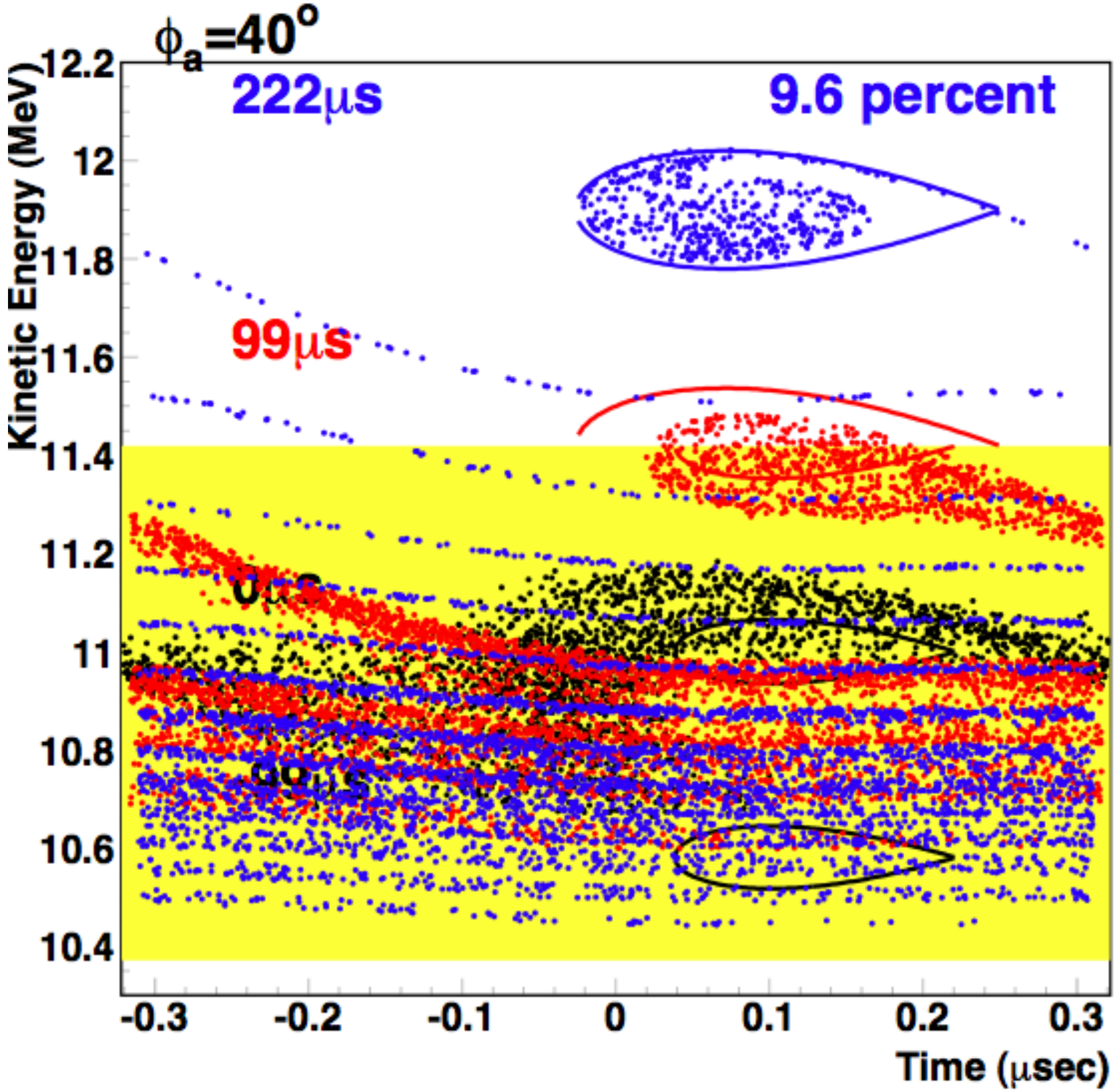
=== Stimulation studies ===

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.

