Photon Flux Simulations in Geant4

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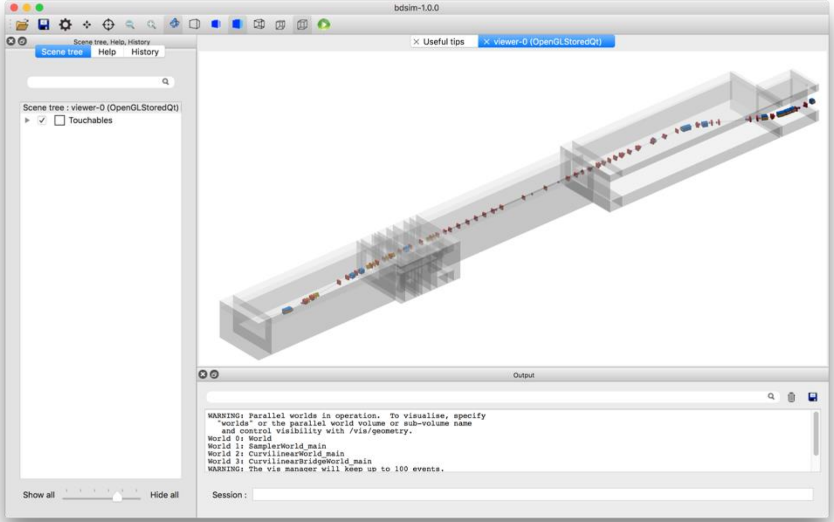
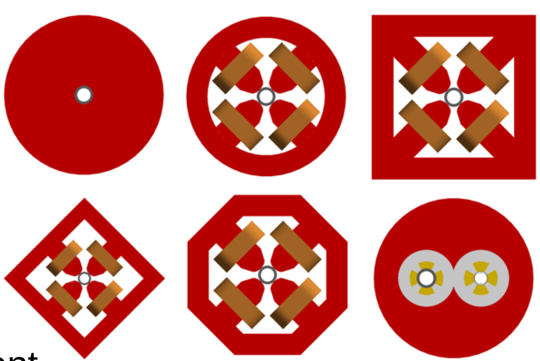
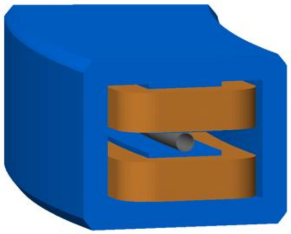
BDSIM & Geant4

- BDSIM is an application to create a Geant4 model of an accelerator
  - developed at RHUL for many years
  - start from optical description like MADX
  - text file input - no C++ required
  - uses CLHEP & ROOT
  - ROOT output format
  - power analysis suite included
- Library of scalable generic accelerator geometry provided
  - any aperture works with any magnet
- Thick lens tracking and curvilinear coordinate system provided in Geant4 for accelerator tracking
  - generic multipole fields in yokes
- Can customise geometry with external pieces as well as field maps

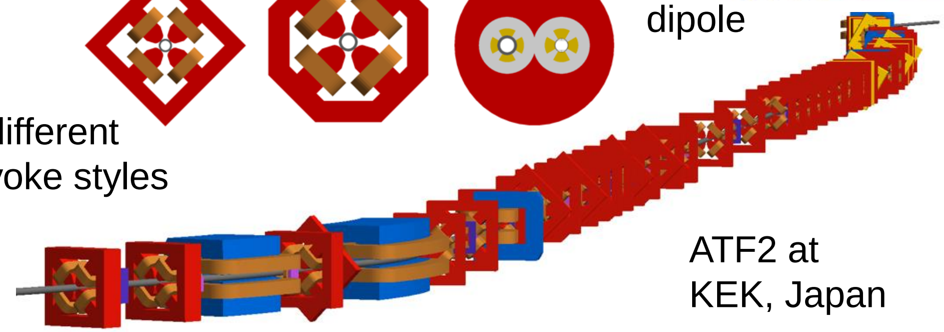




different yoke styles



dipole



ATF2 at KEK, Japan

Possible Contributions

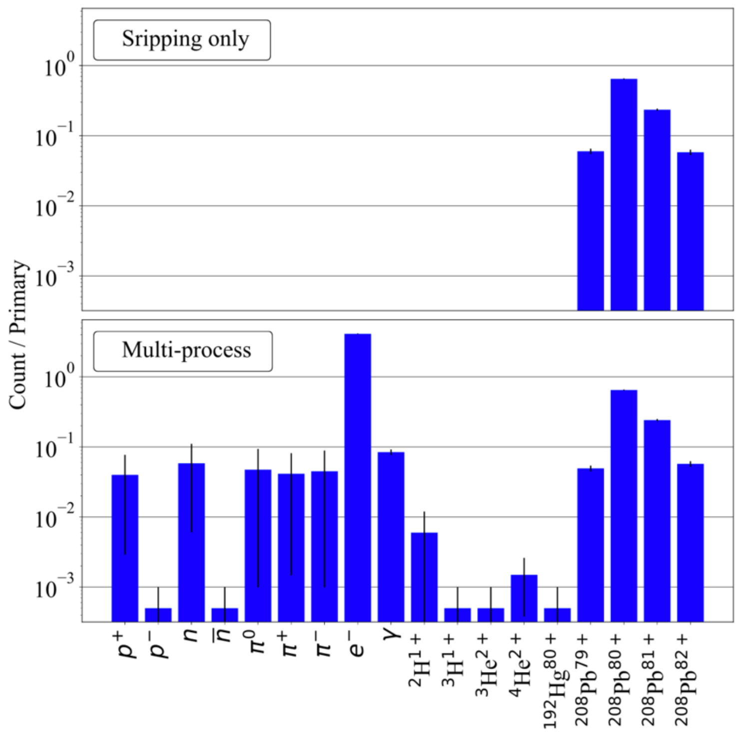
- Simulate laser interaction, secondary particles including accelerator tracking all in one model
  - full particle physics library
  - track all particles
  - track partially stripped ions (not common in codes)

- Estimate detector signal to background and overall efficiency

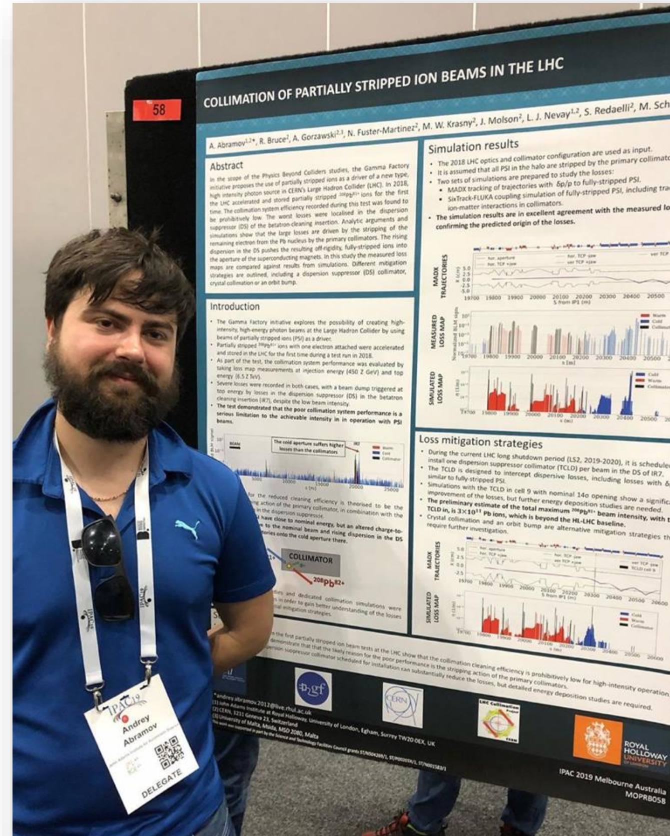
- Therefore, help estimate best detector placement

