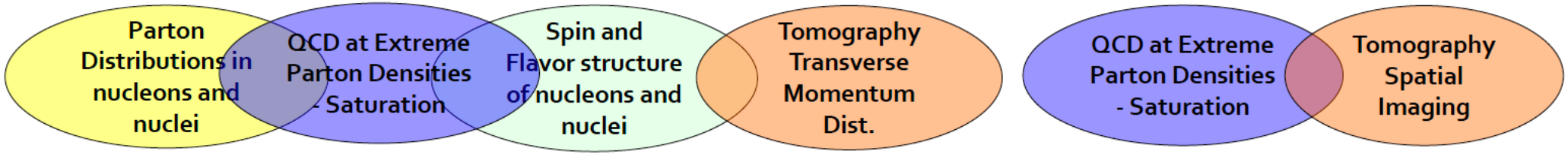
How to join Physics studies at ePIC
A layman's guide

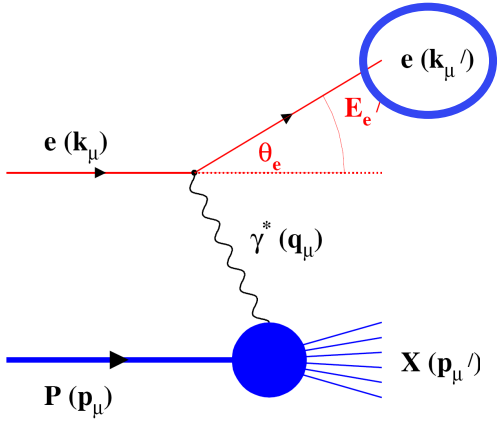
Salvatore Fazio (*U. of Calabria & INFN Cosenza)*

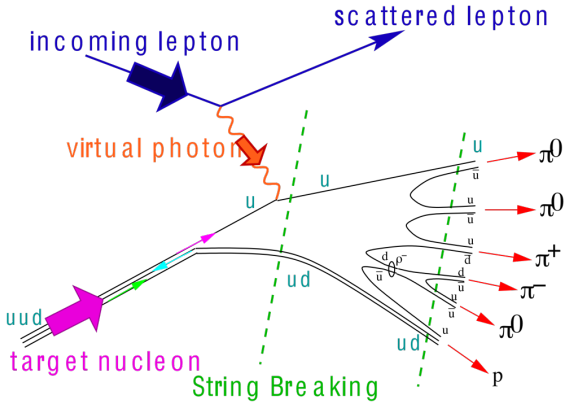
Giornate Nazionali EIC_net

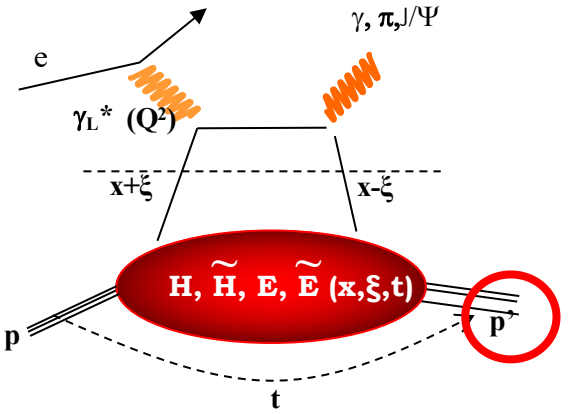
Corigliano Calabro, June 21-22, 2023

What process must be measured?









Inclusive DIS | **Semi-Inclusive DIS** | **Exclusive Reactions**

$\int \mathcal{L}dt$: $1\ \mathrm{fb}^{-1}$ | $10\ \mathrm{fb}^{-1}$ | $100\ \mathrm{fb}^{-1}$

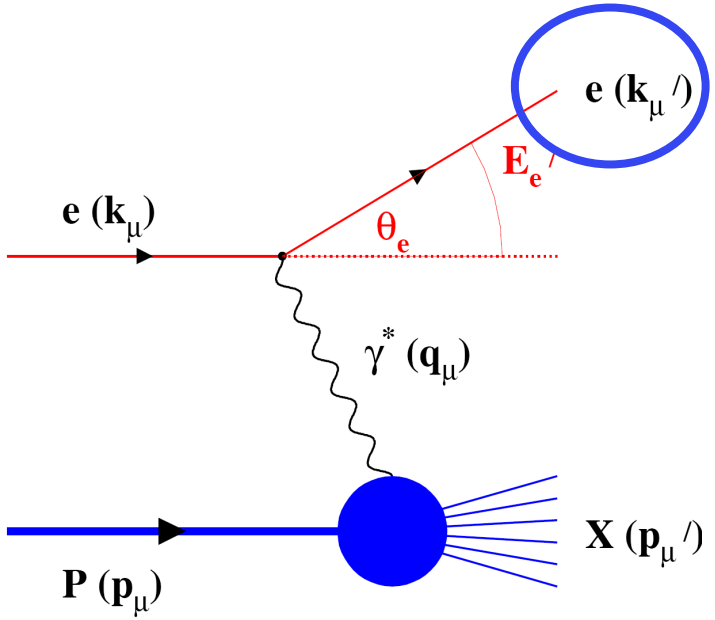
So many peculiar processes!

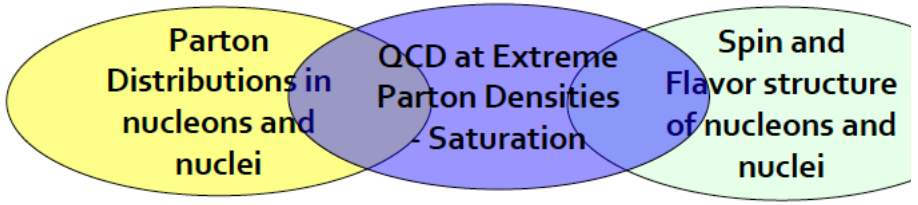
What experimental Collaborations usually do?

Split into: Physics working Groups

- **Inclusive** (conveners: Claire Gwenlan , Tyler Kutz)

Focus: on measurements that involve detecting, identifying, and measuring the kinematics of the scattered electron





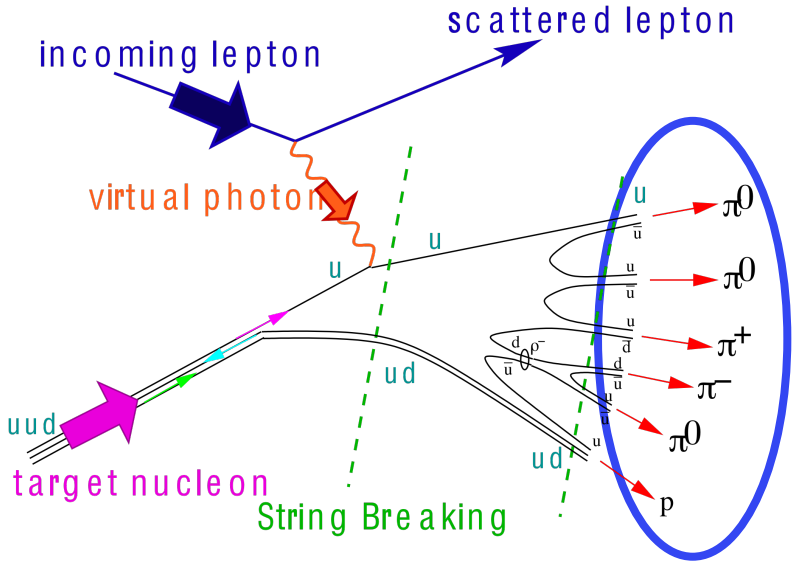
Meeting time: Mondays (biweekly) at 12pm ET
Mailing list: eic-projdet-Inclusive-l@lists.bnl.gov
Indico: https://indico.bnl.gov/category/417/
Mattermost:
https://eic.cloud.mattermost.com/main/channels/inclusive-physics

