IR design and impact on measurements at an EIC

J.H. Lee
BNL

INT, Nov 2018

BROOKHAVEN
NATIONAL LABORATORY

Outline

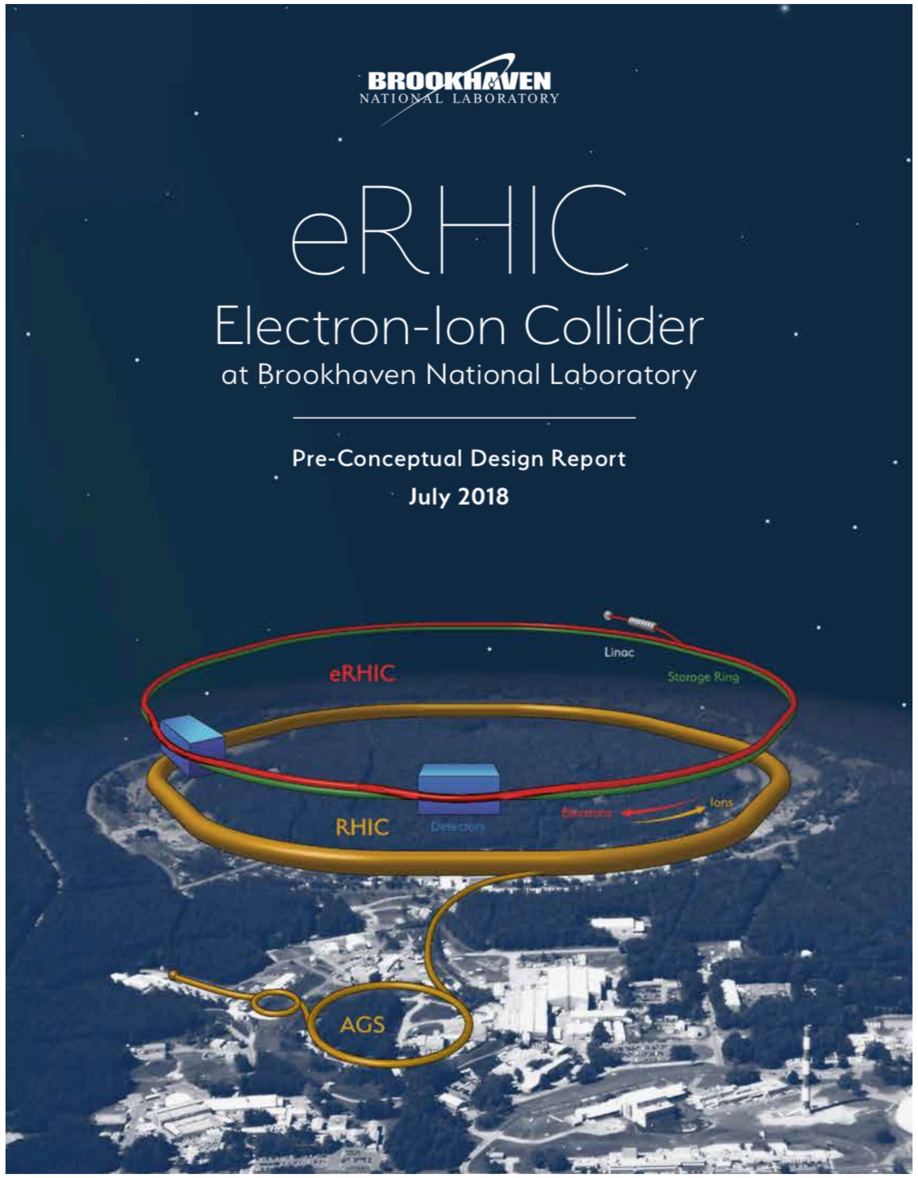
- EIC physics and machine requirements for Interaction Region
  - Interaction Region integration

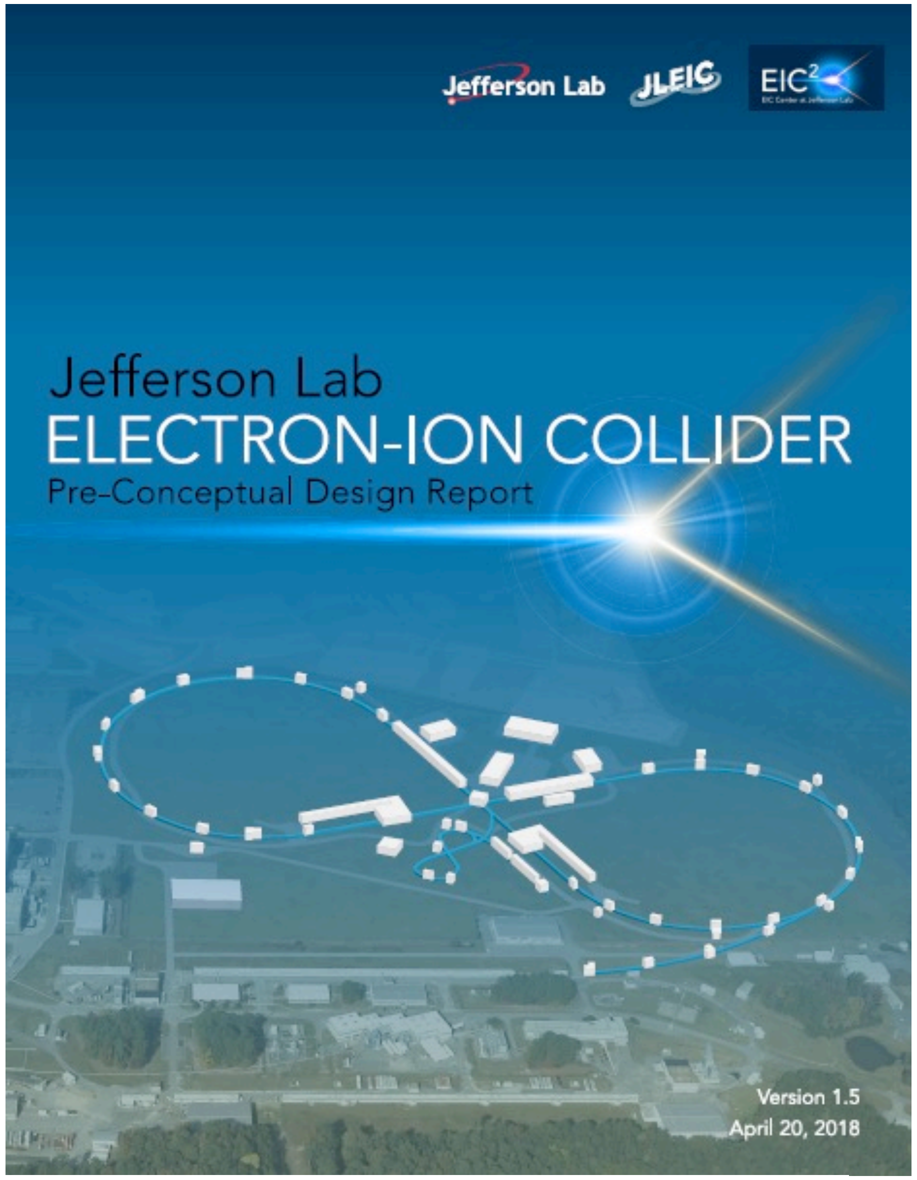
  - focusing on eRHIC case
- (far-)forward nucleon detection
  - Requirement and considerations for the measurements

Two concepts for an EIC in the US

- **eRHIC** at BNL
- RHIC + new electron machine

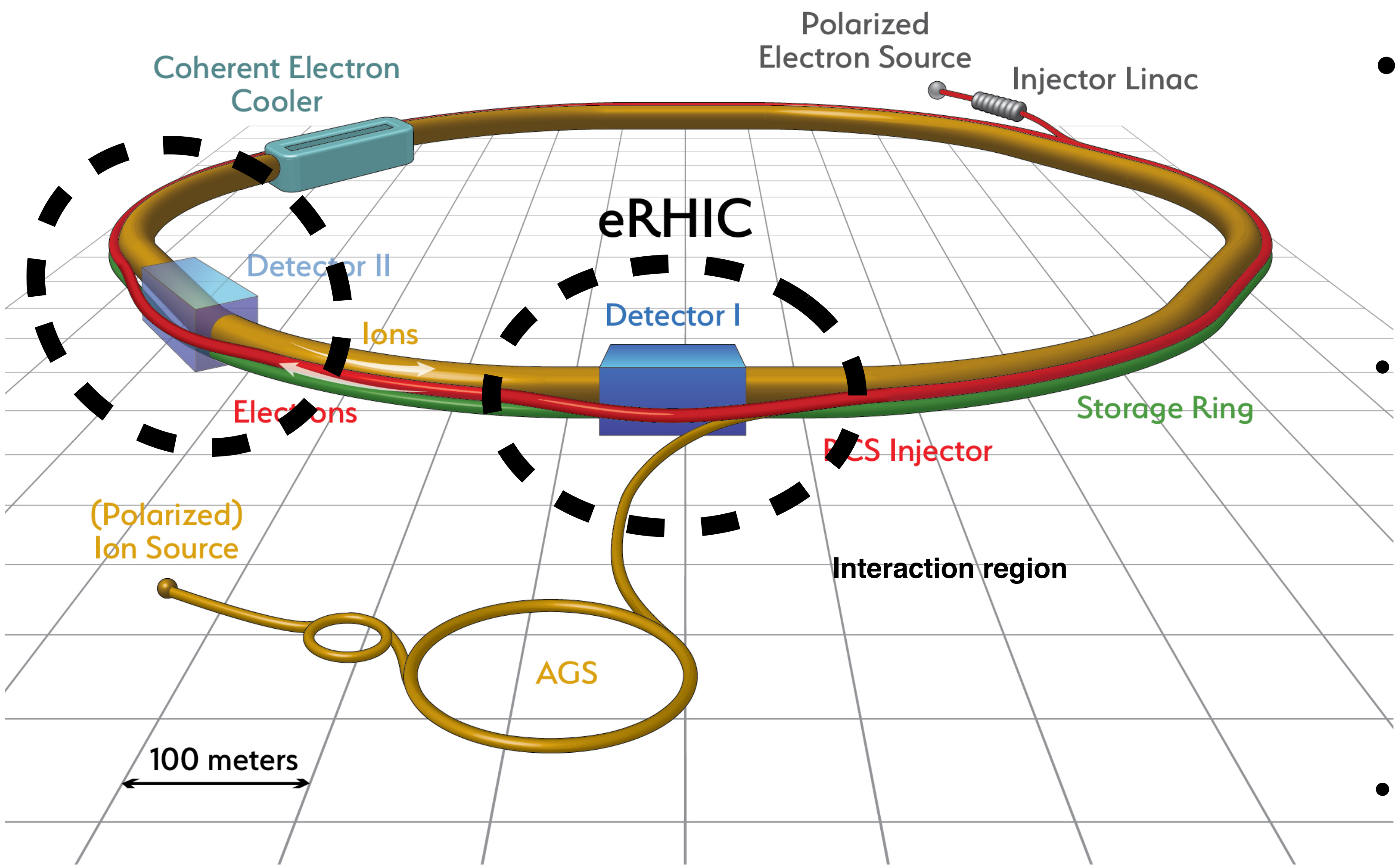
- **JLEIC** at JLab
- CEBAF + new hadron machine





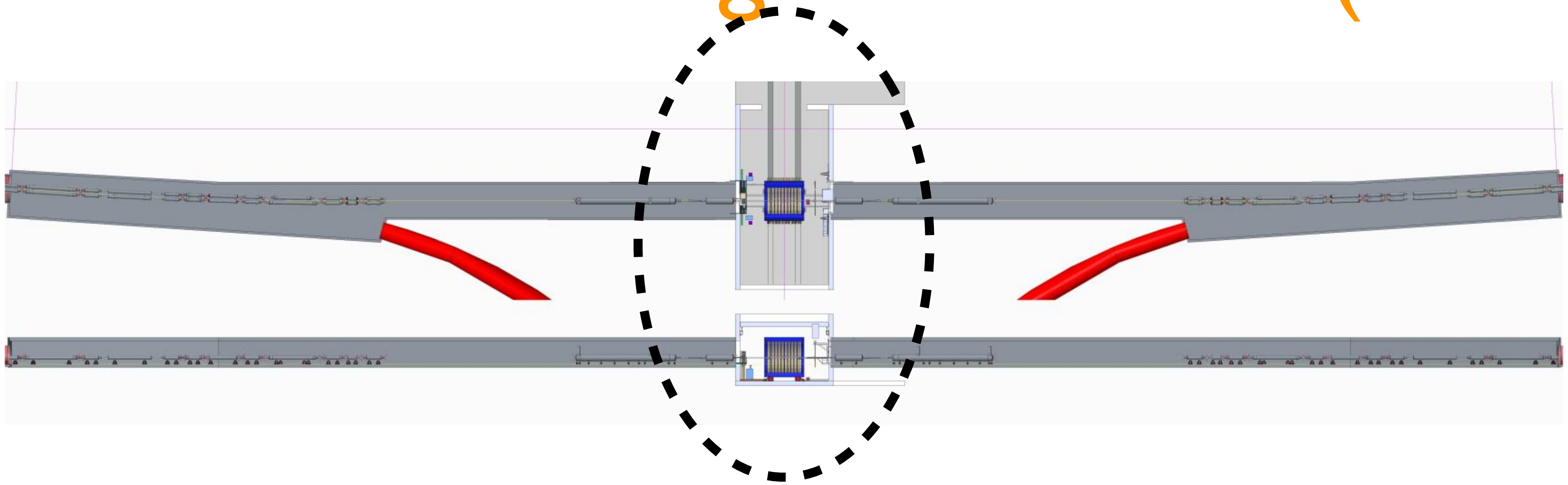
- Maximum utilization of past and current investment
- US Nuclear Science Advisory Committee recommendation (2015): "highest priority for new facility construction"
- US National Academies of Science EIC science assessment (2018) "the science that can be addressed by an EIC is compelling, fundamental and timely"

