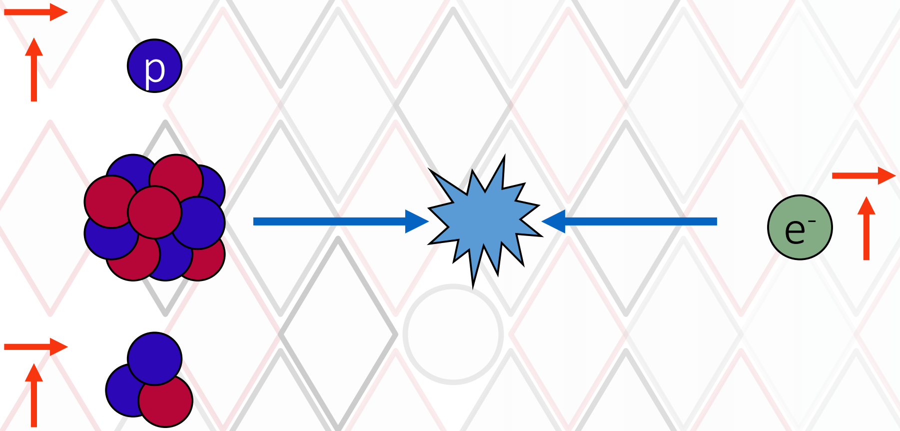
EIC Comprehensive Chromodynamics Experiment: ECCE

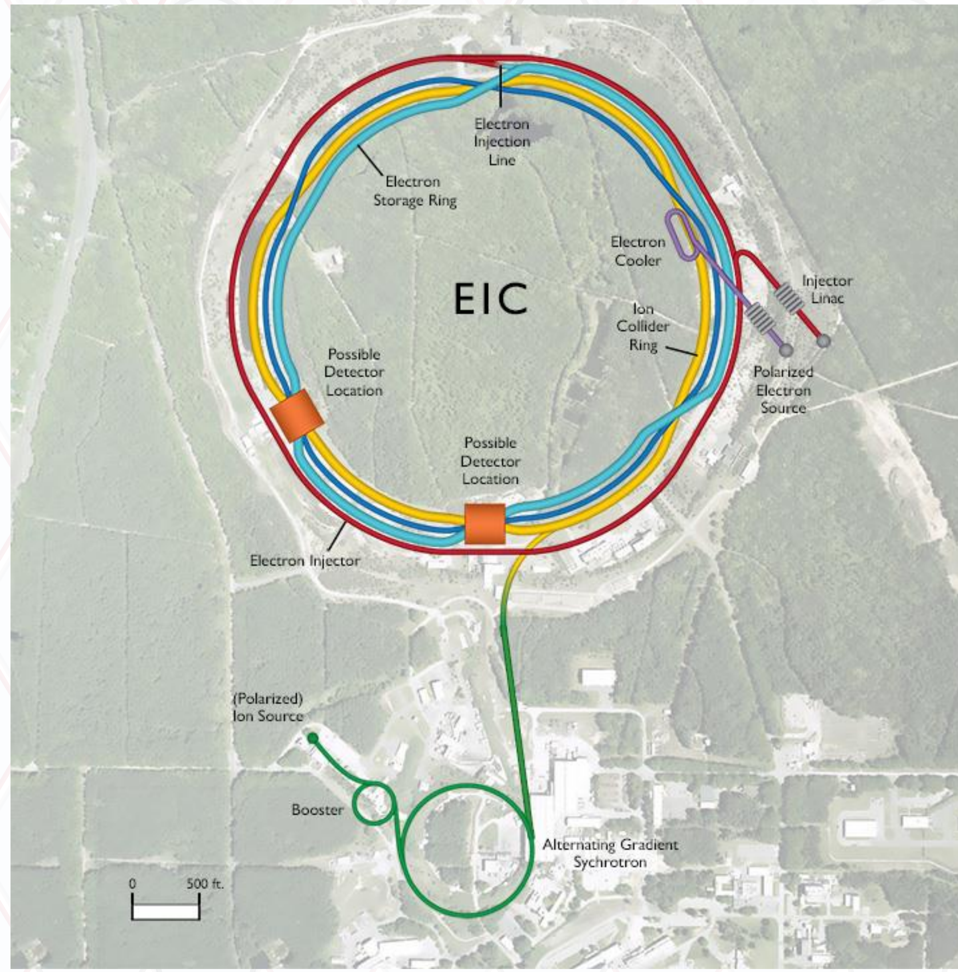
Sardinian Workshop on Spin, September 7

Ralf Seidl (RIKEN), for the ECCE Collaboration

EIC accelerator to be build at BNL



- 80% polarized electrons from 5-18 GeV
- 70% polarized protons from 40-275 GeV
- Ions from 40-110 GeV/u
- Polarized light ions 40 -184 GeV (He^3)
- 1000x HERA luminosities: 10^{33}-10^{34} cm^2s^{-1}
- CMS energies $\sqrt{s}$ = 29 – 140 GeV
- CD1 obtained in July 2021



SIDIS Measurements

Spin of the nucleon:

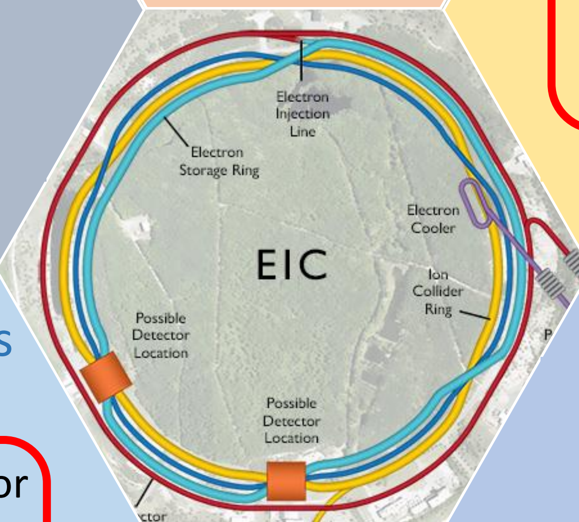
- Gluon spin
- Role of Sea quarks

QCD at high gluon densities

- Saturation effects

Tomography :

- 3D momentum structure (q, g Sivers, Tensor charge, TMD Evolution)
- 3D spatial structure



Nucelar effects

- Nuclear PDFs
- Passage of color through nuclear matter (nFFs, pT broadening)

Origin of the Mass

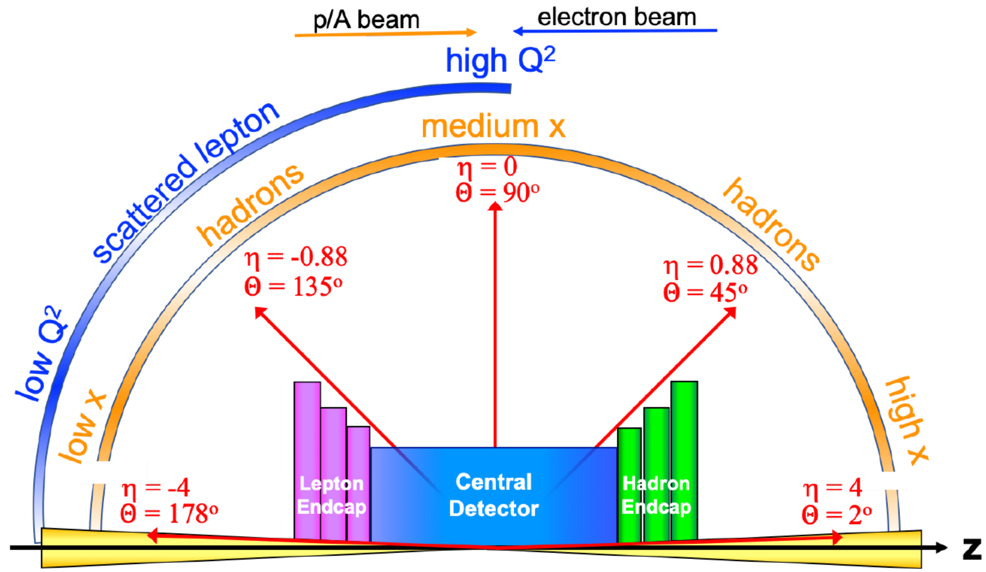
- Axial anomaly contributions
- Hadron structure

