PARTICLE COLLIDER INTERACTION REGIONS

Backgrounds and Machine-Detector Interface

5. Simulation Tools and Computing Aspects

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OUTLINE

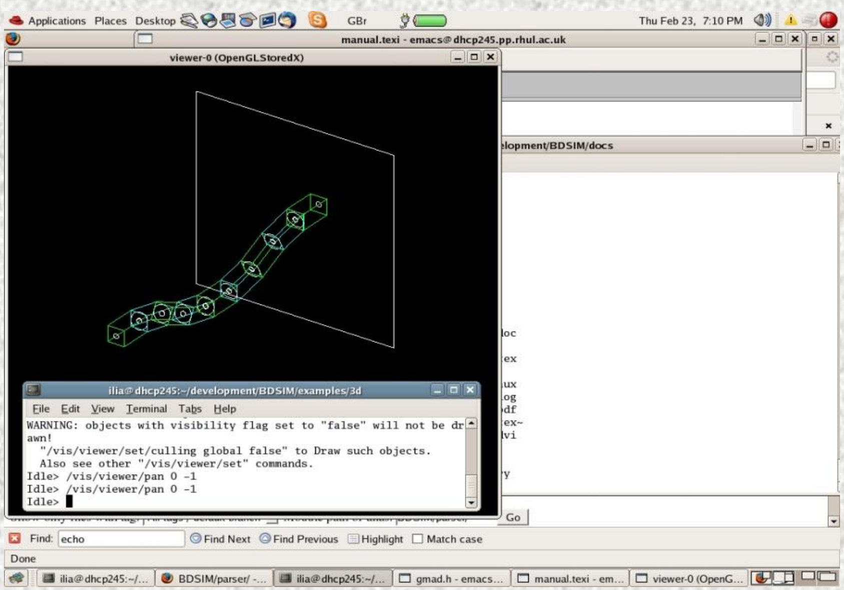
- Background and MDI Modeling Tools
  - e^+e^-
  - pp
  - $\mu^+\mu^-$
- Details of SLIC/LCSIM, BDSIM, ILCroot and MARS
- Overview of General Purpose Particle Transport and Interaction Codes

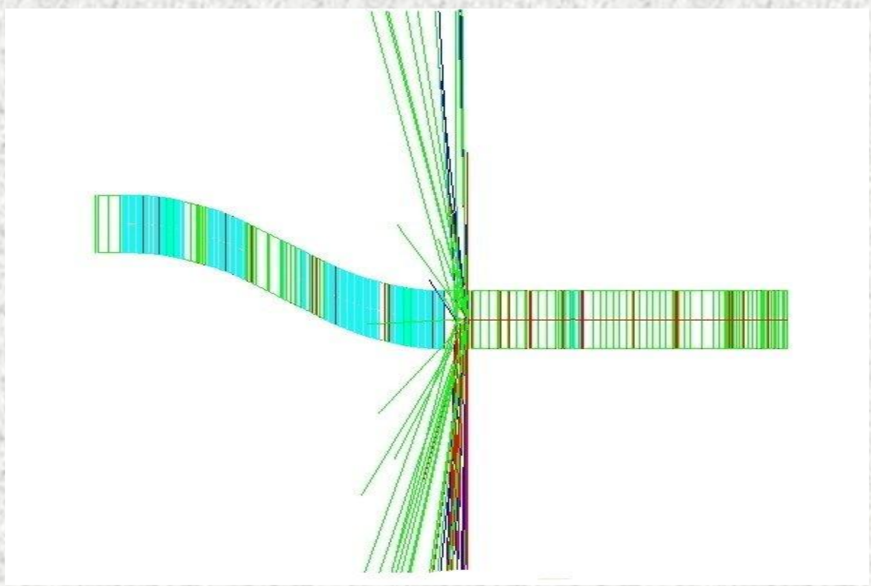
e^+e^- Colliders

- IP Generator
  - e^+e^- events: **PYTHIA**
  - Radiative Bhabas from beam-beam interactions and synchrotron radiation: **GuineaPig, CAIN**
- Beam Loss, Collimation and Source at MDI
  - **TURTLE+MUCARLO, STRUCT, MARS, BDSIM**
- Radiation and Background Loads
  - **MARS, FLUKA, GEANT**
- Detector Physics
  - **SLIC/LCSIM, MOKKA, JUPITER, ILCroot**

BDSIM

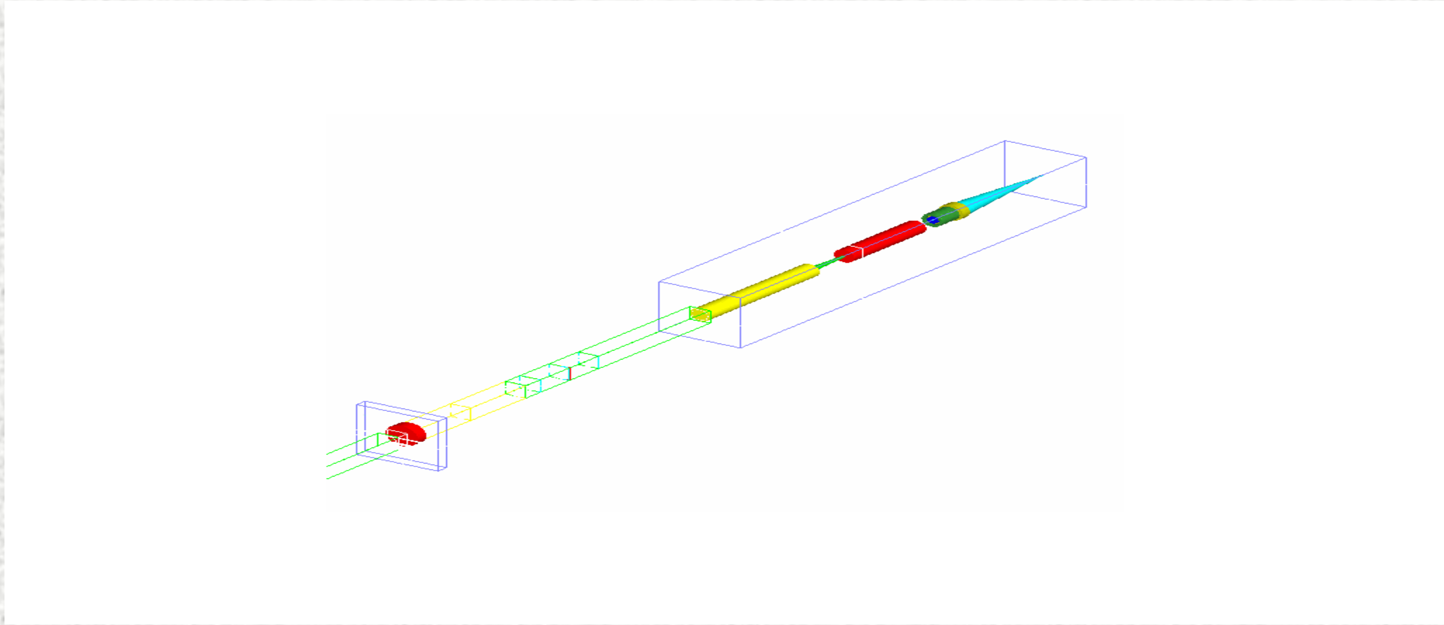
- Geant4 toolikit for beamline simulations
- Geometry construction framework
- Additional transportation processes
- Physics lists for various accelerator applications
- Extensive development/benchmarking underway and planned
- ttp://flc.pp.rhul.ac.uk/bdsim.html - docs, cvs, etc





BDSIM geometry

- Accelerator description is in the GMAD language (EUROTeV-Memo-2006-003)
- parameters and commands relevant for Monte-Carlo
- Mokka (EUROTeV-Report-2006-XXX) and GDML support
- ILC decks are under cvs on http://cvs.pp.rhul.ac.uk/ILCdecks
- Integration into LCIO may be desirable in the future
- CAD tool will soon be ready (GDML)



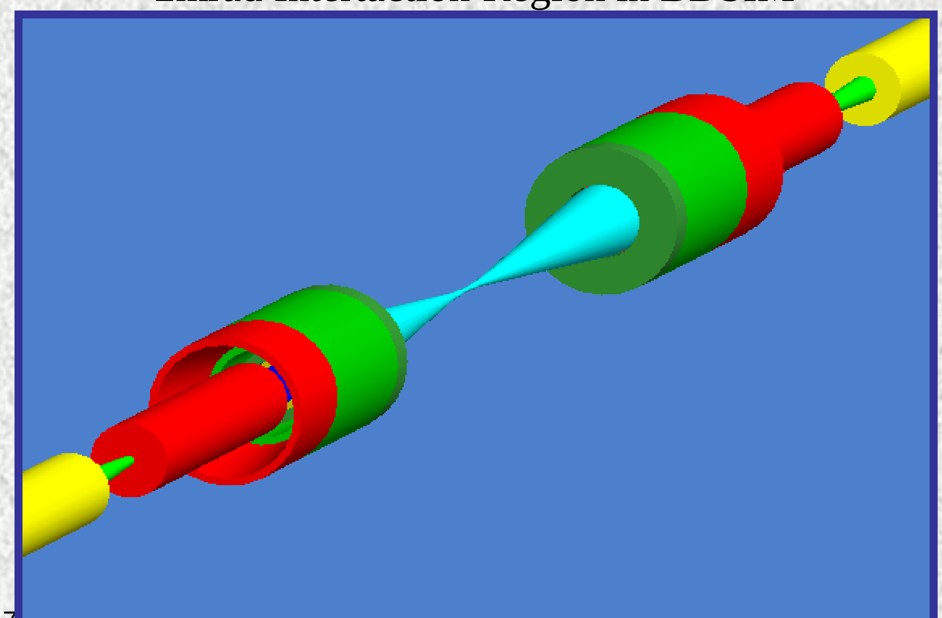
GMAD -- accelerator description

- Extension of a MAD subset to support geometry features
- Commands for run control, process cuts etc.
- Provides „drivers“ to other geometry formats, so arbitrarily complicated geometries are possible
- Can be used as a standalone parser library

Mokka

- Several detector groups utilise the Mokka framework to interface Geometry into Geant4
  - Built around a MySQL database containing the geometry descriptions
- BDSIM loads complex geometry from MySQL dump files
  - Follows the same principle as the Mokka database
  - Standardises the structure of the MySQL tables
  - Allows for the detector regions to be included in the optics decks

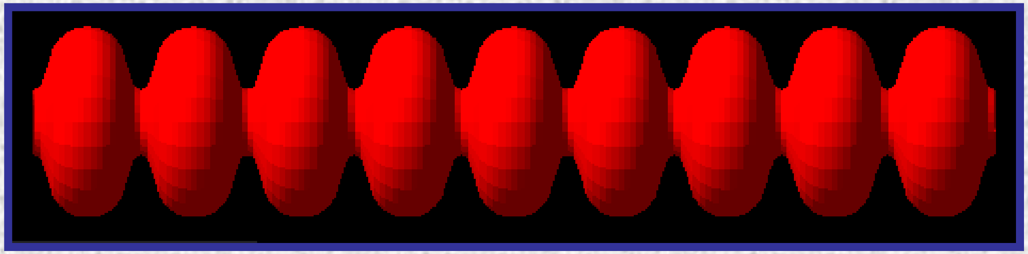
2mrad Intertaction Region in BDSIM

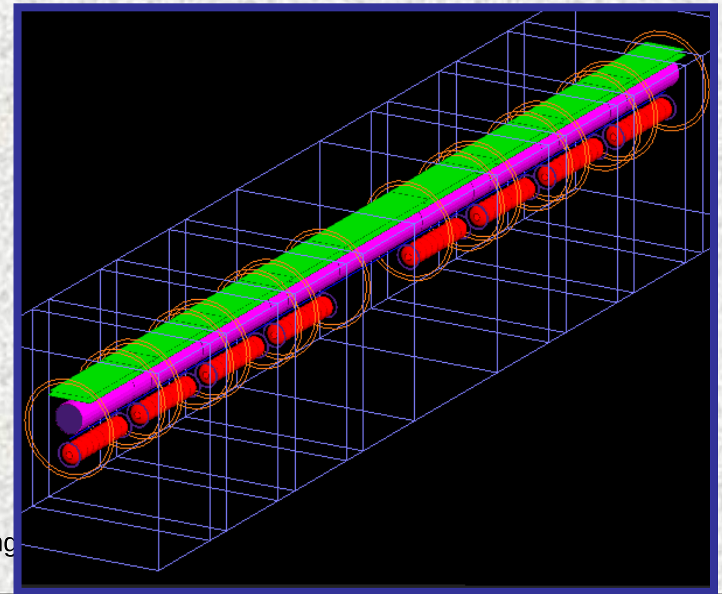


Mokka Geometry Description

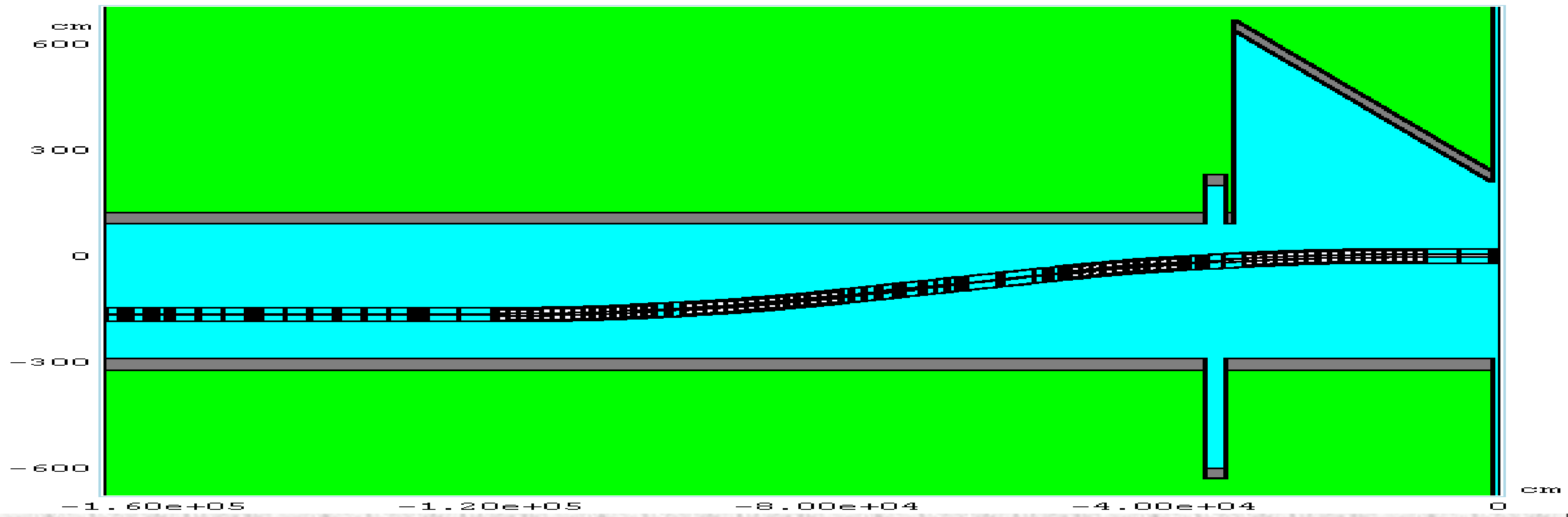
- Constantly improving and adding functionality - currently allows for:
  - Field Maps - e.g. Solenoid Field (all fields use Runga-Kutta tracking methods)
  - Basic solids (Box, Tube, Cone, etc)
  - Complex Solids (Torus, Polycone, Trapezoid, Elliptical Cone, Boolean Solids, etc)
  - Dipole, Quad, Sext, and Oct magnets
    - Allows for one-off magnets to be modelled where realistic descriptions may be important
  - Sensitive volumes

