Electron Cloud studies in J-PARC MR and Fermilab RR

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US-Japan collaboration meeting

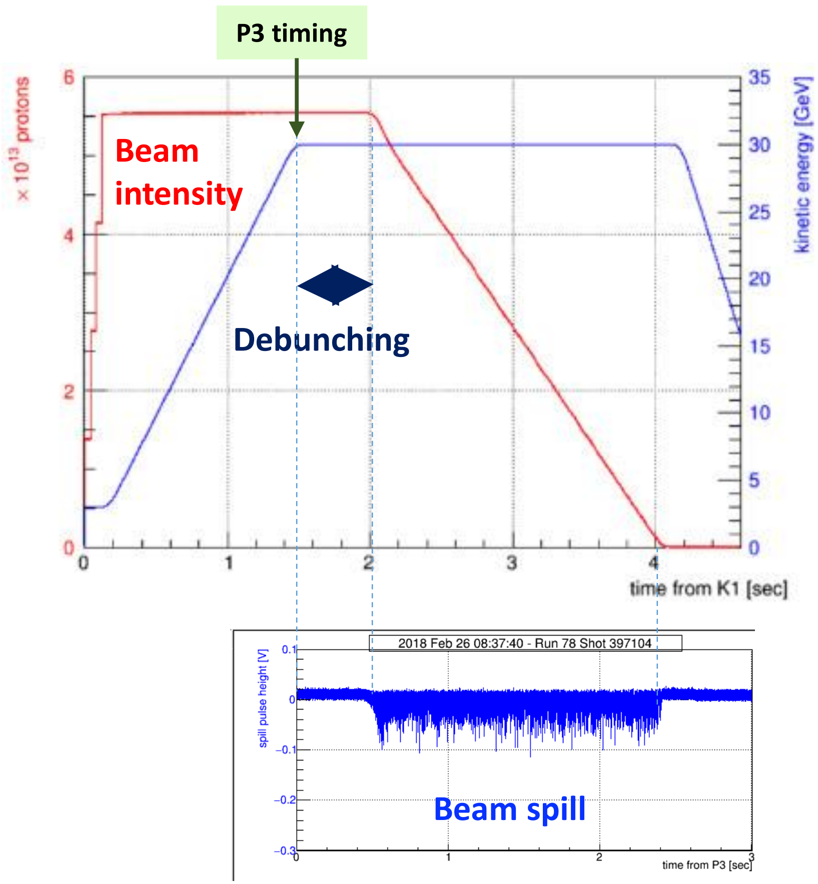
Thanks to M. Tomizawa and T. Toyama, B. Yee-Rendon