Partially Stripped Ions in Geant4

- 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



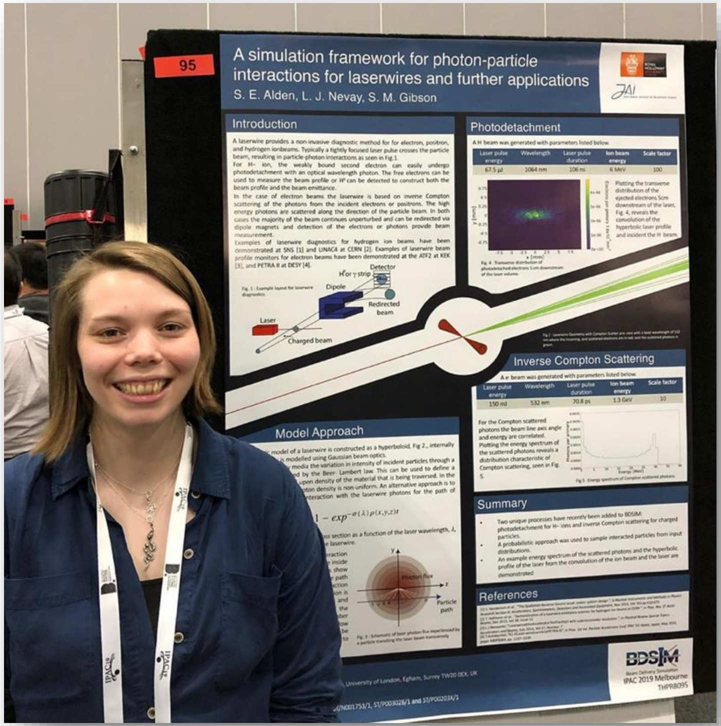
Andrey Abramov presenting at IPAC 2019

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

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

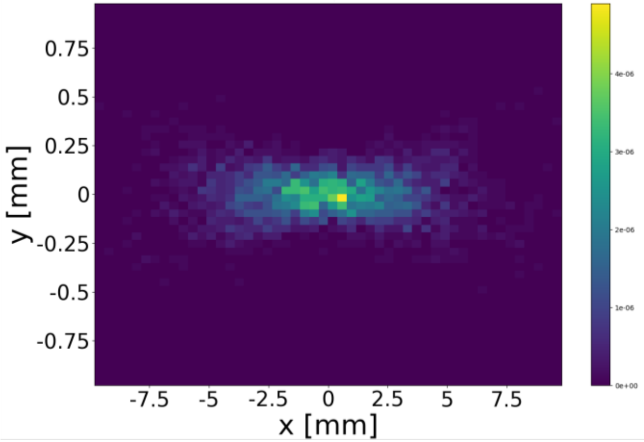
Geant4 for Gamma Factory

- Introduce new Geant4 physics processes
  - work by Siobhan Alden, RHUL PhD student
- 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



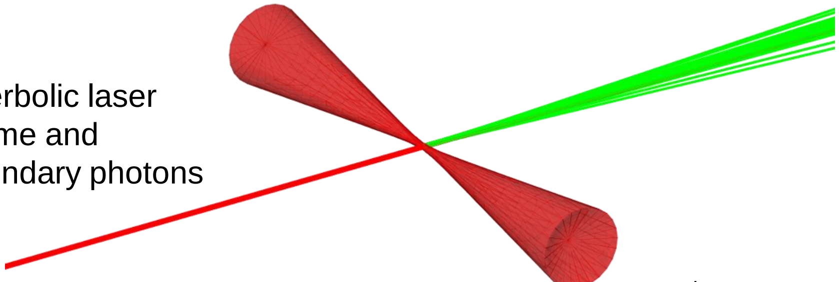
Siobhan Alden presenting at IPAC 2019

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



interaction distribution showing hyperbolic laser shape

hyperbolic laser volume and secondary photons



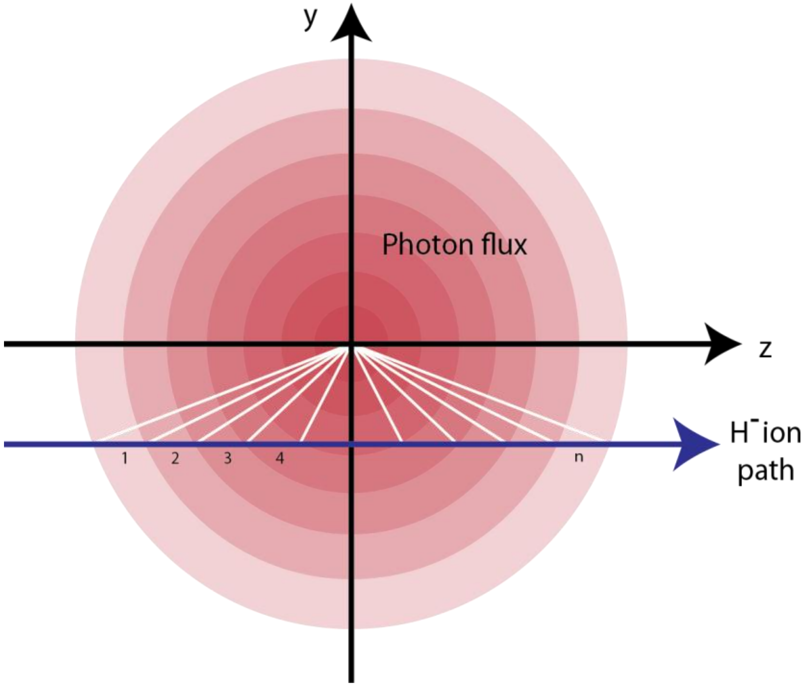
Updates to Excitation Process

- Previously created a new Geant4 process for the ion excitation.
- Development to this process now sees the mean free path set to $\sigma_l/10$ with the condition forced.
- This creates discrete steps for the particle through the laser volume and therefore through the laser flux.
- At each step a probability of interaction is generated as per

$$P_s = 1 - exp^{-\sigma(\lambda)\rho(x,y,z)t}$$

where $\sigma(\lambda)$ is the cross section of interaction, and $\rho(x,y,z)$ is the medium density, and t the integrated time of the step.

- The probability is then compared to a randomly generated number for the excitation to be assigned.
- If the ion is excited the momentum and energy are modified to match the photon absorption.



Physics Process Status

- Processes implemented
  - apart from stimulated emission
  - including biasing to increase interaction rate
- Revised implementation from previous GF meeting
  - cannot allow use of Beer-Lambert Law with normal cross-section in Geant4
  - force process to happen and decide probability internally
- Compton scattering and photo-detachment validated
- Absorption and emission processes implemented but transient information to be finalised
  - need to keep the energy level of the electron associated with the G4DynamicParticle
  - will used derived class from G4ElectronOccupancy that can be detected
  - requires no direct modification of Geant4 (use a standard installation)
- Estimated completion in June
- Will add laser bandwidth
  - we Monte Carlo the photon energy before the boost

SPS Model

- Model of SPS prepared in BDSIM for Gamma Factory POP
- Optics for Q26 used
  - "lhc_newwp.madx" from SPS folder on AFS optics
- Customised geometry with main dipole and quadrupole geometric parameters
- Aperture from MADX model
- Two pronged approach:
  1) launch externally generated gamma distributions (from Camilla & Alexey) into model (reported in this talk)
  2) generate gammas directly by simulating partially stripped ion beam and laser interaction (ongoing… - completed in June)

