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

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Project Members

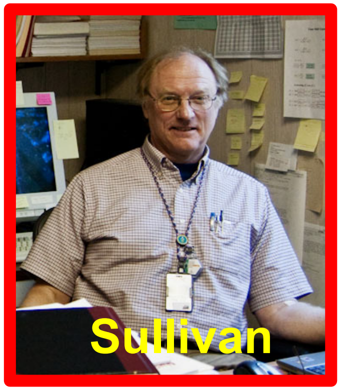
Background
Simulation studies

Machine/IR design
& SR modeling

Detector design

CAD modeling
& Vacuum calculation

KIM



Background Sources

Study background generated by machine operation in simulation:

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

Focus of this talk

- 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**
- **Beam wakefields**
- **SR masks**
- **Excellent vacuum system**

Tools and Methods

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

- **Molfow+**
- **Synrad**

Vacuum Modeling Installed at JLab

Input

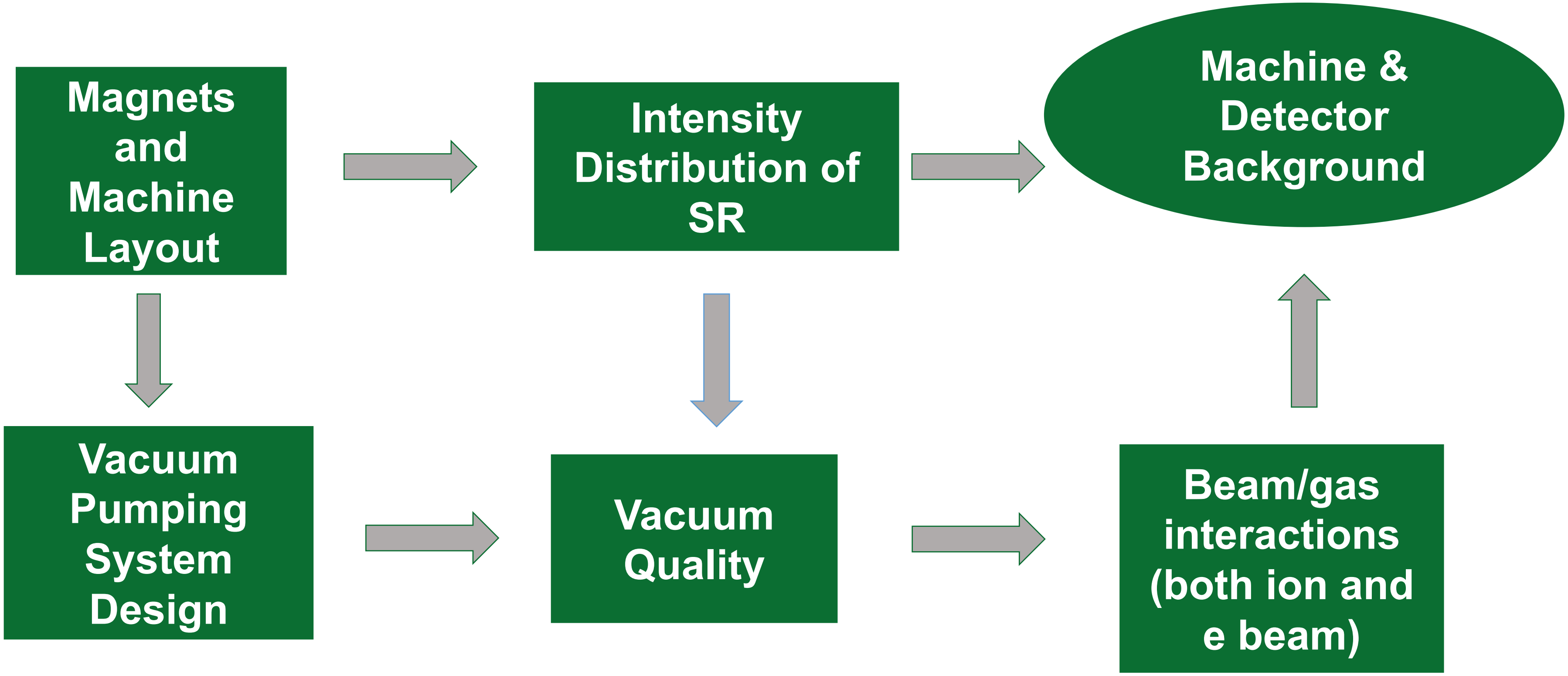
GEANT4

Completed so far!

- ✓ Completed HERA simulation (writing a report)
- ✓ Modeled designed of IR beam pipe concept in GEANT4 simulations.
- ✓ Benchmarked synchrotron radiation rates produced within GEANT4 and compare with SR code simulations.
- ✓ Developed an interface of the SR code to GEMC
- ✓ Modeled the designed IR beam pipe concept in a 3D CAD model.
- ✓ 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 GEANT4 interfaced with SR code
- ✓ Using validated software tools and result of beam pipe design, in the process of evaluating the background contributions from hadron beam/gas interactions under nominal vacuum levels.
- ✓ Interfaced CAD drawings with Molflow+ and Synrad+ for vacuum studies

Note: all the work in this presentation is based on the JLEIC IR design

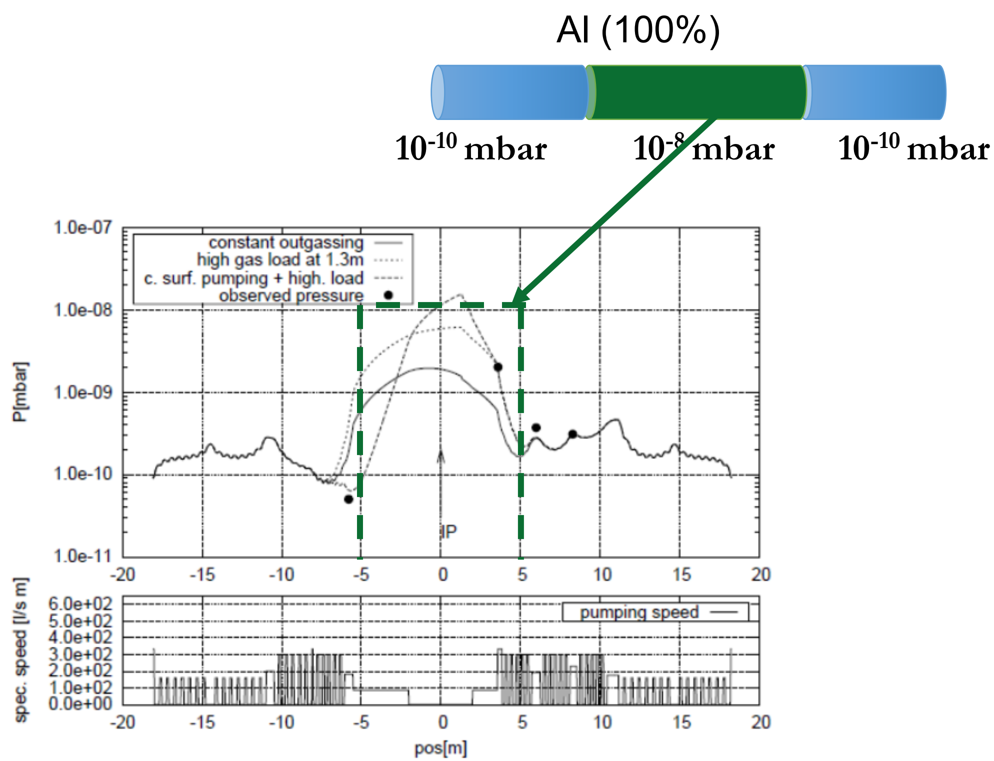
Background Studies Workflow



Lessons from HERA II Upgrade

- **Severe background problems in the year 2002 significantly delayed startup of HERA after luminosity 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 Data as Benchmark for our Simulation Tools