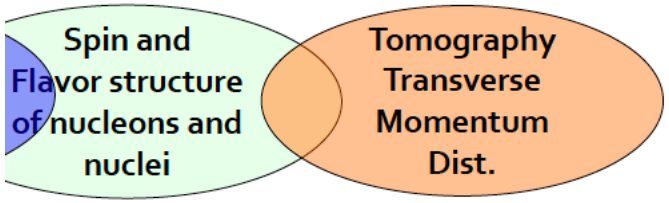
Split into: Physics working Groups

- **SiDIS** (conveners: Charlotte Van Hulse, Stefan Diehl)

Focus: on measurements that require detecting, identifying and measuring a final state hadron or hadrons in addition to the scattered electron

Meeting time: Tuesdays (biweekly) at 8:30am ET
Mailing list: eic-projdet-semiincl-l@lists.bnl.gov
Indico: https://indico.bnl.gov/category/418/

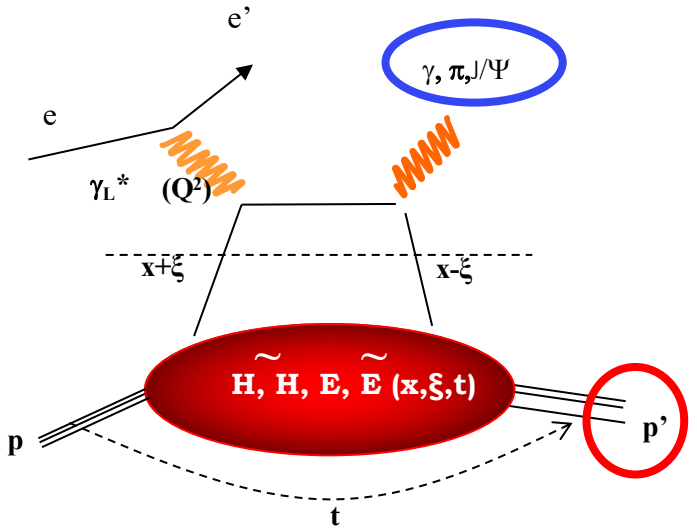




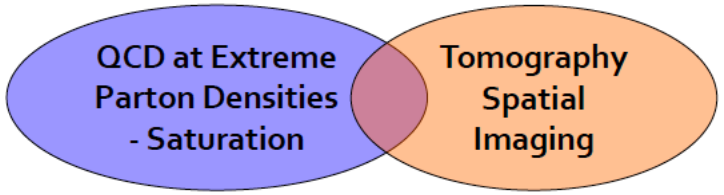
Split into: Physics working Groups

- **Exclusive + Diffraction + Tagging**
  (conveners: Raphael Dupré, Rachel Montgomery)

Focus: on measurement that require detecting the scattered proton/ion, whether it remains intact or not, together with all the final state produced particles, in addition to the scattered electron

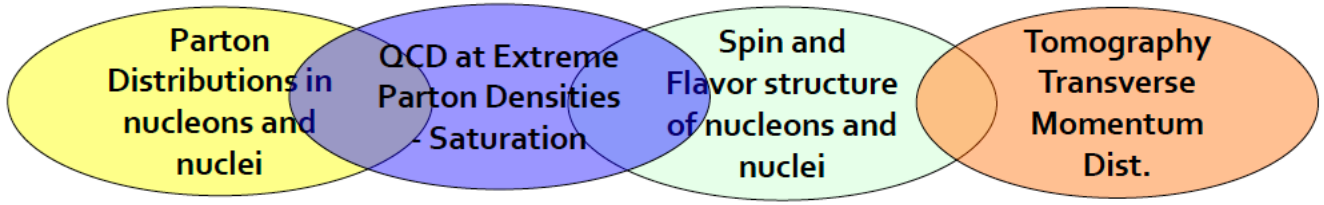


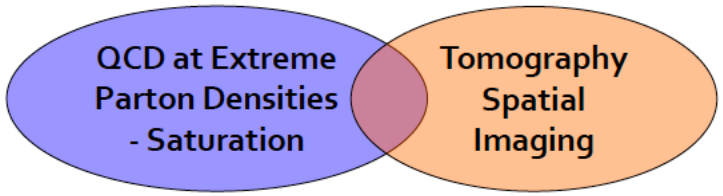
Meeting time: Mondays (biweekly) at 12pm ET
Mailing list: eic-projdet-excldiff-l@lists.bnl.gov
Mattermost: https://indico.bnl.gov/category/419/

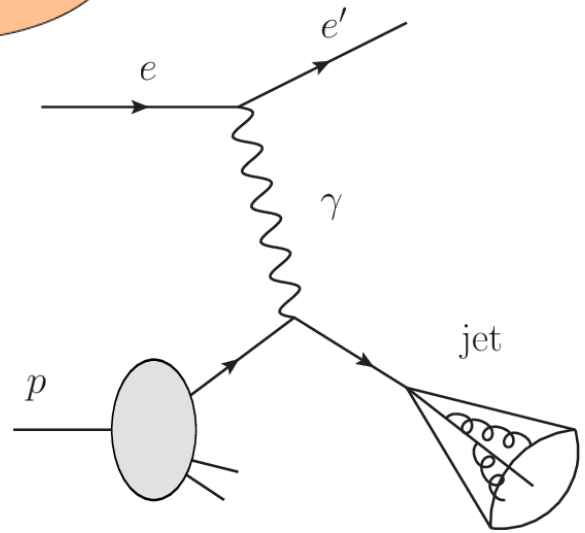


Split into: Physics working Groups

- **JETS + Heavy Flavor** (conveners: Olga Evdokimov, Brian Page)





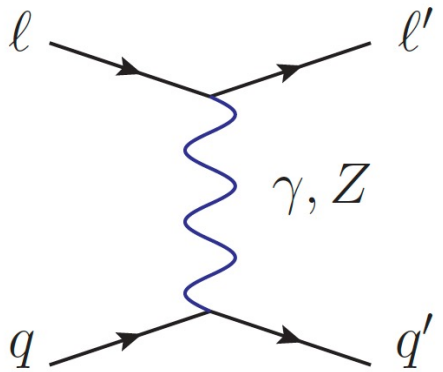


Focus: on measurements that involve high momentum exchanged processes, which could produce a spray of final state particles or hadrons that have one or more heavy quark constituents

Meeting time: Wednesdays (biweekly) at 12:00pm ET
Mailing list: eic-projdet-jethf-l@lists.bnl.gov
Indico: https://indico.bnl.gov/category/420/