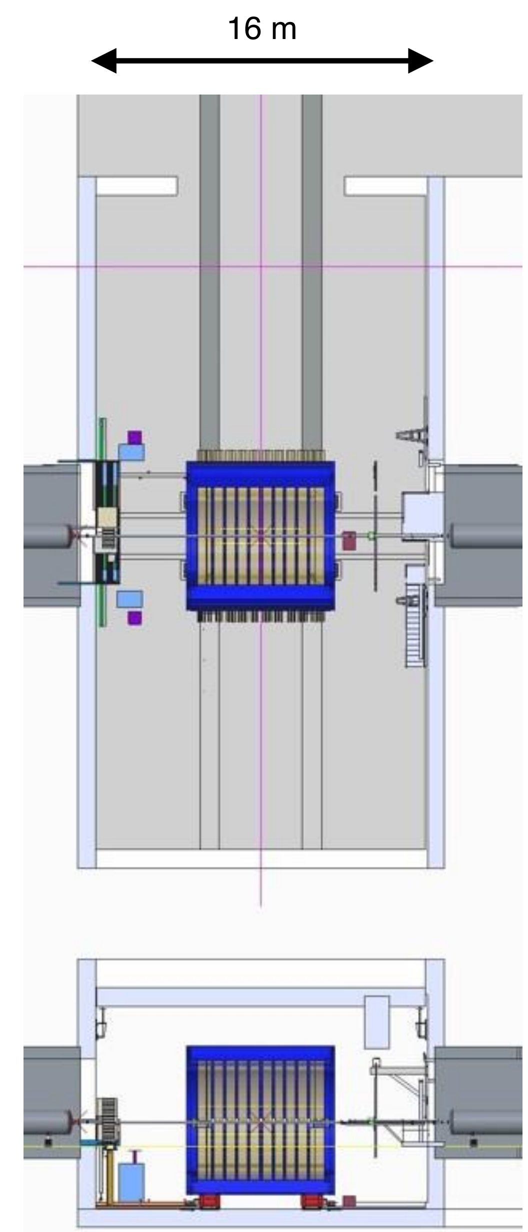
eRHIC realization



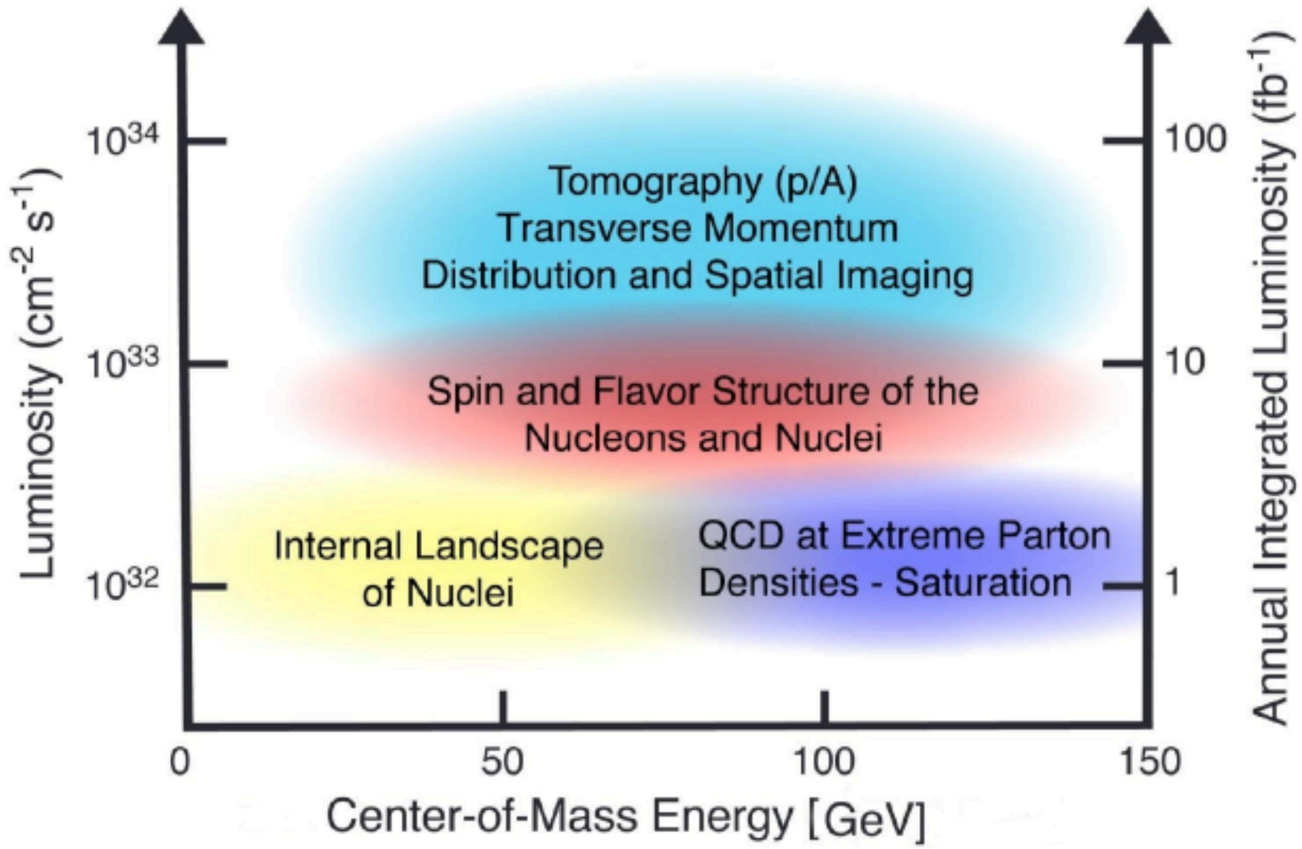
- **Hadron Beam**
  - entirely re-uses injection chain and one of RHIC rings (Yellow ring)
  - partially re-uses components of other ion RHIC ring
- **Electron Accelerator** added inside the existing RHIC tunnel:
  - 5-18 GeV Storage Ring
  - On-energy injector: 18 GeV Rapid Cycling Synchrotron
  - Polarized electron source and 400 MeV injector linac
- **Hadron cooling system**
  Required for L= $10^{34}cm^{-2}s^{-1}$
  Without cooling the peak luminosity reaches 4.4 $10^{33}cm^{-2}s^{-1}$

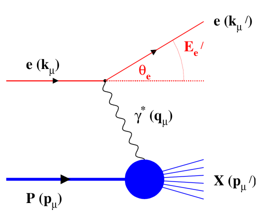
Interaction Region at RHIC (STAR at 6 o'clock)





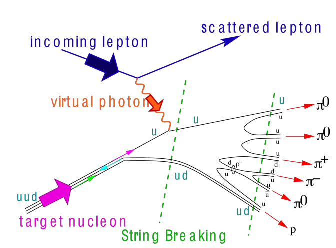
EIC physics and measurements





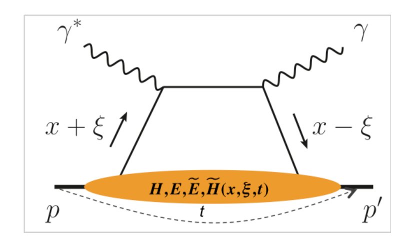
inclusive DIS

measure scattered electron with high precision



semi-inclusive DIS

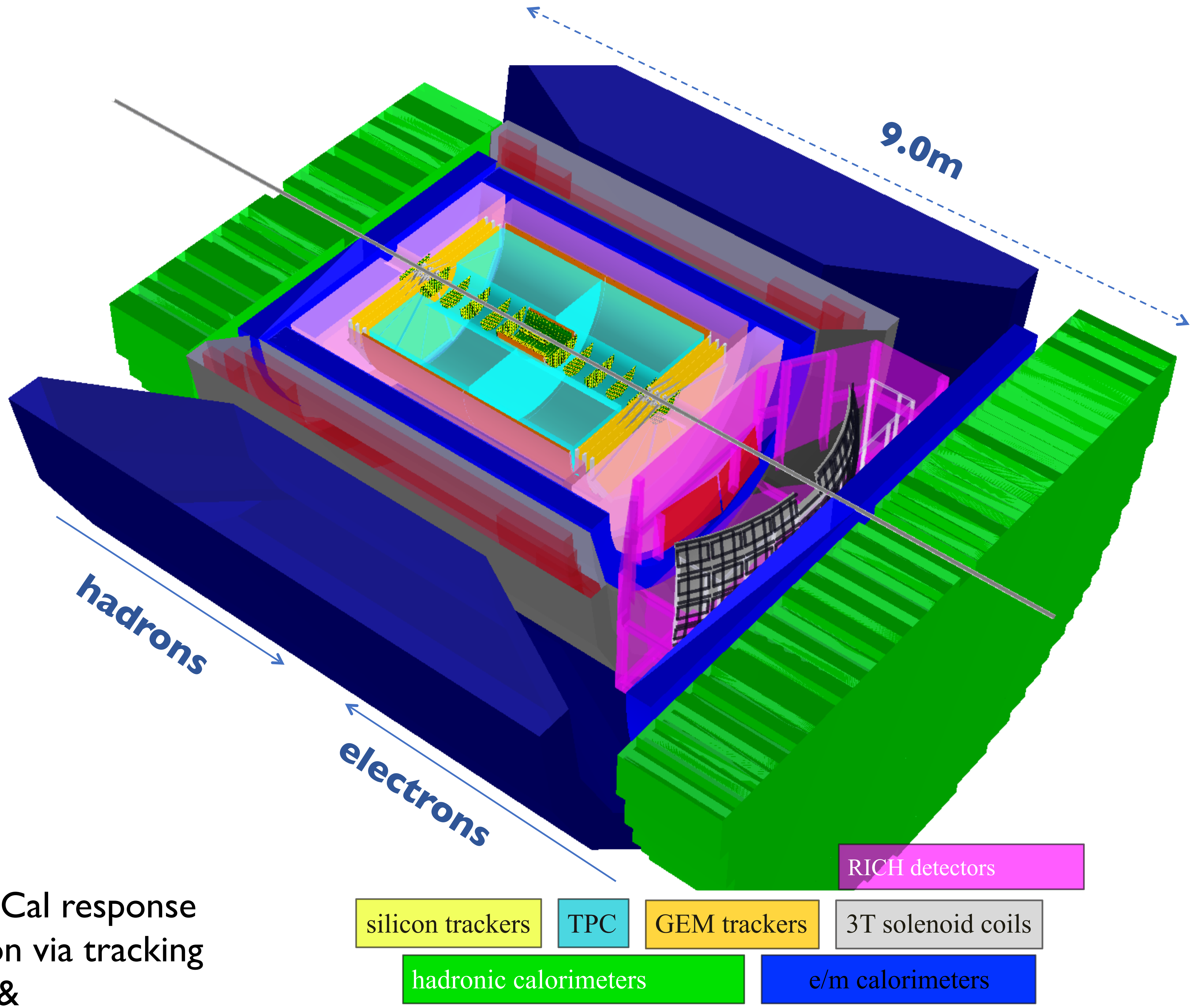
detect the scattered lepton and final state (jets, hadrons, correlations in final state)



exclusive processes

all particles in the event identified

eRHIC main detector



-4<η<4: Tracking (TPC+GEM+MAPS) & E/M Calorimetry (hermetic coverage)

Hadron PID:

-1<η<1: proximity focusing RICH + TPC: dE/dx

1<η<3: Dual-radiator RICH

-1>η>-3: Aerogel RICH

Lepton PID:

-3 <η< 3: e/p

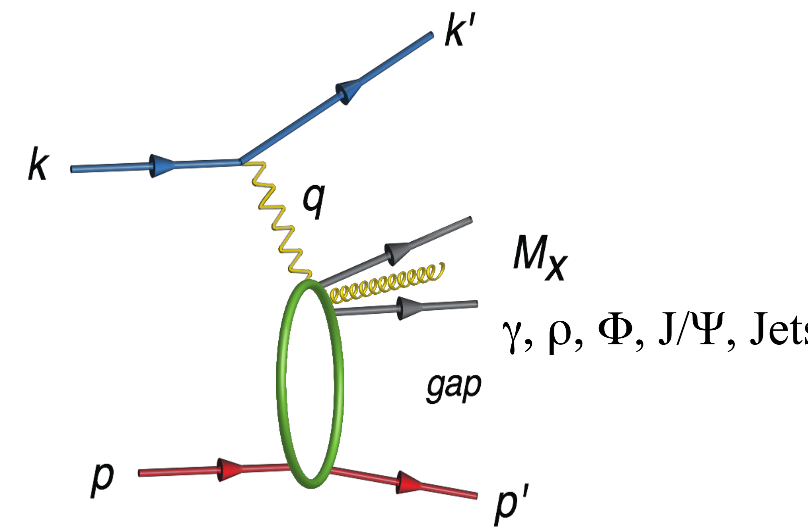
1<|η|<3: in addition HCal response & γ suppression via tracking

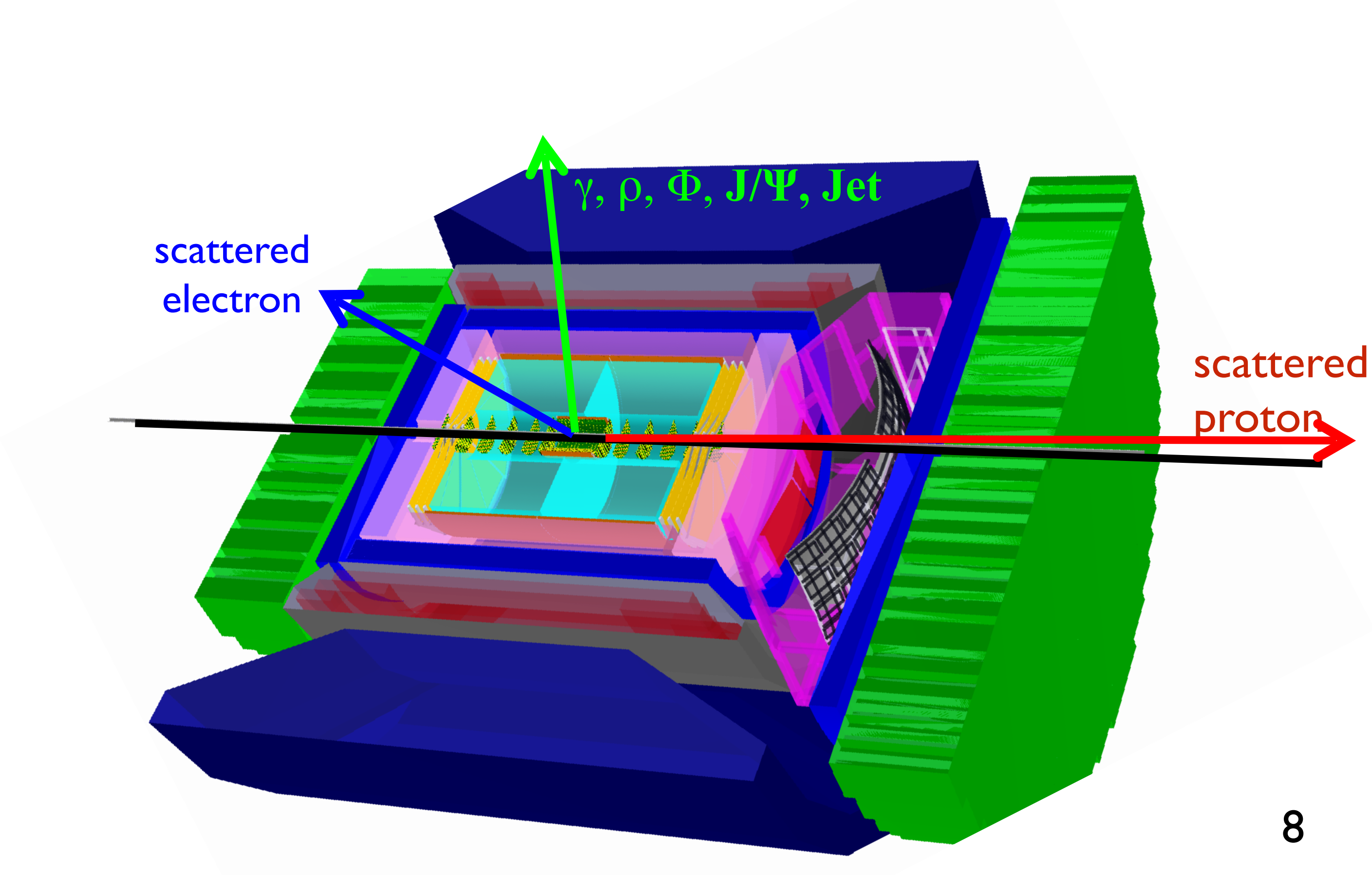
|η|>3: ECal+Hcal response & γ suppression via tracking

