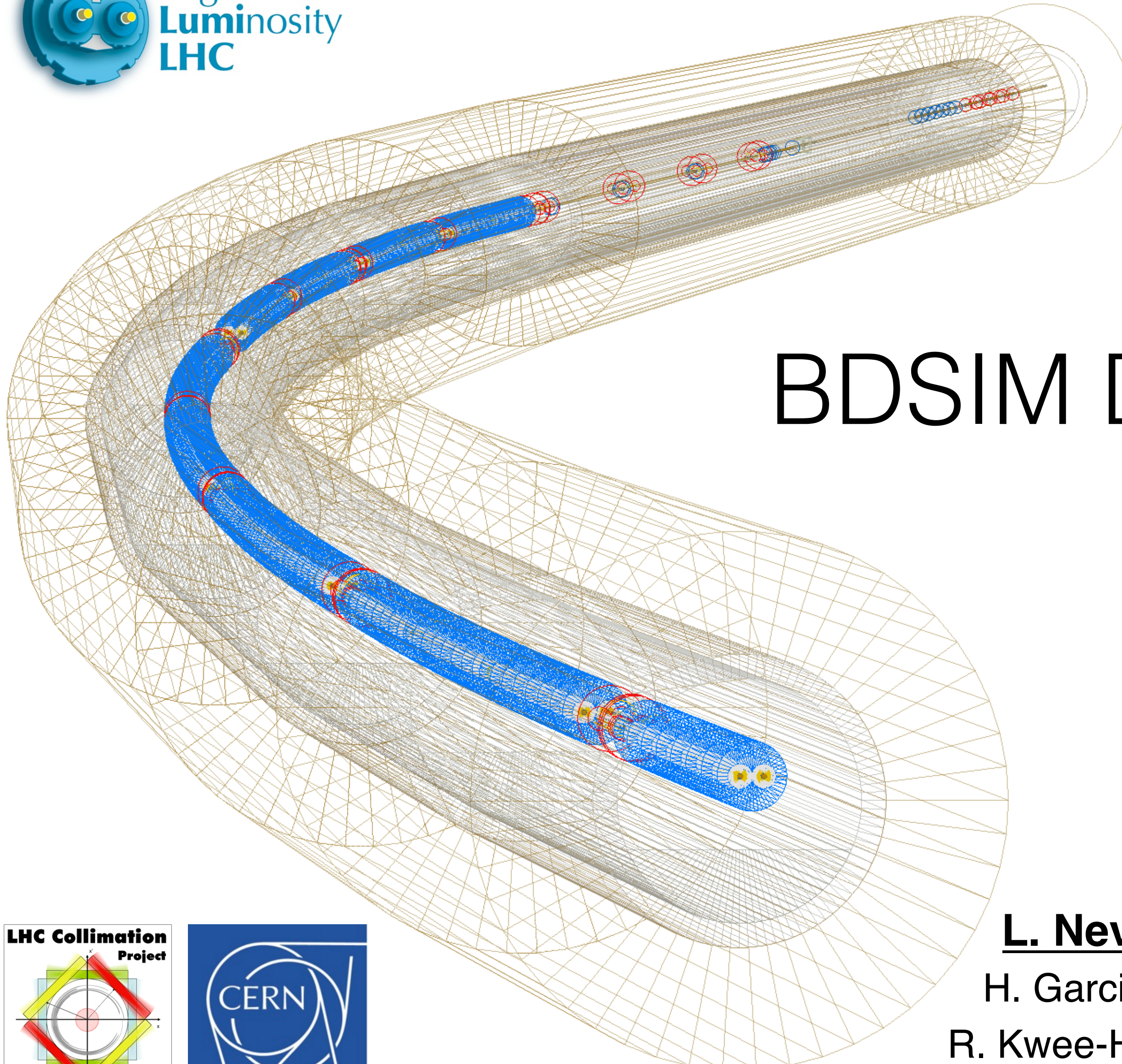


BDSIM Development 2014 - 2015

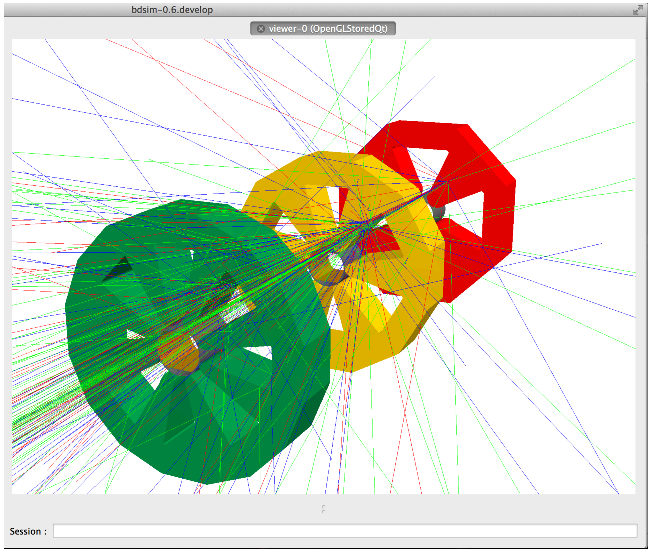
L. Nevay, J. Snuverink, S. Boogert, H. Garcia-Morales, S. Gibson, L. Deacon R. Kwee-Hinzmann, S. Walker, A. Abramov

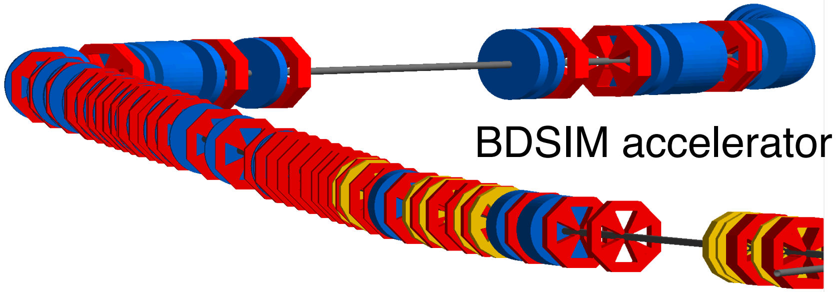
30th October 2015

(LHC – not coaxial cable)

Beam Delivery Simulation - BDSIM

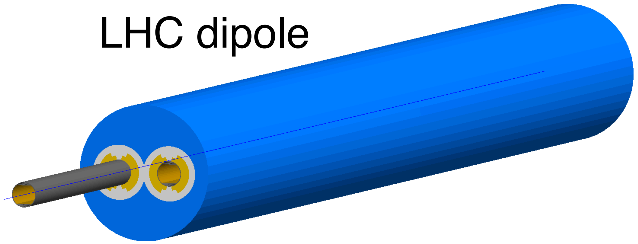
- Tracking code that uses Geant4
- Open source C++
- Automatically builds Geant4 model
- Uses MadX-like syntax for test input
- Mixes normal accelerator tracking & Monte Carlo particle physics
- Full showers of secondaries created by Geant4 processes
- Ability to simulate synchrotron radiation
- Simulate energy deposition and detector backgrounds
- Ability to import external geometry and field maps