Split into: Physics working Groups

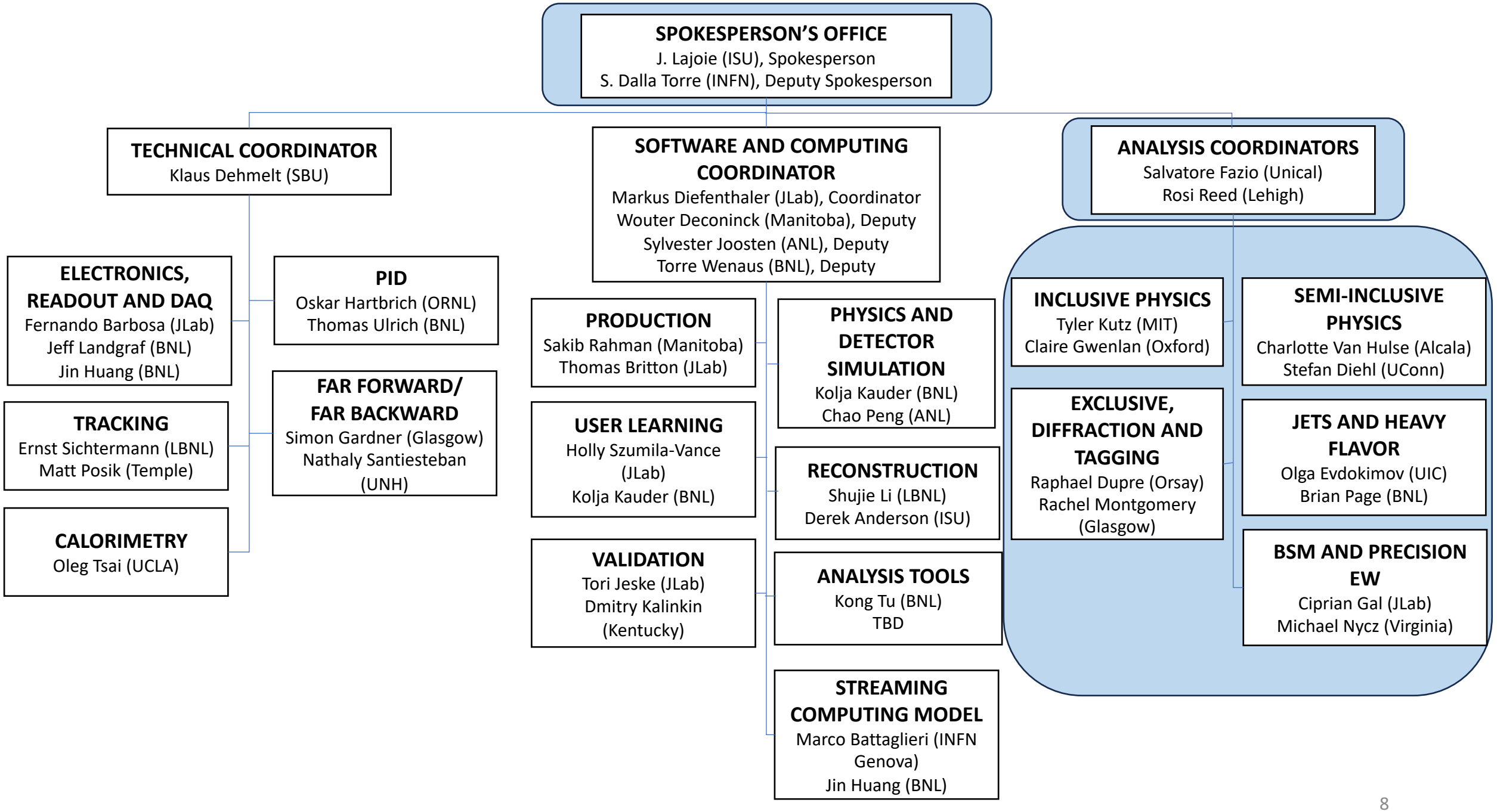
- **Beyond Standard Model + Precision Electro-Weak**
  (conveners: Ciprian Gal, Michael Nycz)



Beyond
EIC «core science»

Focus: on measurements of the cross-sections, helicities of electroweak gauge bosons that can lead to a better understanding of quark-level electroweak couplings and the potential for measurements beyond the standard model

Meeting time: Tuesdays (biweekly) at 8:30am ET
Mailing list: eic-projdet-semiincl-l@lists.bnl.gov
Indico: https://indico.bnl.gov/category/421/
Mattermost: https://eic.cloud.mattermost.com/main/channels/ew-bsm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S. Dalla Torre (INFN), Deputy Spokesperson
TECHNICAL COORDINATOR
Klaus Dehmelt (SBU)
SOFTWARE AND COMPUTING COORDINATOR
Markus Diefenthaler (JLab), Coordinator
Wouter Deconinck (Manitoba), Deputy
Sylvester Joosten (ANL), Deputy
Torre Wenaus (BNL), Deputy
ANALYSIS COORDINATORS
Salvatore Fazio (Unical)
Rosi Reed (Lehigh)
ELECTRONICS, READOUT AND DAQ
Fernando Barbosa (JLab)
Jeff Landgraf (BNL)
Jin Huang (BNL)
PID
Oskar Hartbrich (ORNL)
Thomas Ulrich (BNL)
TRACKING
Ernst Sichtermann (LBNL)
Matt Posik (Temple)
FAR FORWARD/ FAR BACKWARD
Simon Gardner (Glasgow)
Nathaly Santiesteban (UNH)
CALORIMETRY
Oleg Tsai (UCLA)
PRODUCTION
Sakib Rahman (Manitoba)
Thomas Britton (JLab)
USER LEARNING
Holly Szumila-Vance (JLab)
Kolja Kauder (BNL)
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Tori Jeske (JLab)
Dmitry Kalinkin (Kentucky)
PHYSICS AND DETECTOR SIMULATION
Kolja Kauder (BNL)
Chao Peng (ANL)
RECONSTRUCTION
Shujie Li (LBNL)
Derek Anderson (ISU)
ANALYSIS TOOLS
Kong Tu (BNL)
TBD
STREAMING COMPUTING MODEL
Marco Battaglieri (INFN Genova)
Jin Huang (BNL)
INCLUSIVE PHYSICS
Tyler Kutz (MIT)
Claire Gwenlan (Oxford)
EXCLUSIVE, DIFFRACTION AND TAGGING
Raphael Dupre (Orsay)
Rachel Montgomery (Glasgow)
SEMI-INCLUSIVE PHYSICS
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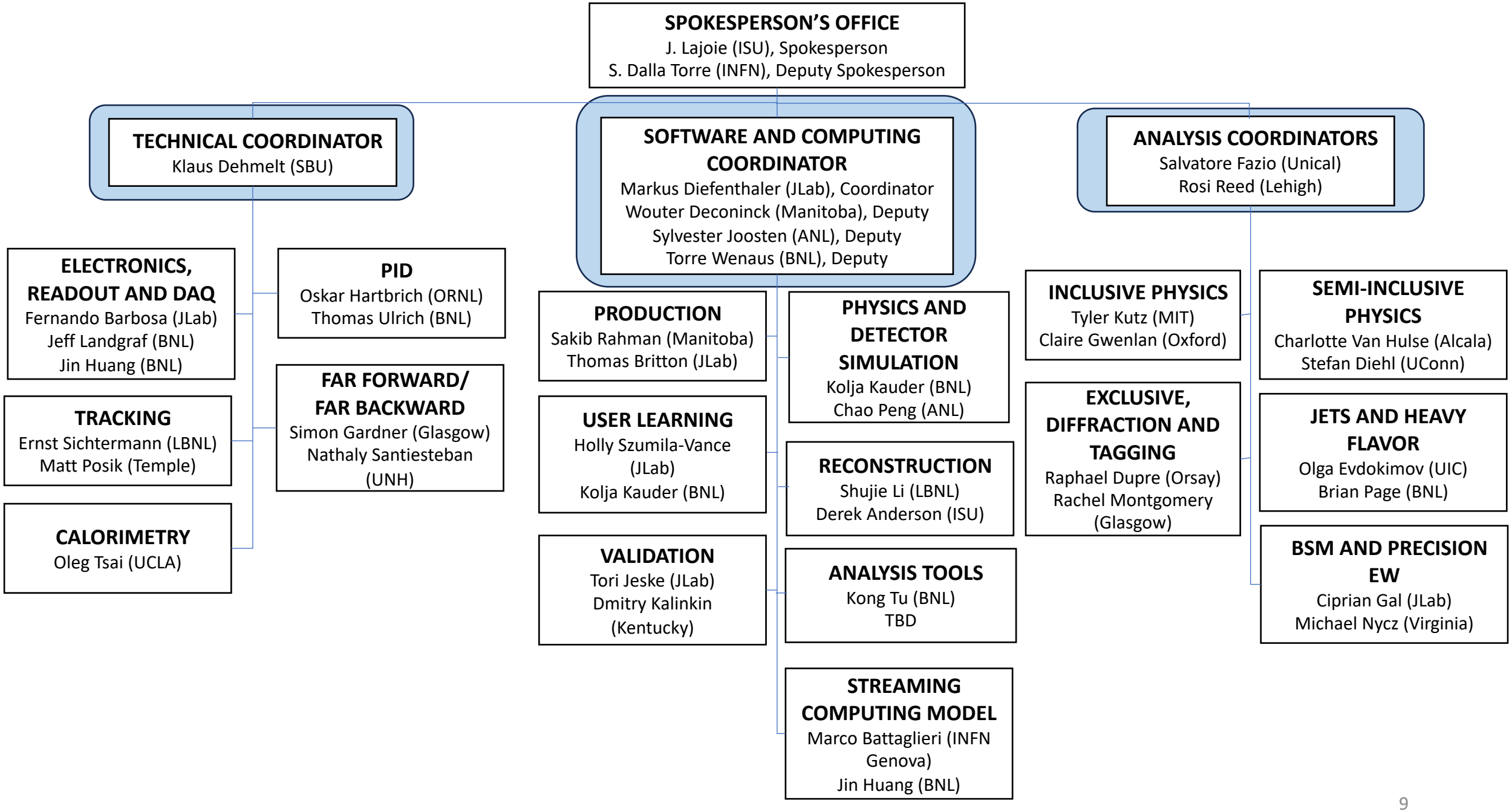
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The beautifully intense relationships between Physics and S&C

