Physics with forward processes at EIC

C. Weiss, Yu. Furletova, IR2@EIC: Science and Instrumentation of the 2nd IR for the EIC, 17-Mar-2021

Forward physics with EIC

Processes in ep, eA(light), eA(heavy)

Physics objectives

Forward detection requirements

Interest, novelty, support

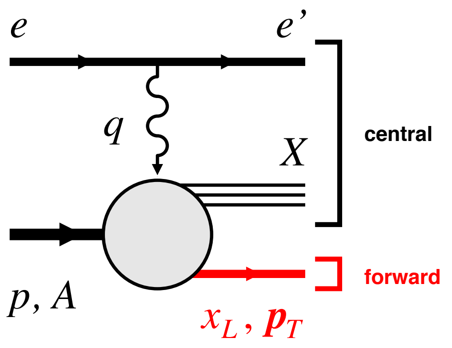
Forward detection at IR2

Design considerations and challenges

Complementarity directions

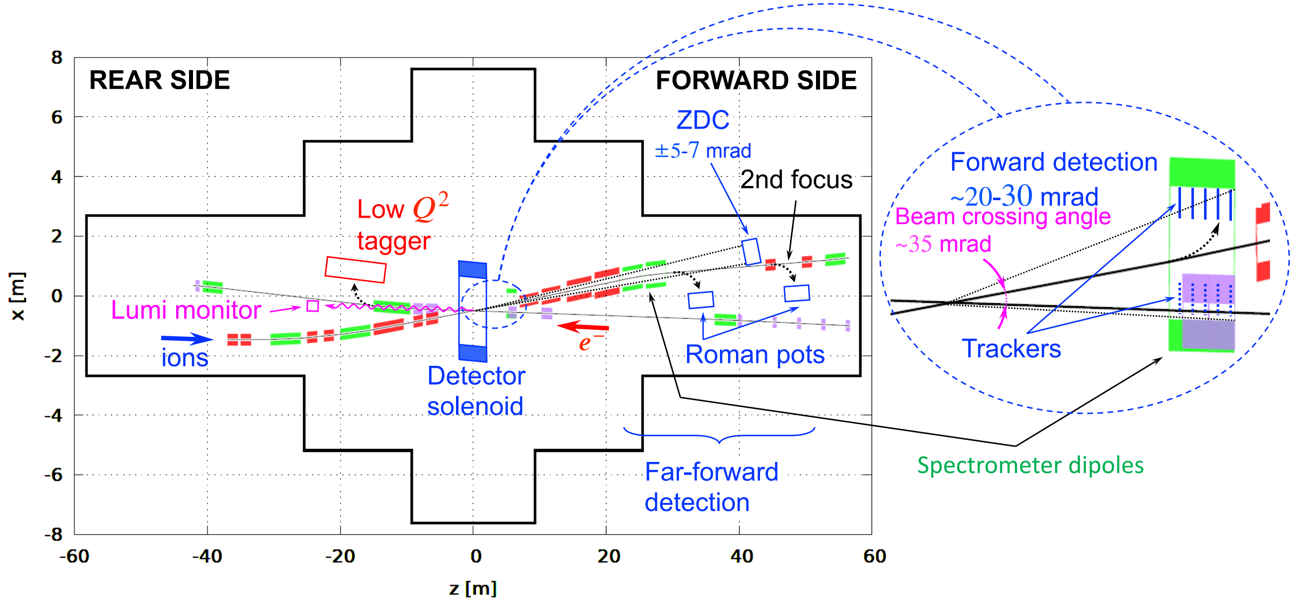
→ V. Morozov, Thu

[This presentation: Basis for discussion/assessment of IR2 options, not specific proposal]



x_L — longitudinal momentum fraction relative to proton/ion beam

p_T — transverse momentum relative to proton/ion beam → angle θ



Forward in ep: Exclusive processes

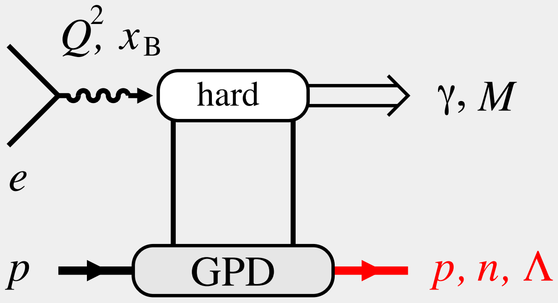
DVCS, TCS and light meson production

Physics: GPDs, transverse imaging of quarks/gluons, energy-momentum tensor form factors, angular momentum, QCD forces [→ X. Ji, this session]

Detection: Proton x_L = [~0.5, 0.999]
p_T = [0, ~2 GeV], δp_T ~ 100 MeV

Neutron detection "as good as possible"
Λ, Σ^0 for strange meson production K, K*

