Bridging the Machine Detector Interface

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Warwick Particle Physics Seminar

[1]

Motivation

- Questions then:
  - how can we get rid of muons for linear collider detectors?
  - where does that background come from?
  - is this beam loss too much for my future super-conducting collider?

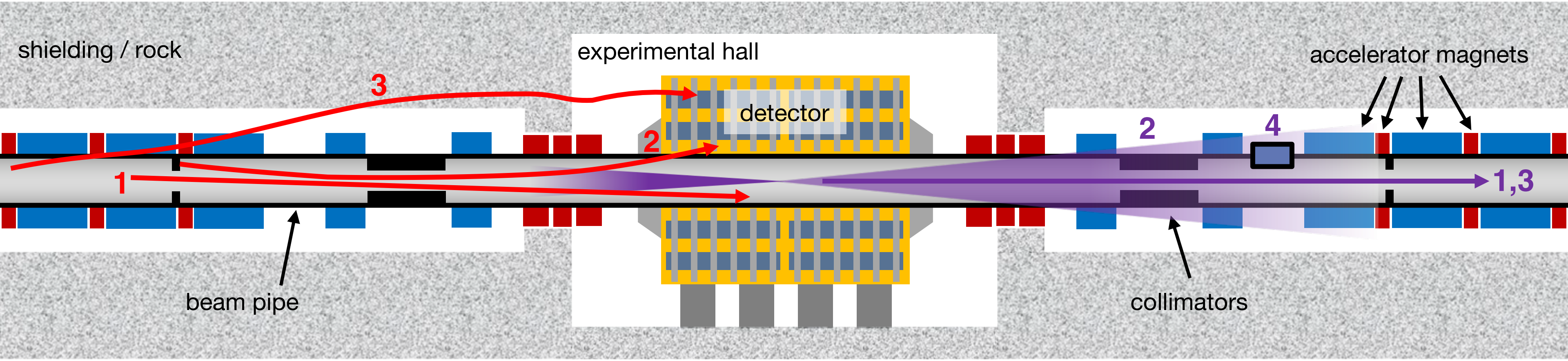
- Questions now:
  - is this beam loss too much for my current super-conducting collider?
  - where does that ~~background~~ ***signal*** come from?
  - where will these ion fragments end up?
  - what dose is caused by beam loss and how small can I make my gantry?

The Machine Detector Interface

- Radiation / particles in both directions - *both* are interesting

Incoming:
1. products from residual gas interaction
2. leakage from collimation system
3. secondaries from beam loss

Outgoing:
1. lightly scattered primaries
2. physics debris
3. forward physics
4. forward experiments



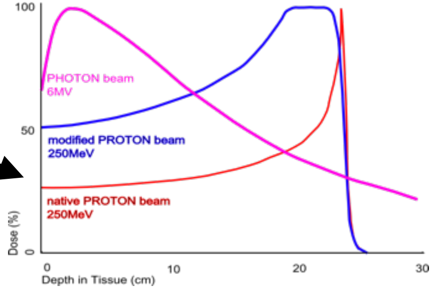
Goal: Simulate far reaching particles ***in*** and ***out*** of experiment and understand them
Need: accurate magnetic particle tracking + interaction with matter

not to scale

Medical Hadron Therapy

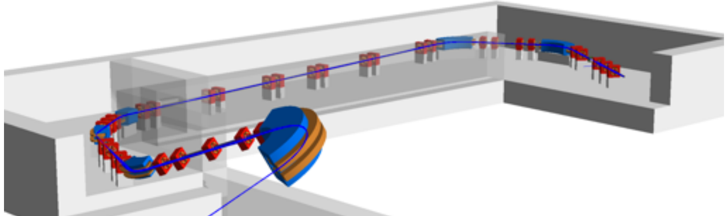
- Protons and ions are used to treat cancers
  - greater relative biological efficiency (RBE) compared to X-rays
- Accelerator must move around isocentre
- Low energy + nozzle leads to large beam pipe and magnets
- Large national-level therapy centres
- Societal need greater than availability
- Cheaper if much smaller
  - leads to coupling between source and treatment room

Bragg curve



D. A. Miller, https://commons.wikimedia.org/wiki/File:BraggPeak.png

H. Owen et al., International Journal of Modern Physics A (29), 14, 1441002 (2014)



Introduction

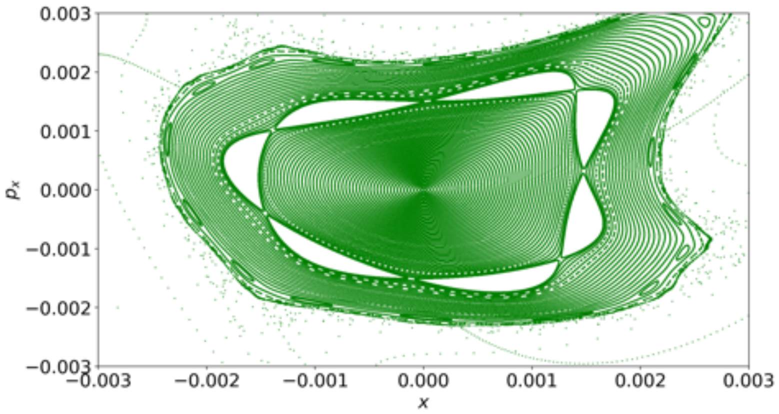
1. Conceptual problem of mixed simulation
2. A solution! … and practicalities
3. Examples of applications
   - LHC Ion Collimation, ATLAS Non-Collision Backgrounds, Physics Debris
   - NA62, MAGIX @ MESA,
   - IBA Proton Therapy, LhARA
   - Laserwire & Gamma Factory
4. Geometry handling, conversion and challenges
5. FASER
6. Outlook & Conclusions

Accelerator Particle Tracking

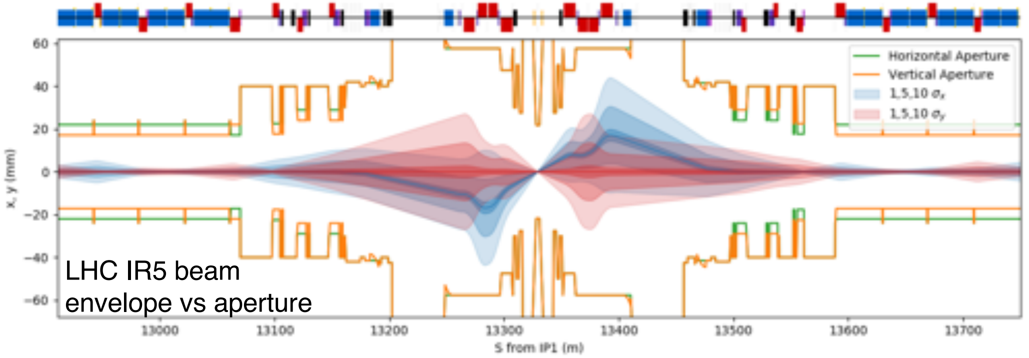
- Accurate tracking required for many (>100s) of magnets
  - numerical integration (like 4th order Runge Kutta) is not accurate enough
- Specialised codes exist for accelerator tracking
  - MADX, SAD, PTC, Elegant, COSY Infinity, SixTrack, OPAL, Zgoubi, Merlin
  - these often exploit specific maps for specific pure fields
- Typically one type of particle and only with a small perturbative energy deviation
  - ***no*** secondaries tracked or their production considered
- 'losses' are when coordinates exceed aperture
  - or when a certain amplitude is reached (i.e. no aperture as such)
  - high energy particles don't just stop! (although correlation works in some cases)
- Uses ***curvilinear*** coordinate system

$$\begin{pmatrix} x_1 \\ x_1' \\ y_1 \\ y_1' \\ l_1 \\ \delta \end{pmatrix} = \begin{pmatrix} \cos\Theta_x & \frac{\sin\Theta_x}{\sqrt{K_x}} & 0 & 0 & 0 & \frac{1-\cos\Theta_x}{\sqrt{K_x}} \\ -\sqrt{K_x}\sin\Theta_x & \cos\Theta_x & 0 & 0 & 0 & \sin\Theta_x \\ 0 & 0 & \cosh\Theta_y & \frac{\sinh\Theta_y}{\sqrt{K_y}} & 0 & 0 \\ 0 & 0 & \sqrt{K_y}\sinh\Theta_y & \cosh\Theta_y & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_0 \\ x_0' \\ y_0 \\ y_0' \\ l_0 \\ \delta \end{pmatrix}$$

'thick' dipole matrix



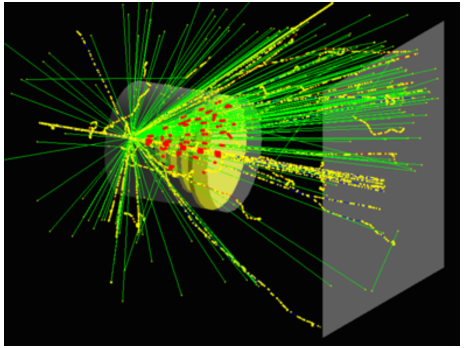
example Poincaré map through nonlinear fields



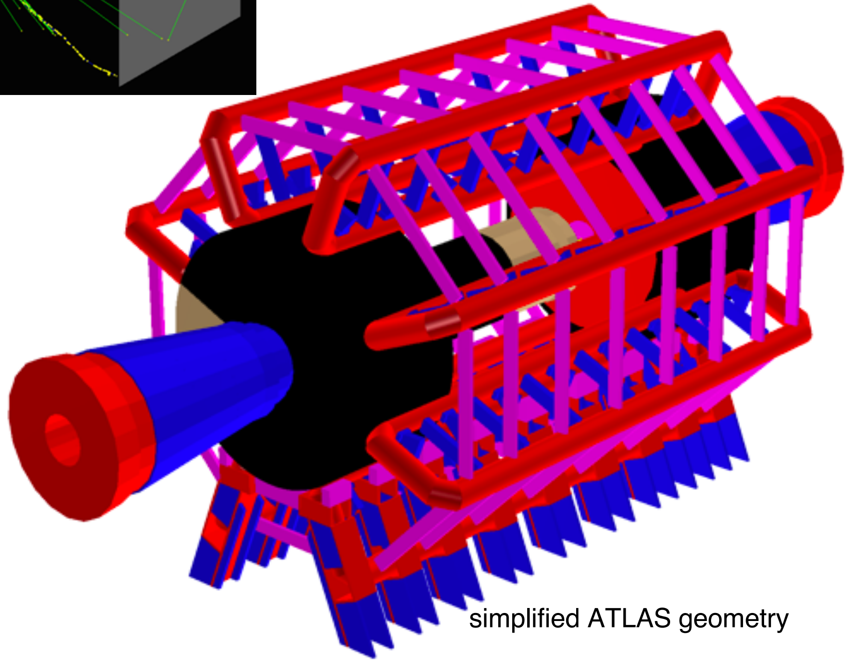
LHC IR5 beam envelope vs aperture

Detector Simulation

- 3D radiation transport model to predict detector response and compare to data
- Detailed 3D geometry
  - complex and specialised to an experiment
- Often includes magnetic field for particle identification
  - not a uniform field
- Use numerical integration for particle tracking
  - e.g. 4th order Runge Kutta
  - can track all particles
  - in Cartesian coordinates



simple example Geant4 detector model



simplified ATLAS geometry

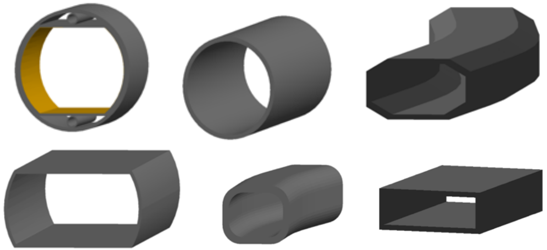
Mixed Tracking Premise

- For the MDI and scenarios described we need both features
- Need:
  - accurate tracking of all particles in an accelerator up to the detector
  - particle matter interaction for scattering and secondary production
- Solution:
  - build radiation transport model like a detector
  - provide coordinate transforms between curvilinear and Cartesian
  - provide accelerator-style integrators for particle motion
  - fall back to numerical integration where needed (e.g. non-paraxial particles)
- Tricky bits:
  - making the 3D model takes forever and even then it's hard coded
  - 'thin' things - accelerator tracking uses thin kicks to represent imperfections
  - dipoles - where the curvilinear frame bends - surprisingly more involved
  - angled pole faces (input / output face) on dipoles

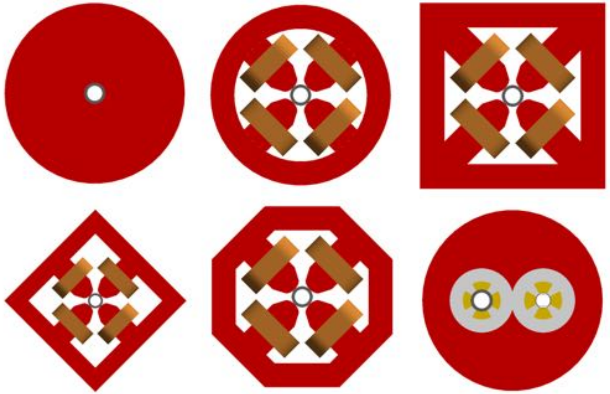
The 3D Model - Complexity & Time

- Accelerators are typically repetitive and similar in design
- Described by list of elements in order:

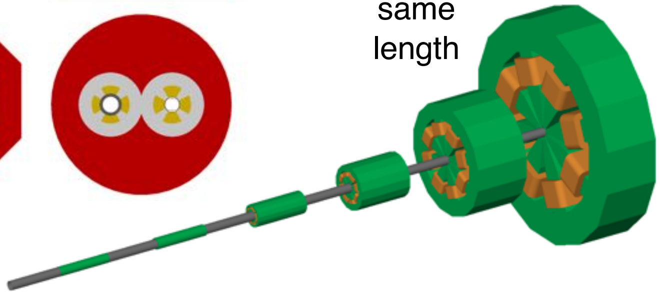
```
drift, dipole, drift, quadrupole, drift, quadruple, drift
```

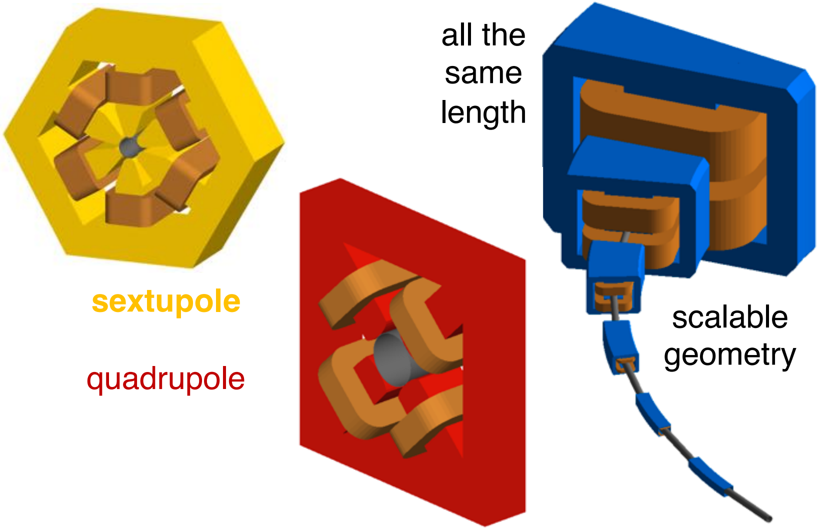


- Provide library of typical accelerator components with adjustable proportions



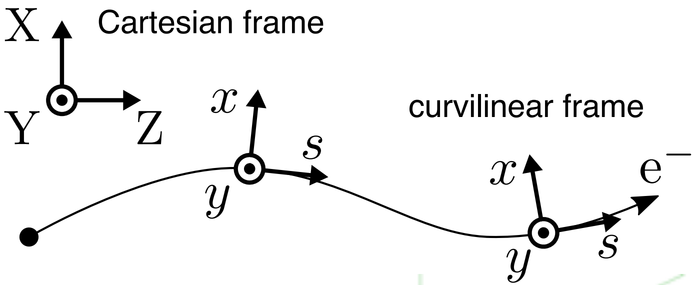
different yoke styles

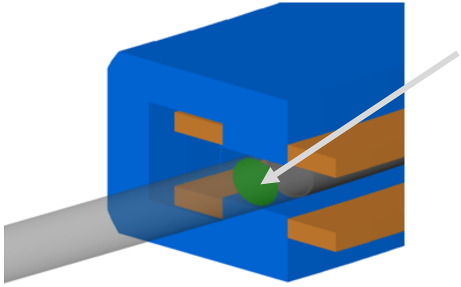




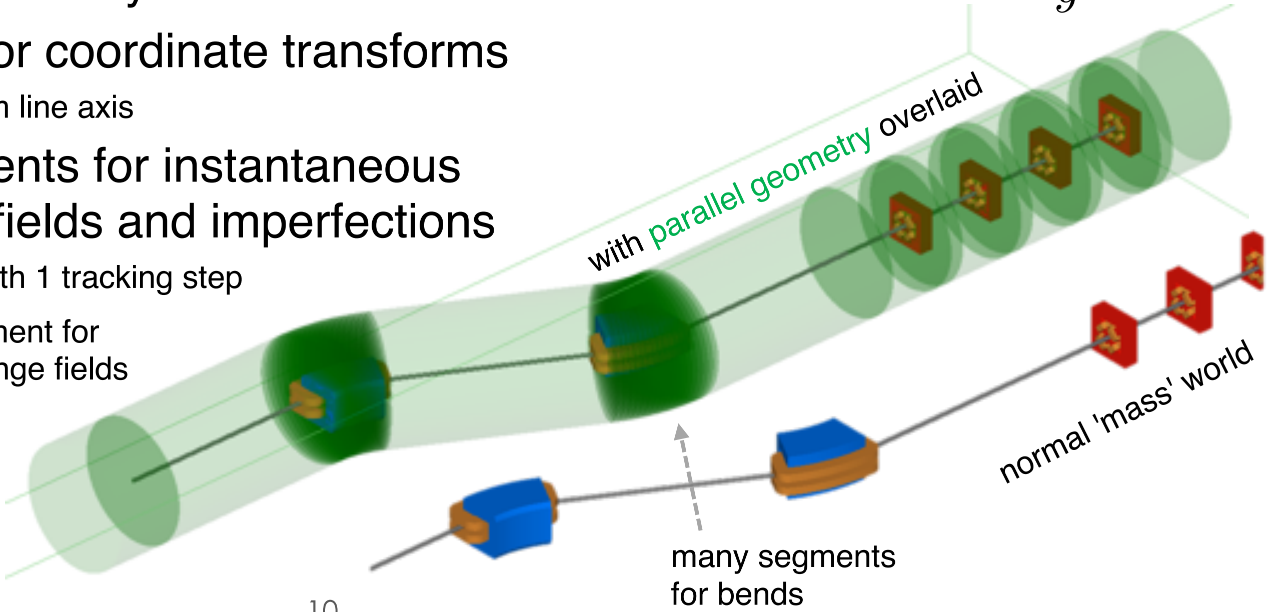
Coordinate Systems & "Thin" Elements

- Accelerator tracking is done in a ***curvilinear*** coordinate system following the beam line
  - increased precision and only relative motion
  - beam of particles typically moves together in one direction
- Most convenient mathematically to use curvilinear
- Use ***parallel geometry*** for coordinate transforms
  - cylinders that correspond to beam line axis
- Tracking uses 'thin' elements for instantaneous kicks - for magnet fringe fields and imperfections
  - include as very short elements with 1 tracking step



