Simulating the LHC Collimation System with the Accelerator Physics Library MERLIN, and Loss Map Results

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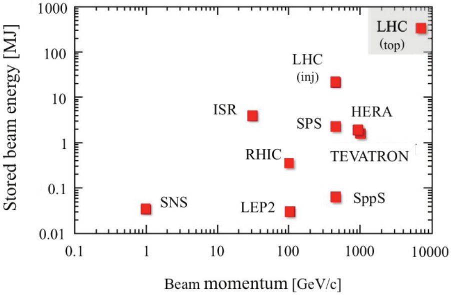
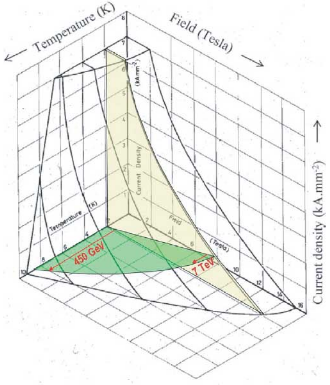
The Large Hadron Collider (LHC)

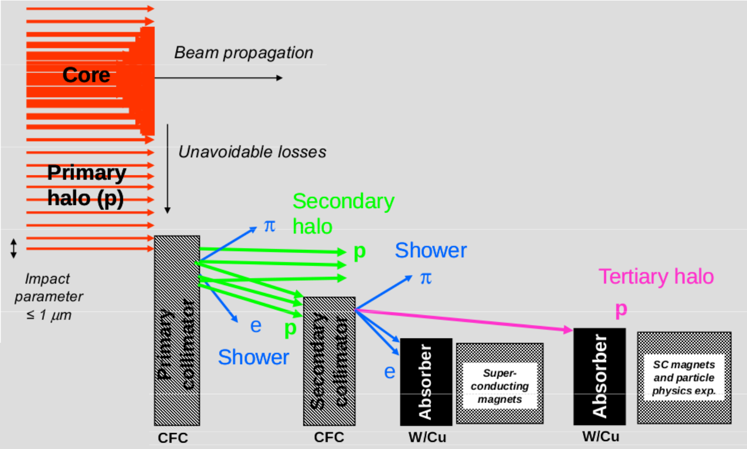
- 7 TeV proton-proton synchrotron, 26.65km length
- Beams collide at 4 experimental regions - (ATLAS, ALICE, CMS, LHCb)
- 2 collimation regions
- Additional regions for RF, and the beam dump
- Injection at 450 GeV, ramp to up 7000 GeV (Currently running at 4000 GeV)
- Superconducting magnet system, 1.9K, 8.33T dipoles
- High stored beam energy!





- 360MJ stored beam energy.
- 4.5mW/cm^3 will quench a magnet at top energy!

Collimation



Collimator families

Collimator	Type	Material
TCP	Primary	C
TCSG	Secondary	C
TCLA	Absorber	W
TCT	Triplet protection	W
TCLP	Physics debris Absorber	Cu
TCDQ	Dump protection	C
TDI	Injection protection	C

What is Merlin?

- C++ Accelerator physics library
- Provides a set of useful functions for accelerator modelling
- Initially used to simulate ground motion in the ILC BDS and linac
- Later the ILC damping rings
- Written by Nick Walker et al (DESY)
- Now adapted for large scale proton collimation simulations by Manchester and Huddersfield
- Three main sections of the library:
- Accelerator lattice loading/creation and storage
- Tracker
- Physics processes
- Modular design - easy to modify and extend

Accelerator Lattice

- Can load directly from MAD (TFS table output)
- Can also use XTFF format
- Direct element addition
- The created AcceleratorModel element can be further manipulated in the future, e.g. adjust aperture, alignment errors, etc
- AcceleratorComponent: The base class for each element in the lattice that all elements inherit from.
- EMField: The field associated with the element
- AcceleratorGeometry: Any Geometry transforms for the element, e.g. tilt
- Aperture: The aperture for the element, e.g. the beam pipe or collimator jaws
- WakePotentials: Any wakes for the element - resistive wall, geometric and cavity wakes