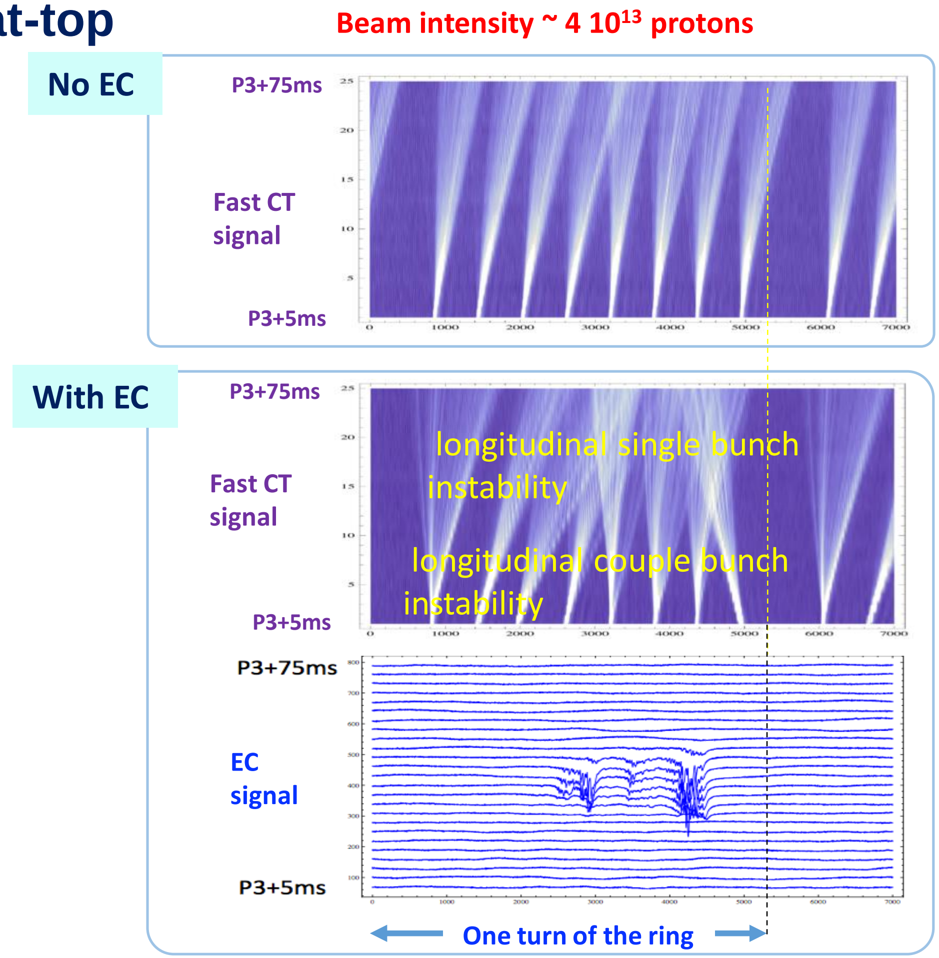
Electron cloud effects in J-PARC

- Seen only in Slow extraction mode.
- Longitudinal microwave instability occurs simultaneously with the electron cloud signal.
- Longitudinal emittance is enlarged to suppress the micro-wave instability.
- The instability has not been seen in Fast extraction mode in spite of much higher intensity.

SX mode

EC at the debunching process at the flat-top





With EC

Coupled bunch instability occurs at the top energy. Longitudinal dipole motion, $dz/ds \neq 0$. Single bunch (MW) instability occurs at overlap on debunching. High frequency component of the bunch profile induces electron cloud.

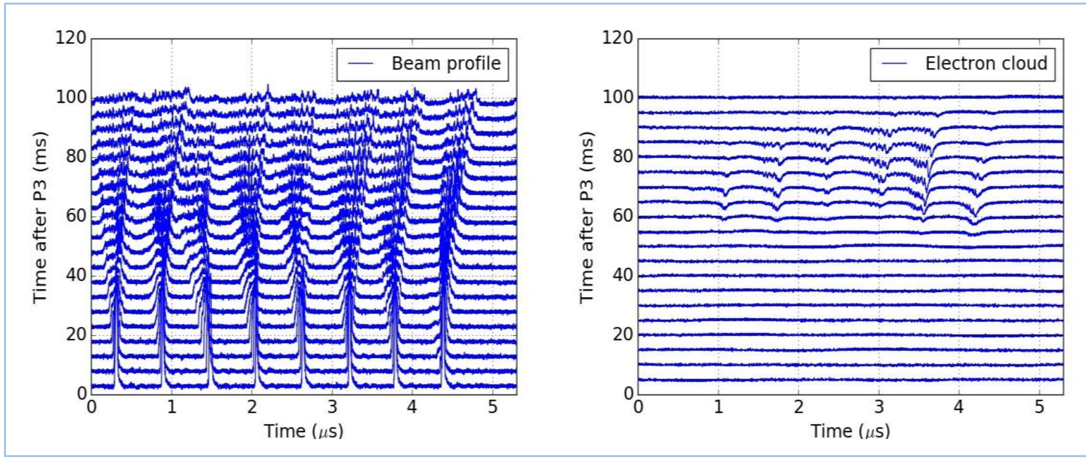
Electron cloud build up is triggered by longitudinal single bunch instability which is induced by longitudinal couple bunch instability.

a, Ibaraki, Japan

ble 1: Relevant beam parameters during the SX operat MR.