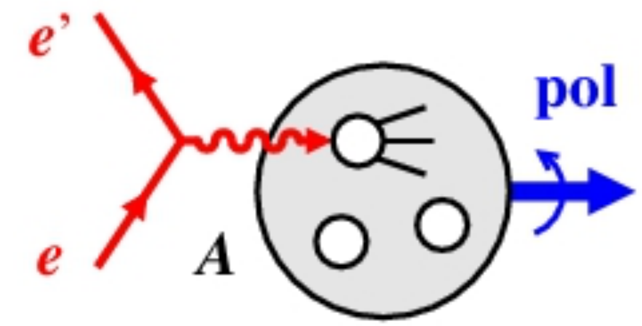
MAPS: CMOS Monolithic Active Pixel Sensors

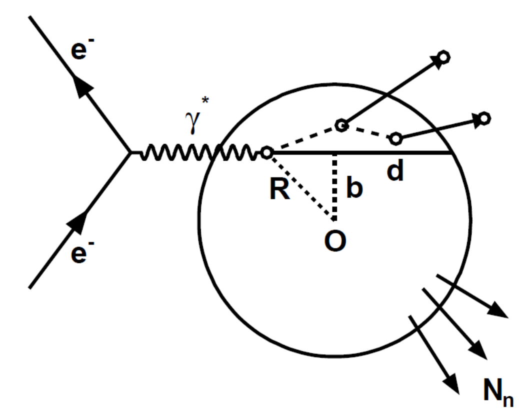
Physics with forward tagging

- Defining exclusive reactions in ep/eA:
  - ep: reconstruction of all particles in (diffractive) event including scattered proton with wide kinematics coverage
  - eA: identify with rapidity gap. need wide rapidity coverage [HCal for 1<η<4]
- Identifying coherence of nucleus in diffractive eA: with neutrons from nucleus break-up
- Sampling target in e+³He,d with spectator tagging
- Accessing event geometry in semi-inclusive eA with evaporated nucleons

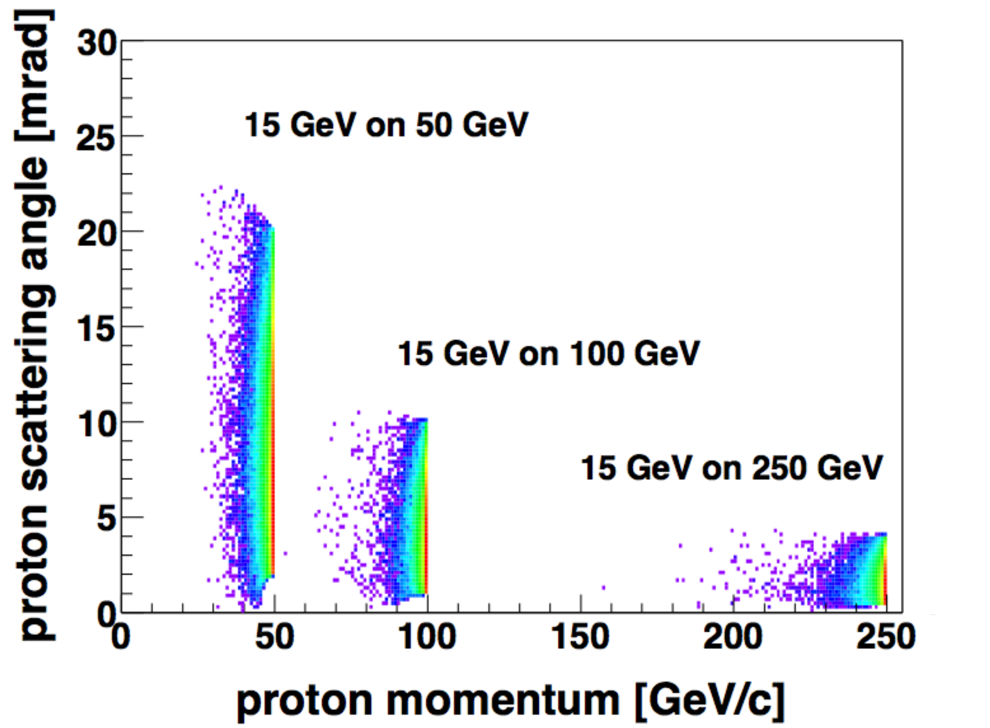


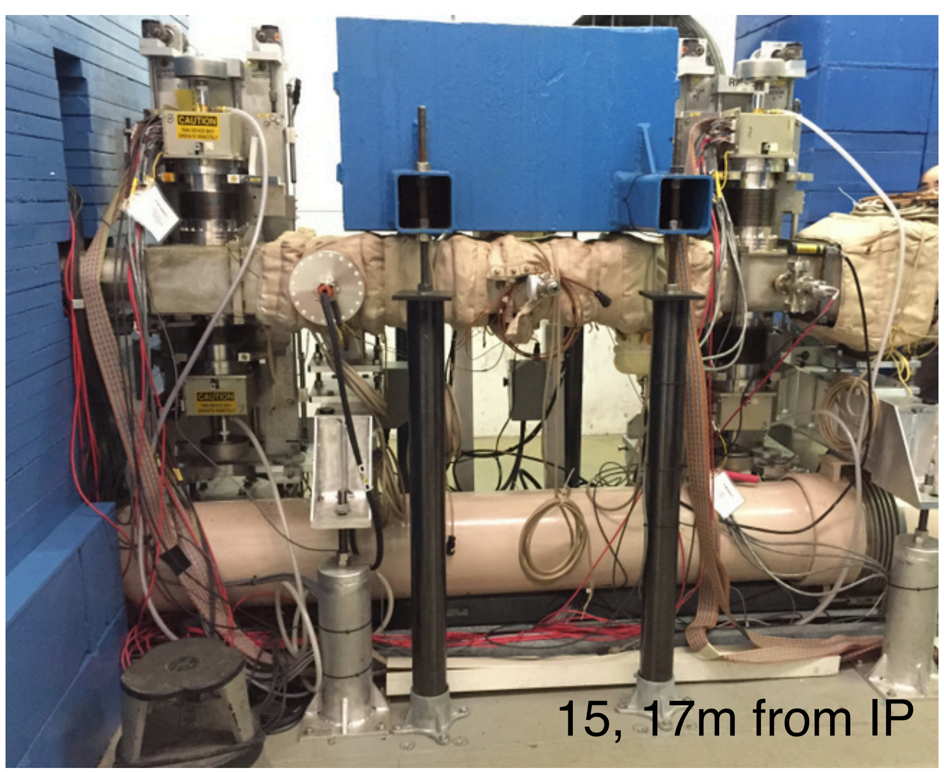






Forward protons in diffraction

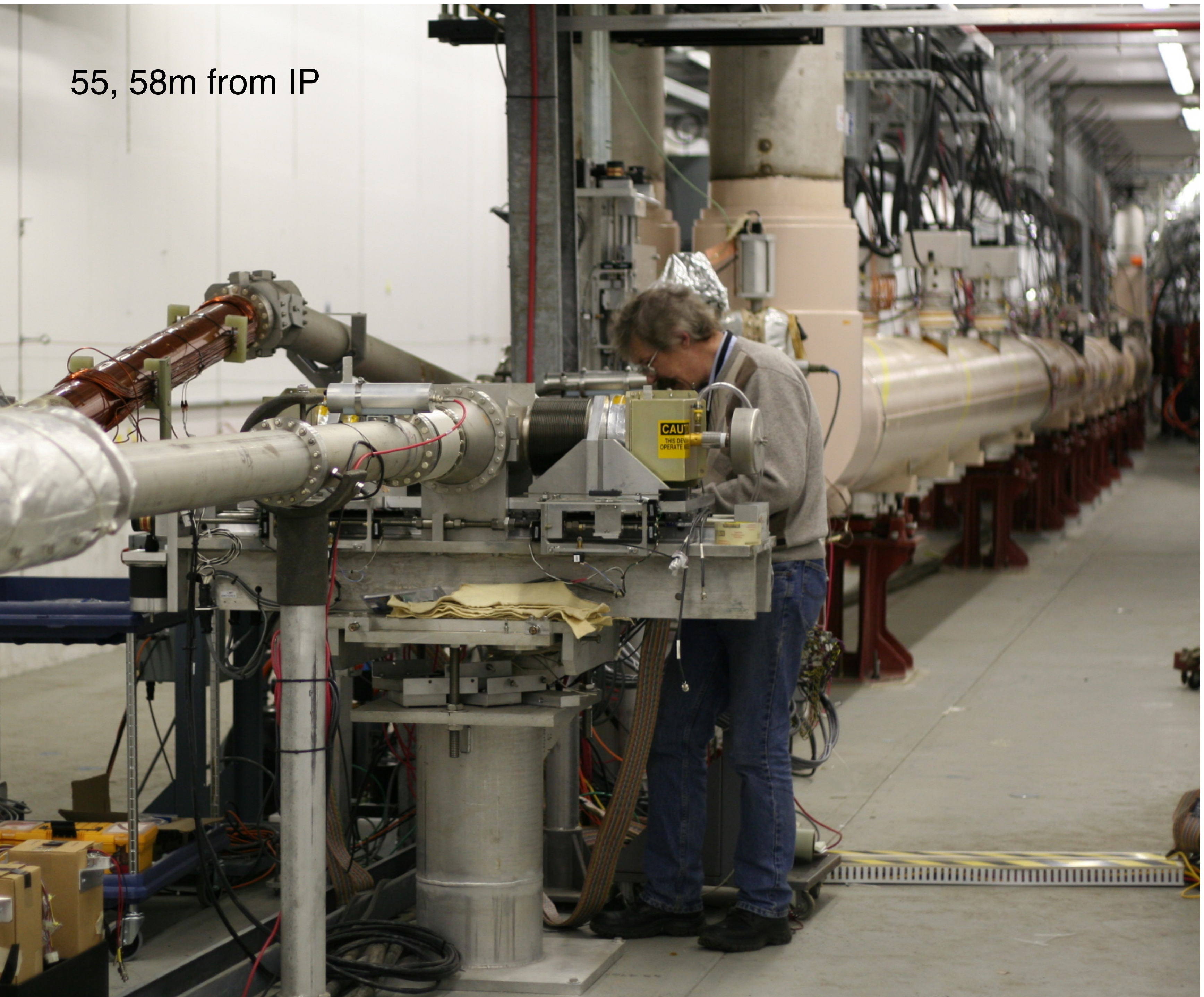


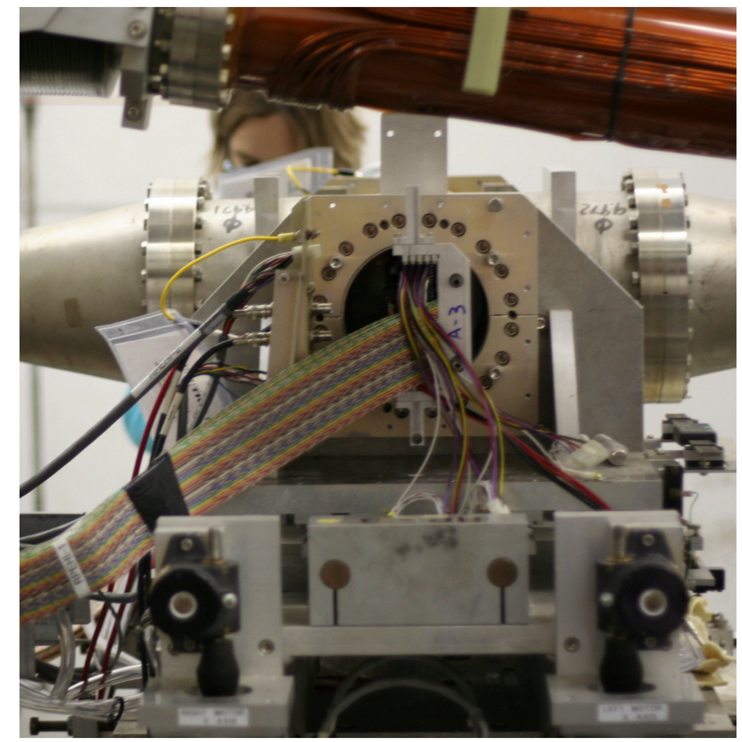


Roman Pots set up at STAR / RHIC

- Scattered with ~O(mrad): Need a detector close to the beam - Roman Pot to detect
- Large angle (high-t) acceptance mainly limited by beam aperture [$t \sim p_T^2 \sim p^2\theta^2$]
- Small angle (low-t) acceptance limited by beam envelop (~<$10\sigma_{beam}$)
- Reconstruction resolution limited by
  - beam angular divergence (~O(100μrad)), emittance
  - uncertainties in beam offset, crossing, transport, detector alignment, vertex reconstruction resolution
  - at RHIC
    - $\delta p/p \sim 0.005$
    - $\delta t/t \sim 0.03/\sqrt{t}$
  - in addition, effect of crab crossing (expected to be << beam divergence) need to be simulated