When you talk to people in Physics WGs

- I wish I could do my favorite physics studies, but... reconstruction must be improved!
- Where's my electron finder?
- I want secondary vertices!
- Oh, I can't do *this* if the software doesn't do *that*!

When you talk to people in S&C and Reco. WGs

- We want to implement *that* into the reco frame, but it's a huge effort and takes time
- Manpower! Where's everyone!?
- We need physics benchmarks for the continuous assessment of the ePIC detector

S&C Coordinators + Analysis Coordinators meeting
May 17th

… All right, we need to come together!

- Indico at: https://indico.bnl.gov/event/19473/
- Live notes at: Live Notes
- Identified 4 priorities:
  - **Electron Finder**: Developing an efficient and accurate algorithm for identifying electrons and identifying the scattered electron of the DIS process
  - **Vertexing and PID**: Enhancing the vertexing capabilities and particle identification techniques to study heavy flavor physics
  - **Particle Flow**: Improving the jet reconstruction using particle flow information
  - **Low-Q^2**: Integration of the low-Q^2 tagger into the reconstruction framework for precise measurements of photo production and vector mesons

Formation of the Reconstruction Task Squadrons

Points of Contact (POCs) for each squadron

Electron Finder: Daniel Brandenburg (brandenburg.89@osu.edu)

Vertexing and PID: Shujie Li (shujieli@lbl.gov)

Particle Flow: Derek Anderson (dmawxc@iastate.edu)

Low-Q^2: Simon Gardner (simon.gardner@glasgow.ac.uk)

Contact the POC to get involved in activities ASAP!

Electron Finder

Goal / Product: Provide identified (DIS) electron info

- Progress in May / early June (for June Sim Campaign)
  - PR #666: Provides association containers + truth associations (Wouter Deconinck et al.)
  - Identified immediate need, discussion of design / integration plan
- Major Tasks (June):
  - Electron-pion separation, implementation of E/p cuts using existing association information (*volunteer?*)
  - Track Projection Factory: provide track projections at relevant detectors (Tyler Kutz)
  - Track Match Factory: Matching of projecting tracks to clusters (*volunteer?*)
  - DIS lepton identification (Andrii Verbytskyi) + implementation
  - Integrated Electron Finder Factory (Daniel Brandenburg)
- These tasks make progress towards two goals for July sim campaign
  - Setup complete framework: utilize existing association + simple electron id + existing DIS lepton finder -> output DIS lepton
  - First steps towards towards fully RECO level (track matching / compare to truth level)

Vertexing & PID

Goal / Product: Provide reconstruction of secondary vertices and particle identification

- **Three primary tasks:**
  1) Integrate primary vertexing in reconstruction
  2) Integrate vertex information in ePIC data model
  3) Survey common secondary vertex reconstruction packages
- **Task (1):**
  - **Done** and in for the July campaign!
  - Implemented by **Joe Osborne** and **Barak Schmookler**
- **Tasks (2)** and **(3)** in progress…

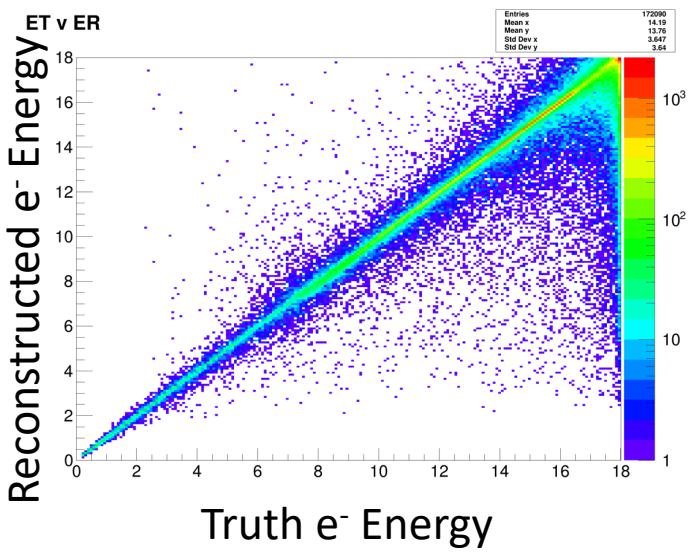
Particle Flow

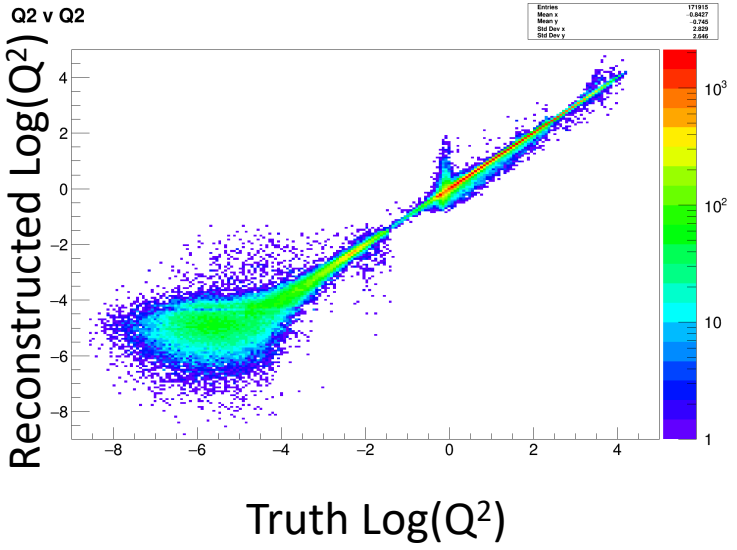
Goal / Product: Reconstruct particles based on combining inputs from multiple detector systems

