EIC machine backgrounds

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CFNS workshop on Forward Physics And Instrumentation
From Colliders To Cosmic Rays
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Introduction

- EIC IR and Detector concepts are designed to best enable the physics of the EIC whitepaper and made in close collaboration with the accelerator design

- **EIC High Luminosity** performance is mandatory in order to start the nucleon nuclear structure measurements on **Day 1**

This requires thorough quantitative background studies to ensure the high luminosity and full acceptance reach

Goals of the Proposal

Study background generated by machine operation in simulation:

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

- 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

Main Background Sources

- **Electron beam**
  - **Synchrotron radiation**
    - Backscattering
    - Photo desorption
      -> degradation of vacuum
  - **Beam gas interactions**
    - Off momentum electrons
  - **Higher order mode losses**
    - Local heating at injection
    - and ramp (short bunches)
    -> degradation of vacuum

- **Proton\Ion beams**
  - **Beam gas interaction, large hadronic cross section**
    - Background in detector
    - Secondary interactions with aperture limitations, i.e. with magnets, beam pipe, masks

Need:

- **Careful design of the IR**
- **SR masks**
- **Excellent vacuum system**

Tools and Methods

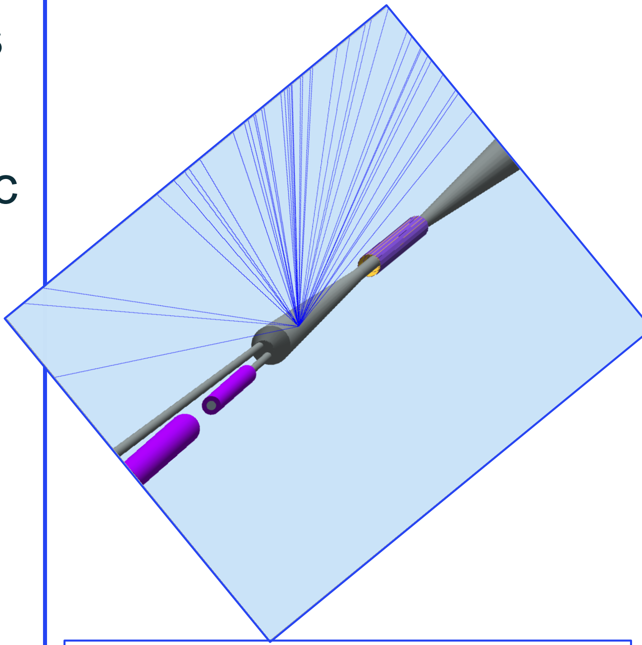
- **GEANT4/GEMC, GEANT3 and Fluka**
  - Detector and beam pipe modeling
- **Beam distribution/emittance**
  - Input to GEANT4
- **Synchrotron Radiation tools developed at SLAC (SR code)**
  - Input to GEANT4

- **Molflow+**
- **Synrad**

Vacuum Modeling Installed at JLab → Input → GEANT4

SR- Photon Generation (SR-Code)

- A gaussian transverse electron beam profile with wide gaussian tails
- Each electron is traced through the given magnetic elements and a photon critical energy is calculated based on the trajectory curvature
- The SR fan start and stop points of each magnetic element are also found and traced through a series of beam pipe apertures where the fraction of the fan hitting each aperture is recorded
- A generator of scattered photons is built from of SR photons found in the energy ranges for a give aperture: the result is the number of scattered photons from the mask tip for example
- **Each photon (energy, position and direction) are then saved to a file that can be read in by a GEANT**

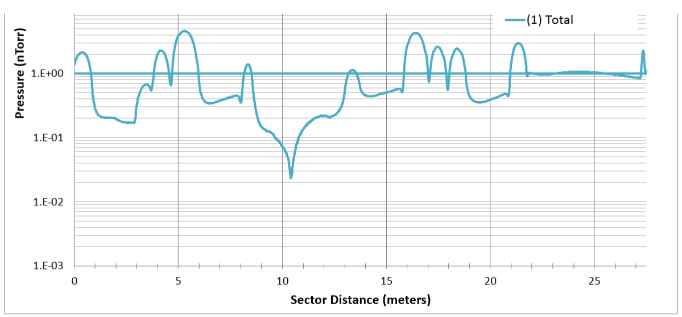


Number of incident photons on this mask tip per beam bunch: 6.9e7.

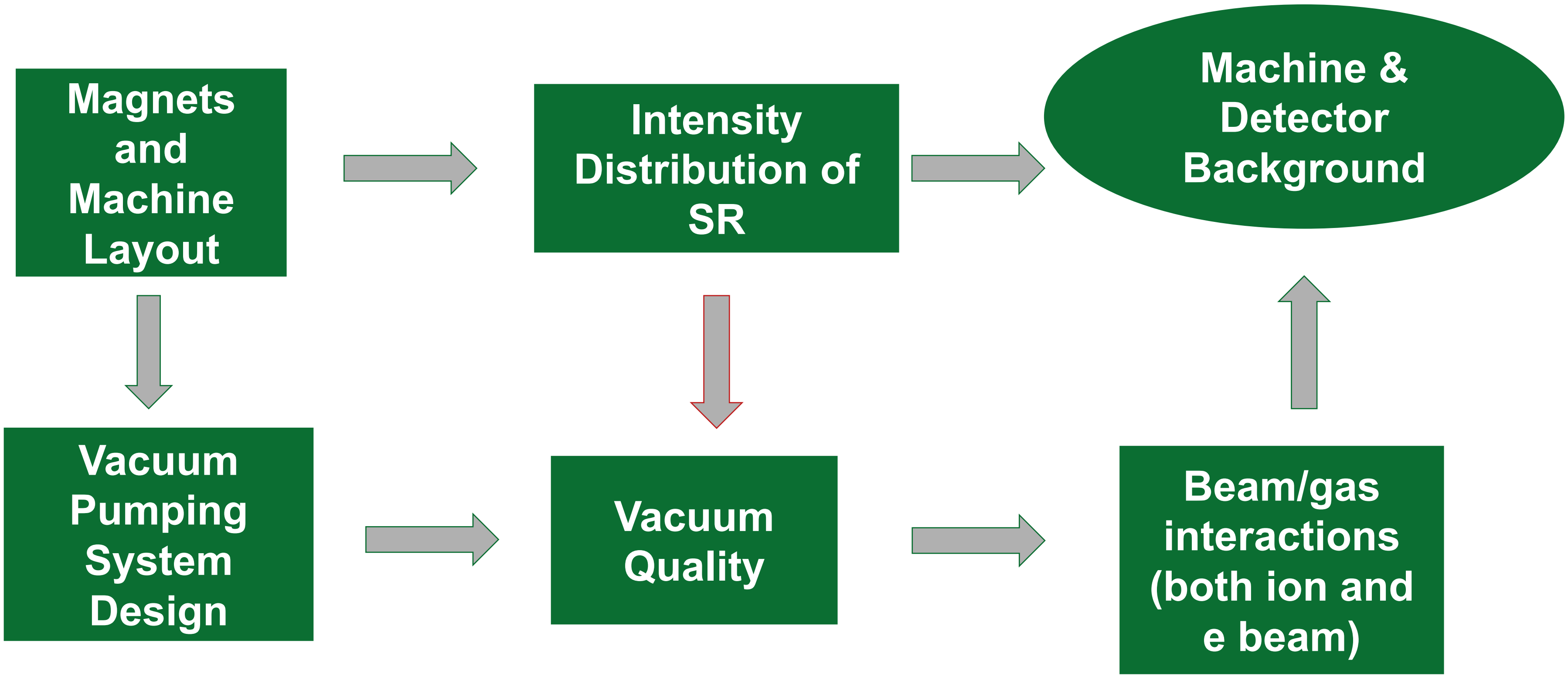
The actual number of scattered photons per beam bunch : 9751

Vacuum Modeling Tools

- Molflow+ and Synrad modeling software developed by Roberto Kersevan & Marton Ady
  - **Molflow+**: static vacuum modeling
  - **SynRad:** model of vacuum events due to beam
- Jason Carter, ANL, used Molflow+/Synrad to model static and dynamic vacuum for APS upgrade
- Jason Carter, ANL, and Marton Ady, CERN, used Molflow+/Synrad for SuperKEKB interaction region
- **CAD designs of beamline are combined with pumping speeds and outgassing rates of elements yield expected pressure becomes input to our GEANT simulations.**

