ePIC Collaboration Meeting

Brookhaven National Laboratory

Jefferson Lab

U.S. DEPARTMENT OF ENERGY

Modifications to the Interaction Region (IR) and its Influence on Far Detectors

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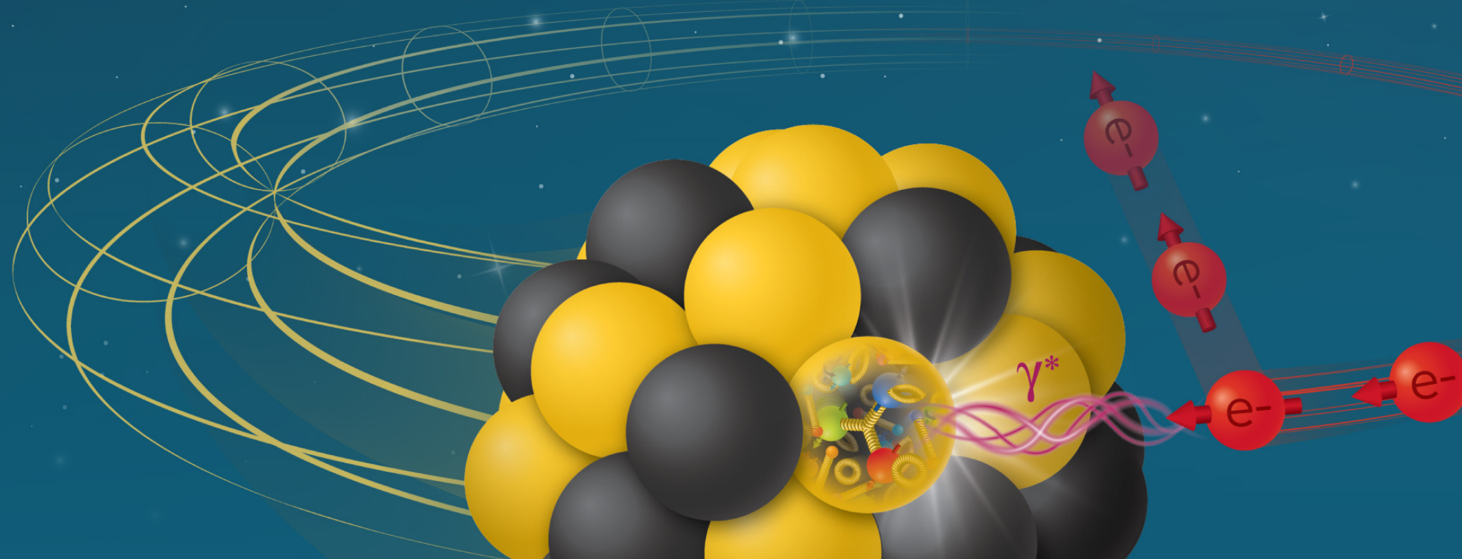
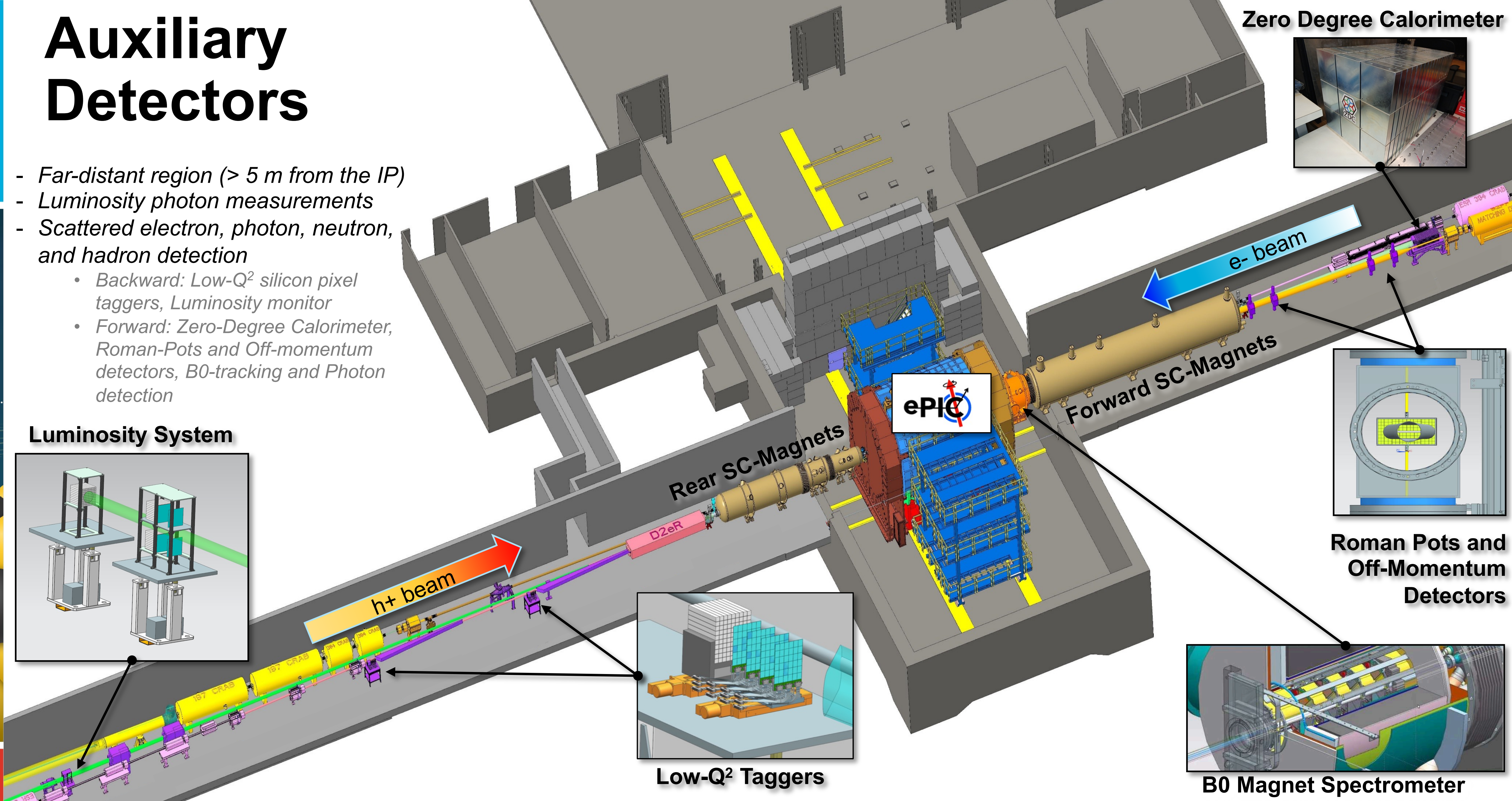


Electron-Ion Collider

Auxiliary Detectors

- *Far-distant region (> 5 m from the IP)*
- *Luminosity photon measurements*
- *Scattered electron, photon, neutron, and hadron detection*
    - *Backward: Low-Q^2 silicon pixel taggers, Luminosity monitor*
    - *Forward: Zero-Degree Calorimeter, Roman-Pots and Off-momentum detectors, B0-tracking and Photon detection*



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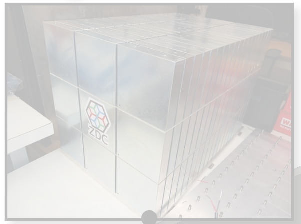
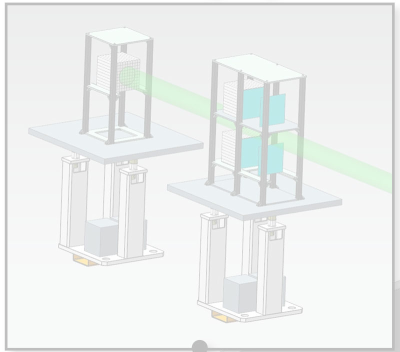
- **Central Detector Region (±5 from IP6):**
  - The beam pipe design modifications are under discussions
- **Far-FWD Detector Region (> +5 from IP6):**
  - No updates for the hadron beam pipe
- **Far-BWD Detector Region (< −5 from IP6):**
  - B2eR magnet moved
  - Low-Q2 tagger's chamber was modified
  - Q1/2eR magnet beam pipe modification is under discussion

