Polarized D at the EIC

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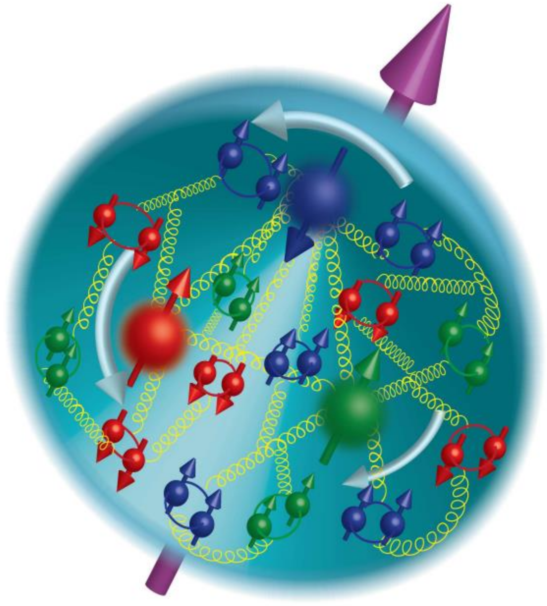
10/14/2025

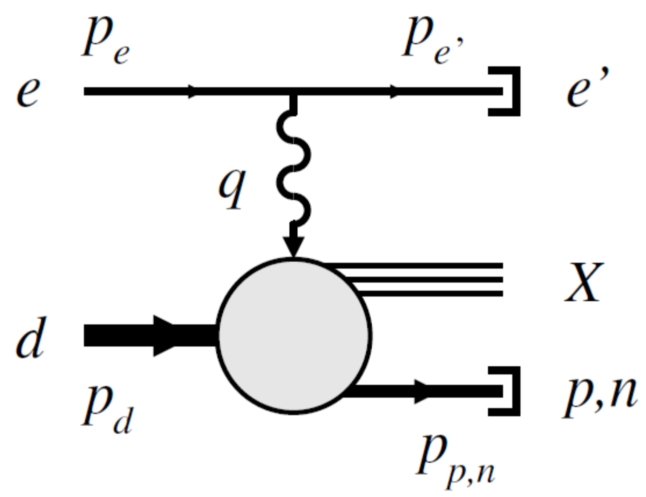
PHYSICS MOTIVATION

- Main motivation: Understanding of internal structure of nucleons
- Historically was studied via Deep Inelastic Scattering (DIS) on protons
  - Relatively experimentally easy as we can accelerate electrons or protons
  - Structure functions and Parton Distribution Functions (PDFs) of proton reasonably well known
  - Despite long experimental efforts, still many open questions:
    - Spin structure of nucleons, Transverse and Generalized PDFs…
- We need also to need to measure **neutron internal structure** for full understanding of nucleon internal structure and QCD in general
  - Extraction of structure function F_2 of neutron
- Main challenges:
  - Neutrons are neutral and cannot be easily accelerated
  - Generally difficult to handle free neutrons



EXPERIMENTAL METHOD OVERVIEW

- Possible experimental solution: **Tagged DIS (TDIS)**
  - DIS on deuteron (d)
  - Measurement of the scattered electron and the spectator p or n
- **Challenges:**
  - Neutron is bound and not free, but we are interested in free n structure functions
    - Possible solution – pole extrapolation
  - Detection of the spectator p or n
    - Very difficult in fixed target experiments, as spectators have very low momentum and generally will stay in the target
    - Possible to measure at collider, such as the future Electron Ion Collider (EIC), as "target" is boosted
      - Still challenging, as spectators are very close to the hadron beam
- **Advantages:**
  - Straightforward, when spectators are successfully detected
  - Possible to measure p and cross-check with standard methods



A. Jentsch, Z. Tu, Ch. Weiss: Phys. Rev. C **104**, 065205.

DEUTERON REDUCED CROSS SECTION

- Differential cross section on d can be written in terms of deuteron reduced cross ($\sigma_{red,d}$) section and photon flux:
  - $\mathrm{d}\sigma_d = Flux(x, Q^2) \times \sigma_{red,d} \times \frac{\mathrm{d}x}{2} \mathrm{d}Q^2 \frac{\mathrm{d}\phi_{e'}}{2\pi} [2(2\pi)^3]^{-1} \frac{\mathrm{d}\alpha_p}{\alpha_p} \frac{\mathrm{d}p_{pT}^2}{2} \mathrm{d}\phi_p$