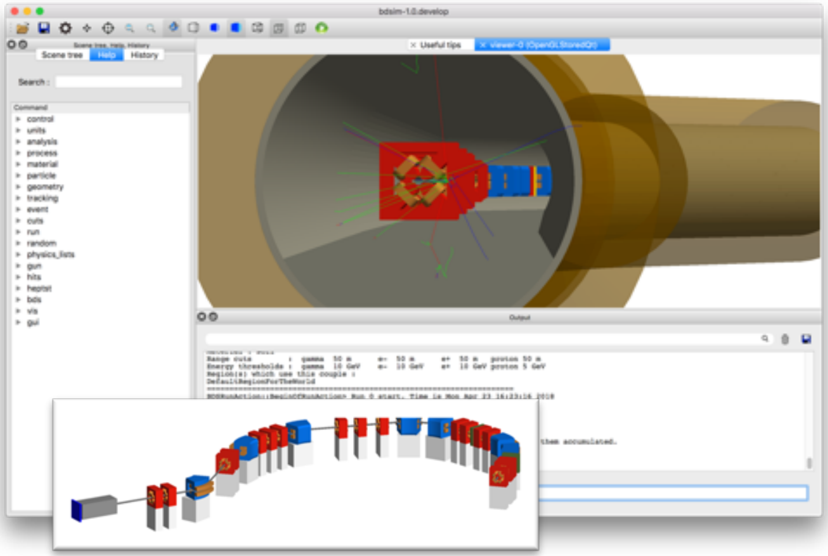


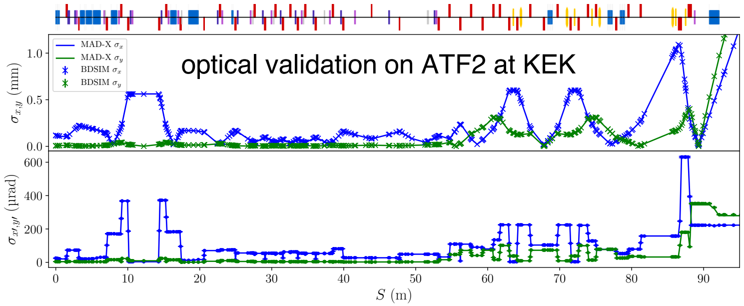
thin element for
dipole fringe fields



Beam Delivery Simulation (BDSIM)

- Geant4 is a widely used open source C++ library for modelling detectors
  - regularly updated and developed based on latest results by community
- Use this and add accelerator tracking
- BDSIM* started in 2004 by G. Blair at Royal Holloway for Linear Collider backgrounds
  - open source C++ - see references at end for links
- Automatic Geant4 models of accelerators
  - start from scratch with text input or convert from optical format
  - actively developed and modernised since 2013
- Applied to many experiments and machines
  - ***ILC / CLIC***, ***AWAKE***, ***XFEL*** *undulators*, ***LHC*** *collimation*, ***Laserwires***,
  - ***FASER***, ***ATLAS*** *non-collision backgrounds*, ***MAGIX*** *at* ***MESA***





[Computer Physics Communications (252), July 2020, 107200]

*don't forget the 'i' when googling it

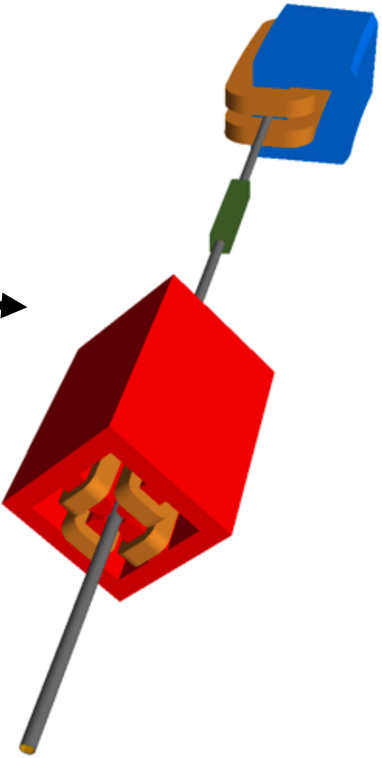
Example BDSIM Syntax

- "GMAD" - Geant4 + MAD (MAD is an accelerator optics code)

sm.gmad

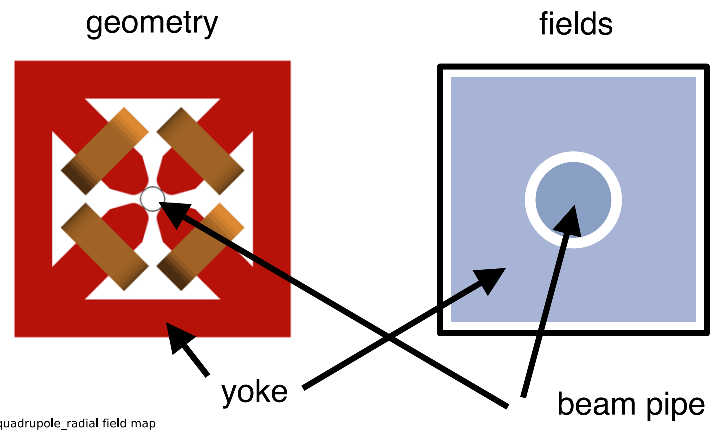
```
d1: drift, l=1*m;
q1: quadrupole, l=1*m, k1=1.3, magnetGeometryType="polesfacet";
c1: rcol, l=0.6*m, ysize=5*mm, xsize=5*mm, material="Copper", outerDiameter=10*cm;
s1: sbend, l=1*m, angle=0.10;

l1: line = (d1, q1, d1, c1, d1, s1);
use,period=l1;

sample, all;

option, ngenerate=1,
        physicsList="em";

beam, particle="proton",
      energy=10.0*GeV,
      X0=0.001,
      Y0=0.001;
```

```
-:---  sm.gmad        All L3    Git:develop  (Fundamental)
Wrote /Users/nevay/physics/reps/bdsim/examples/simpleMachine/sm.gmad
```

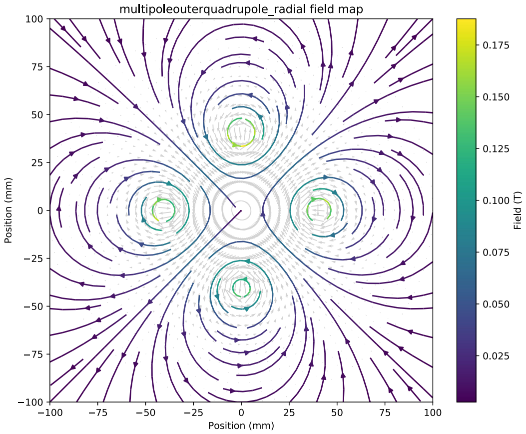


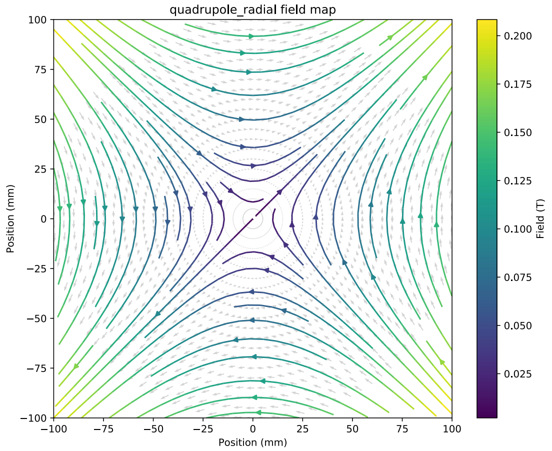
Tracking Implementation

- Custom numerical integrators
  - for 1st order matrix transport maps
- These ignore the field and are constructed with a strength
  - like "k1" for quadrupole
  - scaled with rigidity of each particle
- Fall back to RK4 if…
  - non-paraxial (sideways)
  - low radius of curvature (spiralling)
- Provide suitable fields
  - pure field in vacuum
  - current source yoke field
  - normalise at pole tip
- Requires curvilinear coordinate system



$$B_x = \frac{\partial B_y}{\partial x} y$$
$$B_y = \frac{\partial B_y}{\partial x} x$$
$$B_z = 0$$

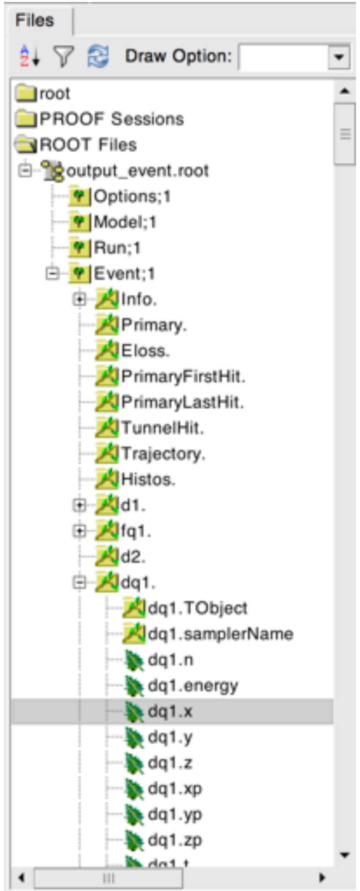




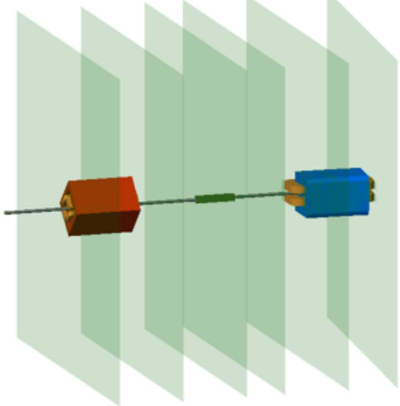
BDSIM Integration & Data

- Modern CMake build system
  - uses Geant4, ***ROOT & CLHEP***
- Can be used as a class inside another application
- Data is stored in ROOT format with per-event structure
  - accelerator tracking simulations are typically 1 particle in, 1 particle with much simpler data format
  - radiation transport model requires more advanced format and analysis tools
  - ***trajectory filtering*** and linking back to primary
- Data format and included analysis tools key to understanding the origin of energy deposition
  - easy filtering / selection in analysis and skimming
- Strong reproducibility from output data
  - recreate single or multiple events afterwards
- Invisible "sampler" planes to record distributions after an object
  - in another parallel world

example data tree structure

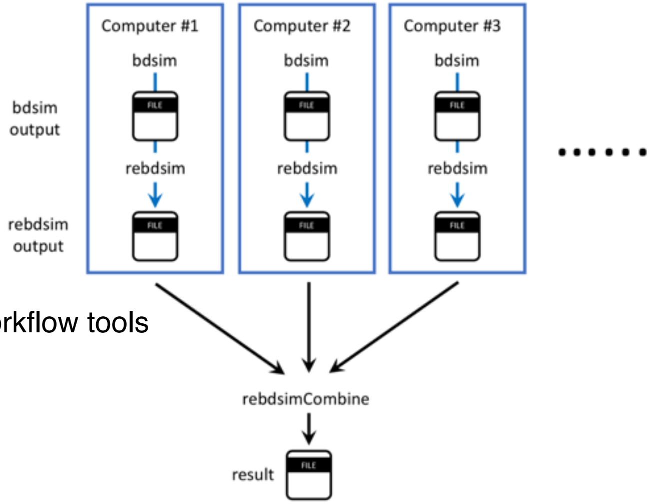


sampling planes after each element (normally invisible)

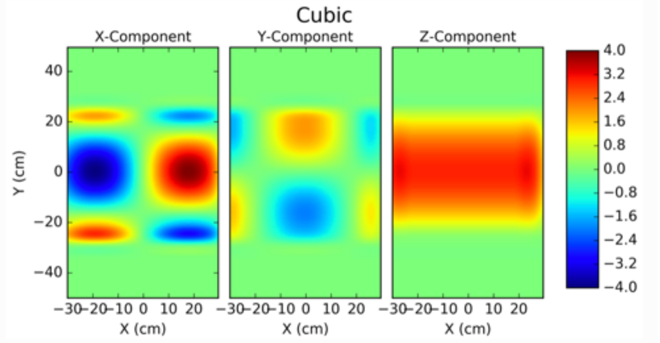


Features / Tools

- Ability to include custom GDML in model
- Can overlay E or B or combine EM field maps
  - 1D to 4D field maps supported in arbitrary order
  - numerical interpolation 1D to 3D included with several algorithms
- Supports all Geant4 physics lists
  - modular and reference
- Cross-section biasing per volume
  - combine multiple biases (particle:processes)
  - overlay only on vacuum or yokes or world
- Beam distribution generator for accelerators
- 3D scoring meshes and beam loss monitor scoring
- Automatic tunnel building following beam line
- Circular tracking control!
  - stop particles after N turns of circular accelerator



HTC workflow tools

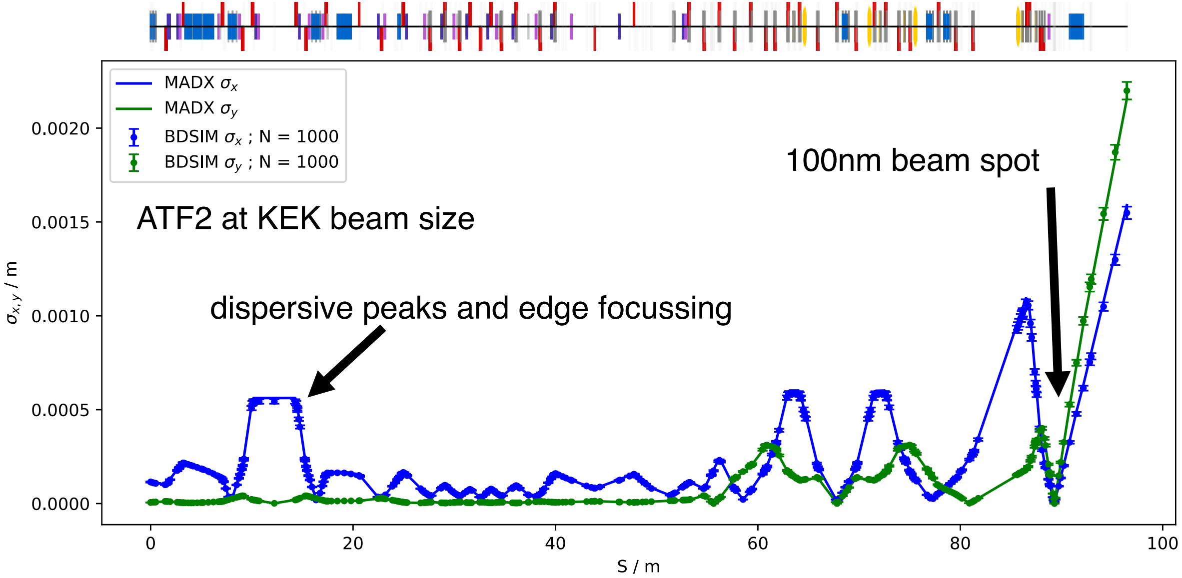


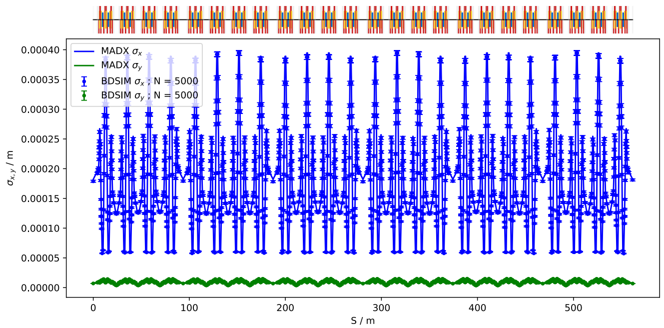
Example 2D field value components with cubic interpolation.

field map interpolation

Optical Function Comparison

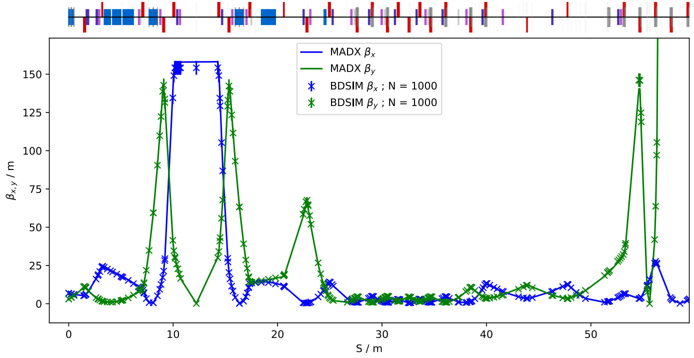
- Crucial to compare 'optics' of machine models
- Compare particle distribution after each element
- Calculate optical functions from particle distribution
  - using (up to) 4th order moments including statistical uncertainty





Diamond Light Source

ATF2 Beta Functions

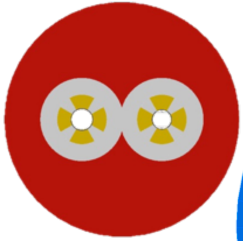


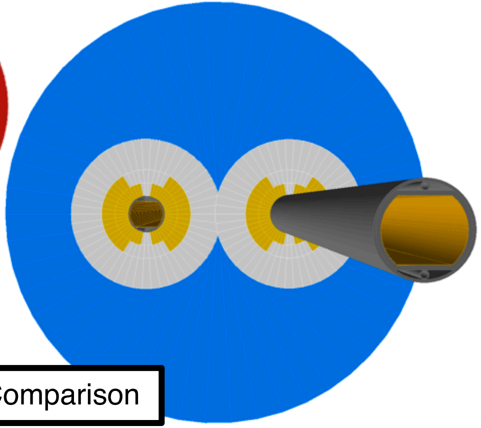
Examples

LHC Ion & Proton Collimation

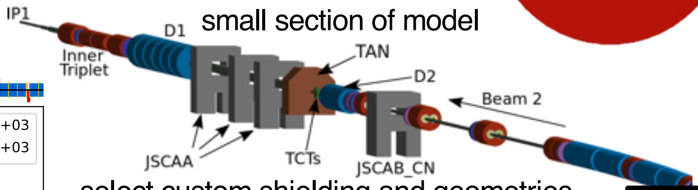
- Full LHC ring model created in BDSIM / Geant4
  - for studying collimation and detector backgrounds
  - ~15k beam line elements with ~300k volumes
  - supports multi-turn tracking
  - mostly based on simplified geometry