Roman Pot system at RHIC

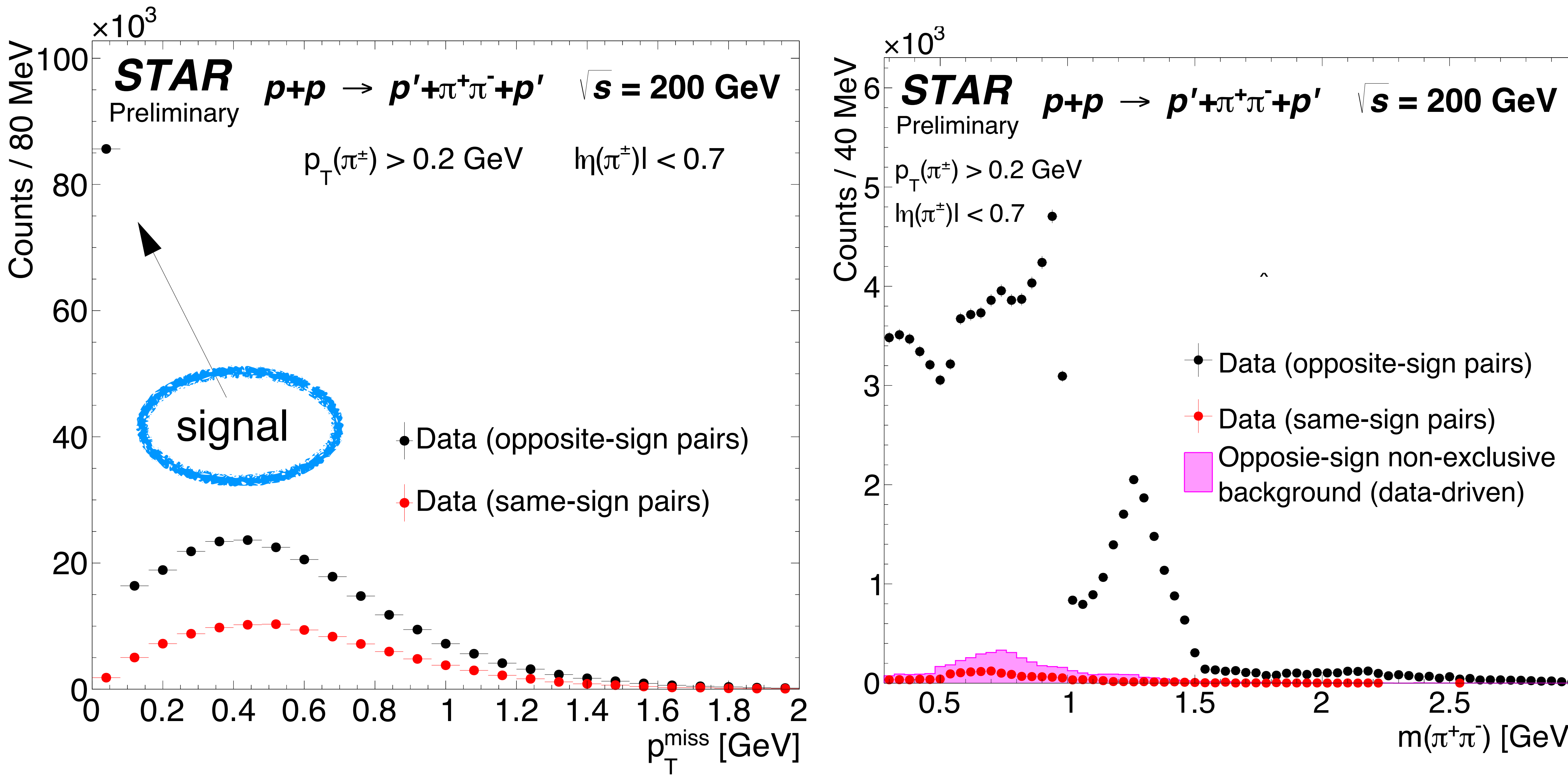




Roman Pot vessel:

Silicon Strip Detector packages:

Exclusive diffraction tagging with RP at RHIC

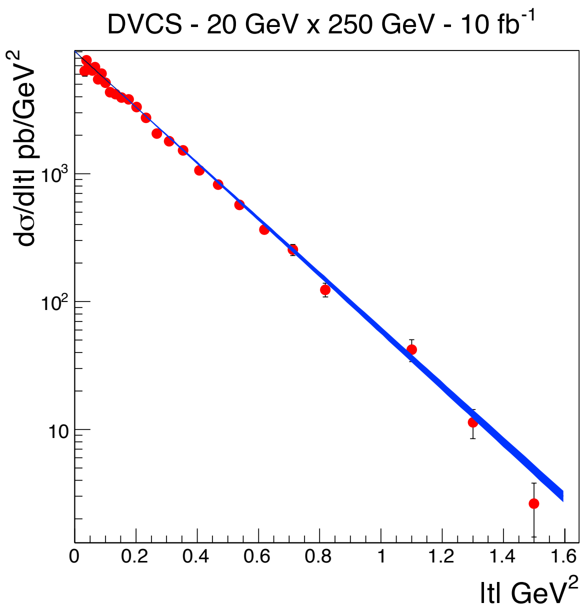


R. Sikora at Diffraction and Low-x 2018

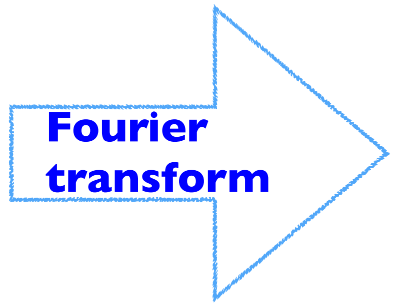
EIC: Impact of proton acceptance in RP

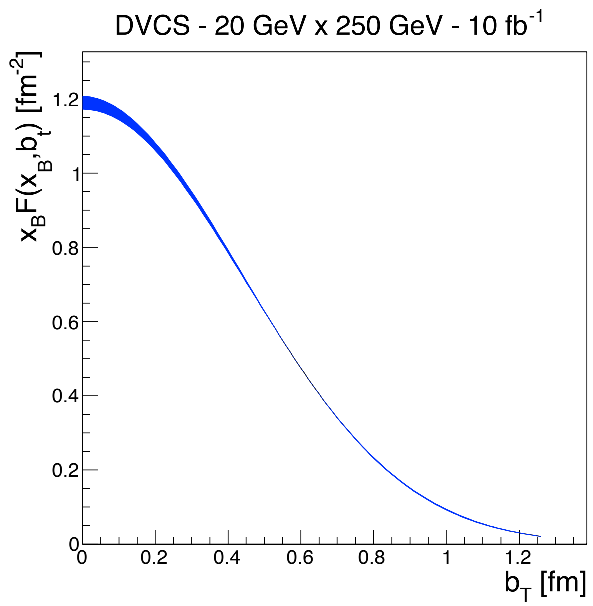
Measurement

Physics observable (cross-section vs impact parameter)



Plots from EIC White Paper:



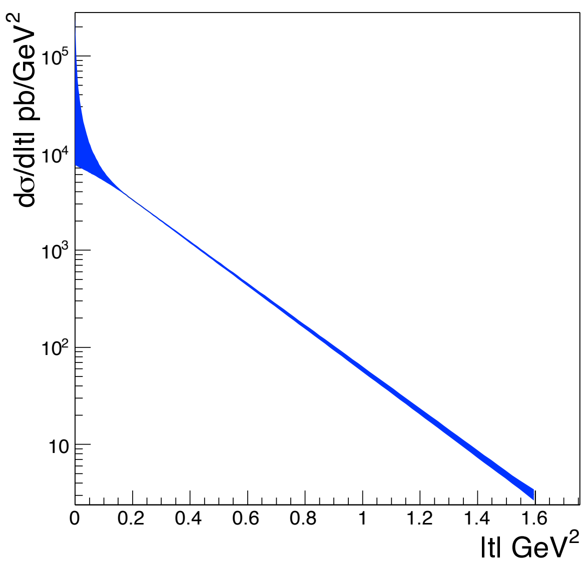


Requirement:

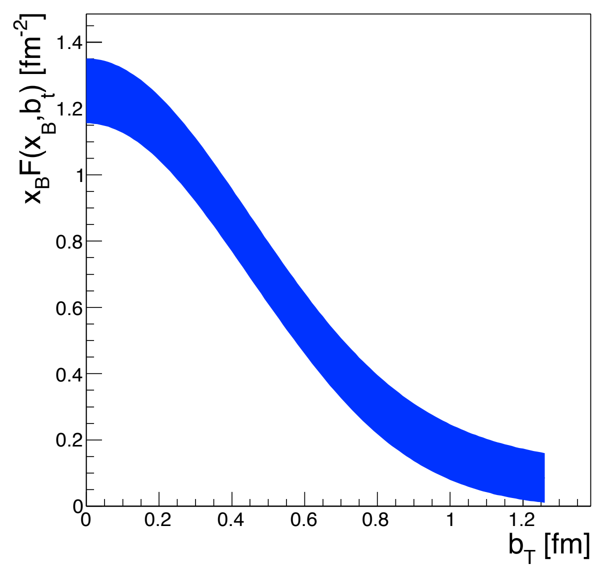
$\int L_{int}=10fb^{-1}$

$0.18 < p_t$ (GeV) < 1.3

$0.03 < |t|$ (GeV^2)< 1.6

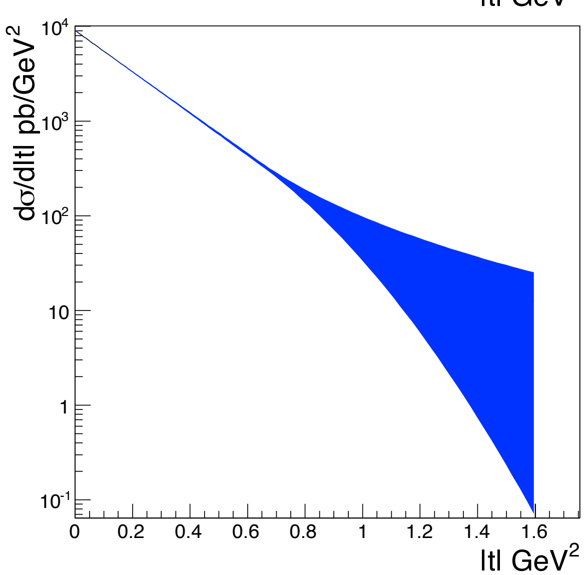


limited lower p_T-acceptance

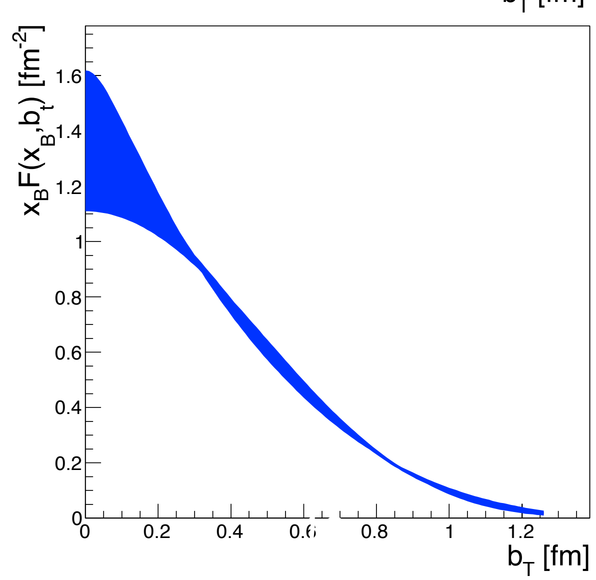


$\int L_{int}=10fb^{-1}$

$0.44 < p_T$(GeV) < 1.3



limited higher p_T-acceptance



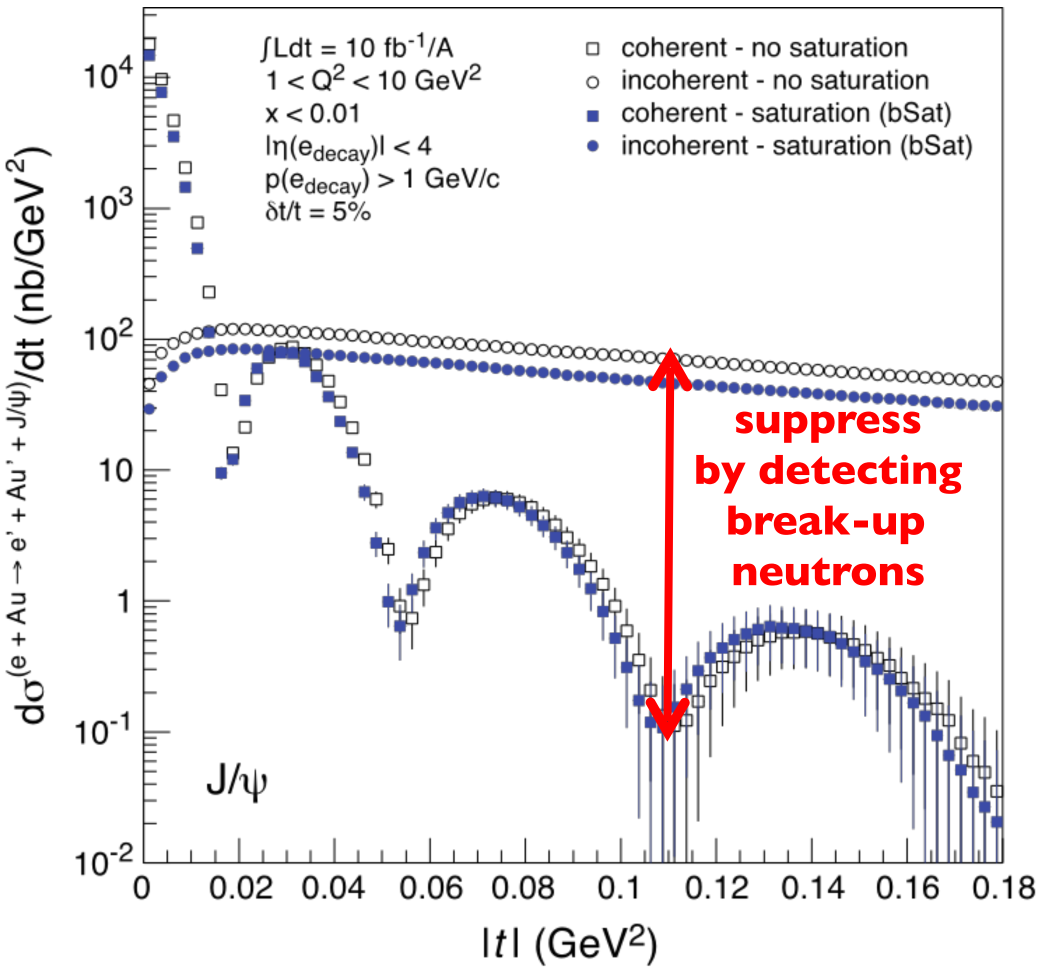
$\int L_{int}=10fb^{-1}$

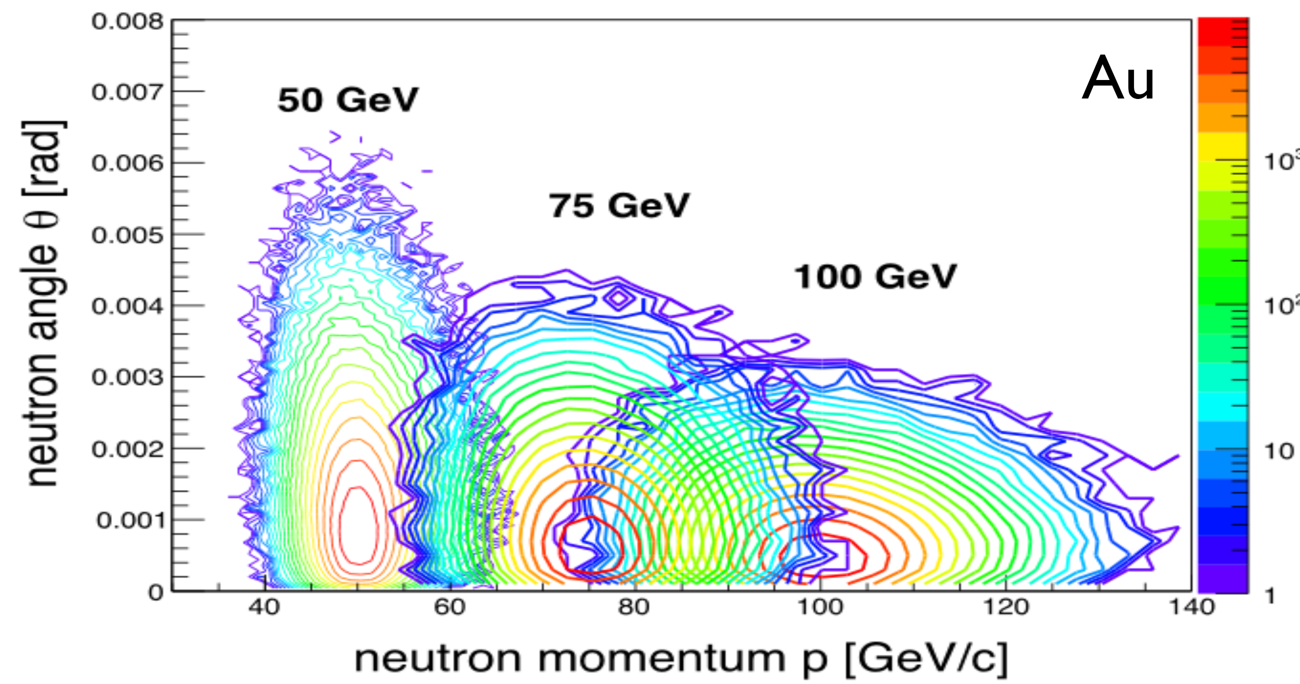
$0.18 < p_T$ (GeV) < 0.8

Forward neutrons from nucleus break-up

Diffractive physics in eA

- Measure spatial gluon distribution in nuclei
- Reaction: $e + Au \rightarrow e' + Au' + J/\psi, \phi, \rho$