Interest: Major program at JLab12 and EIC, theoretical/computational developments.
Extensive studies for IR1 [A. Jentsch et al]



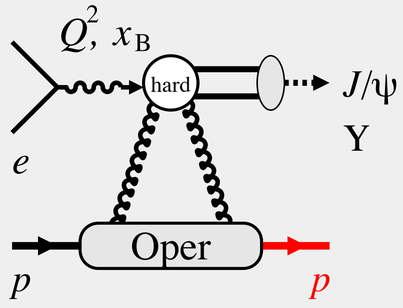
Heavy quarkonium production

Physics: Gluonic structure at small and large x. Near-threshold: local operators, trace anomaly, "origin of mass". Spectroscopy.

Detection: Protons x_L <~ 0.5 for large-x/near-threshold regime
p_T = [0, ~2 GeV]

Interest: Growing community, theoretical developments.
Workshop ANL Jan 2021
[Webpage]

EIC YR simulations
[S. Joosten et al → Thu]



Baryon resonance production

Physics: DVCS/meson production with N → N* transition, e.g. N → Δ.
Transition GPDs, QCD structure of resonances

Detection: Forward N + π, N* reconstruction

Interest: EIC Spectroscopy Workshop ECT* 2018 [Webpage]

Forward in ep: π/K structure, N fragmentation, u-channel

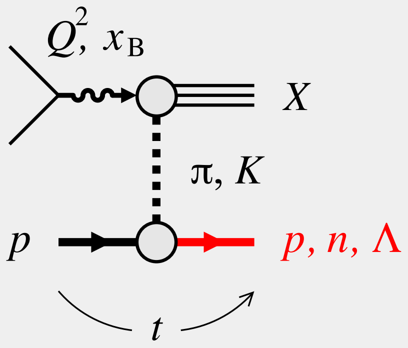
Pion/kaon structure

Physics: Structure of Goldstone bosons of chiral symmetry breaking in QCD → "origin of mass"

Detection: Proton x_L ~ 0.7-0.99
p_T = [0, ~1 GeV], δp_T ~ 100 MeV

Neutron for p → π^+ + n
Λ, Σ^0 detection for p → K + Λ; large Λ decay length

Interest: Sizable community. Workshop CFNS Jun 2020 [Webpage]
YR simulations [T. Horn et al]

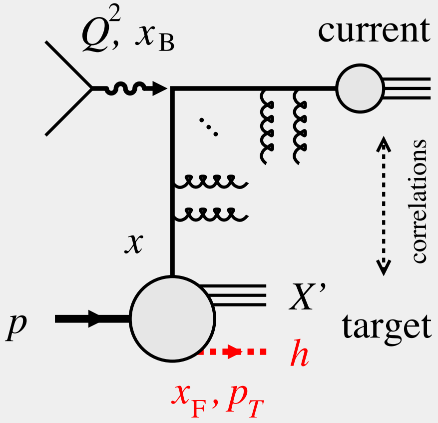


Nucleon or target fragmentation

Physics: Multiparton correlations in QCD, hadronization dynamics, diffraction, nuclear final-state interactions

Detection: Forward protons/neutrons/pions: x_F ~= x_L ~ 0.1-1
Continuous η coverage between forward and central

Interest: Workshop CFNS Sep 2020 [Webpage]
YR topic [C. Weiss et al]

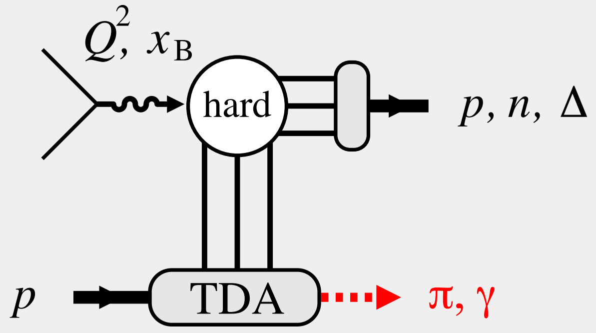


u-channel processes

Physics: TDAs, baryon Regge trajectories, baryon number transport

Detection: Forward π+, π- and π0/γ, includes negative charge

Interest: Dedicated group
Workshop JLab Sep 2020 [Webpage],
YR simulations [Wenliang Li et al]



Others apps: Elastic scattering

Forward in eA(light): Spectator tagging, coherent processes

Spectator tagging with light ions

Physics: Neutron structure PDF/GPD/TMD, spin, flavor

Nuclear interactions: NN short-range correlations, non-nucleonic DoF

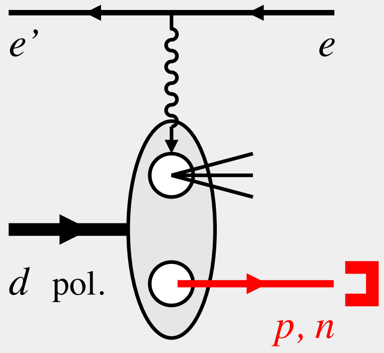
Nuclear modifications of partons: EMC effect incl. sea quarks, gluons, spin/flavor; antishadowing; shadowing [→ I. Cloet]

