EIC Comprehensive Chromodynamics Experiment: ECCE

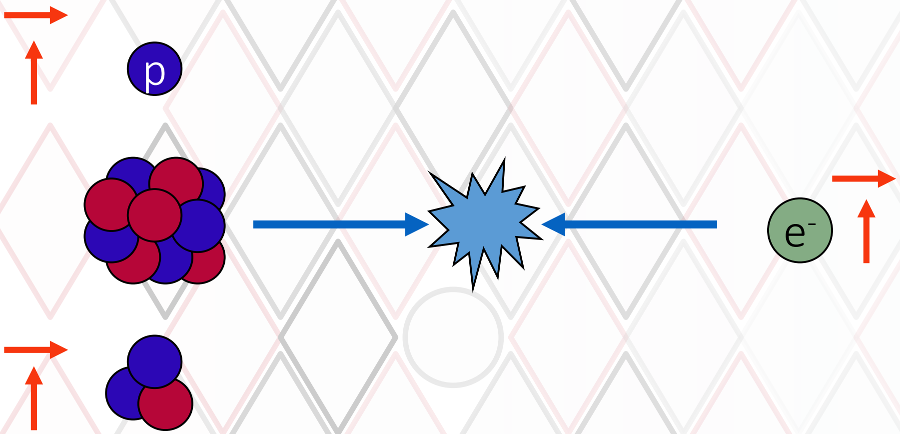
RBRC meeting, October 26,

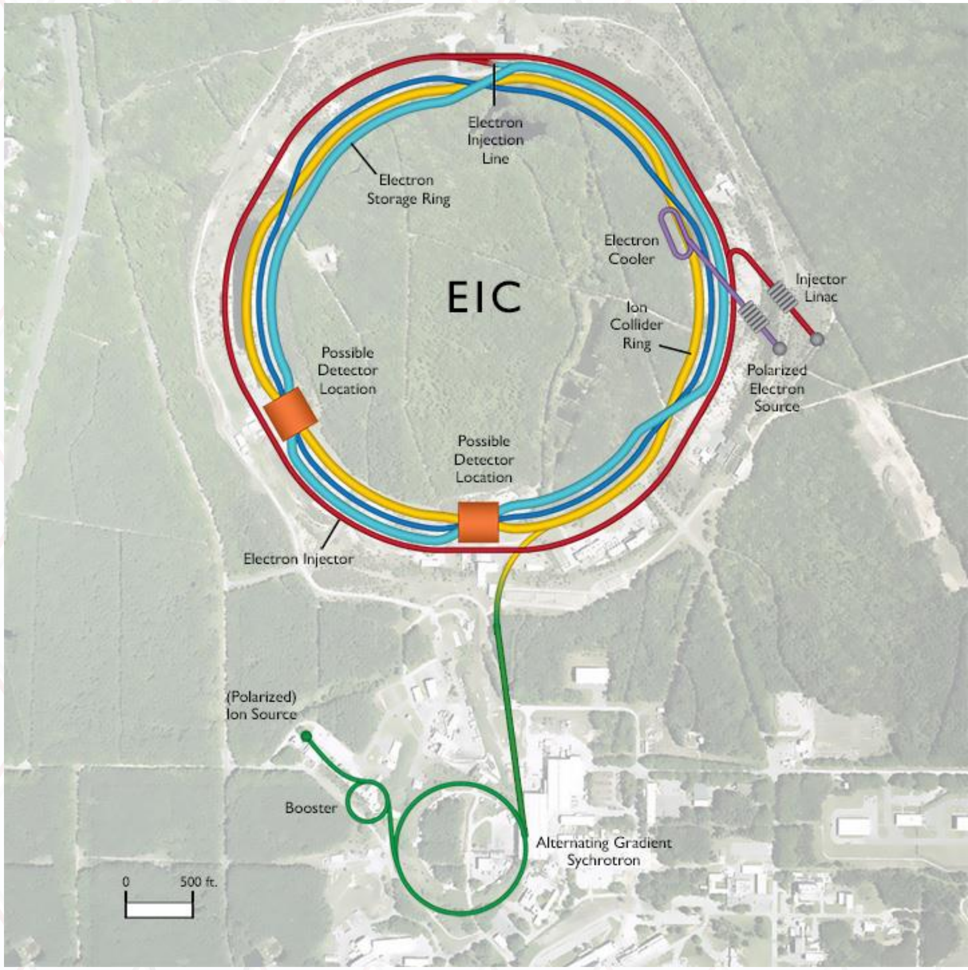
Ralf Seidl (RIKEN)

ECCE

RIKEN

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 √s = 29 – 140 GeV
- CD1 obtained in July 2021

SIDIS Measurements

Spin of the nucleon:

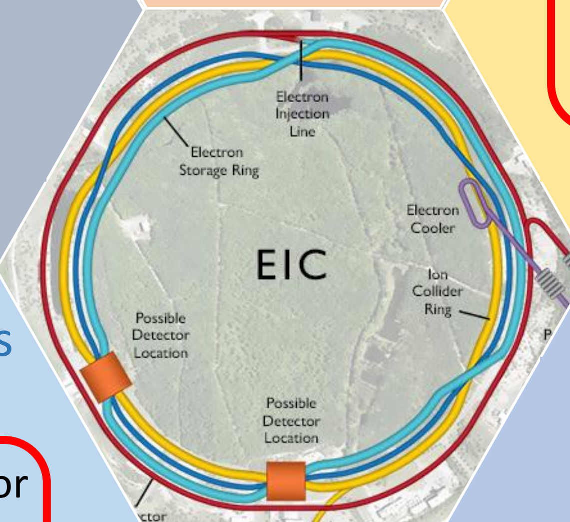
- Gluon spin
- Role of Sea quarks

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

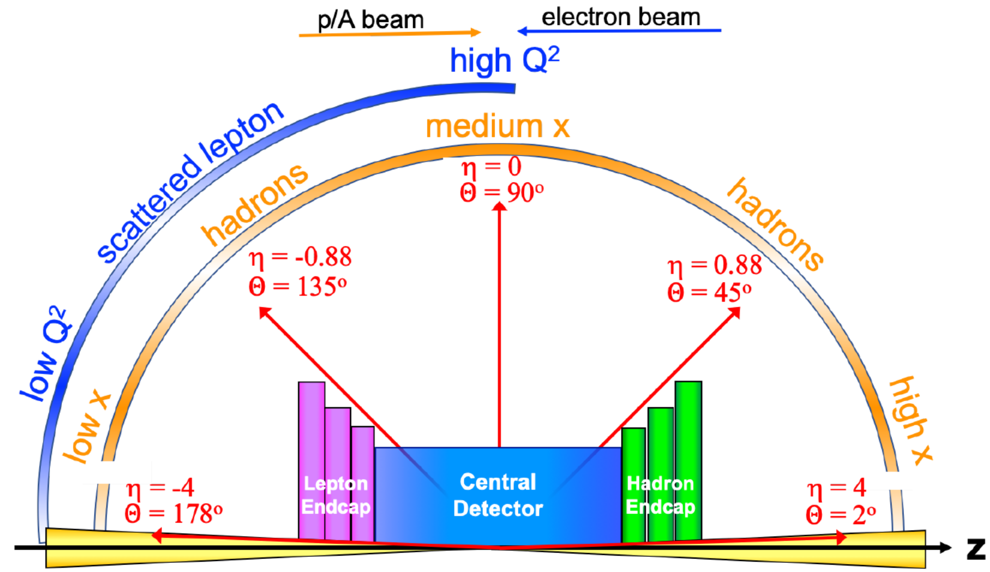
- Axial anomaly contributions
- Hadron structure

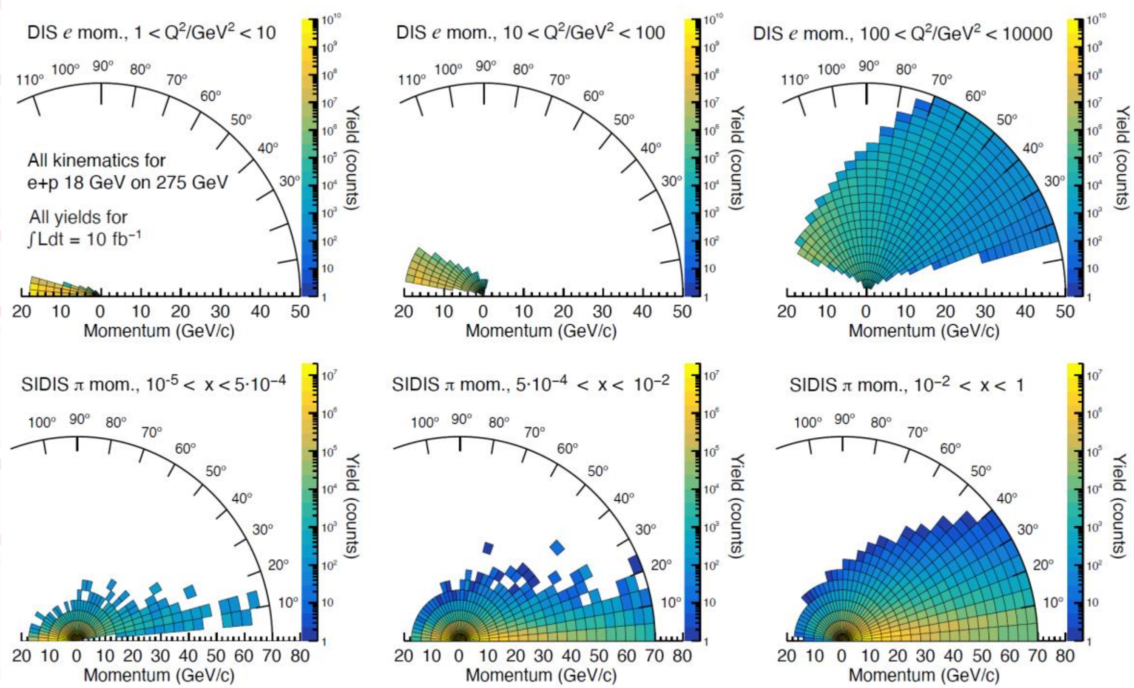
Other

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

General (SI)DIS kinematics

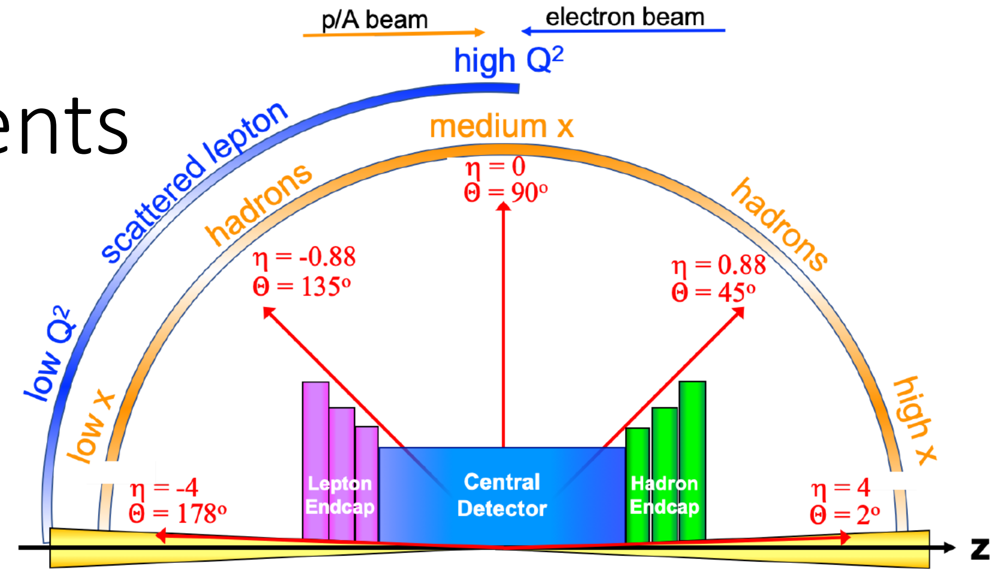
- Scattered lepton:
  - Low Q^2: Backward
  - Med Q^2: central
  - High Q^2: slightly forward
- SIDIS hadrons:
  - Low x: Backward-central
  - Med x: central-forward
  - High x: Forward