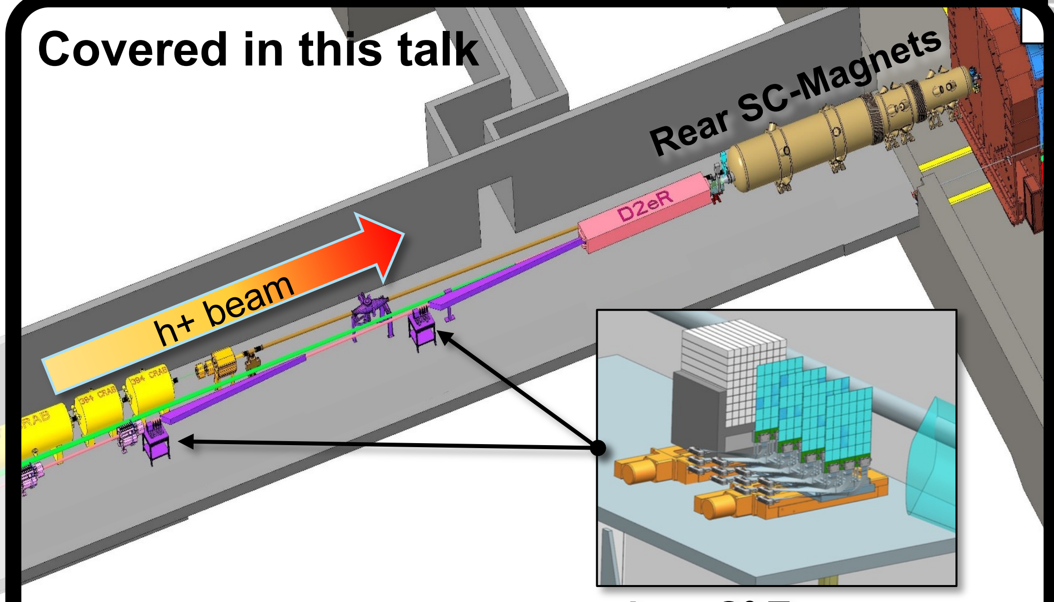
Zero Degree Calorimeter



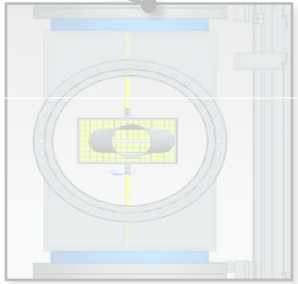
Luminosity System



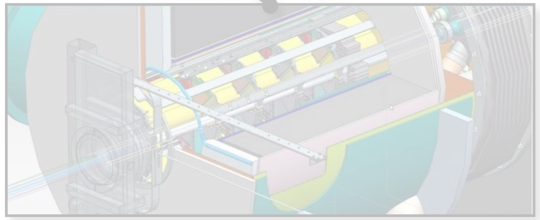
Covered in this talk



Low-Q^2 Taggers



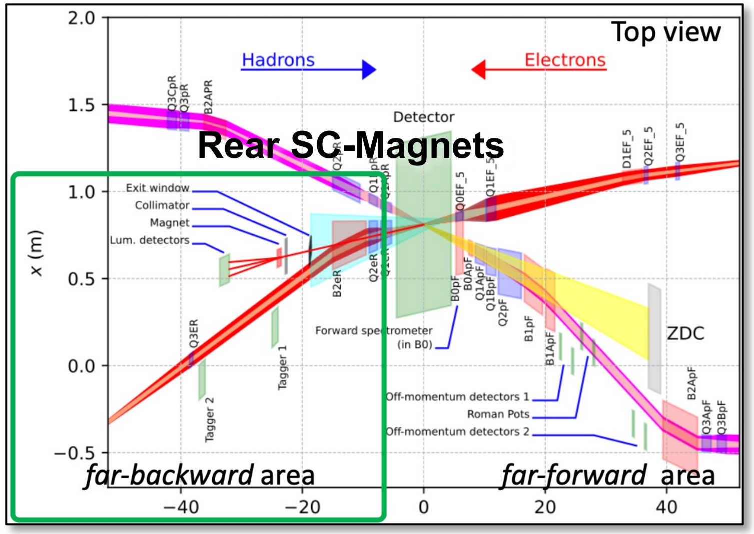
Roman Pots and Off-Momentum Detectors

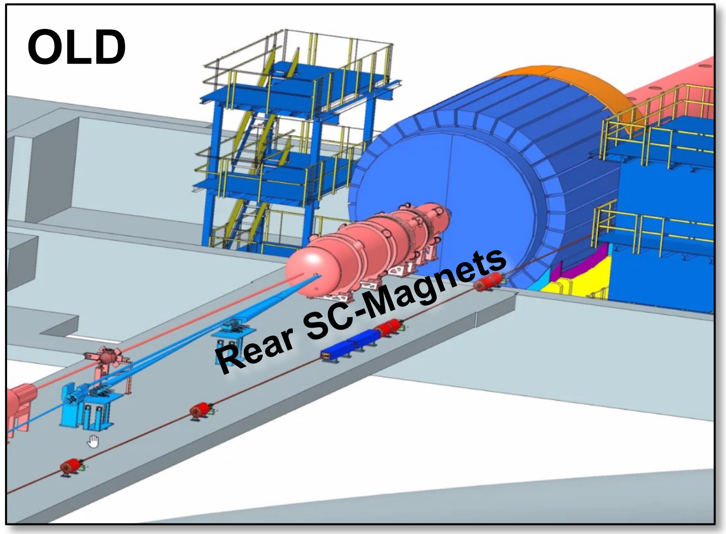


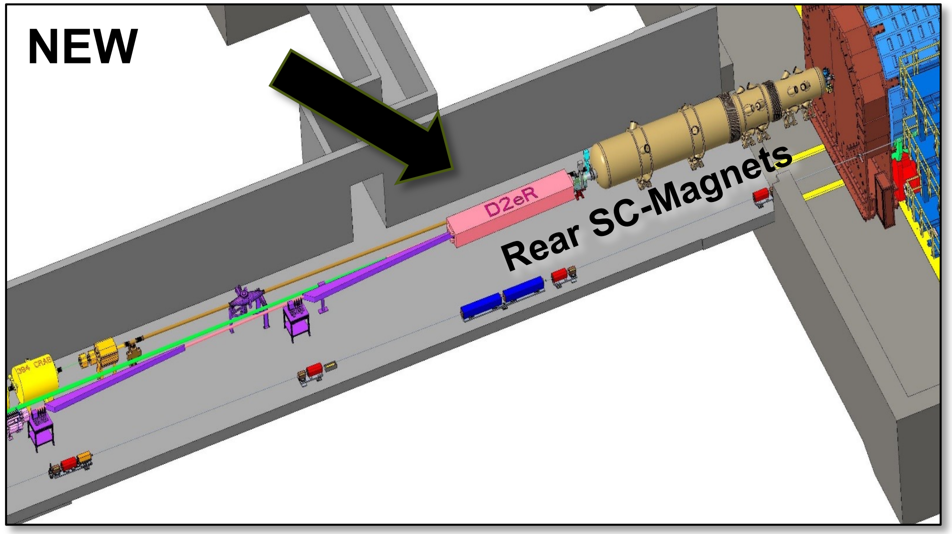
B0 Magnet Spectrometer

B2eR Relocation

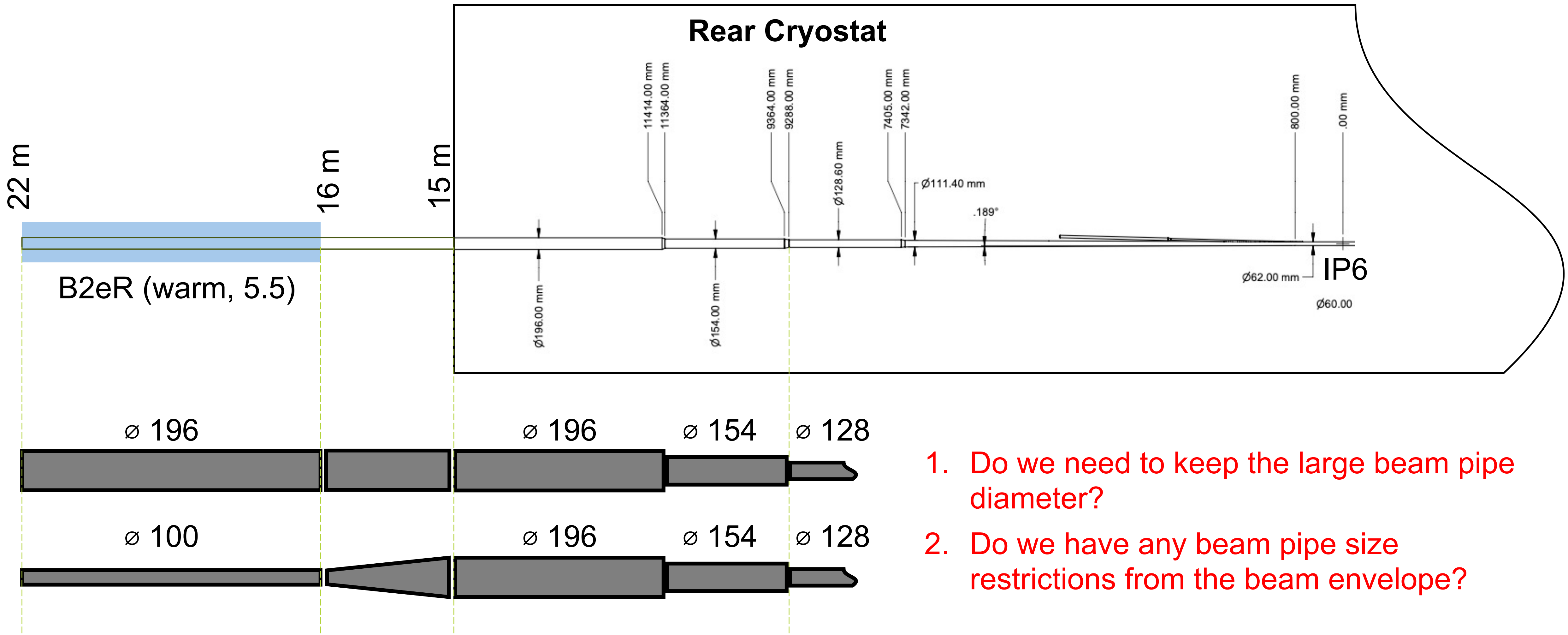
- During 2024 we changed the rear side optics by moving B2eR dipole outside the cryostat
    - Cold 18 mrad → Warm 20 mrad
  - Simplify the cryostat design
  - Relax requirements for the heat load in the cold region
- Consequences
  - Synchrotron radiation (SR) change in the rear region
  - Beam pipe design







