USC/UCLA (Tom Katsouleas, Warren Mori) have developed 3-D PIC codes for the study of plasma-beam interaction. OSIRIS and QUICKPIC solve Maxwell equations on a 3-D Cartesian grid by finite differences in time domain. The current and charge density sources come from depositing the positions and velocities of a collection of $\sim 10^6$ charged particles on the grid. The fields are used to update particles' positions and velocities and the cycle is repeated.
These codes have been used to predict plasma wake field acceleration, and their results successfully benchmarked with experiments at UCLA.

The collaboration between CERN and USC has been proposed at the ECLOUD'02 Workshop, where Tom Katsouleas presented QUICKPIC and its potential use for e-cloud detailed 3-D simulations.

Goals of the visit

→ Add transverse focusing, synchrotron motion and chromatic effect in the bunch particles motion.

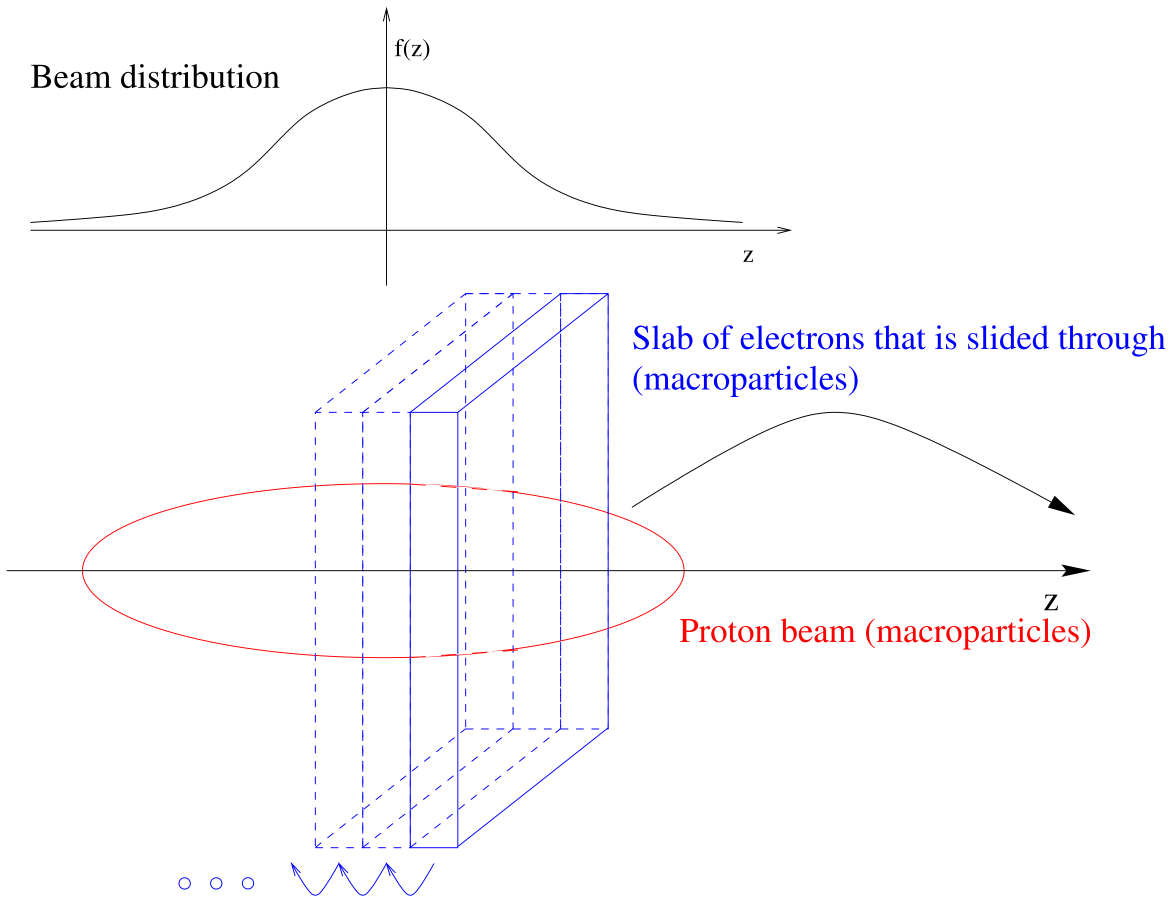
→ Test the code and its performances in multi-processor runs.

→ Apply QUICKPIC to the study of beam propagation in an ELECTRON CLOUD (specifically, e-cloud tune shift and instability).

Main difference with HEADTAIL: the bunch evolves under the continuous action of the external focusing forces plus the electron cloud forces.

