Phase-Space Engineering towards Intense and Bright Accelerators

Department of Physics, UNIST
정모세 (Moses Chung, 鄭模世)

Intense Beam and Accelerator Laboratory (iBal)

Email: mchung@unist.ac.kr

Plasma physics vs Accelerator physics

∝Charge density

Particle density

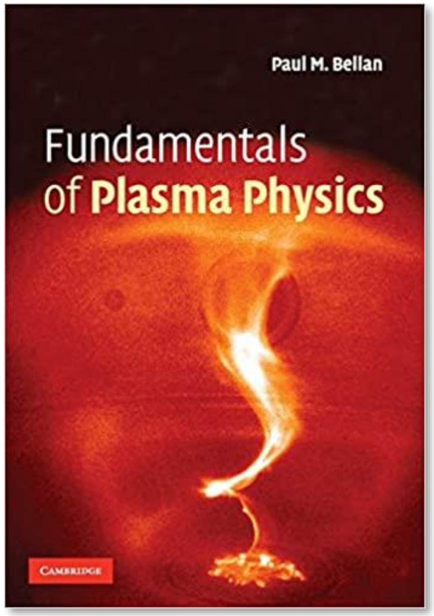
$$\hat{\rho} = \frac{Zn_i - n_e}{n_i + n_e} = \begin{cases} +Z, & n_e \longrightarrow 0, \\ \approx 0, & Zn_i \approx n_e, \\ -1, & n_i \longrightarrow 0, \end{cases}$$