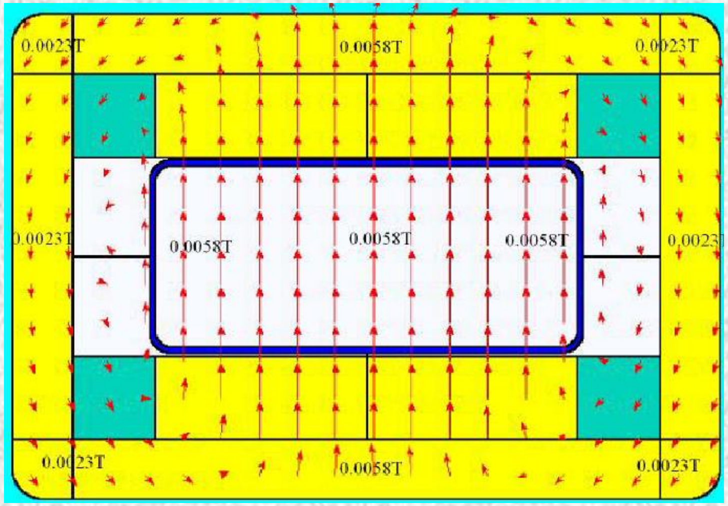
Complex geometry being used to build up cryomodules in the linac for laserwire signal/background studies
(L. Deacon - PhD Student @ RHUL)