Parameters	Units	Value
Circumference	m	1567.5
Energy	GeV	30
Power	kW	38.2

- Electron current~80μA/cm^2.
- Electron production rate 0.25A/m.
- If Electrons stay 50ns in chamber, the line density is 7.5x10^{10}/m.
- Threshold line density is 10^8/m.
- Measured density is very high.



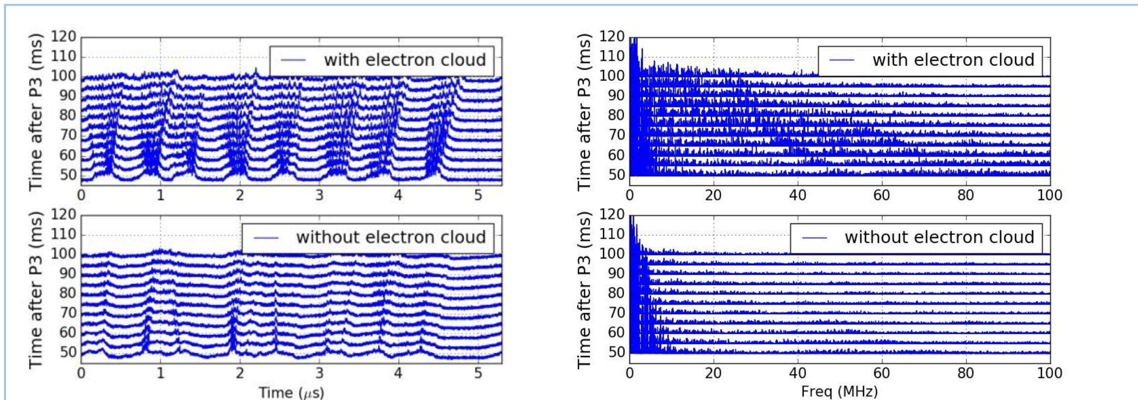


Figure 4: The beam current signals for events with and without electron cloud in the time domain, top and bottom left, respectively. The corresponding Fourier transform plots are shown in right side in the same order.

Simulation for SX mode (debunching)

Simulation with the sinusoidal beam density modulation

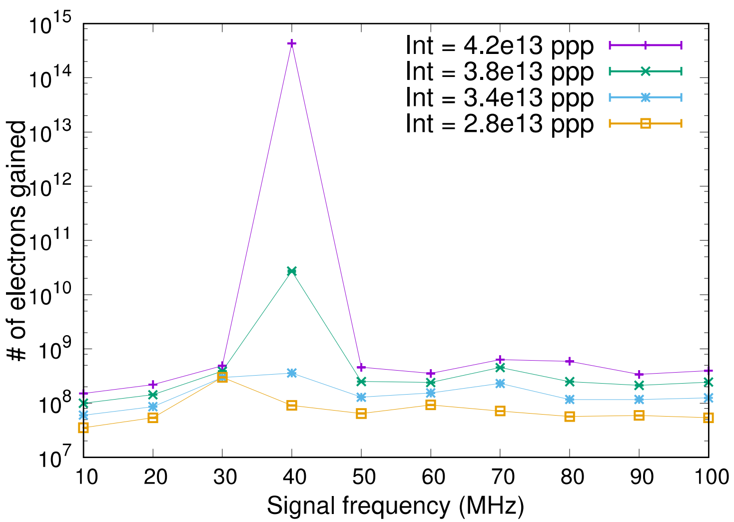
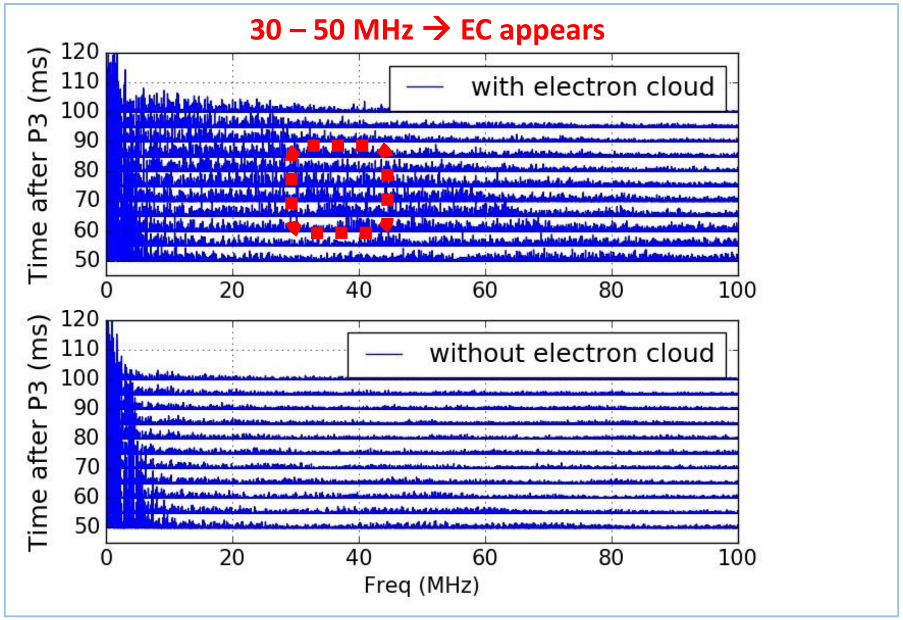


