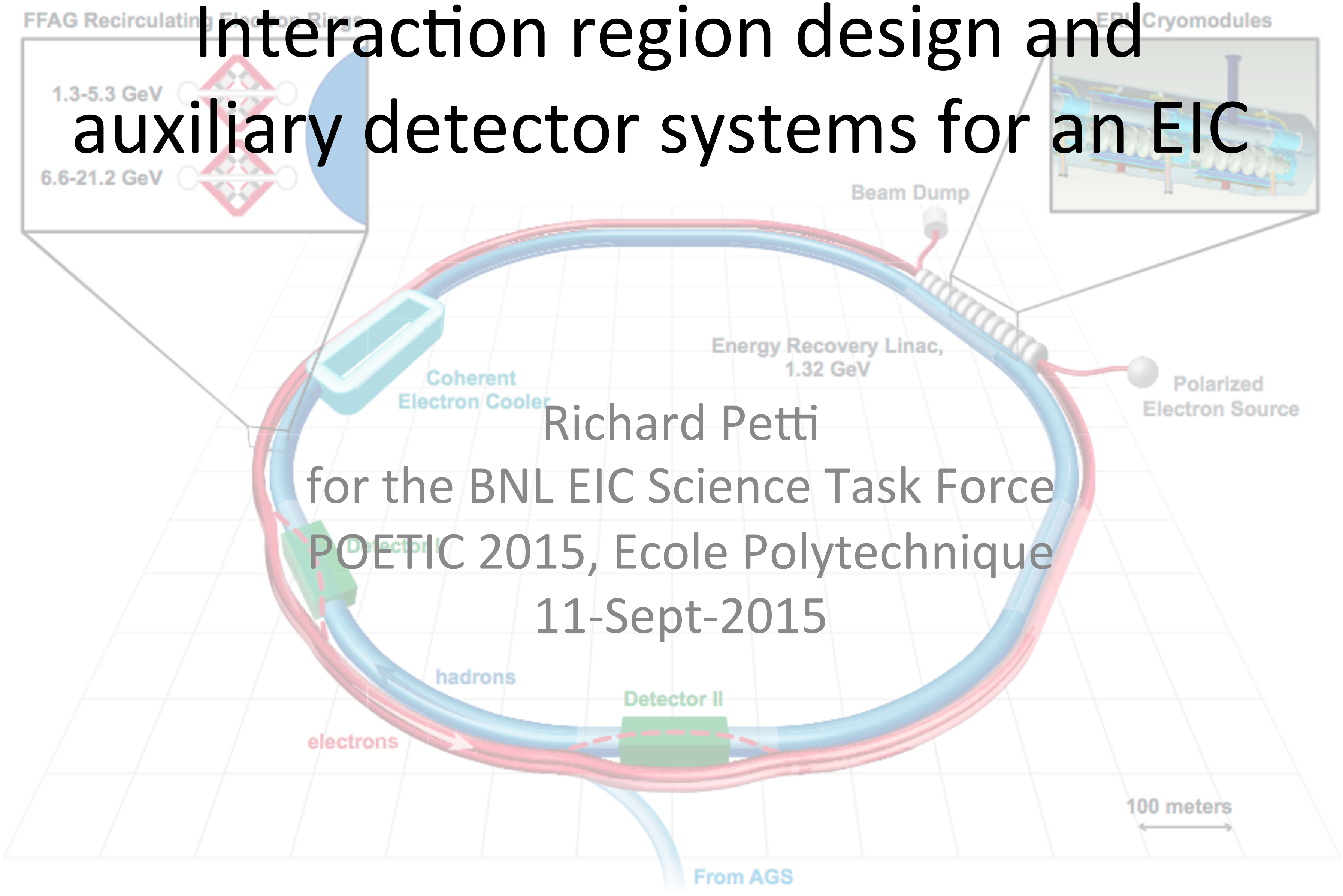
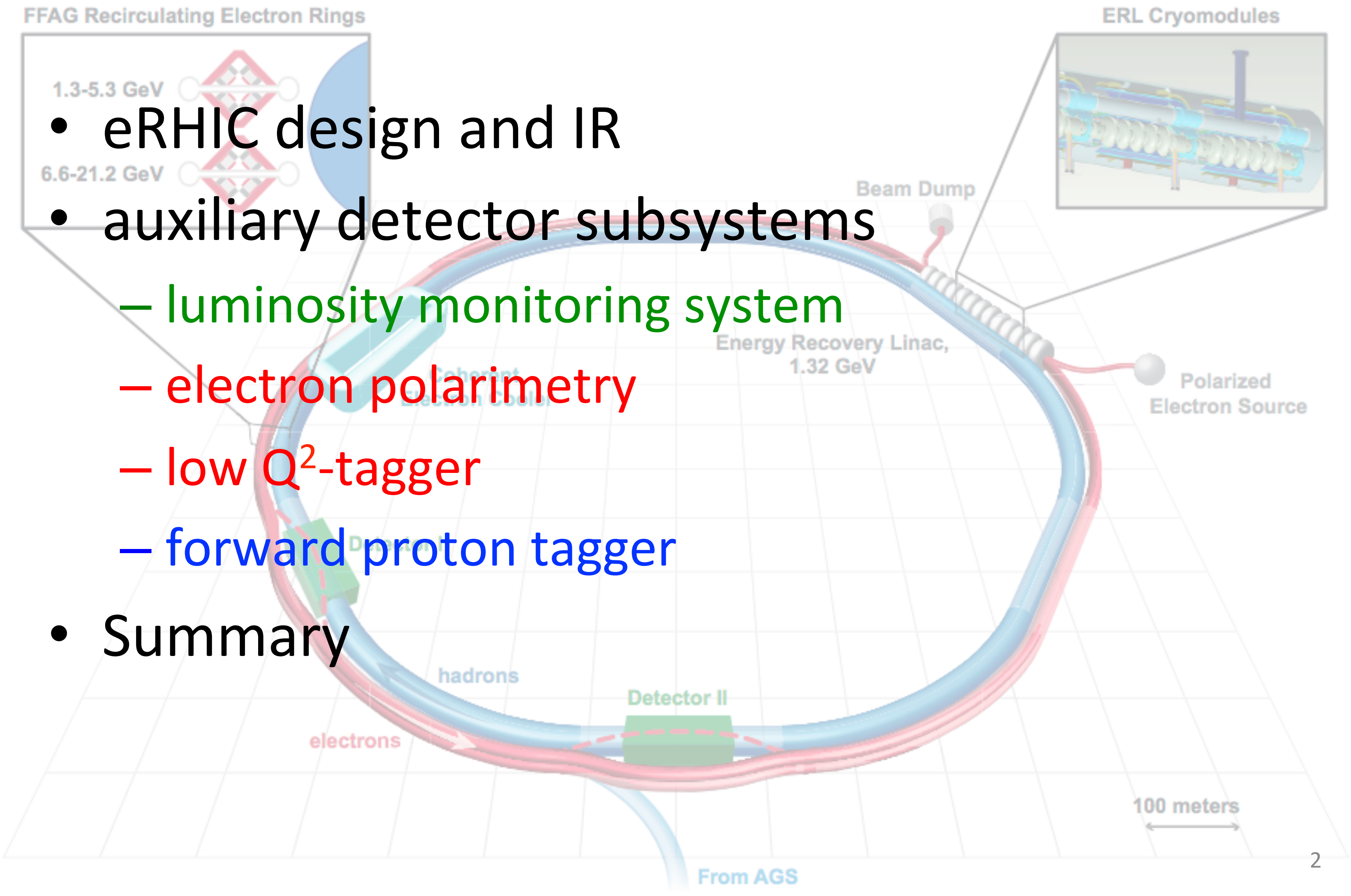
Interaction region design and auxiliary detector systems for an EIC



Richard Petti
for the BNL EIC Science Task Force
POETIC 2015, Ecole Polytechnique
11-Sept-2015

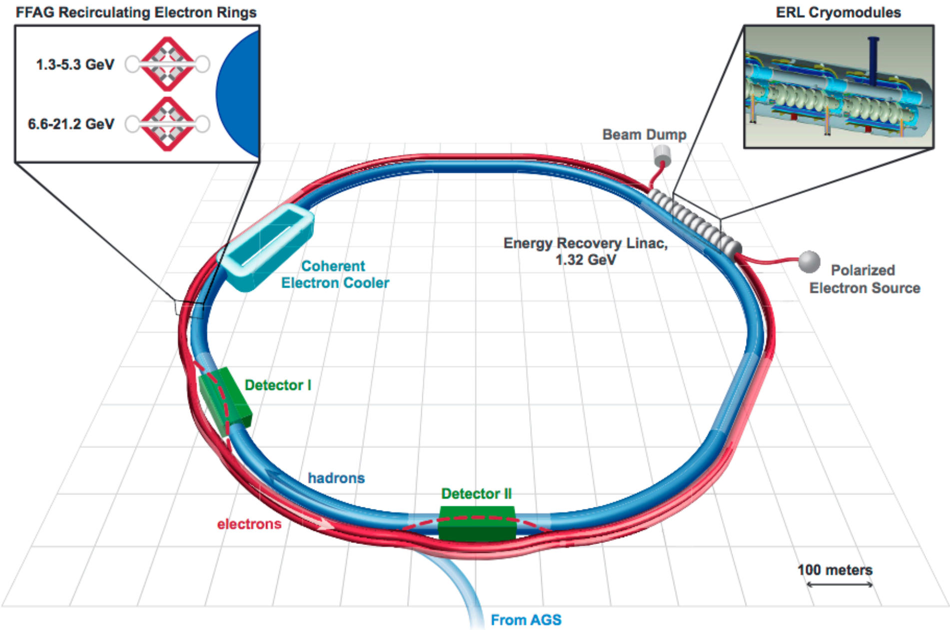
Outline



- eRHIC design and IR
- auxiliary detector subsystems
  - – luminosity monitoring system
  - – electron polarimetry
  - – low Q^2-tagger
  - – forward proton tagger
- Summary