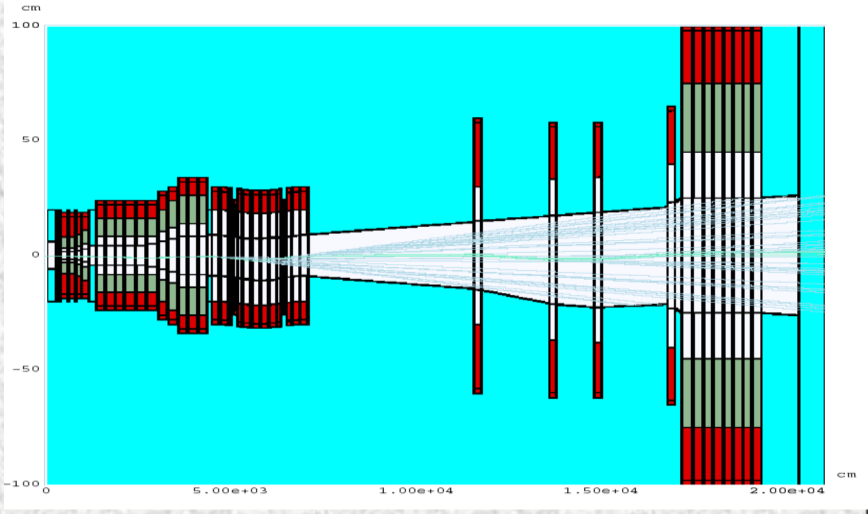


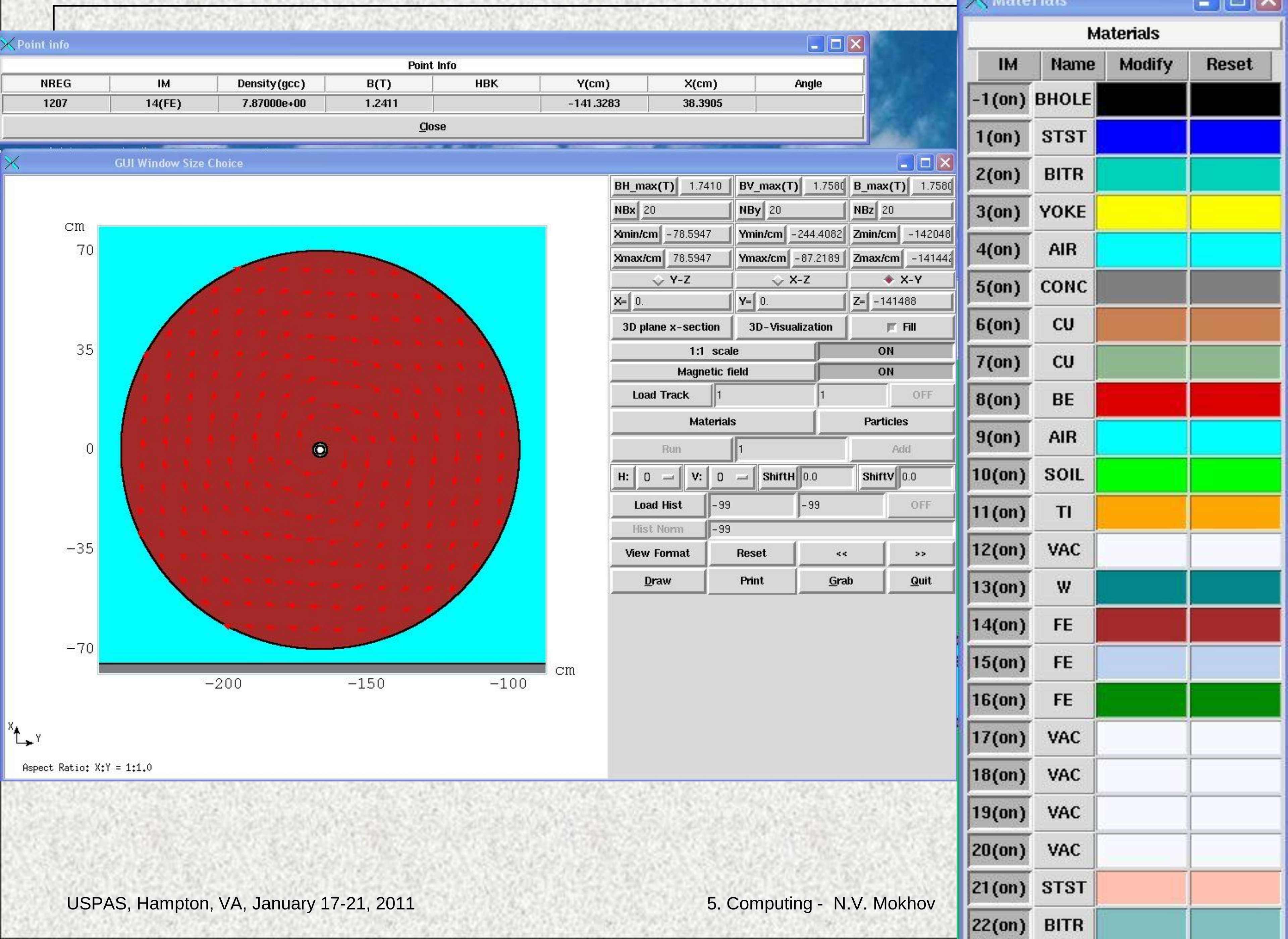


MARS15 GUI Examples for ILC BDS





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Point Info
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Close
GUI Window Size Choice
cm
70
35
0
-35
-70
-200
-150
-100
cm
Aspect Ratio: X:Y = 1:1.0
BH_max(T) 1.7410
BV_max(T) 1.7580
B_max(T) 1.7580
NBx 20
NBy 20
NBz 20
Xmin/cm -78.5947
Ymin/cm -244.4082
Zmin/cm -142048
Xmax/cm 78.5947
Ymax/cm -87.2189
Zmax/cm -141442
Y-Z
X-Z
X-Y
X= 0.
Y= 0.
Z= -141488
3D plane x-section
3D-Visualization
Fill
1:1 scale
ON
Magnetic field
ON
Load Track
OFF
Materials
Particles
Run
Add
ShiftH 0.0
ShiftV 0.0
Load Hist
-99
OFF
Hist Norm
View Format
Reset
Draw
Print
Grab
Quit
Materials
IM | Name | Modify | Reset
-1(on) BHOLE
1(on) STST
2(on) BITR
3(on) YOKE
4(on) AIR
5(on) CONC
6(on) CU
7(on) CU
8(on) BE
9(on) AIR
10(on) SOIL
11(on) TI
12(on) VAC
13(on) W
14(on) FE
15(on) FE
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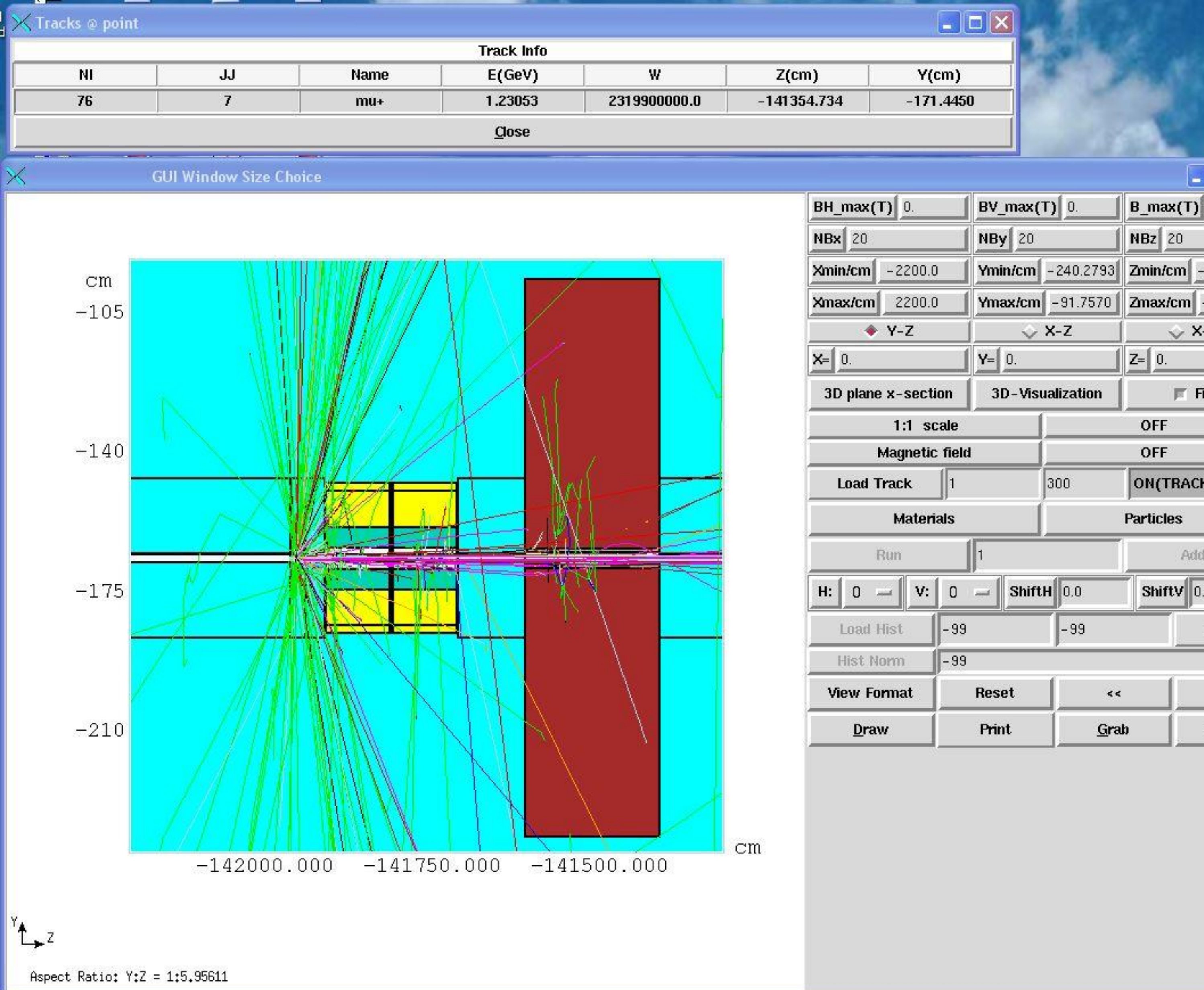
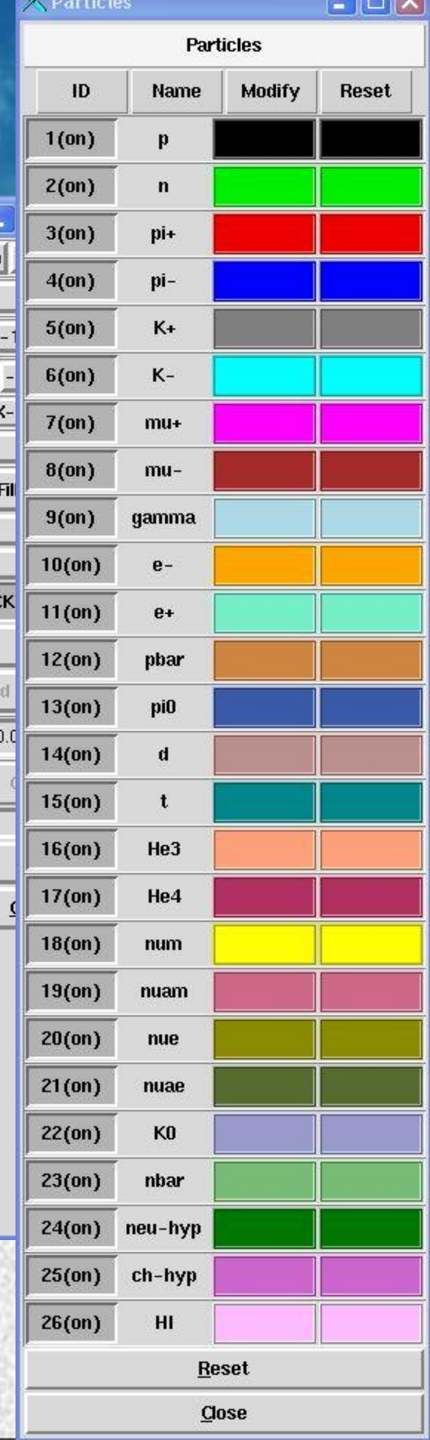
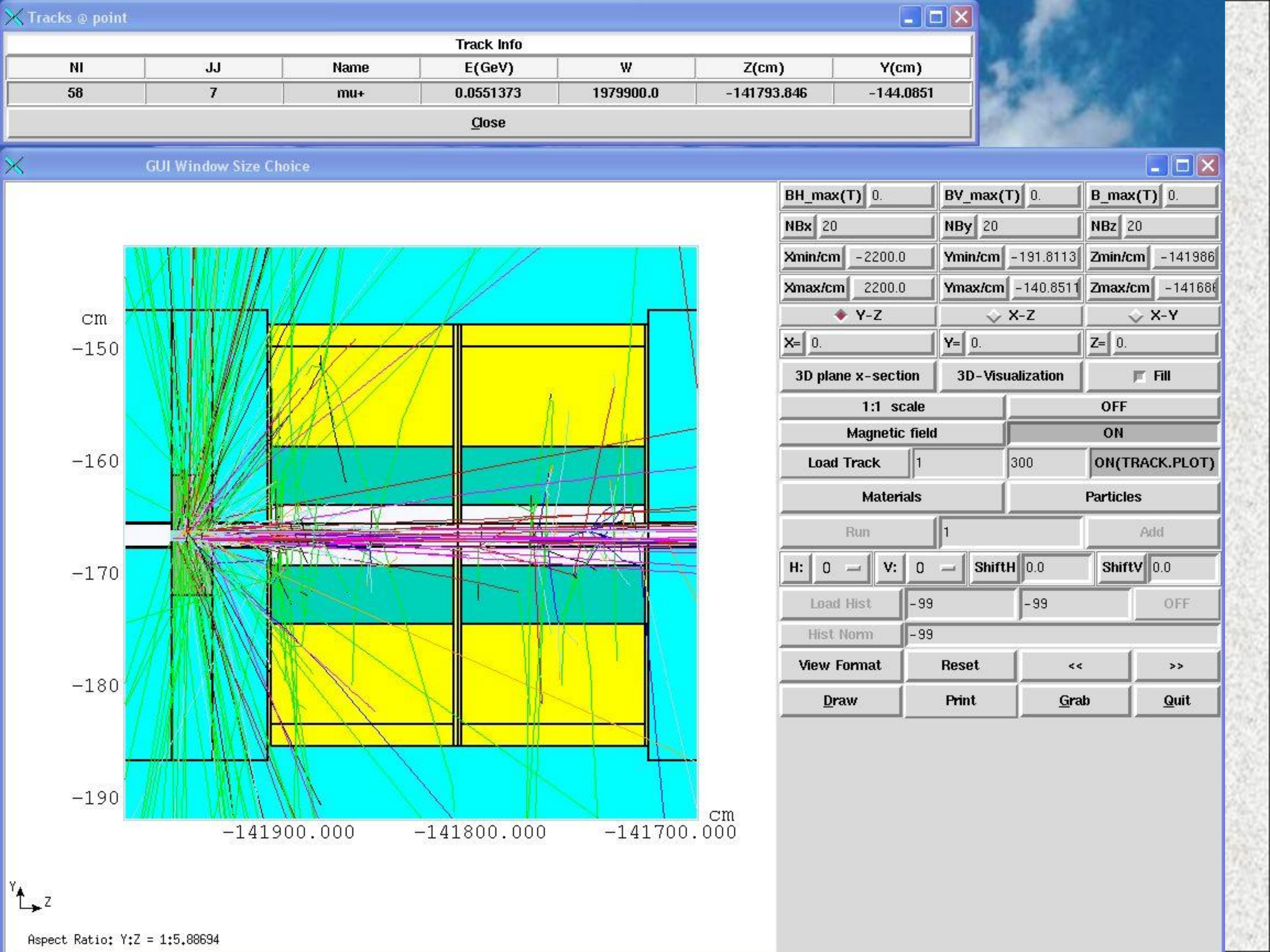
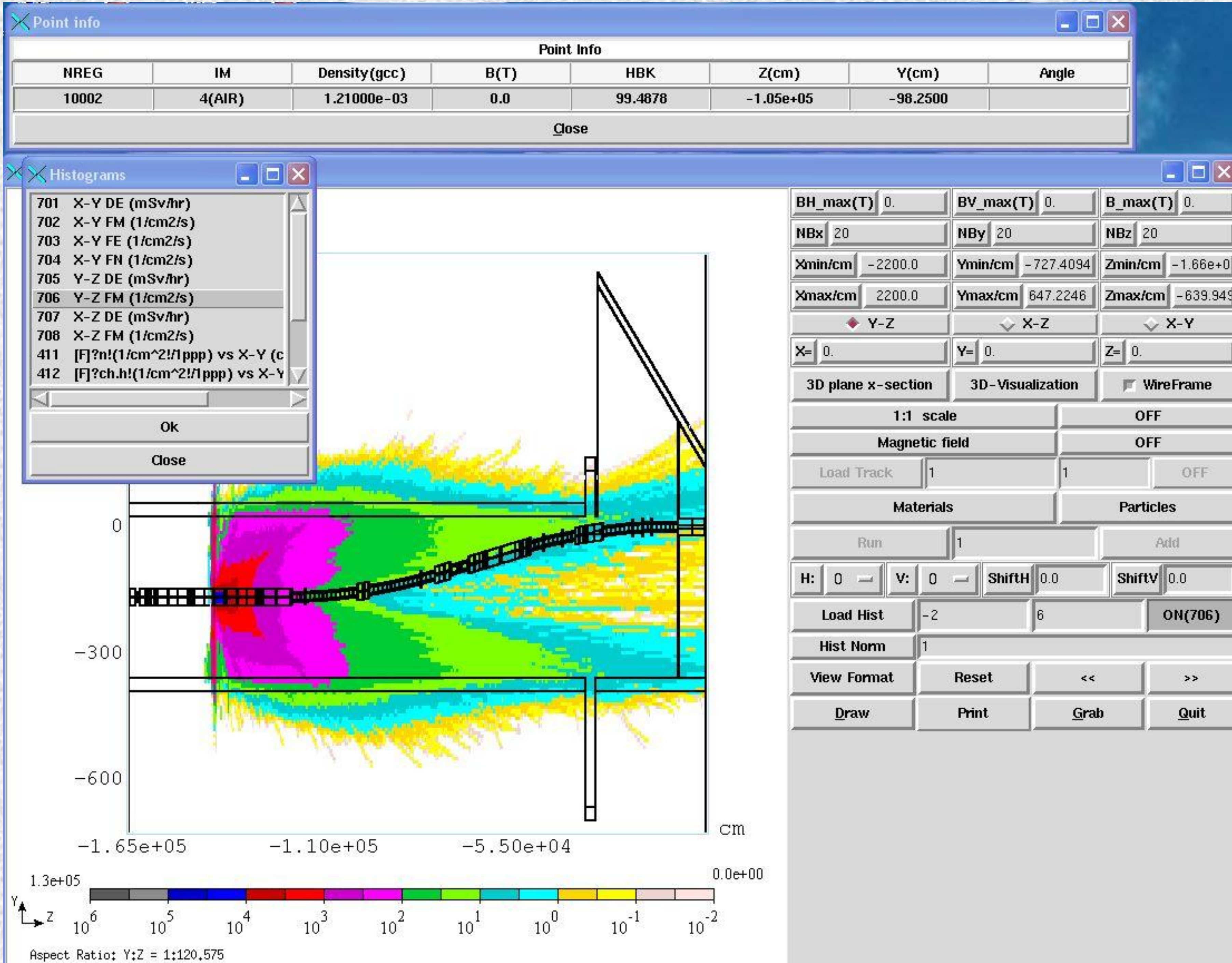
21(on) STST
22(on) BITR


Tracks @ point
Track Info
NI | JJ | Name | E(GeV) | W | Z(cm) | Y(cm)
76 | 7 | mu+ | 1.23053 | 2319900000.0 | -141354.734 | -171.4450
Close
GUI Window Size Choice
cm
-105
-140
-175
-210
-142000.000
-141750.000
-141500.000
cm
Aspect Ratio: Y:Z = 1:5.95611
BH_max(T) 0.
BV_max(T) 0.
B_max(T)
NBx 20
NBy 20
NBz 20
Xmin/cm -2200.0
Ymin/cm -240.2793
Xmax/cm 2200.0
Ymax/cm -91.7570
Y-Z
X-Z
X= 0.
Y= 0.
Z= 0.
3D plane x-section
3D-Visualization
1:1 scale
OFF
Magnetic field
OFF
Load Track 1 300
Materials
Particles
Run 1
H: 0
V: 0
ShiftH 0.0
Load Hist -99 -99
Hist Norm -99
View Format
Reset
<<
Draw
Print
Grab

Particles
ID | Name | Modify | Reset
1(on) p
2(on) n
3(on) pi+
4(on) pi-
5(on) K+
6(on) K-
7(on) mu+
8(on) mu-
9(on) gamma
10(on) e-
11(on) e+
12(on) pbar
13(on) pi0
14(on) d
15(on) t
16(on) He3
17(on) He4
18(on) num
19(on) nuam
20(on) nue
21(on) nuae
22(on) K0
23(on) nbar
24(on) neu-hyp
25(on) ch-hyp
26(on) HI
Reset
Close


Tracks @ point
Track Info
NI JJ Name E(GeV) W Z(cm) Y(cm)
58 7 mu+ 0.0551373 1979900.0 -141793.846 -144.0851
Close
GUI Window Size Choice
BH_max(T) 0.
BV_max(T) 0.
B_max(T) 0.
NBx 20
NBy 20
NBz 20
Xmin/cm -2200.0
Ymin/cm -191.8113
Zmin/cm -141986
Xmax/cm 2200.0
Ymax/cm -140.8511
Zmax/cm -14168
Y-Z
X-Z
X-Y
X= 0.
Y= 0.
Z= 0.
3D plane x-section
3D-Visualization
Fill
1:1 scale
OFF
Magnetic field
ON
Load Track
1
300
ON(TRACK.PLOT)
Materials
Particles
Run
1
Add
H: 0
V: 0
ShiftH 0.0
ShiftV 0.0
Load Hist
-99
-99
OFF
Hist Norm
-99
View Format
Reset
<<
>>
Draw
Print
Grab
Quit
cm
-150
-160
-170
-180
-190
cm
-141900.000
-141800.000
-141700.000
Y
Z
Aspect Ratio: Y:Z = 1:5.88694


Point info
Point Info
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10002 | 4(AIR) | 1.21000e-03 | 0.0 | 99.4878 | -1.05e+05 | -98.2500 |
Close
Histograms
701 X-Y DE (mSv/hr)
702 X-Y FM (1/cm2/s)
703 X-Y FE (1/cm2/s)
704 X-Y FN (1/cm2/s)
705 Y-Z DE (mSv/hr)
706 Y-Z FM (1/cm2/s)
707 X-Z DE (mSv/hr)
708 X-Z FM (1/cm2/s)
411 [F]?n!(1/cm^2!/1ppp) vs X-Y (c
412 [F]?ch.h!(1/cm^2!/1ppp) vs X-Y
Ok
Close
BH_max(T) 0.
BV_max(T) 0.
B_max(T) 0.
NBx 20
NBy 20
NBz 20
Xmin/cm -2200.0
Ymin/cm -727.4094
Zmin/cm -1.66e+0
Xmax/cm 2200.0
Ymax/cm 647.2246
Zmax/cm -639.949
Y-Z
X-Z
X-Y
X= 0.
Y= 0.
Z= 0.
3D plane x-section
3D-Visualization
WireFrame
1:1 scale
OFF
Magnetic field
OFF
Load Track
1
1
OFF
Materials
Particles
Run
1
Add
H: 0
V: 0
ShiftH 0.0
ShiftV 0.0
Load Hist
-2
6
ON(706)
Hist Norm
1
View Format
Reset
<<
>>
Draw
Print
Grab
Quit
0
-300
-600
cm
-1.65e+05
-1.10e+05
-5.50e+04
1.3e+05
0.0e+00
10^6 10^5 10^4 10^3 10^2 10^1 10^0 10^-1 10^-2
Y
Z
Aspect Ratio: Y:Z = 1:120.575