- **Two primary tasks:**
  1) Survey existing implementations of **p**article **f**low (PF)
  2) Explore necessity of custom approach (rather than an existing package) in the barrel and backwards regions
- **Task (1):**
  - Survey is in progress!
  - Look for presentations by PF experts from other experiments once regular Reco WG meetings get started
- **Tasks (2)**
  - July campaign will see deployment of features prerequisite for PF (e.g., track-cluster matching)
  - Output of July campaign will serve as testbed for exploring implementations

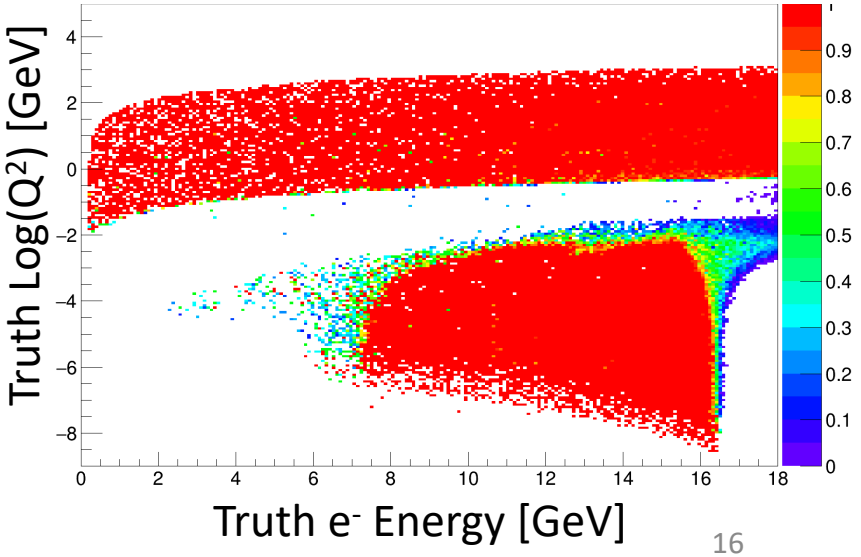
Low-Q^2 Tagger

- Not included in current campaign
- Particle track reproduced with ROOT TMVA model
- Plots produced from addition into `InclusiveKinematicsElectron` factory
- Still some longer term issues to resolve but could be merged in (almost) current state
- Exploring other C++ neural networks tools for use in EICRecon which might have better long-term support.
- Keen to explore GraphNN to approach increased combinatorics when including backgrounds (Anyone with experience, please get in contact)





Total ePIC Quasi-Real Photoproduction Acceptance

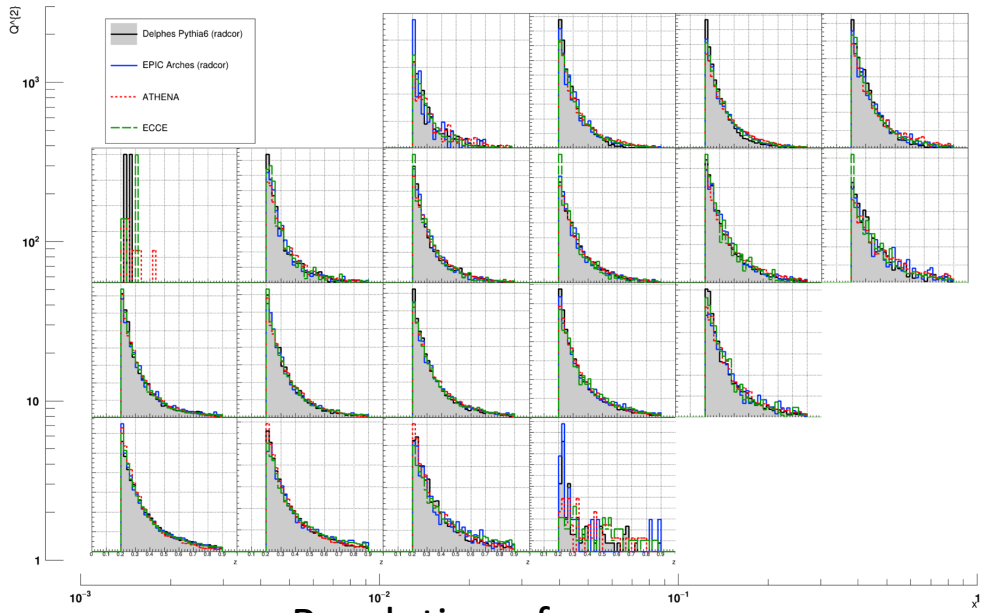


Analysis Coordination Meetings

- Details at: AC Meeting
- Meeting with PWG conveners (but open to everyone) every other Friday (staggered with the General Meetig)
- Recent topics: Discussion of Benchmarks, Communications
- Each PWG proposes some Benchmarks
  - Should test performance and physics
  - Automatized macros that will run at each simulation campaign
    - more advanced observables being also considered
  - First discussions with the PWGs ongoing…

Physics Benchmarks

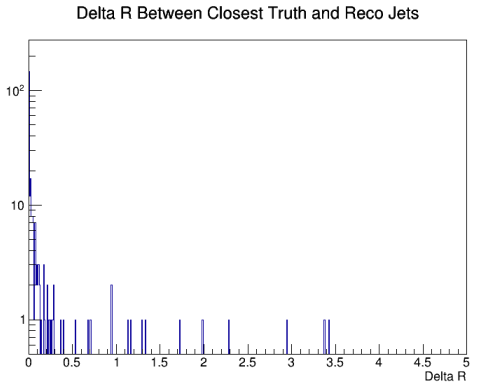
- **Inclusive**
  - Resolutions (electron, hadronic final state, kinematic variables)
  - Electron purity and efficiency
  - Reduced NC cross sections
  - Double-spin asymmetry A^p_1
- **SIDIS**
  - (SI)DIS resolutions (xB, Q^2, z, P T)
  - PID quality (e/π K/π separation)
  - A_{LL} measurements → Sea-quark helicity PDFs
  - Unpolarized cross sections → Spin-independent TMD PDFs/FFs
  - Sivers/Collins asymmetries → Sivers TMD, Collins FF
  - Dihadron asymmetry → Transversity and tensor charge via collinear dihadron FF
  - Back-to-back di-hadron asymmetries → Saturation
  - Lambda Polarization → Polarized FFs

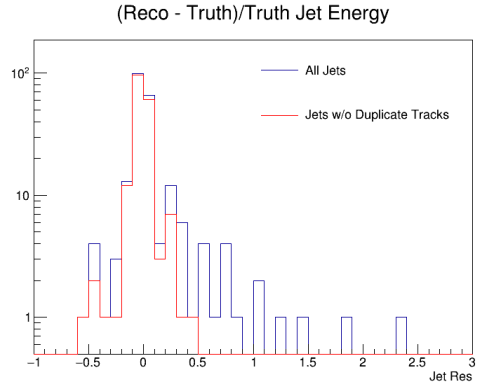


Resolution of z

Physics Benchmarks

- **Jets/HF**
  - Kinematic Distributions (Jet p_T, Eta, Phi, E, correlations)
  - Reconstructed / Generator Jet Delta R
  - Duplicate Track Plots
  - Jet Energy Resolution / Scale (Vs Eta and E)
  - DCA & Secondary Track Efficiency + DCA





- **Exclusive + Diffraction + Tagging**
  - Deeply virtual π^0 production e.g. from neutron in D_2 with tagging in FF region (important background, more challenging than DVCS)
  - Deeply virtual meson production decaying into charged pair
  - Additional Benchmarks under discussion…
- **BSM + precision EW**
  - Electron Identification
  - Charge Lepton Flavor Violation (CLFV) → Tau ID, Muon ID

Need to expand our involvement with physics at ePIC

A few ideas…

Spatial 3D imaging – our goals!