SPS Model Preparation

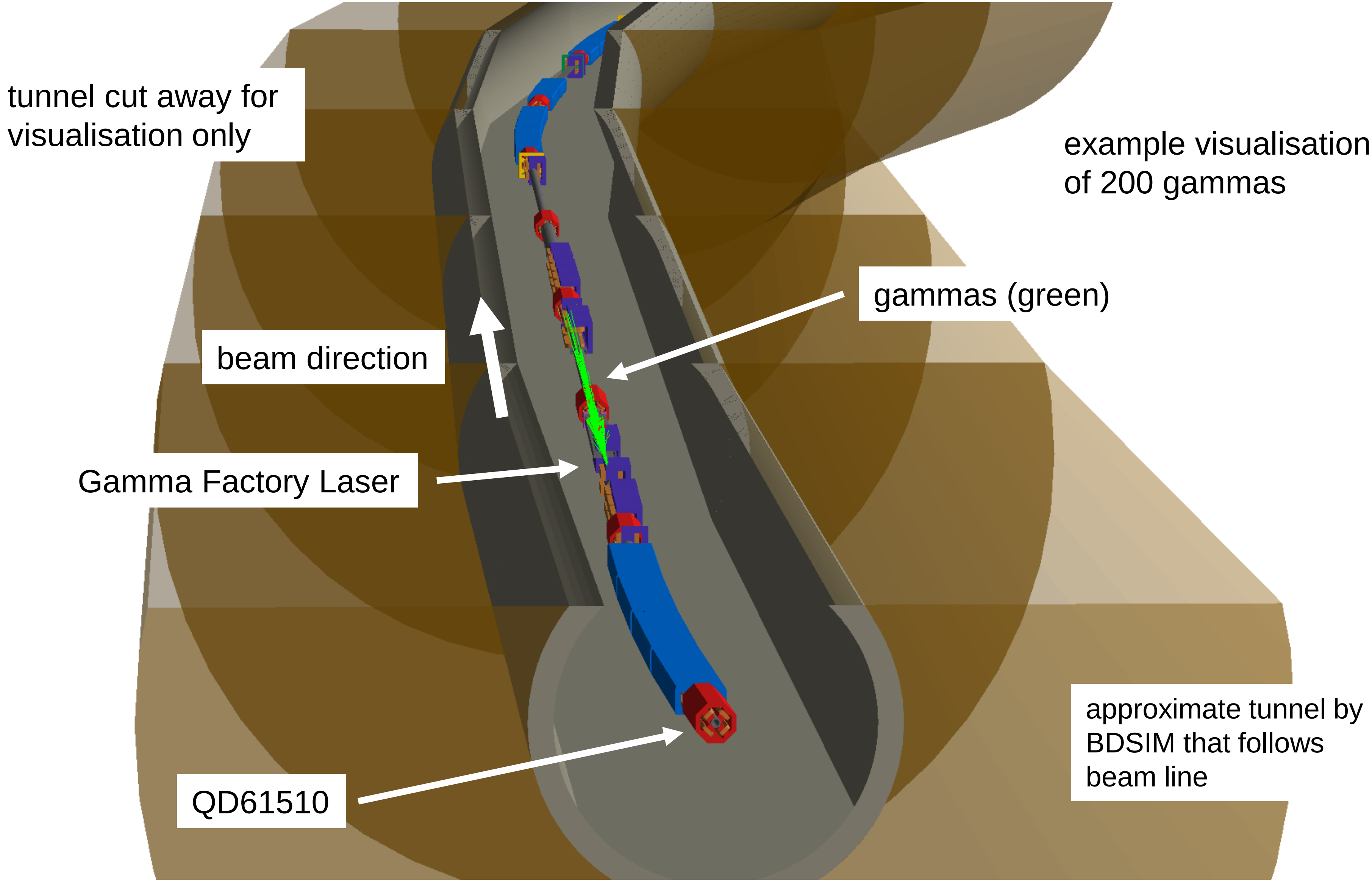
- pybdsim Python library used to convert to BDSIM and include aperture and customisations
- Tunnel added from approximate dimensions from CERN layout database
- Geant4 "FTFP_BERT" reference physics list used for these simulations
  - photon production range cut lowered to 10um and minimum kinetic energy for models to 0.1keV
- Can prepare whole ring but used only section relevant
  - work here is a single pass simulation
  - completely capable of multi-turn simulation

convert.py

```python
import pybdsim
import pymadx

tfsfile      = '../madx/out/optics_SPS_Q20.outx'
apertureFile = '../madx/out/aperture-fixed.tfs'
outname      = 'gf/spsq26'

# general options we want written out
optionsdict = {'beampipeThickness' : 0.02}

# dictionary of dictionaries for patterns of options for various components
partparameters = {}

# dipoles
dipoleparams = {'vhRatio' : 0.548725637181,
                'hStyle'  : 1,
                'horizontalWidth' : 0.667}
partparameters['MBA'] = dipoleparams
partparameters['MBB'] = dipoleparams

# quadrupoles
quadparams = {'magnetGeometryType' : 'polesfacetcrop',
              'horizontalWidth' : 0.515}
partparameters['QD'] = quadparams
partparameters['QF'] = quadparams

# vkickers and hkickers
kickerparams = {'horizontalWidth' : 0.4}
kns = ['MD', 'MK', 'MPS', 'ZKV', 'MPN', 'MPL', 'MST', 'ZKH', 'ZS', 'MSE']
for n in kns:
    partparameters[n] = kickerparams

# aperture
ap = pymadx.Data.Aperture(apertureFile)
ap = ap.GetNonZeroItems()

# convert
pybdsim.Convert.MadxTfs2Gmad(tfsfile, outname,
                             aperturedict=ap,
                             partnamedict=partparameters,
                             optionsDict=optionsdict)
```

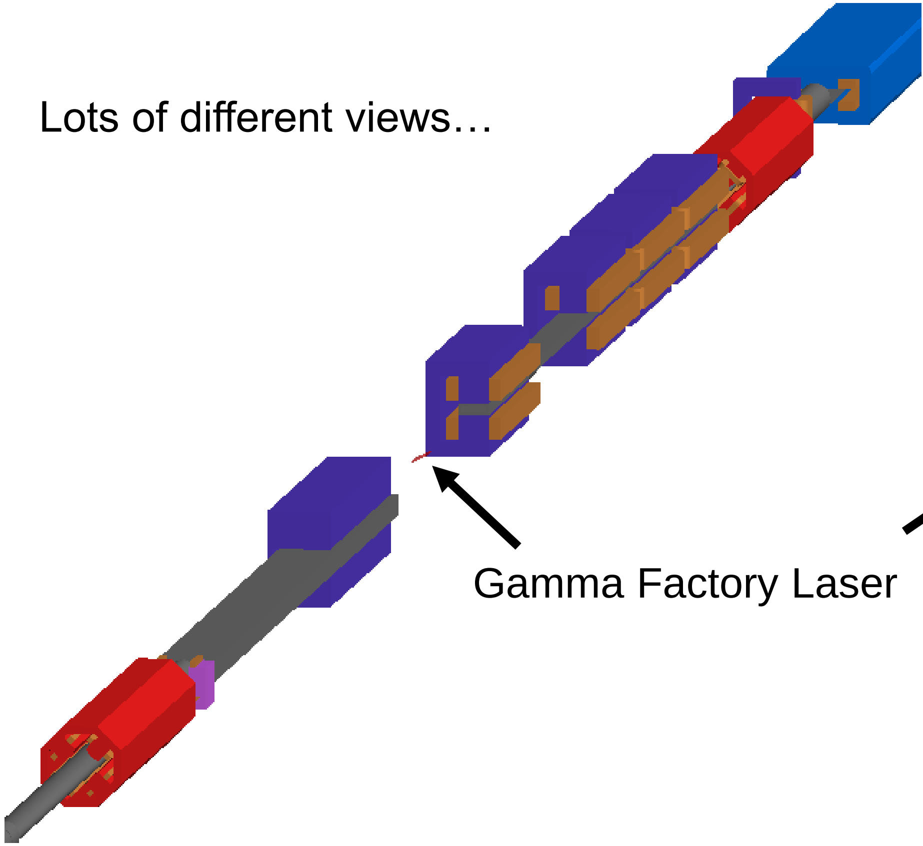
```
U:---  convert.py      All L41     (Python ElDoc)
Wrote /Users/nevay/physics/reps/rhulgammafactory/sps/bdsim/convert.py
```