LCIO

slic	MOKKA	JUPITER
org.lcsim	MarlinReco	Satellites
Java		root

LCIO

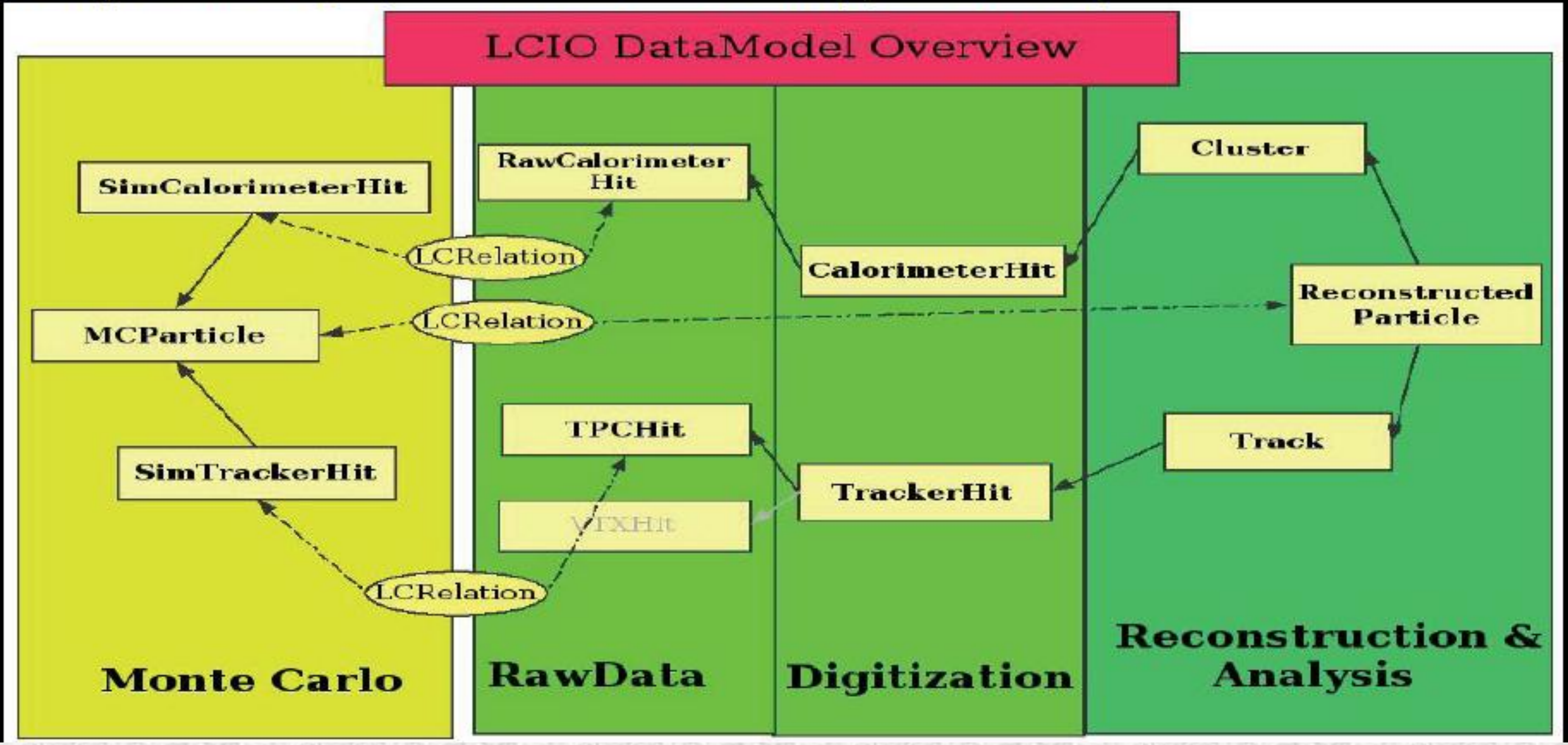
Common Data Model

Common IO Format

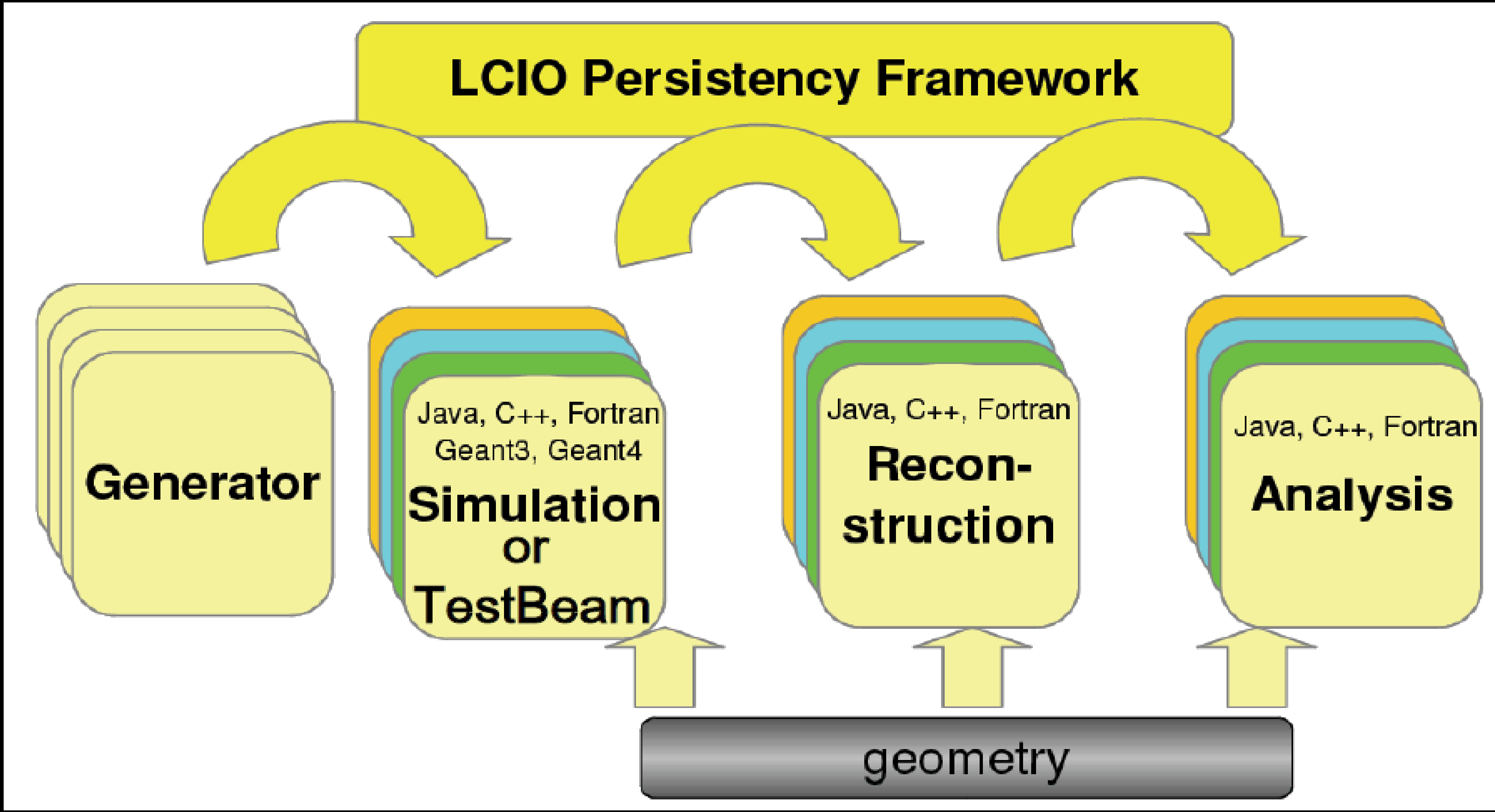
5

LCIO Overview

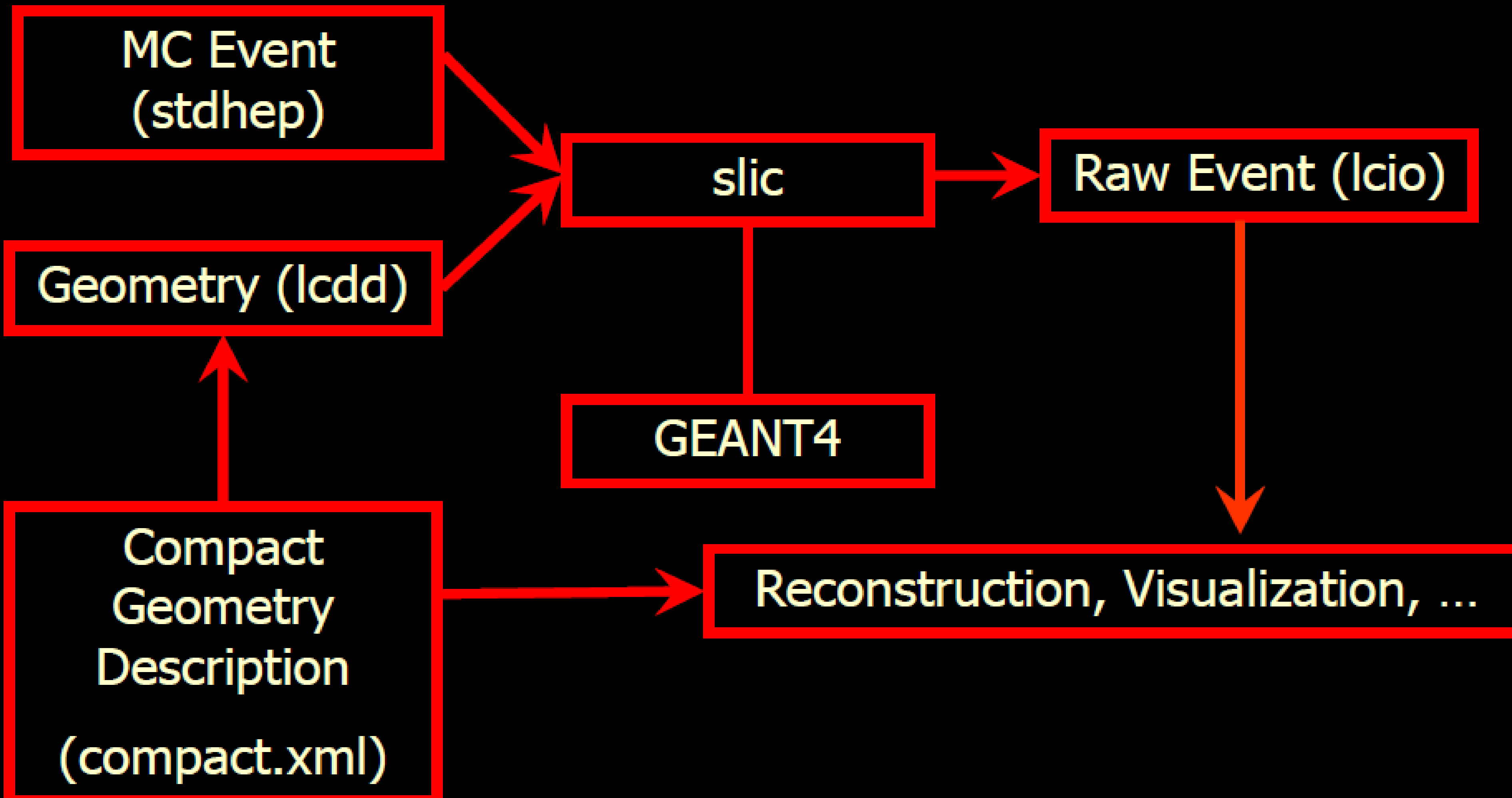
- Object model and persistency format for HEP events
  - MC simulation
  - Test Beam data
  - Reconstructed Objects
- Multiple bindings (C++, Java, Fortran, python, root)