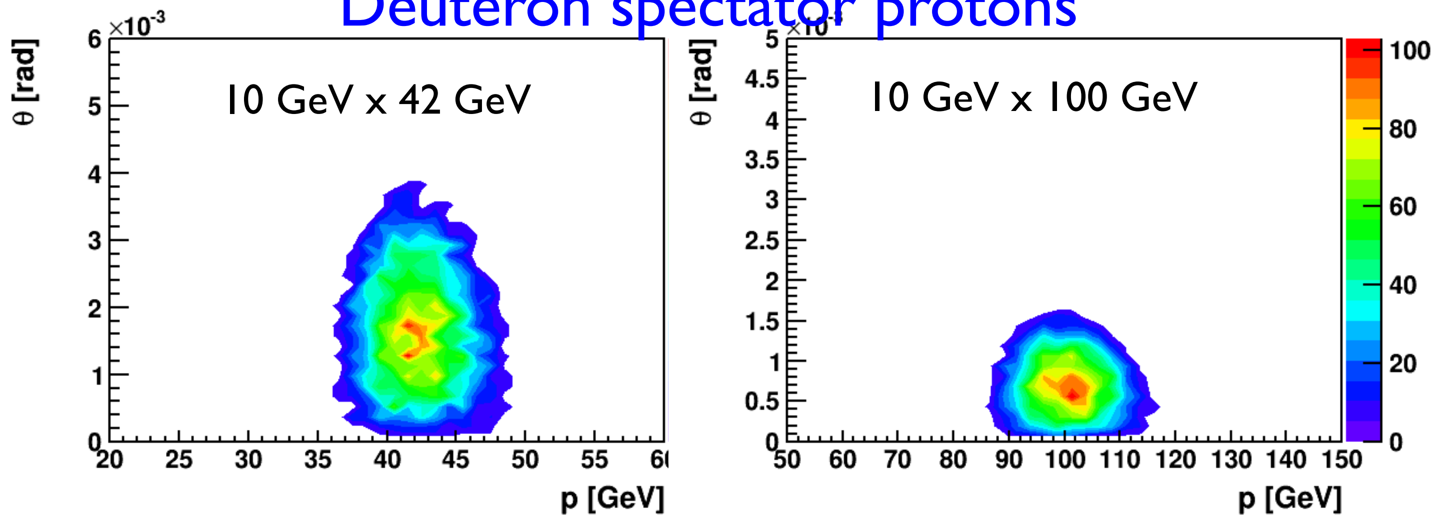
- Physics requires forward scattered nucleus needs to stay intact
  - Veto incoherent diffraction with break-up (evaporated) neutron detection
  - discussions on additional requirements: M Baker's talk

Requirements

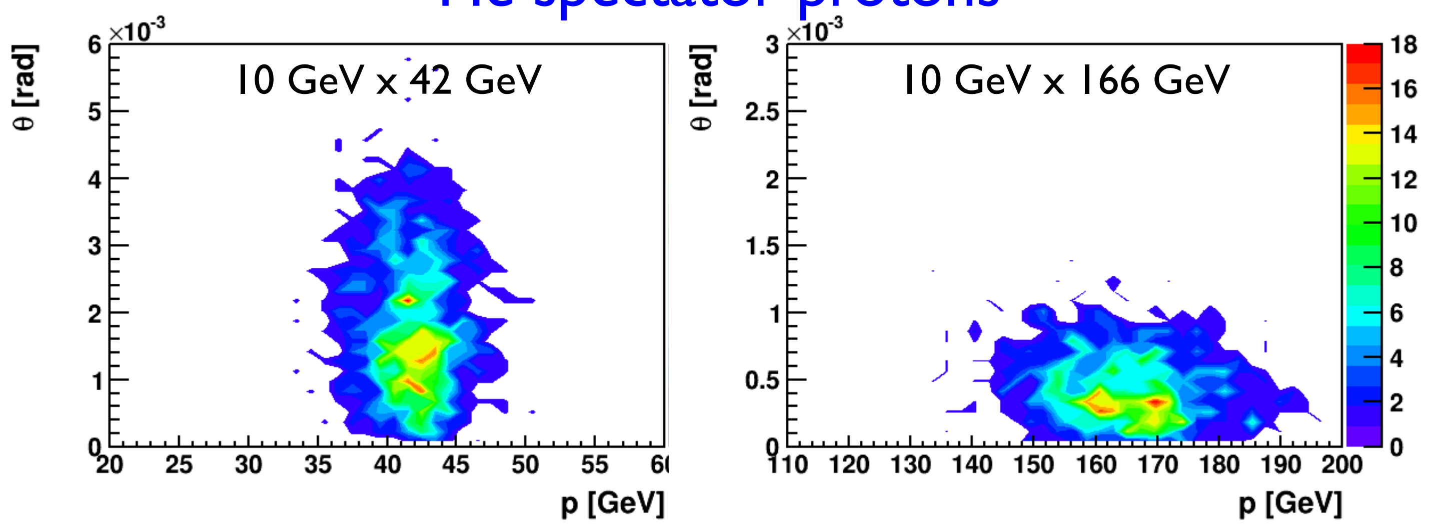
- Need at +/- 4 mrad beam element free region before the zero degree calorimeter for 100% acceptance to detect the break-up neutrons at 100 GeV
- Evaporated neutrons can be utilized to reconstruct collisions geometry ➔ precision neutron energy with good reconstruction resolution with complete coverage

Spectator protons in ^{3}He, d

Deuteron spectator protons

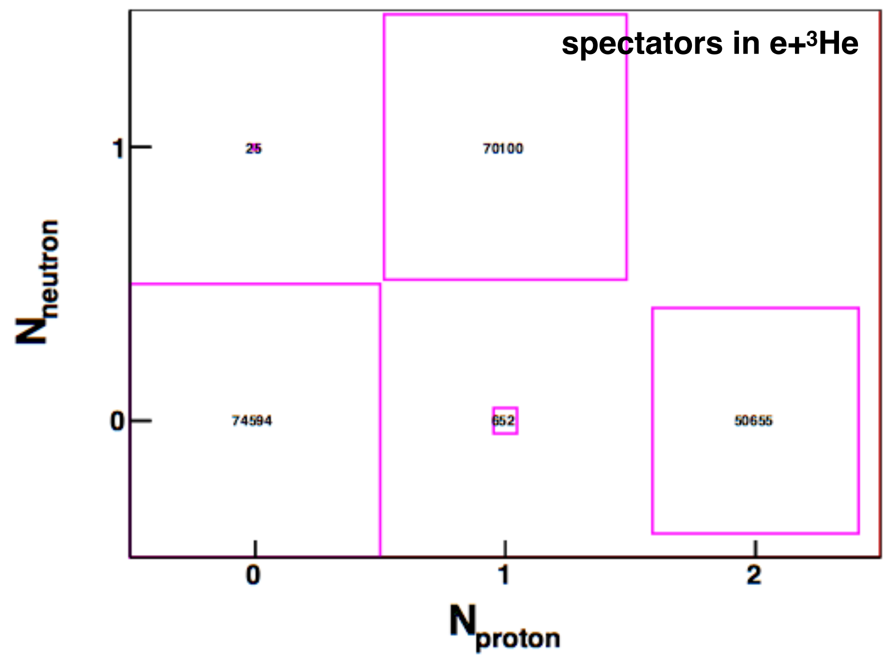


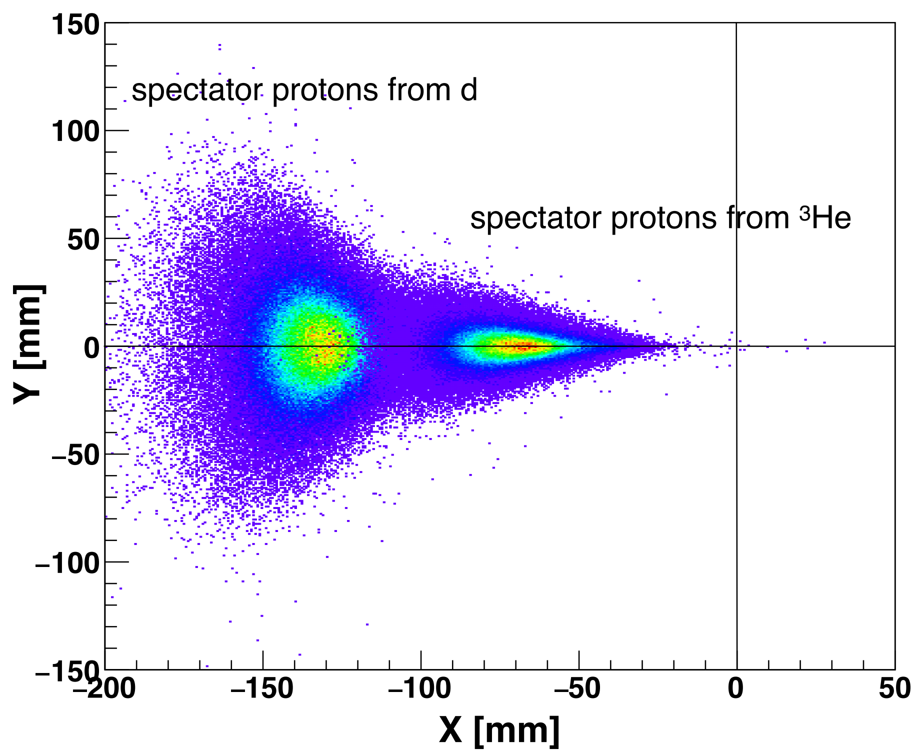
^{3}He spectator protons



- Crucial for identifying processes with a neutron "target" [e(p)+n] in light ions - d, ^{3}He
  - Spectator neutron can be identified by a calorimeter at beam rapidity (zero degree calorimeter)
  - Tagging spectator protons from d, ^{3}He
    - Relying on separation from magnetic rigidity (B_r) changes
      ^{3}He: p = 3/2:1 d:p = 2:1
    - Momentum spread mainly due to Fermi motion + Lorentz boost

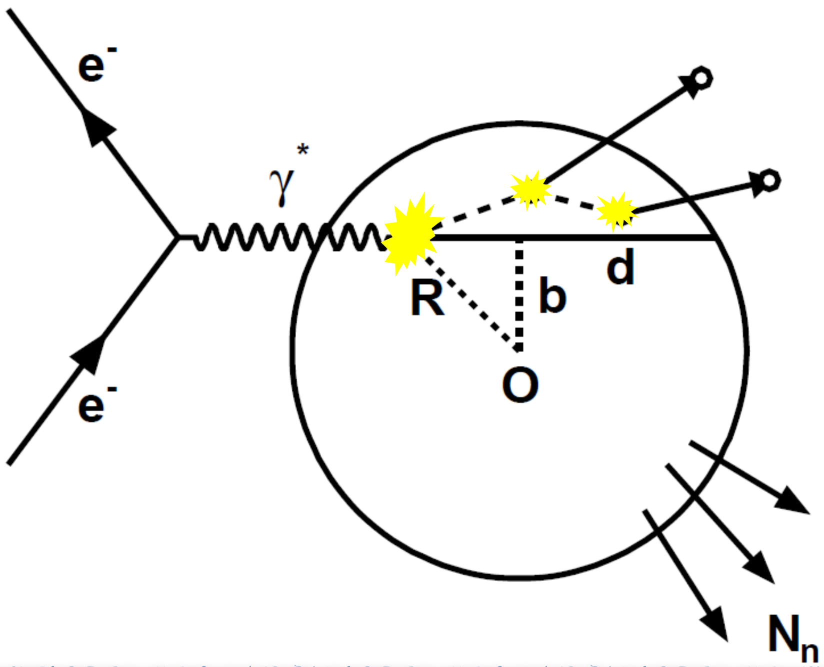
Tagging spectator protons with Roman Pots