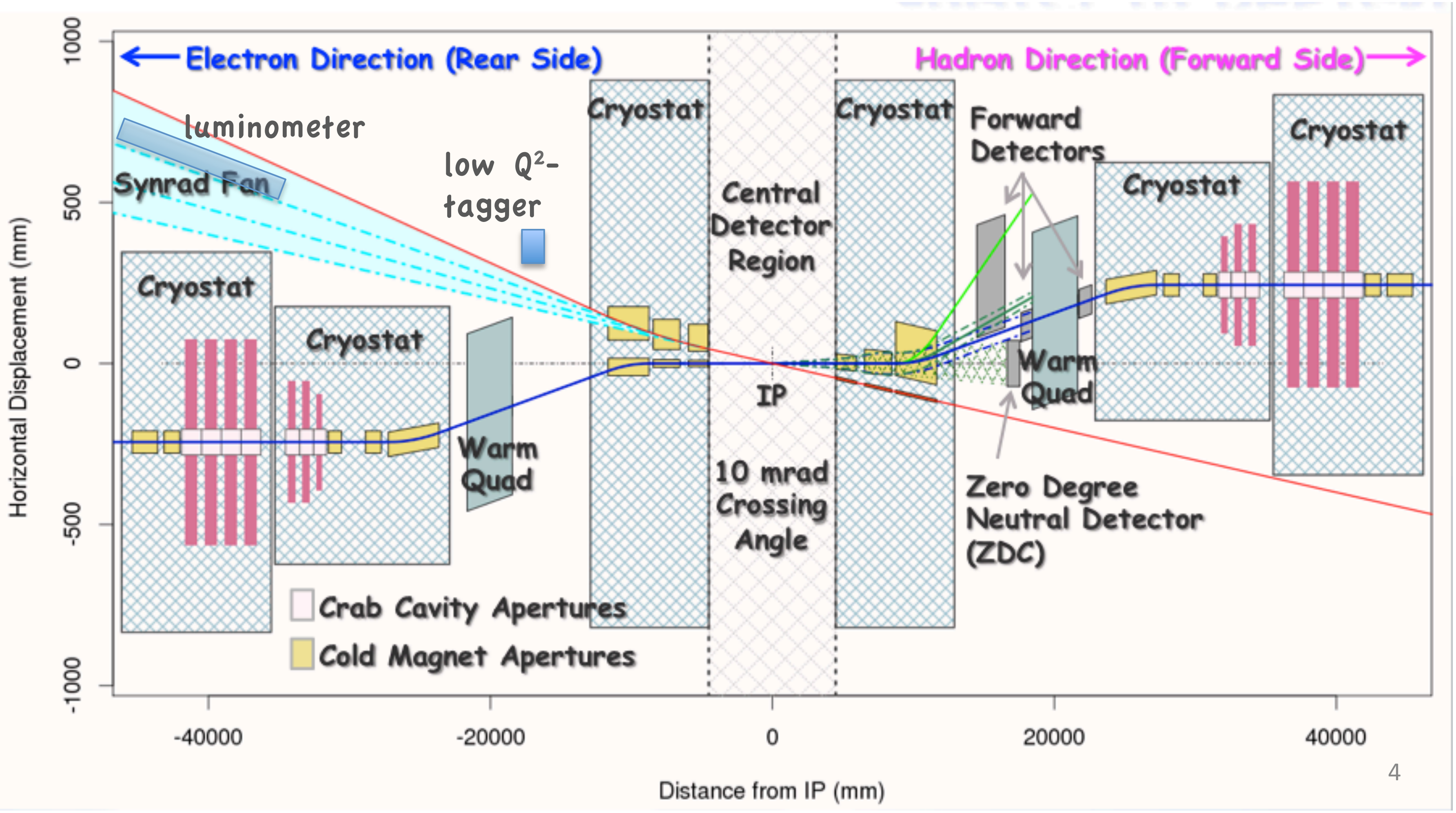
The eRHIC design

- Main features:
  - hadron species: polarized protons (up to 250 GeV), polarized $^3He^{+2}$ ions (up to 167 GeV/u), heavy ions (typically $^{197}Au^{+79}$ or $^{238}U^{+92}$ ions (up to 100 GeV/u))
  - polarized electrons: from 2 GeV up to 21 GeV
  - high luminosity: 10^{33}-10^{34} $cm^{-2}s^{-1}$



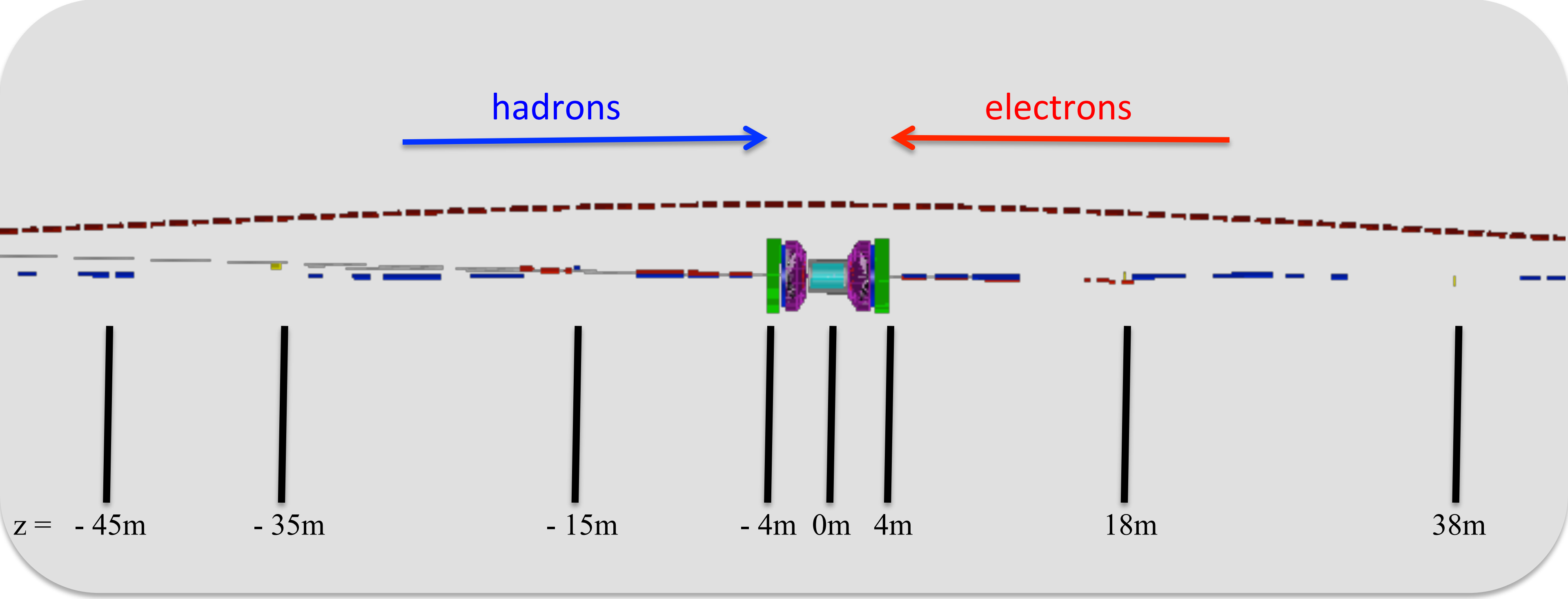
A schematic of the interaction region

- integrate detector systems into machine lattice to optimize acceptance and minimize backgrounds



The IR setup inside the detector simulation framework

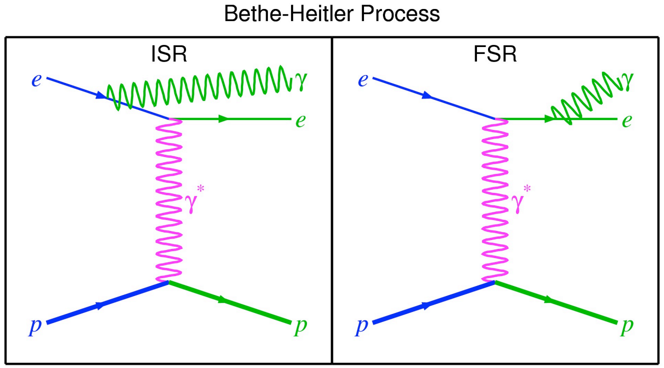
- incorporate machine lattice into EicRoot (https://wiki.bnl.gov/eic/index.php/Eicroot)



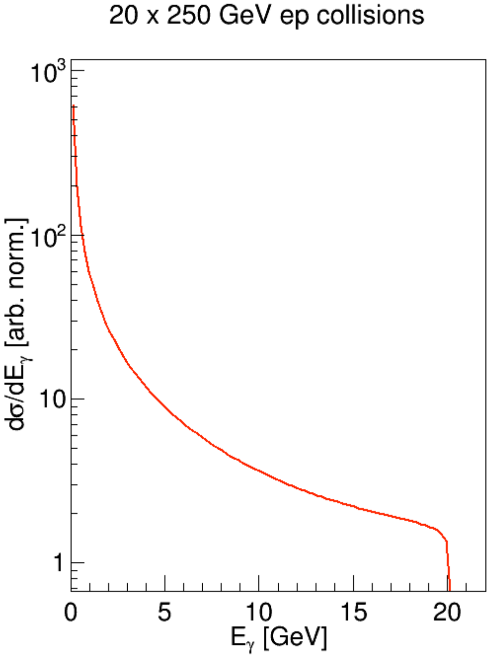
Luminosity monitoring system: ep bremsstrahlung process

- measure luminosity via e+p → e+p+γ
  - well known calculable pure QED process
  - large cross-section
- performance requirements:
  - need to know luminosity better than 1%
  - system needs to be fast enough to give live feedback to machine on luminosity steering
- photons are sharply forward-peaked
  - θ_γ is dominated by beam optics
  - need good control on beam parameters
- from measured photon rate, N_γ, photon acceptance, A, and cross section, σ, we can calculate the luminosity, L