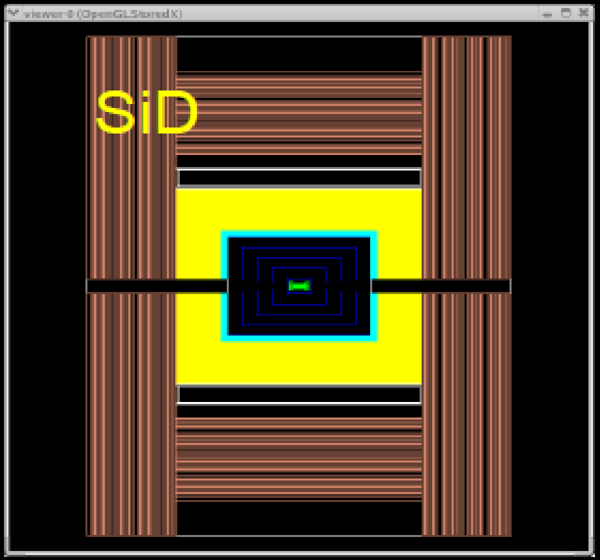
LCIO Overview

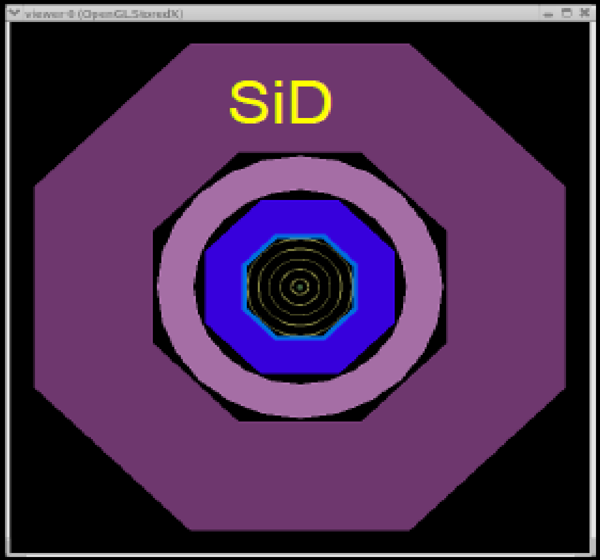


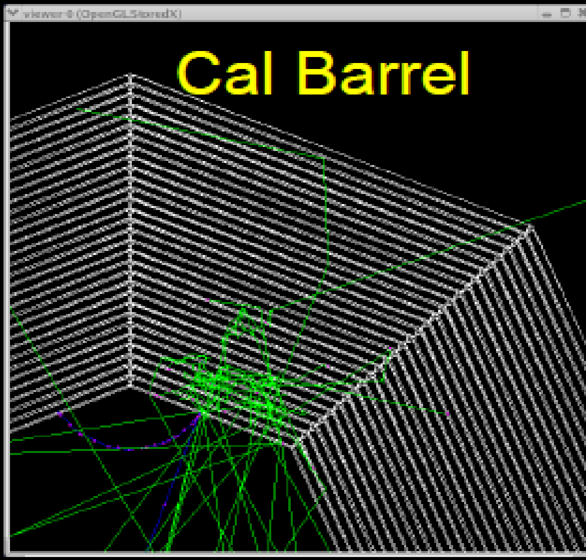
LC Detector Full Simulation

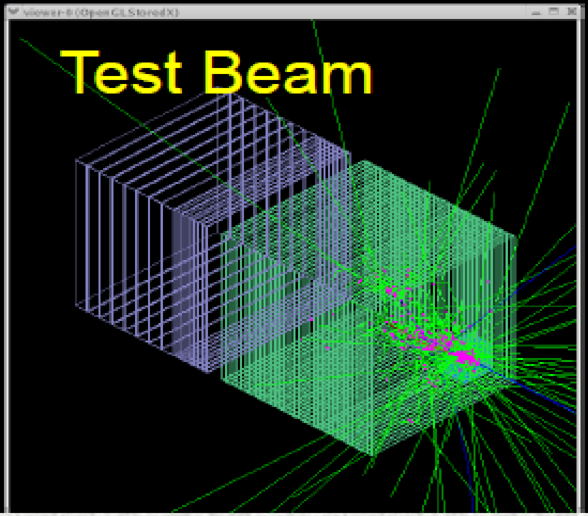


Example Geometries

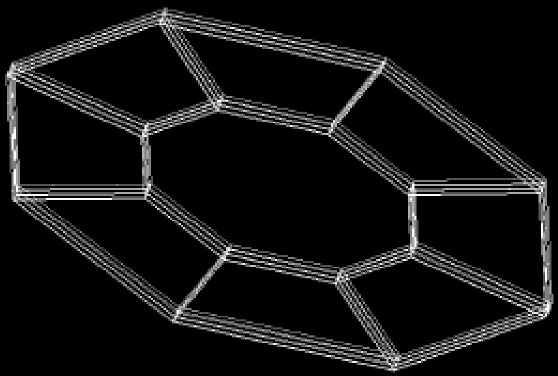




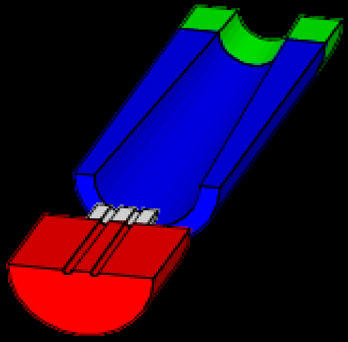




Cal Endcap

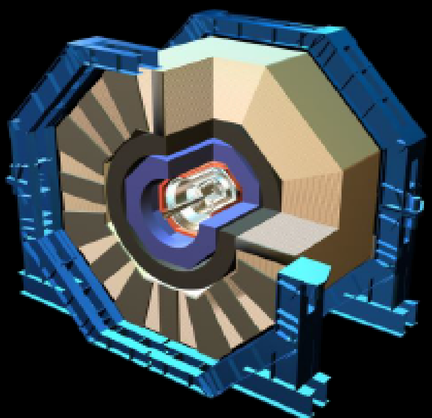


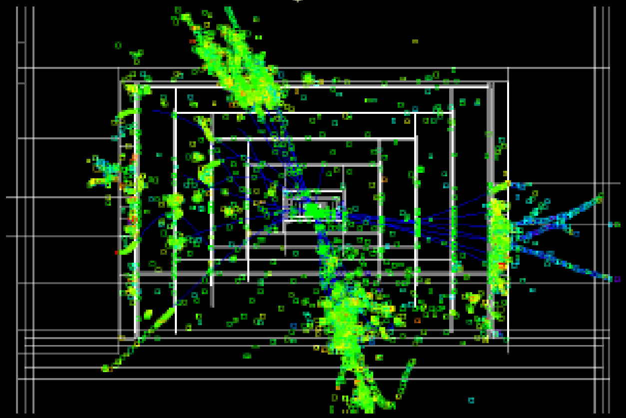
MDI-BDS



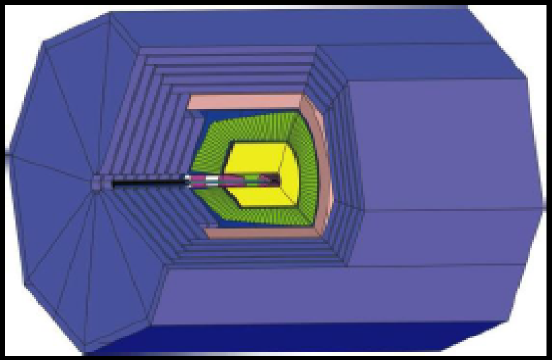
ILC Full Detector Concepts

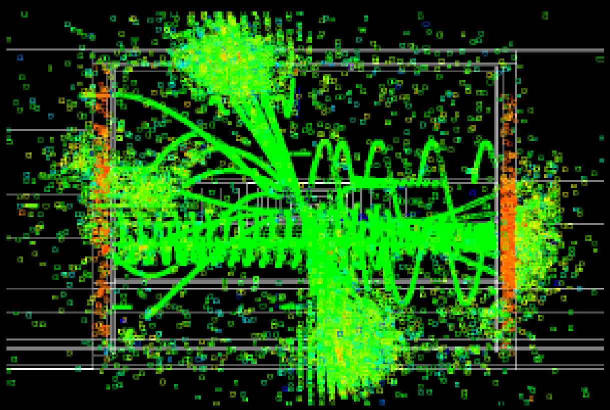
SiD



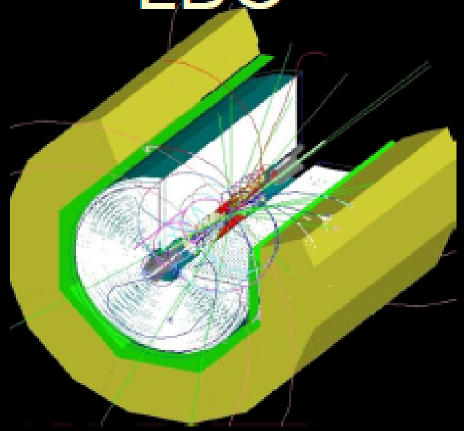


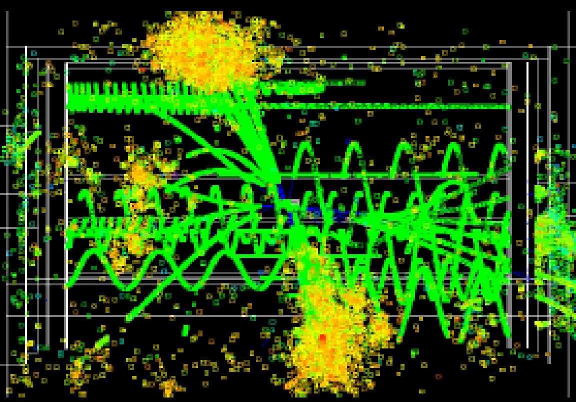
GLD





LDC





Additional Information

- Wiki - http://confluence.slac.stanford.edu/display/ilc/Home
- lcsim.org - http://www.lcsim.org
- ILC Forum - http://forum.linearcollider.org
- LCIO - http://lcio.desy.de
- SLIC - http://www.lcsim.org/software/slic
- LCDD - http://www.lcsim.org/software/lcdd
- JAS3 - http://jas.freehep.org/jas3
- AIDA - http://aida.freehep.org
- WIRED - http://wired.freehep.org

Primary contact: Norman Graf

Hadron Colliders

- IP Generator
  - pp events: **DPMJET, PYTHIA**
- Beam Loss, Collimation and Source at MDI
  - **SixTrack, STRUCT, MARS**
- Radiation and Background Loads
  - **MARS, FLUKA, GEANT**
- Detector Physics
  - **GEANT4 Family, ILCroot**

Main Codes for B&MDI at Hadron Colliders

MARS15

The MARS code system is a set of Monte Carlo programs for detailed simulation of hadronic and electromagnetic cascades in an arbitrary 3-D geometry of shielding, accelerator, detector and spacecraft components with energy ranging from a fraction of an electronvolt up to 100 TeV. It has been developed since 1974 at IHEP, SSCL and Fermilab.

The current MARS15 version combines the well established theoretical models for strong, weak and electromagnetic interactions of hadrons, heavy ions and leptons with a system which can contain up to 10^5 objects, ranging in dimensions from microns to hundreds kilometers (in the same setup!).

MARS15 (cont'd)

A setup can be made of up to 100 composite materials, with arbitrary 3-D magnetic and electric fields. Powerful user-friendly GUI is used for visualization of geometry, materials, fields, particle trajectories and results of calculations.

MARS15 has 5 geometry options and flexible histograming options, can use as an input MAD optics files through a powerful MAD-MARS Beam Line Builder, and provides an MPI-based multiprocessing option, with various tagging, biasing and other variance reduction techniques.

It can be interfaced to MCNP, ANSYS (thermal and stress), MESA/SPHINX (hydrodynamics), FRONTIER (magneto-hydrodynamics), DPMJET, GuineaPig, STRUCT and other codes.

MARS15 Applications at Hadron Colliders

- **Tevatron** complex (over 31 years): beam abort and beam collimation systems; backgrounds & MDI for the CDF and D0 collider detectors; Linac/Booster/Main_Injector chain; beam instrumentation; numerous radiation problems; fixed target experiments: neutrino (NuMI/MINOS, NoVA, MiniBoone, DONUT, LBNE), mu2e, g-2, SeaQuest etc.

- **LHC** (since 1993): beam abort and beam collimation systems; studies and full responsibility for machine-induced backgrounds in CMS (and partially in ATLAS); forward-physics experiments, fusion with hydrodynamics etc.

- **VLHC** (around year 2000): collimation, machine protection, MDI, catastrophic events etc.

Muon Colliders

- IP Generator
  - $\mu^+\mu^-$ events: **PYTHIA**
- Beam Loss, Collimation and Source at MDI
  - **STRUCT, MARS, G4beamline (in early stage)**
- Radiation and Background Loads
  - **MARS, GEANT3, G4beamline (in early stage)**
- Detector Physics
  - **ILCroot, SLIC/LCSIM (in early stage)**

G4beamline

- This program provides an interface to the *GEANT4* toolkit that allows the user to perform particle tracking simulations without having to code in C++ or to compile the program himself.
- The input to *G4beamline* is a script of line commands that describe the geometry, fields and other parameters to setup the simulation.
  - The input format is particularly well suited for beam line descriptions with dipole, quadrupole, etc. beam elements.
- *G4beamline* makes effective use of graphics for verifying geometry setup and visualization of particle tracking.
- *G4beamline* is freely available to the community (the price is right) at http://G4beamline.muonsinc.com

ILCroot: root Infrastructure for Large Colliders

- **Software architecture based on root, VMC & Aliroot**
  - All ROOT tools are available (I/O, graphics, PROOF, data structure, etc)
  - Extremely large community of users/developers
- **Re-allignement with latest Aliroot version every 1-2 years (v4.17 release)**
- **It is a simulation framework and an Offline Systems:**
  - **Single framework, from generation to reconstruction through simulation. Don't forget analysis!!!**
  - It naturally evolves into the offline systems of your experiment
  - It is immediatly usable for test beams (read stream and static data formats)
  - Six MDC have proven robustness, reliability and portability
- ***It is Publicly available at FNAL on ILCSIM since 2006***

Primary contact: Corrado Gatto

ILCroot: main add-ons to Aliroot

1. Interface to external files from Event Generators in various format (STDHEP, text, ***MARS***, etc.)
2. Standalone VTX track fitter
3. Pattern recognition from VTX (for Si central trackers)
4. Track fitters for different trackers technologies (Si Pixels, Si Strips, Drift Chambers, Straw Tubes, TPC's) and a ombination of them
5. Full simulation of ***Dual Readout calorimeters***
6. Parametric beam background (# integrated bunch crossing chosen at run time)

Very important for detector and Physics studies of New Projects

Growing number of experiments have adopted it: Alice (LHC), Opera (LNGS), (Meg), CMB (GSI), Panda(GSI), 4th Concept, (SiLC ?) and **LHeC**

The Virtual Montecarlo Concept

- Virtual MC provides a virtual interface to Monte Carlo
- It allows to run the same user application with all supported Monte Carlo programs
- The concrete Monte Carlo (Geant3, Geant4, Fluka) is selected and loaded at run time

Generator Interface

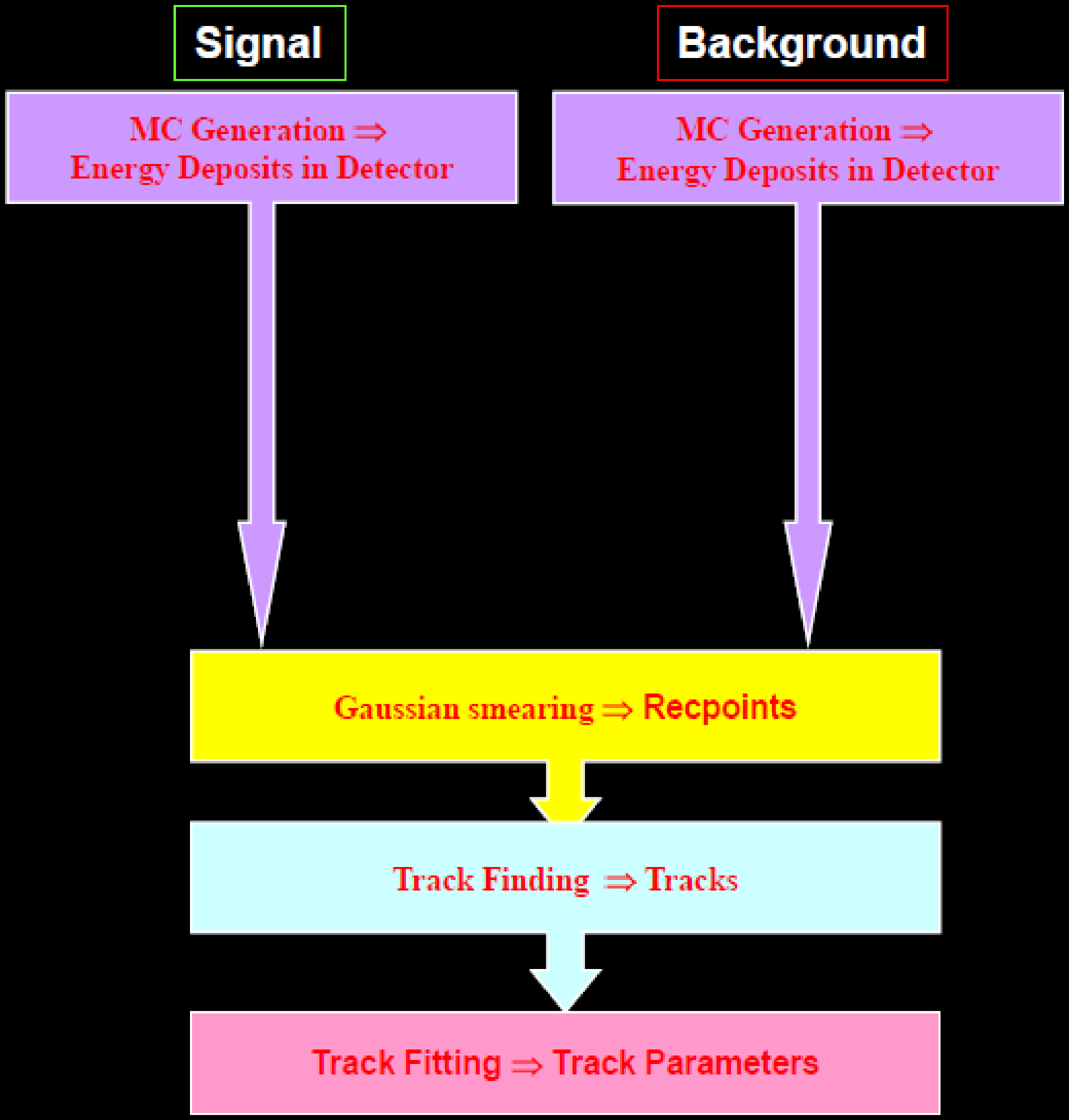
- ***TGenerator*** is an abstract base class, that defines the interface of ROOT and the various event generators (thanks to inheritance)
- Provide user with
  - Easy and coherent way to study variety of physics signals
  - Testing tools
  - Background studies
- Possibility to study
  - Full events (event by event)
  - Single processes
  - Mixture of both ("Cocktail events") with weigh
  - Mixture of signal and background
- **TGenerator interface to MARS added for MC studies**

Fast Simulation: no digitization + reconstruction

- Hits: produced by MC (G3,G4,Fluka)