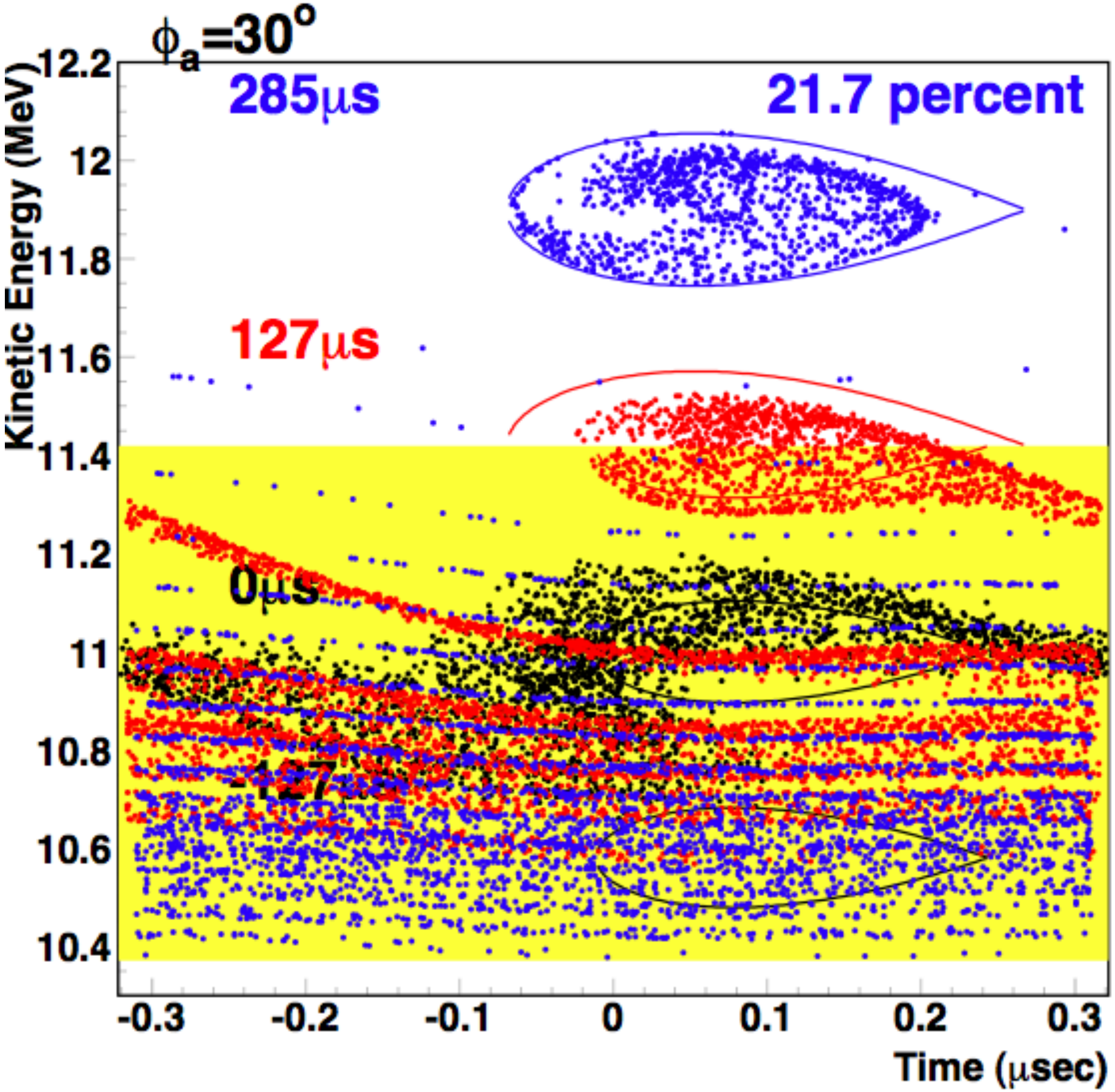


Example (1) Fast acceleration



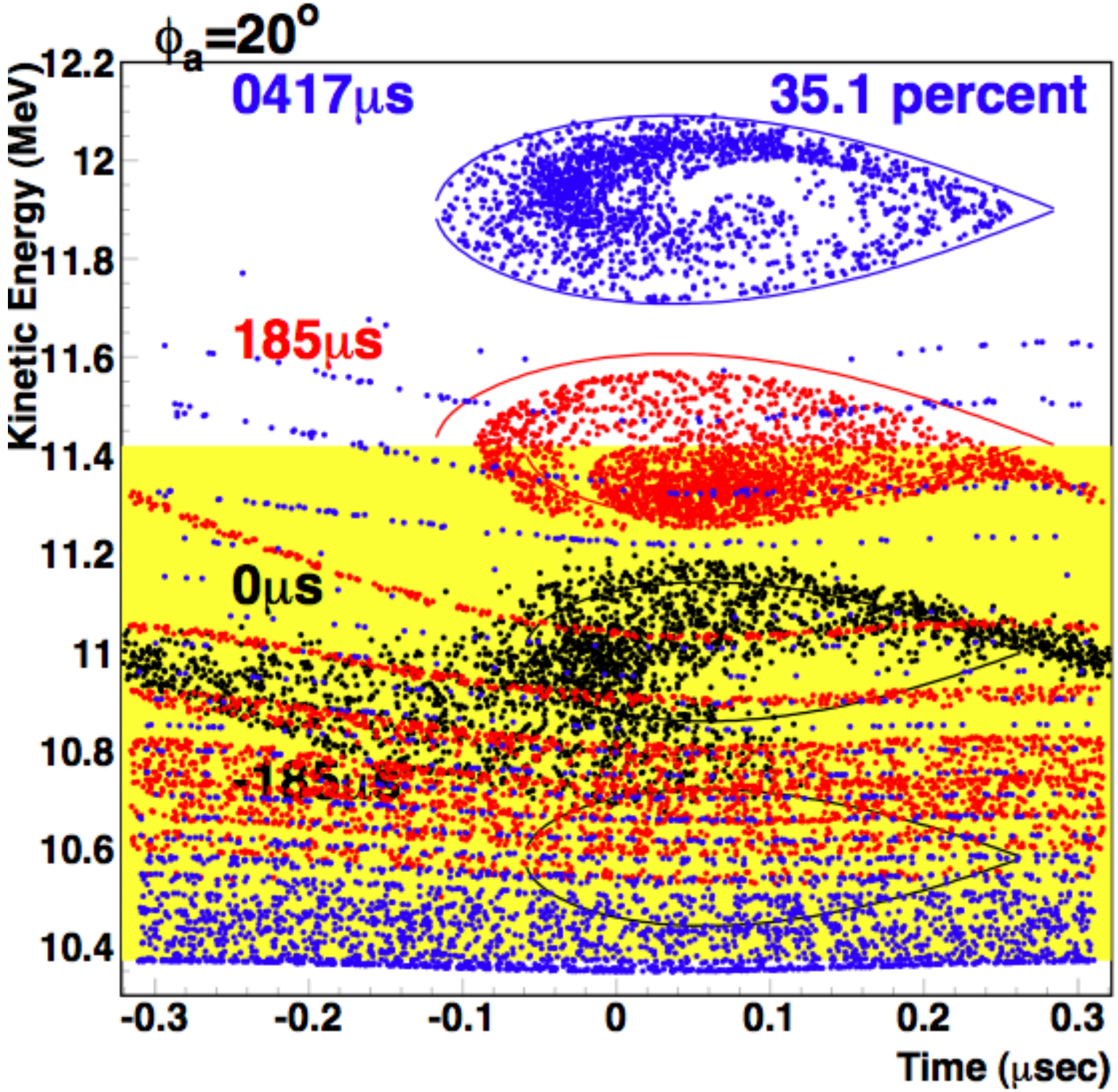
$\phi_a = 40^o$

Example (2) Present operation



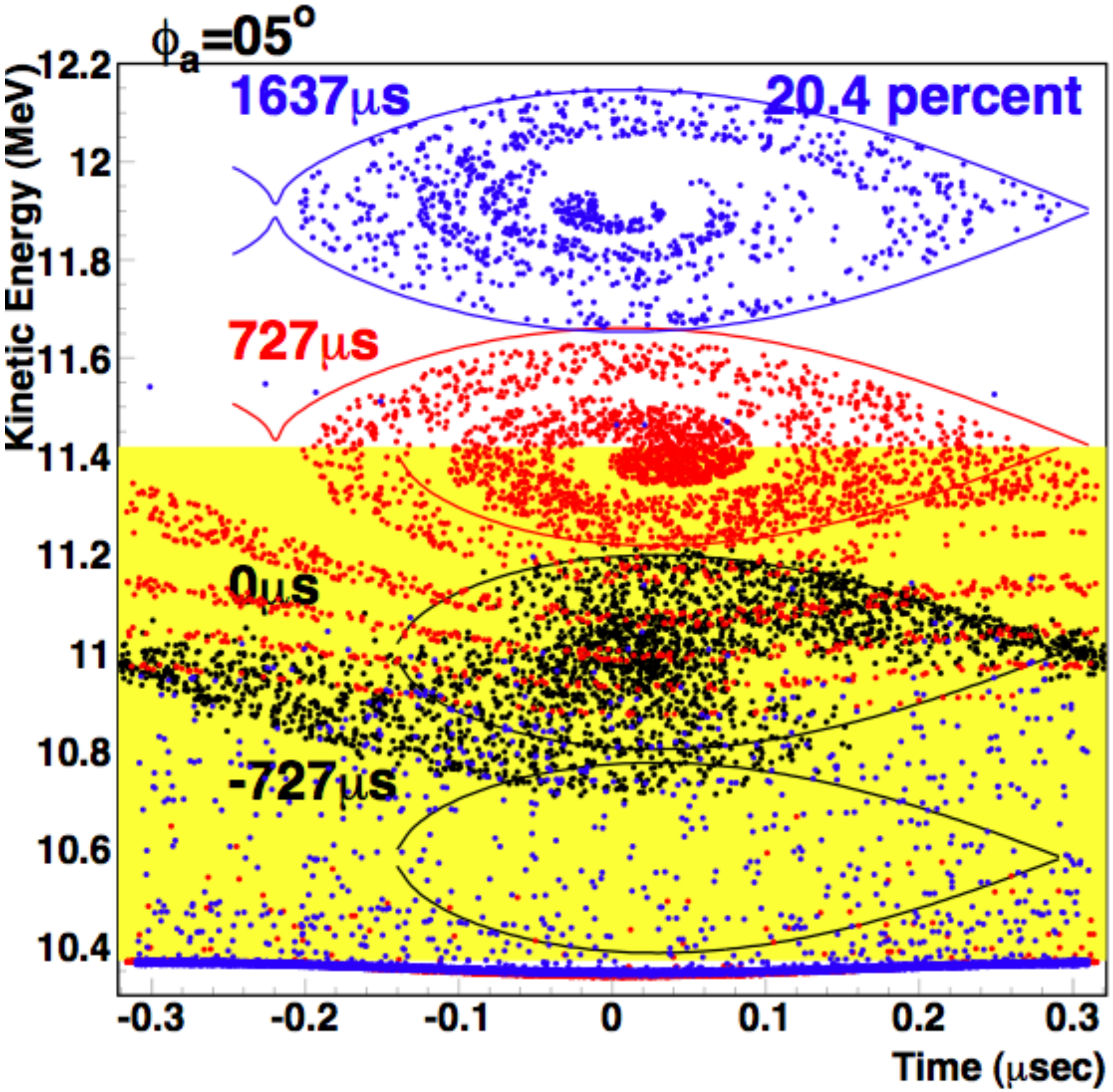
$\phi_a = 30^o$

Example (3) etc…



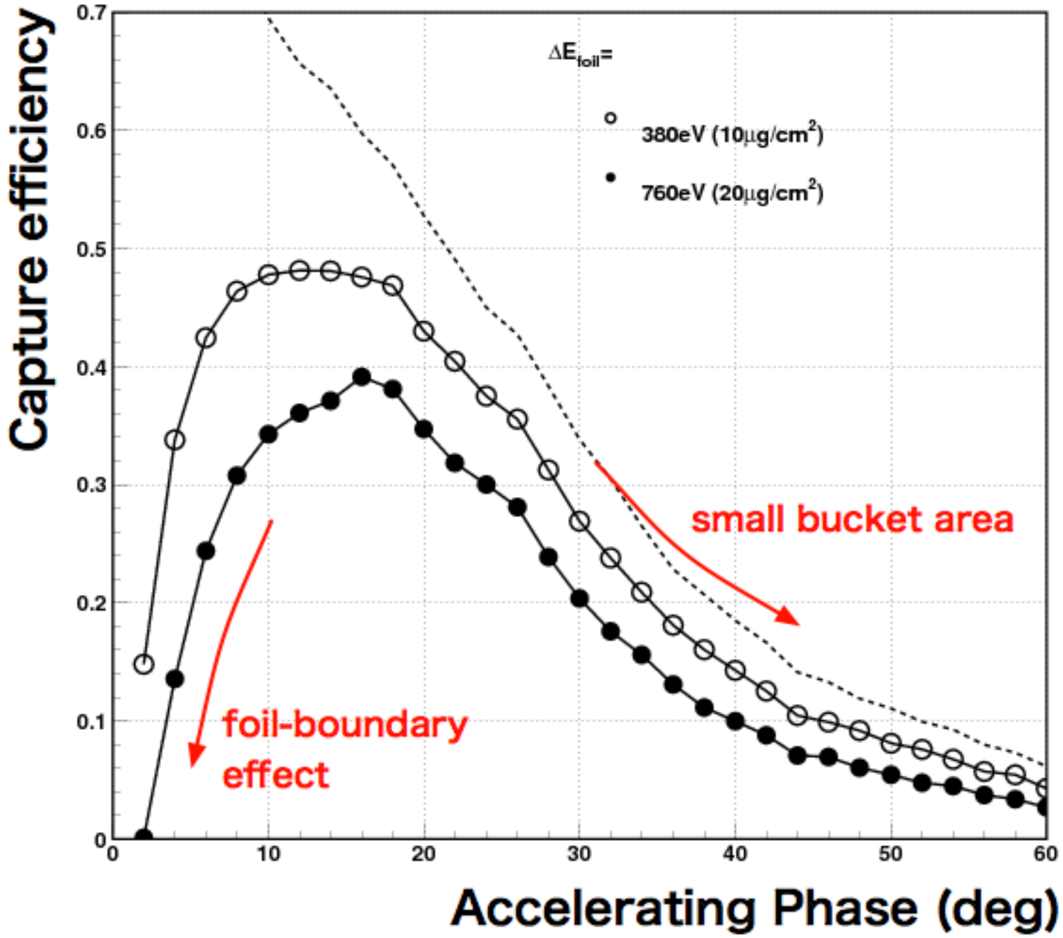
$\phi_a = 20^o$

Example (4) Large bucket



$\phi_a = 5^o$

Capture efficiency depending on ϕ_a .