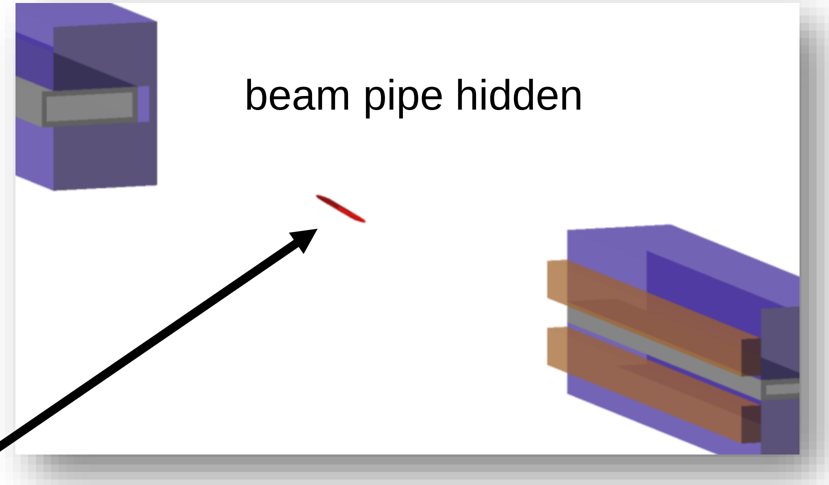
SPS Model Visualisation



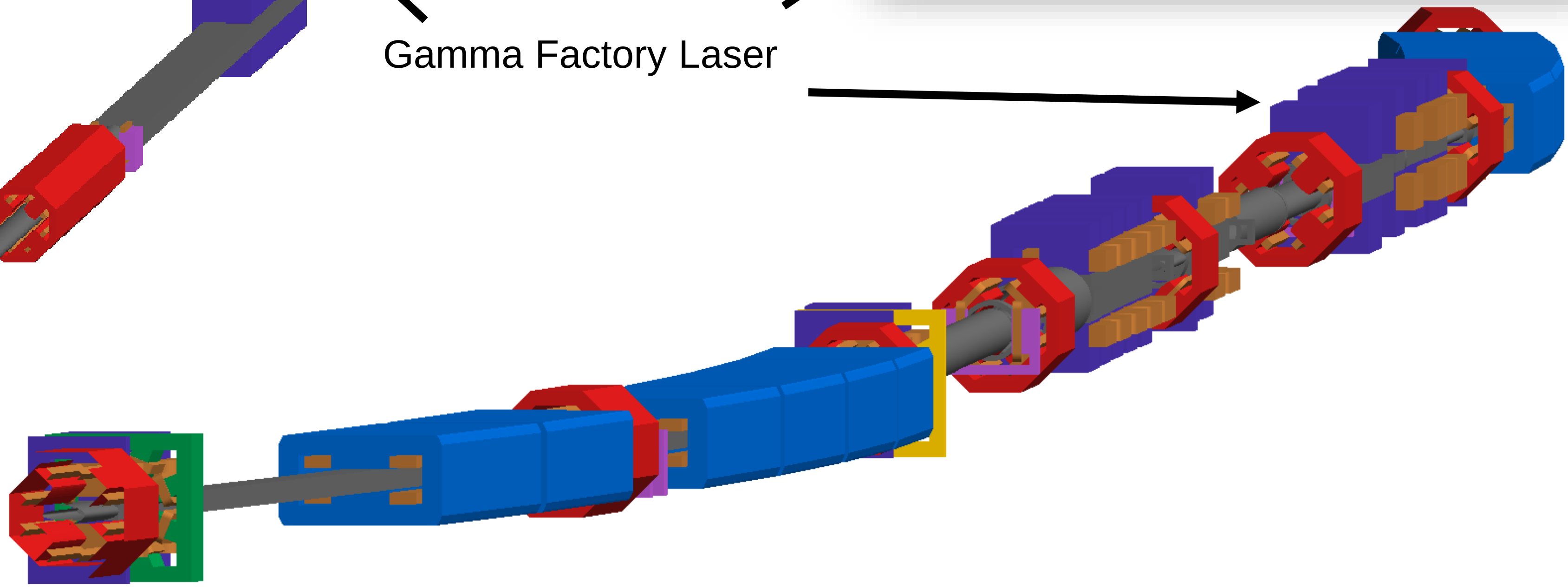
SPS Model Visualisation II

Lots of different views…





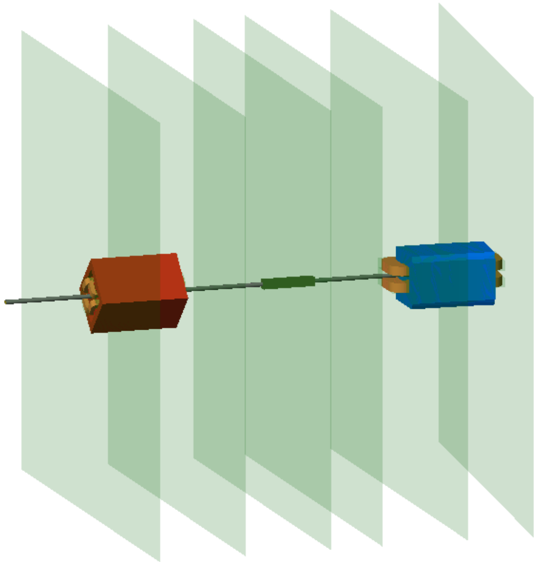
Gamma Factory Laser



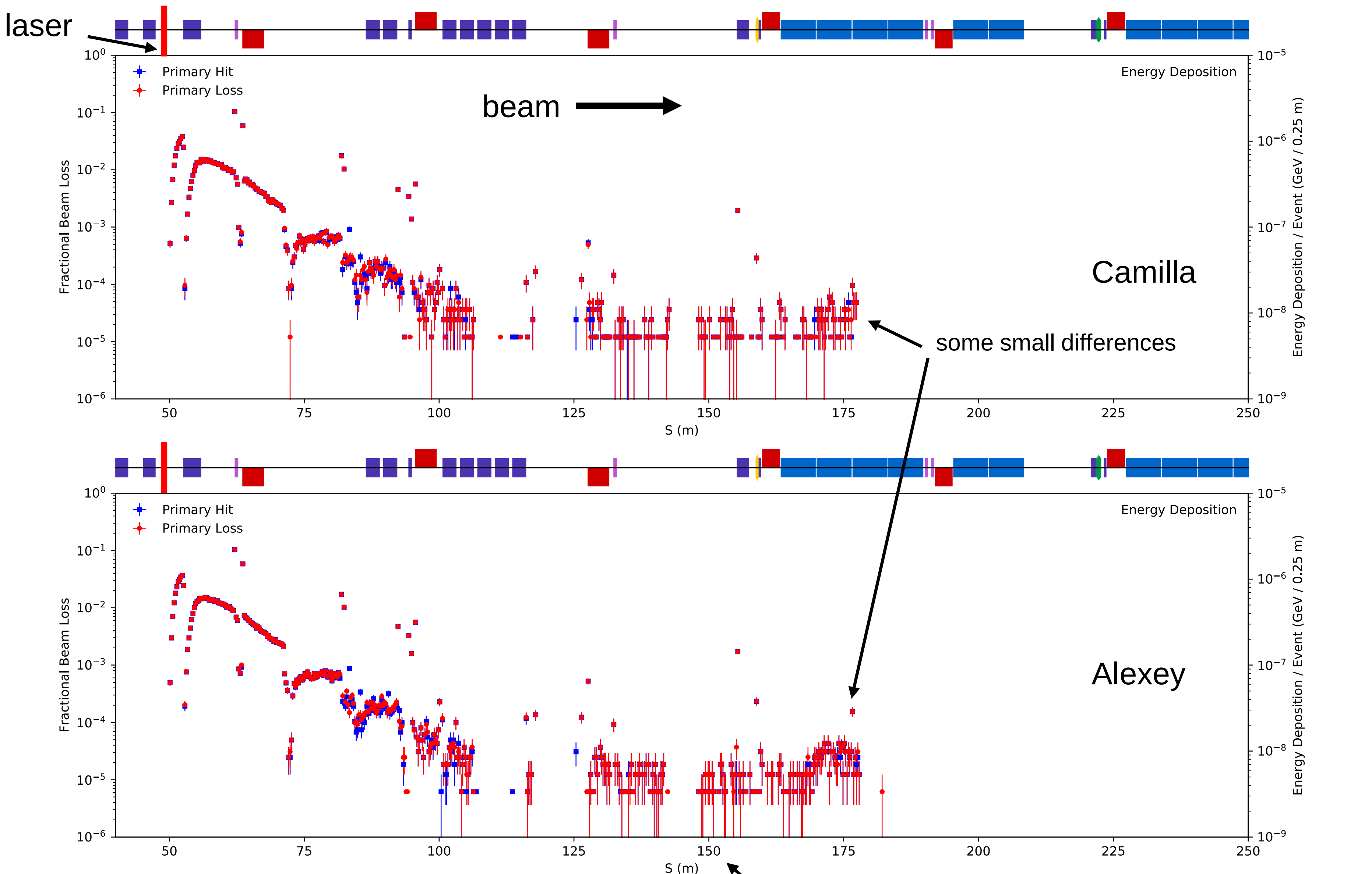
Simulation Setup

- Gamma distributions from Camilla & Alexey
  - thank you!!
  - Alexey (~186k), Camilla (~80k) gammas
- All particles provided have been tracked
- Results are per-gamma fired as a rate that can be scaled
- Record complete coordinates of all particles at 'samplers'
- Samplers are invisible planes 5x5m at the end of an element in the beam line
  - can record backwards particles too!
- Also record aperture impacts
- Section simulated starts from QD61510
  - with S = 6239.5046m - add this to all x axis values