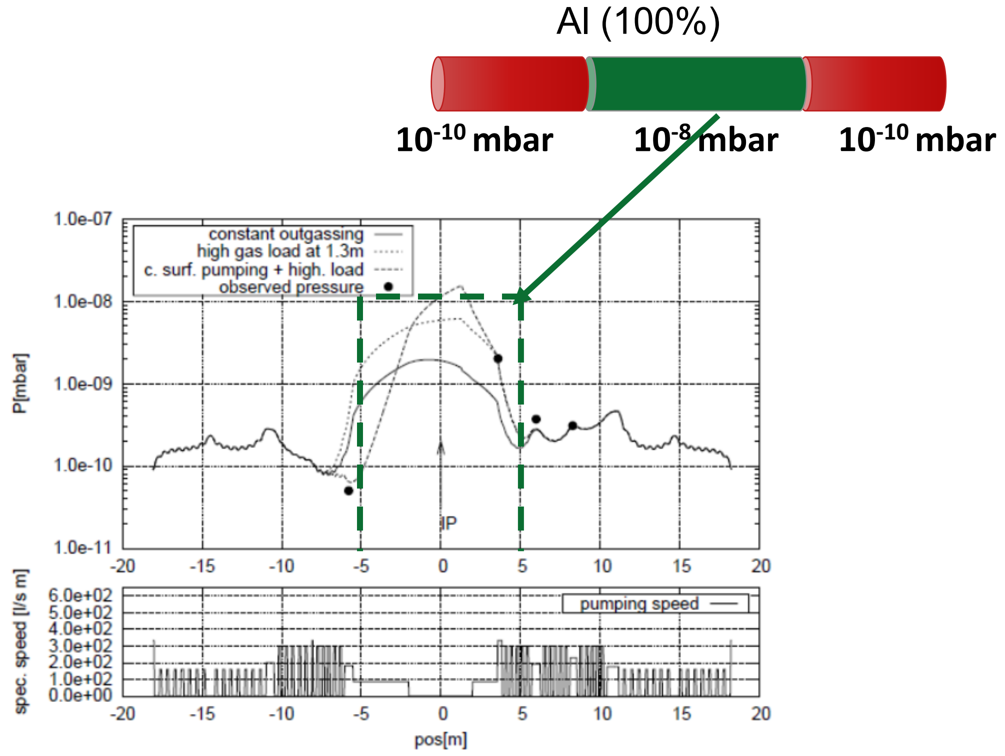


Background Studies Workflow



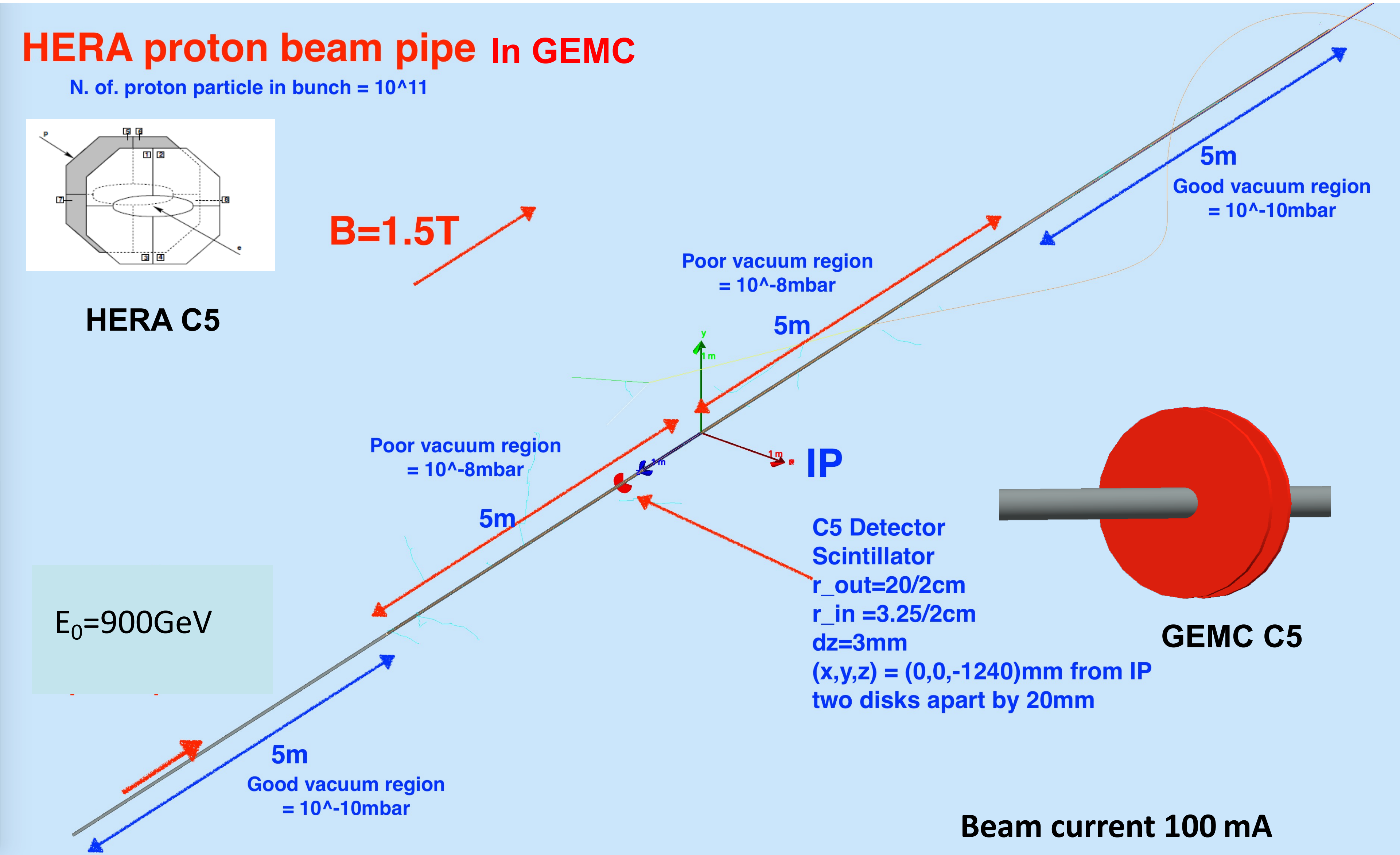
Lessons from HERA II Upgrade

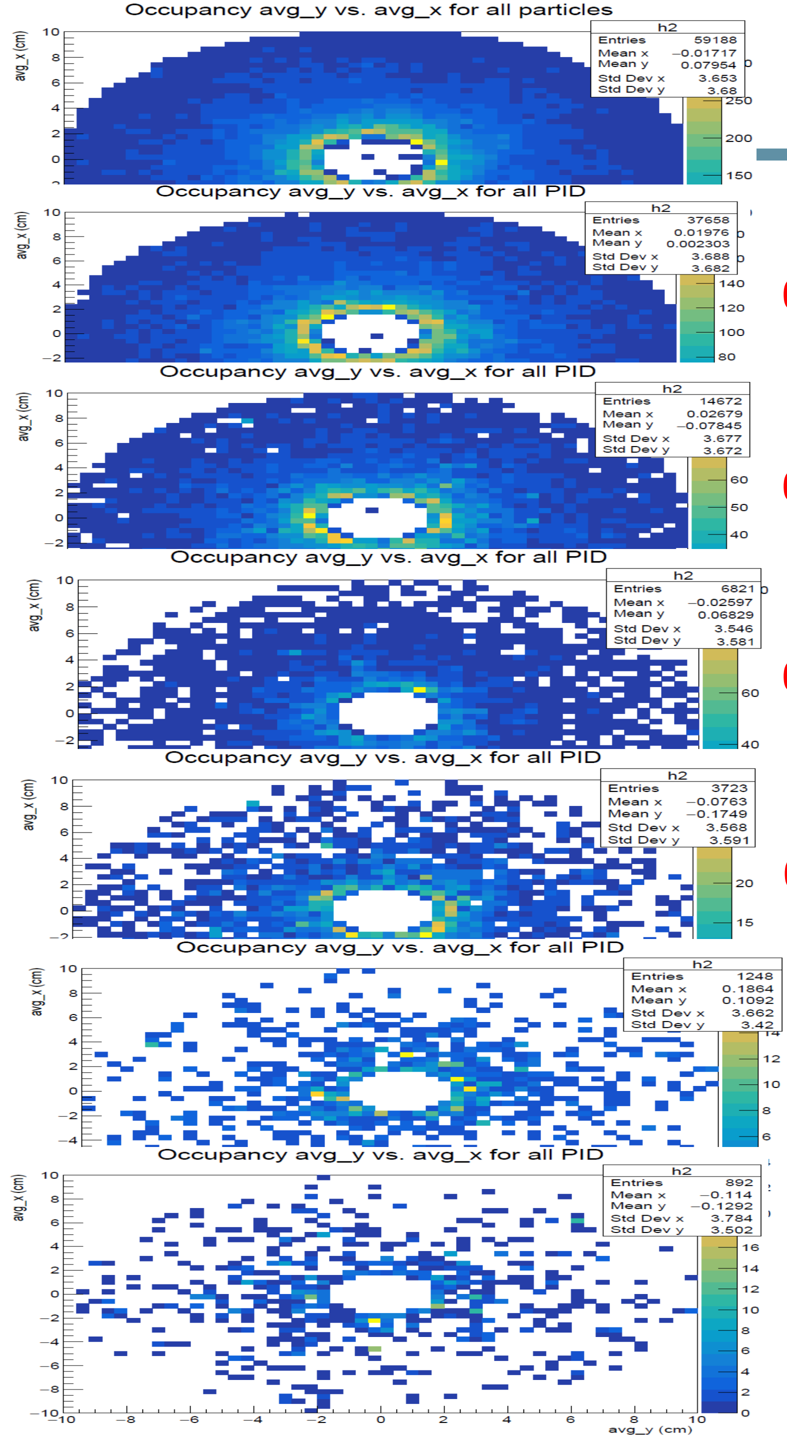
- Severe background problems in the year 2002 significantly delayed startup of HERA after luminosity upgrade
  - No detailed simulations prior to the upgrade
- Most of the background came from proton-beam gas interactions where vacuum deteriorated due to synchrotron radiation.



