Fast Transverse Beam Instability Caused by Electron Cloud Trapped in Combined Function Magnets

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Acknowledgements

Advisors: Sergei Nagaitsev (FNAL/U.Chicago) and Young-Kee Kim (U.Chicago)

Fermilab AD Operations, Phillip Adamson, Ming-Jen Yang, Victor Grzelak, Rob Ainsworth for help with conducting the experiments

Valeri Lebedev, Alexey Burov, Yuri Alexakhin, Jeff Eldred, and all Fermilab e-cloud group for numerous useful discussions of the results

Fritz Caspers (CERN) for sharing his experience with microwave measurements

Mike Billing, Jim Crittenden (Cornell) for comments and ideas on e-cloud

Kazuhito Ohmi (KEK) for help with numerical simulations

Fermilab Accelerator Complex

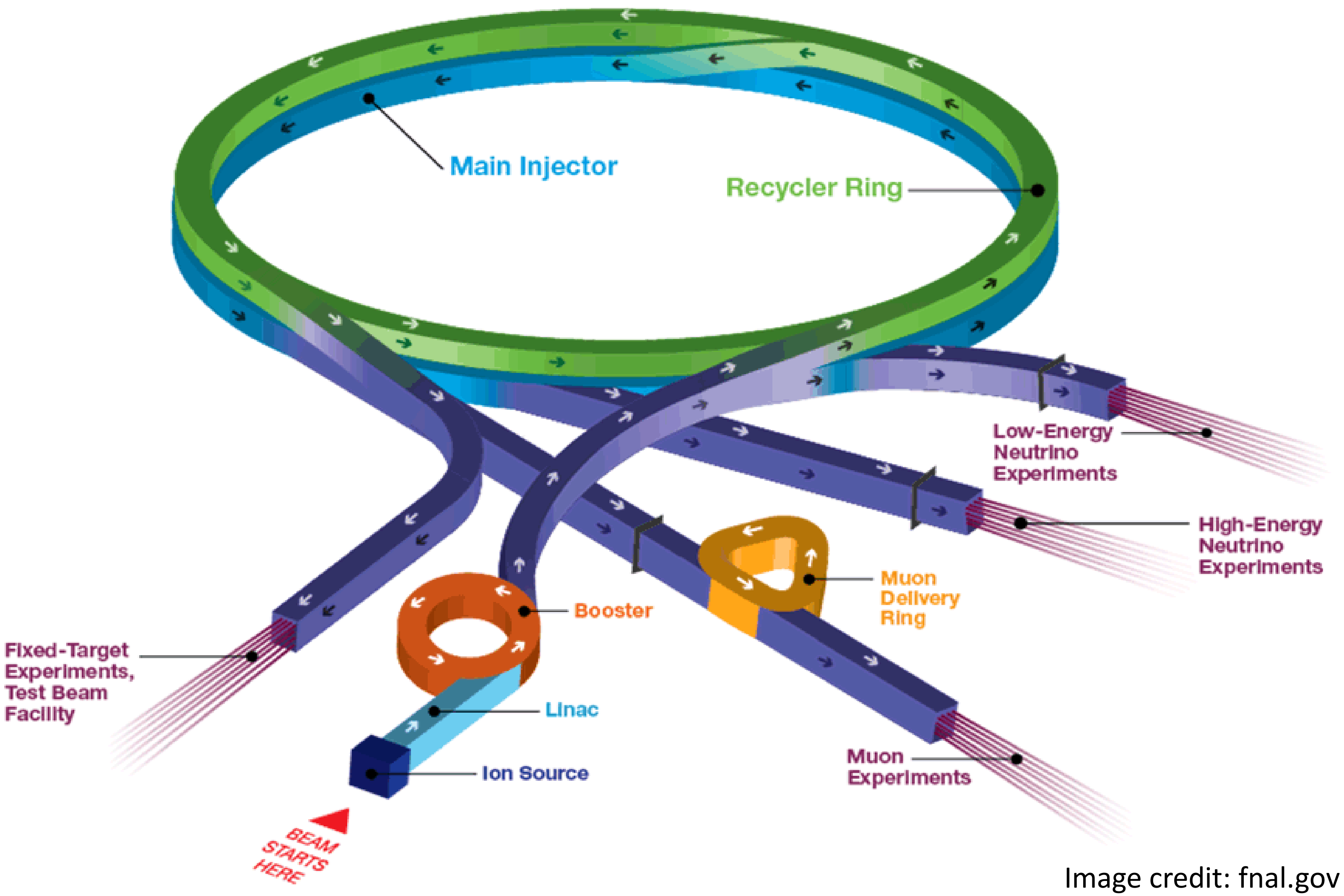
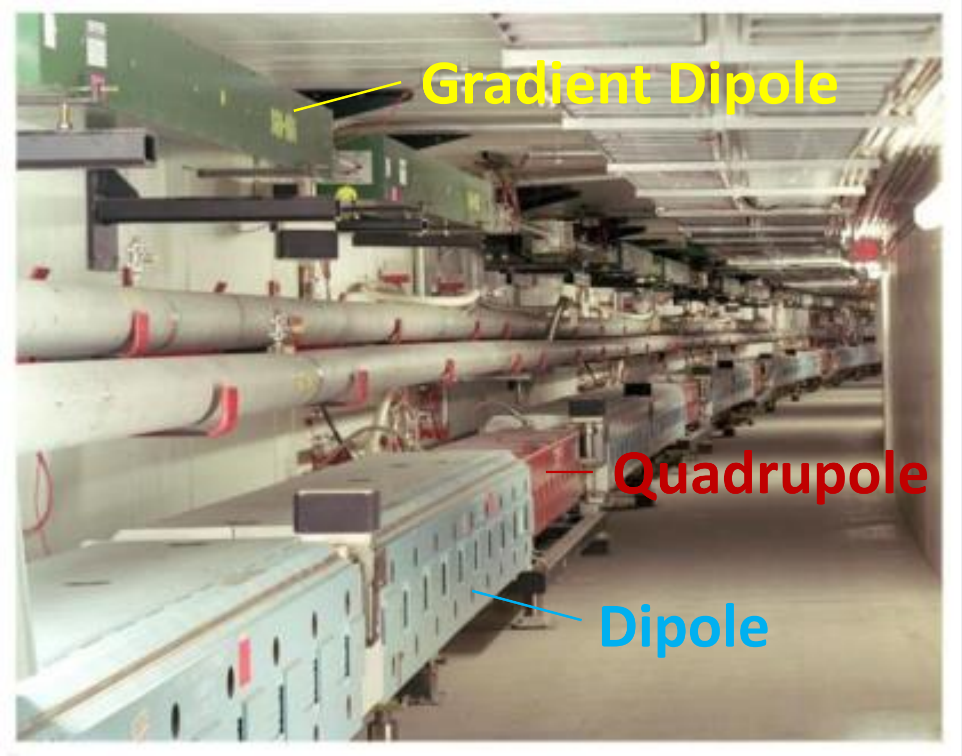
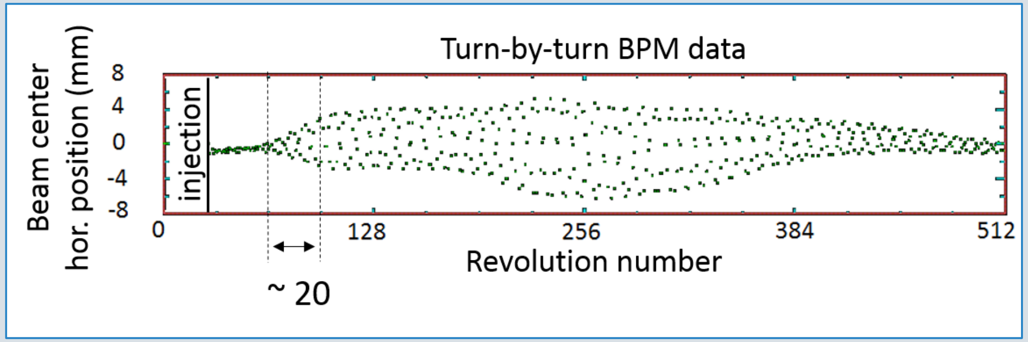