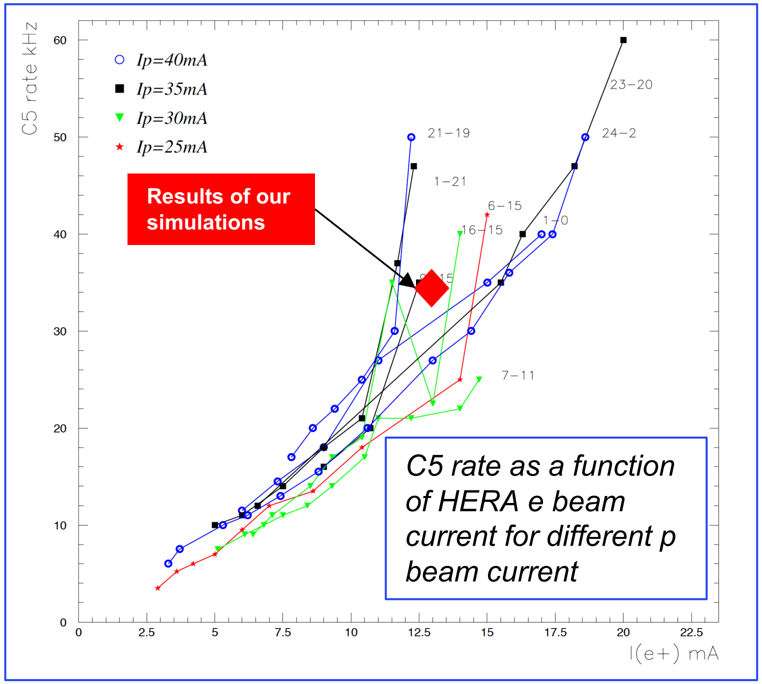
Good agreement of our simulation rate to the measured rate at HERA!

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

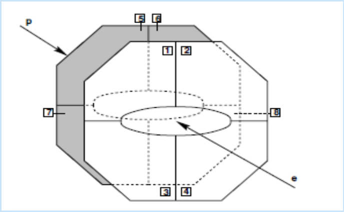


Validation and benchmarking of our simulation tools and procedures

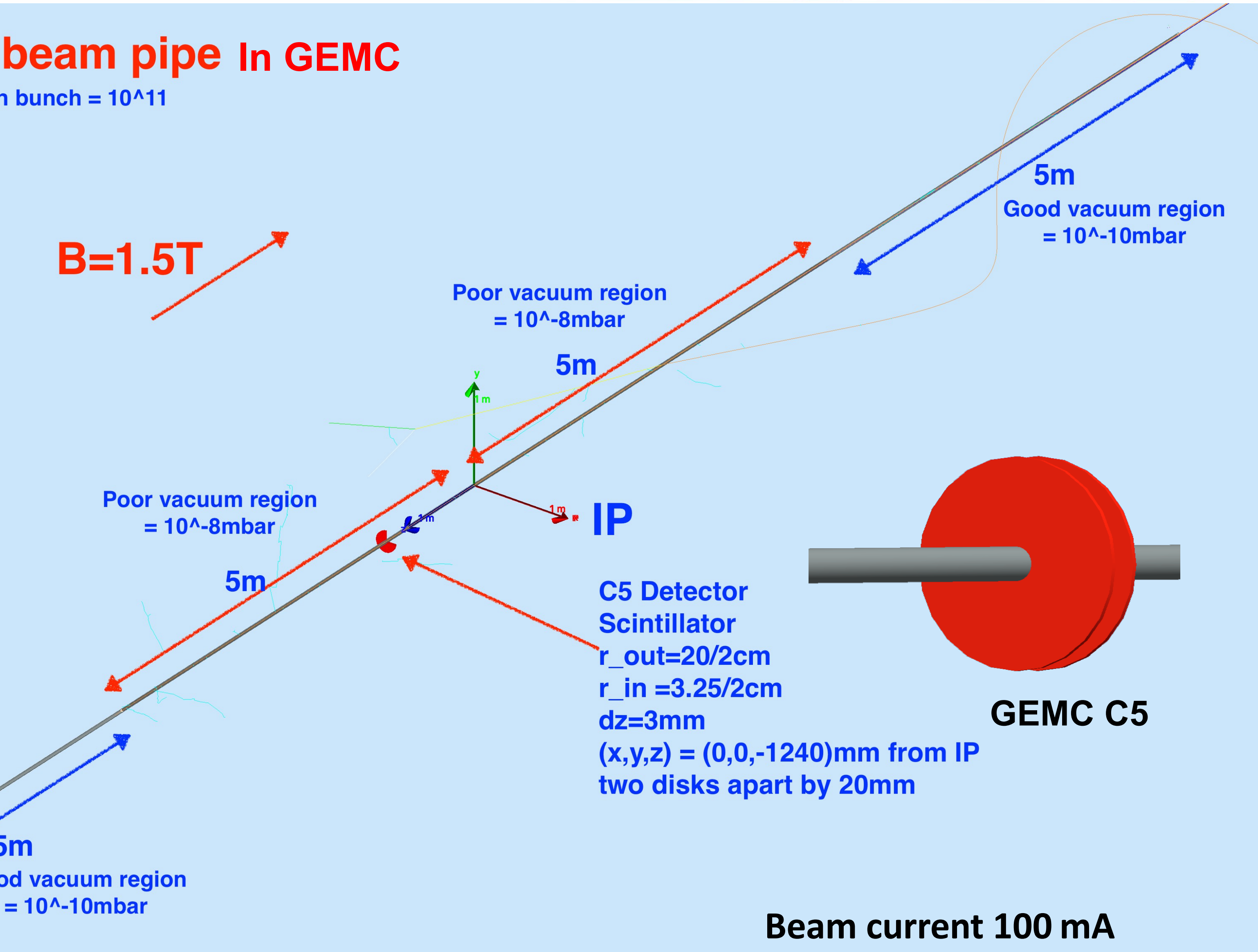
HERA Configuration Simulated in our Framework