We used HERA II data to benchmark our tools and procedures

HERA Configuration Simulated in our Framework





10^{-8}mbar BG rate ~ 66kHz (33kHz from Charge particles)

$0.5*10^{-8}$mbar BG rate ~ 31kHz

$0.2*10^{-8}$mbar BG rate ~ 13kHz

$0.1*10^{-8}$mbar BG rate ~ 7kHz

$0.05*10^{-8}$mbar BG rate ~ 3kHz

$0.02*10^{-8}$mbar BG rate ~1.3kHz

$0.01*10^{-8}$mbar BG rate ~0.4kHz

10^{-8}mbar

Results of our simulation of HERA

10^{-10}mbar

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HERA Data as Benchmark for our Simulation Tools

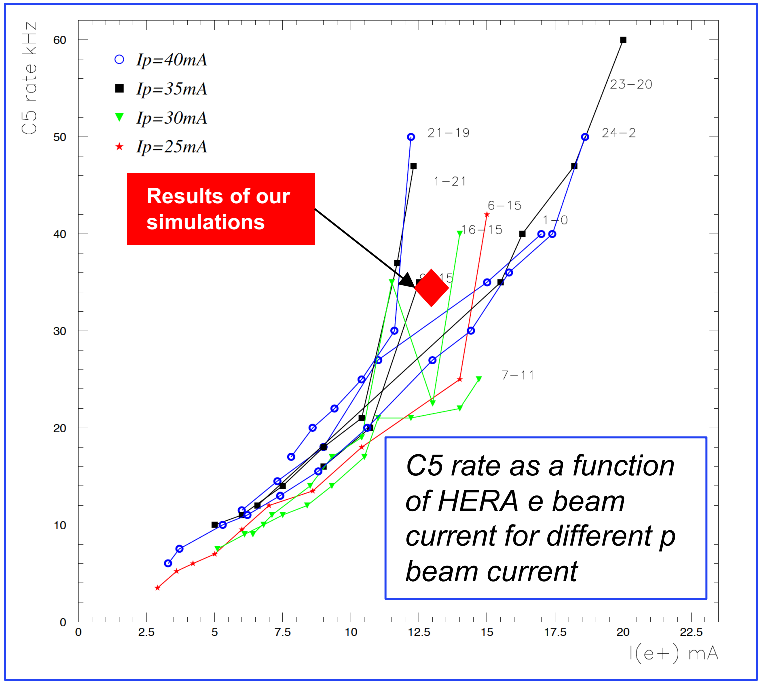
Good agreement of our simulation rate to the measured rate at HERA!

From our simulation of HERA

- The rate of the particles in the simulated C5 detector was calculated for HERA parameters and measured **33 kHz** for charged particles in agreement with ZEUS data

- For more systematics, additional studies were made, varying the vacuum region length, physics model and beam pipe material composition, whish showed the expected dependence on each parameter

From measurement at HERA

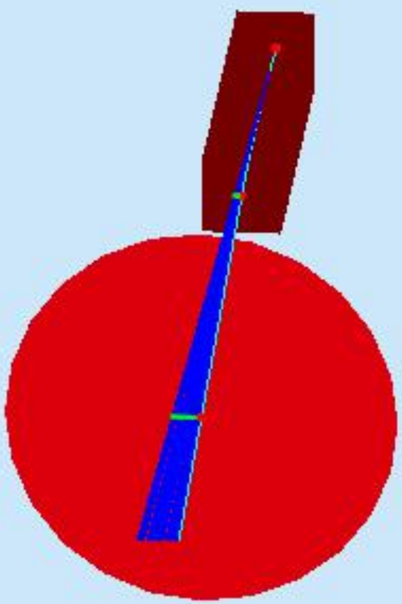


Validation and benchmarking of our simulation tools and procedures

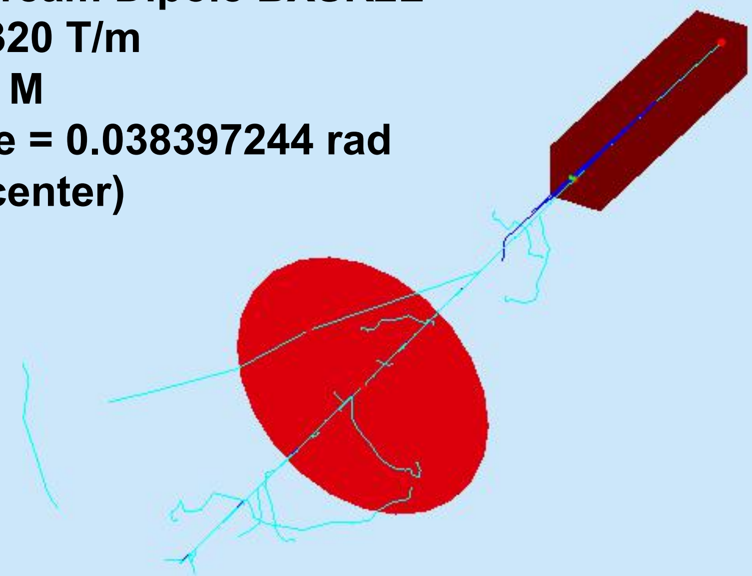
Synchrotron Radiation available in GEMC

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!

