Example analysis with evaluators

2nd ECCE Simulation workshop
May 21

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General setup

- PythiaeRHIC files created for the YR available in /gpfs02/eic/DATA_YR_SIDIS/ (in eic-smear formatted TTrees)
- Test GEANT production of one(?) ep18x100 file by Cameron → DSTs and various evaluators (in chunks of 1k events)

Today:

- concentrate on the EventEvaluator output
- Used a local copy of it that has added branches related to the HEPMC information (needed for the struck quark, process id, etc information)

DST → Evaluator

```
int Fun4All_G4_EICDetector(    const int nEvents = 1,
const string &inputFile = "testdst.root",    const
string &outputFile = "G4EICDetector.root",    const
string &embed_input_file = "",
//https://www.phenix.bnl.gov/WWW/publish/phnxbld/sPHENIX
/files/sPHENIX_G4Hits_sHijing_9-11fm_00000_00010.root",
const int skip = 0,    const string &outdir = ".")

{

…

 bool use_event_evaluator = true;

 Input::READHITS = true;

 INPUTREADHITS::filename[0] = inputFile;

…

 Enable::TRACKING = true;

 Enable::TRACKING_EVAL = Enable::TRACKING && true;

 if (use_event_evaluator)

  {

    EventEvaluator *eval = new
EventEvaluator("EVENTEVALUATOR",  outputroot +
"_eventtree.root");

    eval->set_reco_tracing_energy_threshold(0.05);

    eval->Verbosity(0);
```

```
if (Enable::TRACKING_EVAL)
    {

      eval->set_do_TRACKS(true);

      //eval->set_do_HITS(true); //Potential problem

      eval->set_do_PROJECTIONS(true);

      if (G4TRACKING::DISPLACED_VERTEX)

        eval->set_do_VERTEX(true);

     }

 //if (Enable::CEMC_EVAL) eval->set_do_CEMC(true);

    if (Enable::EEMC_EVAL) eval->set_do_EEMC(true);

 //if (Enable::FEMC_EVAL) eval->set_do_FEMC(true);

    if (Enable::HCALIN_EVAL) eval->set_do_HCALIN(true);

    if (Enable::HCALOUT_EVAL) eval->set_do_HCALOUT(true);

    if (Enable::FHCAL_EVAL) eval->set_do_FHCAL(true);

    //if (Enable::FHCAL_EVAL || Enable::FEMC_EVAL ||
Enable::EEMC_EVAL)

    ///  eval->set_do_CLUSTERS(true);

    eval->set_do_MCPARTICLES(true);

    eval->set_do_HEPMC(true);

    se->registerSubsystem(eval);

  }
```

EventEvaluator output

```
 TTree          *fChain;   //!pointer to the analyzed TTree or TChain
   Int_t           fCurrent; //!current Tree number in a TChain
// Fixed size dimensions of array or collections stored in the TTree if any.
   // Declaration of leaf types
   Int_t           nTracks;
   Float_t         tracks_ID[40];   //[nTracks]
   Float_t         tracks_px[40];   //[nTracks]
   Float_t         tracks_py[40];   //[nTracks]
   Float_t         tracks_pz[40];   //[nTracks]
   Float_t         tracks_trueID[40];   //[nTracks]
Int_t           nMCPart;
   Float_t         mcpart_ID[7000];   //[nMCPart]
   Float_t         mcpart_ID_parent[7000];   //[nMCPart]
   Float_t         mcpart_PDG[7000];   //[nMCPart]
   Float_t         mcpart_E[7000];   //[nMCPart]
   Float_t         mcpart_px[7000];   //[nMCPart]
   Float_t         mcpart_py[7000];   //[nMCPart]
   Float_t         mcpart_pz[7000];   //[nMCPart]
 Int_t           nHepmcp;
   Int_t           hepmcp_procid;
   Float_t         hepmcp_x1;
   Float_t         hepmcp_x2;
   Float_t         hepmcp_ID[150];   //[nHepmcp]
   Float_t         hepmcp_ID_parent[150];   //[nHepmcp]
   Float_t         hepmcp_status[150];   //[nHepmcp]
   Float_t         hepmcp_PDG[150];   //[nHepmcp]
   Float_t         hepmcp_E[150];   //[nHepmcp]
   Float_t         hepmcp_px[150];   //[nHepmcp]
   Float_t         hepmcp_py[150];   //[nHepmcp]
   Float_t         hepmcp_pz[150];   //[nHepmcp]
   Int_t           hepmcp_m1[150];   //[nHepmcp]
   Int_t           hepmcp_m2[150];   //[nHepmcp]
```