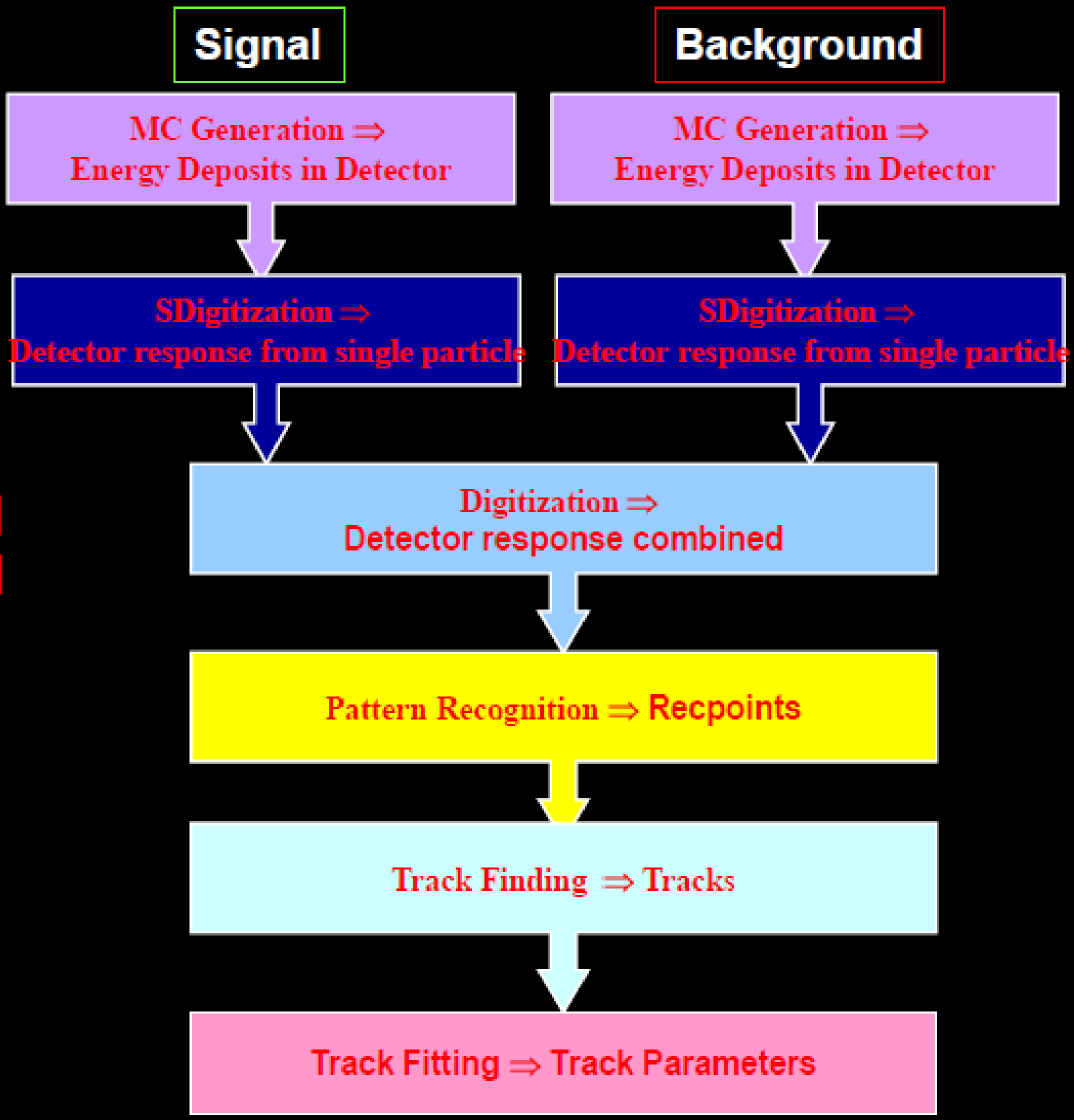
- FastRecpoints: gaussian smearing of hits

- Pattern recognition + track fit through full Parallel Kalman Filter



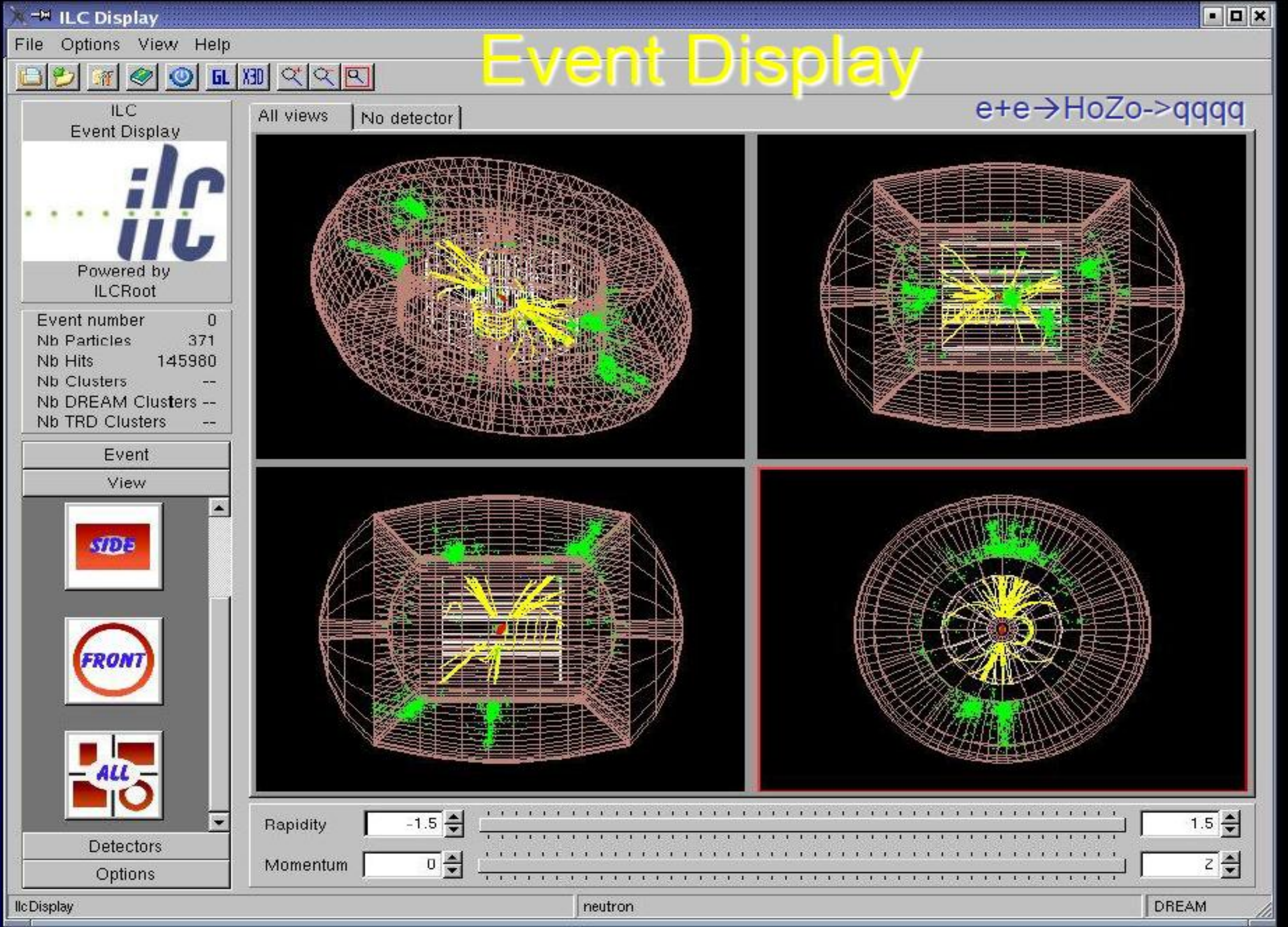
Full Simulation: digitization + reconstruction

- Hits: produced by MC (G3,G4,Fluka)
- SDigits: simulate detector response for each hit
- Digits: merge digit from several files of SDigits (example Signal + Beam Bkgnd)
- Recpoints: Clusterize nearby Digits
- Pattern recognition + track fit through full Parallel Kalman Filter



Event Display

e+e→HoZo->qqqq



How long it takes to learn ILCroot?

Physics Analysis Study

- Specify the detector configuration in config.c
- Specify the digitization/clusterization type (full or gaussian smearing)
- Specify the Event Generator (and the channel) in config.c
- Run the job
- Get several .root files for doing your analysis (kinematics, reconstructed particles, trkref, etc.)

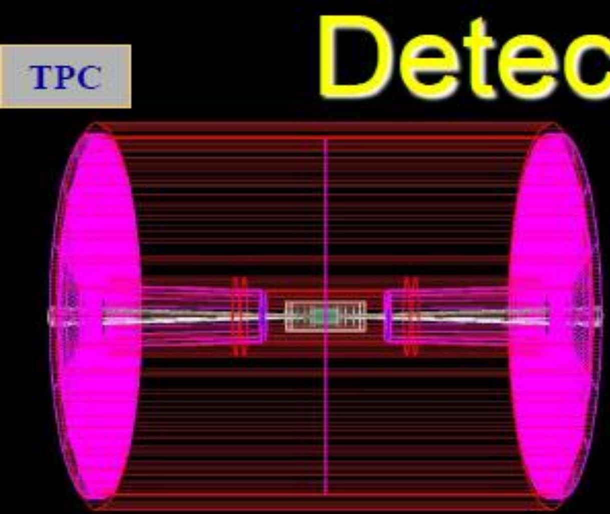
Few weeks are sufficient

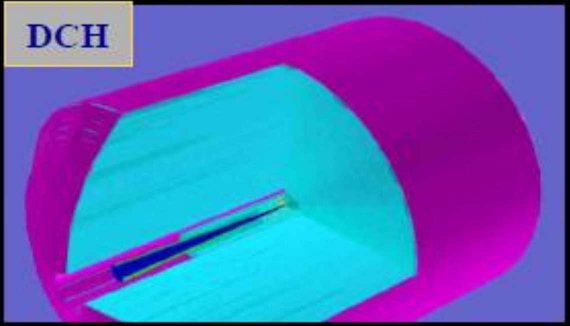
Detector Simulation/Reconstruction

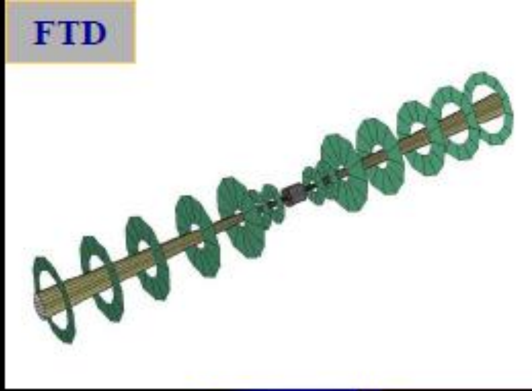
- Learn how the framework is structured
- Learn how to read/write your data into persistent objects
- Eventually, need to learn how to modify the geometry