B2eR Relocation: Beam Pipe

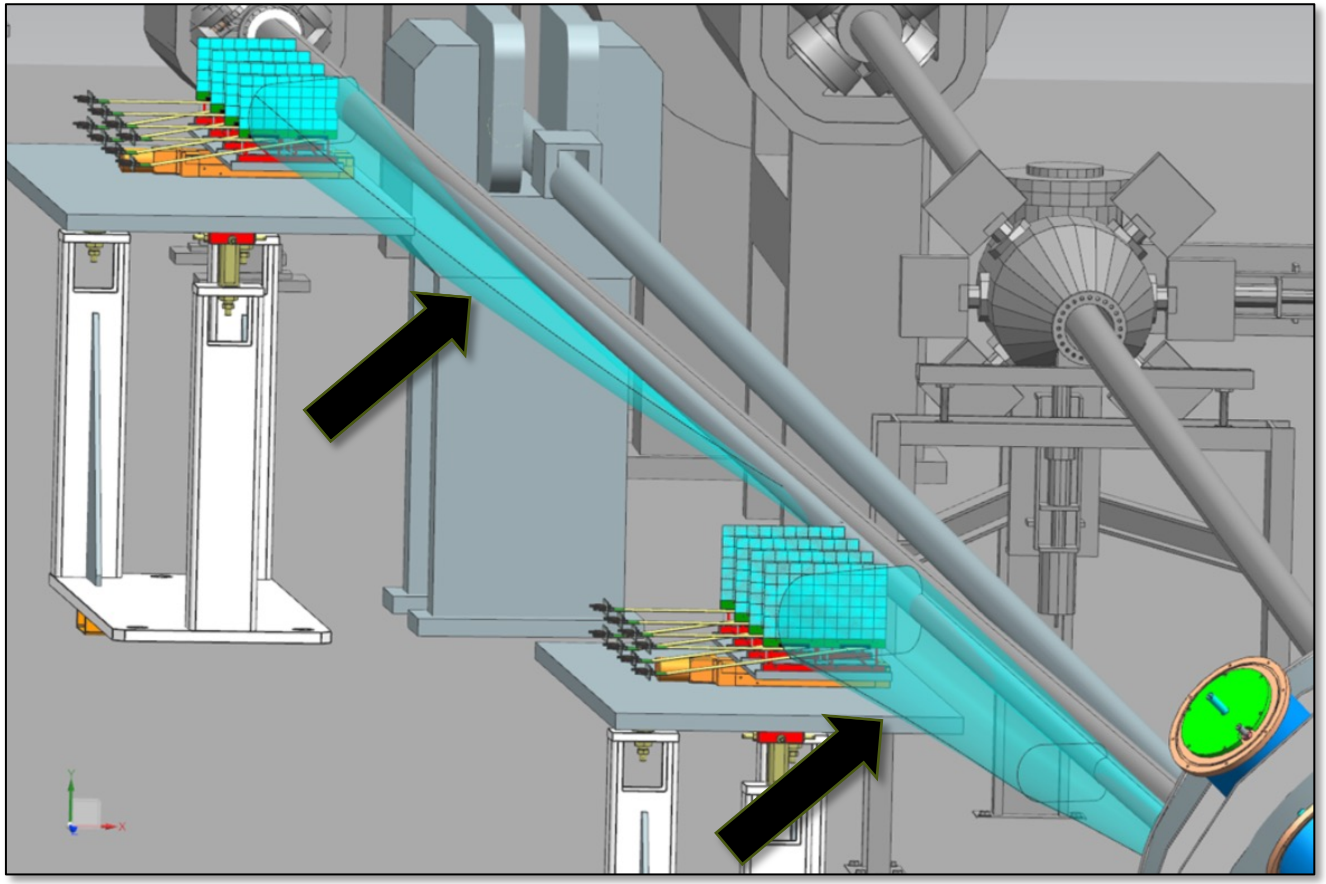


1. Do we need to keep the large beam pipe diameter?
2. Do we have any beam pipe size restrictions from the beam envelope?

Low-Q^2 Tagger Chamber

Requirements:

- The Low- Q^2 detectors need to measure the energy and position of the scattered electrons with Q^2 below 1 GeV^2 in the far-backward direction.
- The acceptance for the low-Q^2 tagger should complement the central detector to reach the coverage close to the limit given by the divergence of the beam.



Can we make the tagger chamber smaller than the main beam pipe to avoid the impedance issue?

Problem:

- The large vacuum chamber attached to the main beam pipe can significantly contribute to the machine impedance related to the weak fields in the far-BWD region.

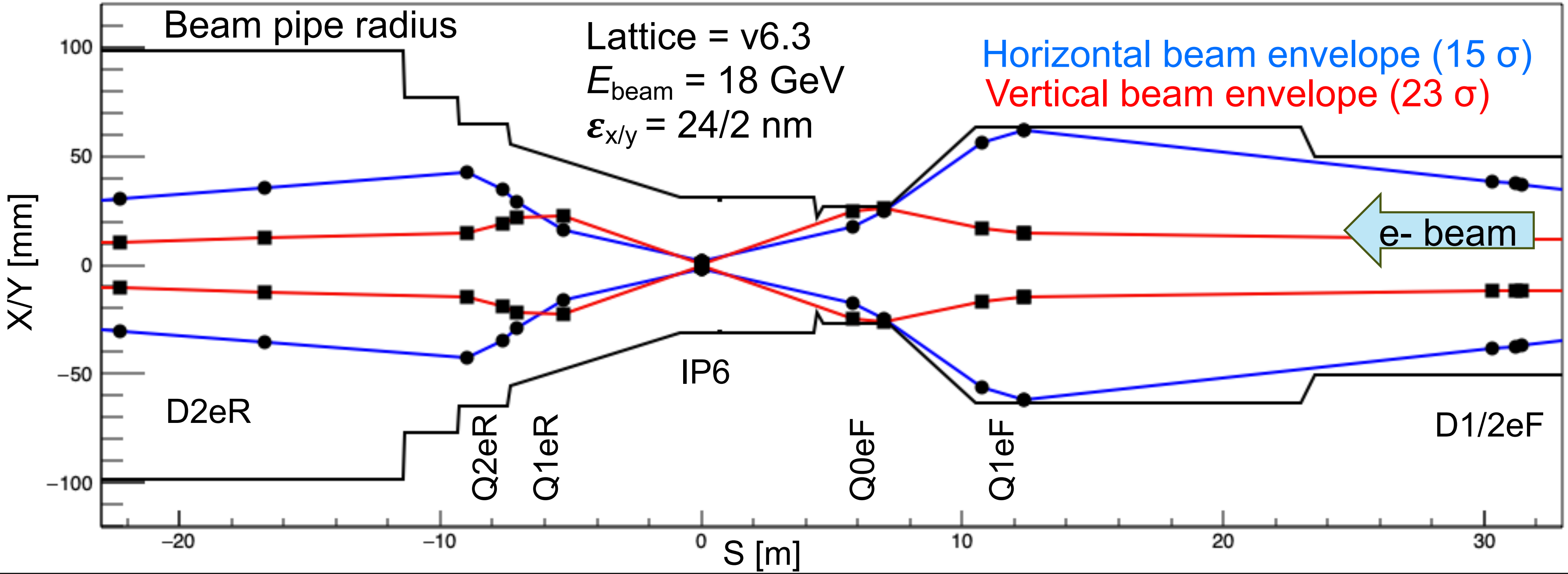
Rear Quad Standardization

Triggered by the magnet system design group:

1. Can the rear ESR quadrupoles be made identical?
2. How much the rear beam pipe aperture **narrowing** affects the SR heat load on the quads?