Tracker

- Different types of tracker, particle tracking and bunch moment tracking
- Takes the input of a bunch and beamline, and tracks the bunch along the beamline
- Can use specific integrator sets, e.g. transport, thin lens, symplectic
- Can override specific integrators, e.g. crab cavities
- Step both along the accelerator lattice and within individual elements

Physics processes

- Additional physics on top of tracking to be applied at selected elements and positions
- Can be enabled or disabled as required - processes are attached to trackers
- Examples: Synchrotron radiation, collimation, wakefields, etc
- Easy to create, template examples exist
- Trackers manage stepping within processes - inputs are the AcceleratorComponent and bunch

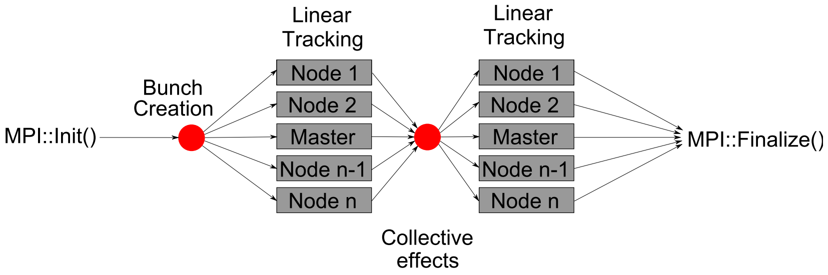
Accelerator errors

- Can offset element positions, x,y,z
- Can adjust angular tilts
- Can add in field errors including additional multipoles
- Can generate errors inside Merlin
- We generate errors in MAD, correct for errors, then transfer this information to merlin
- Tested loss maps with an errored and corrected lattice, with collimators aligned to the perfect orbit
- Little difference from the perfect configuration in loss maps

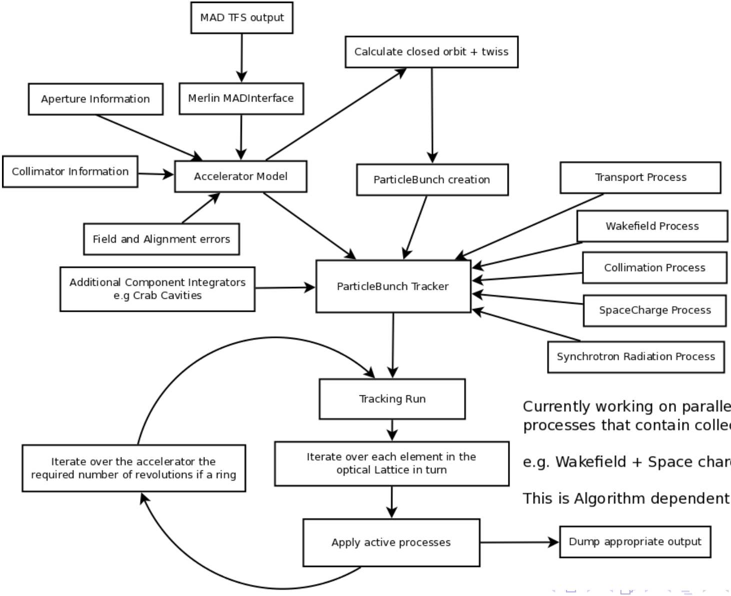
Parallel running

- Wish to run large simulations - very cpu heavy - use MPI
- Must use multiple physical machines with interconnects
- Run multiple copies of the same binary that can communicate with each other
- Tracking, collimation, etc, are all independent on a per-particle basis, do not need any knowledge about other particles
- Collective effects such as space charge and wakefields do require this information
- Functions exist such as parallel bunch moment calculations (mean, standard deviation) in addition to the ability to move particles between computers
- Parallel running is implemented at a per process algorithm level

Parallel running



Example run



Currently working on parallelising processes that contain collective effects

e.g. Wakefield + Space charge effects

This is Algorithm dependent.