Figure 6: Electrons produced in the simulations vs. the frequency of the sine signal at different intensities, using $\delta = 1.1$ and $E_{max} = 200\ eV$.

Frequency spectrum of the beam measured by the Fast CT



"Multipactor condition" may be satisfied

Electron frequency and instability threshold

- Electron frequency bounded in proton beam potential

$$\omega_{e,y}^2 = \frac{\lambda_p r_e c^2}{(\sigma_x + \sigma_y)\sigma_y}$$

- $\omega_{e,x}=\omega_{e,y}$=32MHz (2.8x$10^{13}$ppp), 40 MHz (4.2x$10^{13}$ppp) for σ_{xy}=7.5mm.
- λ_p=averaged proton line density=1.8x10^{10}-2.7x10^{10}m^{-1}.
- These frequencies are consistent with the electron amplification in the previous page. ω_e resonates with the frequency component (30-50MHz) of the bunch profile.

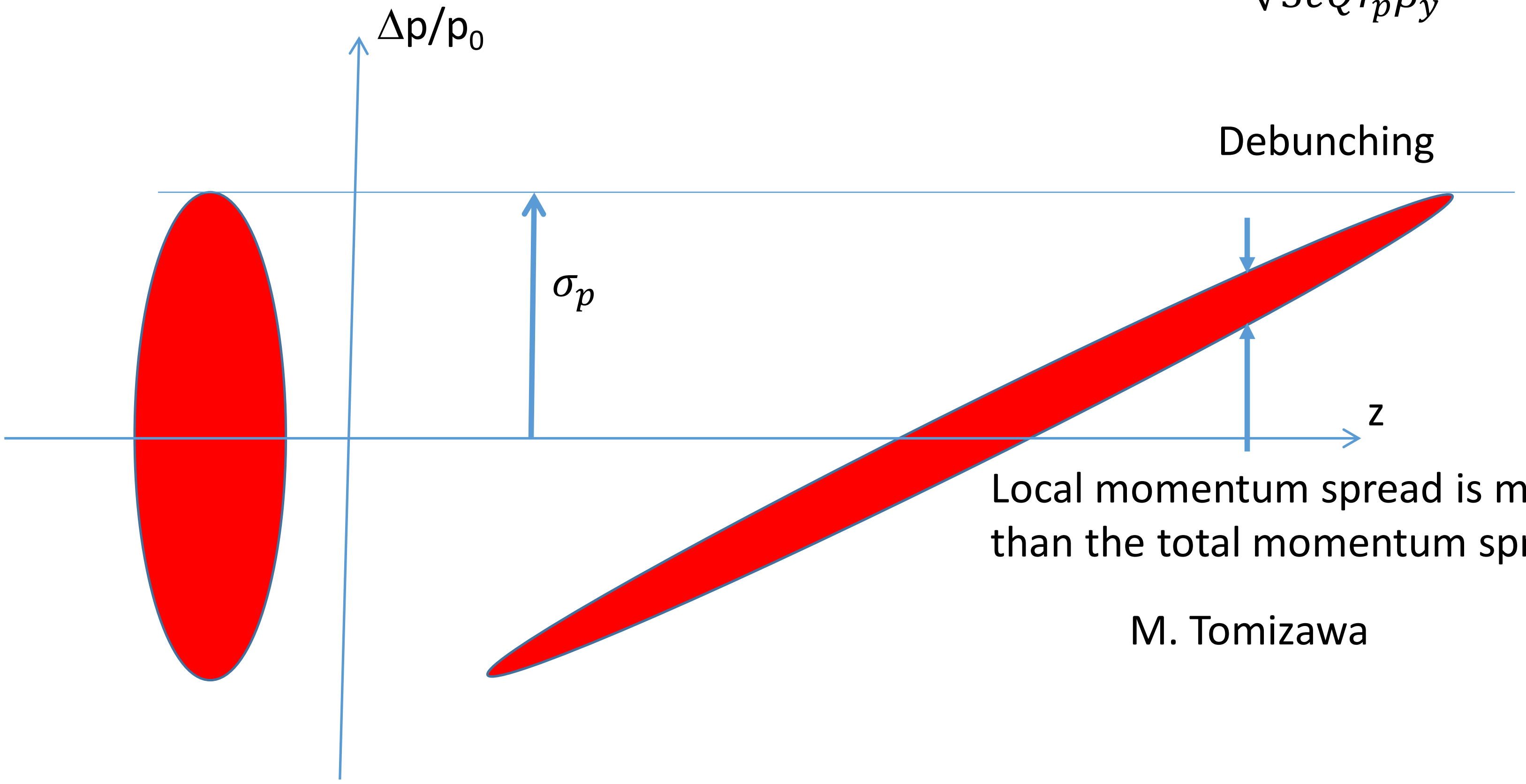
- Threshold of the beam instability

$$\lambda_{e,th} = \frac{2\gamma\omega_e|\eta_p|\sigma_p(\sigma_x + \sigma_y)\sigma_{x,y}}{\sqrt{3}cQr_p\beta_y} = 7.6 \times 10^7\ m^{-1}$$

Why the instability is seen in SX mode

- Beam intensity (ppp)
  - FX mode 3x10^{14} >> SX mode 6x10^{33}
- Energy spread is similar?

$$\lambda_{e,th} = \frac{2\gamma\omega_e|\eta_p|\sigma_p(\sigma_x+\sigma_y)\sigma_{x,y}}{\sqrt{3}cQr_p\beta_y}$$

