University of Glasgow

ePIC

Exclusive/Diffractive/Tagging (EDT) Group and *Examples* of Past Studies

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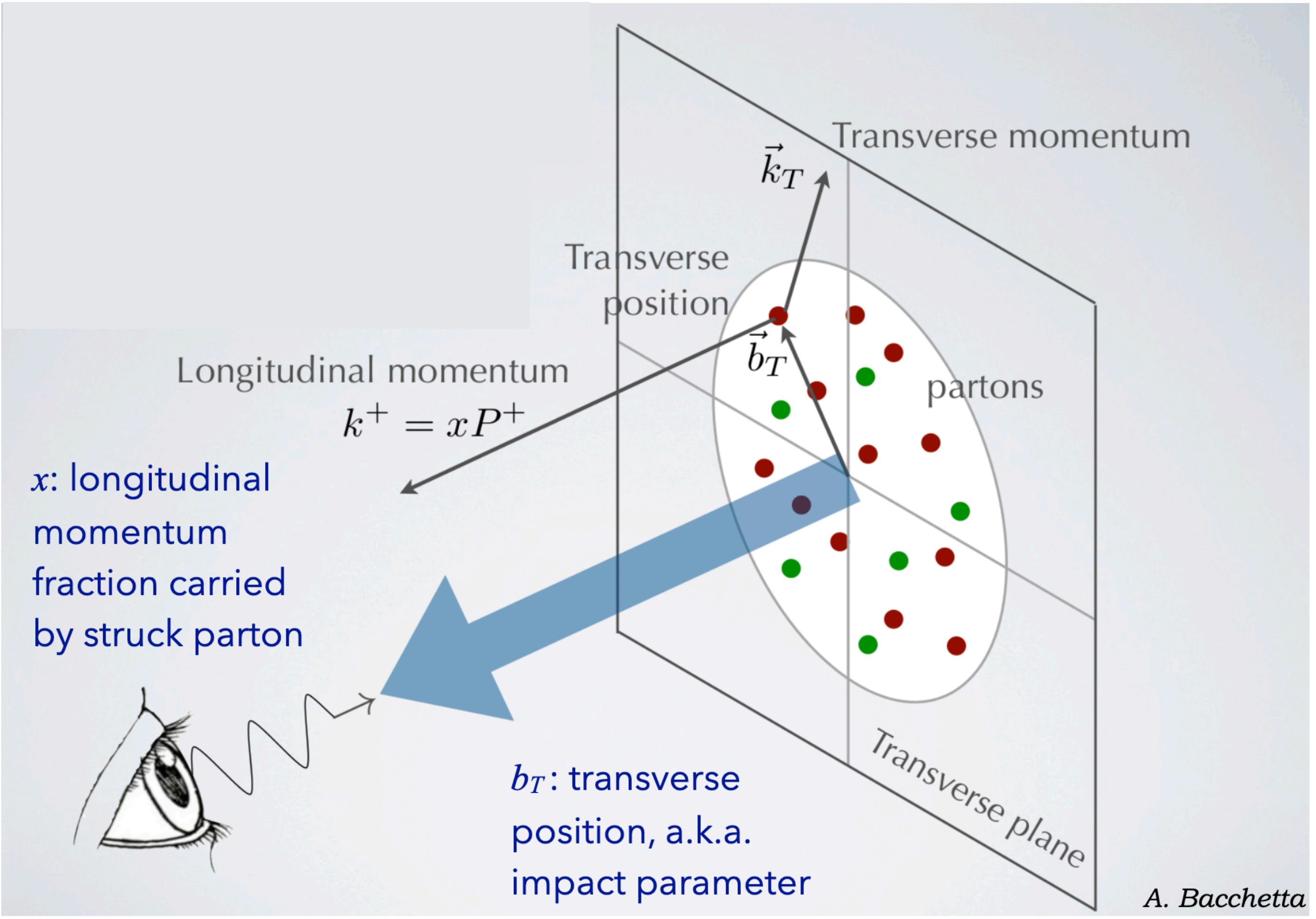
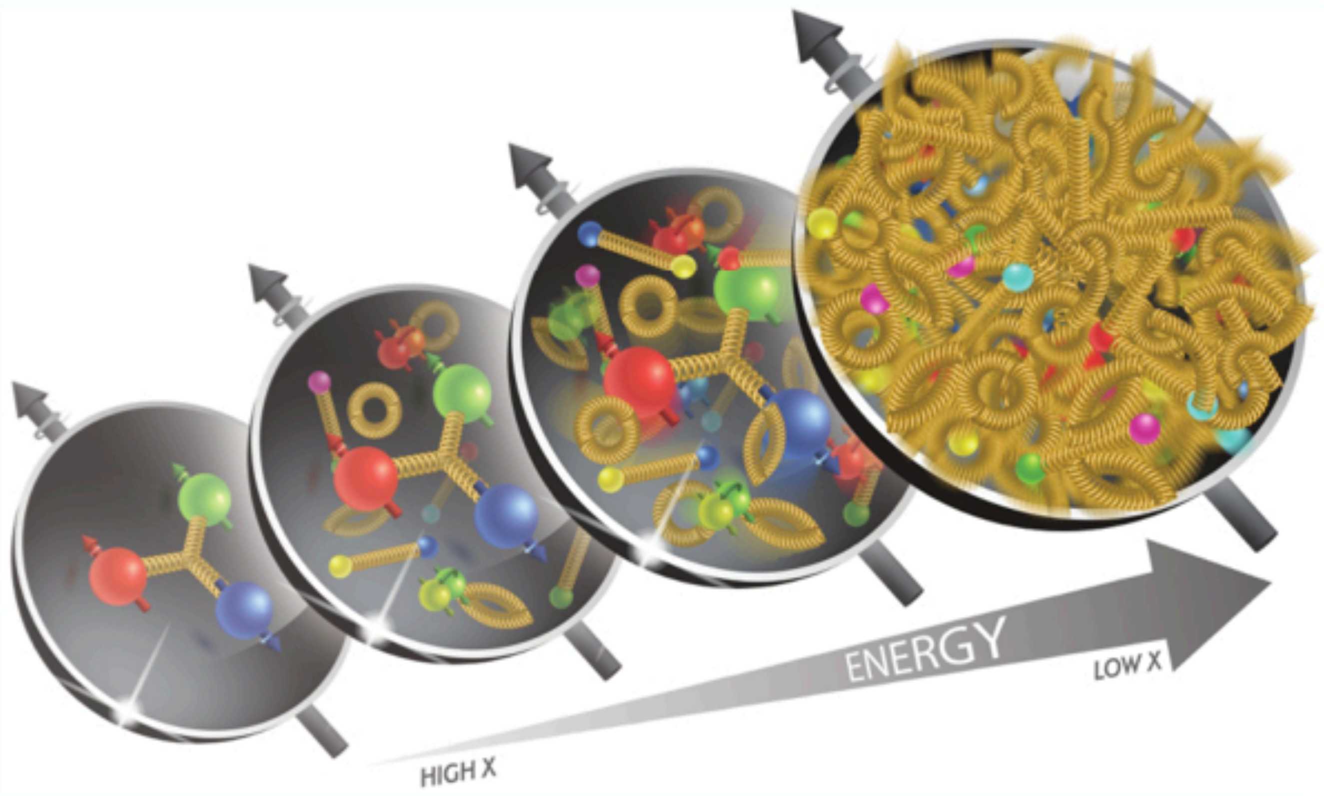
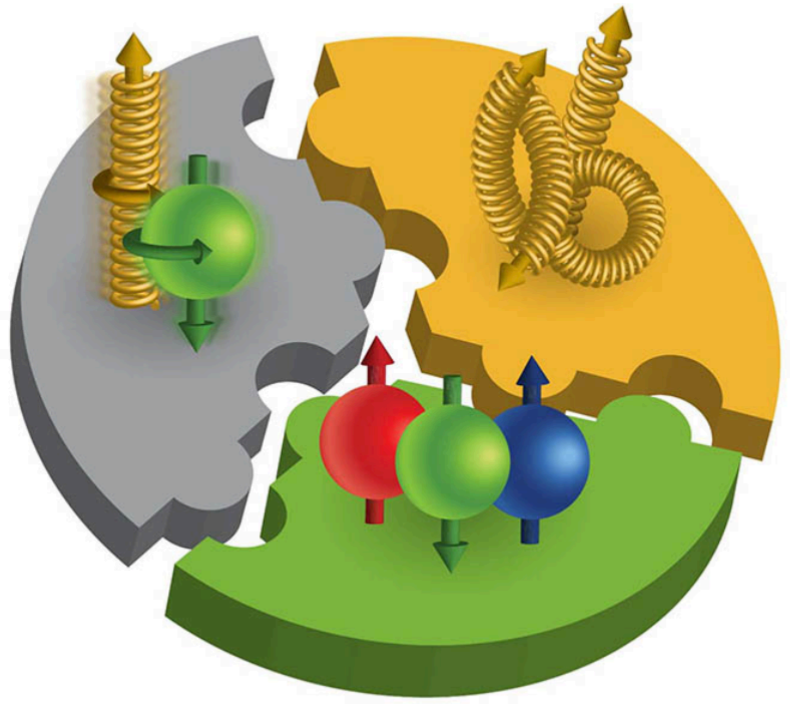
Raphael Dupree (IJCLab)

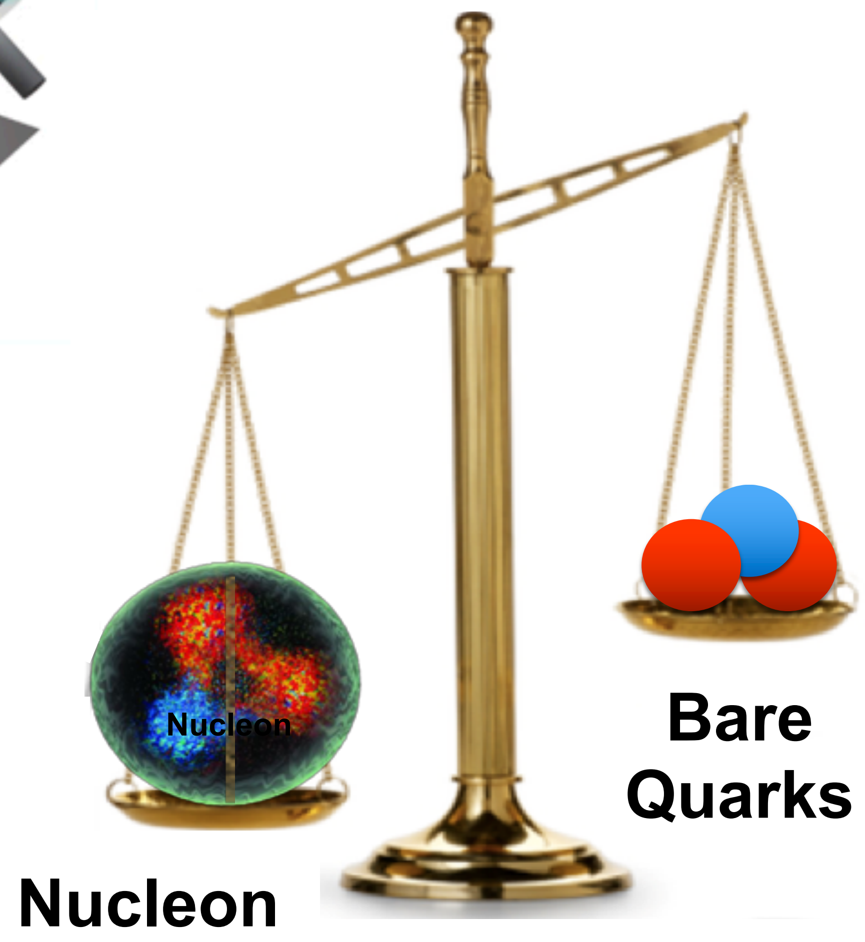
on behalf of many from
ePIC Collaboration
Exclusive, Diffractive, Tagging Working Group
and beyond

Scope - Physics



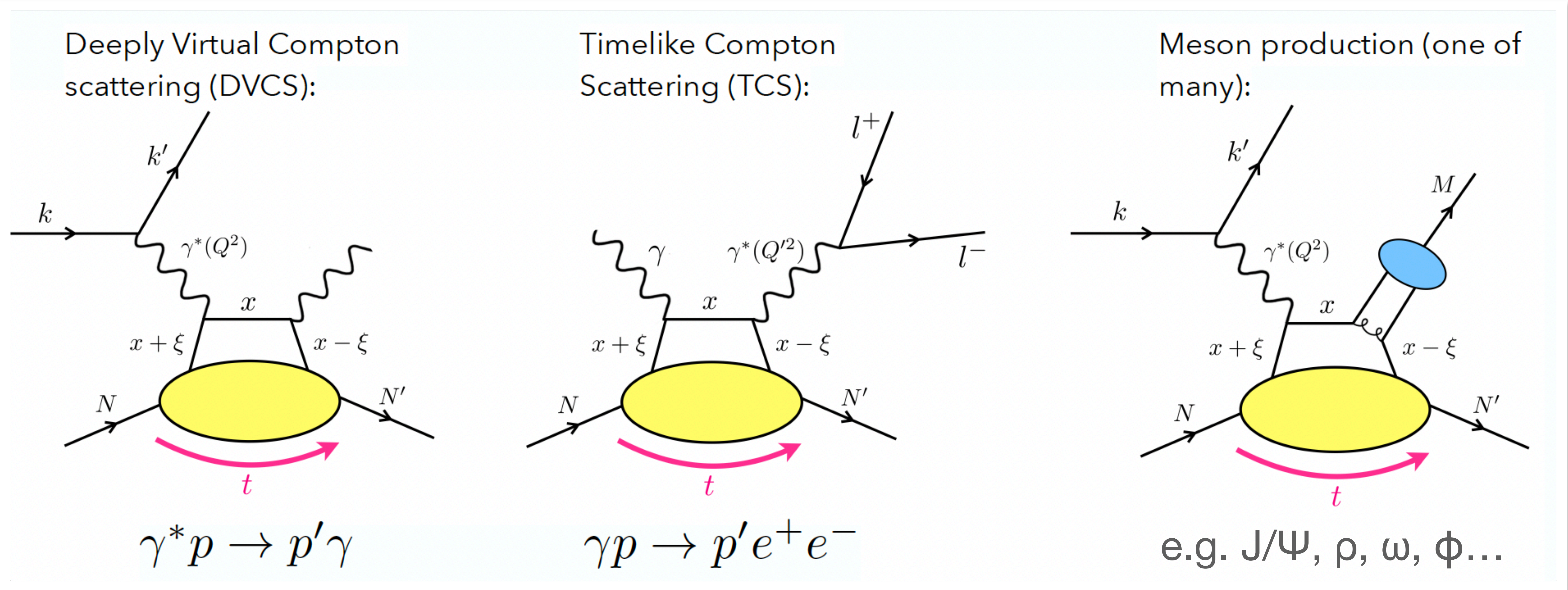






- Group encompasses ***numerous*** different reactions
  - Many different previous and current studies
  - Many future possible topics
  - YR and detector-1 proposals are great references
- Validate physics performances, including check that can satisfy key EIC scientific goals laid out in white paper, 2018 NAS report, YR (etc…)
- Different NAS topics EDT group can contribute to:
  - Origin of nucleon spin
  - 3D structure of nucleons and nuclei (tomography)
  - Gluon structure of nuclei
  - Origin of hadron mass
- Open/welcoming to any science beyond this and to extending the scope to more topics…!