General simulation strategy

- 1: Comparison and benchmarking with existing codes - Sixtrack, MAD-X
- 2: Enhance features - e.g. New scattering, new materials
- 3: Predict future operations - e.g. New collimator/optics layouts, new collimator materials and methods
- Currently working on 1 and 2 in parallel as will be shown

Collimation simulation configuration

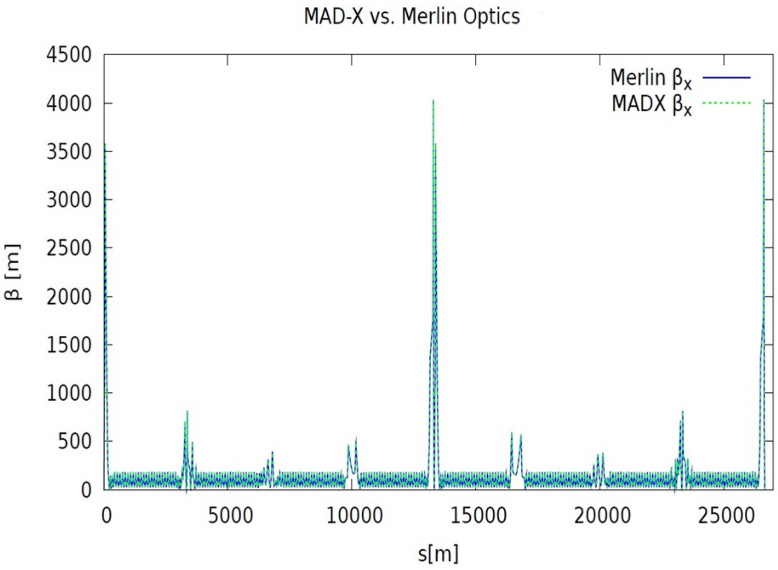
- Want to have a comparison with Sixtrack
- Thick-lens version V6.5.2012.02.seq
- Using Beam 1
- β^* for IP1 and IP5: 0.6m
- β^* for IP2 and IP8: 3m
- 6.4 M particles simulated
- No field or alignment errors
- Energy= 4 TeV, $\epsilon_n = 3.5$ mm-mrad, dp/p $= 0$, $\sigma_z = 0$
- Crossing angle[μrad]: X1=-145, X2=-90, X5=145, X8=-220
- Parallel separation on at all IP: sep $= \pm 0.65$mm
- Horizontal halo distribution
- Impact parameter $= 1\mu m$ and 10 cm longitudinal loss resolution

Collimation simulation configuration

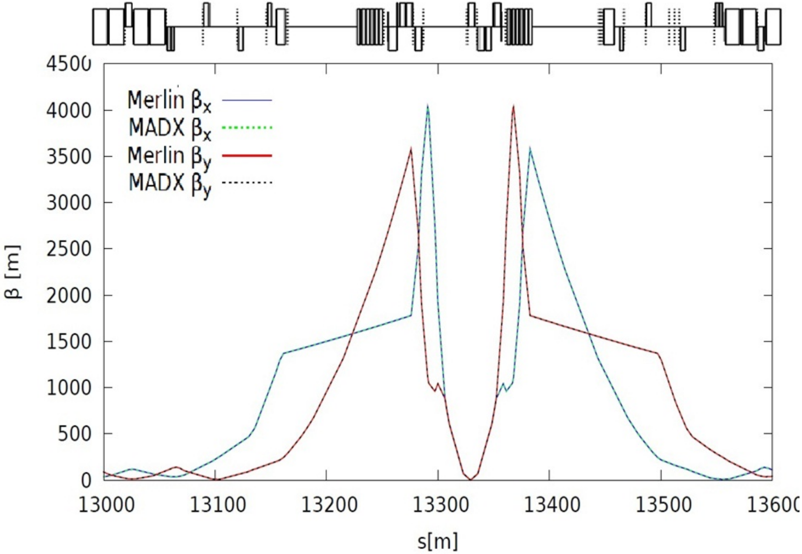
- Beam injected at TCP.C6L7.B1 (primary horizontal collimator)
- Collimators aligned to orbit and beam envelope

Collimator	Aperture (σ)
TCP IR7	4.3
TCP IR3	12
TCSG IR7	6.3
TCSG IR3	15.6
TCLA IR7	8.3
TCLA IR3	17.6
TCLP	10
TCT IR1/IR5	9
TCT IR2/8	12
TCDQ IR6	7.6
TCLI	open
TDI	open

