Activités HPC au SACM

Journée High Performance Computing de l'Irfu

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Overview

1. **Computational Resources of SACM**
2. **Space Charge Compensation in Low Energy Beam Transport Lines**
3. **Massive Calculations for High Intensity Linacs**
4. **HiLumi LHC/FCC Simulations Activities**

Overview

Isipic Cluster

Isipic Cluster

- Funded by **Synergium Intenité** (2/3 from Région Ile-de-France grant): 90 k€ .
- 256 cores: Intel(R) Xeon(R) CPU E5-2650 v2 @ 2.60GHz.
- 1024 Goof DDR3 RAM @ 1866 MT/s $\Longrightarrow$ 4 Go of RAM by core.
- Infiniband @ 40 Gb/s
- 37 To of storage (10 hard disk drives)

Overview

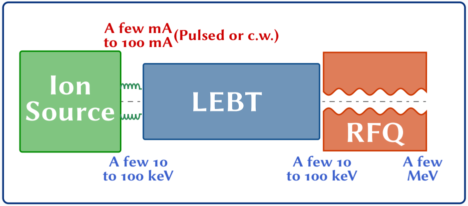
Beam Dynamics in LEBTs of High Intensity Accelerators

High Intensity Hadron Accelerators

- Transport is dominated by space charge
- Defocusing effect
- May induce beam losses and emittance growth

Role of a LEBT

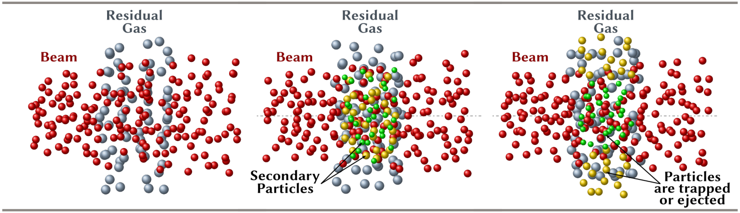
- Transport and adapt the beam to the next accelerating section
- Minimize losses and emittance growth



Low energy beam

- High space charge effects
- Space charge compensation

Space Charge Compensation (SCC) Principle



Example

We consider a proton beam propagating through a H_2 residual gas. It induces a production of pairs e^-/H_2^+ by ionization.

$$p + H_2 \to p + e^- + H_2^+$$

We assume that $n_{gas}/n_{beam} \gg 1$, with n_{gas} and n_{beam} the gas and beam density.

The space charge compensation...

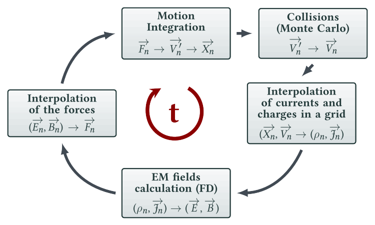
- depends on the beam distribution: non-linear phenomenon
- is partial
- is time dependent

To describe correctly the beam dynamics in a LEBT, one have to characterize **the degree of space charge compensation** and, for pulsed beam **the time to establish** the SCC.

→ Self-consistent numerical simulations are needed.

A 3D Particle-In-Cell is used: WARP

- Developed at LBNL
- Runs in parallel using MPI
- Python interface
- Open source



Input

- Beam distributions
- Reactions (ionization...)
- Beam line geometry and pressure
- External fields
- Mesh and boundary conditions

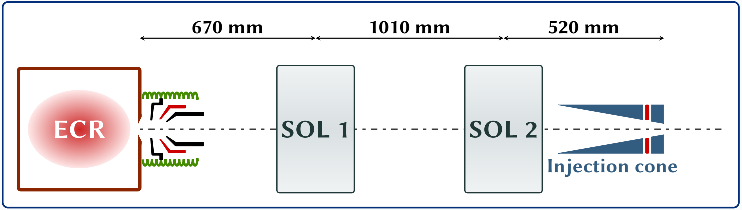
Output

- Beam and secondary particles distributions
- Potential maps induced by particles
- Field maps