Consequences of the aperture narrowing:

- Standardize the ESR and HER magnets
- More spear magnets
- Cost-effective production

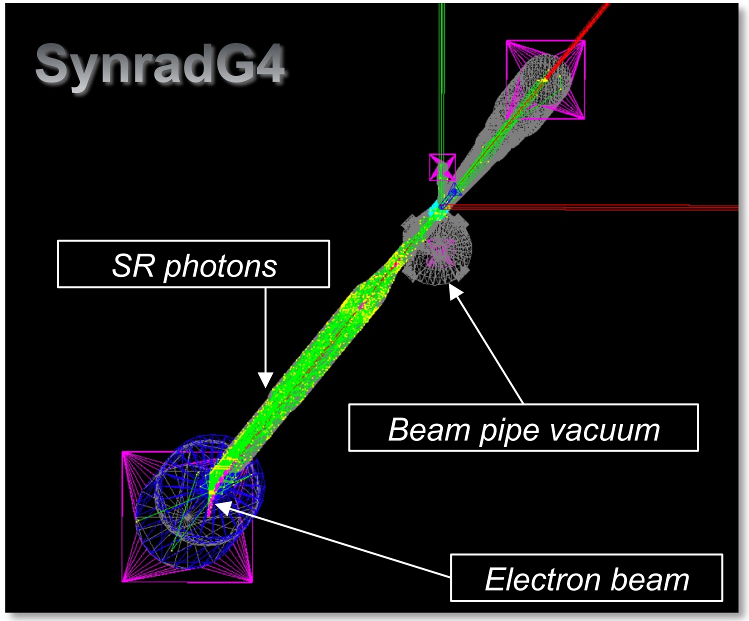


The Tool to Answer the Questions

Developed a dedicated Geant4-based framework, SynradG4, for the accurate SR simulation in the vacuum beam pipe.

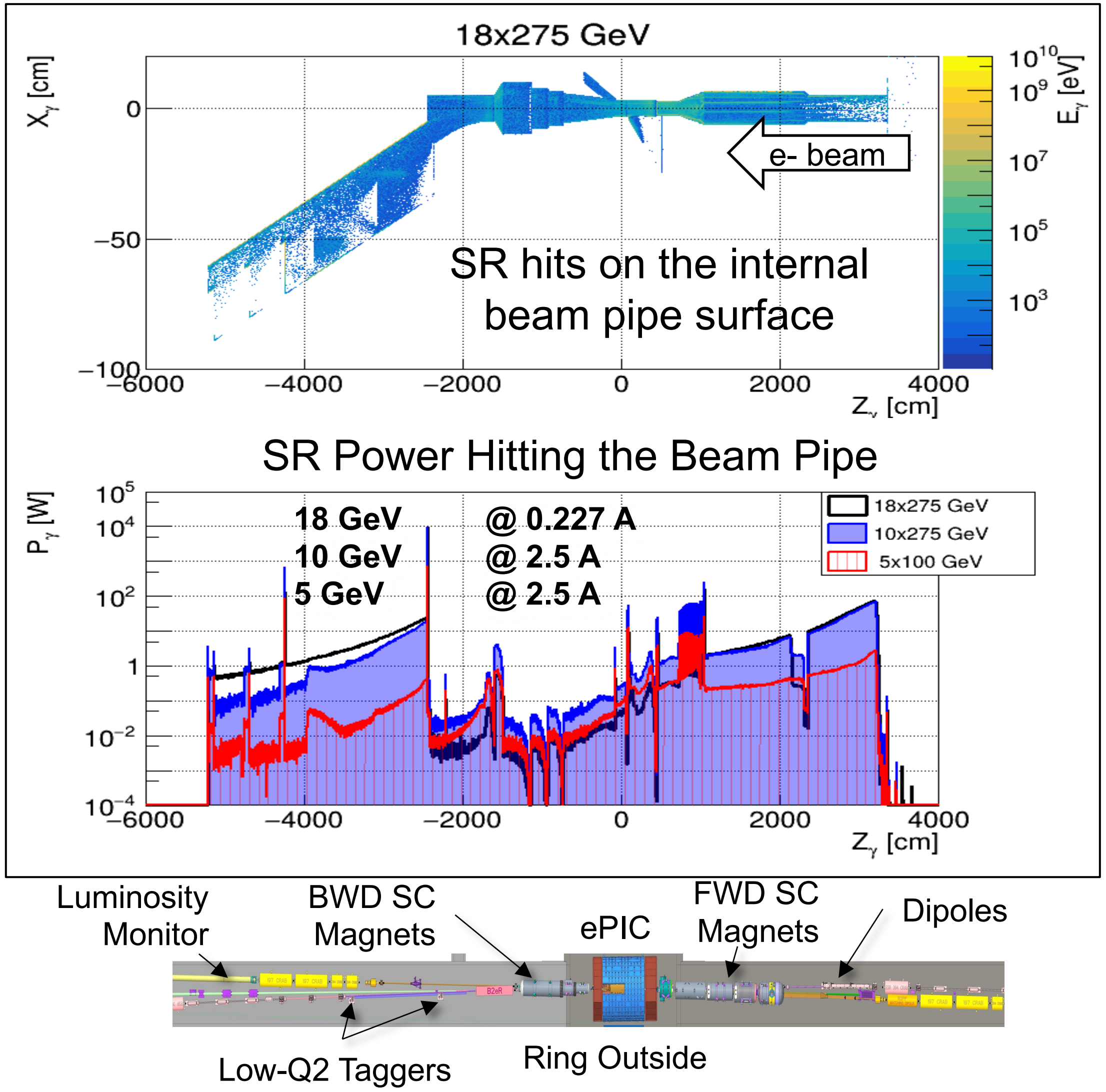
Preprint and **open-source** code:
A. Natochii (2024)
https://arxiv.org/abs/2408.11709

- **Features:**
  - Precise particle tracking using Geant4 libraries with complex 3D geometries imported from CAD files.
  - Same X-ray reflection models as Synrad+.
  - Multiprocessing support:
    - *runs on personal computers and large-scale computer farms.*
- **Outputs:**
  - Absorbed SR photons exportable as ROOT/HepMC3 for the DD4hep ePIC detector simulation.
  - Benchmarked against other well-known frameworks.
- **Impact:**
  - SynradG4 enhances SR background simulations, ensuring precision for ePIC detector studies.