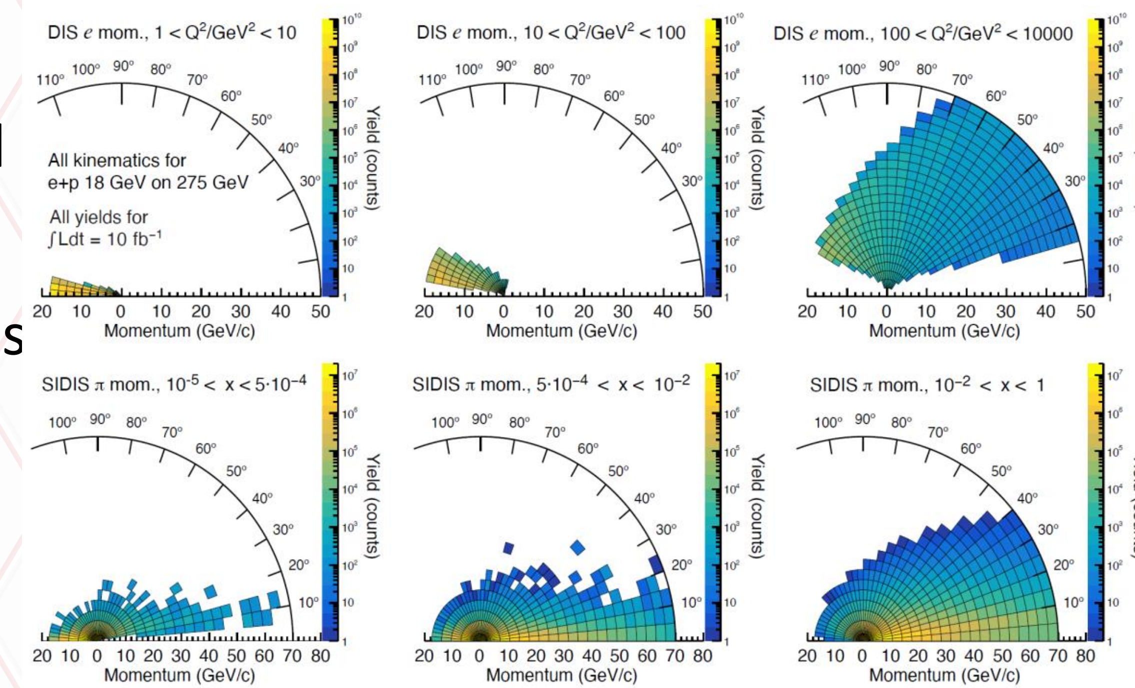




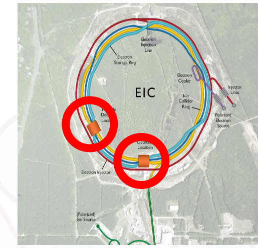
Detector requirements

- 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



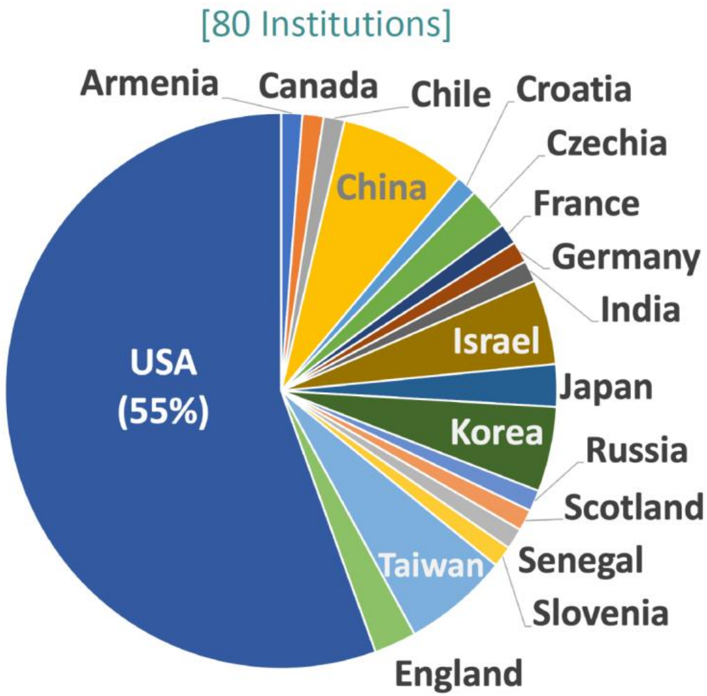


ECCE consortium



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

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- Tracking
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- 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)

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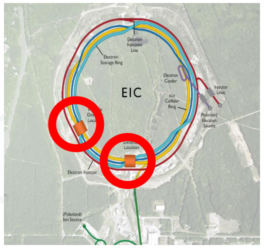
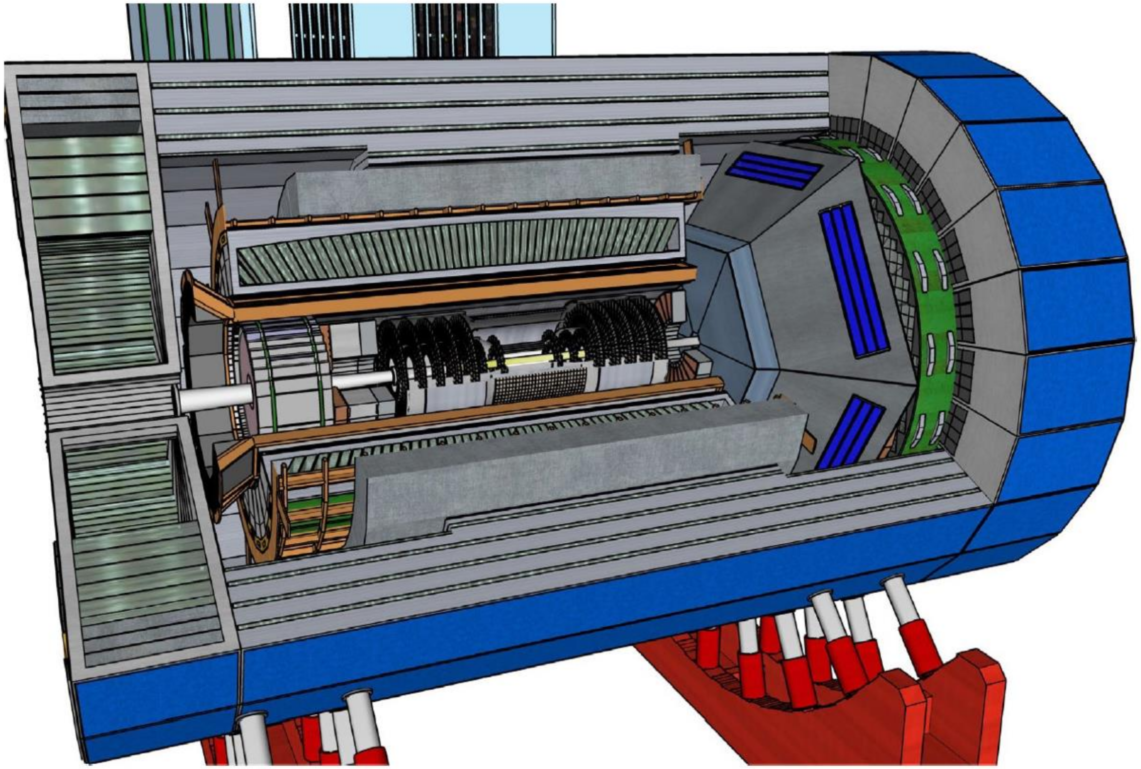
ECCE detector layout



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)

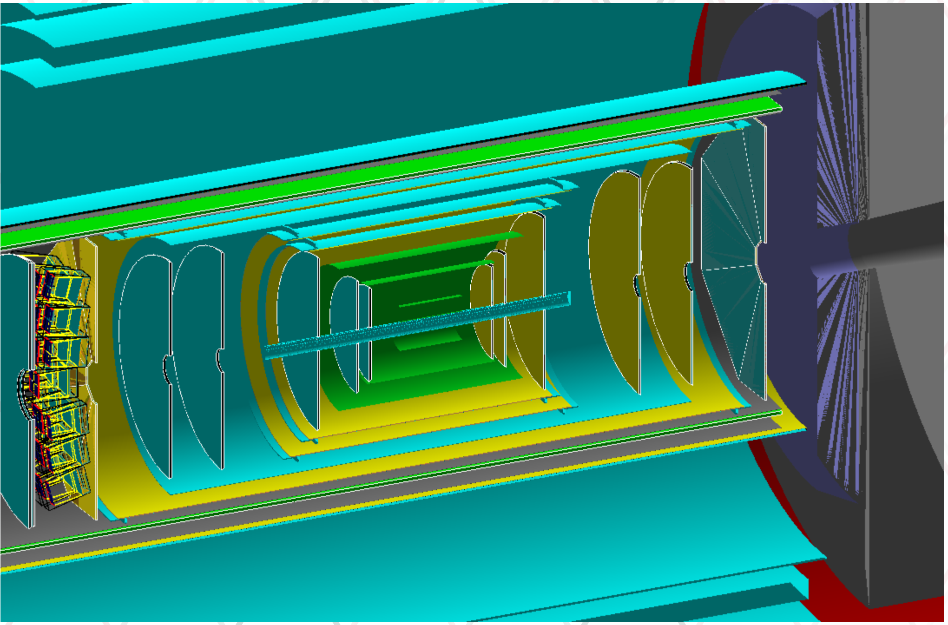
CENTRAL BARREL

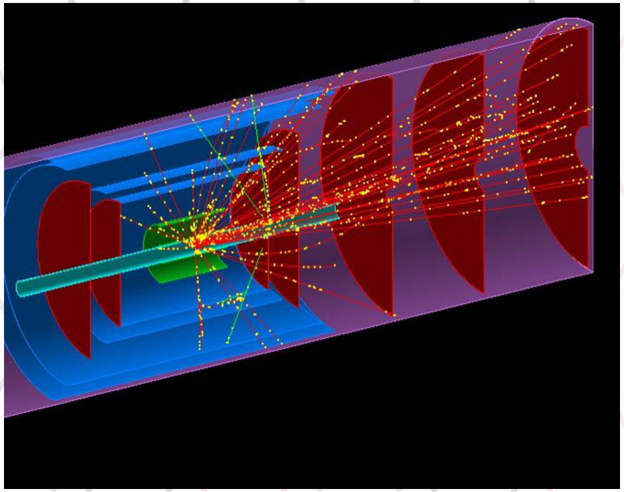
Tracking: MAPS Si + μRWELL
(design under optimization)
Electron PID: SciGlass (alt: PbGl or W(Pb)/Sc shashlik)
(plus instrumented frame)
h-PID: hpDIRC & AC-LGAD
HCAL: Fe/Sc (sPHENIX re-use)

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)

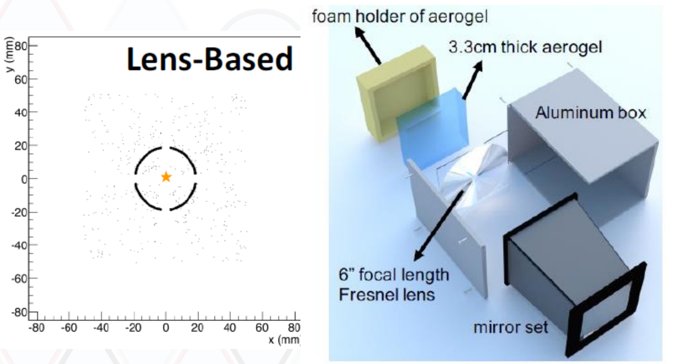
Tracking



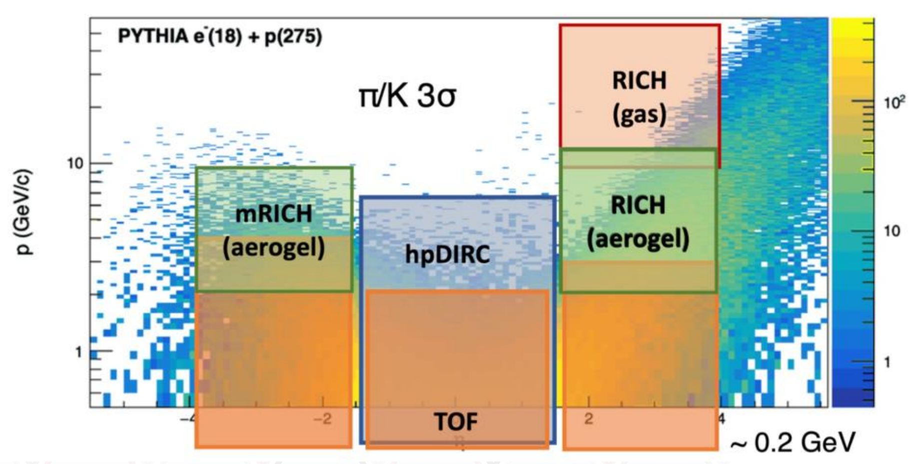


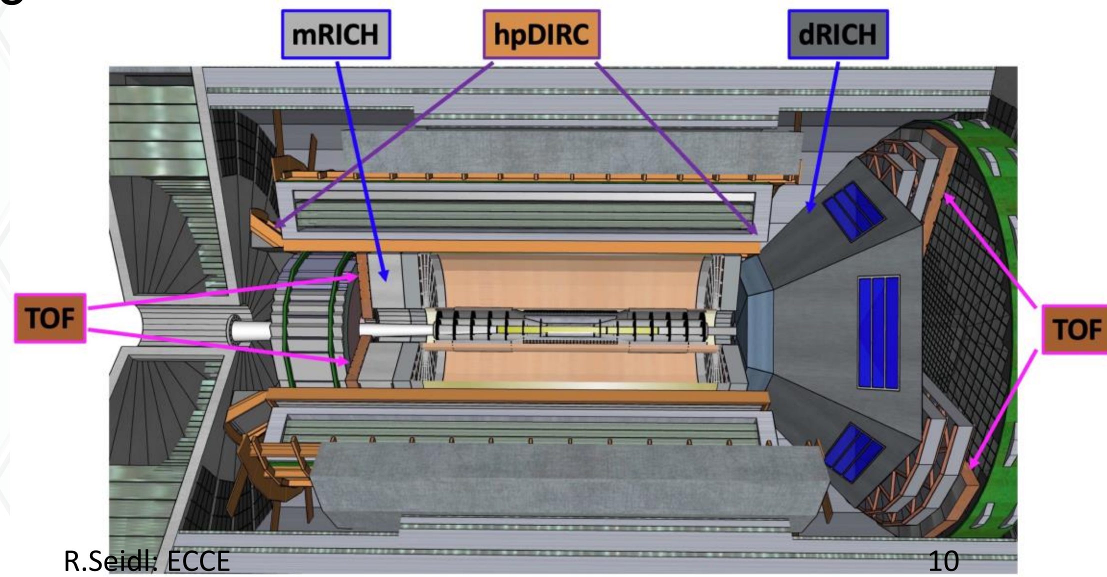
- Central tracker:
  - MAPS based Silicon tracker (2 double layers)
  - AC-LGADS at intermediate radii
  - µRWELL around DIRC
- Forward/Backward Endcaps:
  - Silicon disks
  - AC-LGADS
  - µRWell around calorimeters
- Use AI to improve tracking resolutions