Some Example Topics



Example hard exclusive processes

- Hard exclusive reactions: eg DVCS/TCS/DDVCS… for GPD topics, tomography, nucleon spin (orbital angular momentum), mechanical properties of nucleon (pressure, shear forces)
- Hard exclusive vector meson for gluon GPDs and 3D gluon transverse spatial tomography
- Diffractive vector meson production in eA: saturation probe, gluon distributions in nuclei
- Sullivan process: meson form factors and structure functions - meson structure, nucleon mass enigma
- At threshold quarkonia production - mass generation and trace anomaly
- Spectroscopy: structure of nucleons, search for exotics
- Spectator tagging in light nuclei - free neutron structure, EMC effect
- Quasi-elastic electron scattering, tagging in e+d exclusive J/psi production - SRCs

Not exhaustive! See YR for more examples

Some Example Topics

- **Example** activities for EIC detector 1 proposals, not exhaustive (apologies for any missed):

DVCS in ep	u-channel DVCS and π^0 in ep	J/Psi in eA	Pion structure functions
DVCS (incoherent) in eD	u-channel: ω, ρ in ep	Phi in eA	Pion form factors
TCS in ep	J/Psi in ep	Υ (1S, 2S, 3S) in ep	X,Y Ψ(2S) in ep → $J/\Psi\pi^+\pi^-p$
DVCS in eHe-4	A1n (3He double tagging)		

- **Example** activities from our ePIC EDT working group:

DVCS in ep (O. Jevons)	u-channel: ω, ρ in ep (Z. Schweger)	Pion DVCS via Sullivan (O. Bylund)	VM in eA, coherent and incoherent (M. Pitt, Z. Citron, E. Mautner)
DVCS in eHe-4 (G. Penman)	Υ (1S, 2S, 3S) in ep (S. Yoo, M. Kim)	Phi in eA (see Benchmark session) (K. Tu)	And others are working on getting other reactions ready

- Today since we want to discuss TDR level plots, focus on proposal level plots
- (Apologies if any names/references wrong or missing, let me know and I can correct)

Some Example Topics Mentioned in Proposals

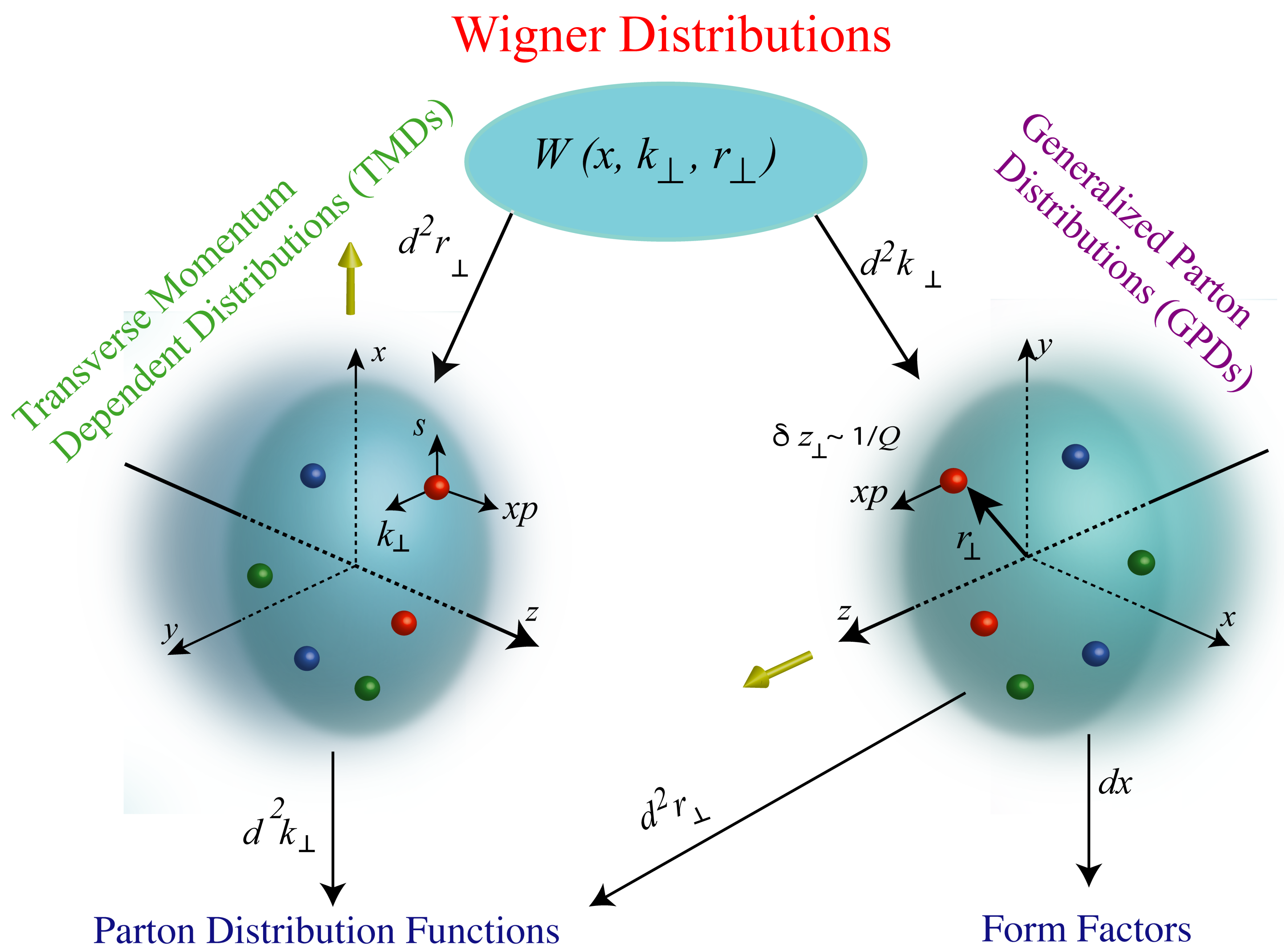
- **Today aim to discuss TDR level plots, so focus on overview of proposal level plots to decide what we want to aim for, rather than on-going analyses**

- NAS topics reported in proposals:
- Nucleon spin and tomography
  - Double spectator proton far forward tagging in e^3He for neutron A_1^n
  - Orbital Angular Momentum via GPD topics and hard exclusive reactions
  - 3D structure of nucleons and nuclei - quark and gluon tomography in impact parameter space - via hard exclusive reactions
- Gluon Structure of Nuclei
  - Measurements of heavy nuclei in kinematics relevant for parton saturation studies and gluon structure of nuclei (eg density profiles) - diffractive vector meson production
- Hadron Mass
  - Heavy quark threshold production (eg Y or J/psi), meson structure studies
- Beyond NAS Report
  - XYZ Spectroscopy - spectroscopy of mesons with charm quarks
  - U-channel DVCS and DVMP (π^0)

Nucleon Spin and Tomography

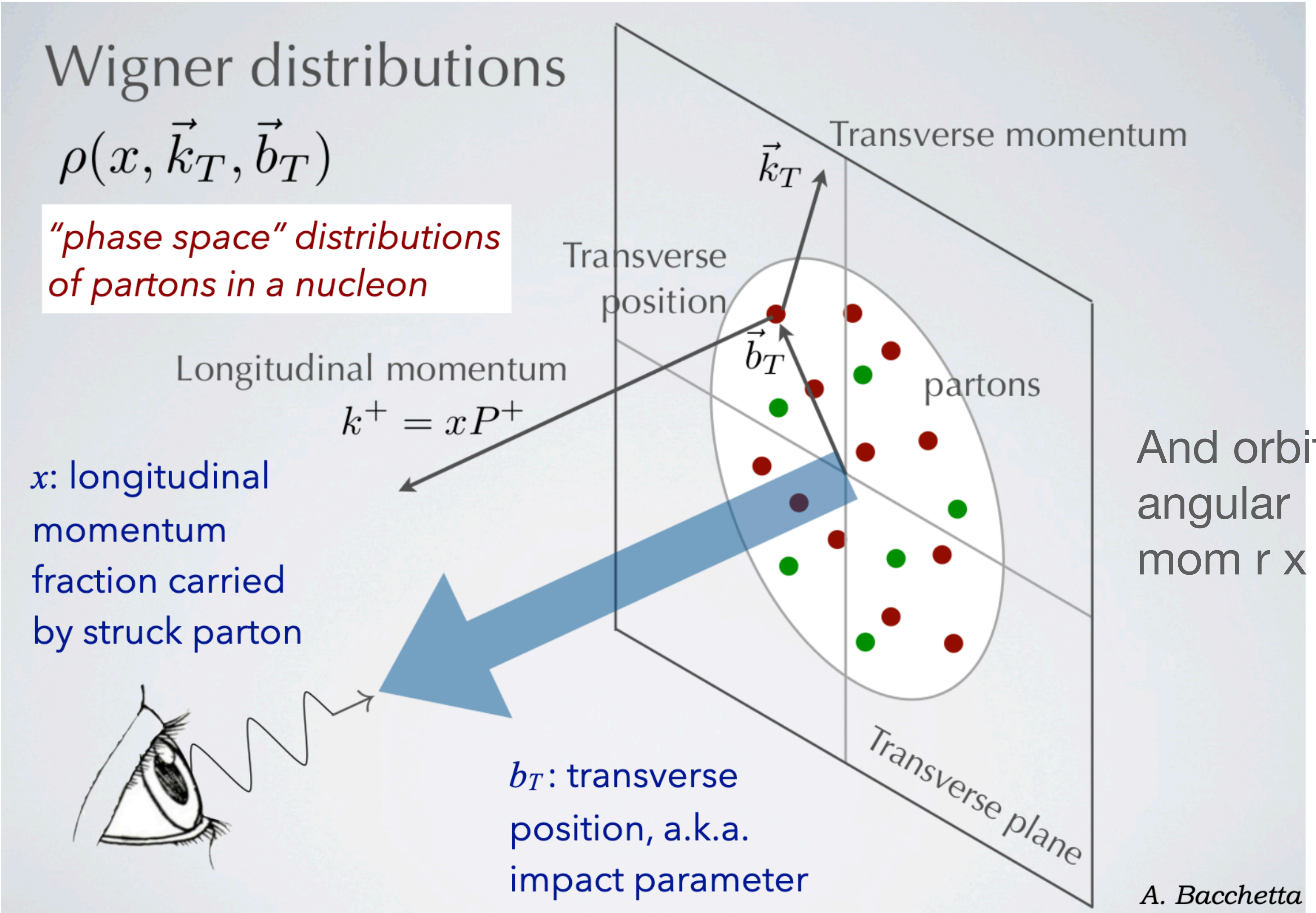
longitudinal momentum and transverse momentum $f(x, k_T)$