HERA proton beam pipe In GEMC

N. of. proton particle in bunch = 10^11



HERA C5

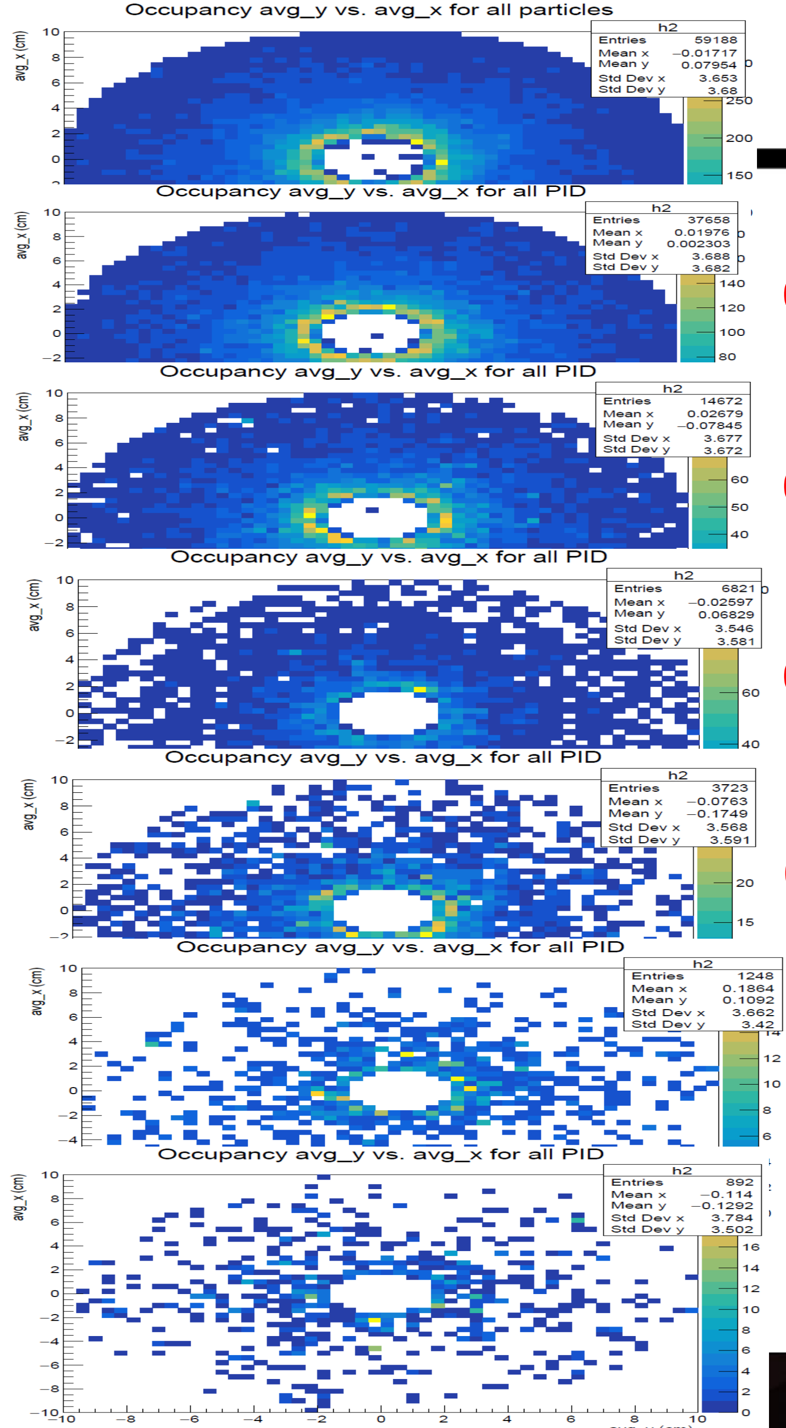


E_0=900GeV

C5 Detector Scintillator
r_out=20/2cm
r_in =3.25/2cm
dz=3mm
(x,y,z) = (0,0,-1240)mm from IP
two disks apart by 20mm

GEMC C5

Beam current 100 mA



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

Next steps in Beam Gas Interaction Studies

- Use Molflow+ and Synrad to realistically simulate vacuum conditions.

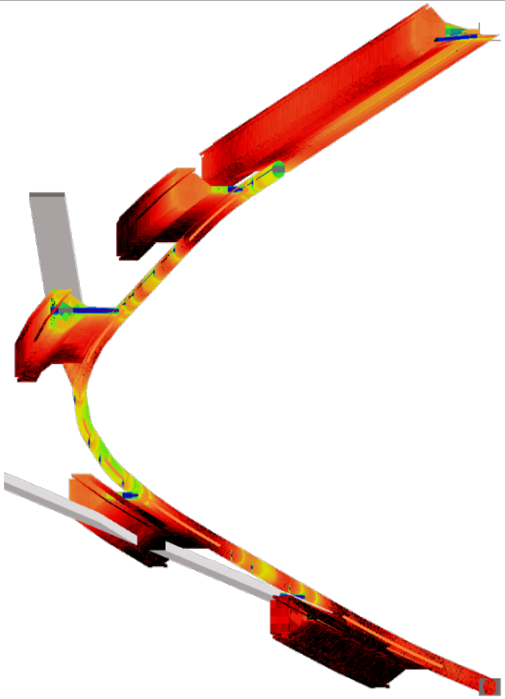
- Design vacuum system based on requirements of the IR vacuum tube and vacuum vessels and its translation into the simulation.

- Use SR level to determine the level of dynamic vacuum.

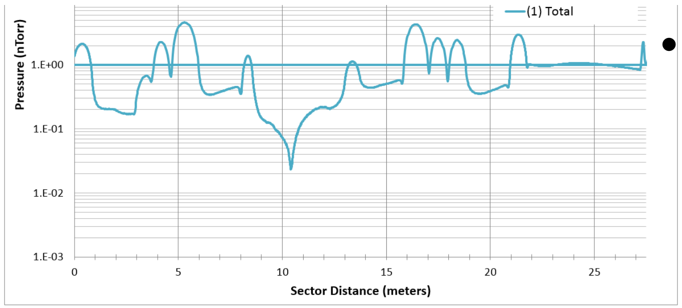
- Evaluate the background type and distribution due to the beam gas interaction giving feed back to the vacuum engineer and IR designer towards design optimization.

- 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.

