HIAT 2015

A Compact Hadron Driver for Cancer Therapies with Continuous Energy Sweep Scanning

Leo Kwee Wah, T. Adachi, T. Kawakubo, T. Monma, T. Dixit, and K. Takayama

Full paper
Leo Kwee Wah, T. Adachi, T. Kawakubo, T. Monma, T. Dixit, and K. Takayama,
"A Compact Hadron Driver for Cancer Therapies with Continuous Energy Sweep Scanning ", under reviewing by *Phys. Rev. ST-AB*.

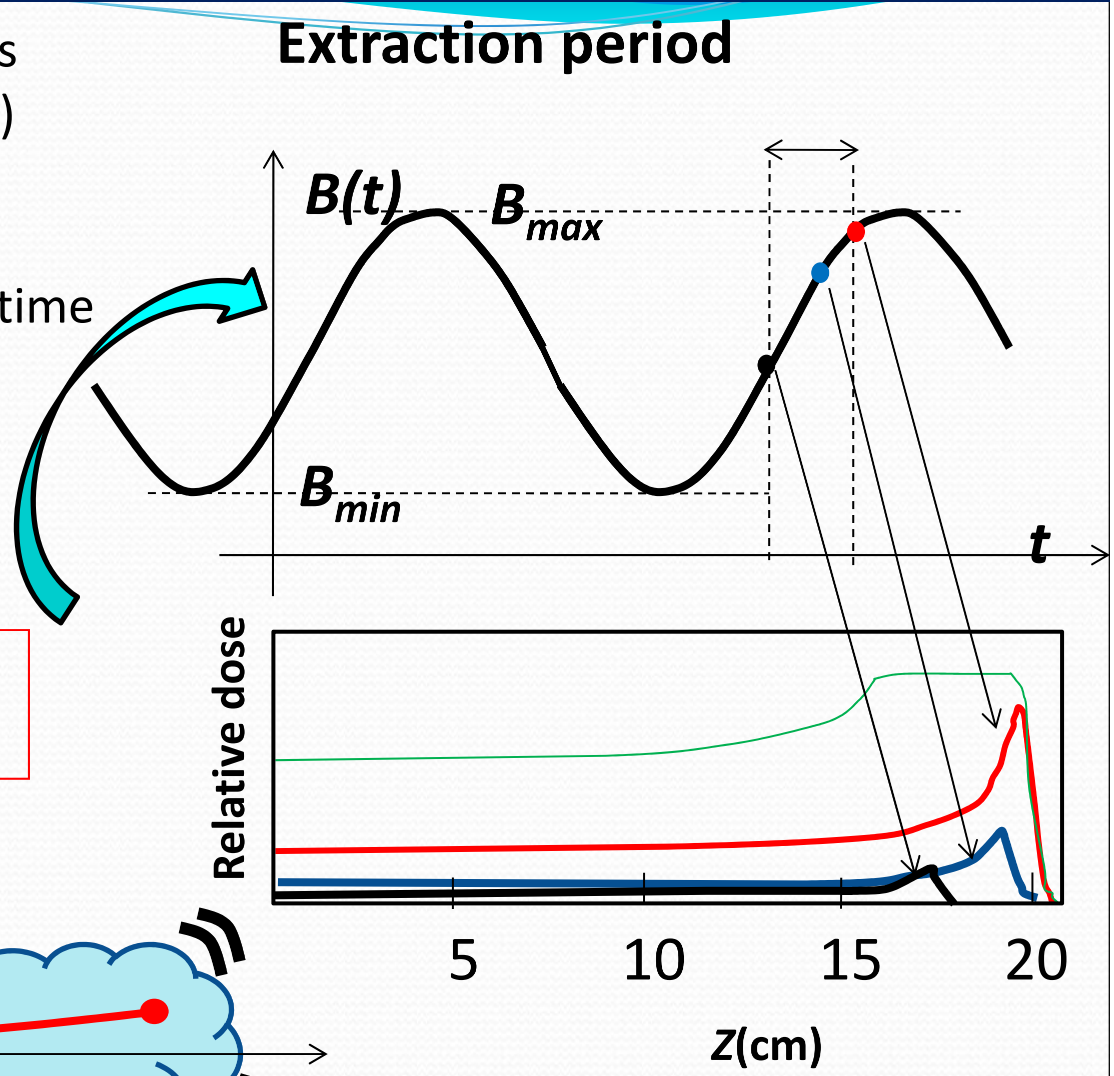
Content

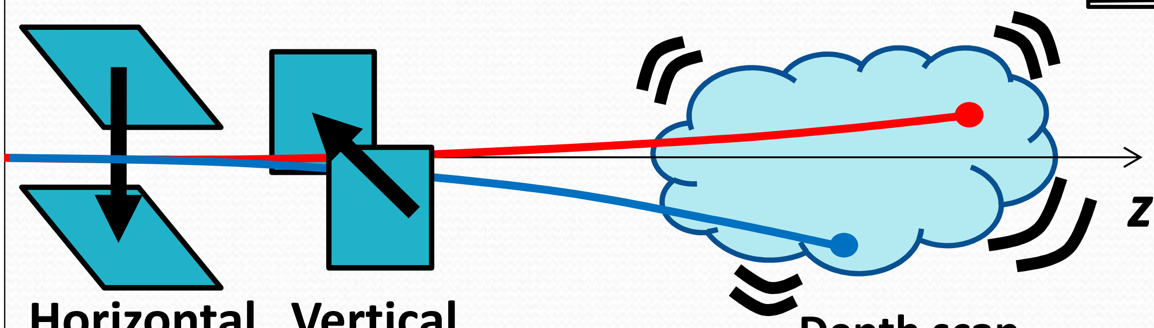
Fast 3D Spot Scanning to the Target

To remove the constraints, such as respiratory synchronization (~ sec)

Expected energy sweep irradiation time ~ 10 msec

Continuous energy sweep from the fast cycling synchrotron

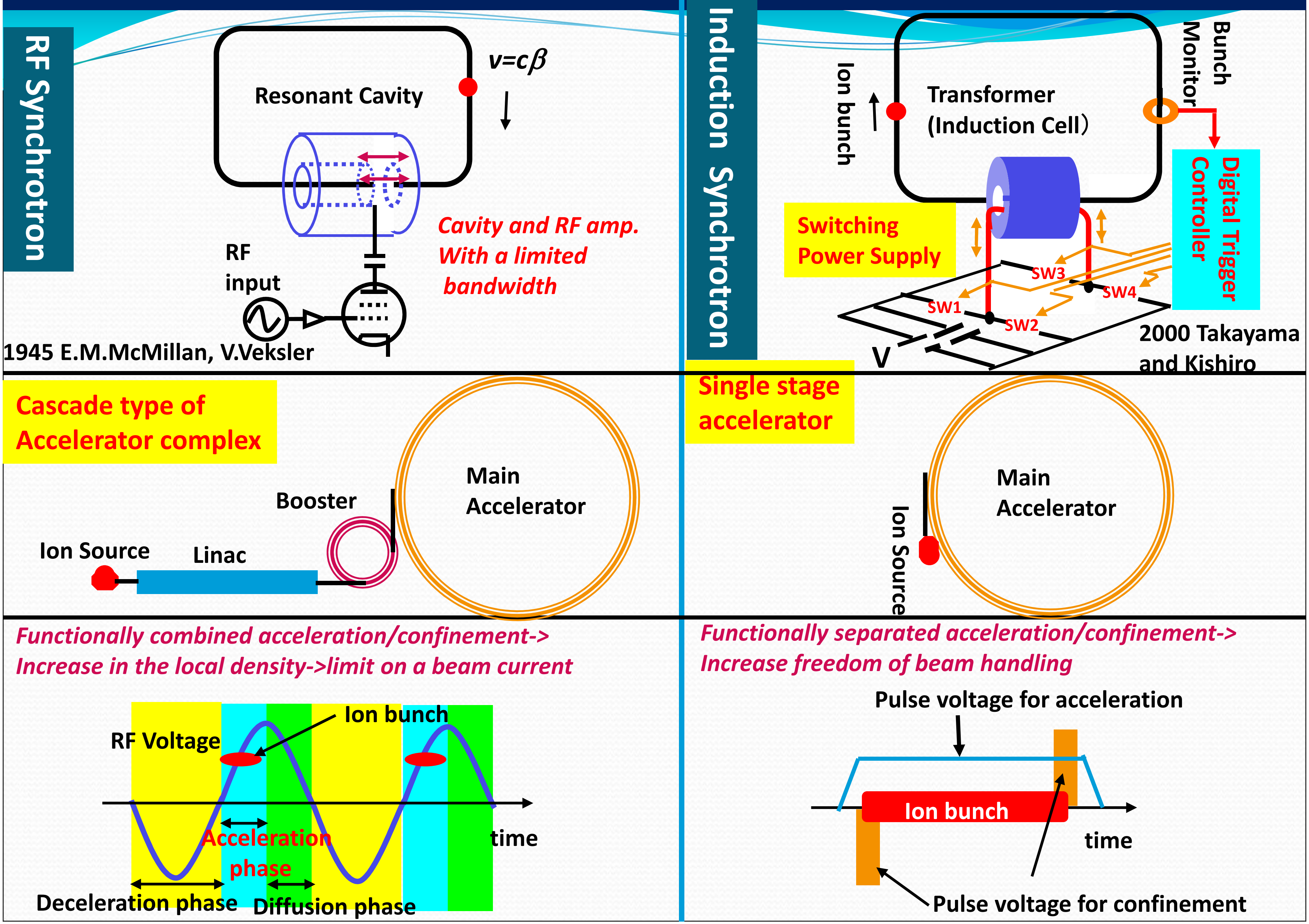




By what sort of fast cycling accelerator can Energy Sweep Extraction be realized?

RF Synchrotron or Induction Synchrotron?