Other people involved: mainly A. Ghalam and T. Katsouleas (USC), with the key help from V. Decyk, C. Huang and W. Mori (UCLA)

Principle of QUICKPIC



(1) Initialize beam

(2) Solve $\nabla_\perp^2 \phi = \rho_b + \rho_e$, $\nabla_\perp^2 \psi = \rho_e \Rightarrow F_e \propto \nabla \phi, \psi$

(3) Push electrons, store ψ

(4) Step slab and go to (2)

(5) Use ψ to giant step beam

Maxwell equations in Lorentz gauge

$$\left(\frac{1}{c^2}\frac{\partial^2}{\partial t^2} - \nabla^2\right)\mathbf{A} = \frac{4\pi}{c}\mathbf{j}$$

$$\left(\frac{1}{c^2}\frac{\partial^2}{\partial t^2} - \nabla^2\right)\phi = 4\pi\rho$$

$$\mathbf{j} = \mathbf{j}_b + \mathbf{j}_e = \mathbf{j}_b = c\rho_b\hat{z}$$

$$(\mathbf{A} = A_{//}\hat{z})$$

$$\Psi = \phi - A_{//}$$

Quasi-static approx.

$$\phi, A = \varphi, A(z - ct)$$

Reduced Maxwell equations

$$-\nabla_\perp^2\mathbf{A} = \frac{4\pi}{c}\mathbf{j}$$

$$-\nabla_\perp^2\phi = 4\pi\rho$$

Local-ϕ,A at any z-slice depend only on ρ,j at that slice!

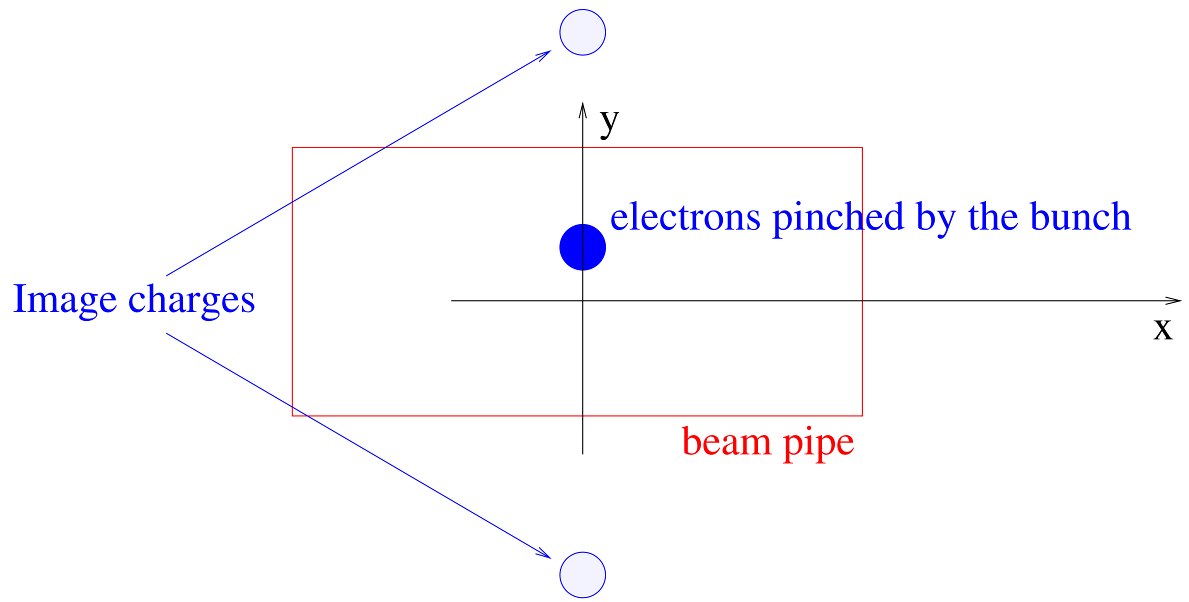
Forces :

plasma : $F_{e\perp} = -e\nabla_\perp\phi$

beam : $F_{b\perp} = -e\nabla_\perp\Psi$

- 10 turns with the SPS parameters run in about 7 hours on single processor under MAC OS IX.
- Computing speed increases by a factor 5 using 16 processors on the NERSC cluster.

The NERSC IBM SP RS/6000, named seaborg.nersc.gov, is a distributed memory machine with 2,944 compute processors.
The processors are distributed among 184 compute nodes with 16 processors per node. Each node has a common pool of between 16 and 64 GBytes of memory.



