EIC Detector eRD21 Update and Proposal Request for Extension

July 27, 2018

EIC Background Studies and the Impact on the IR and Detector Design

Project Leader: Latifa Elouadrhiri* and Charles Hyde

(*) Contact Person

EIC Detector eRD21 Progress Report & Proposal Request for Extension to FY19

July 27, 2018

Project Name: **EIC Background Studies and the Impact on the IR and Detector Design**

Period Reported: **from 10/01/2017 to 07/27/2017**

Project Leader: **Latifa Elouadrhiri* and Charles Hyde**

(*) Contact Person

Project Goals

Study background generated by machine operation in simulation:

- **Synchrotron radiation**
- **Beam-gas interactions**

Focus of this proposal

- Beam halo effects and beam losses
- Neutron flux
- Others

➢ **Quantify background rates and radiation doses in order to assess the impact on**

- **Detectors' operation, electronics, beamline components, etc.**

➢ **Provide input**

- **Machine lattice, IR design: beam pipe, magnets, vacuum/pumping**
- **Detector design, technology choices & Support structures, etc.**

It is critical to perform a thorough study of the type/dose and distribution of machine induced background **NOW** that the IR is being designed

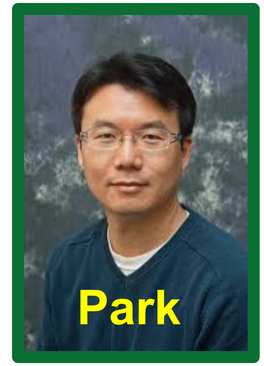
Project members (FY18) – As presented in the proposal

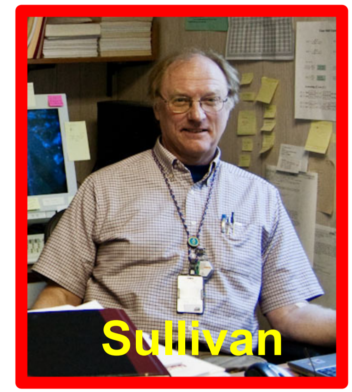
Background Simulation studies

Machine/IR design & SR modeling

Detector design

CAD modeling & Vacuum calculation





Project members (FY18) – Current Status

Background Simulation studies

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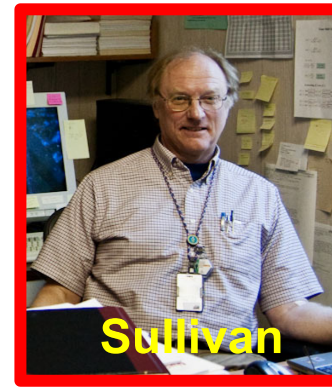
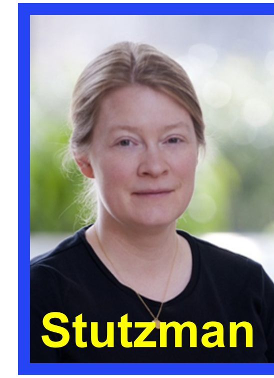
CAD modeling & Vacuum calculation





Project members (FY18) – Current Status

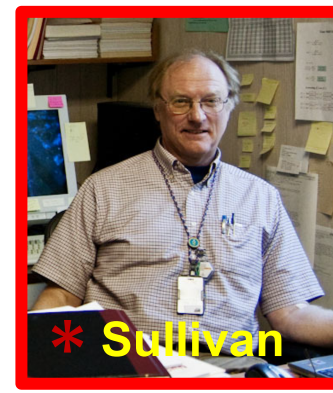
Background Simulation studies

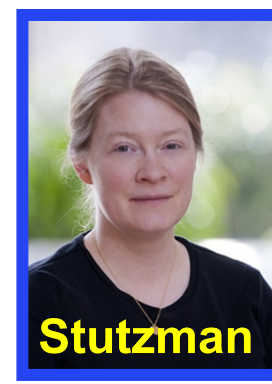
Machine/IR design & SR modeling

Detector design

CAD modeling & Vacuum calculation

* Funded by the project





Planned Deliverables for FY18 – as in the proposal

FY18: First and second quarters

- Complete HERA simulation & documentation
- Model the current baseline design of JLEIC IR beam pipe concept in GEMC/GEANT4 simulations.
- Benchmark synchrotron radiation rates produced within GEANT4 and compare with SR code simulations.
- Develop an interface of the SR code to GEMC
- Model the current baseline design of JLEIC IR beam pipe concept in a 3D CAD model.

FY18: Third and fourth quarters:

- Determine background rates as a function of vacuum levels for the JLEIC configuration
- Determine the intensity and distribution in the beam pipe and in the various detectors using GEMC interfaced with SR code
- Using validated software tools and result of beam pipe design, evaluate background contributions from hadron beam/gas interactions under nominal vacuum levels.
- Interface CAD drawings with Molflow+ and Synrad+ in preparation of FY19 project

Deliverables: Planned and Achieved for this Period

FY18: First and second quarters:

- Complete HERA benchmarking
  Analysis completed draft paper produced. Tools to analyze/evaluate background developed
- Model the current baseline design of JLEIC IR beam pipe concept in GEMC/GEANT4 simulations
  Implementation procedure from CAD to GEANT developed, tested and being used to model beam-pipe components in GEANT
- Benchmark synchrotron radiation rates produced within GEANT4 and compare with SR code simulations
  Quantitative studies and comparison completed on simple model
- Develop an interface of the SR code to GEMC
  Interface developed and being used
- Model the current baseline design of JLEIC IR beam pipe concept in a 3D CAD model.
  Updated Beam pipe design produced with close discussion with engineering& accelerator physicists to meet physics requirements
  CAD model in continuous development, this becomes the input to GEANT simulations and background evaluation

Planned Deliverables for FY18 – as in the proposal

FY18: Third and fourth quarters:

- Determine background rates as a function of vacuum levels for the JLEIC configuration
- Determine the intensity and distribution in the beam pipe and in the various detectors using GEMC interfaced with SR code
- Using validated software tools and result of beam pipe design, evaluate background contributions from hadron beam/gas interactions under nominal vacuum levels.

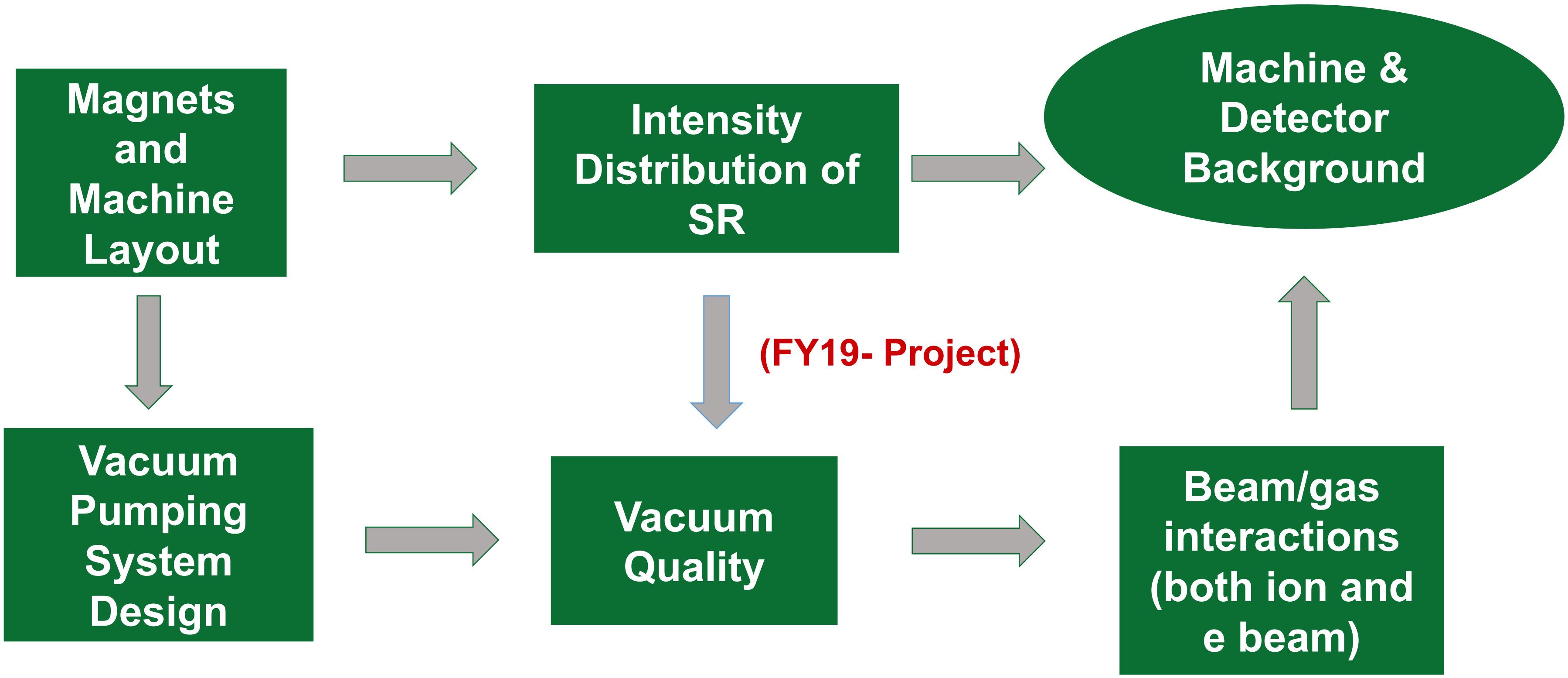
Geometry from CAD of JLEIC beam pipe and beamline components imported and implemented in GEMC. All the necessary tools developed and validated to calculate rate and occupancies, from both beam gas interaction and SR at any detector or beamline component location. With the developed tools we are able to trace the origin of the background particle, type, and momentum and angles. The analysis is ongoing in the JLEIC configuration to perform background rate analysis on the vertex detector as a detailed example.