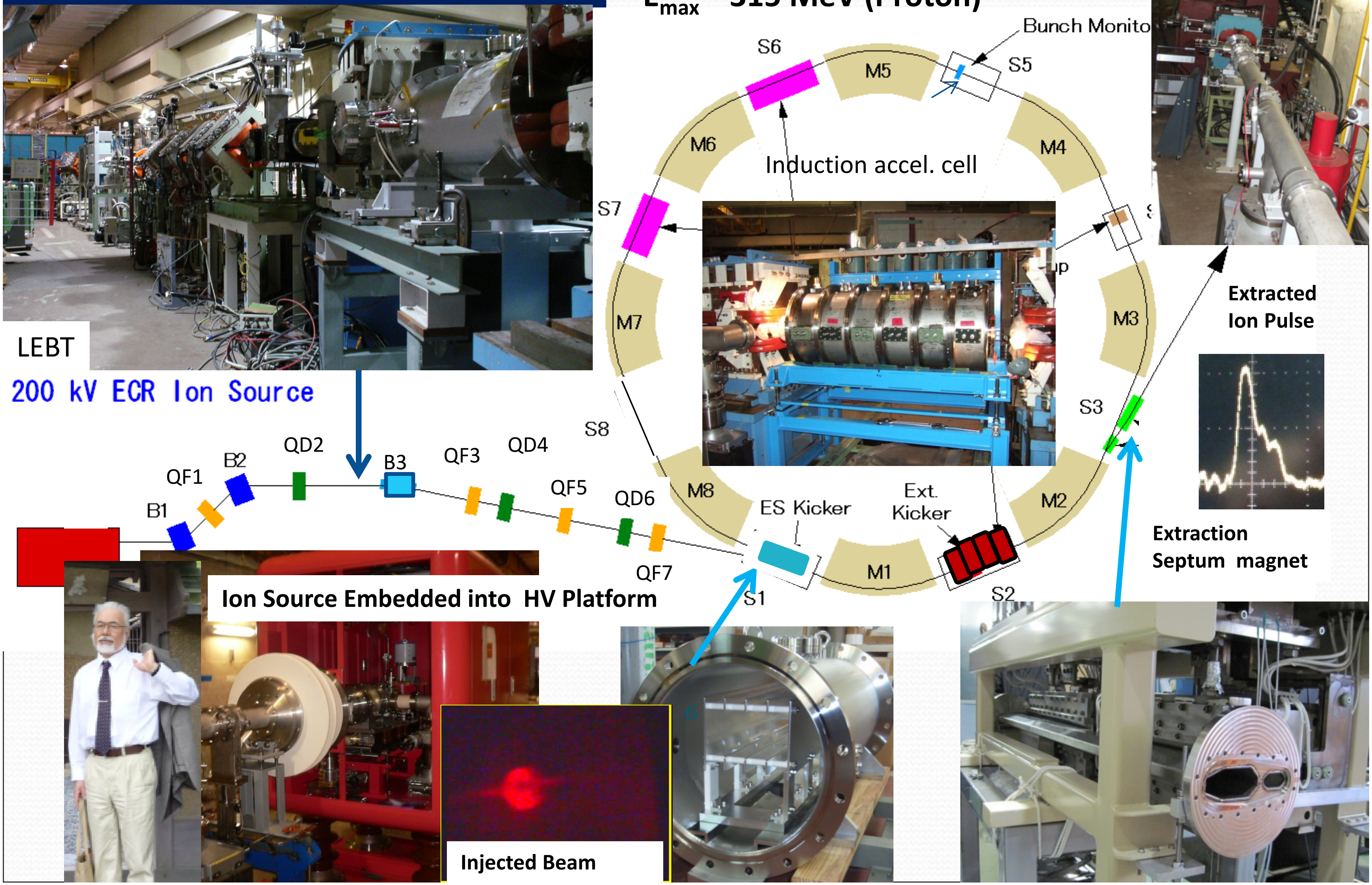
Principle of KEK-Digital Accelerator (Induction Synchrotron)



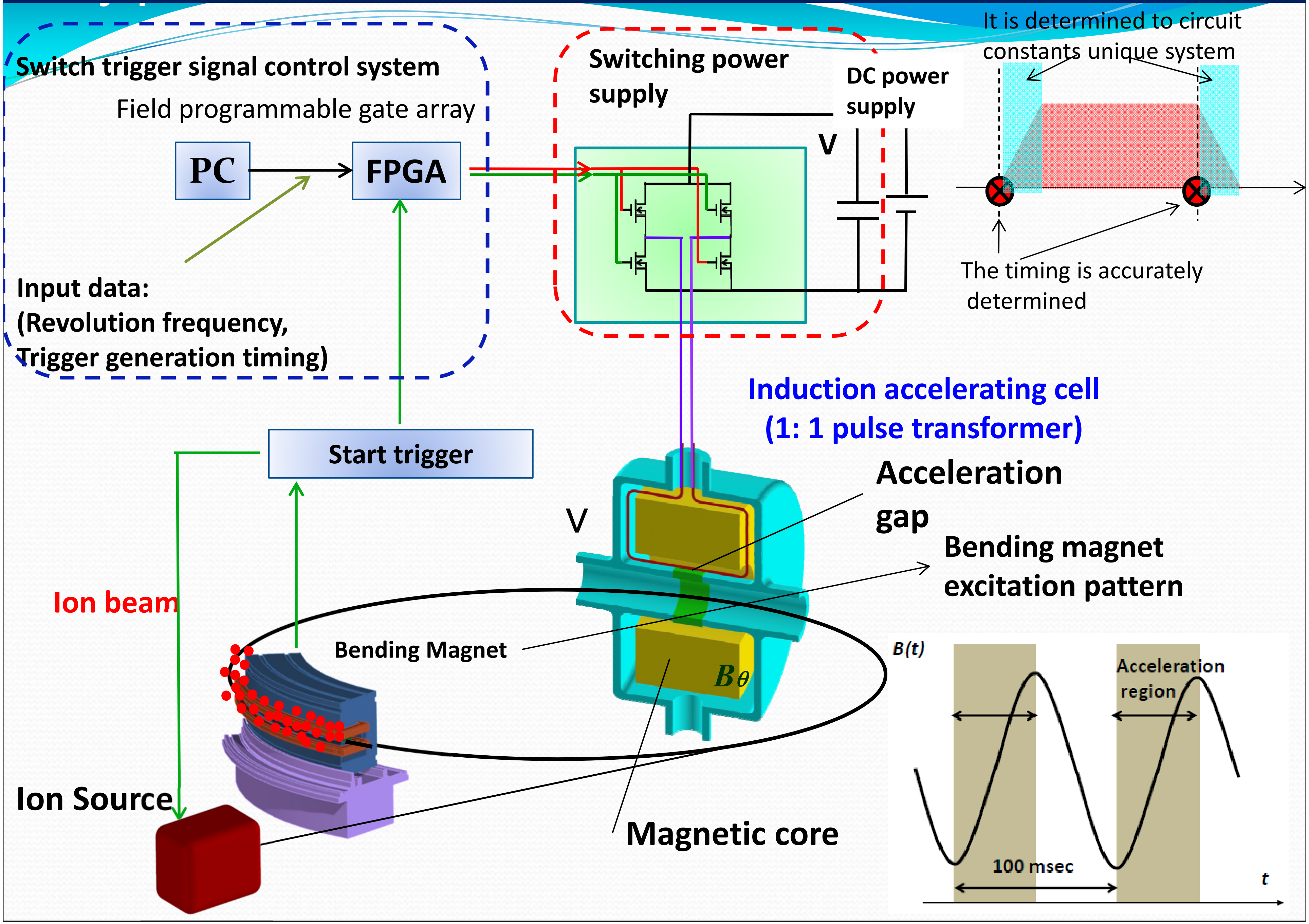
KEK Digital Accelerator (Induction Synchrotron without Injector)

T. Iwashita *et al.*, *"KEK Digital Accelerator"*
Phys. Rev. ST-AB 14, 071301 (2011).

C_0 ~ 37.7 m, B_{max} ~ 0.84 T,
E_{max} ~ 315 MeV (Proton)



Schematic View of KEK Digital Accelerator (fast cycling IS) Operation



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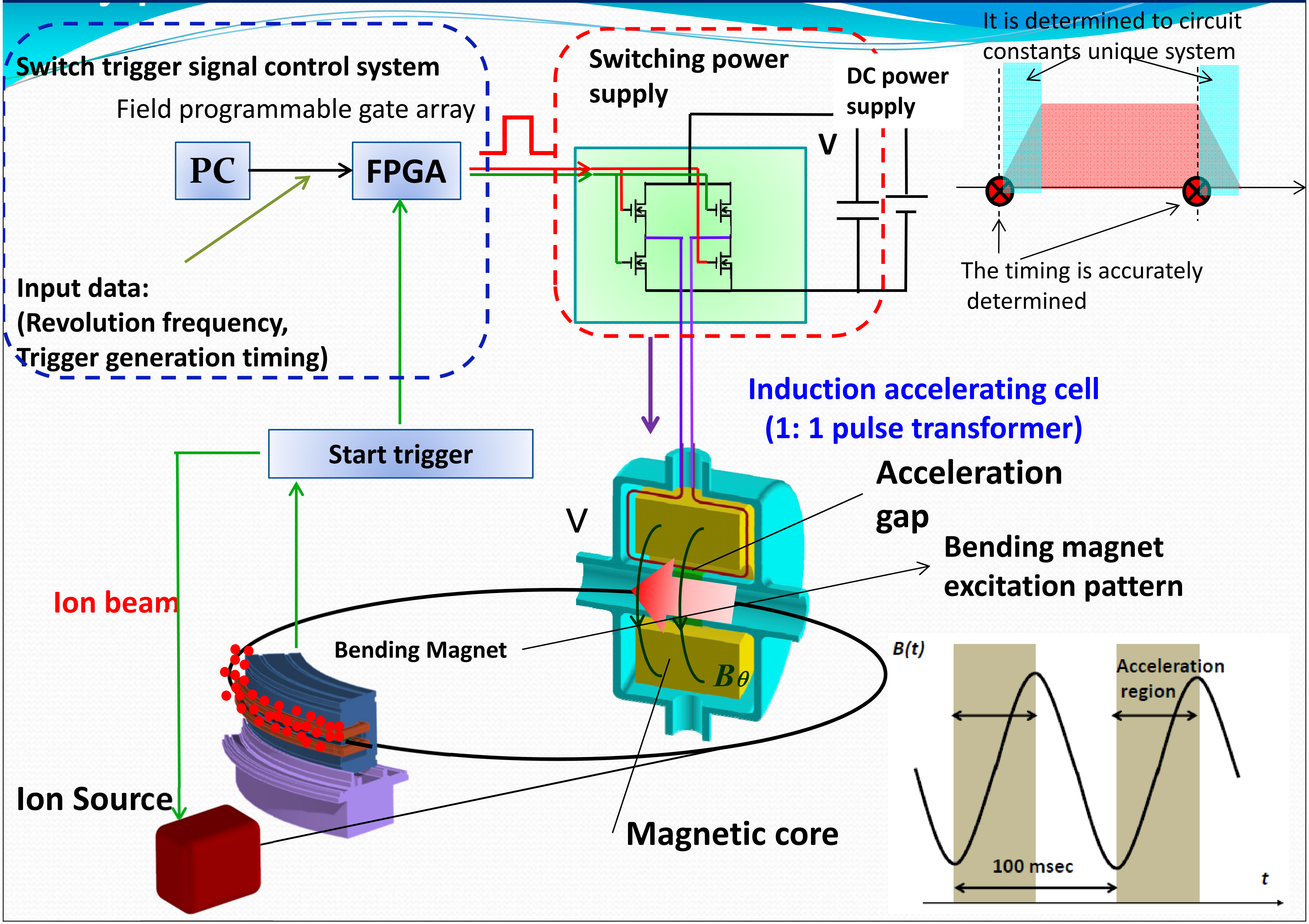