samplers in green



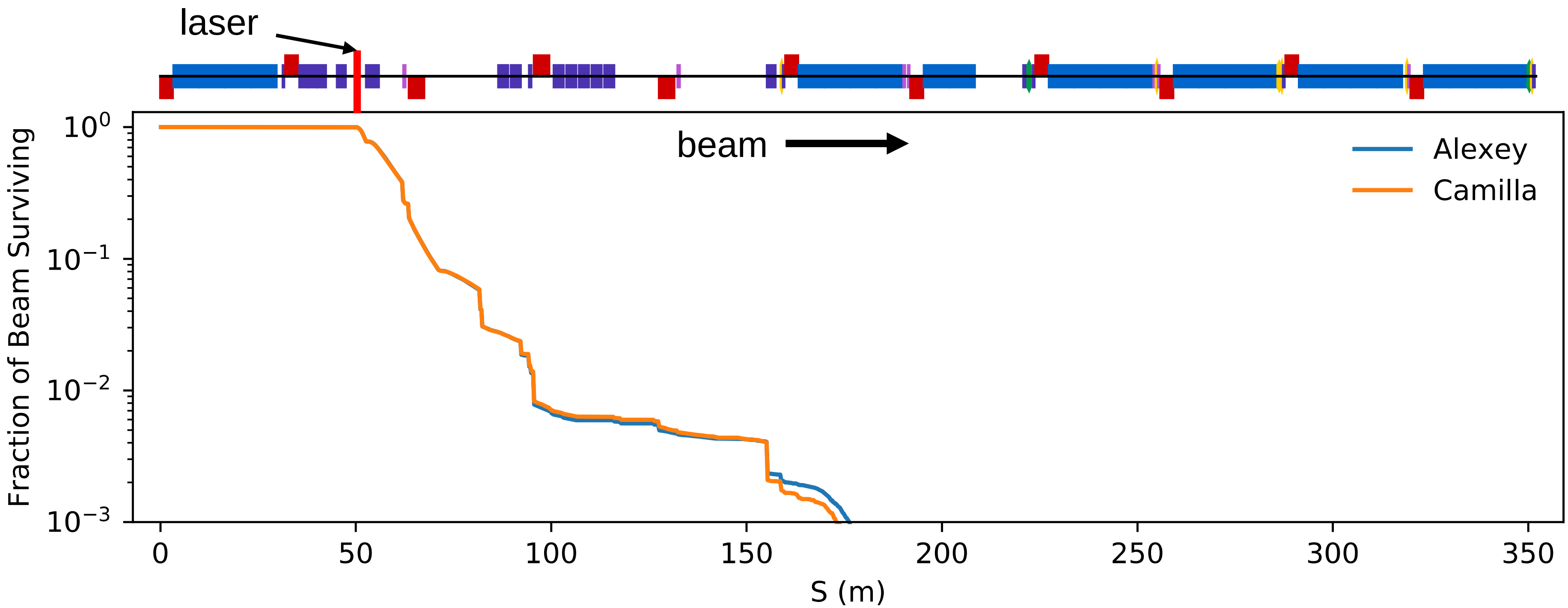
General Losses



S + 6239.5046m to match SPS optics

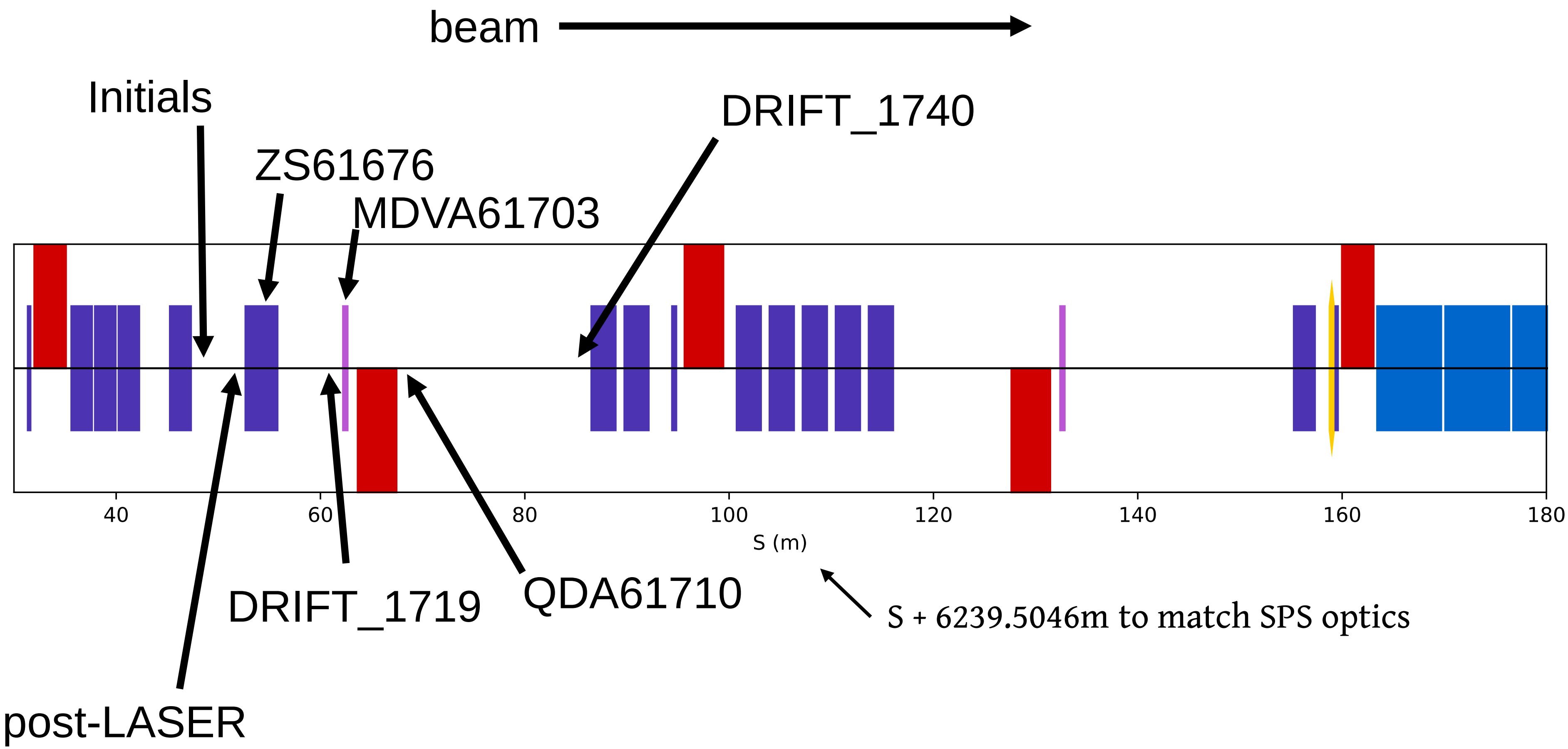
Photon Survival

- Fraction of surviving photons along machine
- Similar until the very end at start of arc
- Require higher statistics for clearer picture