- Interface CAD drawings with Molflow+ and Synrad in preparation of FY19 project

Interface successfully developed from the 3D CAD designs of the system, the magnets and the beam optics so that we can use the Molflow+/Synrad software to investigate the JLEIC interaction region vacuum.

(Next steps have already started modelling the JLEIC IR with Molflow+/Synrad to include improvements in accuracy from all aspects of the system: the physical pump placement, the beam size and behavior through the quads, and the gas load generated by the synchrotron radiation induced desorption and heating, FY19 project)

Background Studies Workflow



Synchrotron Radiation available in GEMC (github)

Synchrotron Radiation in Vacuum

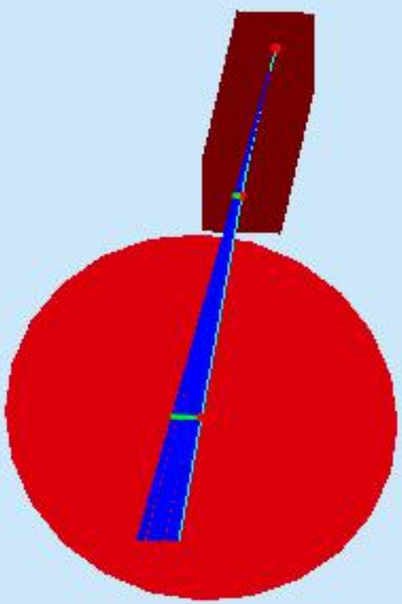
procID = 13

```
$ gemc file.gcard -SYNRAD=1
```

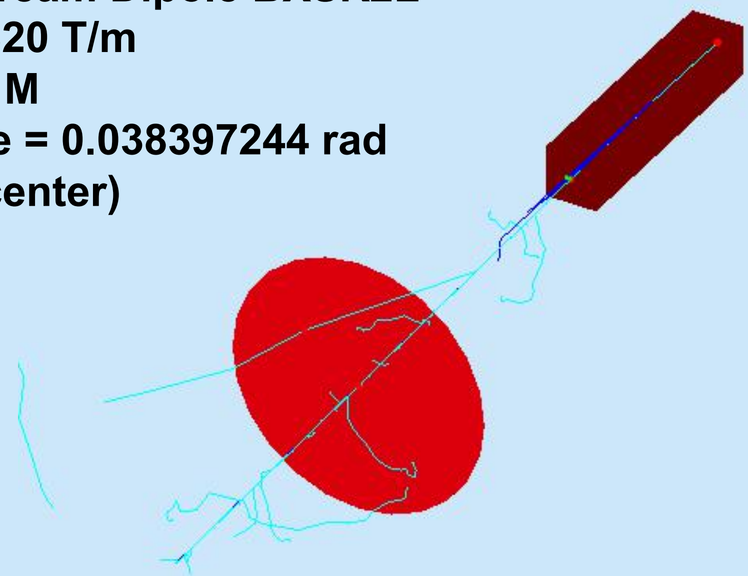
Synchrotron Radiation in Material (air)

procID =14

```
$ gemc file.gcard -SYNRAD=2
```



Electron Upstream Dipole BXSR2L
Strength ~ 0.320 T/m
Length ~ 2.00 M
Bending angle = 0.038397244 rad
Z = 4.0 m (at center)



SR options 1 and 2 are mutually exclusive!