- We can get the n reduced cross section ($\sigma_{red,n}$) from the d reduced cross section and pole of d spectral function
  - $\sigma_{red,n} = \frac{\sigma_{red,d}(x,Q^2)}{[2(2\pi)^3] S_d(p_{pT},\alpha_p)[pole]}$
  - And similarly for proton reduced cross section

- Light-cone momentum fraction:
  - $\alpha_p \equiv \frac{2p_p^+}{p_d^+} = \frac{2(E_p + p_{z,p})}{M_d}$

- Proton transfer momentum
  - $p_{pT} = \sqrt{p_{x,p}^2 + p_{y,p}^2}$

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M. Strikman and C. Weiss: Phys. Rev. C **97**, 035209.
C. Weiss and W. Cosyn: Phys. Rev. C **102**, 065204.

DEUTERON REDUCED CROSS SECTION

- Scattered electron
- Spectator proton + struck deuteron
- Photon flux

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POLE EXTRAPOLATION METHOD

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- $\sigma_{red,n}$ at the pole corresponds to a free n
  - $p_{pT}^2 \to -\alpha_T^2$ which means negative (unphysical) p_{pT}^2

- Solution is to experimentally measure $\sigma_{red,n}$ as a function of p_{pT}^2 for small positive values and extrapolate to the pole
  - We are using DIS on bound n to extract F_2 of free n

- Same measurement can be done for p
  - Cross check with proton F_2 extracted with traditional method
  - Can be used to select optimal deuteron spectral function

- Deuteron spectral function
  - $S_d(p_{pT}, \alpha_p)[pole] = \frac{R}{(p_{pT}^2+\alpha_T^2)}$
  - Position of pole
    - $a_T^2 = m_N^2 - \alpha_p(2-\alpha_p)\frac{M_d^2}{4}$
  - Residue of spectral function
    - $R = 2\alpha_p^2 m_N \Gamma^2(2-\alpha_p)$

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POLE EXTRAPOLATION METHOD

- $\sigma_{red,n} = \frac{\sigma_{red,d}(x,Q^2)}{[2(2\pi)^3]S_d(p_{pT},\alpha_p)[pole]}$