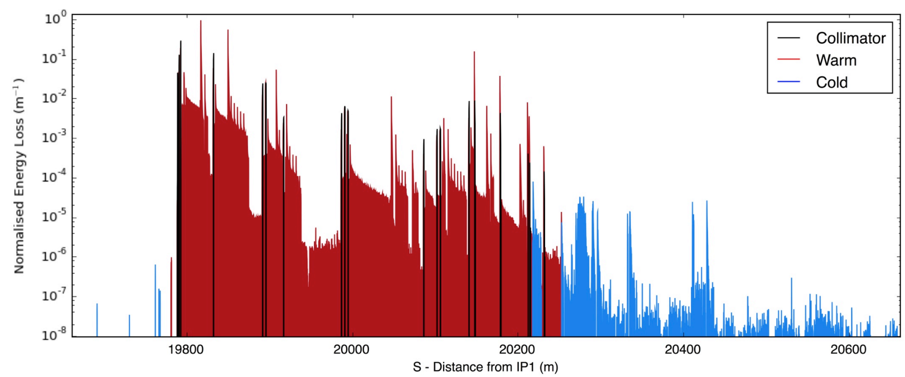
BDSIM accelerator

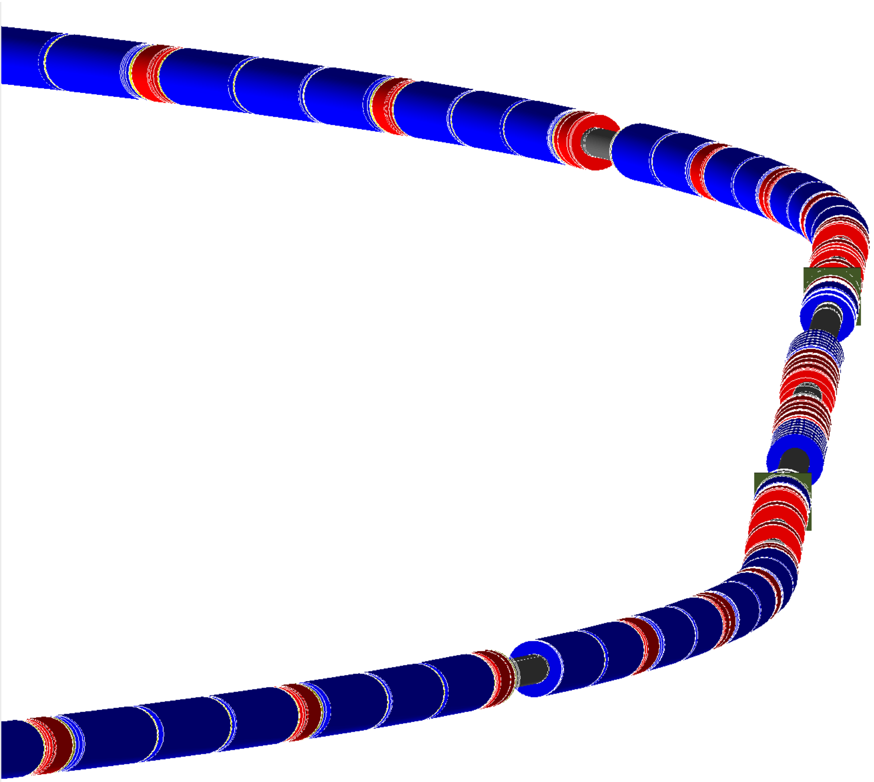
LHC dipole

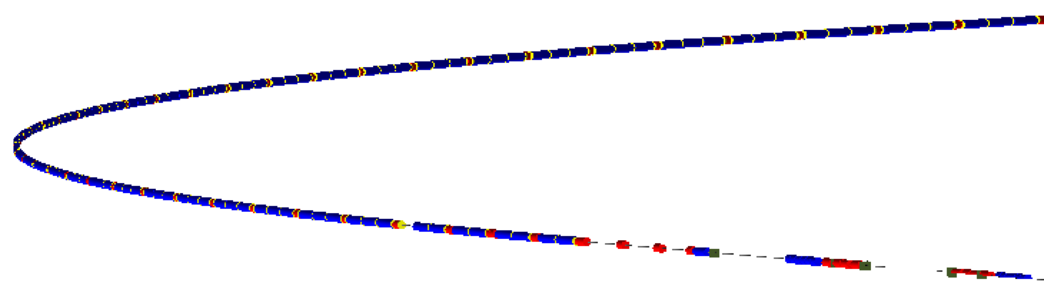


Previously…

- Initial conversion and loss maps using BDISM
- First Geant4 based loss map of LHC
- Simplistic geometry
  - symmetric geometry
  - only circular & elliptical aperture







BDSIM Development

- BDSIM heavily developed since 2012 / 2013
- Recent development followed 3 main themes:

- ***Geometry*** ✓
- ***Tracking*** ✓
- ***Physics processes*** ✓

- Previous questions & issues fell into these three categories

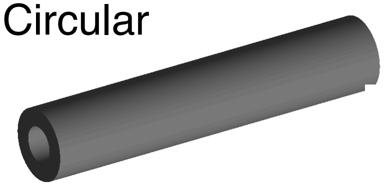
- LHC Specific developments
- Documentation & general development
- Analysis tools & workflow

Geometry

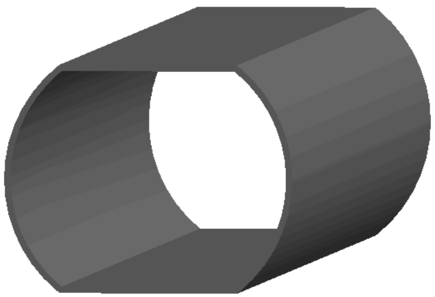
- Previous geometry relatively simple
  - Adequate for conceptual studies
  - Great detail required for real machines
- Main geometry library rewritten
- Extensive use of factory pattern
  - Each factory represents a style and can make every type of say magnet
- 6 different ***aperture*** types (including detailed LHC)
- 6 different ***magnet styles*** (again with LHC style)
- 4 different ***tunnel styles***
  - can follow the beam line
  - will be able to have external geometry and customise for certain ranges
- Most importantly all geometry works together
- Any beam pipe will work with any magnet!
- Very simple to extend with new geometry
  - guaranteed to work with all magnets
- New collimators by ***H. Garcia-Morales***

Geometry

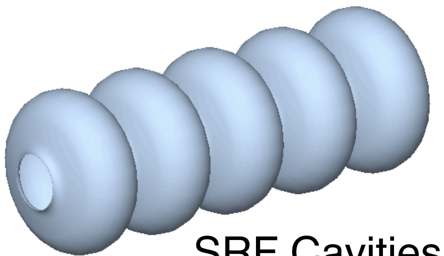
- 6 aperture models
  - circular, rectangular, elliptical, lhc, lhcdetailed, rectellipse
- Modelled on MadX aperture parameterisation
- Works with any other geometry
- 6 different magnet styles



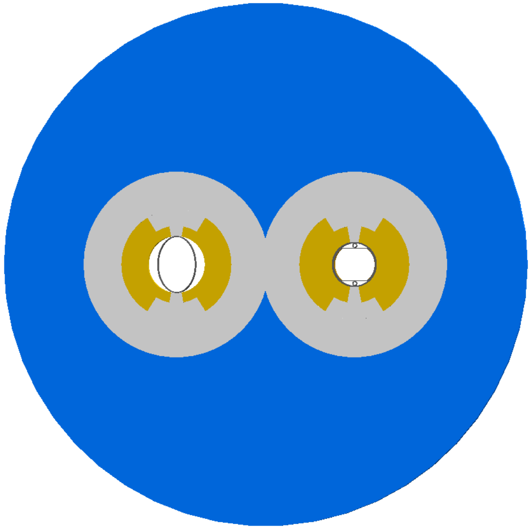
Circular



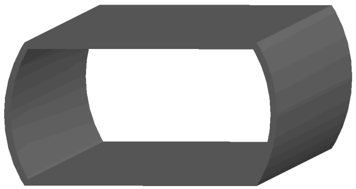
LHC screen



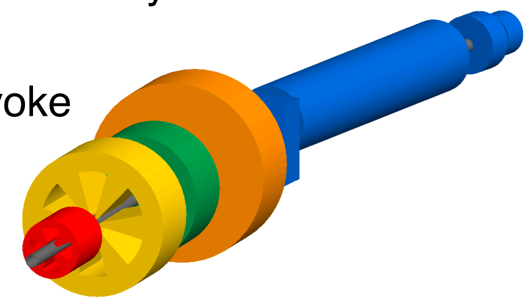
SRF Cavities (***S. Walker***)