The coherent tune shift is dominated by the images of the electron cloud with respect to the perfectly conducting boundary.

$$Q'_y(z) = \frac{\lambda_{cl}(z)\pi^2 \mathrm{r}_p R_0^2}{8\gamma h_y^2 Q_y}$$

Compared to the beam images induced shift:

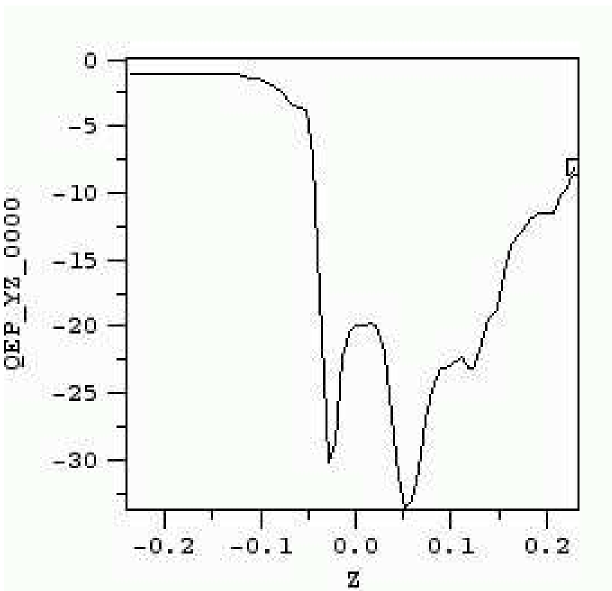
$$Q'^{b}_y \approx \boxed{\frac{1}{\gamma^2}\left(\frac{\lambda_b}{\lambda_{cl}}\right)} Q'^{cl}_y$$

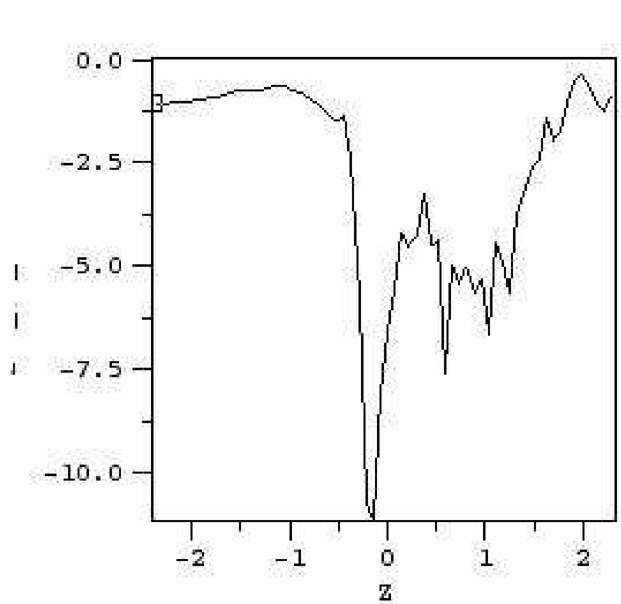
~0.077 for SPS at 26 GeV

The electron cloud line density is the product of an enhancement factor due to the pinching $H(z)$ by the unperturbed line density of the cloud (its volume density multiplied by the cross sectional area of the bunch):

$$\lambda_{cl}(z) = H(z) \times n_{cl} 2\pi\sigma_x\sigma_y$$

The enhancement factor can be estimated from the pictures below:





$n_{cl} = 10^{12}\ m^{-3} \longrightarrow Q'_y = 0.017$

$n_{cl} = 10^{14}\ m^{-3} \longrightarrow Q'_y = 0.4$

How far we have gone

- The synchrotron motion, betatron motion and chromaticity in the ring are added to QuickPIC
- Test runs for cartoon parameters agree with the specified tune, and with the cloud effects included, the tune shift from the cloud is in agreement with our analytic estimates.
- A rough draft of a Phys. Rev. paper is 75% complete – this looks like it will be a definitive work on the tune shift caused by electron clouds.
- The new code has been ported to NERSC and run in parallel on 16 processors! It is fast enough to complete roughly 100 turns of SPS in 12 hours (x16 processors), so several hundred or even thousand turn runs are possible as we had hoped.

Near term to do

- Finish and analyze first production run (50 turns, non-cartoon parameters).
- Port code to the linux clusters at USC and CERN
- Add the effect of dipole fields on cloud response – i.e., for 2/3 of the ring, the cloud is constrained by the strong B-field to flow in y only and for 1/3 it is both x-y (the present default).
- Add restart capability to QuickPIC.

Longer Range Plan

- Direct comparisons to experiments if possible, look for emittance growth and thresholds if any.
- Create an executable with documentation that can be put on the web.