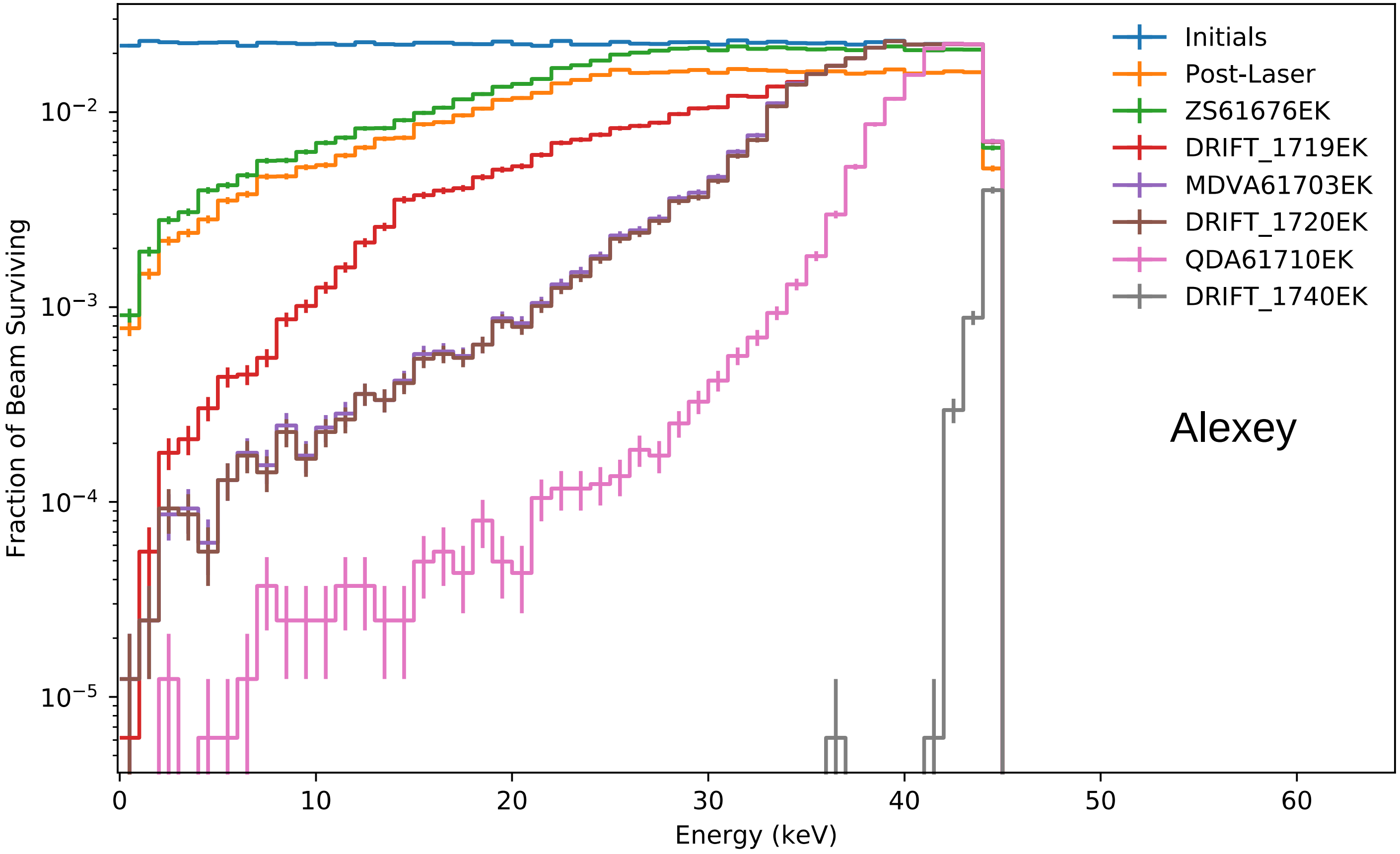
Which Samplers?

- Choose certain points after elements



Spectra of Surviving Photons

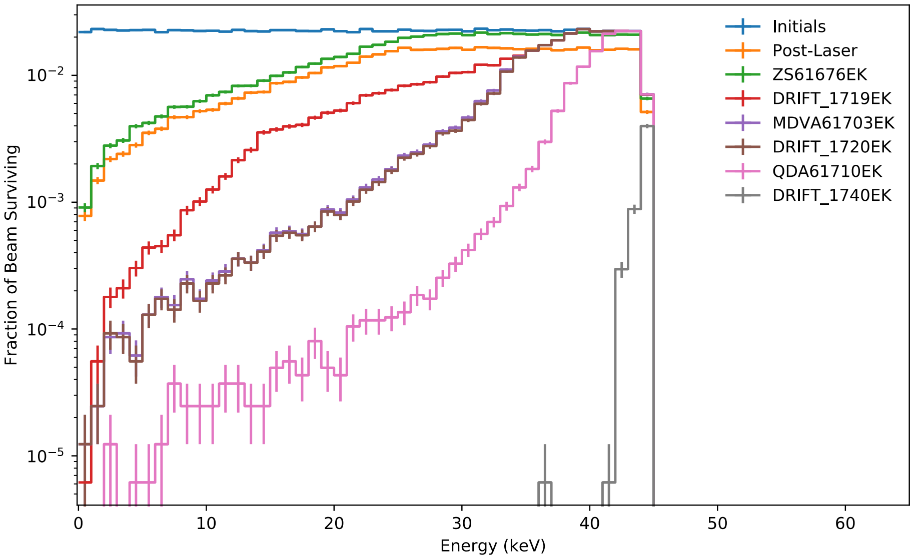
- Look at the spectra after select elements after laser
- Lower energy photons cut further along