- We can measure/calculate this
- External input from model/experiment

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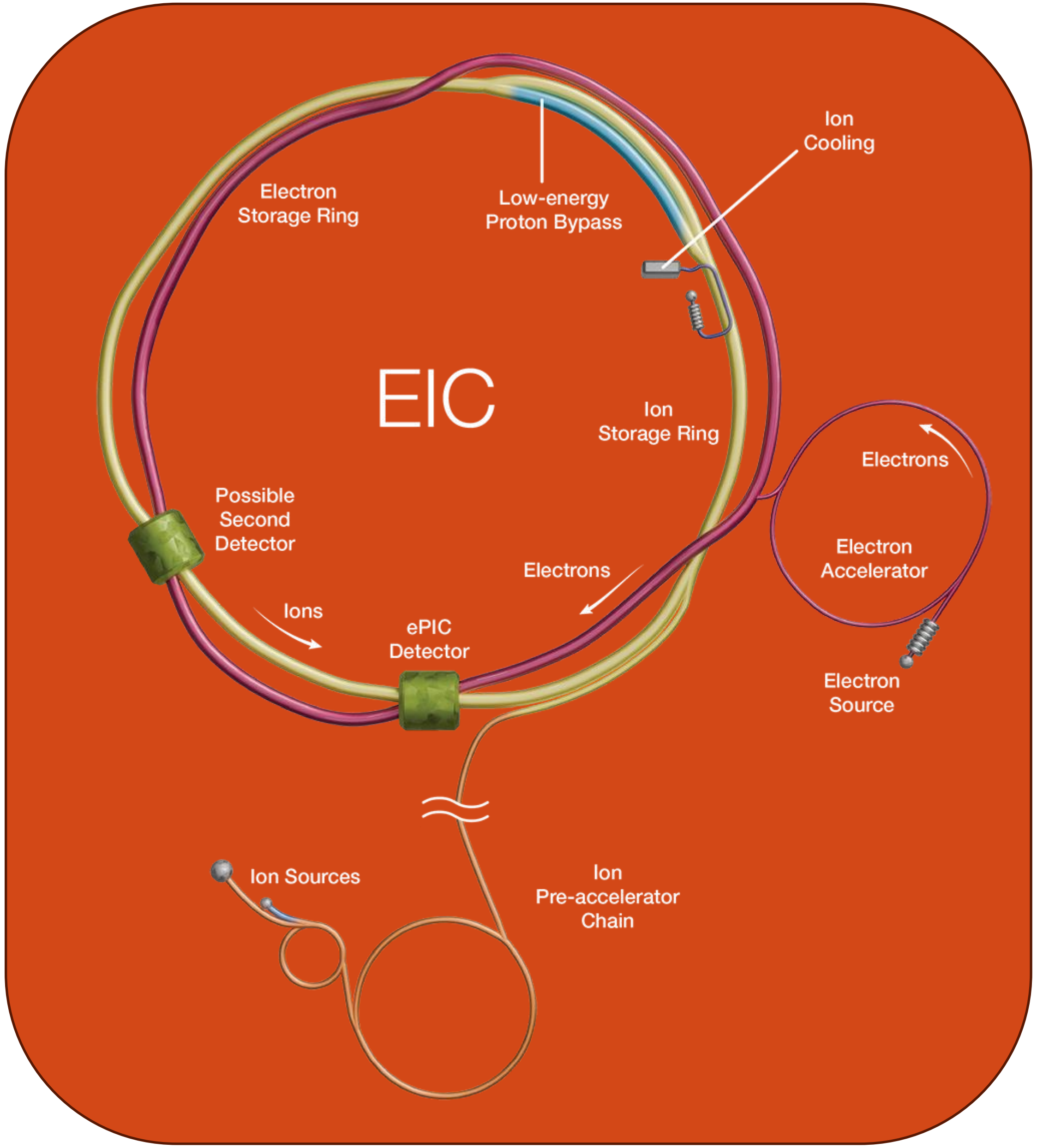
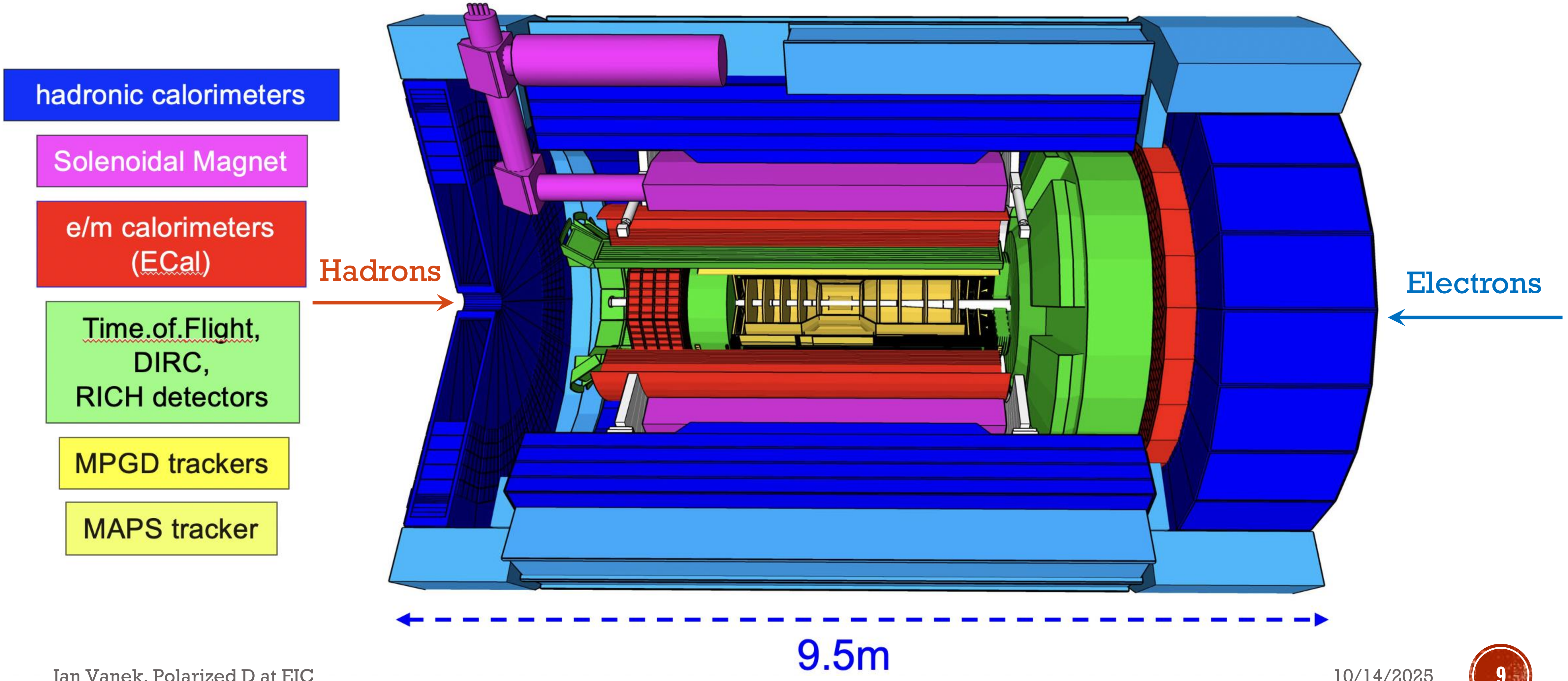
ELECTRON-ION COLLIDER