SvtxTrackMap node

- Relates to trueID from PHG4TruthInfoContainer

PHG4TruthInfoContainer node → PHG4Particle:

- Only final state/secondary particles
- Neg ID: secondary
- ancestry

HEPMC output (not yet in official EE):

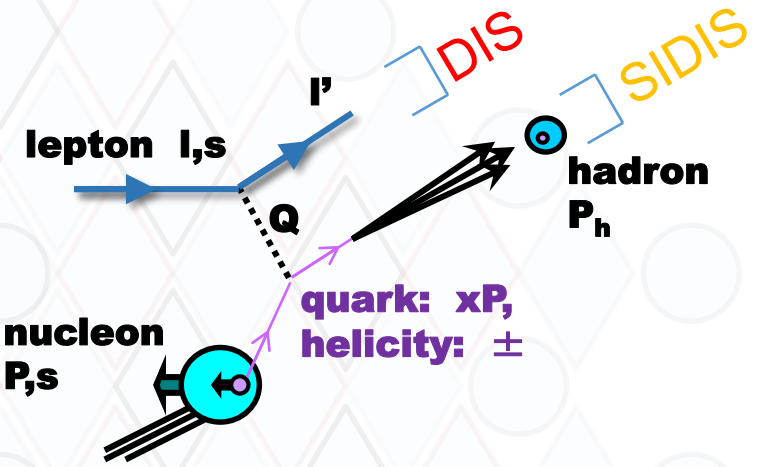
- Process ID (Pythia 99, 131/132, 135/136, etc)
- All generated particles: use status (4/3/0/1) for initial/PS/decaying/final info (not Pythia!!!)
- Parton info

Various other evaluators not shown here (Calorimeters)

Physics analysis strategy

- For any (SI)DIS analysis:

1. Find DIS kinematics: easiest case (other methods include hadronic final state) via scattered lepton l'
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