Semi-inclusive deep inelastic processes



longitudinal momentum and transverse position $f(x,b_T)$

Exclusive Processes



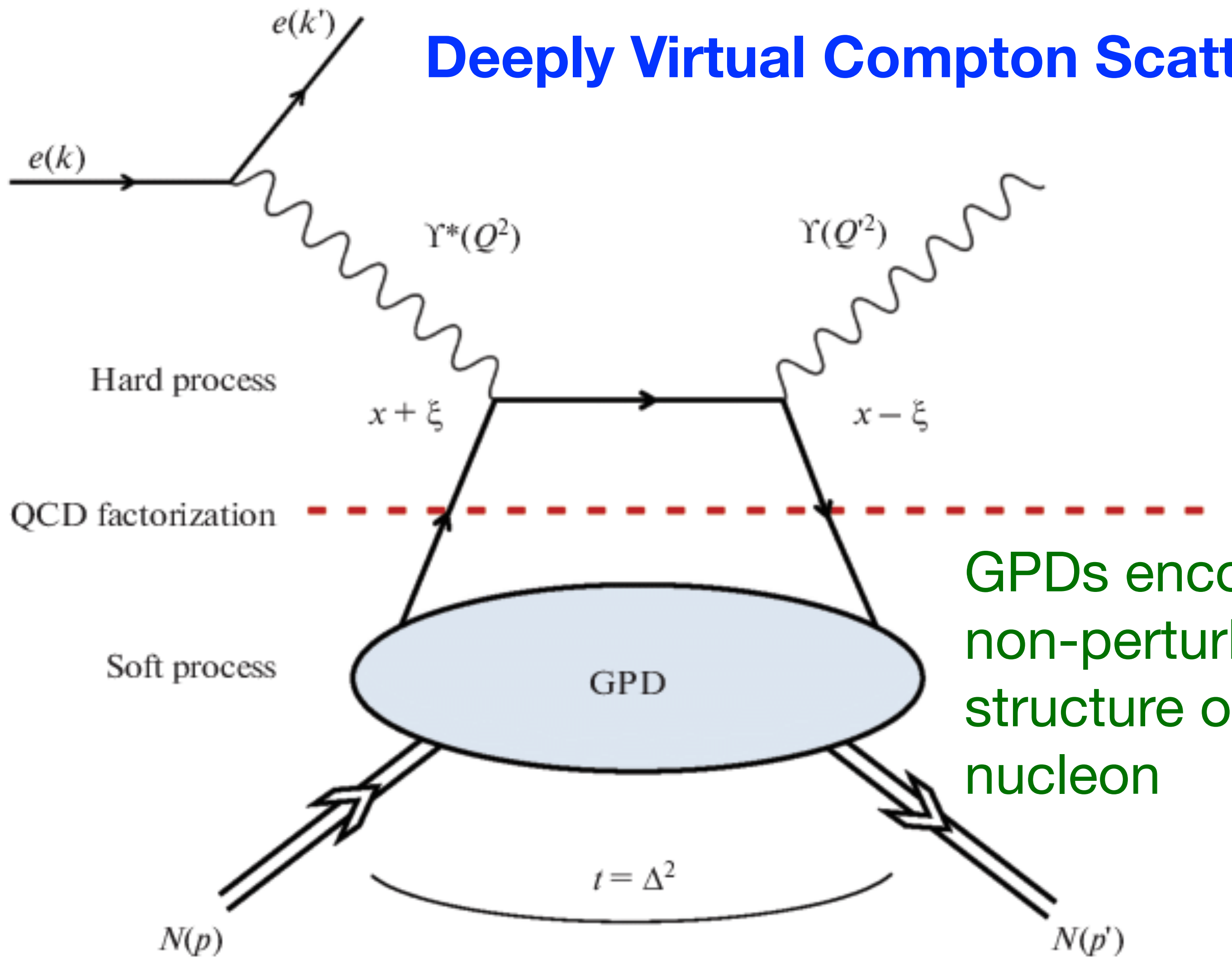
And orbital angular mom r x p

t = mom transfer squared at nucleon vertex

$x \pm \xi$ *longitudinal momentum fractions of the struck parton*

Skewness: $\xi \cong \dfrac{x_B}{2 - x_B}$

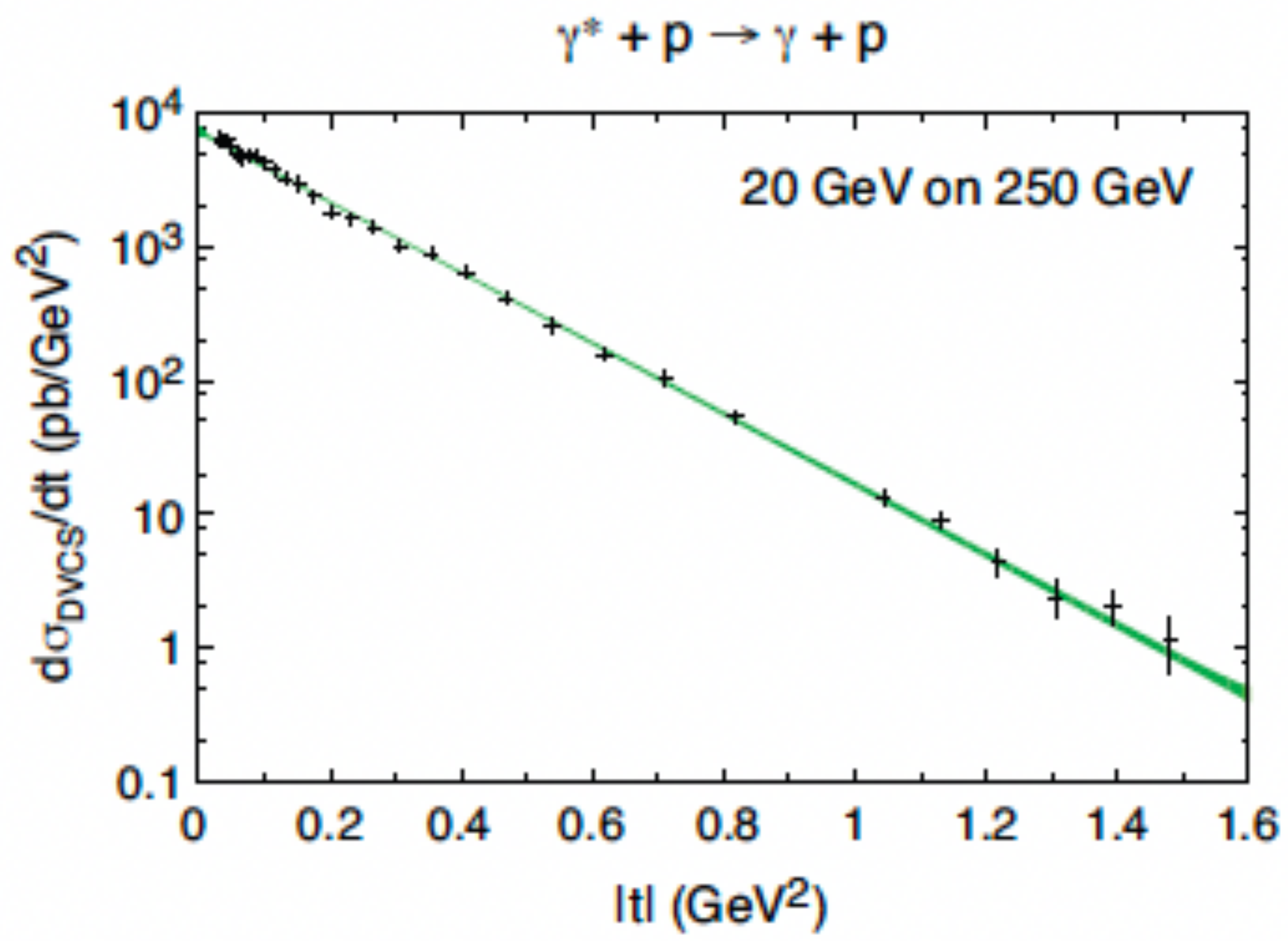
Deeply Virtual Compton Scattering



GPDs encode non-perturbative structure of nucleon

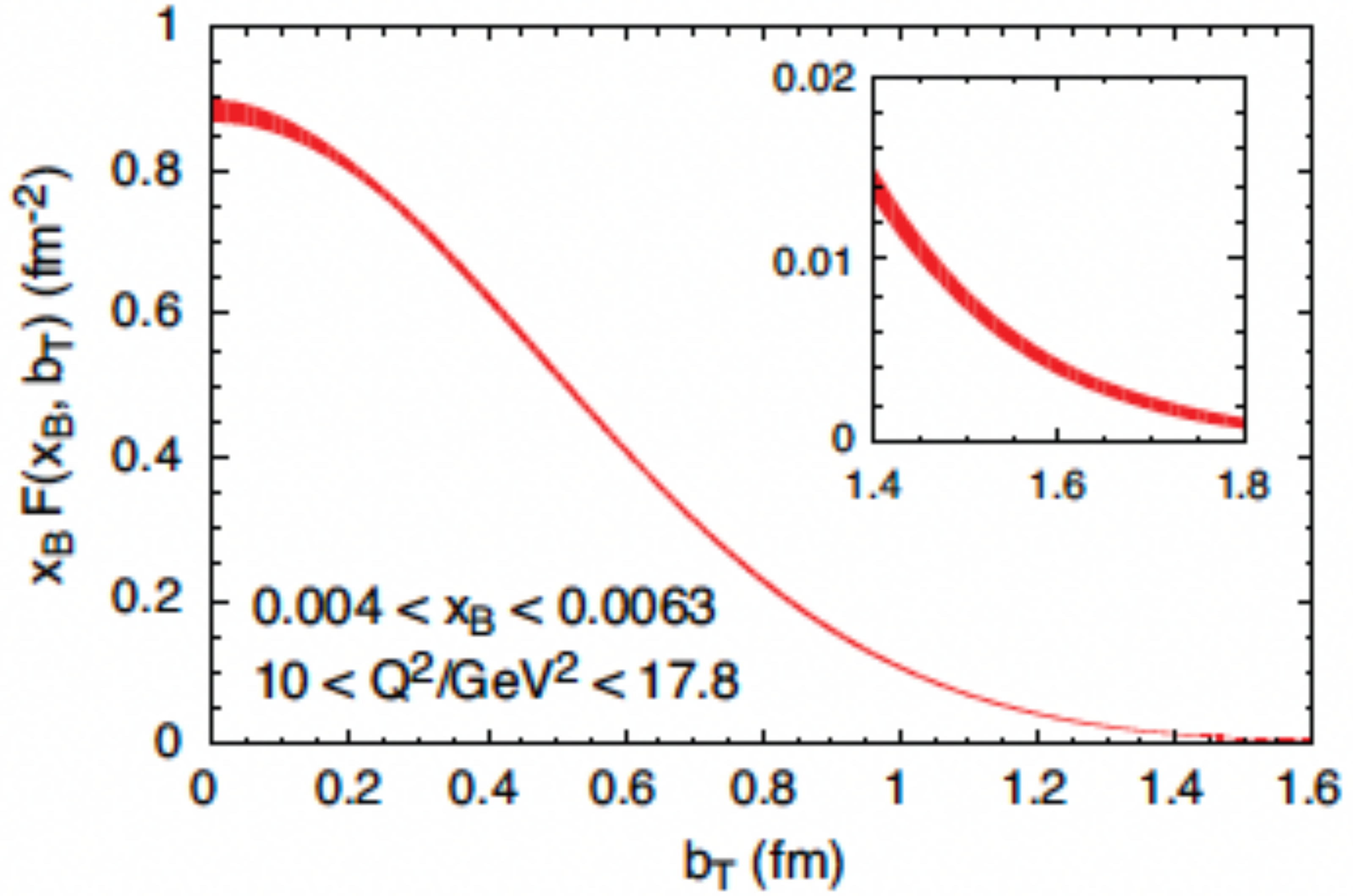
- High Q^2, low t → hard exclusive reactions for GPD topics
- Observables parameterised in terms of Compton Form Factors
- These reactions offer studied into: transverse spatial positions in longitudinal mom space; pressure distributions (indirectly); orbital angular momentum