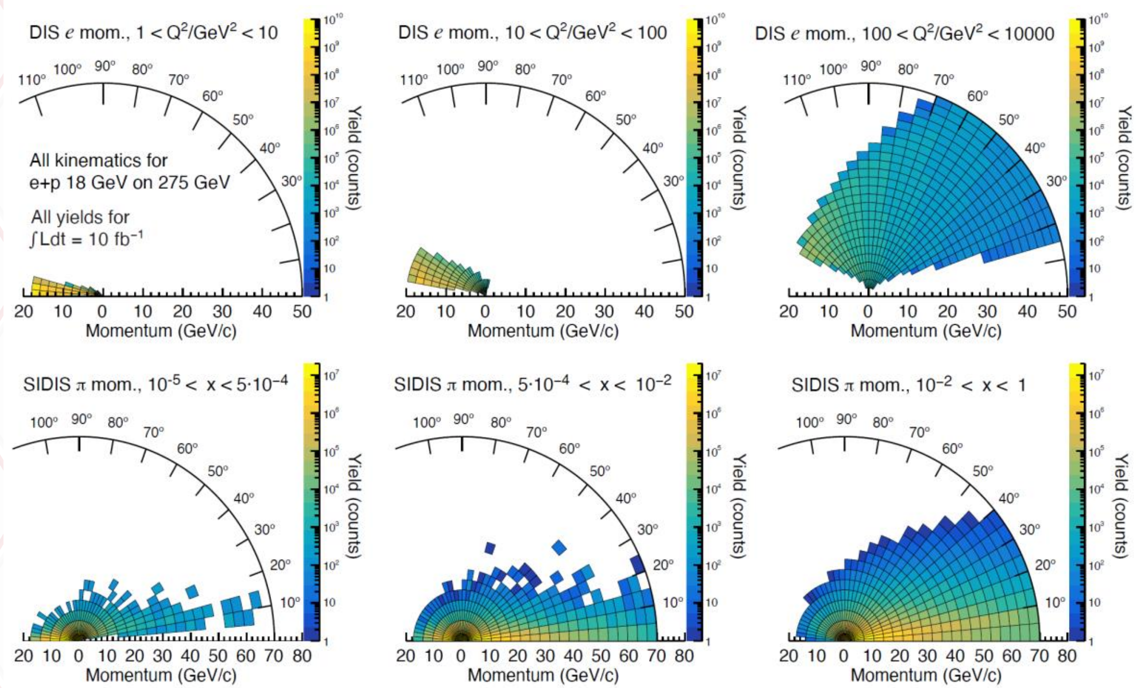
Other

- Spectroscopy (XYZ)
- EW physics
- Fragmentation
- Unpol PDFs

General (SI)DIS kinematics

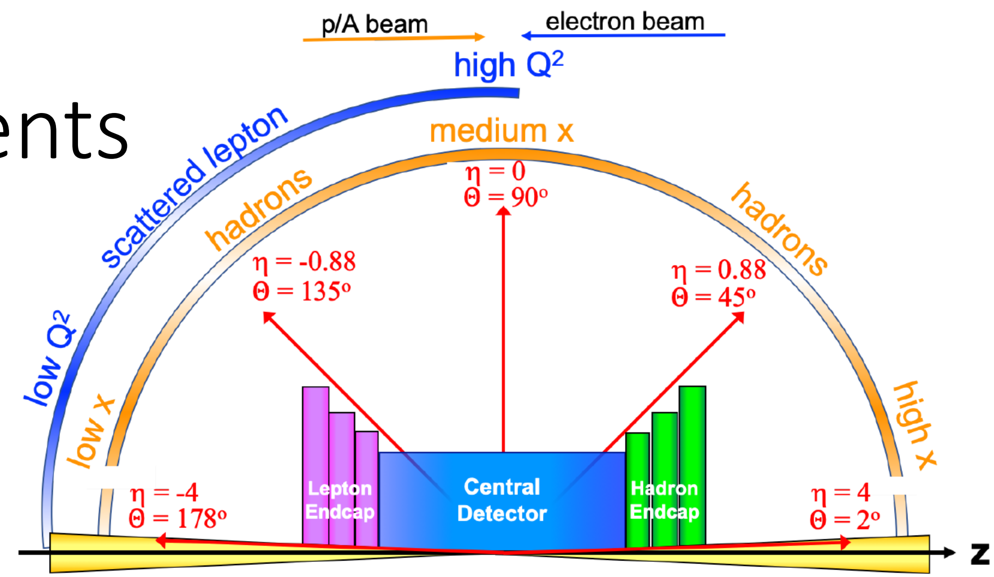
- Scattered lepton:
  - Low Q^2: Backward
  - Med Q^2: central
  - High Q^2: slightly forward
- SIDIS hadrons:
  - Low x: Backward-central
  - Med x: central-forward
  - High x: Forward

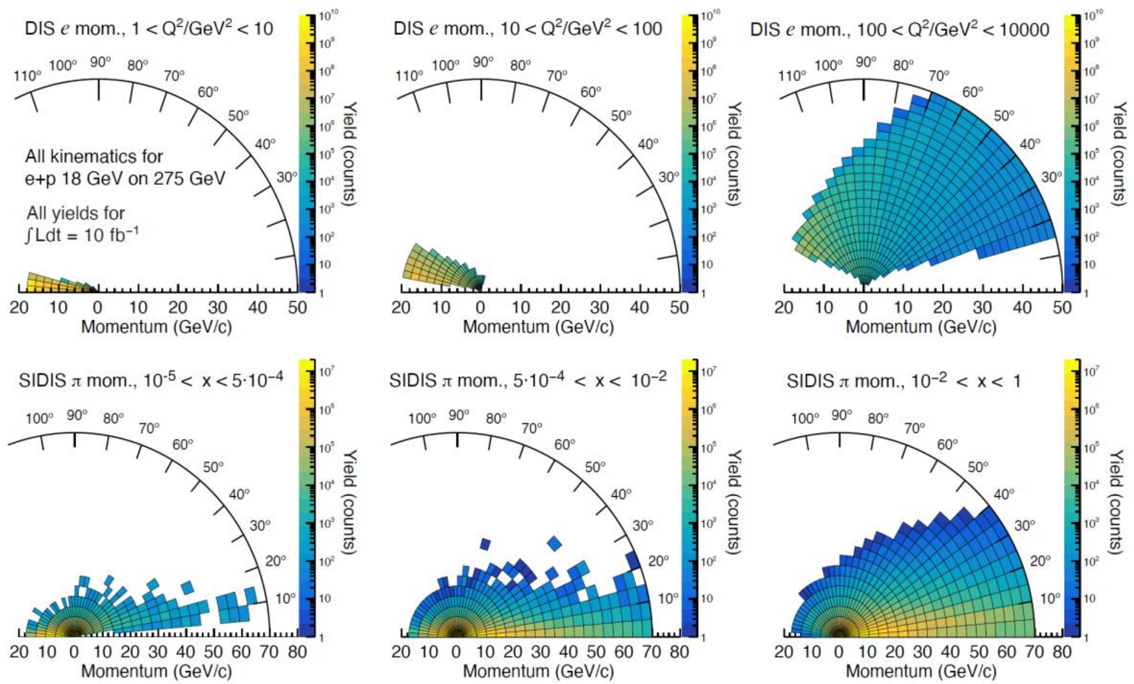




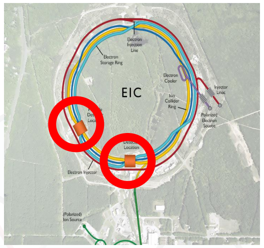
Detector requirements

- Need full coverage over a large range of rapidities
- Precise lepton kinematic measurements in backward/central/forward rapidities
- Precise hadron kine and PID in the forward/central region
- Auxiliary detectors far forward (ZDCs, roman pots
- Auxiliary detectors far backward (low Q^2 tagger)
- Dedicated polarimetry/luminosity detectors



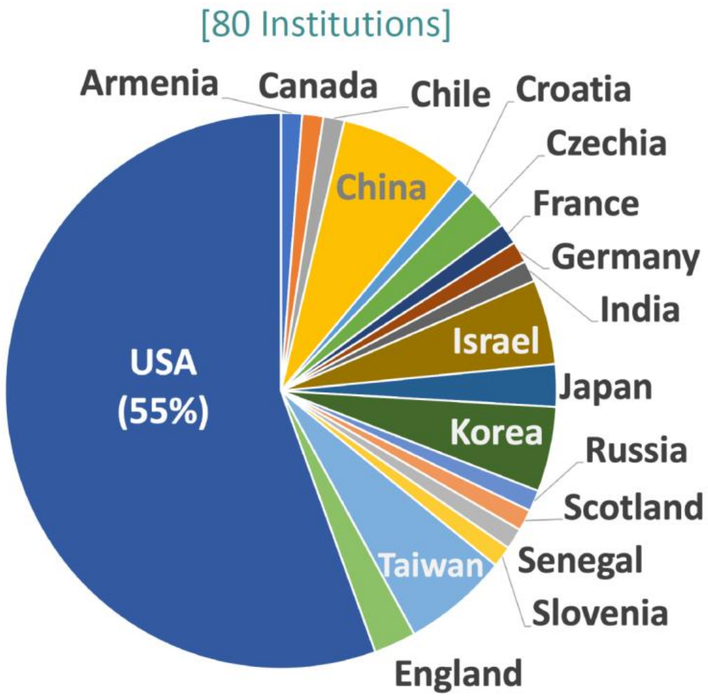


ECCE consortium



ECCE is developing a low-risk, cost-effective, flexible and optimized EIC detector, capable of delivering on the full EIC physics program!

- Reuse: 1.5T BaBar solenoid and some sPHENIX detectors/infrastructure
- Explore both EIC interaction regions (i.e. with/out secondary focusing, IP6 and IP8)
- Respond to 'Detector 1' EIC call for proposals (i.e. ready for CD4a)
- Share & support community vision that the EIC science mission is best served by two detectors



ECCE Consortium

EIC Project POC
Rolf Ent (JLab)

ECCE Steering Committee
Or Hen (MIT)
Tanja Horn (CUA)
John Lajoie (ISU)

Institutional Board

Computing Team
Cristiano Fanelli (MIT)
David Lawrence (JLab)

__Computing Working Groups:__
- Artificial Intelligence
  William Phelps (CNU/JLab)
- Computing and Software
  Joe Osborn (ORNL)

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Christine Nattrass (UTK, co-chair)
Simonetta Liuti (UVA)
Elena Long (UNH)

Physics Benchmarks Team
Carlos Munoz-Camacho (IJCLab-Orsay)
Rosi Reed (Lehigh U.)