✔ Milestone y21-22 novel MC generator for hard exclusive processes based on available and upcoming GPD models, featuring first and second order initial- and final-state radiative effects

E.C. Achenauer, V. Batozskaya, S.F., K. Gates, H. Moutarde, D. Sokhan, H. Spiesberger, P. Sznajder
Eur. Phys. J. C 82 (2022) 9, 819

Milestone y23 extract GPDs by performing global NLO fits of various models in order to quantify the impact of the future Electron-Ion Collider at BNL in constraining CFFs and GPDs, from DVCS and TCS measurements

Future Goal 1 assess the feasibility of extracting the energy-momentum tensor, through which gravity couples to matter and generates fundamental properties such as mass and spin

Future Goal 2 include HEMP into the generator and explore the possibility of disentangling the contribution to GPDs from different partonic flavor

Longer term perspectives:

- Seed future topical collaborations
- Guide future executive decisions on the EIC second experimental apparatus

Contact S. Fazio

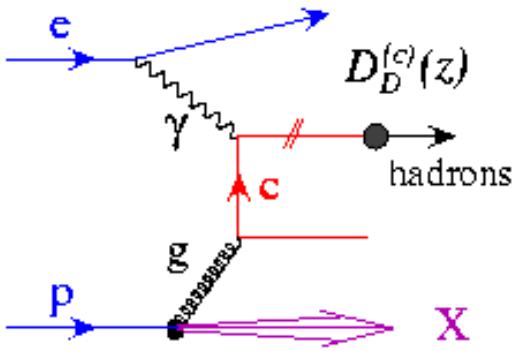
Slide by Marta Ruspa

Diffractive PDFs

- **Proton DPDFs not yet exploited for the EIC!**
  - good constrain on the gluon densities though scaling violation
- **A DPDF fit releasing the assumption or Regge factorization was never done**
  - though the HERA data might suggest a breaking.
- **PLAN: Evaluate the impact of the EIC to disentangle to which extent Regge factorization holds**
  - Understand the detector acceptance for inclusive diffractive processes
  - Full Monte Carlo chain generation-detector-reconstruction
  - Generation of pseudodata to be used in DPDF fit
  - Additional inclusion of the HERA data to evaluate the impact

Contact M. Ruspa

nPDFs (and proton PDFs) with *b*-tagging



Novel probe!

E.C. Aschenauer, S. F., M.A.C. Lamont, H. Paukkunen, P. Zurita
Phys.Rev. D 96 114005 (2017)

- Study of nPDFs with charm-tagging
- Direct access to gluons at medium to high *x* by tagging photon-gluon
- Helps determining heavy quarks mass scheme

Ratio: $F_2(x,Q^2)_{Pb}/F_2(x,Q^2)_p$

Selection of charm-production events

We select **kaons** in the final state of the ***D*** meson decay, looking for:

- a displaced vertex: 0.01 cm <|Vertex|< 3 cm
- Momentum within the acceptance of an EIC model detector (BeAST @ eRHIC)

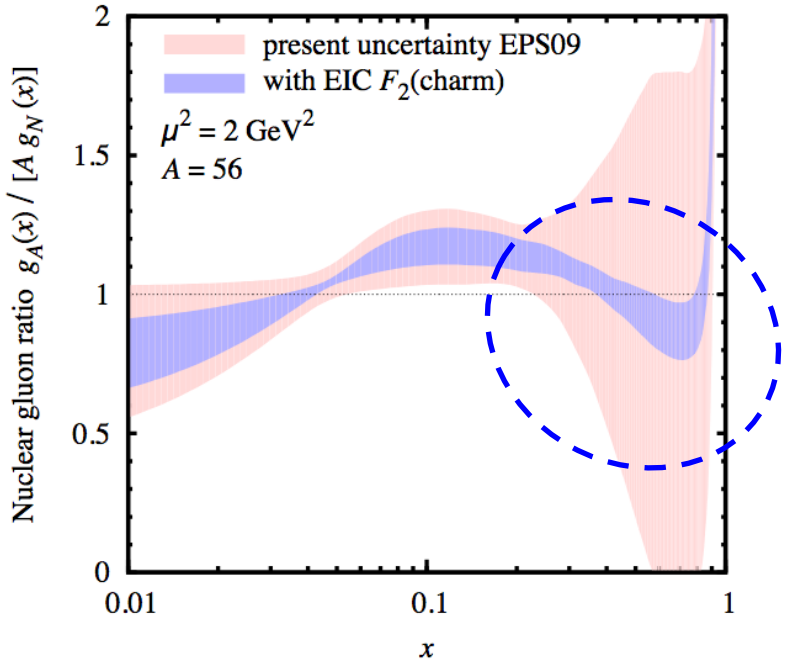
CENTRAL DETECTOR (-1 < η < 1)
dE/dx -> 0.2 GeV < P < 0.8 GeV
RICH -> 2 GeV < P < 5 GeV

FORWARD (1 < η < 3.5)
RICH -> 2 GeV < P < 40 GeV

REAR (-3.5 < η < -1)
RICH -> 2 GeV < P < 15 GeV

nPDFs (and proton PDFs) with *b*-tagging

C. Weiss et al. , Santa Fe Jets and heavy flavor Workshop Jan 18



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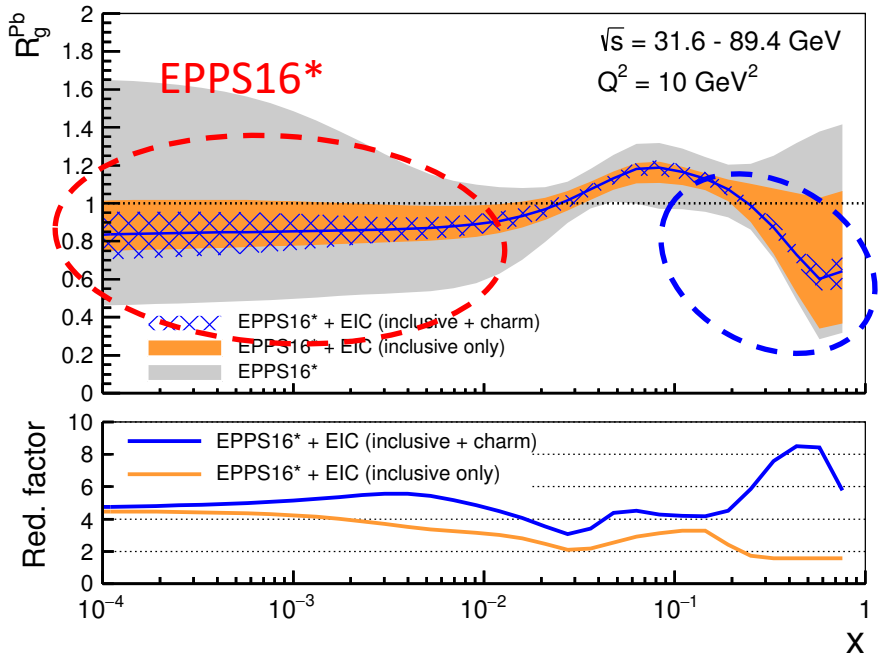