- Electron-Ion Collider (EIC) will be built in Brookhaven National Laboratory in the place of current Relativistic Heavy Ion Collider (RHIC)
- Hadron ring:
  - Upgrade of one of the existing RHIC rings
  - Possibility to accelerate wide range of hadrons
    - Protons, light nuclei (d, ^{3}He…), heavy nuclei (^{197}Au, ^{238}U…)
  - Protons and some light nuclei can be polarized
  - Large range of energies
    - From 41 GeV to 275 GeV for protons
- Electron ring:
  - Longitudinally polarized electrons
  - Continuous operation
    - One electron bunch replaced every second
  - Wide range of energies
    - From 8 GeV to 18 GeV

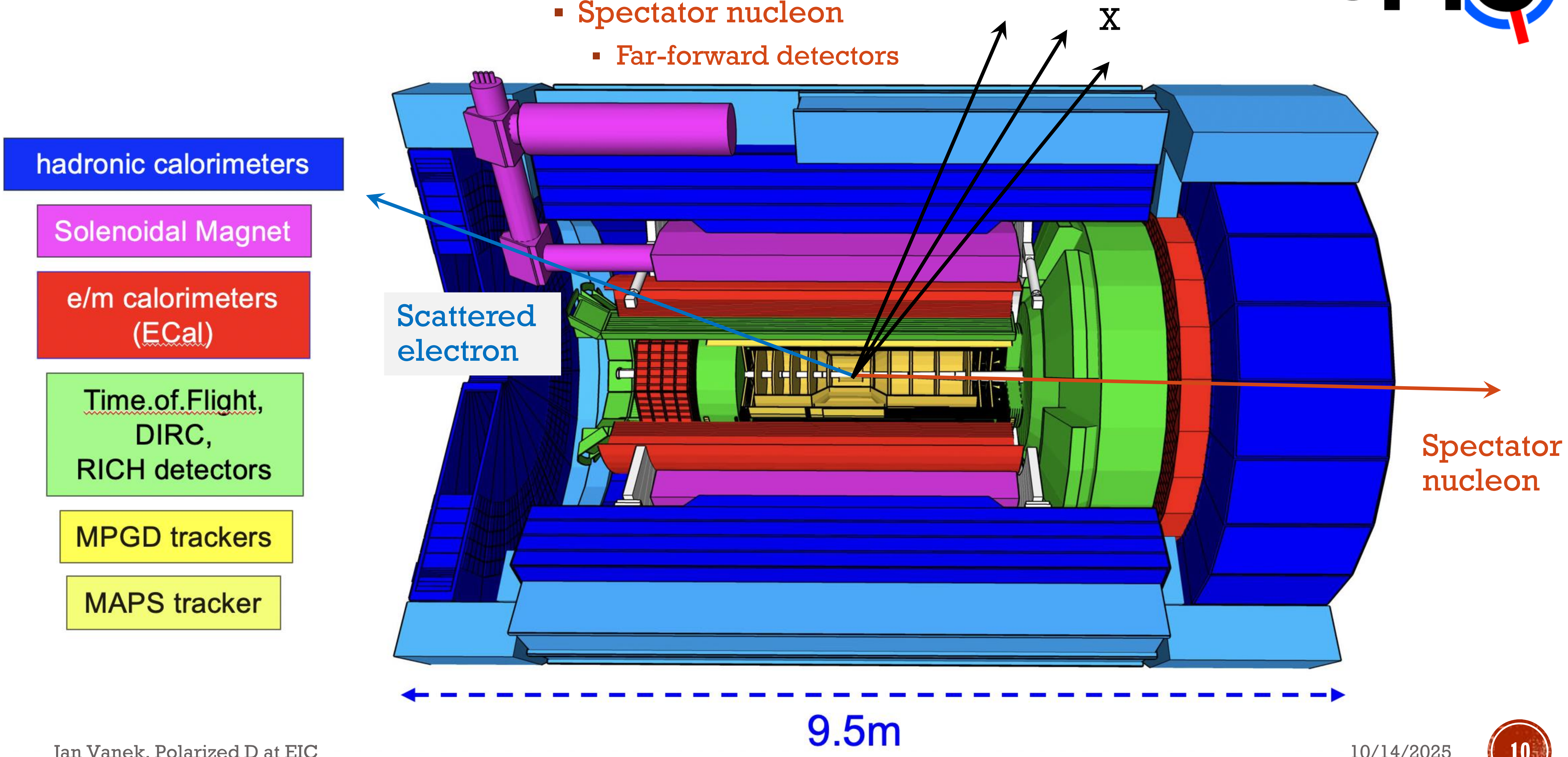


ePIC DETECTOR



ePIC DETECTOR

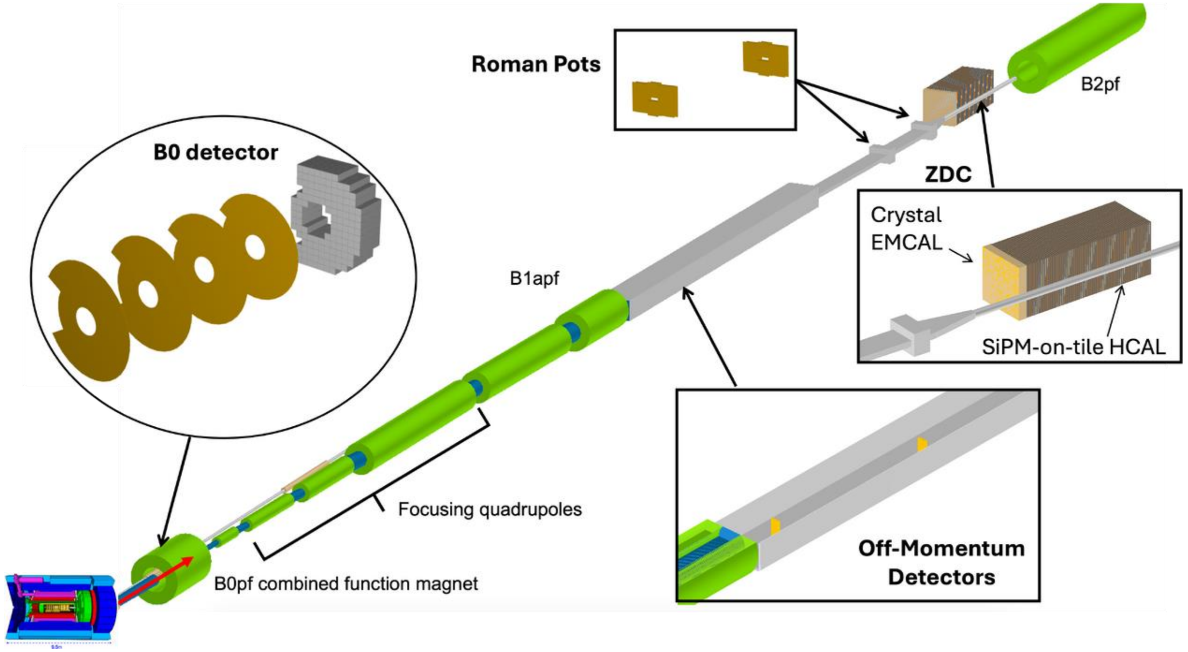
- What do we need for TDIS?
  - Scattered electron
    - Central barrel detectors
  - Spectator nucleon
    - Far-forward detectors