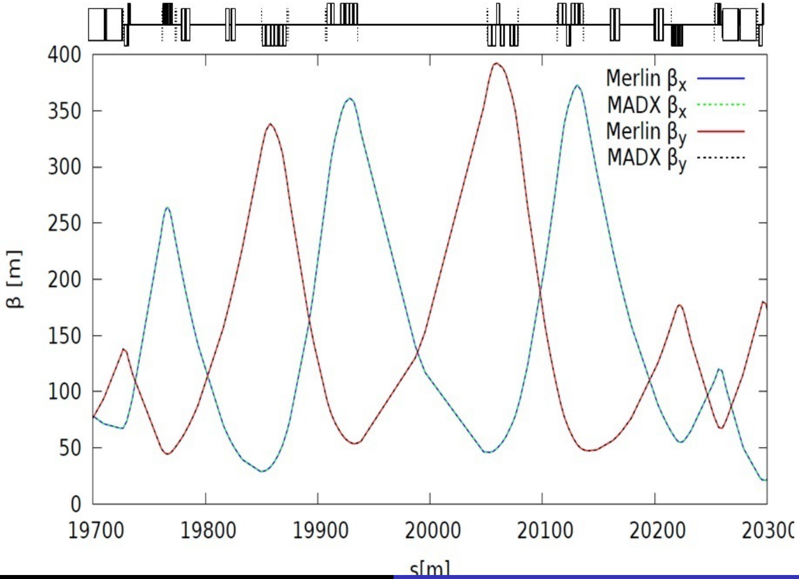
Beta functions



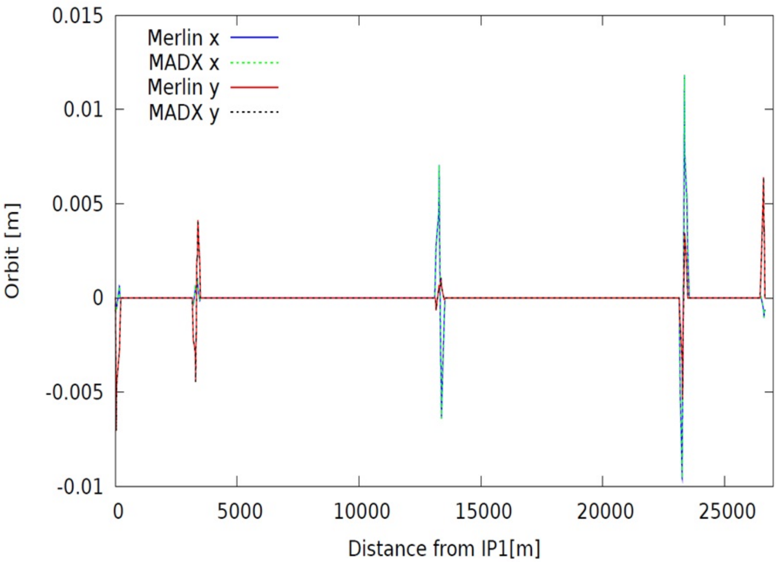
Beta functions - IR5



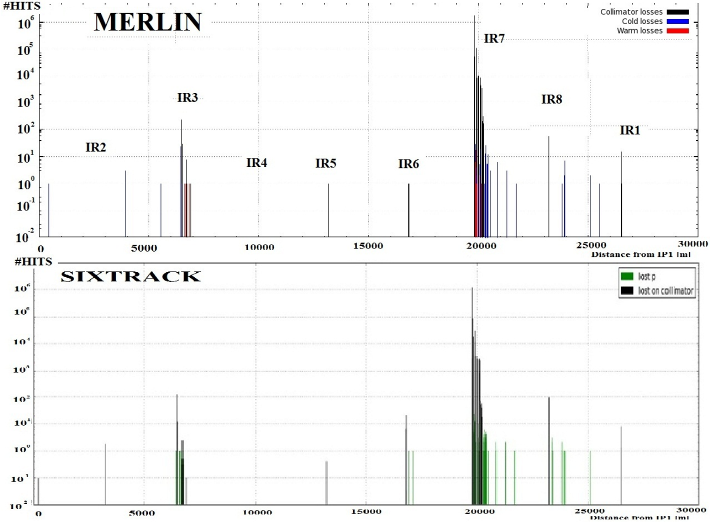
Beta functions - IR7



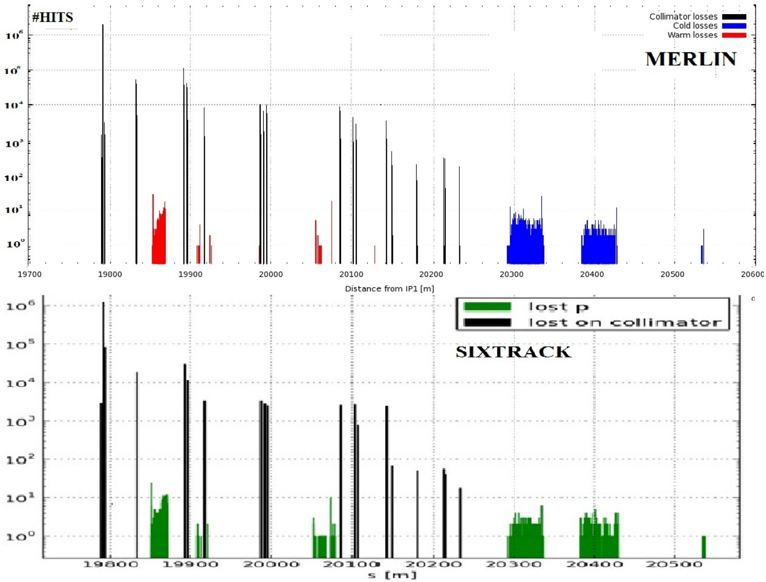
Reference orbit



Loss map results comparison (Sixtrack plots from LHC collimation group (R. Bruce))



Loss map Results IR7



Enhanced scattering physics

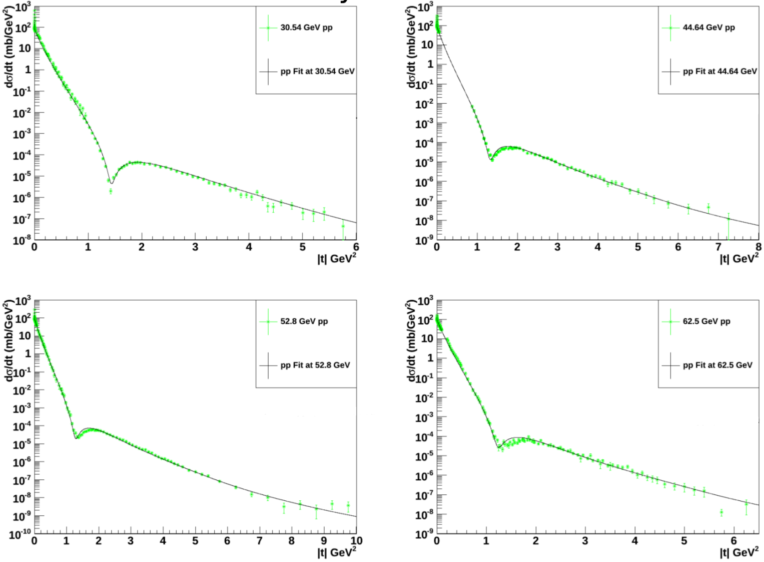
- Have been working on enhanced scattering physics inside a collimator jaw
- Nuclear interactions - pA scattering
- Nucleon scattering: elastic and single diffractive
- Higher level electron interactions - multiple coulomb scattering, atomic ionization
- Do not care about any secondary particles, similar to sixtrack
- Aiming to be precise and fast
- Our range of interest is of beam energy between 450 and 7000 GeV/c
- This is $\sqrt{s} = 30 \longrightarrow 115 GeV$ for fixed target interactions

Elastic scattering

- Use the model of Donnachie and Landshoff: arXiv:1112.2485v1 [hep-ph]
- Interested in the differential cross section $\frac{d\sigma}{dt}$
- Fit all appropriate existing pp and $p\bar{p}$ data
- Data exists on either side of the region of interest so interpolation is possible
- Add low t coulomb peak to the fit