LHC Style

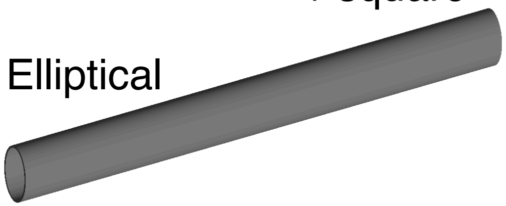


RectEllipse

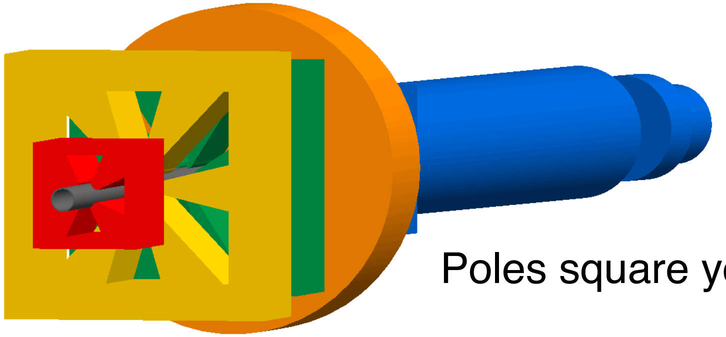


Poles circular yoke

Rectangular / square



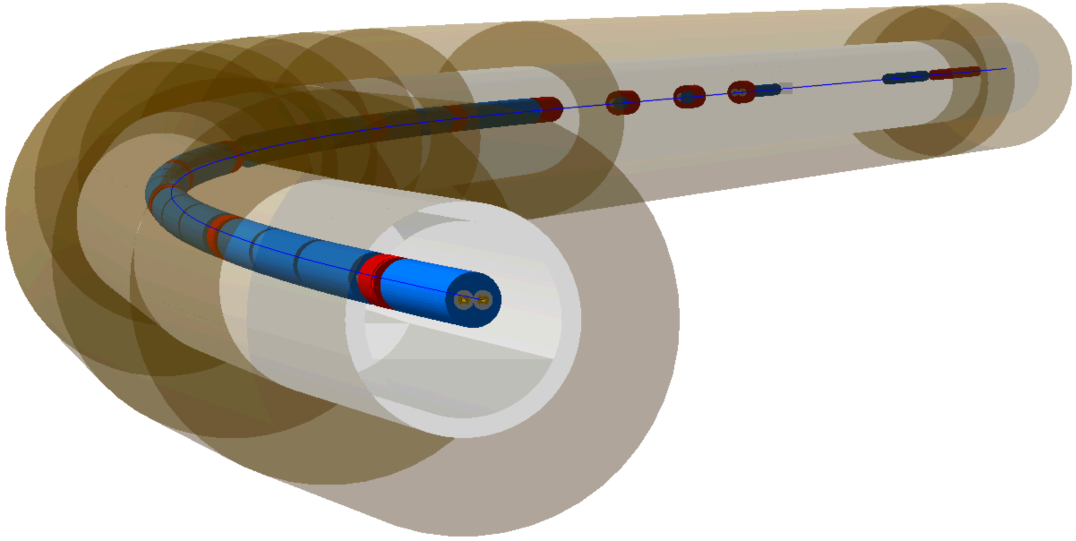
Elliptical

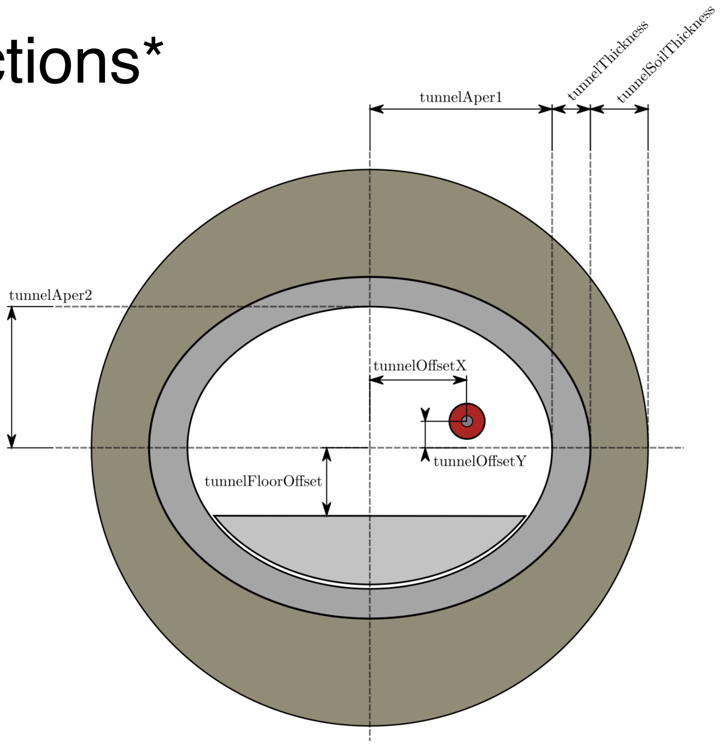


Poles square yoke

Tunnel Geometry

- Was only partially implemented previously
- Rewritten using factories
- Currently 4 different styles
- Can automatically follow beam line
- Can describe different styles for different sections*
- Can use external geometry for sections*