Image credit: fnal.gov

Transverse beam instability in Fermilab's Recycler

The Recycler (top) and the MI (bottom) rings installed in a common tunnel.

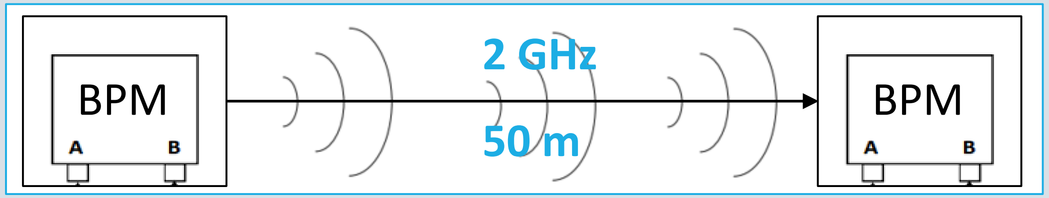




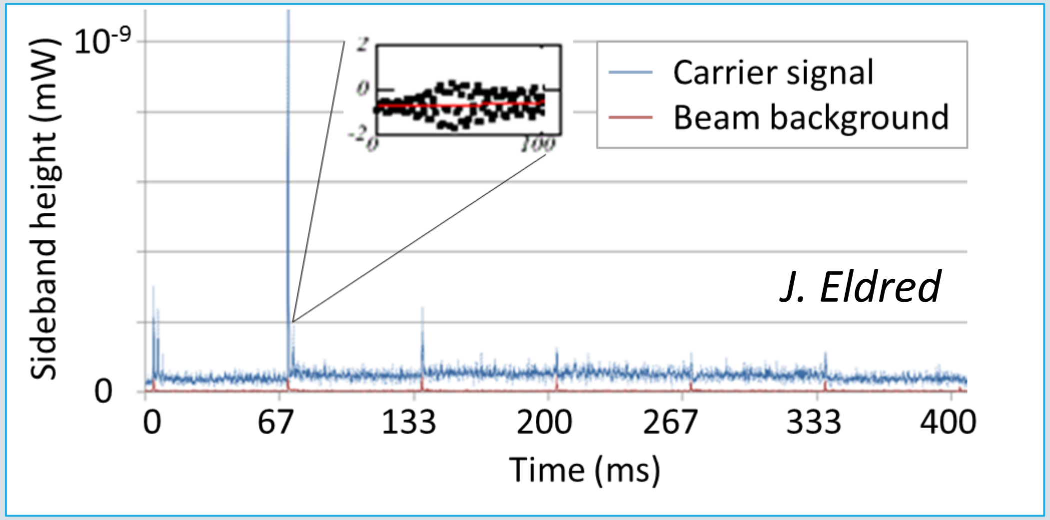
Proton momentum	8.9 GeV/c
Circumference	3.3 km
Number of bunches	80 per train
Number of bunch trains	6 (+6)
Bunch spacing	19 ns
Revolution period	11 µs