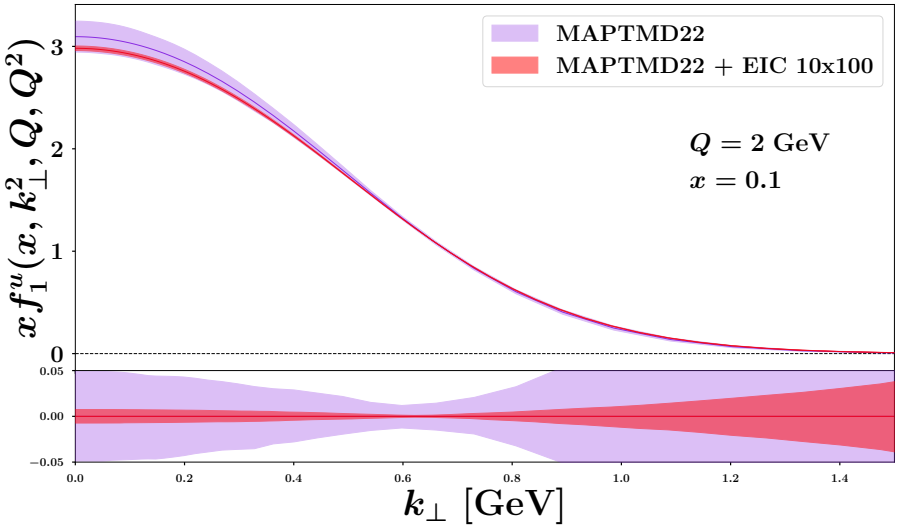
- **Inclusive DIS alone has a huge effect at low-*x***
- **Charm-tagging *(via displaced vertex)* has a dramatic effect at high-*x***
- ***b*-tagging: clean, more precise (not yet investigated at EIC!)**
  - **exploits both the vertex tracker and the Cherenkov PID detectors (INFN key involvement)**