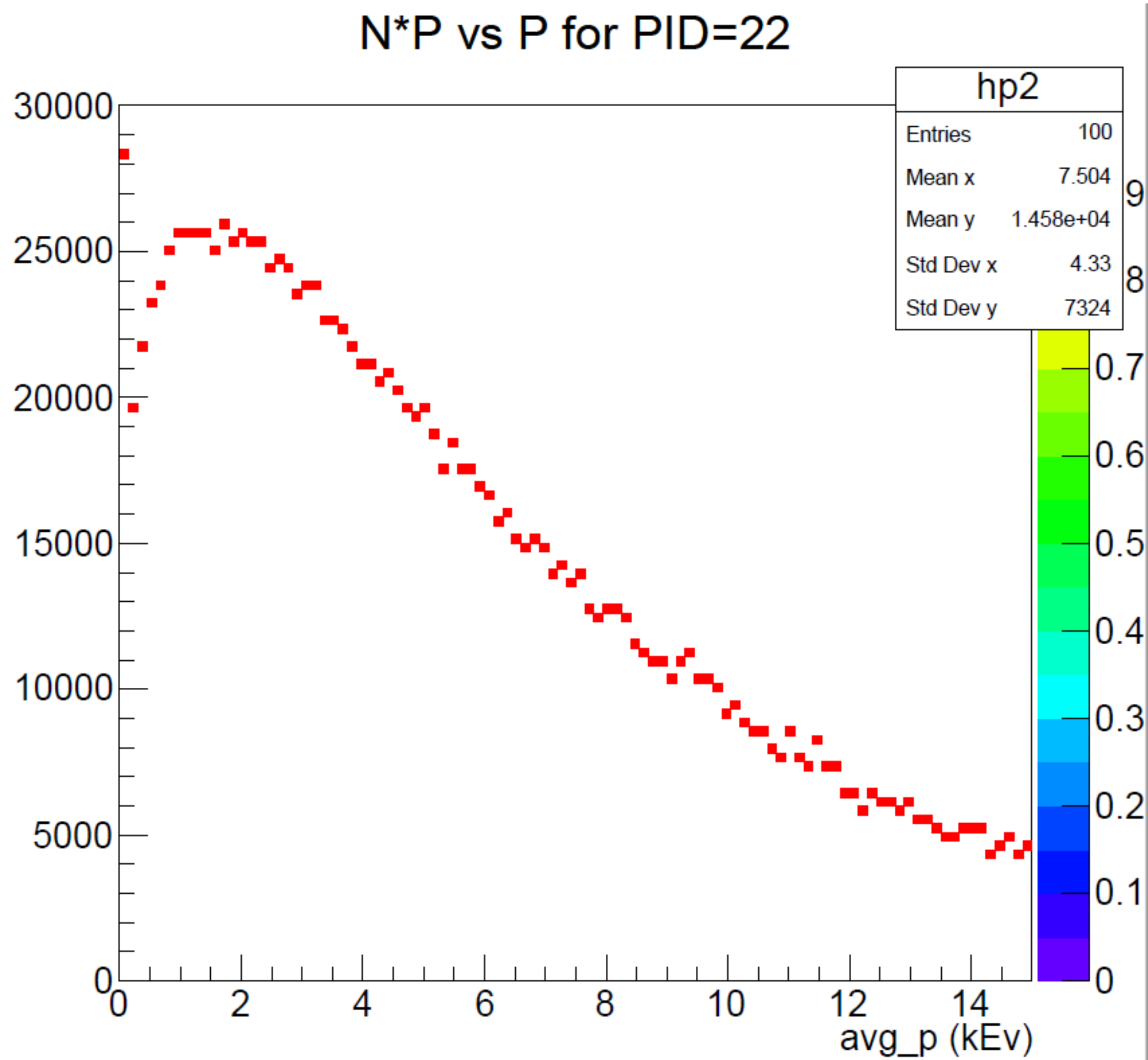
Verifying Energy Spectrum

Photon Critical Energy

$\varepsilon_c = 0.665 * E\,[\text{GeV}]^2 * B\,[\text{T}]$

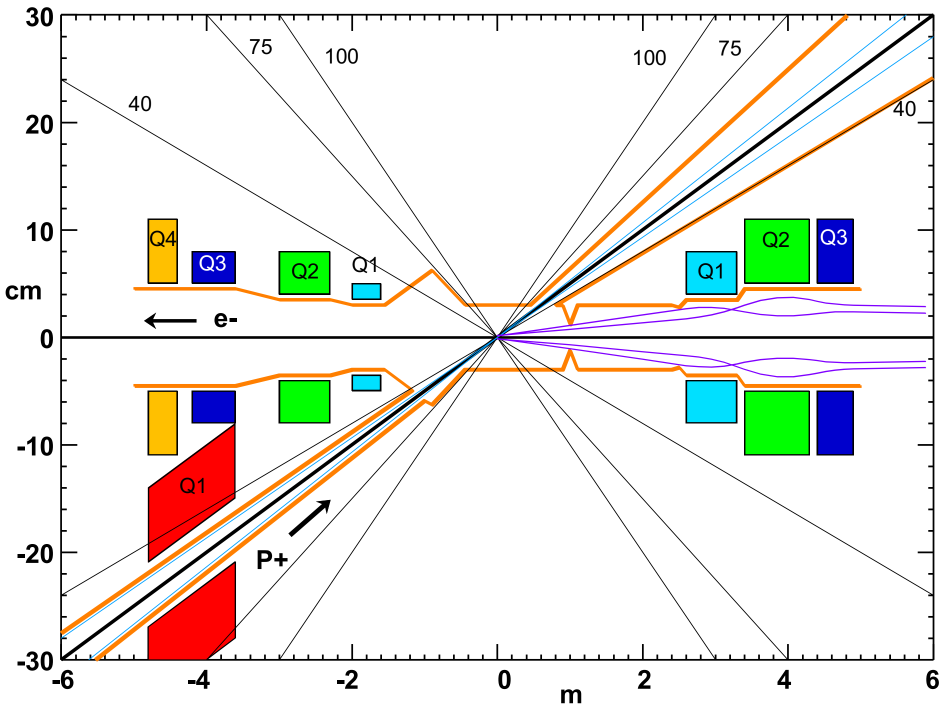
~ 5.22 keV

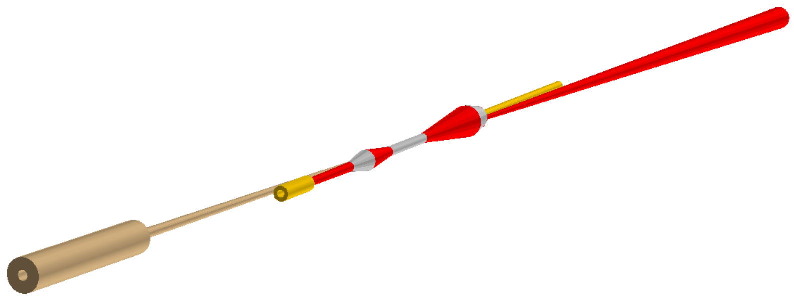
- Expect to see peak at $0.3*\varepsilon_c$, or 1.57 keV
- **Peak approximately correct**.
- Next Steps: currently verifying that integrated photon density = 6.49 keV



Beam Pipe Conceptual Design Updated

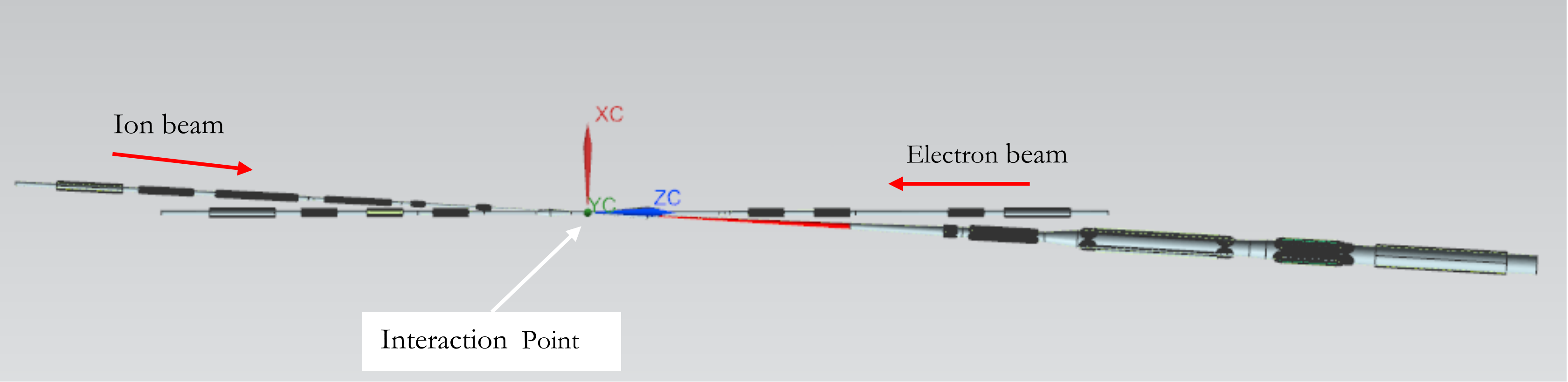
- Minimum multiple scattering in the beam pipe material
- Synchrotron radiation collimation
- L. Elouadrhiri et al. (JLab), C. Hyde (ODU), M. Sullivan (SLAC)





CAD Model - Update

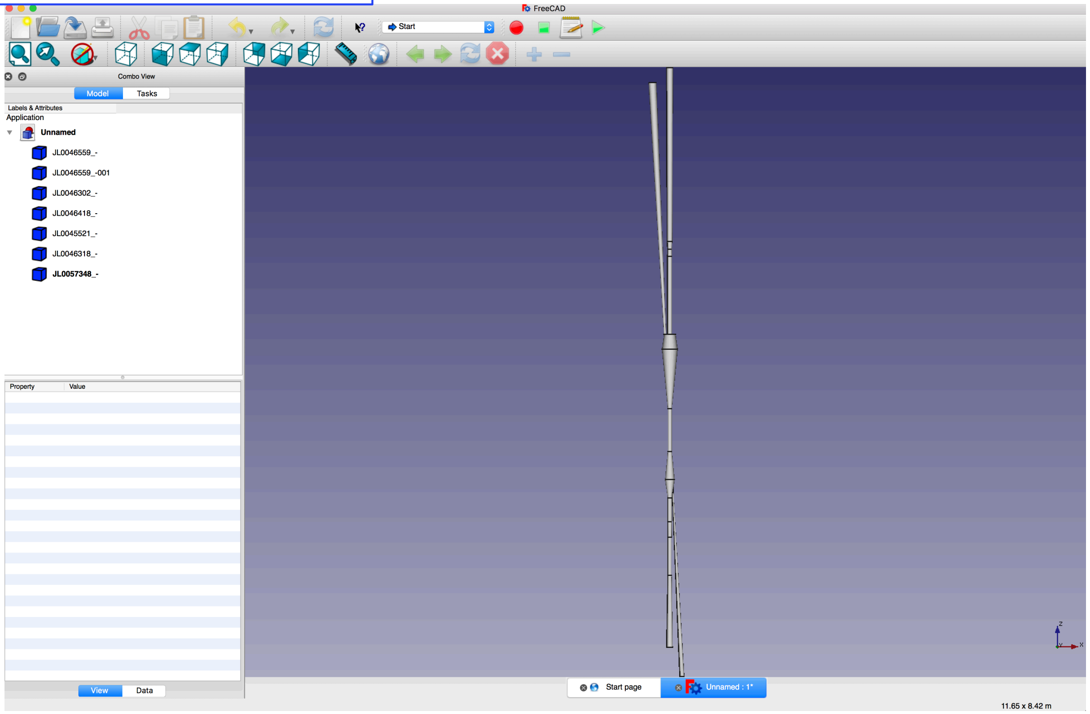
- The CAD model has been updated with the latest electron beam transport requirements
- Added water cooling channel to the central vacuum chamber
- Provided Nick Markov with the latest beam transport requirements and a STEP file of vacuum tubes for modeling in GEMC
- Provide Marcy Stutzman with STL file of the central vacuum chamber for initial modeling in MolFlow+



From Drawing to GEANT

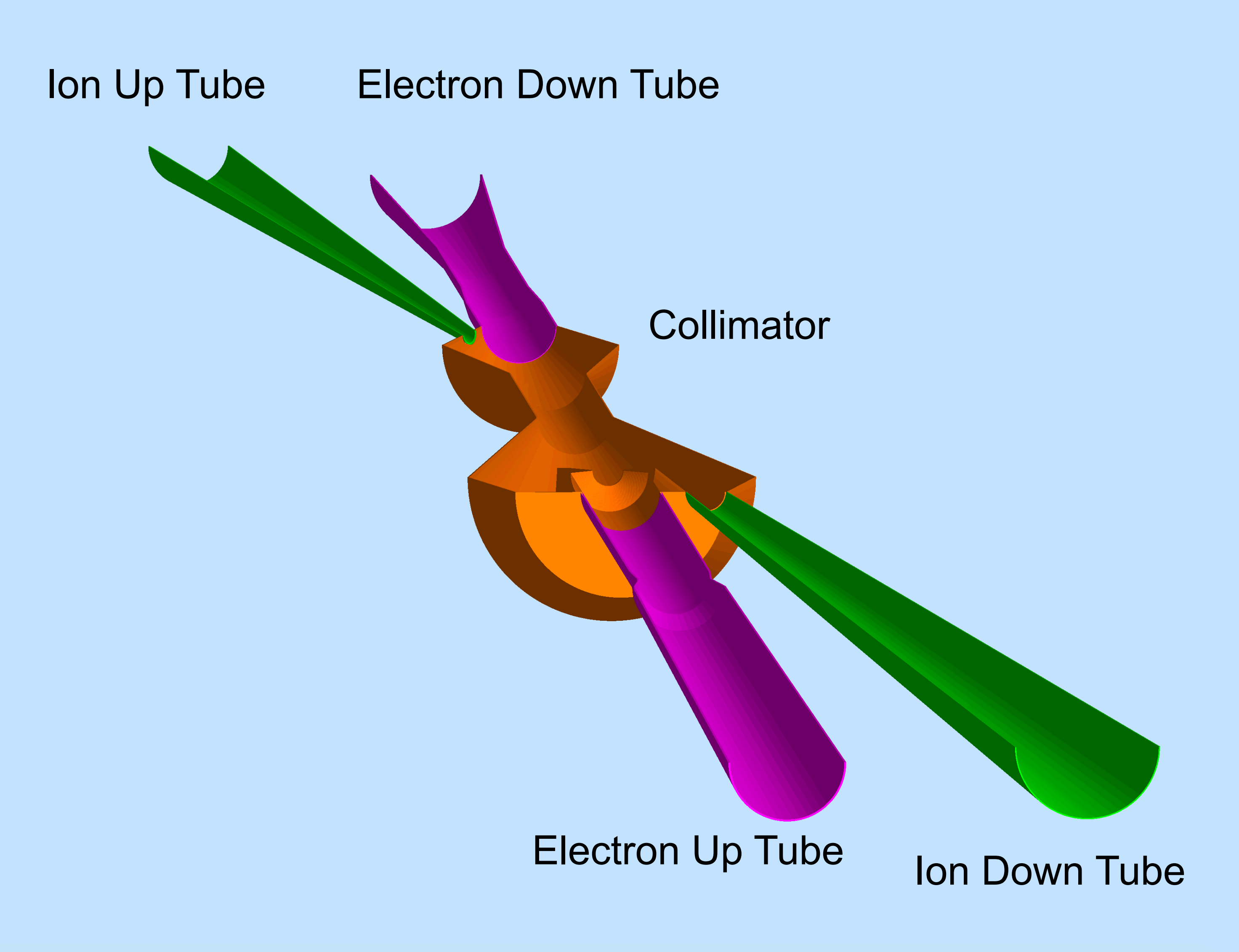
- Start with stp file which contains full design
- Save each object as a separate file
- Assign material to each object
- Put into the GEMC/GEANT4