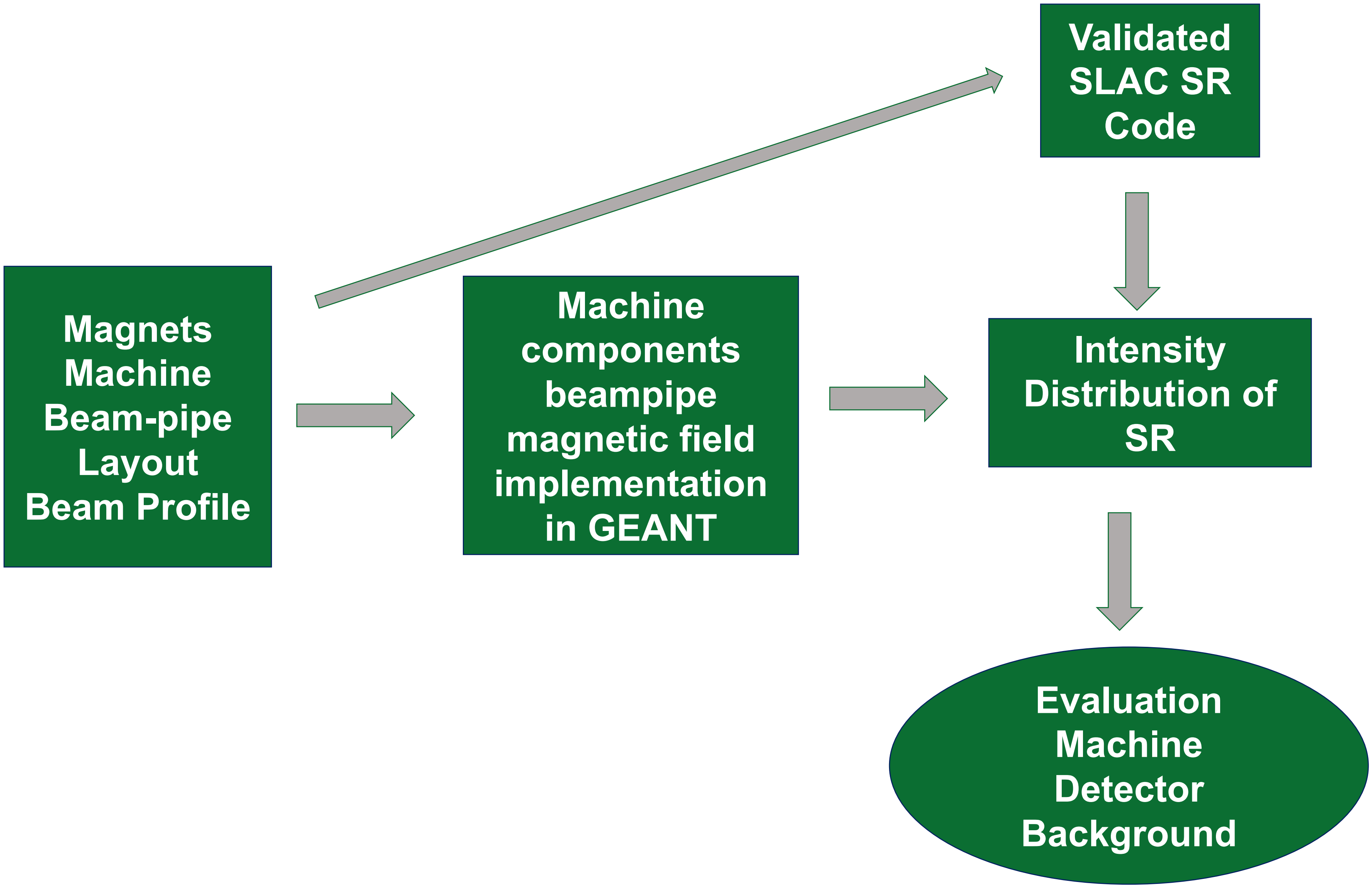
Vacuum Modeling Tools



- 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.

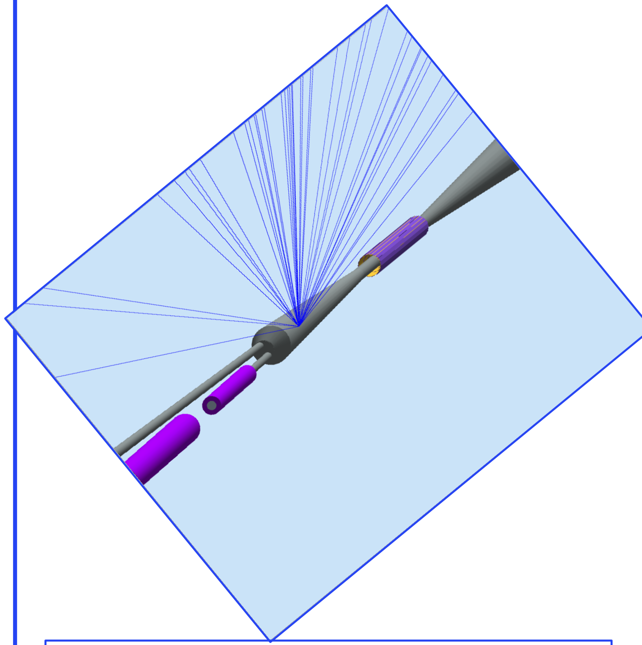


Background Studies Workflow



SR- Photon Generation (SR-Code)

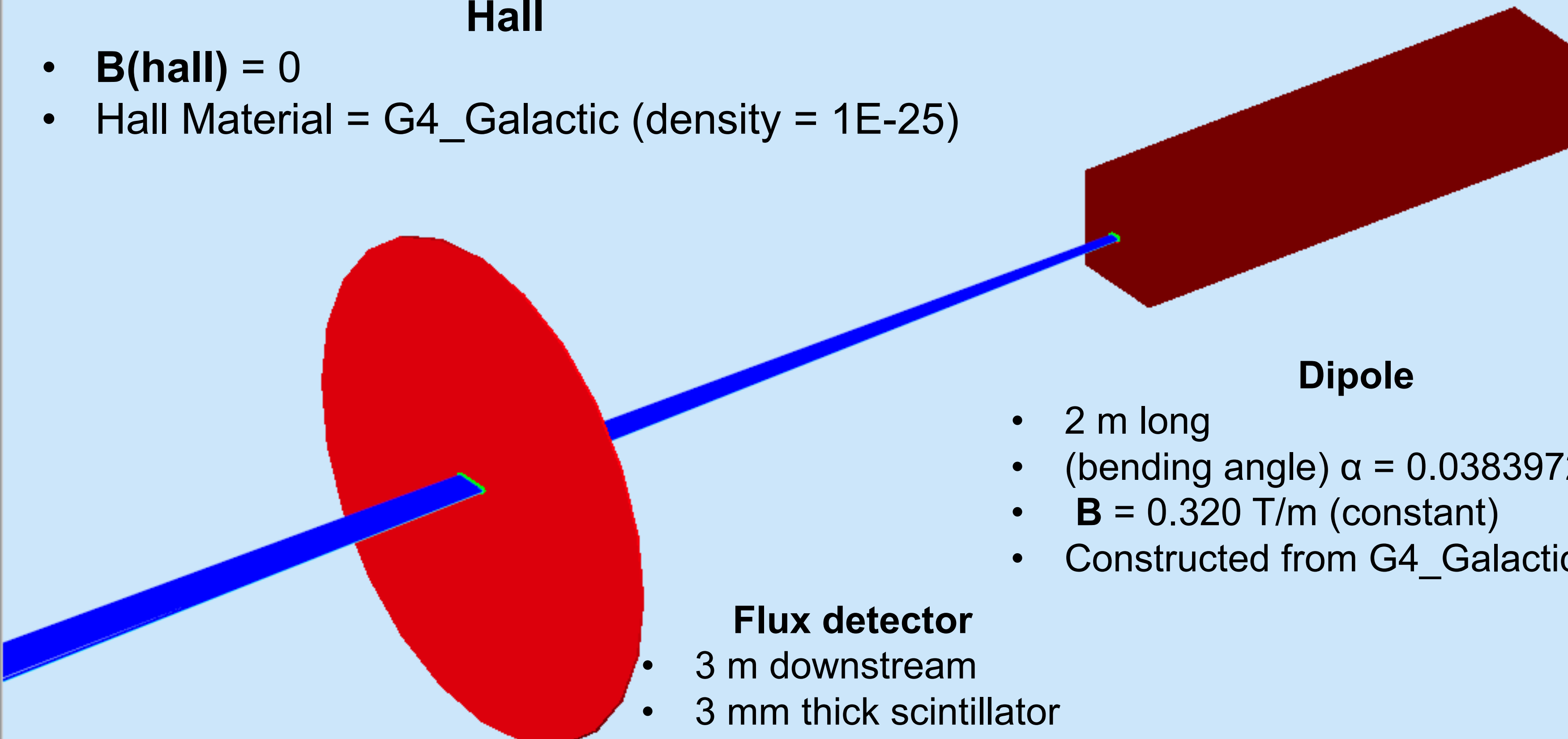
- A gaussian transverse electron beam profile with wide gaussian tails
- Each electron is traced through the given magnetic elements and a photon critical energy is calculated based on the trajectory curvature
- The SR fan start and stop points of each magnetic element are also found and traced through 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