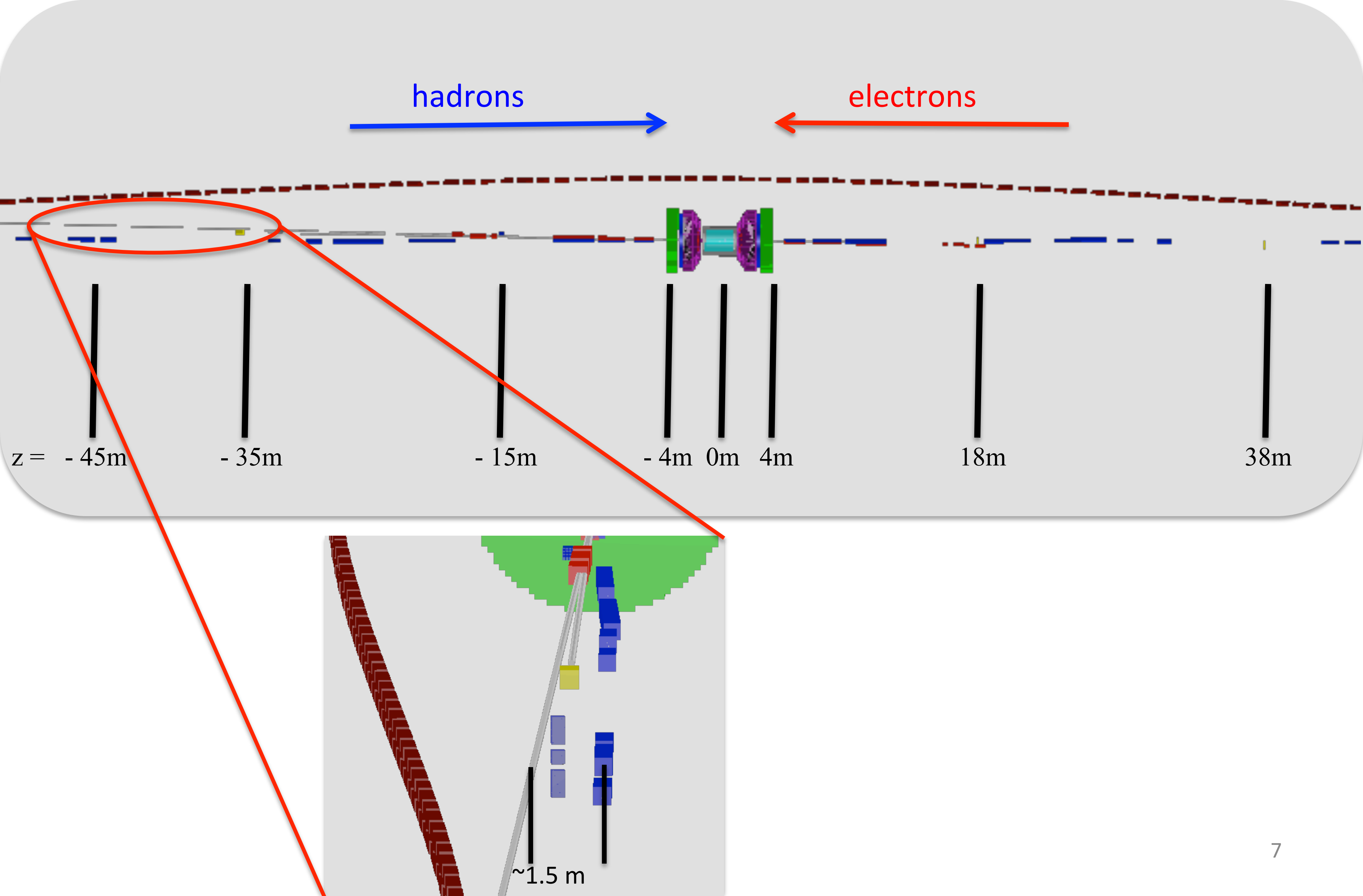
$$L = \frac{N_\gamma}{A\sigma}$$



http://brock.physik.uni-bonn.de/~brock/feynman/misc/bethe-heitler.jpg

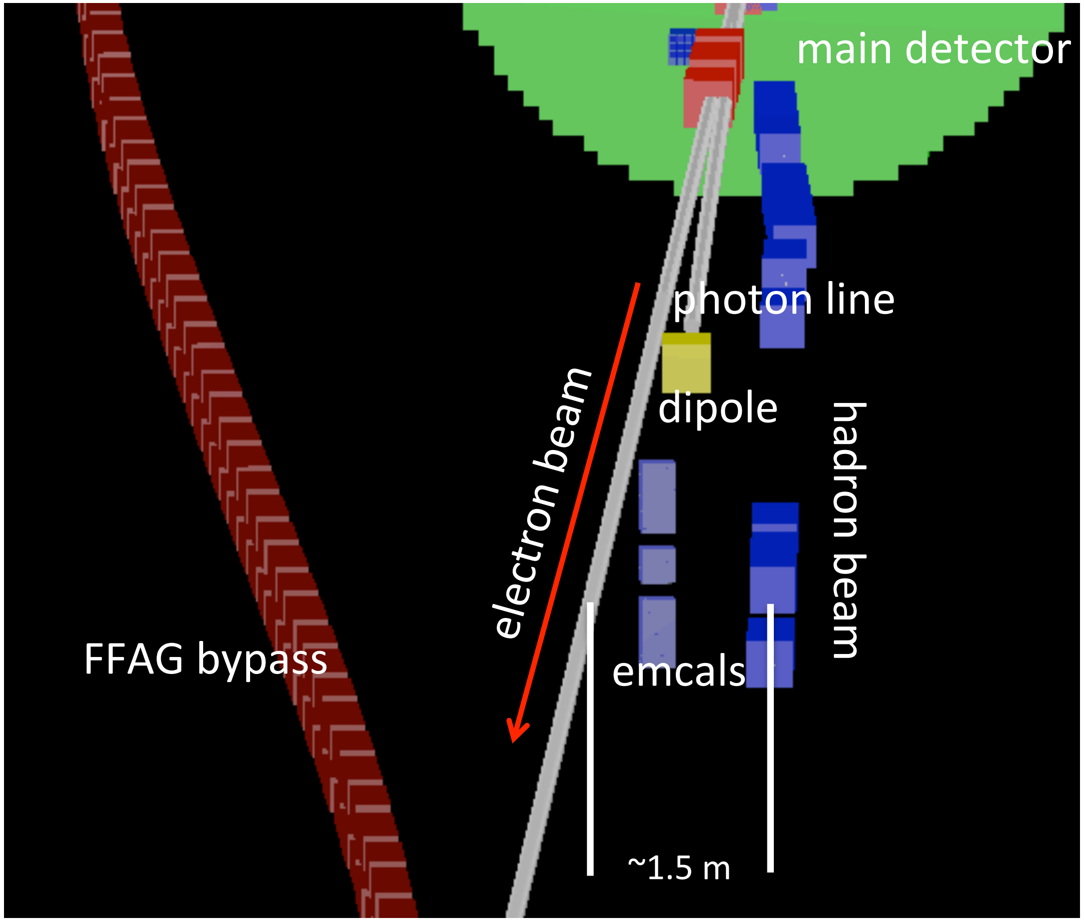


Luminosity monitoring system: Proposed configuration

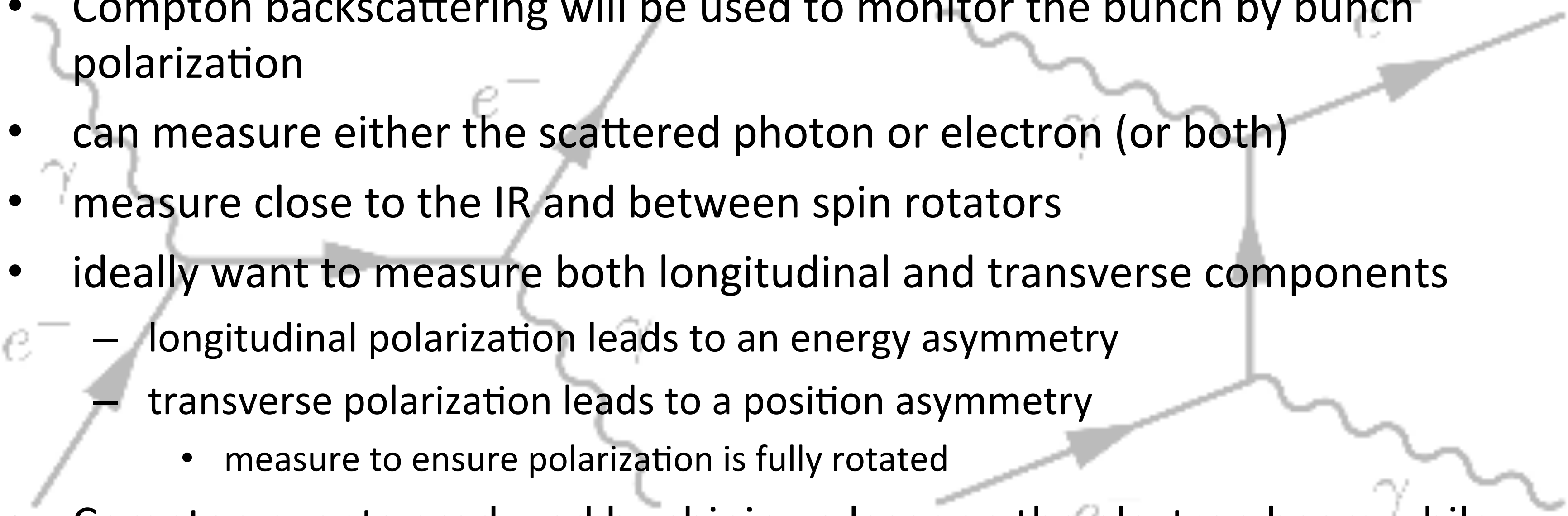


Luminosity monitoring system: Proposed configuration

- main features:
    - zero degree calo (lzdc)
    - pair spectrometer
- allows two measurements with very different backgrounds
    - lzdc in synch. fan
    - pair spec. not in synch. fan
    - pair spec is tunable to measure a certain photon energy range
    - pair spec reduces rate
- Major contributors to uncertainty
    - lzdc: knowledge of acceptance
    - lzcd: pileup
    - lzdc: pedestal shift from synch radiation
    - pair spec: knowledge of acceptance
    - pair spec: converter thickness
    - pair spec: pileup