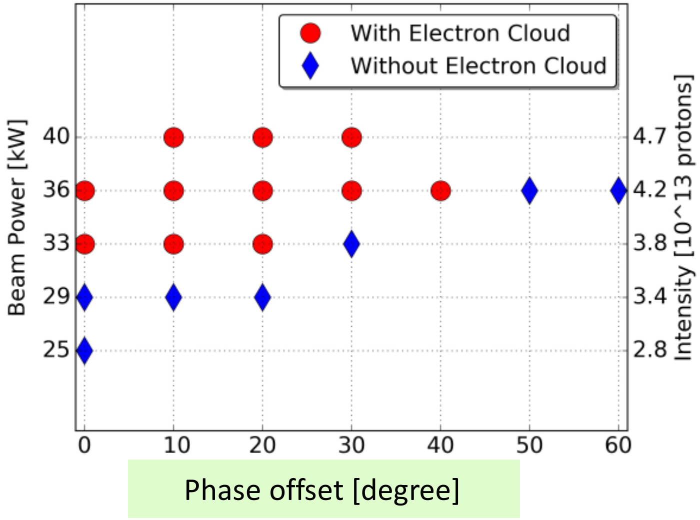


Local momentum spread is much less than the total momentum spread

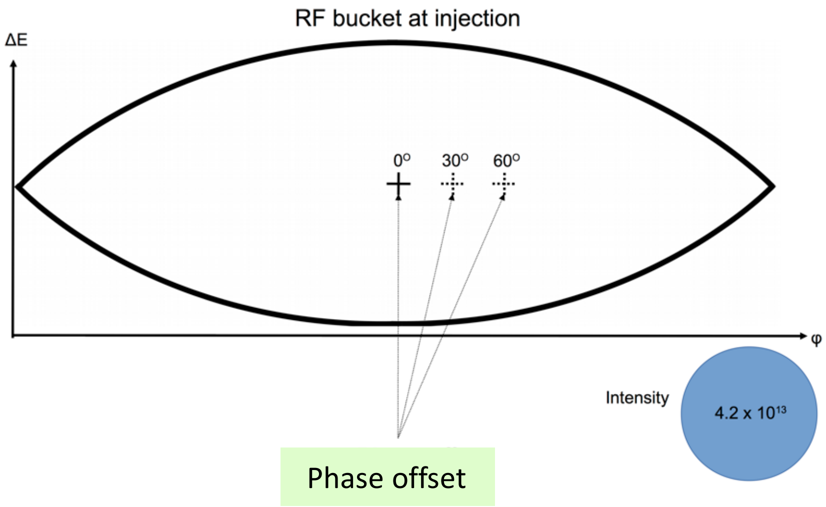
M. Tomizawa

Effort of mitigation

- Increase longitudinal emittance at the injection



Injection at RF phase



EC presence depends on the RF phase at MR injection and the beam intensity / beam power

Larger RF phase results longer bunch length before debunching.

Electron cloud in Fermilab Recycler

Parameters

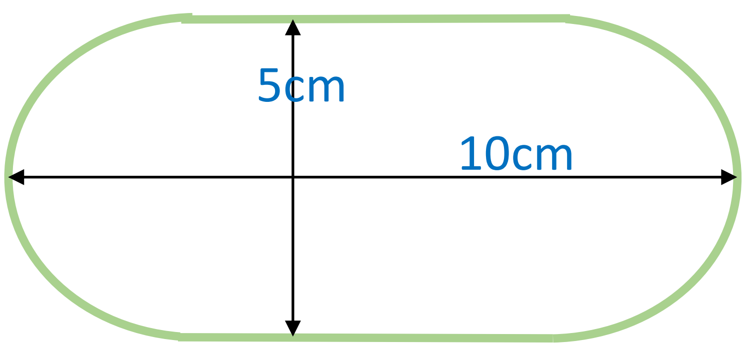
$L=3300\text{m}$, $h=588$, $N_{bunch}=500$, $N_{p/bunch}=5\text{x}10^{10}$

$\varepsilon_{x,rms}=5.5\text{x}10^{-8}$ m, $<\beta>=40$ m

$\sigma_{z,rms}=0.6\text{m}(0.3\text{m})$, $\sigma_{\delta,rms}=0.03\%$

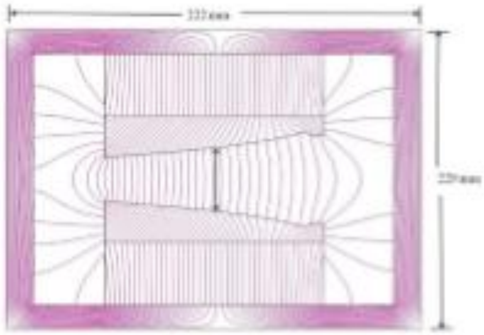
$L_{bsep}=5.6\text{m}$ (1.87ns), $\lambda_p=8.9\text{x}10^9$ m^{-1}(line density).