Bend Test Parameters



Hall

- **B(hall)** = 0
- Hall Material = G4_Galactic (density = 1E-25)

Dipole

- 2 m long
- (bending angle) α = 0.038397244 rad
- **B** = 0.320 T/m (constant)
- Constructed from G4_Galactic

Flux detector

- 3 m downstream
- 3 mm thick scintillator

Total Photons Comparison

GEMC/GEANT4 Internal Event Generator

- Generates beam based on gcard input
- 5Gev e- beam, specified # of event

➢ 3.97 photons/electron

- Horizontal spot = *tan(α/2)*(L+2D)* = 15 cm at 3 m downstream from magnet exit window

- Energy Spectrum

Mike's Beam

- Separate script calculates total photons from beam/bunch/turn characteristics

➢ 5.45 photons/electron

- Mike Sullivan's code produces ~ same spot size at comparable location

- Similar Spectrum

Verifying Energy Spectrum

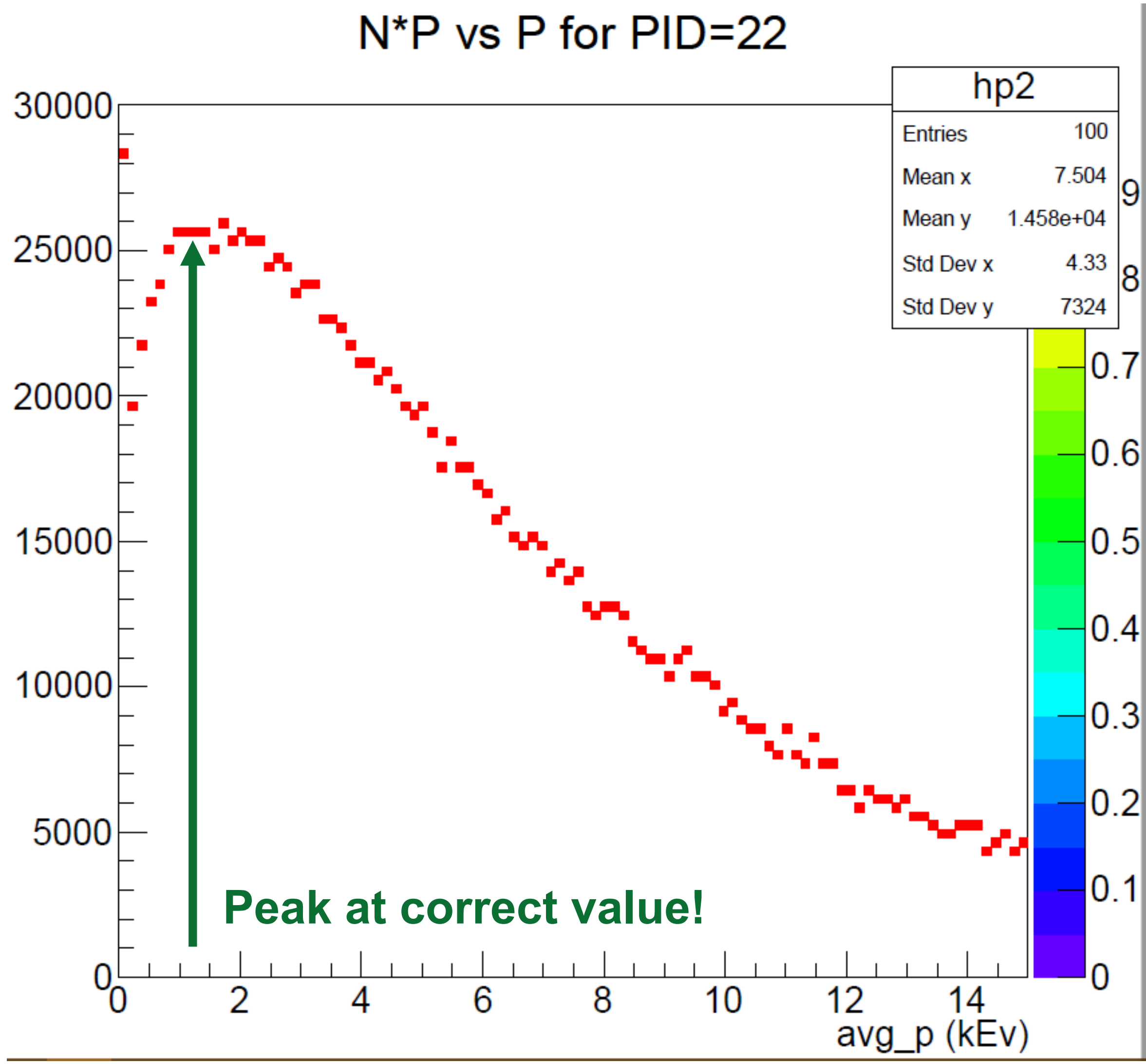
Photon Critical Energy