Example of EIC beam pipe implementation

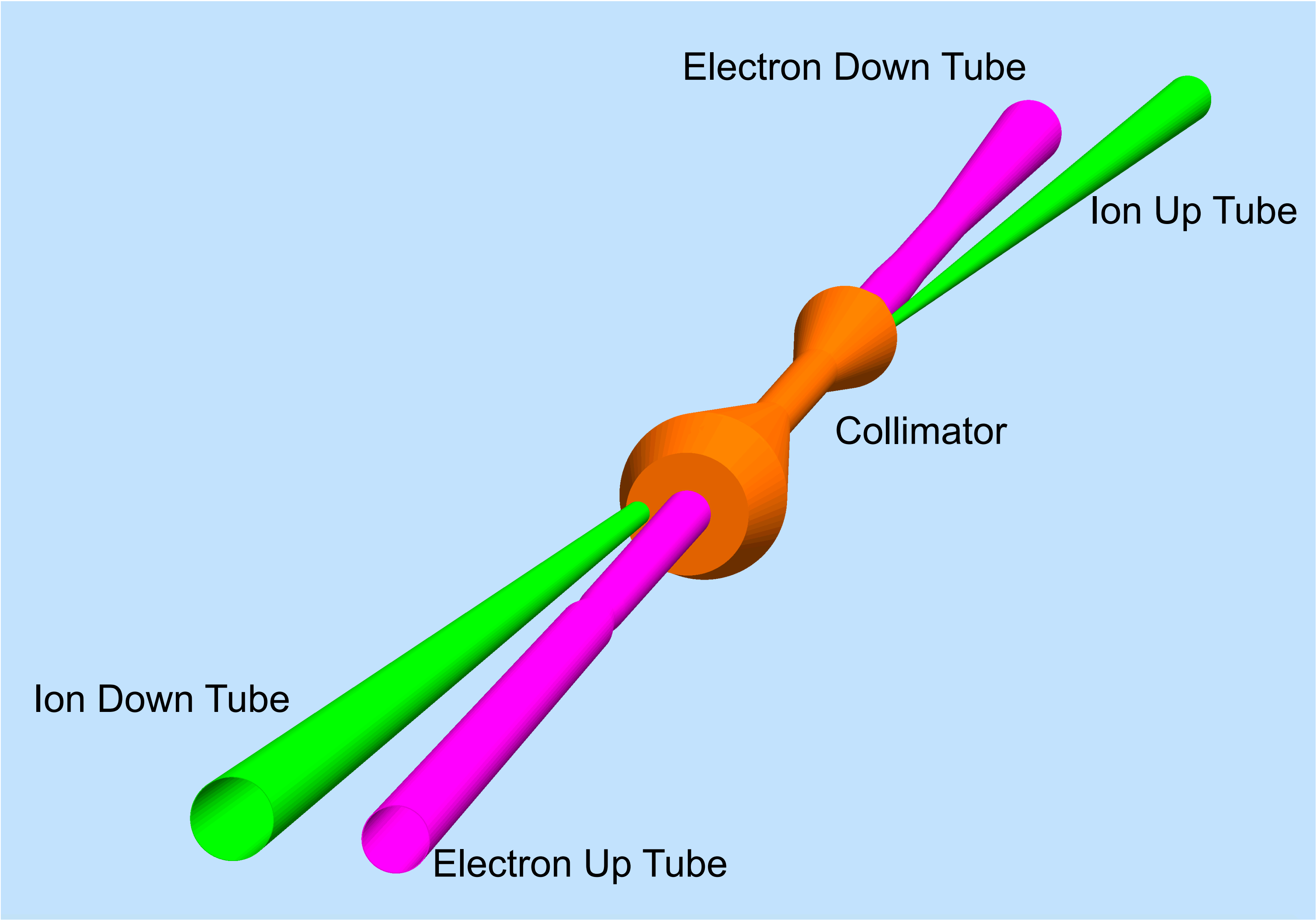


Technical note will be written, as part of making our procedure accessible

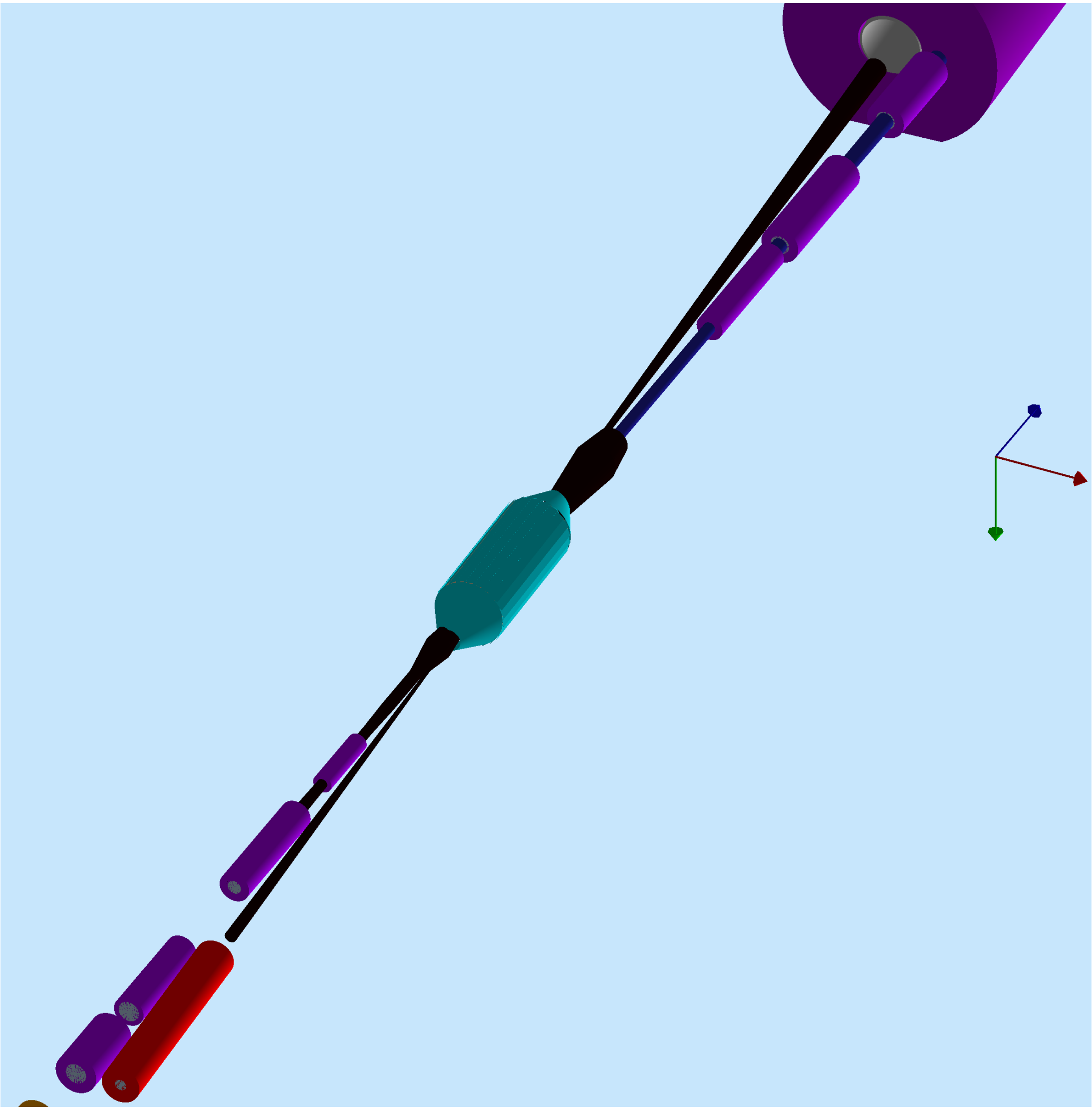
Beam-pipe in GEANT Simulation



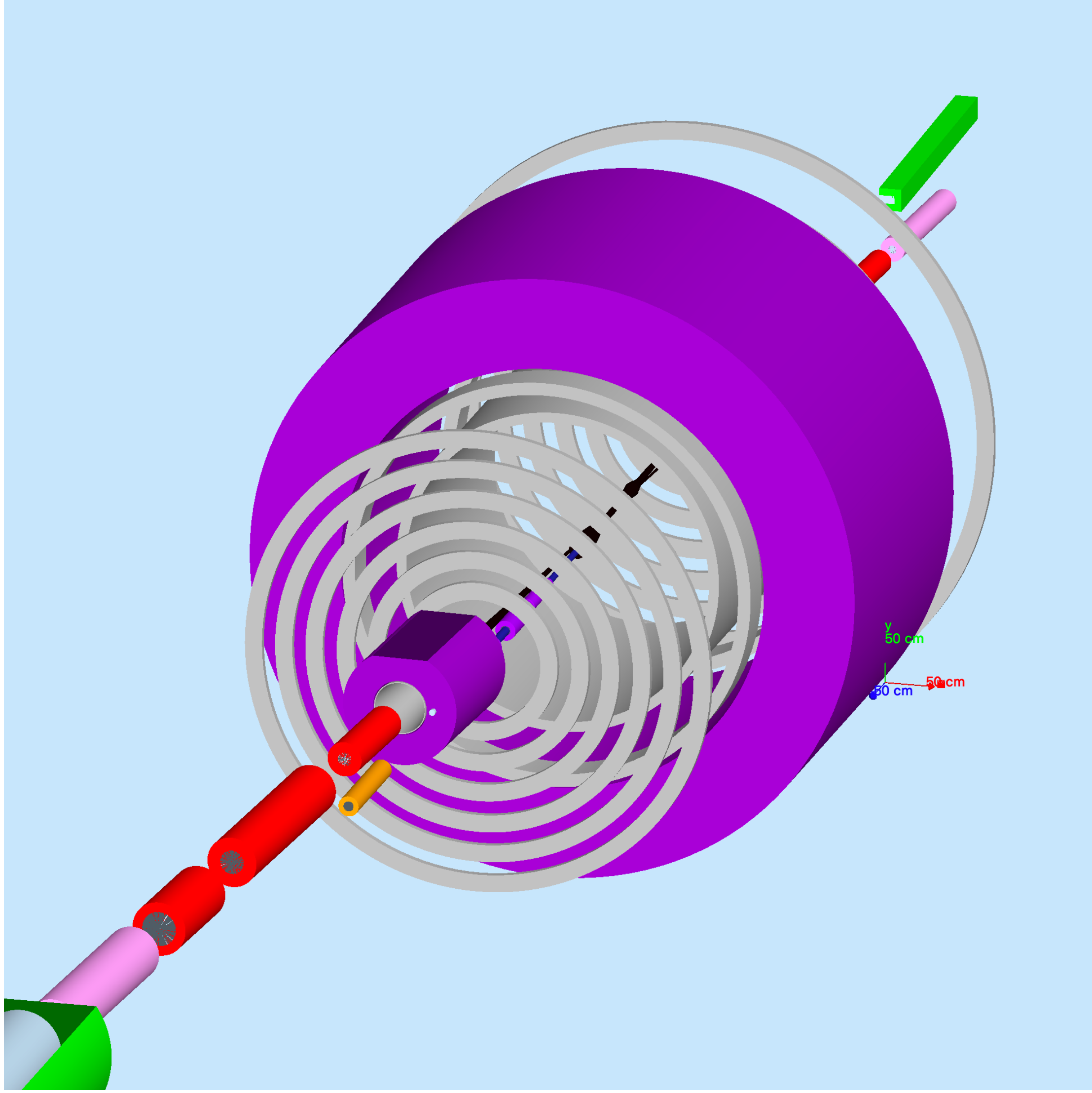
Beam-pipe in GEANT Simulation: another view



Original gcard from the EIC gemc, interaction regions from CAD



IR and JLEIC GEMC

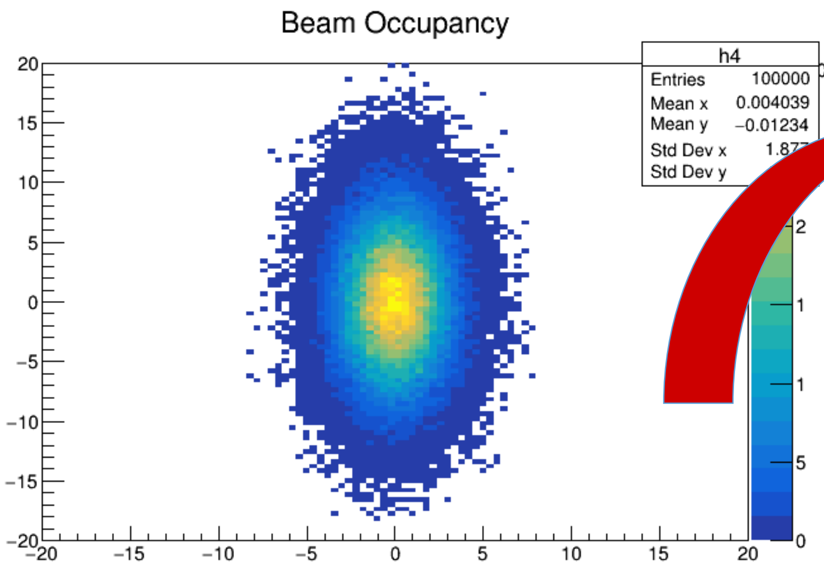


