Collaboration in intra-beam scattering activities for the CERN CLIC Damping Rings

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Credits

- “Upgrade of the MOCAC Code and Creation of Library Modules”, A. Bolshakov, P. Zenkevich, ITEP, Moscow.
- “Kinetics Effects in Multiple Intra-beam Scattering” (IBS), P.R.Zenkevich*, A.E.Bolshakov*, O. Boine-Frenkenheim** - *ITEP, Moscow, Russia, **GSI, Darmstadt, Germany.
- “Last Advances in Analysis of Intra-Beam Scattering in the Hadron Storage Rings”, P. Zenkevich, ITEP, Moscow, 2006.
- “A new algorithm for the kinetic analysis of intra-beam scattering in storage rings”, P.R.Zenkevich*, A.E.Bolshakov*, O. Boine-Frenkenheim**, 2005, - *ITEP, Moscow, Russia, **GSI, Darmstadt, Germany.
- “Hybrid Monte Carlo Methods for Fluid and Plasma Dynamics”, R. Caflisch, Mathematics Department, Materials Science & Engineering Department, UCLA, 2007.
- “A Binary Collision Model for Plasma Simulation with a Particle Code”, T. Takizuka*, H. Abe**, 1977, - *Japan Atomic Energy Research Institute, Tokai, Ibaraki, Japan, ** Department of Electronics, Kyoto University, Japan.

Proposed workplan

- **The aim of the collaboration**

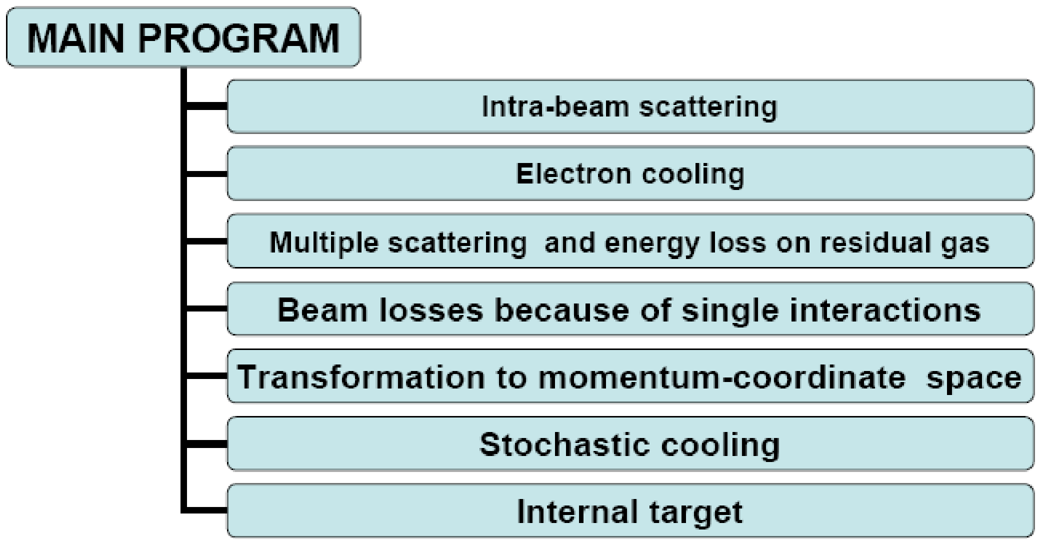
❖ Investigate the issue of equilibrium beam distribution (emittance) and relaxation time in the CLIC damping rings (DR) in the presence of strong intra-beam scattering (IBS) effect, radiation damping and quantum excitation.

- **What is expected to be achieved?**

1. Detailed description of the kinetic analysis of intra-beam scattering.
2. Full understanding of numerical code for IBS ***MOCAC*** (P. Zenkevich and A. Bolshakov) and algorithms used.
3. Implementation of ***MOCAC*** at CERN with application to the CLIC DR.
4. Benchmarking of ***MOCAC*** against Gaussian models (Bjorken-Mtingwa, Piwinski) on simplified DR lattices (single cell, cf. Y. Papaphilippou).
5. Upgrading of ***MOCAC*** code to include the radiation damping and quantum excitation effects.

MOnte-CArlo Code (MOCAC) 1

Structure of MOCAC



- **Module 1**: Intra-beam scattering
  - The method can be regarded as "collective map" in momentum space; input data is a set of 6-D vectors characterizing the ensemble.
- **Module 5**: Transformation to momentum-coordinate space
  - Transform input set of particles invariants in output set of particle 6-D vectors in momentum coordinate space.