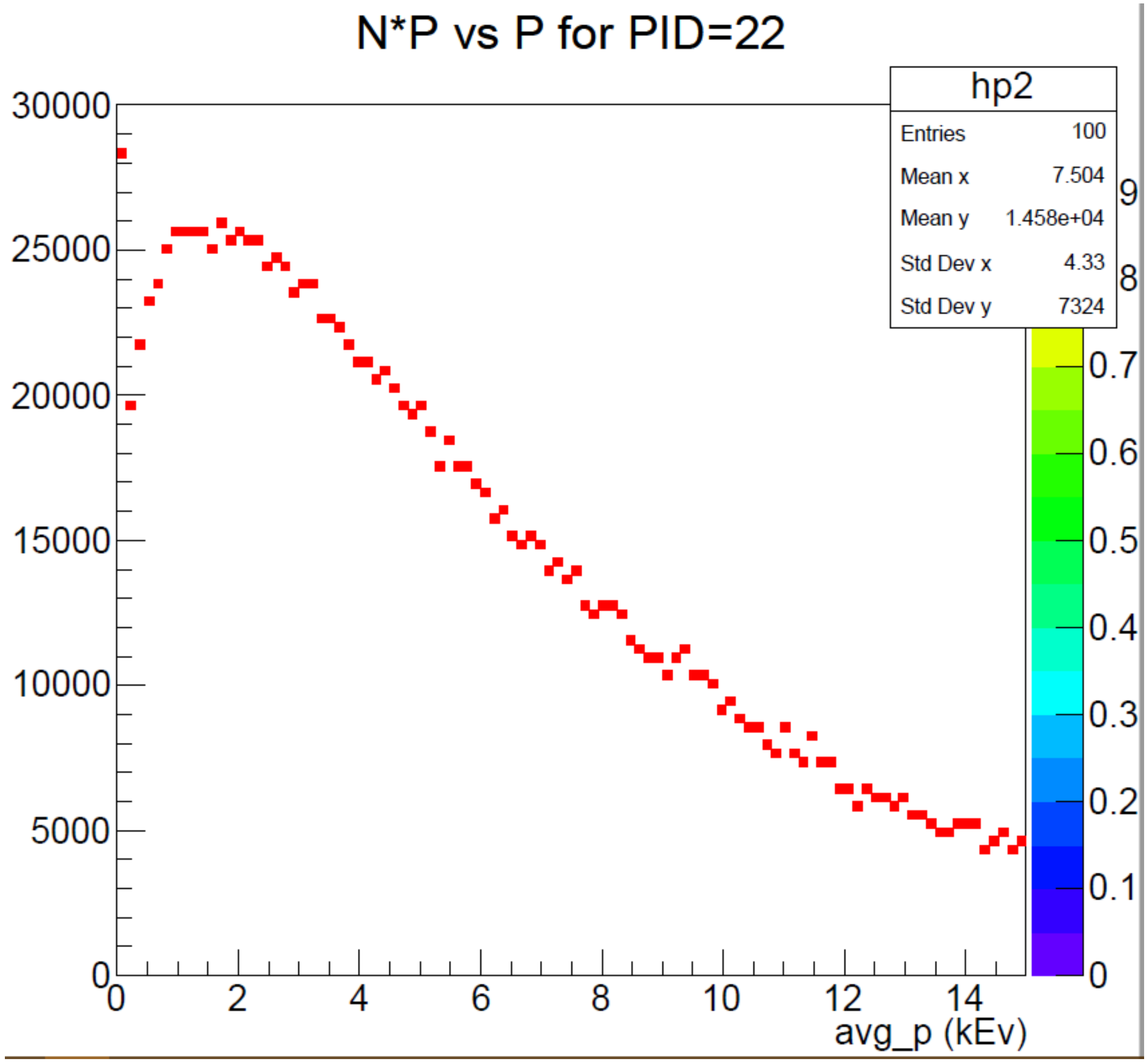
Verifying Energy Spectrum

Photon Critical Energy

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

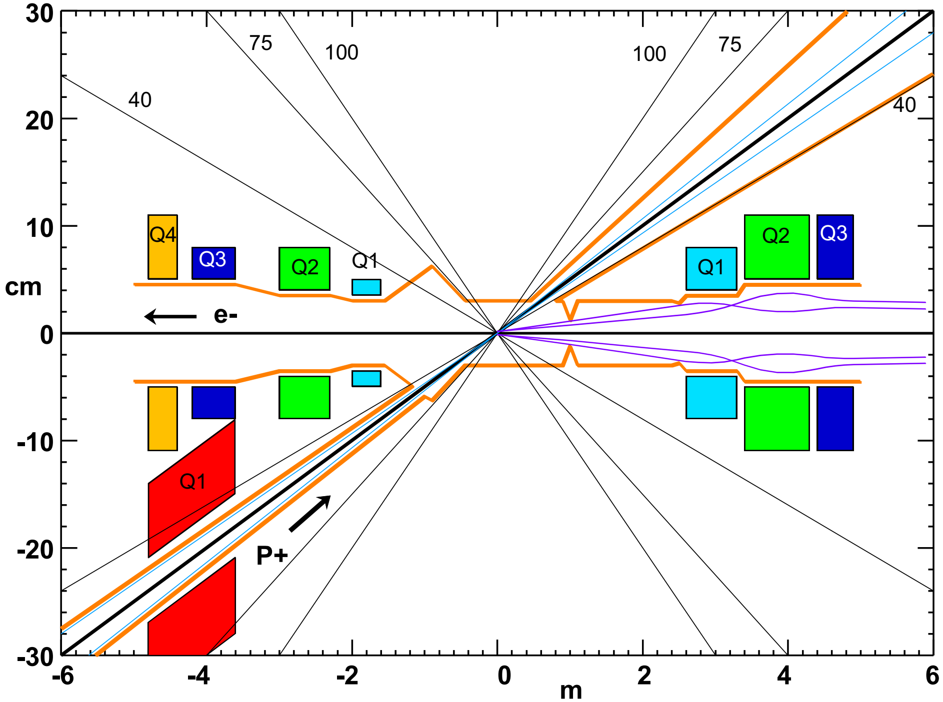
~ 5.22 keV

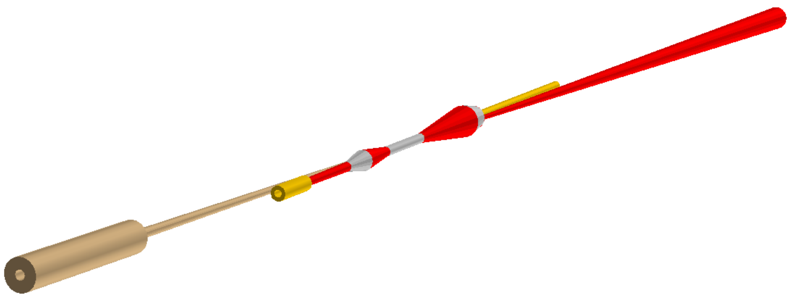
- Expect to see peak at $0.3*\varepsilon_c$, or 1.57 keV
- **Peak approximately correct**.
- Next Steps: currently verifying that integrated photon density = 6.49 keV



Beam Pipe Conceptual Design Updated

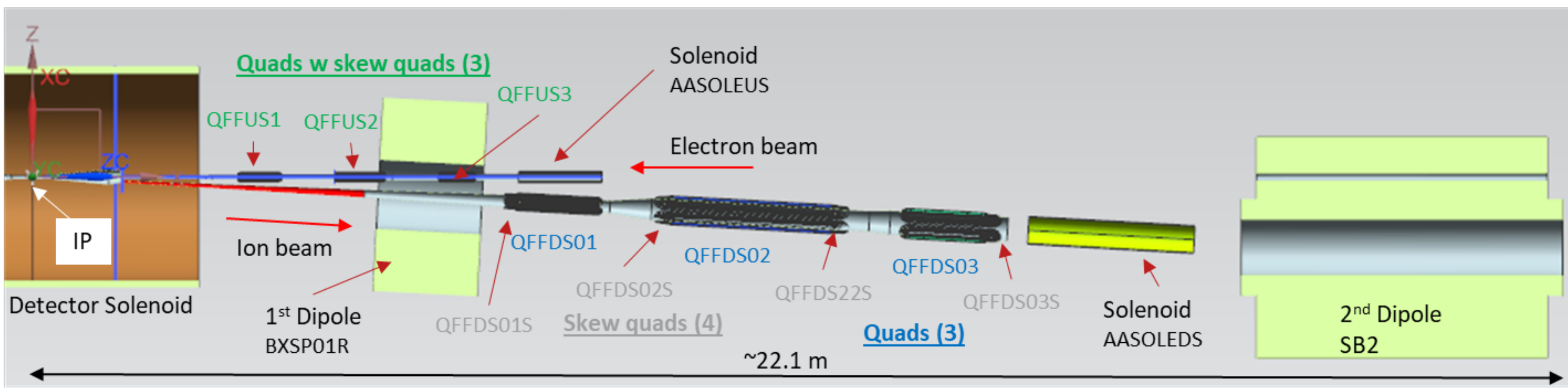
- Minimum multiple scattering in the beam pipe material
- Synchrotron radiation collimation
- L. Elouadrhiri et al. (JLab), C. Hyde (ODU), M. Sullivan (SLAC)





Development of IR Magnet Specifications

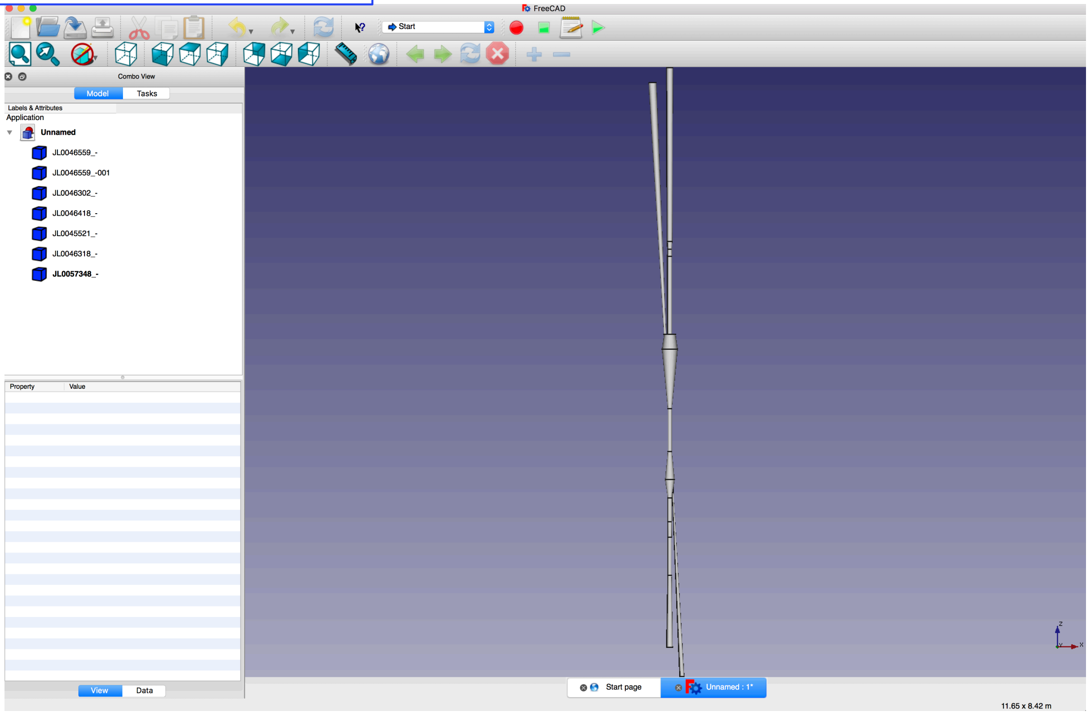
- IR magnet engineering design/analysis
  - Heat and radiation loads on IR magnets
  - Perform magnetic analysis and initial optimization design
  - Mechanical and magnetic design of an optimized IR quadrupole
  - Incorporate optimized IR quadrupole lessons/features and finalize JLEIC IR layout