Hadron Particle identification

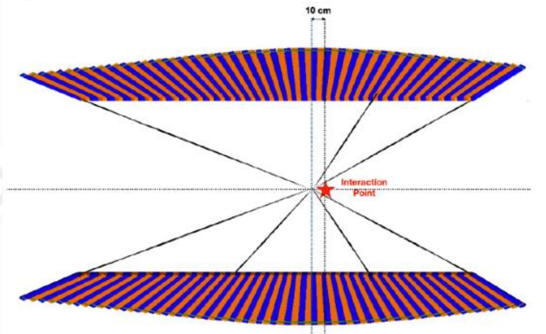


- Good Pion-kaon (>3σ) separation over all central detectors from:
- Aerogel RICH (mRHIC) for intermediate momenta (2-10 GeV)
- Dual radiator Aerogel/Gas RICH for highest momenta in forward region (>2 / >10 GeV)
- DIRC at central rapidities (<7GeV)
- Time of Flight LGAD detectors for momenta < 2GeV

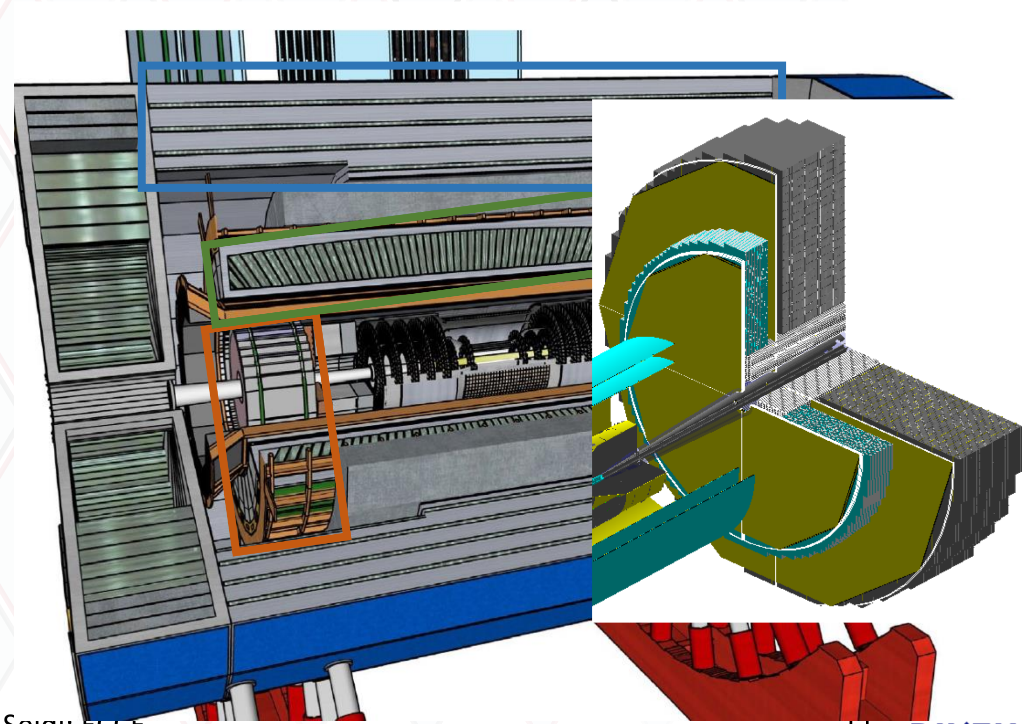




Calorimetry

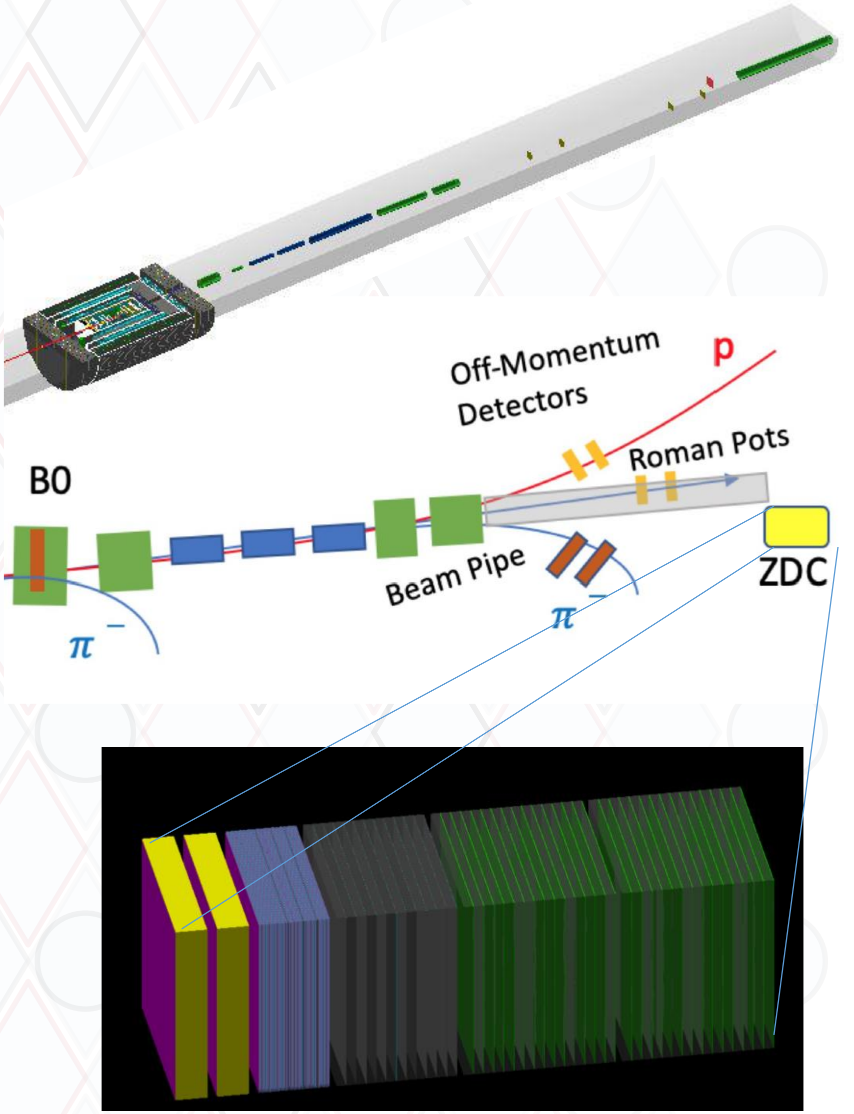


- Electron direction:
  - PbW04 crystals (inner part)
  - SciGlass or PbGlass (outer part)
  - Potentially Hadronic Calorimeter resued from STAR forward HCAL
- Central direction:
  - Projective homogeneous SciGlass EMCAL
  - Re-use sPHENX outer HCAL
  - New inner HCAL
- Forward direction:
  - Upgraded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



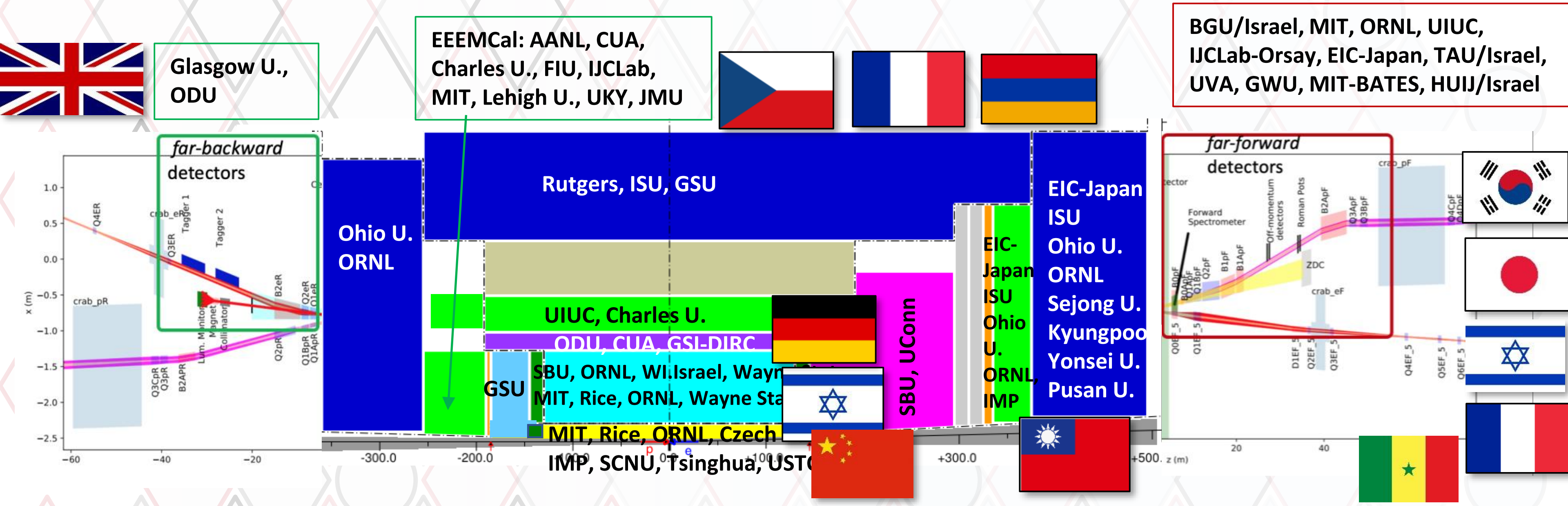
Far forward detectors

- 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



→Shimizu

ECCE International interests/know-how



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

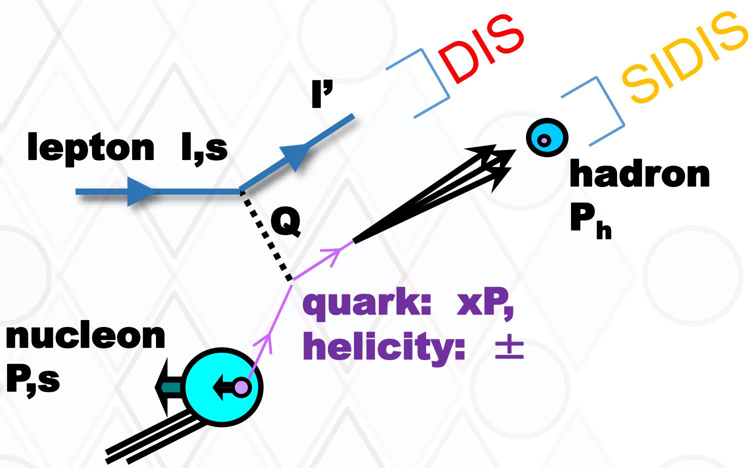
Polarized Beam and polarimetry: MIT, UNH, SBU

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, $W^2>10$GeV^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)

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

Momentum transfer

$$x = \frac{Q^2}{2p \cdot q}$$

Parton momentum fraction*

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

Inelasticity

$$W^2 = M_p^2 + (1-x)Q^2/x$$

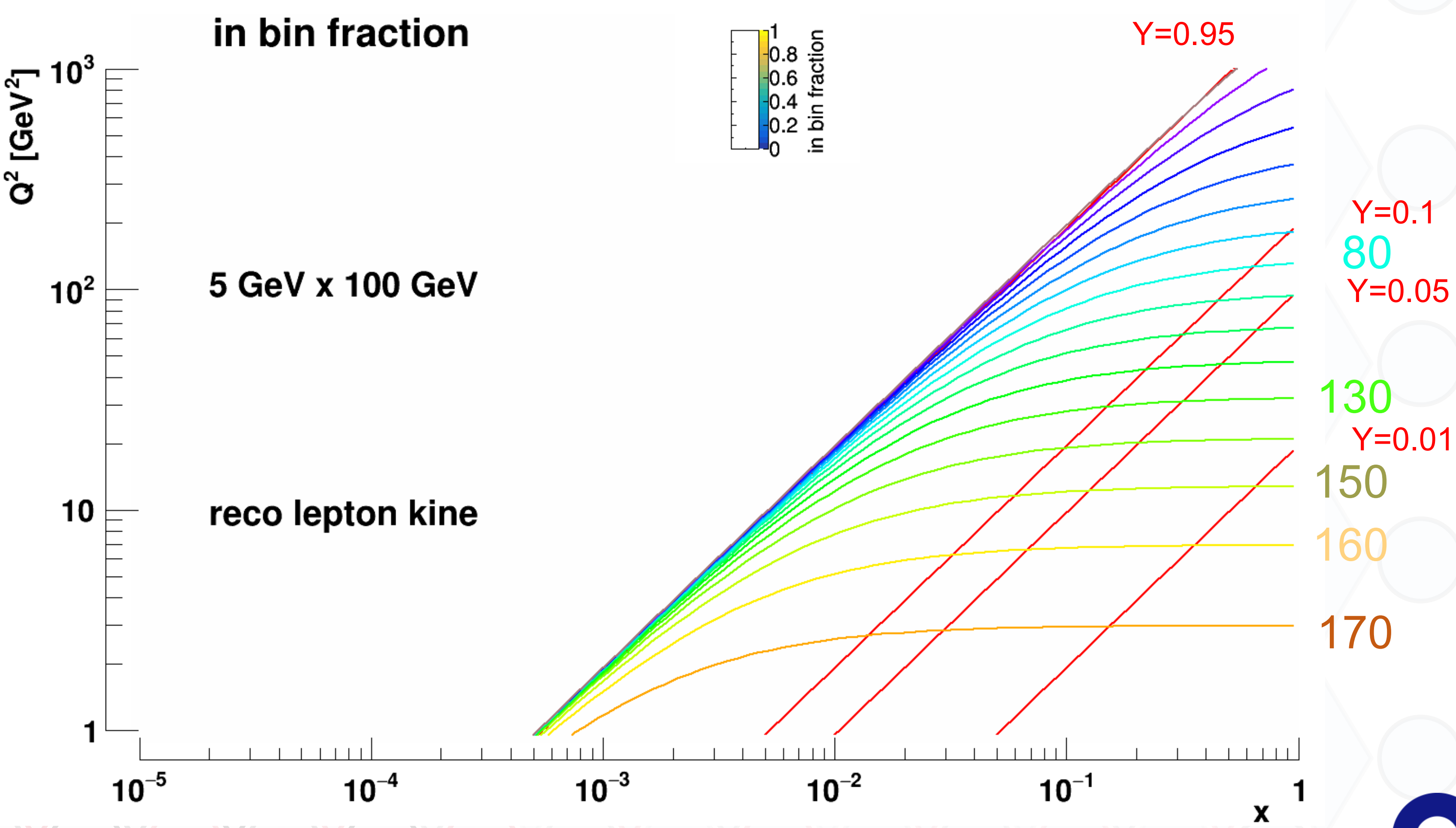
Mass of had final state

$$z = \frac{p \cdot P_h}{p \cdot q}$$

SIDIS hadron momentum fraction

DIS kinematic regions

Inelasticity
$y = 1 - E'/E \sin^2 \theta/2$



Lepton scattering angle θ

DIS Kinematic reconstruction using hadronic Final State:

- JB method: use only hadronic final state

$$y_{JB} = \frac{E_p \sum_h E_h - p_{z,p} \sum_h p_{z,h} - m_p^2}{E_p E_e - p_{z,p} p_{z,e}}$$

$$Q^2_{JB} = \frac{\sum_h p^2_{x,h} + \sum_h p^2_{y,h}}{1-y}$$

$$x_{JB} = \frac{Q^2}{ys}$$

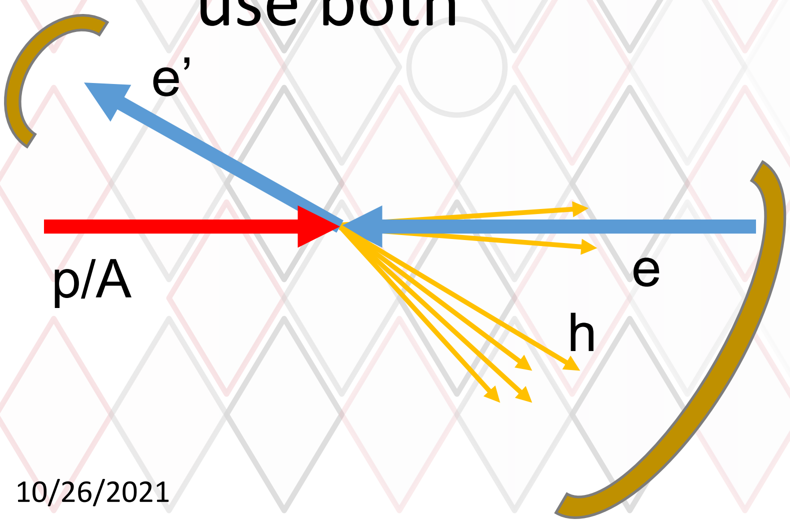
- Double Angle method: use both

$$y_{DA} = \frac{\tan\theta_h/2}{\tan\theta_e/2 + \tan\theta_h/2}$$

$$Q^2_{DA} = \frac{4E_2^2}{\tan\theta_e/2\,(\tan\theta_e/2 + \tan\theta_h/2)}$$

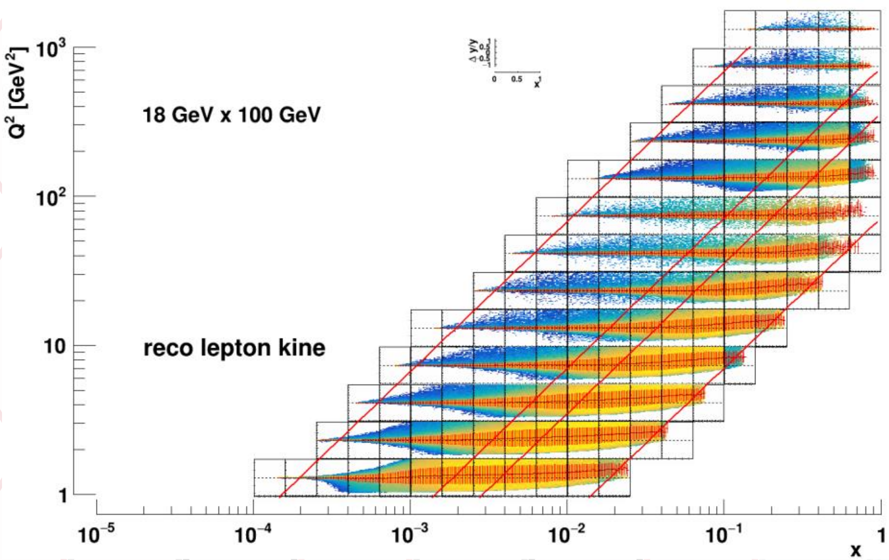
$$x_{DA} = \frac{Q^2}{ys}$$

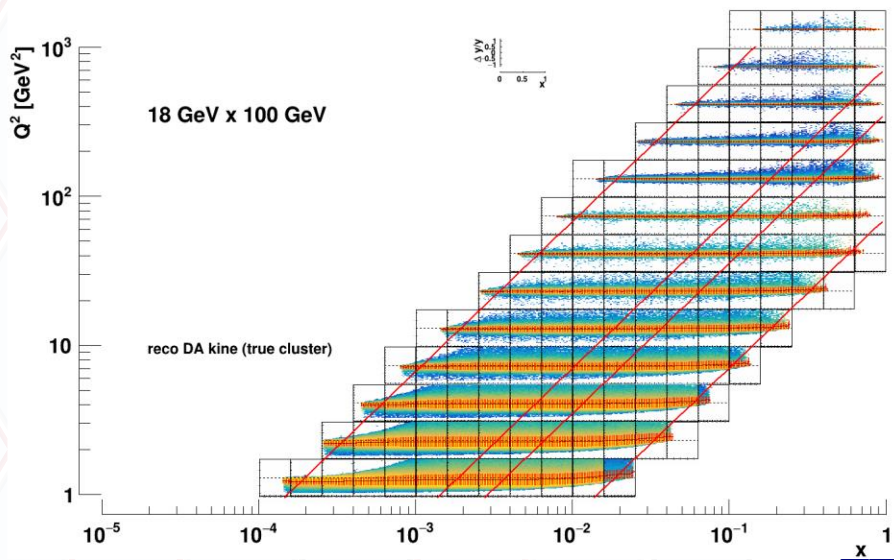
$$\tan\theta_h/2 = \frac{\sum_h E_h - \sum_h p_{z,h}}{\sqrt{\sum_h p^2_{x,h} + \sum_h p^2_{y,h}}}$$



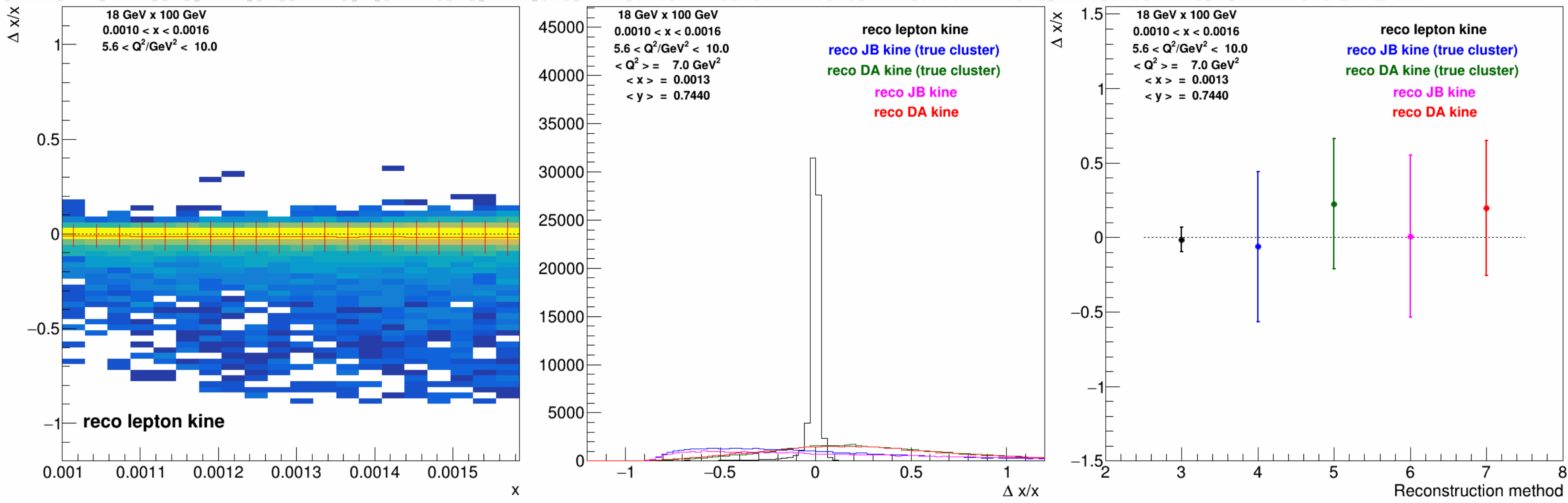
DIS kinematic reconstruction

- First try to understand the best reconstruction methods for different kinematic regions
- Especially low y (bottom right corner in x-Q2 plane) is important for overlap of many (SI)DIS measurements to existing fixed-target measurements (HERMES, COMPASS, JLAB)



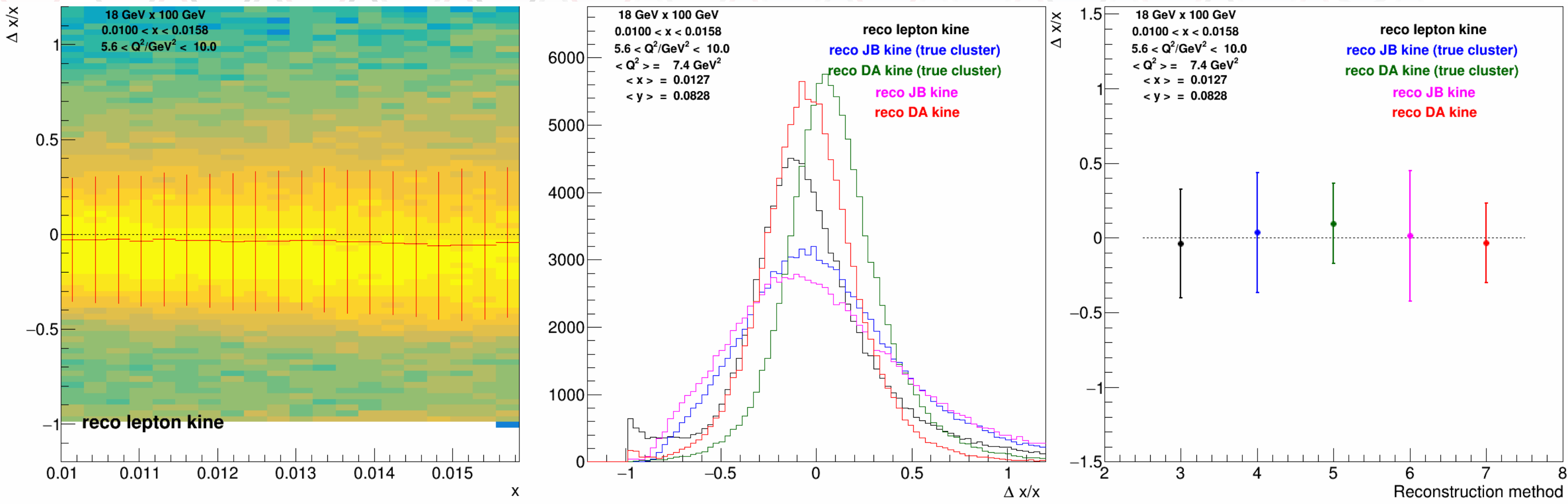


Kinematic reco example plots (x, high y)



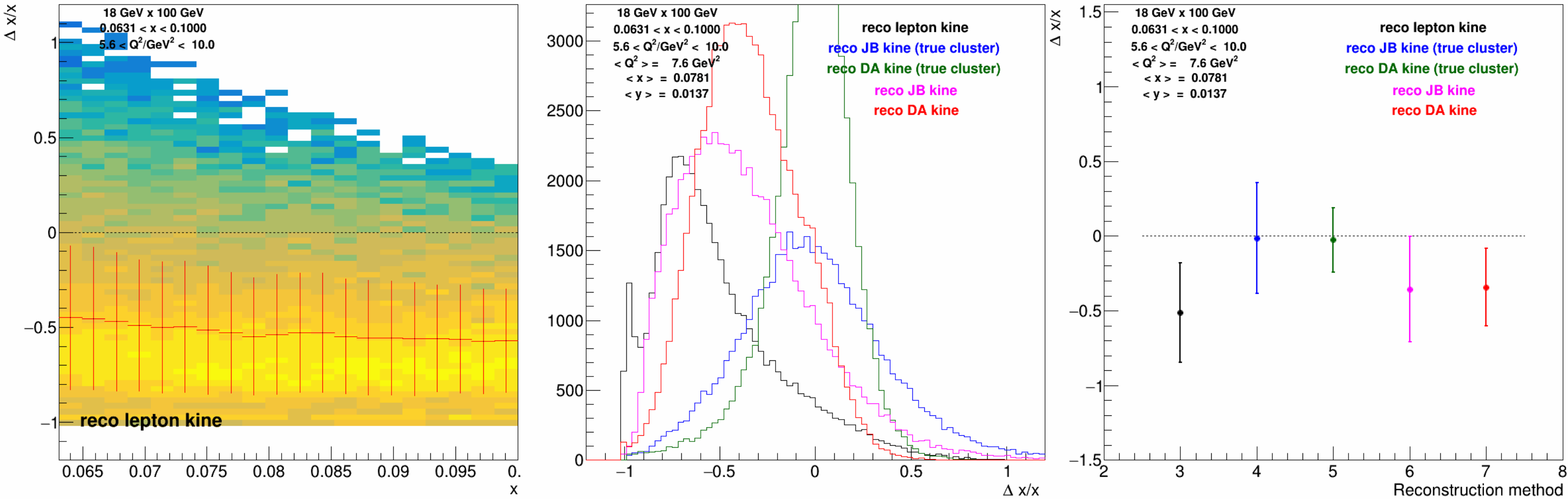
1. $(var_{reco} - var_{true} / var_{true})$ distributions as a function of variable/x/z in one x-Q2 bin
2. $(var_{reco} - var_{true} / var_{true})$ distribution in one x-Q2 bin
3. Mean and width for various reconstruction methods