LEBT Simulation Example
MYRRHA LEBT

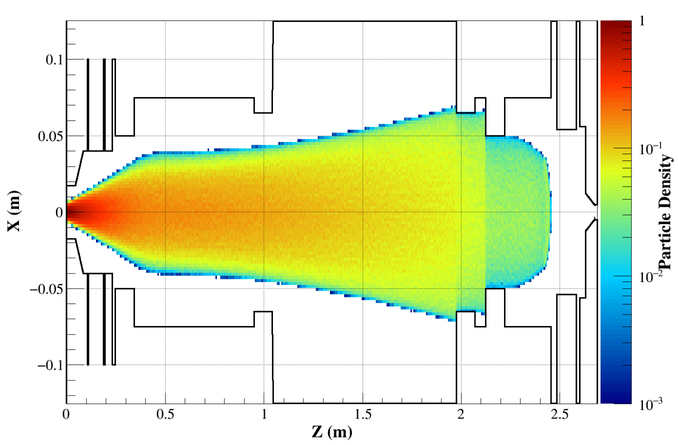
Simulation Conditions

- Beam type: continuous protons beam
- Beam intensity: 7.9 mA
- Beam energy: 30 keV
- Gas: Ar @ 6.4 $\times 10^{-5}$ hPa
- Magnetic field in solenoid 1/2: 0.17 T / 0.19 T
- Simulation time: 20 μs