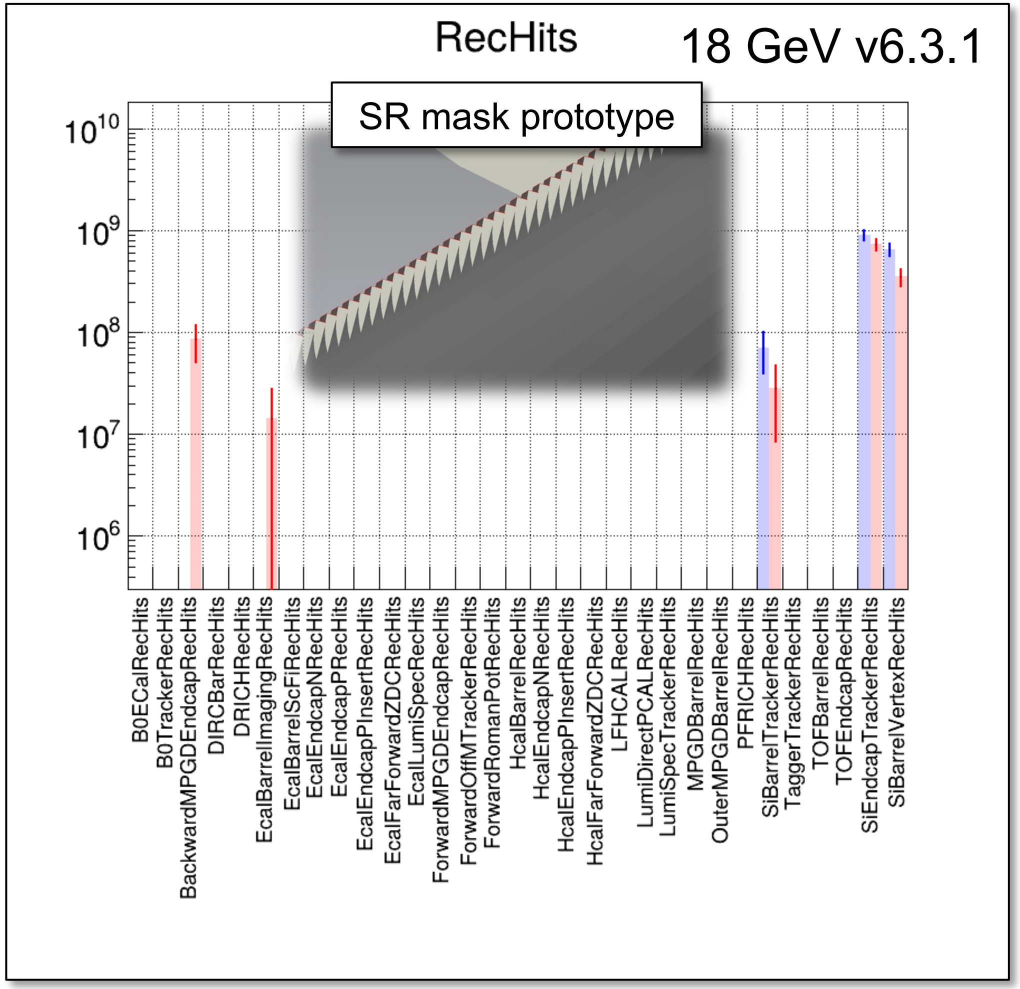


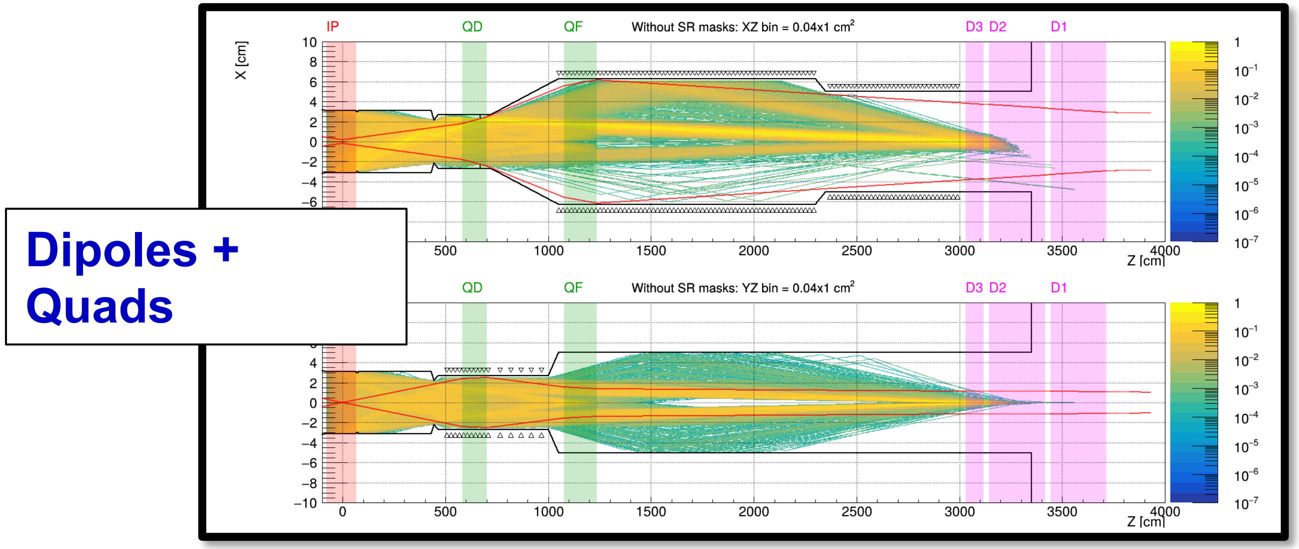
Advancements in SR Studies with the New Code

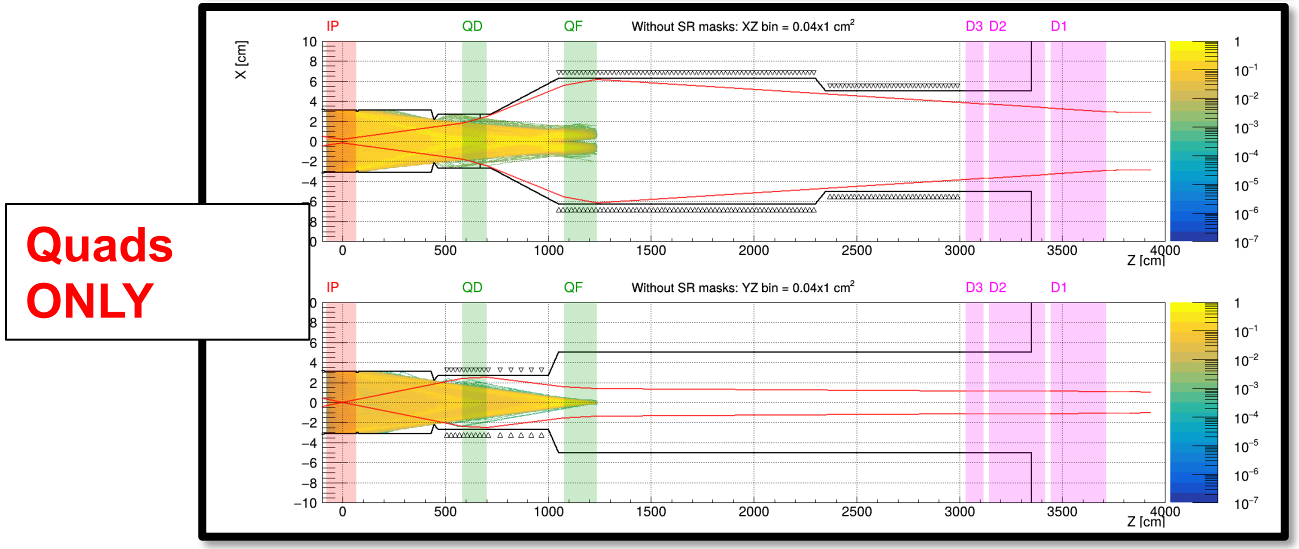
- **SR Simulation Capabilities:**
  - Enables detailed SR studies in the ESR across varying machine and detector configurations
- **Key Findings:**
  - Highest SR load of ~0.1 kW and ~0.1 W on the superconducting (SC) quad cold mass is at 18 GeV (0.2 A) and 10 GeV (2.5 A), respectively
  - The ePIC detector SR background rates are ~1 THz at 18 GeV (0.2 A)
- **Countermeasures:**
  - High-Z shielding can reduce the load on SC quads by a few orders of magnitude below the safety limit
  - Dedicated SR masking significantly reduces detector rates down to ~0.1 GHz
    - *Contributions from upstream dipoles and final focusing quadrupoles are nearly equivalent*