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

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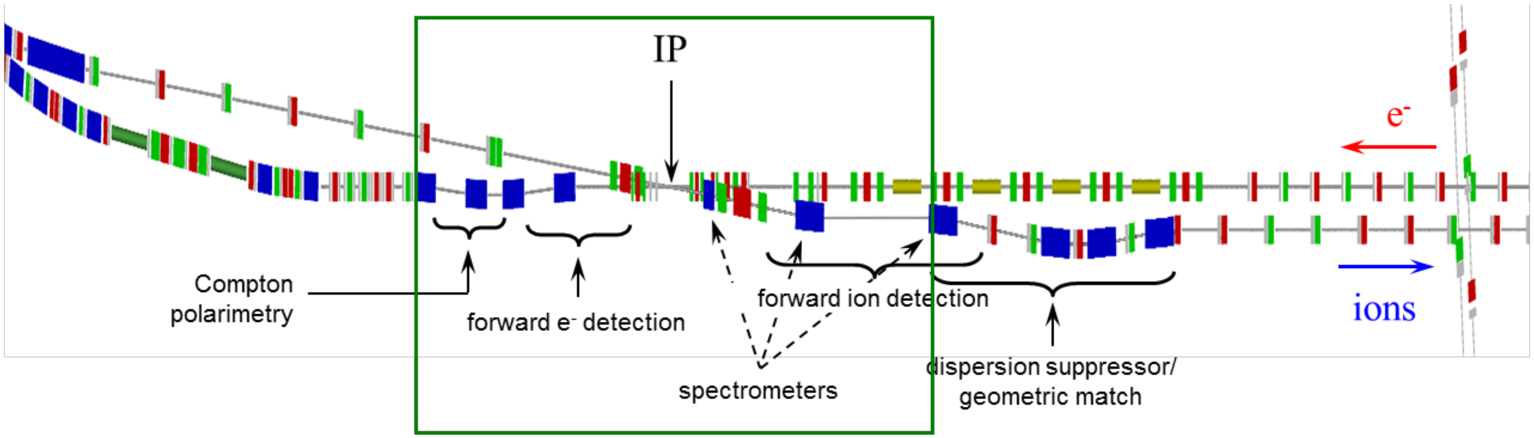
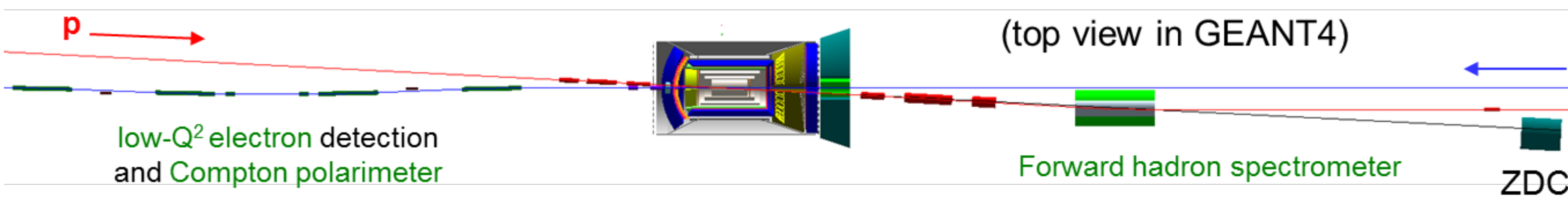
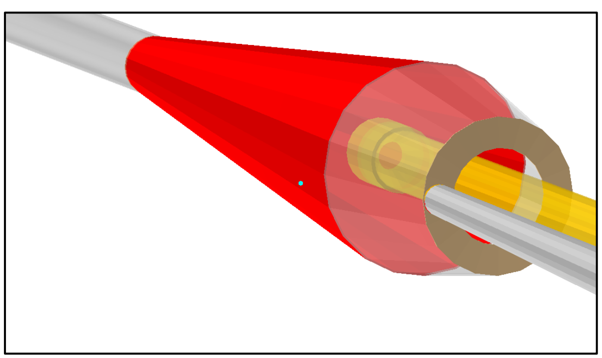
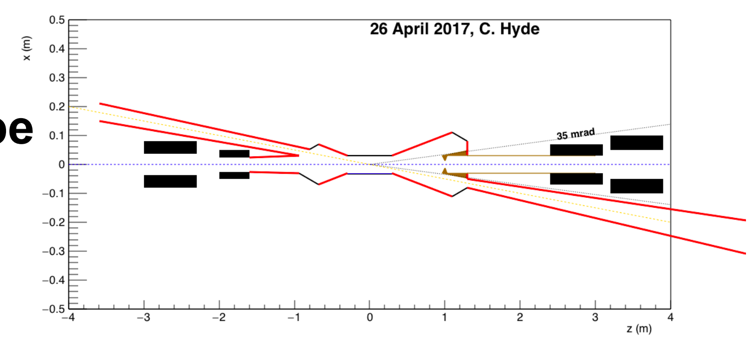
JLEIC Interaction Region