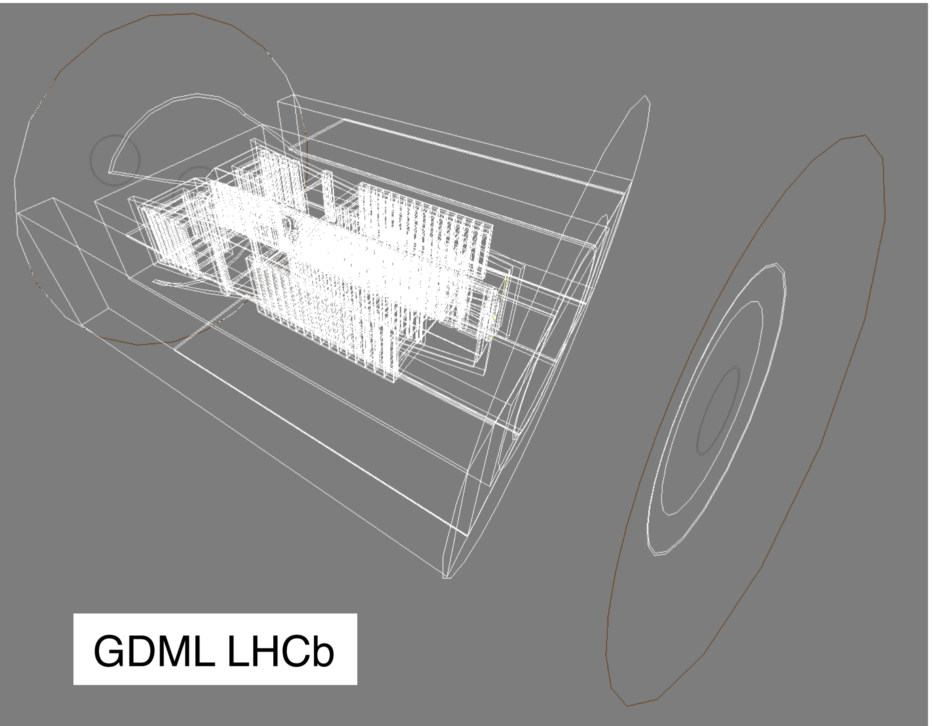




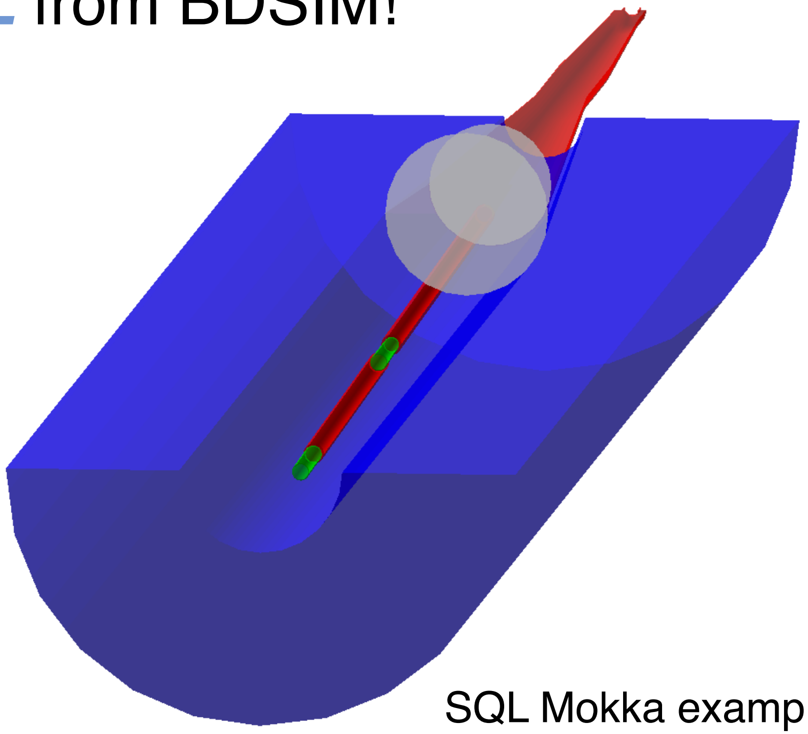
* nearly complete

External Geometry?

- For when the generic components just won't suffice
- Can import external geometry
  - SQL, Mokka, GDML, STL
- Can also overlay field maps and interpolate
  - 2D, 3D, etc.
- You can also ***export to GDML*** from BDSIM!



GDML LHCb

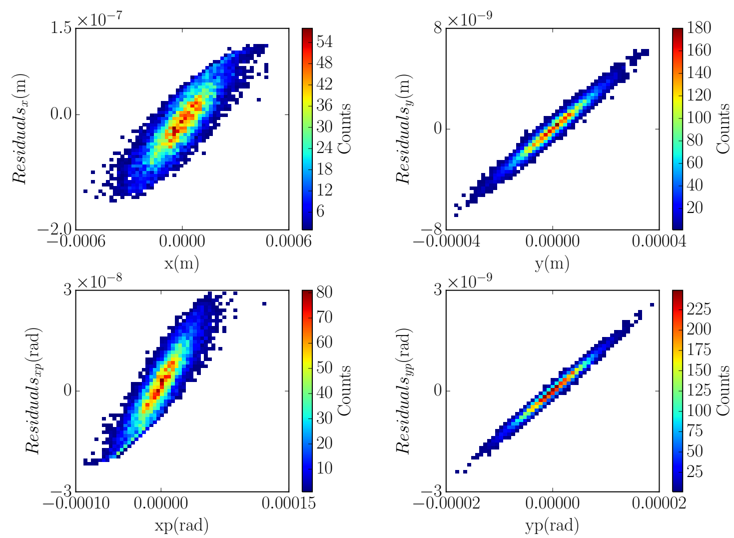


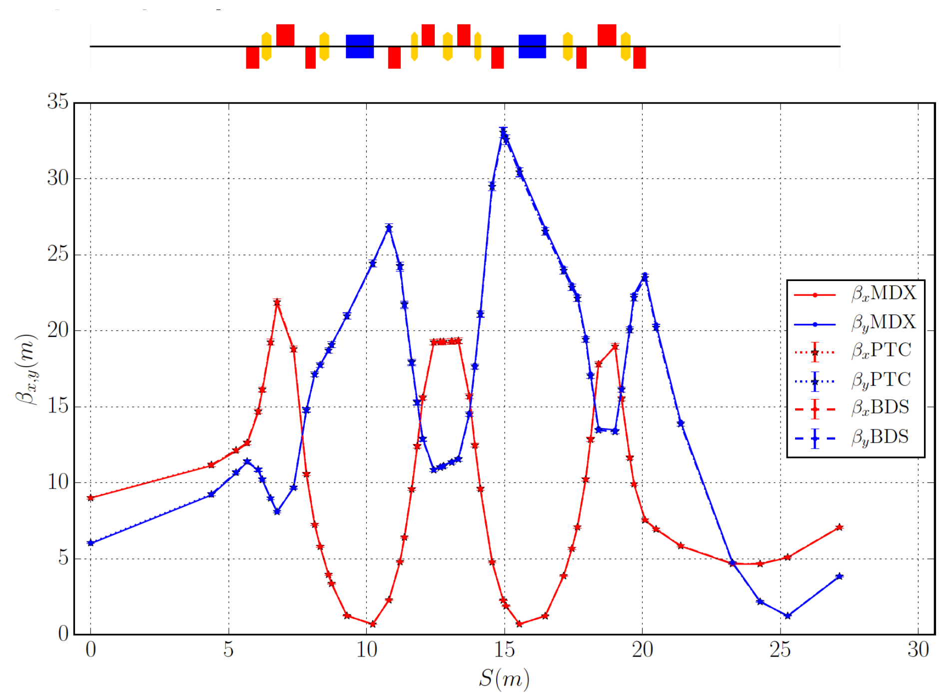
SQL Mokka example

Tracking

- Quantitative comparison with PTC & SixTrack underway
- Very good agreement with PTC
  - Tracking & optical function calculation
- Factorising tracking into library
  - will reduce tracking time by order of magnitude
  - Will allow choice of integrators
  - Will be able to use other tracking lib
  - Expected complete early 2016

A. Abramov





Double Bend Achromat agreement with PTC

Symplecticity

- Clearly not symplectic
- Factorising into a tracking library opens door to this
- Track first and test aperture continuously
- When approaches aperture -> shift to Geant4 model
- Non-symplectic tracking sufficient from then on
  - — impact inherently non-symplectic!
- Faster
  - — get the particle to the impact point
- Ideally use an external library!

Current LHC model very stable to 1000s of turns

"I thought I was on to something but I can't figure out how to move it."