Electron Polarimetry



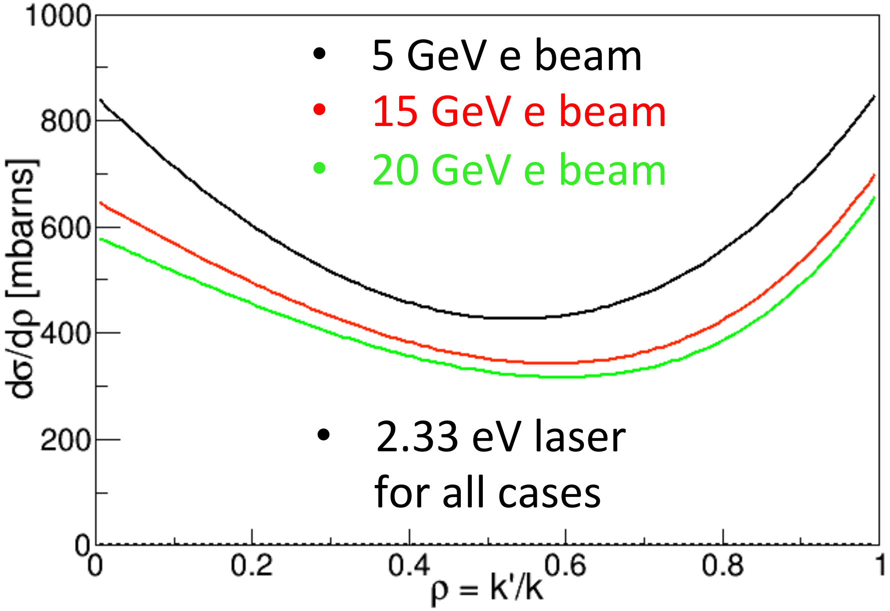
- need to measure with high precision ~1%
- Compton backscattering will be used to monitor the bunch by bunch polarization
- can measure either the scattered photon or electron (or both)
- measure close to the IR and between spin rotators
- ideally want to measure both longitudinal and transverse components
  - longitudinal polarization leads to an energy asymmetry
  - transverse polarization leads to a position asymmetry
    - measure to ensure polarization is fully rotated
- Compton events produced by shining a laser on the electron beam while flipping the helicity state and measuring the resulting asymmetry

$$A_{\exp} = P_e P_\gamma A_\ell$$

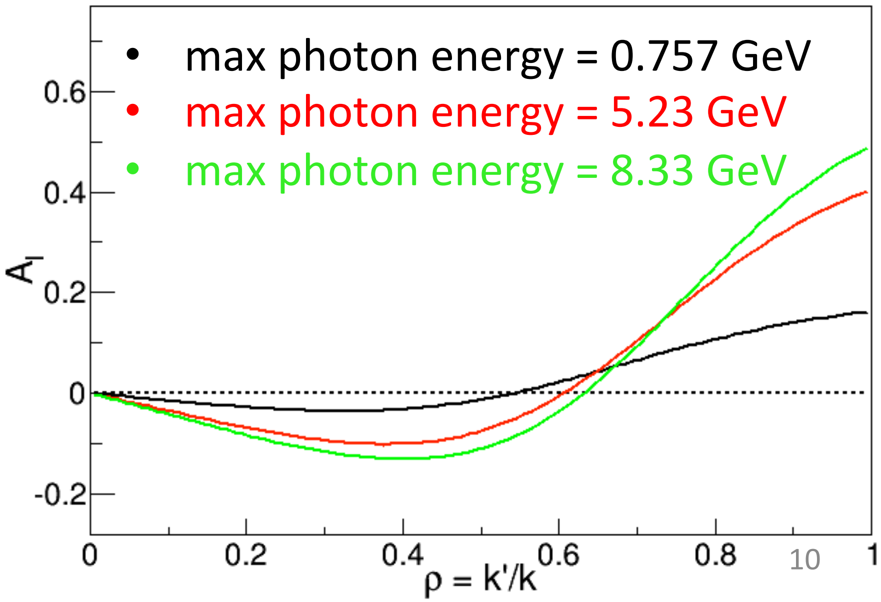
Compton scattering

- most probable energy of scattered photon is at the Compton edge
- scattered photons highly collimated in electron beam direction
- fairly large analyzing power at the Compton edge

Cross section



Longitudinal asymmetry (analyzing power)



A possible implementation of the polarimeter

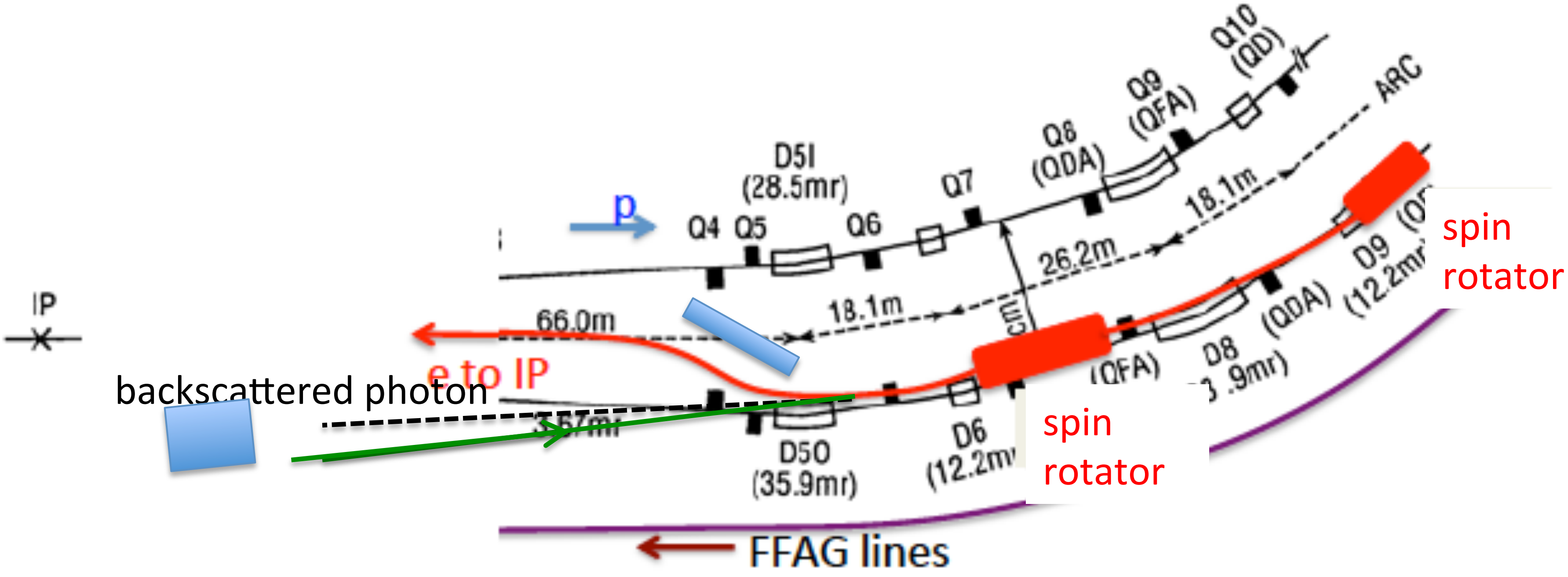
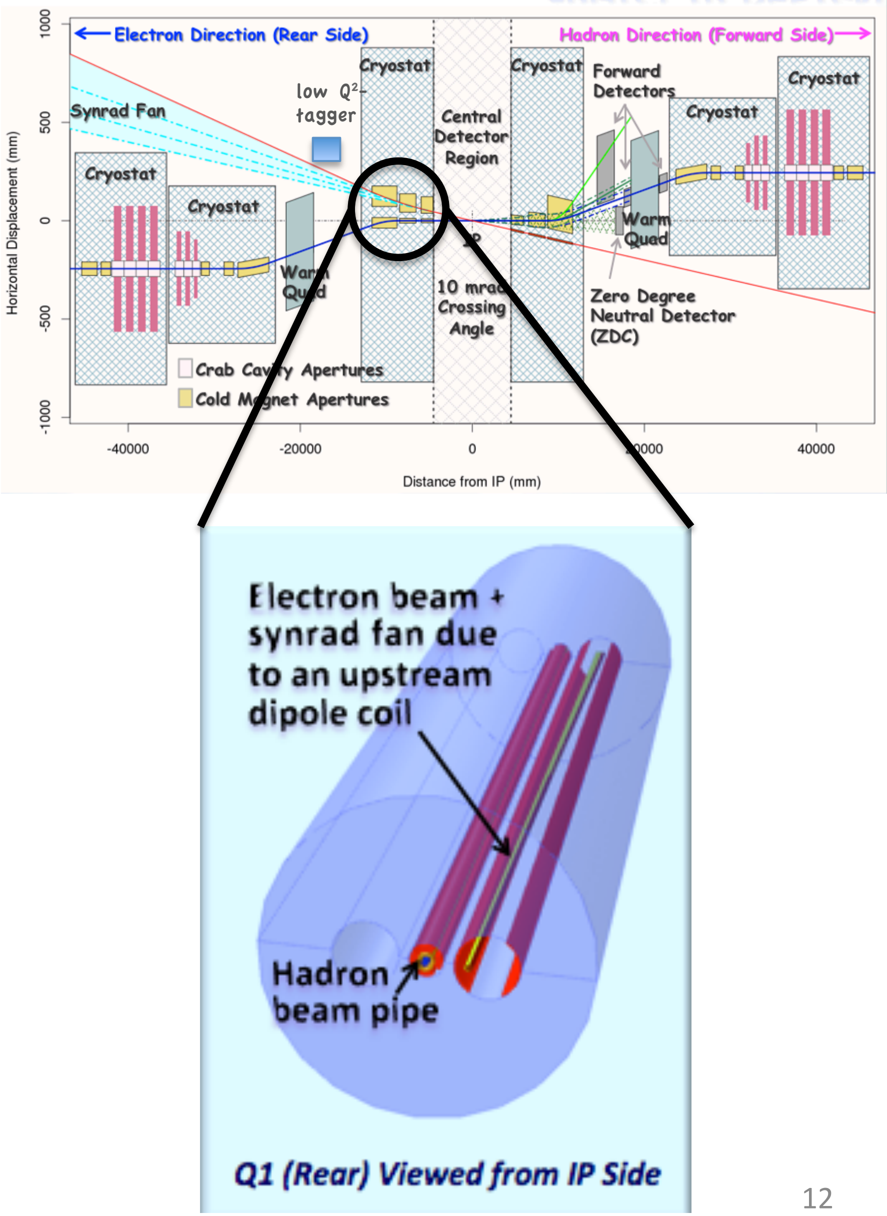


figure courtesy of Vadim Ptitsyn (BNL)