generic arc geometry

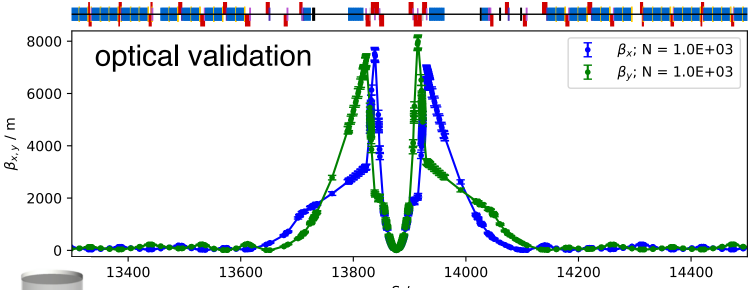




small section of model

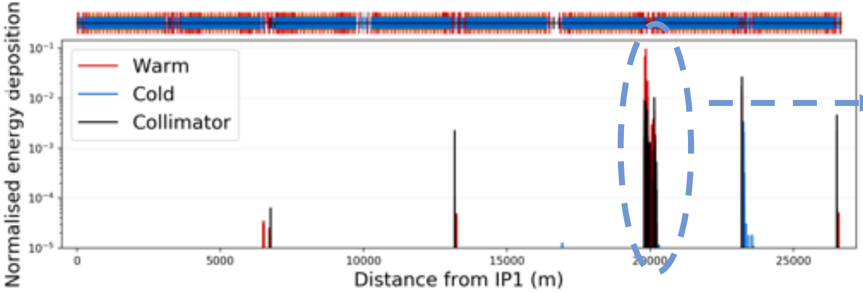


select custom shielding and geometries

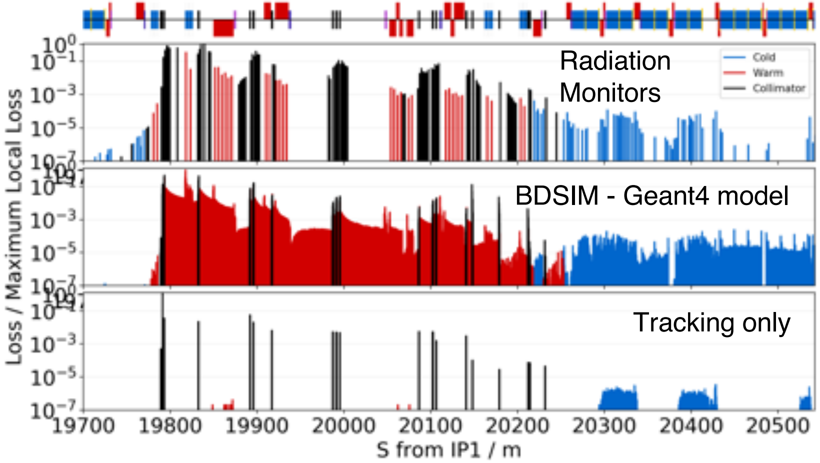


BLM modelling

proton loss map for collimation



IR7 Comparison

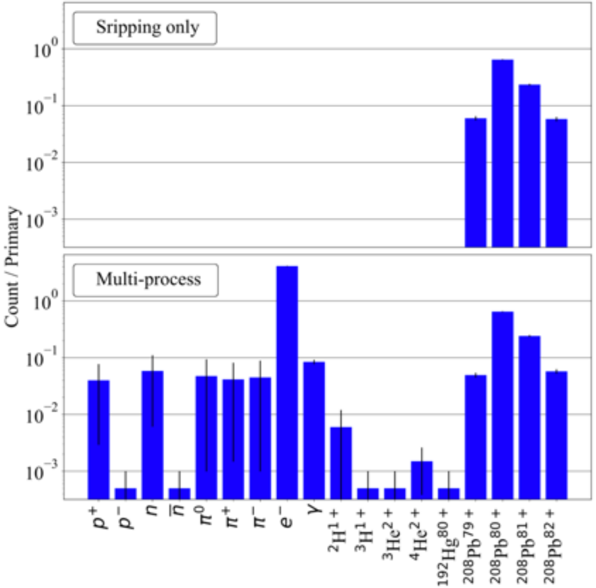


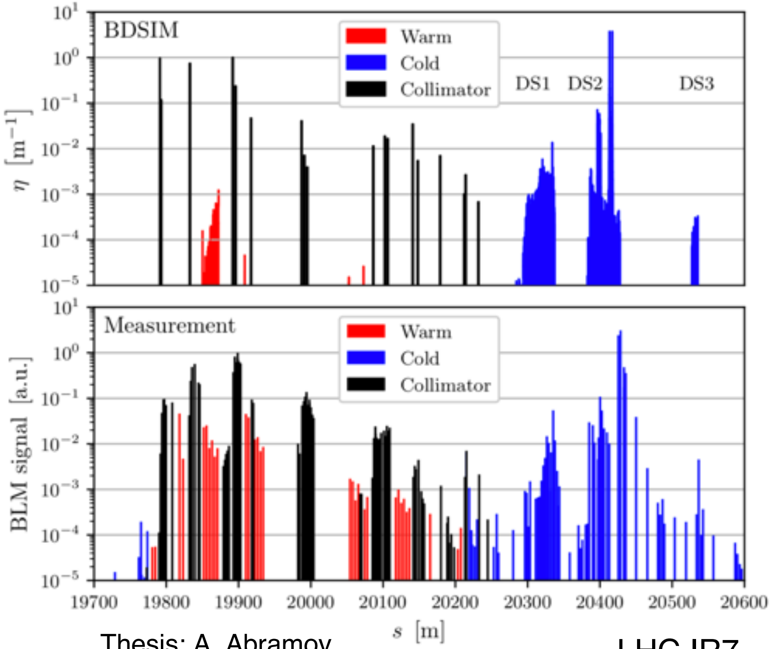
Partially Stripped Ions in Geant4

A. Abramov thesis 2020

- No partial stripping of ions in Geant4
- RHUL PhD Student Andrey Abramov adding the physics process
- Andrey also working as part of CERN collimation team with CERN simulation framework

different partially stripped ions after passing through thin foil





Thesis: A. Abramov

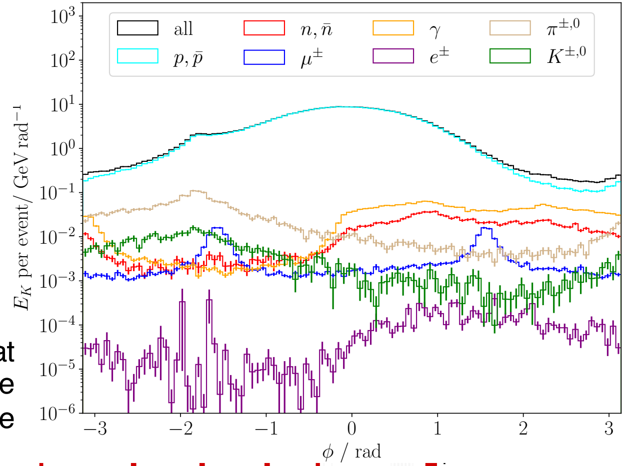
LHC IR7

PSI collimation
https://ipac2019.vrws.de/papers/moprb058.pdf

new physics in Geant4 / BDSIM
https://ipac2019.vrws.de/papers/thpmp034.pdf

ATLAS Non-Collision Backgrounds

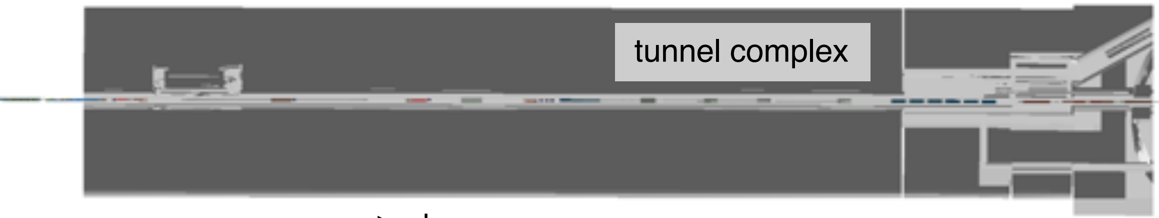
- Detailed model of IR1 leading up to ATLAS created
- Beam simulated up to "interface plane" 22.6m before
  - hand off to dedicated ATLAS simulation
- Simulate experimental pressure bumps using cross-section biasing in select regions
- Simulations allow understanding of origin and transport of penetrating background
- Good agreement with experimental data found



spectra at interface plane

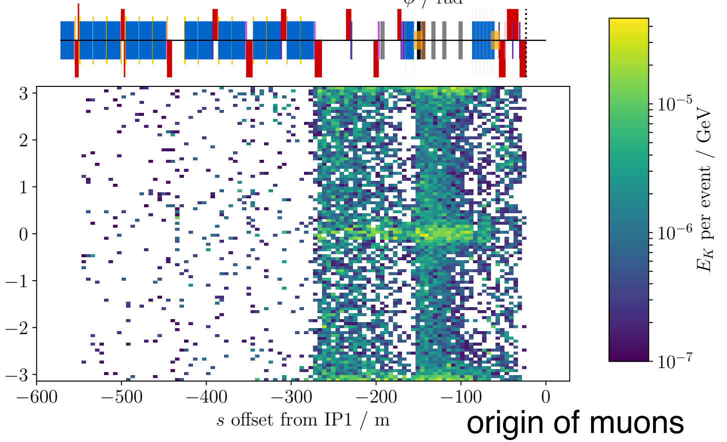
S.D. Walker thesis 2020

~300m before ATLAS



beam

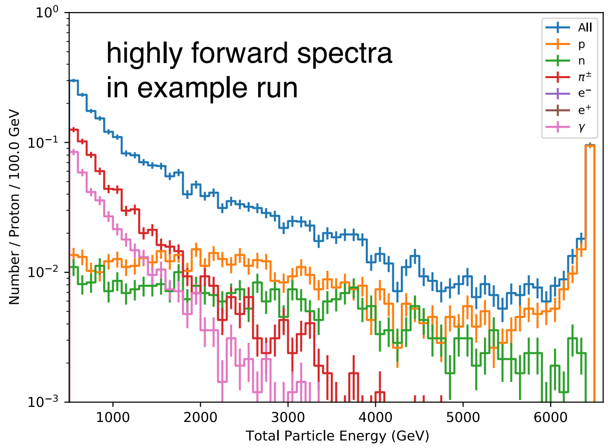
ATLAS IP

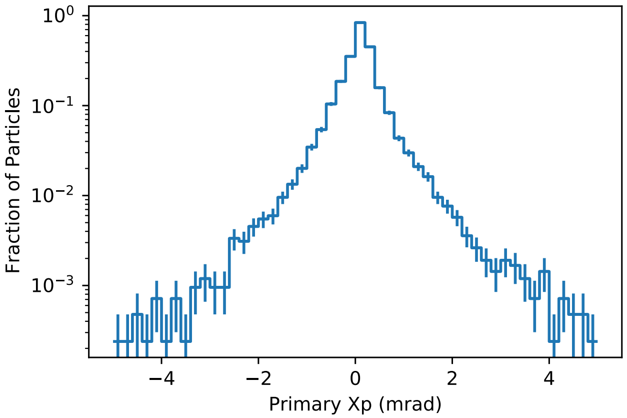


origin of muons

LHC Physics Debris

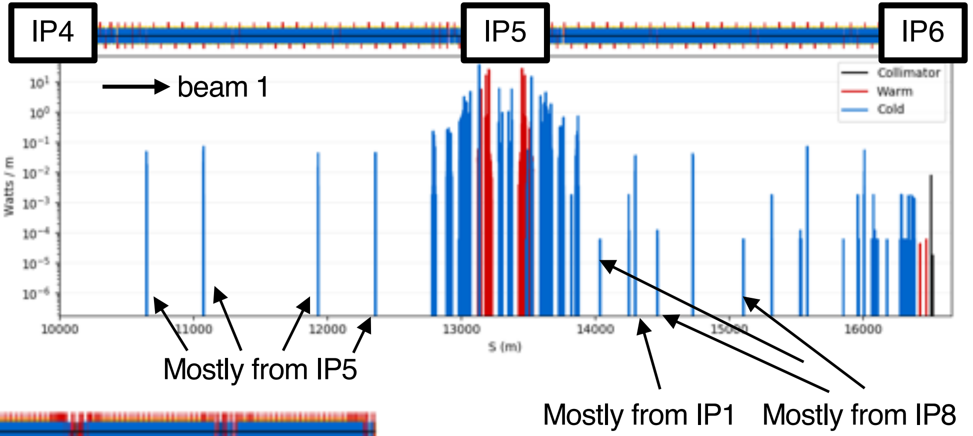
- A very interesting application is physics debris
- Elastically and inelastically scattered protons and *secondaries* can reach far from the experiments into the accelerator
- Certain beam loss monitors are highly correlated with luminosity and not with the stored beam intensity
- This isn't a problem for the machine but it is measurable
- We can use this to measure the luminosity or, assuming the luminosity: the total cross-section
  - with down-selection to beam loss monitors that only represent luminous beam losses
- *Potential for forward physics simulations!*

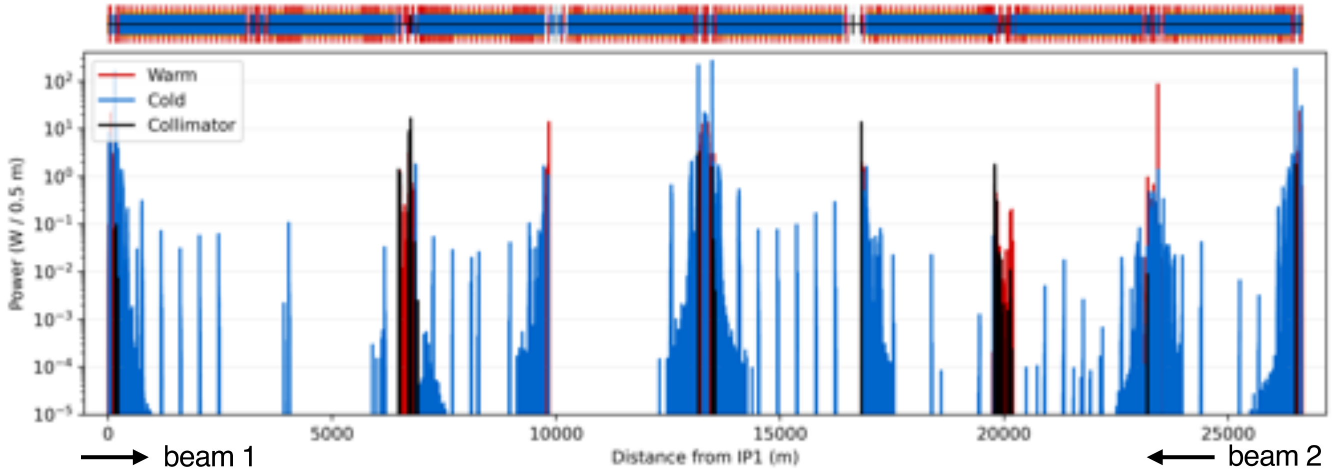




LHC Physics Debris Simulations

- Simulate head-on p-p collision with event generator at IPs 1,5 and 8
  - CRMC using SIBYLL 2.3 model
  - add on beam collision angle to primaries and propagate from each IP
- Record energy deposition throughout
  - individual peaks in arcs agree well with known BLMs to be correlated with luminosity





Weighted combination of each study according to luminosity

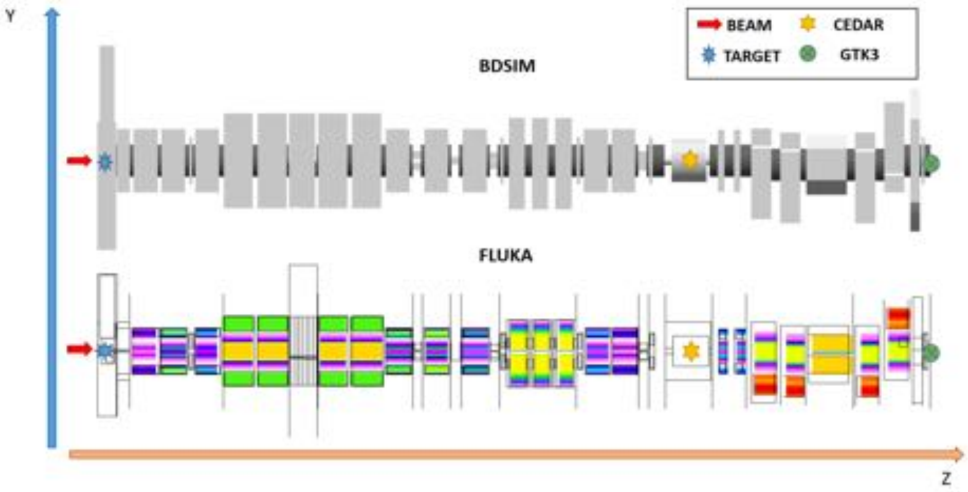
IP	Luminosity
1	1.5×10^{34}
5	1.5×10^{34}
8	0.05×10^{34}

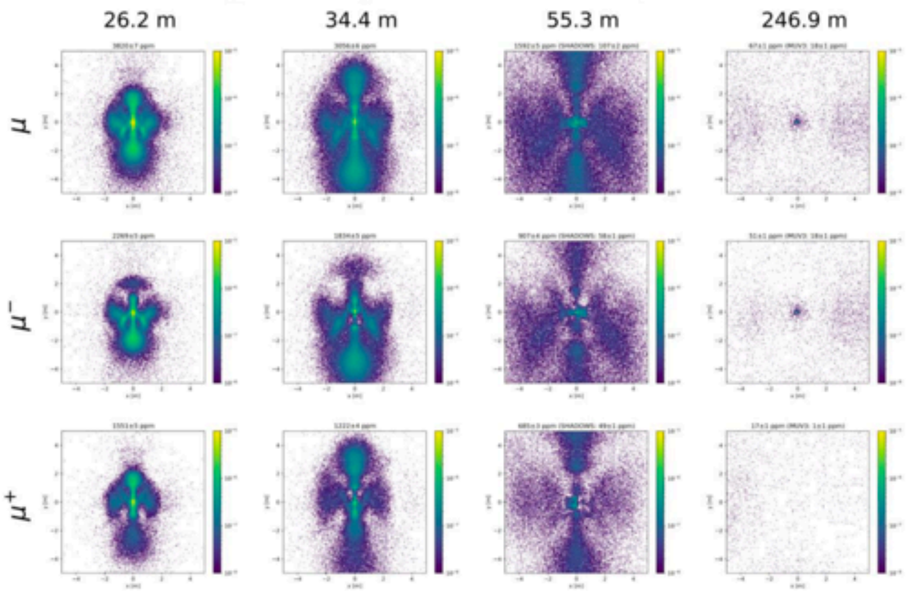
NA62 / KLEVER

G.L. D'Alessandro, F. Stummer

https://arxiv.org/abs/1703.08501

- NA62 at CERN to study rare charged Kaon decay
- Highly detailed model built by PhD stude Gian Luigi D'Alessandro
  - joint CERN BE-EA-LE & RHUL PhD