Microwave measurements confirm the presence of electron cloud

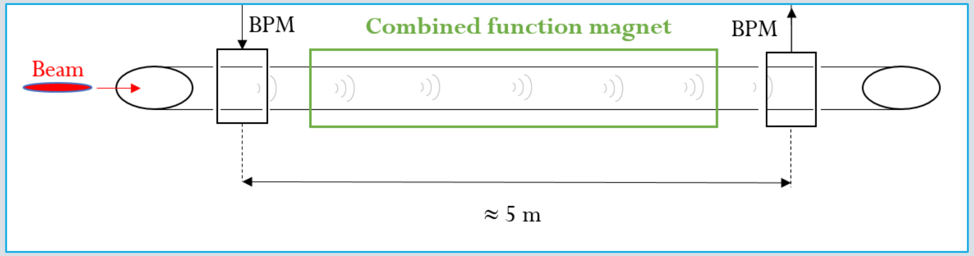
EC SIGNAL CORRELATED WITH INSTABILITY

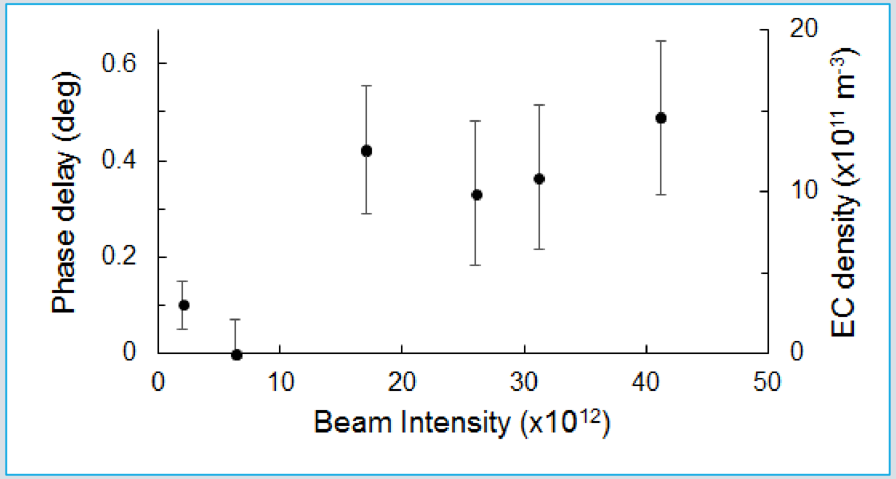


Phase modulation at beam revolution frequency



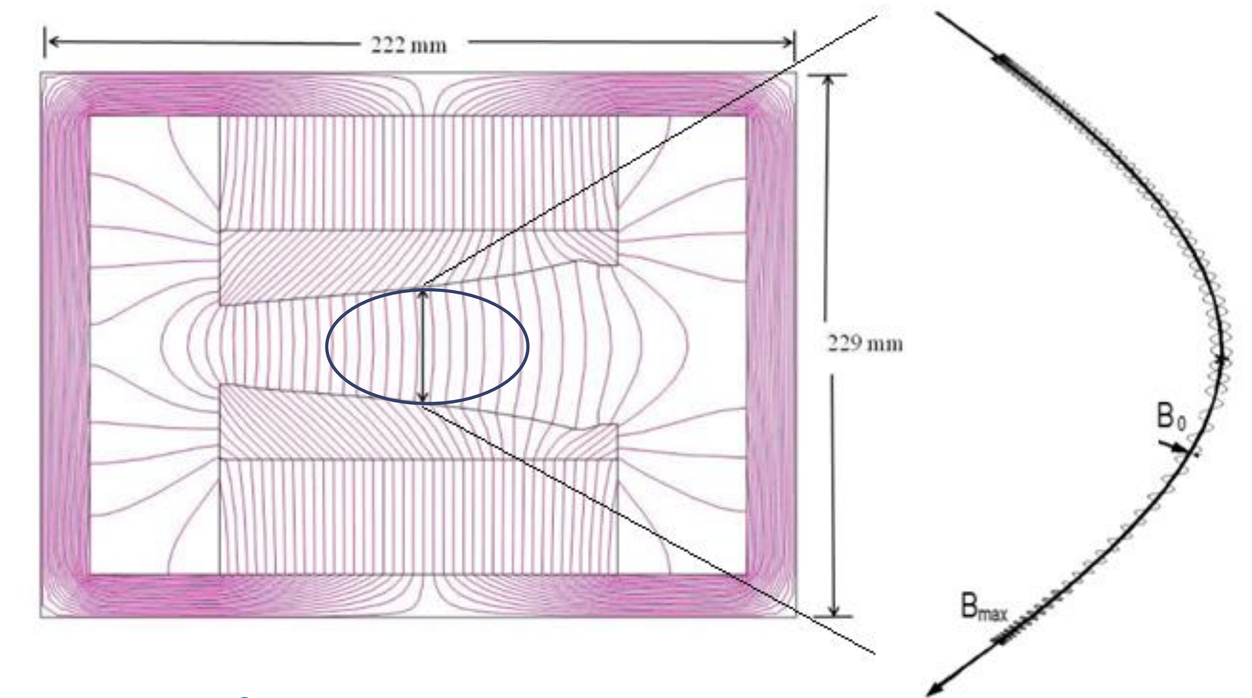
LOCATED IN COMBINED FUNCTION DIPOLES





Combined function dipole as a “magnetic bottle”