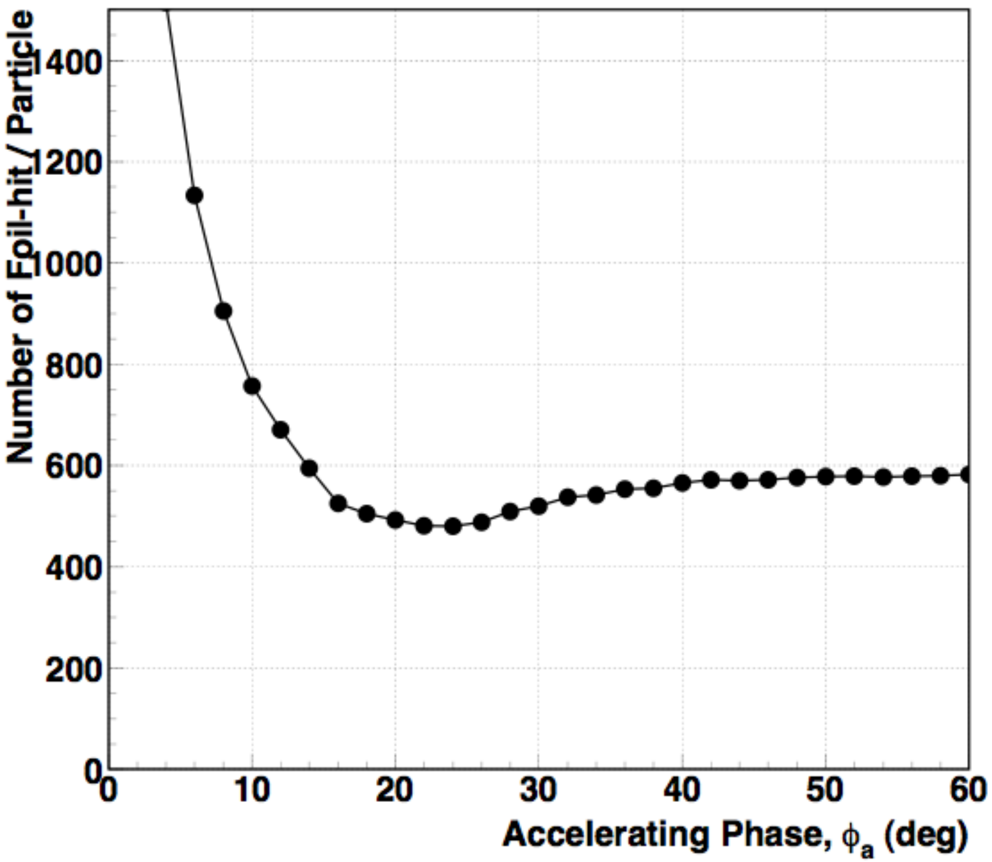


Efficiency takes maximum around

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

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

Number of foil-hit depending on ϕ_a .

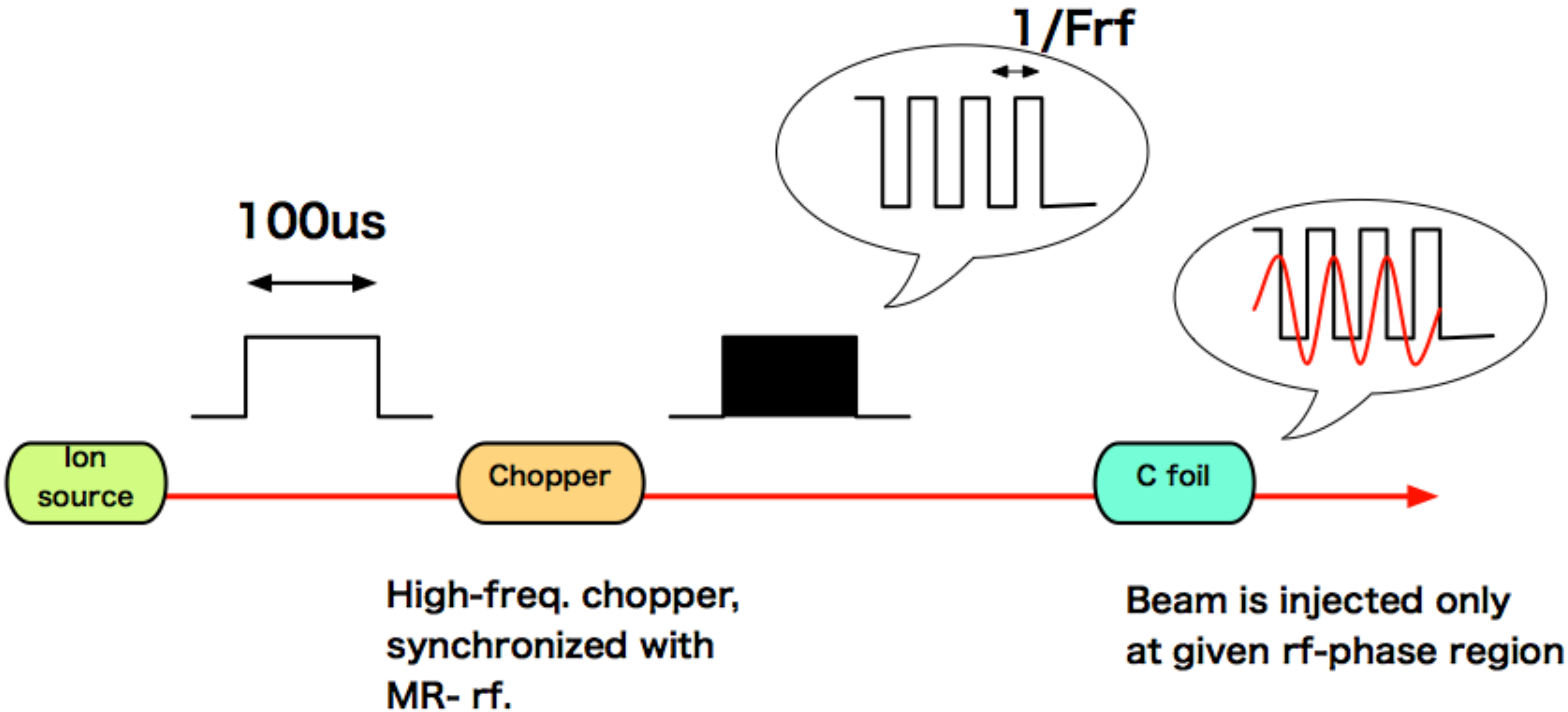


The number of foil hits is very high.

However, the number foil-hits at high phi_a is dominated by the particles which has dropped from the bucket!

In order to decrease the Number of hits, ---->

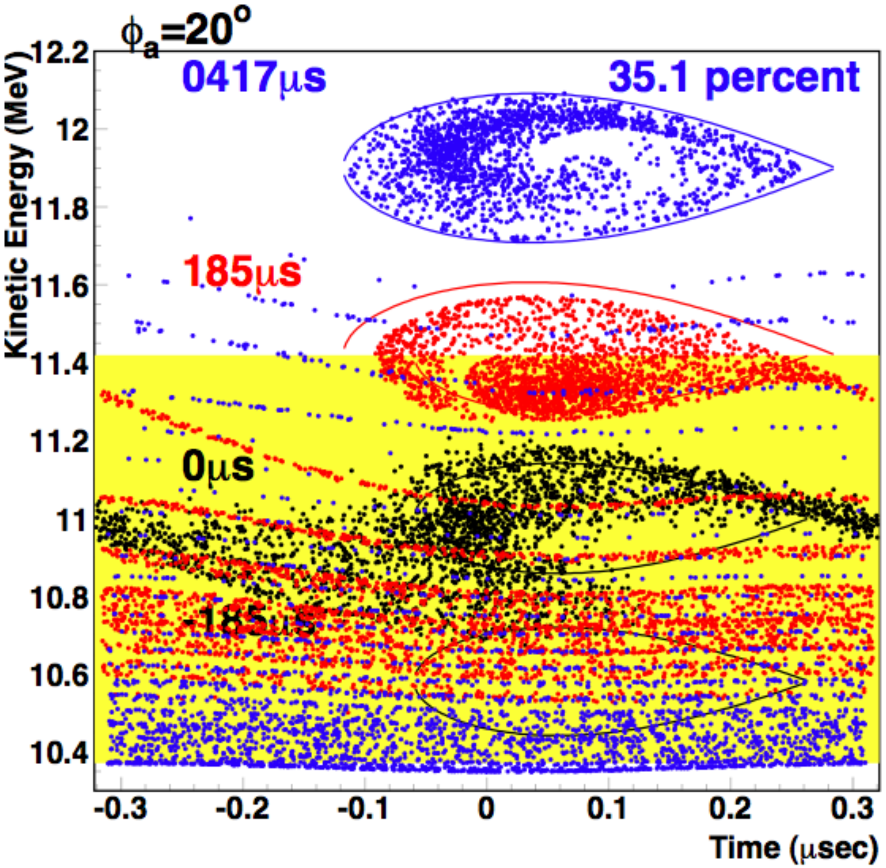
Chopper ?