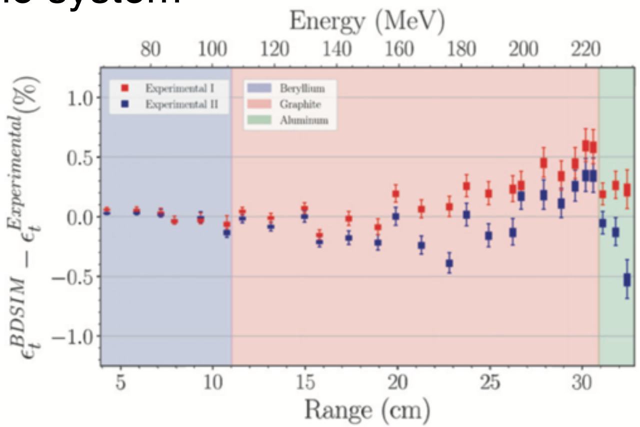
muon distribution at various planes

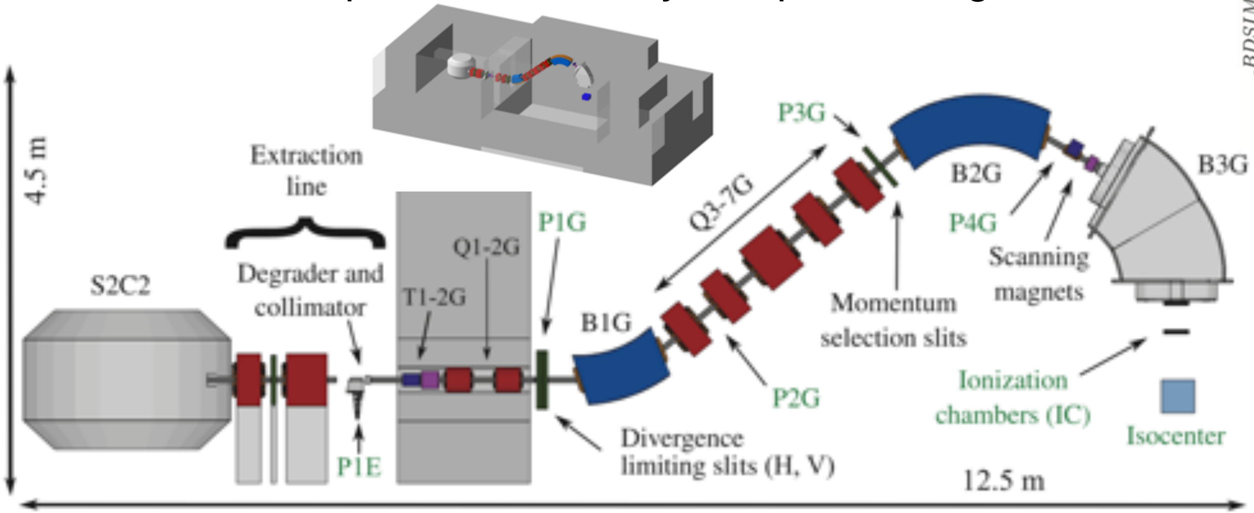
IBA Proton Therapy

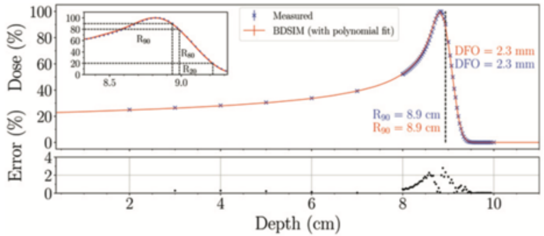
W. Shields, C. Hernalsteens, R. Tesse

ROYAL HOLLOWAY UNIVERSITY OF LONDON

- In collaboration with ULB & IBA we simulated their Proteus One system
- Beam launched from exit of cyclotron
  - interaction in material throughout including degrader
- Excellent agreement in Bragg peaks in water phantom
  - start-to-end simulation
- Further developments underway for space-charge





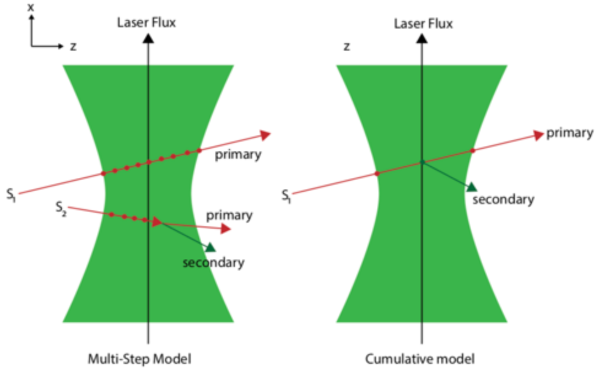


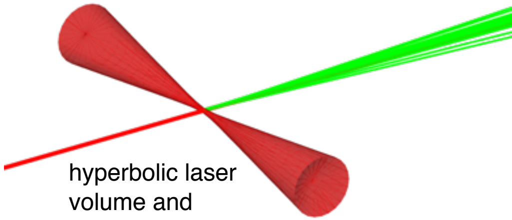
(a) Depth-dose profile for a range of 8.82 cm.

[C. Hernalsteens, L. Nevay et al., European Physics Letters, 132 (2020) 50004]

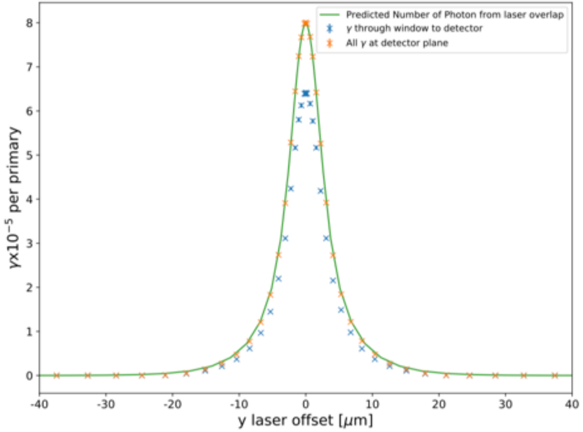
Gamma Factory & Laserwires

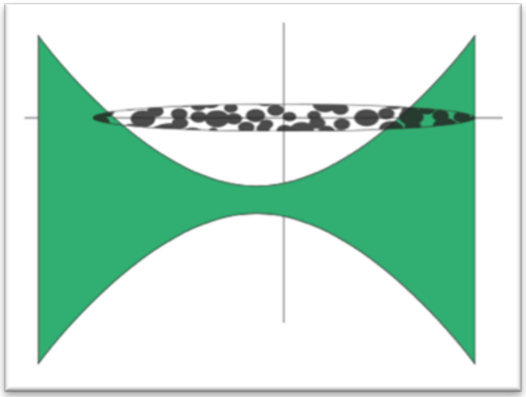
- Gamma Factory proposes to use partially stripped ion beams at the LHC (Pb + 1e-)
  - laser excites electron
  - spontaneous emission photon boosted
- Long history of Laserwires at RHUL
  - laser profile scanner -> Compton scattered photons
  - also H^- laserwire where H^- is stripped - LINAC4 & FETS
- Model in Geant4 with new process
  - work by Siobhan Alden, RHUL PhD student
  - ion tracking by Will Shields in BDSIM
- Discrete processes for:
  - photo-detachment
  - Compton scattering
  - Absorption
  - Spontaneous emission
  - Stimulated emission
- Modified G4LogicalVolume for laser interaction specifically
  - allows for non-uniform 'density' of photons
  - ie custom probability





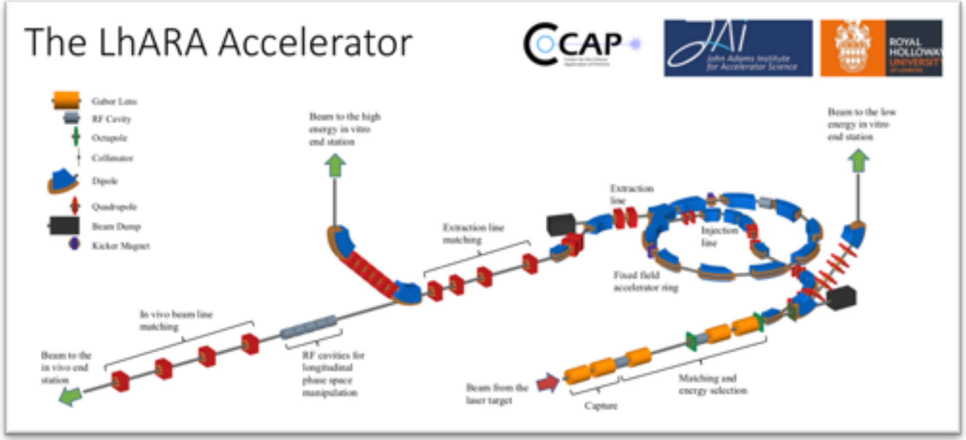
hyperbolic laser volume and secondary photons

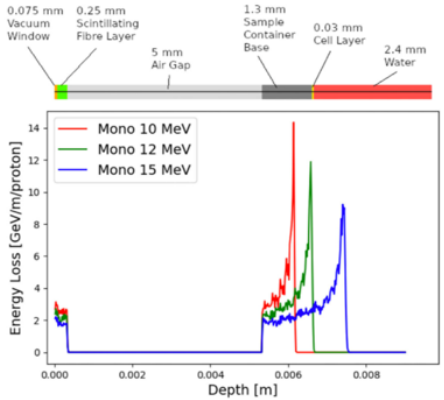




https://ipac2019.vrws.de/papers/thprb095.pdf

Notable Mentions



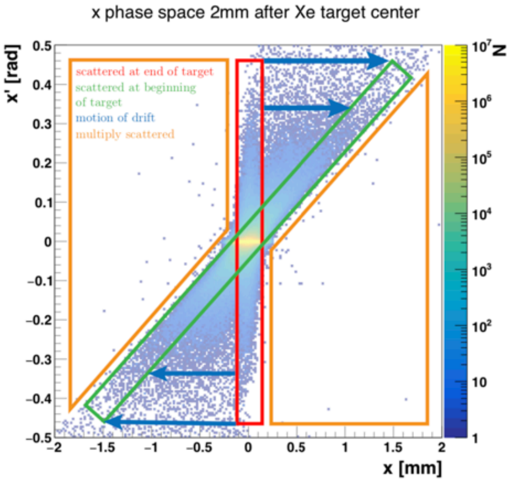


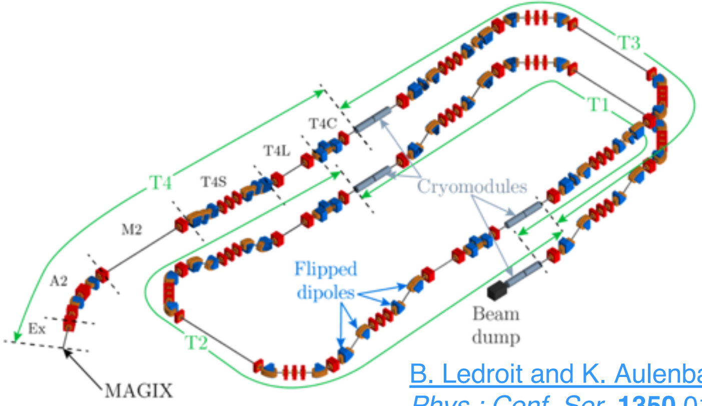
LhARA and **CCAP**
Proposed radiobiological research facility
W. Shields calculating beam transport throughout and expected dose in experimental station

[LhARA: The Laser-hybrid Accelerator for Radiobiological Applications, Frontiers in Physics, 8 (2020), 432]

MAGIX @ MESA
Target Induced Halo Formation
in Energy Recovery Linac

Thesis by Ben LeDroit JGU Mainz





[B. Ledroit and K. Aulenbacher 2019 *J. Phys.: Conf. Ser.* **1350** 012138]

More Detailed Geometry

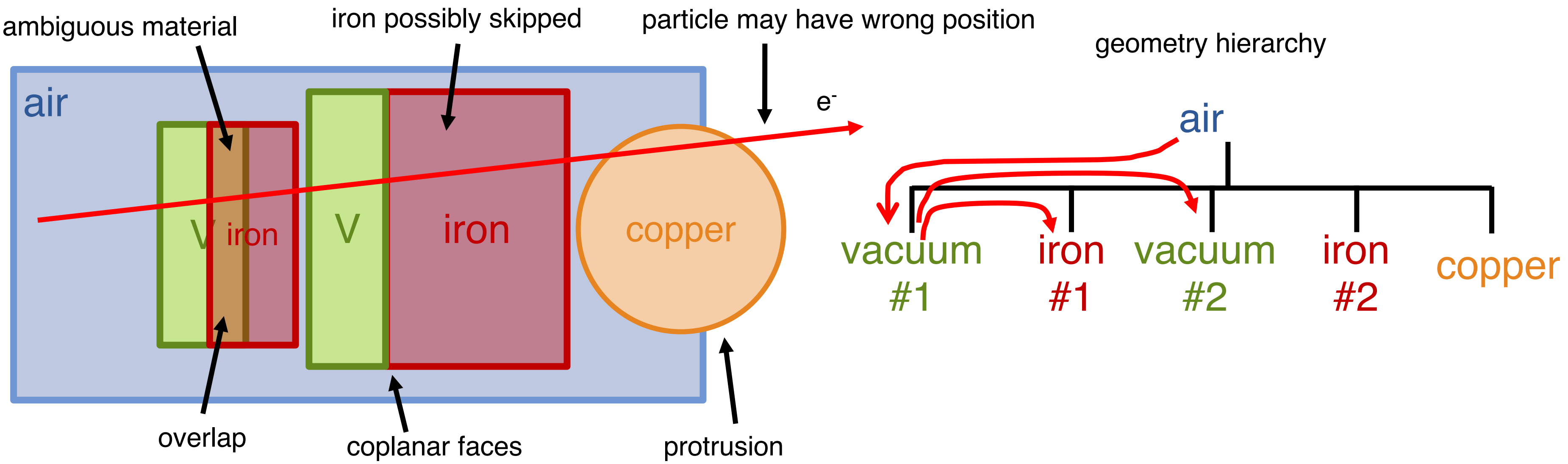
• • •

More Detailed Geometry

- So far, we've used a library of scalable geometry
  - predefined components for a common purpose, e.g. quadrupole
  - built into BDSIM
- What about other geometry specific to an experiment?
  - not looking to make the detector model - assume this is specialised
  - but some more detailed geometry relevant to get the right outcome
- 3 hurdles:
  - ability to **import** / **place** it in a Geant4 model
  - **creation** of geometry from scratch
  - **conversion** of detailed geometry from another format
- Goal: a PhD student can reasonable geometry in reasonable time for study
  - days to weeks, not months to years
  - what can 1 person do and learn

Overlaps & Tracking

- When defining geometry, it's entirely possible to define something non-sensical
- Shapes are just instances of classes with translations and rotations
- Users must contend with Constructive Solid Geometry (or combinatorial)
- Unlike the real world, we can't place things 'against' another in CSG



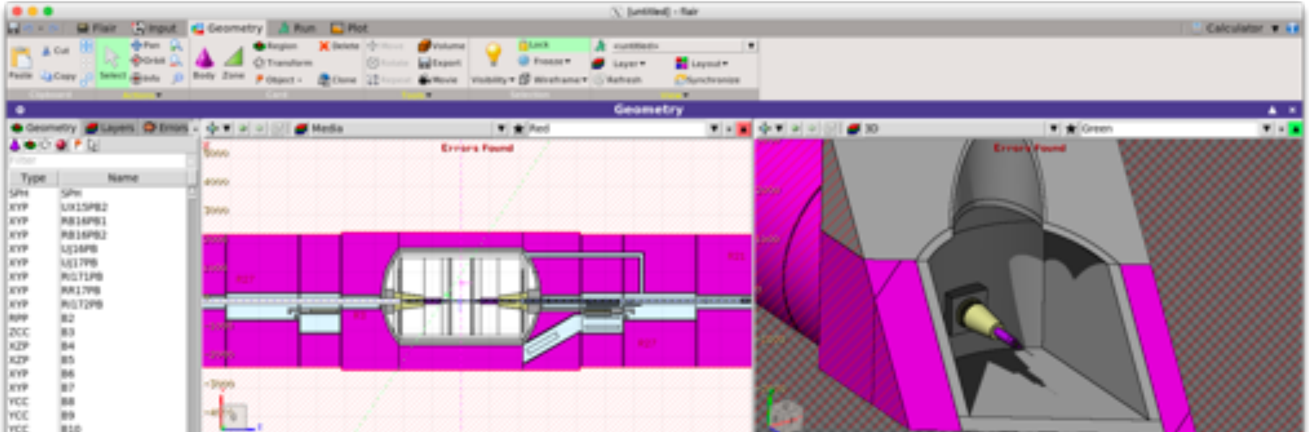
Geometry Formats - Possible Sources

- GDML
  - persistency format of Geant4 - made for single file dump of geometry
  - XML
  - NB solids parameterised different to Geant4 C++
- Geant4 C++
  - developer writes C++ in their application using Geant4
  - requires compilation to change (typically)
  - Geant4 constructors of solids register themselves in static registries (1 complete geometry)
- FLUKA
  - text input - a bit hard to read, but comes with FLAIR GUI to create, inspect and debug
  - can have coplanar faces as faces can be used by both 'sides' of a shape
  - need to 'cut' out air as flat hierarchy
- CAD
  - many formats - common features not often present in radiation transport models, e.g. chamfering
- Tessellated Solids / Meshes
  - surface represented by series of polygons - commonly used for finite element simulations
  - potentially huge mesh and slow tracking (lots of research on this!)
  - problems if mesh has holes (waterbag)

FLUKA Geometry

- FLUKA is an alternative to Geant4 and typically used for radiation shielding applications and machine protection
  - also used for variety of nuclear applications
- Certified for radiological protection by many organisations
  - therefore often require a FLUKA model at some point
- A lot of geometry in this format at CERN for example
- Uses combinatorial geometry with ***infinite-half*** solids and ***no hierarchy***

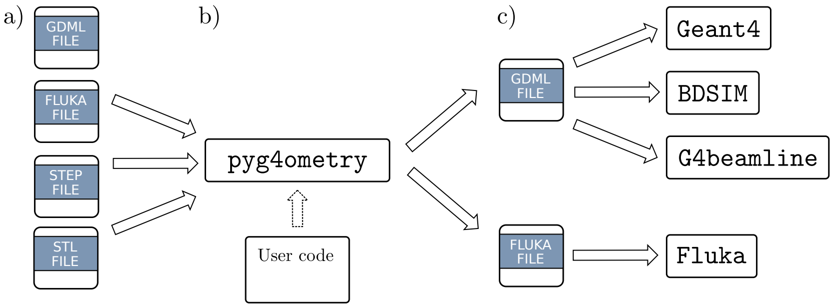
https://fluka.cern

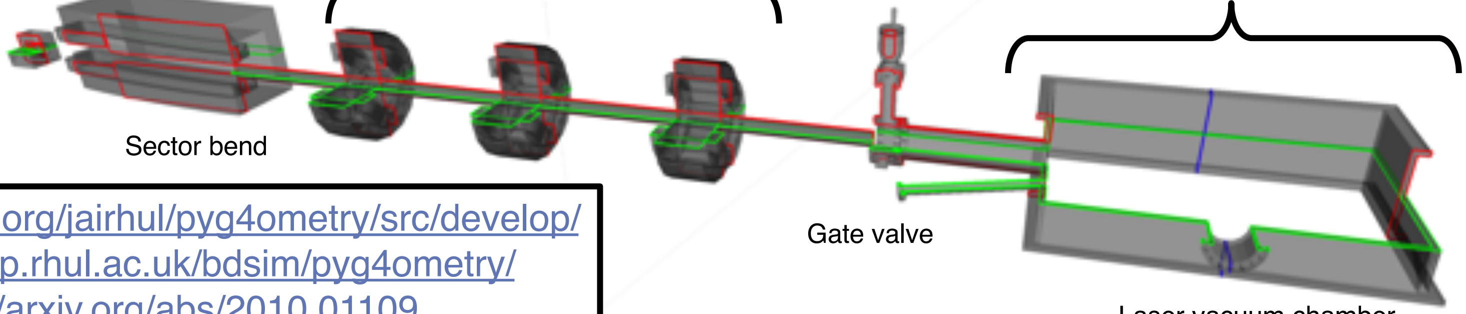


pyg4ometry

Stewart Boogert

- Python package to rapidly prepare and convert geometry for Geant4 & FLUKA
  - create / convert / composite geometry
  - validate and ensure safe for tracking (no overlaps etc)
- Place custom components in Geant4 / BDSIM
- Have parity with models in Geant4 & FLUKA



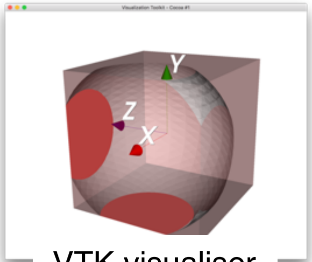


https://bitbucket.org/jairhul/pyg4ometry/src/develop/
http://www.pp.rhul.ac.uk/bdsim/pyg4ometry/
https://arxiv.org/abs/2010.01109