Kinematic reco example plots (x, med y)



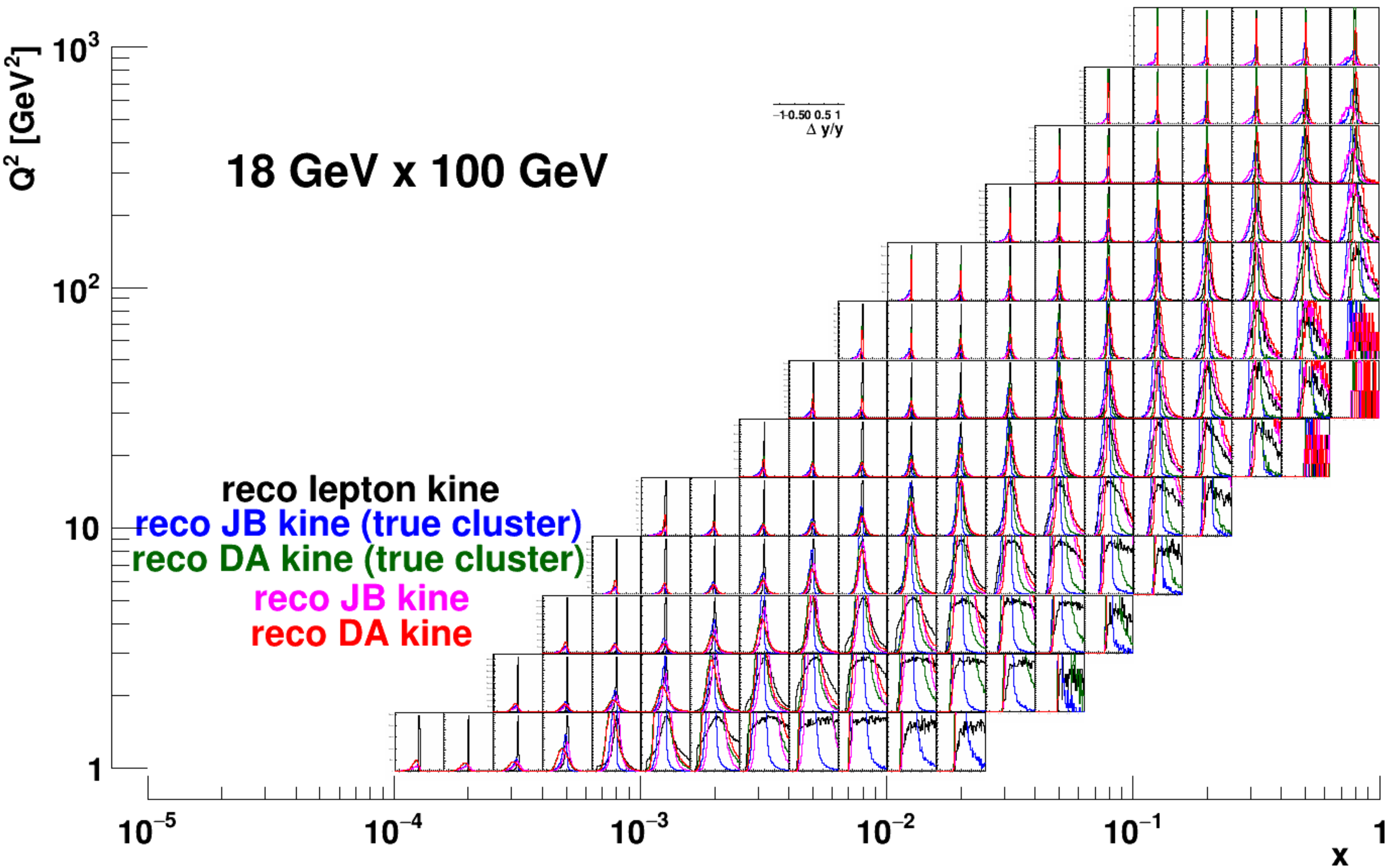
- At medium y all resolutions similar,

Kinematic reco example plots (x, low y)

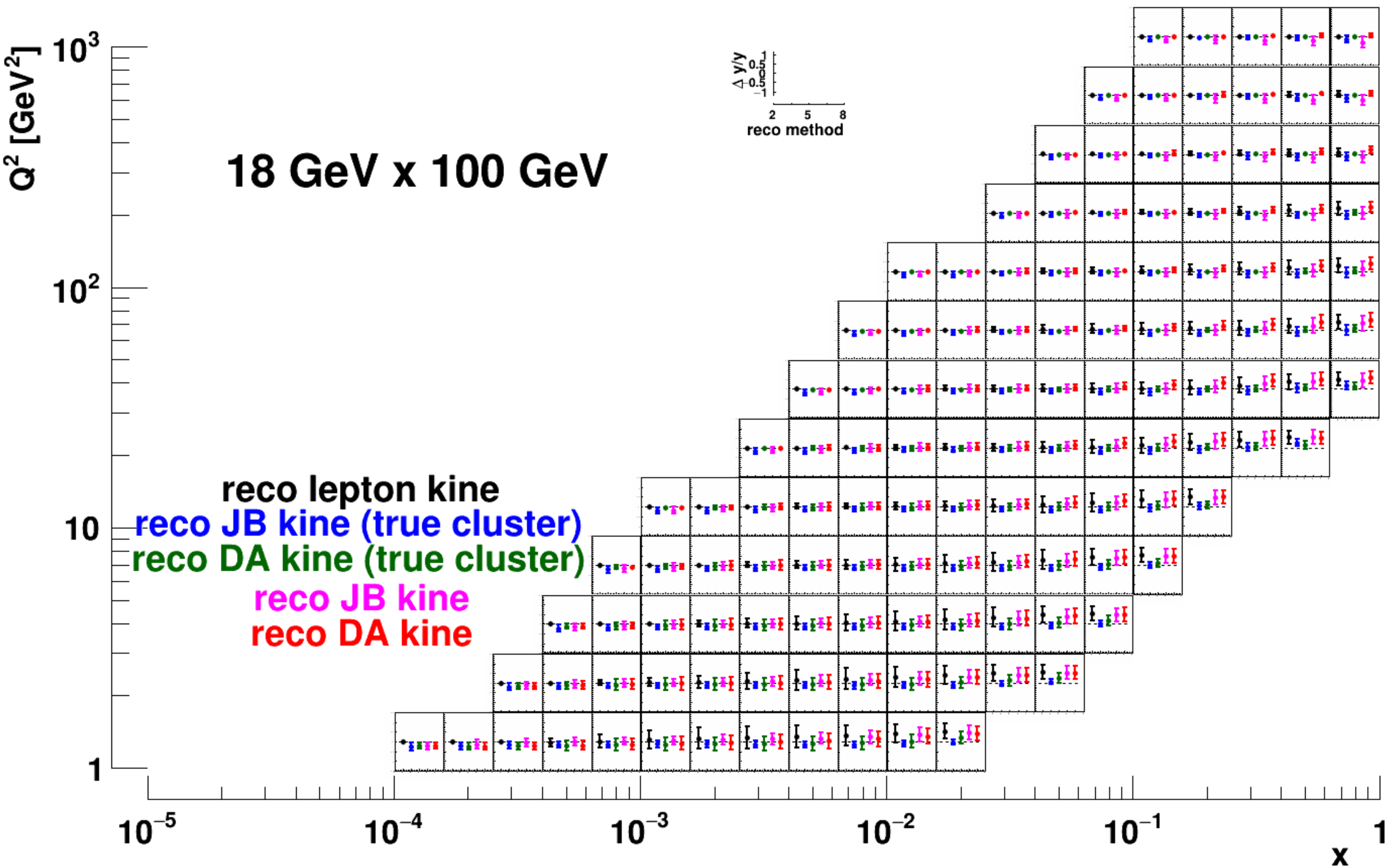


- Low y, lepton shifted and wide, hadronic methods better

Accumulated resolutions

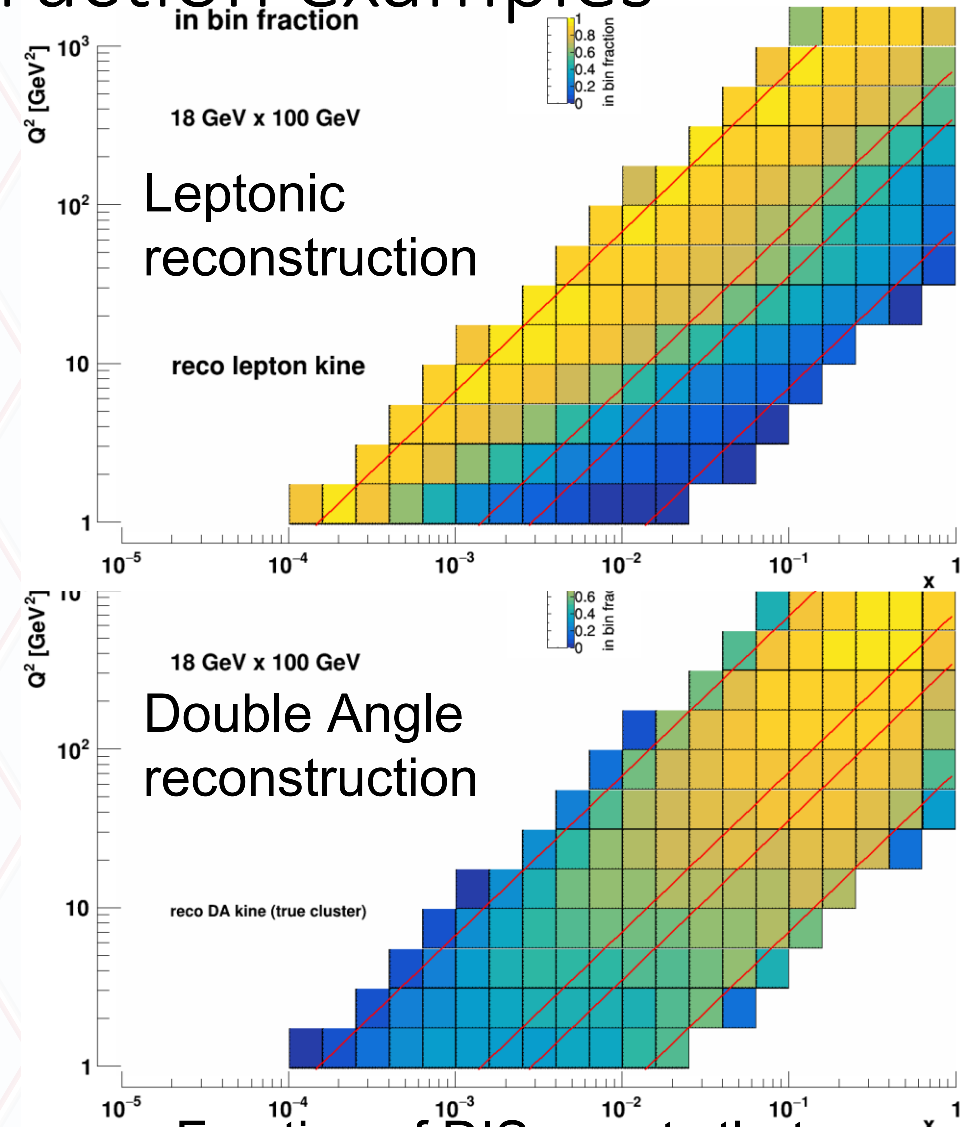


All y resolution widths and means



DIS kinematic reconstruction examples

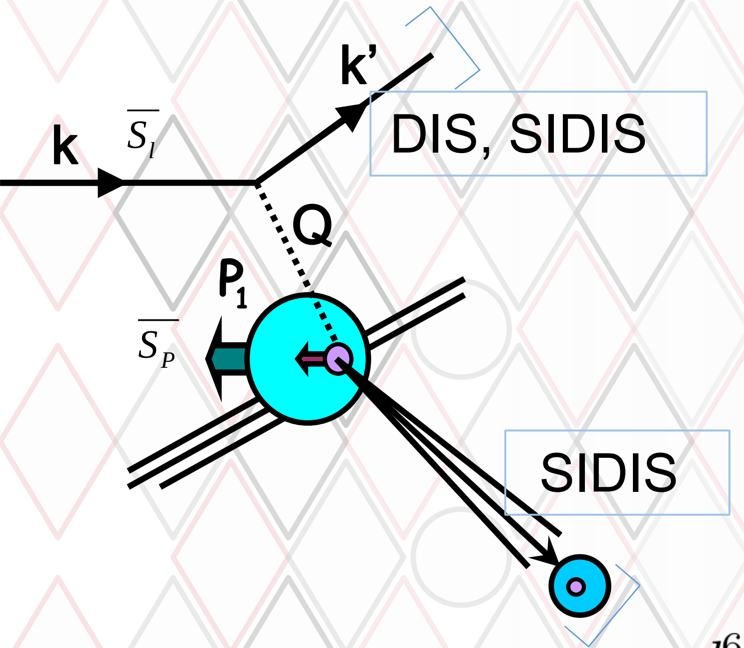
- Full Pythia6+GEANT simulations of the ECCE detector used for various (SI)DIS kinematic resolutions and for various reconstruction methods (lepton, Jaquet-Blondel, Double Angle, etc)
- x and y resolutions suffer from lepton method at lower y, partially recoverable in double angle method(hybrid of scattered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