Nucleon Spin and Tomography



DVCS ep

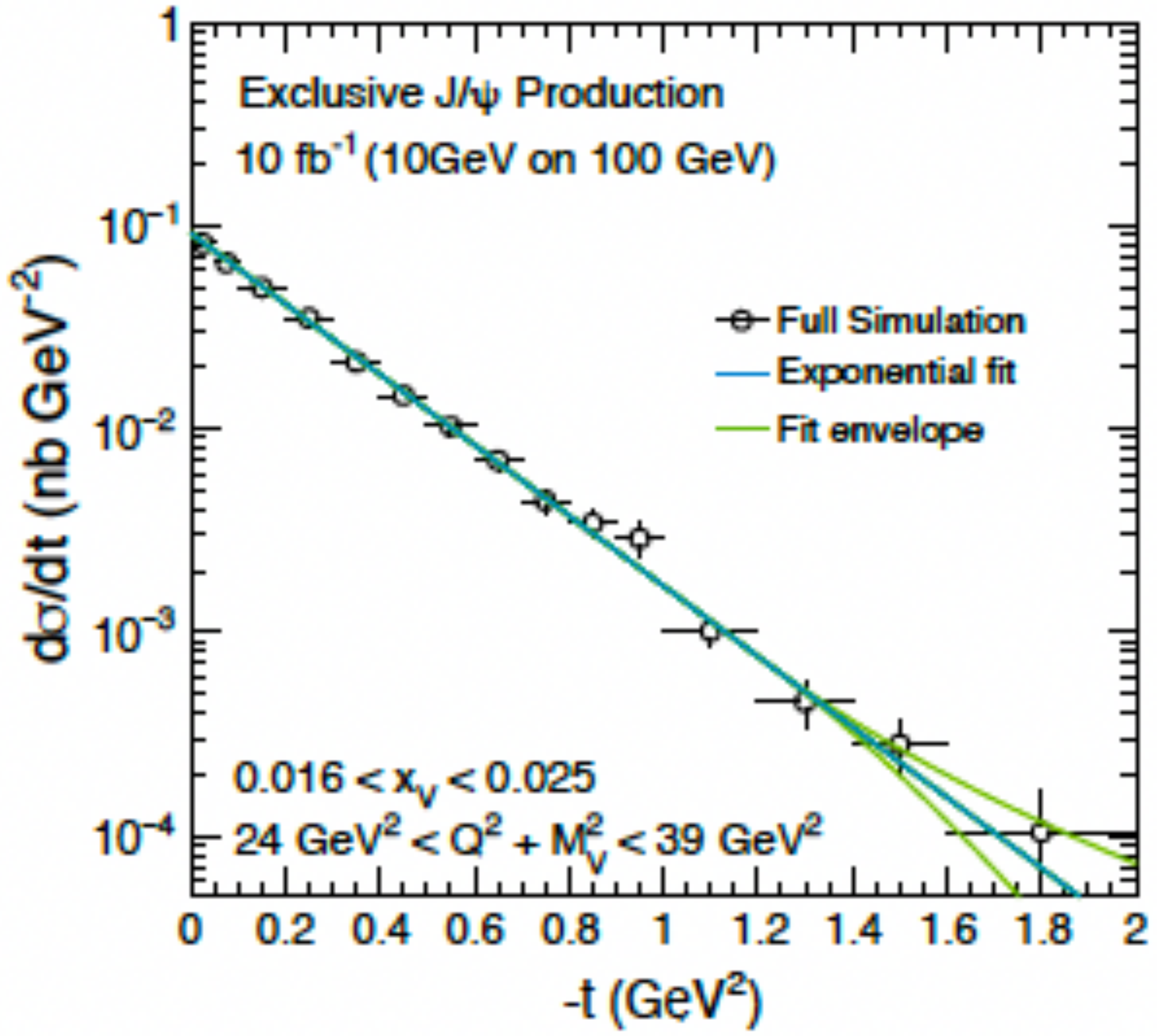
Fourier Transform in t

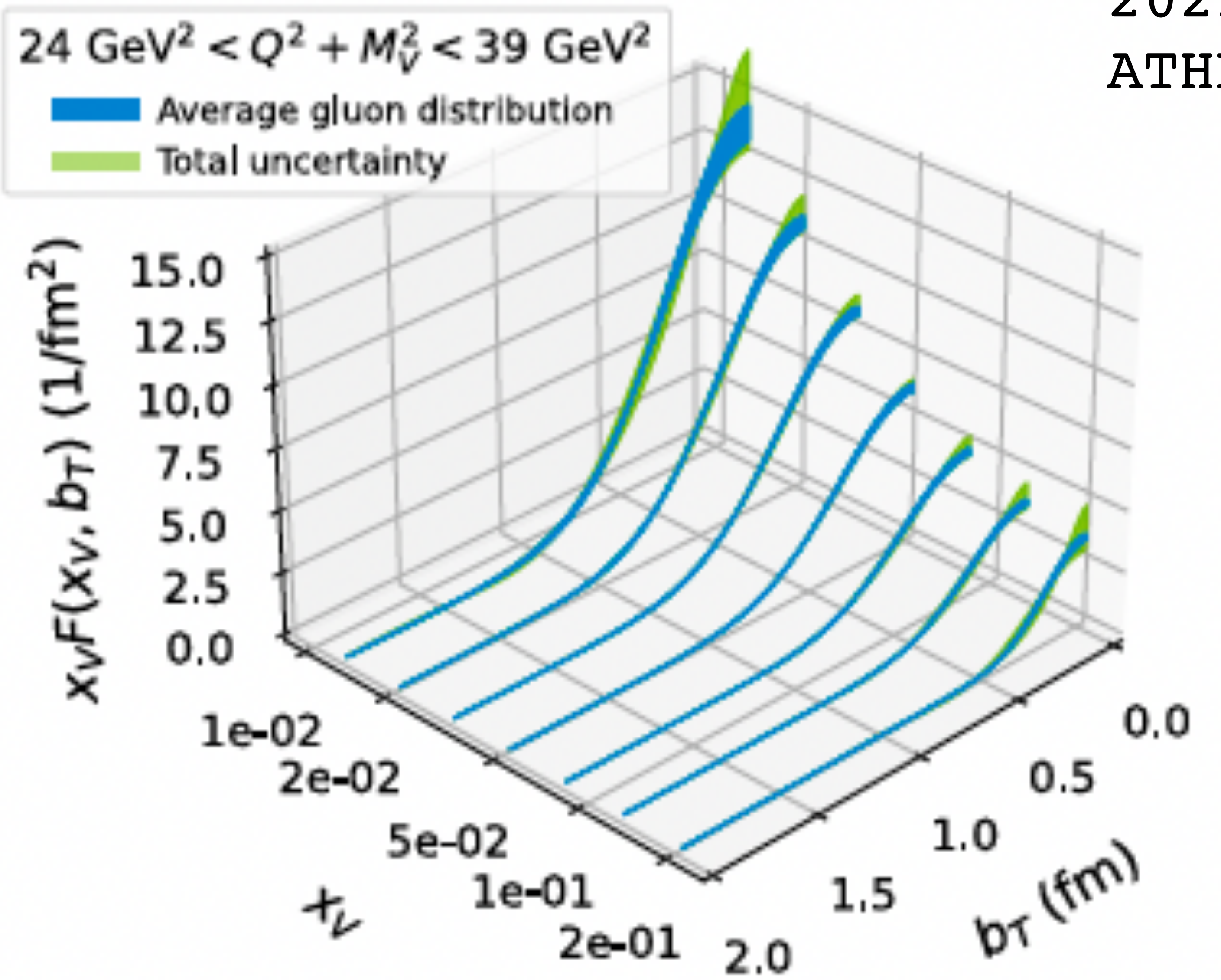


arXiv:1212.1701 [nucl-ex]

At fixed Q2, x and Ɛ=0, slope of cross section related to transverse spatial distributions of quarks inside nucleon

Similar for deeply virtual meson production in ep at EIC (e.g. J/Ψ, ϕ…)
Offers access to gluon spatial distributions at different x-bins





2022 JINST 17 P10019
ATHENA Collab

Also, light vector mesons →flavour decomposition of GPDs

DVCS

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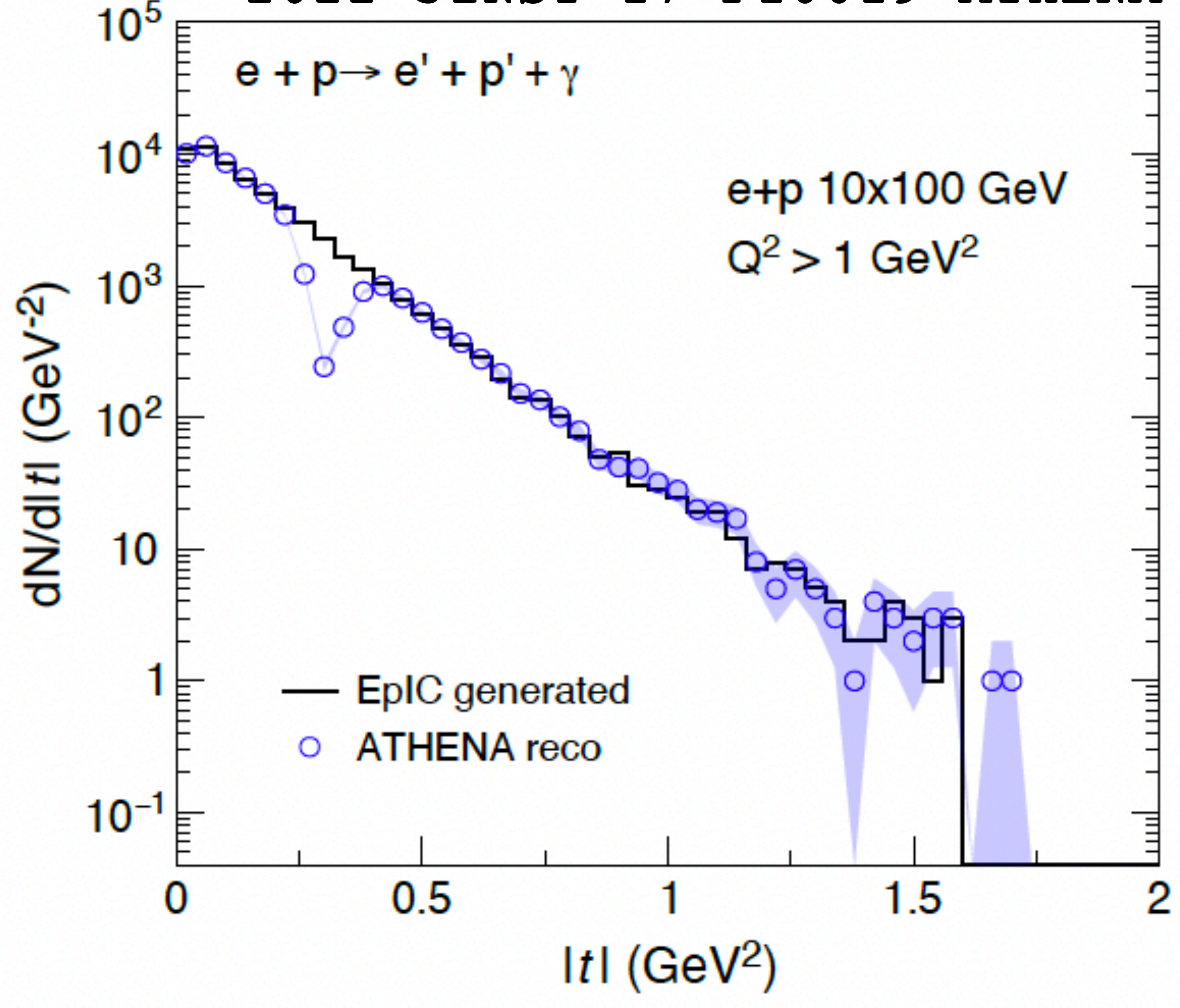
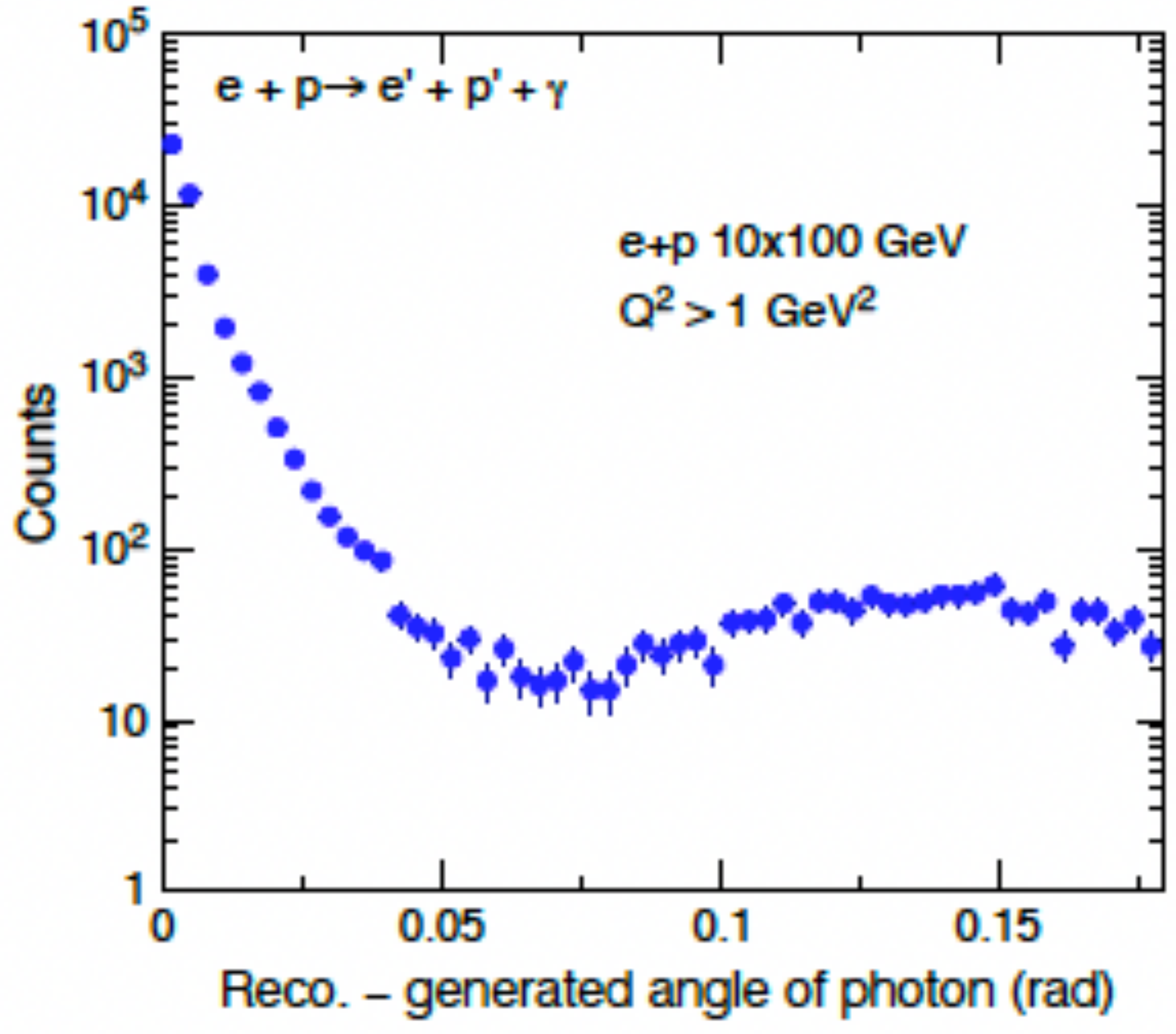
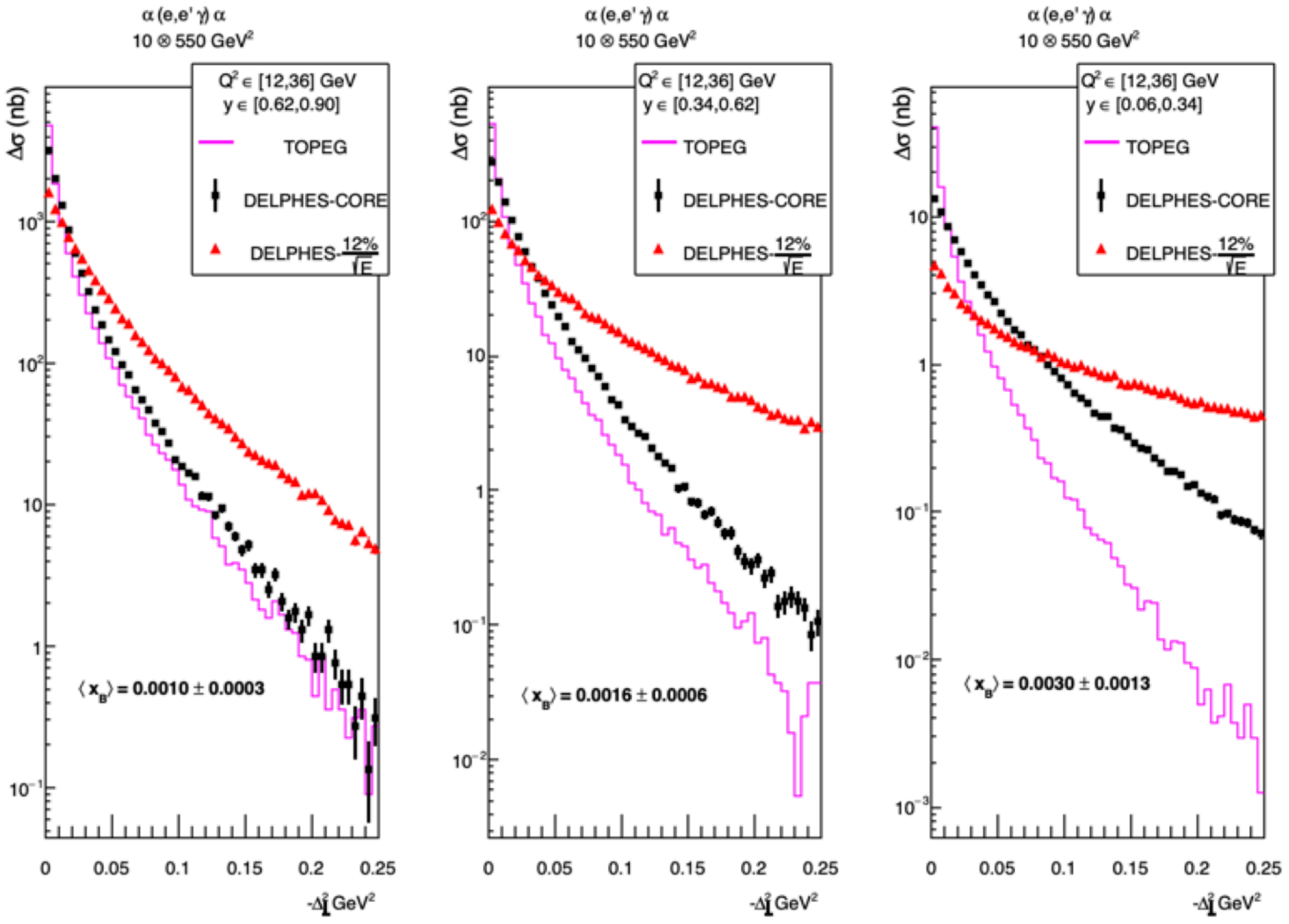
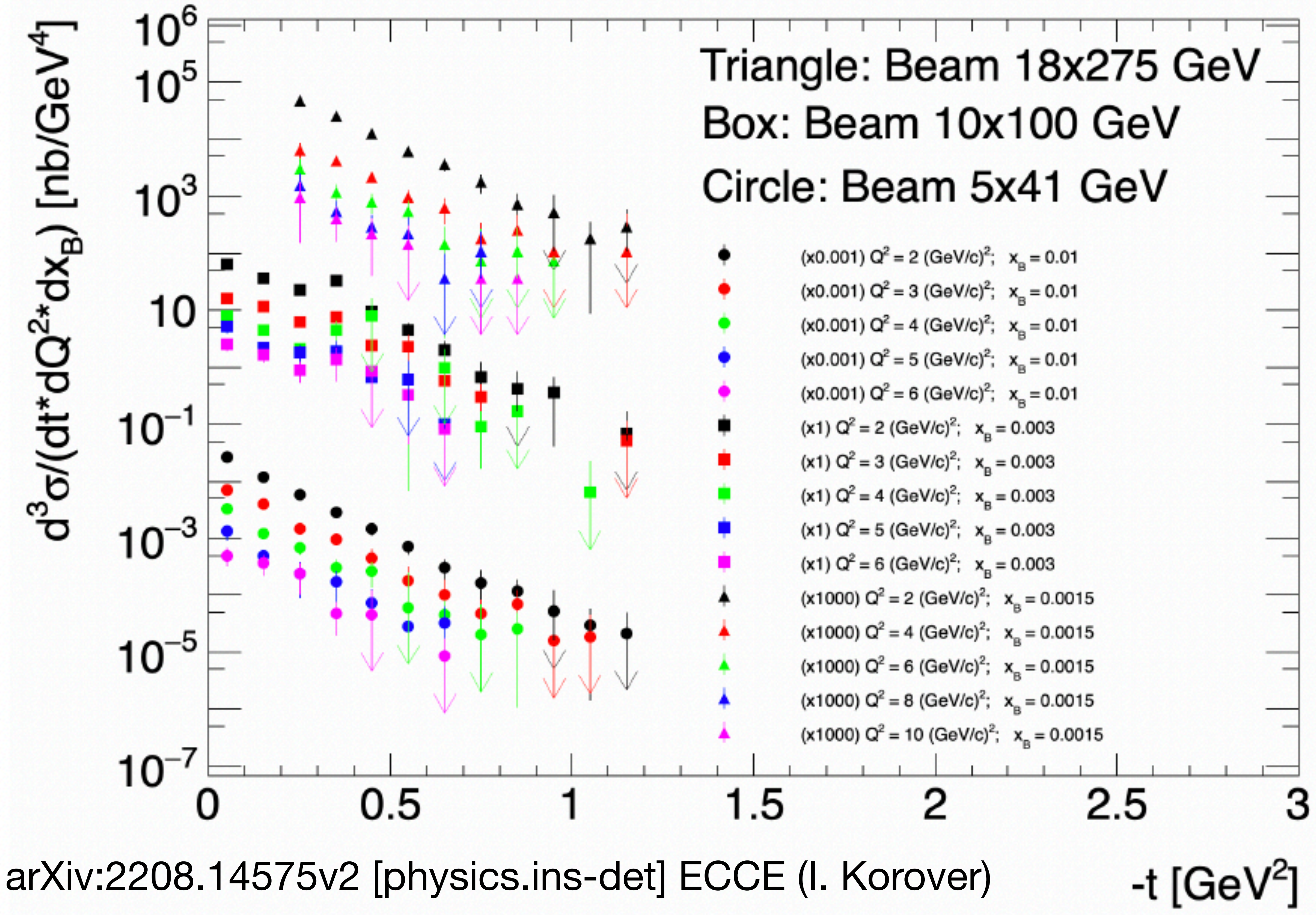