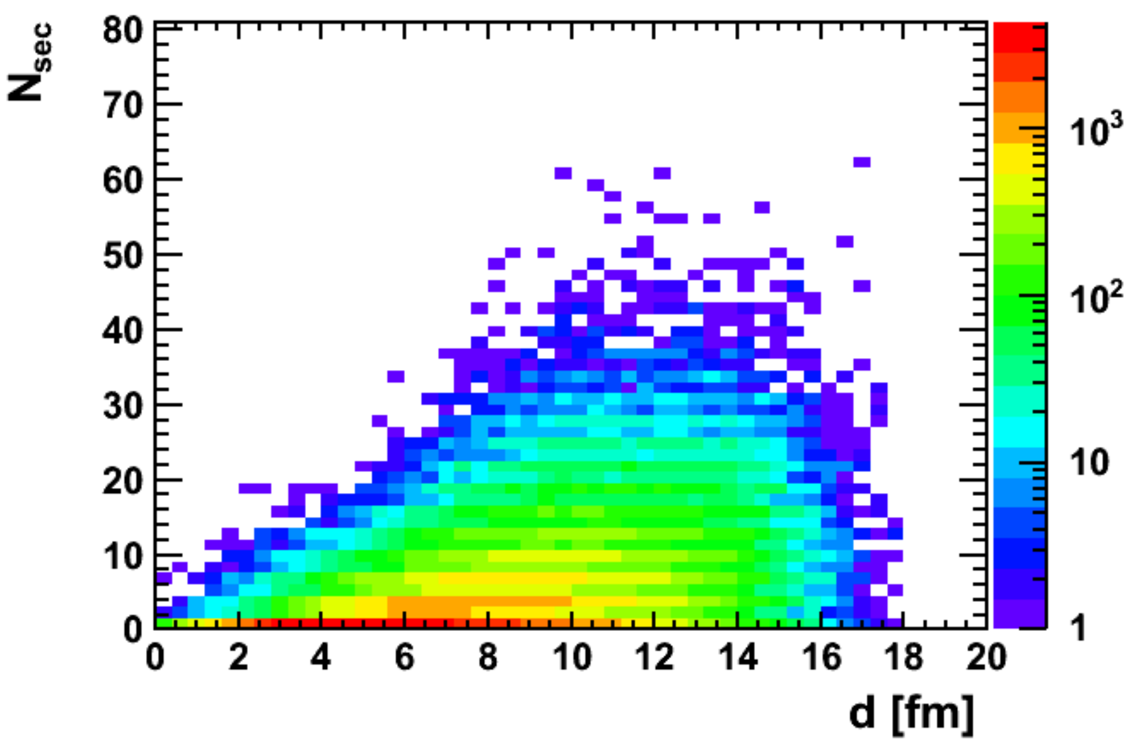
- Unambiguously identified e+p event vs e+n event in e+^{3}He
  1p +1n vs 2p = 30% vs 22% (DPMJetIII)
- Common detector RP be utilized for tagging forward proton from diffraction and the spectator protons from ^{3}He, d?
- measurement can be done with RPs + forward detectors + ZDC
- Shown distribution at fixed RP locations at eRHIC IR
- Detectors (location, size) can be configured to optimize the acceptance
- Acceptance for spectators with p_T kick needs to be considered/simulated

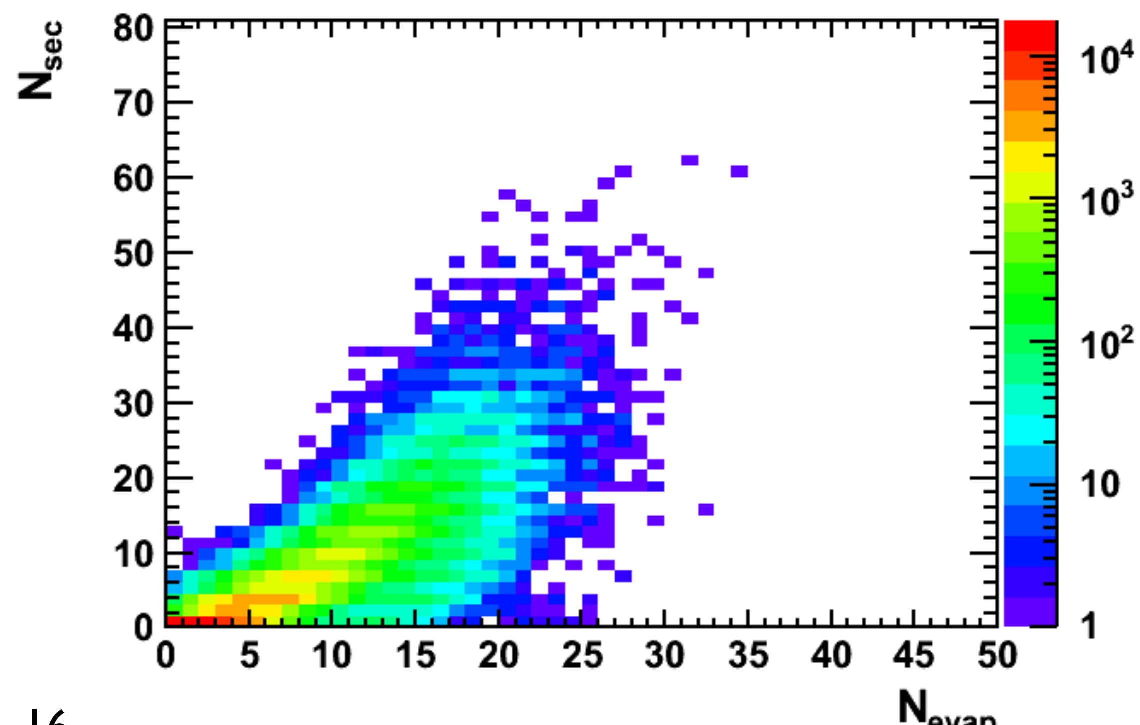
Controlling collision geometry in e-A?



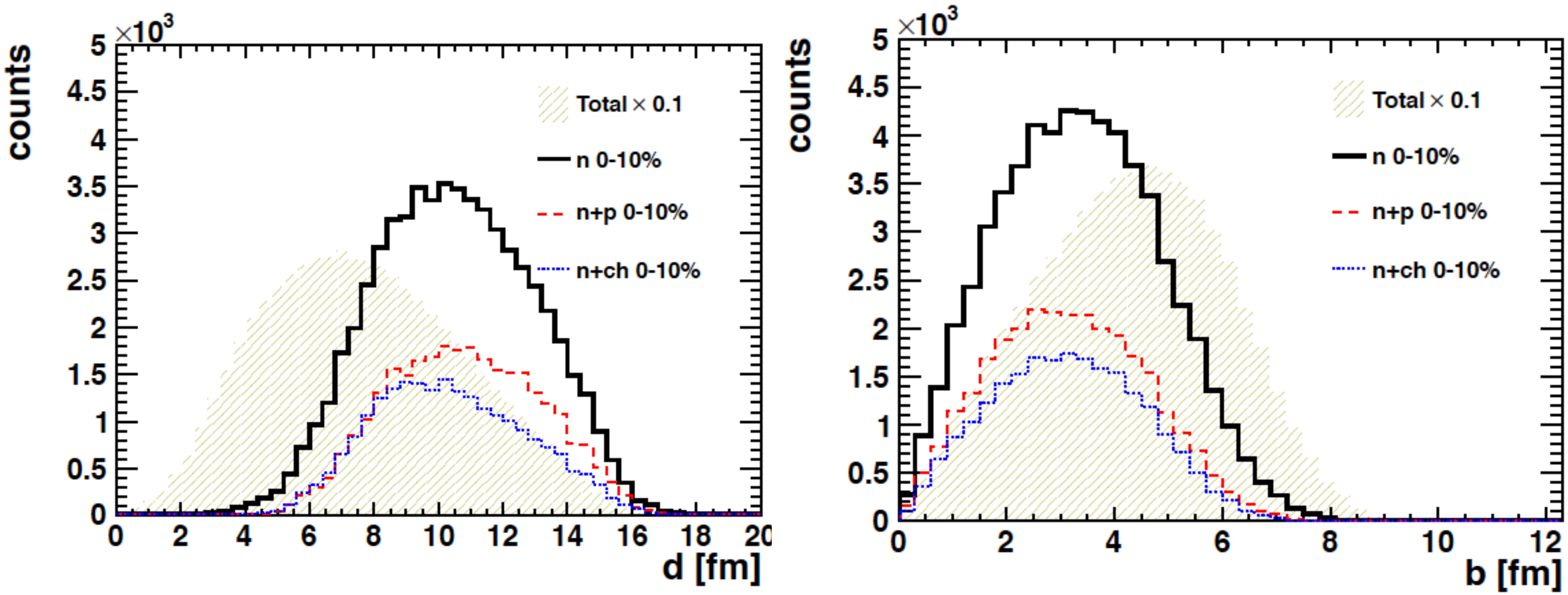
d : in medium traveling length
R : distance from involved nucleon to the center of nucleus
b : impact parameter
N_n: number of neutrons in forward region

d → $N_{secondary}$ → $N_{evaporated\ neutron}$





collision geometry selected by forward neutrons



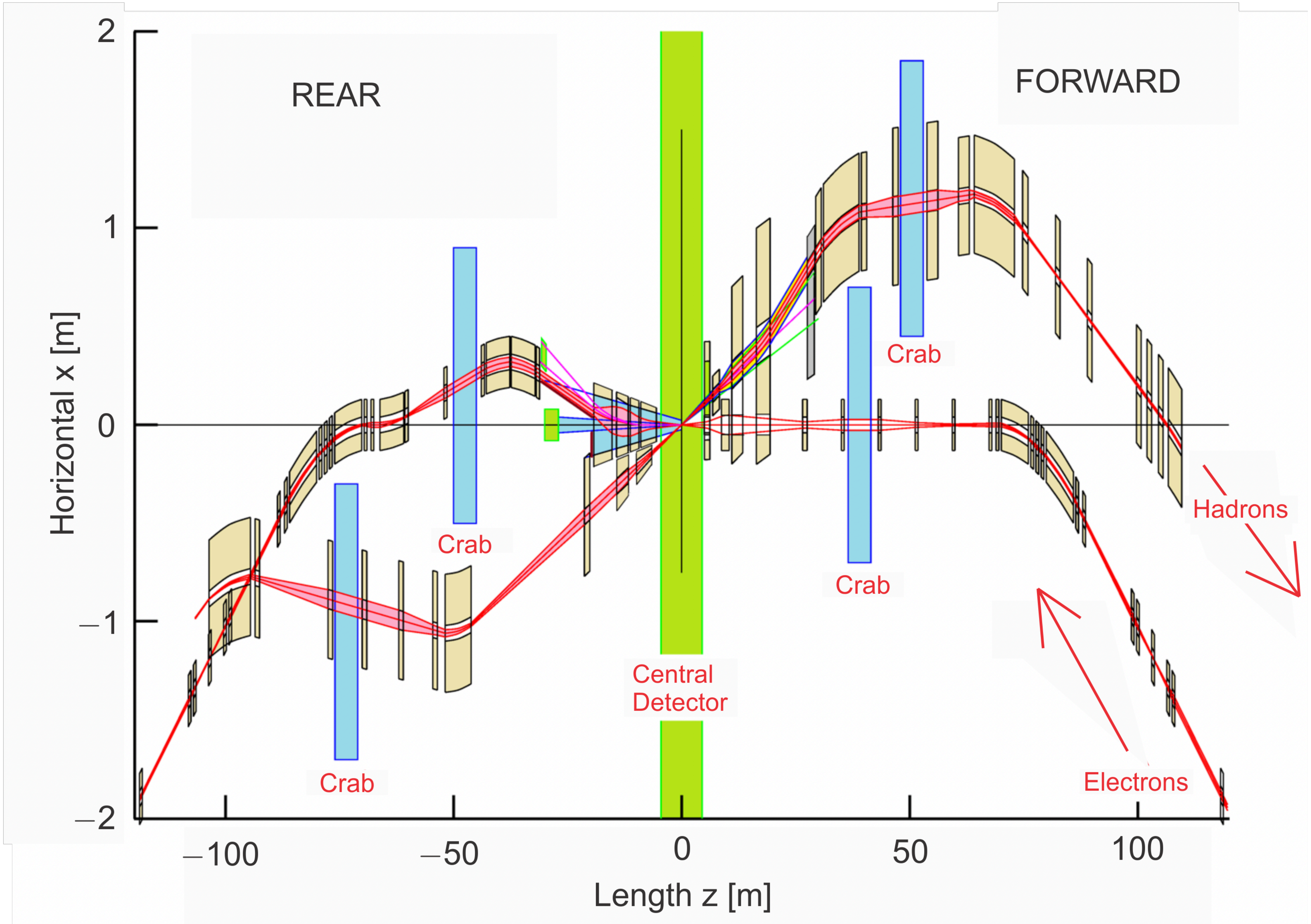
EPJA 50 189 (2014) L.Zheng, JHL, E. Aschenauer

- Forward neutrons dominantly correlated with collision geometry
- Zero Degree Calorimeter (θ<~4 mrad) can be used to count the forward neutrons
- More detailed study including nuclear shadowing effect in progress [BeAGLE]

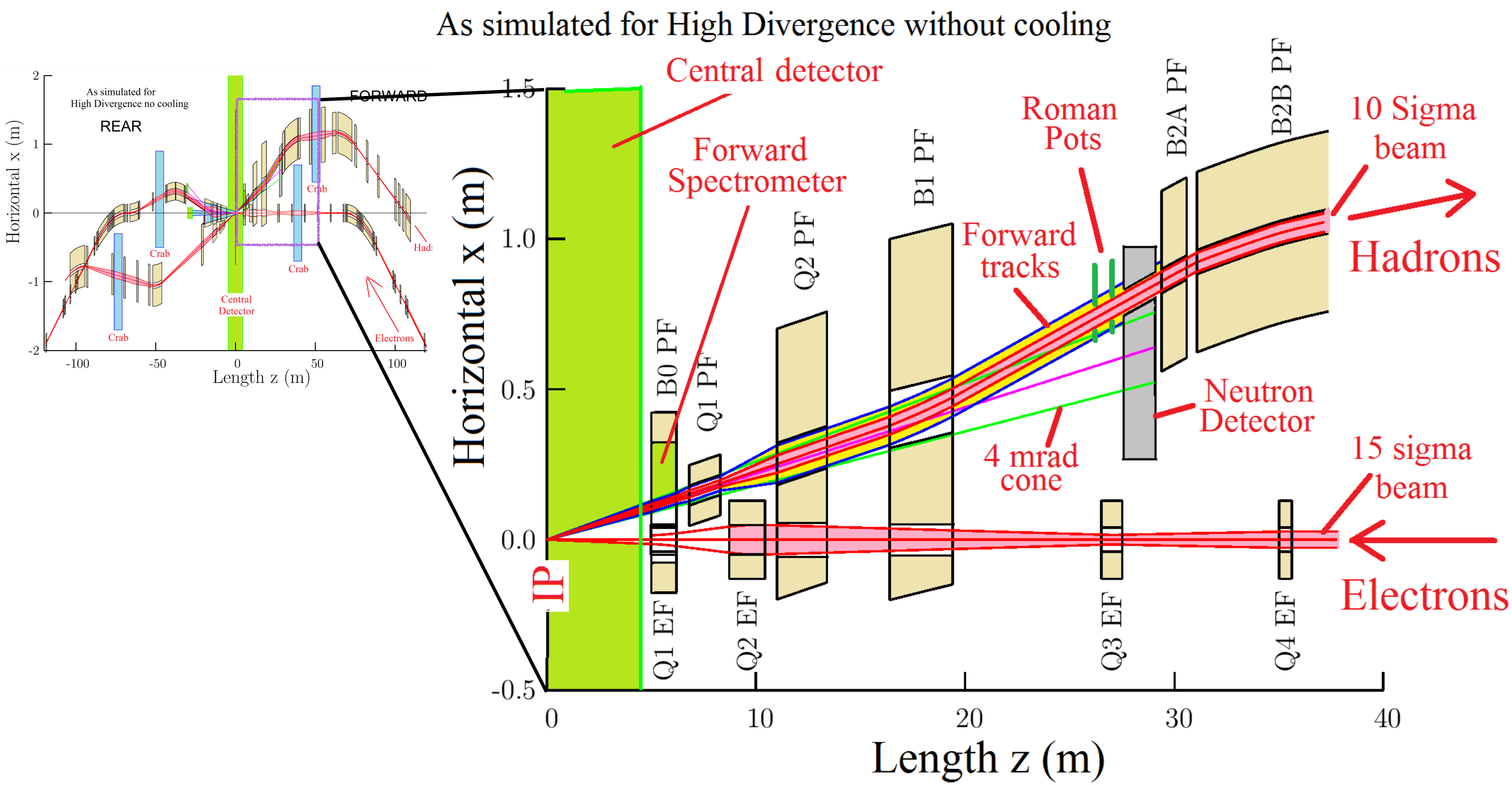
EIC Interaction Region Requirements

- Large detector acceptance
  - No accelerator magnets +/-4.5 m
  - Forward detector component
  - Large aperture of forward hadron
  - Limited beam divergence
  - Hadron dipole spectrometer magnet
- Small (flat) beams, small β^* for high luminosity
  - $\beta x^*/\beta y^*$: 90cm/4cm for p, 42cm/5cm for e
- Fast beam separation using 22 mrad crossing angle
  - Minimize parasitic collisions, clearance for forward neutrons
- Managing synchrotron radiation
  - no electron bends on the forward (hadron) side
  - large aperture electron magnets on rear side to absorb SR far from IP
- Electron chicane on electron side
  - luminosity measurement and electron tagging