Pure ion plasma $\xrightarrow{\beta = \frac{v}{c} \to 1}$ Ion beam

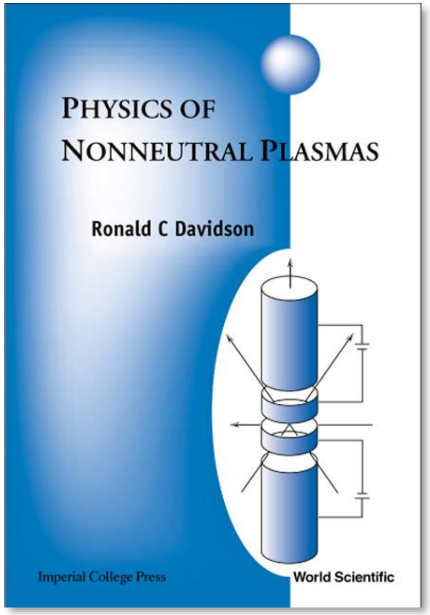
Quasi-neutral plasma

Pure electron plasma $\xrightarrow[\beta = \frac{v}{c} \to 1]{}$ Electron beam

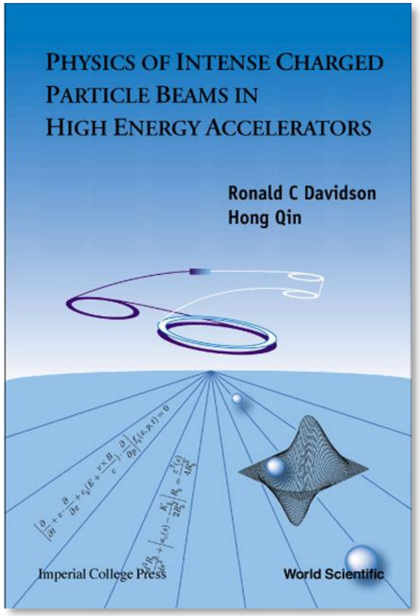
$\lambda_D, \quad \omega_p$



$\lambda_D, \quad \omega_p$

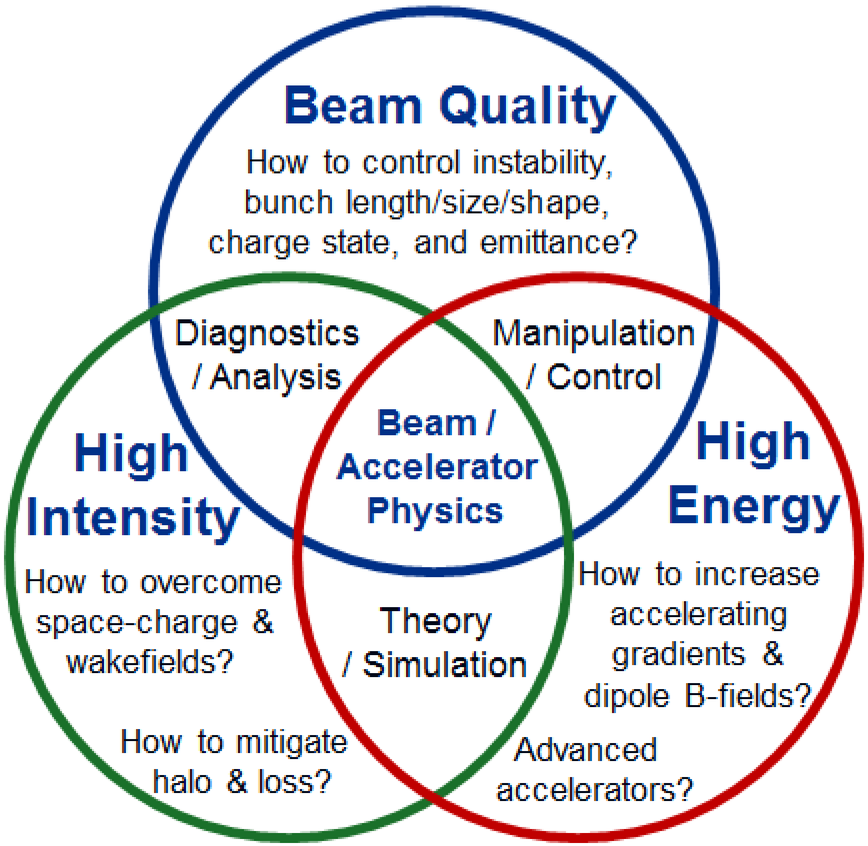


$\lambda_D, \quad \omega_p$



Frontiers of Modern Accelerators

승차감/사양



탑승인원

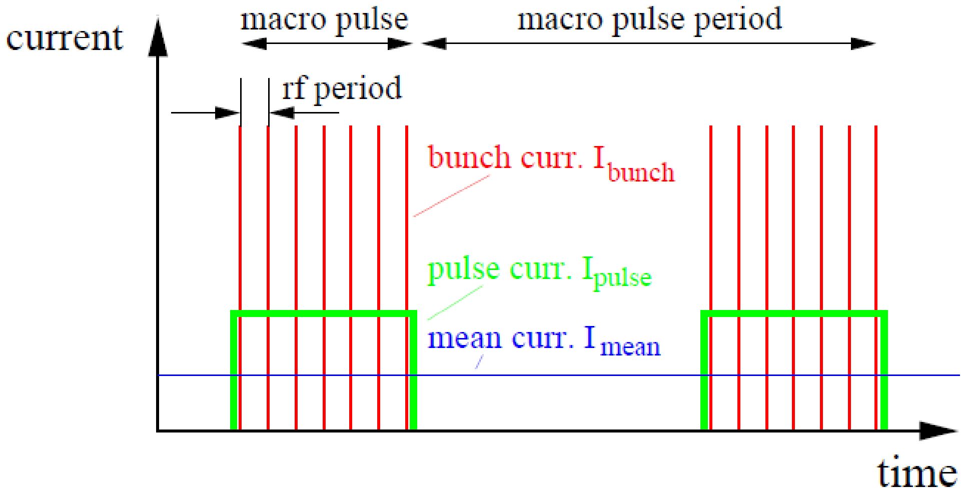
속도

Figure of Merit

Intensity

$$P[\mathrm{MW}] = I_{\mathrm{pulse}}[\mathrm{mA}] \times E[\mathrm{GeV}] \times \mathrm{Duty}[\%]$$