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

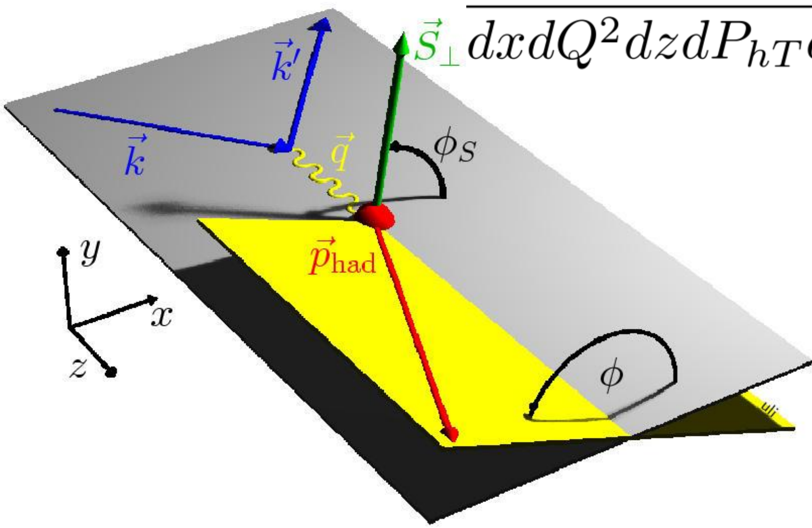
SIDIS Kinematics

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

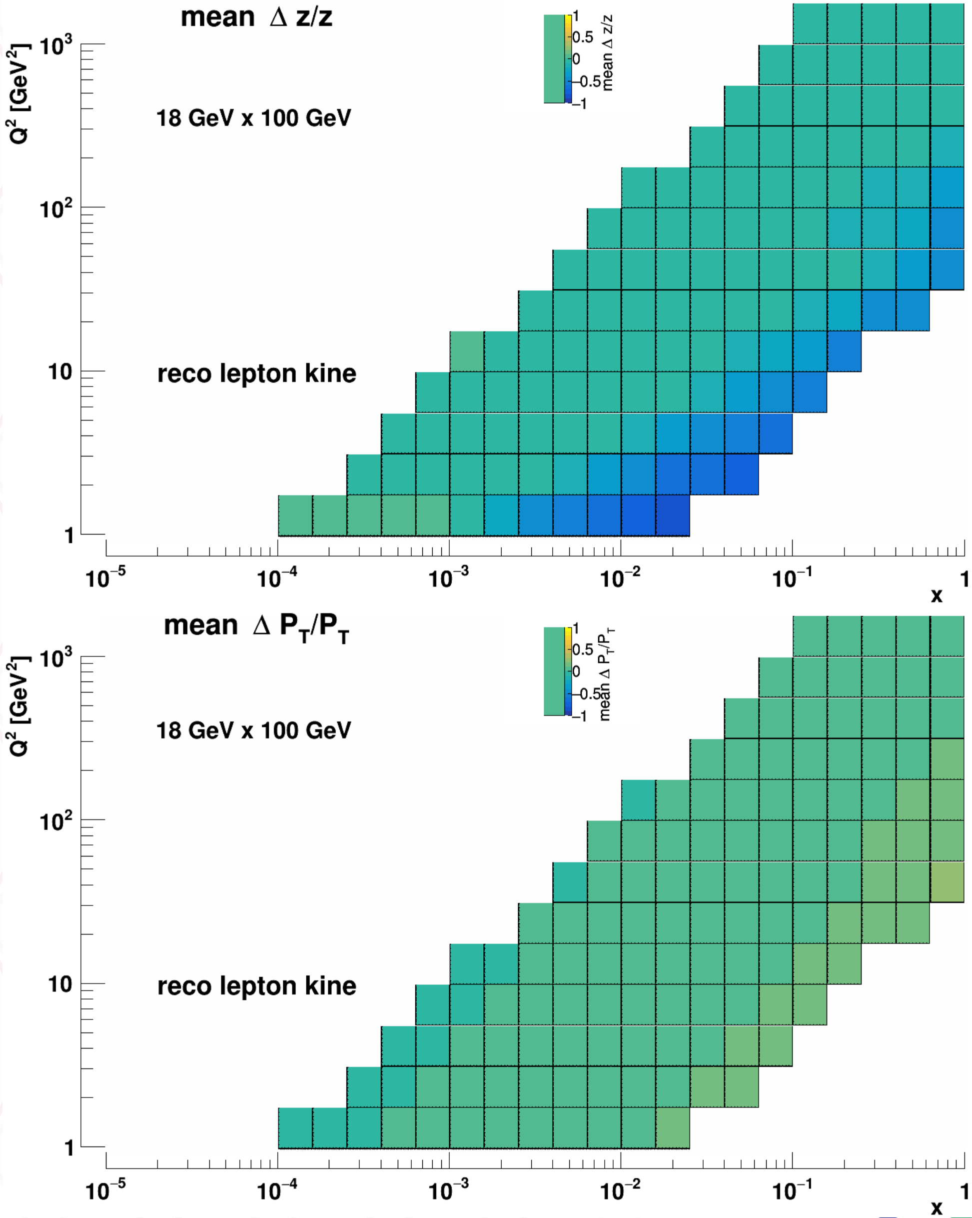
$$\frac{d^6\sigma}{dx\,dQ^2\,dz\,dP_{hT}\,d\phi_S\,d\phi_h} \overset{LO}{\propto} \sum_{q,\bar{q}} e_q^2\, q(x, Q^2, k_t) \otimes D_{1,q}^h(z, Q^2, p_t)$$



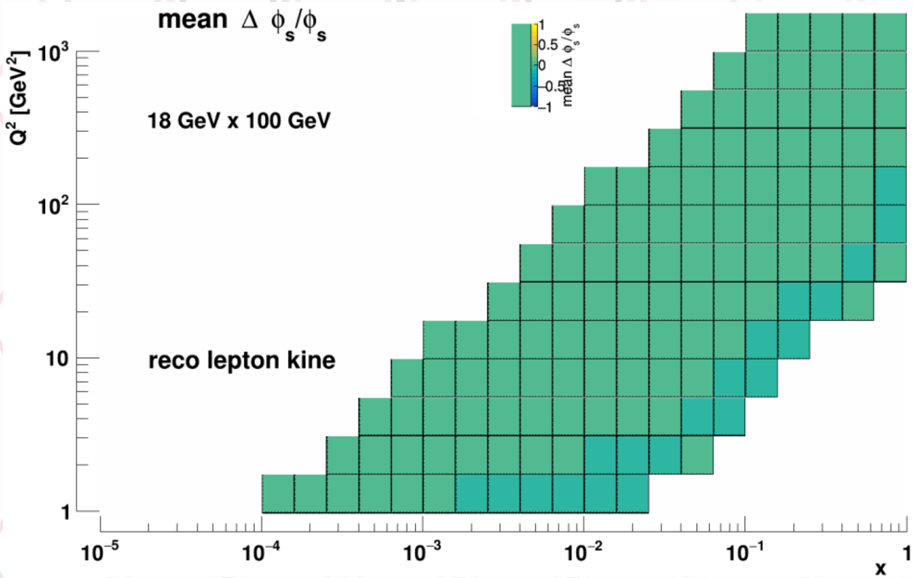
- Transverse momentum and angles rely also on correct boost to hadron rest system
- Current fragmentation: related to struck quark
- Target fragmentation: related to nucleon remnant

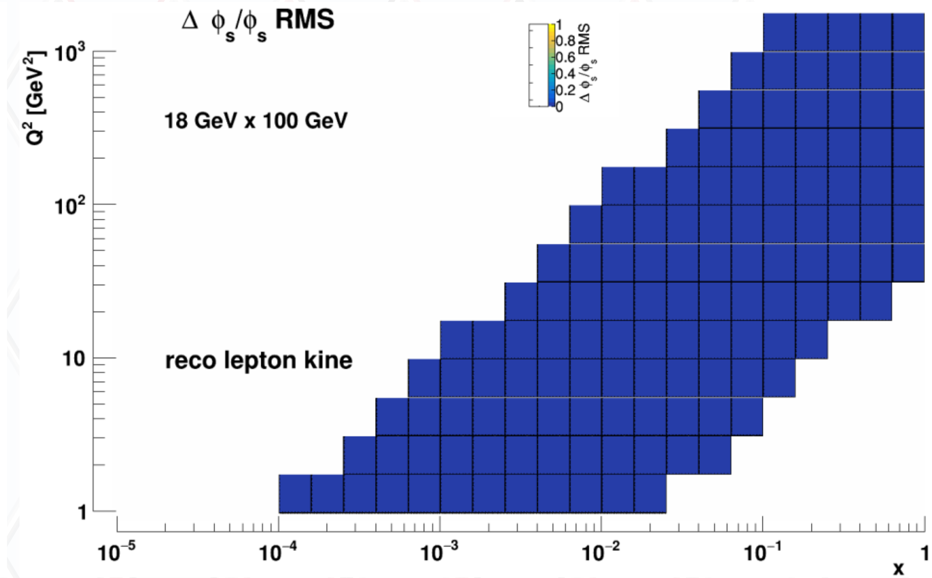
Example of ongoing resolutions studies

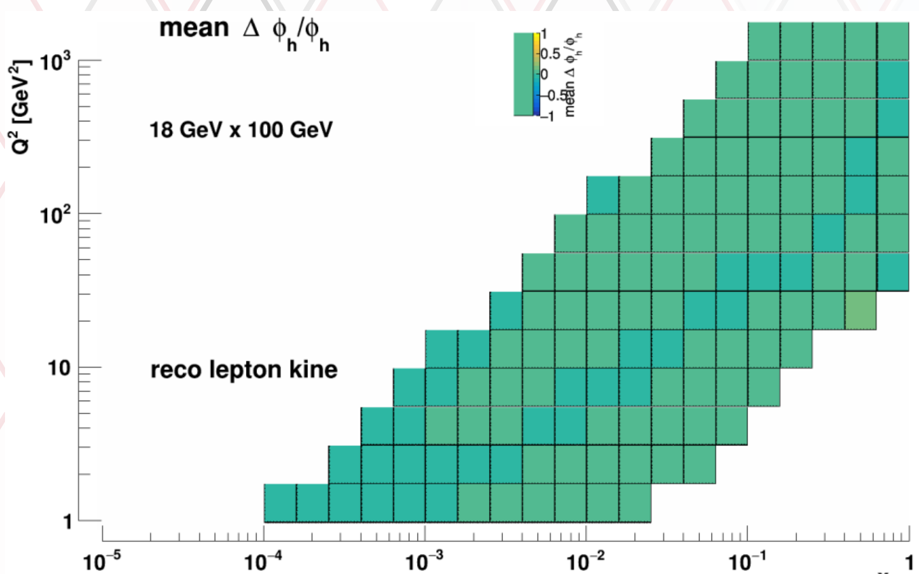
- Full Pythia6+GEANT simulations of the ECCE detector for various (SI)DIS kinematic resolution and reconstruction methods:
  - z resolution suffers in lepton method at lower y, partially recoverable in double angle method
  - p_T and azimuthal angles ϕ_h, ϕ_S very robust