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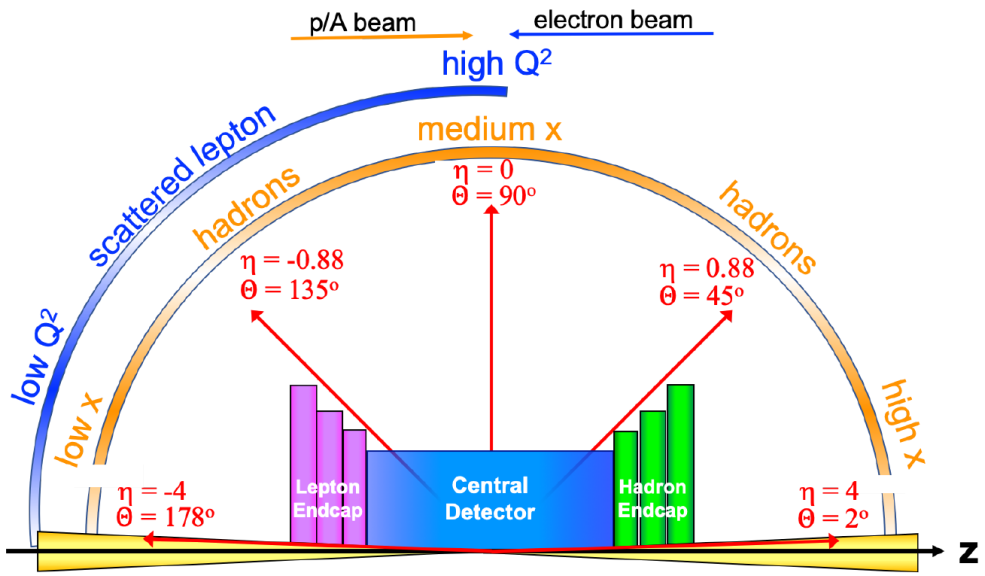
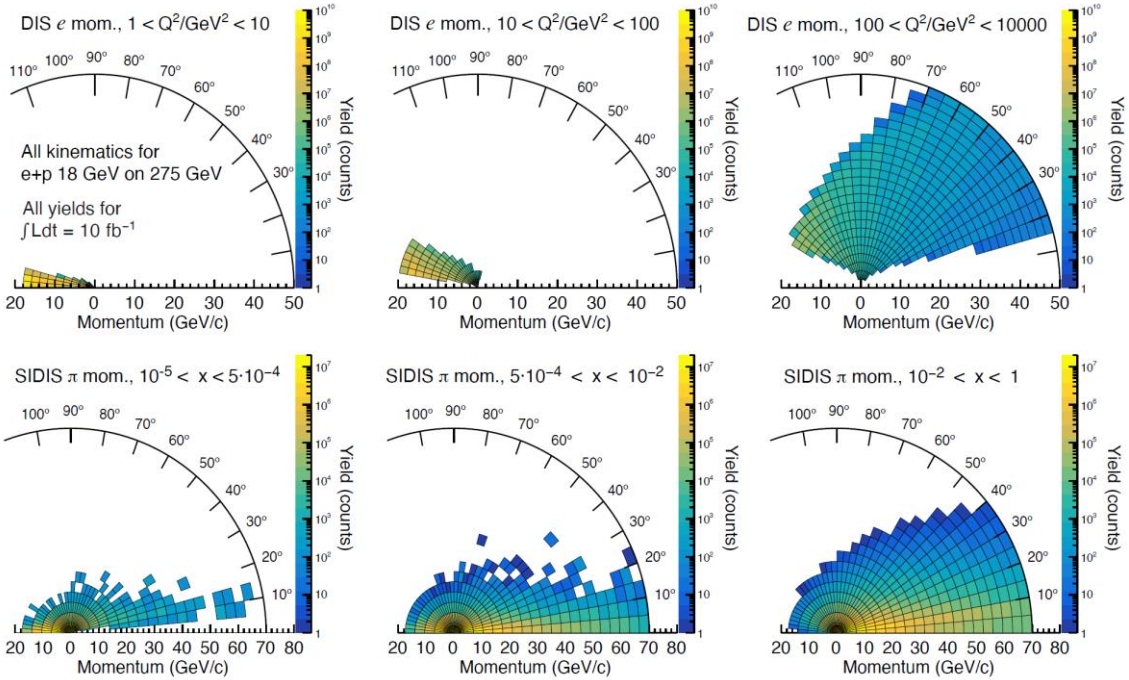
General (SI)DIS kinematics

- 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





Doing this in the EventTrees

```
for ( int itrack=0; itrack < evt.nTracks; itrack ++){
      TVector3 track3( evt.tracks_px[itrack],
            evt.tracks_py[itrack],evt.tracks_pz[itrack]);
      if ( track3.Mag() < 0.1 )continue;
      auto search = mcidmap.find((int)(evt.tracks_trueID[itrack]));
      if (search != mcidmap.end()) {
            int imc = search->second;
            TVector3 trackgen3( evt.mcpart_px[imc],
            evt.mcpart_py[imc],evt.mcpart_pz[imc]);
            if ( (int)(evt.mcpart_PDG[imc]) == 11 ){
              gleptons.push_back( trackgen3);
              leptons.push_back( track3);
            }
            else if ( fabs((int)(evt.mcpart_PDG[imc])) == 211
            || fabs((int)(evt.mcpart_PDG[imc])) == 321
            ||fabs((int)(evt.mcpart_PDG[imc])) == 2212  ){
              ghadrons.push_back( trackgen3);
              hadrons.push_back( track3);
              hadids.push_back(evt.mcpart_PDG[imc]);
              hadcounter++;
            }
      }// found entry
}
```

