Status update for eRD12: Integration of electron polarimetry, lumi monitor, low Q^2-tagger, etc. into the IR

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Generic EIC Detector R&D Advisory Committee Review

7/6/2016

Proposed Deliverables

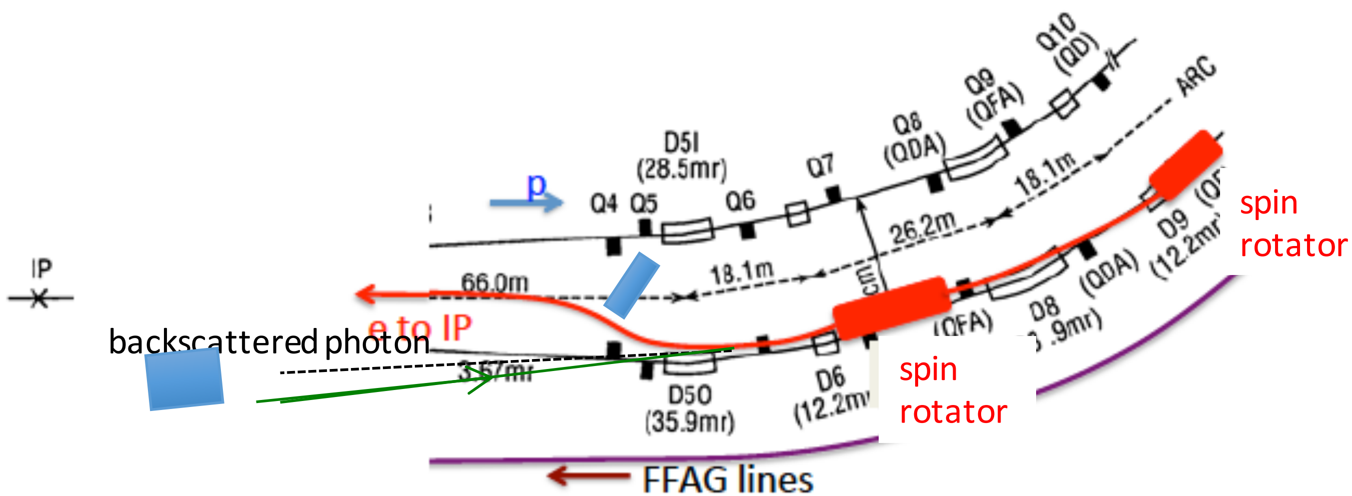
- Optimize the IR design to integrate:
  - The luminosity monitor
  - The lepton polarimeter
  - The low Q^2-tagger
- Develop a Monte Carlo code for Bremsstrahlung (wide and collinear cross section emission) taking into account the polarization dependence of the Bremsstrahlung cross section
  - Study impact of relative luminosity and how accurate polarization needs to be known
- Integrate a first layout into the EicRoot simulation package
  - Develop a dedicated e-polarimeter simulation package
- Determine detector performance requirements based on physics and machine backgrounds
- Follow up with targeted detector R&D which fills the determined requirements
- Additional deliverables not originally included:
  - Enhancement and development of the general purpose EicRoot simulation package
  - Optimization of the IR design in terms of forward going proton acceptance (with a Roman Pot detector setup)
  - Cross check of the forward going neutron acceptance

Outline

- Major project accomplishments this past period
  - Electron polarimetry
  - Roman pot acceptance studies and push for new IR designs
  - Neutron acceptance
  - Low Q^2-tagger update
  - Lumi measurement calculations
- Next steps
- Overall status and successes of the project

Electron Polarimetry Update

- Reminder: Overall goal is to find suitable placement of the system and develop a plan for the detector and measurement scheme
- Method of measurement: Compton scattering of circularly polarized laser on polarized e beam



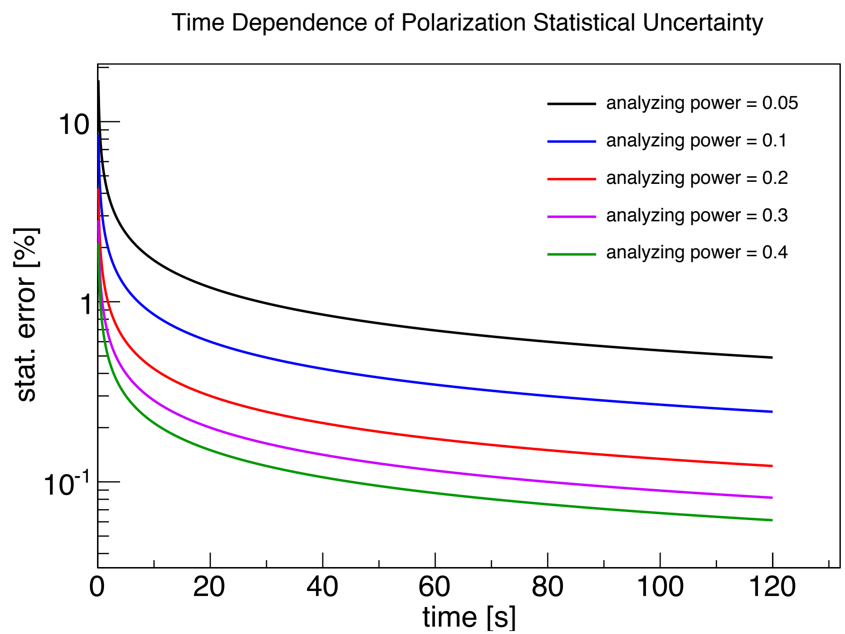
Update on study of laser power

$$L = \frac{f_b N_e N_\gamma}{2\pi\sigma_{x\gamma}\sigma_{y\gamma}\sqrt{1 + (\theta\sigma_{z\gamma}/2\sigma_{y\gamma})^2}}$$

- Estimate the laser power needed to achieve roughly one Compton scattering per beam crossing
- Some basic assumptions:
  - Scheme assumes the linac-ring design
  - f_b = 9.4 MHz
  - N_e = 0.07 x 10^{11}
  - $\sigma_{x\gamma}$ = $\sigma_{y\gamma}$ = 400 microns
  - $\sigma_{z\gamma}$ = 0.4 cm
  - θ = 25 mrad
  - Assume the laser is clocked with the eRHIC 9.4 MHz clock
  - σ_{Compton} = 400 mb (roughly for a 20 GeV electron on a 2.33 eV laser photon)
- The above parameters leads to needing 3.6 x10^{12} photons per pulse →1.3 uJ per pulse →12 W laser power in total
- Achievable with an off the shelf laser

Estimation of time needed for measurement

- Estimate an effective bunch rate by accounting for:
  - 111 out of 120 bunches filled
  - Half the bunches are one particular polarization direction
  - 20 individual cathodes produce bunches and we desire bunch cathode by cathode monitoring to look for polarization differences from the sources
  - → effective rate 2.2 x 10^5
- Expect 1% level statistical precision in less than 2 minutes
- Assumes measuring in single photon mode