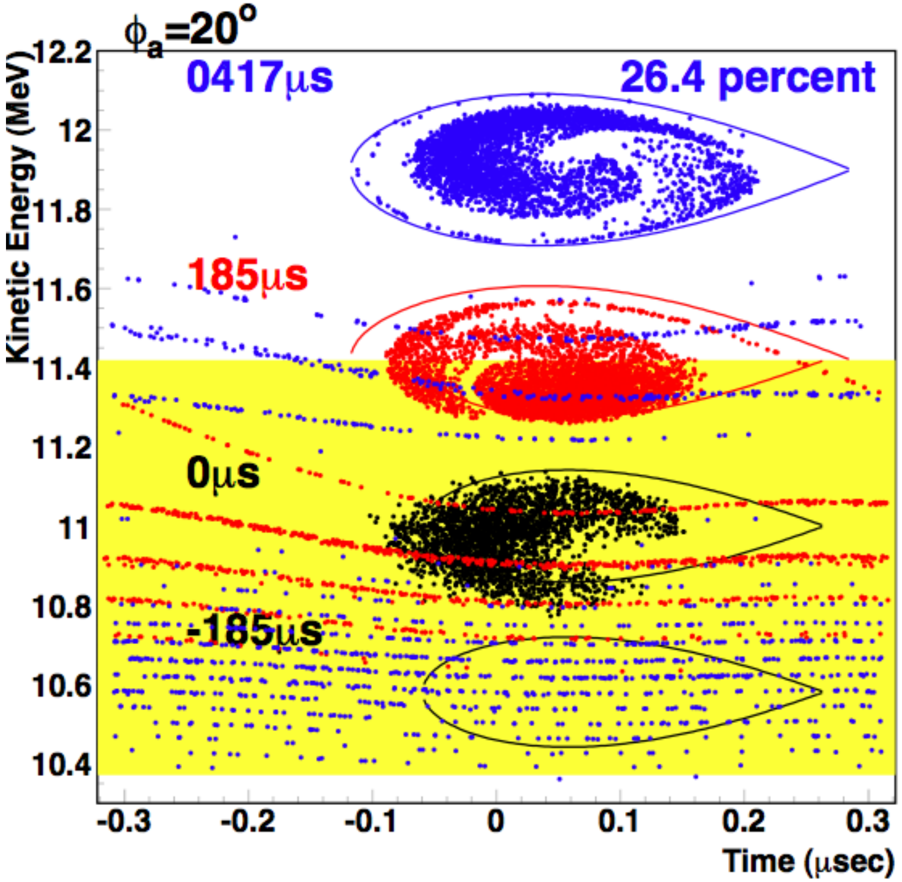
Number of foil-hits is expected to decrease --->

Example of chopper work

Without chopper (again)



With chopper (0-130deg)



	Without chopper	With chopper
Accelerated particles;	35.1%	26.4%
Number of foil-hits ;	679	190

SUMMARY

- Longitudinal simulation studies were done with energy-loss at stripping-foil.
- Capture efficiency took maximum when PHI_a = 10-20deg.
- Number of foil-hits by particles can be problem.
- Number foil-hits can be reduced when we use a chopper at injection beam-line.

RF of KURRI FFAG Main Ring

And Proposal of Combined-Cut-Core experiments

2011.09.15

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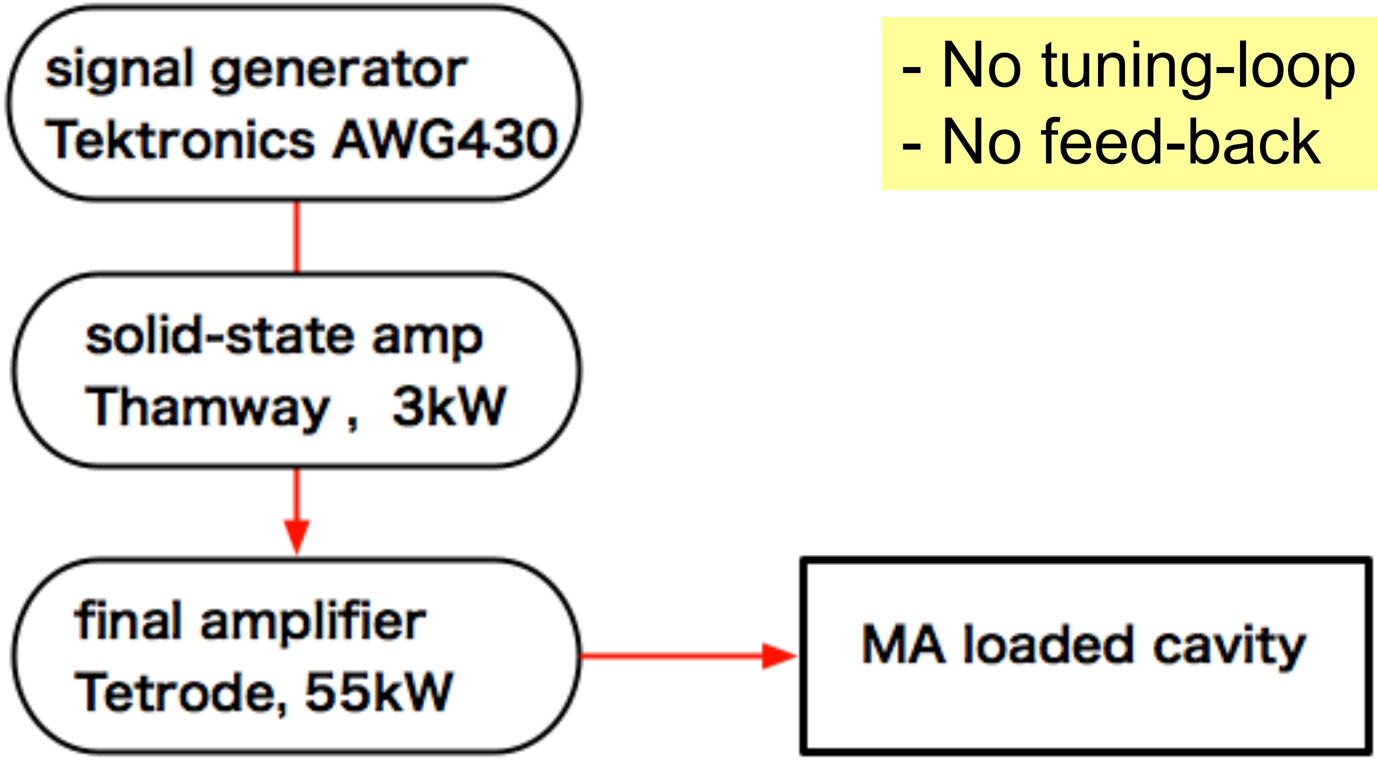
=== Existing RF system ===