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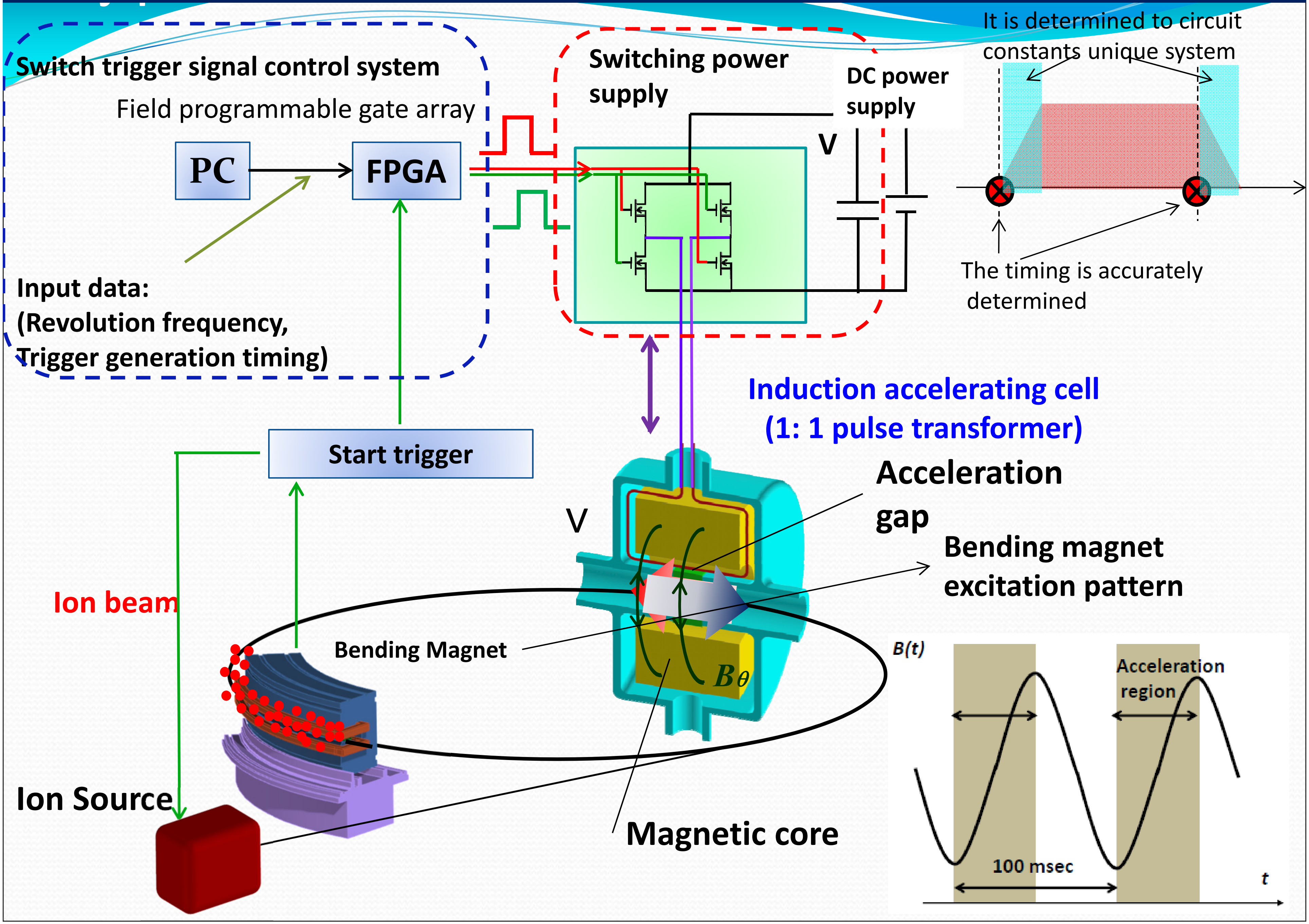

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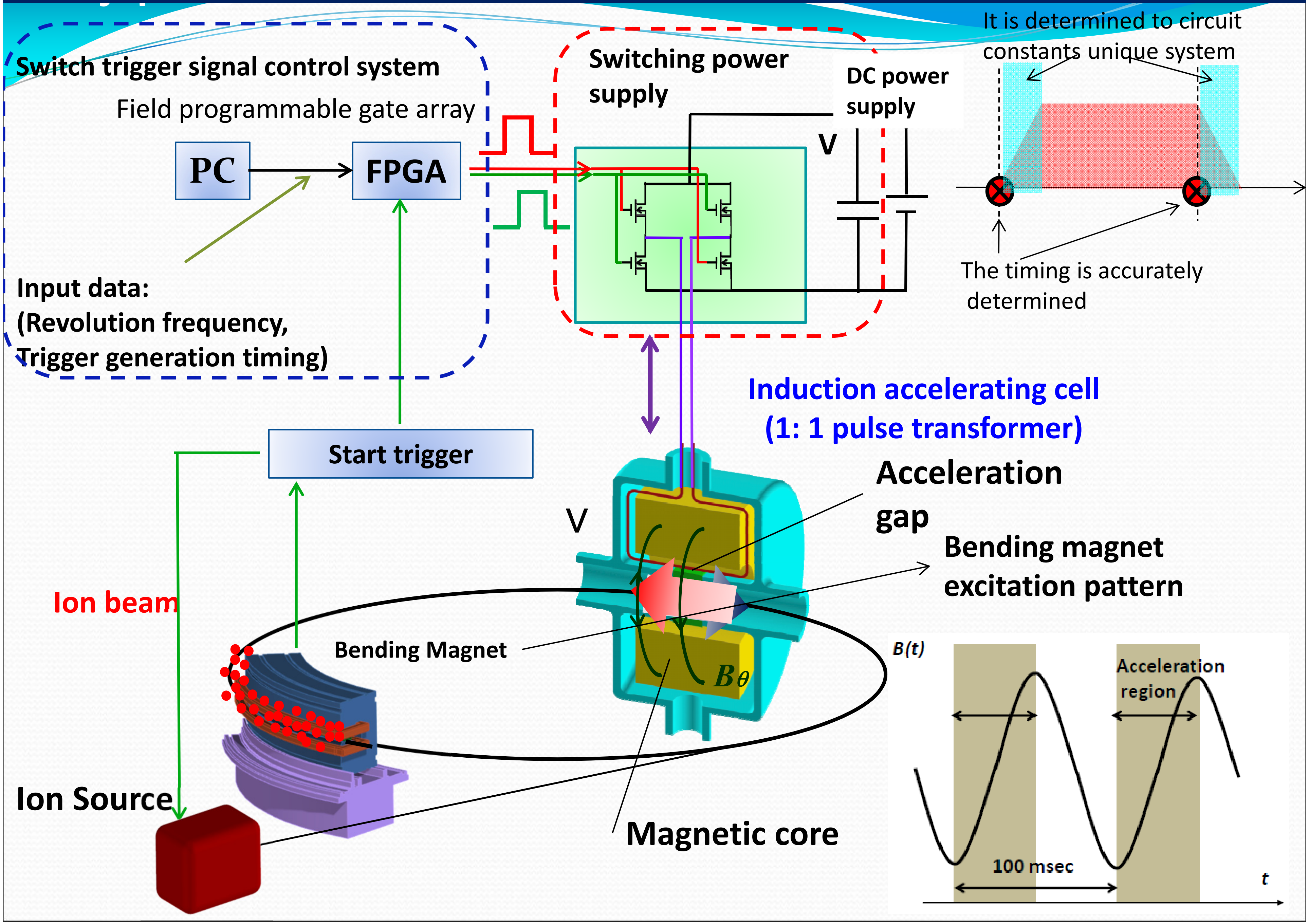