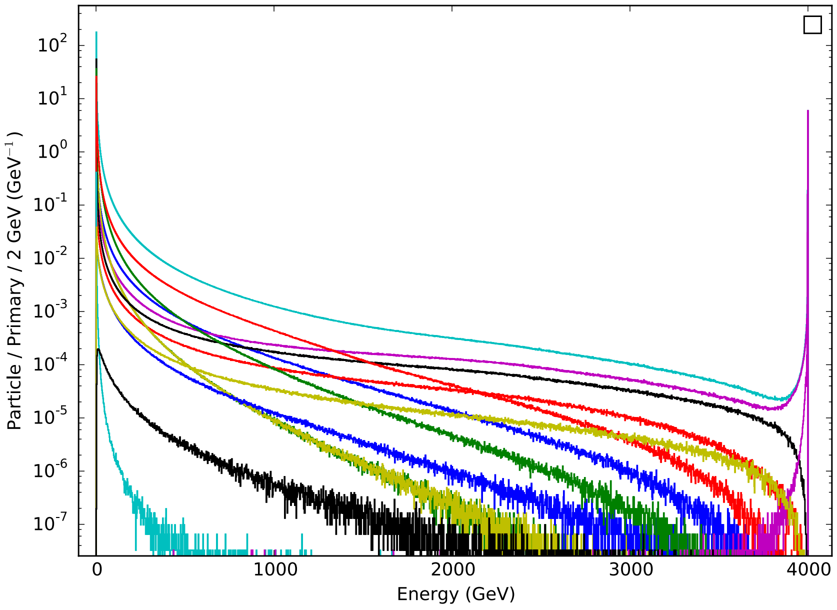
Bill Abbott http://www.toonpool.com/

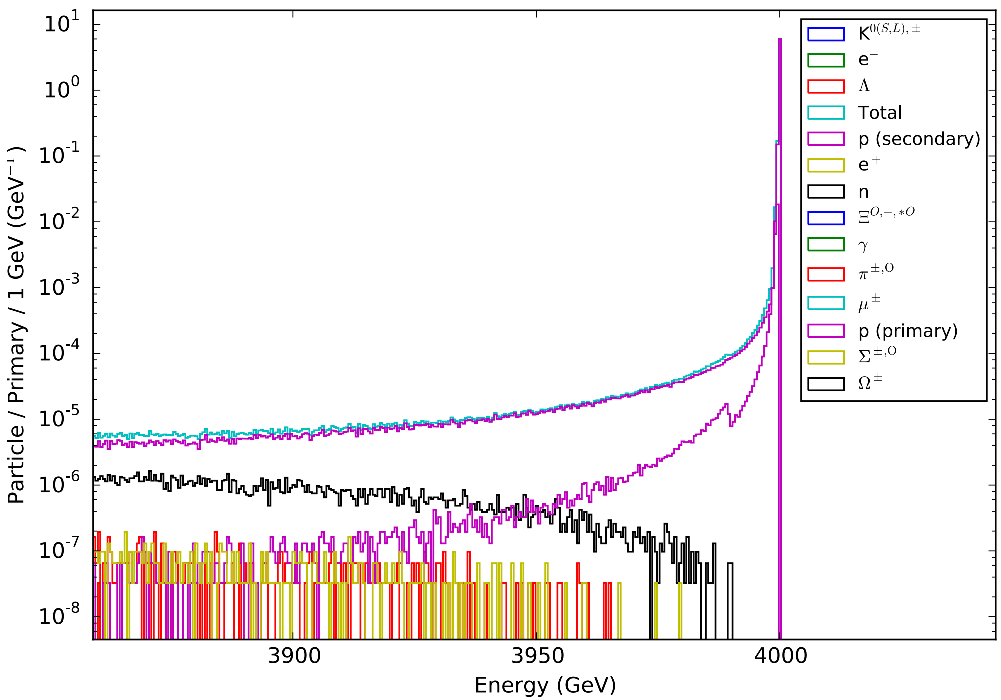
Physics & Processes

- Benefit from regular Geant4 updates to many many models
- Moved entirely to range cuts
  - several bugs fixed in this
- Cut particles not on energy but on range to produce a secondary particle
- Much more accurate stopping location
  - and therefore energy deposition
- Improved physics accuracy for lower CPU usage
- Modular physics list implemented in Geant4
  - can mix and add to physics processes very easily
- Remember, if it can be wrapped in C++, you can add the physical processes

Processes

- Quantitative comparison of scattering cross-sections on-going
- Benefiting from updated Geant4 all the time
- Example spectra from scattering at end of TCP
    - 1 x 10^8 primaries simulated





Process Biasing

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S. Boogert

- Introduced interface to Geant4 process biasing
- ***Any*** process for ***any*** particle can be biased for ***any*** volume or set of volumes

Define bias 'object'

which particles

which processes

cross-section scaling

```
biasDef0: xsecBias, particle="e-", proc="msc eIoni eBrem CoulombScat", xsecfact={10,10,10,10}, flag={1,1,1,1};
biasDef1: xsecBias, particle="e-", proc="msc eIoni eBrem CoulombScat", xsecfact={10,10,10,10}, flag={1,1,1,1};
biasDef2: xsecBias, particle="e+", proc="msc eIoni eBrem annihil CoulombScat", xsecfact={10,10,10,10,10}, flag={1,1,1,1,1};
biasDef3: xsecBias, particle="e-", proc="msc eIoni eBrem CoulombScat", xsecfact={10,10,10,10}, flag={1,1,1,1};

d1 : drift, l=1*m, bias="biasDef0 biasDef1"; ! uses the process biasDef0 and biasDef1
q1 : quadrupole, l=1*m, material="Iron", biasMaterial="biasDef2", biasVacuum="biasDef3";
d2 : drift, l=1*m, bias="biasDef3";

beamLine: line = (d1,q1,d2); !defines the beam line
use, period=beamLine; !Chooses the beam line to use
```

primary, secondaries or all

attach sets of biases to objects

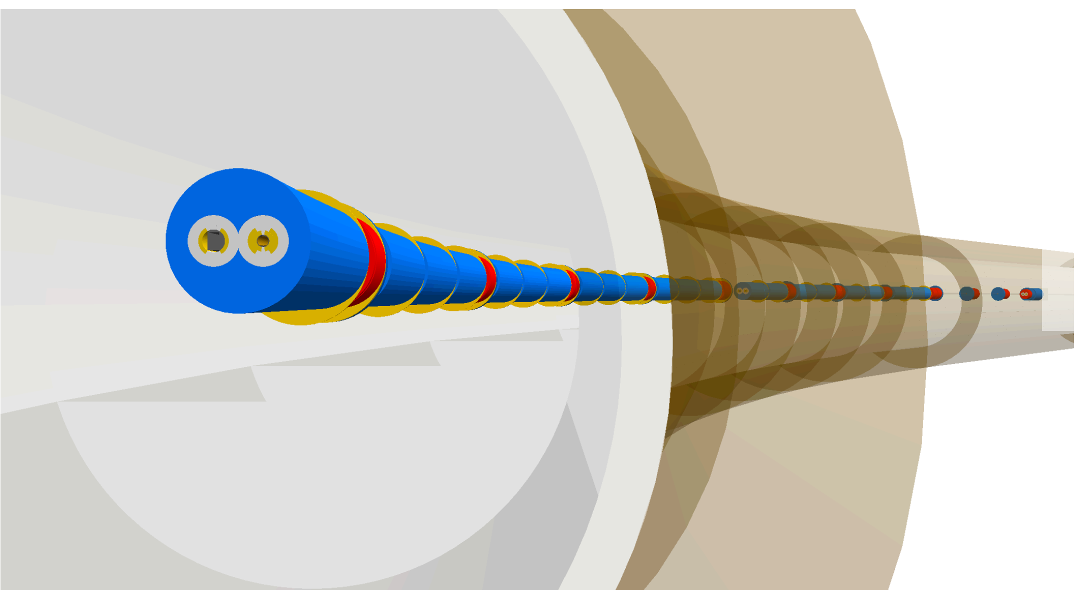
- Extremely flexible interface
- Attach to vacuum or general accelerator material
- Previously required specially written wrapper class for each

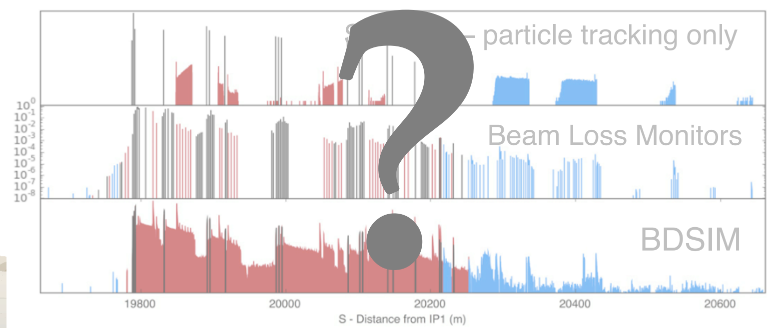
LHC Specific Developments

- Beam pipe geometry & magnet style
- Most development *can* and *has been* very general
- Rewriting of geometry was necessary
  - gives the required aperture flexibility
  - key to correct results!
- Python utilities extend for large automatic conversion
  - definitely required for the LHC
  - now integral part of work flow for all studies
- Primary trouble in piecing together information
- Aperture information significantly different from magnetic
- Tools nearly finished to split and match elements