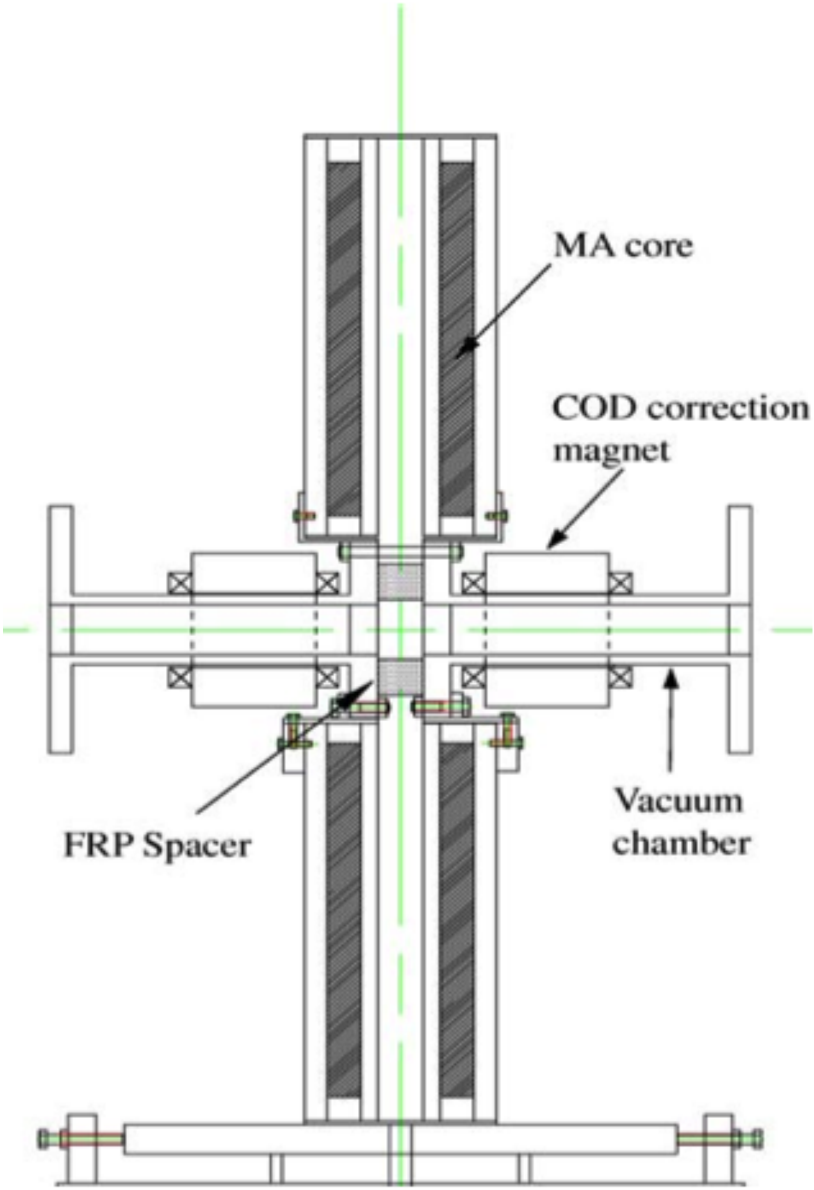
Systems

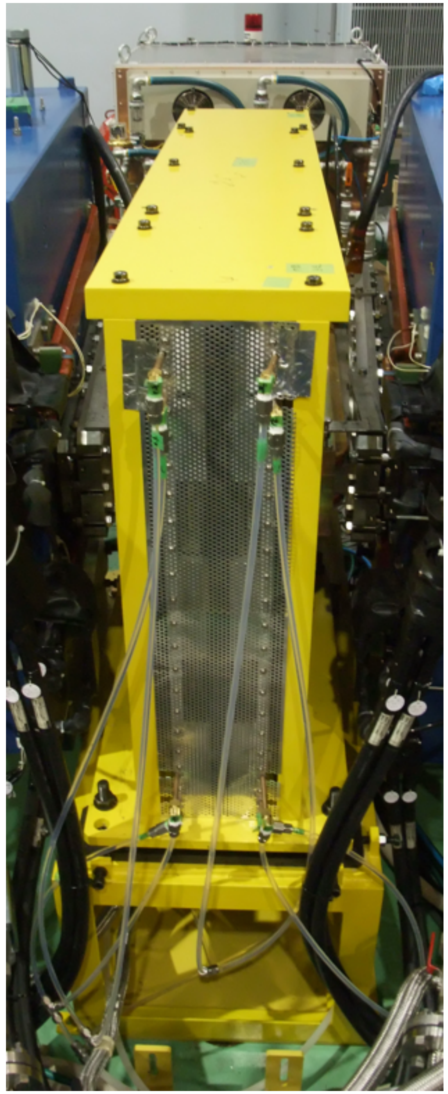


- No tuning-loop (low Q)
- No feed-back

4kV at 1.5 - 5.0 MHz

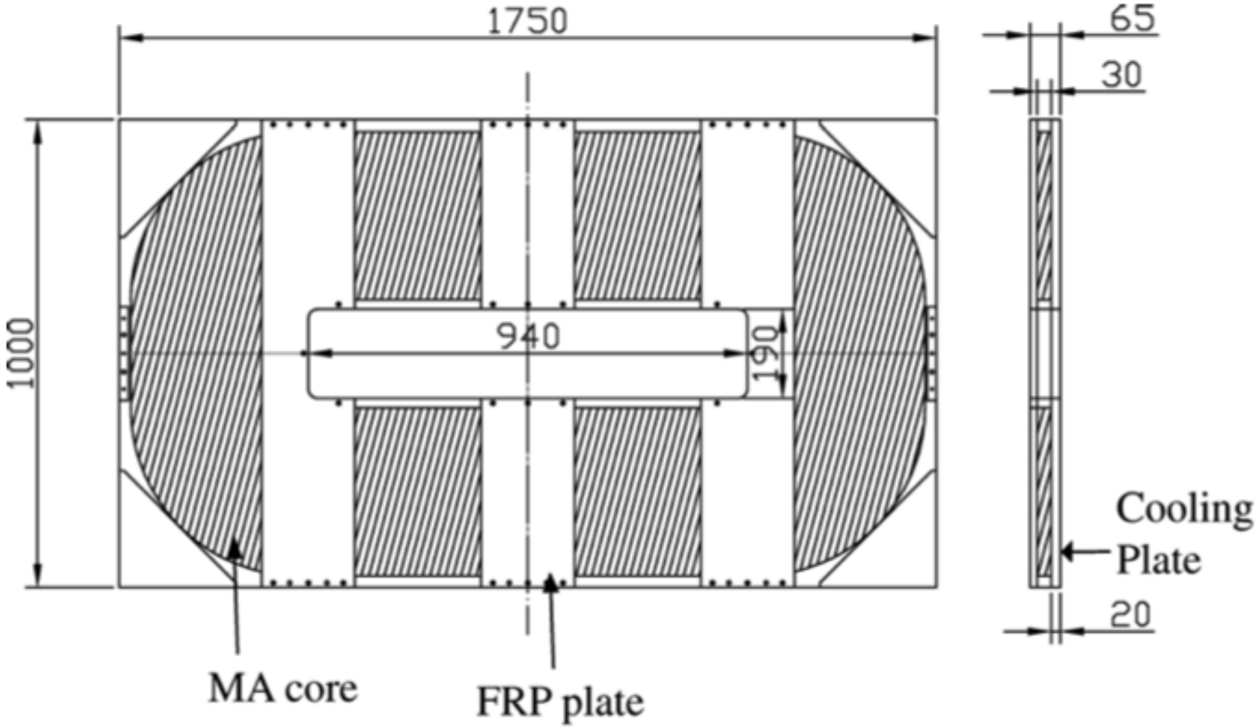
Cavity photo



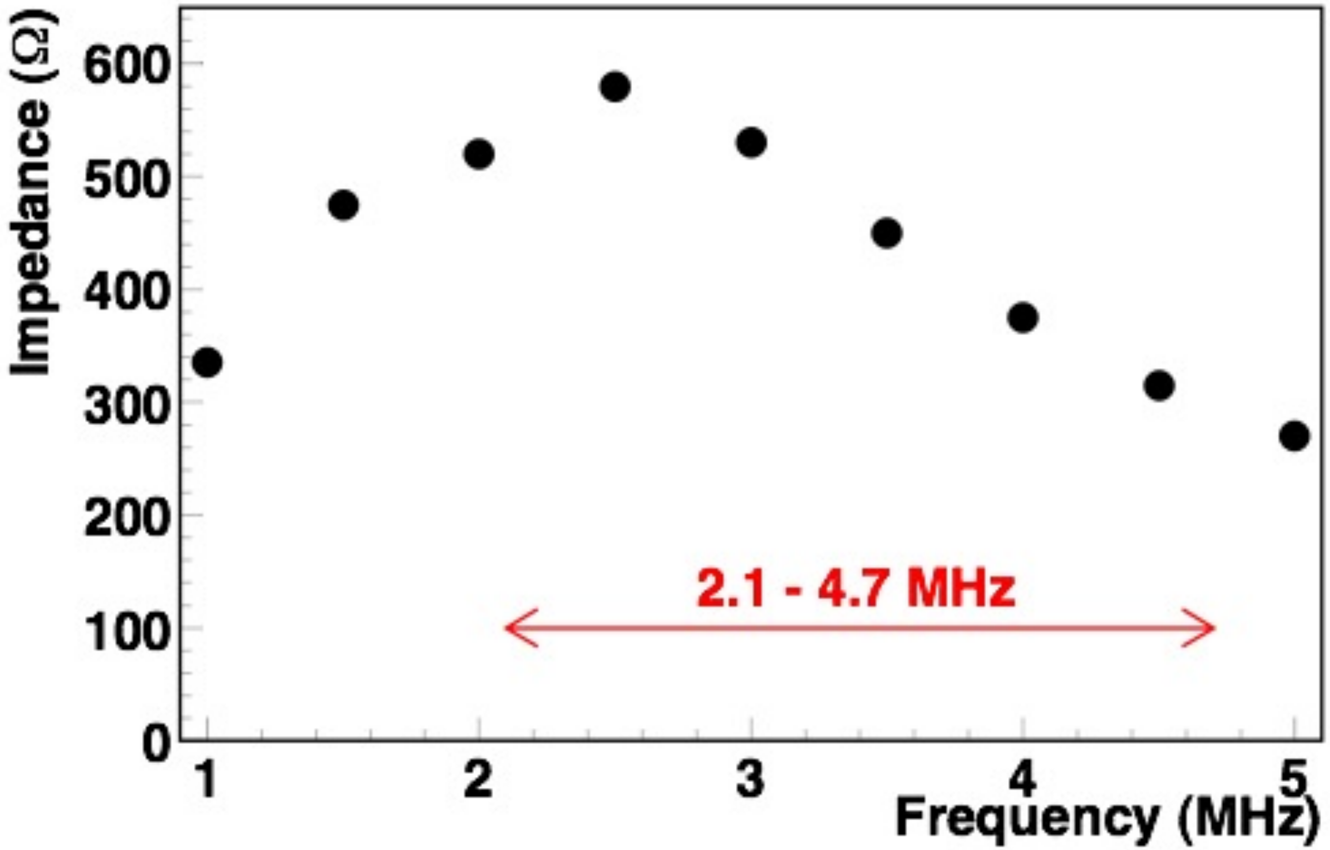


Magnetic alloy cores

Magnetic-alloy (FT-3M) x 2 pieces,
1700mm x 1000mm x 30mm



Impedance



V ~ 4 kV (1500-4500 kHz)

=== 2nd RF cavity ===

Motivation of Installing a new RF cavity

- Increase voltage

 ---> (1) fast acceleration,

 for (1A) higher repetition, and/or

 (1B) larger turn separation at inj.