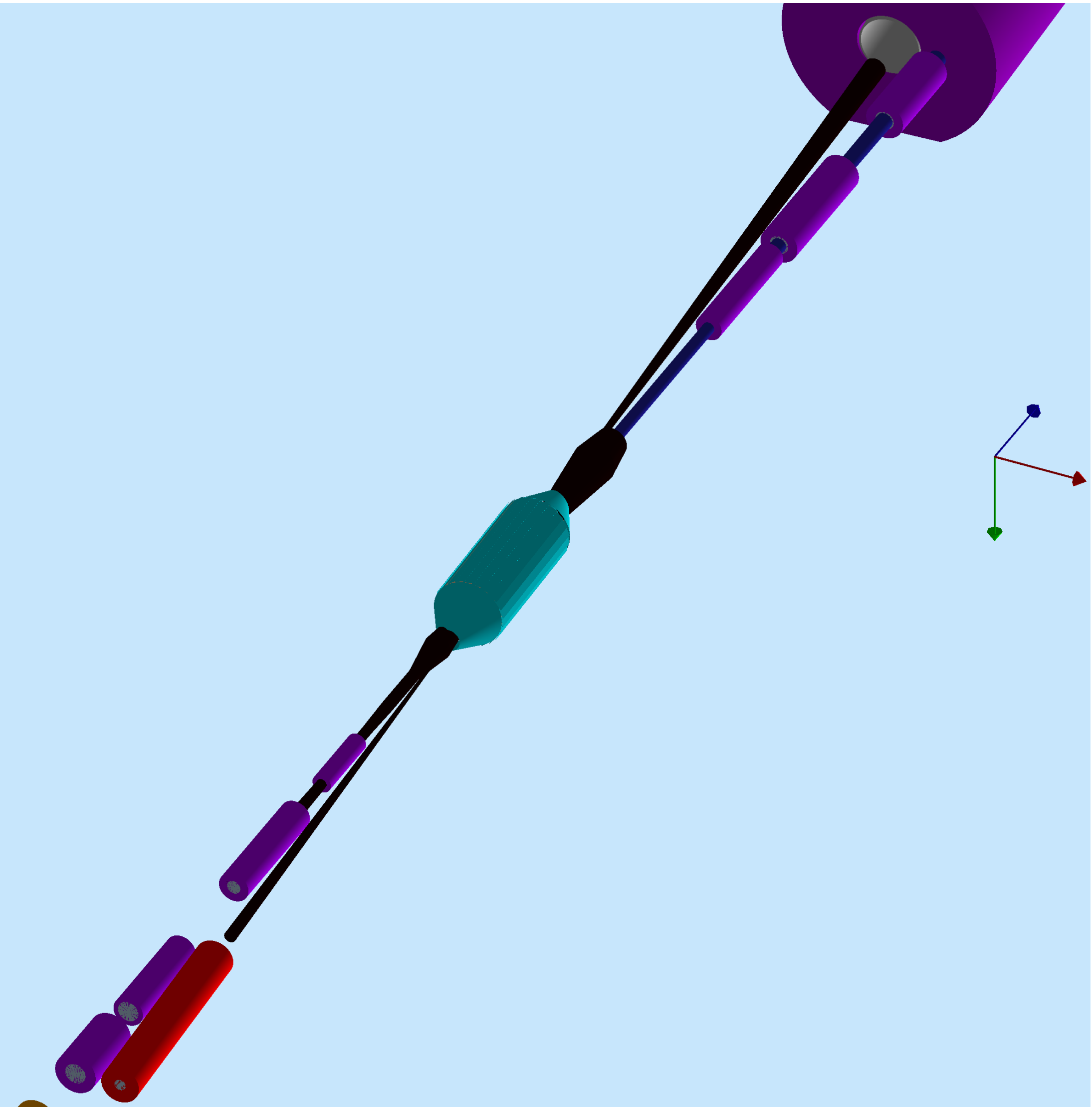




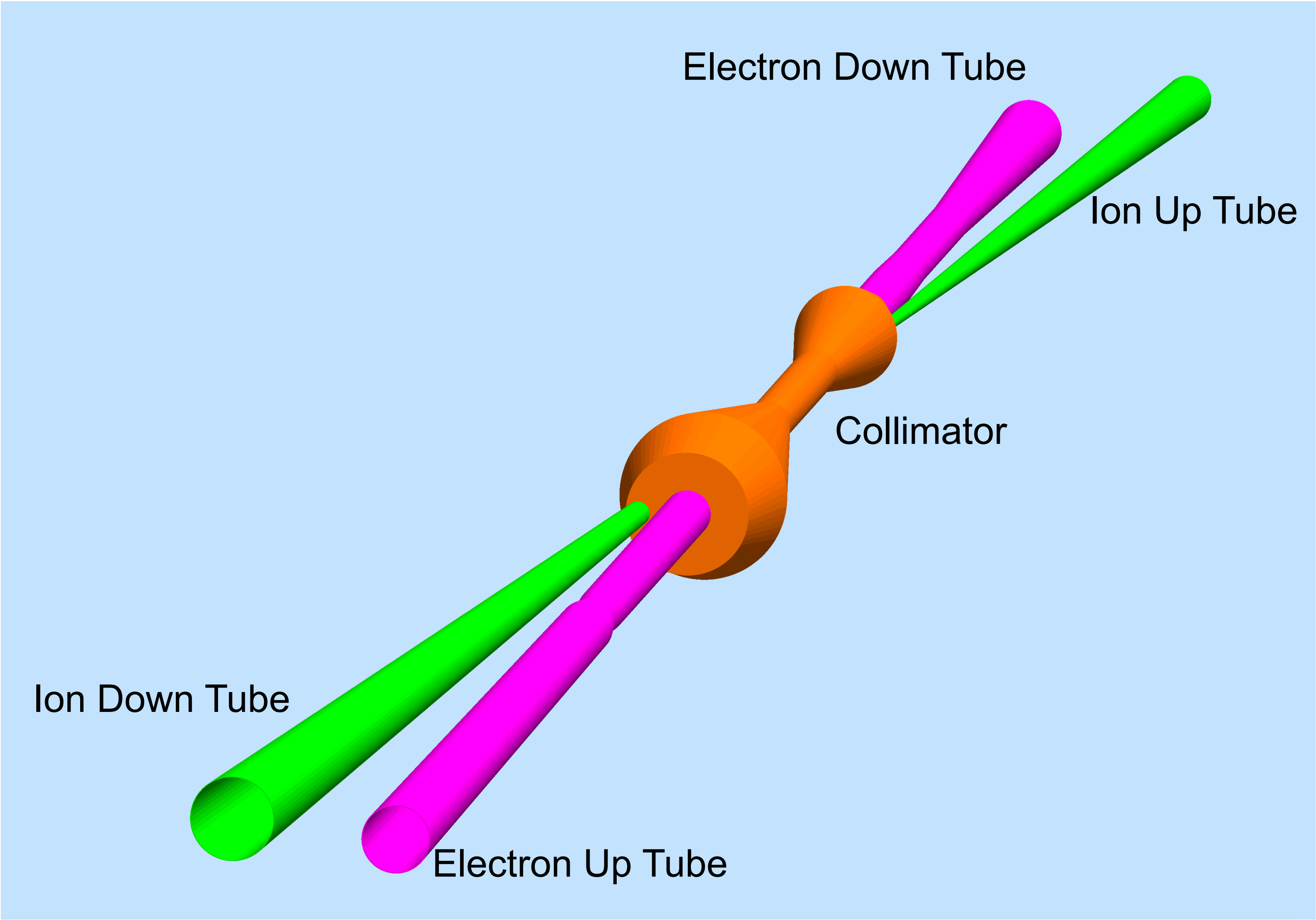
Beam Pipe



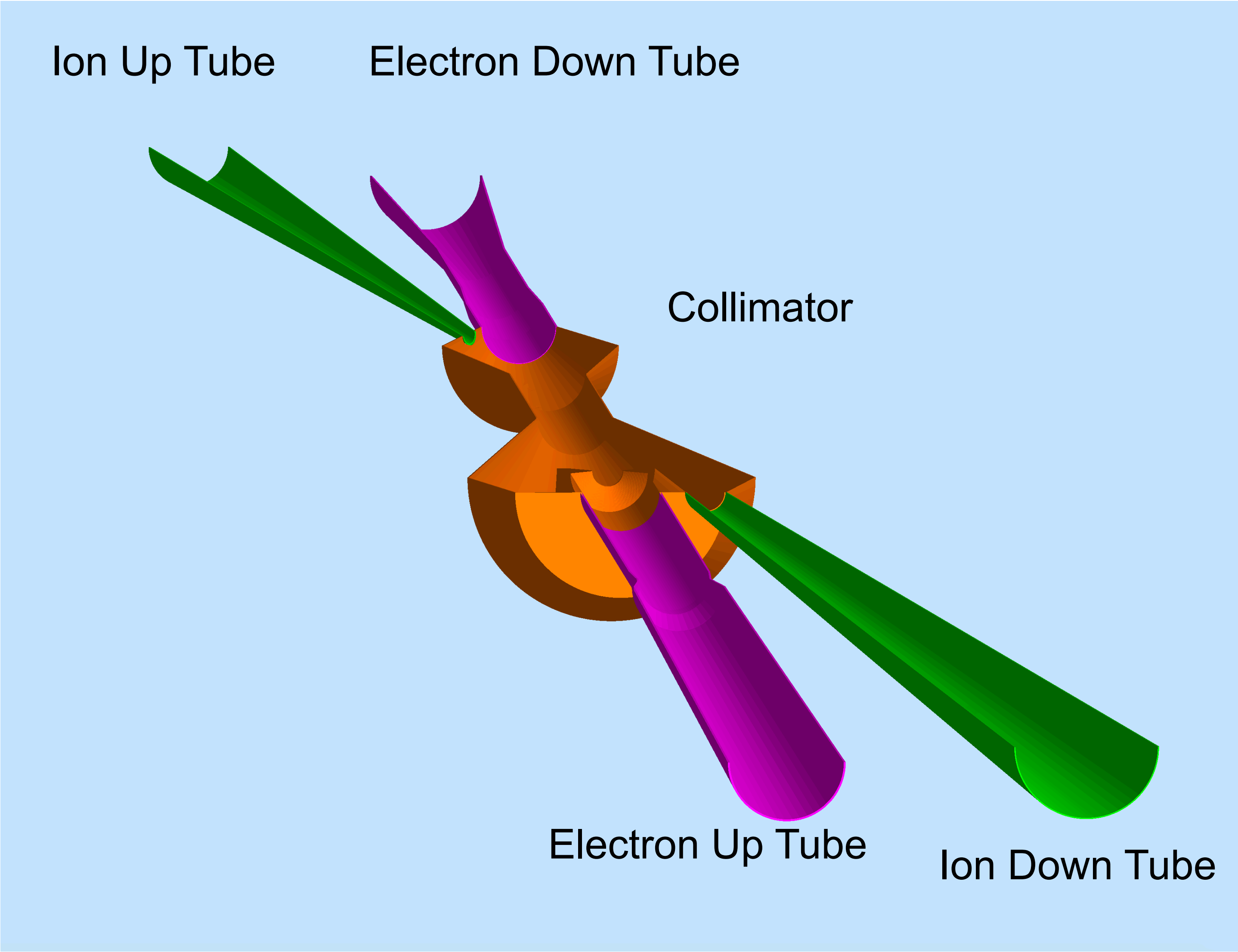
Original gcard from the EIC gemc, interaction regions from CAD



Beam-pipe in GEANT Simulation: View



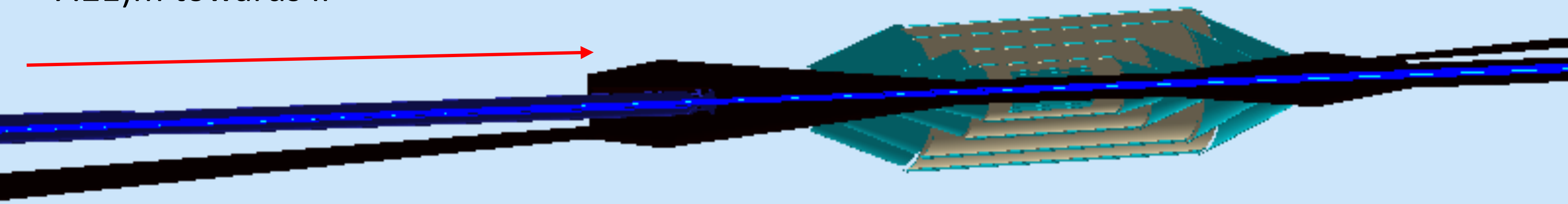
Beam-pipe in GEANT Simulation: another view



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



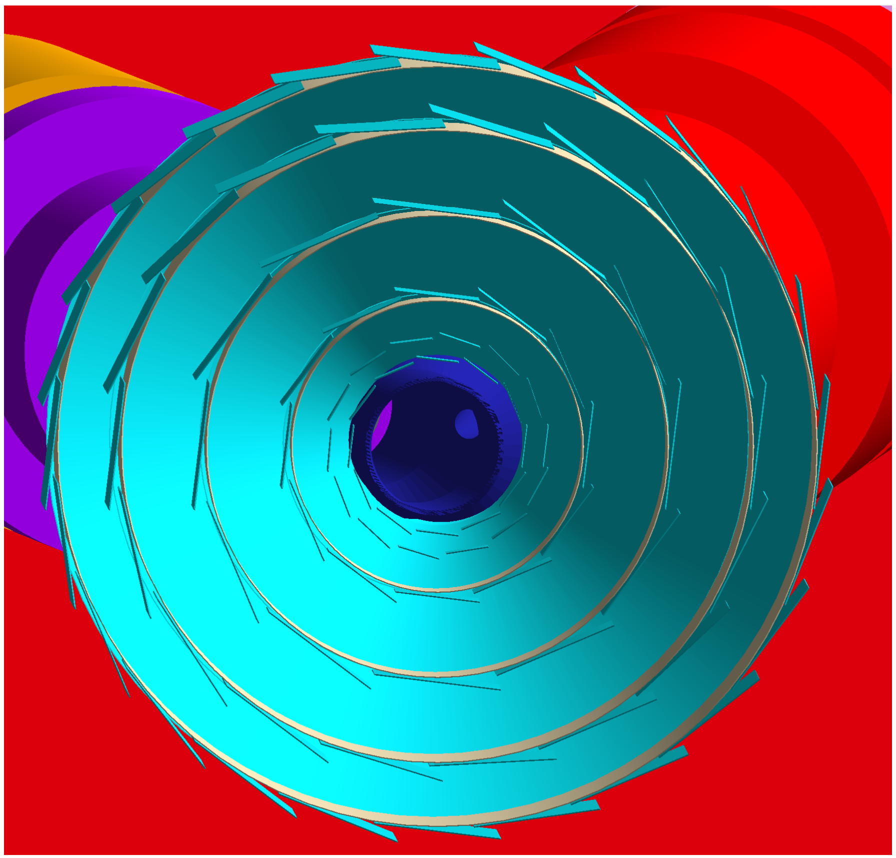
Vertex Tracker (SVT):
6 Layer Si Pixel Detector
1st layer +0.5 cm from central beam pipe