Detector Team
Doug Higinbotham (JLab)
Ken Read (ORNL)

Editorial Team
Tom Cormier (ORNL)
Richard Milner (MIT)
Peter Steinberg (BNL)

__Detector Working Groups:__
- IP8/Equipment Re-use
  John Haggerty (BNL)
- Far Forward/Far Backward*
  Michael Murray (KU), Yuji Goto (RIKEN), Igor Korover (MIT)
- Tracking
  Xuan Li (LANL), Nilanga Liyanage (UVA)
- Calorimetry
  Friederike Bock (ORNL), Yongsun Kim (Sejong U.)
- Particle ID
  Greg Kalicy (CUA), Xiaochun He (GSU)
- Magnetic Field
  Paul Brindza (JLab), Renuka Rajput-Ghoshal (JLab)
- DAQ/Electronics/Readout
  Chris Cuevas (JLab), Martin Purschke (BNL)

***Alex Jentsch, Yulia Furletova** (far-forward/backward POC)

__Physics Working Groups:__
- Simulations
  Cameron Dean (LANL), Jin Huang (BNL)
- Inclusive Processes
  Tyler Kutz (MIT), Claire Gwenlan (Oxford)
- Semi-Inclusive
  Ralf Seidl (RIKEN), Charlotte Van Hulse (Orsay)
- Exclusive
  Rachel Montgomery (Glasgow), Julie Roche (OU)
- Diffractive and Tagging
  Wenliang Li (W&M), Axel Schmidt (GWU)
- Jets and Heavy Flavor
  Cheuk-Ping Wong (LANL), Wangmei Zha (USTC)
- BSM and Precision Electroweak
  Sonny Mantry (UNG), Xiaochao Zheng (UVa)

__Editorial Working Groups:__
- Proposal Editing, Verification and Version Control
- Costing and Management

__Website:__
https://www.ecce-eic.org/

__Mailing Lists:__
https://lists.bnl.gov
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- ecce-eic-ib-l
- ecce-eic-dei-l
- ecce-eic-det-l
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__Indico:__
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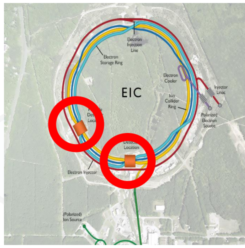
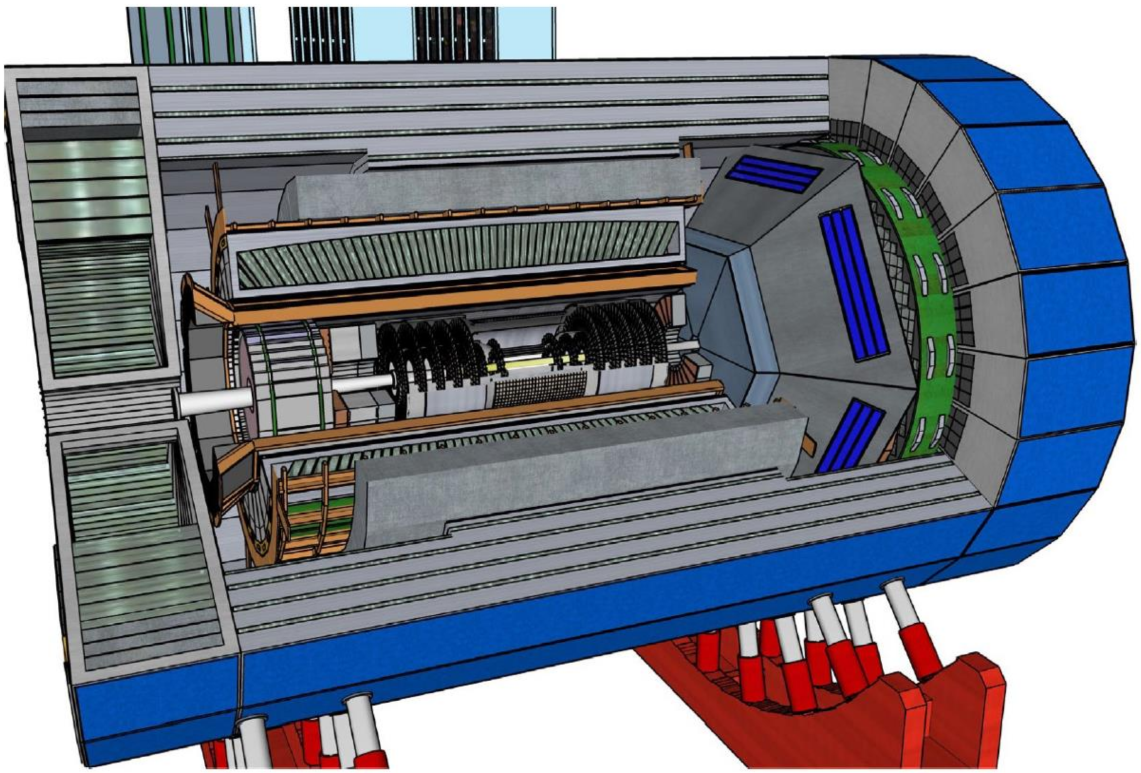
ECCE detector layout



EIC Comprehensive Chromodynamics Experiment

ECCE Detector Layout



ELECTRON ENDCAP

Tracking: Si discs + Large area μRWELL
Electron Detection:
- Inner: PbWO4 crystals (reuse some)
- Outer: SciGlass (backup PbGl)

h-PID: mRICH & AC-LGAD
HCAL: Fe/Sc (STAR re-use)

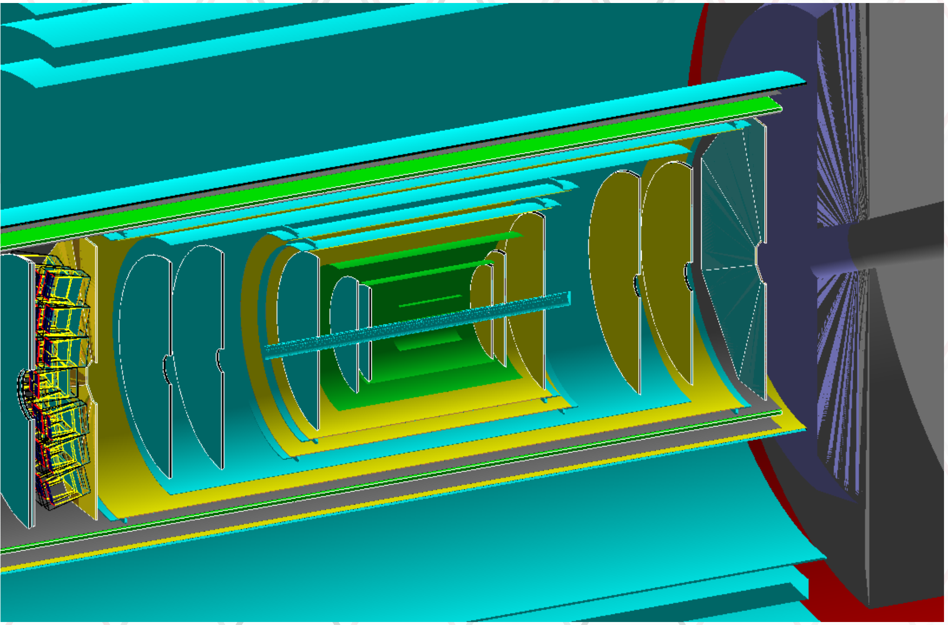
CENTRAL BARREL

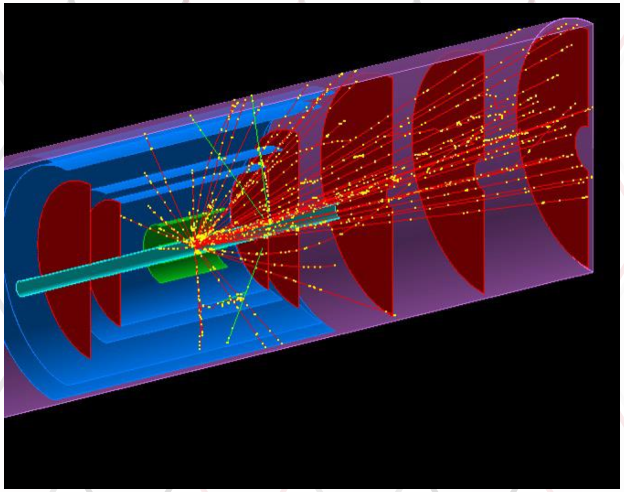
Tracking: MAPS Si + μRWELL
(design under optimization)
Electron PID: SciGlass (alt: PbGl or W(Pb)/Sc shashlik)
(plus instrumented frame)
h-PID: hpDIRC & AC-LGAD
HCAL: Fe/Sc (sPHENIX re-use)

HADRON ENDCAP

Tracking: Si discs + Large area μRWELL
PID: dual-RICH & AC-LGAD
Calorimetry:
Standard Pb/ScFi shashlik (PHENIX re-use)
Long. sep. HCAL
(other options under study)