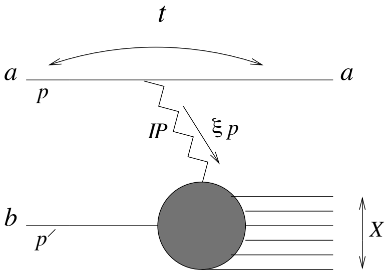
Elastic scattering experimental data

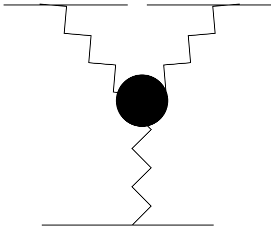
Preliminary Results



Single diffractive Scattering

- Incident proton interacts with a target nucleon
- Exits with reduced energy (M_x), and an angular kick
- Again, use the Donnachie-Landshoff model: arXiv:hep-ph/0305246v1
- Two regions of M_x: baryon resonances at low mass, tripple regge at higher mass

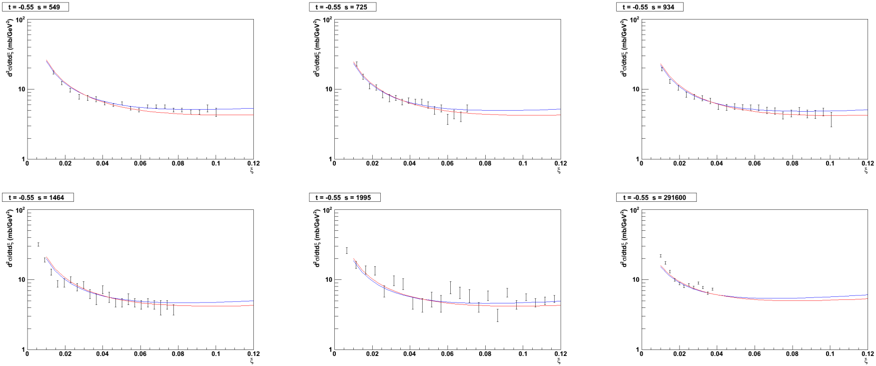




Tripple Regge exchange region

- Fitting over 6000 data points, over 8 experiments!
- More than 70% of the cross section exists at large M_x