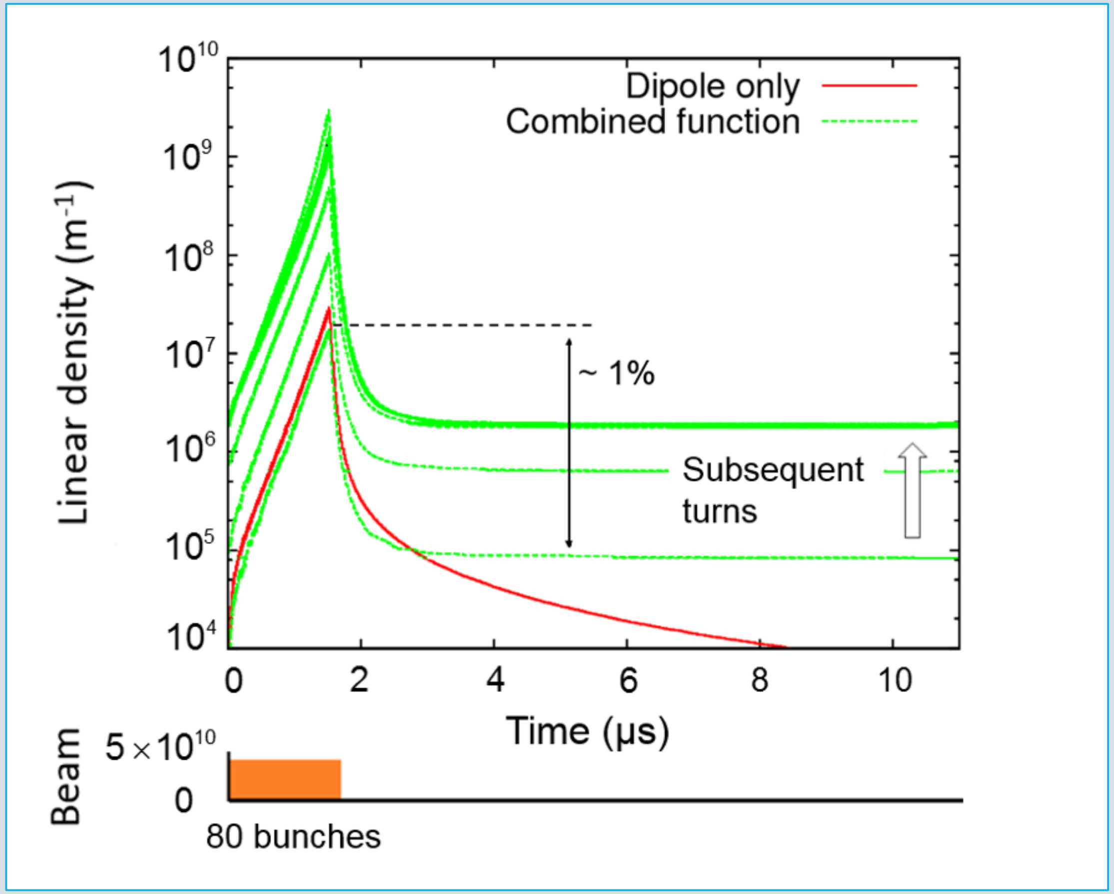
Cross-section of a Recycler permanent combined function dipole



About 10^{-2} of electrons are trapped by magnetic field

Central field	Gradient
1.38 kG	3.4 kG/m

Thanks to trapping, the cloud reaches much higher densities than in a pure dipole



Numerical simulation with PEI code

Beam energy	8 GeV
Machine circumference	3.3 km
Batch structure	80 bunches, 5e10 p
Tunes: x, y, s	25.45, 24.40, 0.003
RF harmonic number	588
RMS bunch size: x, y, s	0.3, 0.3, 40 cm
Secondary emission yield	2.1 @ 250 eV
Density of ionization e^-	10^4 m^{-1} (at 10^{-8} Torr)
B-field and its gradient	1.38 kG, 3.4 kG/m
Beampipe	Elliptical, 100 x 44 mm