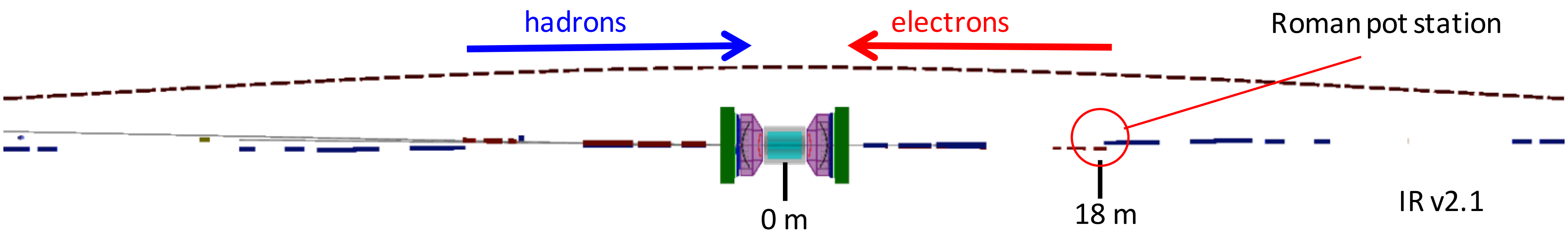


$$\delta P_e \approx \frac{1}{\sqrt{N}}\frac{1}{A}$$

Considerations for the ring-ring design option

- Ring-ring means bunches recirculate rather than being dumped after interaction as in the linac-ring
- Beam-beam interactions
  - Beam-beam becomes more important for the **ring-ring** option
    - Since electrons recirculate (vs linac-ring where electrons are dumped after crossing) beam-beam interactions can bunch dependent
    - Requires bunch by bunch monitoring
- Bunch replacement
  - Current plan is to replace one bunch every second because of self-polarization

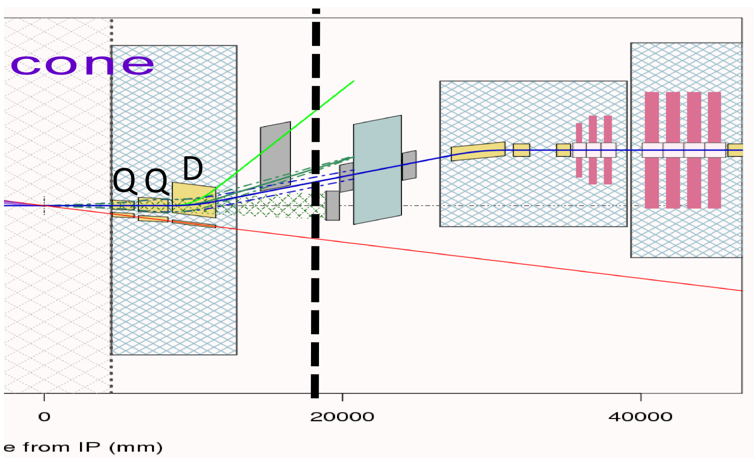
Roman Pot Acceptance Studies



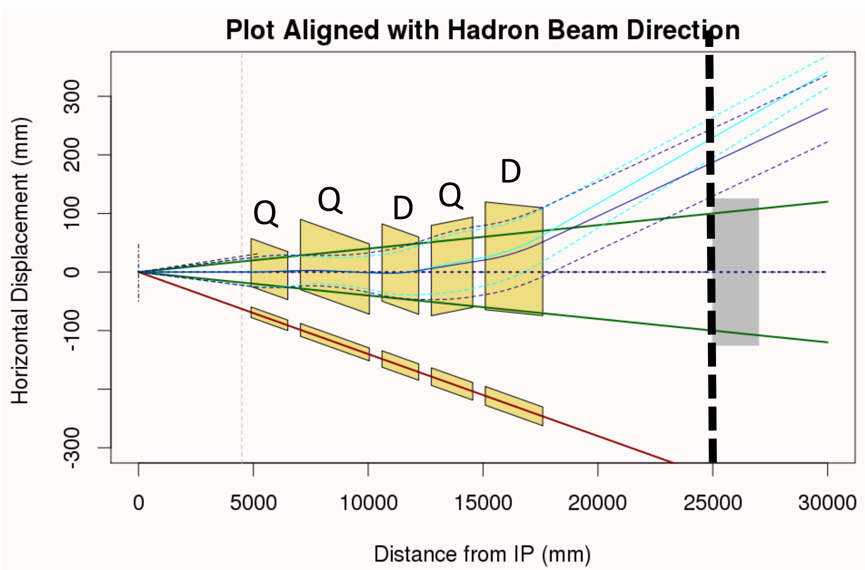
- Some software development
  - New format for information exchange between accelerator developers and experiment developers integrated into EicRoot package
  - Allowed for study of two new designs in a short period of time and a quick turnaround in study for any new incoming design
- Previously reported acceptance study prompted machine designers (of the IR) to revisit the design and make **major** improvements
- Additionally a first ring-ring IR layout was handed off and studied

New IR Designs Incorporating previous study findings

Linac-ring v2.1

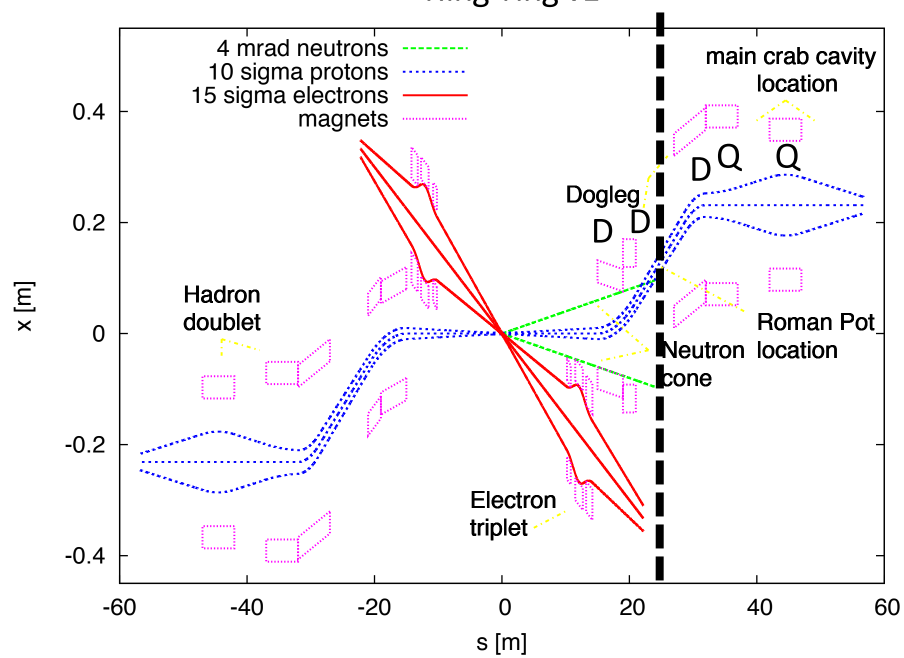


Linac-ring v3.01



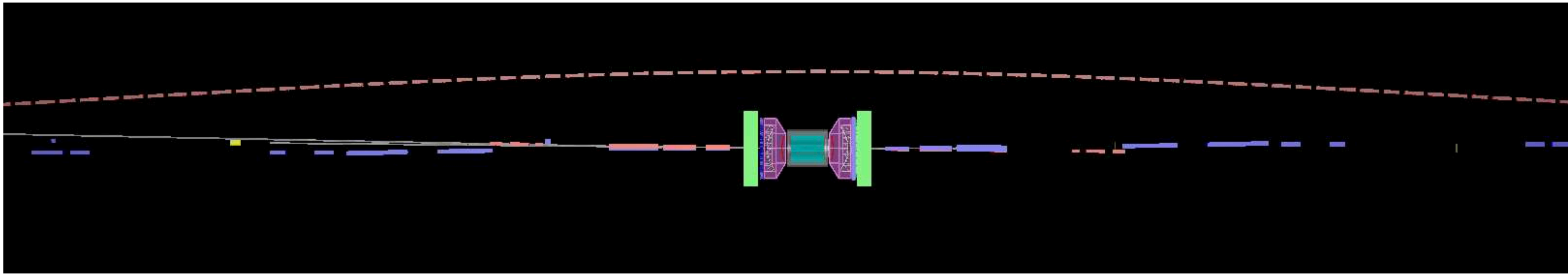
- Dashed line represents the location of the Roman Pot and/or ZDC