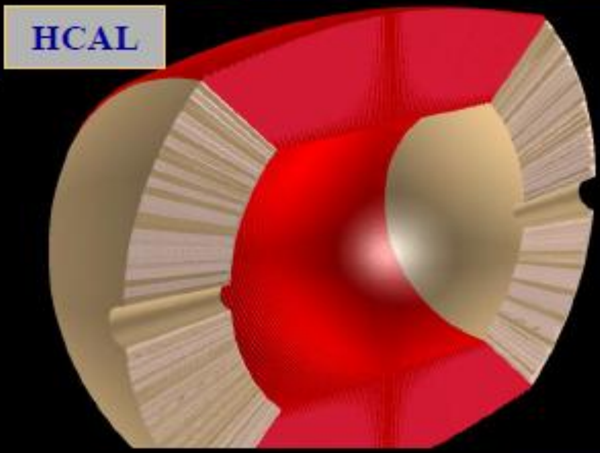
Expect 1-3 months lead time

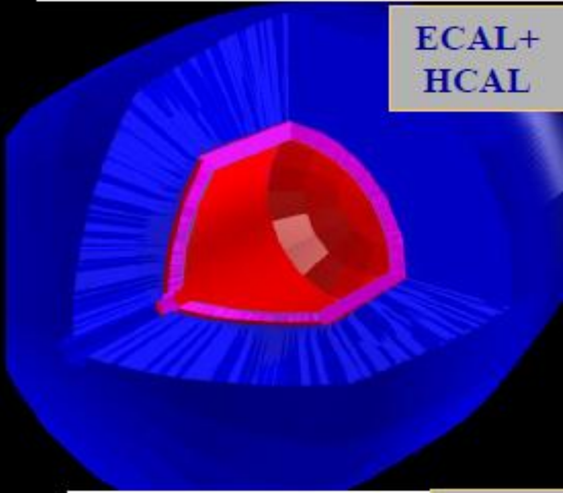
Detectors in ILCroot

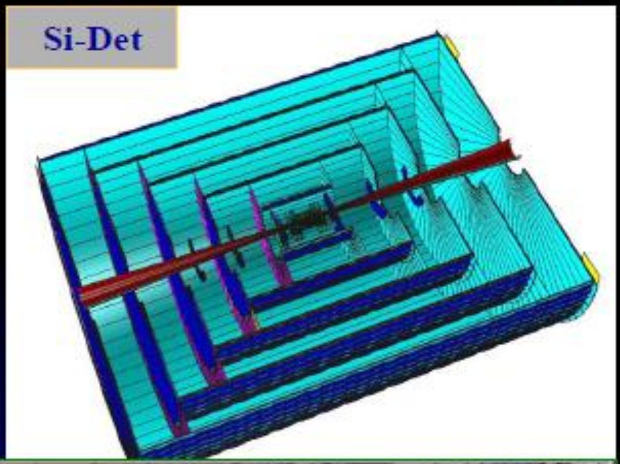


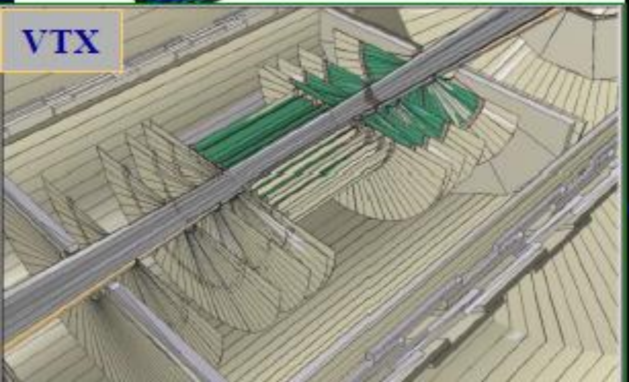


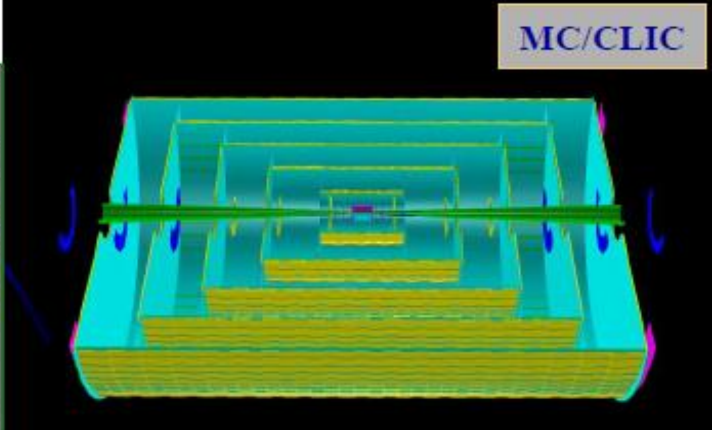


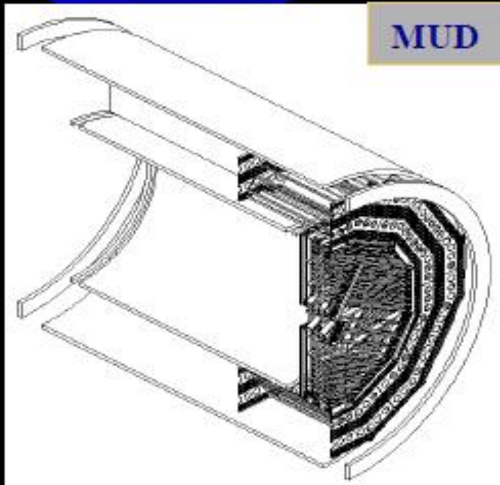












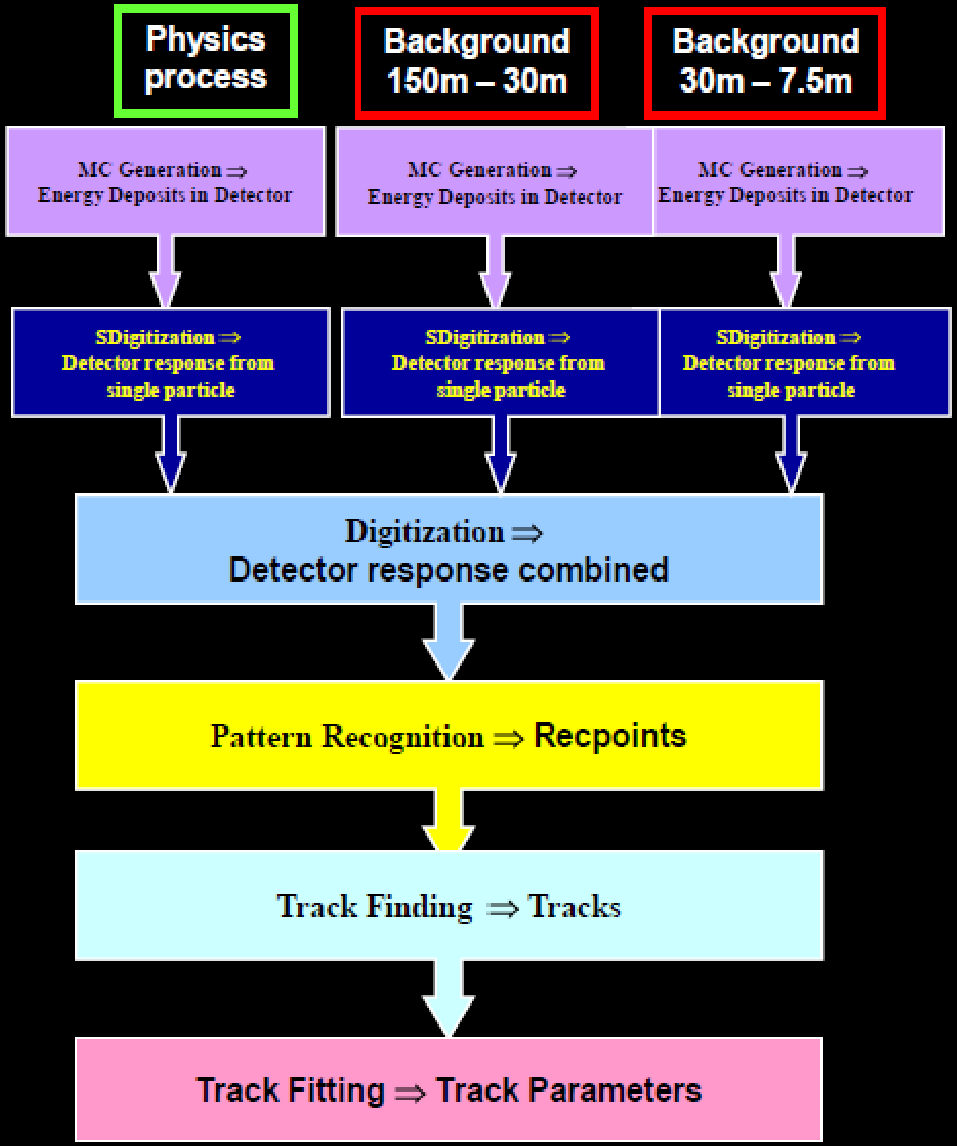
MARS + ILCroot (Oct. 2009)

- The ingredients:
  - Final Focus descripted in MARS & ILCroot
  - Detector description in ILCroot
  - MARS-to-ILCroot interface (Vito Di Benedetto)

- How it works
  - The interface (ILCGenReaderMARS) is a *TGenerator* in ILCroot
  - MARS output is used as a config file
  - ILCGenReaderMARS create a STDHEP file with a list of particles entering the detector area at z = 7.5m
  - MARS weights are used to generate the particle multiplicity for G4
  - Threshold cuts are specified in Config.C to limit the particle list fed to G4
  - Geant4 takes over at 7.5m
  - Events are finally passed through the usual simulation (G4)-> digitization->reconstruction machinery

Simulation + full digitization + reconstruction

1) Merge background with physics events or with jets
2) Reconstruct tracks with proper pattern recognition + Kalman Filter
3) Reconstruct Calorimetric Clusters
4) Study the effect on detector performance and measuremnts of Physics quantity



General Purpose Particle Transport & Interaction Codes

- FLUKA - http://www.fluka.org/fluka.php
- GEANT4 - http://www.geant4.org/geant4/
- MARS15 – http://www-ap.fnal.gov/MARS/
- MCNPX – https://mcnpx.lanl.gov/
- PHITS - http://phits.jaea.go.jp/

APPLICATION-DRIVEN CODE DEVELOPMENTS

Requirements to particle transport simulation tools and needs for physics model and calculation code developments are **all driven by application**. The most demanding among them are high-power accelerators (Spallation Neutron Source, J-PARC, neutrino factories), heavy-ion and ADS facilities (RIB, AEBL, FAIR, EURISOL), high-energy colliders (LHC, ILC), and space exploration programs.

Feasibility, design and specific radiation issues are addressed in detailed Monte-Carlo simulations, therefore, **predictive power and reliability** of corresponding codes are absolutely crucial.

MARS15: Biasing

Many processes in MARS15, such as electromagnetic showers, most of hadron-nucleus interactions, decays of unstable particles, emission of synchrotron photons, photohadron production and muon pair production, can be treated either analogously or inclusively with corresponding statistical weights. The choice of method is left for the user to decide, via the input settings.

Other variance reduction techniques used in MARS: weight-window, splitting and Russian roulette, exponential transformation, probability scoring, step/energy cutoffs.

Goal: Maximize computing efficiency $\varepsilon = t_0/t$, where t is CPU time needed to get a RMS error σ equal to the one in the reference method with CPU time t_0 provided σ < 20%.

MARS15: Tagging

• Enhanced tagging module in MARS15 allows one to tag the origin of a given signal/tally: geometry, process and phase-space. Invaluable in studying a source term and for sensitivity analysis.

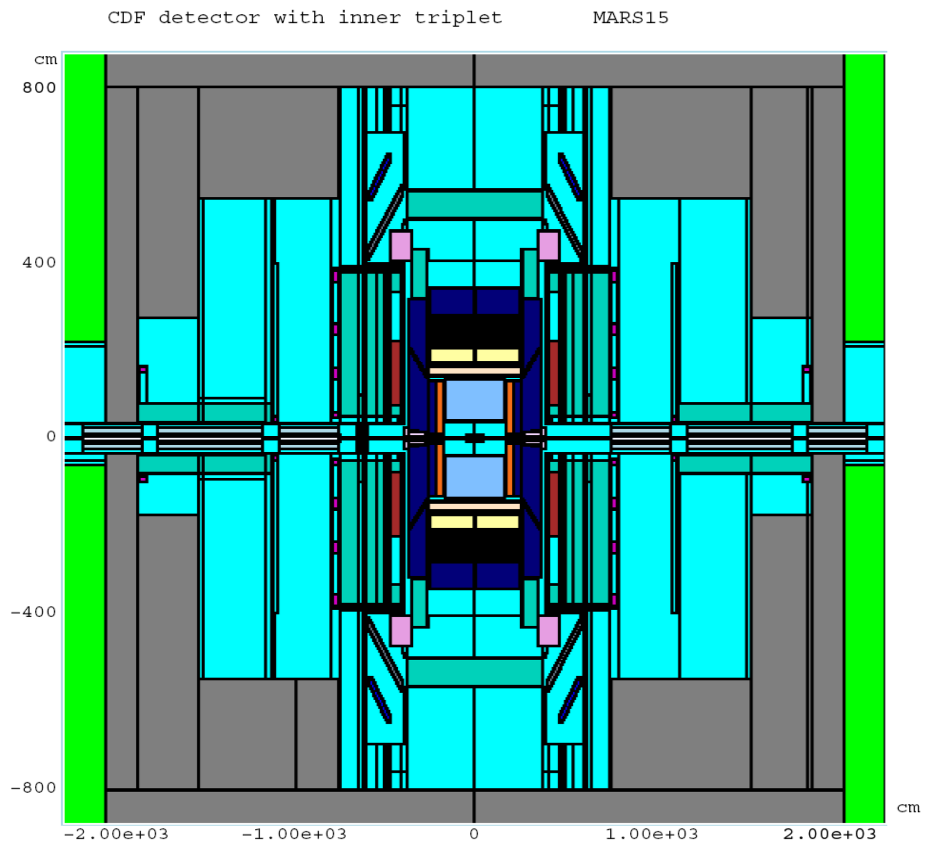
• User-friendly access to process ID at scoring (histograming) stage: flags to 50 process types.

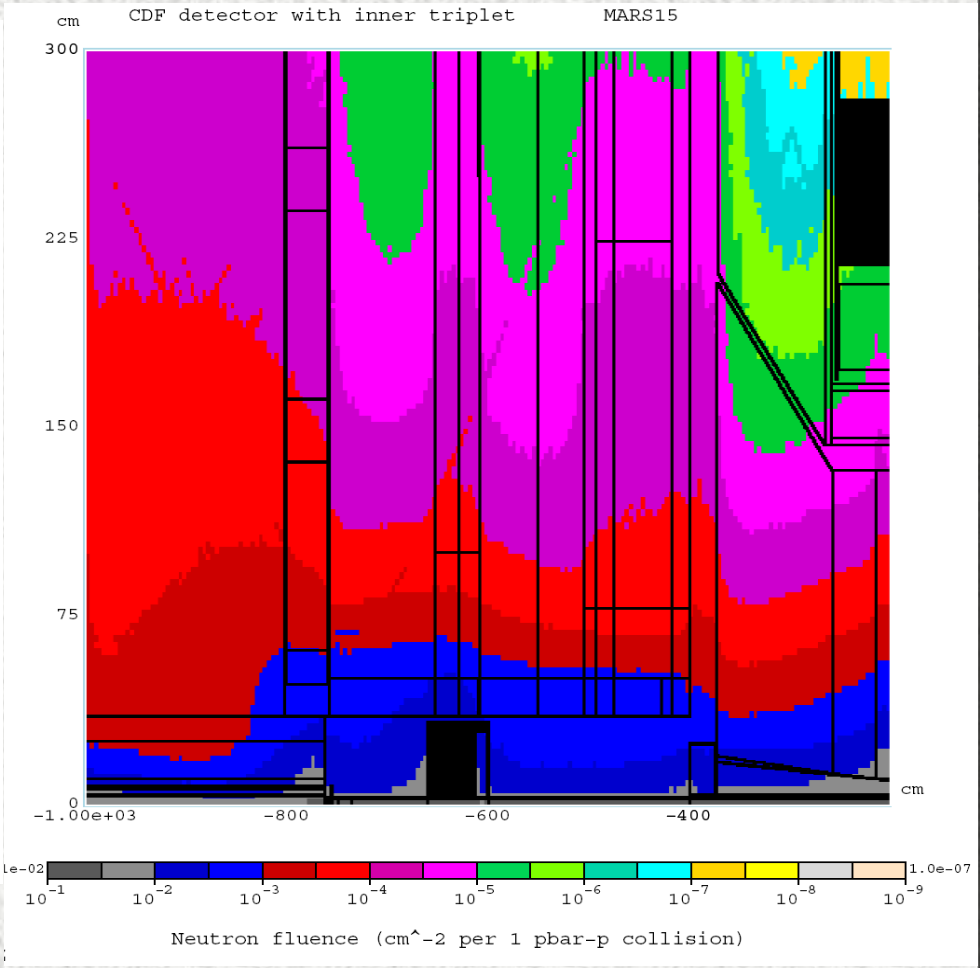
GEOMETRY DESCRIPTIONS IN MARS15

Five geometry description options

1. **Standard**: heterogeneous *R-Z-Φ* cylinder (in most cases this is just a mother volume).
2. **Non-standard**: arbitrary user-defined in Fortran or C.
3. **Extended**: a set of contiguous or overlapping geometrical shapes, currently, boxes, spheres, cylinders, truncated cones, tetrahedra, elliptical tubes, elliptical cone and conical sector. Can be subdivided into many sub-regions in each direction; arbitrary transformation matrices can be applied to any object.
4. **MCNP**: read in an input geometry description in the MCNP format.
5. **FLUKA**: read in an input geometry description in the FLUKA format (requires pre-processing).

MARS MODELING OF CDF DETECTOR





CDF detector, experimental hall, Tevatron beamline elements and neutron fluence isocontours as seen in MARS15 GUI

AUTOMATIC GEOMETRY GENERATION

It is a modern approach for accelerator complexes like Tevatron, LHC and J-PARC to build a **realistic model of the whole machine** for multi-turn beam loss, energy deposition, activation and radiation shielding studies: read in **MAD lattice** and create a complete geometry and magnetic field model in the framework of such codes as FLUKA, MARS and GEANT.

The experience says that such realistic modeling takes time and substantial efforts but always pays off.