Optically Matched Bunch Distribution

electron halo intensity $I(halo) = 10^4\, I(beam\ core)$

Transverse E Beam Profile Generated at (0, 0, -7.21m)

Transverse E Beam Profile at IP = (0, 0, 0 m)



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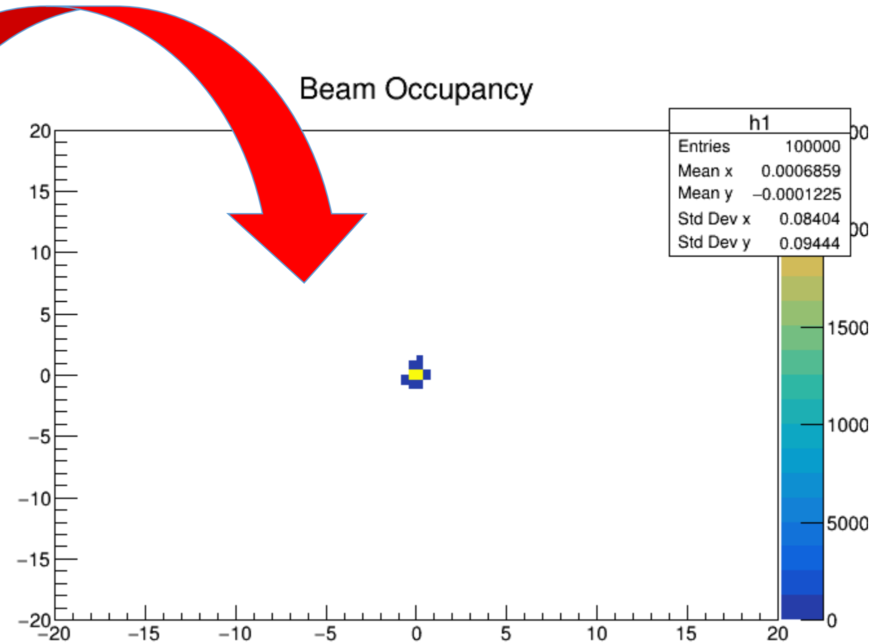

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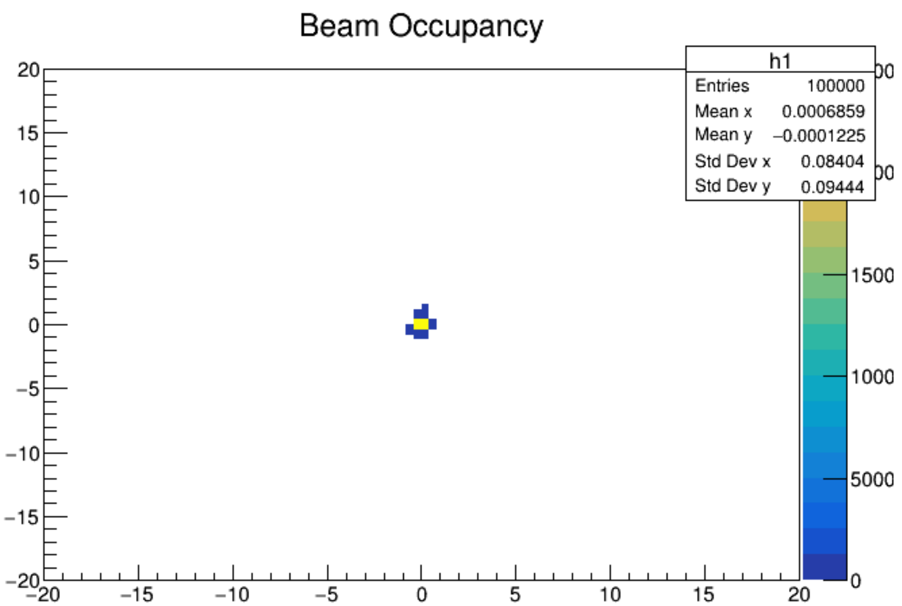
Matched distribution traced through machine lattice demonstrates strong focusing by FFQs