Detection: Protons with $x_L \sim (0.5 - 1.5)/A$, $p_T = [0, \sim 500$ MeV$]$, $\delta p_T < 50$ MeV

Neutrons with p_T ~< 500 MeV, "as good as possible"

Interest: Large active community, many events. EIC Workshop CFNS Jan 2020 [Webpage]

Simulations for IR1 and YR: [K. Tu et al, A. Jentsch et al → Thu, Dien Nguyen et al]



Coherent scattering on light ions

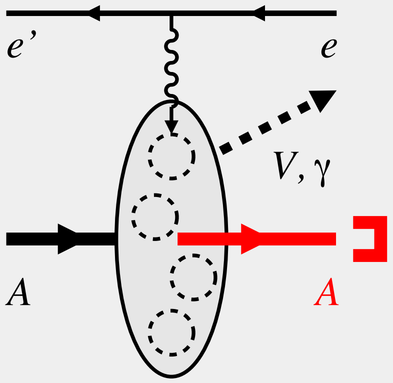
Physics: Imaging nucleus as quark/gluon system, matter vs charge distribution, shadowing and multiple scattering with N = 2, 3, … nucleons

Detection: Nucleus with $x_L \sim 0.8$-0.999, $p_T = [0, \sim 700$ MeV$]$, $\delta p_T < 50$ MeV

Angular acceptance at $\theta \to 0$ much more demanding than in exclusive processes on proton

Interest: Growing community, Meeting March 2020 [Webpage]

Simulation tool development in progress [R. Dupre, S. Scopetta, S. Fucini et al]



Forward in eA(heavy): Nuclear breakup, coherent processes

Nuclear breakup in hard processes

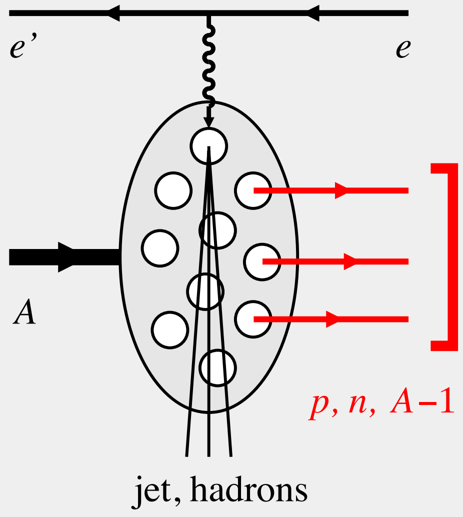
Physics: Interaction of jet/hadrons with nuclei medium, understanding of hard probes for heavy-ion collisions, centrality determination from breakup

Input for neutrino-nucleus interactions
Generation of unstable isotopes (?)

Detection: Protons/neutrons with $x_L \sim 1/A$, $p_T \sim< 100$ MeV
possibly fragments with A' < A, Z' < Z

Interest: Diverse community, connections with neutrino and heavy-ion physics. Workshop CFNS Sep 2020 [Webpage]

Simulations: FLUKA, BeAGLE [M. Baker et al]



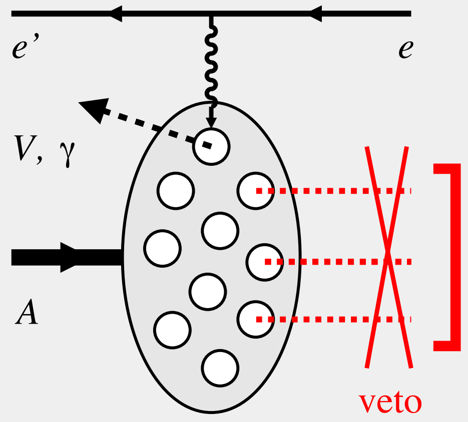
Coherent scattering on heavy ions

Physics: Transverse gluon profile of nucleus, nuclear shadowing, soft-hard transition