- Loop through all tracks in an event
- Search for corresponding true particle (I used a map `mcpart_ID` – `imc` for it)

- PID currently from truth
  11 → Lepton;
  211,321,2212 → π, K, p

- Added to hadron and lepton lists, same for truth particles
- Calculate (SI)DIS kinematics based on these for true and reco
- Optionally: check whether gen (HEPMC) particles (currently via momentum matching
- Optionally: Reweight based on flavor, true kine, process, etc

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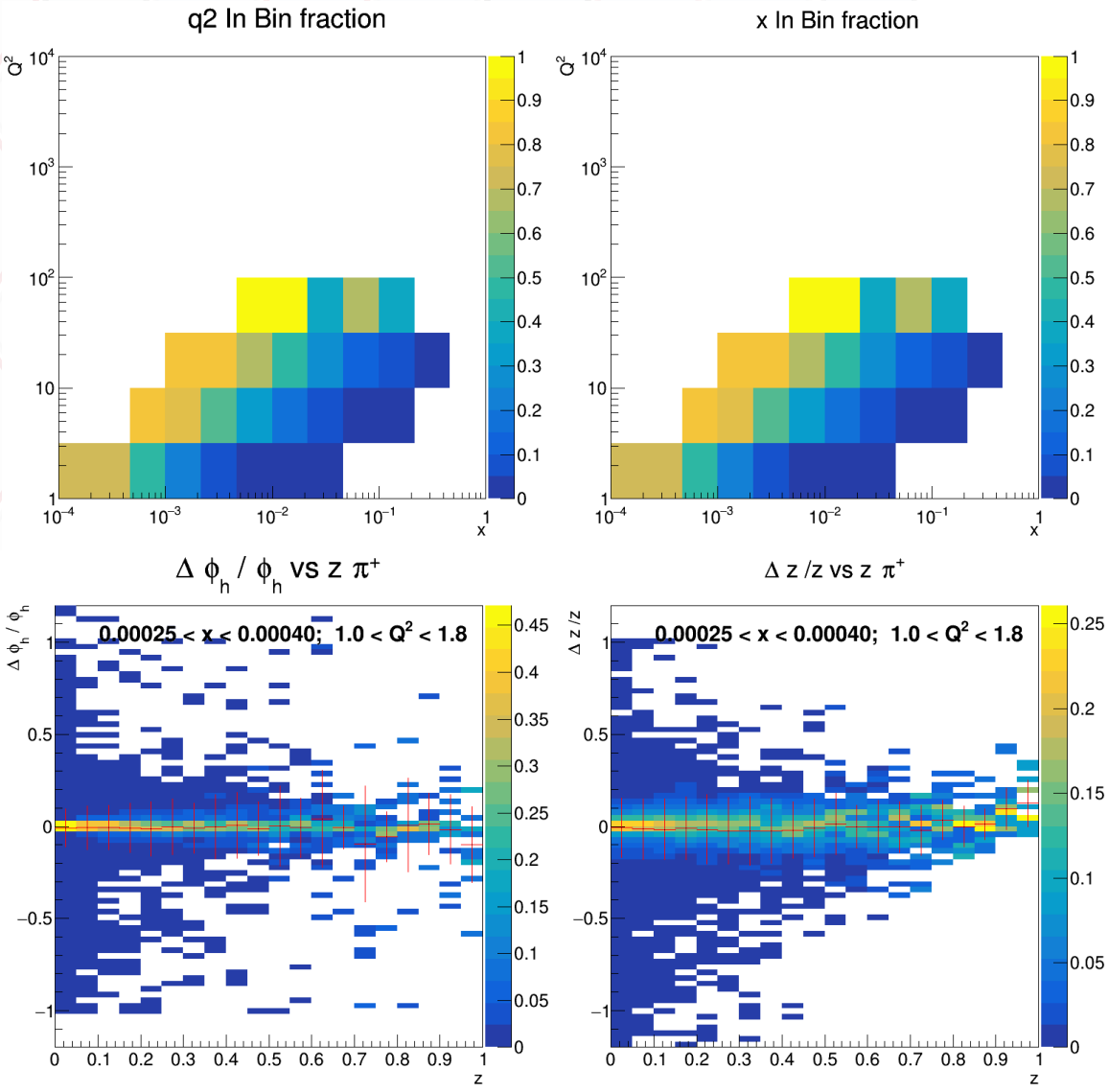
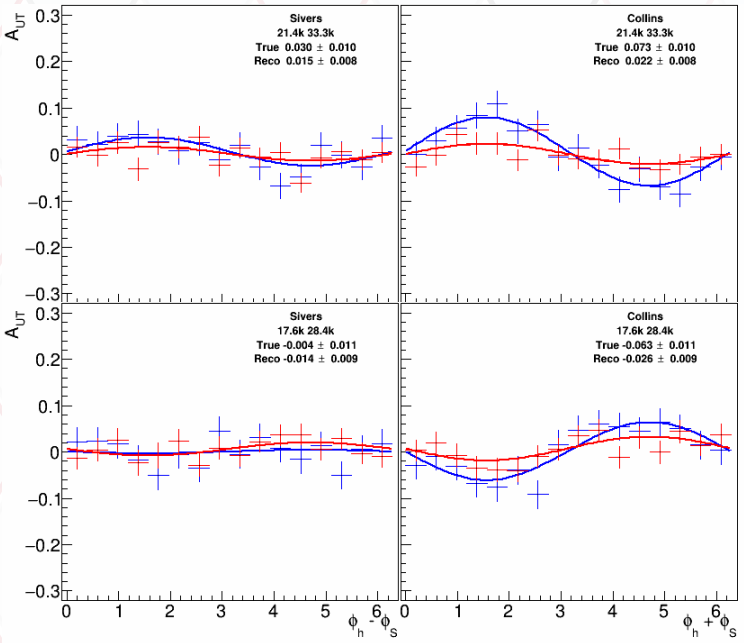
Some example Output I