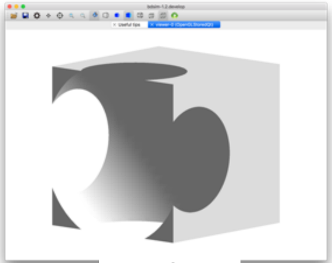
email stewart.boogert@rhul.ac.uk

pyg4ometry

- Geant4 visualiser has some limitations
  - limited support of Booleans
  - no visualisation of overlaps
- Create our own meshes to render geometry in our visualiser
- Use VTK visualiser and CGAL for mesh operations
- Use ANTLR for parser
  - abstract syntax trees of input geometry files
- Expression engine support for variables
  - maintain variables and expressions that GDML can handle



VTK visualiser



BDSIM

Python Scripting of GDML

Geometry scripting using Python

```python
import pyg4ometry.gdml as gd
import pyg4ometry.geant4 as g4
import pyg4ometry.visualisation as vi

# create empty data storage structure
reg = g4.Registry()

# materials
wm = g4.MaterialPredefined("G4_Galactic")
bm = g4.MaterialPredefined("G4_Fe")

# solids
wb = g4.solid.Box("wb",100,100,100,reg)
b  = g4.solid.Box("b",10,10,10,reg)

# structure
wl = g4.LogicalVolume(wb, wm, "wl", reg)
bl = g4.LogicalVolume(b, bm, "b", reg)
bp1 = g4.PhysicalVolume([0, 0, 0], [0, 0, 0],
                        bl, "b_pv1", wl, reg)
bp2 = g4.PhysicalVolume([0, 0, -0.25],
                        [-2*10, 0, 0],
                        bl, "b_pv2", wl, reg)
bp3 = g4.PhysicalVolume([0, 0, 0.5],
                        [20,0,0],
                        bl, "b_pv3", wl, reg)

# define world volume
reg.setWorld(wl.name)

# gdml output
w = gd.Writer()
w.addDetector(reg)
w.write("output.gdml")

# visualisation
v = vi.VtkViewer()
v.addLogicalVolume(wl)
v.setRandomColours(); v.setOpacity(1)
v.addAxes()
v.view()
```

Materials

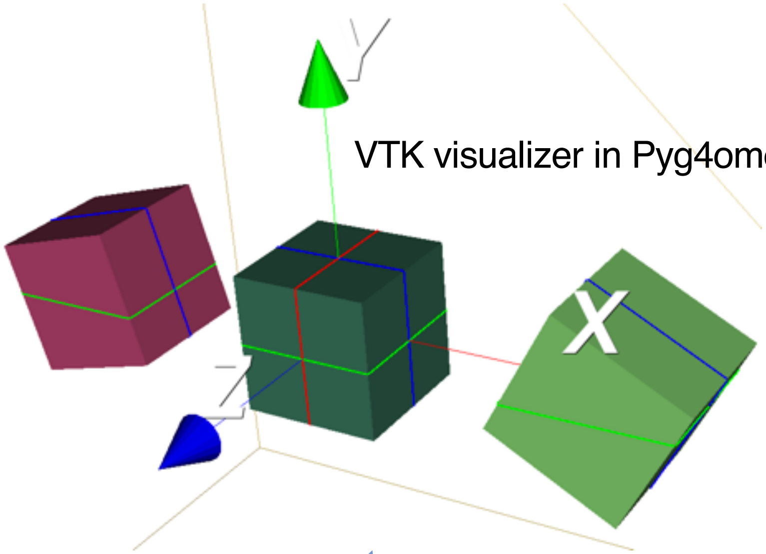
Solids

Geometry hierarchy definition

Write to GDML

Visualise (shown right)

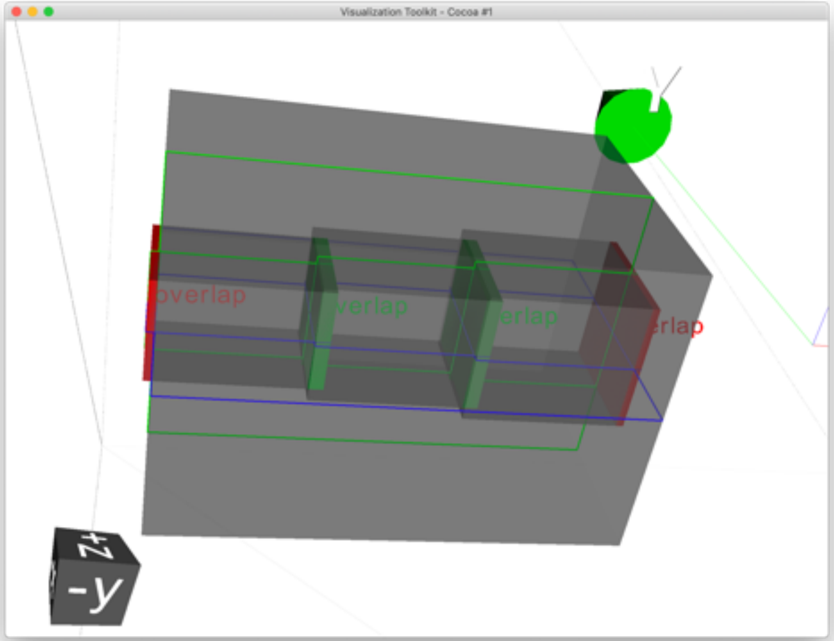
VTK visualizer in Pyg4ometry



Overlap Identification

- Use visualisation meshes to identify geometry problems
- e.g. an overlap will form a valid intersection of meshes
- Use this overlap mesh also for visualisation
  - if the user can see where the problem is it's often easy to fix
- In Geant4 overlap reports can be hard
  - local coordinates etc, -> better in 10.7!
  - not always identified

```
Checking overlaps for volume bbrr_pv (G4Orb) ...
-------- WWWW ------- G4Exception-START -------- WWWW -------
*** G4Exception : GeomVol1002
      issued by : G4PVPlacement::CheckOverlaps()
Overlap with volume already placed !
          Overlap is detected for volume bbrr_pv:0 (G4Orb)
          with bbr2_pv:0 (G4Orb) volume's
          local point (562.925,-491.466,564.793), overlapping by at least: 6.32957 cm
NOTE: Reached maximum fixed number -1- of overlaps reports for this volume !
*** This is just a warning message. ***
-------- WWWW -------- G4Exception-END --------- WWWW -------
```

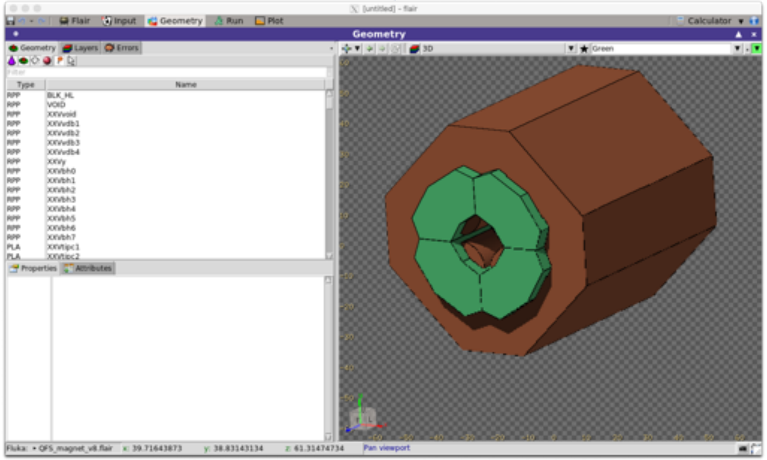


Conversion: FLUKA TO GDML

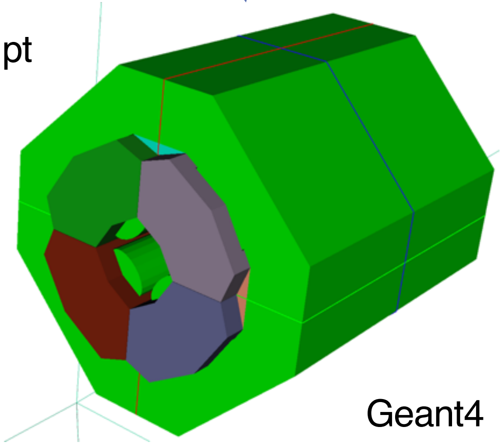
- KLEVER QFS Quadrupole designed in FLAIR and translated to Geant4.

```
import pyg4ometry.fluka as fluka
import pyg4ometry.convert as conver

reader = fluka.Reader("qfs.inp")
greg = convert.fluka2Geant4(reader.flukaregistry)
wlv = greg.getWorldVolume()

v = vi.VtkViewer()
v.addLogicalVolume(wlv)
v.setOpacity(1)
v.setRandomColours()
v.view()
```

Simple Pyg4ometry script



FLUKA (FLAIR)

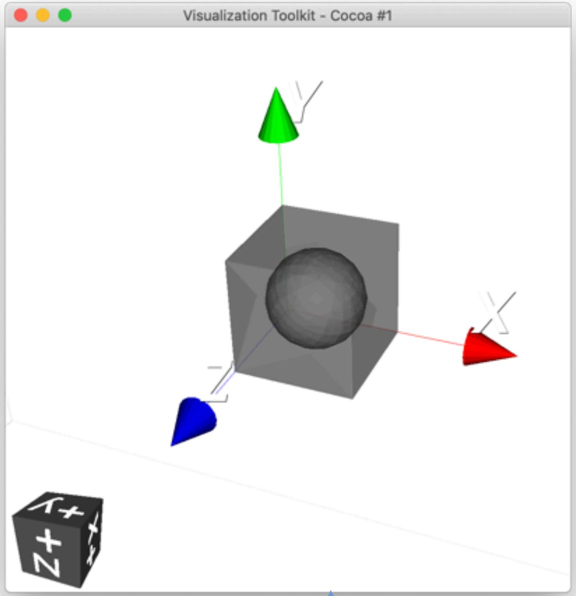


Geant4

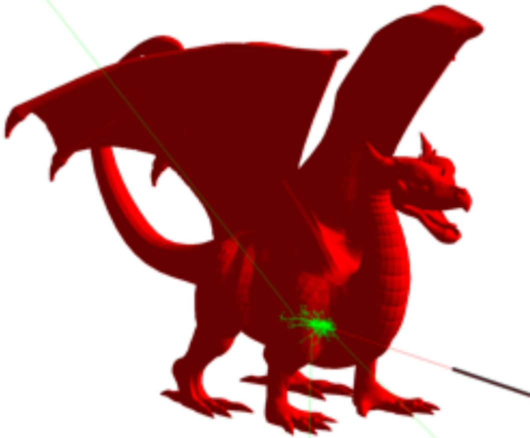
FLUKA scripting

- Also support pure Python FLUKA scripting.
- Enables programmatic manipulation of FLUKA geometries: previously not possible.
- Includes conversion to and from FLUKA.

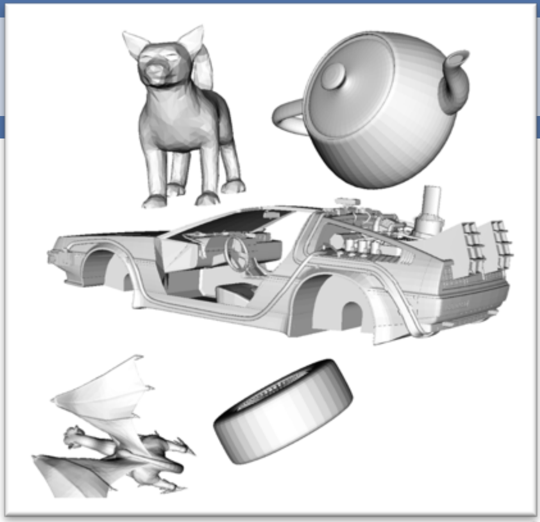
```python
import pyg4ometry.convert as convert
import pyg4ometry.visualisation as vi
from pyg4ometry.fluka import RPP, Region, Zone, FlukaRegistry, SPH


freg = FlukaRegistry()

rpp1 = RPP("RPP_BODY1", 0, 10, 0, 10, 0, 10, flukaregistry=freg)
sph = SPH("sph_body", [5, 5, 5], 4, flukaregistry=freg)

z = Zone()
z.addIntersection(rpp1)
z.addSubtraction(sph)
region = Region("RPP_REG")
region.addZone(z)
freg.addRegion(region)
freg.assignma("COPPER", region)

greg = convert.fluka2Geant4(freg)

v = vi.VtkViewer()
v.addAxes(length=20)
v.addLogicalVolume(greg.getWorldVolume())
v.view(interactive=interactive)
```

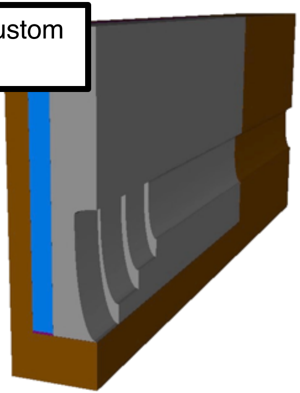


Examples

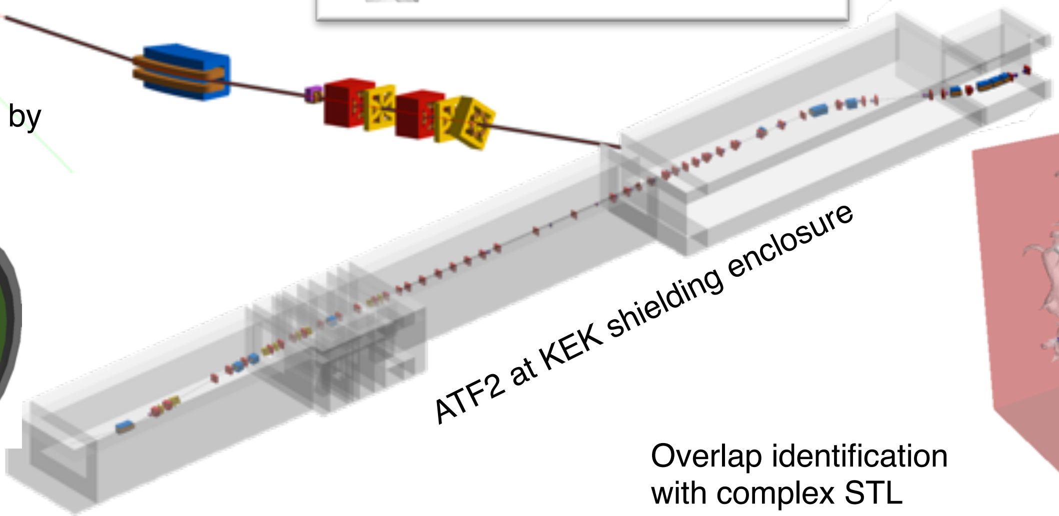


"Complex" STL mesh test by humorous PhD student

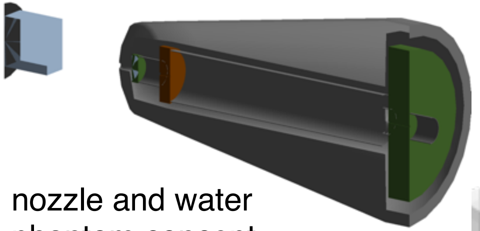




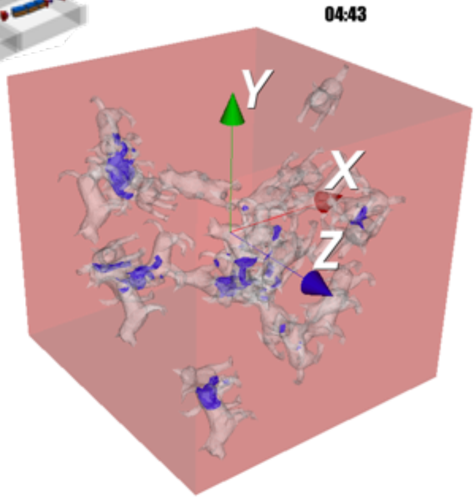
Cut away view of custom collimator for CLIC



ATF2 at KEK shielding enclosure



nozzle and water phantom concept

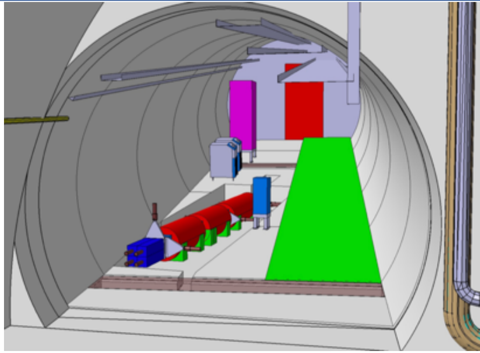


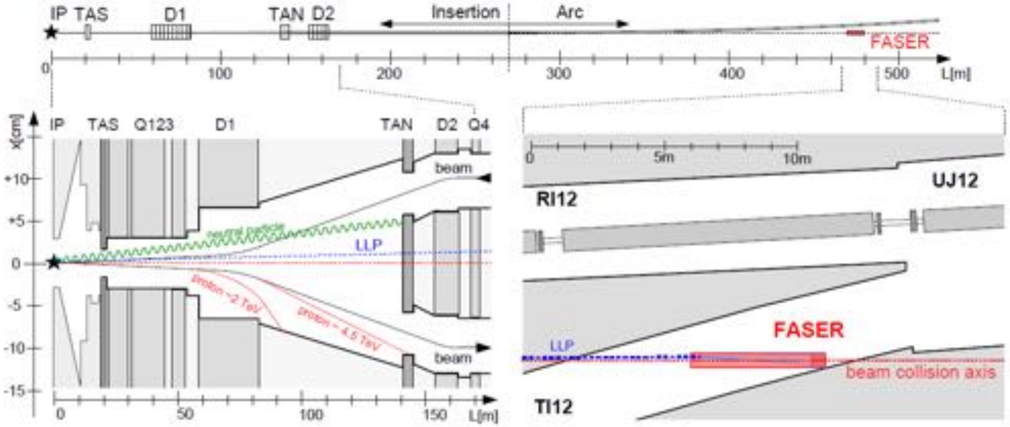
Overlap identification with complex STL meshes - box of dogs

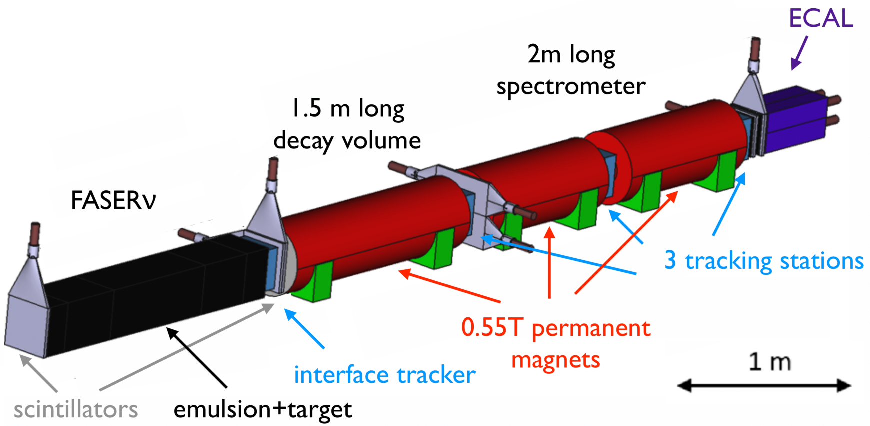
A More Complex Example: FASER

FASER / FASERnu

- Forward Search -> for Long Lived Particles
  - possible undiscovered exotic particles that are lightly coupled
- Along line of sight from ATLAS IP1 collisions at the LHC, CERN
- Minimal detector now being built for Run III (2022)
- Could make first measurement of collider-produced neutrinos (~TeV)!