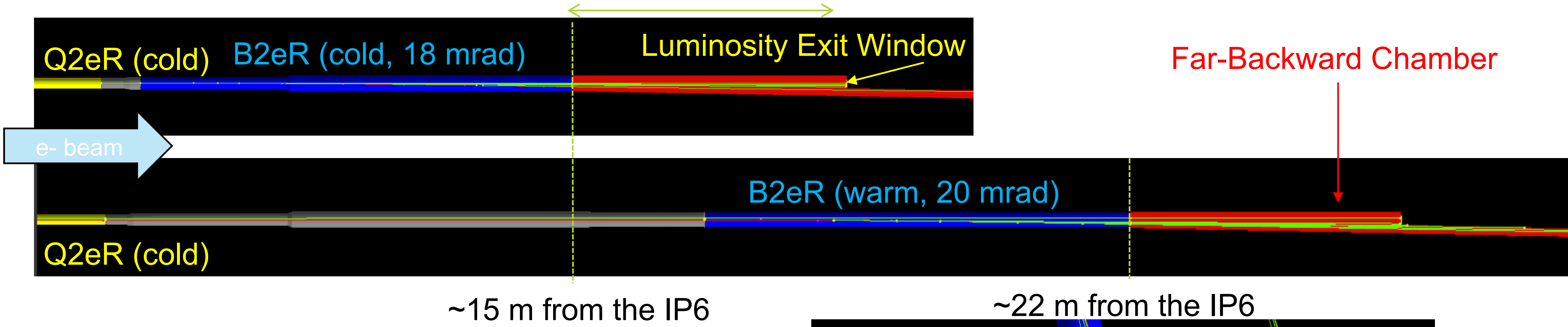
ePIC Detector SR Background Rates



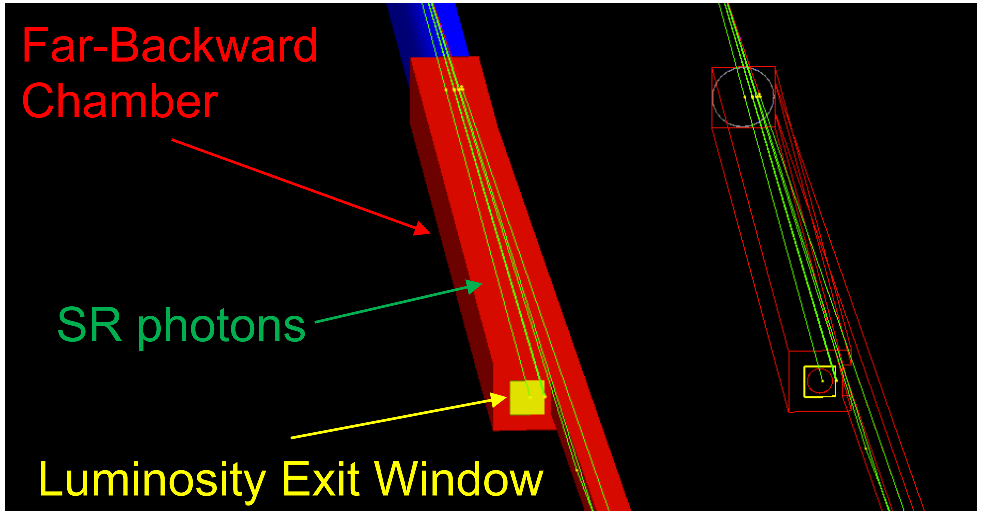




B2eR Relocation: SR Impact on the Lumi Window

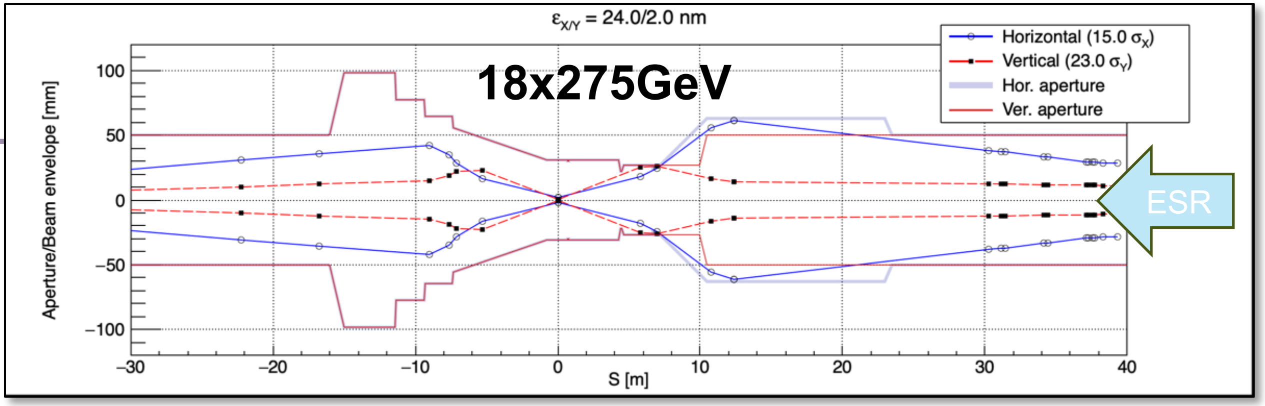


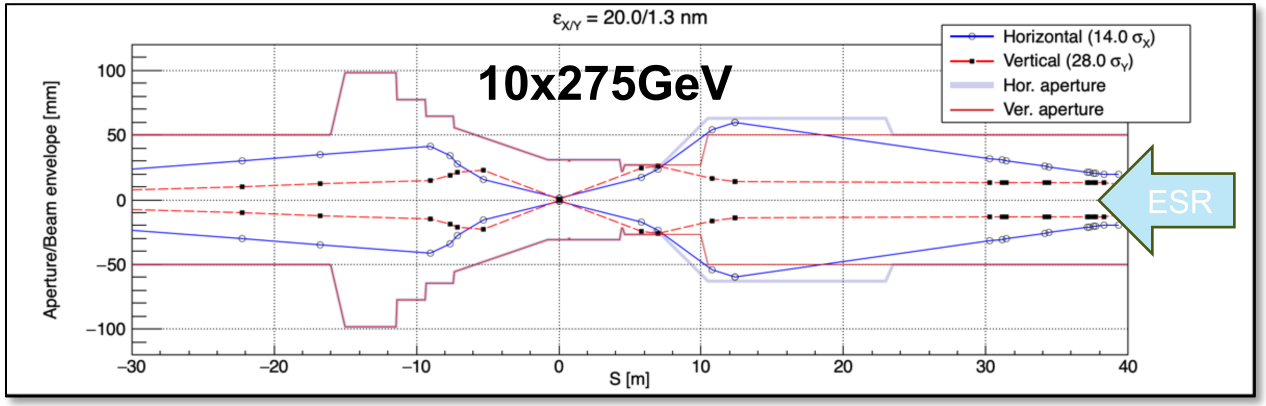
- Moving B2eR outside the rear cryostat requires a larger bending angle to match the orbit
- A 10% increase in the bending angle leads to about **20% increase in the radiated SR energy**
- The expected **SR power** on the luminosity window is about **4 kW (1cm Al)** → manageable: *requires proper cooling*

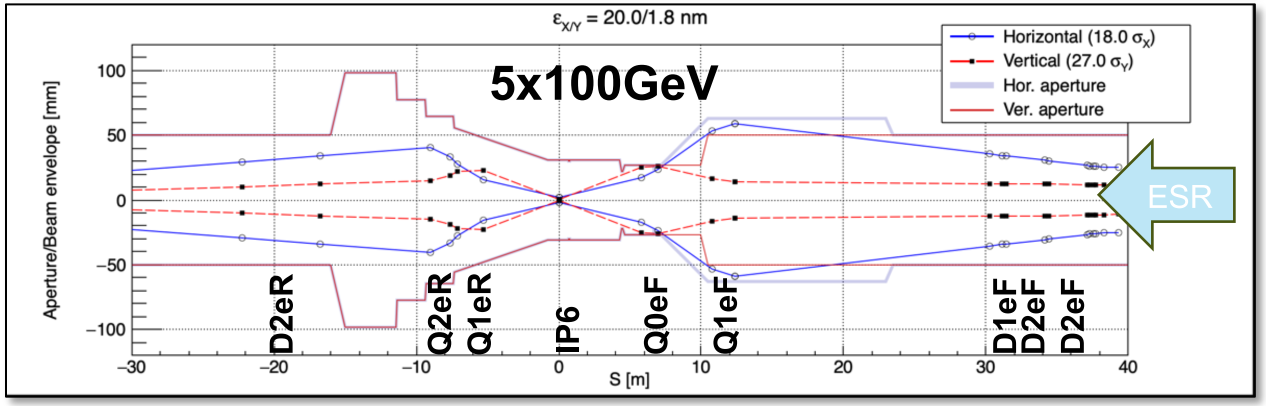


Aperture Change

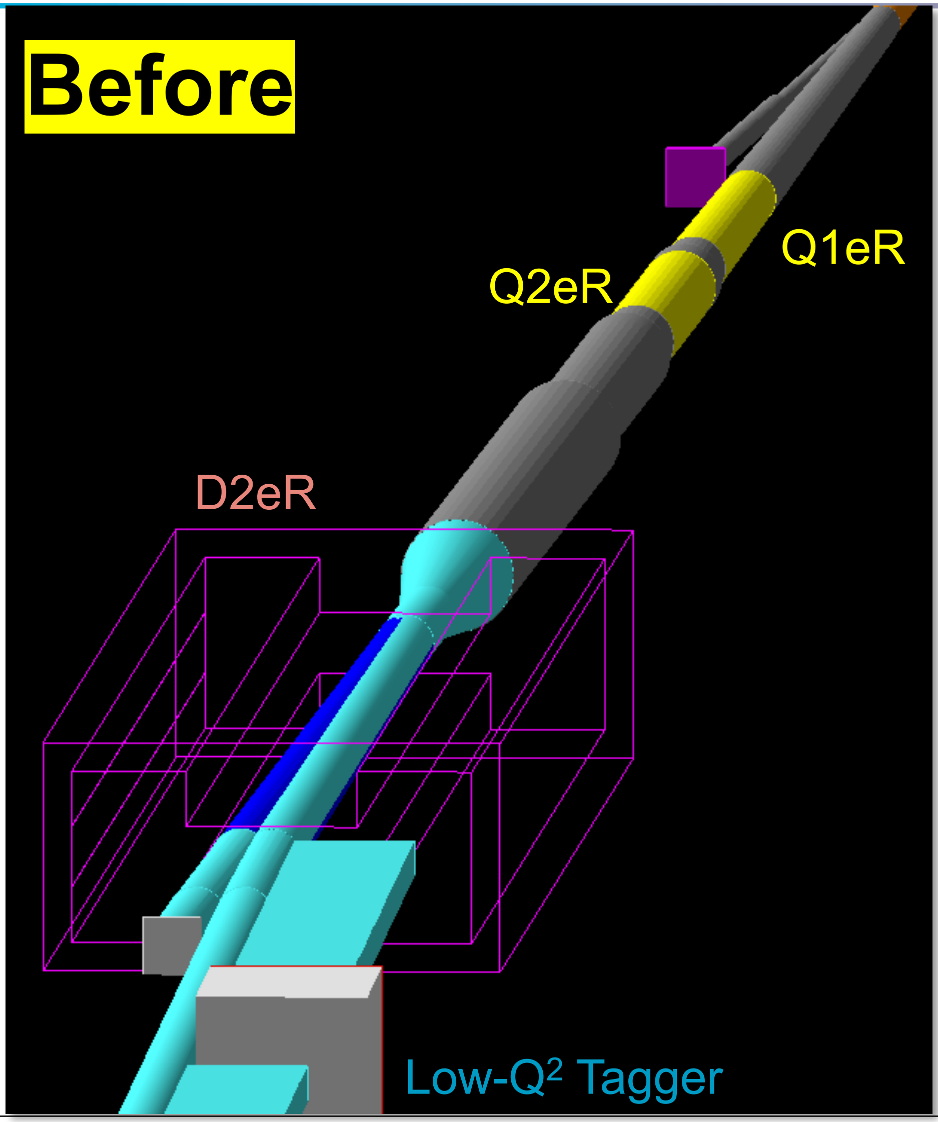
- Initially, the beam pipe aperture was made relatively large (approximately ⌀20 cm) to allow SR to pass through.
- However, it is now feasible to reduce the aperture to ⌀10 cm (the same as the CRAB cavities), as the magnet can handle higher SR loads, similar to the arc dipoles.
    - *This aperture allows the luminosity photons exit the primary vacuum through the Lumi Window within a ±2 mrad cone.*
- Despite this adjustment, the BWD beam pipe aperture within the cryostat remains significantly larger than the maximum beam size, which is dictated by the narrowest aperture in the FWD region.