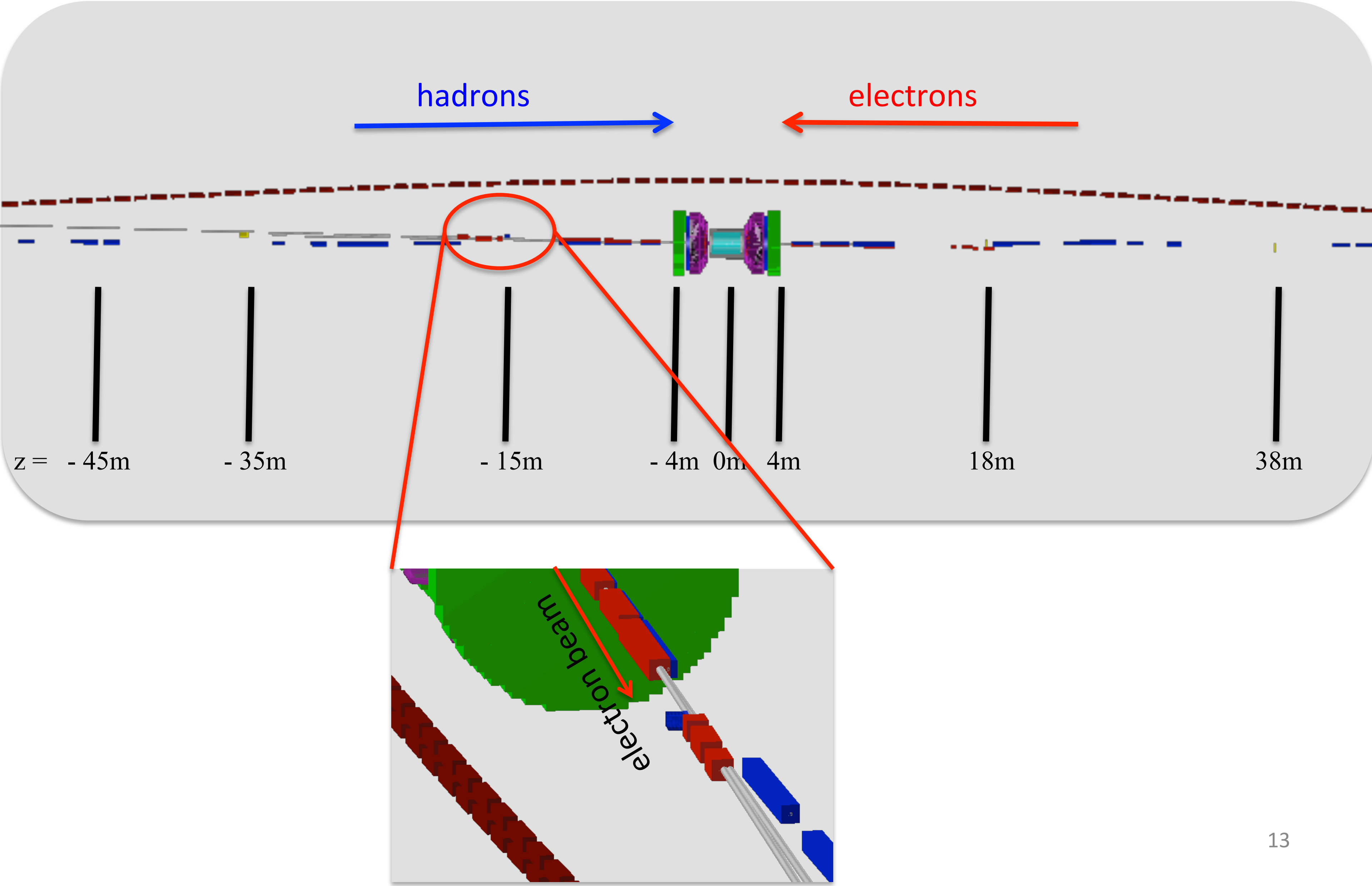
Low Q^2-tagger

- implement a dedicated electron detector for tagging low Q^2 events
- electrons from these events scatter at very small angle and are outside main detector acceptance
- machine designed so that apertures are rather large in the outgoing electron direction
- current idea is to have a calorimeter with tracking layers in front
- place as close to the beam as possible to maximize acceptance
- outside of primary synchrotron radiation fan



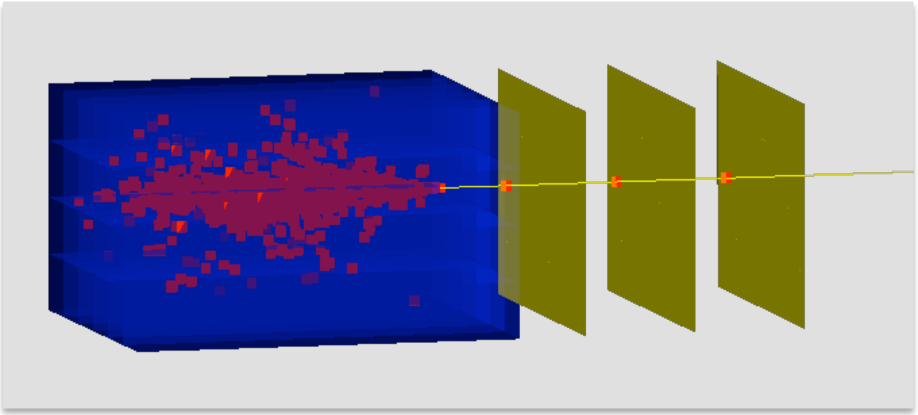
courtesy of Brett Parker (BNL)

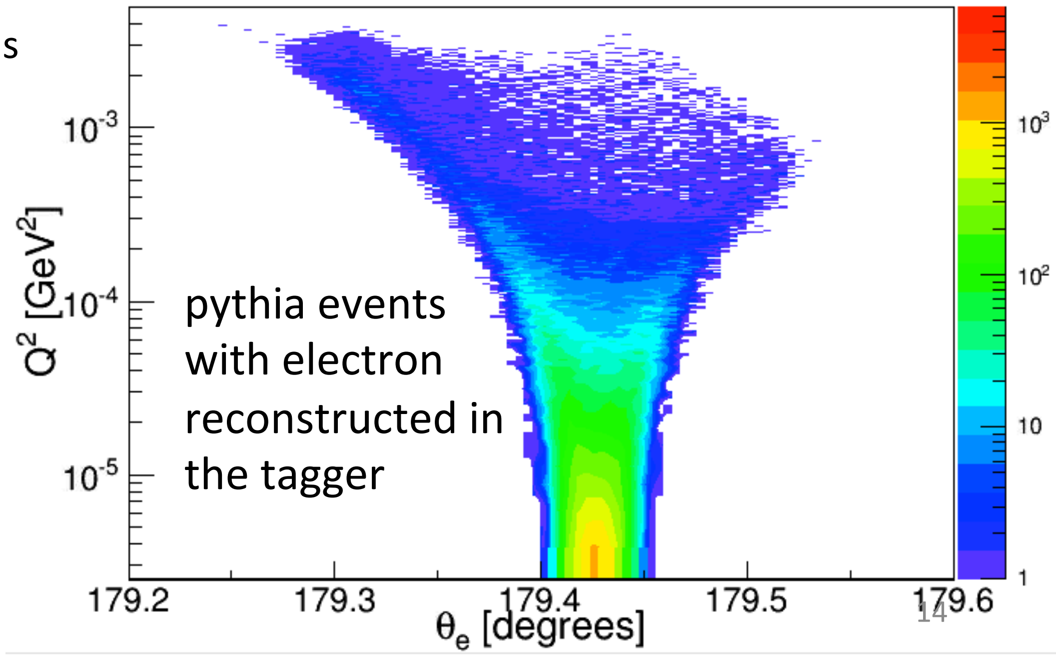
A possible implementation of a low Q^2-tagger



Physics with a low Q^2-tagger

- acceptance of electrons from events down to $Q^2 \sim 10^{-5}$ GeV^2
- allows for further study of photoproduction physics
  - represents large portion of total cross section
  - probing the quark structure of photons
    - direct vs resolved photon
  - look for change in event properties associated with transition of real to virtual photon

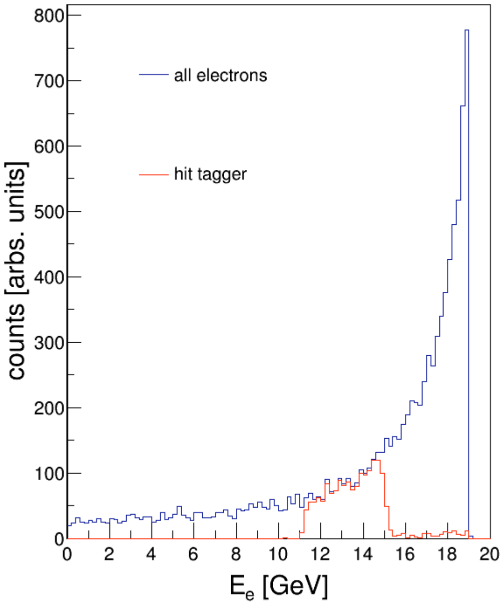




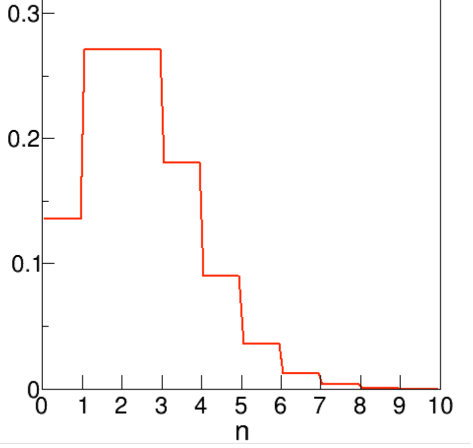
pythia events with electron reconstructed in the tagger