arXiv:2209.00496v1 [physics.ins-det] (CORE Collab, C. Hyde, P. Turonski et al.))





arXiv:2208.14575v2 [physics.ins-det] ECCE (I. Korover)

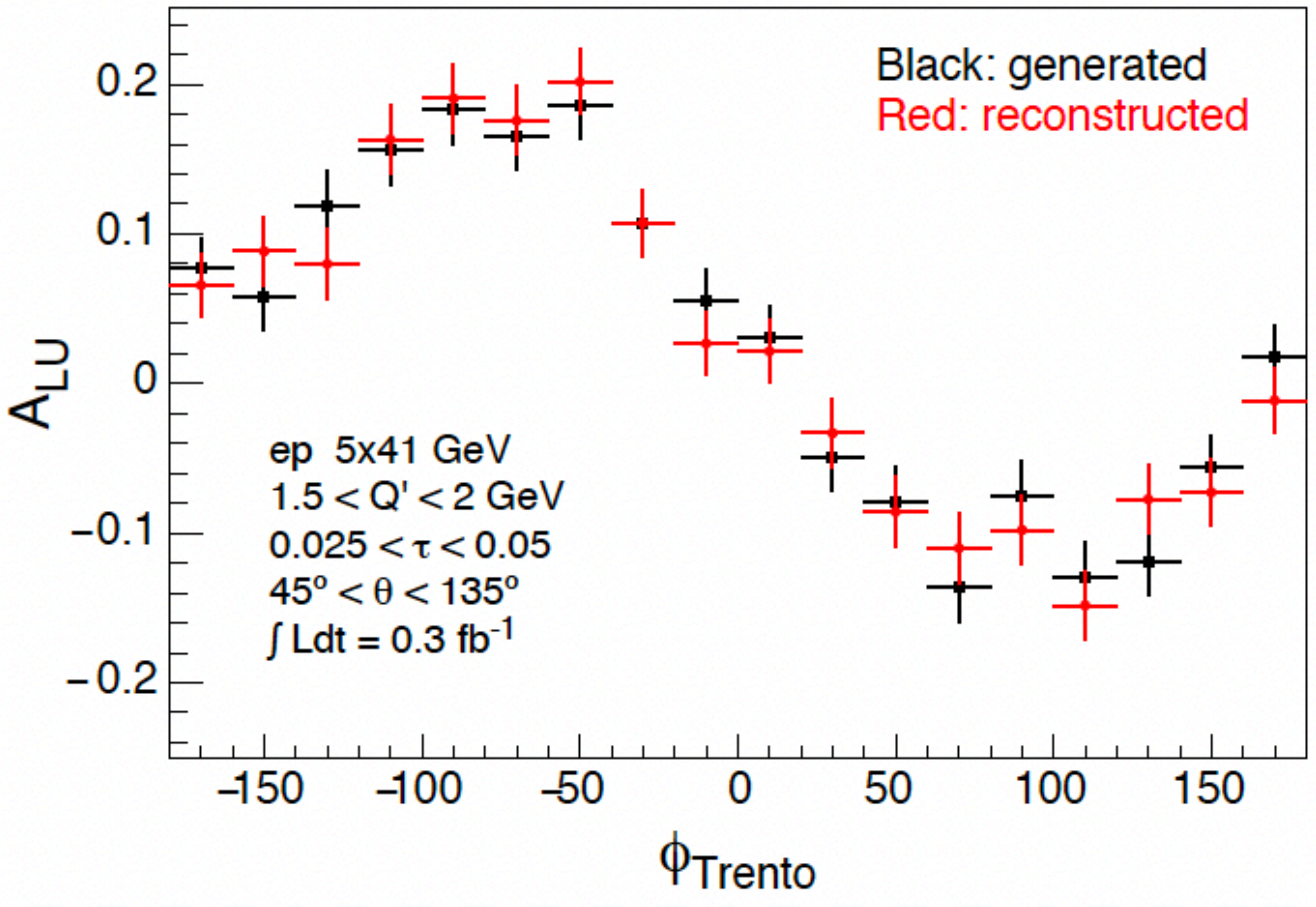
DVCS ep→e'p'γ:

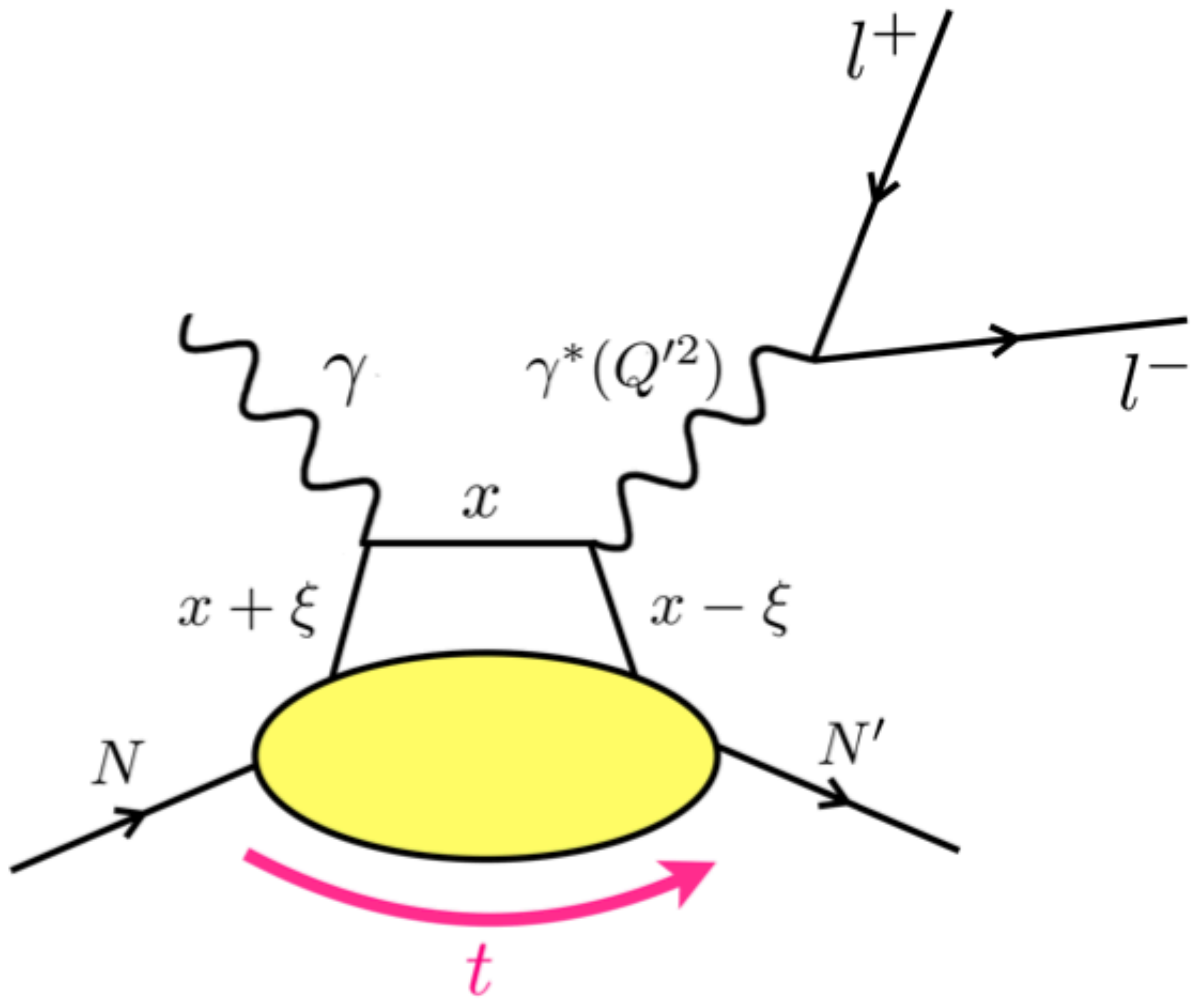
- |t| distribution
- Real photon reconstruction allows to separate main background ($\pi^0 \to \gamma\gamma$)
- Multidimensional binning over large t range

DVCS eHe→e'He'γ:

- Integrated cross-sections in different y-bins

2022 JINST 17 P10019 ATHENA (D. Sokhan)



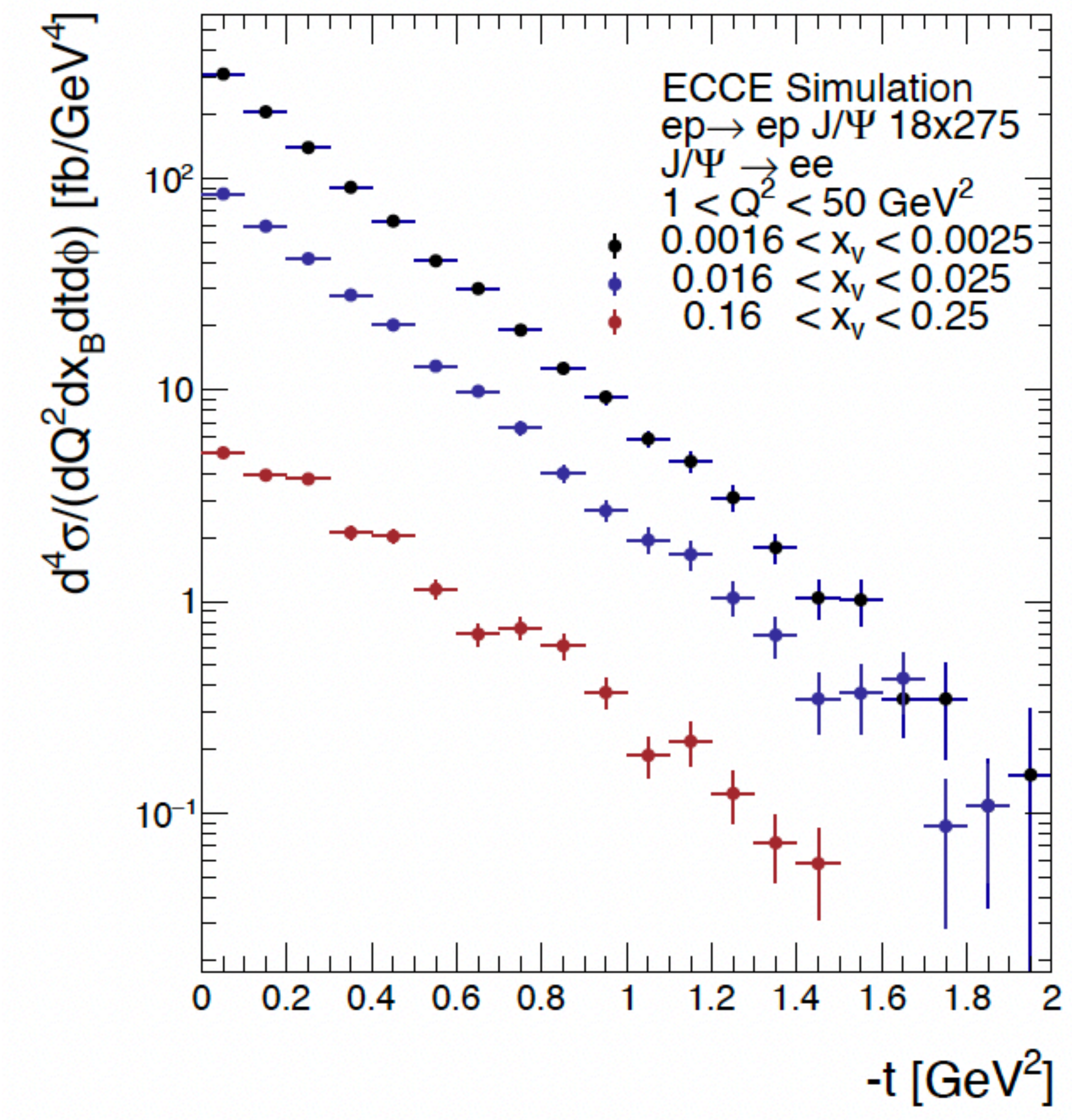


TCS ($\gamma p \rightarrow p' e^+ e^-$)

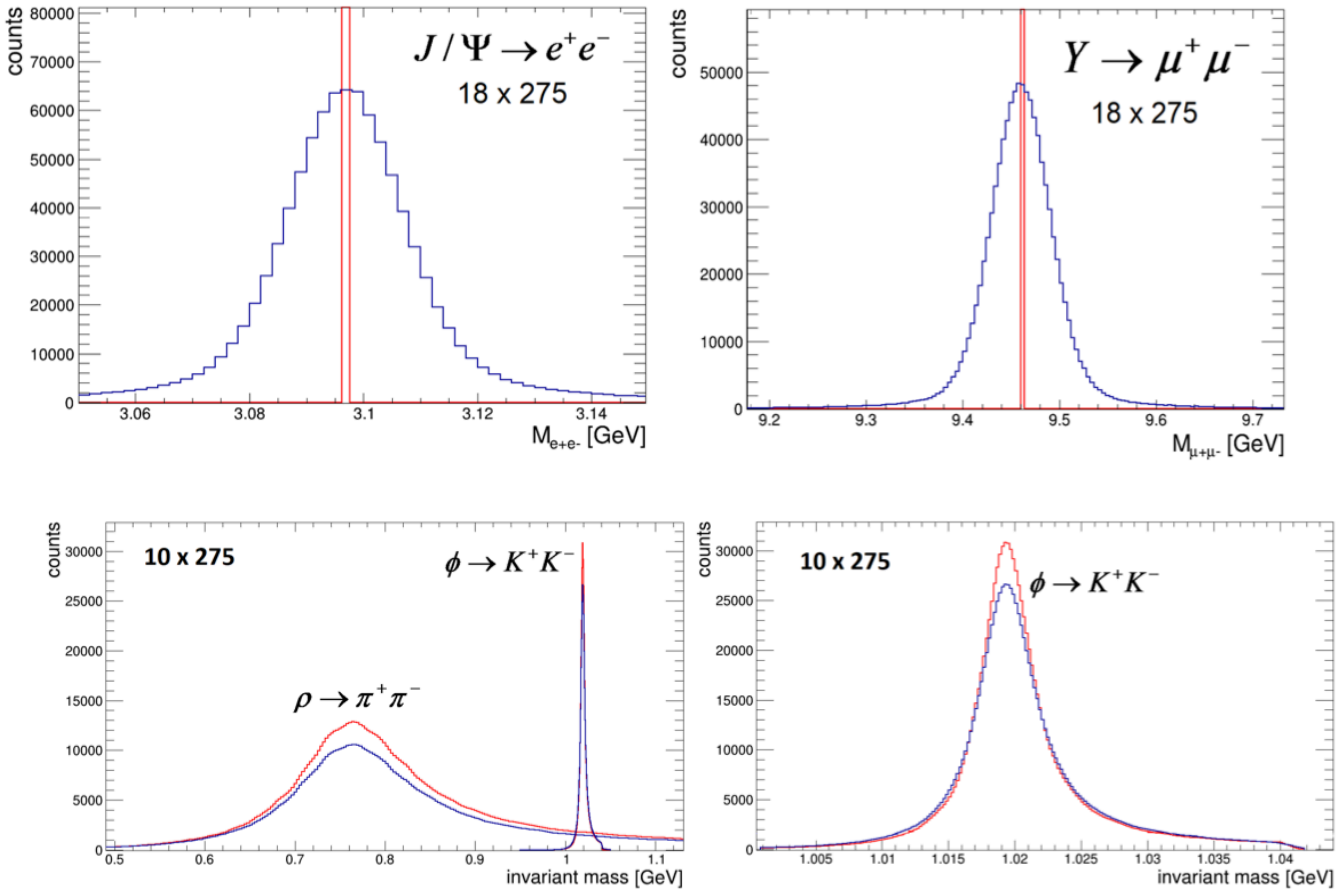
- Complimentary to DVCS
- TCS highly suppressed by BH
- Spin asymmetries sensitive to interference between BH and TCS amplitudes
- → BSA to recover sensitivity to GPDs

Exclusive Meson Production

arXiv:2208.14575v2 [physics.ins-det] ECCE (N. Santiesteban, S. Fegan)



arXiv:2209.00496v1 [physics.ins-det] (CORE Collab, C. Hyde, P. Turonski et al.))



- Hard exclusive electro-production of vector mesons (e.g. J/Ψ,Υ), access gluon GPD topics (multi-dimensional imaging)
- e.g. J/Ψ electroproduction cross section
- Invariant mass resolutions from different meson decays in ep production (including major competing background for phi)

Gluon Structure of Nuclei and Saturation

See benchmark session for latest ePIC study

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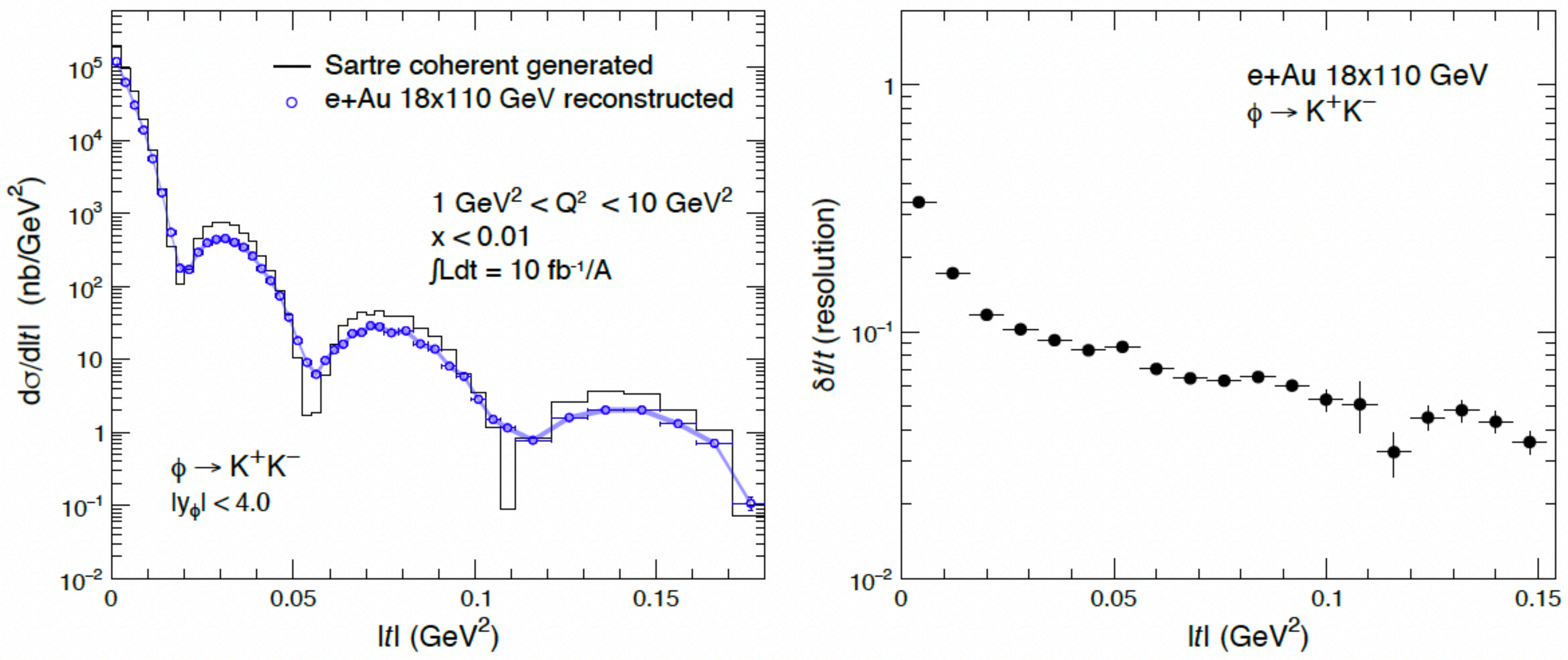
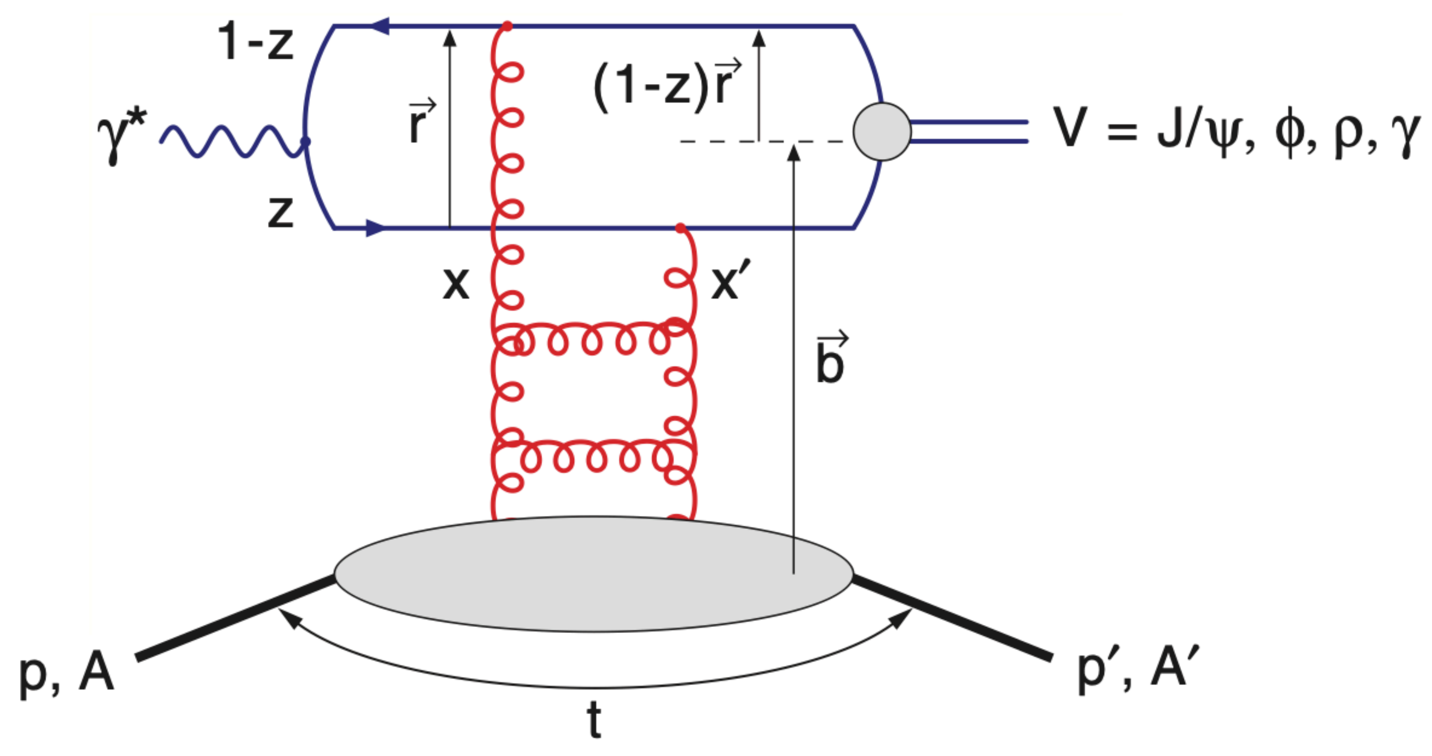
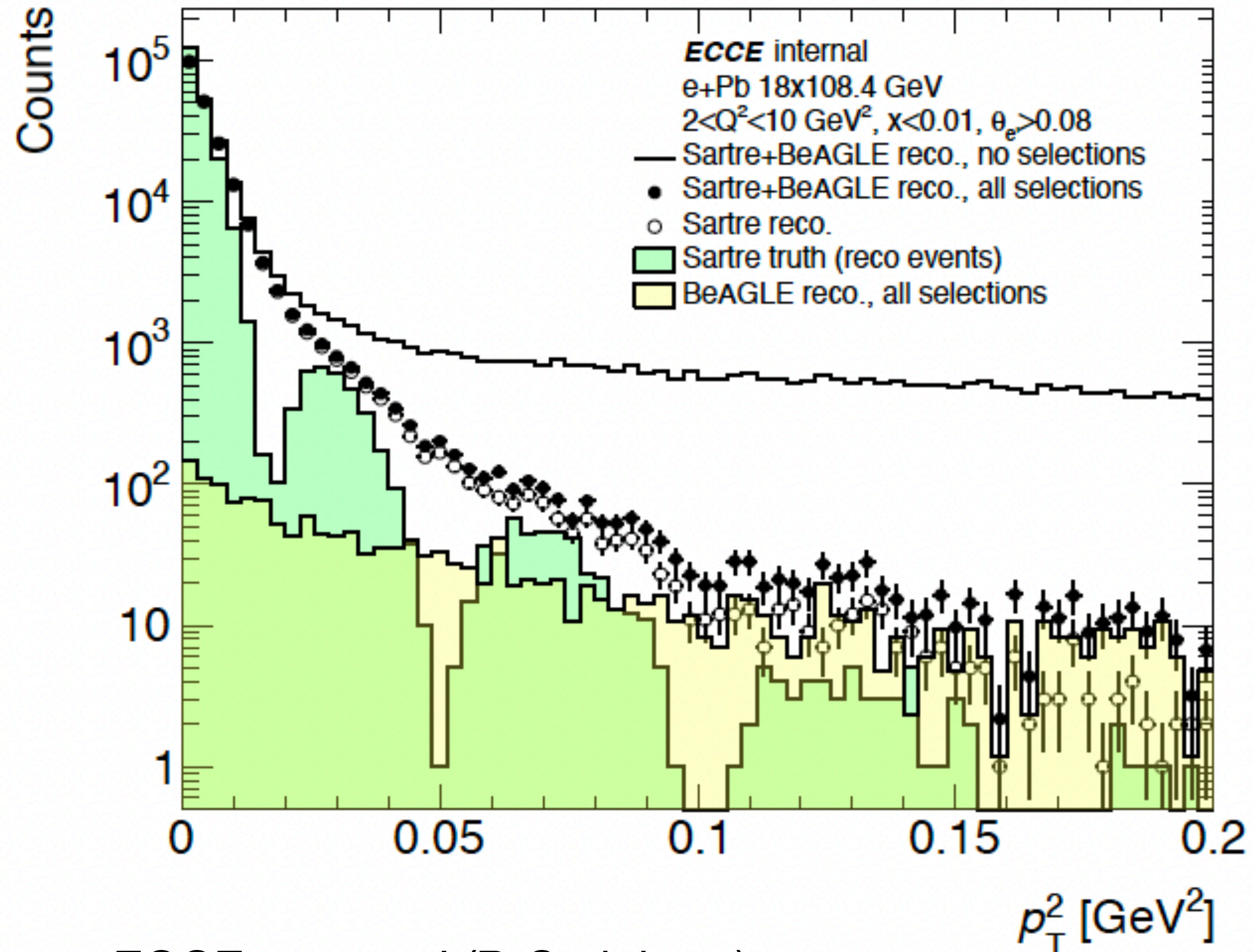