Ring-ring v1

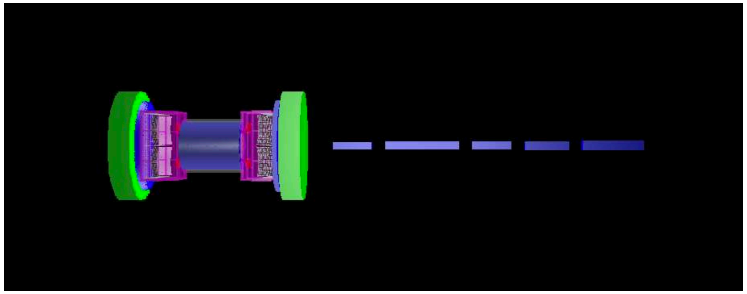


IR layouts in EicRoot

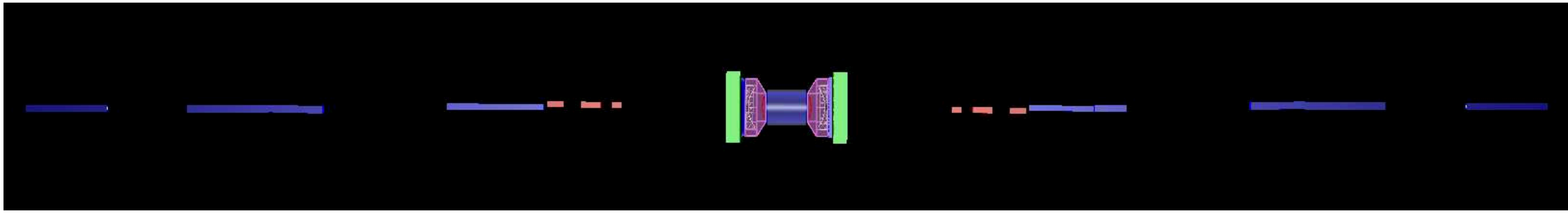
v2.1_LR



v3.0_LR

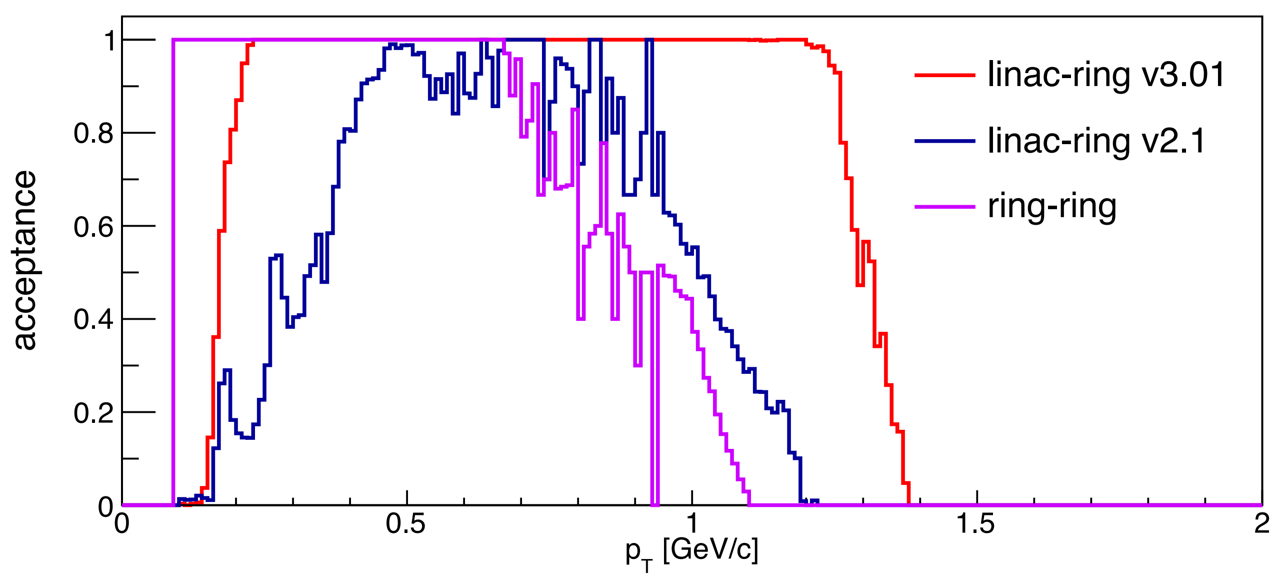


v1.1_RR



Comparison of Roman Pot acceptance for different IR designs

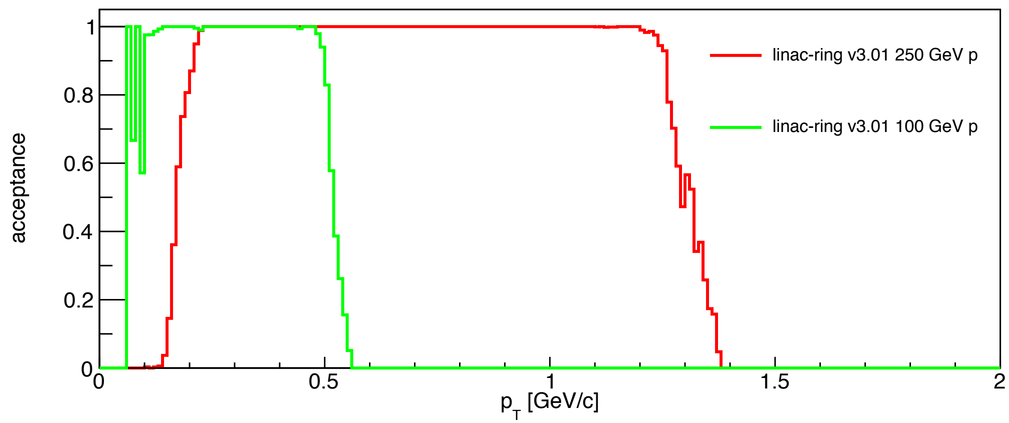
- Roman pots placed fully around beam giving full azimuthal acceptance
- Placed at a distance of 10σ of the width to the core of the beam
  - Calculated from the beta functions obtained from the machine developers
- Dist. from the IP 18m (linac-ring v2.1), 25m (linac-ring v3.01), 20m (ring-ring v1)
- Sent in 20x250 GeV ep collisions simulating DVCS in MILOU to EicRoot and analyzed results