- Low level: DIS in-bin efficiencies (using scattered lepton only)
- Medium level: Some resolutions for hadron z, azimuthal angles in one particular z-Q^2 bin



Some example Output II

- High level: Reweighted azimuthal single spin asymmetries
  - Very simplified constant (in x, Q^2, z, P_{hT}) weights in true variables
  - Far from enough statistics, but demonstration of smeared asymmetry test

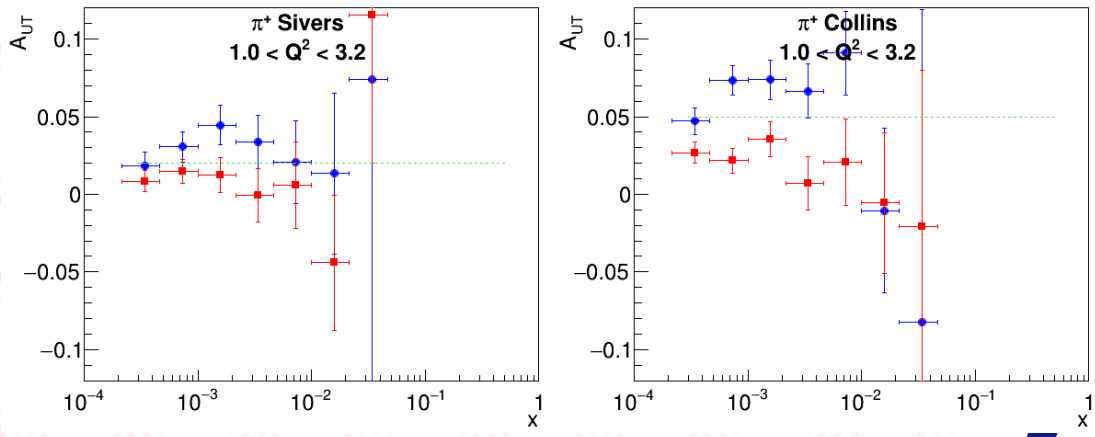


$0.0005 < x < 0.0010$
$1.0 < Q^2 < 3.2$
π^+

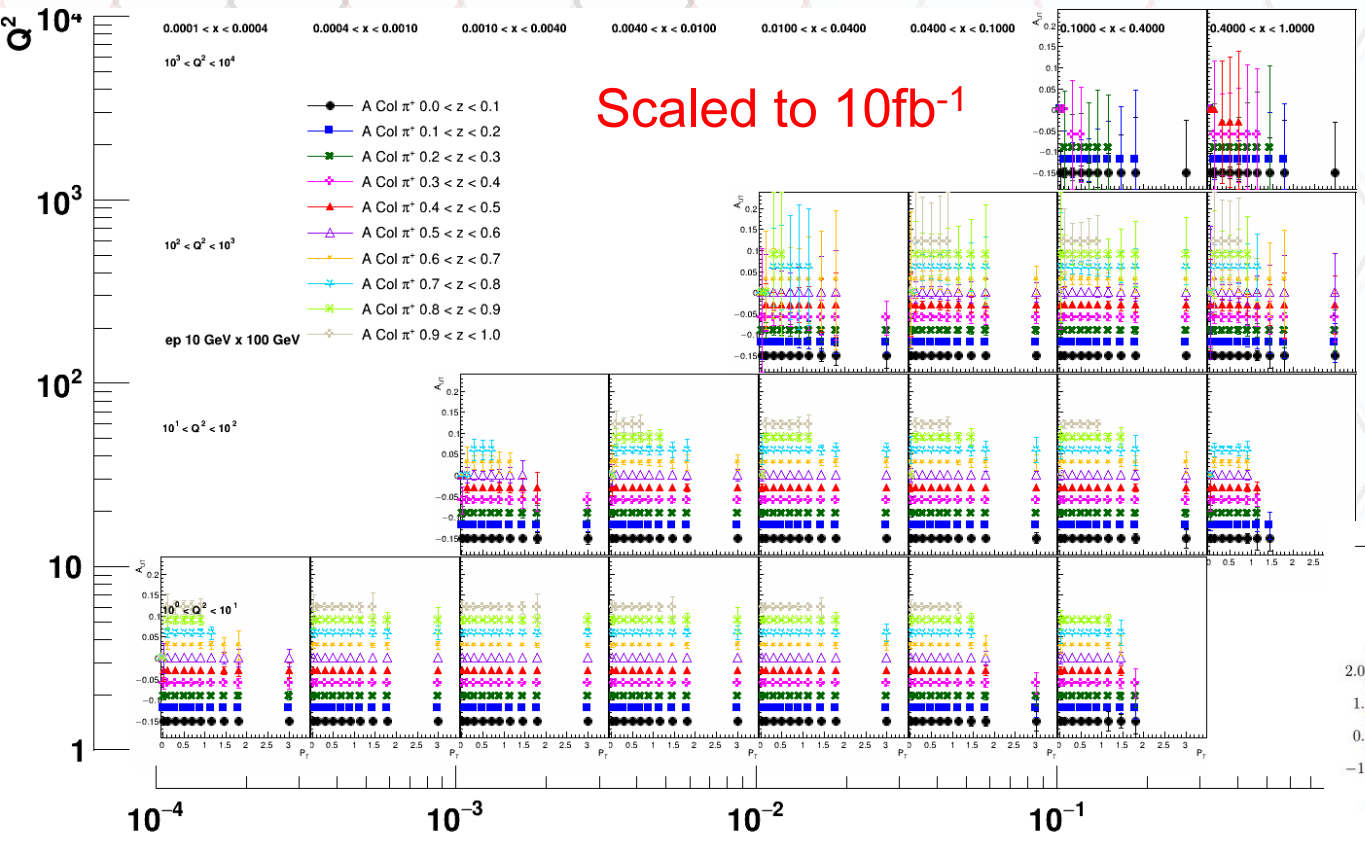
Truth
Smeared

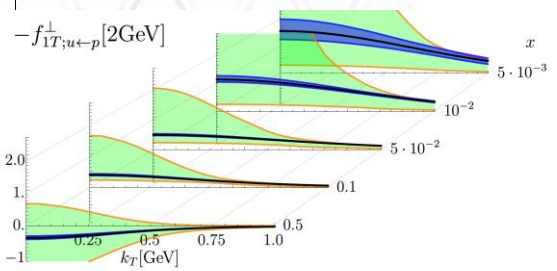
$0.0005 < x < 0.0010$
$1.0 < Q^2 < 3.2$
π^-

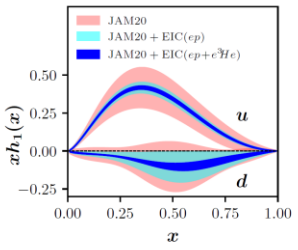