MYRRHA LEBT, in operation at LPSC Grenoble

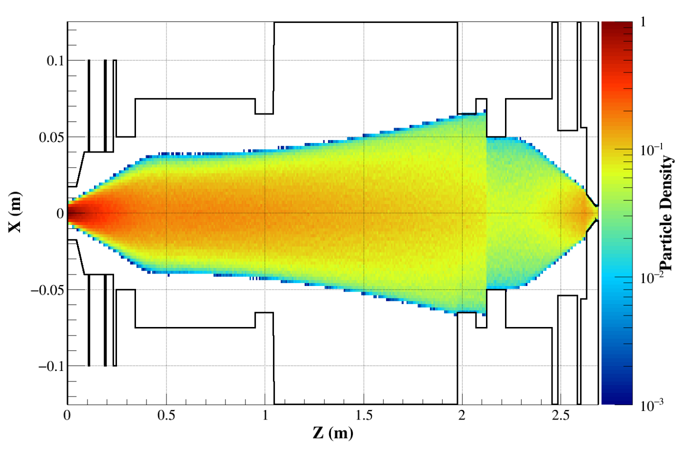
Beam Dynamics Evolution
Beam Density



t = 1 μs

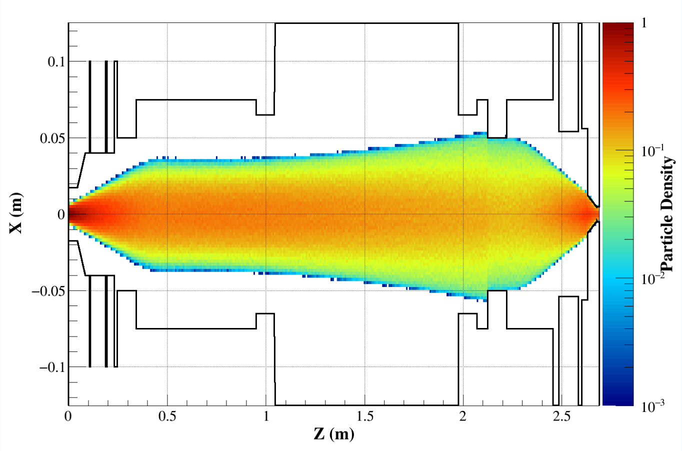
Beam Dynamics Evolution

Beam Density



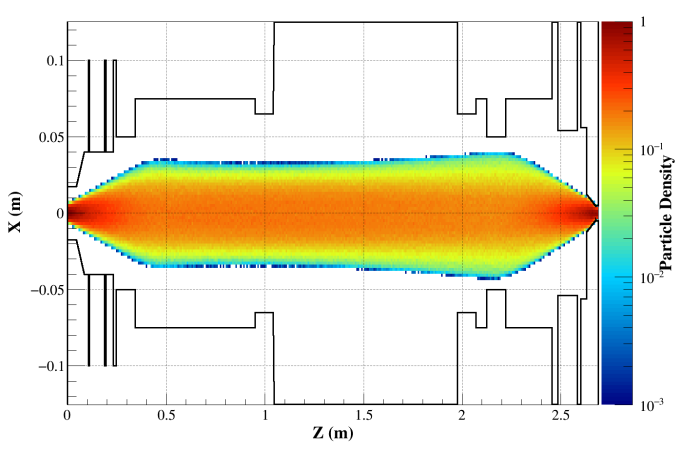
t = 2 μs

Beam Dynamics Evolution
Beam Density



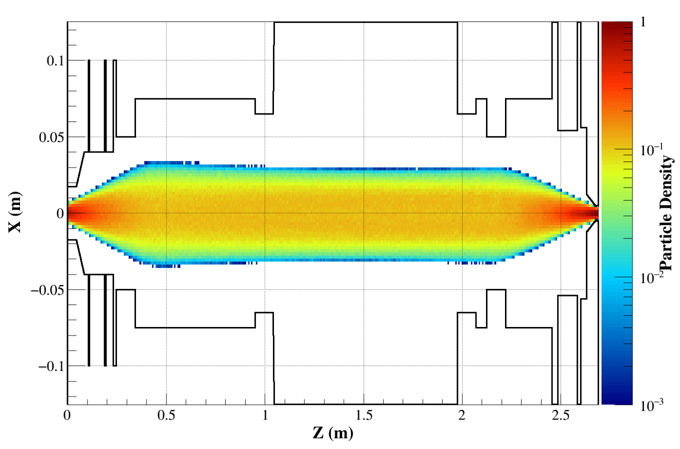
t = 4 μs

Beam Dynamics Evolution
Beam Density



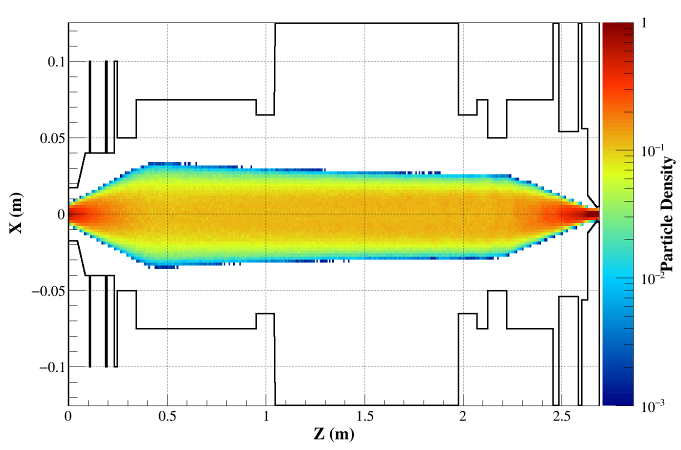
t = 6 μs

Beam Dynamics Evolution
Beam Density



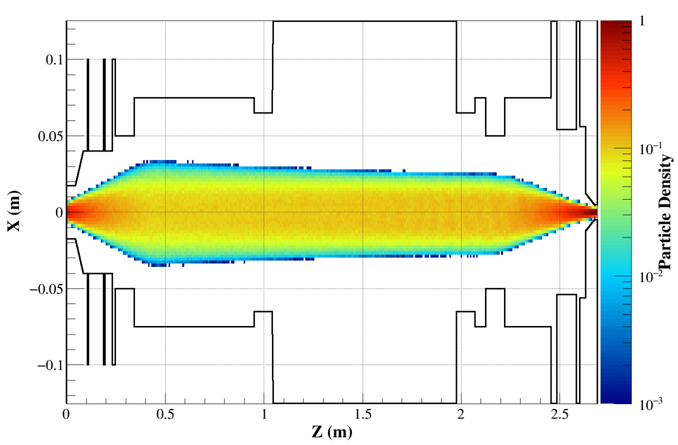
t = 8 μs

Beam Dynamics Evolution
Beam Density



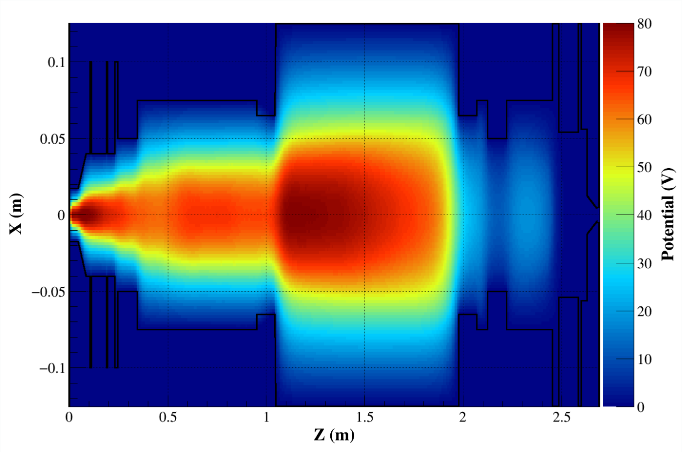
t = 10 μs

Beam Dynamics Evolution
Beam Density