Loss Map & 6T Hits -> Loss Map

- Unfortunately, this will have to follow
- Significant time to get aperture correct
- Large combination of files in many formats to be converted
- Model must be carefully checked
- Will present at ColUSM in November

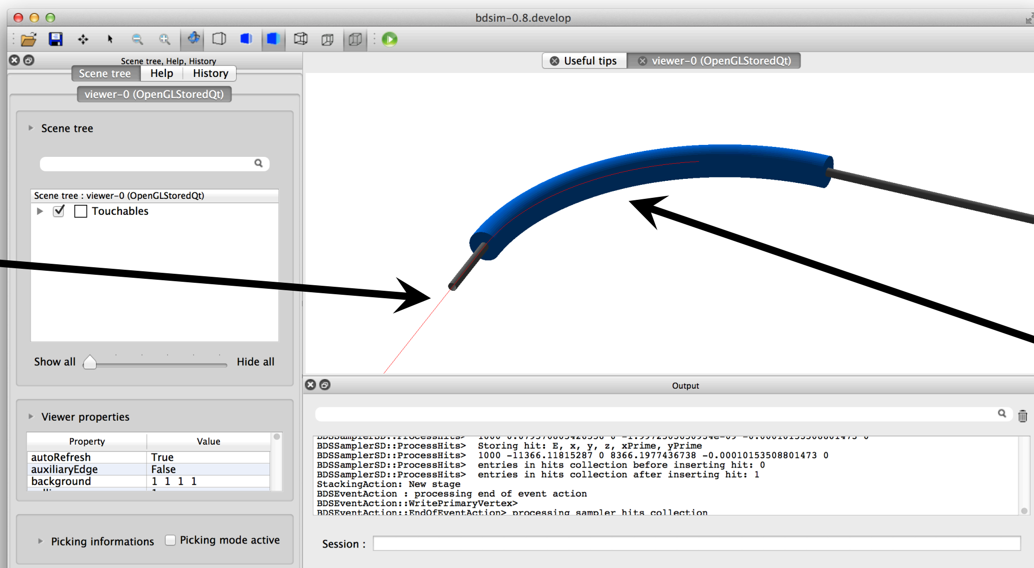




Direct Injection

- Had the ability to read out in curvilinear coordinates – now in too
- Introduced ability to inject particles anywhere in lattice
- Any beam distribution as function of S
  - Interpolation of trajectory within arcs
  - Efficient look up of transforms
- Sixtrack loader written by ***R. Kwee***
- Can therefore convert SixTrack hits to energy deposition

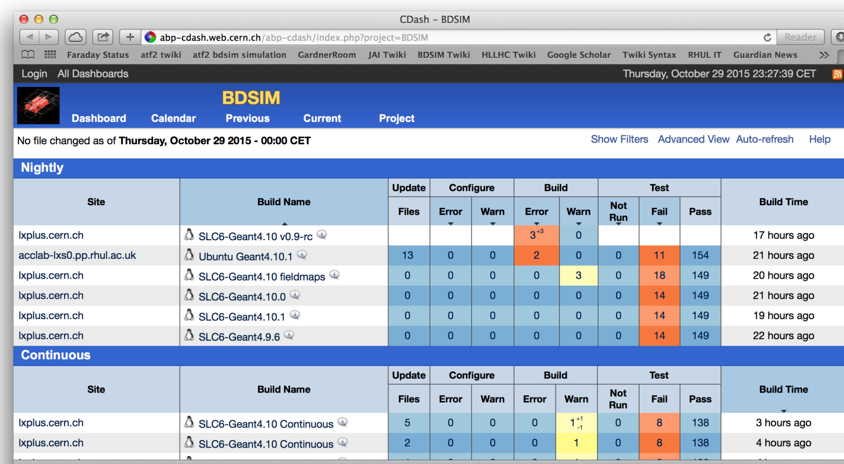
exits on 0,0



reference particle starts here

Code & Software Develoment

- 60 000 lines of C++
- Revised ***class hierarchy*** & ***factory patterns*** – improved geometry
- Increased factorisation – much easier to extend
- Consolidation of development branches
- C++ 11 adoption & latest versions of Geant4, ROOT, CLHEP,
- Parser significantly revised by ***J. Snuverink***
  - memory leaks, and problems fixed
  - written in object-orientated C++
- CTest test suite, CMake build system
  - much easier to use as compared to old configuration scripts
- CDash **nightly** and **on demand** automated building & testing
- Issue tracking & reporting
- Built in configuration for AFS
- Automated manual updates
- Regular release cycle



Output Analysis

- ASCII & ROOT output formats
- ASCII useful for initial and single particle trials
  - ASCII isn't suited to large data
  - ASCII inefficient storage and not as strongly structured
- ROOT output used for studies
  - ability to introduce other formats if / when required (HDF5)
- RoBDSIM analysis tool written in C++
  - compiled C++
- Can use in 3 ways with exactly the same functionality
  - C++ linked to, use interactively in ROOT, use in python
- RoBDSIM typically used in Python, ROOT and on farm
- Can add and produce histograms
- Suitable for farm analysis of job files
- https://bitbucket.org/jairhul/robdsim

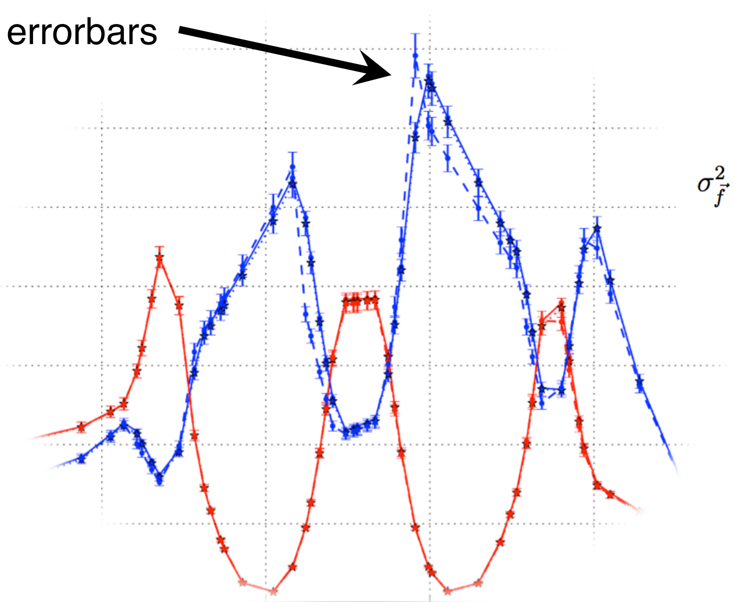
Statistical Comparison of Tracking

- Can calculate optical functions from particle distribution
- Another measure as compared to single particle tests
- Used to compare BDSIM with design of lattice
  - — useful for spotting conversion discrepancies
- Can compare with PTC
- Significant work on uncertainty calculation of optical functions from particle distribution

$$\epsilon_x = \sqrt{\langle x^2\rangle\langle x'^2\rangle + \langle xx'\rangle^2},$$

$$\beta_x = \frac{\langle x^2\rangle}{\epsilon_x},$$

$$\mathbf{\Sigma} = \begin{pmatrix} \langle x^2\rangle & \langle xx'\rangle \\ \langle x'x\rangle & \langle x'^2\rangle \end{pmatrix}$$



$$\sigma^2_{\vec{f}} = \left(\frac{\partial \vec{f}}{\partial a_1}\right)^2 cov[a_1, a_1] + \left(\frac{\partial \vec{f}}{\partial a_2}\right)^2 cov[a_2, a_2] + \left(\frac{\partial \vec{f}}{\partial a_3}\right)^2 cov[a_3, a_3] + $$
$$+ 2\left(\frac{\partial \vec{f}}{\partial a_1}\frac{\partial \vec{f}}{\partial a_2}\right) cov[a_1, a_2] + 2\left(\frac{\partial \vec{f}}{\partial a_1}\frac{\partial \vec{f}}{\partial a_3}\right) cov[a_1, a_3] + 2\left(\frac{\partial \vec{f}}{\partial a_2}\frac{\partial \vec{f}}{\partial a_3}\right) cov[a_2, a_3].$$