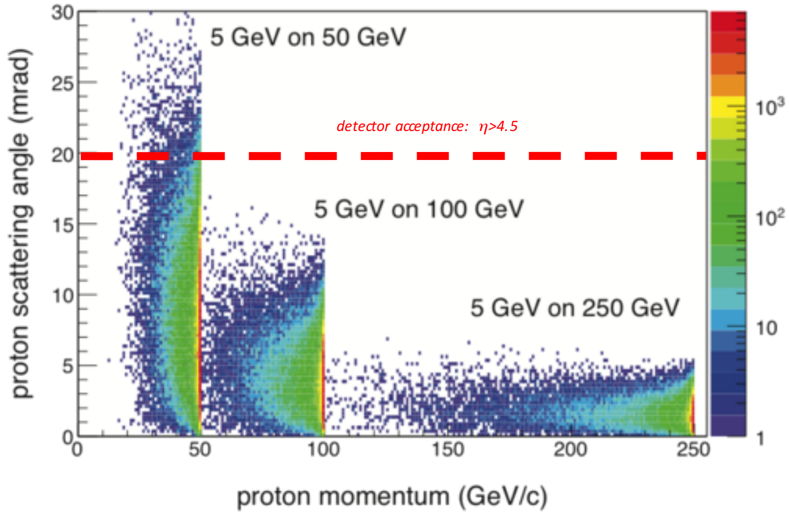
- **Huge improvement** for the linac-ring IR design in terms of forward going proton acceptance, near perfect
- Ring-ring design is limited by a +/-4 mrad neutral cone aperture where linac-ring is +/- 5 mrad
- An increase in aperture gives acceptance back to higher pT

Roman pot acceptance with lower energy proton beams

- Simply scale magnetic fields (a feature of the software implemented last year) for the beam energy difference
- Acceptance smaller due to wider scattering angle distribution of protons in the DVCS process
  - Possible to place a station closer or an Hcal to recover the acceptance
- Little dependence of scatting angle on the electron beam, so can vary electron beam energy with a 250 GeV proton beam and still get good kinematic reach
- Assumed same beta function for lower energy, which may not be the case

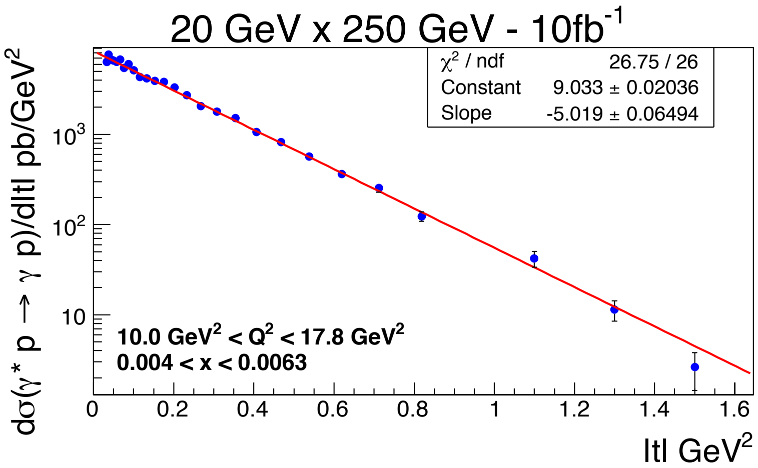


p beam energy dependence from simulation



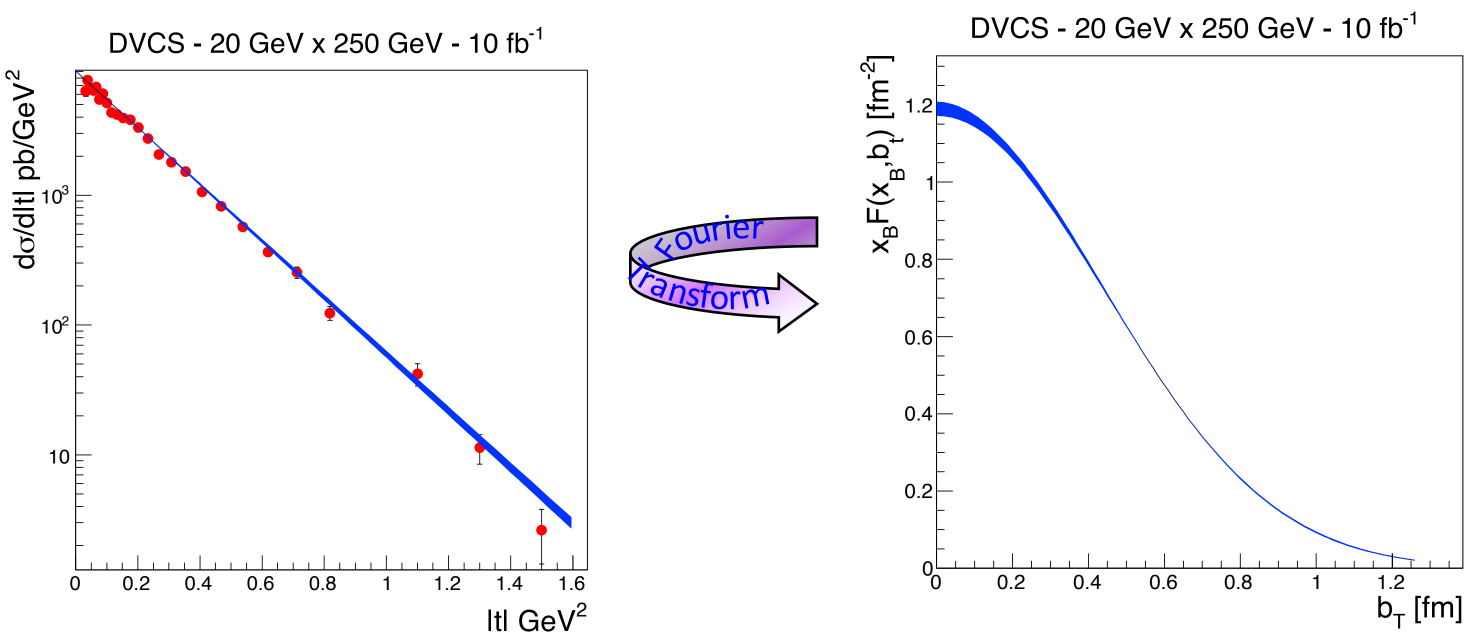
Impact to DVCS physics measurements of limited acceptance (I)

- Plots from the EIC white paper



- eRHIC with 20x250 GeV^2 and 10fb^{-1} - what changes for the error bands if we fit different |Pt|-ranges?
- Ideal acceptance shown here
- $|t| = p_T^2$