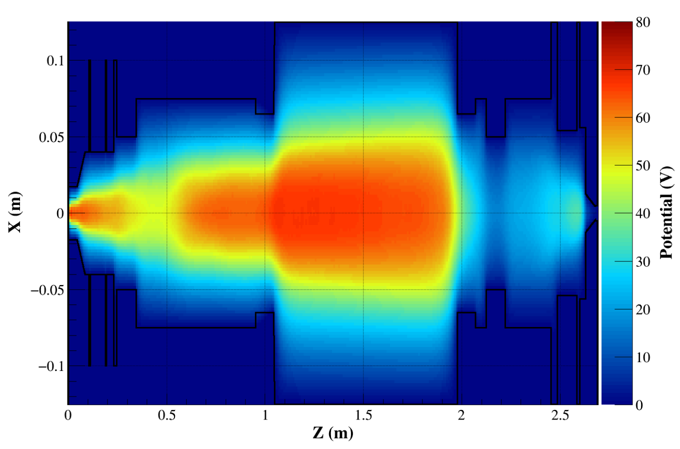
t = 12 μs

Space Charge Potential Evolution



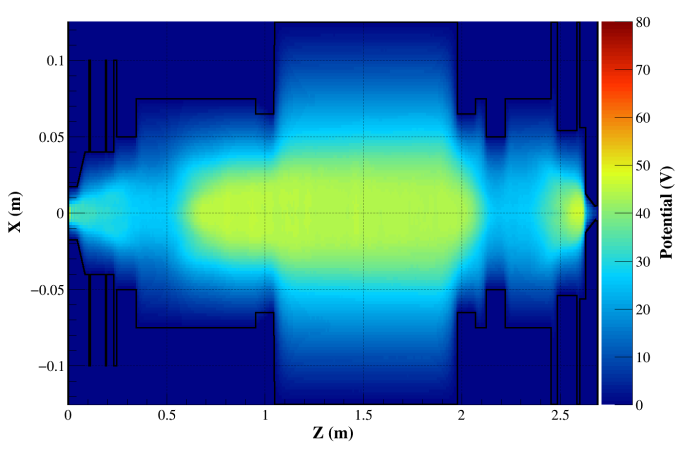
t = 1 μs

Space Charge Potential Evolution



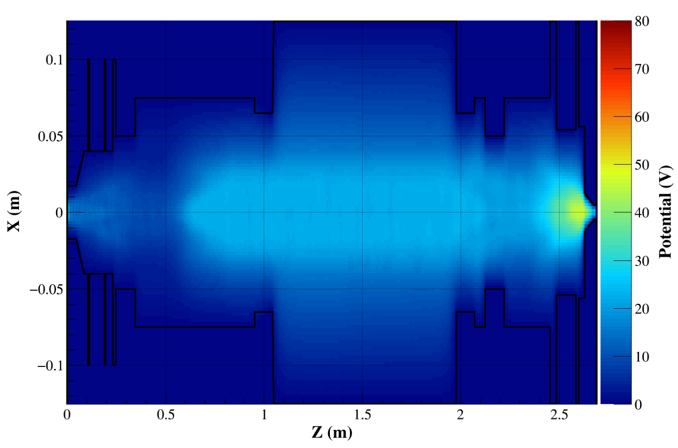
t = 3 μs

Space Charge Potential Evolution



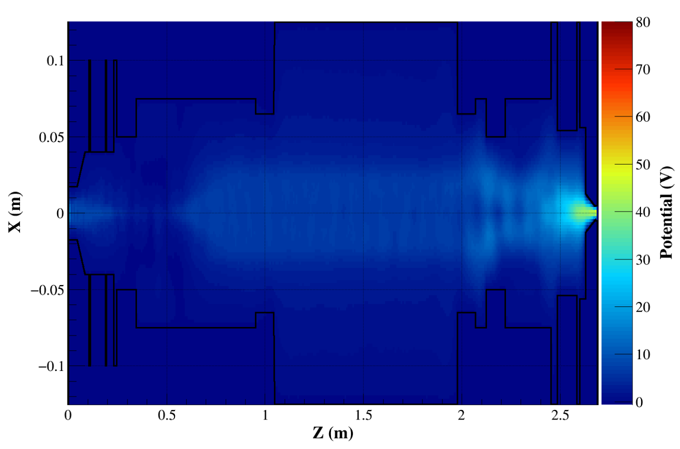
t = 4 μs

Space Charge Potential Evolution



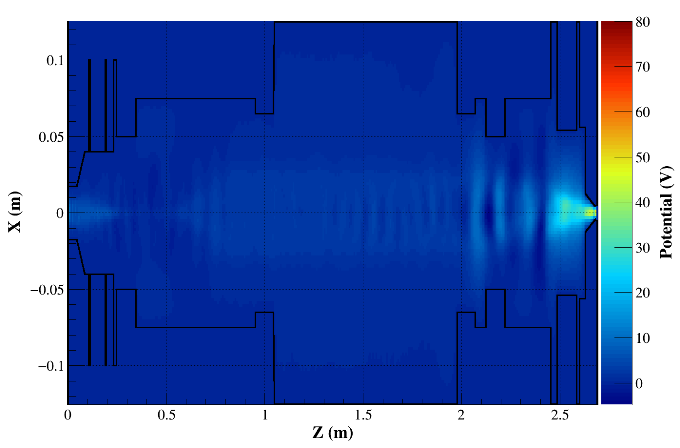
t = 6 μs

Space Charge Potential Evolution



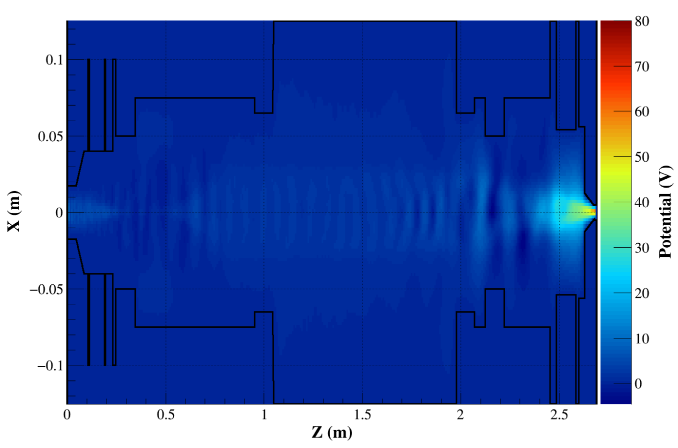
t = 8 μs

Space Charge Potential Evolution

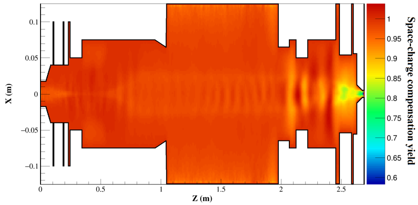


t = 10 μs

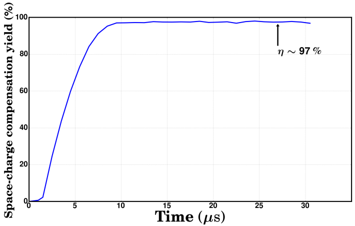
Space Charge Potential Evolution



t = 12 μs



Degree of SCC in the LEBT



SCC Evolution Time