 (2) wide bucket area

- Suppress harmonic field components excited by RF cavity

Requirements

Kinetic energy	Orbit radius at straight-section	Revolution frequency
11.0 MeV (linac output)	4398 mm	1557. kHz
11.57 MeV (booster output)	4414 mm	1591.84 kHz
100 MeV	5024 mm	3845. kHz
150 MeV *1	5154 mm	4435. kHz

Frequency 1500-4500 kHz (Q<1)

Aperture >~ 750 mm ---> Very wide !

One candidate ; Mitsubishi-cavity

Compared to
the existing cavity,

Thickness is twice
.. larger COD source
Impedance is half
.. lower voltage

We (I) want to try another

=== Combined Cut Core (CCC) ===

Components of New RF System (planned)

Cavity

---> newly made

Magnetic cores

---> used cores of JPARC-RCS ---> main topic

Amplifier

---> 200 kW, tetrode (sleeping in KEK-PS)

Cooling System

---> direct-cooling, with oil ?

Used MA Cores of JPARC-RCS

- MA (FT-3M) core x 4 pieces (at least),
- Which was used in the JPARC-RCS RF
- Partially damaged by heat
- 850mm(OD)-375mm(ID)-35mm(Th)

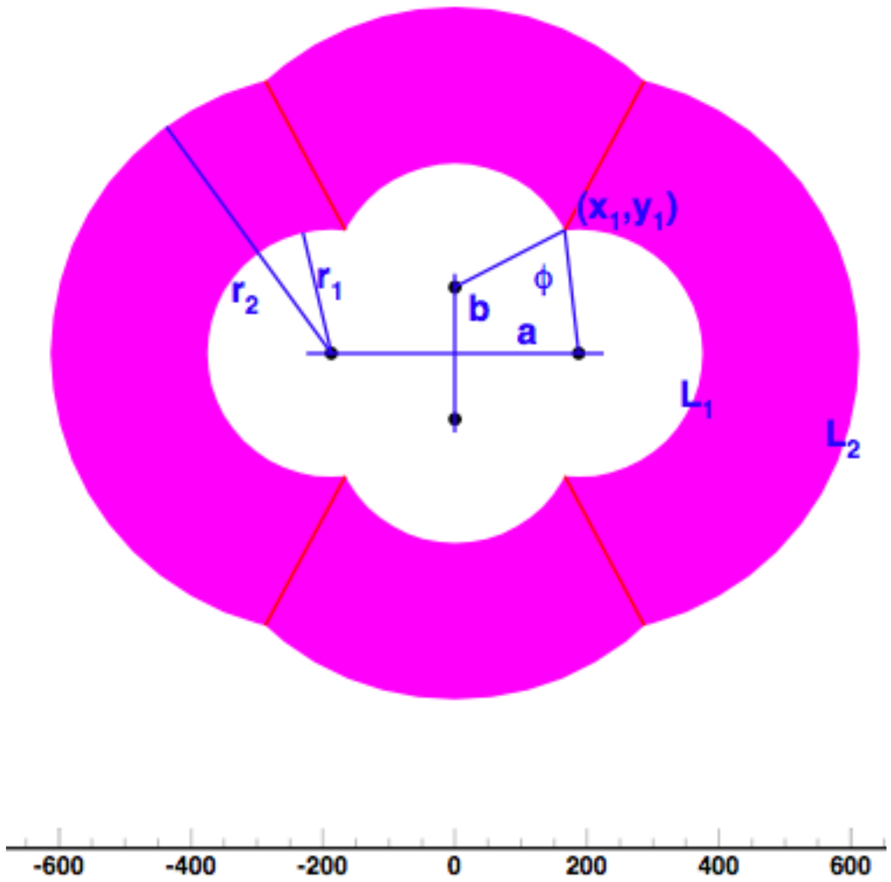
Can we reuse them in our main-ring?

Horizontal aperture is not enough

--> Combined cut-core (???)

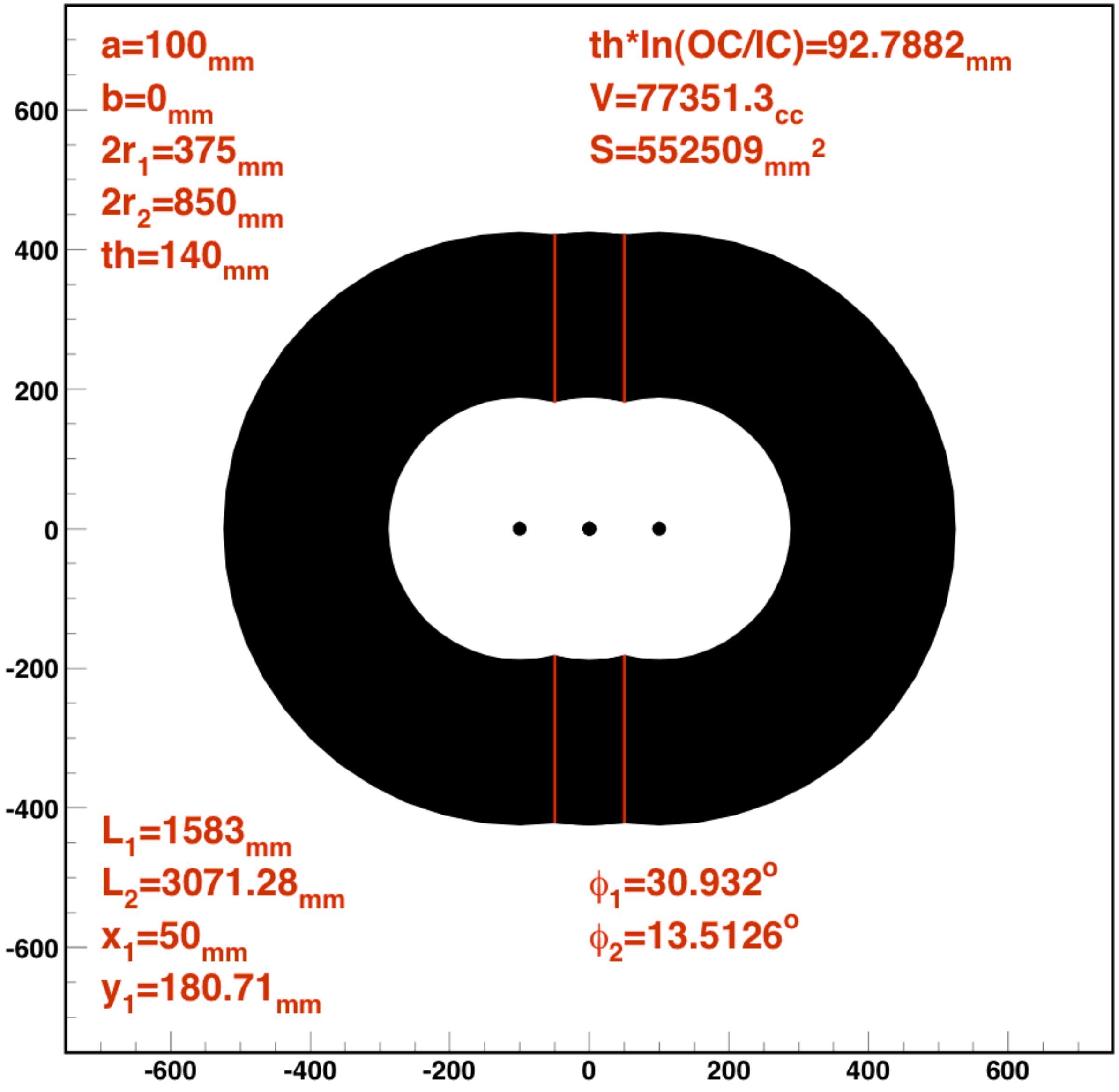
Combined cut-core
--- basic idea ---

Combining cut-cores
in order to enlarge the aperture to fit the MR



This technique enables to make a large aperture core piece by piece, without a large oven.