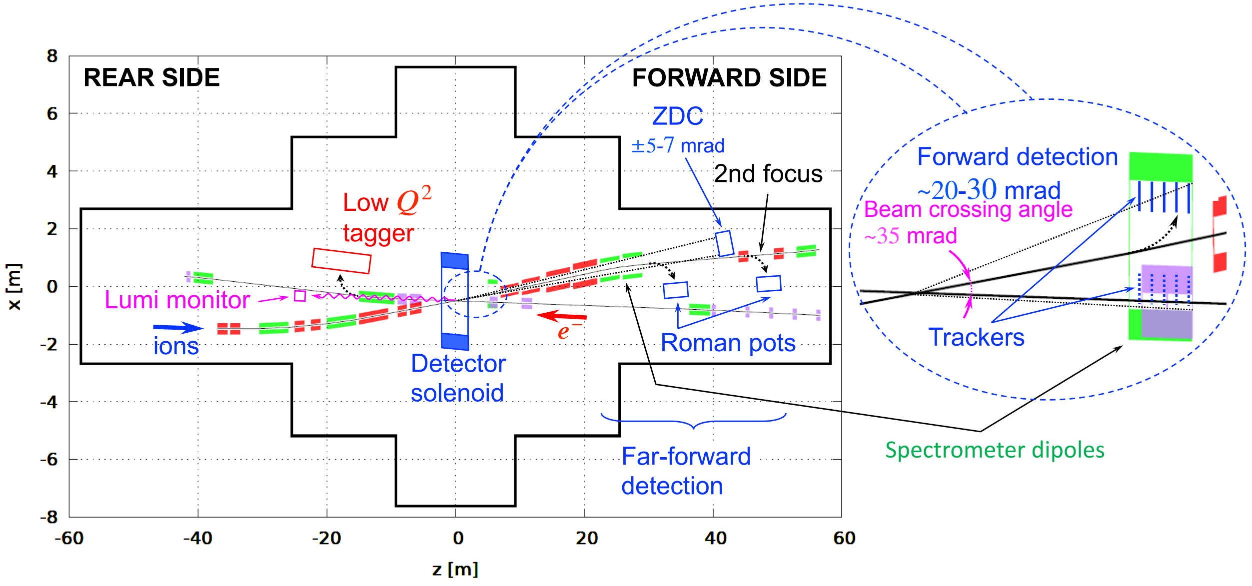
Detection: Veto of protons/neutrons with $x_L \sim 1/A$
Photons from nuclear γ decays? Efficiency needed?

Interest: Growing community. Connections with ultraperipheral AA/pA collisions (LHC, RHIC)
Workshop U Kansas/JLab Jan 2020 [Webpage]

Simulations:
IR1 physics program.
YR simulations
[T. Ullrich et al,
S. Klein et al]



Forward detection at IR2: Design, complementarity



IR2 and forward detector schematic [V. Morozov et al. → Thu]

Forward cone: ±20-30 mrad before B0, ±5-7 mrad after FFQ

Spectrometer: Dipole magnets, dispersion

Charged detection: Roman Pots, off-momentum detectors, elements inside B0 dipole

Neutral detection: Zero-degree Calorimeter

Complex design problem

Variable Rigidity(forward)/Rigidity(beam)

Variable beam energies

Tradeoffs with luminosity optimization

Accelerator constraints: Beam return

Space constraints: Hall size, assembly

Engineering constraints: Magnets

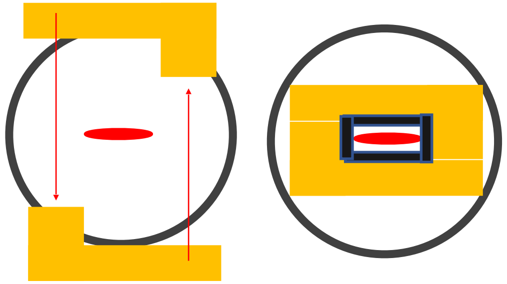
[IR1 summary: H. Witte, IP6 meeting]

Potential complementarity to IR1

- Secondary focus at Roman Pot location: Substantially improved acceptance at low p_T or θ
- Transition between Roman Pots and B0 detectors: Improved p_T - x_L coverage
- Spectrometer optimization at lower CM energies

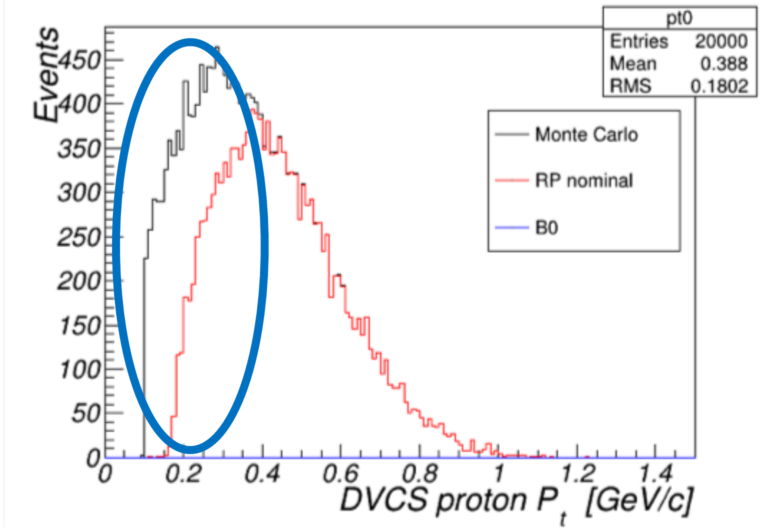
Forward detection at IR2: Secondary focus