Toll, Ulrich, PRC 87 (2013) 024913



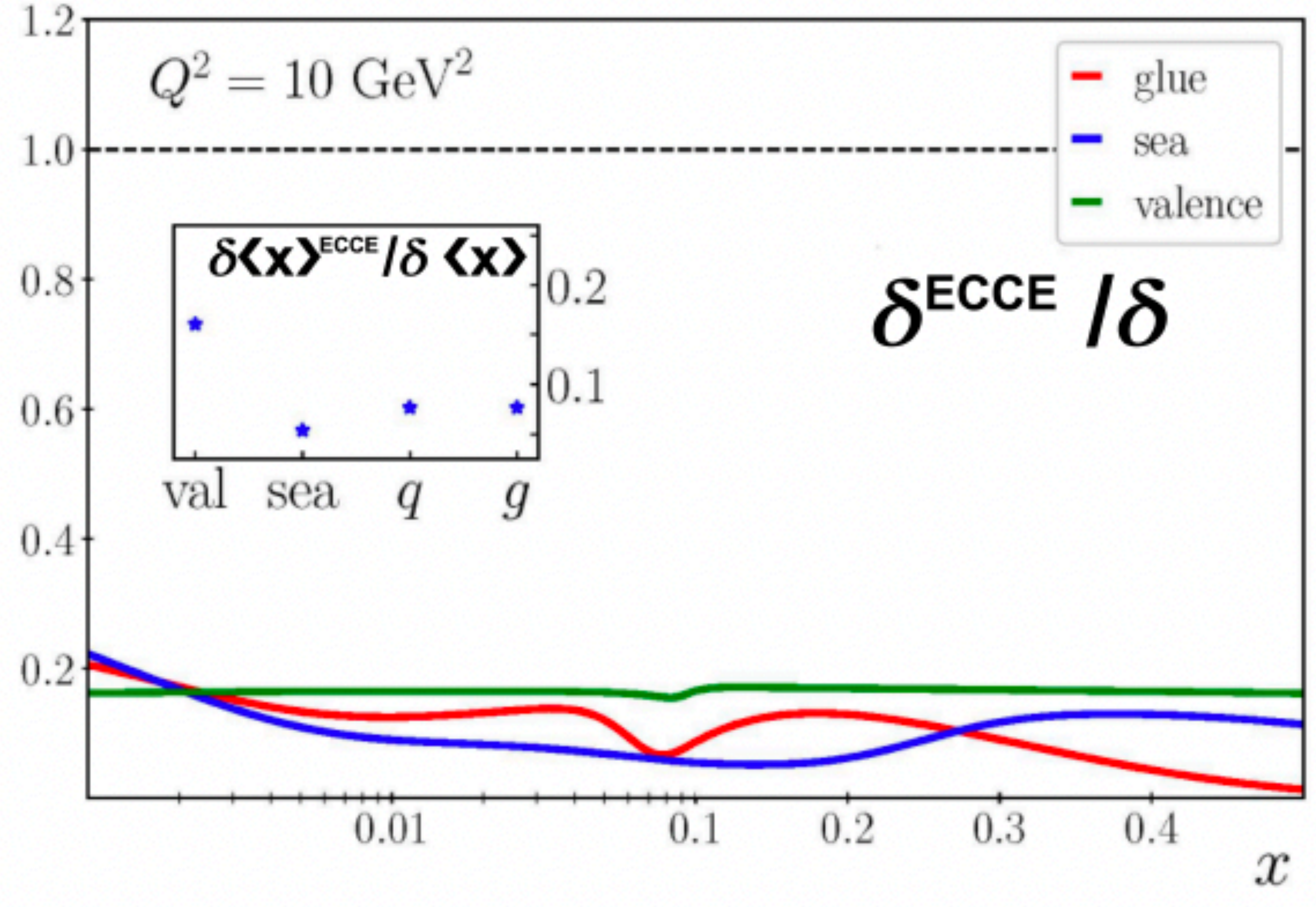


ECCE proposal (P. Steinberg)

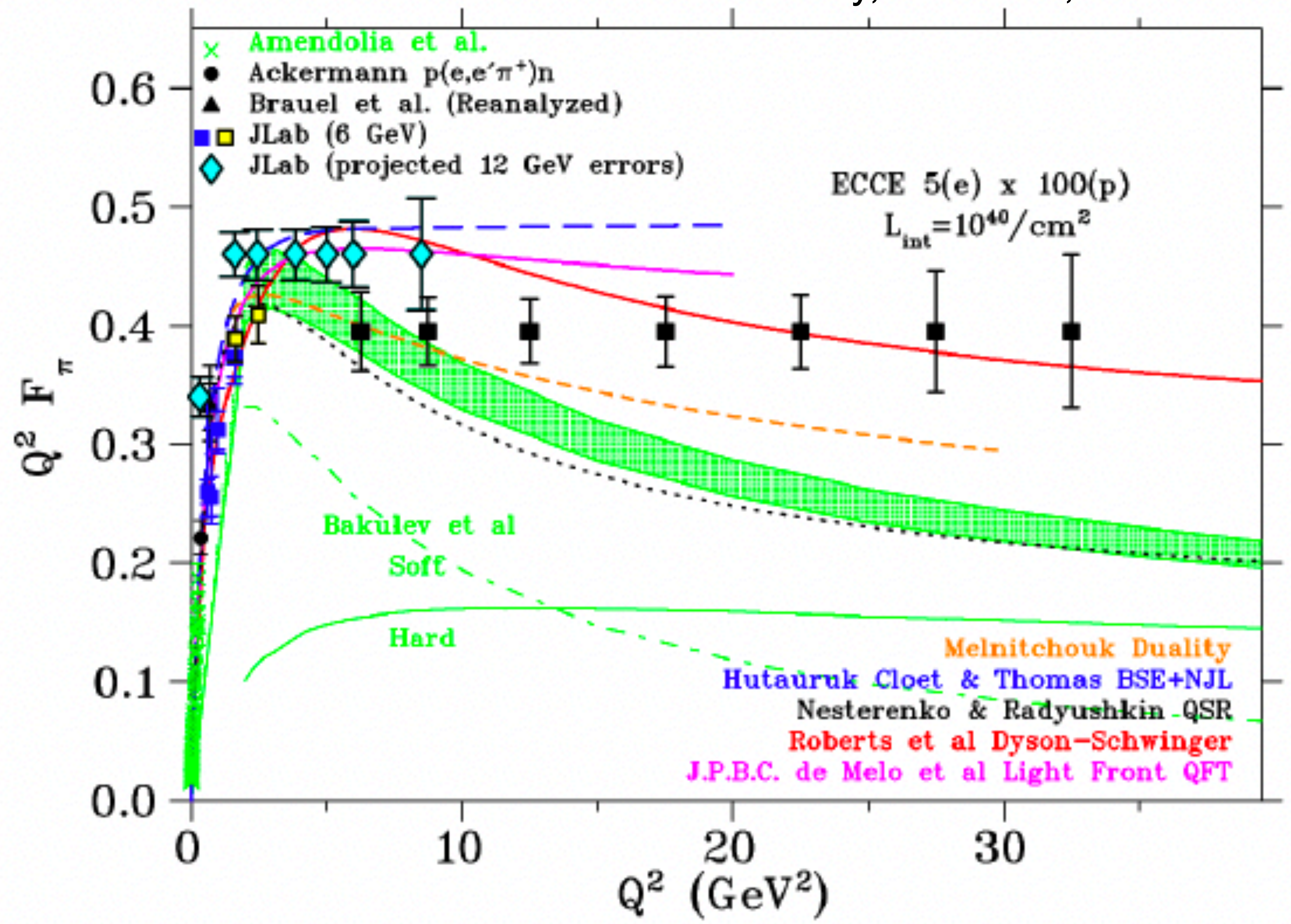
- Diffractive vector meson production e + A → e' + A' + VM
- Cross section sensitive to gluon density
  - Gluon spatial distributions within nuclei
  - Low-x structure of nucleus, probe of gluon saturation (with Q^2)
- Coherent - sensitive to average nuclear geometry
- Incoherent - largest background, interesting in own right (partonic fluctuations?)
- EIC: range of mesons (e.g. J/Ψ, ϕ, ρ, ω, ϒ), several ions, wide range Q^2
- A' escapes, reconstructed from decay products and exclusive kinematics
- Shown - t/p_t dependence of production and |t| resolution