MOnte-CArlo Code (MOCAC) 2

- ***MOCAC*** IBS module is based on "binary collision model" (***BCM***): the idea is to change the real IBS by a set of artificial "scattering" events built in such a way that the mean invariants rates are same as due to real IBS process.

Algorithm steps (change of kernel calculation by successive application of the "binary collision" map in 3D momentum space):

1. Choose phases randomly for a given set of macro-particles invariants.
2. Calculate the momenta and coordinates of macro-particles.
3. Work out the macro-particles distribution on the space cells and link test particles to a "partner" in the cell.
4. Apply binary collision map on each macro-particle pair (test & "partner") using "local ensemble" for each cell: i.e. calculate the collision angles for given "collision events" and update momentum components for the test particle and its partner.
5. Calculate the new set of macro-particles invariants.

MOnte-CArlo Code (MOCAC) 3

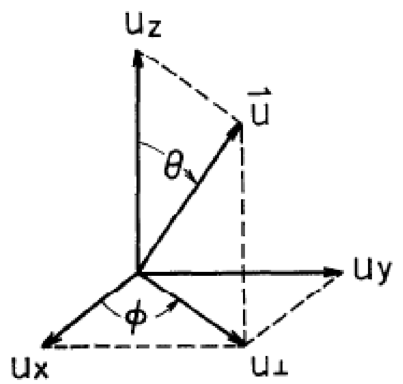
- This operation can be considered as "collective map"; each particle is "test" and "field" particle simultaneously.
- The map is repeated through the time interval Δt.
- The lattice is described as set of discrete points related to different longitudinal coordinates. Each point is characterized by its set of optical parameters.
- This algorithm is many-dimensional integration by Monte-Carlo method and needs high number of macro-particles (10^5-10^6) to diminish a noise.

Collision Map 1

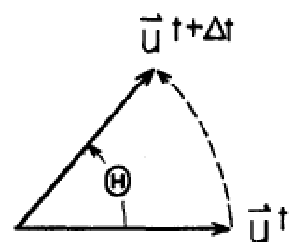
- Compute the scattering angle $\Theta_{sc}^{i,j}$ for two colliding macro-particles using the expression (ρ_0 = particle density, u =momentum, log Λ = Coulomb logarithm).

$$\sin\left(\frac{\Theta_{sc}^{i,j}}{2}\right) = \sqrt{\frac{2A\rho_0 \log\Lambda^{i,j}\Delta t}{N_{mp}\left|\vec{u}^{\,i} - \vec{u}^{\,j}\right|^{3/2}}}$$

- Compute the momentum change of each interacting particle (test & partner).
- Azimuthal angle $\Phi_{sc}^{i,j}$ is defined by random choice on interval $[0, 2\pi]$.
- This map was included in ***MOCAC***. This idea was suggested earlier by T. Takizuka & H. Abe (1977). At each step random choice of partner are assumed.



Coordinates in the laboratory frame and the relative momentum u at the time t.



Change in the relative momentum frame after collision at the time t+Δt.

Collision Map 2

Integration step [s]	$\Delta t \approx T_{\mathrm{IBS}}/100N_{\mathrm{per}}$
Number of macro-particles	$N_{\mathrm{mp}} \geq N_{\mathrm{long}}N_{\mathrm{tr}}$
Number of points per period	$N_{\mathrm{per}} \times N_{\mathrm{mag}}/5$
Size of transverse cell [m]	$\Delta_{tr} \leq \min(\sigma_{x,y}/5, D\sigma_p)$
Size of longitudinal cell [m]	$\Delta_{long} \geq \sigma_s/10$
Maximal collision angle [rad]	$\chi_{\max} < 0.5$

List of code parameters

Collision Map 3

- T. Takizuka & H. Abe, J. Comp. Phys. 25 (1977).
- T & A binary collision model is equivalent to the collision term in Landau-Fokker-Planck equation
  - The scattering angle Θ is chosen randomly from a Gaussian random variable $\delta \equiv \tan(\Theta/2)$.
  - δ has mean 0 and variance $\langle\delta\rangle^2 = (n_L e^4 \log\Lambda / 8\pi\varepsilon_0 m^2 u^3)\ \Delta t$.
  - Parameters: • $\log\Lambda$ = Coulomb logarithm • u = relative velocity.
- Simulation
  - Every particle collides once in each time interval: scattering angle depends on Δt.
  - Implemented in ICEPIC by Birdsall, Cohen and Procassini.