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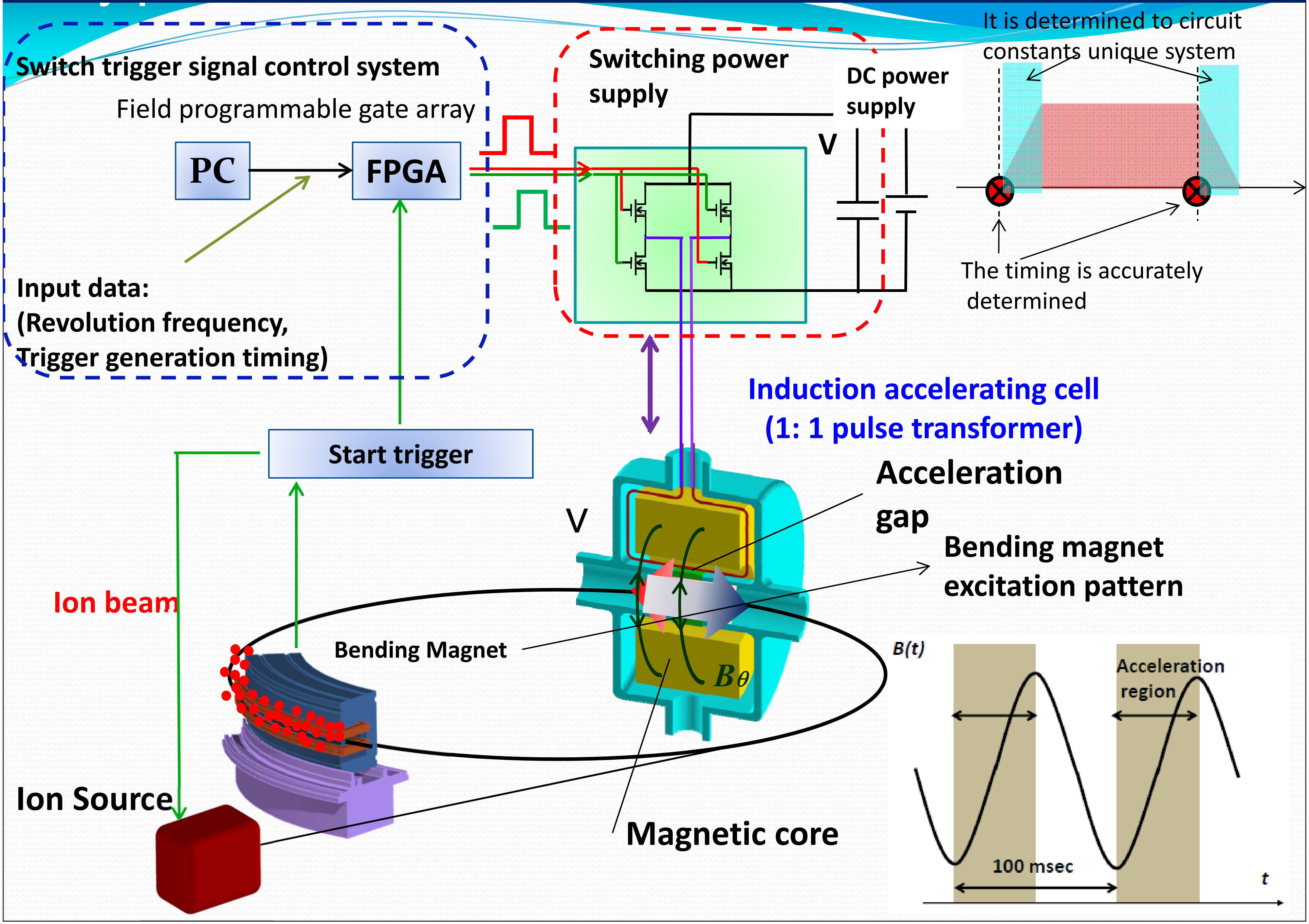
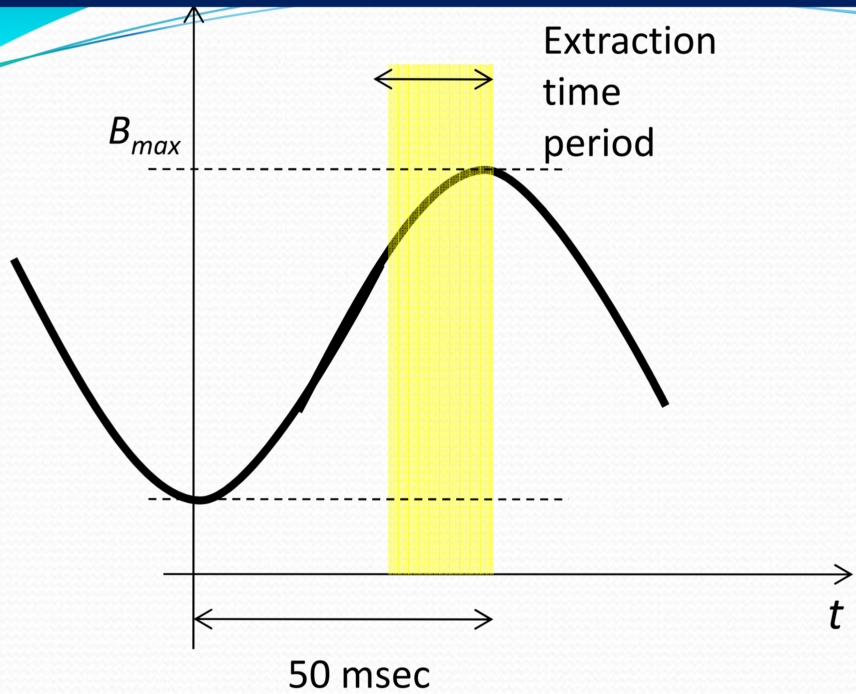
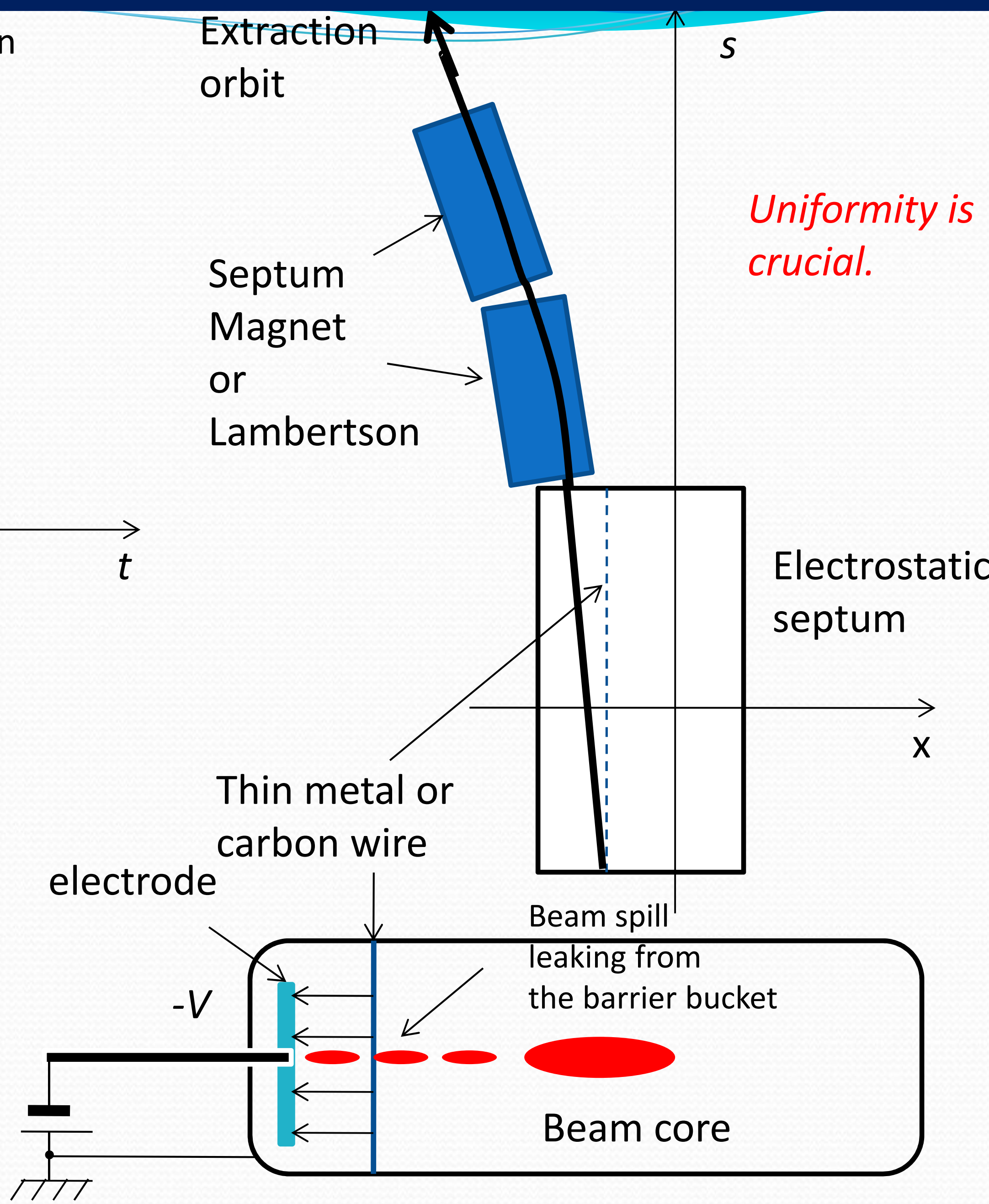


Extraction with Energy Sweeping



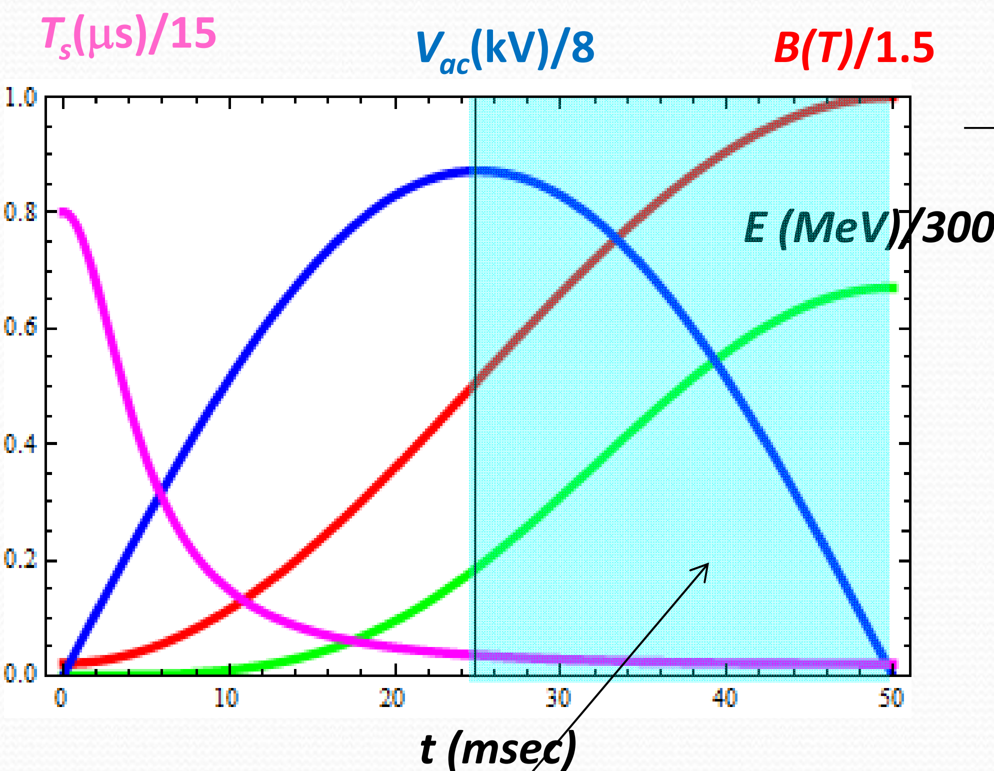


Extraction method:
This relies on a <u>finite momentum dispersion function</u>
and <u>large momentum deviation</u>