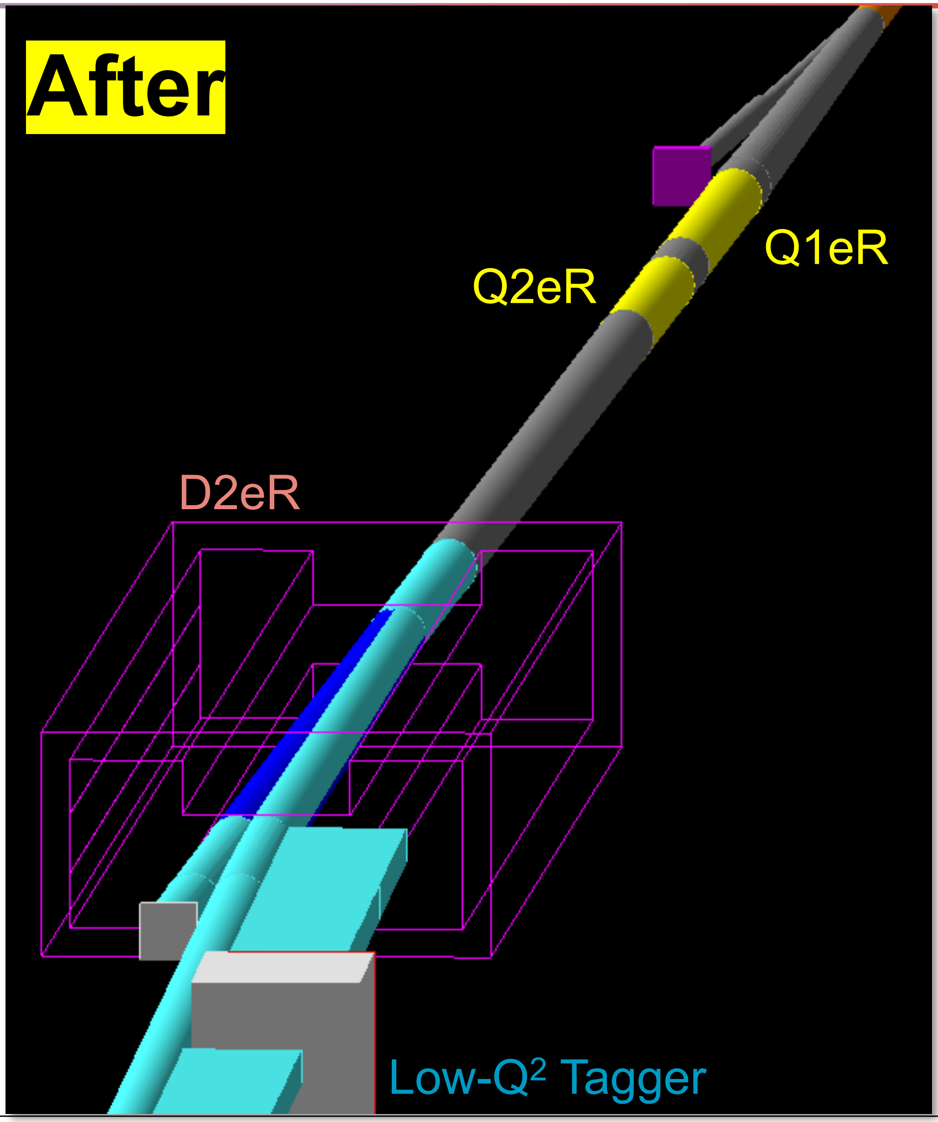






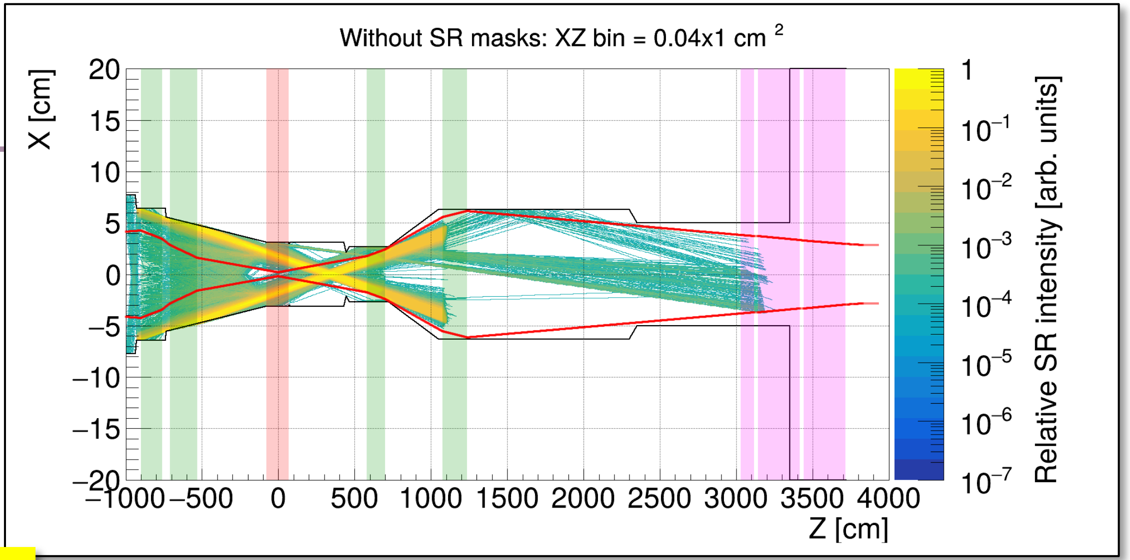
Q1/2eR Beam Pipe Aperture Change



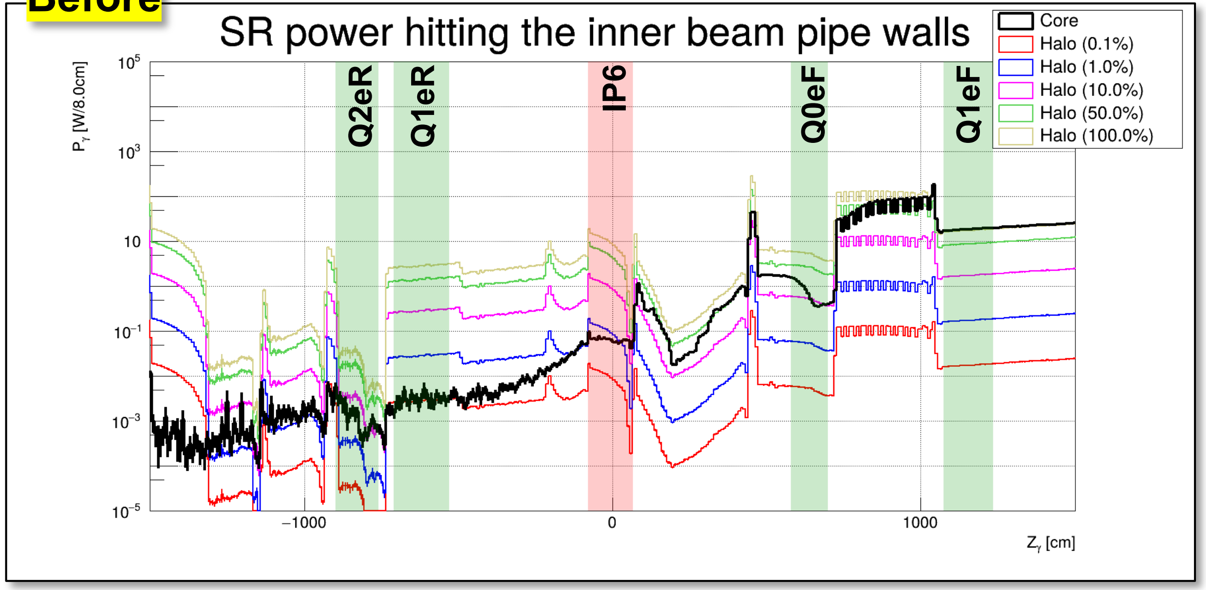


SR Impact on the Design

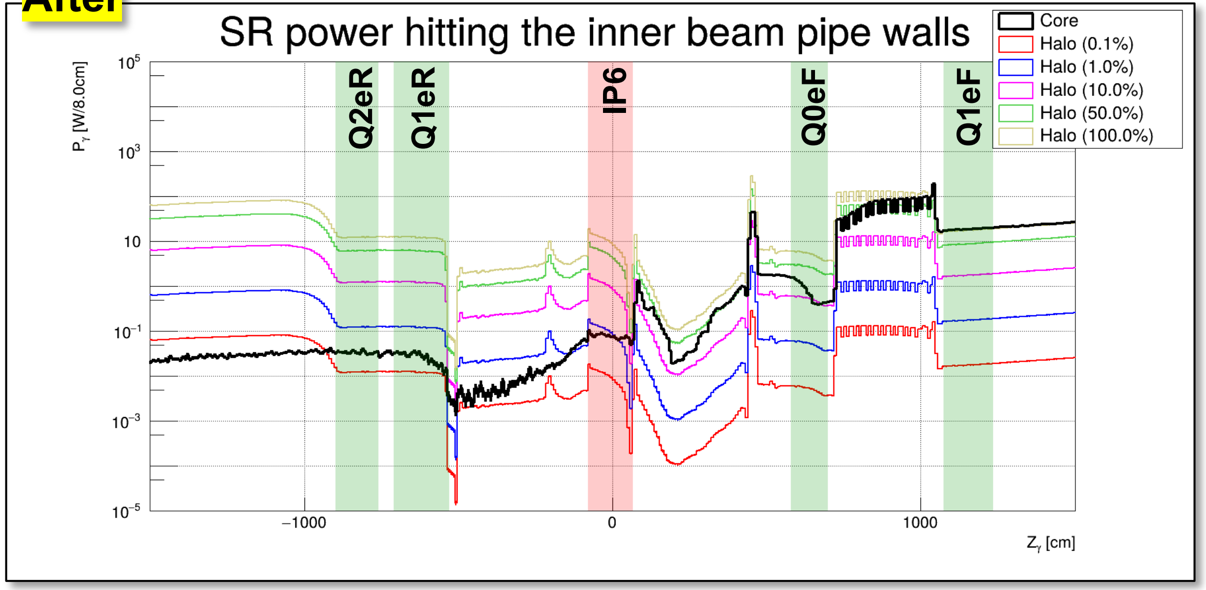
- The tapering beam pipe in the rear side is mainly defined by the SR cone from the FWD quads
- By narrowing their aperture, the SR power on the rear quads increases
- However, it is expected to be much lower than in the FWD side which can be managed by using additional radiation shielding and cooling.



Before

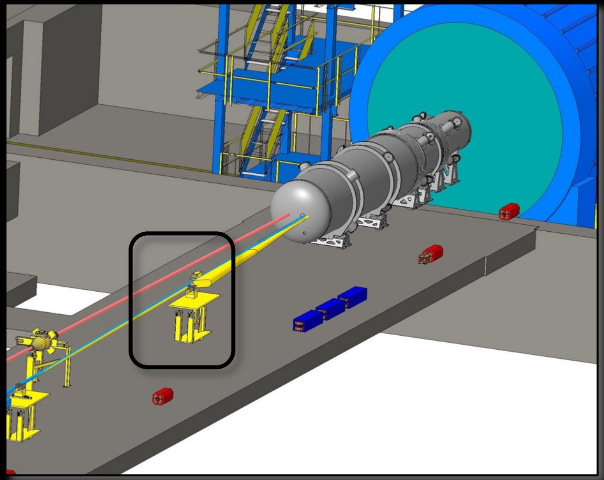


After

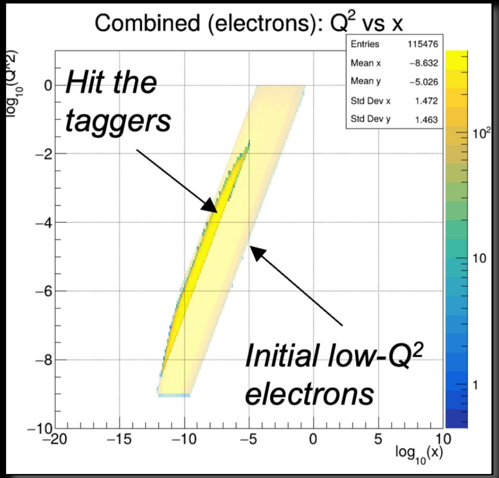


18x275 GeV, v6.3.1 lattice, w/o SR masks, roughness RMS = 500 nm, 10^7 electrons , 0.227 A

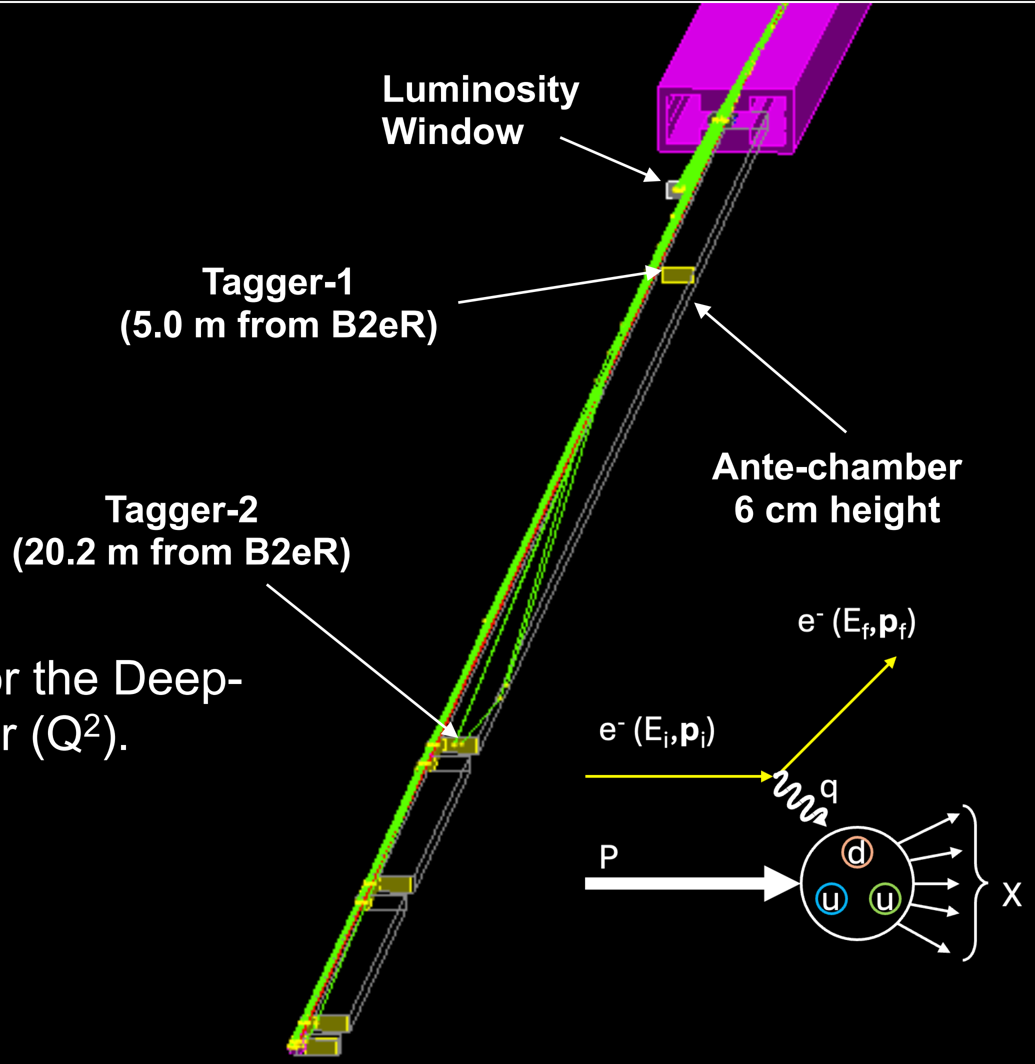
SynradG4 Applications: Low-Q^2 Taggers



Far-backward setup



Momentum transfer (Q^2) vs Bjorken variable (x)



- SynradG4, helps us optimize the far-backward experimental setup for the Deep-Inelastic Scattering (DIS) measurements at a low momentum transfer (Q^2).
- Currently, only **12%** low-Q^2 electrons are detected by the taggers.
  - A big part of the electrons (~65%) goes through the quads.
- Further tunings of optics and tagger's configuration are ongoing.

Summary

- We work hard to ensure the optimal integration and interaction between the machine and the detectors
- The recent modifications of the IR6 beam pipe are mainly dictated by synchrotron radiation
- We have developed a dedicated and accurate framework for SR simulation in the ESR
- We modified the beam pipe ensuring the manageable SR heat load on the SC magnets and avoiding interference with the beam envelope
- We are studying the impact of SR on detector (ePIC, low-Q^2 tagger) performance
- We are working on finalizing the IR6 beam pipe and its interface with detectors
- Further developments are planned for SR mitigation in the IR

Acknowledgements

Many thanks to the EIC accelerator, optics, and vacuum groups for their dedicated work on developing this unique machine; to the BNL and JLab computational teams for on-site support; and to our colleagues at ePIC for their contributions to the detector design and development of the DD4hep model.

Thank you for your attention!