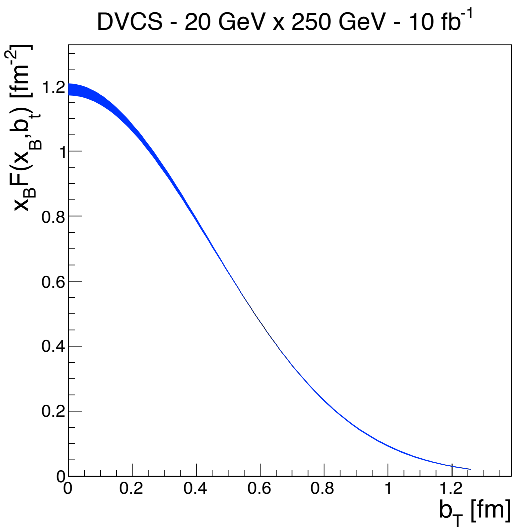
0.18 < |Pt| (GeV) < 1.3

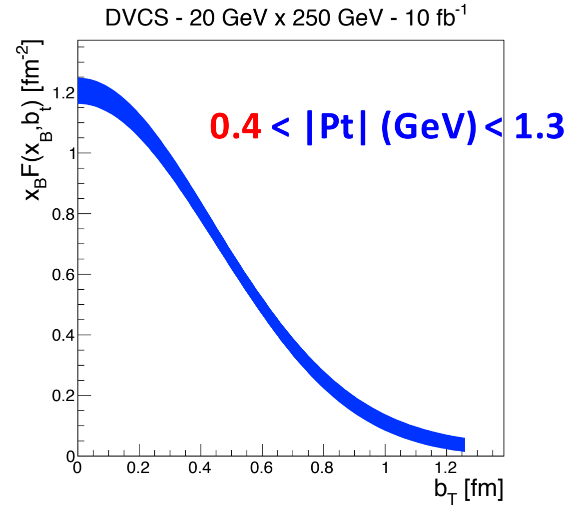


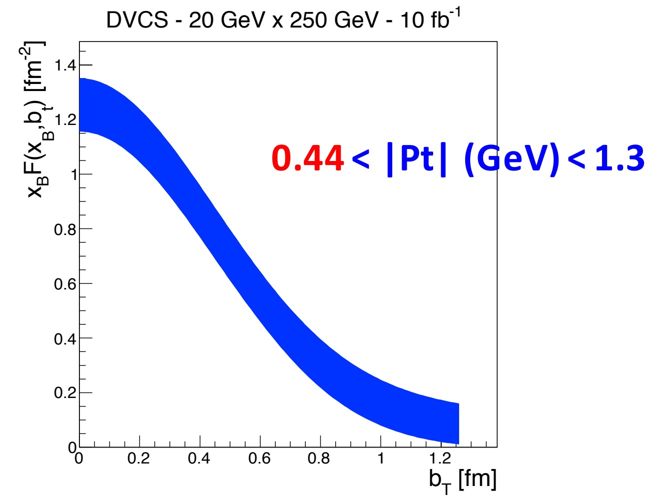
Impact to DVCS physics measurements of limited acceptance (II)

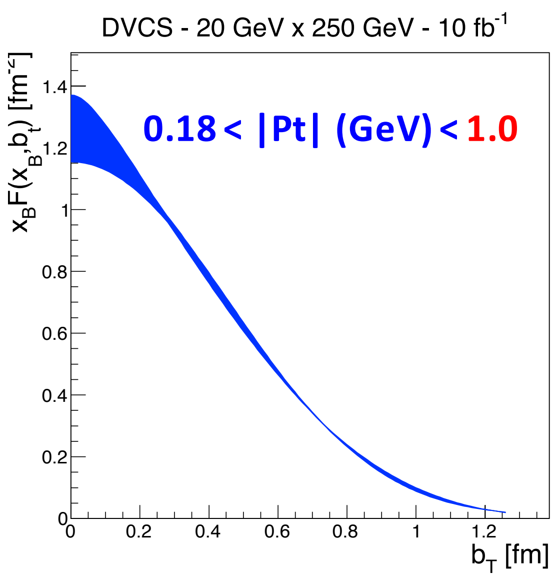
- Lets look at how the uncertainty changes on the gluon form factor with different acceptance cuts