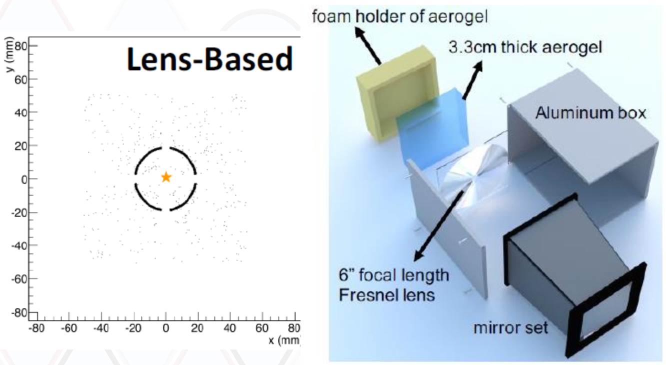
Tracking



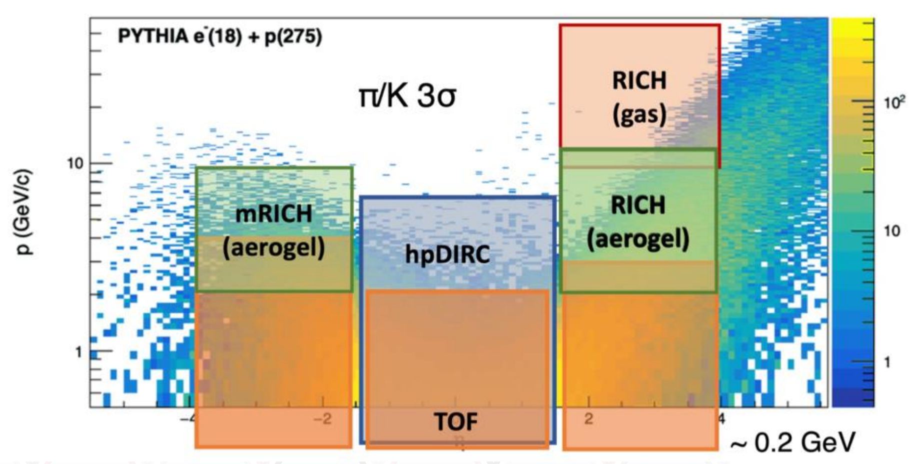


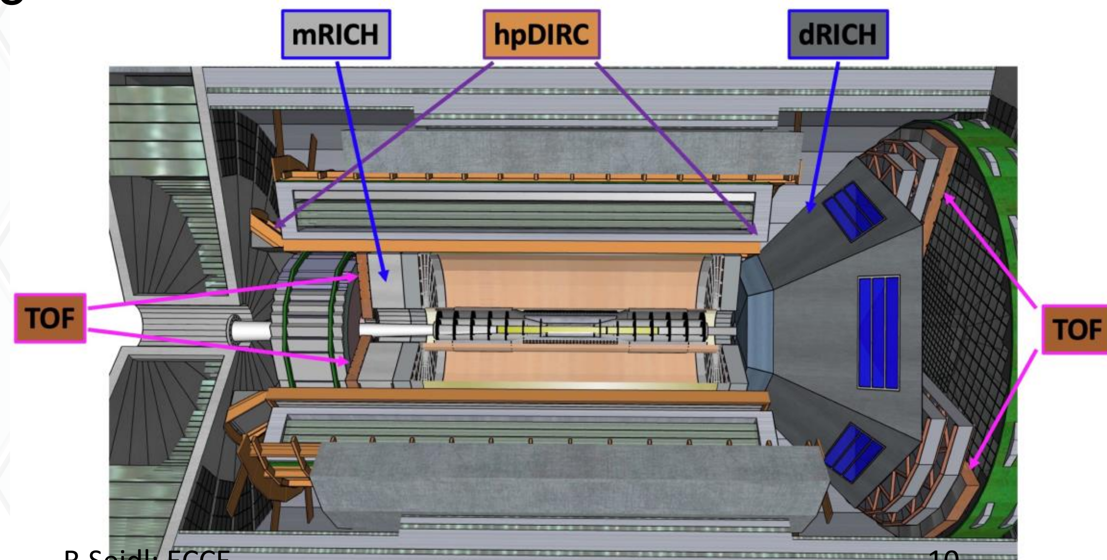
- Central tracker:
  - MAPS based Silicon tracker (2 double layers)
  - AC-LGADS at intermediate radii
  - µRWELL around DIRC
- Forward/Backward Endcaps:
  - Silicon disks
  - AC-LGADS
  - µRWell around calorimeters
- Use AI to improve tracking resolutions

Hadron Particle identification

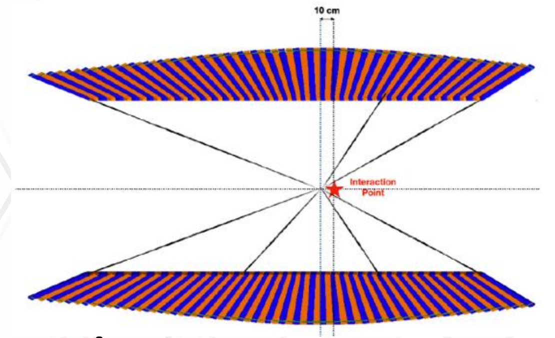


- Good Pion-kaon (>3σ) separation over all central detectors from:
- Aerogel RICH (mRHIC) for intermediate momenta (2-10 GeV)
- Dual radiator Aerogel/Gas RICH for highest momenta in forward region (>2 / >10 GeV)
- DIRC at central rapidities (<7GeV)
- Time of Flight LGAD detectors for momenta < 2GeV

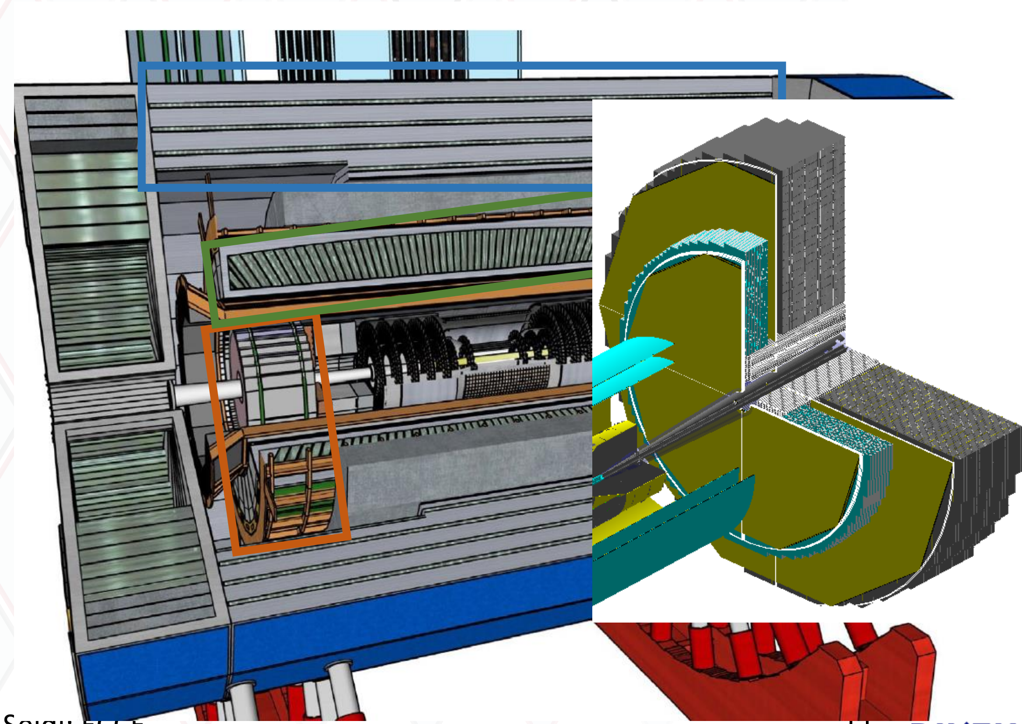




Calorimetry

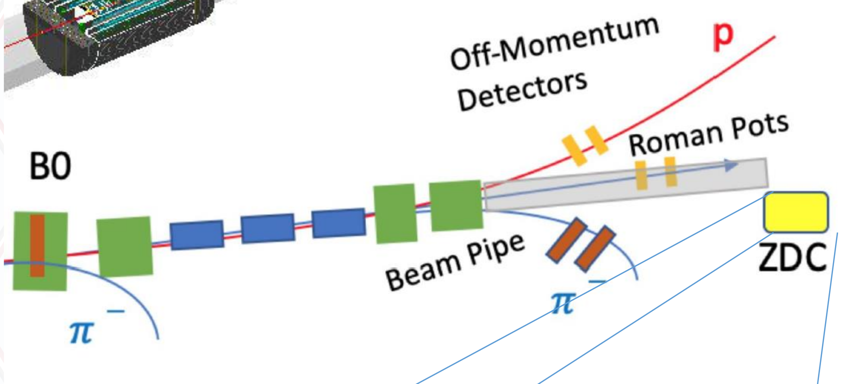


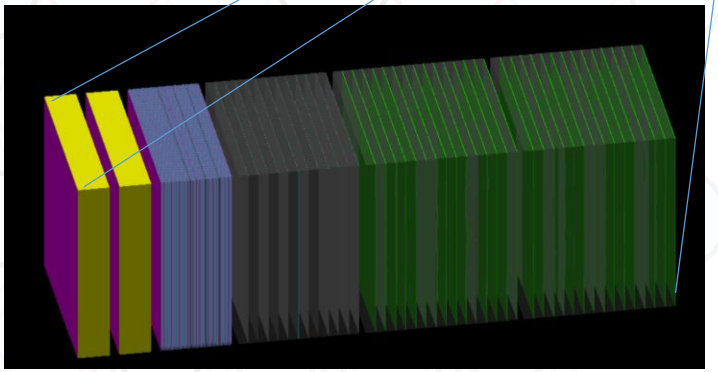
- Electron direction:
  - PbW04 crystals (inner part)
  - SciGlass or PbGlass (outer part)
  - Potentially Hadronic Calorimeter resued from STAR forward HCAL
- Central direction:
  - Projective homogeneous SciGlass EMCAL
  - Re-use sPHENX outer HCAL
  - New inner HCAL
- Forward direction:
  - Upgraded (readout) PHENIX Shashlik EMCAL
  - Longitudinally segmented Forward HCAL