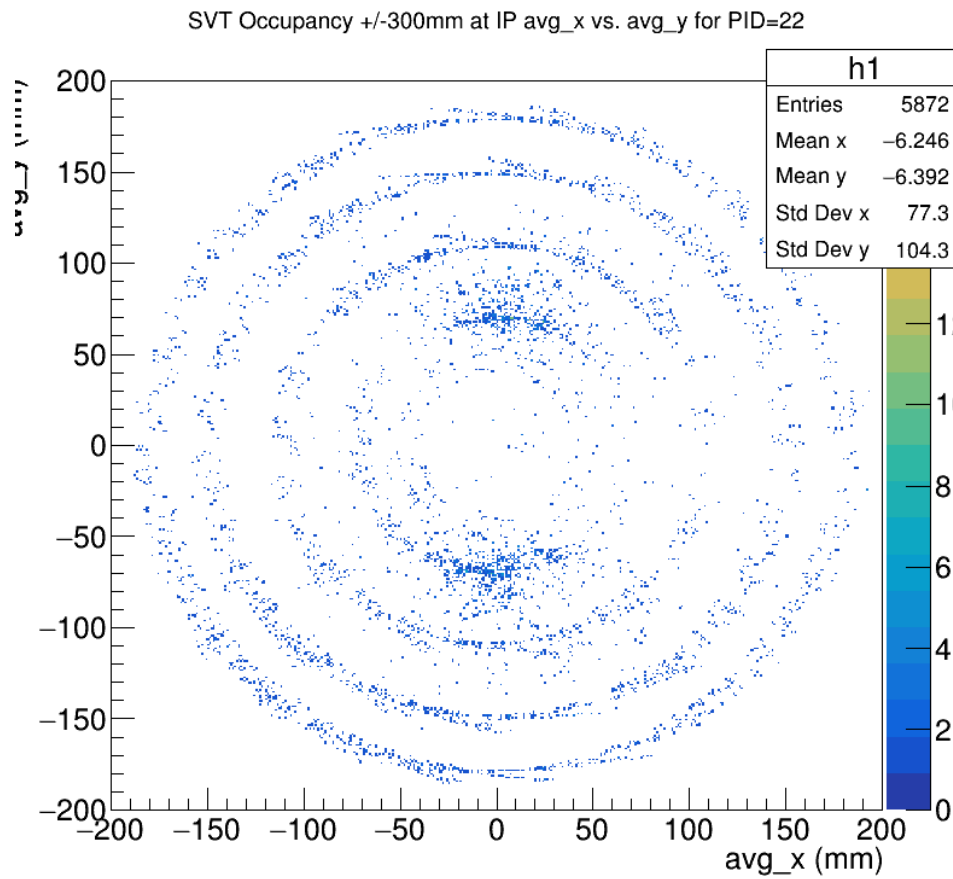
Synchrotron Distribution at IP

Silicone Vertex Tracker

Transverse profile of SVT in GEMC simulation

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



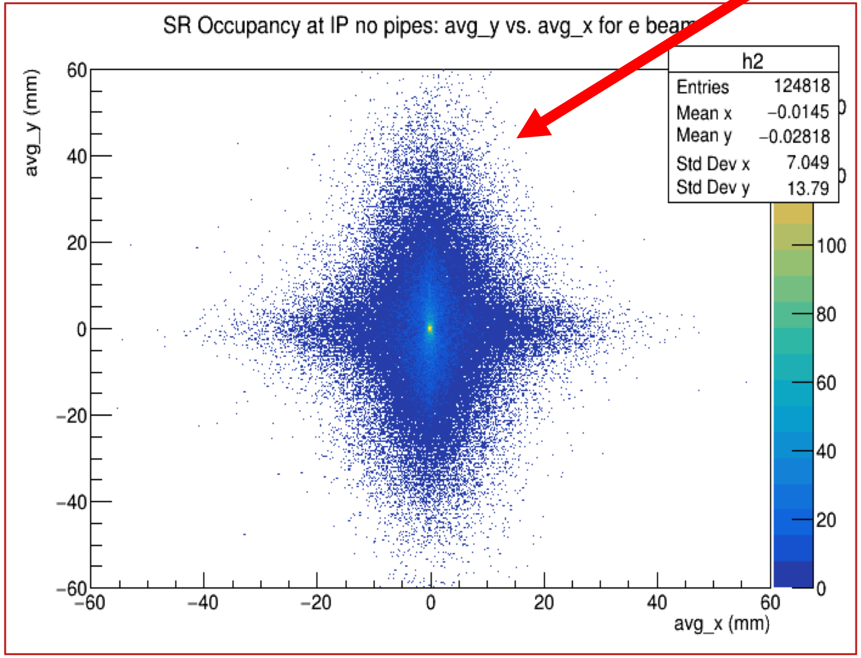


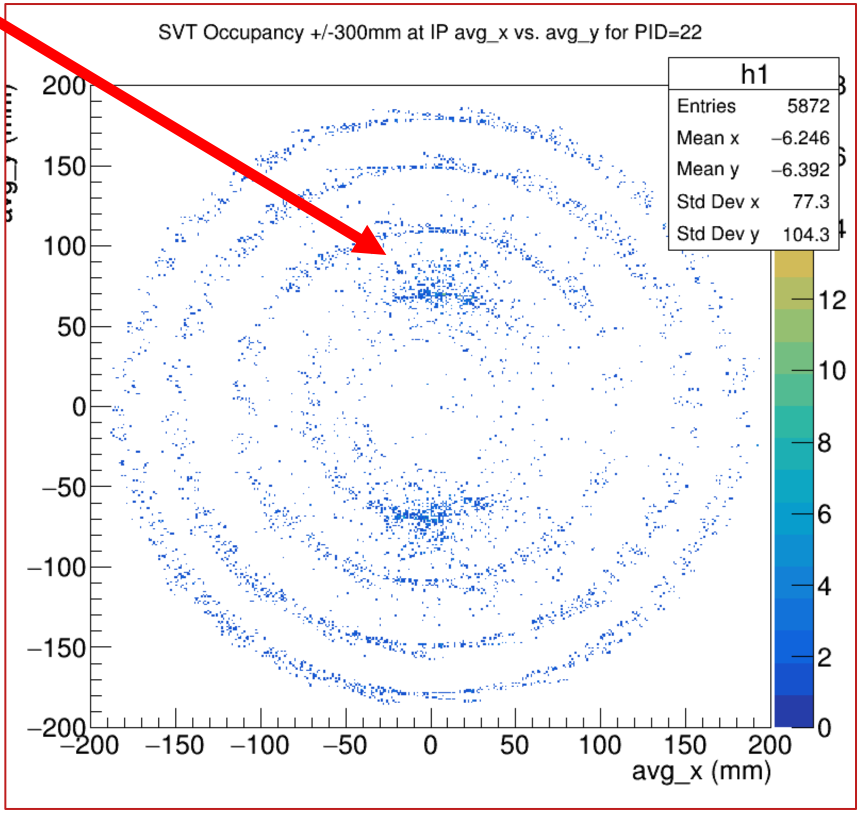
Synchrotron Distribution at IP

Synchrotron Spot at IP (no pipe nor detector)

Synchrotron in SVT at IP

Shape of photon distribution consistent in both plots*

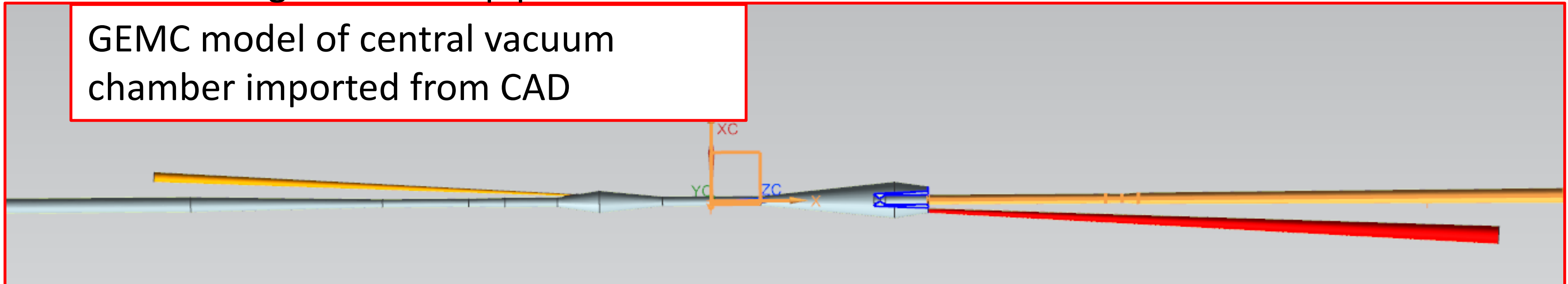




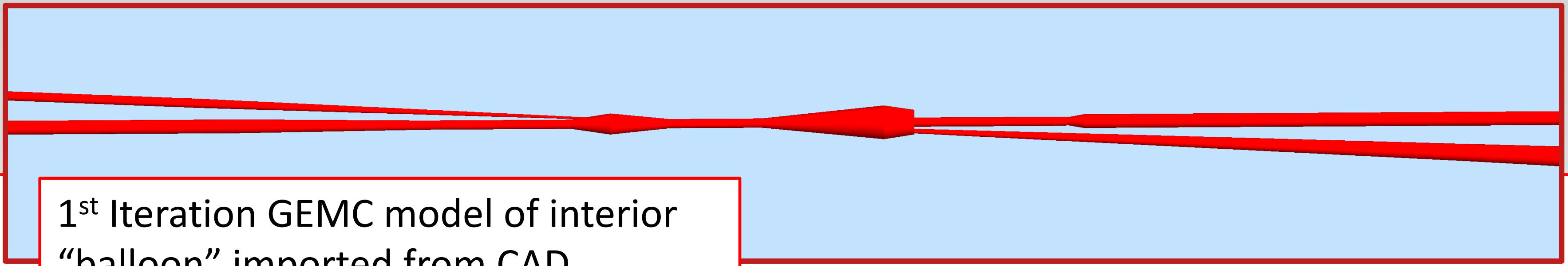
*Graphs generated from different # of beam statistics

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 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.