Preliminary Results

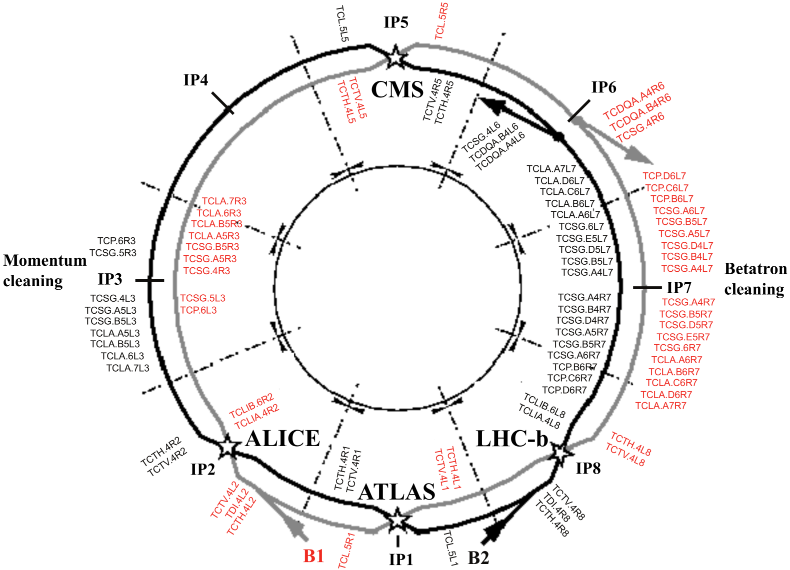


Conclusions

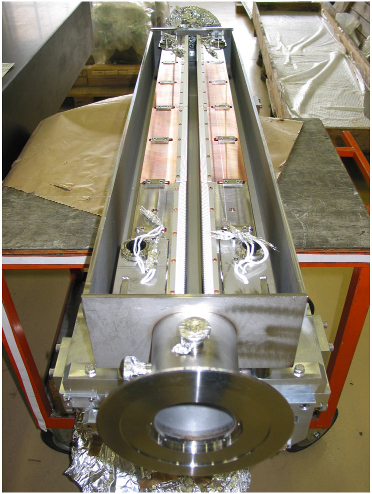
- We are developing the code Merlin to operate with proton machines for high energy collimation simulations
- When running in sixtrack like scattering mode, similar loss maps to sixtrack are generated for 4 TeV 2012 running
- Enhanced scattering physics models are almost complete and will soon be implemented into Merlin
- New material classes allow simulation of novel collimator materials, e.g. SiC, CuD, etc
- Parallel running allows large scale simulations
- We welcome new code users (and brave developers)