$$\mathrm{Duty} = f_{\mathrm{rep}} T_{\mathrm{pulse}}$$

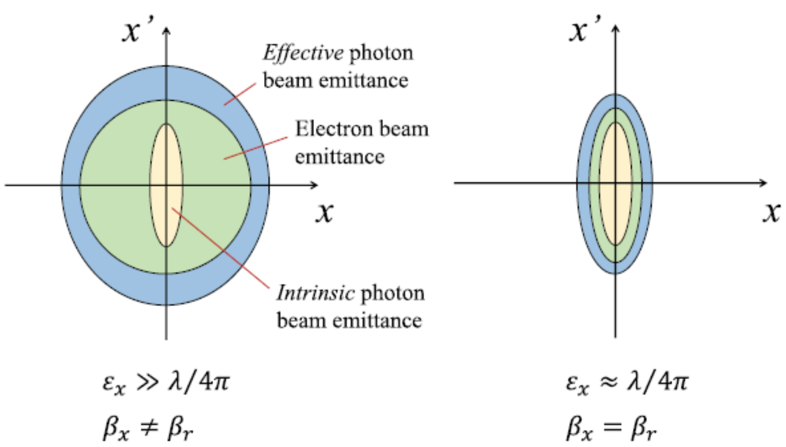


Brightness

$$B[\#/\mathrm{s}/\mathrm{mm}^2/\mathrm{mr}^2/0.1\%\mathrm{BW}]$$

$$= \frac{d^4 N_{photon}}{dt dS d\Omega (d\lambda/\lambda)}$$

$$\propto \frac{N_{beam}}{\epsilon_x \epsilon_y}$$

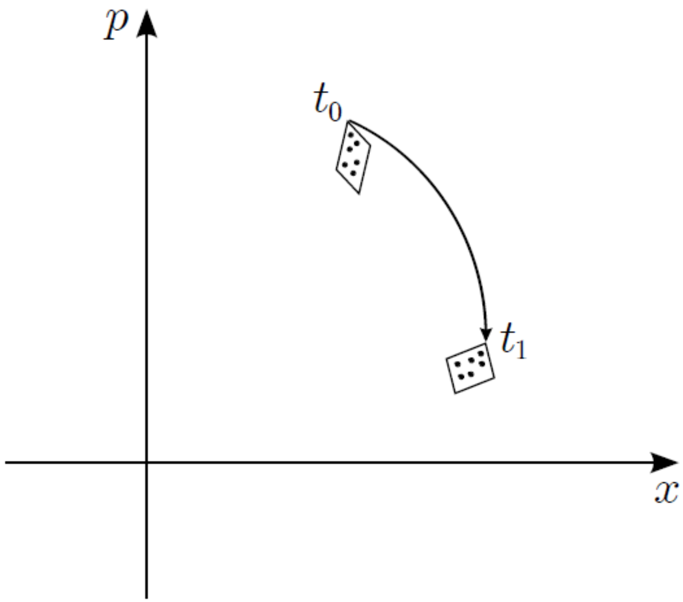


Phase Space

Distribution function: evolves according to Vlasov equation on time scales < binary collision time.

$$f(x,p_x,y,p_y,z,\delta;s) \neq f_x(x,p_x;s)f_y(y,p_y;s)f_z(z,\delta;s)$$

Due to coupling in general $\quad z = \frac{s}{\beta_0} - ct,\ \delta = \frac{1}{\beta_0}\frac{\Delta E}{E_0}$



Liouville's theorem: for particles obeying Hamilton's equations, the density of particles in phase space is conserved as the system evolves.

Emittance: a measure of the area of phase space occupied by a bunch of particles.

Eigen-emittance: invariant under linear symplectic transformation even in the presence of coupling.

RMS-emittance (including Eigen-emittance): tends to increase in the presence of nonlinearity.

Non-symplectic processes: can change the eigen-emittance.

Elements of Phase-Space Engineering

- Magnet:

  Dipole, Quadrupole, Sextupole, Octupole, Solenoid
  Permanent Magnet, Superconducting Magnet
  Wiggler, Undulator, Kicker Magnet

- Electromagnetic wave:

  RF system, Laser, Radiation, Wakefields

- Matter:

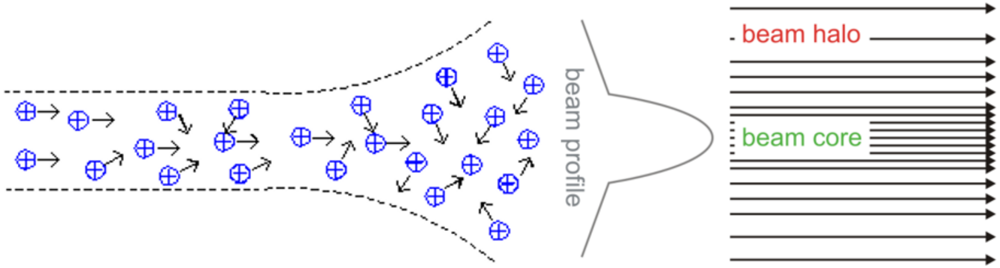
  Beam itself, Gas, Plasma, Collimator/Scraper, Stripper, Degrader

Beam itself

- Macroscopic self-fields are most often termed space charge when they arise from the near-field of the beam's charge distribution and wakefields when they arise from the beam's collectively radiated fields.

Space charge effects

→ Resonance, Instability, Coupling

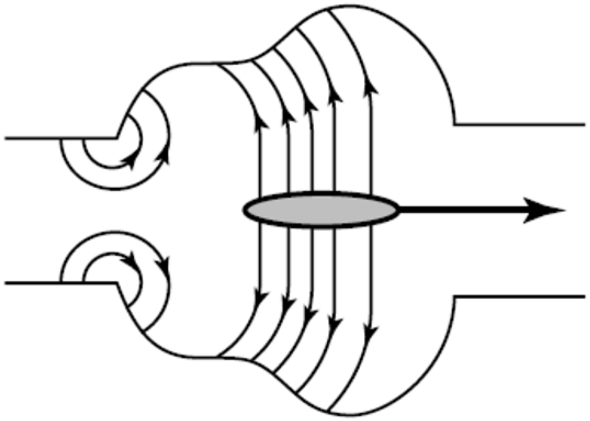


→ Dominant for low energy (hadrons)