SCC Simulations

Simulations:

- Performed on isipic (infiniband is needed)
- Typical computing time: several day on 16 to 64 CPUs
- Dedicated data analysis software (ROOT)

F. Gerardin's (LEDA) PhD thesis on Space Charge Compensation in High Intensity LEBTs.

Overview

Several MW class Linacs in operation, in construction or in project: SNS, J-Prarc, ESS, IFMIF, MYRRHA, SPIRAL2...

Issues

High intensity: accelerator matching and tuning is delicate

High power: beam losses have to be kept as low as possible ($\lesssim$ 1W/m)

The **combination** of high beam **intensity** and high beam **power** leads to a **challenging** situation

Accelerator Tuning

- Halo Matching
- Simulations with at least 10^6 macro-particles
- Beam loss detection @ 10^{-6} of the beam
- Simulated matching method should be transpose to the real machine

Massive Computing for Beam Dynamics Simulations

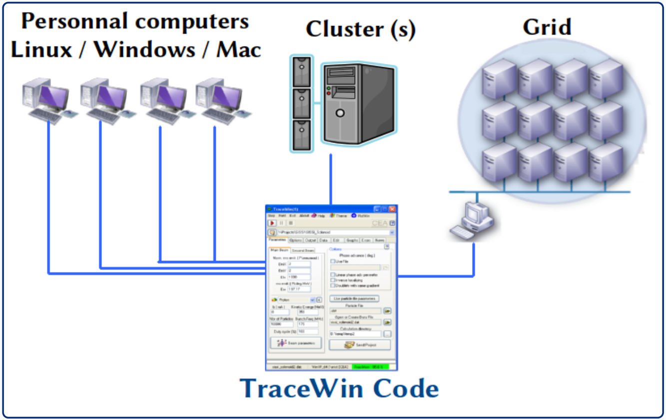
Goals

- Simulations with $\sim 10^9$ macro-particles
- Halo formation and longitudinal dynamics
- Statistical error studies
- Improvement of simulation tools

Method

- TraceWin code is used
- Distributed calculations on several machine types
- Massive hard drive storage (70 To HDD has been bought by LEDA/IFMIF)
- Dedicated data analysis software

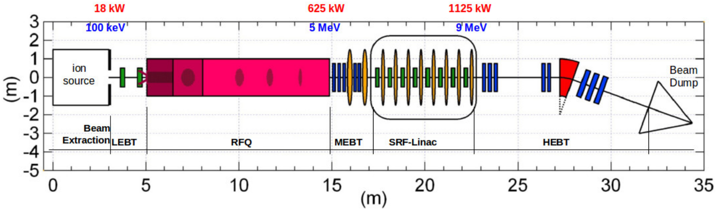
Massive Computing for Beam Dynamics Simulations