Background considerations in the low Q2-tagger

- a major background is the ep bremsstrahlung
  - high rate
- based on 10^{33} cm^{-2} s^{-1} luminosity and 20x250 GeV ep collisions, expect roughly 2 brem. electrons per bunch crossing hitting the tagger
- brem. rate much larger than photoproduction rate
  - O(10^3) difference in rates
- can veto these events
  - look for coincidence in the lumi monitor
  - ensure no activity in the main detector



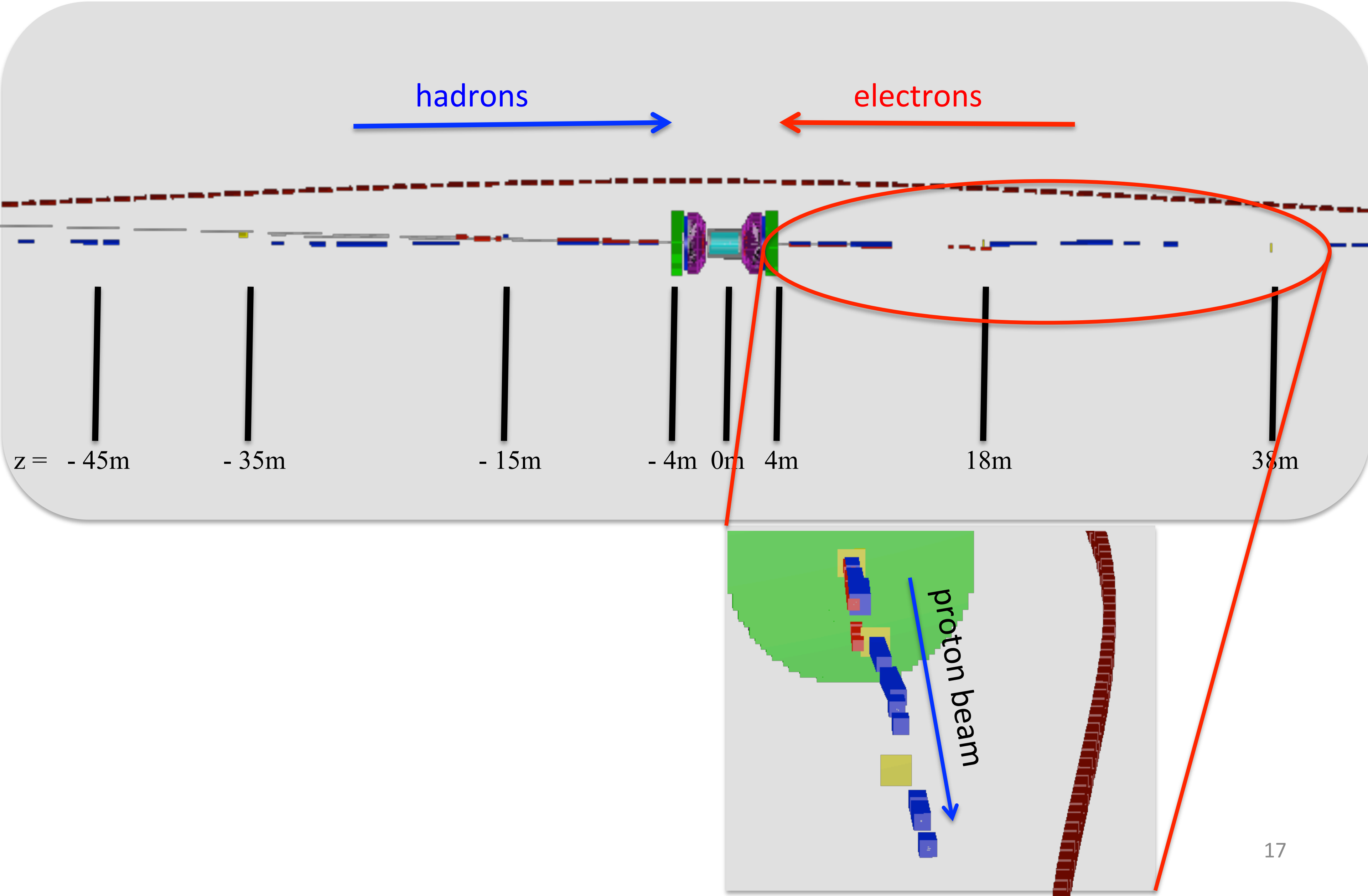
poisson distribution with mean of 2



Forward proton tagger

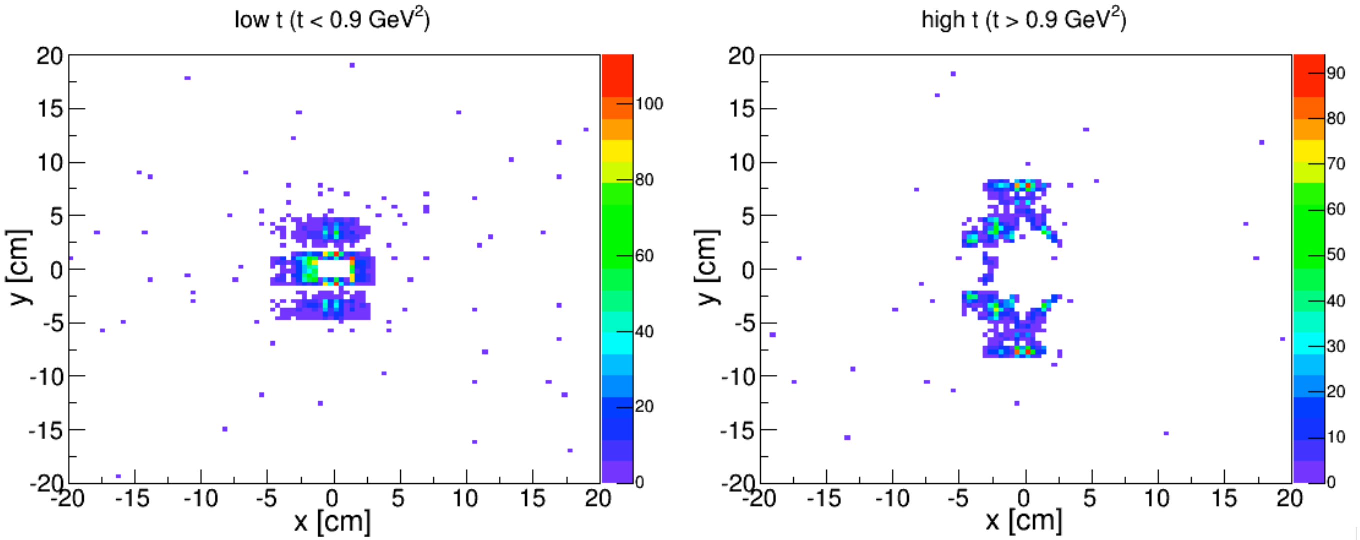
- considering installation of roman pots
  - sensors can be moved in and out
  - designed to go as close to the beam as is safely possible
  - this maximizes acceptance for forward going particles
- essential to tag forward going protons in exclusive reactions
  - for example exclusive DVCS events
  - will allow study of GPDs

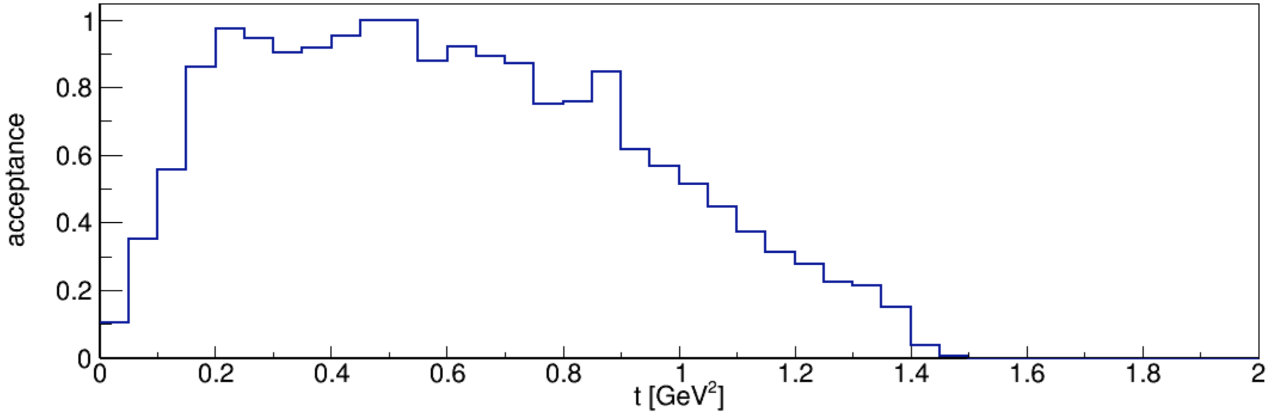
A possible forward proton tagger implementation