(cf., scattering effect)

Beam pipe with discontinuity

→ Wakefields

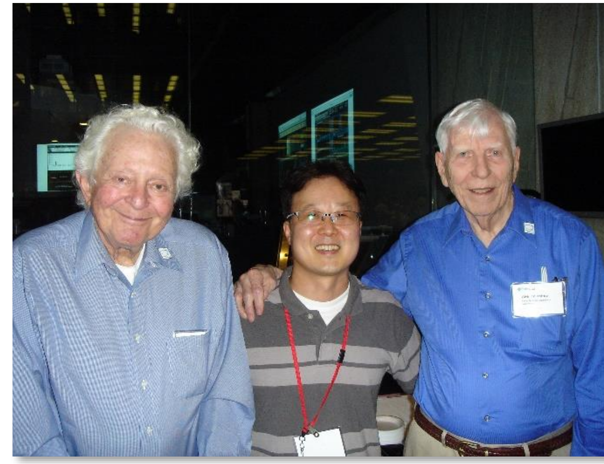


→ Dominant for high energy (electrons)

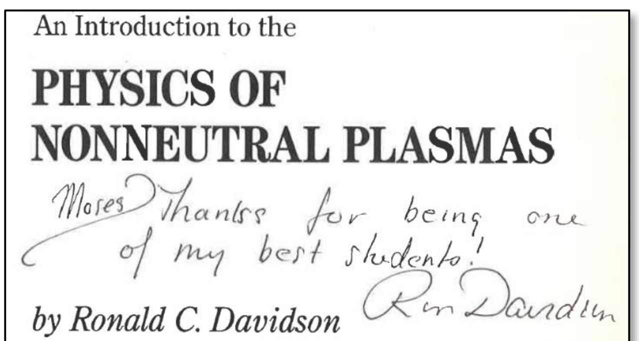
(cf., plasma wakefield)

My Mentors

The late Prof. Ronald C. Davidson:
~6 years at Princeton University



The late Dr. Alvin V. Tollestrup:
~5 years at Fermilab



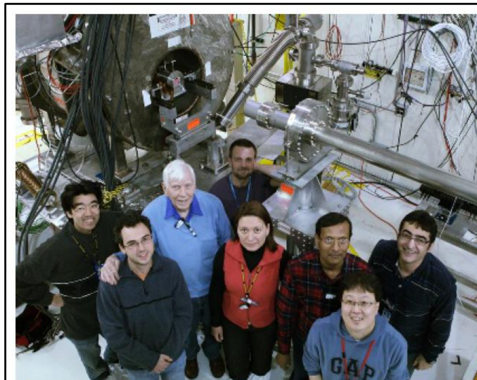
An Introduction to the

PHYSICS OF
NONNEUTRAL PLASMAS

Moses) Thanks for being one of my best students!

by *Ronald C. Davidson* *Ron Davidson*

Theorist

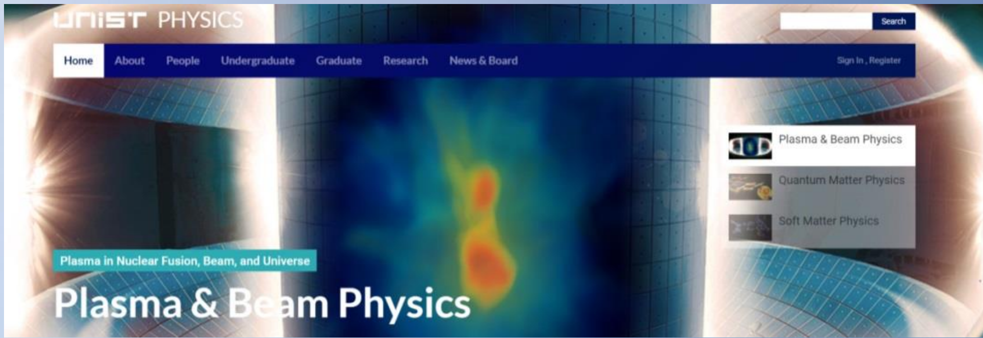


The experimenters at the Muon Ionization Cooling Experiment (MICE) in May 2012; Left to Right: Katsuya Yonehara (page 40), Ben Freemire, Alvin, Pierrick Hanlet, Maria Leonova, Mukti Ranjan Jana (page 22), Moses Chung, and Yagmur Torun

Experimentalist

My Group

Please find Prof. Chung…



Thank you for your attention !

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