$\omega_e/2\pi=344$ MHz, $\omega_e\sigma_z/c=2.2$



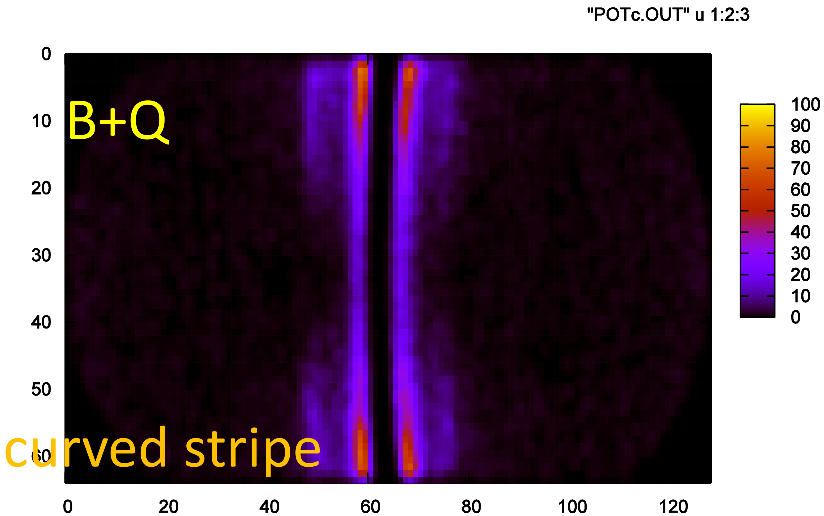
Combined bend

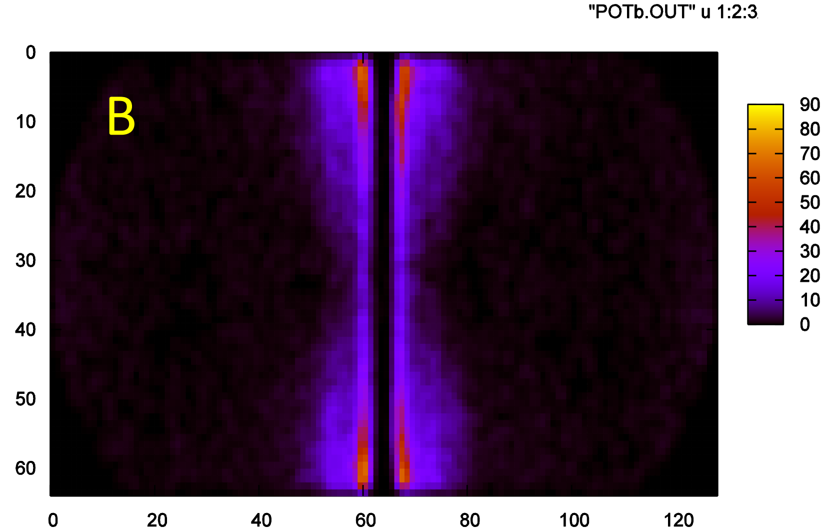
Magnet	Central Field, kG	Bdl, kG-m	Quadrupole, kG/m
RGF	1.3752	6.182	3.355
RGD	1.3752	6.183	-3.238
SGF	1.330	4.121	6.682
SGD	1.330	4.121	-6.824