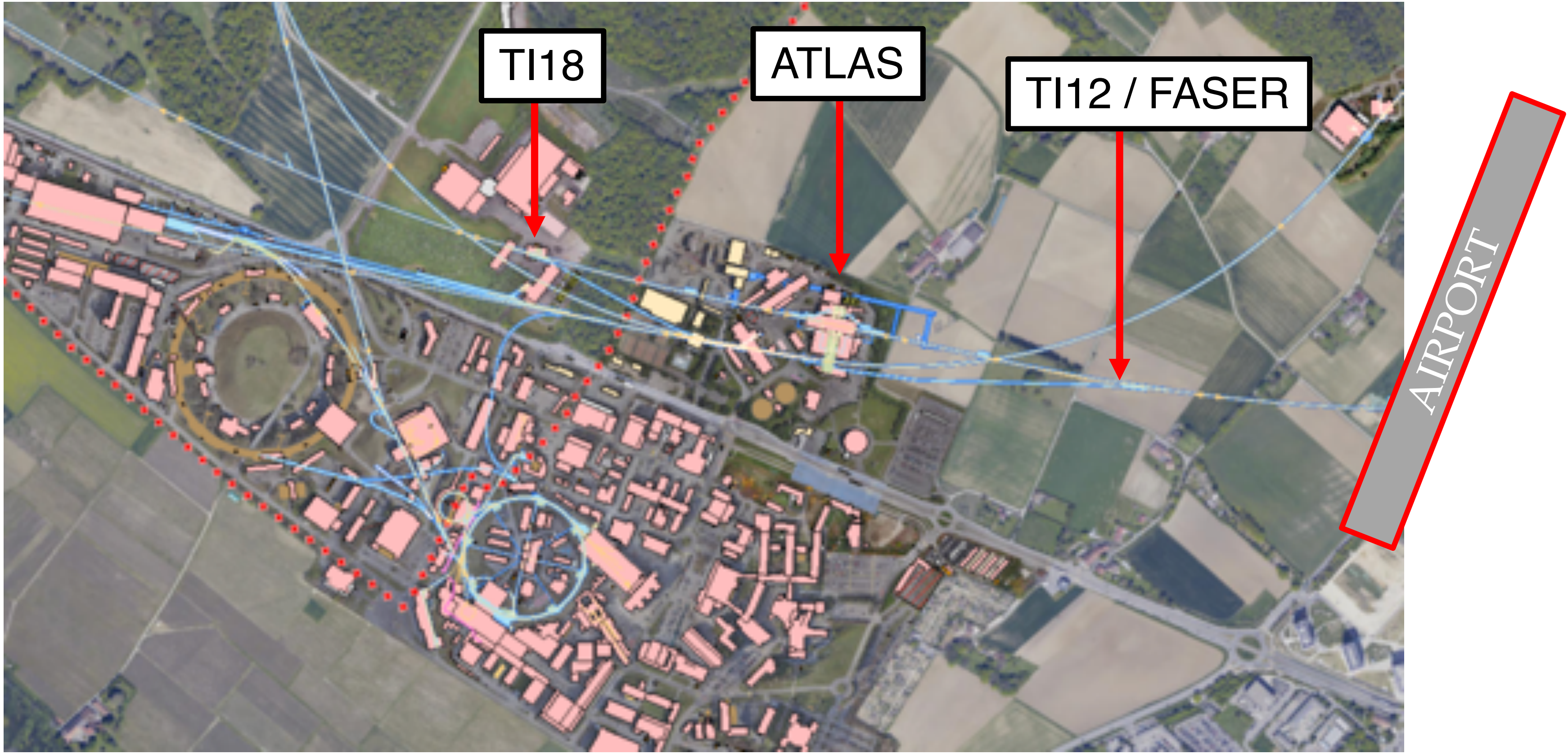






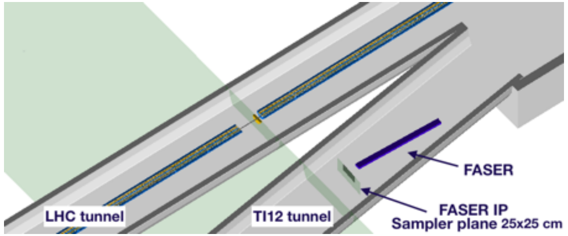
FASER Collaboration, Technical Proposal for FASER: ForwArd Search ExpeRiment at the LHC (2018) https://arxiv.org/abs/1812.09139
FASER Collaboration, Letter of Intent for FASER: ForwArd Search ExpeRiment at the LHC (2018) https://arxiv.org/abs/1811.10243

FASER Location at CERN



Forward Experiment Simulations

- Improve ATLAS NCB model: use outgoing from IP towards FASER
  - further detail added in tunnel geometry, side tunnel and absorbers
- Work by PhD student Helena Lefebvre
  - https://indico.cern.ch/event/868940/contributions/3815740/
- Used to predict muon and neutrino flux

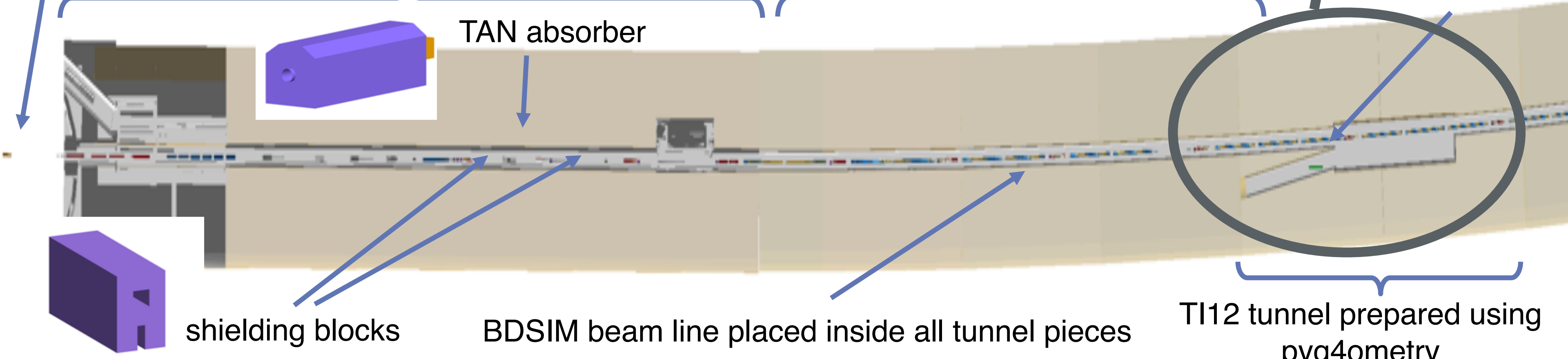


ATLAS IP

FLUKA converted tunnel complex

BDSIM generic tunnel

FASER



shielding blocks

BDSIM beam line placed inside all tunnel pieces

TI12 tunnel prepared using pyg4ometry

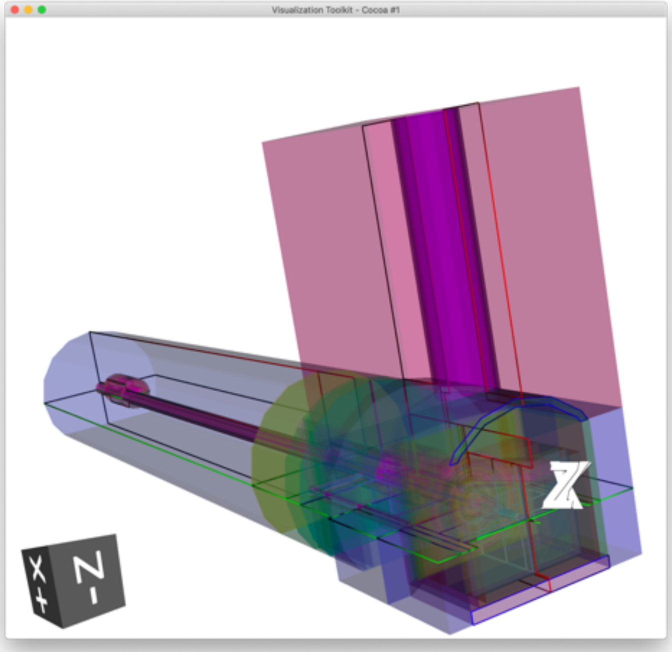
H. Lefebvre

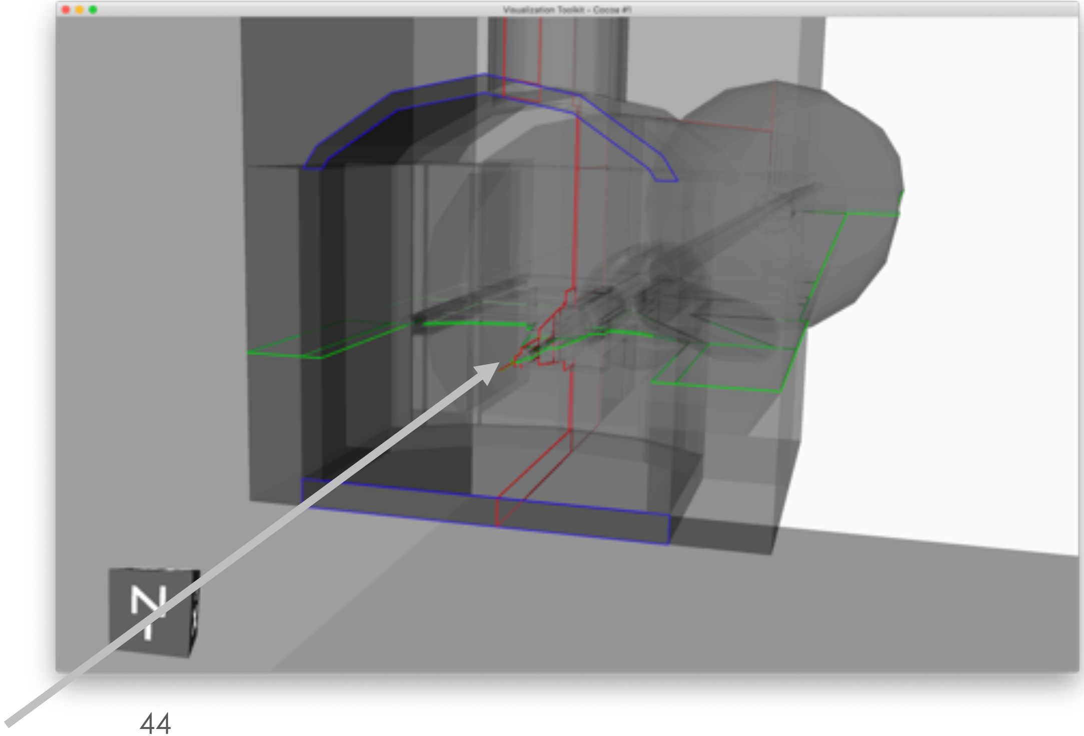
Model Rough Composition

- Model formed from 3 parts:
  1. FLUKA IR1 tunnel complex (already made) -> converted to Geant4 / GDML (up to S=239m)
  2. BDSIM-generated tunnel that follows beam line for a bit
  3. TI18 tunnel complex created by us in GDML using pyg4ometry
- Composite all 3 parts together into 1 model that's used as the "world"
- Using this world geometry, BDSIM will build the accelerator model in it
- Control geometry parameters in BDSIM for accurate shapes & sizes
  - LHC-style magnets, appropriate materials
- Get the TAN at the beam pipe split correct

FLUKA IR1 Conversion

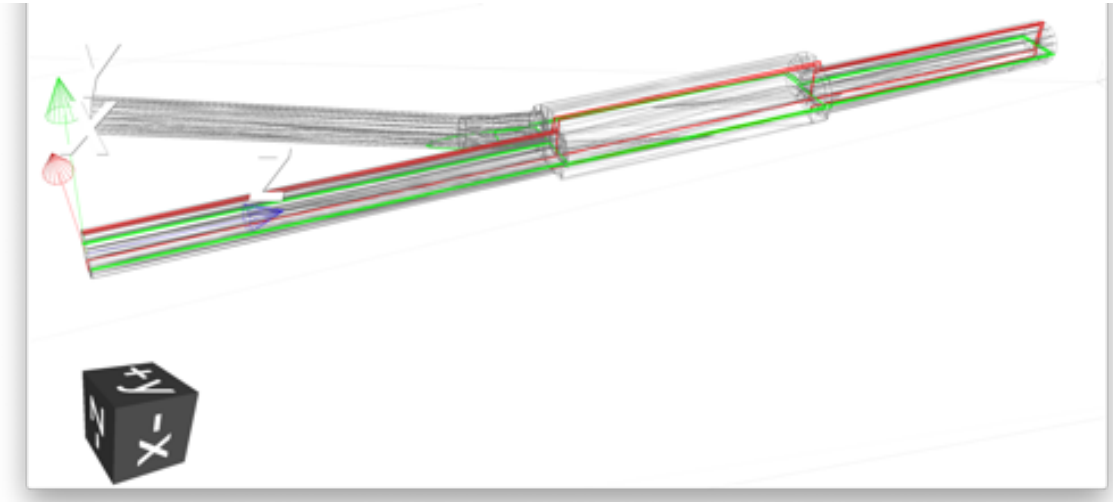
- Scripted removal of certain volumes (e.g. air, left over beam line bits)
  - remember no hierarchy in FLUKA so air volumes individually specified

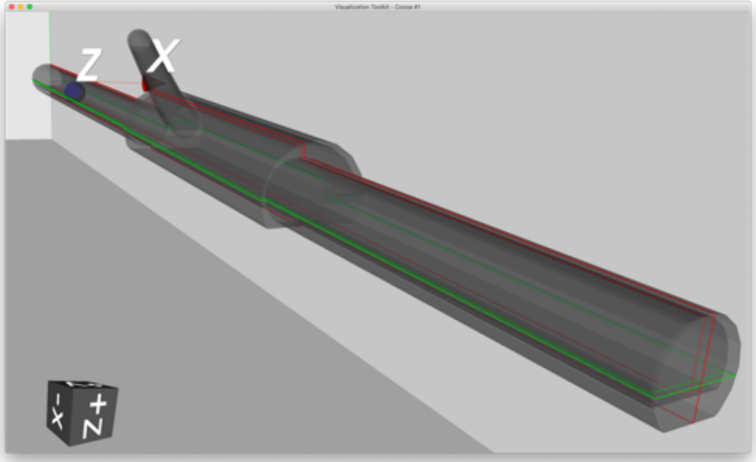




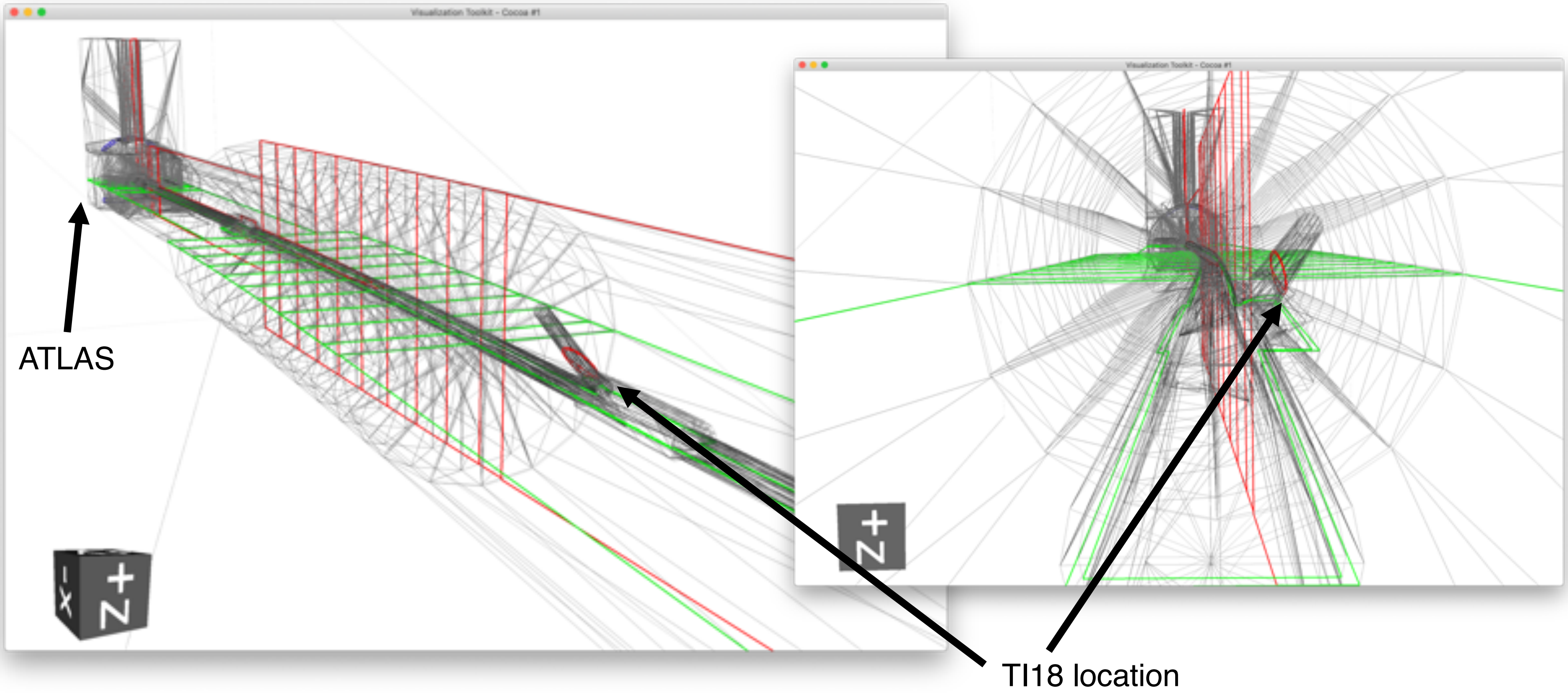
TI18 Tunnel Complex

- ~550 lines of python using pyg4ometry including various functions
- 4 rough parts (main tunnel, UJ18 hall, TI18 tunnel, RT18 hall)
- TI18 tunnel includes 3 sections with different grades and angles
  - ramp also included in UJ18 hall