Interaction region at eRHIC

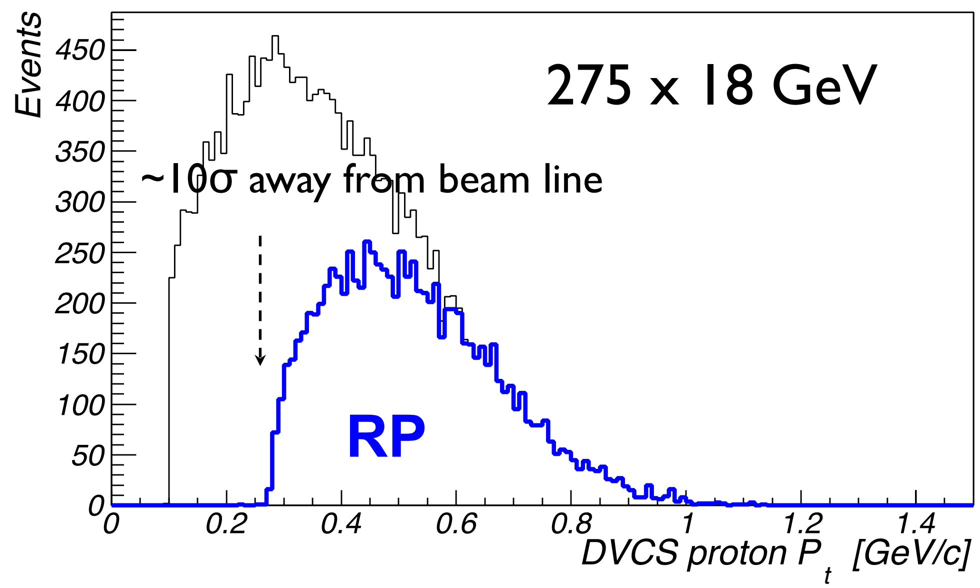


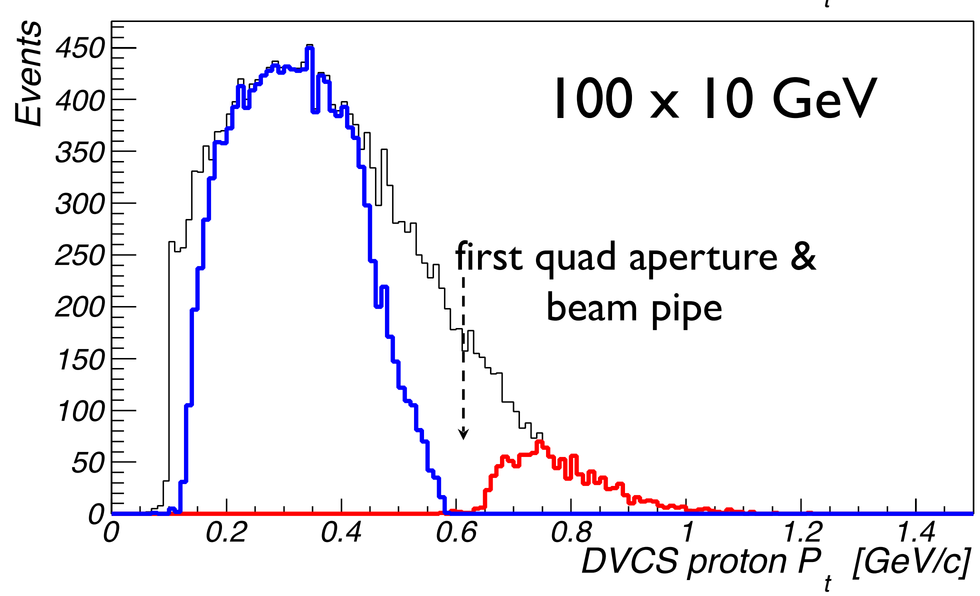
IR design at eRHIC

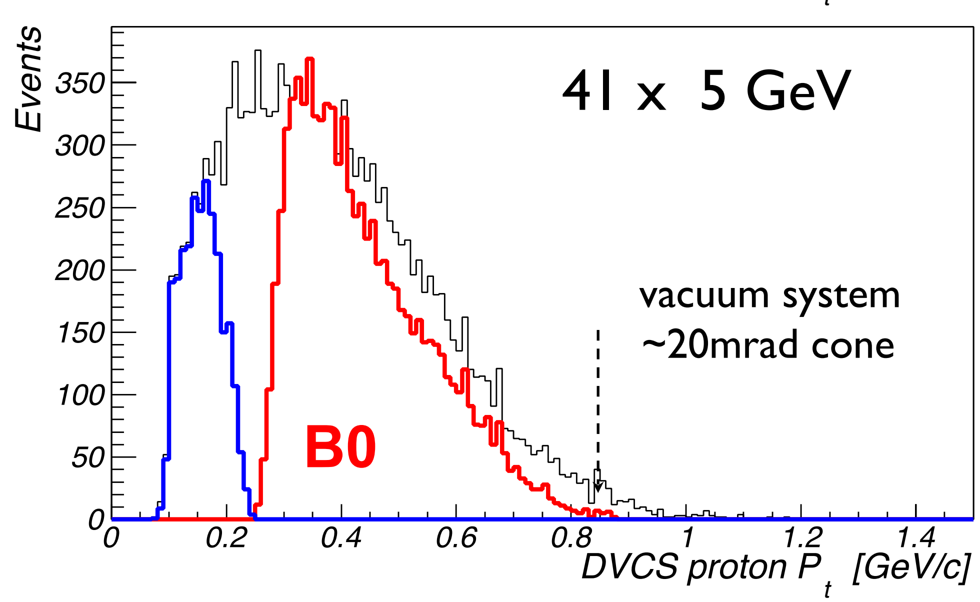


- Integrating requirements for hadron beam direction
  - Forward Detector (6 - 20 mrad)
  - Neutron detector ZDC (0 to 4 mrad)
  - Roman Pots (sensitive 1 to 5 mrad)

Proton acceptance with eRHIC

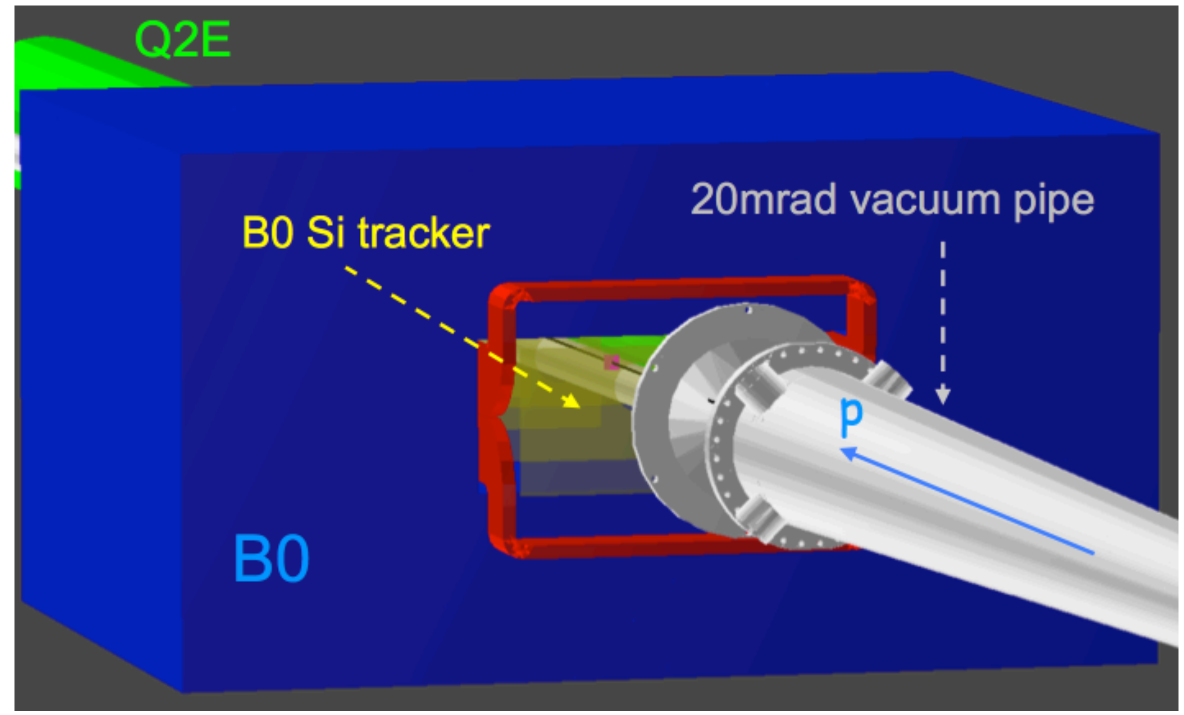




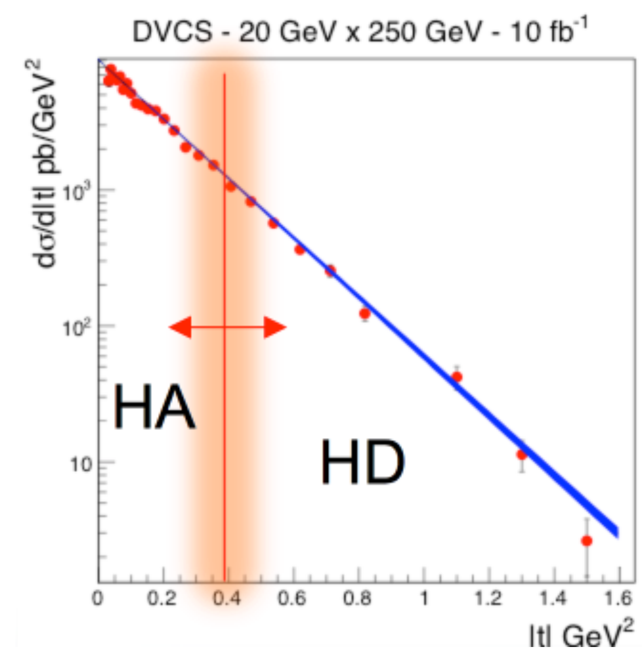


Simulation: A. Kiselev

p_T acceptance for forward scattered protons from exclusive reactions

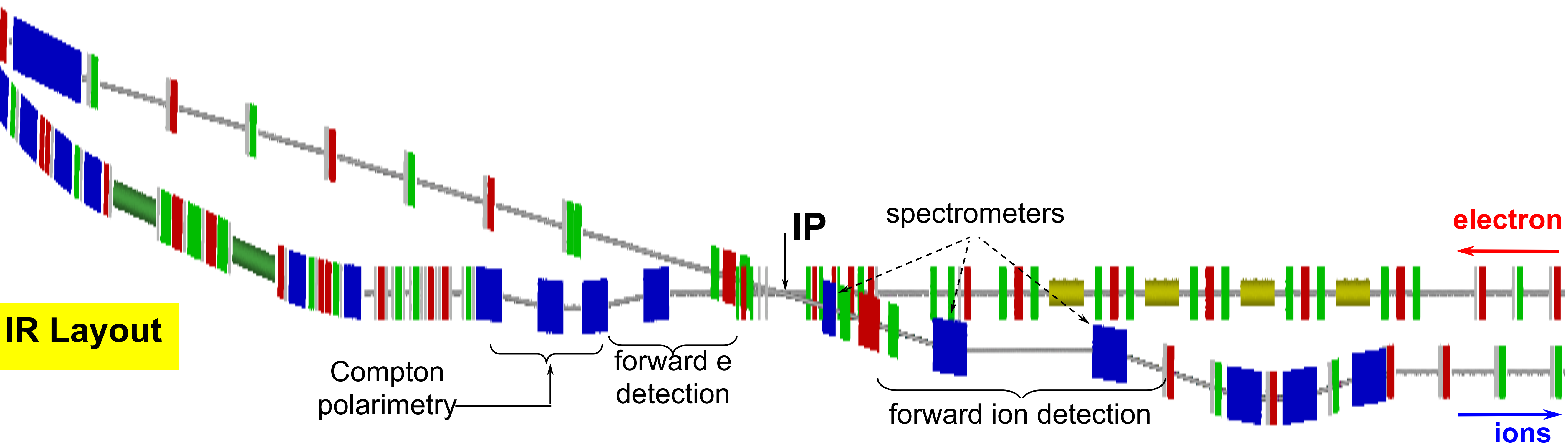


- Plots: HD (high divergence) mode
- Acceptance gap between RP and B0 will be further optimized