Far forward detectors

- Exclusive physics:
  - Intact proton detection, nucleons from broken up nuclei
- (SI)DIS measurements:
  - Spectator proton, neutron for neutron structure in D, He^3 beams
- Meson structure:
  - Neutron, proton, Λ detection for π^+,π^0 and K^+ structure
- ZDCs for neutrals (n, K_S, $\Lambda \rightarrow n\pi^0 \rightarrow n\gamma\gamma$ decays), combined E and HCAL with high granularity layers
- Roman pots (LGADs) for protons



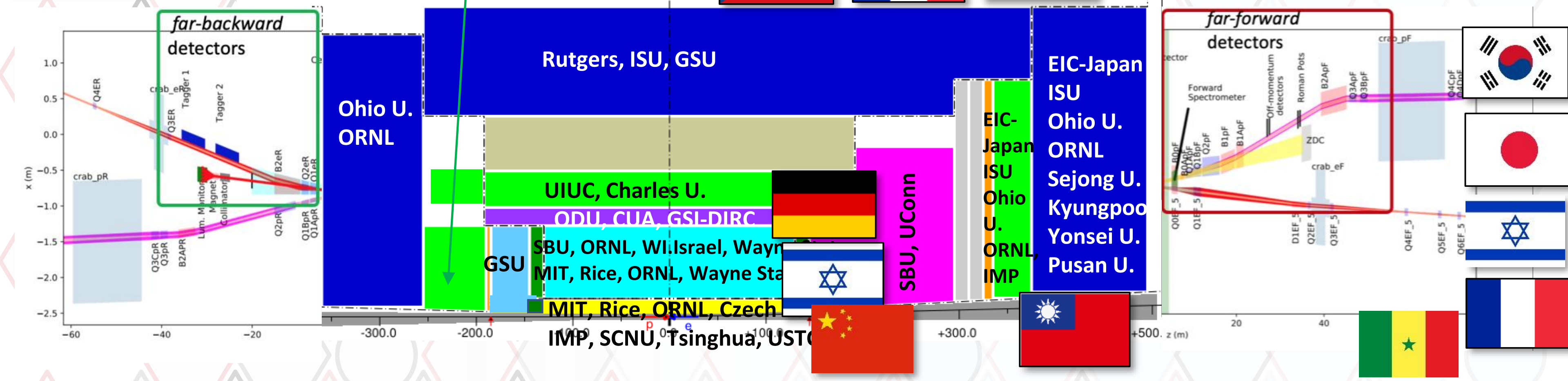


International interests/know-how

Glasgow U., ODU

EEMCal: AANL, CUA, Charles U., FIU, IJCLab, MIT, Lehigh U., UKY, JMU

BGU/Israel, MIT, ORNL, UIUC, IJCLab-Orsay, EIC-Japan, TAU/Israel, UVA, GWU, MIT-BATES, HUIJ/Israel



CENTRAL

Tracking:

- Silicon: China, Czech Republic, Japan

Calorimetry

- PWO and SciGlass: Czech Republic, Armenia, France
- Forward Calo/Dual Readout: China, Japan, South Korea

Particle ID

- DIRC: GSI/Germany

FAR FORWARD – FAR BACKWARD

- Roman pots: France
- Off momentum: Israel
- ZDC: Japan
- Luminosity monitors: Israel
- Low Q2 tagger: UK

Polarized Beam and polarimetry: MIT, UNH, SBU

Electronics: Columbia, ORNL

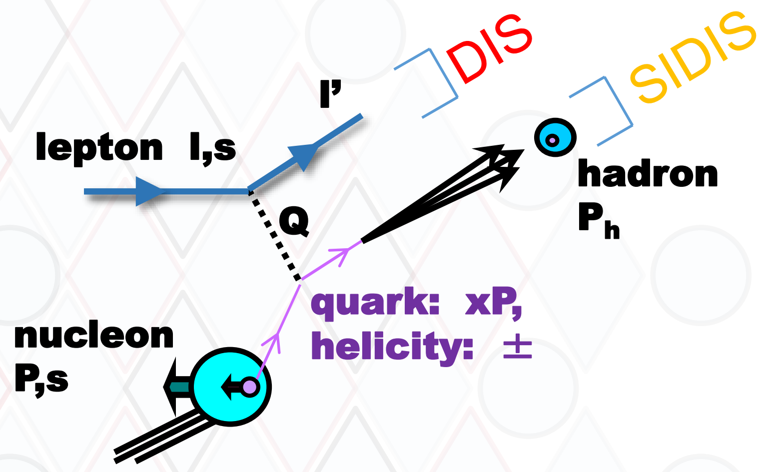
DAQ/Trigger: ISU, CU Boulder, OU, ORNL, SBU, UConn, LLNL

Artificial Intelligence: MIT, CNU, Brunel U.

Exp.Physics analysis strategy

- For any (SI)DIS analysis:

1. Find DIS kinematics: easiest case via scattered lepton l' (other methods include hadronic final state)
2. Calculate DIS variables: x,y,Q^2, W^2, ϕ_S (around virtual photon in proton rest frame, wrt to scattering plane)
3. Select DIS events (typically Q^2>1 GeV^2, W^2>10GeV^2,0.01<y<0.95)
4. Search for final state hadrons → SIDIS
5. Calculate SIDIS variables: z, P_{hT} (wrt to virtual photon in proton rest frame), ϕ_h (around virtual photon in proton rest frame, wrt to scattering plane)



$$q = l - l'$$
Momentum transfer

$$Q^2 = -q^\mu q_\mu$$

$$x = \frac{Q^2}{2p \cdot q}$$
Parton momentum fraction*

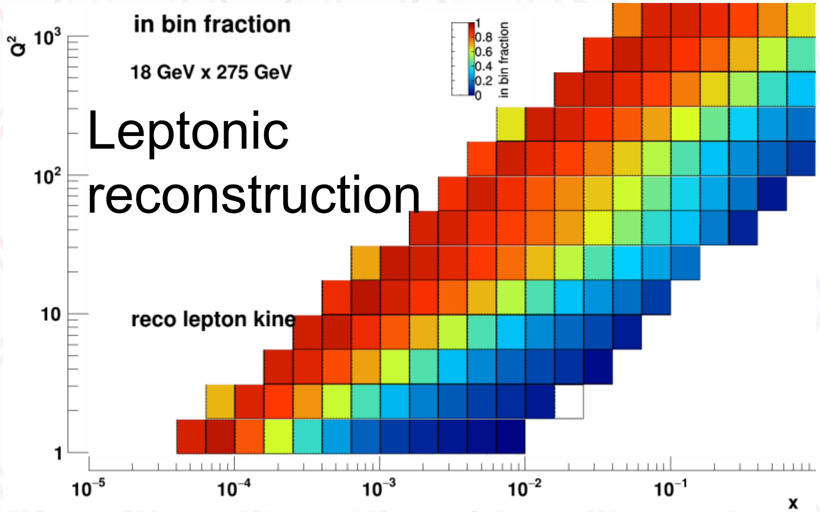
$$y = \frac{q \cdot p}{l \cdot p}$$
Inelasticity

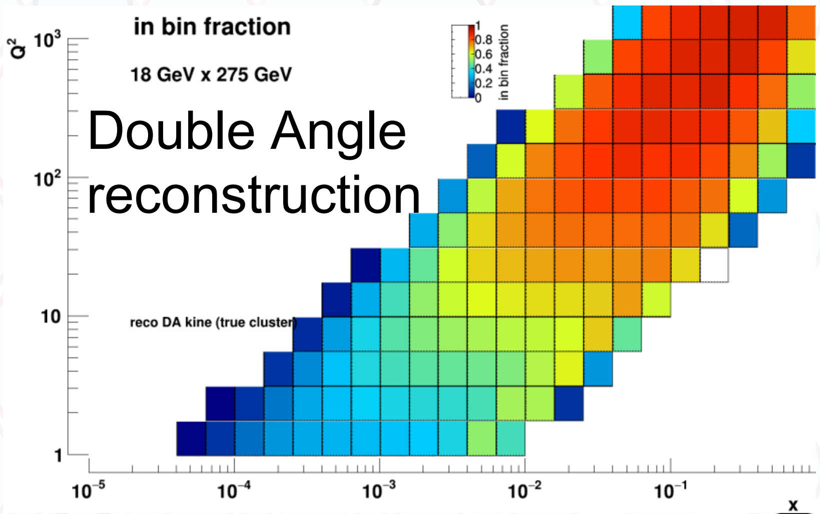
$$W^2 = M_p^2 + (1-x)Q^2/x$$
Mass of had final state

$$z = \frac{p \cdot P_h}{p \cdot q}$$
SIDIS hadron momentum fraction

DIS kinematic reconstruction examples

- Full Pythia6+GEANT simulations of the ECCE detector used for various (SI)DIS kinematic resolutions and for various reconstruction methods (lepton, Jaquet-Blondel, Double Angle, etc)
- x and y resolutions suffer from lepton method at lower y, partially recoverable in double angle method(hybrid of scattered lepton + hadronic final state)