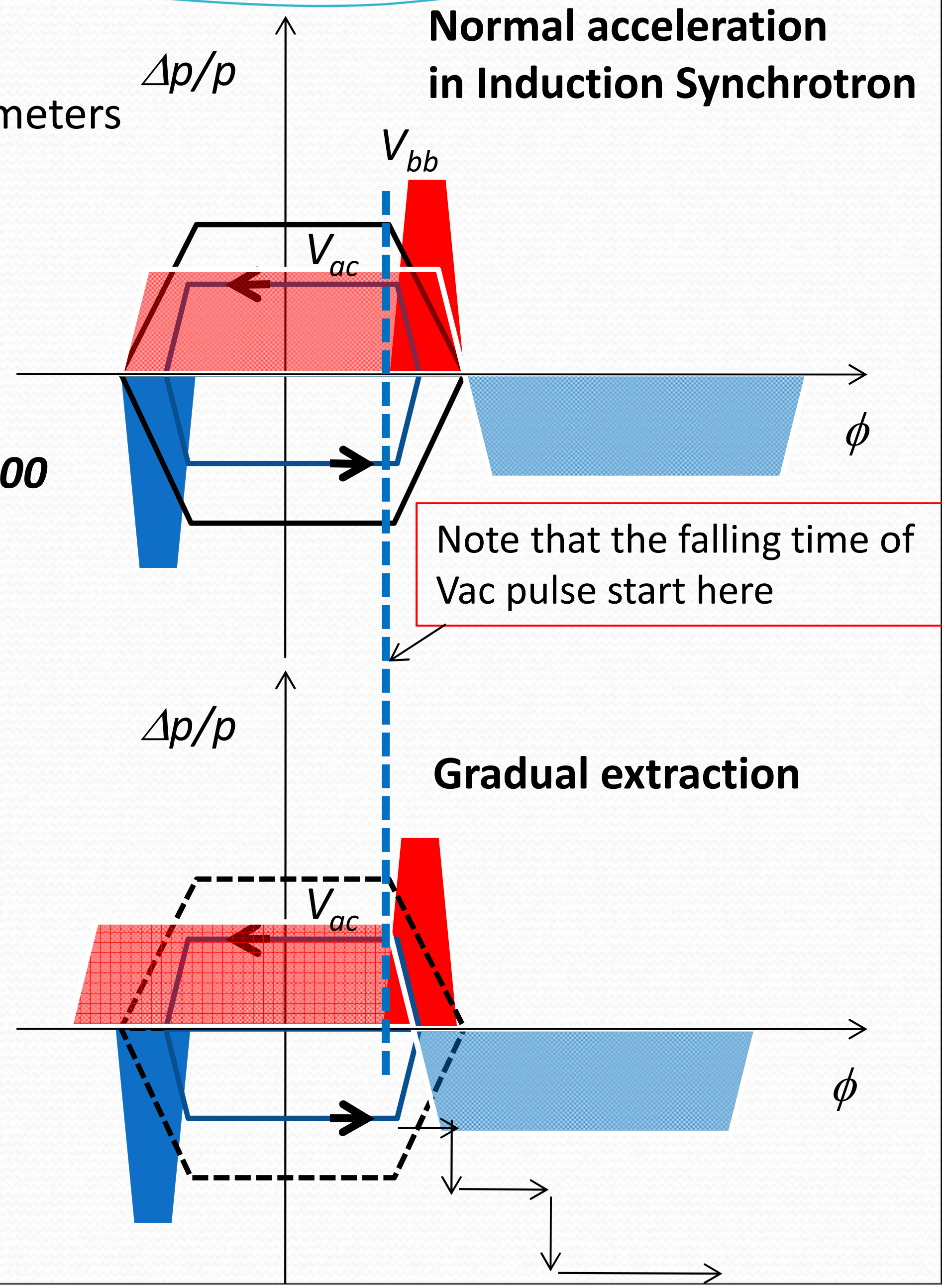
$x_{eq}=D(s)\Delta p/p$

Leakage of Particles from the Barrier Bucket

Time variation of the accelerator and beam parameters



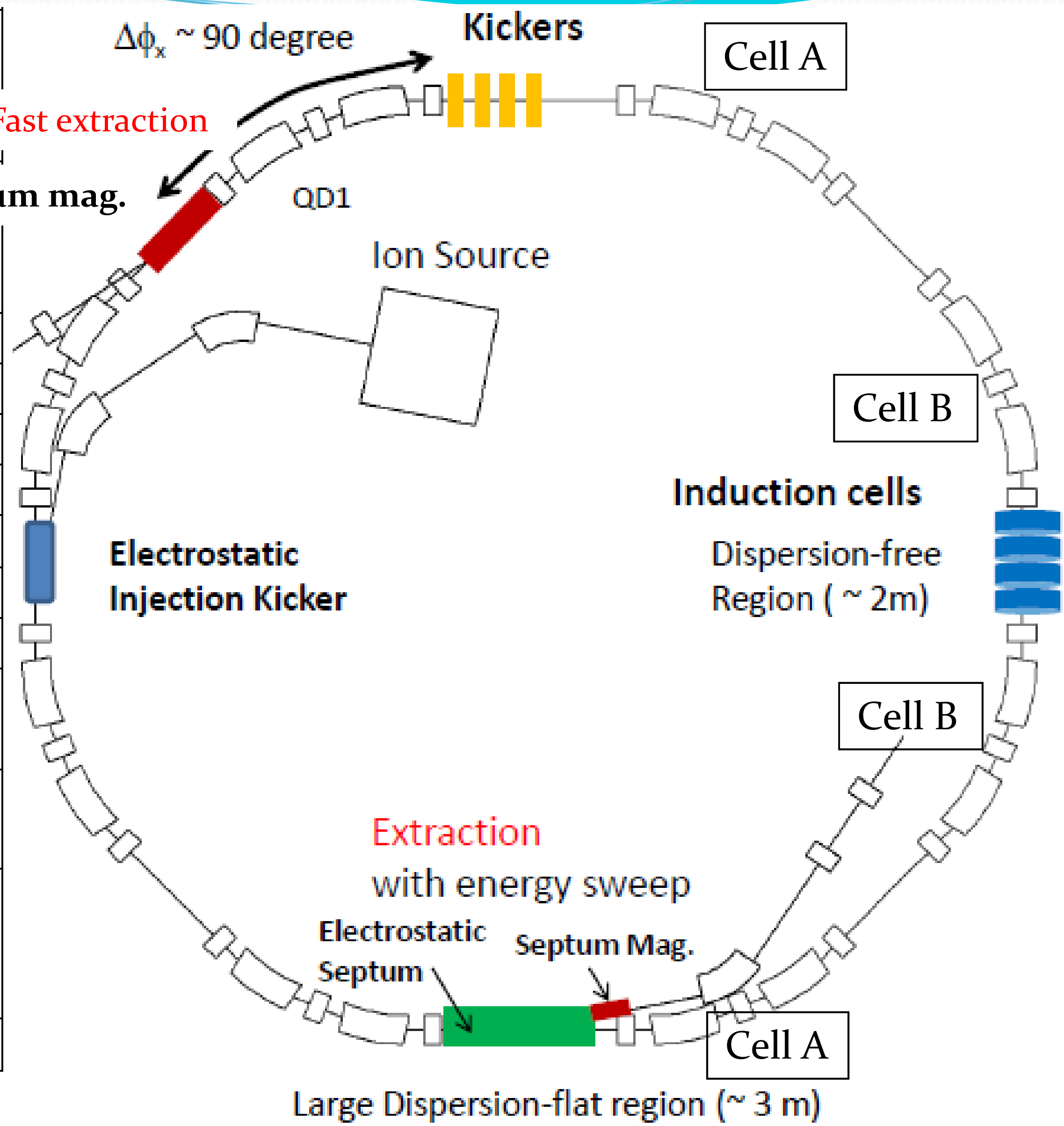
Extraction time region
（starting/stopping is flexible.）



What lattice is required to realize this extraction method?

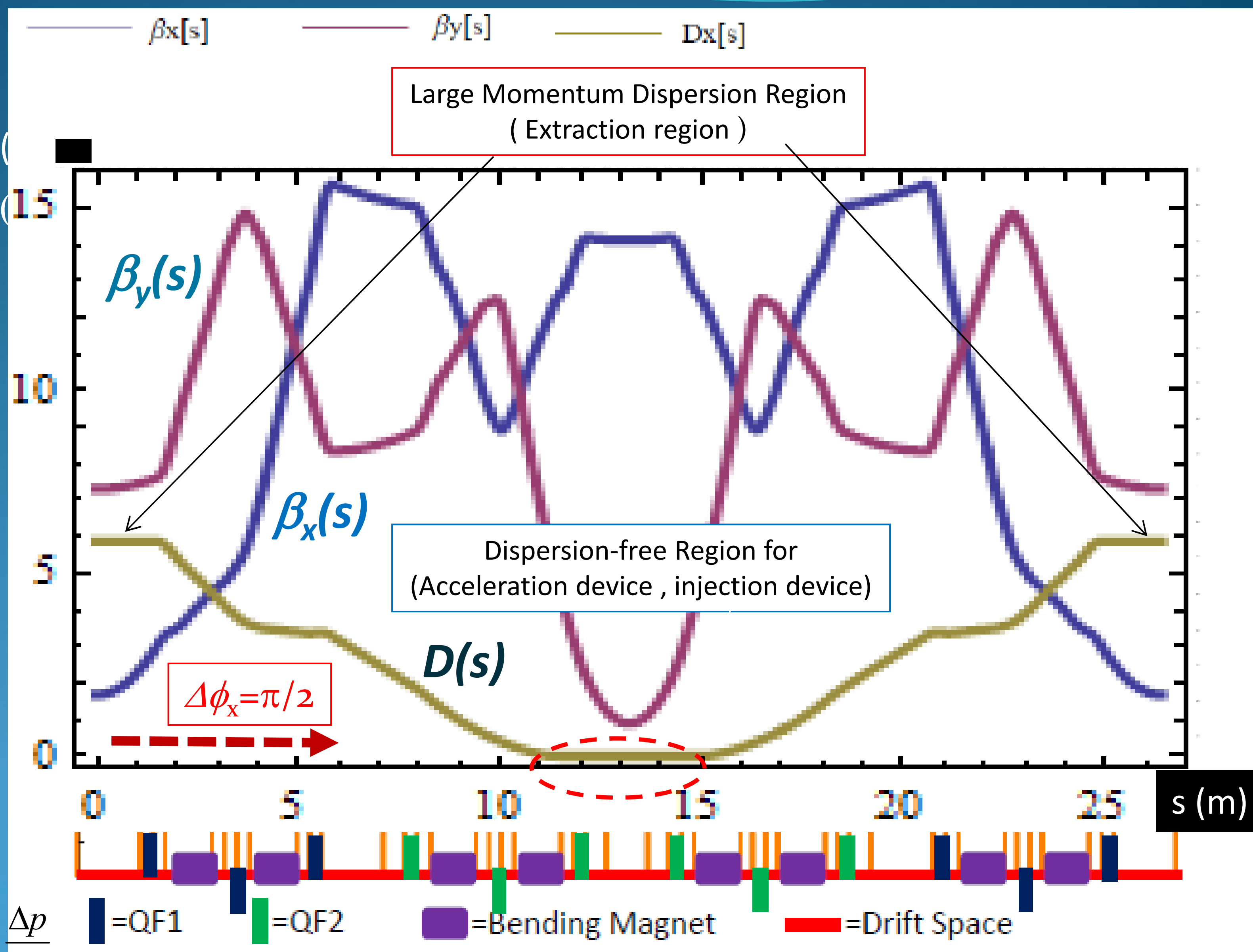
Dedicated Hadron Driver System

Energy	656 MeV for proton 200 MeV/nucleon for $A/Q = 2$ ion
C_0	52.8 m
Ion species	Gaseous/metal ions
Ion source	Laser ablation IS ECRIS
Injector	200 kV (electrostatic)
Ring	Fast cycling (10 Hz)
	$B_{max} = 1.5$ T
	$\rho = 2.8662$ m
	FODOF cell with edge focus of B
	Mirror symmetry
	$\nu_x/\nu_y = 1.3143/1.4635$
	2m long dispersion-free region 3m long flat large dispersion region
	a_p=0.273088 γ_T=1.92, E_T=864.7 MeV
Acceleration	Induction cells driven by SPS employing SiC-MOSFET $V_{acc} = \rho C_0 dB/dt$ (max 7 kV)
Vacuum	10^{-8} Pa