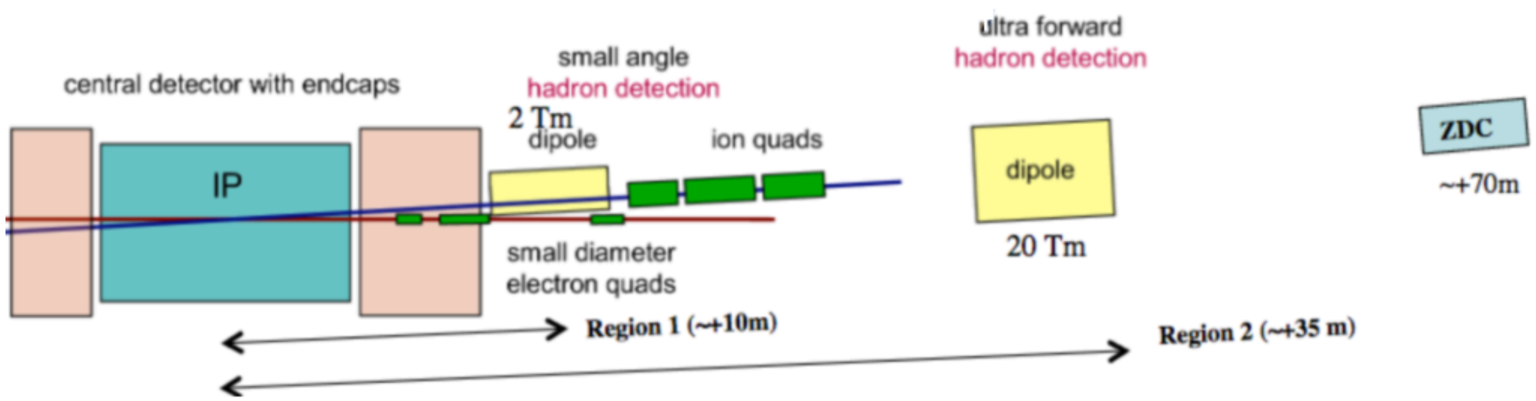
Accept 0.3 < p_T < 1.3 GeV and higher
→ Low p_T-part can be filled in with HA (high acceptance, smaller beam divergence) running mode

Proton acceptance with JLEIC

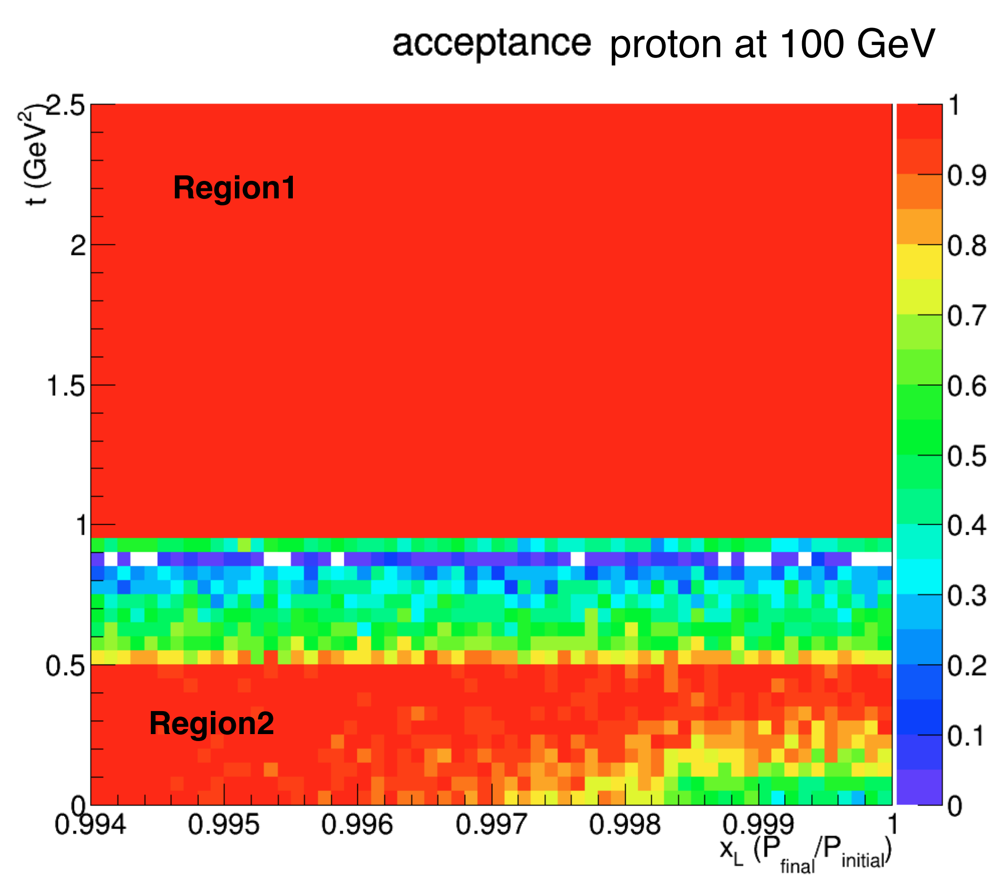


Two forward charged hadron detector regions:

- Region 1: Small dipole covering scattering angles from 0.5 up to a few degrees (before quads)
- Region 2: Far forward, up to one degree, for particles passing through (large aperture) accelerator quads. Use second dipole for precision measurement. (Hi Res)



R.Yoshida Polarized Light Ions at EIC 2018



Roman Pots at EIC: considerations

- Integral part of IR design
  - beam divergence, aperture limit, multiple running mode/beam parameters
  - optimized location for optimal performance and acceptance
- Coverage
  - need to measure diffractive protons in beam envelop - aperture limit with full φ acceptance
  - need wide coverage in momentum for tagging spectator protons from light ions
  - "grey" area in acceptance: between RP+forward spectrometer and main tracker (20 - ~50 mrad)
- Operation
  - operation no disturbance to the beam, routine operation
  - run simultaneously with normal operation for high luminosity sampling (ref: RHIC, LHC)
- Detector technology
  - tracking silicon/pixel + timing/triggering counter (ref: latest development at LHC)
  - potential space constraint for full φ coverage in horizontal: 2d-move
  - geometrical configuration/size for maximal coverage for various energies

Summary

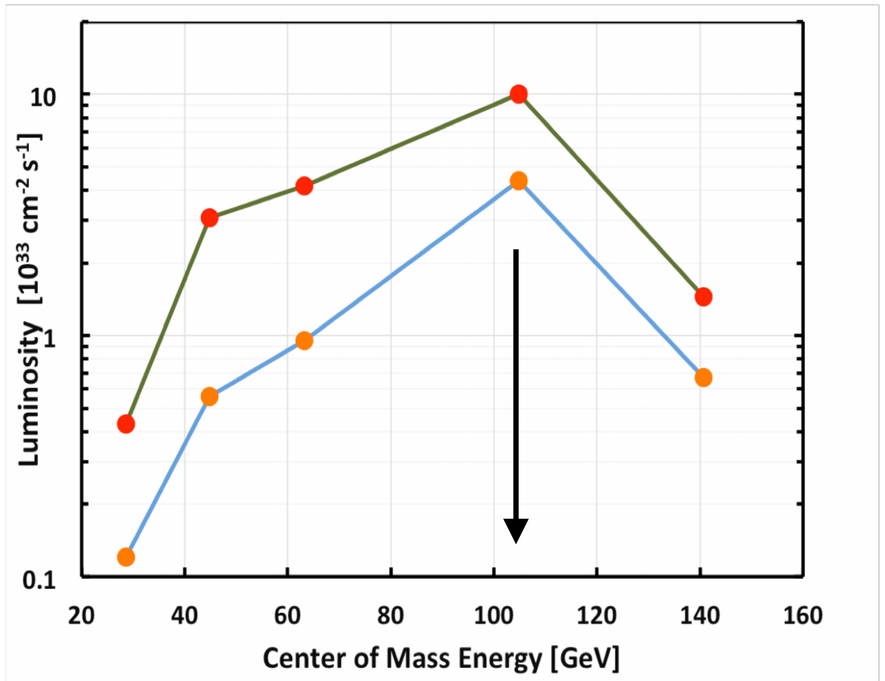
- IR is crucial part of machine and physics performance and needs
- Stringent requirements are (being) integrated in the EIC IR design
  - The IR with the forward detector system can cover physics needs for wide ranges of nucleon energies in ep and eA (50 - 275 GeV/nucleon)
- More detailed physics simulations and detector design studies with further optimization underway

backup

Interaction Region Requirements

	Hadron	Lepton
Machine element free region	$\pm 4.5\,\mathrm{m}$ main detector beam elements $< 1.5^o$ in main detector volume	
Beam Pipe	Low mass material, i.e. Beryllium	
Integration of detectors	Local Polarimeter	
Zero Degree Calorimeter	$40\,\mathrm{cm} \times 40\,\mathrm{cm} \times 1\,\mathrm{m}$ @$s = 30\,\mathrm{m}$	
scattered proton/neutron acc. all energies for $e + p$	Proton: $0.18\,\mathrm{GeV/c} < p_T < 1.3\,\mathrm{GeV/c}$ Neutron: $p_T < 1.3\,\mathrm{GeV/c}$	
scattered proton/neutron acc. all energies for $e + A$	Proton and Neutron: $\theta < 6\,\mathrm{mrad}$ (for $\sqrt{s} = 50\,\mathrm{GeV}$) $\theta < 4\,\mathrm{mrad}$ (for $\sqrt{s} = 100\,\mathrm{GeV}$)	
Luminosity	Relative Luminosity: $R = L^{++/--}/L^{+-/-+} < 10^{-4}$	
		γ acceptance: $\pm 1\,\mathrm{mrad}$ $\rightarrow \delta L/L < 1\%$
Low Q^2-Tagger		Acceptance: $Q^2 < 0.1\,\mathrm{GeV}$

Interaction Region Requirements

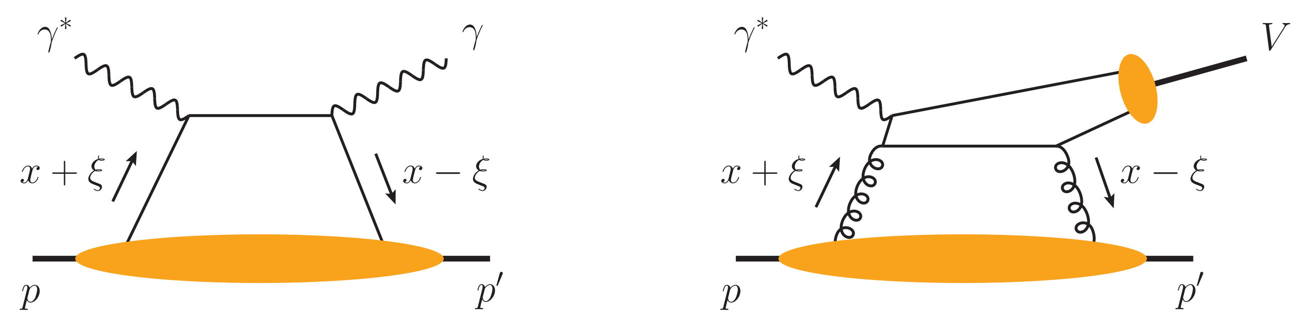


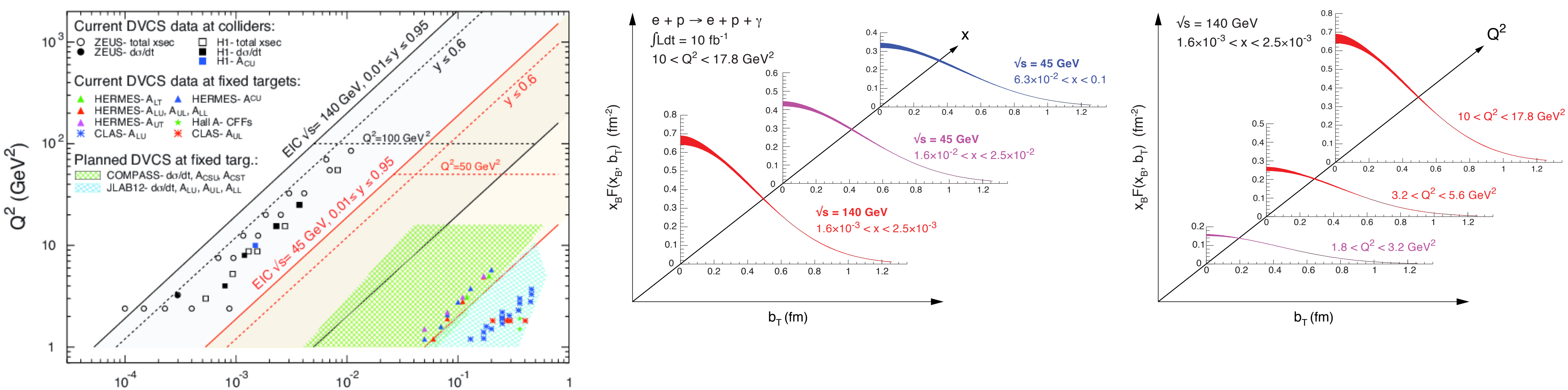
275 GeV (p) x10 GeV (e)

	Nominal Design (with cooling)			Risk Mitigation (no cooling)	
Species	p	e		p	E
Bunch frequency [MHz]	112.6			56.3	
Bunch intensity [10^11]	0.6	1.5		1.05	3.0
Number of bunches	1320			660	
Beam current [A]	1	2.5		0.87	2.5
Rms norm. emit. h/v [um]	2.7/0.38	391/20		4.1/2.5	391/95
Rms emittance h/v [nm]	9.2/1.3	20/1		13.9/8.5	20/4.9
β* h/v [cm]	90/4	42/5		90/5.9	63/10.4
IP rms beam size h/v [um]	91/7.2			112/22.5	
IR rms angular spread h/v [urad]	101/179	219/143		124/380	179/216
b-b parameter (/IP) h/v	0.013/0.007	0.064/0.099		0.015/0.005	0.1/0.083
Rms bunch length [cm]	5	1.9		7	1.9
Rms energy spread, 10^-4	4.6	5.5		6.6	5.5
Max space charge parameter	0.004	neglig.		0.001	neglig.
IBS growth time tr/long, h	2.1/2.0			9.2/10.1	
Polarization, %	80	70		80	70
Hourglass and crab crossing factor	0.87			0.85	
Peak luminosity [10^33 cm-2s-1]	**10.1**			**4.4**	
Integrated luminosity/week, fb^{-1}	**4.51**			**1.12**	

Hadron cooling provides ~factor 4 integrated luminosity increase at E_{CM}=105 GeV.
But larger increase, by factor 7-10, is expected in low range of E_{CM} (29-70 GeV).

Nucleon spatial imaging: Deeply Virtual Compton Scattering





Current data: Limited and mainly unpolarized data at low-*x*

- exclusive process with forward proton measured
- evolution of impact parameter transformed from measured *t*

P_t resolution for recoil protons (eRHIC)

- B0 magnet [100 GeV/c beam energy @ p_t ~ 1.3 GeV/c (worst case)]

  (~1.3T field, ~1.2m long; 4 Si stations with ~20μm resolution; Kalman filter)
  - ~30 MeV/c without IP vertex constraint
  - ~15 MeV/c with reasonable assumptions about beam envelope size at the IP

- Roman Pots [275 GeV/c beam energy]

  (2 stations ~30m from IP, 20cm apart, ~20μm resolution; matrix transport)
  - ~20 MeV/c at φ ~ 0 degrees (recoil in horizontal plane)
  - ~10 MeV/c at φ ~ 90 degrees (recoil in vertical plane)

NB: these estimates do not include beam divergence at the IP