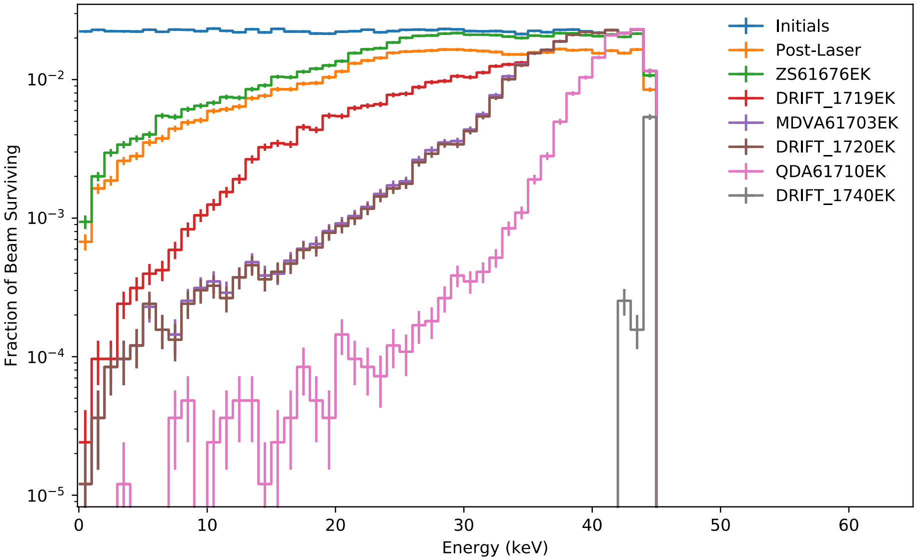
Spectra II

- Similar forms, but marginally different transmission

Alexey



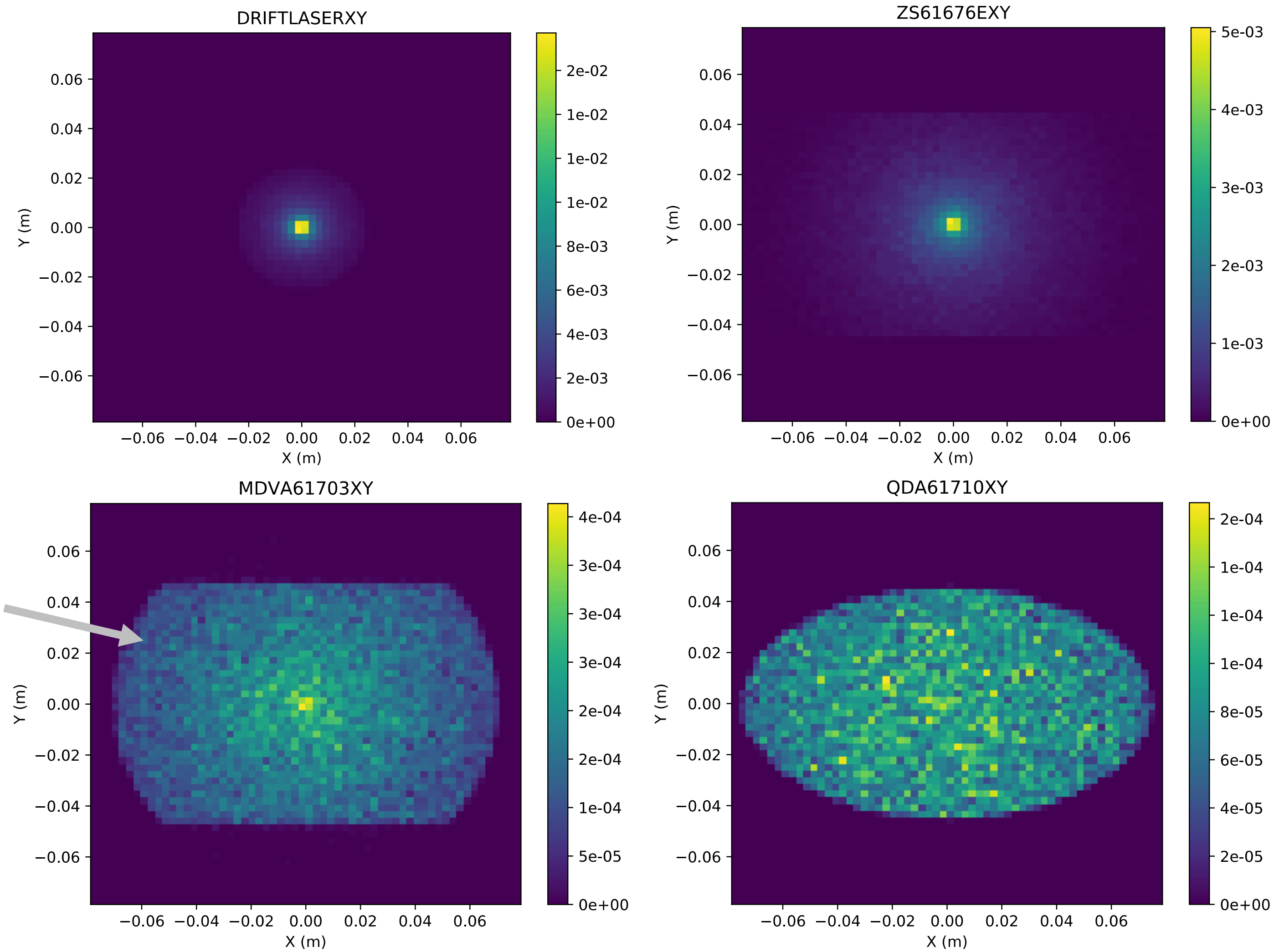
Camilla



Photon Distribution

- Look at the transverse distribution of photons after the same select elements

mostly limited by aperture



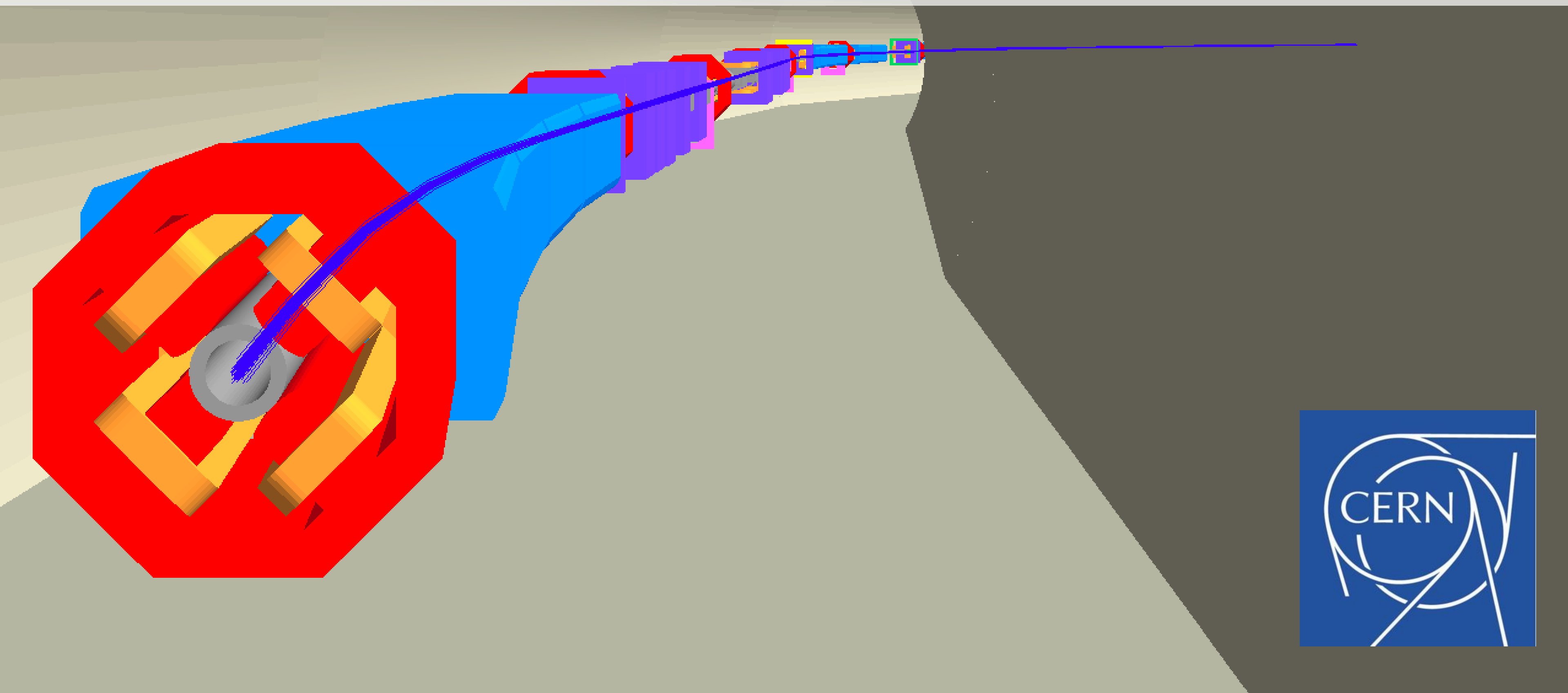
Next Steps

- Compare our generated gammas with that of Camilla & Alexey
  - up the simulation statistics considerably
- Fill in aperture discontinuities
  - open space transversely between large jumps in aperture
- Simulate potential detector positions
  - highly suited to try out different detector responses
- Add stimulated emission physics process
- Produce additional Monte Carlo samples
  - core beam halo for any aperture losses - **beam background**
  - **beam gas** interaction around ring
    - do these type of simulations already for ATLAS backgrounds
  - can easily combine with gamma simulations to get more complete estimate of losses

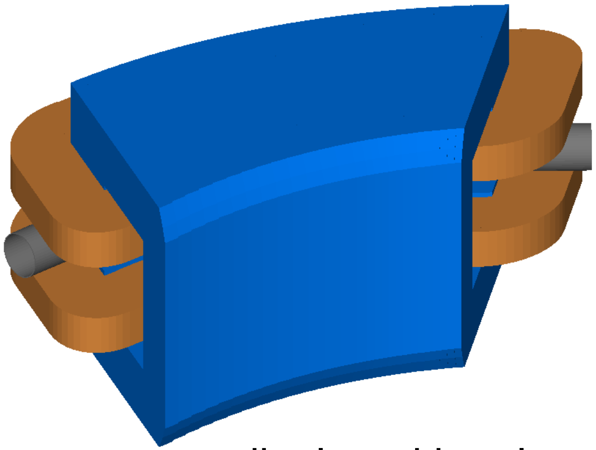
Summary

- New Geant4 physics processes individually tested
- Developed mechanism for laser beams in Geant4 models
- Decay and emission processes soon to be complete
- Preliminary SPS model created with some customisation
- Demonstrated propagation of gammas from external generation