Truth
Smeared

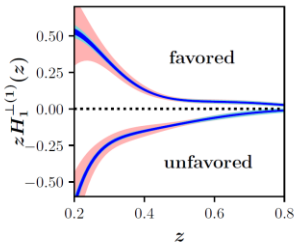


Expected Sivers/Collins asymmetries









- Note: This is still from YR work, based on eic-smear output only, NOT YET GEANT based!!

Summary

- Many types of ECCE analysis (at least where detector systems and individual evaluators are already implemented) can be performed using just the EventEvaluator (one evaluator to rule them all):
  - Simple TTree
  - Tracking, Vertexing, calorimetry, PHG4Truth, HEPMC*, etc
- Already useful for:
  - Resolution studies
  - Impact studies
- Potentially to be added: PID info (likely via moment-dependent PID separations)
- Still only very limited test output available, but good to get started

Key SIDIS physics measurements (must-do)

- Quark Sivers function as a function of x, k_t for valence and sea flavors: $A_{UT}\sin(\phi_S-\phi_h)$ moments for IDed pions and kaons (Golden channel)
- Tensor charges for valence and sea quarks $A_{UT}\sin(\phi_S+\phi_h)$ moments for IDed pions and kaons (silver channel)
- Unpolarized TMD PDFs and its QCD evolution (silver channel, implicit requirement for Sivers)
- Sea quark helicities via SIDIS A_1 (A_{LL}) measurements for IDed pions and kaons (golden channel)
- Gluon Sivers function via di-jet or HF pair A_{UT}s (Still open)

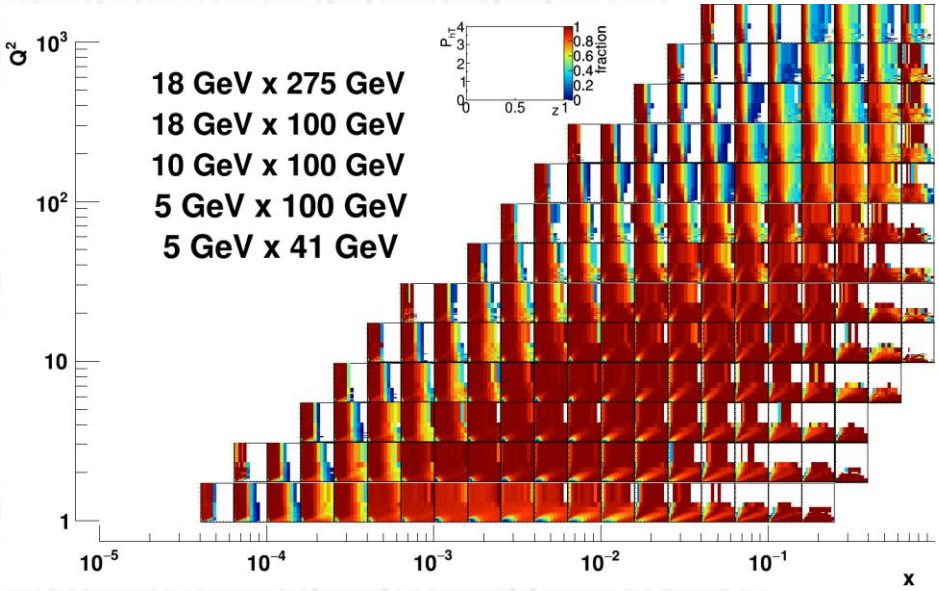
Other measurements (can-do)