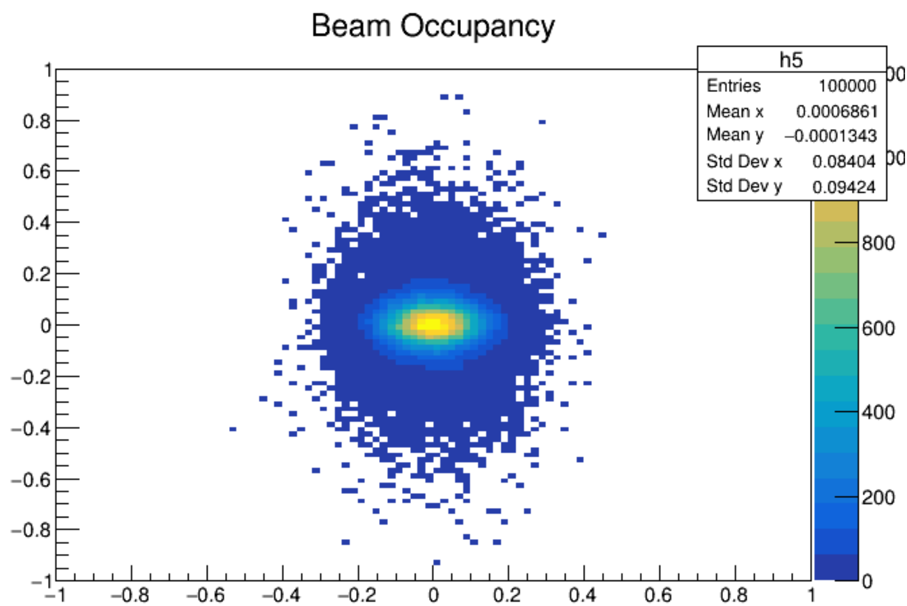
Optically Matched Bunch Distribution

Beam spot at IP

Same scale as initial distribution

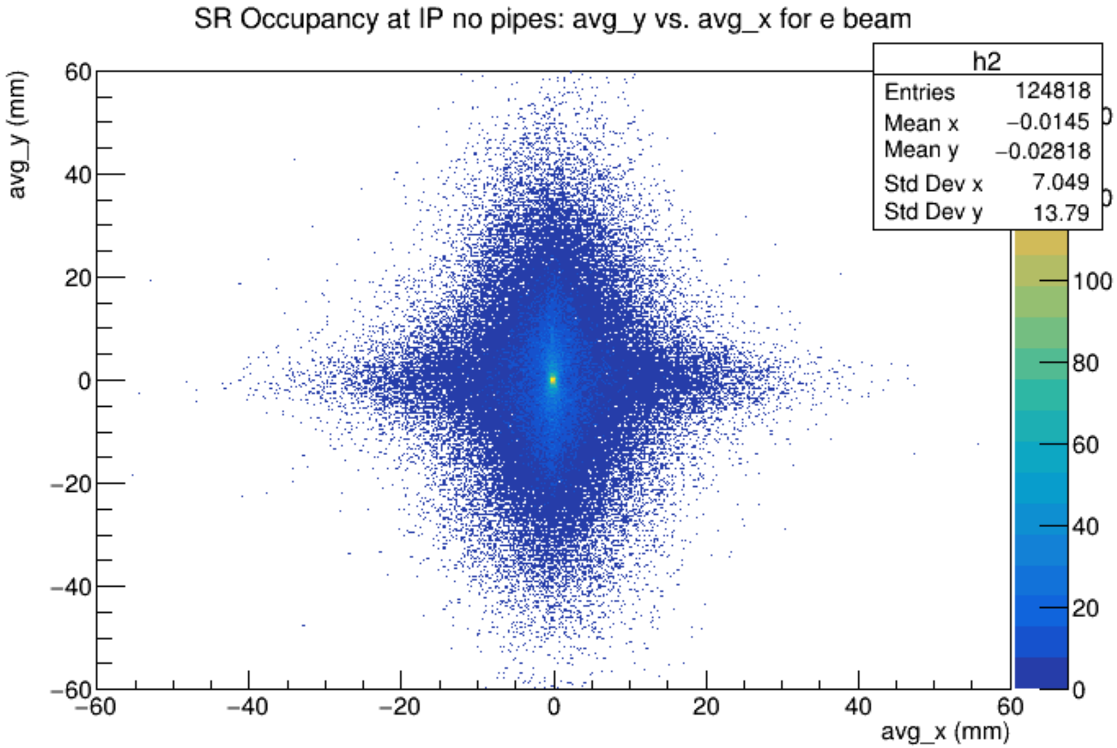
20x Zoom





Synchrotron Spot at IP

SR produced from e beam halo through FFQs:
Distribution at IP with no obstructions in particles' paths

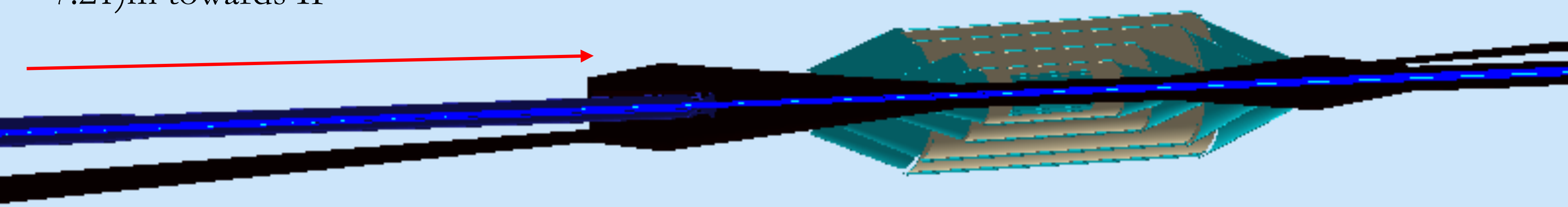


- ✓ Magnetic Fields & FFQs
- ✓ Electron Beam + Tails
- ➢ no beam pipe
- ➢ no collimation
- ➢ no detectors

Synchrotron Distribution at IP

GEMC (stable release) now interfaced with GEANT4 SR Code

Input: 5 GeV e beam (matched distribution + halo) at (0, 0, -7.21)m towards IP

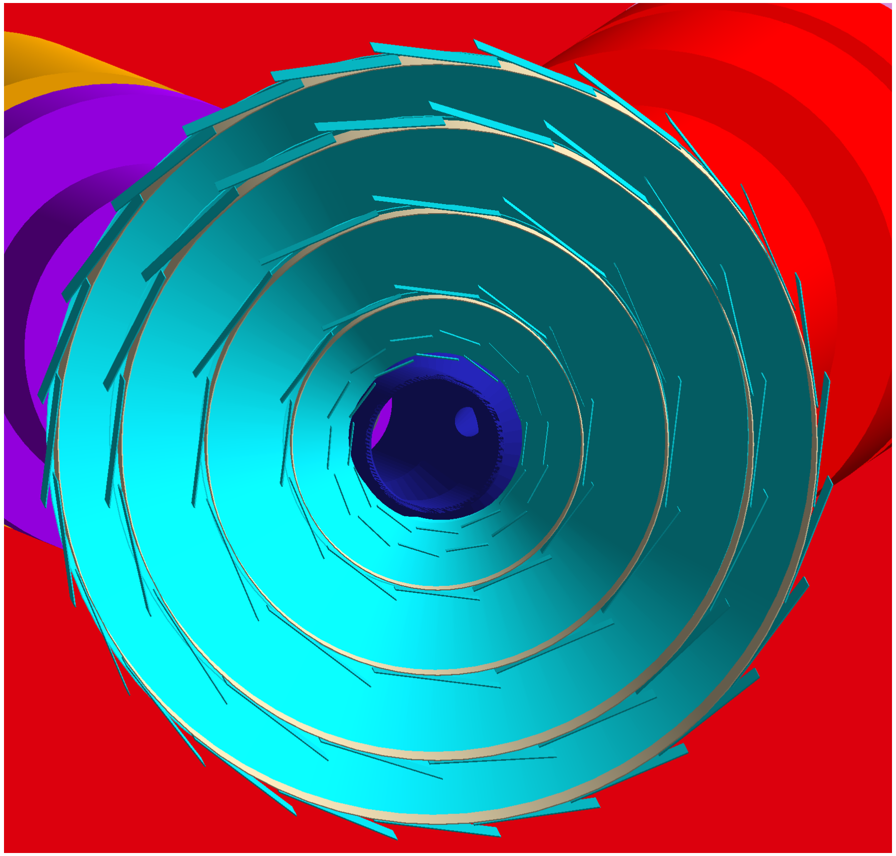


Vertex Tracker (SVT):
6 Layer Si Pixel Detector
1st layer +0.5 cm from central beam pipe