CCC(1) Flower type

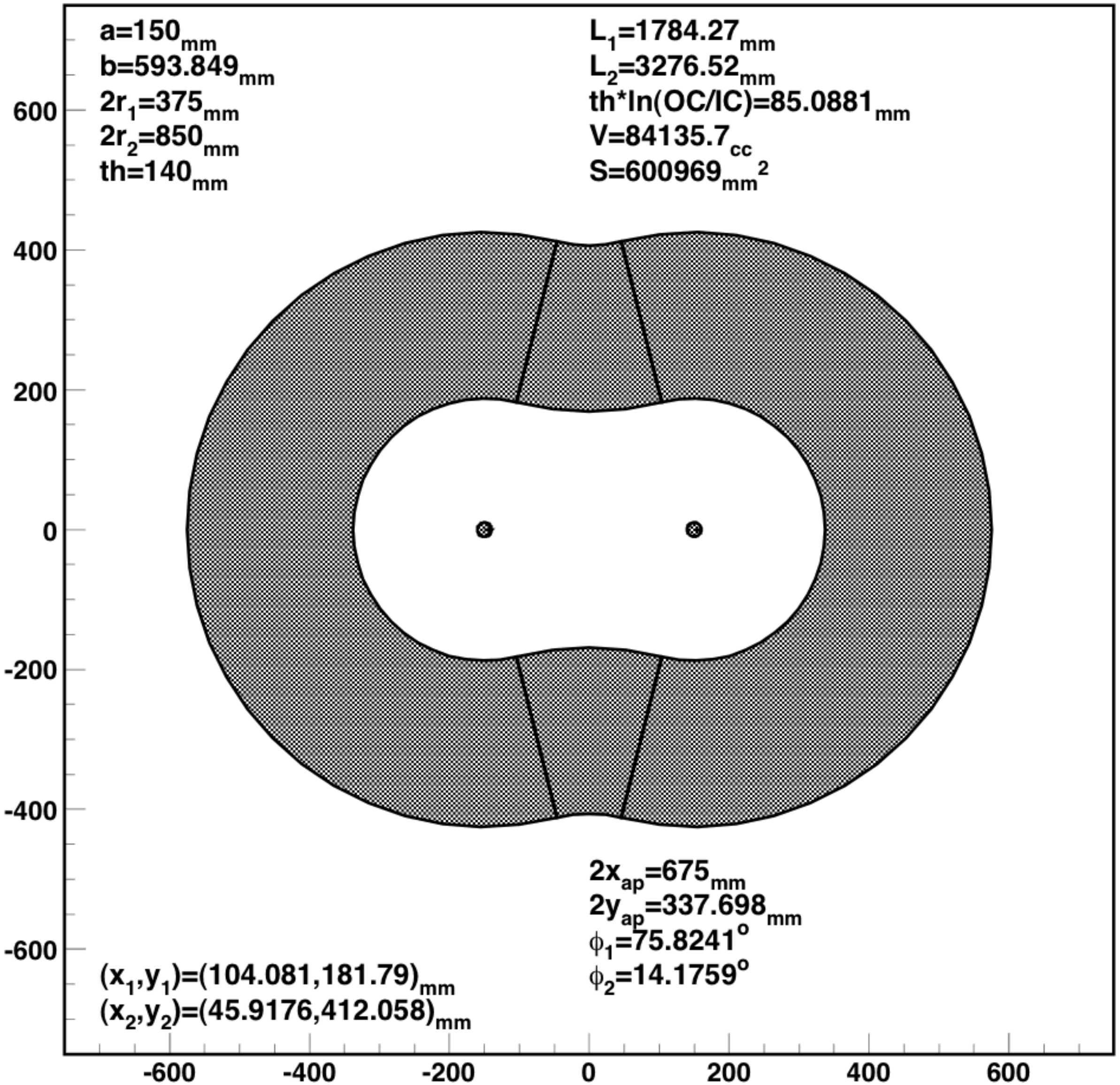


Degree of freedom: 2

H/V aperture independently

Angular discontinuity at the boundary

CCC(2) Ribbon type



Smoothly connect
at the boundary

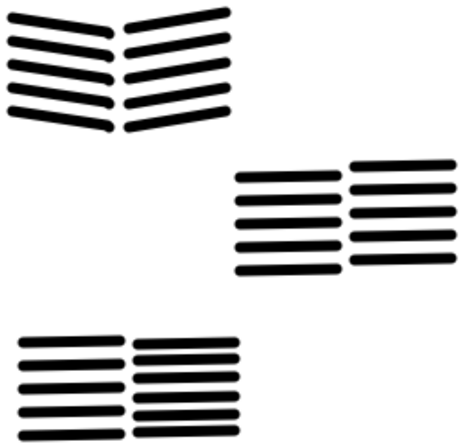
Degree of freedom: 1

H/V apertures
are trade-off

Potential problems (?)

1. Simple Combined-cut-core technique has been established by J-PARC RF group.
   Quality factor was controlled by changing gap-width.
   cf. Q=0.6(without cut), 2.0(gap 0.5mm), 10(10mm)

2. In our case, the two pieces coming from different cores are connected. --> Discontinuity of MA layers.
   . angular mismatch (flower type)
   . layers offset
   . number of layers



3. Boundary treatments
   . mechanical strength
   . gap width control (--> larger gap increases Q)
   . flatness

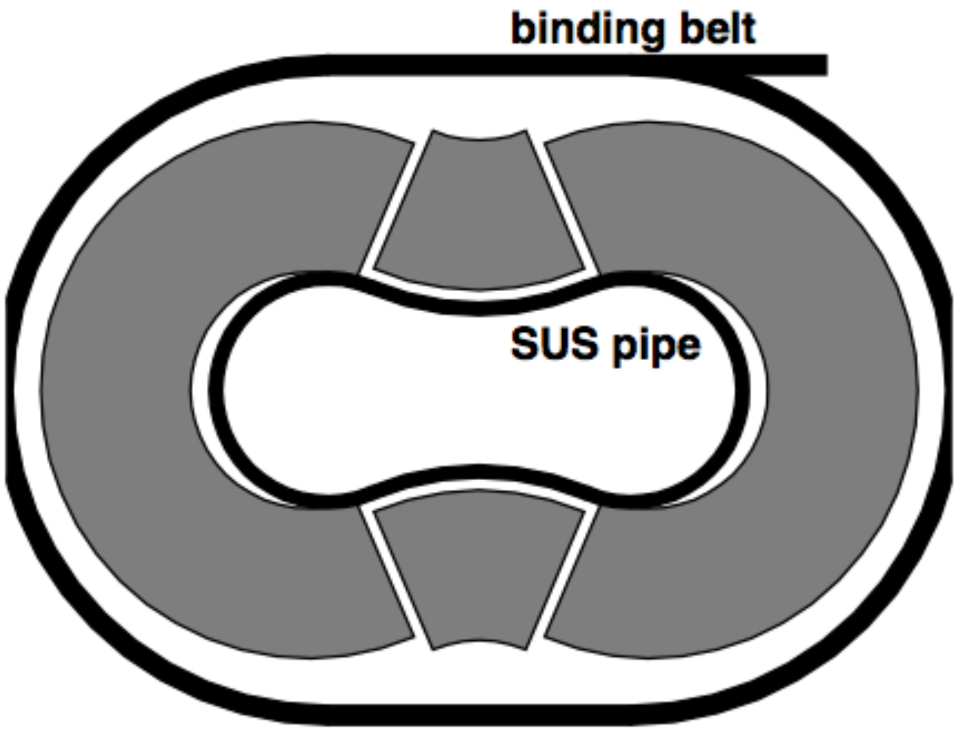
Experiments with sample cores are necessary !!

Purposes of the experiment

- Is it possible to combine cut-cores?
- to keep it rigid?
- R proportional to (th)log(L_2/L_1),
  even for those strange configuration ?
- Does the layers discontinuity make problem ?
  such as heat concentration ?
- Q reduction ?

How to fix?