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

~ 5.32 keV

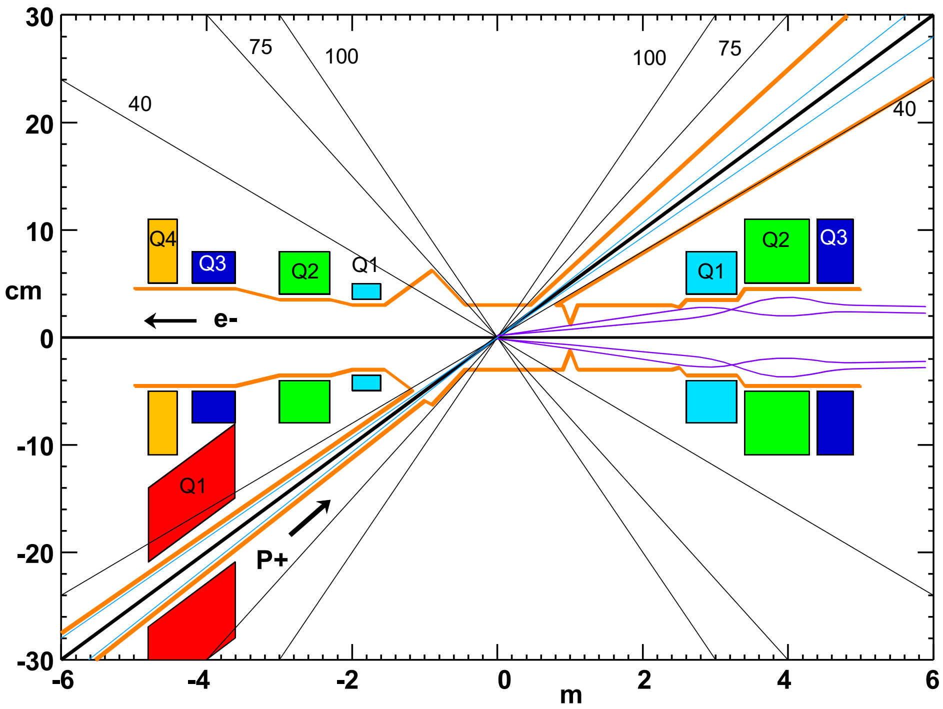
- Expect curve to fall off exponentially after

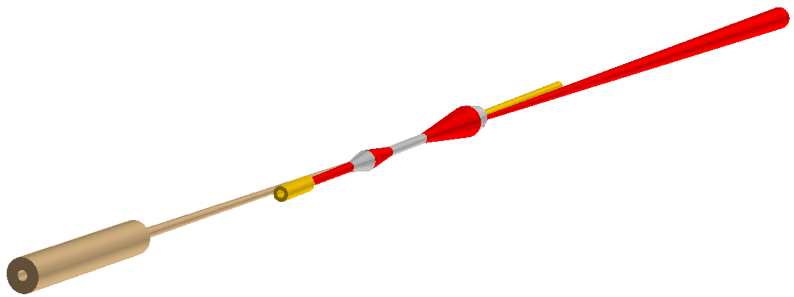
  $0.3*\varepsilon_c = 1.6$ keV



Beam Pipe Conceptual Design Updated

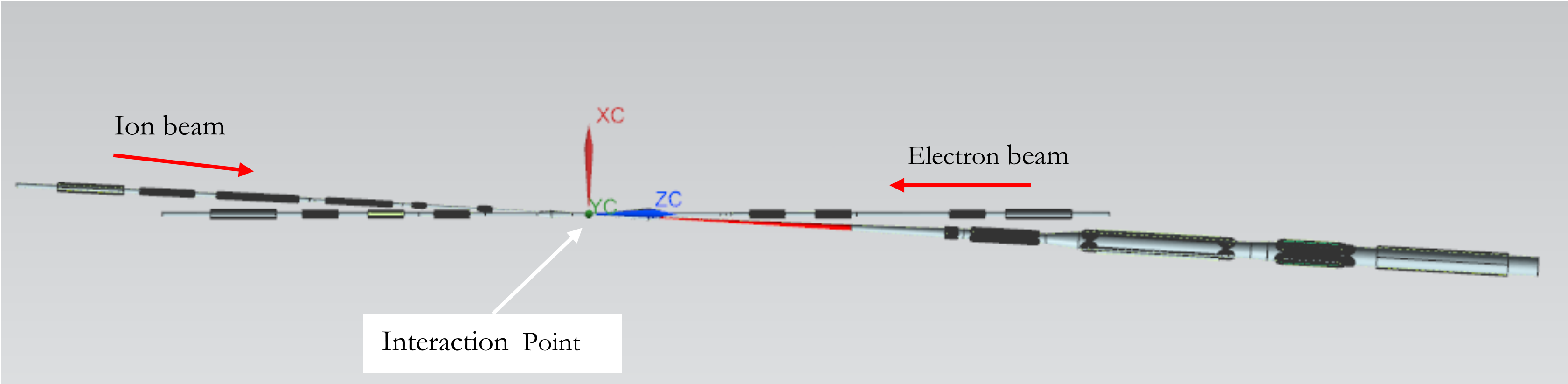
- Minimum multiple scattering in the beam pipe material
- Synchrotron radiation collimation
- L. Elouadrhiri et al. (JLab), C. Hyde (ODU), M. Sullivan (SLAC)





CAD Model - Update

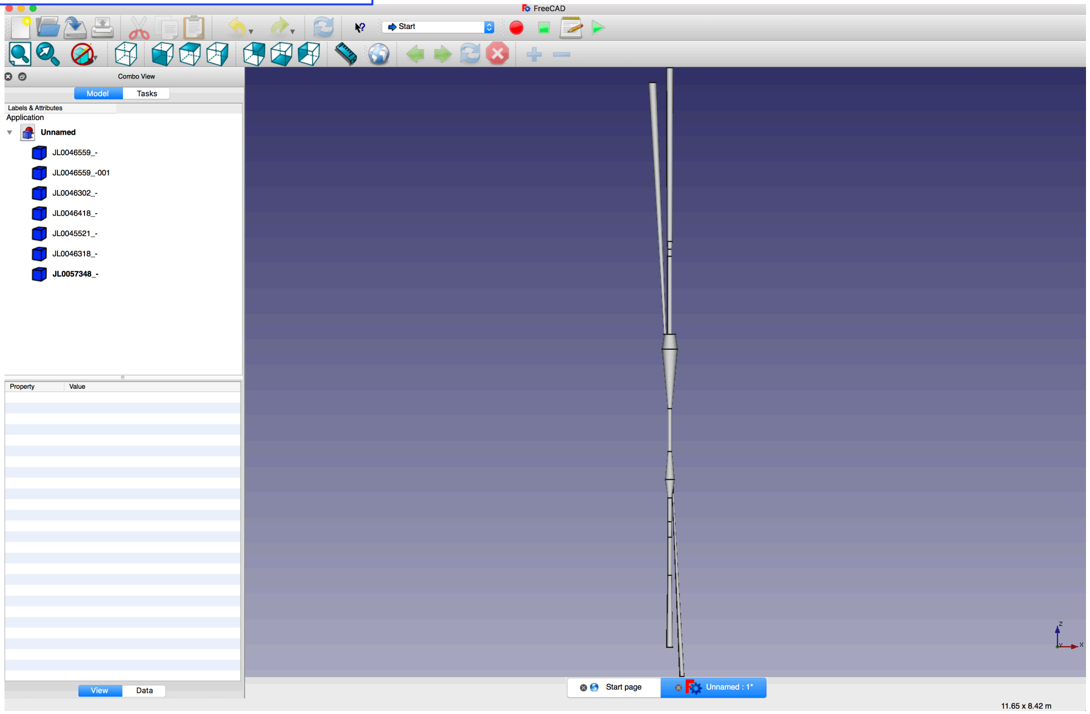
- The CAD model has been updated with the latest electron beam transport requirements
- Added water cooling channel to the central vacuum chamber
- Provided Nick Markov with the latest beam transport requirements and a STEP file of vacuum tubes for modeling in GEMC
- Provide Marcy Stutzman with STL file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