Distributed calculations with TraceWin

iclust is used for the simulation with $\sim 10^9$ macro-particles

Simulation of IFMIF–LIPAc
Layout and Main Parameters



LIPAc Main Parameters

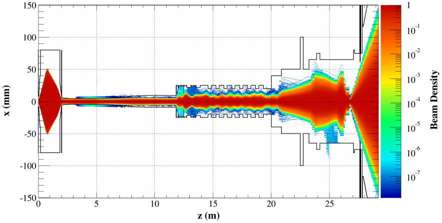
- Continuous D^+ beam
- Intensity: 125 mA
- LIPAc final energy: 9 MeV
- Hands-on maintenance
- ECR source & 2 solenoids LEBT
- 9.78 m 4-vanes RFQ @ 175 MHz
- MEBT and SFR linac (HWR)
- HEBT, Diagnostics Plate and Beam Dump

- Simulation with the actual number of particles in a bunch: **4.7×10^9**
- Storage of 6D beam distributions at 2000 positions along the accelerator ($\sim$ every 2cm): **38 To**
- **170 CPUs** over **25 days**
- Post processing: $\sim$ 12 hours with dedicated software running on 30 CPUs

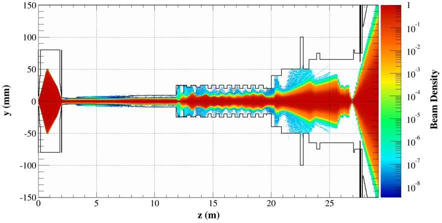
- Initial conditions: particles are randomly generated from a simulation of the ion source extraction system
- LEBT: space charge compensation profile determined with a PIC self-consistent code
- RFQ, SRF Linac and HEBT are modeled by field maps (1D or 3D)