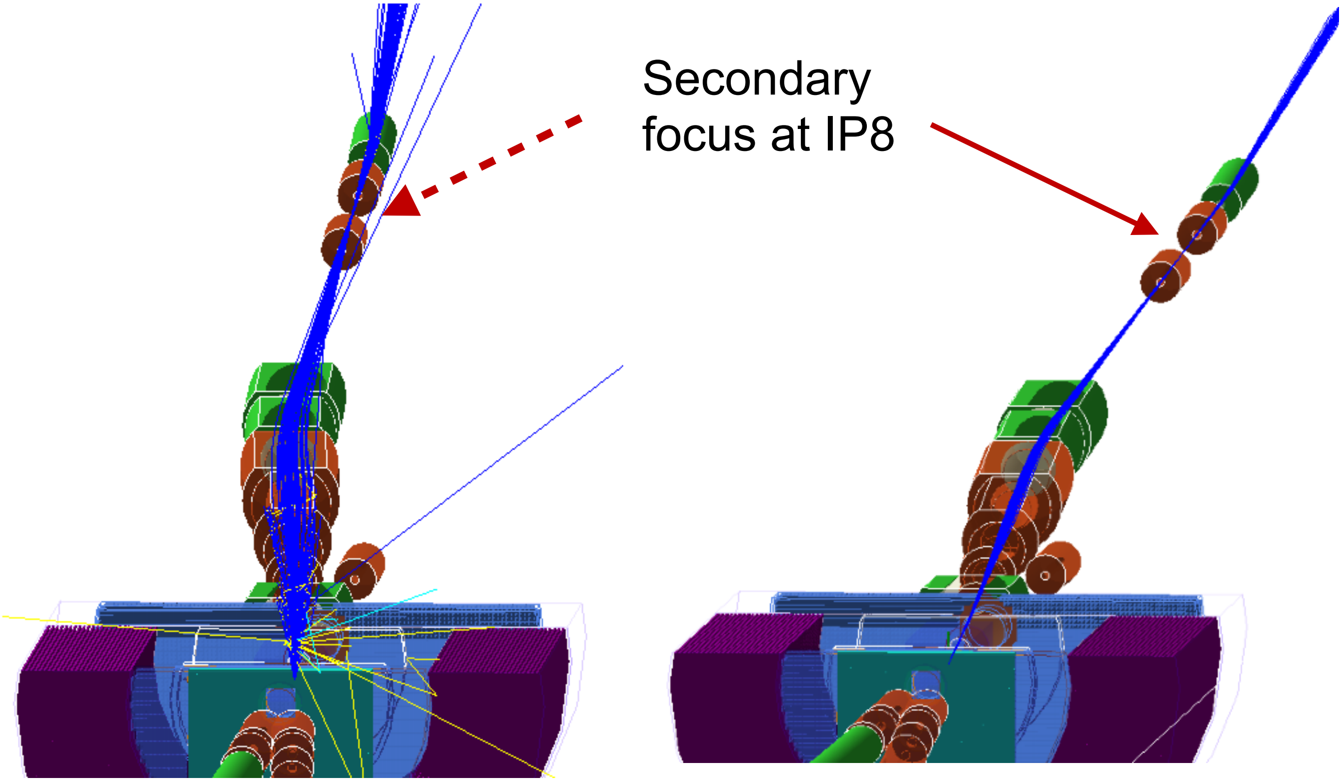
$$\sigma(z) = \sqrt{\varepsilon \bullet \beta(z))}$$



- Optics with secondary focus at Roman Pot location allows placement of detectors closer to beam
- Substantially improved coverage at pT ~ 0 for xL ~ 1
- Critical for coherent scattering on light ions
- Acceptance simulations on-going

DVCS IR1 18x275 GeV [A. Jentsch]





Forward processes: Summary

- Forward detection is an essential element of exploring hadrons and nuclei as emergent phenomena of QCD. New ideas/processes/methods beyond EIC White Paper and NAS Study are being pursued → Yellow Report, Workshops

- IR2 interaction region and far-forward detector design developing [→ V. Morozov, Thu]

- Clear directions for complementarity to IR1 are emerging, especially the secondary focus and optimization for lower CM energies

- IR2 collaboration(s) should pursue the far-forward detector design both as a necessity and as an opportunity

- The idea of a **large-acceptance far-forward detector at EIC** is conceptually new and goes beyond all previous collider experiments