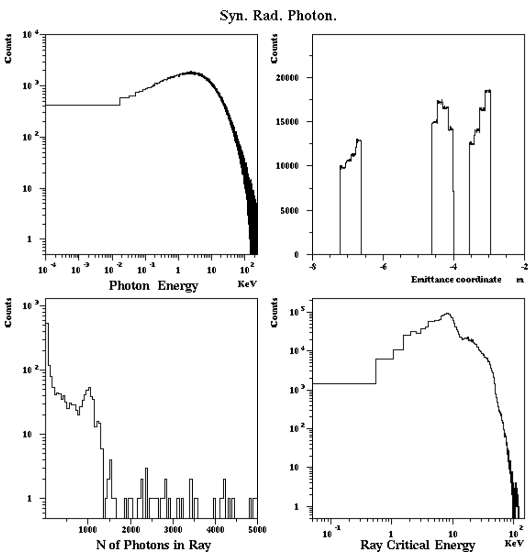
Example of EIC beam pipe implementation

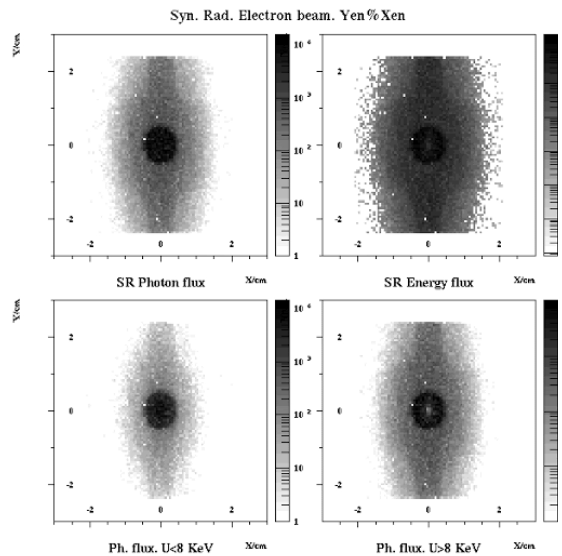


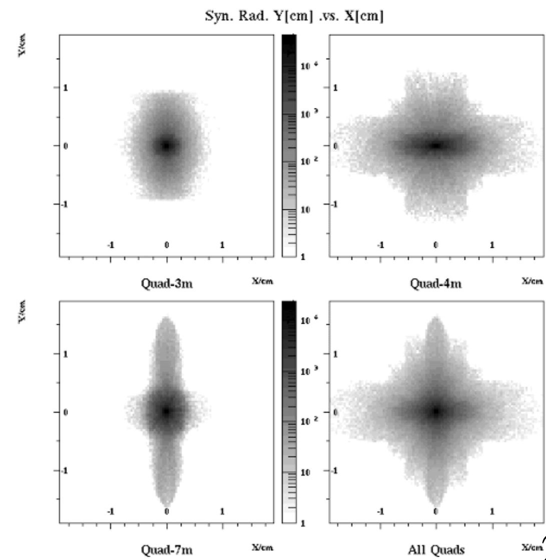
Technical note will be written, as part of making our procedure accessible

Synchrotron Photon Generation

- Semi-analytic code ported from SLAC
- Power Distribution as a function of critical energy turned into ensemble of photons for further propagation by GEANT4.G







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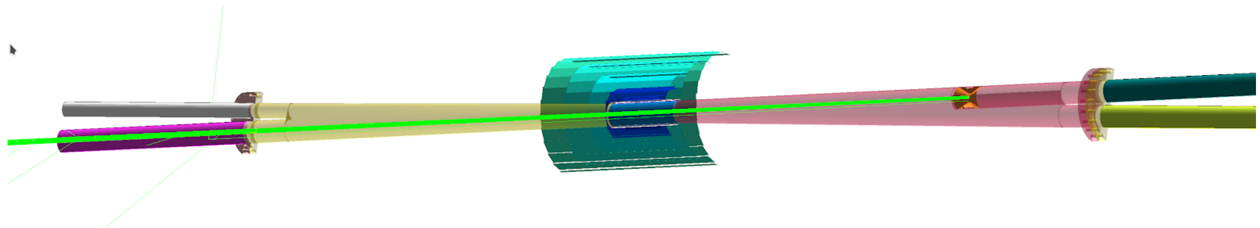
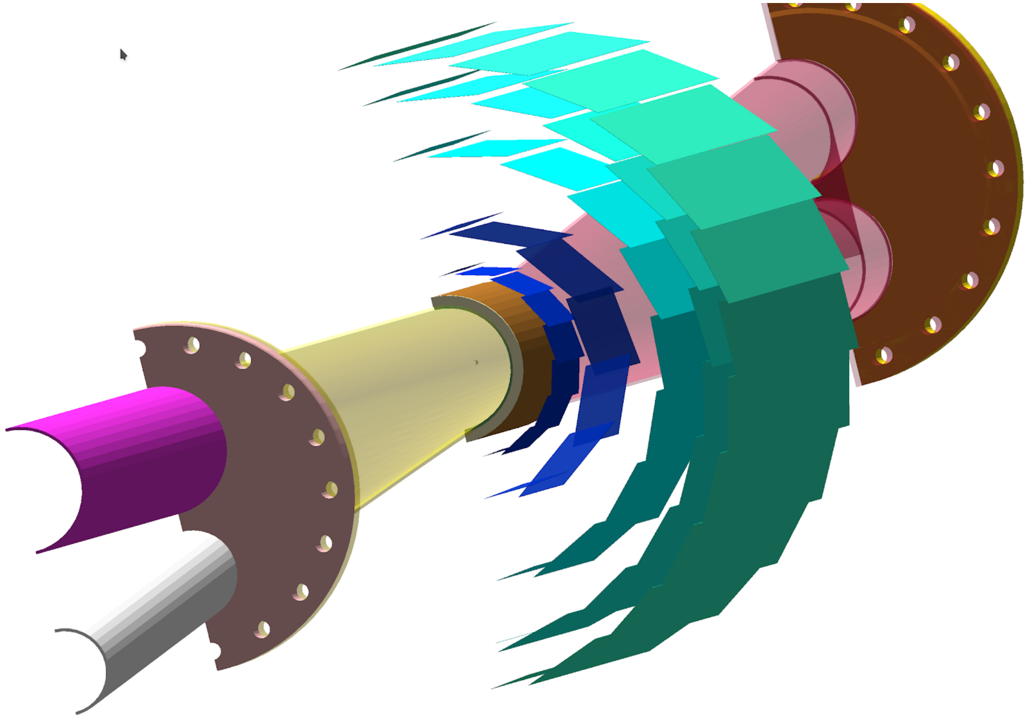
C.Hyde eRD21