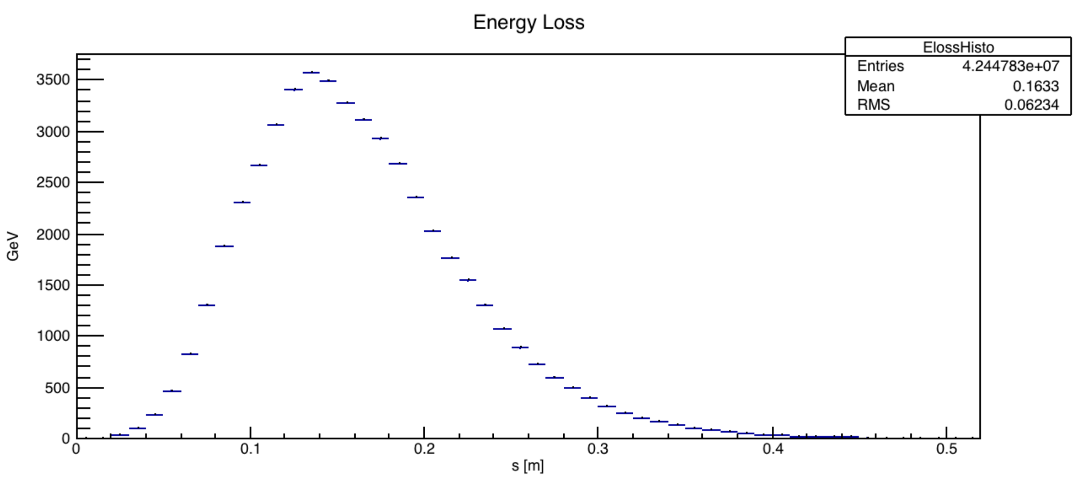
$$cov[a_3, a_3] = -\frac{(-2+n)\mu_{1,1}^2}{(-1+n)n} + \frac{\mu_{0,2}\mu_{2,0}}{(-1+n)n} + \frac{\mu_{2,2}}{n},$$

A. Abramov, S. Boogert

Regression Testing

- Rapid development of BDSIM
- Occasionally, simple / basic things break
- Code too large to test all features yourself
- Automated build & testing system implemented
- Each example is also a test
- Reference histograms and results compared
- RoBDSIM executable used for comparison and testing
- ***145 tests*** so far
- ***Run nightly***

- Hadronic & EM Shower development
- Tracking in each component
- Parser
- Geometry construction
- Geometry overlaps
- Many more….



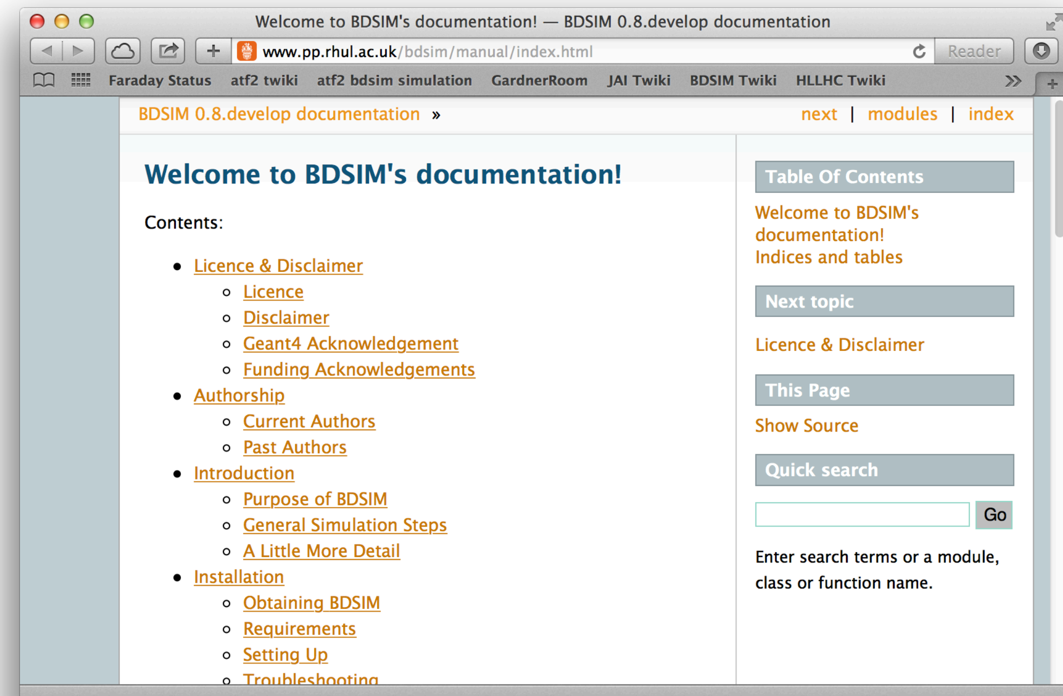
EM Shower in Collimator

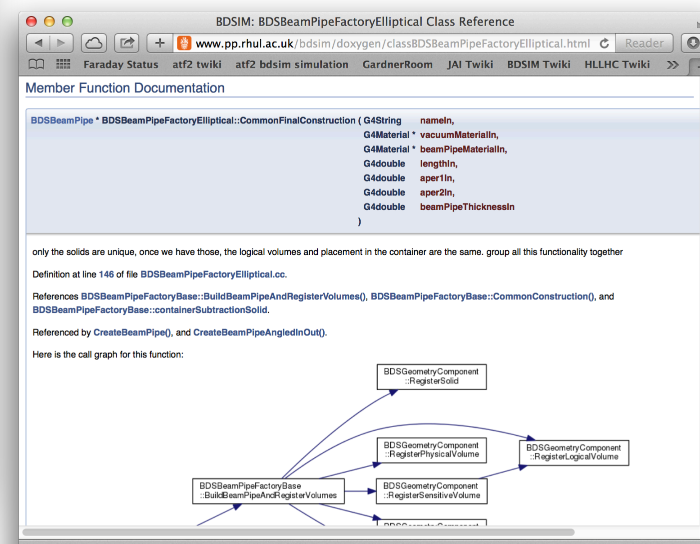
Python Utilities Galore

- pymadx, pybdsim, pymad8, robdsim, pytransport, pylhc
- pymadx
  - loading and manipulation of TFS files
  - range iterating, filtering, matching
  - PTC segments supported
  - use to plot a lattice above a graph – interactive too!
- pybdsim
  - conversion from Madx, Mad8, Transport etc
  - ASCII output analysis
  - programmatic model construction
- pylhc
  - utilities for parsing lhc model specific information
  - collimation files, aperture information (filtering, matching etc)
- Again, all open source and distributed with BDSIM

Documentation

- New manual (html & pdf) automatically updated weekly
  - lots of syntax examples
  - www.pp.rhul.ac.uk/bdsim/manual
- Detailed Doxygen code documentation similarly
  - www.pp.rhul.ac.uk/bdsim/doxygen