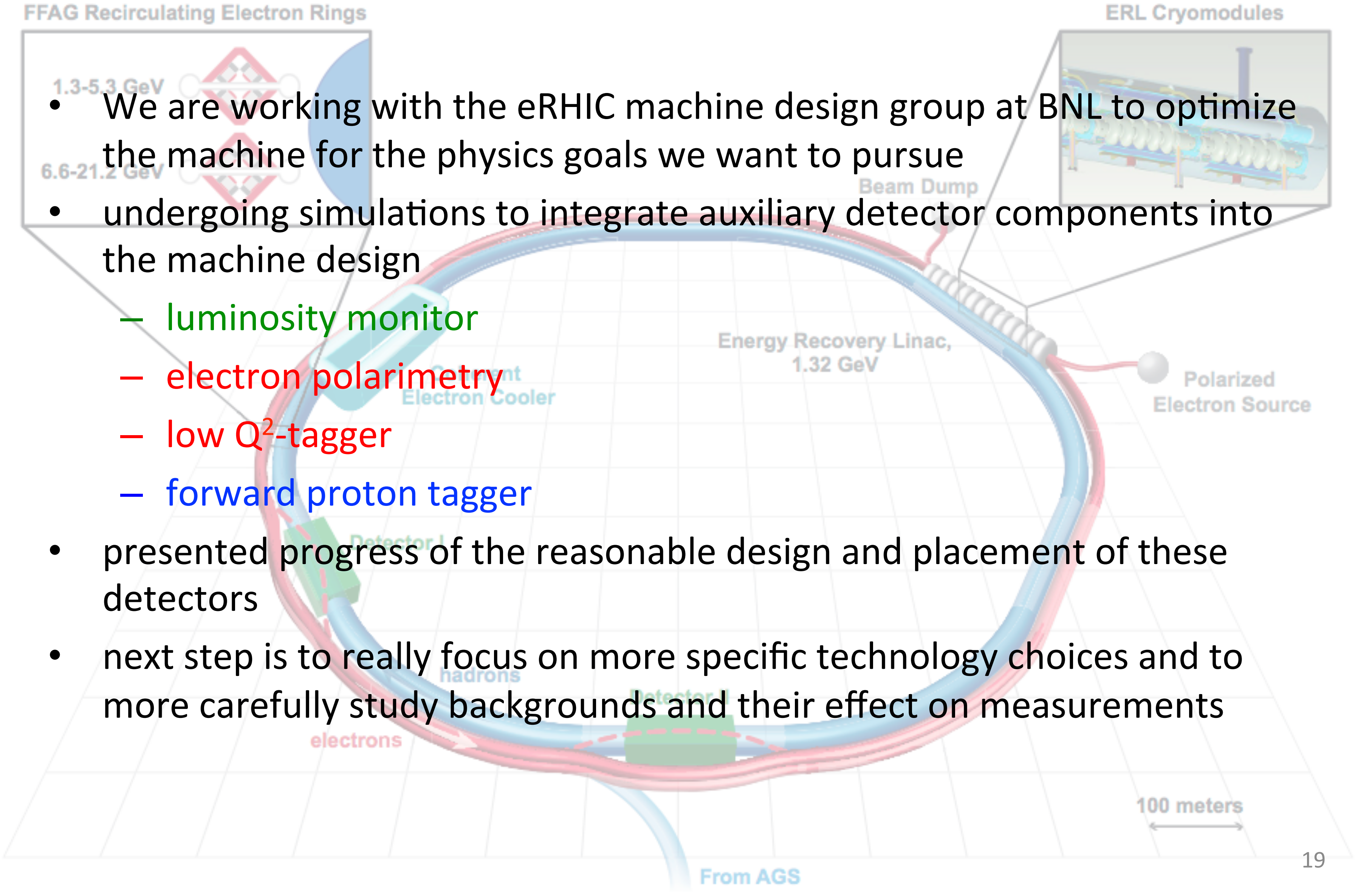
roman pot acceptance: one station at 18m

- feed in MILOU simulations of DVCS events
  - following studies have no beam effects taken into account and event production at (0,0,0)
  - coordinates relative to the center of the beam





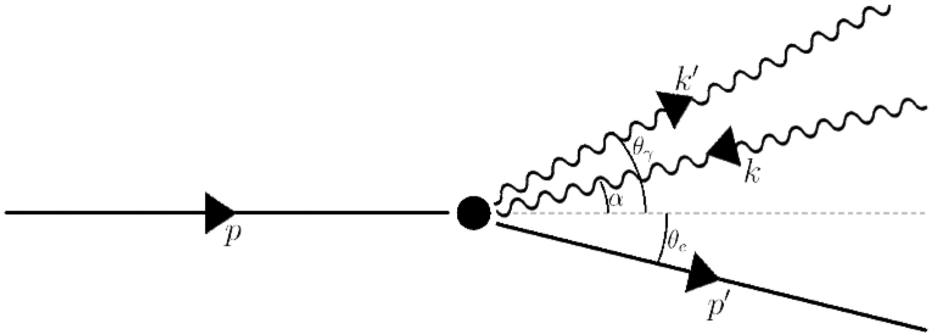
Summary



- We are working with the eRHIC machine design group at BNL to optimize the machine for the physics goals we want to pursue
- undergoing simulations to integrate auxiliary detector components into the machine design
  - luminosity monitor
  - electron polarimetry
  - low Q^2-tagger
  - forward proton tagger
- presented progress of the reasonable design and placement of these detectors
- next step is to really focus on more specific technology choices and to more carefully study backgrounds and their effect on measurements

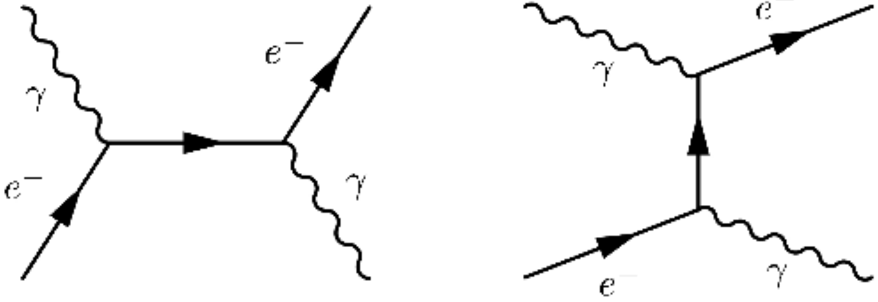
Backups

Compton Scattering



- some references from which the following originates (and is the basis for the MC shown in the next few slides)
  - http://nuclear.uwinnipeg.ca/theses/dstorey_thesis.pdf
  - https://tel.archives-ouvertes.fr/tel-00920424/document
- note the following applies for $\alpha \approx 0$
- define some convenient kinematic variables:
  - $\rho = k'/k'_{max}$ is the scattered photon energy relative to the compton edge
  - $k'_{max} = 4ak\gamma^2$ is the maximum photon energy (compton edge)
  - $a = 1/(1+4k\gamma/m_e)$
  - k is the photon energy, E is the electron energy

Compton scattering cross section and longitudinal asymmetry



- QED calculation
- for laser crossing angle, α=0 and with respect to ρ (unpolarized):

$$\frac{d\sigma}{d\rho} = 2\pi r_0^2 a \left[\frac{\rho^2 (1-a)^2}{1-\rho(1-a)} + 1 + \left(\frac{1-\rho(1+a)}{1-\rho(1-a)} \right)^2 \right] \qquad (1)$$

- The longitudinal asymmetry:

$$A_\ell = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{2\pi r_0^2 a}{\frac{d\sigma}{dp}} (1-\rho(1+a)) \left(1 - \frac{1}{(1-\rho(1-a))^2} \right) \qquad (2)$$

Investigating the size of the bremsstrahlung photon cone

- Want to ensure that the bremsstrahlung photon cone has good acceptance in the IR design
- Look at simulations from e+p → e+p+γ (unpolarized) from DJANGOH
- also compare to toy simulation of photons pulled from the Bethe-Heitler calculation
- fold in effect of beam optics
  - angle smearing from angular beam divergence
  - steering of vertex position also studied

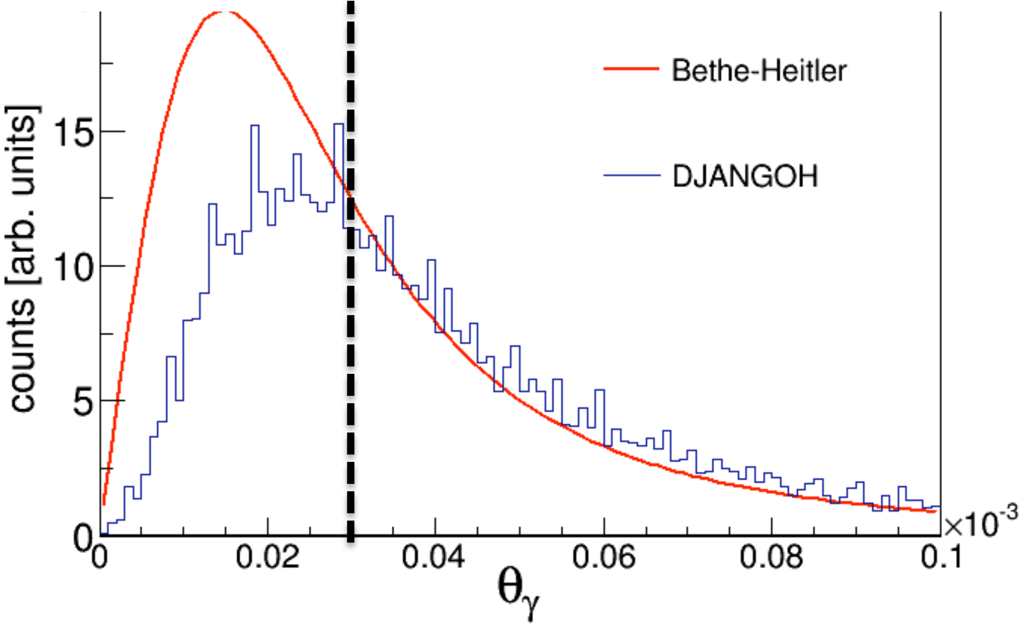
Lumi monitor study – the e+p → e+p+γprocess

- Two estimates of the expected angular distribution of Bremsstrahlung photons
  - Bethe-Heitler calculation

$$\frac{d\sigma}{d\Theta_\gamma} \approx \frac{\Theta_\gamma}{\left(\left(m_e/E_e\right)^2 + \Theta_\gamma^2\right)^2}$$

  - DJANGOH simulation
    - MC generator for DIS and bremsstrahlung processes

Note: relative scaling (please ignore numbers on yaxis)



- typical angle of emission is less than 0.03mrad
- roughly factor of 10 less than contribution from beam divergence for top energy ep collisions (see next slide)
- +/- 4mrad cone is the approximate space available