- Boer-Mulders function measurements via IDed pion and kaon cos($n\phi_h$) moments (likely most acceptance sensitive)
- Fragmentation function FF measurements and nFF measurements for light hadrons
- Unpolarized sea quark PDF meausurements using FFs
- Various other single and di-hadron azimuthal moments related to tensor charge, higher twist function e, and others
- XYZ production measurements (mostly photo-production, not SIDIS but part of SIDIS YR, could also be in HF group
- Other Jet related TMD measurements →HF/Jet group?

Main figures for the report

- 4D (x-Q^2-P_{hT}-z) kinematical + PID coverage figure similar to YR
  - Concentrate for the most part on certain x-Q2 ranges due to simulation cost
- Closely related: z, P_{hT} and ϕ_s, ϕ_h smearing figure for different ECCE configurations
- Simulations can start from the YR Pythiaerhic/eic-smear files

Fig. 8.29



➔Already prepared for the most part

Sivers/Collins/unpol TMD figures

- Redo these YR analyses (AUTs require reweighting of events in truth kinematics+parton flavor)
- Need to take into account crossing angle and related acceptance/smearing effects
- Similar to YR guess systematics via variation between perfect and smeared options
- Extrapolate from some x-Q2 bins to all and give to Alexey Vladimirov (Sivers, unpol TMD) or Daniel Pitonyak (Tensor charge) for impact studies

Fig. 7.53: Sivers

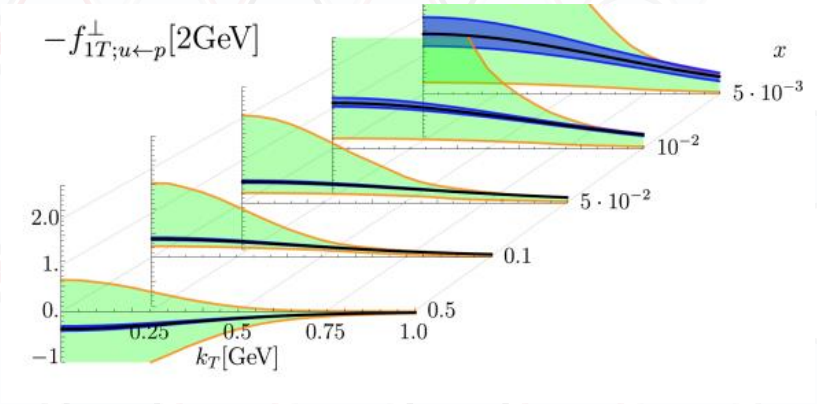
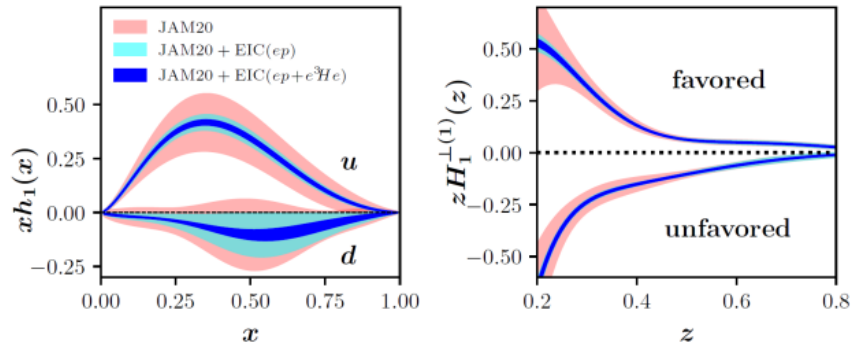


Fig. 7.54: Transversity



➔feasible using EventEvaluator, reweighting machinery still to be transferred from eic-smear based work