Supplementary material

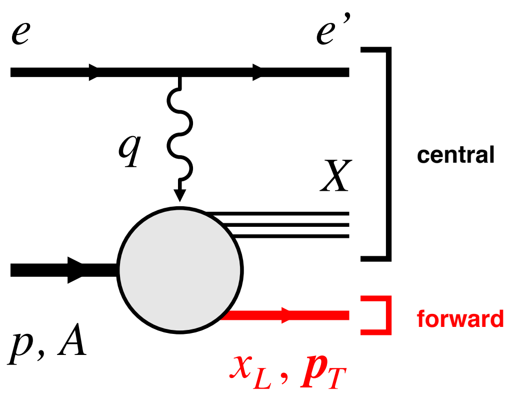
Physics: Kinematic variables in forward processes

Physics variables

xL — longitudinal momentum fraction with respect to proton/ion beam

pT — transverse momentum with respect to proton/ion beam -> angle θ

(1 - xL) ~ x(Bjorken) ~ 2ξ in exclusive processes ("skewness").
Coverage/resolution requirements specified in (1 - xL).



Connection with detection angle

θ = pT / pL(forward)   For processes with (1-xL) << 1: θ ~= pT / p(beam)

Angle depends on beam momentum and therefore on mass of beam/forward particle

Example: Proton beam 100 GeV: pT = 100 MeV -> θ = 1 mrad

Example: 4He beam with 50 GeV/u: pT = 100 MeV -> θ = 0.5 mrad

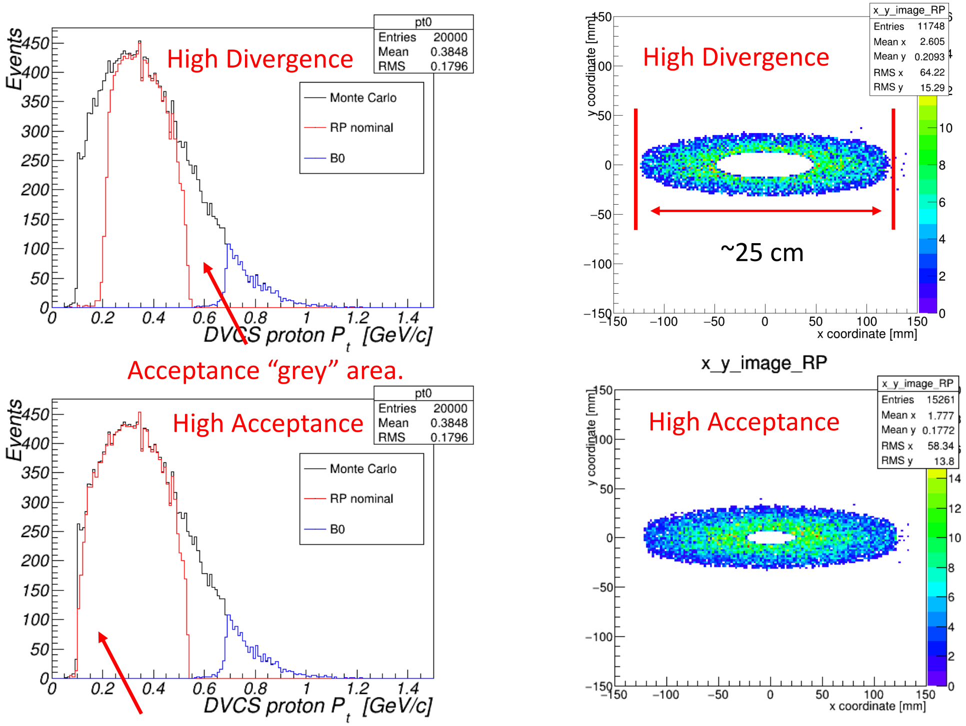
Same angular acceptance limit has different impact on processes with forward protons and ions!

Physics: Detector requirements in forward processes

Processes	Beam -> Fwd	Rigidity Fwd/Beam	Coverage	Resolution (Charged)	Neutrals	Comments
Exclusive & diffractive scattering on proton	p -> p, n	1	pT = [0, ~2 GeV] xL = [~0.5, ~0.999] 1-xL = [~1E-3, ~0.3]	ΔpT ~ 50 MeV ΔxL/xL << 0.1 Δ(1-xL)/(1-xL) < 0.1	n Λ, Σ0	Inelastic diffraction physics & background
Coherent scattering on light nuclei	A -> A (A = D, He)	1	pT = [0, ~700 MeV] 1-xL = [~1E-3, ~1E-1]	ΔpT ~20 MeV Δ(1-xL)/(1-xL) < 0.1	none	Ion beam divergence (pT spread) significant
Spectator tagging in deuteron	D -> p (n)	1/2	pT = [0, ~500 MeV] xL = [~0.25, ~0.75] xL relative to 1/2 deuteron beam momentum	ΔpT ~ 10-20 MeV ΔxL/xL << 0.1	(n)	Ion beam divergence (pT spread) significant
Breakup of light and heavy nuclei	A -> p, n, A-1	various	pT = [0, ~500 MeV] xL various	?	multiple n	Veto detection for heavy nuclei