ePIC DETECTOR – FAR FORWARD

- Far-forward detector system for ePIC is designed to capture spectator hadrons which are very close to the beam

Detector	Hadron	Acceptance [mrad]
B0 Tracker	p	5.5-20.0
Off-momentum det.	p	0.0-5.0
Roman Pots	p	0.0-5.0
Zero Degree Calorimeter	n	0.0-4.0



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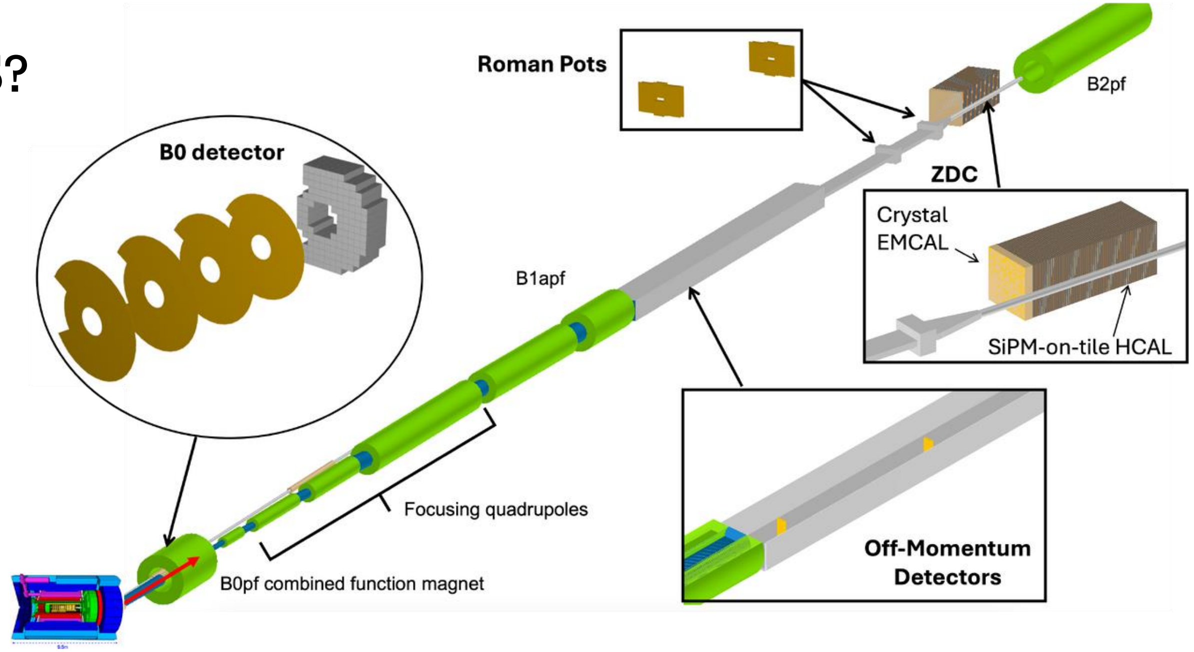
- What do we need for TDIS?
  - Off-momentum detector
    - Protons with $\sim {}^{1}/_{2}$ of beam energy
  - ZDC
    - Spectator neutrons



SIMULATION TOOLS

- **Event generator:** BeAGLE
  - **B**enchmark **eA G**enerator for **LE**ptoproduction
  - Key parts for deuteron simulation – PYTHIA 6.4 and deuteron light-front spectral function