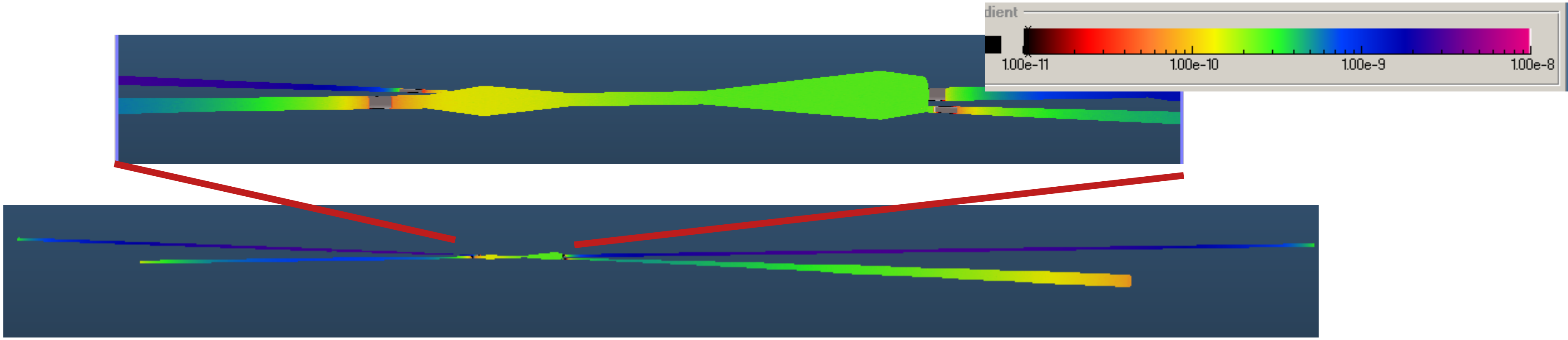
GEMC model of central vacuum chamber imported from CAD



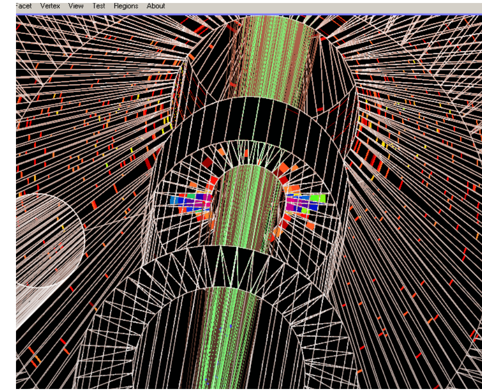
1st Iteration GEMC model of interior "balloon" imported from CAD

Molflow+ investigations of static vacuum

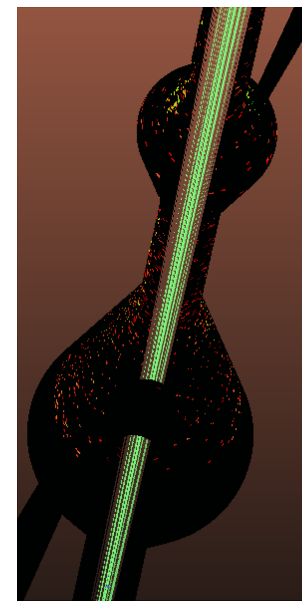
- All lines warm, outgassing estimated at standard 304 SS: 5×10^{-12} $TorrLs^{-1}cm^{-2}$
- Pumps simulated within beamline at ends of IR chamber
  - 2400 L/s in 6.2 cm ID electron lines
  - 1200 L/s in 3 cm ID ion lines
  - Pump speeds feasible using arrays of NEXTorr compact getter/ion pumps
- Expected 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



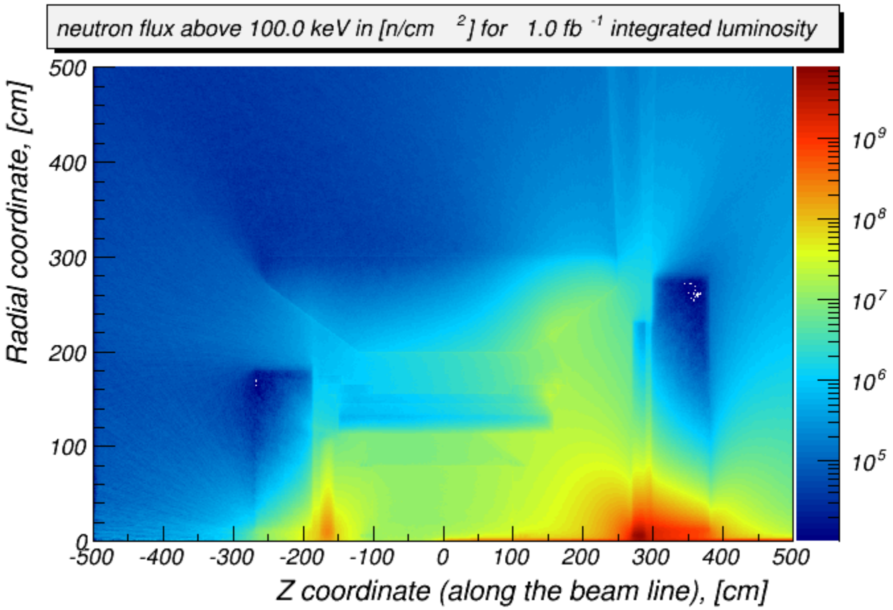
- Input parameters
  - e- line: 3 quadrupole field strengths and positions
  - Beam parameters (emittance, coupling, $\beta_{x,y}$, $\varepsilon_{x,y}$ as a function of position
  - Geometry of collimator and interaction region
  - 10 GeV beam, 3000 mA current
- Output synchrotron radiation
  - Max. collimator: 300 W/cm^2
  - Max chamber: 3 mW/cm^2

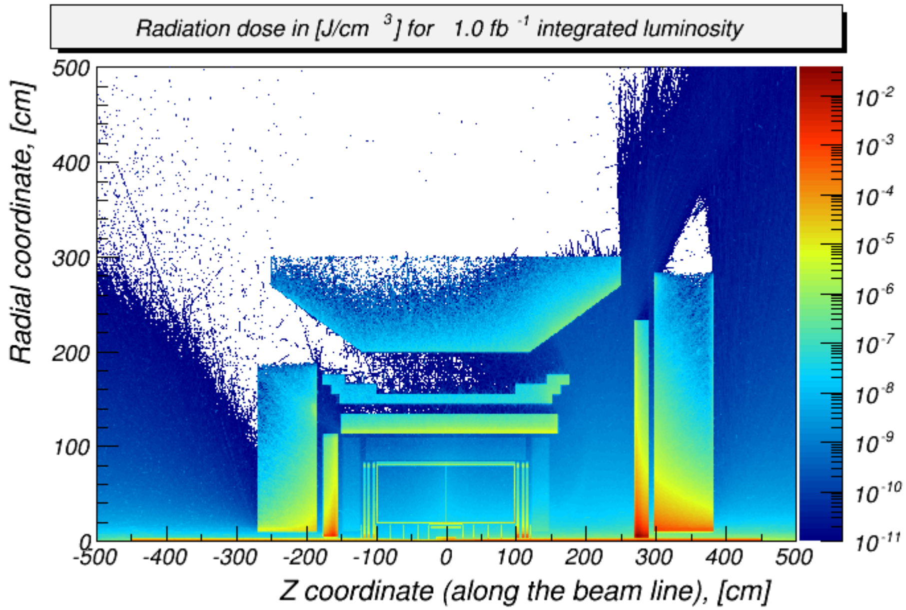


- **Refinements needed**
  - Refined beam parameters
  - Surface roughness analysis for reflection
  - Beryllium window properties determined and added
  - Photon heat load due to beam/gas interaction from GEMC
  - Synchrotron induced heating and outgassing to input to Molflow+ for dynamic vacuum calculations

Neutron Flux and Radiation Dose at eRHIC

- Background from primary interactions at the IP is simulated
- Neutron Flux = “a sum of neutron path lengths”/“cell volume” for N events
- Radiation dose: “a sum of dE/dx”/”cell volume” for N events





-> forward EmCal: up to ~5*10^9 n/cm^2 per fb^{-1} (*inside the towers*); perhaps ~5 less at the SiPM location;

-> backward EmCal: ~250 rad/year (at a “nominal” luminosity ~10^{33} cm^{-2} s^{-1})

-> just a basic EicRoot Monte-Carlo pass using BeAST geometry

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

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 beam pipe interior for both JLEIC and eRICH;
- Model proton beam matched distribution with halo;
- Refine results by implementing density distribution from vacuum engineers around IP.

Simulation Frame Work – SR – Next Steps

- 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.

Beam Gas Interaction Next Steps

- 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.

Neutron Flux – Next Steps

- 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.**

Team

- **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)*

IR/Luminosity Working Group Charge

The EICUG IR working group's mission is to provide an interface between the machine design / IR design and the physics needs to ensure that the EIC physics program is properly implemented with a broad range of physics measurements in particular those requiring forward / backward instrumentation. This should include challenging questions related to the measurement of nuclear fragments for a variety of processes and associated measured energy / momentum range and spatial acceptance. The requirements for the IR design should be determined from detailed simulations for proposed processes. In addition to specific aspects of the IR design, the working group should also address the scheme for luminosity measurement and its impact on the machine element layout. It is strongly suggested that the new EICUG IR working group interface directly with existing efforts at BNL and JLab. The working group will be open to all members of the EICUG. It will communicate via a new mailing list and organize regular online and in-person meetings that enable broad and active participation from within the EICUG as a whole.

Summary

Created validated and benchmarked simulations tools and procedures

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

Tools and procedures are completed or being finalized and documented

Next perform detailed simulations of the EIC machine related background for both JLEIC and eRICH configurations towards optimized beam- pipe design for both machine options

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

Ready to perform detailed rates and occupancies due to different background sources to optimize the design – input to technology choices

Thank You

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