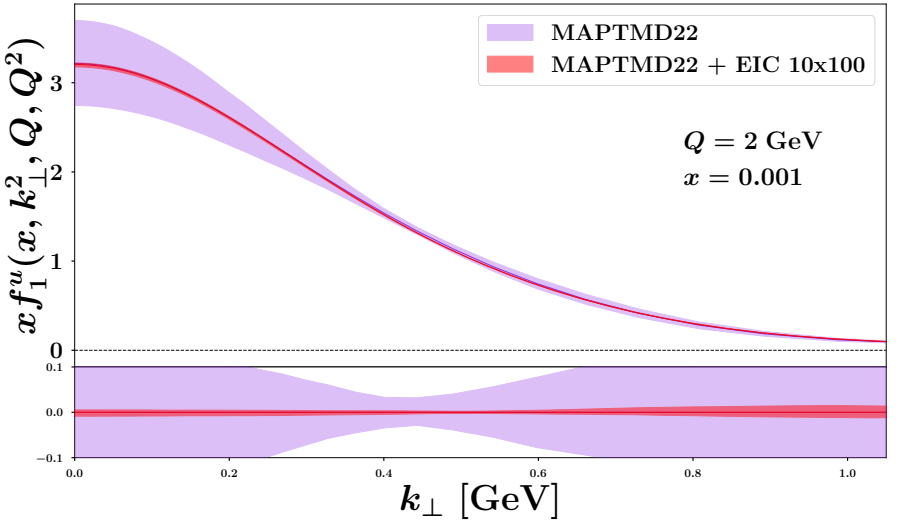
Contact S. Fazio

TMDs: Impact Studies

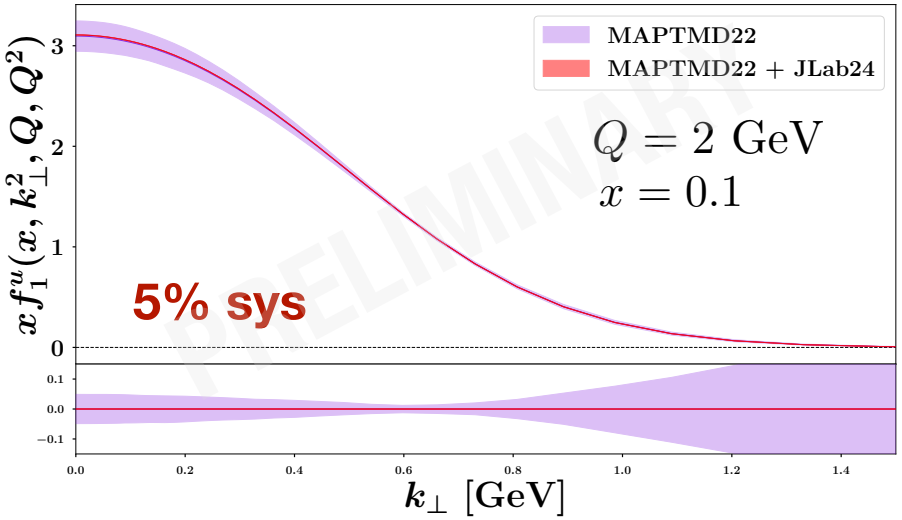
unpolarized up quark

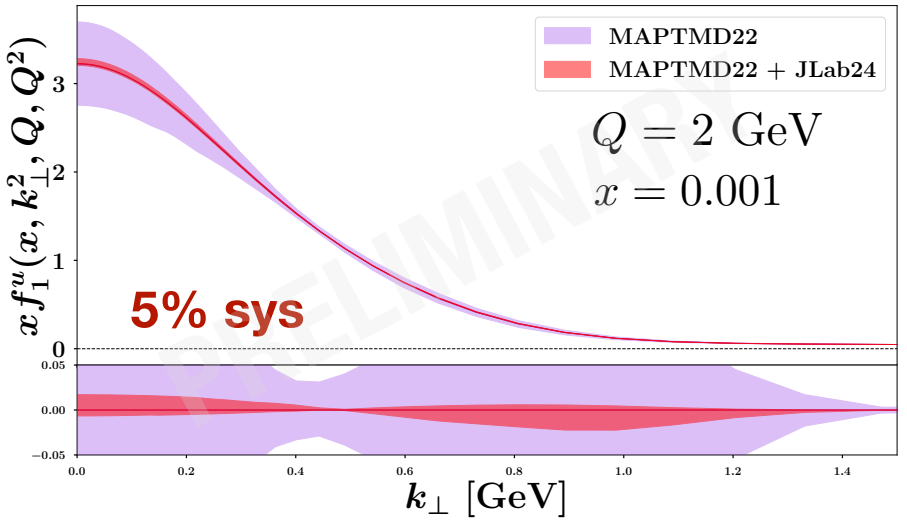
Map Collaboration impact studies





EIC





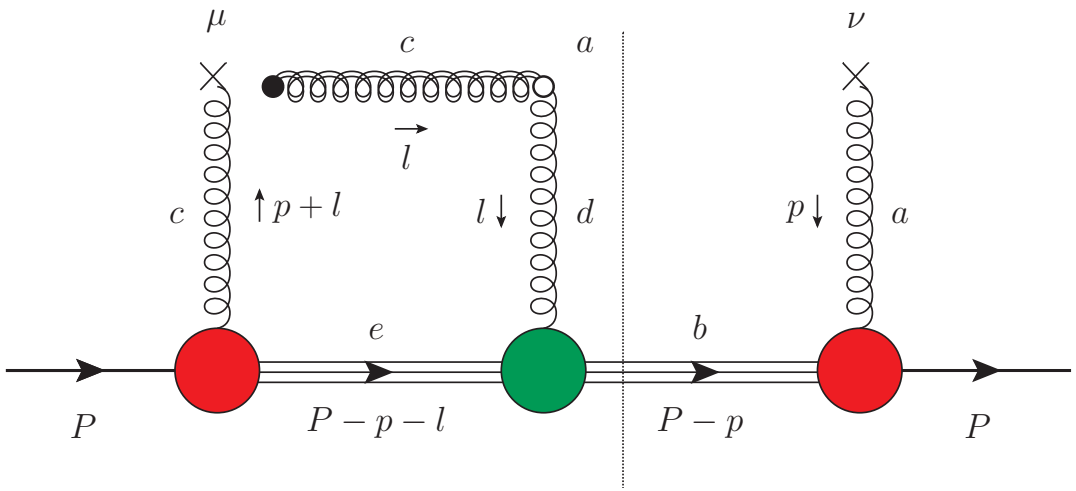
JLAB

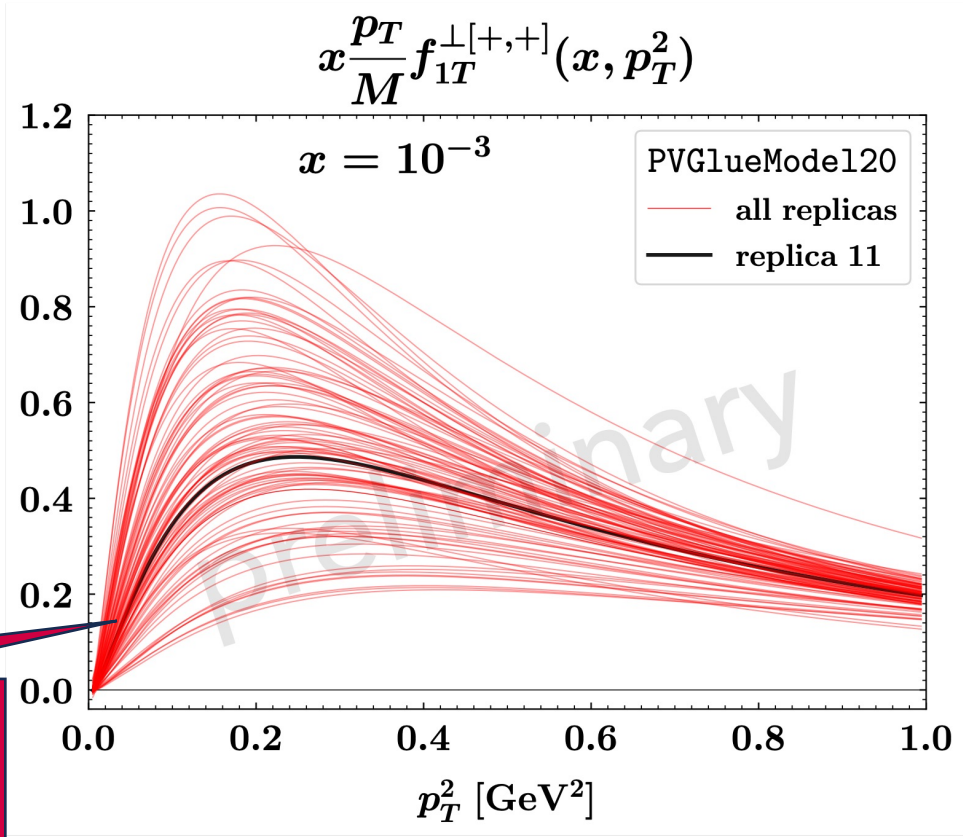
TMDs: Gluon Sivers Modeling

WW-type Sivers function, detectable at the EIC in

$ep^\uparrow \to e'Q\bar{Q}X$ and $ep^\uparrow \to e'\,\text{jet jet}\,X$

Bacchetta, Celiberto, Radici, in preparation



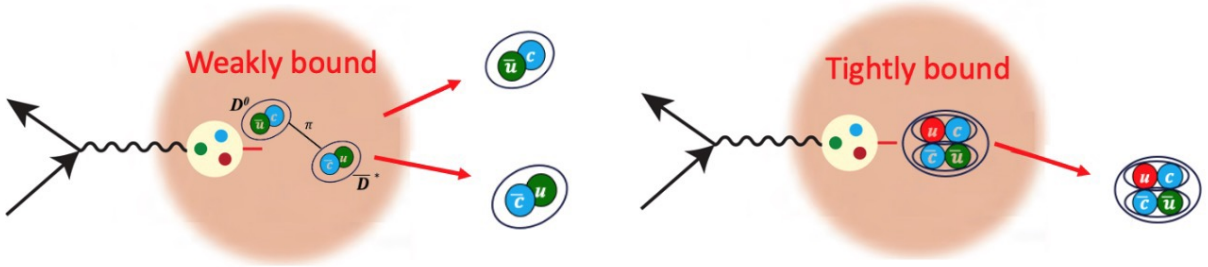


Large size.
High sensitivity to model parameters.

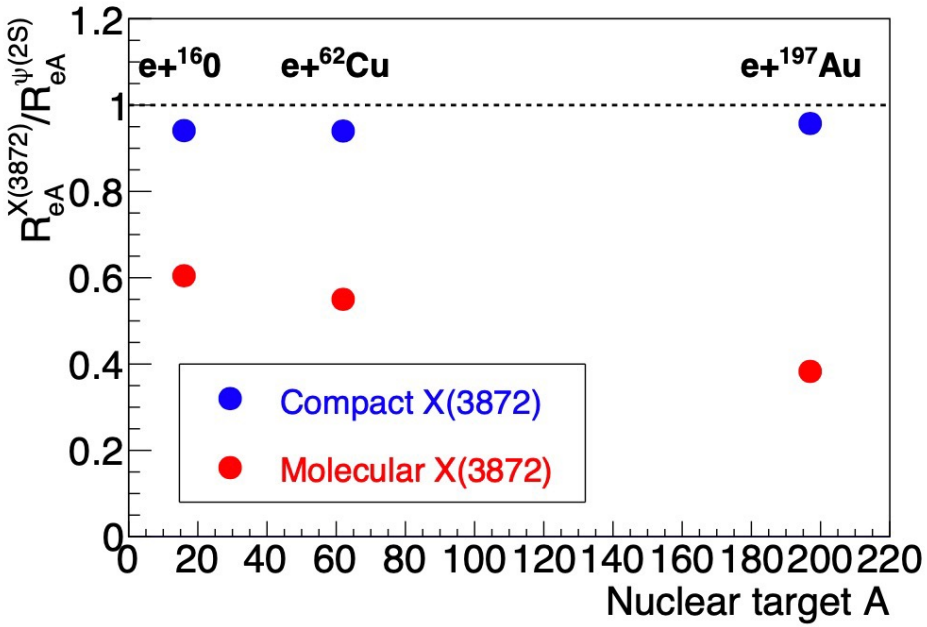
Contact M. Radici

Spectroscopy

Studying exotic hadrons nature via eA



Pan-Pan Shi et al., arXiv:2208.02639



$3\times10^4 - 1.5\times10^5$ events
assuming $\mathcal{L} = \int 300$ fb^{-1}

- Search for exotics at EIC is possible
- May provide complementary information with respect to e+ e- colliders and hadron facilities

Contact A. D'Angelo

Your beloved physics of choice!

Wrapping up…

- 4 “task squadron” priorities: Electron Finder, Vertexing and PID, Particle Flow, Low-Q^2
  - Need volunteers to join efforts
  - How do I join: email the Point-of-Contact for your favorite task!
- Initial list of PWG Benchmarks being discussed
- HOW do I join a PWG?
  - step 1: email the conveners of your favorite PWG and subscribe the mailing list!
  - step 2: join the (bi)weeky meetings
  - step 3: actively engage in studies and efforts

WE WANT YOU