Munemoto *et al.*, " Laser Ablation Ion Source for Highly Charge-State Ion Beams" , WEPB19

Lattice Function and Cell Structure



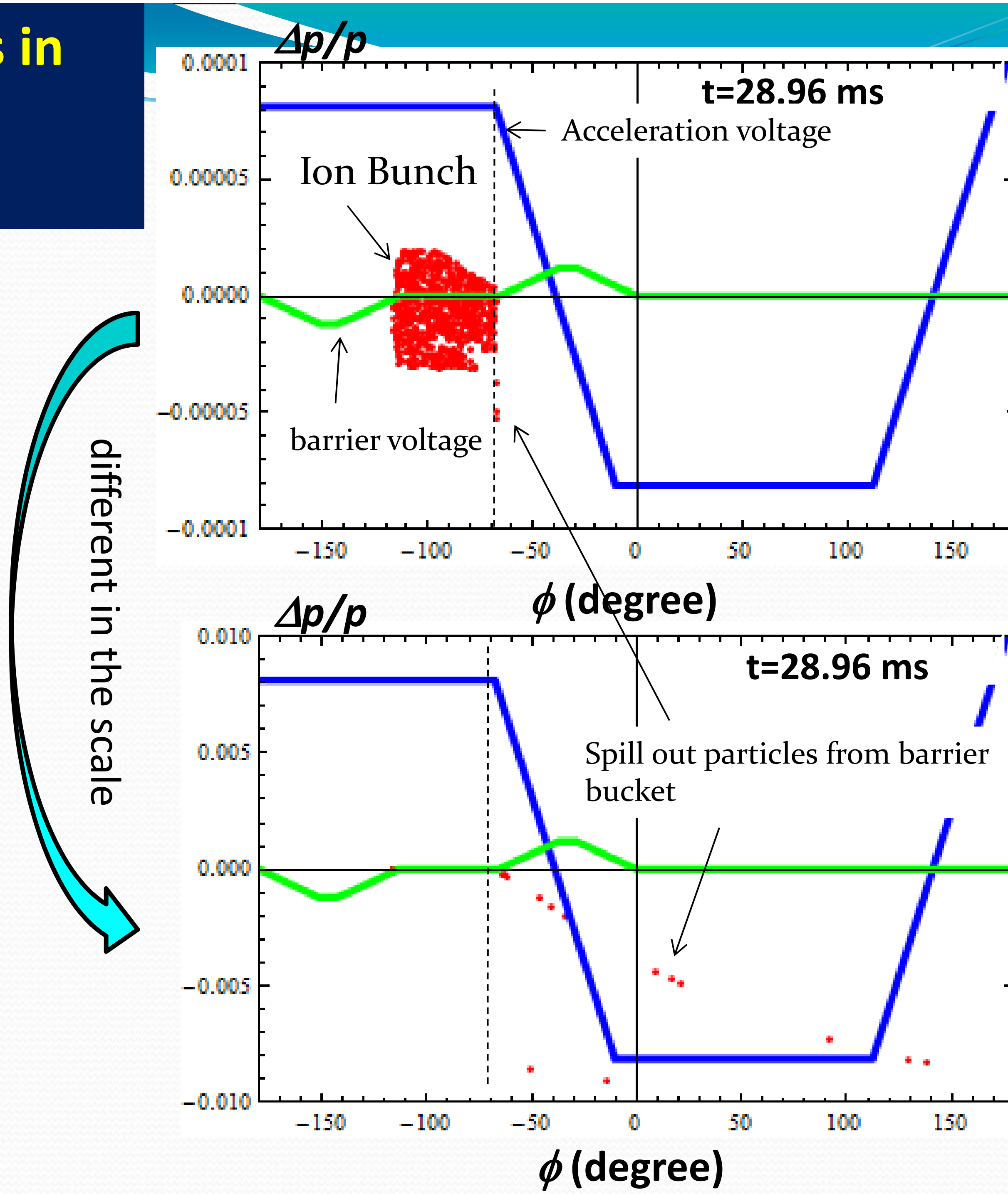
Small β_x(s) is crucial for small momentum purity

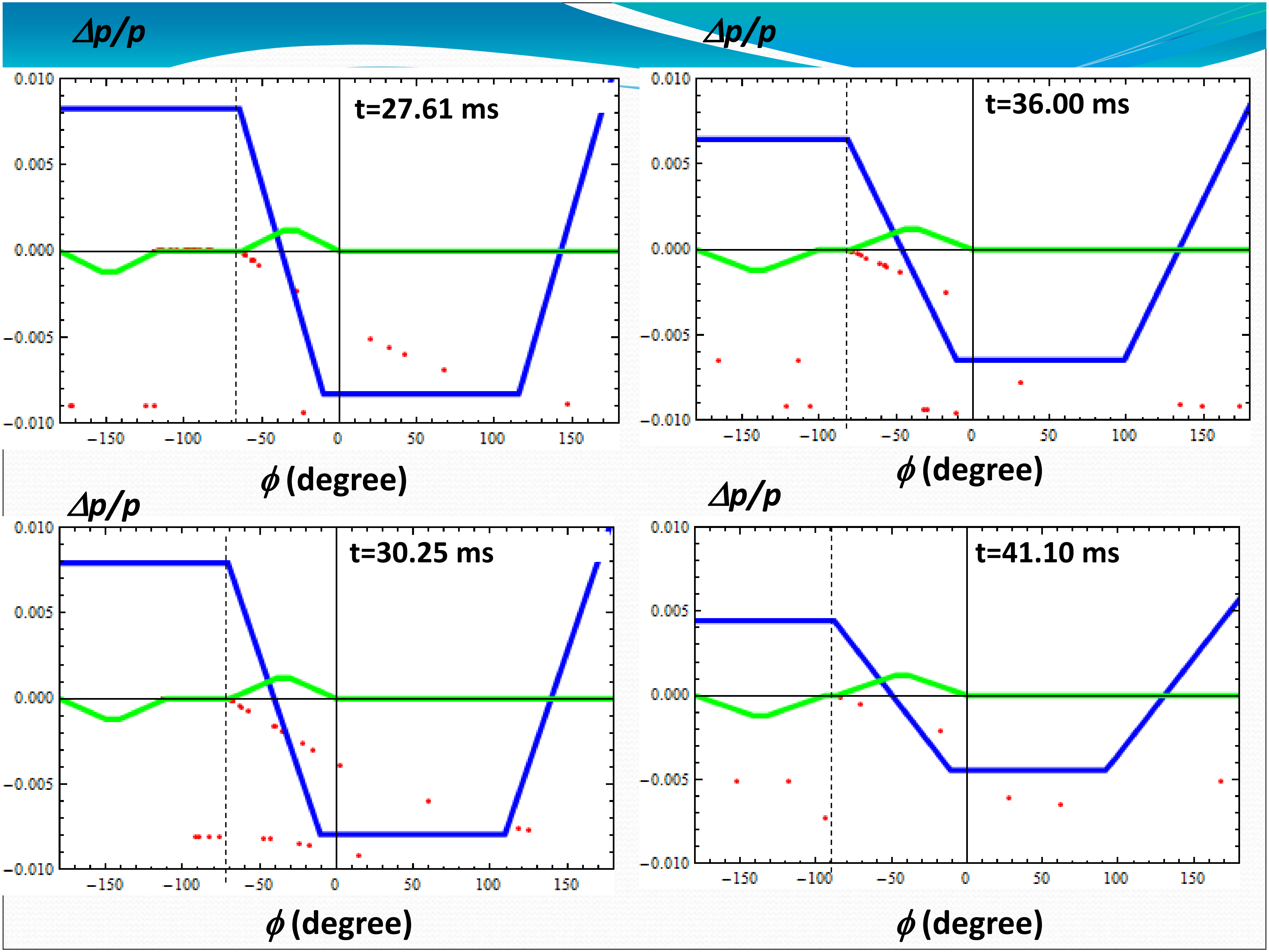
$$\sqrt{\varepsilon\beta_x(s)} << D(s)\frac{\Delta p}{p}$$

Cell A Cell B Cell B Cell A

Simulation of Extraction with Energy Sweep:
Behavior in the Phase Space

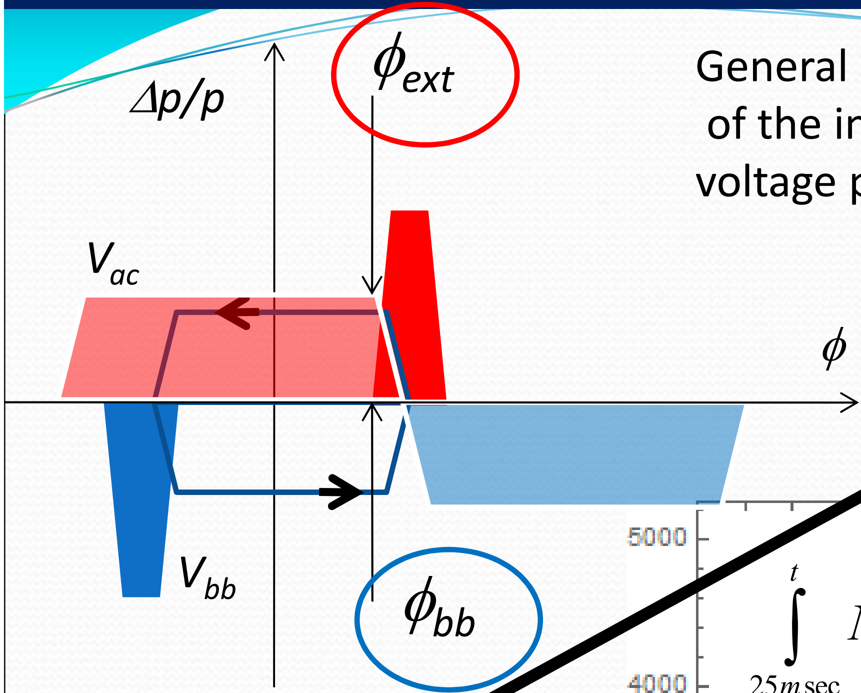
Behaviour of particles in the phase space during the extraction