Bonus material

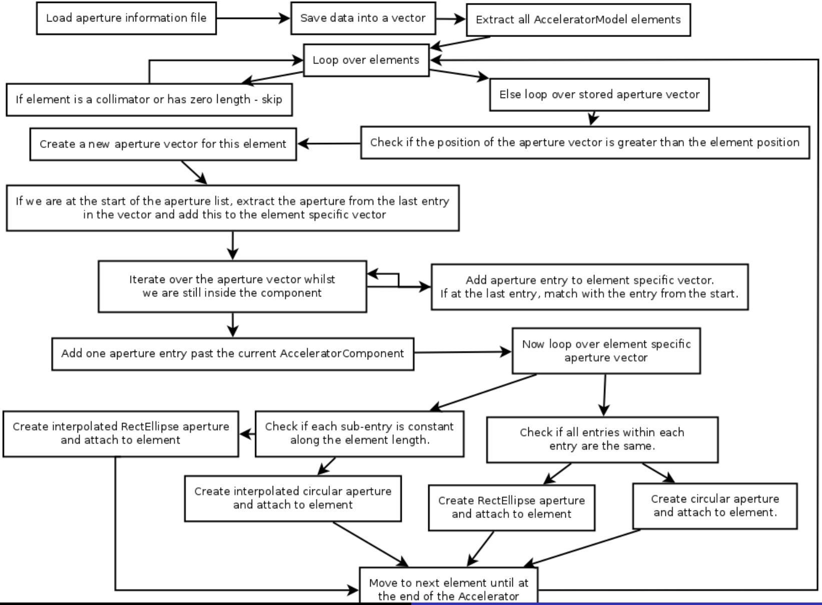
Collimation Layout



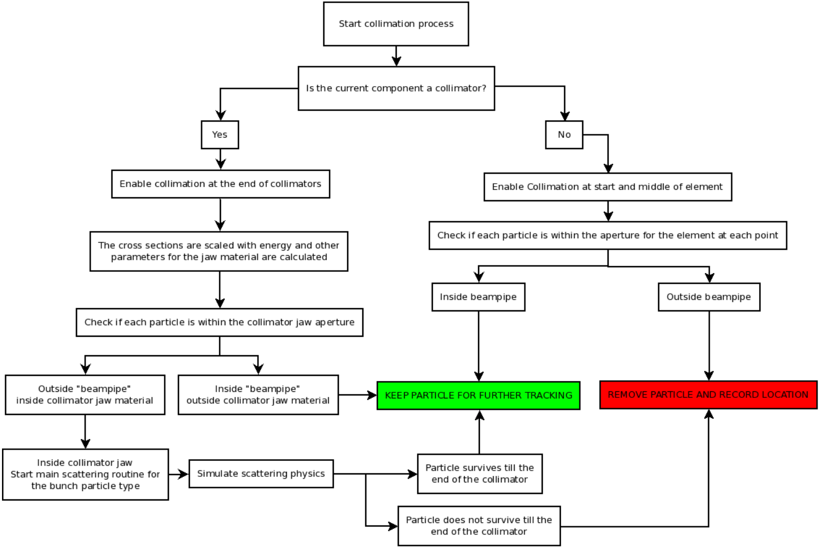
Collimator Images



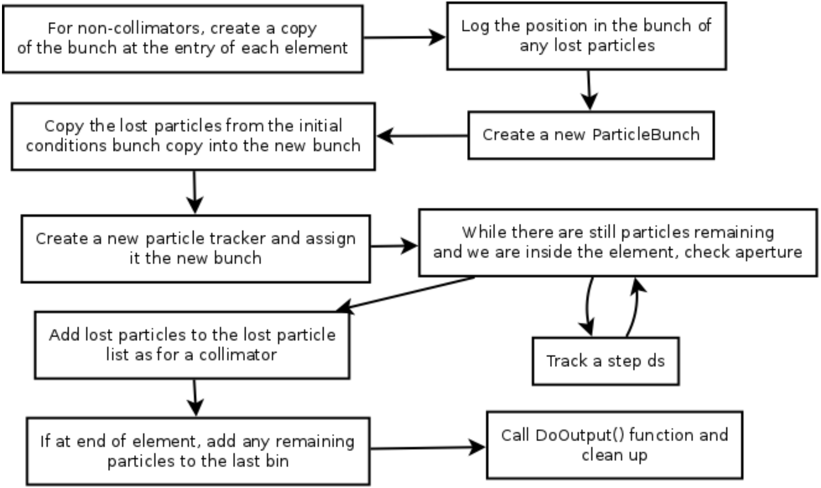
Aperture configuration



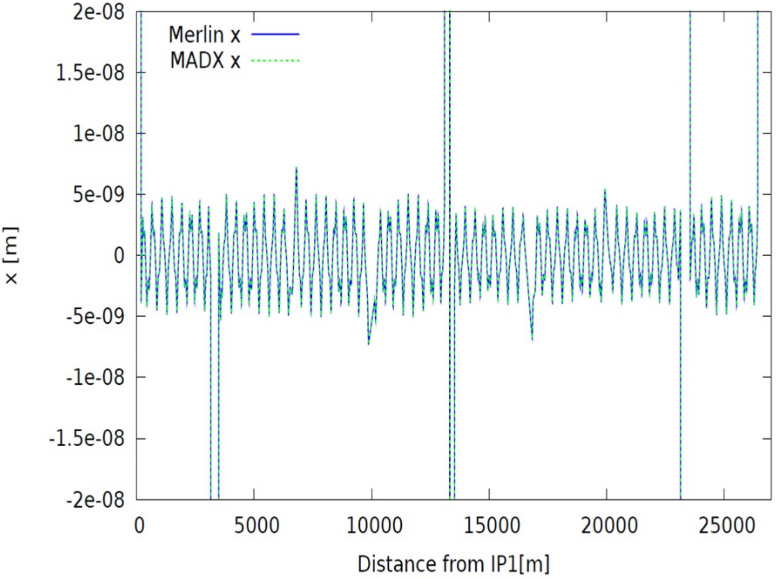
Collimation Process



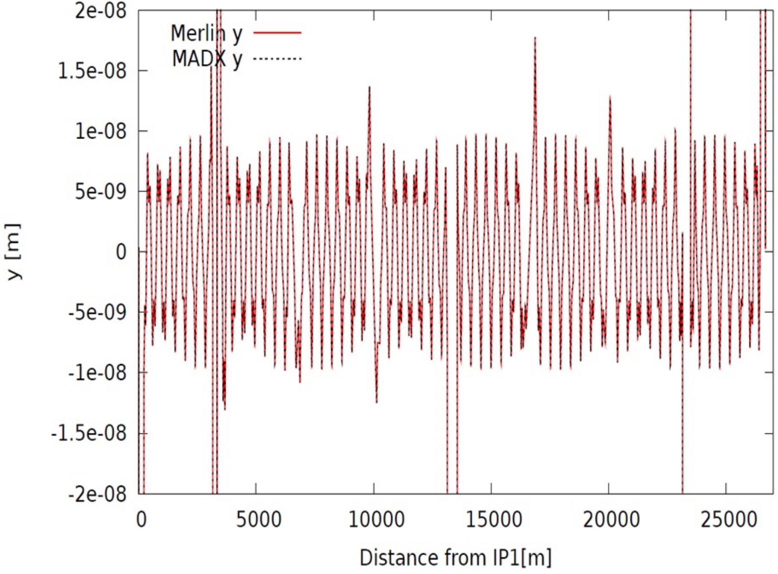
Collimation Process



Reference orbit - zoom x



Reference orbit - zoom y



Cross sections