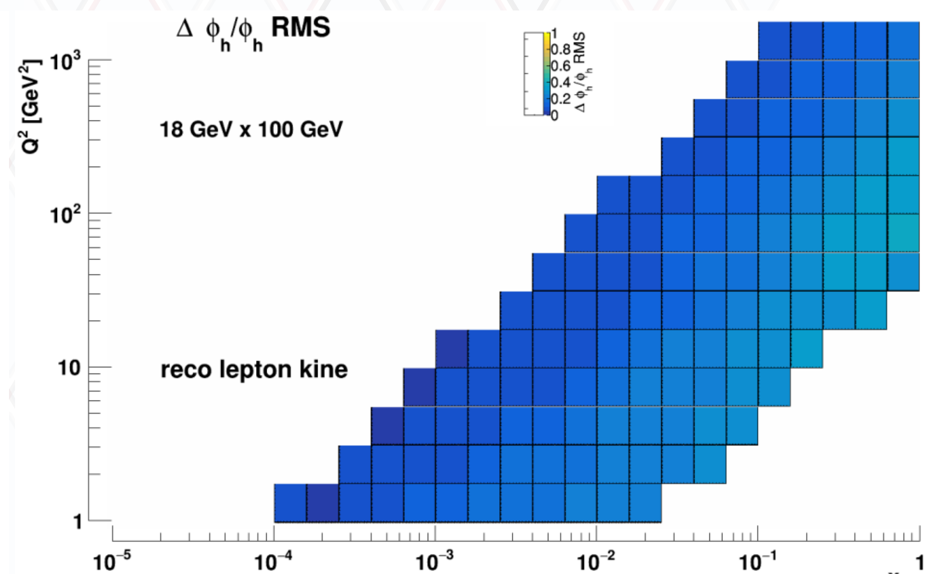


Azimuthal angles

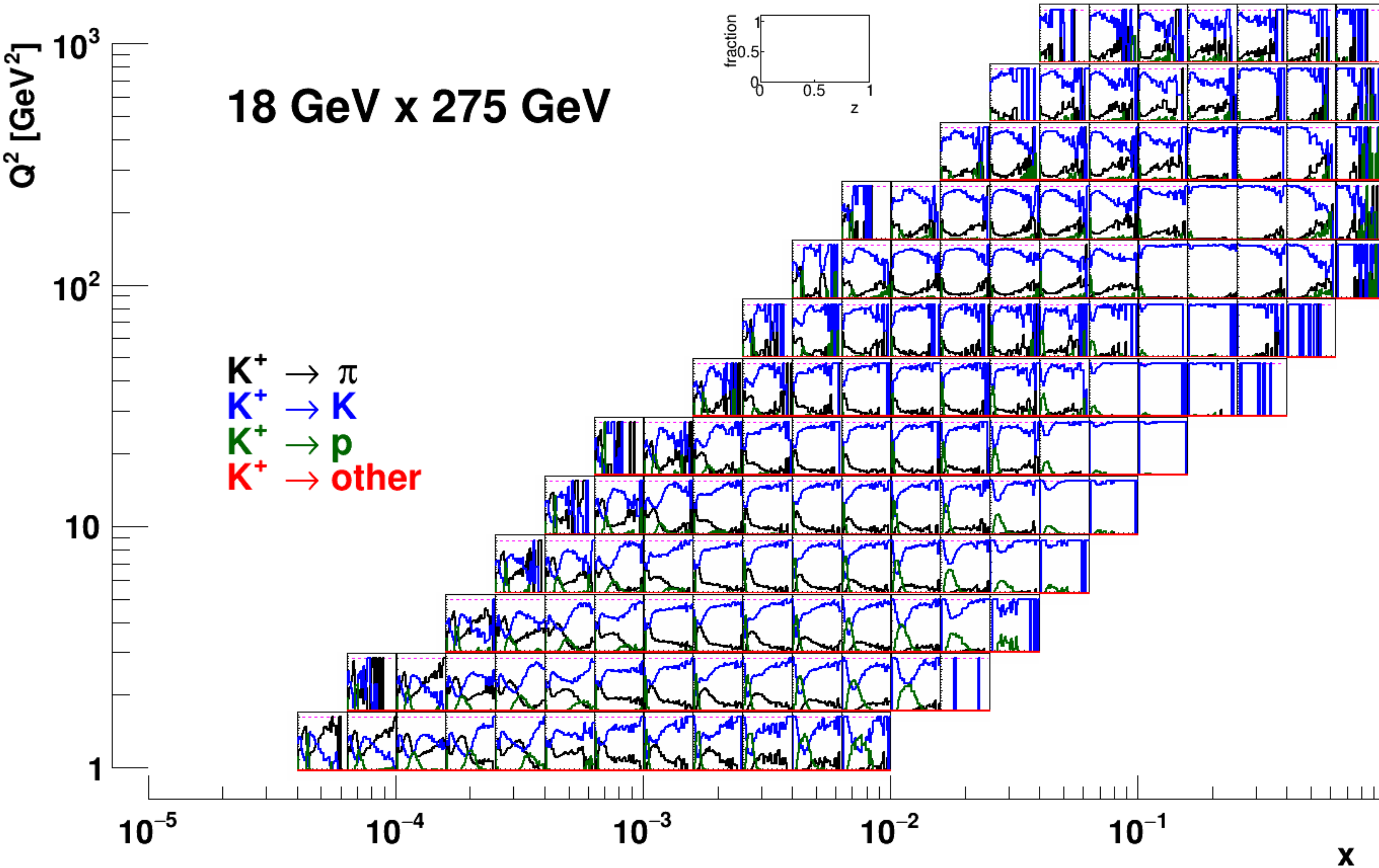




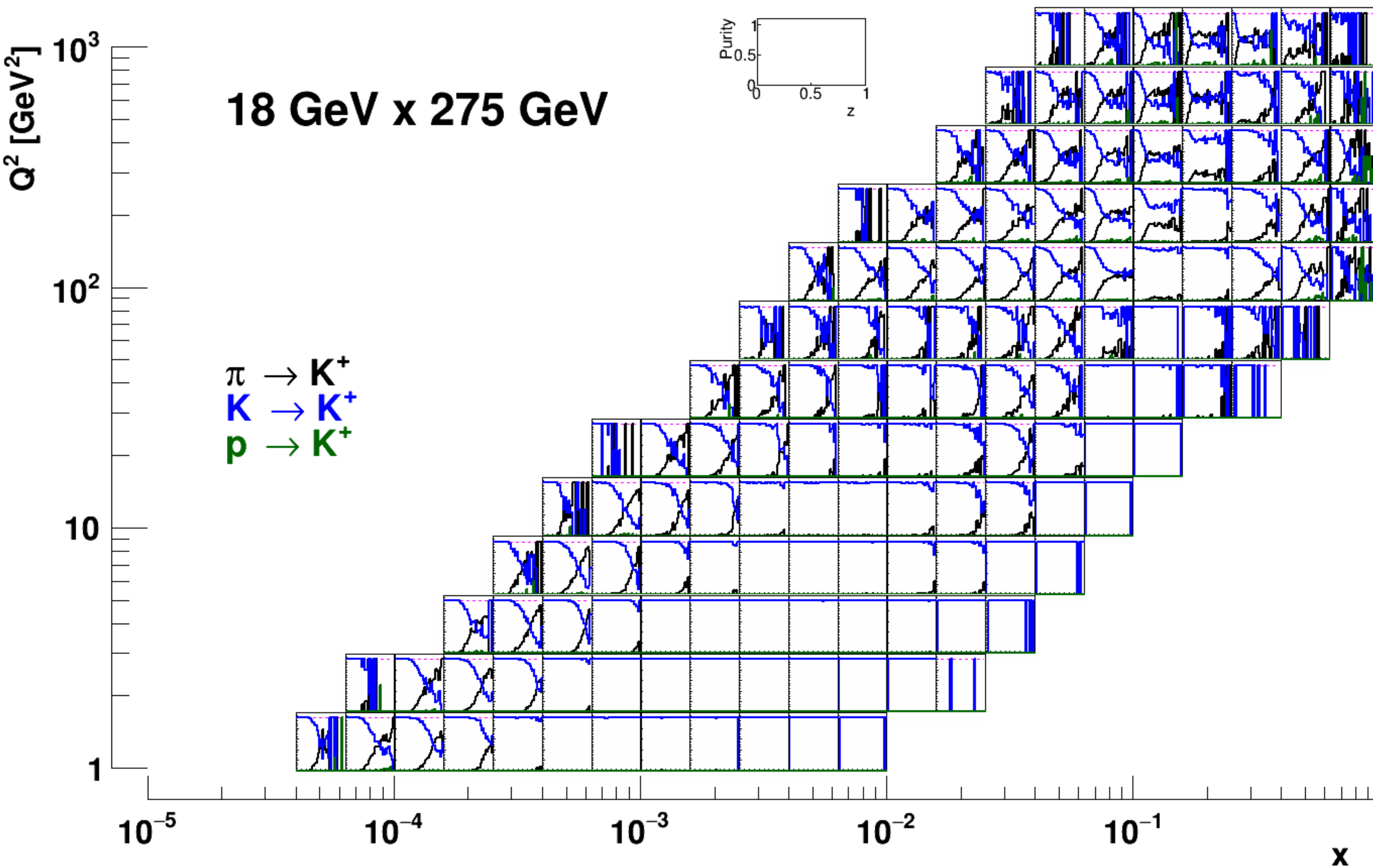


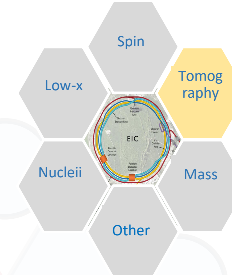


PID efficiencies
(fast PID based on dRICH, DIRC, and mRICH)