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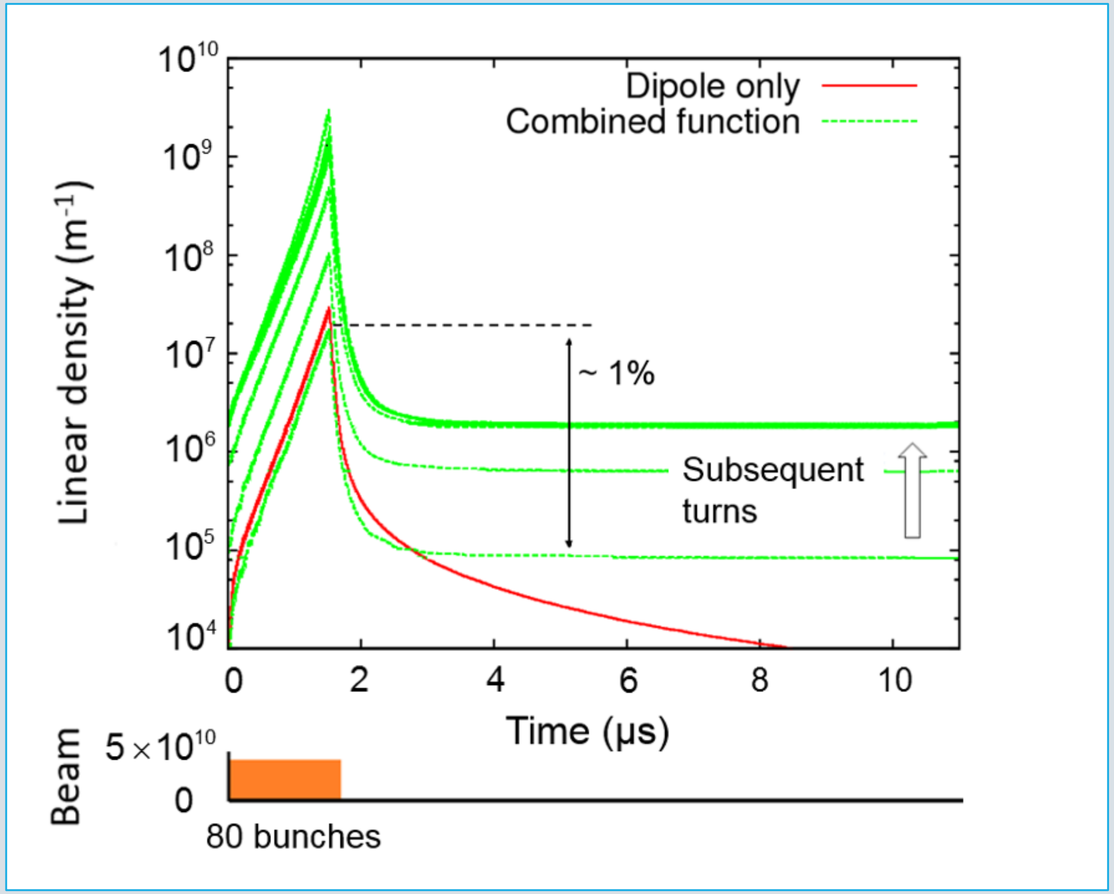
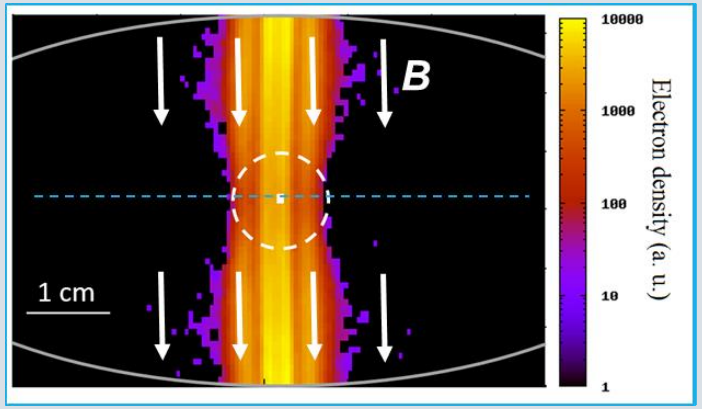
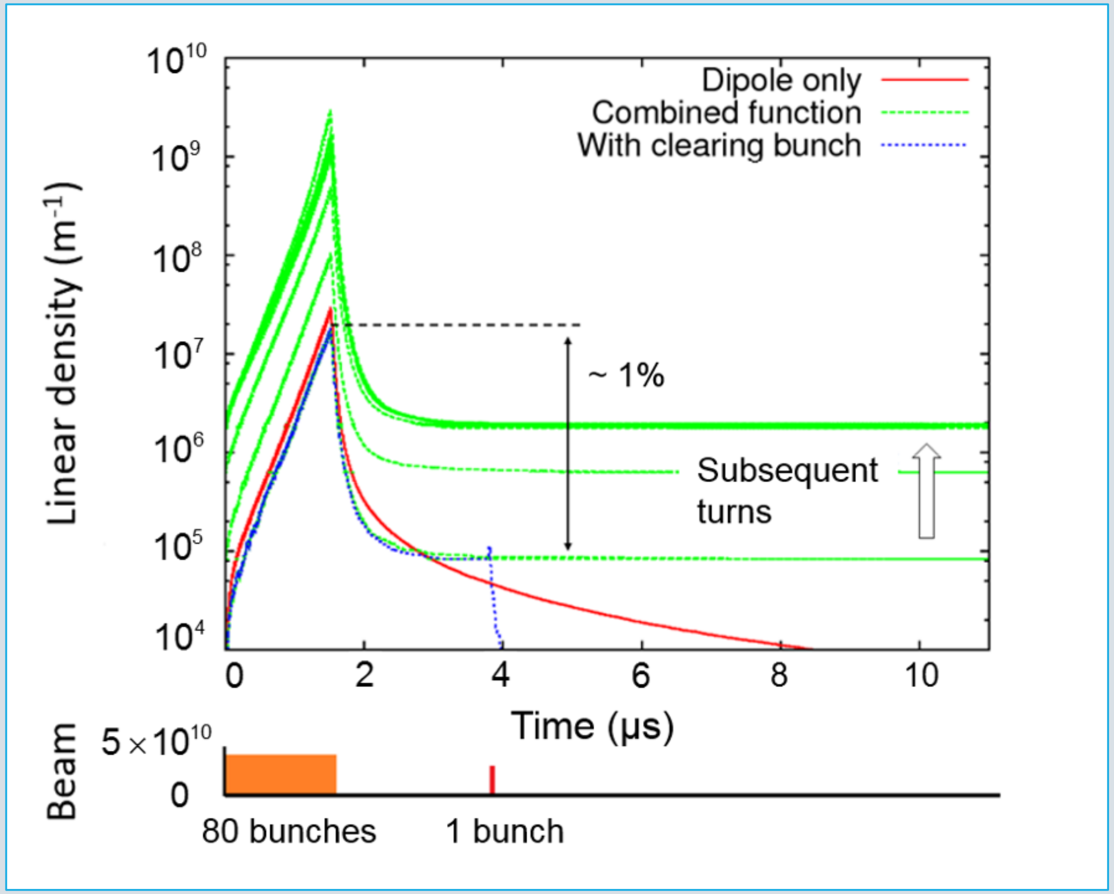