Schematic classification of processes with estimated coverage/resolution requirements
Used in IR2 planning
Approximate numbers, to be updated through simulations, evolving

Physics: Forward acceptance for protons at IR1



DVCS on 100 GeV proton
A. Jentsch, Zero-Degree Physics Workshop, Stony Brook, Sep 2019

Exclusive scattering on proton

$e + p \rightarrow e' + M + p$ (M = meson, photon, X)

Physics objectives and kinematics

- GPDs/Quark-gluon imaging, $p_T = [0, \sim 1.5$ GeV], $1\text{-}x_L \sim 10^{-3} - 10^{-1}$
- Diffractive scattering $p_T = [0, \sim 2$ GeV], $1\text{-}x_L < 10^{-2}$

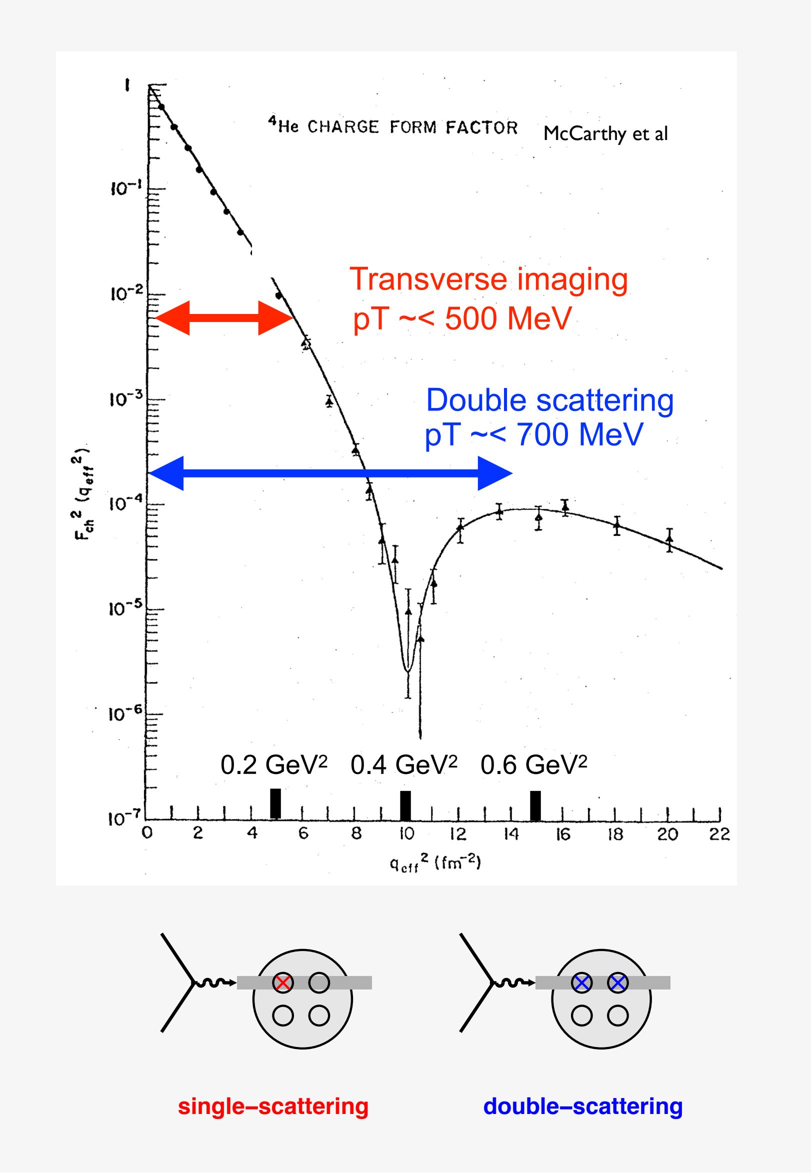
Forward acceptance requirements

- Detection down to $p_T \sim 100$ MeV

Limitations from IR1 and baseline detector

- IR1 acceptance limit $\theta > O(1$ mrad) from RP 10σ distance implies $p_T > 100$ MeV for 100 GeV protons
- Combination of high-acceptance and high-divergence modes
- IR2 limits -> V. Morozov

Physics: Coherent scattering on light ions



Coherent scattering on light ions

$e + A \rightarrow e' + M + A$,   (A = d, 3He, 4He)