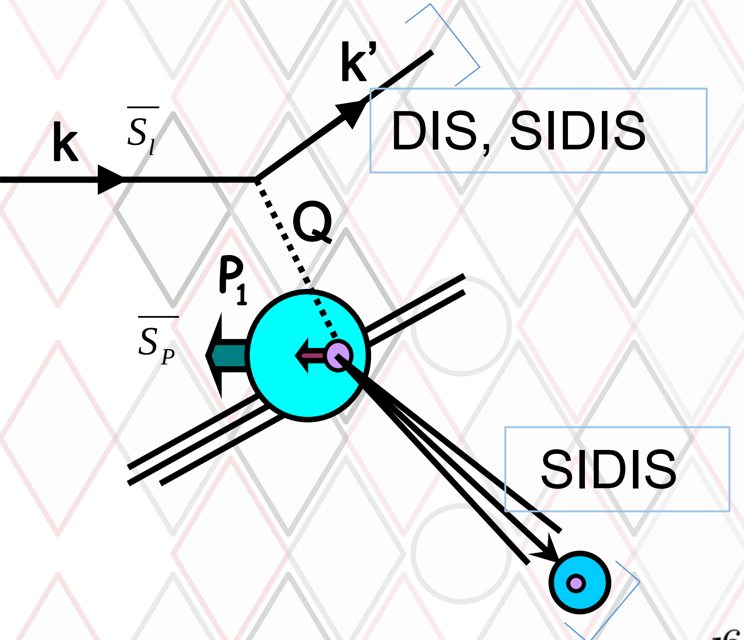




Fraction of DIS events that stay in their x-Q^2 bins

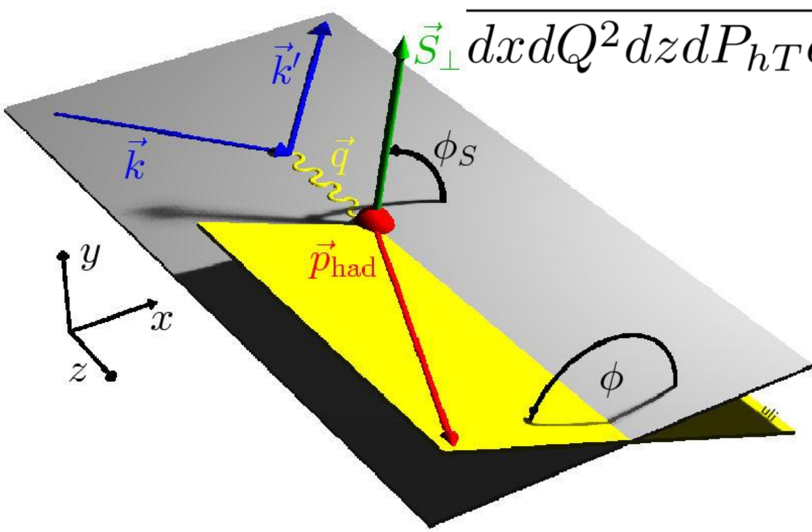
SIDIS Kinematics

Detect also final-state hadron(s) and make use of flavor, etc. sensitivity of Fragmentation functions



z:	Fractional hadron momentum wrt to parton momentum (0<z<1)
P_{hT}:	transverse hadron momentum wrt to virtual photon (convolution over intrinsic transverse momenta of PDFs and FFs)
ϕ_S:	Azimuthal angle of nucleon (transverse) spin wrt to scattering plane, along virtual photon axis
ϕ_h:	Azimuthal angle of hadron wrt to scattering plane, along virtual photon axis

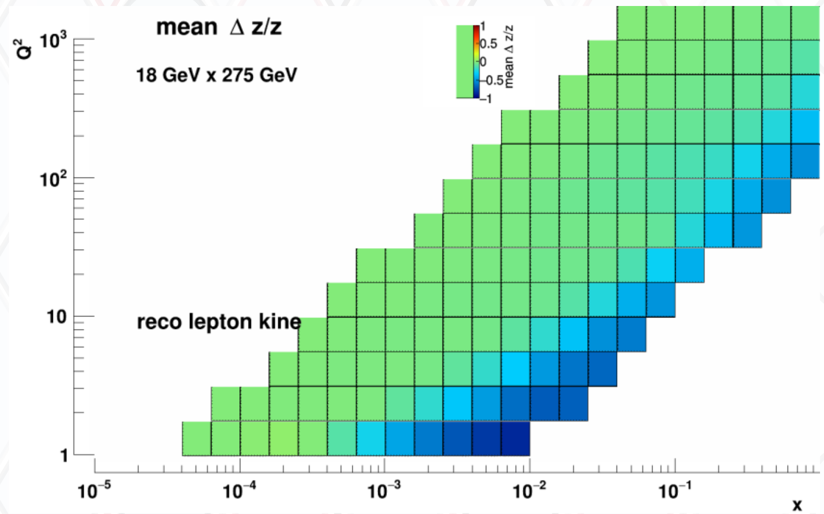
$$\frac{d^6\sigma}{dx\,dQ^2\,dz\,dP_{hT}\,d\phi_S\,d\phi_h} \overset{LO}{\propto} \sum_{q,\bar{q}} e_q^2\, q(x,Q^2,k_t) \otimes D_{1,q}^{h}(z,Q^2,p_t)$$

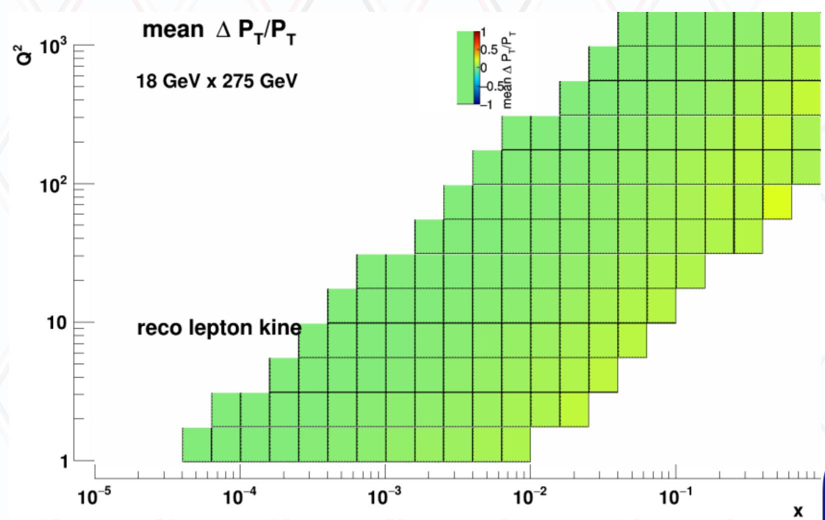


- Transverse momentum and angles rely also on correct boost to hadron rest system
- Current fragmentation: related to struck quark
- Target fragmentation: related to nucleon remnant

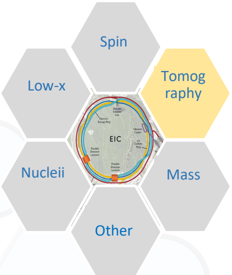
Example of ongoing resolutions studies

- Full Pythia6+GEANT simulations of the ECCE detector for various (SI)DIS kinematic resolution and reconstruction methods:
  - z resolution suffers in lepton method at lower y, partially recoverable in double angle method
  - p_T and azimuthal angles ϕ_h, ϕ_S very robust