Simulation Results

Beam Density along the Linac



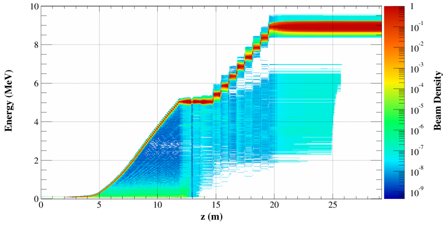
Beam Density: X plane



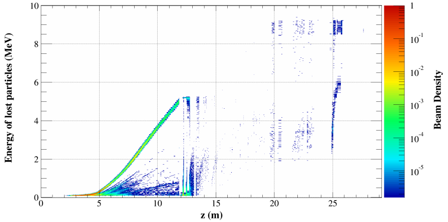
Beam Density: Y plane

Simulation Results

Beam Density along the LIPAc



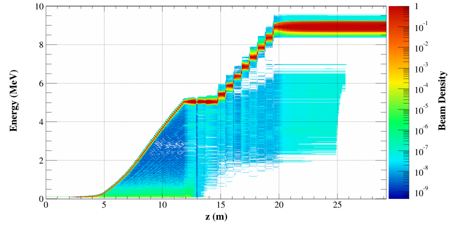
Beam Density: energy



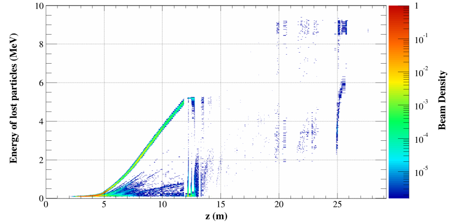
Lost Particles Density: energy

Simulation Results

Beam Density along the LIPAc



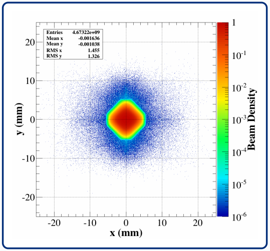
Beam Density: energy



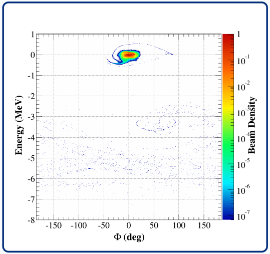
Lost Particles Density: energy

Simulation Results

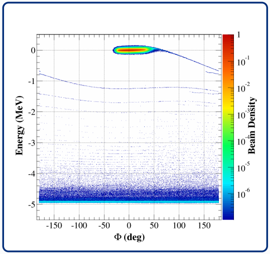
Beam Distributions in Phase Spaces



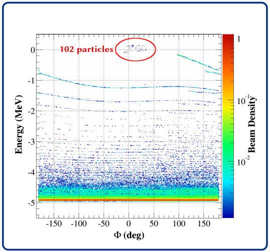
XY distribution after RFQ



ΦΔE distribution after SRF-linac



ΦΔE distribution after RFQ



Particles lost downstream, distribution after RFQ

Overview

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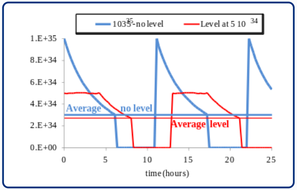
3. Massive Calculations for High Intensity Linacs
4. **HiLumi LHC/FCC Simulations Activities**

HiLumi LHC

The goal is to reach an integrated luminosity of 250 fb^{-1} per year.

- Study of alternative optics
- Field quality study of the new magnets
- Fringe field magnets modelisation



EuroCirCol dans FCC-hh

Design of a 100 TeV proton-proton collider

- Study and optimization of the arcs optics
- Definition of the magnet fields quality

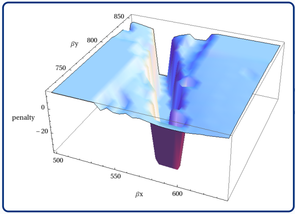
Boundary condition search

Scan of initial boundary condition to search for a matched optics configuration:

- system of 40 variables and 44 constraints
- implemented in bash scripts + MadX

CPU:

- $\sim$5-6 h, CPU X9650, 4Cores, 3GHz
- $\sim$30 min on iclust (9000 matching distributed on 40-60 jobs)



Scan of initial boundary condition to search for a matched optics configuration:

- single scan 1.4 Go
- asked 100 Go: /home/nfs/manip/mnt/perso/payet $\rightarrow$ no automatic back-up!

Long Term Tracking Simulations

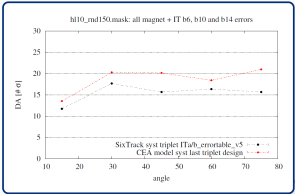
Calculation of Dynamic Aperture (the region in phase space where stable motion occurs) for LHC upgrades.
Typically the DA is computed simulating the particles motion over 10^5 turns, using a set of initial conditions distributed on a polar grid, Five different phase space angles are used.

Currently running on lxplus (CERN):

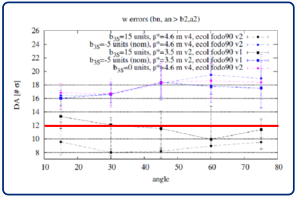
- bash scripts to run SixTrack code
- 100 jobs in parallel per user
- $\sim$ 1 week for one full scan ($\sim$6000 jobs)
- possibility to use BOINC system
- *can we join LHC@home?*

Porting on iclust ?

- *what is max # jobs a single user can run?*
- *possibility to have $\sim$ 1 To of back-up space?*



HL-LHC



FCC

Conclusions and Perspectives

Conclusions

- Space charge compensation studies (thesis) – *isipic*
- High power linac beam dynamics simulations: multi-parametric calculations, statistics – *iclust* (+ $\sim$ 100 To HDD)
- Hi-Lumi/FCC optics optimization and magnet studies – *iclust*

Perspectives

- Linac optimization for IFMIF-DONES (1 post-doc) – *iclust*
- Laser-plasma acceleration simulations in the framework of Eupraxia (1 post-doc) – *isipic*
- HL-LHC/FCC dynamic aperture calculations – *iclust*

Conclusions and Perspectives

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Thank you for your attention !