Electron cloud forms a stripe inside the vacuum chamber

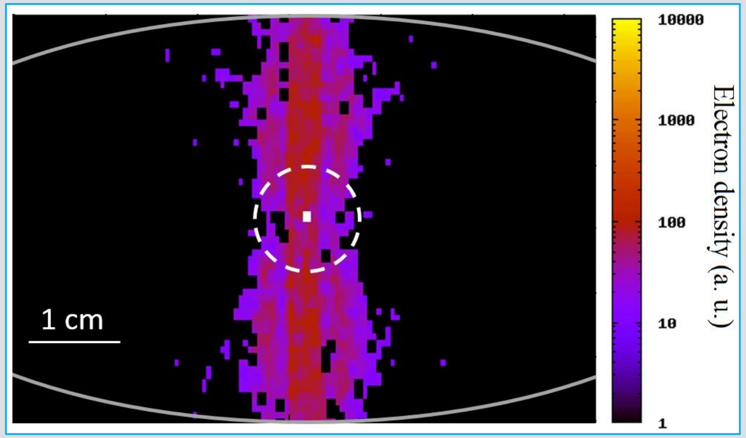


Instability rise time 20 – 30 turns

Clearing prevents the multi-turn the build-up



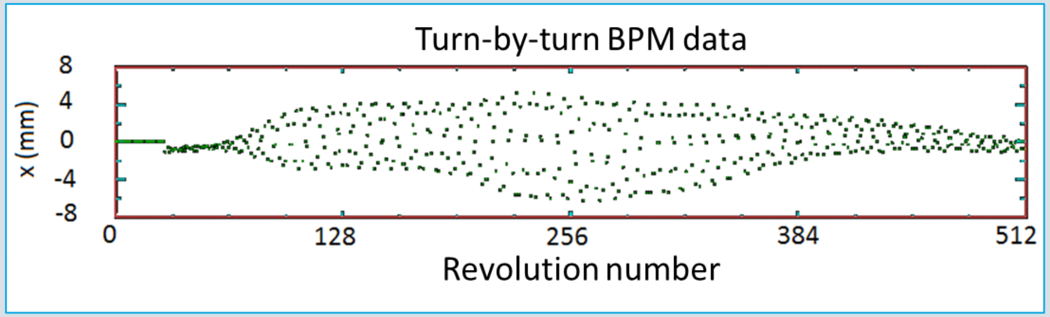
With clearing bunch



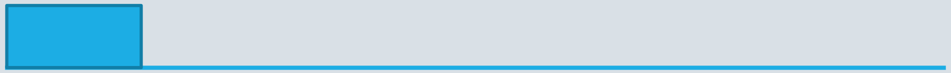
Stable

Stabilization by a low-intensity clearing bunch

WITHOUT A CLEARING BUNCH

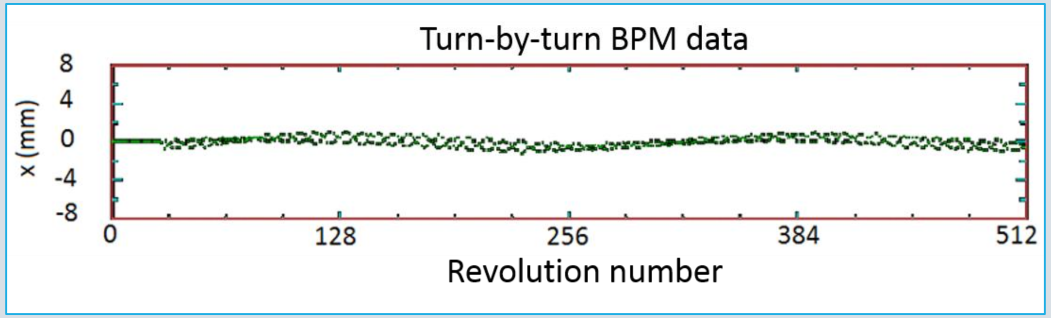


80 b., 4.5×10^{10} p



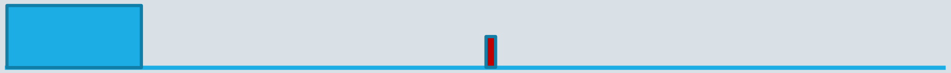
Machine circumference, 3.3 km

WITH A CLEARING BUNCH



80 b., 4.5×10^{10} p

1.5×10^{10} p



Machine circumference, 3.3 km

Conclusion

Combined function magnets trap the electron cloud

- Trapping of the order $10^{-3} – 10^{-2}$ leads to multi-turn accumulation of the cloud
- The cloud reaches the densities orders of magnitude greater than in a pure dipole
- May lead to a fast transverse beam instability