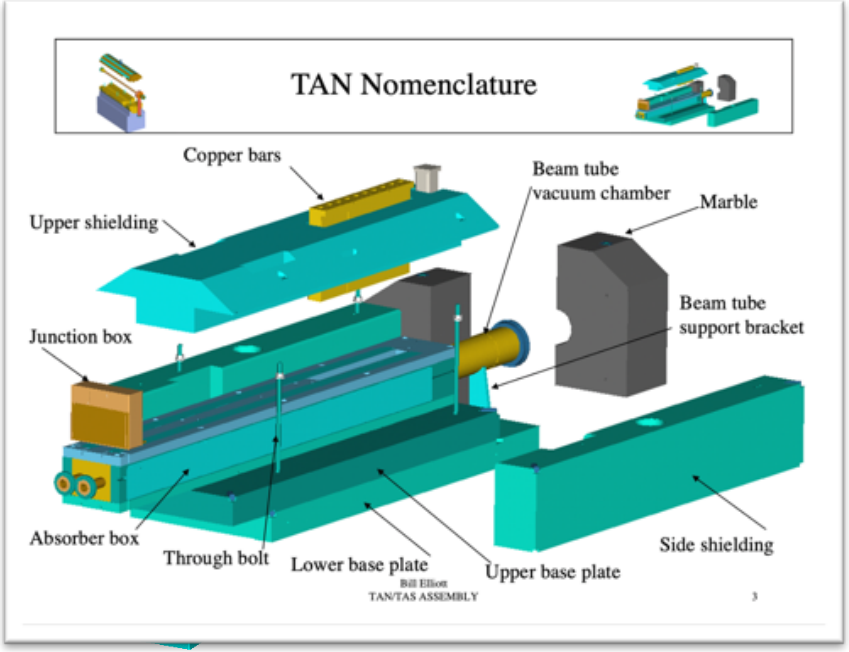


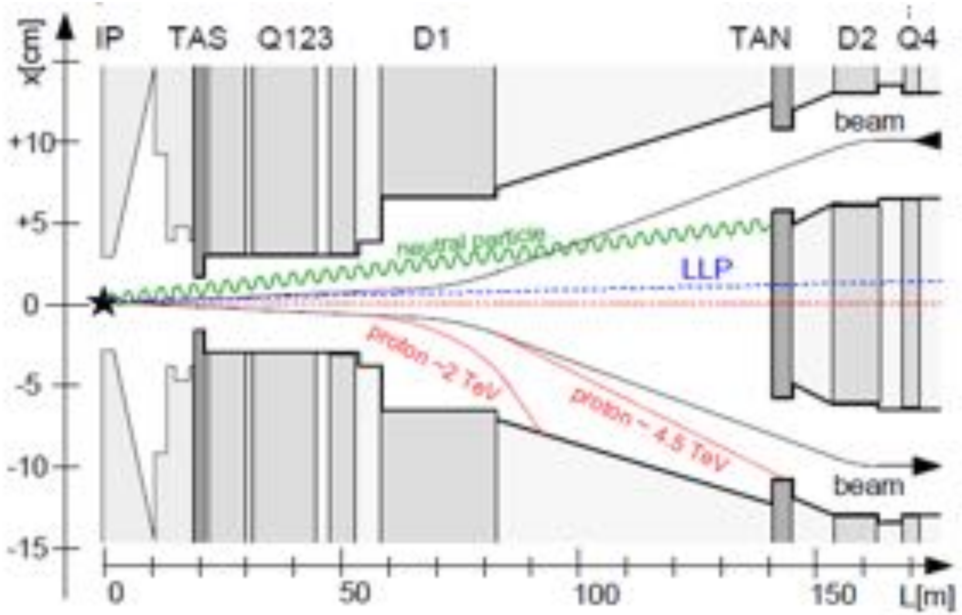
Composited Model



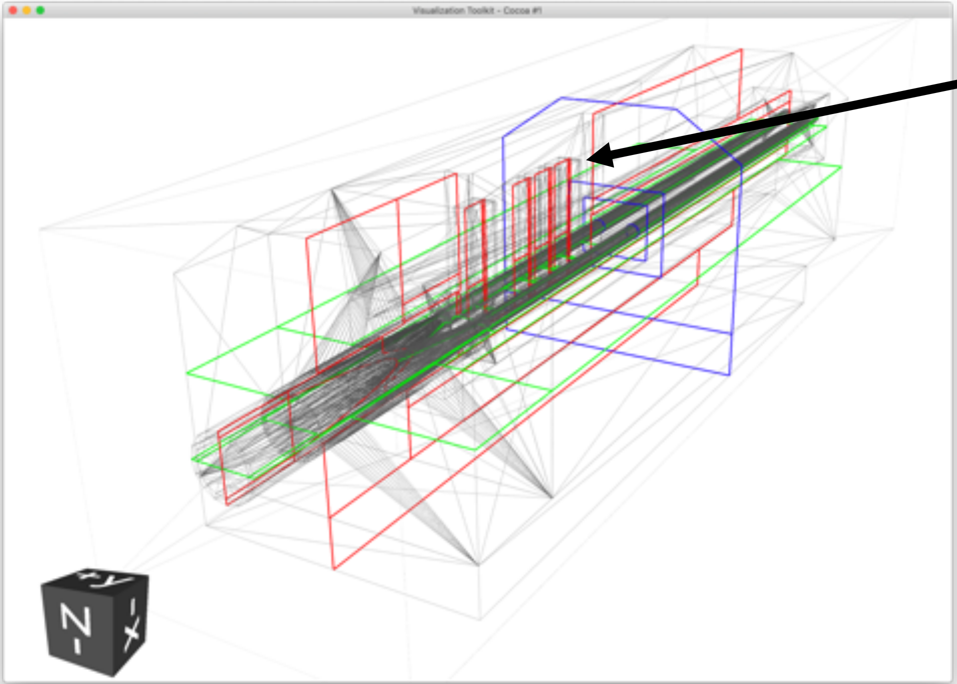
The TAN

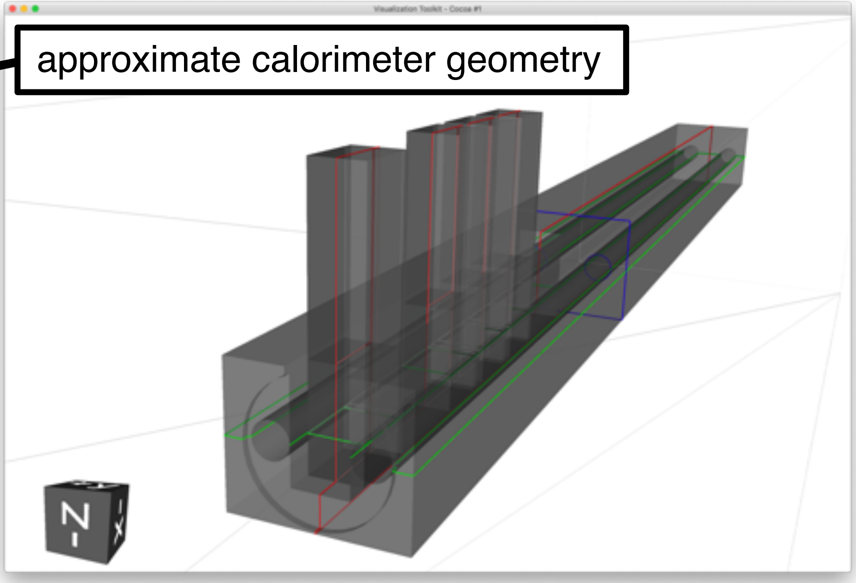
- Target Absorber Neutrals (TAN) is the absorber where the beam pipe splits into 2 from 1 after the interaction point
- Important as a lot will hit it



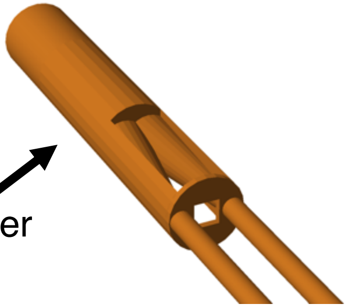


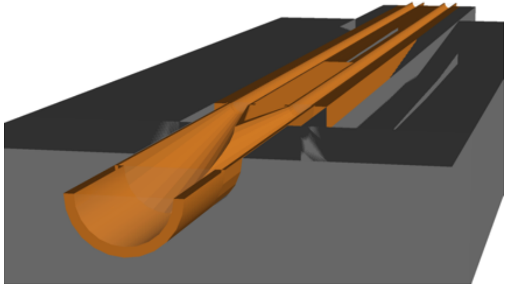
TAN Geometry





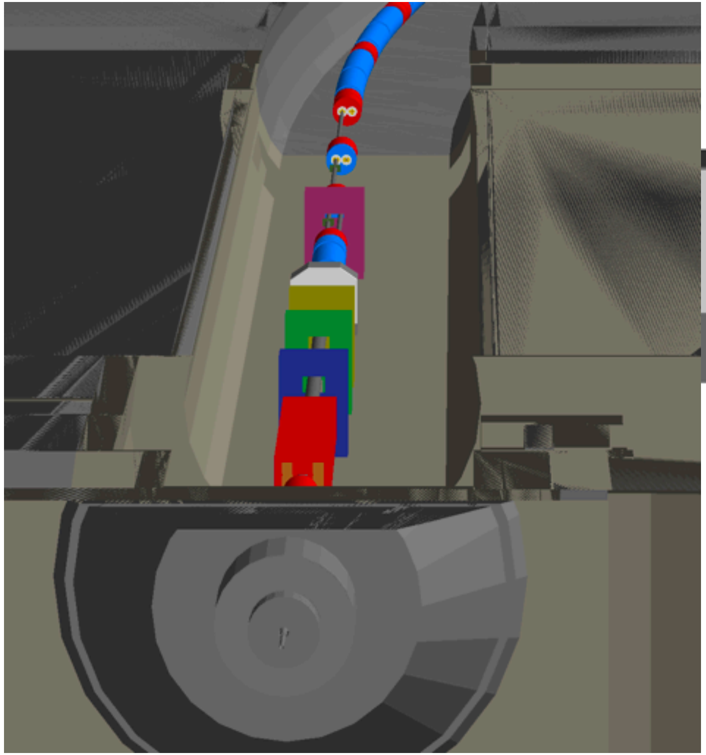
approximate calorimeter geometry

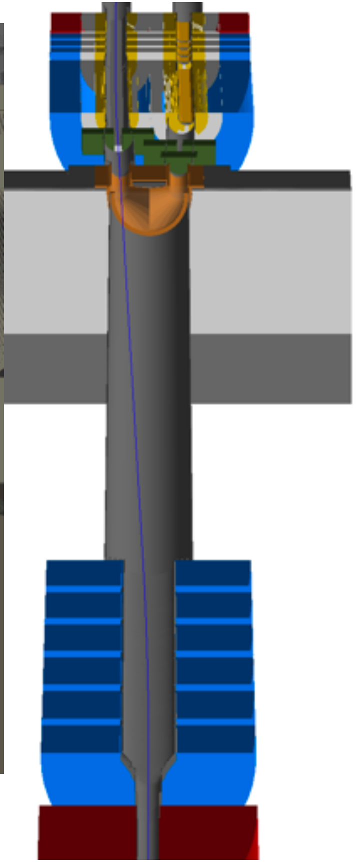


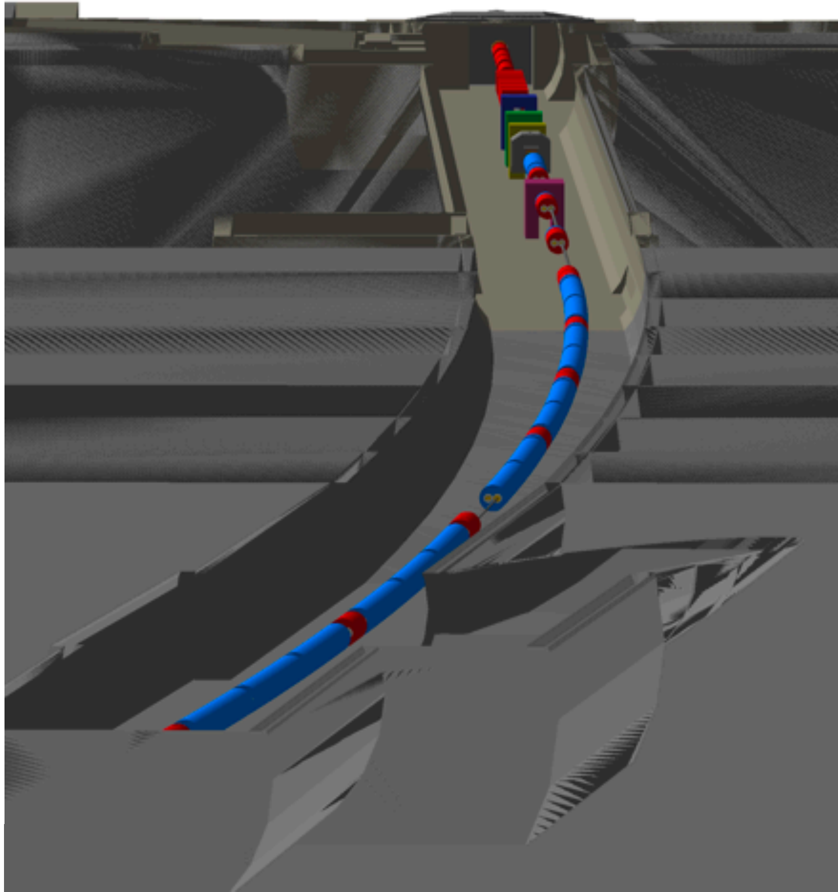


Pair of Pants split vacuum chamber

Complete Model

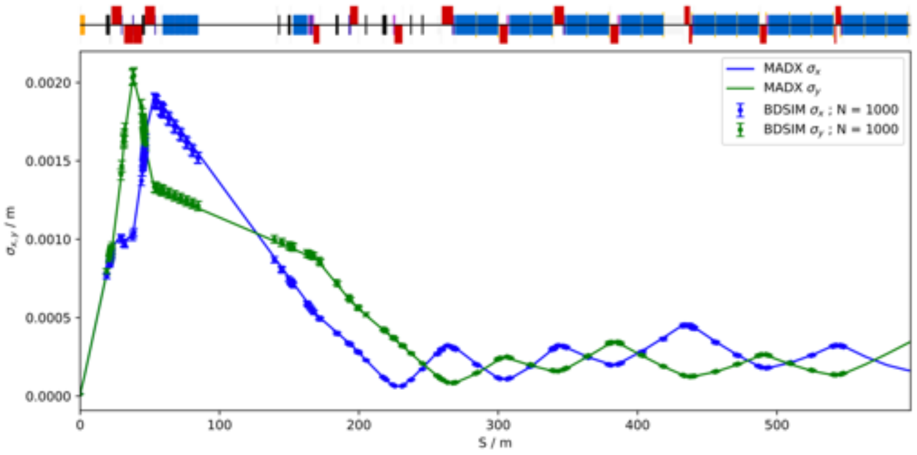




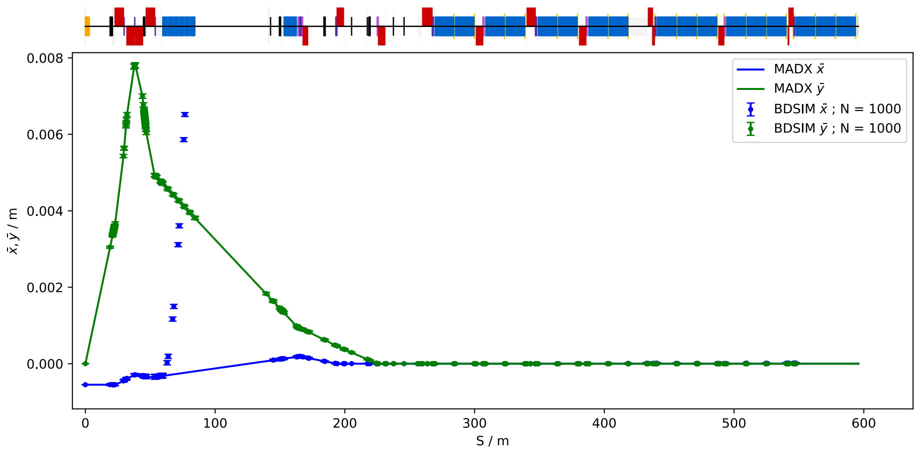


FASER Optical Validation

- Track core Gauss beam through and perform optical analysis to validate model construction
  - no overlaps, correct alignment, no gaps etc



beam size



beam offset

appears to wander off, but due to difference in curvilinear frame vs Cartesian

FASER Simulation

H. Lefebvre, L. Nevay, S. Gibson

ROYAL HOLLOWAY UNIVERSITY OF LONDON

- Goal: predict muon and neutrino flux and spectra at FASER location
- Use CRMC event generator to produce HepMC2 event files of p-p collisions
  - SYBILL hadronic model

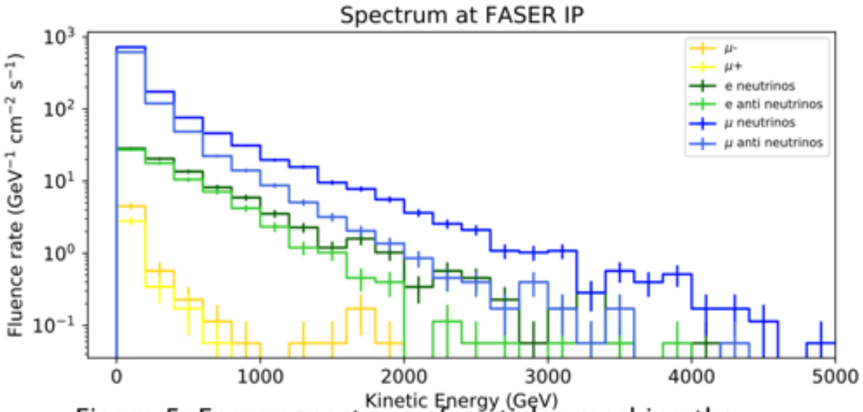
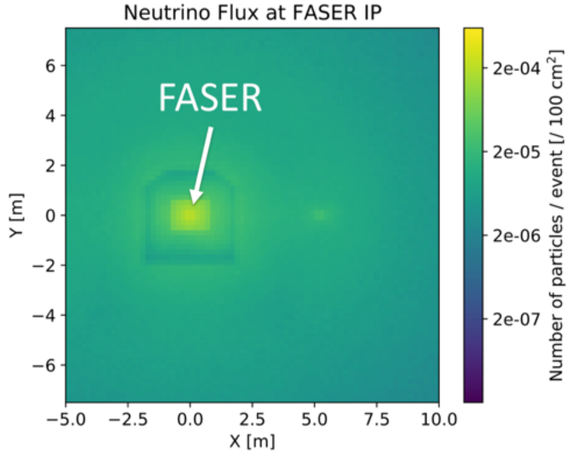
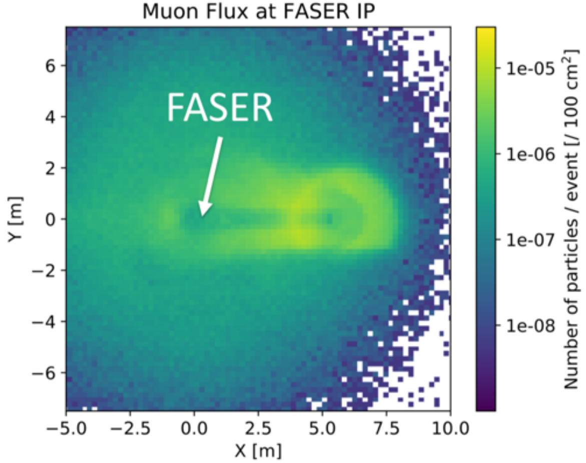


Figure 5: Energy spectrum of particles reaching the FASER detector.