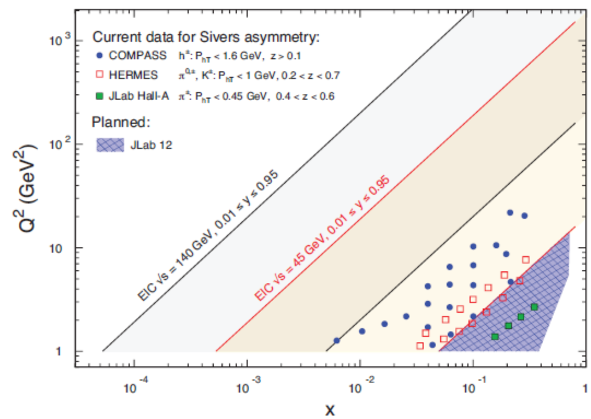
PID Purities



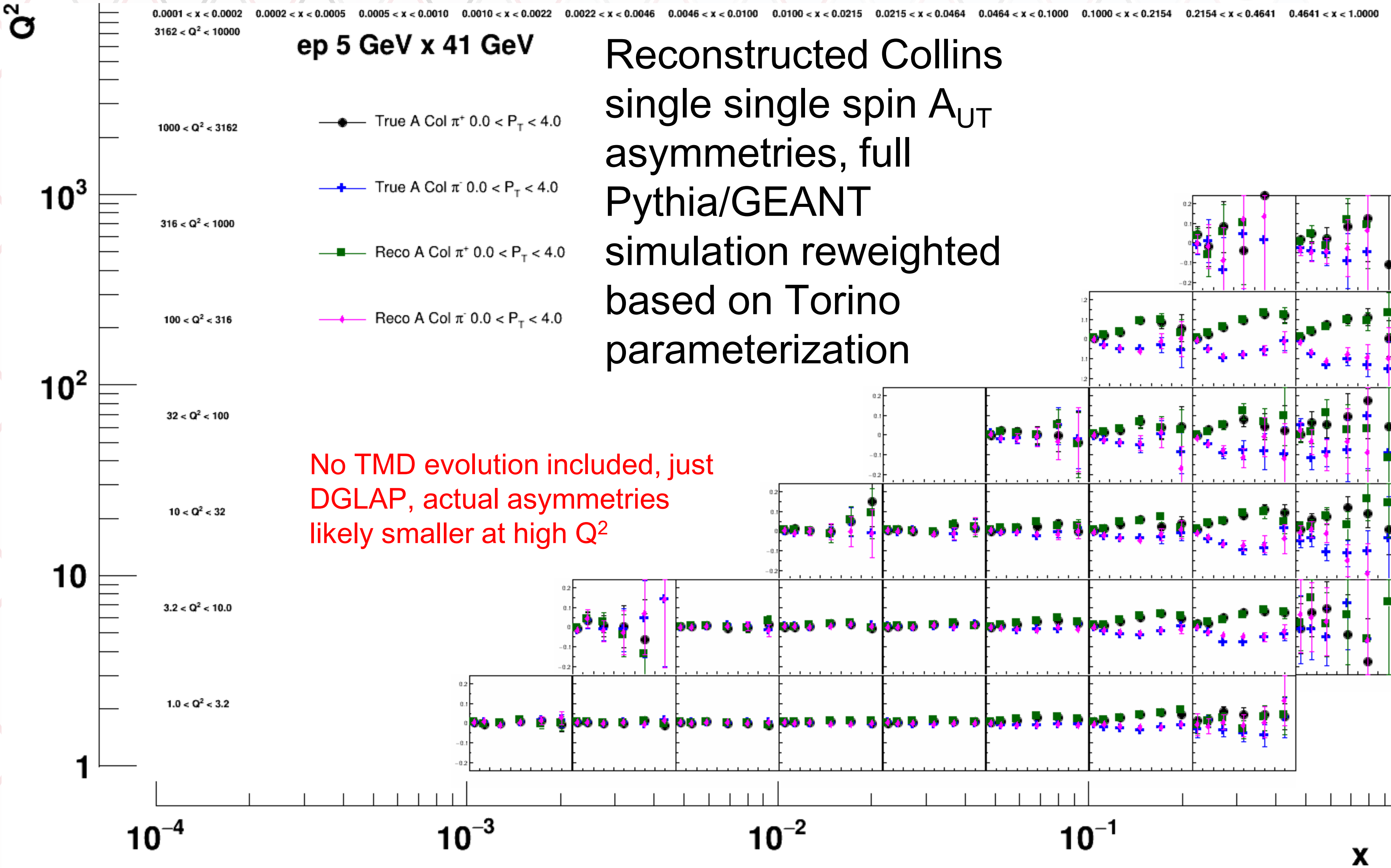


3D Transverse spin and momentum structure

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



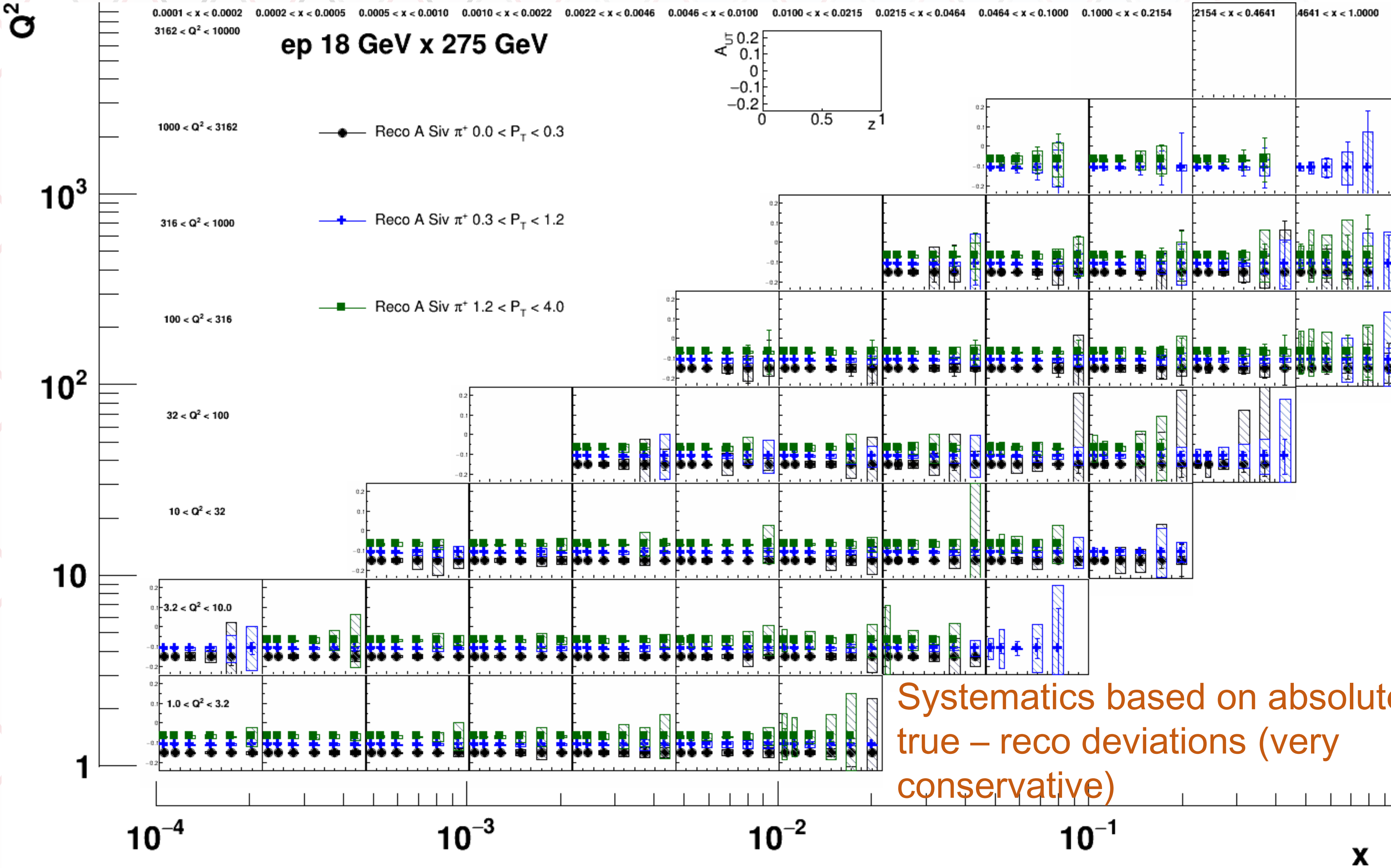
Example of ongoing studies on actual physics variables



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^{+}



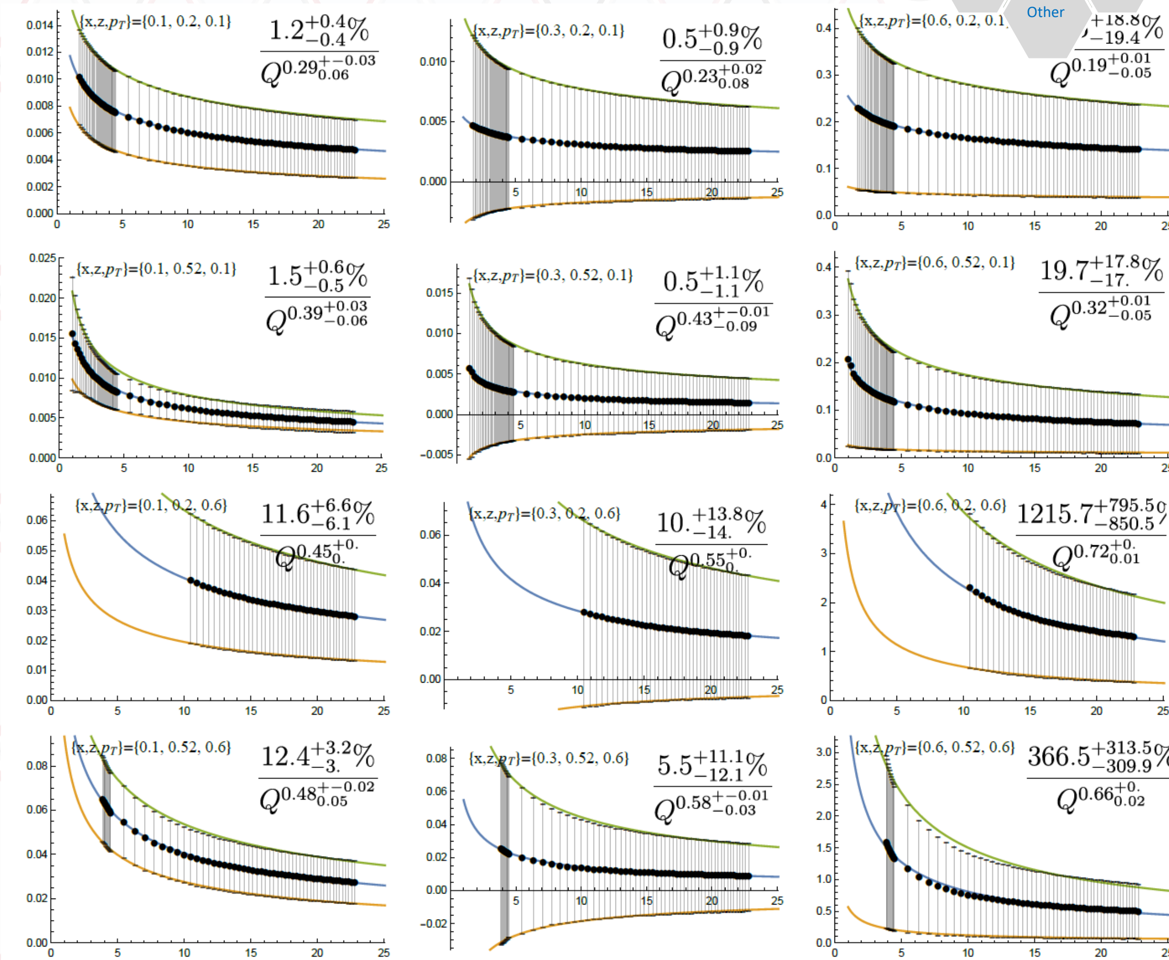
Systematics based on absolute true – reco deviations (very conservative)

ECCE access to TMD evolution

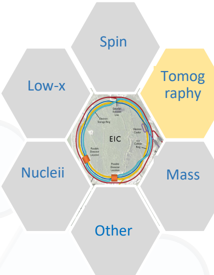
- Very important aspect is the study of TMD evolution
- Sivers asymmetries are expected to decrease at higher scales, but only logarithmically (ie they do NOT "disappear")
- At higher x Asymmetries of several % expected

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

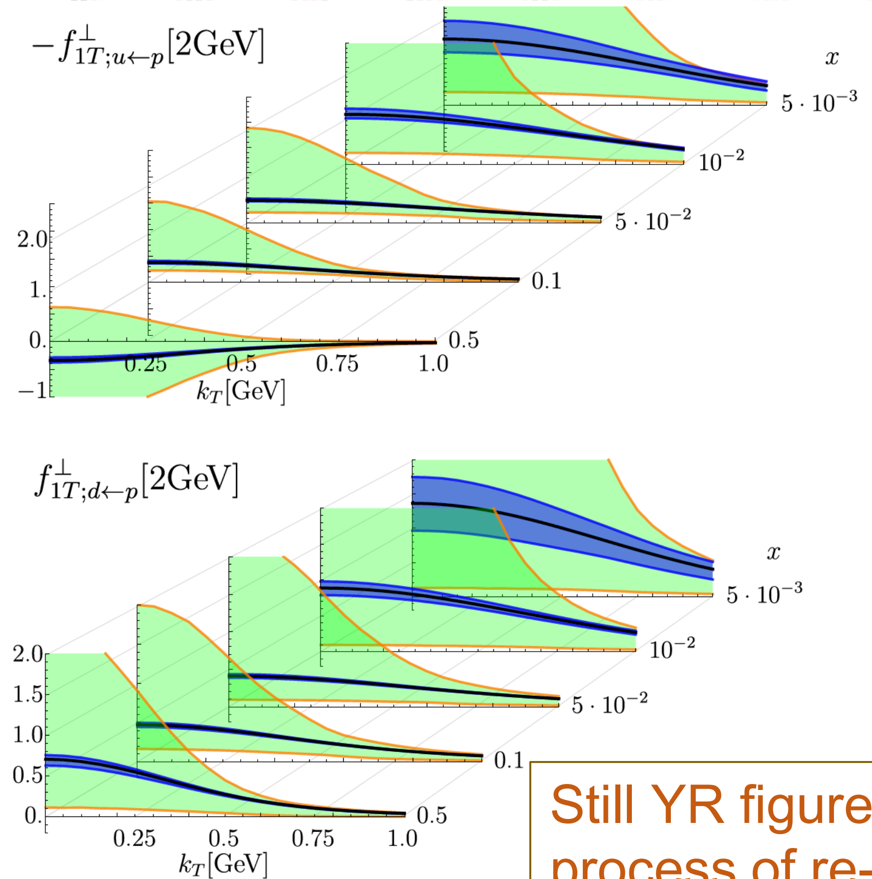
➔Lower x to study sea and glue (both mostly unknown)



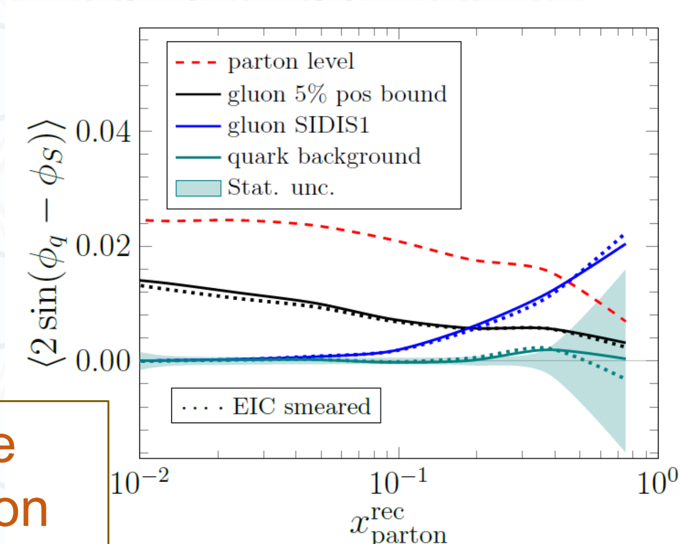
Vladimirov et al.



EIC impact for Sivers Functions



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

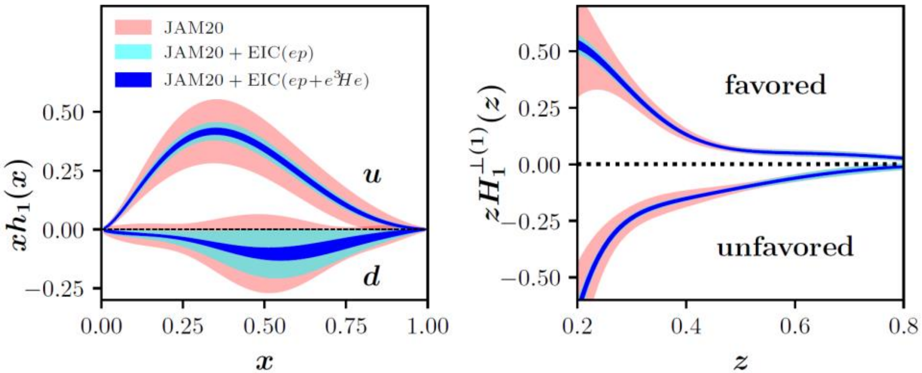


YR: Fig 7.53
Vladimirov, et al

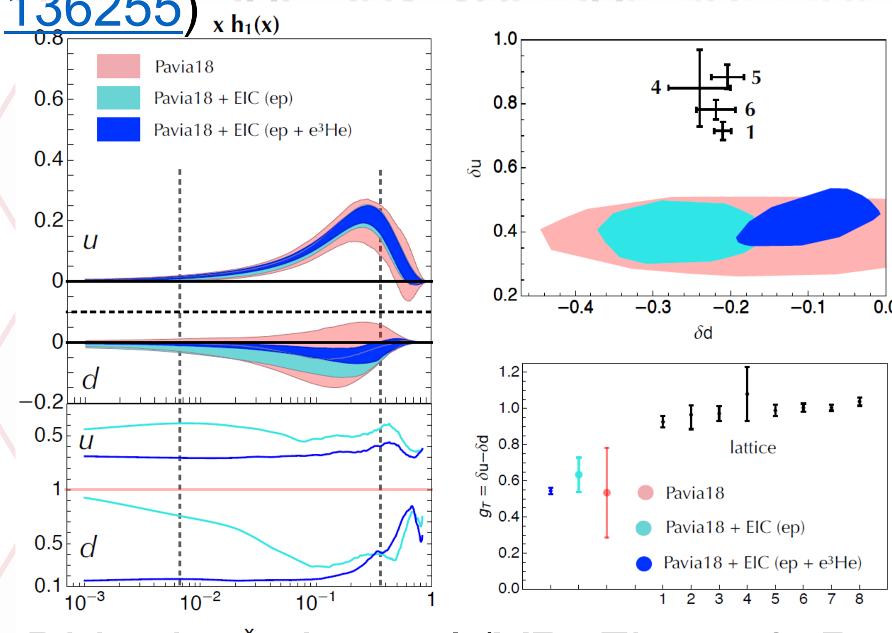
Still YR figures – in the process of re-evaluation using full ECCE simulations

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](#))



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

Status

- Just finished 2nd large simulation campaign w more realistic support structure, etc
- Some issues with lepton scattering angles around 150 degrees found
- SIDIS group is currently preparing 4 notes:
  - (SI)DIS kinematic reconstruction, PID, etc (RCS, Charlotte)
  - AUT asymmetries + impact studies (RCS)
  - Unpolarized TMDs (RCS)
  - SIDIS ALLs (Charlotte)
- ECCE detector proposal writing ongoing (spin godparent)

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