Luminosity monitor study – beam optics

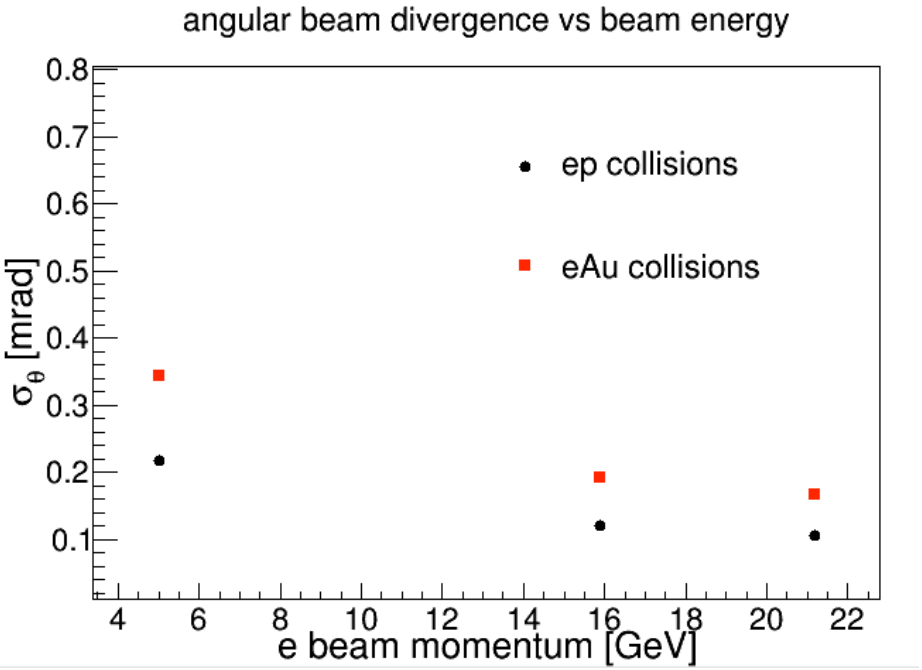
- calculation of the angular beam divergence (in radians)

$$\sigma_\theta = \sqrt{\frac{\varepsilon}{\beta^* \gamma}}$$

  - sigma_theta = angular beam divergence
  - epsilon = (normalized) emittance (taken from table 3-1 of the eRHIC design report)
  - gamma = lorentz factor
  - beta* = beam optics parameter at IP (5cm taken from table 3-1)
- for 20x250 GeV e+p collisions

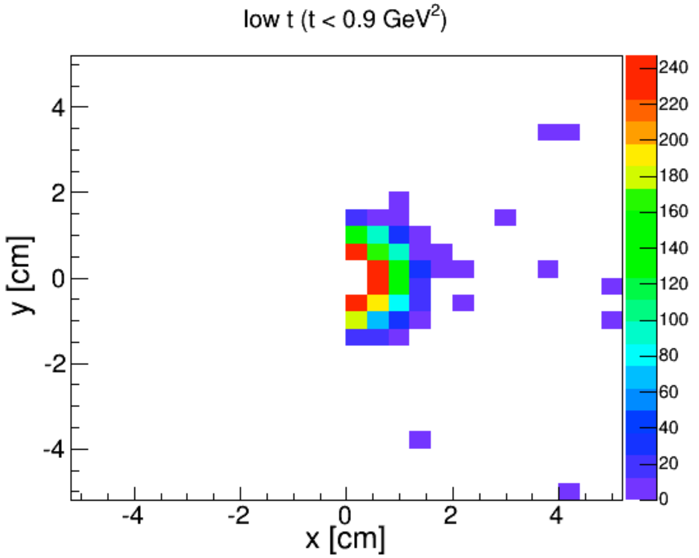
$$\sigma_\theta = \sqrt{\frac{23\times10^{-6}}{0.05 * 5\times10^{4}}} = 0.1 mrad$$

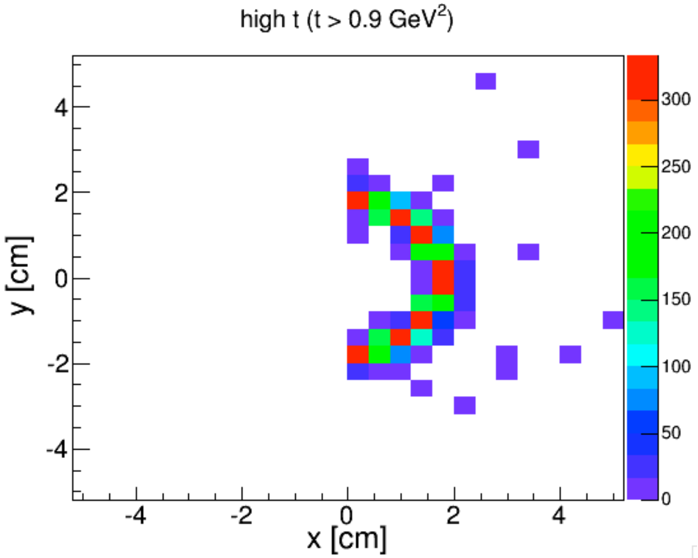
- for other beam conditions

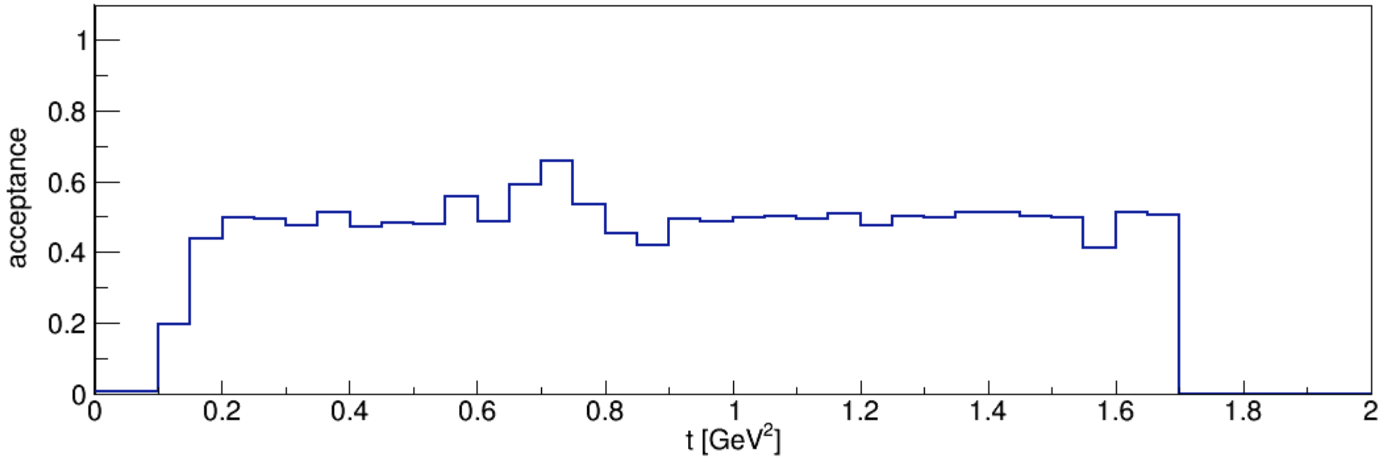


Addition of a close station at 4.25m

- necessary for acceptance at high t (most statistics starved phase space)
- electron beam prevents full 360^{O} acceptance


low t (t < 0.9 GeV^2)


high t (t > 0.9 GeV^2)



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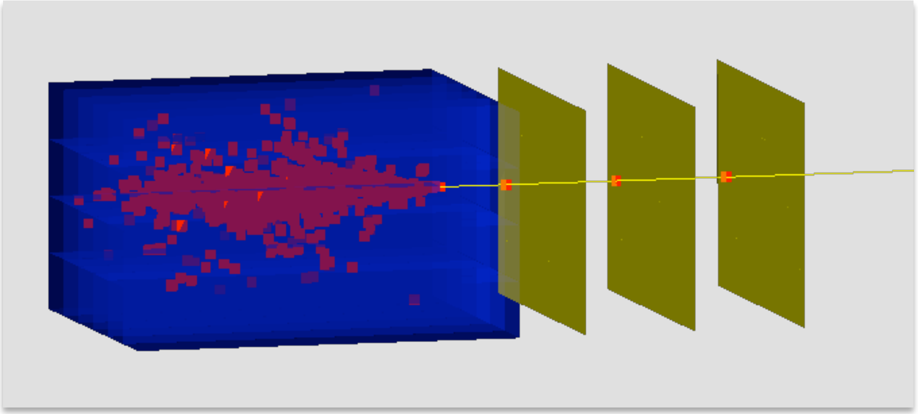

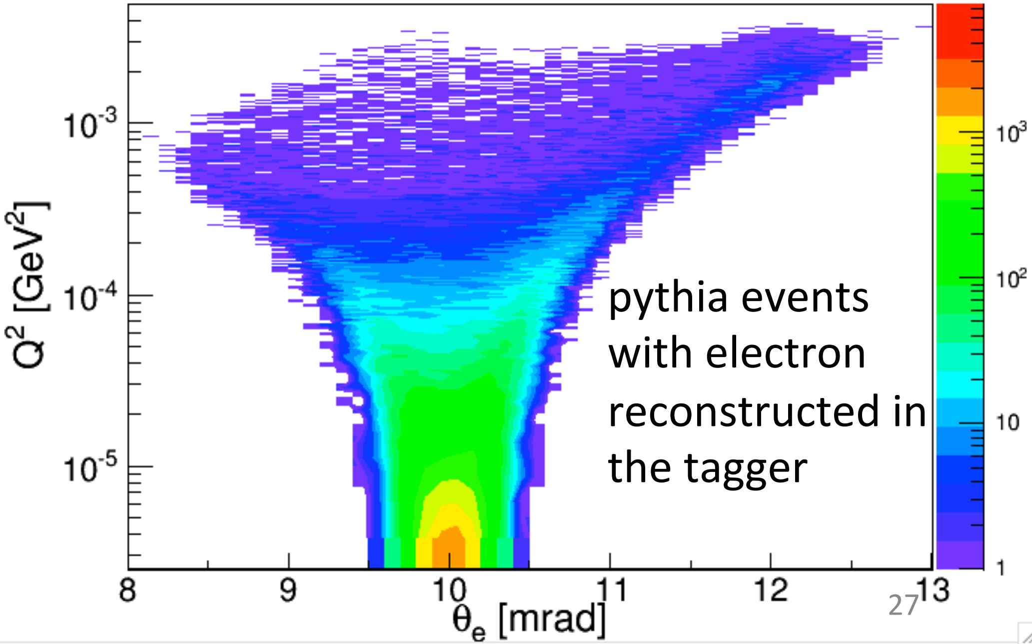

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