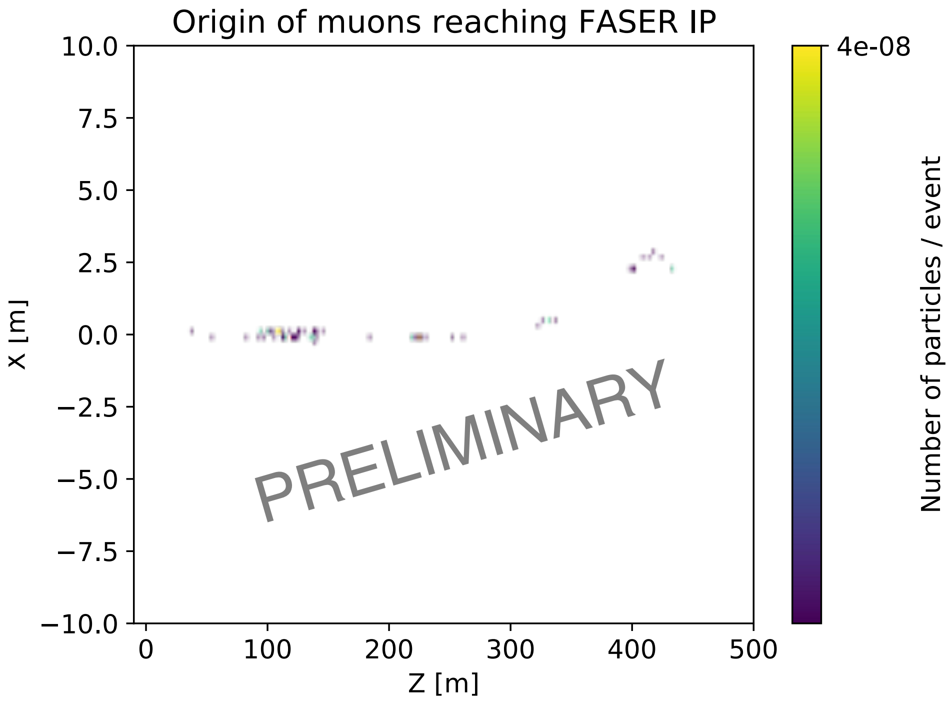


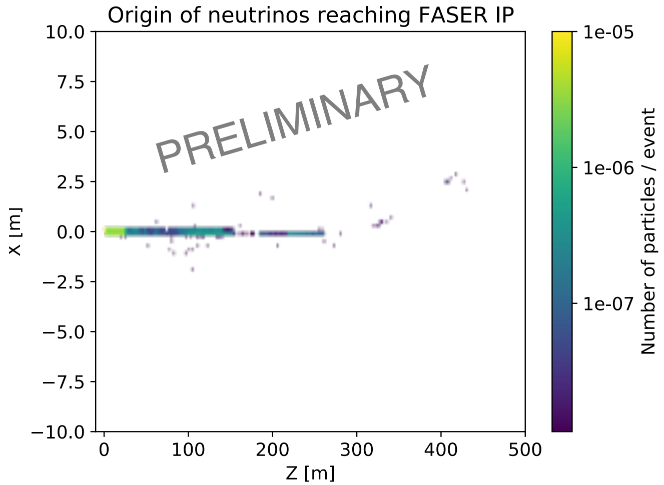


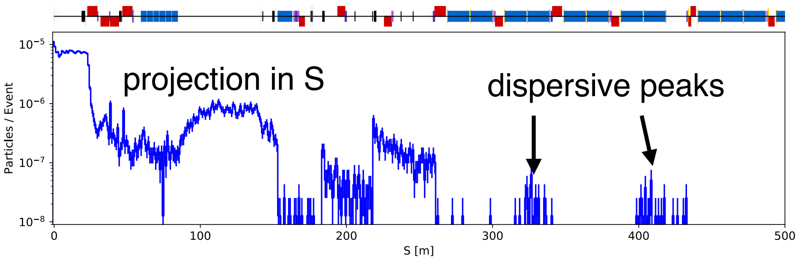
ICHEP poster https://indico.cern.ch/event/868940/contributions/3815740/

Origin of Muons & Neutrinos

- Use select trajectory storage and connections of tracks to determine origin
  - only particles that pass through this plane, connect them back to the primary particle







Conclusions & Outlook

- Methodology for combined particle physics and accelerator simulation
- Many growing applications
- Many current and future experiments are not in an isolated environment and link with the accelerator - many interesting possibilities
- Tools presented for geometry preparation and conversion
  - a single person can achieve and learn something!
  - tools can help guide developer to fix geometry issues
  - it is possible to have parity between FLUKA & Geant4 models
- FASER model simulations ongoing with developments for efficiency

Thank you for your attention

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H. Lefebvre, W. Shields, J. Snuverink[4], R. Tesse[2], S. Walker[5]
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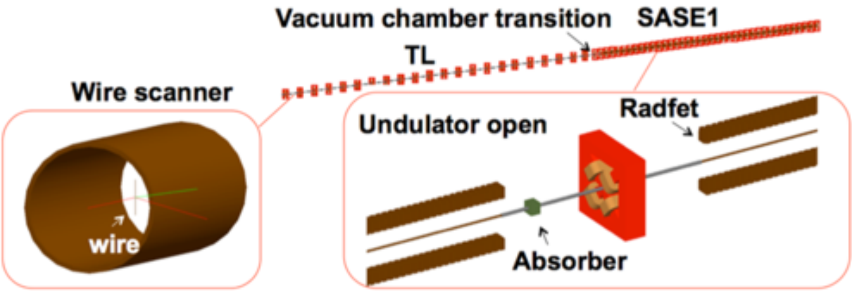
3 CERN 4 Paul Scherrer Institut 5 DESY

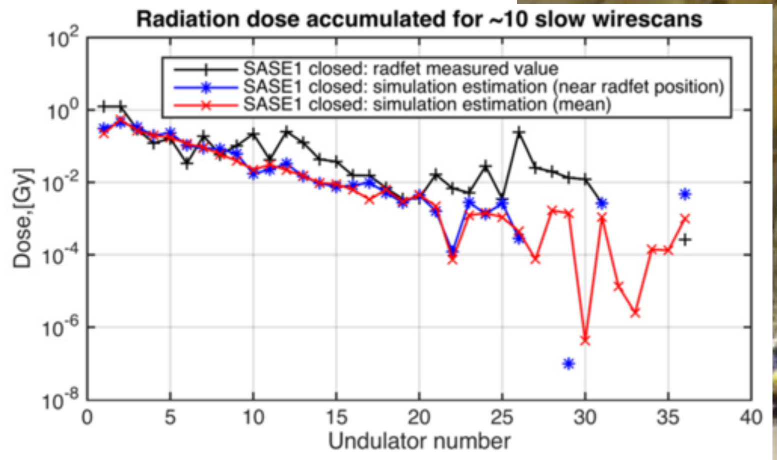
18th Feb 2021
Warwick Particle Physics Seminar

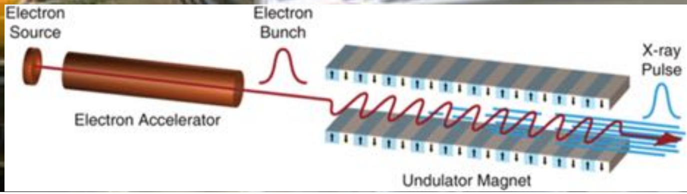
BDSIM - website - manual - paper

DESY XFEL in Hamburg

- X-ray Free Electron Laser l(XFEL)
- Use e^- beam for X-rays
- Radiation can damage permanent magnets
  - from both synchrotron radiation and beam losses
- Simulate maximum use of wire-scanners



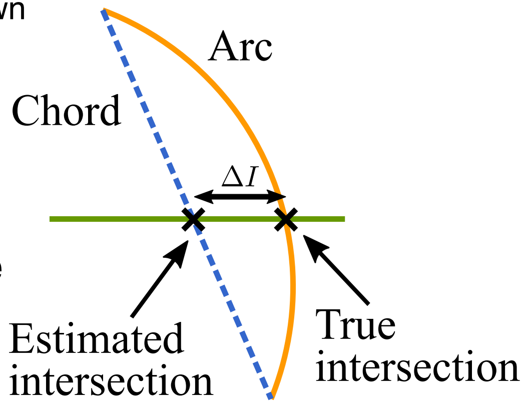




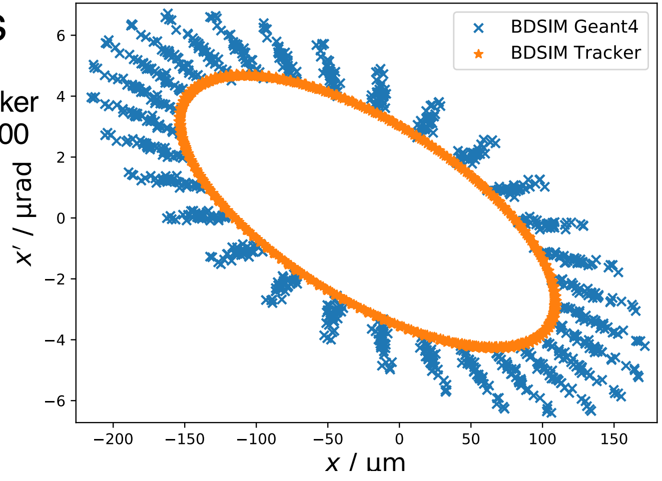
https://iopscience.iop.org/article/10.1088/1402-4896/aa5281

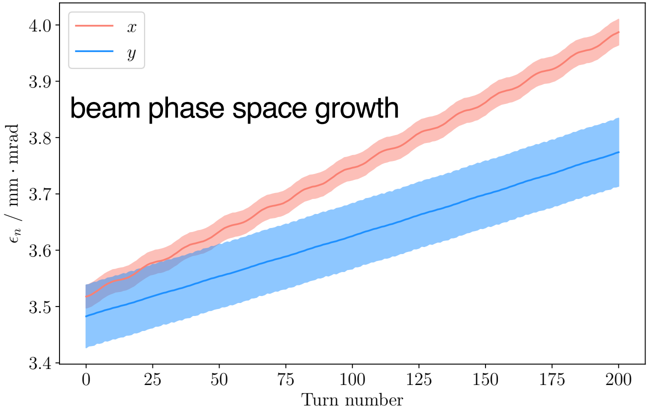
Limitations & Symplecticity

- For longer term ring tracking we start to see limitations
  - "longer term" here is 100s to 1000s of turns of the LHC
  - for single pass models the tracking is very accurate
- Small numerical errors can build up
- '***Symplectic***' tracking conserves phase space
- Here, errors build up due to the convergence of the intersection with each boundary
  - each step of an algorithm is fine on its own
  - there is always a geometrical tolerance
  - leads to inaccurate result eventually
  - loss of precision with large models
  - a particle tracker has no such problem
- Tracker applies one map at a time
  - no ambiguity along direction of travel
- Need to retain accuracy



comparison of tracker with Geant4 for 1000 turns of LHC

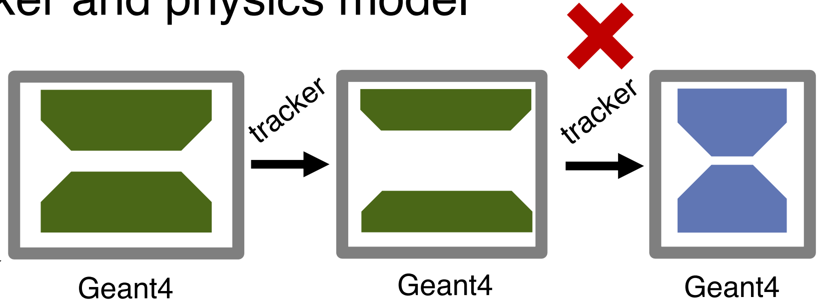


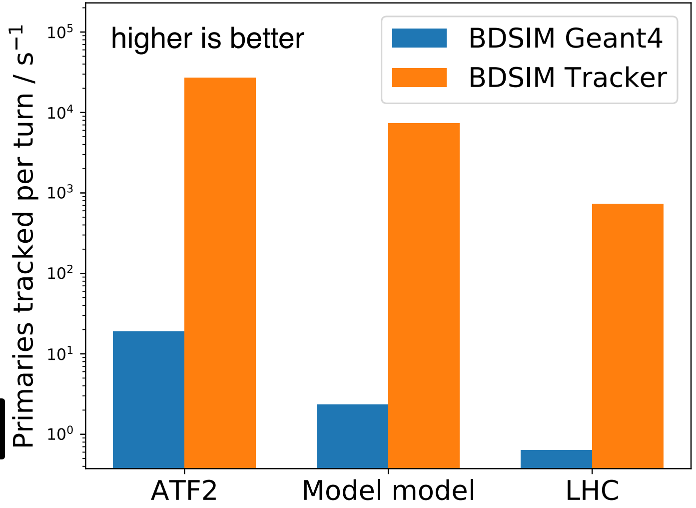


Combined Simulation Strategy

- Several possible strategies for combined tracker and physics model
  - apart from already described BDSIM full Geant4 model

1. Pass over once from tracker to 3D model
   - if particle is expected to go with beam first then be 'lost'
   - after initial scatter assume won't complete multiple turns
2. Discrete regions for physics processes
   - particle tracked in tracker
   - for select elements propagate in 3D model
   - works well for collimation - but no physics in tracker
3. Truly integrated tracking ✓ **choose this option**
   - override transportation process in Geant4
   - maintain concurrent curvilinear and Cartesian coordinates
   - transform from curvilinear to Cartesian to push particle in 3D world
   - no stringent intersection to maintain tracking accuracy (faster)
   - tracking library written ✓
   - ***integration underway***



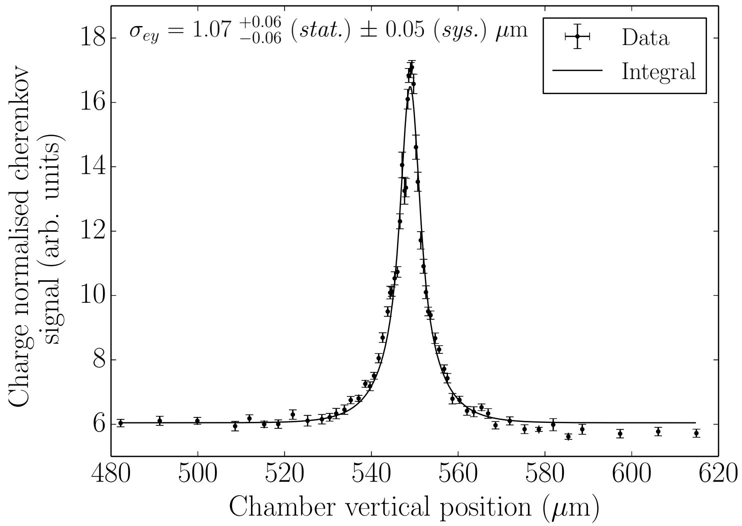


tracker alone is ~10^3 times faster

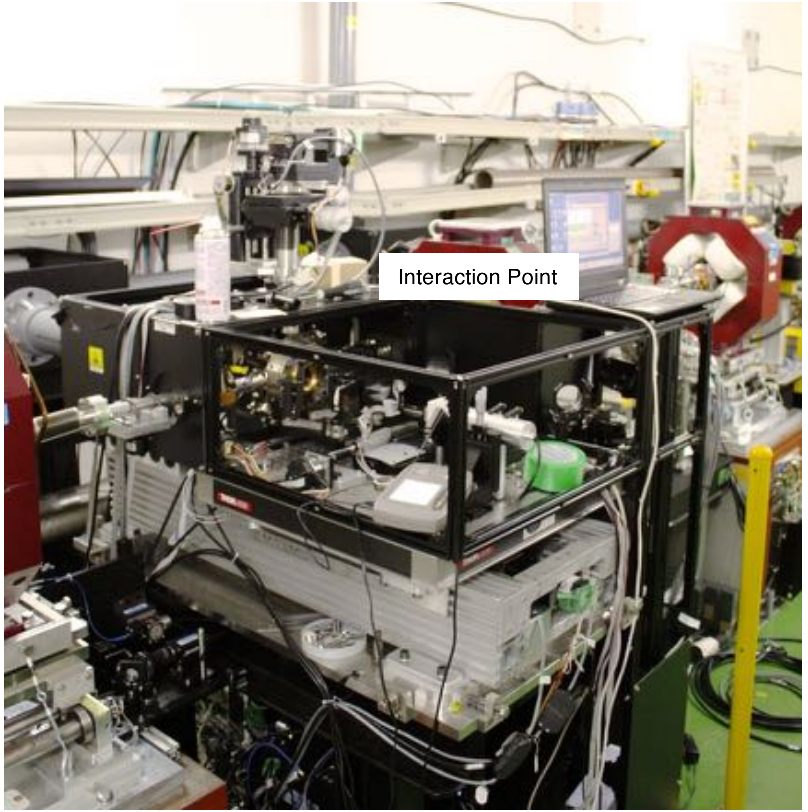
Laserwire at Royal Holloway

ROYAL HOLLOWAY UNIVERSITY OF LONDON

- Previous and ongoing experience in Compton diagnostics
- Created many laserwires
  - ATF2 at KEK, Japan - 1μm beam profile made with green laser
  - PETRA III at DESY - bunch by bunch emittance measurement
  - H- laserwire at FETS (UK), LINAC4 (CERN)

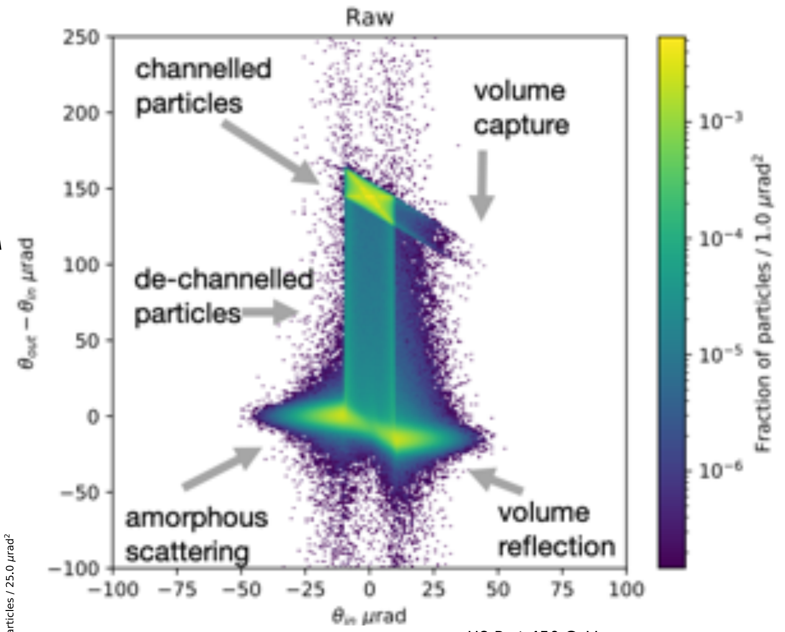


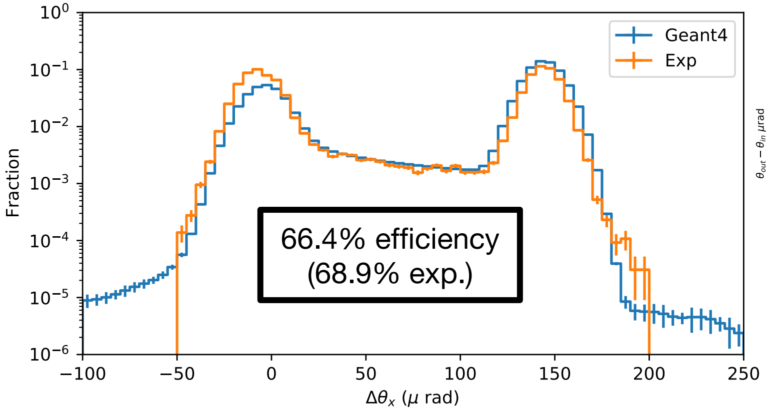
Phys. Rev. ST Accel. Beams 17, 072802 (2014)

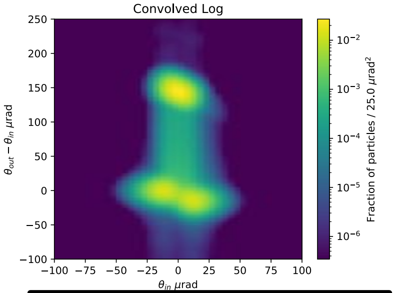


Crystal Collimation & Ion Channelling

- Use Geant4 to model crystal collimation for ions
  - single pass model validation with H8 fixed-target data
- Extending model to simulate ions
- Interfaced G4 into ***SixTrack & SixTrack-FLUKA***
  - use Geant4 for crystal or all collimators: mix with FLUKA
  - leveraging my extensive knowledge of Geant4
- Model uses all Geant4 physics with biasing
  - continuum approach for coherent channelling effect







convolution for detector resolution simulation

nuclear interaction rate