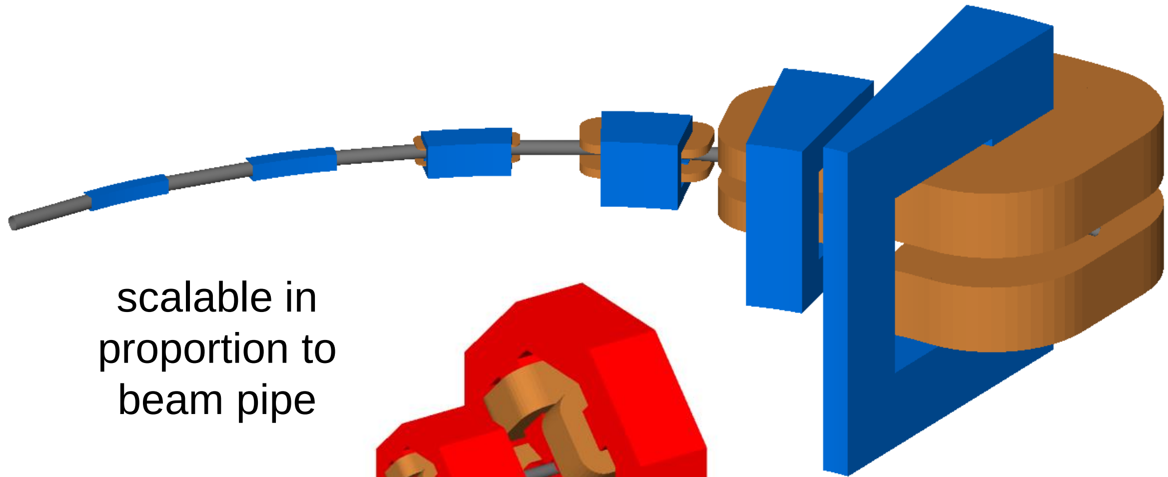
Thank you



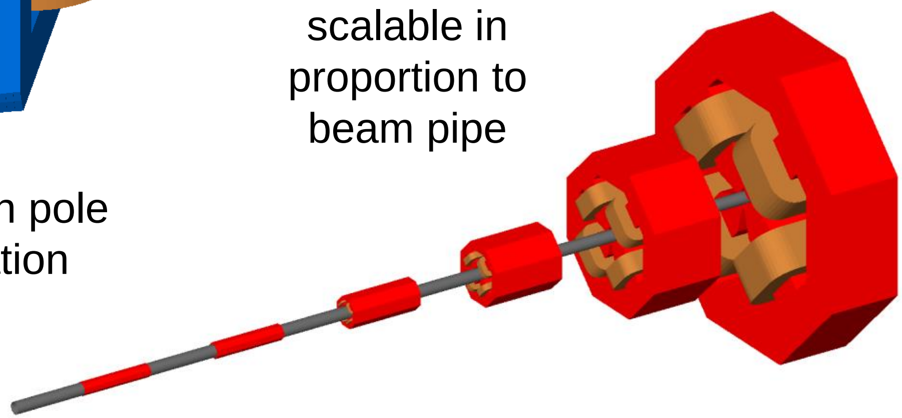
Scalable Geometry



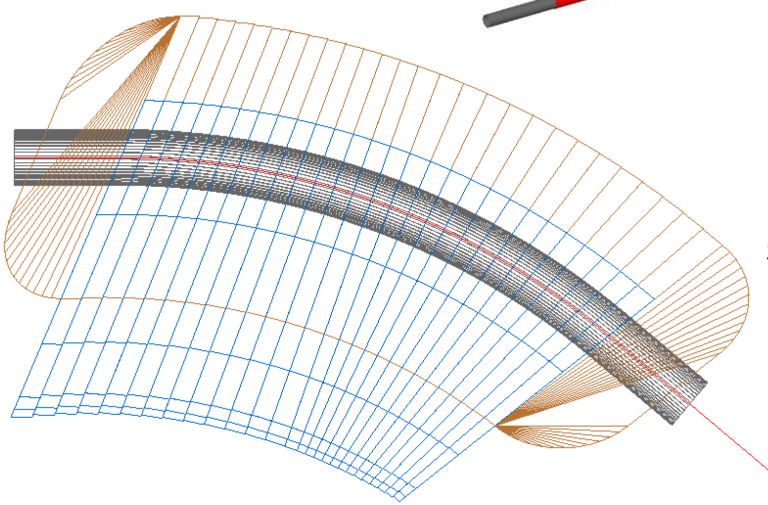
dipoles with pole face rotation



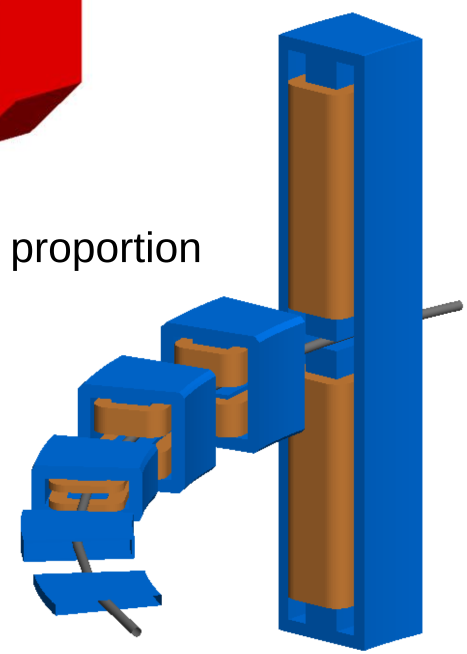
scalable in proportion to beam pipe



scalable in proportion

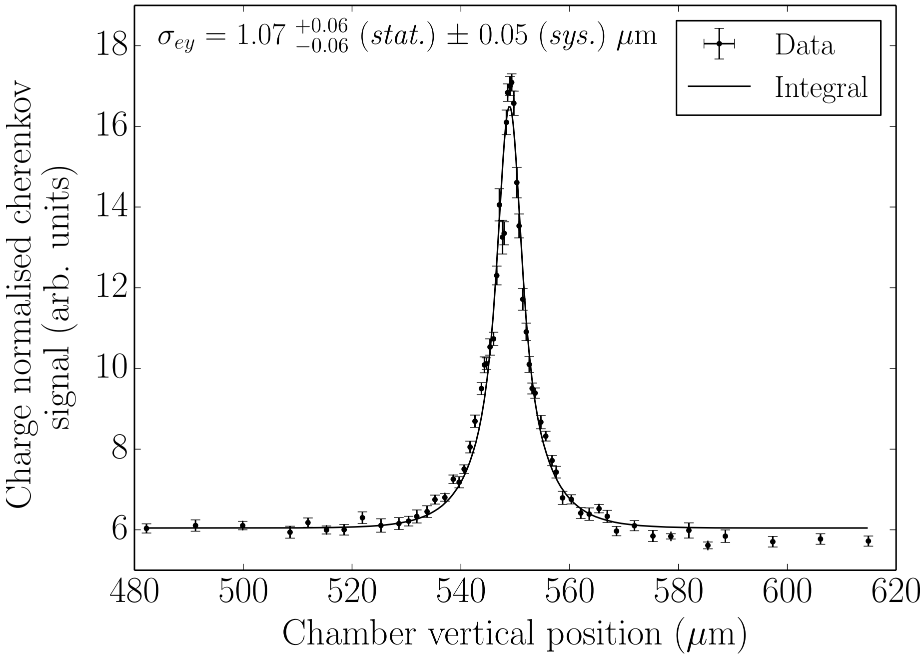


dipoles built in slices to allow any shape required



Laserwire at Royal Holloway

- 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)