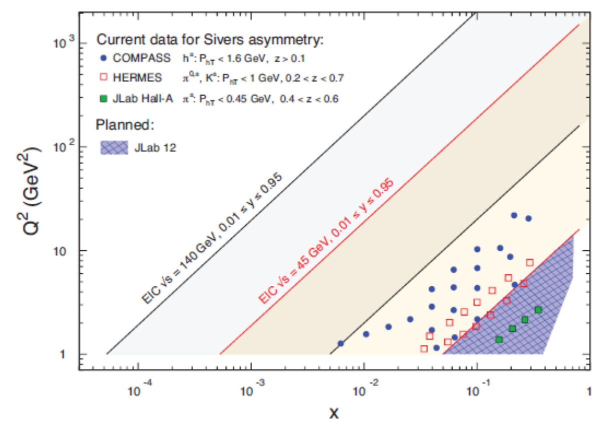




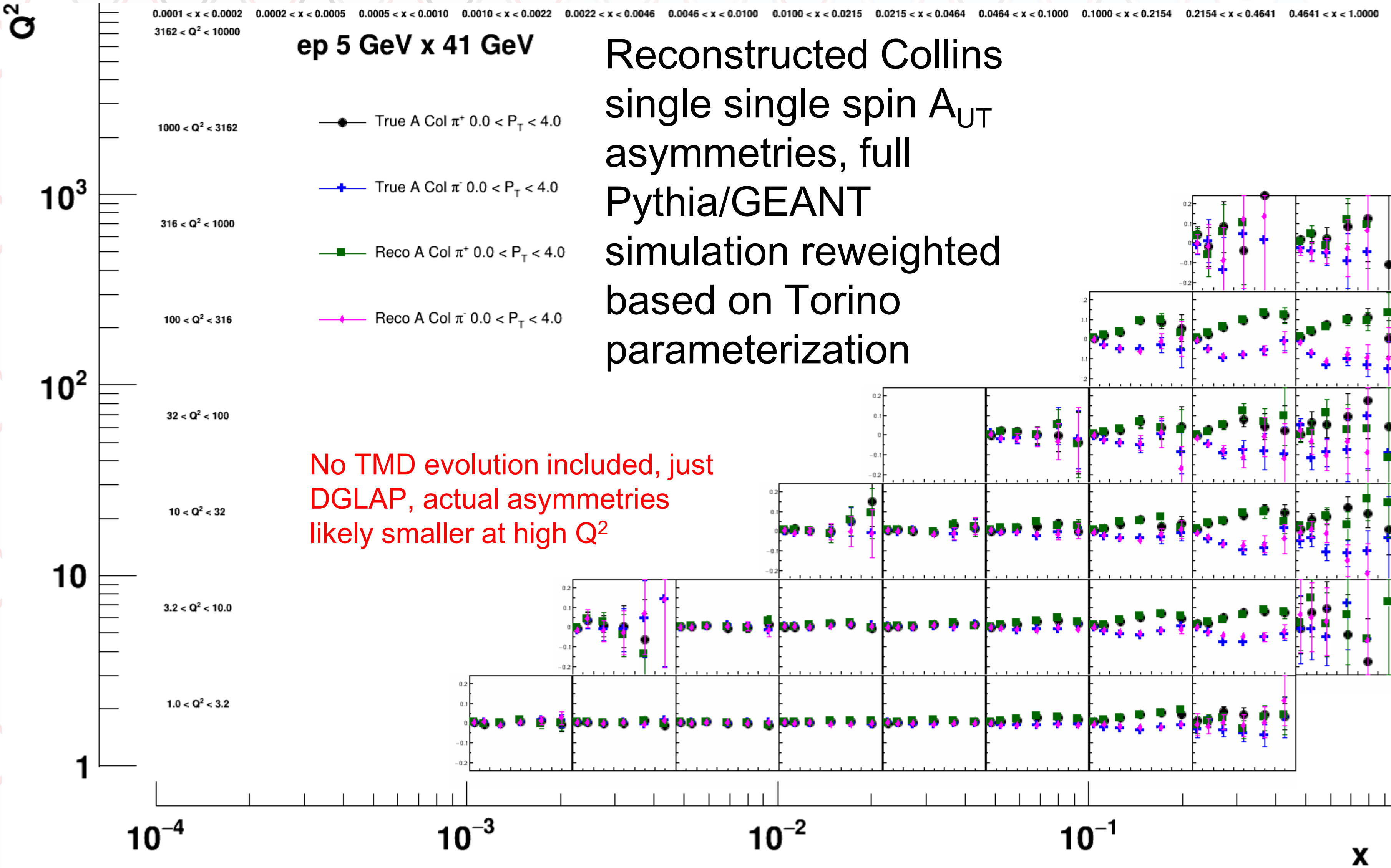
3D Transverse spin and momentum structure



Deliverables	Observables	What we learn	Stage I	Stage II
Sivers & unpolarized TMD quarks and gluon	SIDIS with Transverse polarization; di-hadron (di-jet)	Quantum Interference & Spin-Orbital correlations	3D Imaging of quarks valence+sea	3D Imaging of quarks & gluon; Q^2 (P_{hT}) range QCD dynamics
Chiral-odd functions: Transversity; Boer-Mulders	SIDIS with Transverse polarization	3rd basic quark PDF; novel hadronization effects	valence+sea quarks	Q^2 (P_{hT}) range for detailed QCD dynamics



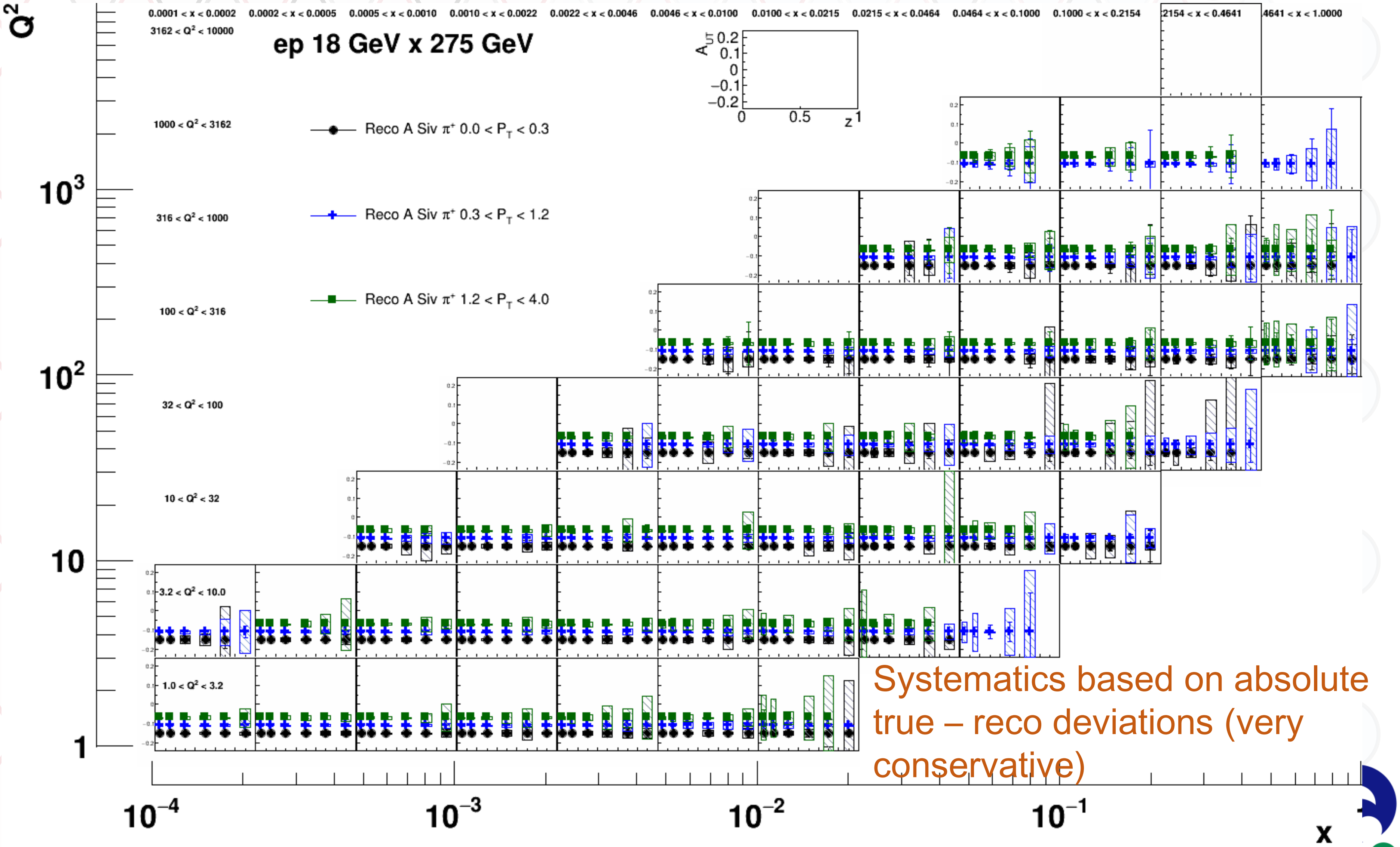
Example of ongoing studies on actual physics variables



Reconstructed Collins single single spin A_{UT} asymmetries, full Pythia/GEANT simulation reweighted based on Torino parameterization

No TMD evolution included, just DGLAP, actual asymmetries likely smaller at high Q^2

A_{UT} projections for $10fb^{-1}$,Sivers π^+



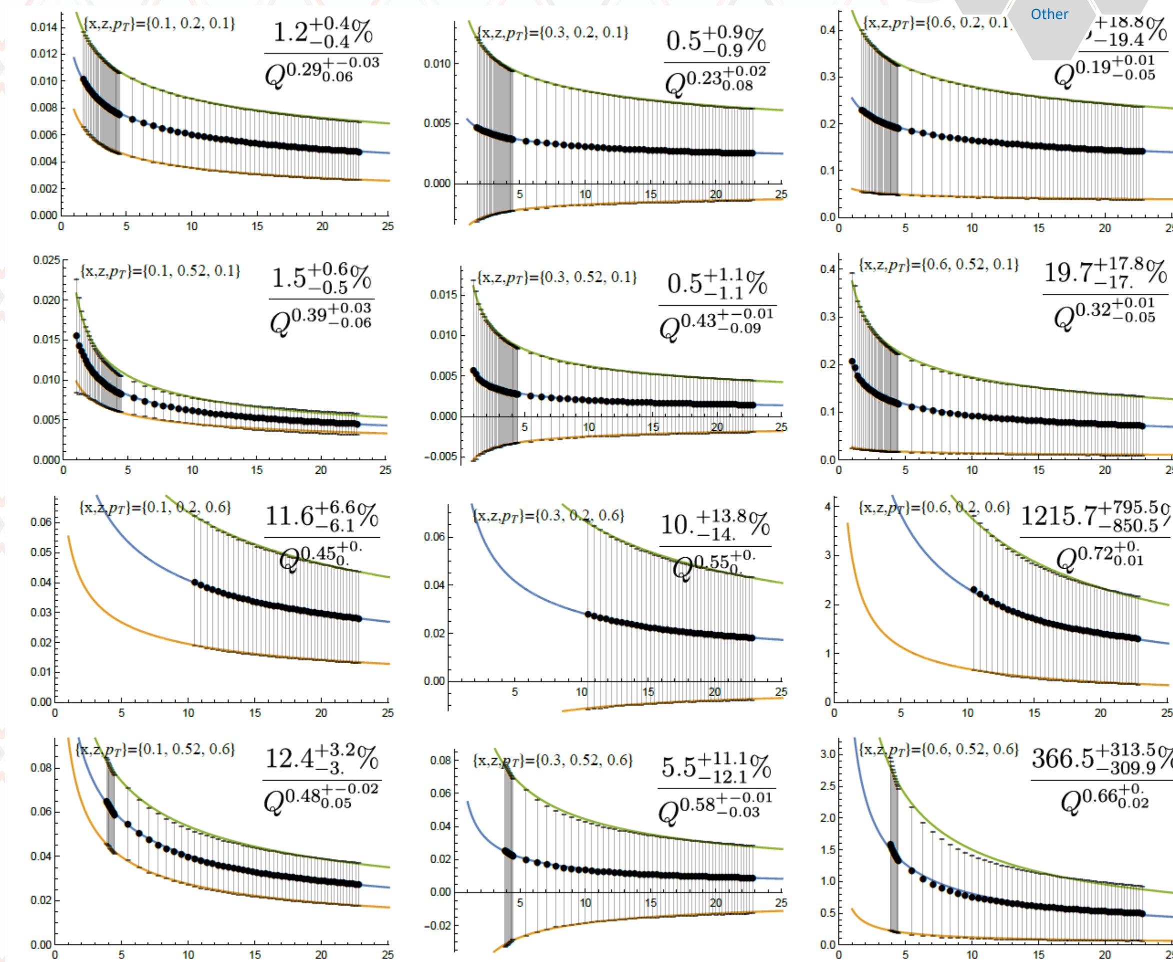
Systematics based on absolute true – reco deviations (very conservative)