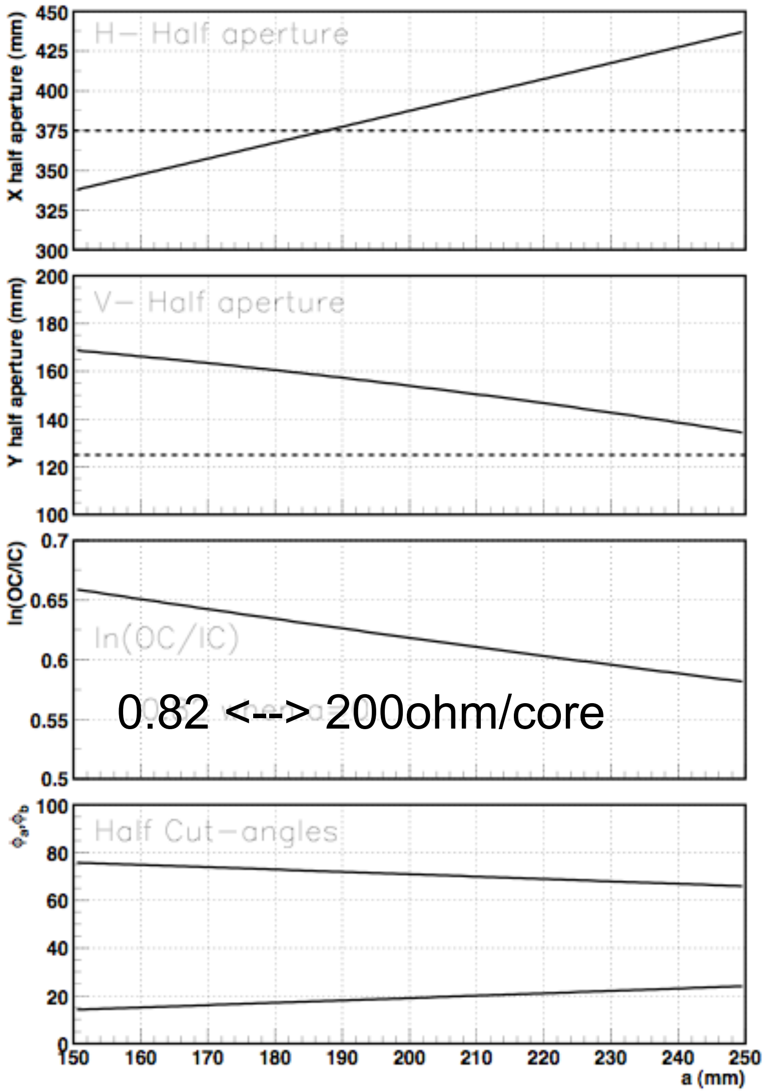
Binding method, for example

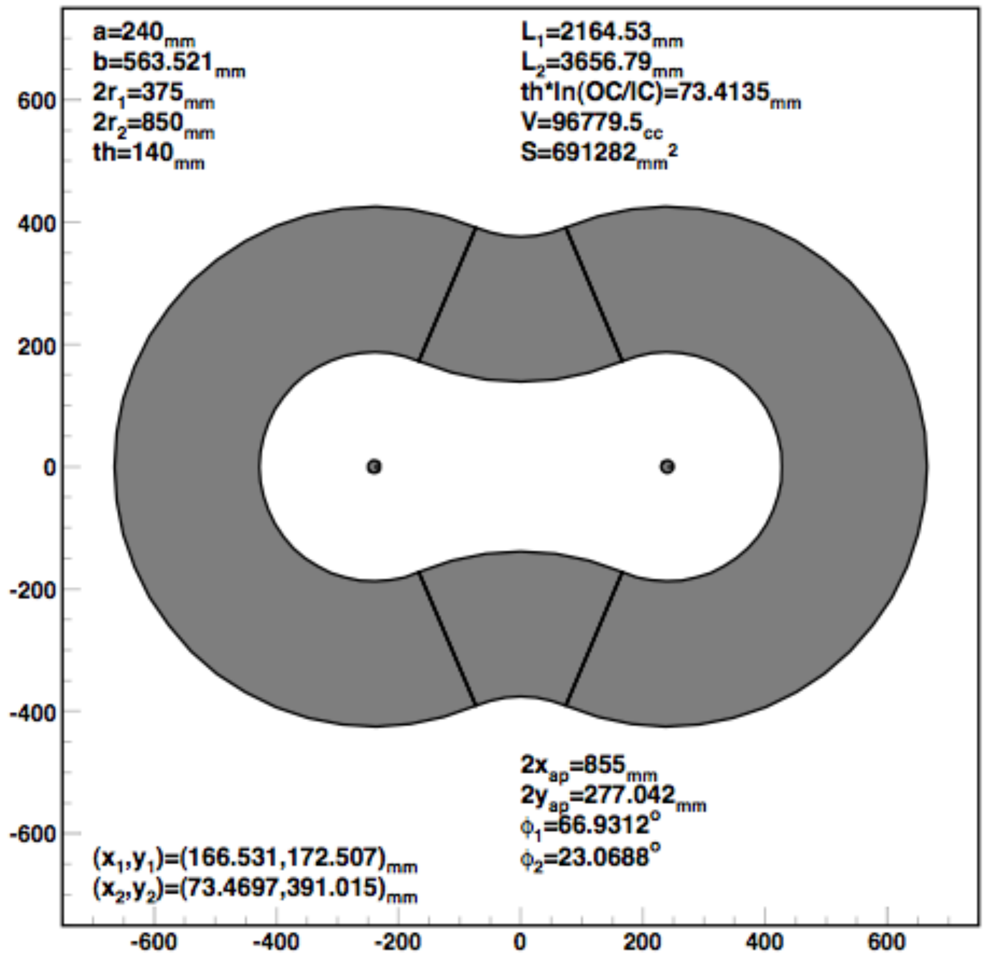


Or, pushing-screw from outsid?   Glue ?

Choosing shape

We choose ribbon-type CCC with a=240mm.





Summary

1. We need to install another rf cavity.

2. One candidate is Mitsubishi-cavity already built,
   but its impedance is relatively low.

3. Instead, we will try a combined cut core configuration.
   It needs basic experiments.

4. CCC may bring a strong advantage,
   such as reuse of damaged core,
   or fabricating of large-aperture core without large oven.

How to make CCC

Thanks to Yoshii-sama

さて、カットコア製造には次のステップを踏んでいます。全て必要がどうかは別にして、どのくらいの費用が必要かお知らせします。
（１）コアの含浸
（２）コアのWJ切断
（３）WJ切断面の低粘度樹脂含浸
（４）切断面の研磨
（５）切断面のシリカコーティング

（１）＋（２）＋（３）
東芝京浜で行っていて、コア１枚当たり１６０万（税込み）
（２）だけの場合、
黒木コンポジット（株）：トロイダル状のコア半切りするのに、１工程　５万（税抜き）
（４）
春川鉄工（株）：半切りコア２枚の切断面（４カ所）を研磨仕上げするのに、約２５万（税込み）
（５）
アート科学（株）（代理店）＋下村漆器（株）：半切りコア２枚の切断面（４カ所）を研磨仕上げするのに、約２５万（税込み）
＊WJ：water-jet

最新のカットコア製造工程は以下の通りです。
1.コアの低粘度樹脂含浸　：東芝
2.コアの防錆コーティング（クロス50ミクロン）：東芝
3.WJ切断　：東芝
4.切断面からの低粘度樹脂含浸　：東芝
5.ダイヤモンド研磨　：春川鉄工
5.ポリシラザンコーティング　：アート科学
6.FRPスペーサーとRTVシリコンゴムによる防錆処理　：J-PARC RFG

WJするには１.２.は必要でしょう。
WJはKEKでも可能です。
ダイヤモンド研磨には４.が必要ですが、樹脂を気にしなければ、春川鉄工で研磨しながら、仕上げの段階で含浸をお願いすることができます。
ポリシラザンコーティング５.は、６.を行うのであれば、省略もできます。

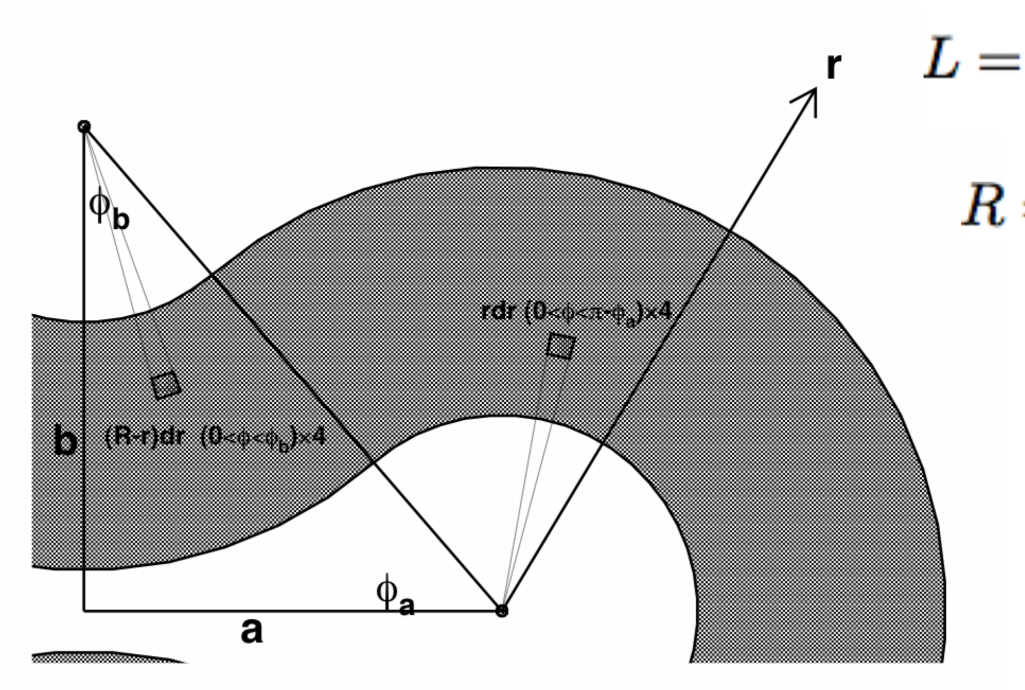
安くするなら、
（１）中古コア利用
（２）KEKで WJ切断
（３）春川鉄鋼で切断面の荒削り、含浸→ダイアモンド研磨（２５万）
（４）JPARC-RFG との共同で FRPスペーサーとRTVシリコンゴム
になります。

フロリのガスで配管破裂の恐れはありません、空胴内での放電などで分解・結合を繰り返し発生します。
十分な検討が必要でしょう。

Impedance of 'Ribbon-Type' core

$$\frac{LI^2}{2} = \frac{1}{2\mu}\int B^2 dV = \frac{1}{2\mu}\left(\frac{\mu I}{\ell(r)}\right)^2 dV$$

Assumption: Flux runs along the MA layers



$$L = \frac{\mu \times (Thick.)}{2\pi} \ln \frac{(Outer\ circum.)}{(Inner\ circum.)}$$

$$R = Q \times \omega L$$