31 Jan 2020

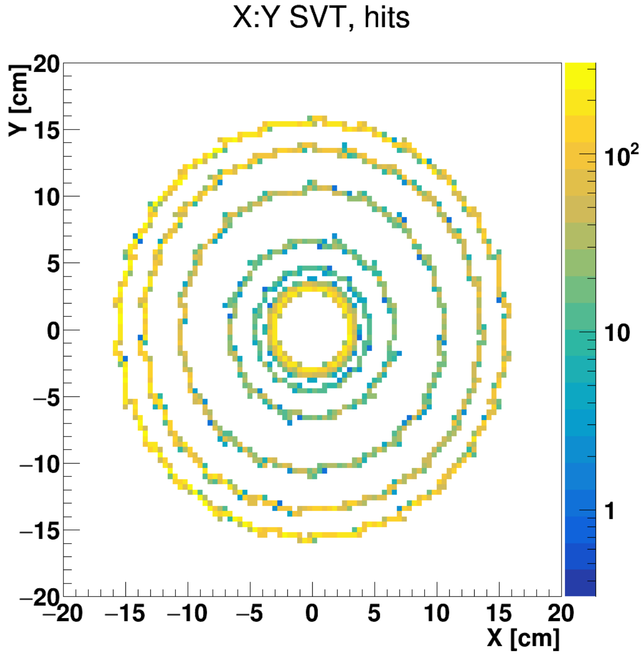
Synchrotron Photons propagated through IR

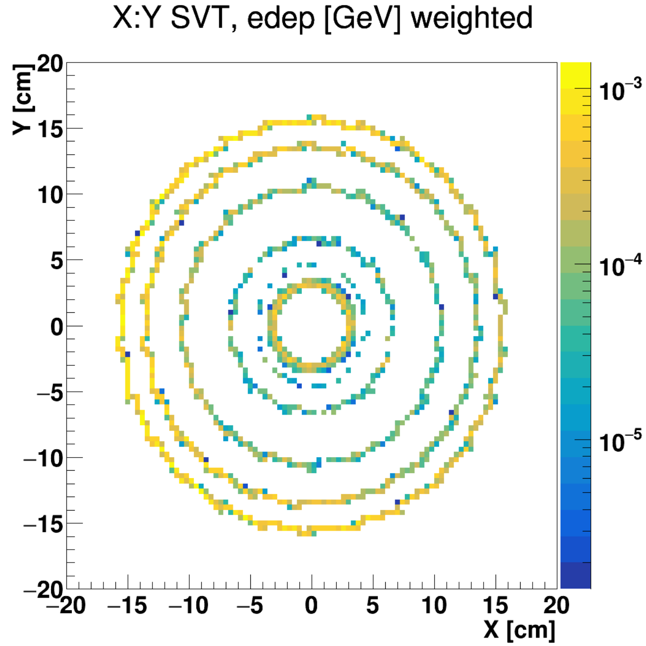


- **Central Be Chamber**
- **5 layers of Si Vertex Tracker**



Hits (left) and Energy Deposition (right)
Be beampipe and 5 Si Layers





- 10^{11} e^- at 10 GeV
- $2.4 \bullet 10^9$ γ through 2cmΦ collimator at z=1m

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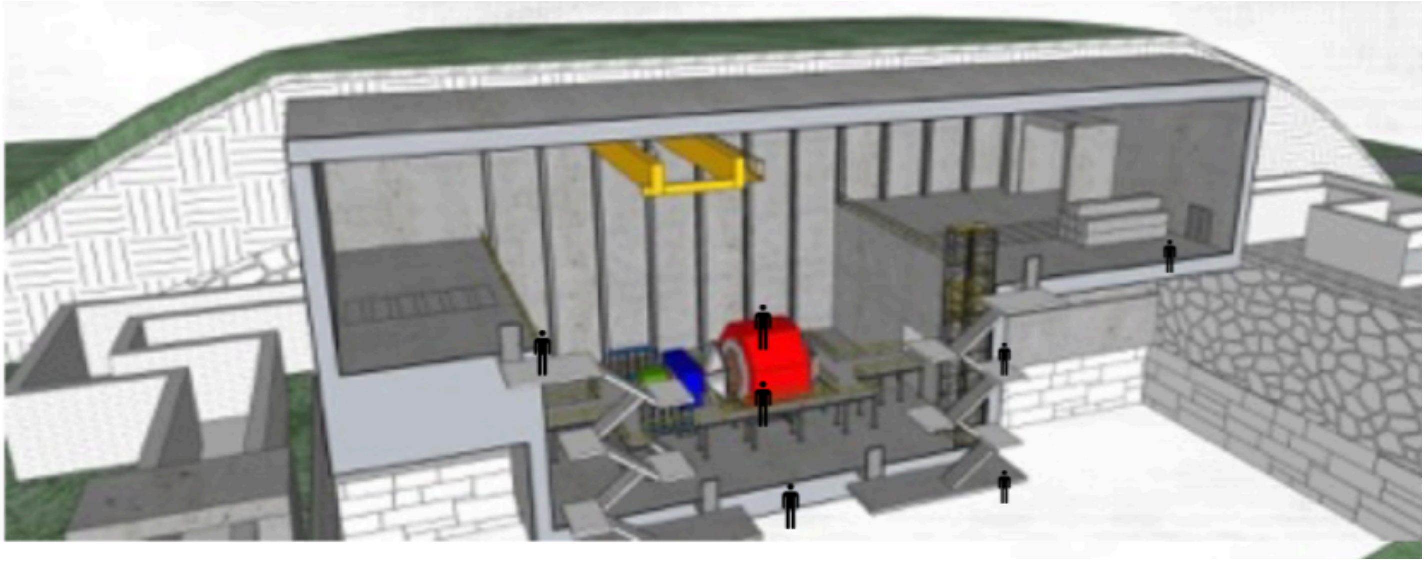
Simulations with FLUKA

- Full inclusion of 70 m upstream beamline
- Magnets
- Tunnel walls, ceiling, floor

- Calculate Neutron flux with different simulation tools and compare to mesurments



Calculate Neutron flux with different simulation tools and compare to measurments

Neutron background simulations

- **MARS**
  - MARS installed on JLab cluster
  - Vitaly Baturin subscribed as MARS user
  - N. Mokhov (FNAL), P.Degtiarenko (JLab) will install advanced MARS version with graphical interface in February
- **FLUKA**
  - New FLUKA version (including ep collisions) installed, simulations started
  - Initial studies done with detector solenoid field: no effect on backgrounds
    - Calculated backgrounds dominated by neutrons.

Summary

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- ✓ Modeled designed of IR beam pipe concept in GEANT4 simulations.
- ✓ Benchmarked synchrotron radiation rates produced within GEANT4 and compare with SR code simulations.
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<u>Note</u>: all the work in this presentation is based on the JLEIC IR design

OUTLOOK

Migrate simulation models to eRHIC beamlines & detectors

- Will need full physical data on locations, strengths of magnets in full Interaction Region
- Approximate iron content of magnet yokes
- Vitaly Baturin will come to BNL later in Spring

Close interaction with the detector group to setup the priorities for the simulations