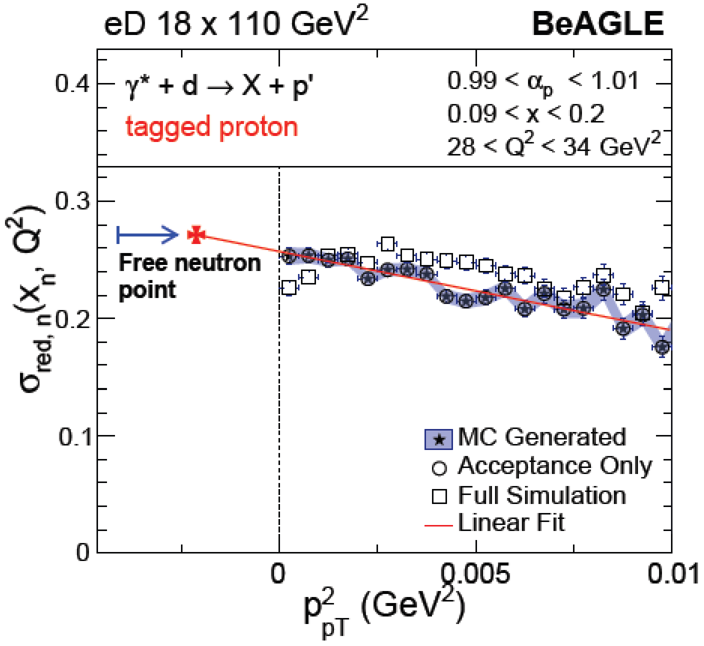
- **Detector simulations:** Full simulation using GEANT4

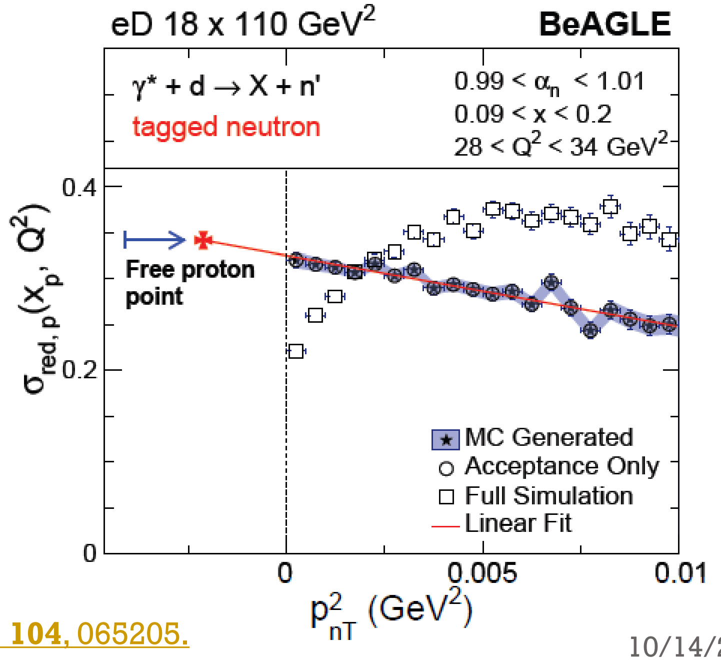
- **Reconstruction:** Transport matrix to calculate spectator momentum at interaction point from momentum at the detector
  - Currently tuned only to spectators with energy very close to $^1/_2$ of beam energy

Wan Chang, Elke-Caroline Aschenauer, Mark D. Baker, Alexander Jentsch, Jeong-Hun Lee, Zhoudunming Tu, Zhongbao Yin, and Liang Zheng: Phys. Rev. D **106**, 012007.

CURRENT RESULTS

- Reduced cross section of n (top) and p (bottom) extracted from MC eD collisions at $18 \times 110\ \mathrm{GeV}^2$
  - MC Generated
    - True MC level information, without any acceptance effects
  - Acceptance only
    - Only detector acceptance is considered
    - Here basically identical to true MC as for the class of true MC events used, all spectator n and p hit the corresponding far-forward detector and efficiency is assumed to be 100%
  - Full Simulation
    - All detector and efficiency effect are considered
- Pole extrapolation
  - Fit to the true MC as a proof of concept
  - Works well for true MC
  - More challenging for full simulation