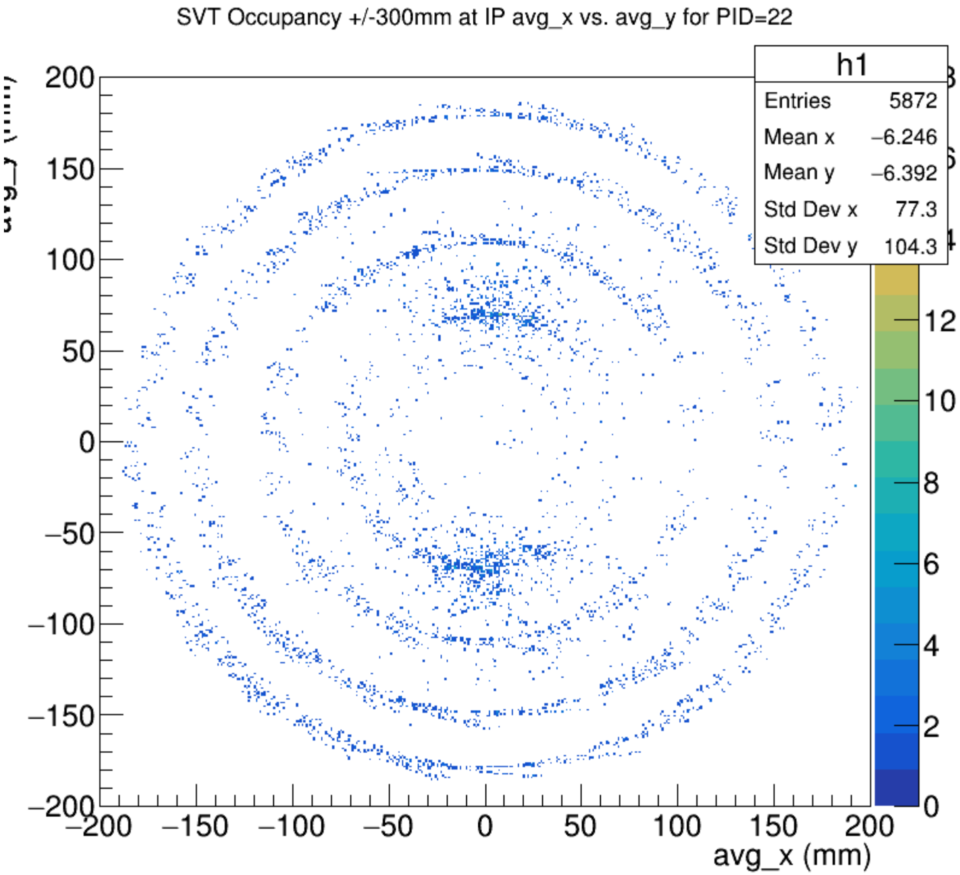
Synchrotron Distribution at IP

Silicone Vertex Tracker

Transverse profile of SVT in GEMC simulation



SR photon occupancy +/- 30 cm around IP indicates detector structure

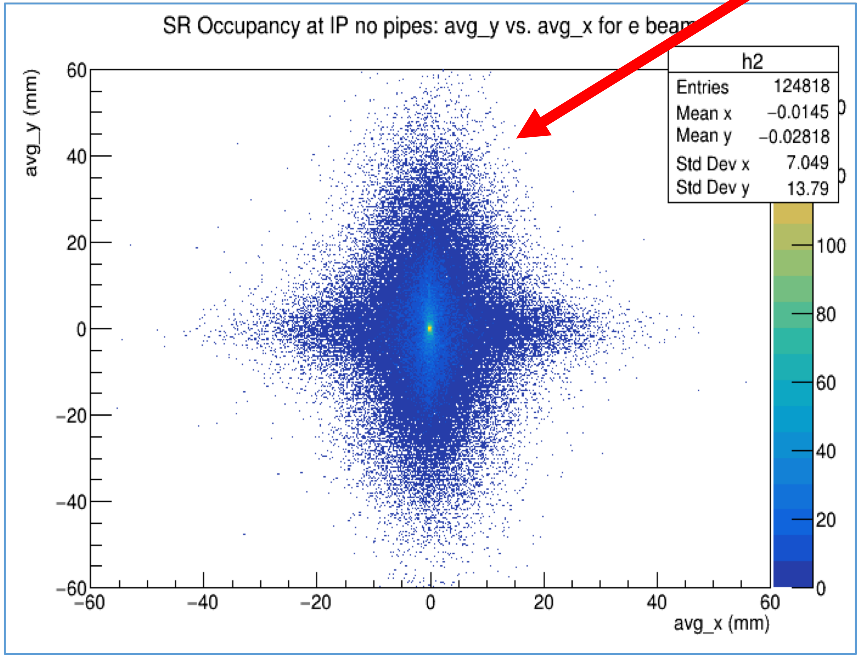


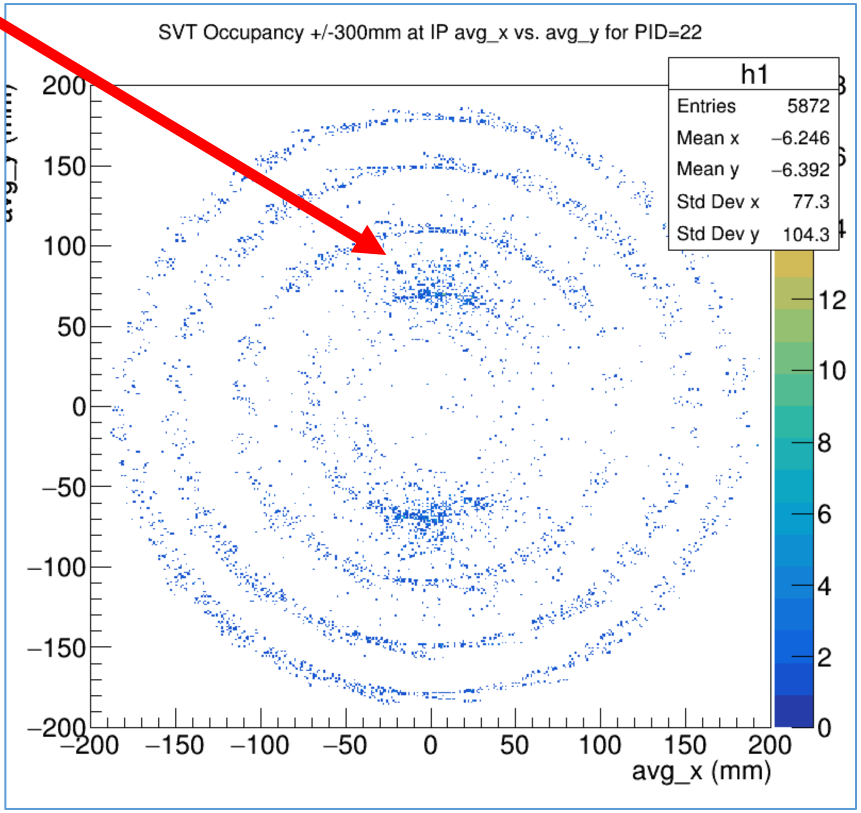
Synchrotron Distribution at IP

Synchrotron Spot at IP (no pipe nor detector)

Synchrotron in SVT at IP

Shape of photon distribution consistent in both plots*





*Graphs generated from different # of beam statistics

Synchrotron Distribution at IP

Accomplished

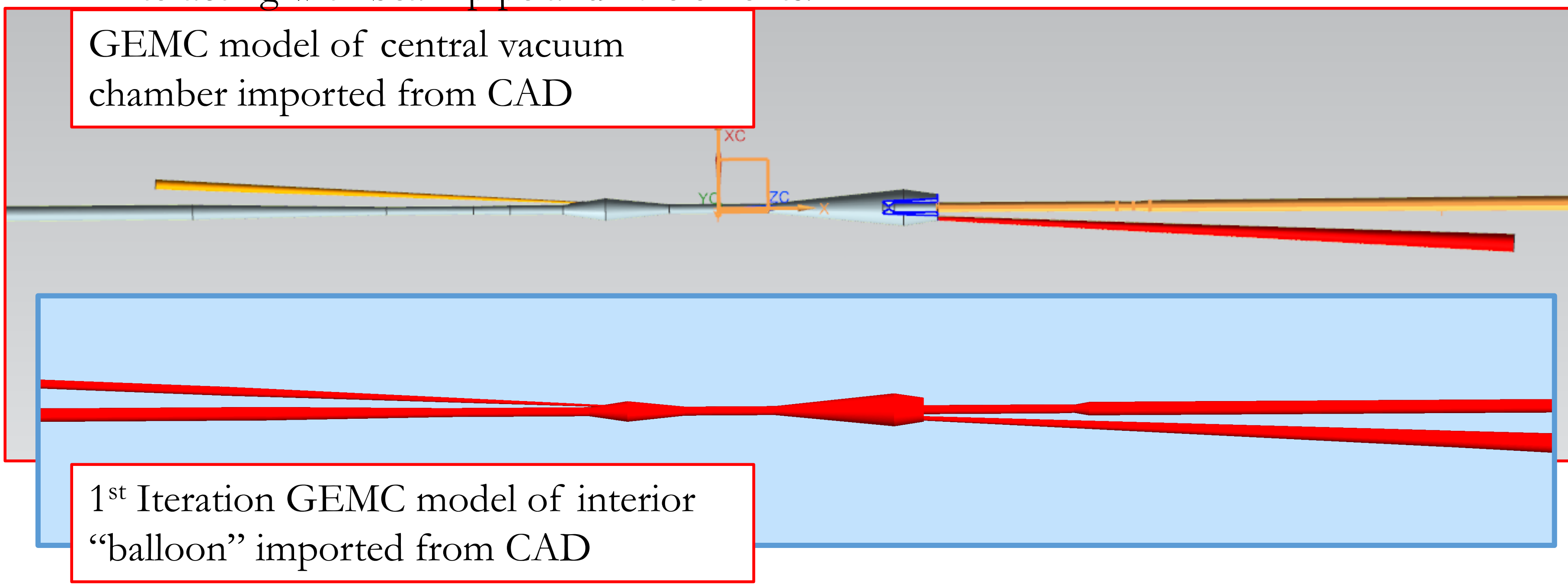
- ✓ Benchmarked GEANT4 SR code against validated SR code from SLAC;
- ✓ Interfaced GEMC with both SR codes;
- ✓ Implemented full chain JLEIC IR configuration;
- ✓ Automated workflow between simulations and lattice design with magnet script;
- ✓ Modeled e beam halo based on work at SLAC;
- ✓ Generated SR photon distribution in SVT around beam pipe.