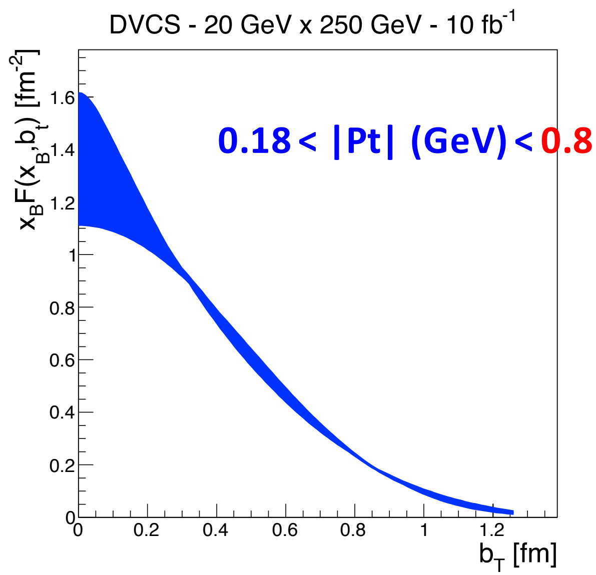
0.18 < |Pt| (GeV) < 1.3







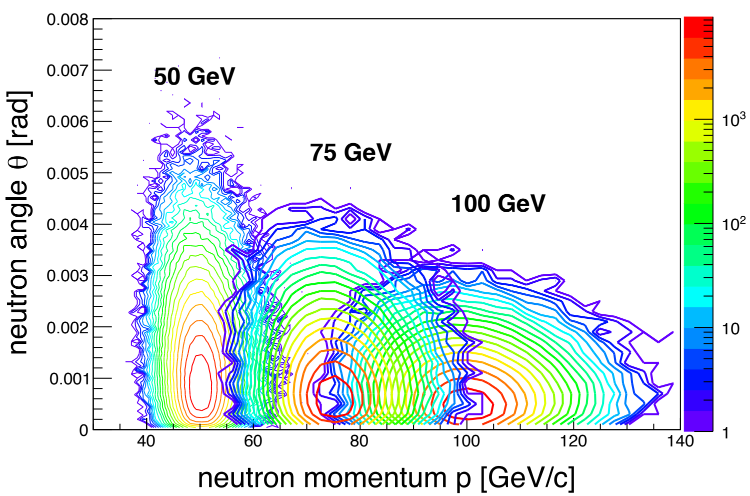


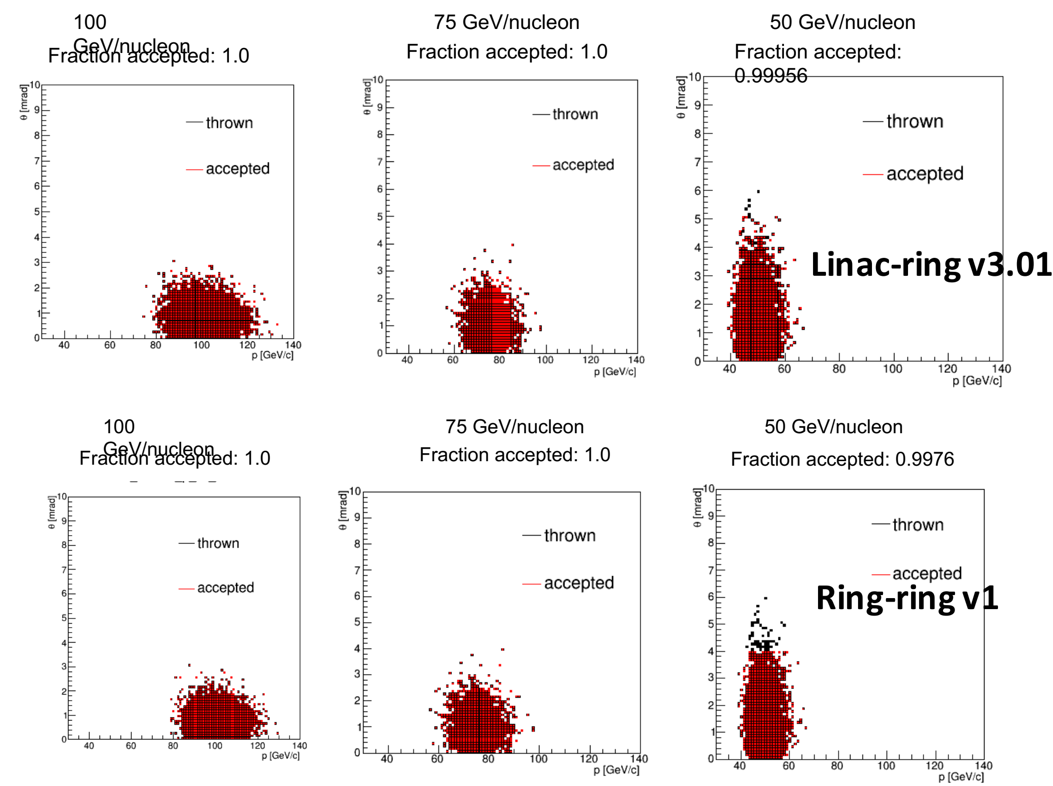


Checking Neutron Acceptance in each design

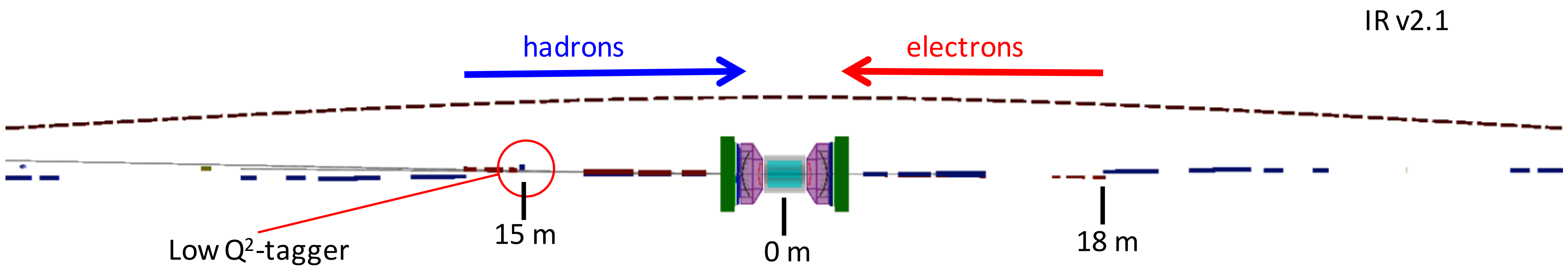
- While we are at it…check to make sure neutrons make it through the lattice
- This works well, not surprising since this was the main constraint given to the IR designers

Expected distributions from DPMJet simulation of neutron evaporation

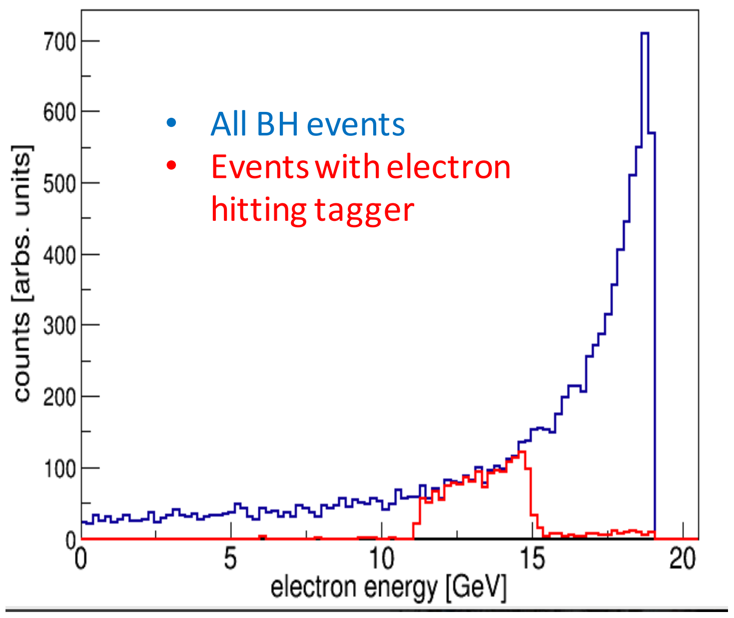




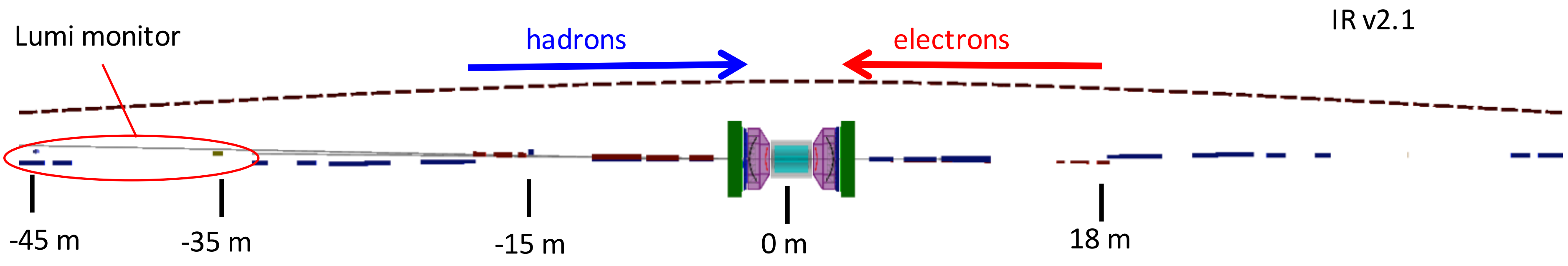
Low Q^2-tagger update



- Dedicated detector to detect electrons from low Q^2 events that miss the main detector
- Previously reported on the basic detector design and integration into the IR
  - Consists of 3 tracking layers followed by a calorimeter
- Begin to study backgrounds
  - One major background is electrons from Bethe-Heitler scattering
    - This is the same process used for the luminosity monitor
  - It is observed that electrons from BH hit the tagger in a limited energy range
  - Looking into moving the detector so that reduce acceptance to BH while still keeping acceptance to DIS events
  - Studies done up do date are with the previous IR version (v2.1)
- Back of the envelope calculation shows we expect roughly 10 electrons per bunch crossing hitting the tagger in this energy range assuming a peak lumi of 4×10^{33} $cm^{-2}s^{-1}$
- DIS events more on the order of 10^{-4} rate



Lumi update



- One of the project objectives was to produce a calculation for polarization dependent cross-sections for the BH process used for the luminosity measurement
- The cross section is needed for the measurement and may depend on the polarization of the beam
- In contact with theorists (Harut Avakian, Svetlana Barkanova)
- Have some guidance for now indicating effect of polarization on the cross section is small
  - From Dieter Müller: $d\sigma^{long.pol}/d\sigma^{unpol.} \approx Q^2/s$
  - The effect is small

Next Steps

- A new iteration of the interaction region design has recently been developed by C-AD
  - Based on the recommendations from the previous study findings
- Additionally an IR design for the ring-ring scheme has been developed
- Studies should be repeated for updated designs and are ongoing
- Propose extended studies studying in detail the background environment due to machine operation that these devices will operate in (see the separate proposal at this meeting)

Closing remarks on the project (I)

- The main project deliverables have been complete:
- Initial design and integration into the IR of a low Q^2-tagger
  - Placed in the IR lattice v2.1
  - Tracking algorithm in place to determine scattering angle
  - Adjusted placement to have good Q^2 coverage verified by Pythia simulations (down to $O(10^{-5}$ GeV^2))
  - Studies show BGs from BH events can be high
- Initial design and integration into the IR of a luminosity monitor
  - Placed in the IR lattice v2.1
  - Detector configuration conceived and integrated into the simulation environment with the IR
  - Acceptance studies performed, as well as study of measurement and constraints on aperture due to beam optics
- Initial design and integration into the IR of the electron polarimetry system
  - A suitable location has been located through communication with C-AD
  - Details of the lattice in the location still need to be worked out
  - A basic plan of action for the measurement has been conceived (Compton scattering)
  - A detector has been designed, implemented in simulation, and studied
  - Basic scheme (in simulation) to measure longitudinal pol. using either the scattered photon or electron works well
  - Made some basic estimates on the type of laser needed
  - Developing a stable fitting procedure to simultaneously measure polarization fraction and angle (to estimate transverse component) within a single finely segmented calorimeter