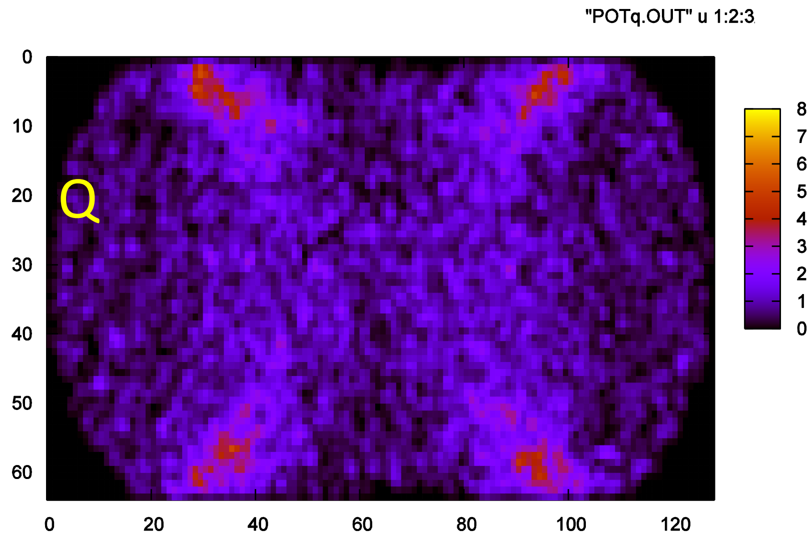


- Integrate cyclotron motion using local mag
- Runge-Kutta integration is slow for high fie..., high cyclotron freq.
- $\omega_c = eB/m = 2\pi \times 3.8 \times 10^{10}$ /s
- $\omega_c \sigma_z / c = 24.2$
- Magnetic Mirror $$\frac{B_0}{B_m} = \frac{v_{\perp 0}^2}{v_0^2}$$ B_0: B at initial position, B_m: B at mirror position

Electron distribution







Studies done by S. Antipov, PRAB20, 044401 (2017)

- Small amount of electrons trapped in combined bending magnets played important role for electron build up.
- Experiments and simulation showed that electrons were swept by a bunch located at separated position from the bunch train.
- Horizontal coupled bunch instability (caused by electron cloud) dominated.

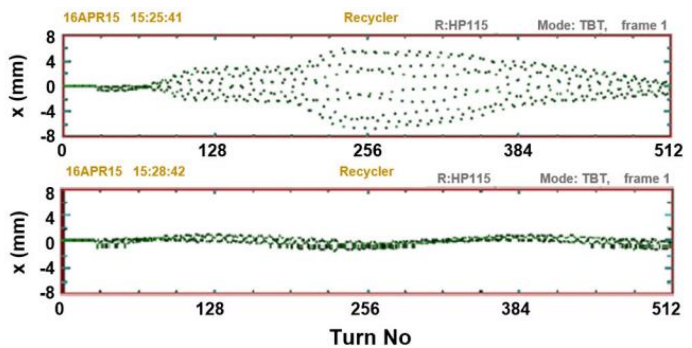
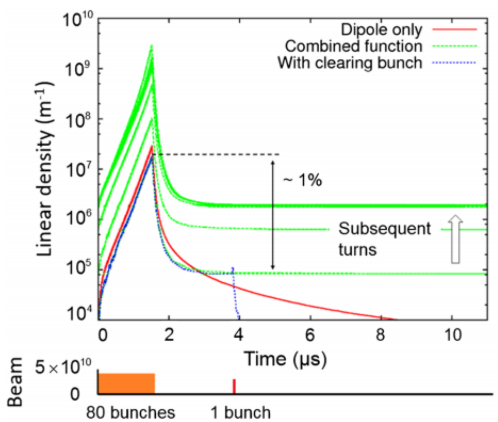
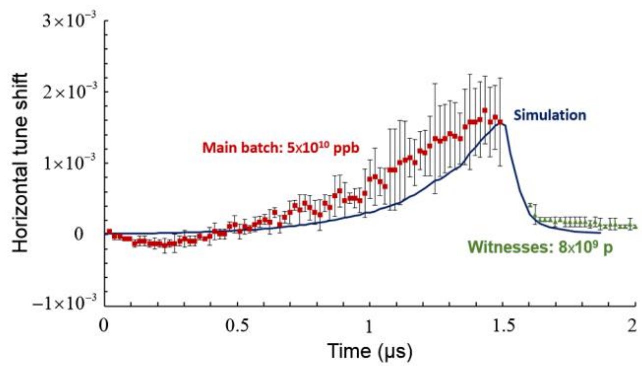


FIG. 6. Without the clearing bunch the beam of 3.6×10^{12} p blows up in about 20 turns (top); with the clearing bunch of 1×10^{10} p it remains stable (bottom). Turn-by-turn measurement of the horizontal position of the beam center.





What should we do?

- J-PARC
  - Manipulate better longitudinal distribution.
  - Feed back the longitudinal coupled bunch instability.
  - Is the measured electron density reasonable?
- Fermi-RR
  - How large is the Secondary emission rate?
  - Measure electron current.
  - Transverse coupled bunch instability has been observed. How is transverse single bunch instability?
  - Transverse Feed back damper?