Next Steps

- ➢ Calculate SVT occupancy based on current knowledge of thresholds, geometries, estimated granularity (in progress);
- ➢ Refine SVT occupancy calculation with:
  - ➢ Next iteration of CAD beam pipe to include gold coatings,
  - ➢ Maturation of SVT design, especially granularity;
- ➢ Add additional IP elements as appropriate (detector, support structure, etc).

Ion Beam/Gas Background at IP

- To determine the rate of ion beam/gas background as a function of vacuum for EIC geometry, we need a CAD model of the internals of the beam pipe and interaction region.
- The detailed interior will be imported into GEMC to simulate specific gas compositions and densities determined by vacuum engineers' simulations.
- This yields the geometry-dependent effects of ion beam/gas background halo interacting with beam pipe and IP elements.



Ion Beam/Gas Background at IP

Accomplished

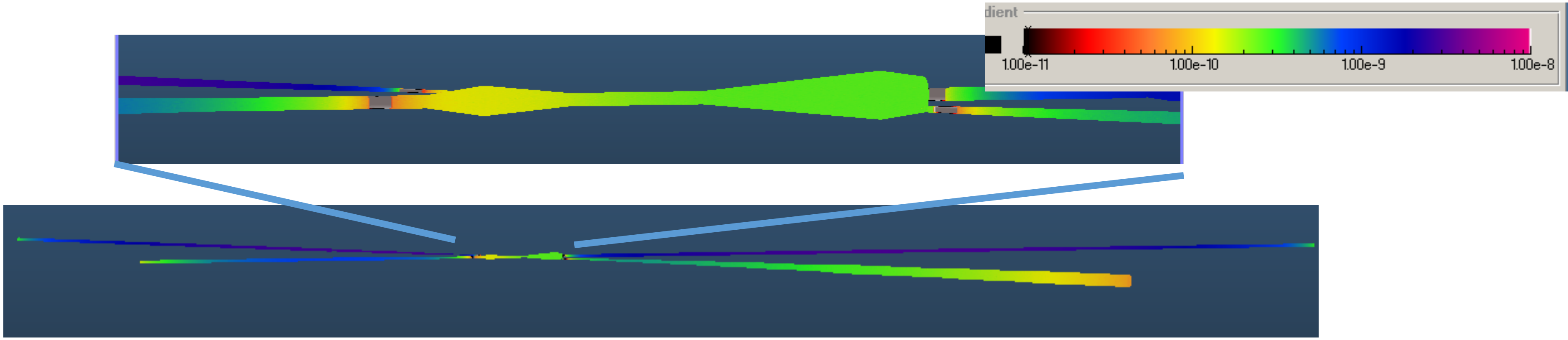
- ✓ Benchmarked GEANT4 beam/gas interactions against data from HERA;
- ✓ Modeled simplified IR based on JLEIC parameters
- ✓ Simulate beam/gas background events using 100 GeV proton beam from internal GEMC generator

Next Steps

- ➢ Complete analysis of beam/gas background vs vacuum level (in progress);
- ➢ Refine balloon of beam pipe interior;
- ➢ Model proton beam matched distribution with halo;
- ➢ Refine results by implementing density distribution from vacuum engineers around IP.

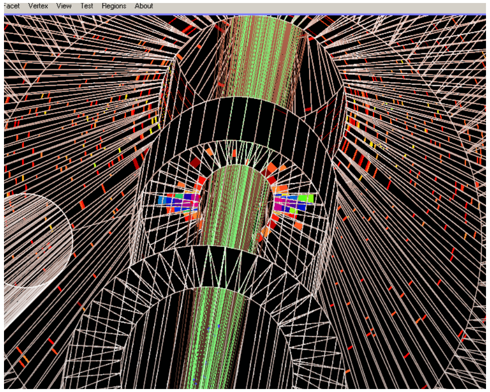
Molflow+ investigations of static vacuum

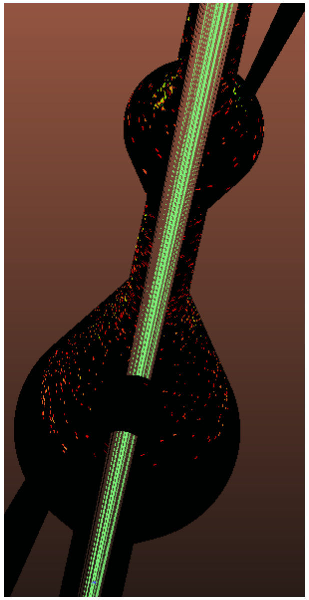
- All lines warm, outgassing estimated at standard 304 SS: 5×10^{-12} TorrLs^{-1}cm^{-2}
- Pumps simulated within beamline at ends of IR chamber
  - 2400 L/s in 6.2 cm ID electron lines
  - 1200 L/s in 3 cm ID ion lines
  - Pump speeds feasible using arrays of NEXTorr compact getter/ion pumps
- Expected static vacuum in this scenario ~5×10^{-10} Torr
- Highest pressures in long electron and ion source lines, room temp
  - ~7×10^{-9} Torr – additional pumping locations to be identified



Initial Synrad calculations

- Input parameters
  - e- line: 3 quadrupole field strengths and positions
  - Beam parameters (emittance, coupling, $\beta_{x,y}$, $\varepsilon_{x,y}$ as a function of position
  - Geometry of collimator and interaction region
  - 10 GeV beam, 3000 mA current
- Output synchrotron radiation
  - Max. collimator: 300 W/cm^2
  - Max chamber: 3 mW/cm^2
- Refinements needed
  - Refined beam parameters
  - Surface roughness analysis for reflection
  - Beryllium window properties determined and added
  - Photon heat load due to beam/gas interaction from GEMC
  - Synchrotron induced heating and outgassing to input to Molflow+ for dynamic vacuum calculations





FY19 Team Members

Project members:

- Latifa Elouadrhiri (Thomas Jefferson National Accelerator Facility)
- Yulia Furletova (Thomas Jefferson National Accelerator Facility)
- Charles Hyde (Old Dominion University)
- Alexander Kislev ((Brookhaven National Laboratory)
- Vasiliy Morozov (Thomas Jefferson National Accelerator Facility)
- Nikolay Markov (University of Connecticut)
- Christoph Montag (Brookhaven National Laboratory)
- Christine Ploen (Old Dominion University)
- Marci Stutzman (Thomas Jefferson National Accelerator Facility)
- Mike Sullivan (SLAC National Accelerator Laboratory)
- Mark Wiseman (Thomas Jefferson National Accelerator Facility)

Note: The project members listed in blue are supported by the eRD21 funds for their work on this project. The project members listed in green are our new collaborator from BNL.

FY19- Deliverables

- Optimize the machine lattice and track matched beam to evaluate changes in background carried to IR and detectors.
- Develop an efficient method to streamline the transfer design between Lattice and GEANT4
- Design and optimize the collimation of the synchrotron radiation to minimize the background rate
- Import detailed engineering model of machine lattice magnets and IR design from CAD to GEMC.
- Evaluate quantitatively the background type and distribution due to the SR radiation, giving feed back to the machine and IR designer towards design optimization.

FY19- Deliverables (cont.)

- Use Molflow+ and Synrad to realistically simulate vacuum conditions.
- Design vacuum system based on requirements of the IR vacuum tube and vacuum vessels and its translation into the simulation.
- Use SR level to determine the level of dynamic vacuum.
- Evaluate the background type and distribution due to the beam gas interaction giving feed back to the vacuum engineer and IR designer towards design optimization.
- Estimate rates, due to both beam gas interaction and SR, in the detectors and beam pipe in the configuration including realistic lattice, vacuum levels and IR. This will serve as an input to the iterative procedure of the lattice and vacuum system optimization.
- Develop an interface to Fluka and GRANT3 to evaluate neutron flux from our simulation framework.
- Benchmark comparison of neutron flux from Fluka, GEANT3 and GEANT4 by checking the list of all the relevant physics processes.
- Evaluate neutron flux from Fluka/GEANT3 by comparison with GEANT4 in the EIC configuration. This is critical task as it has severe impact on detector and electronics lifetime.

Funding Request

	FY18		
Resources	100% Funding	80% Funding	60% Funding
Post-Doc (Uconn & GWU)	$90k	$75k	$54k
Student (ODU)	$20k	$20k	$20k
Travel (Consult M.S. from SLAC) JLab Responsibility	$15k	$5k	$5k
Total	**$130k**	**$104k**	**$78k**

Institutions	100% Funding	80% Funding	60% Funding
UCONN & GWU	$90k	$75k	$54k
ODU	$35k	$35k	$35k

Note: *The costs are fully burdened*

Summary

Created validated and benchmarked simulations tools and procedures during FY18

- GEANT simulation: complete the HERA benchmarking
- Synchrotron radiation modeling code
- Static vacuum modeling

All FY18 tasks are completed or being finalized and documented

Ready to perform detailed rates and occupancies due to different background sources to optimize the design

We request funding to perform detailed simulations of the EIC machine related background for both JLEIC and eRICH configurations:

- Synchrotron radiation modeling code
- Static & dynamic vacuum modeling
- Neutron flux

THANK YOU!