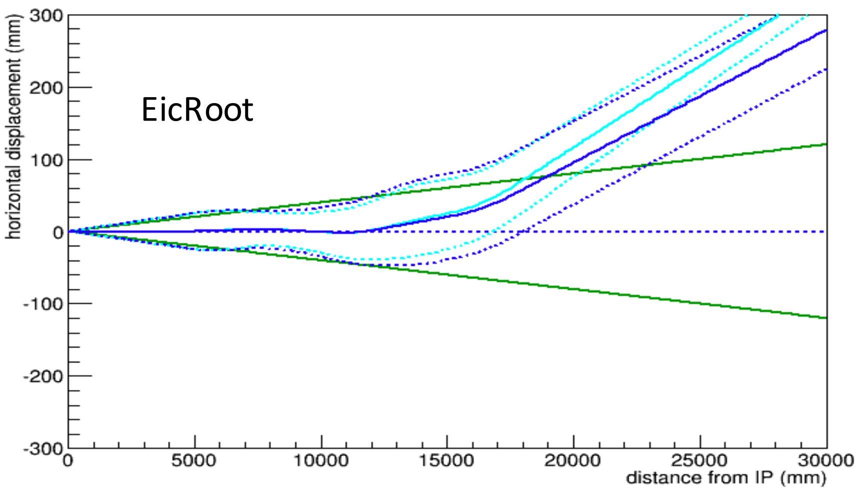
Closing remarks on the project (II)

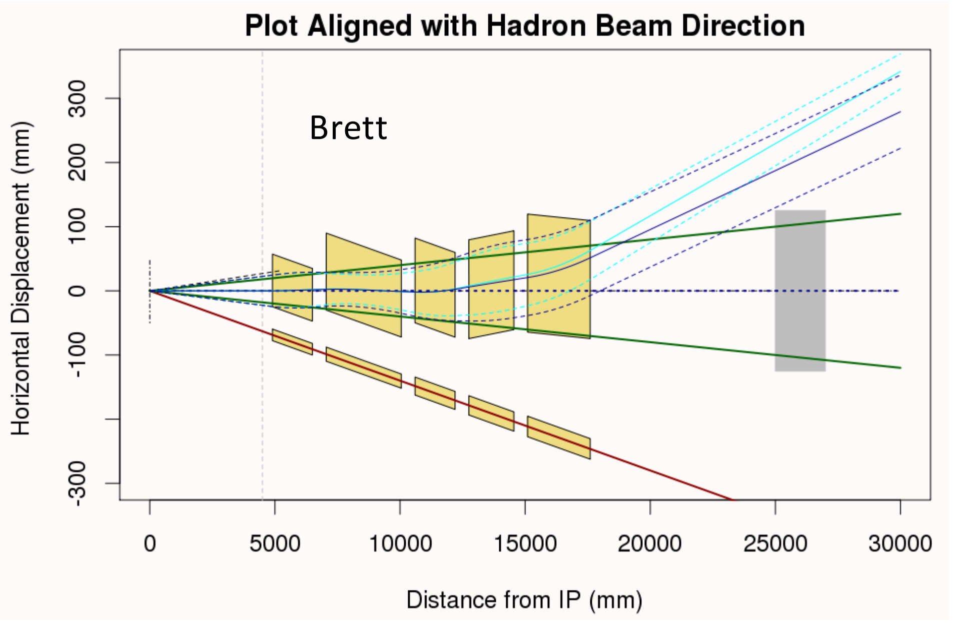
- Calculation of polarization dependent cross-section of Bethe-Heitler scattering for lumi measurement
  - Full calculation still ongoing, but have quantitative estimates that the effect is small
- Initial design and integration into the IR of a forward proton tagger
  - Detector studied is of a Roman Pot design
  - Acceptance studies have been carried out for three different IR designs
  - Studies strongly affect the path forward
- Check of the neutron acceptance
  - Make sure apertures in lattice are clear for neutrons from nuclear breakup
- Additional advancement in general purpose computational tools (simulation framework EicRoot, Monte Carlo code for Compton event generation, etc.)
- Regular meetings with the machine developers has proved to be a successful strategy
- Overall a successful project! Thank you for the funding and opportunity!

Backups

Cross checking importing of magnet lattice

- to further convince us that the bugs are out, I reproduce Brett's IR plot from the tracking in the EicRoot simulation (removes effect of exaggerated scales)





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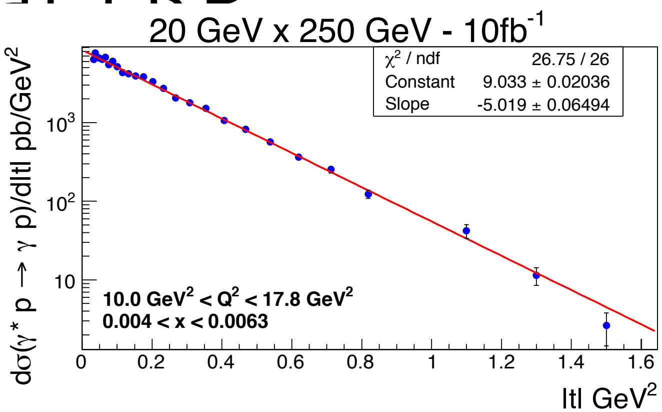
Comparison with lasers and beam parameters at other facilities

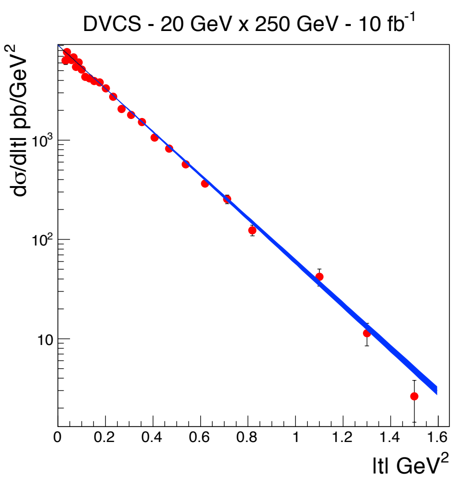
parameter	eRHIC (linac-ring)	HERA LPOL	JLab Hall A
e beam energy [GeV]	20	27.5	1.06
Bunch intensity [number of electrons]	0.07×10^{11}		
e beam current [uA]	10×10^{3}		50
Beam rep. rate [Hz]	9.4×10^{6}		
Laser energy [eV]	2.33	2.33	2.33
Laser power [W]	12		1.74 (increased to 3.7×10^{3} with Fabry-Perot amplifying cavity)
Laser rep. rate [Hz]	9.4×10^{6}	100	
Laser energy per pulse [J]	1.3×10^{-6}	0.1	
Compton cross section [mb]	418	377	641
Crossing angle [mrad]	25	8.7	24
e beam size at IP (x, y, z) [mm]	0.4, 0.4, 4	0.6, 0.2, 11	
Laser beam size at IP (x, y, z) [mm]	0.4, 0.4, 4	0.5, 0.5, 900	