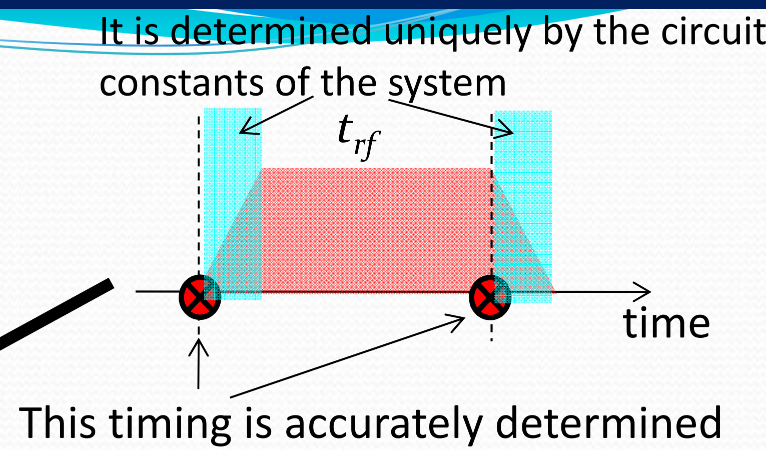


Δp/p
t=27.61 ms
ϕ (degree)
Δp/p
t=36.00 ms
ϕ (degree)
Δp/p
t=30.25 ms
ϕ (degree)
Δp/p
t=41.10 ms
ϕ (degree)

Controlled Spill Structure and Spill Control Parameter

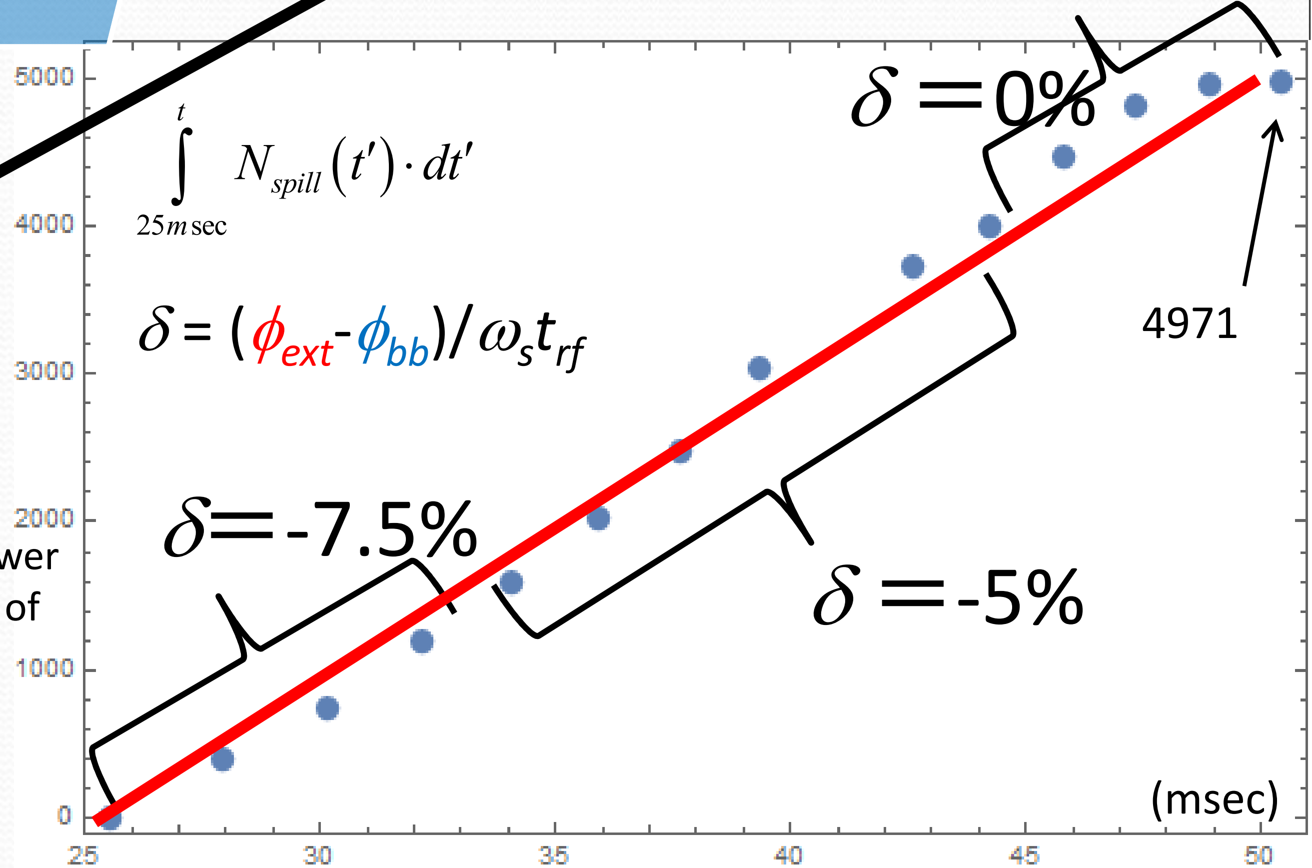


General characteristics of the induction pulse voltage profile control



Control of ϕ_{ext} with ϕ_{bb} :

Realized by the FPGA to manage timing of the gate signal of the power semiconductor switching element of the switching power supply that drives the accelerating cell



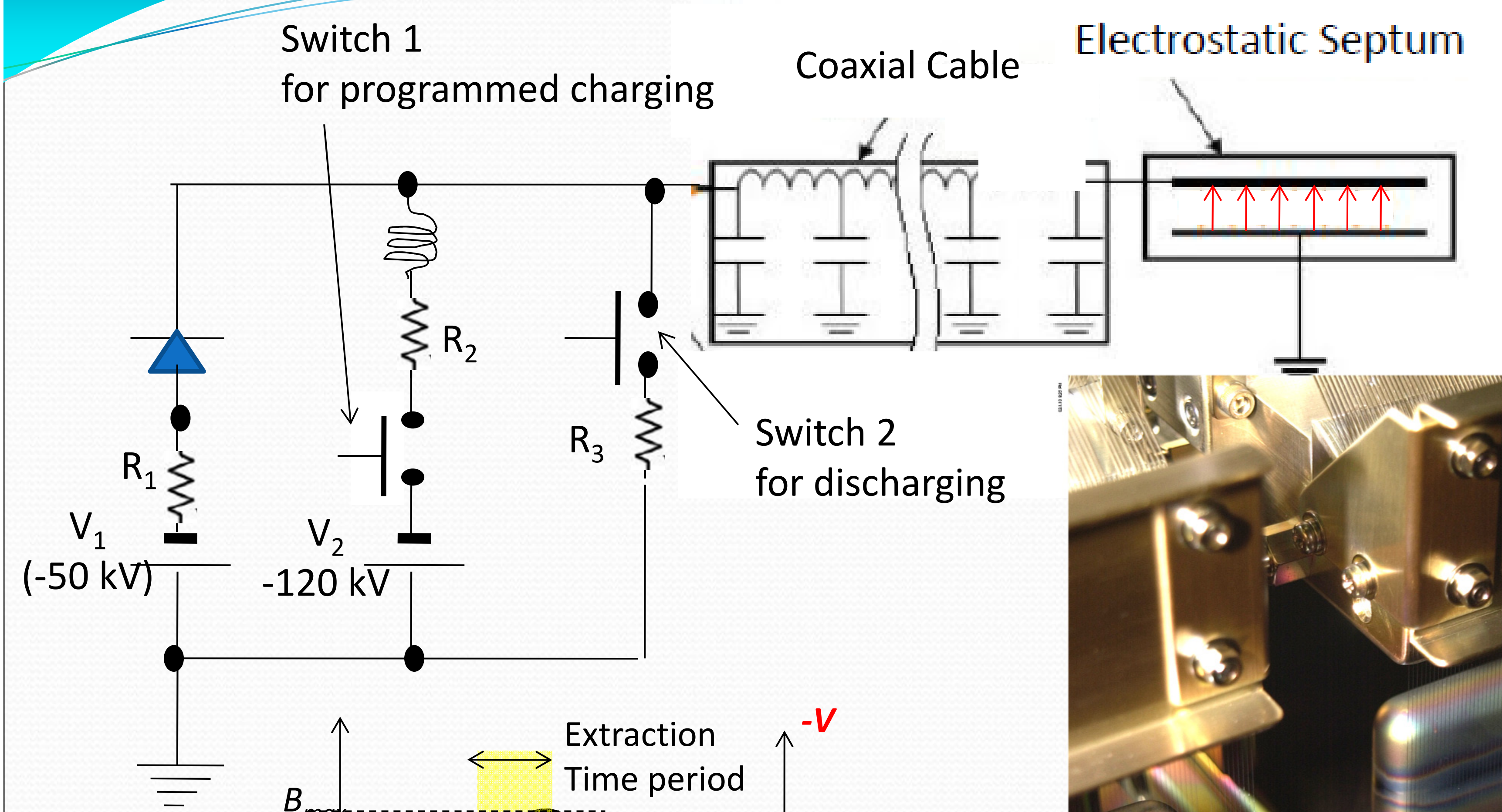
Extraction Devices: Electrostatic Septum and Lambertson Magnet

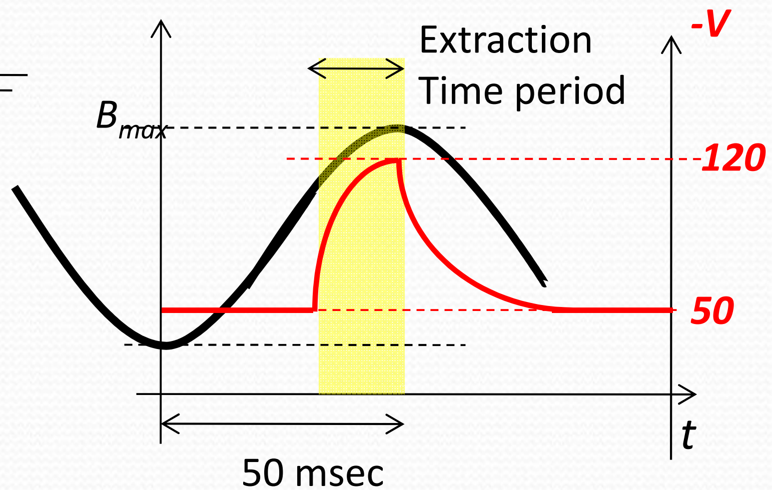
Strong demand → **Extraction orbit must be same.**
It should not depend on energy.