MAD-MARS BEAM LINE BUILDER

The interface system to build beam line and accelerator models in the MARS format. MMBLB reads in a MAD lattice file and puts the elements in the same order into MARS. Each element is assigned six functions: element type/name, geometry, materials, field, volume and initialization. MMBLB has been substantially extended for MARS15:

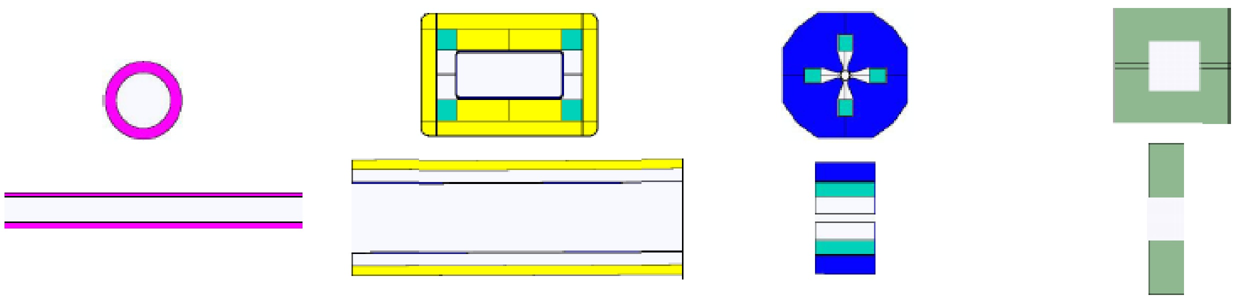
- The set of supported element types includes now almost all the elements supported by MAD.
- An arbitrary number of beam lines – arbitrary positioned and oriented – can be put in a MARS15 model.
- More sophisticated algorithms and new data structures enable more efficient searches through the beam line geometry.
- Tunnel geometry can now follow the beam line or be described independently of it.

MMBLB (1)

Local coordinate (Definition of each component)

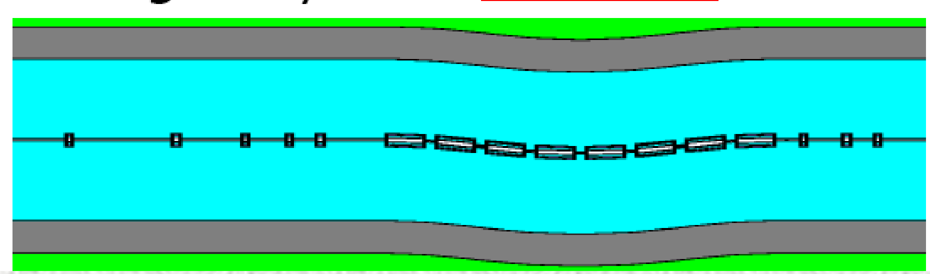
1. Tunnel
2. Beamline component

beam pipe, dipole, quadrupole, collimator etc.



Global coordinate (Put components on tunnel)

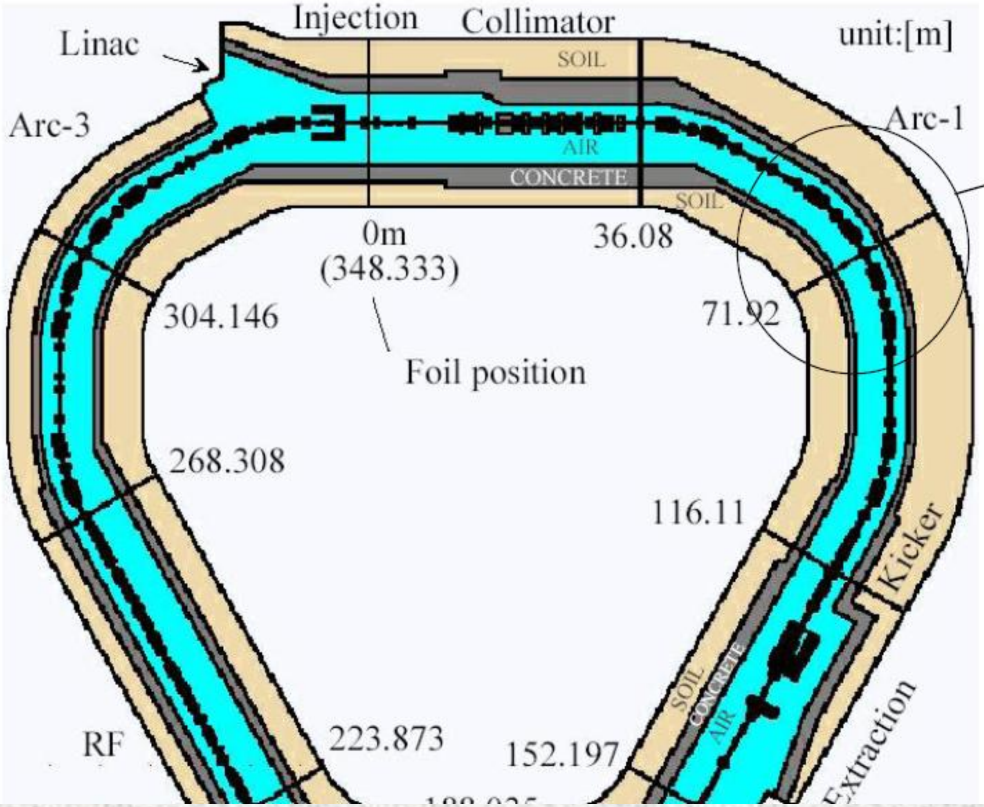
Location, number, length, bending, magnetic field intensity of components are defined and changed by MAD "OPTICS" file

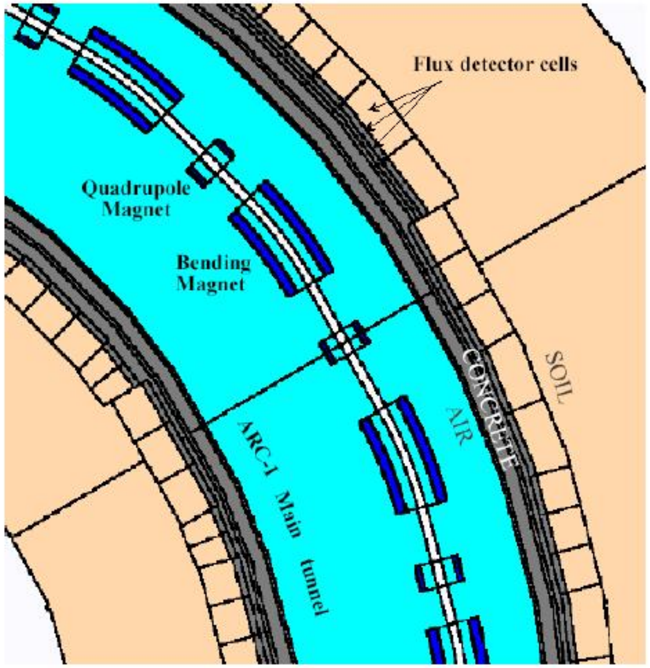


Compiled by N. Nakao

MMBLB (2)

3 GeV proton synchrotron of J-PARC (JAEA & KEK Japan)





Particle Transport & Interaction Codes (1)

General	MCNPX	GEANT4	FLUKA	MARS	PHITS
Version	2.5.0	8.0 p1	2005	15	2.09
Lab. Affiliation	LANL	CERN IN2P3 INFN KEK SLAC TRIUMF ESA	CERN INFN	FNAL	JAEA RIST GSI Chalmers Univ.
Language	Fortran 90/C	C++	Fortran 77	Fortran 95/C	Fortran 77
Cost	Free	Free	Free	Free	Free
Release Format	Source & binary	Source & binary	Source & binary	Binary	Source & binary
User Manual	470 pages	280 pages	387 pages	150 pages	176 pages
Users	2500	~2000	~1000	220	220
Web Site	mcnpx.lanl.gov	cern.ch/geant4	www.fluka.org	www-ap.fnal. gov/MARS	Under const.
Workshops	~7/year	~4/year	~1/year	~2/year	~1/year
Input Format	Free	C++ main Fixed geometry	Fixed or free	Free	Free
Input Cards	~120	N/A	~85	~100	~100
Parallel Execution	Yes	Yes	Yes	Yes	Yes

Particle Transport & Interaction Codes (2)

Geometry	MCNPX	GEANT4	FLUKA	MARS	PHITS
Description	MCNP-based	STEP Solids (Boolean CSG)	MORSE-based	Solids MCNP-based User defined	MCNP-based MORSE-based
Extensions Twisted Nested Repeated Voxel	 No Yes (universes) Yes Lattice (rec, hex)	 Yes Yes (logical vol.) Yes Yes (rec, cyl)	 No No Yes Yes	 No Yes Yes Yes	 No Yes (universes) Yes Lattice (rec, hex)
Reflections	3 types	Yes	Yes	Yes	Neutron albedo
Viewer **Debugger**	Built-in: 2-D Interactive X-Windows External: Vised Moritz	Built-in: 3-D Interactive OpenGL OpenInventor RayTracer External: WIRED VRML DAWN	Built-in: None External: Custom (X11) Others?	Built-in: 2-D Interactive Tcl/Tl 3-D Interactive OpenGL External: Custom	Built-in: 2,3-D Command PS via Angel External: Angel PS
Setup GUI	Vised Moritz	GGE	No	Tcl/Tk	No
CAD	STEP via GUI	STEP	No	No	No
Fields (E/B)	2.6.0	Yes	Yes	Yes	Yes
Moving	2.6.0	Yes	Yes	No	Yes

Particle Transport & Interaction Codes (3)

Source	MCNPX	GEANT4	FLUKA	MARS	PHITS
Fixed					
General					
Explicit	Yes	Yes	Yes	Yes	Yes
Distribution	Yes	Yes	No	Yes	Yes
Dep. Dist.	Yes	GPS	No	Yes	Yes
External	SSW/SSR	Yes	No	Yes	Yes
User Sub.	Yes	Yes	Yes	Yes	Yes
Eigenvalue	Yes	No	No	No	No
Burnup	Yes (2.6.A)	No	No	No	No

Particle Transport & Interaction Codes (4)

Physics	MCNPX	GEANT4	FLUKA	MARS	PHITS
Particles	34	68	68	41	38
Charged particles	CSDA	CSDA	CSDA	CSDA	CSDA
Energy loss	Bethe-Bloch	Bethe-Bloch	Bethe-Bloch	Bethe-Bloch	Bethe-Bloch
Scatter	Rossi	Lewis	Moliere	Moliere*	Moliere
Straggling	Vavilov	Urban	Custom	Custom	Vavilov
XTR/Cherenkov	No	Yes	No/yes	No	No
Baryons					
Neutron					
Low	Cont. (ENDF)	Cont. (ENDF)	Multigroup(72)	Cont. (ENDF)	Cont. (ENDF)
High	Models	Models	Models	Models	Models
Proton					
Low	Cont. (ENDF)	Models	Models	Models	Models
High	Models	Models	Models	Models	Models
Other	Model List: Bertini ISABEL CEM INCL FLUKA89>3 GeV LAQGSM (2.6.D)	Model list: Hadron-nucleous GHEISHA* INUCL(Bertini) BIC CHIPS QGS/FTF>8 GeV	Model list: PEANUT(GINC) DPM+Glauber > 5 GeV	Model list: Custom CEM LAQGSM DPMJET	Model list: Bertini JAM>3 GeV
Leptons					
Electrons	ITS 3.0	EEDL, EADL	Custom	Custom	ITS 3.0
Muon	CSDA/decay	Models	Models	Models	CSDA/decay
Neutrino	Production	Production	Models	Models	Models
Other	Decay	Decay	Decay	Models	Models

Particle Transport & Interaction Codes (5)

Physics	**MCNPX**	**GEANT4**	**FLUKA**	**MARS**	**PHITS**
Mesons	Models	Models	Models	Models	Models
Photons Optical x-ray/γ Photonuclear	 No ITS 3.0 Libraries (IAEA) CEM	 Yes EPDL97, EADL CHIPS	 Yes Custom+EPDL97 PEANUT VMDM	 No Custom Custom CEM	 No ITS 3.0 No
Ions	ISABEL LAQGSM (2.6.D)	AAM EDM BLIC	RQMD-2.4 DPMJET-3	LAQGSM	JQMD JAMQMD > 3 GeV/u
Delayed	n,γ (2.6.C)	α,β,γ	β,γ	γ	n

Particle Transport & Interaction Codes (6)

Tallies	MCNPX	GEANT4	FLUKA	MARS	PHITS
Standard					
Flux					
Volume	Yes	Yes	Yes	Yes	Yes
Surface	Yes	Limited	Yes	Yes	Yes
Point/ring	Yes	No	No	Yes (neutrons)	No
Current	Yes	Limited	Yes	Yes	Yes
Charge	Yes	Yes	Yes	Yes	Yes
Kinetic energy	Yes	Yes	Yes	Yes	Yes
Particle density	Yes	Yes	No	No	No
Reaction rates	Yes	No	Star (inelastic)	Yes	Yes
Energy deposition	Yes	Yes	Yes	Yes	Yes
Rapidity	No	Yes	Yes	Yes.	No
DPA	HTAPE3X	??	Some	Yes	Yes
Momentum	No	Yes	Yes	Yes	No
Pulse-height	Yes	User input	Yes	No	Yes
Termination	Partial	??	Yes	Partial	Yes
Modifiers	9	2	2	2	2
Special					
Mesh	rec, cyl, sph	rec, cyl	rec, cyl	rec, cyl, sph	rec,cyl
Coincidence	Yes	No	Yes	Yes	Yes
Residuals	Yes	No	Yes	Yes	Yes
Activation	2.5.D	??	Yes	Yes	No
Event logs	Yes	Yes	Yes	Yes	Yes
Convergence Tests	10	Error	Error	Error	Error

Particle Transport & Interaction Codes (7)

Tallies	MCNPX	GEANT4	FLUKA	MARS	PHITS
Viewer	Built-in: 1-D, 2-D Custom X-Windows External: IDL Tecplot GNUplot PAW	Built-in: No External: JAS PI Open Scientist	Built-in: None External: Custom (X11) GNUplot PAW ROOT	Built-in: Custom External: PAW	Built-in: Angel External: Angel
Variance Reduction					
Population control Region biasing Weight cutoff Weight window mesh Energy biasing	 Yes Yes Yes Yes	 Yes Yes Yes No	 Yes Yes Yes Yes	 Yes Yes Yes Yes	 Yes Yes Yes Yes
Modified sampling Source biasing Implicit capture Exp. transform Production biasing Angular bias	 Yes Yes Yes Yes Via DXTRAN	 RDM Yes No Yes ??	 Yes Yes Yes Yes Yes	 Yes Yes Yes Yes Yes	 Yes Yes No Yes Yes
DXTRAN	Yes	No	No	No	No
Viewer	2-D contour	No	No	No	No