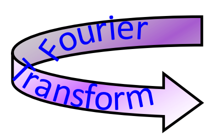
Plots from the EIC WP presented at LRP

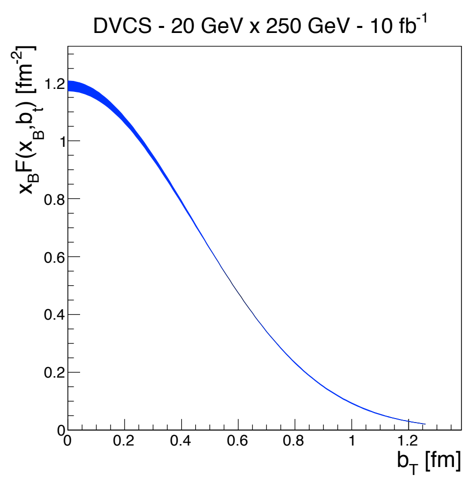


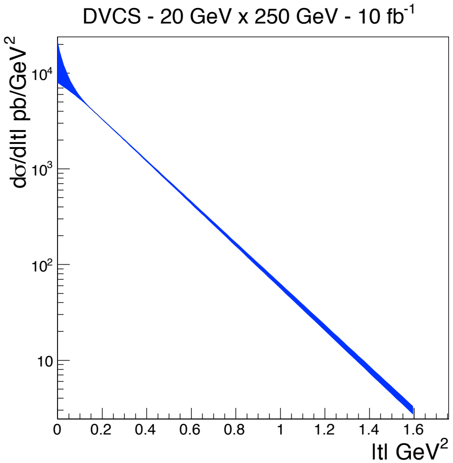
eRHIC with 20x250 GeV^2 and 10fb^{-1} - what changes for the error bands if we fit different |Pt|-ranges?

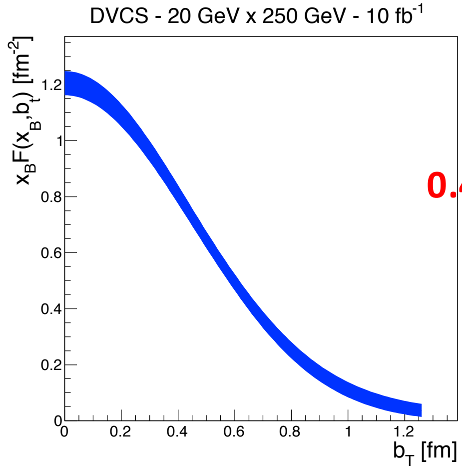
0.18 < |Pt| (GeV) < 1.3



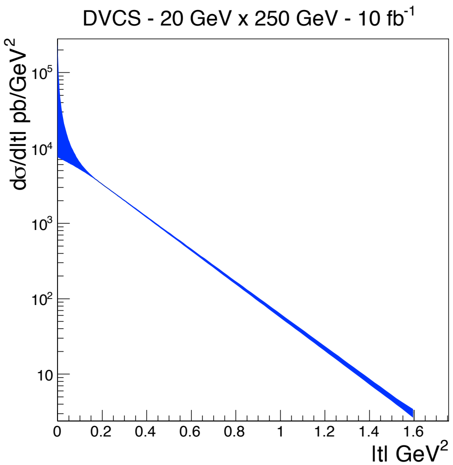


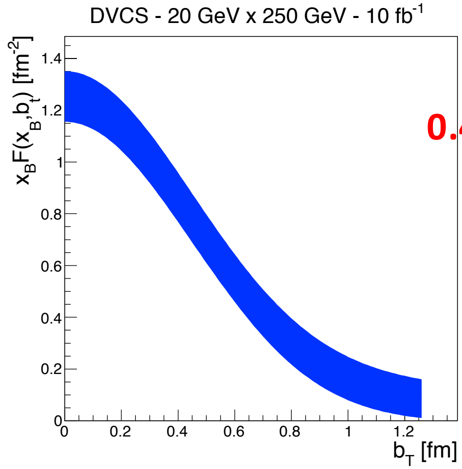




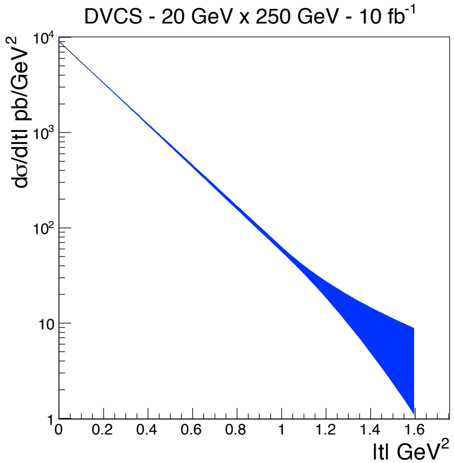


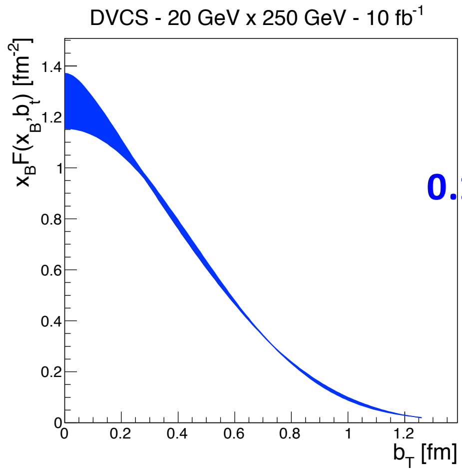
0.4 < |Pt| (GeV) < 1.3



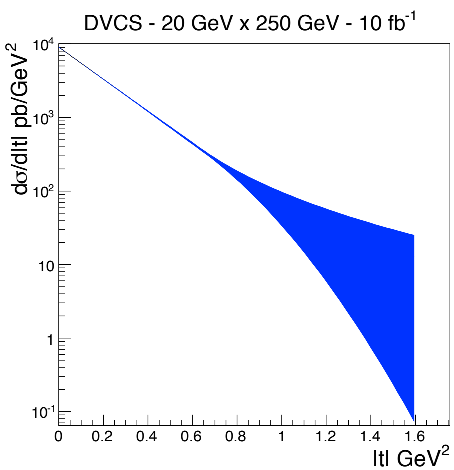


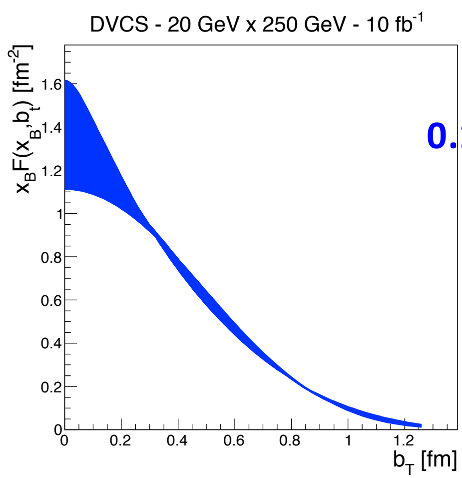
0.44 < |Pt| (GeV) < 1.3





0.18 < |Pt| (GeV) < 1.0





0.18 < |Pt| (GeV) < 0.8

$10\ fb^{-1} \rightarrow 1\ fb^{-1}$

real fluctuations, no rescaling of uncertainties!

0.18 < |Pt| (GeV) < 1.3