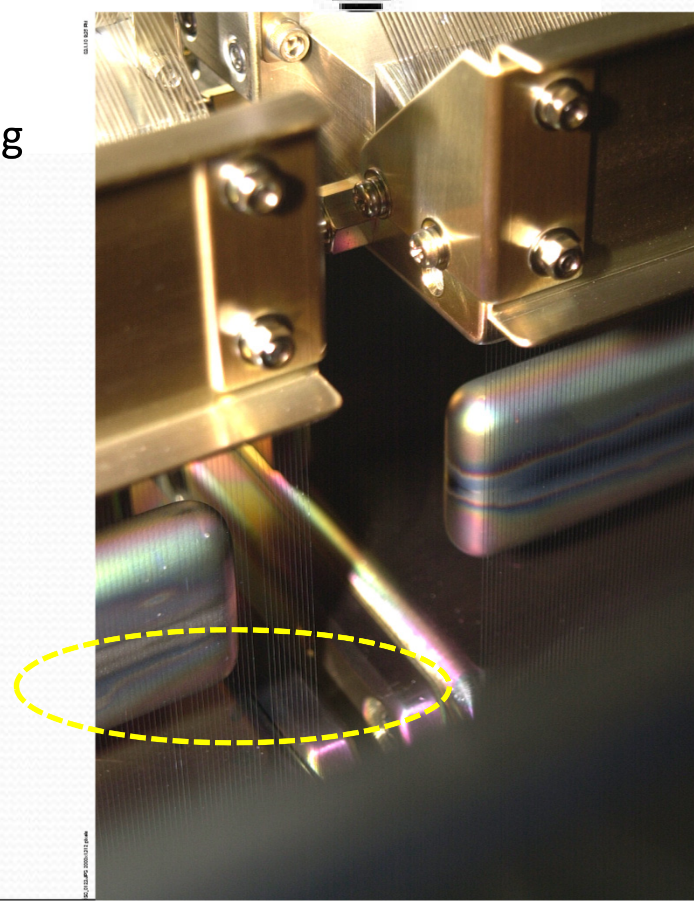
How must the extraction device perform?

$$\boxed{\boldsymbol{B} \sim \beta\gamma, \quad \boldsymbol{E} \sim \beta^2\gamma}$$

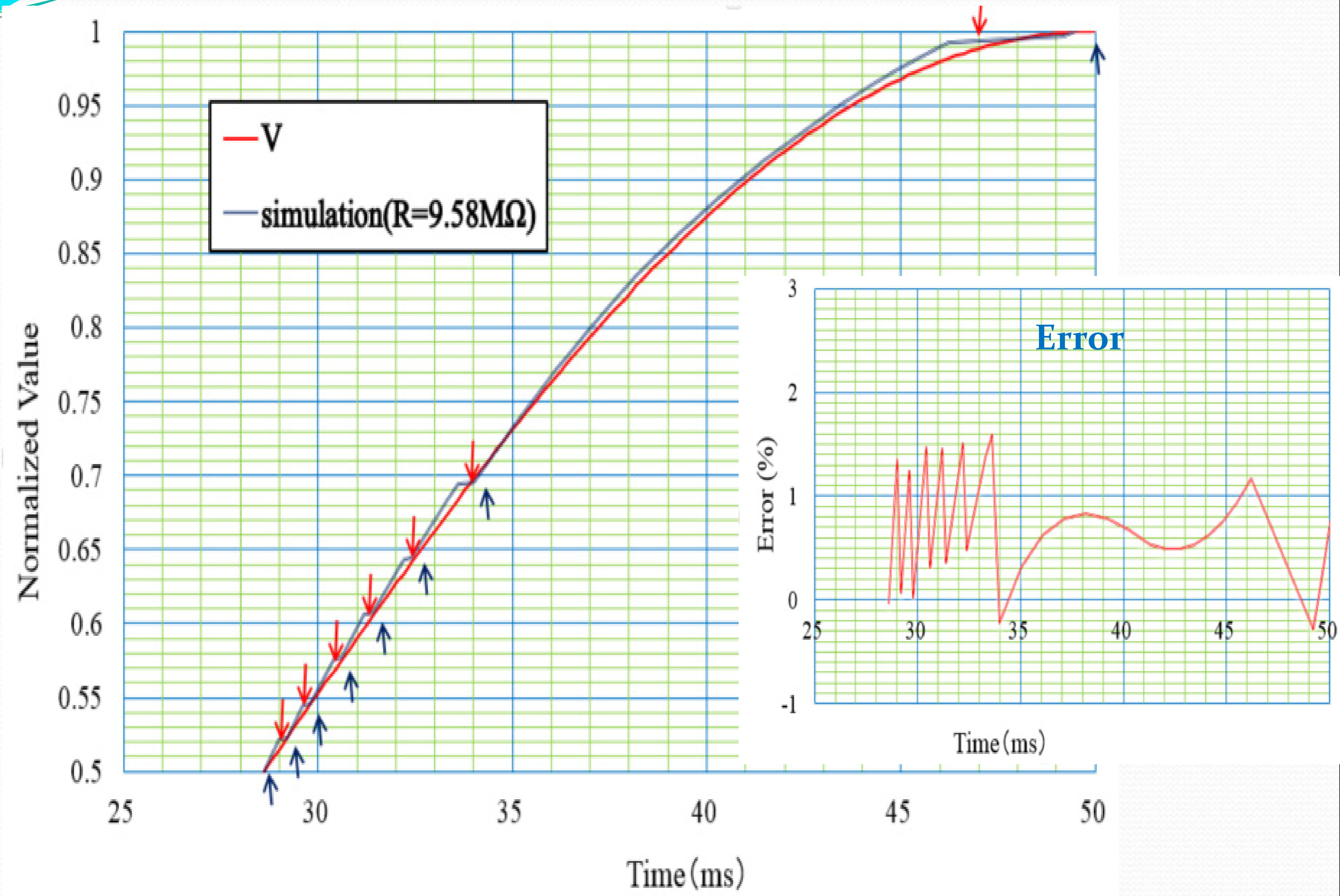
Variable Voltage Electrostatic Septum (Equivalent Circuit)



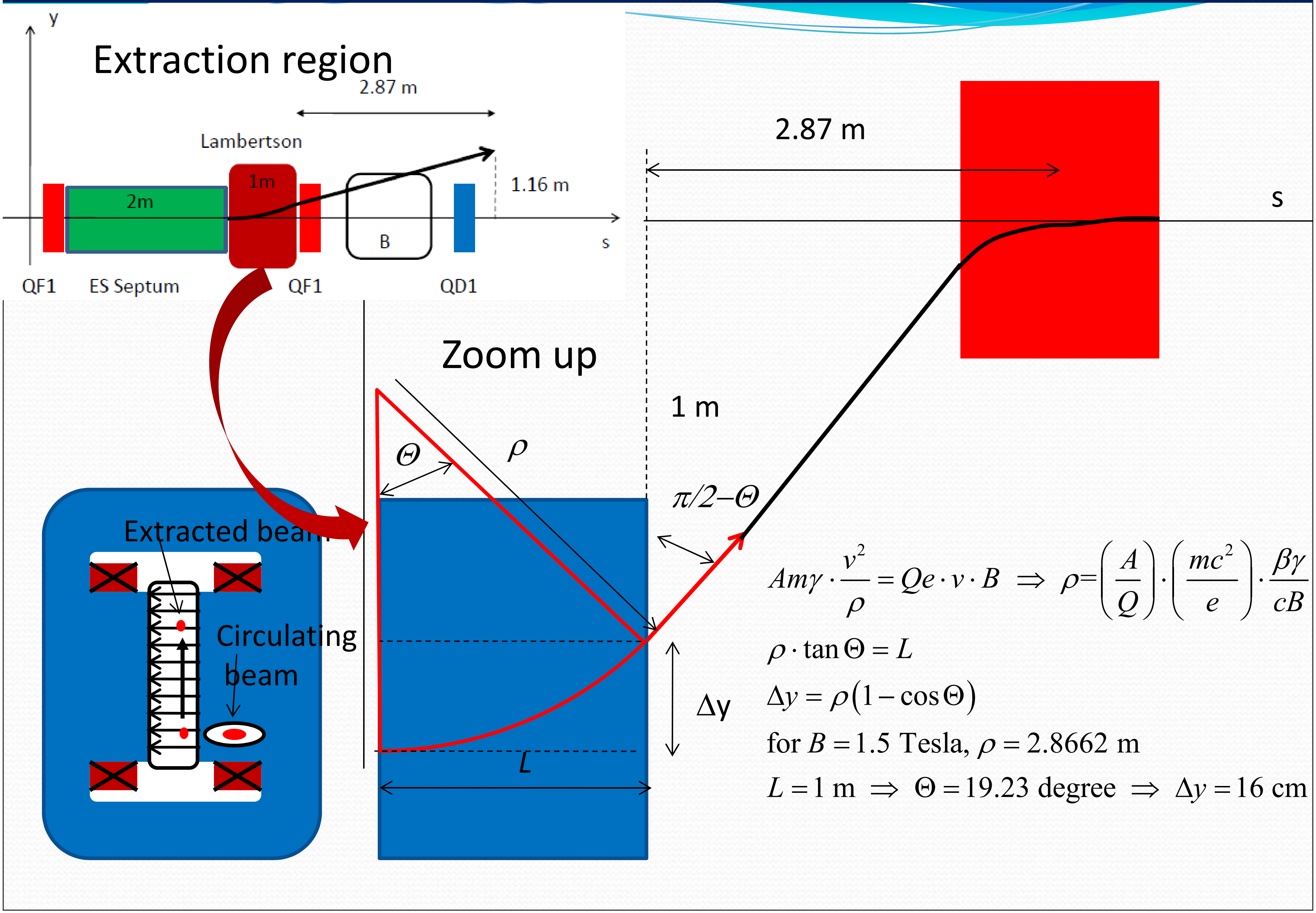




Variable Output Voltage (Simulation and ideal Voltage Profile)



Lambertson Magnet



$$Am\gamma \cdot \frac{v^2}{\rho} = Qe \cdot v \cdot B \;\Rightarrow\; \rho = \left(\frac{A}{Q}\right) \cdot \left(\frac{mc^2}{e}\right) \cdot \frac{\beta\gamma}{cB}$$

$$\rho \cdot \tan\Theta = L$$

$$\Delta y = \rho\left(1 - \cos\Theta\right)$$

for $B = 1.5$ Tesla, $\rho = 2.8662$ m

$L = 1$ m $\Rightarrow$ $\Theta = 19.23$ degree $\Rightarrow$ $\Delta y = 16$ cm

Remained Issues and Summary and Prospect

Remained Issues:

Assessment of the Transverse emittance and energy spread of the extracted beam

Nolinear lattice correction

Practical barriers for social spread: the Pharmaceutical Affairs Law in Japan

It takes more than 5 years to get a license on new scenario.

in any other countries for its first demonstration?

Summary

■Novel scheme of energy sweep extraction in the fast cycling synchrotron, based on the induction synchrotron concept, was introduced.

■Ideal lattice has been proposed for a hadron beam driver for cancer therapies.

■Extraction system for an energy varying beam was introduced

Prospect

Uniform 3D spot scanning on a target

Low intensity operation

In future

3D spot scanning on a moving target integrating real time diagnosis of the target position

Low cost Therapy

- Like Medical examination of stomach cancer by X-ray, where a patient is turned round and his cancer part is modified or moved by gravitation.
- Require monitoring the 3D real time image of the cancer part.

Gantry free 3 D spot scanning

Thank You for Your Attention