Physics objectives and kinematics

- Quark/gluon imaging of nucleus, p_T = [0, ~500 MeV], 1-x_L ~ 10^{-3} - 10^{-1}
- Double scattering, nuclear shadowing, p_T = [0, ~700 MeV] (Strikman et al 2020)

Forward acceptance requirements

- Detection down to p_T = 0 essential on scale of ~50-100 MeV
- Example: 4He form factor $F^2 \sim \exp(-p_T^2/\Lambda^2)$, $\Lambda \sim 200$ MeV

Limitations from angular acceptance

- Acceptance limit θ > O(1 mrad) [IR1 baseline detector + 10σ RP] would imply p_T > 200 MeV for 4He at 50 GeV/u
- *Not sufficient for coherent scattering physics*
- Need angular acceptance down to ~0.25-0.5 mrad [IR2 secondary focus]

Complementarity: Transition B0 - Roman Pots

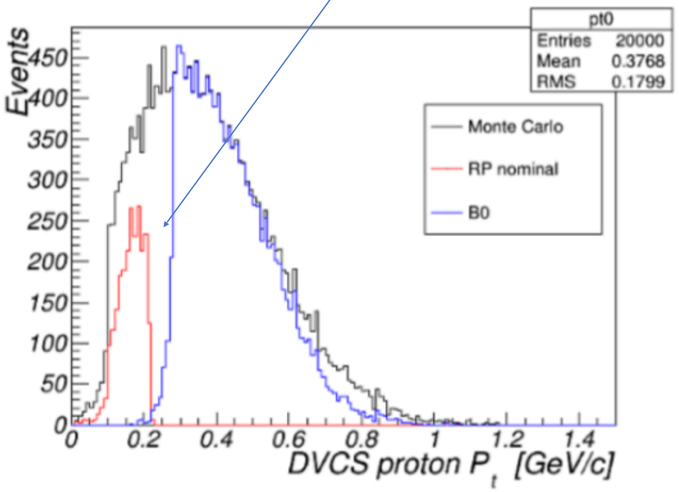
Complementarity option: Transition between Roman Pots and off-momentum detectors in B0

Alter beam pipe size in IR2 B0 off-momentum detector to change the kinematic gap between B0 and RP coverage (currently theta ~ 5mrad). Should not affect apertures for smaller pipe in first dipole.

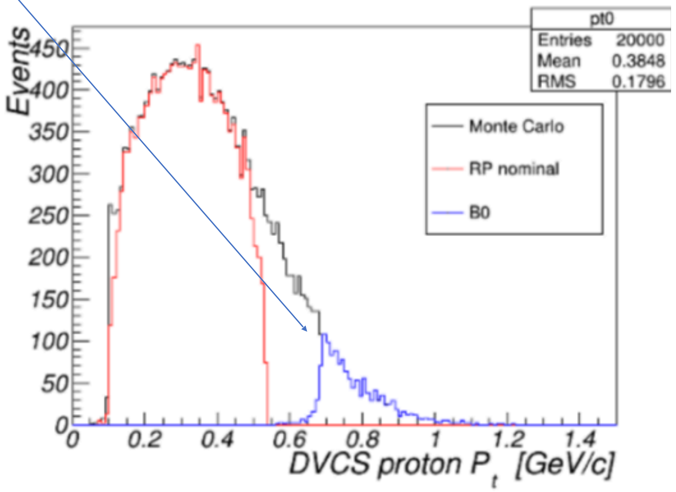
IP1 B0 coverage (5.5 < θ < 20.0 mrad)

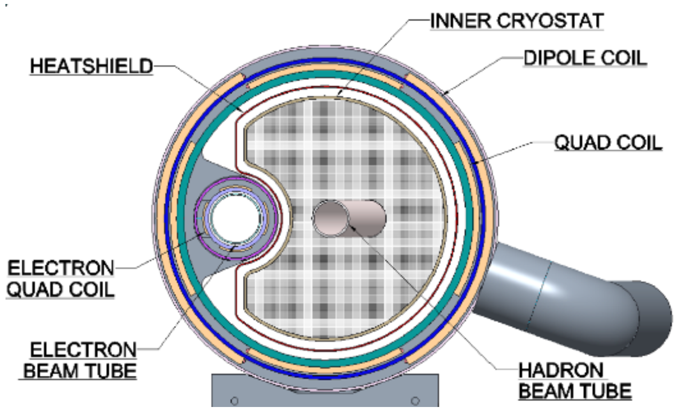
IP1 RP coverage 0.0* (10σ cut) < θ < 5.0 mrad

(DVCS) 5 GeV x 41 GeV



10 GeV x 100 GeV (DVCS)





Need both detector systems together here!

Weiss, Furletova, Far-forward processes, IR2 Workshop 17-March-2021