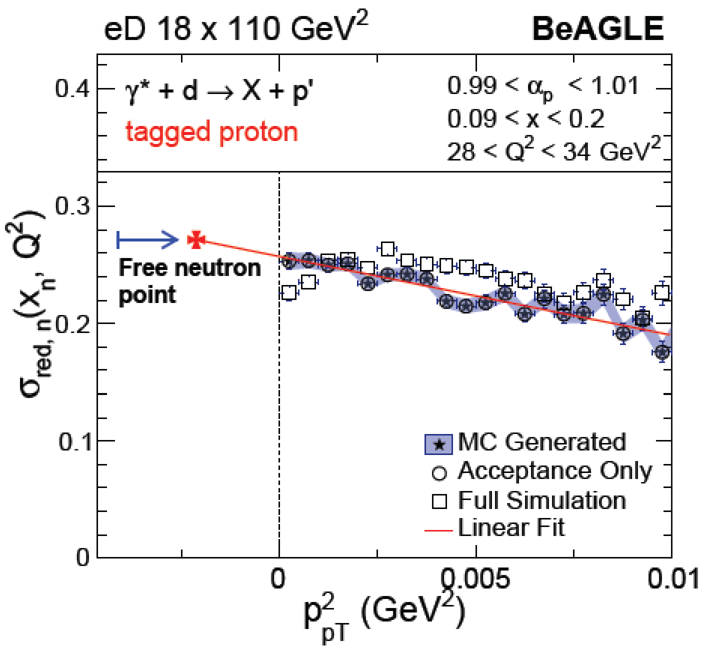


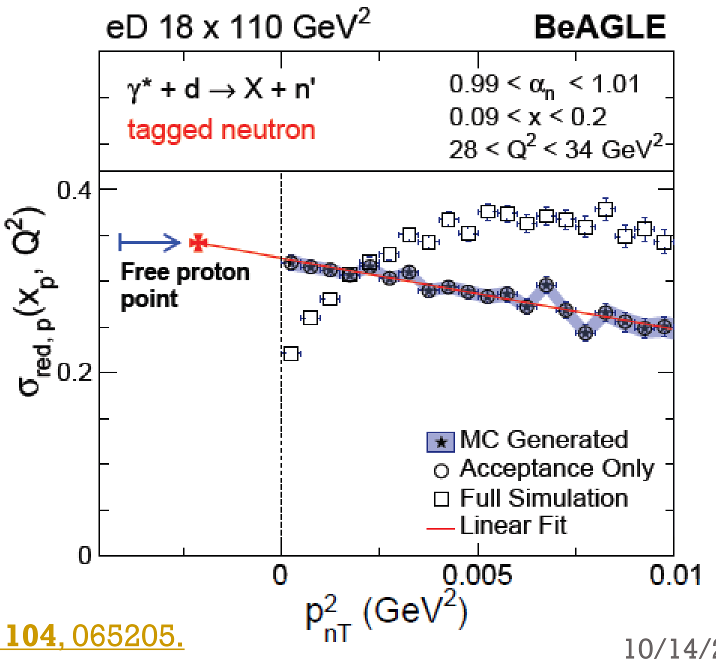
A. Jentsch, Z. Tu, Ch. Weiss: Phys. Rev. C **104**, 065205.

FUTURE PLANS

- New iteration of the presented study is being developed
  - Added full simulation of ePIC central barrel for electron reconstruction
  - Full integration of the whole simulation + reconstruction framework into ePIC simulation environment
  - Reconstruction of full kinematic range of spectator nucleons

- My involvement
  - Validation and checks of the new setup and cross-checks with the original results
  - Developing methods of signal extraction from Full Simulation level information
    - May require full unfolding procedure to correct for all efficiency and acceptance effects





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SUMMARY

- Future EIC will allow measurement of internal structure of neutron via measurement of Tagged DIS on deuterons
  - Measurement of scattered electron and spectator p
- Method can be validated by measurement of structure functions of proton and compare to traditional methods for proton
- Method was validated using a simulation framework combining BeAGLE event generator with detector acceptance
- New version of simulation framework which is fully integrated int ePIC simulation environment is being developed
  - My main involvement is validation of the new simulation setup

THANK YOU FOR ATTENTION