ECCE access to TMD evolution

- Very important aspect is the study of TMD evolution
- Sivers asymmetries are expected to decrease at higher scales, but only logarithmically (ie they do NOT “disappear”)
- At higher x Asymmetries of several % expected

➔Well accessible with ECCE over wide range in x and Q^2

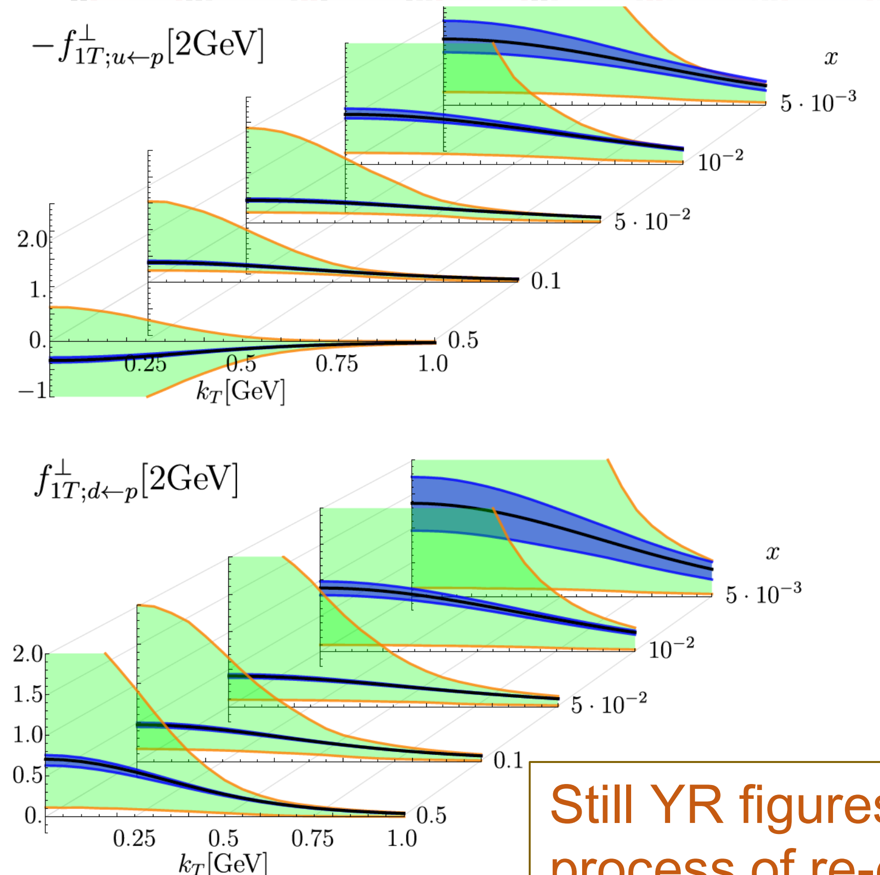
➔Lower x to study sea and glue (both mostly unknown)



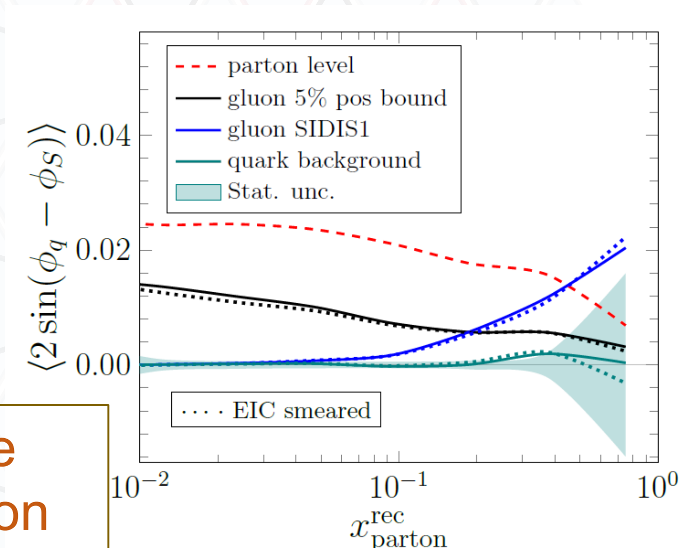
Vladimirov et al.

EIC impact for Sivers Functions

- Precise nucleon image in momentum space for quarks, sea-quarks and gluons



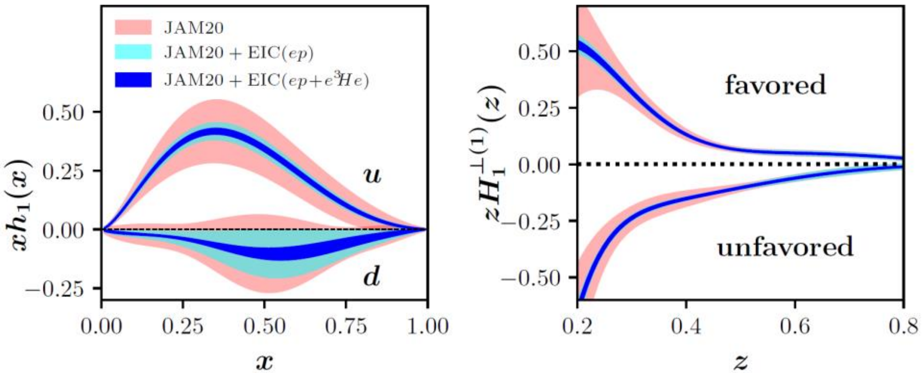
YR: Fig 7.53
Vladimirov, et al



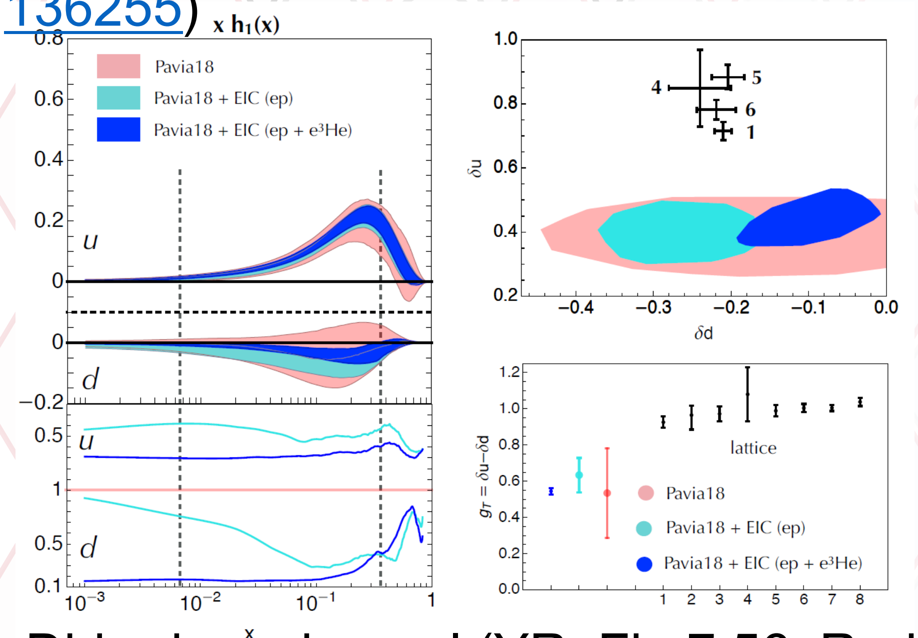
Still YR figures – in the process of re-evaluation using full ECCE simulations

YR: Fig 7.55
Xiao, et al

Tensor charges

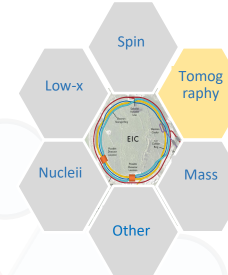


Single hadron channel (YR: Fig 7.54 [Gamberg et al *Phys.Lett.B* 816 (2021) 136255](https://doi.org/10.1016/j.physletb.2021.136255))



Di-hadron channel (YR: Fig 7.56, Radici)

Still YR figures – in the process of re-evaluation using full ECCE simulations



- Precise determination of tensor charges via Collins and di-hadron channels
- Better precision than lattice → potential access to BSM physics in case of discrepancies
- Preform full integrals, study role of sea quark transversity

Summary

- EIC CD1 received earlier this year
- Call for detector proposals to be submitted in December 2021
- ECCE is a detector proposal that addresses the full EIC scope described in white paper/NSAC review/Yellow Report:
  - Re-using 1.5T BaBar Magent and sPHENIX central HCAL
  - Precision tracking options, mostly via MAPS
  - Large momentum and rapidity coverage Particle Identification
  - Either IP6 or IP8 possible
- Full Geant studies show that ECCE successfully addresses the TMD/SIDIS measurements of the YR