Trapped electron cloud can be cleared out with a clearing bunch

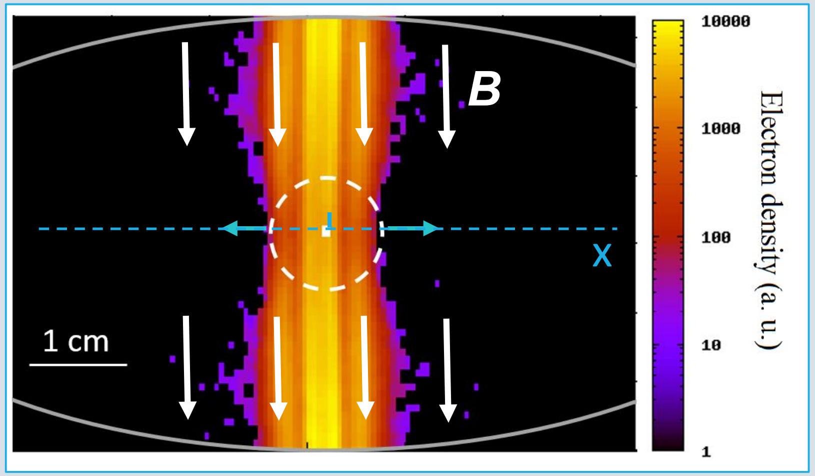
- Stabilizing the beam

Thank you

QUESTIONS?

Analytical model of the instability

Electron cloud forms a vertical 'stripe' that follows the beam (simulation in PEI)



Proton beam:

$$\left(\frac{\partial}{\partial t}+\omega_0\frac{\partial}{\partial\theta}\right)^2 X_p+\Gamma\left(\frac{\partial}{\partial t}+\omega_0\frac{\partial}{\partial\theta}\right)X_p=-\omega_\beta^2 X_p+\omega_p^2(X_e-X_p)$$

Damping — Focusing — Coupling to e-cloud

$$\omega_p^2\approx\frac{e^2 n_e}{2\varepsilon_0\gamma m_p}$$

Electron cloud:

$$\frac{\partial}{\partial t}X_e=\lambda(X_p-X_e)$$

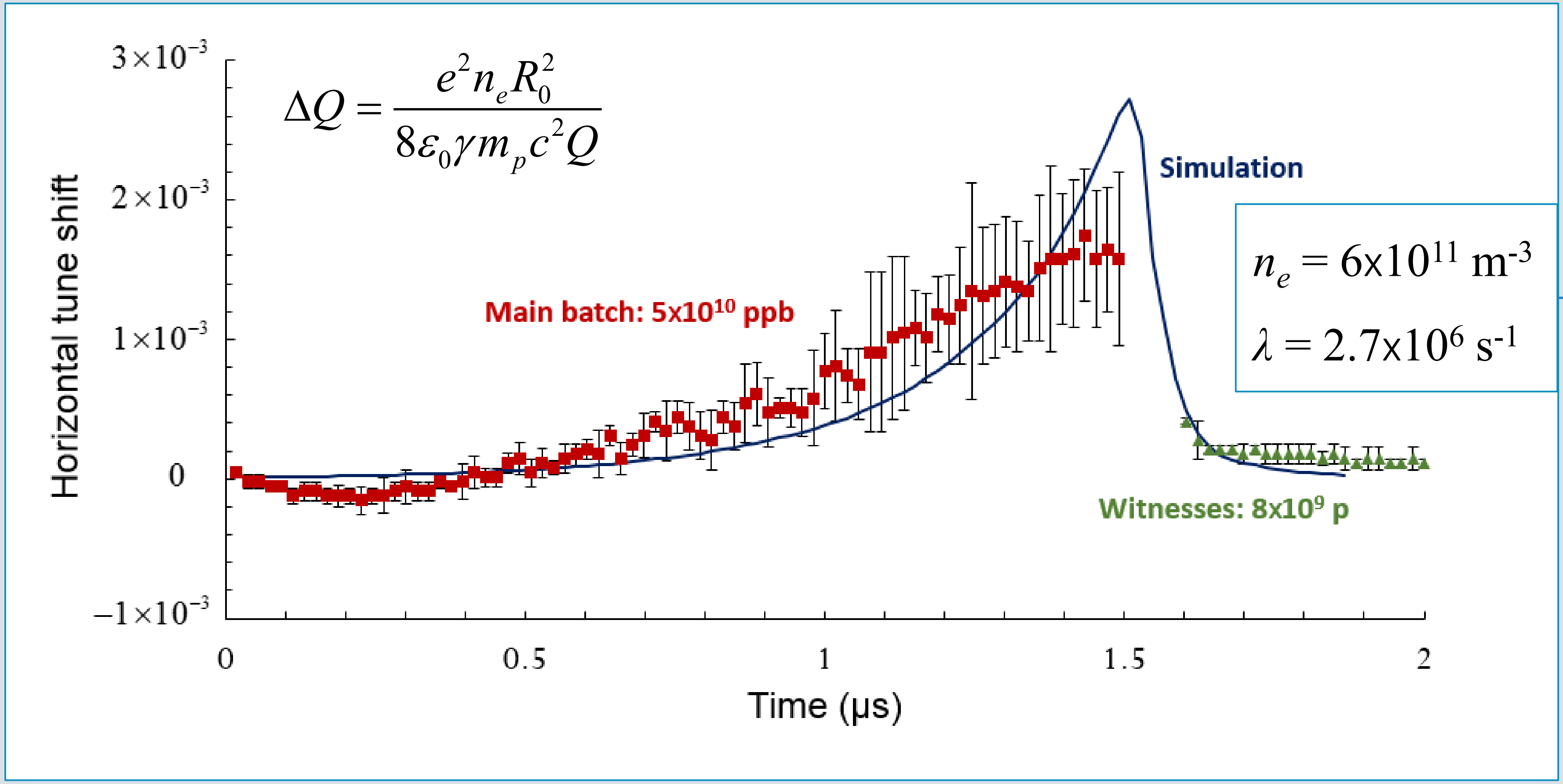
Mobility of the cloud

Parameters:

- Average cloud density n_e
- Mobility of the electron cloud λ

⇦ Tune shift measurement
Build-up simulation

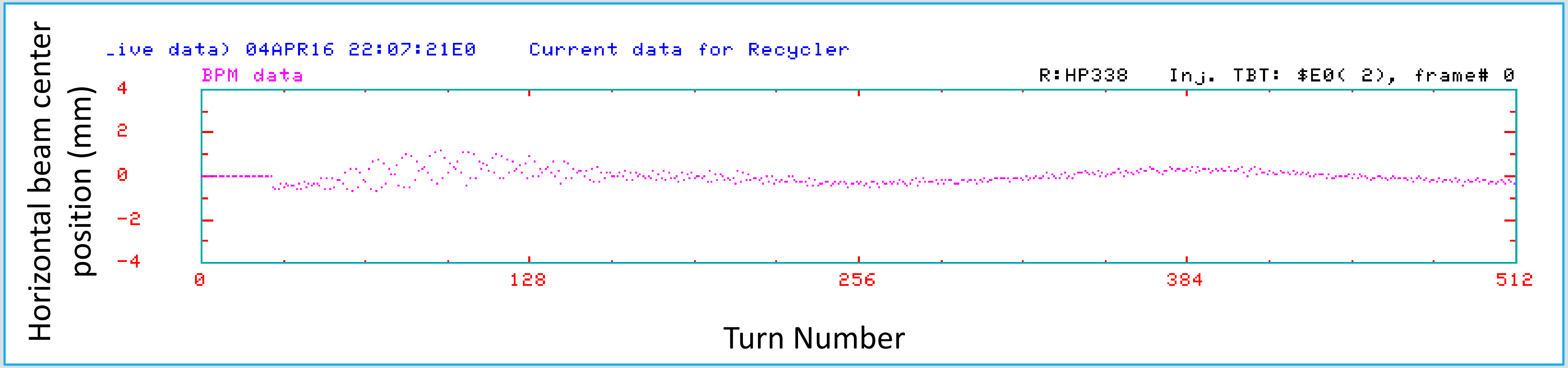
Tune measurement agrees with the simulation



$\tau_{max} \approx 27$turns

Recycler instability at higher intensity: first goes **up** and then **down**

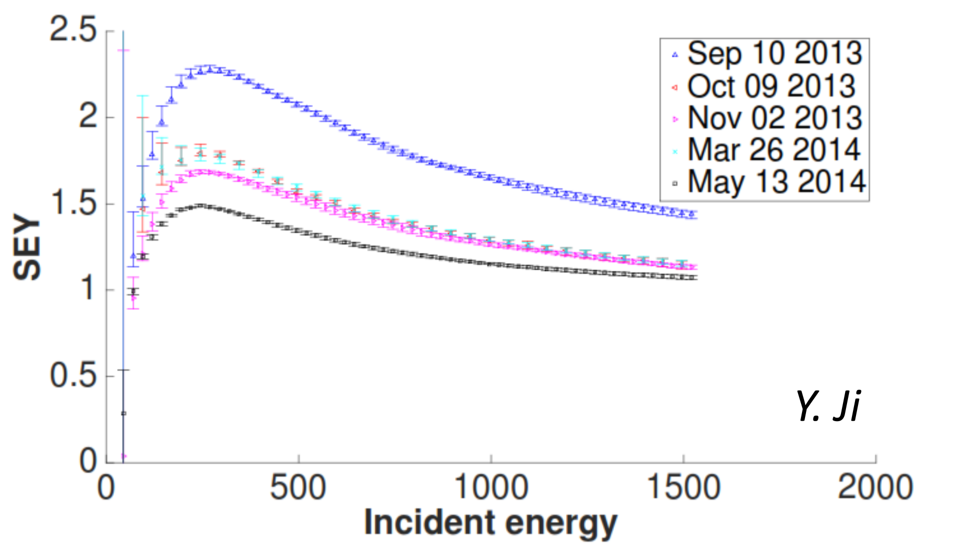
7.0×10^{10} ppb



Beampipe conditioning

As an accelerator runs high-intensity beam beams the secondary yield of its vacuum chambers decreases

SEY goes up immediately after the beam has been turned off



Fermilab SEY measurement stand at MI

Beampipe conditioning: Threshold goes up as the machine operates