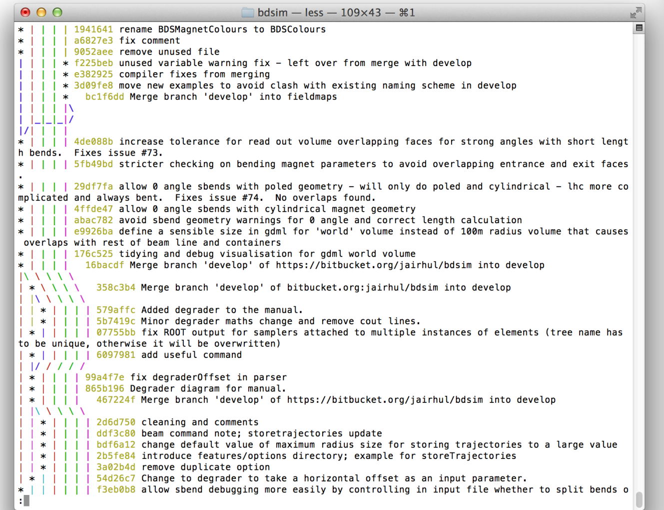


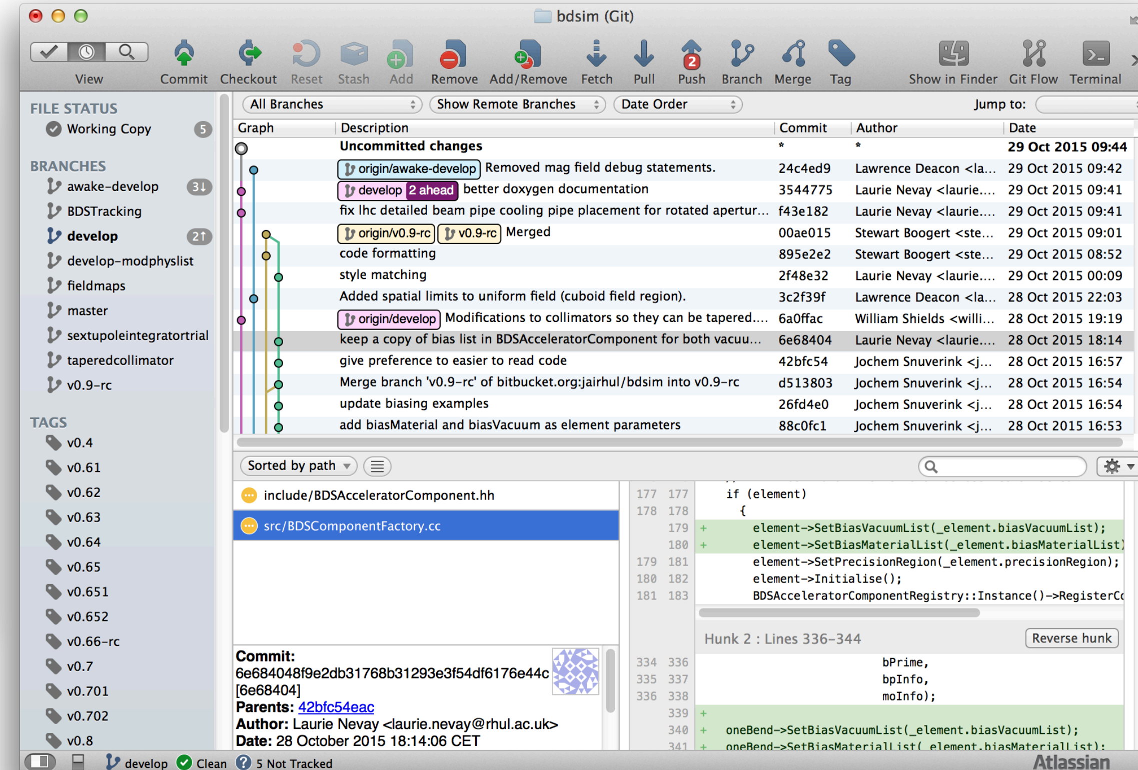
Public Git Access

- www.bitbucket.org/jairhul/bdsim
- Full open source development
- Issue tracking - (100 this year, 20 open)
- ~ 10 regular developers
- ~ 5 branches

300 – 500 commits per version

3 releases per year typically





Many developers working at once without issue on many versions

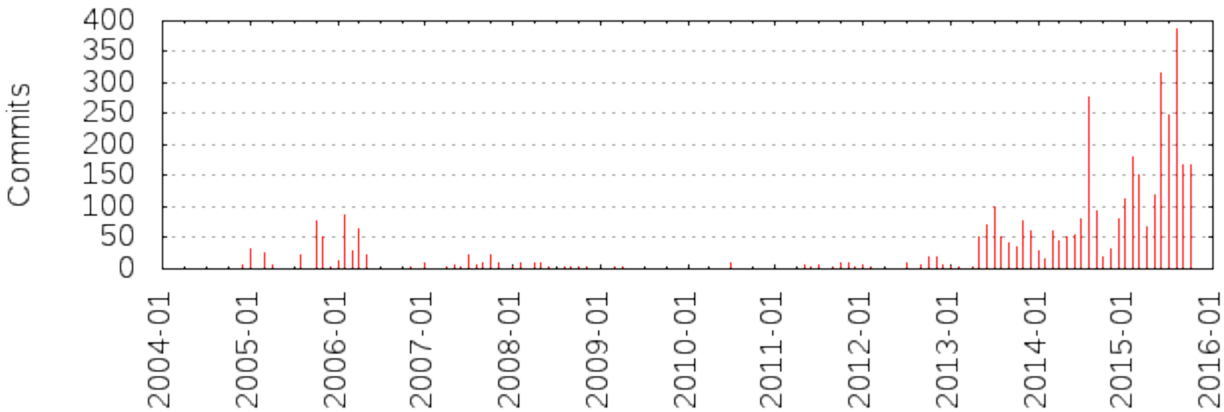
[A successful git branching model]()

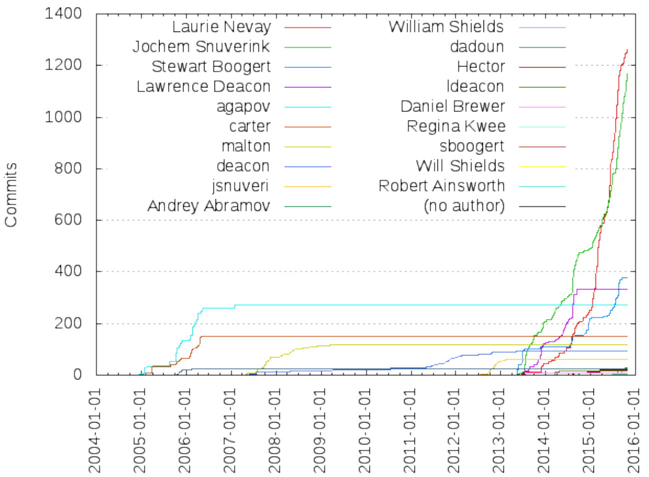
Timeline

- Autumn 2015
  - v0.9 released ***next week***
  - Finish magnet support & BLM geometry
  - Implement magnet coils
  - Implement magnet pole face rotation flexibility
  - Implement Racetrack aperture
  - Complete regression testing suite
  - Support of crystal collimation processes & geometry
- V1.0 by end of 2015
  - paper in preparation
- Spring 2016
  - Factorise tracking
  - Include external tracking library
  - Consider incorporating collimation specific processes

Summary

- BDSIM has great potential for a variety of applications
- Complimentary to existing codes
- Under rapid development – 7 regular developers
- Flexible and easy to explore new scenarios
- Weekly meetings & bi-annual code weeks
- Clear road map for development
- Paper in preparation





Thank you

Acknowledgements:
Regina, Stefano,
Roderik, Andrea, Hector
• • •

www.pp.rhul.ac.uk/bdsim

Reference Slide for URLs

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- ***We've moved!***

- ~~www.bitbucket.org/stewartboogert/bdsim~~
- ~~www.bitbucket.org/lnevay/pybdsim~~

- www.pp.rhul.ac.uk/bdsim
- www.pp.rhul.ac.uk/bdsim/manual
- www.pp.rhul.ac.uk/bdsim/doxygen
- www.bitbucket.org/jairhul/bdsim
- www.bitbucket.org/jairhul/pymadx
- www.bitbucket.org/jairhul/pybdsim
- http://abp-cdash.web.cern.ch/abp-cdash/index.php?project=BDSIM