ECCE proposal and arXiv:2208.14575v2 [physics.ins-det] ECCE

R. Trotta et al



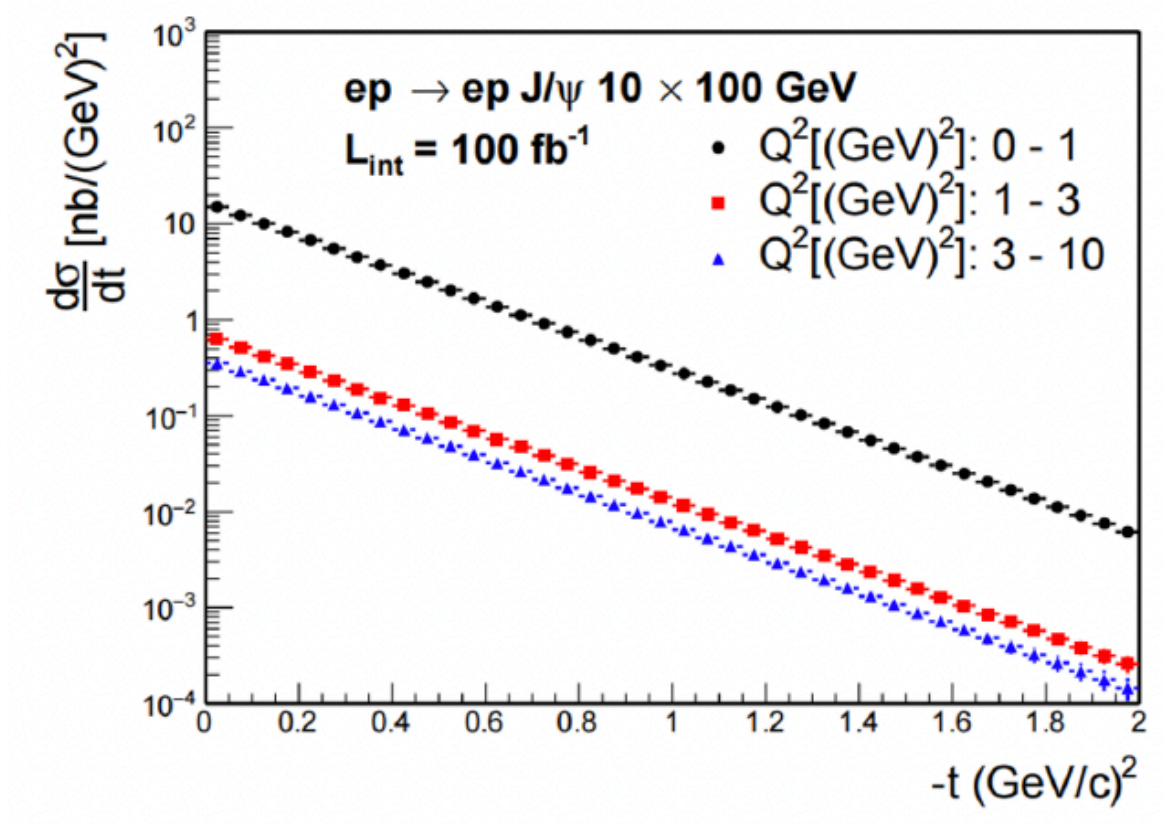
S. Kay, G. Huber, L. Preet

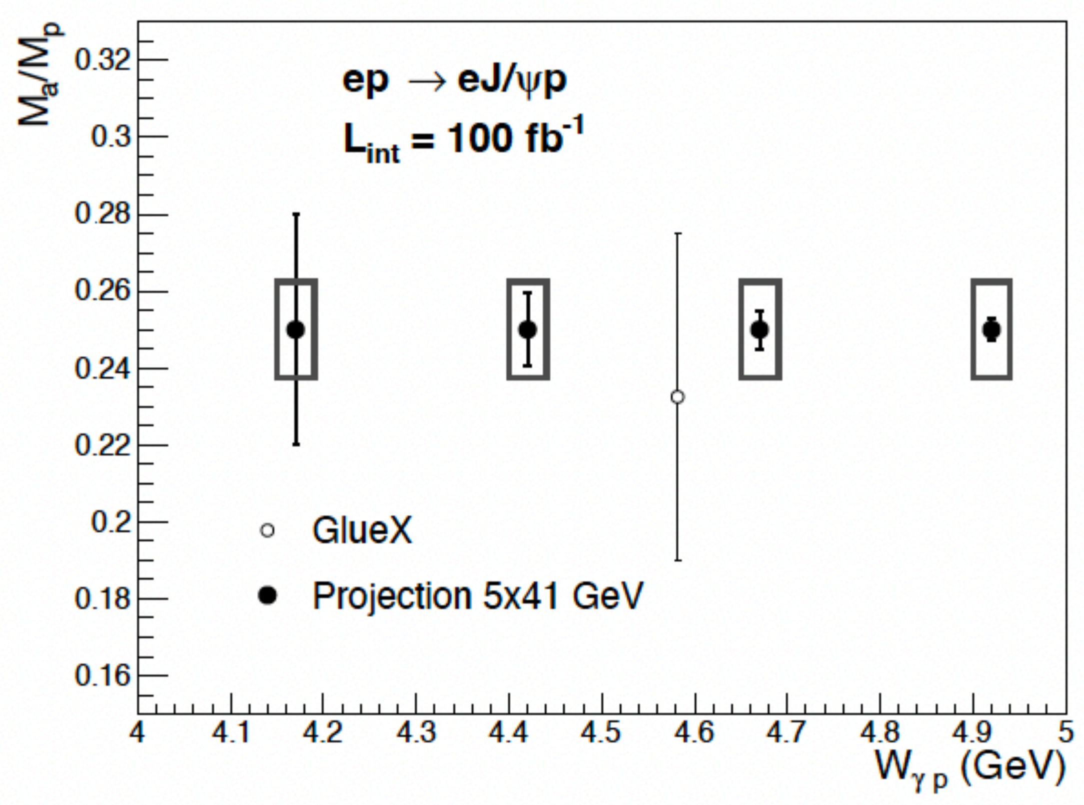


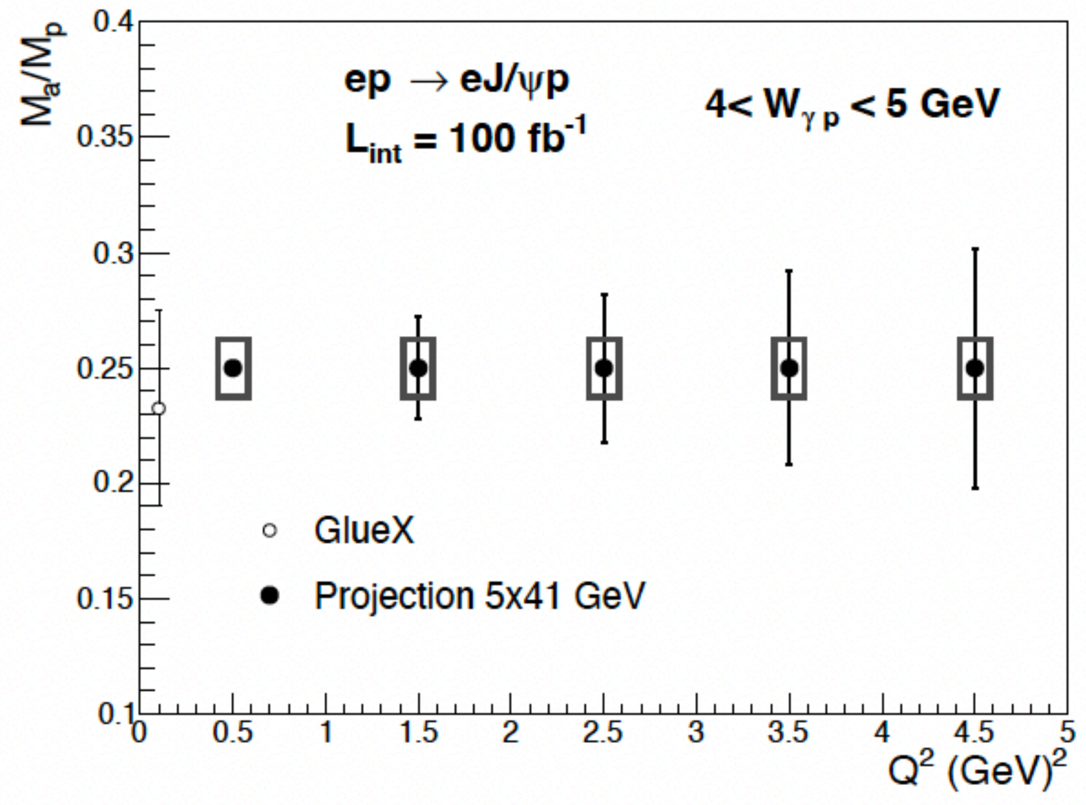
- Meson structure - substantially different masses of pions and kaons compared to protons and neutrons indicate quark and gluon potential energies play a different role in the generation of their masses
- Studying meson structure will shed insight into generation of mass by QCD dynamics beyond nucleon and provide information on goldstone mechanism, and allow to study interplay between Higgs and mass generation by QCD dynamics
    - Shown right: pion FF up to high Q2
    - Shown left: impact on extracted PDFs by pion SF measurements

Emergence of Hadron Mass

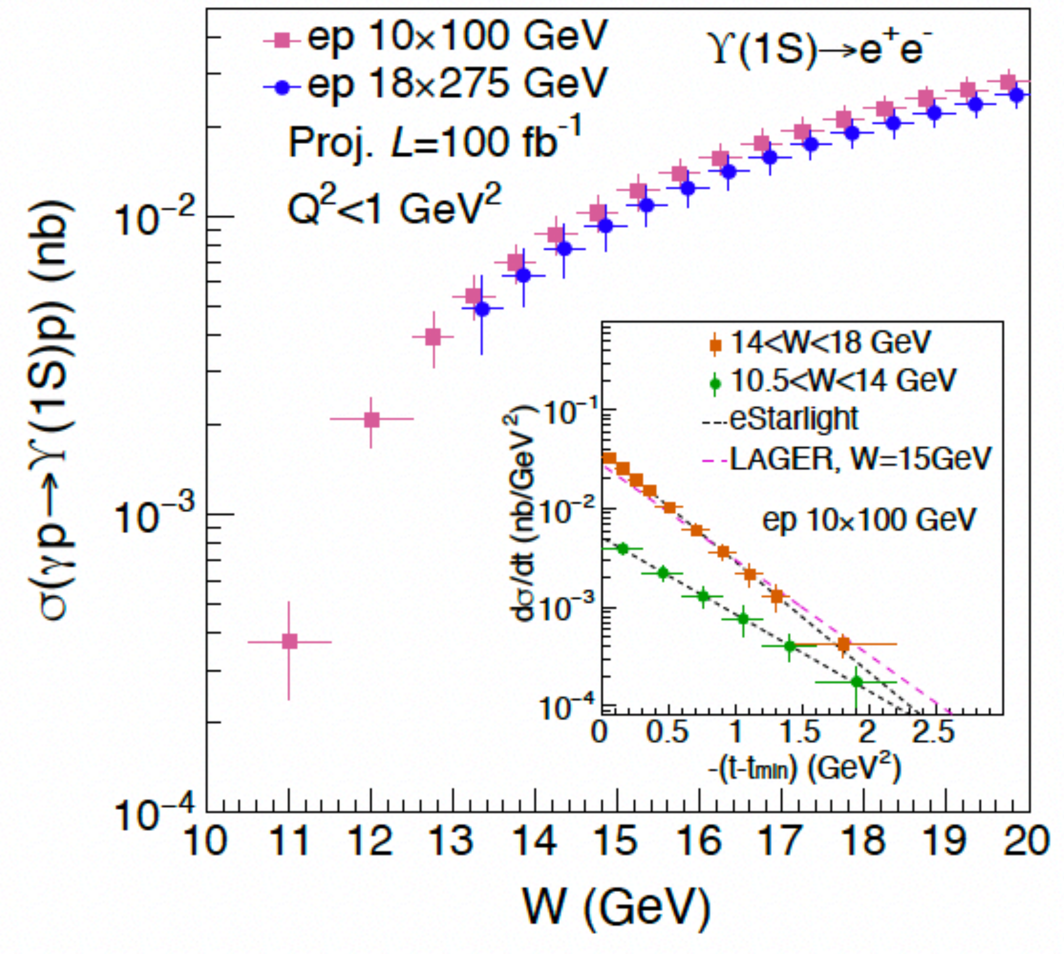
arXiv:2207.10356v1 **[nucl-ex]** ECCE (X. Li et al)

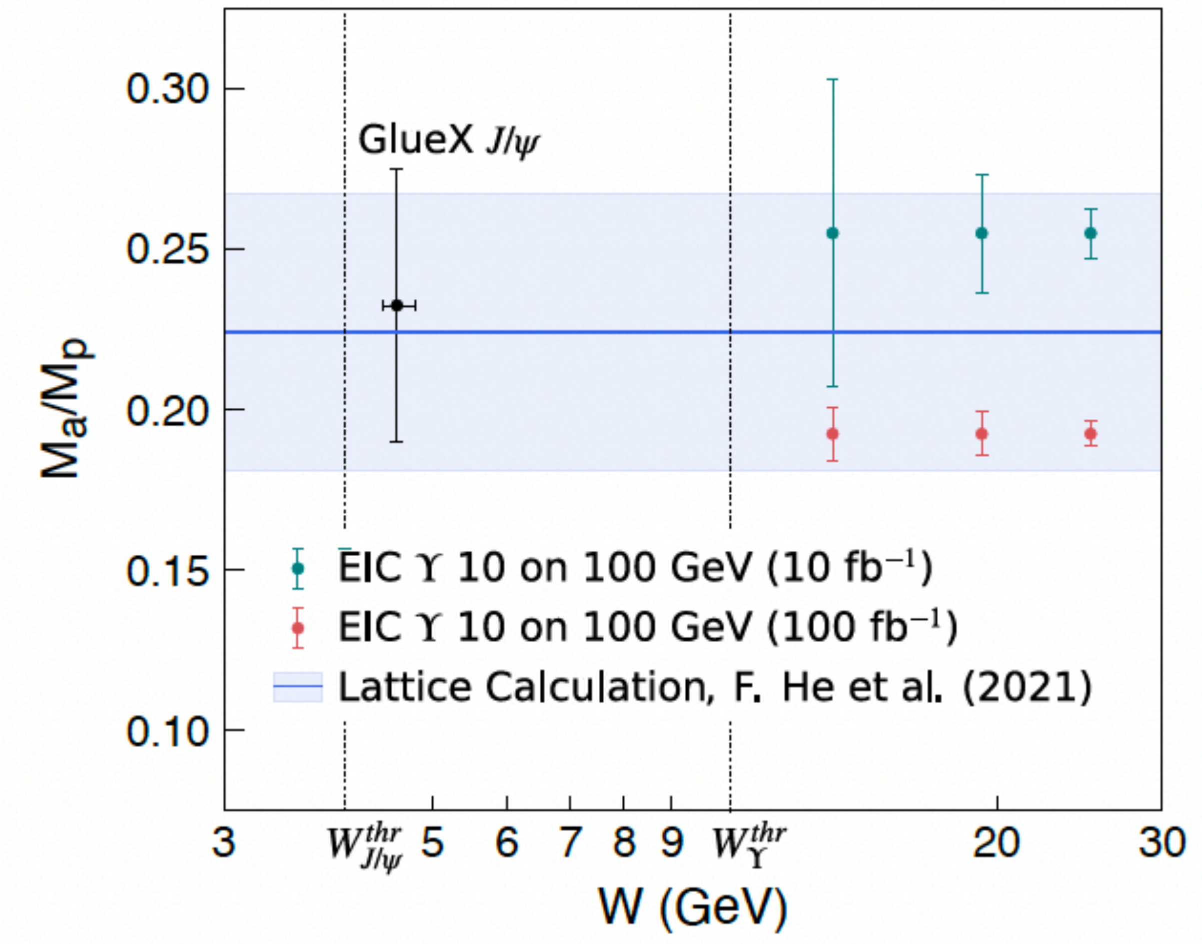






2022 JINST 17 P10019 ATHENA (Y. Ji)



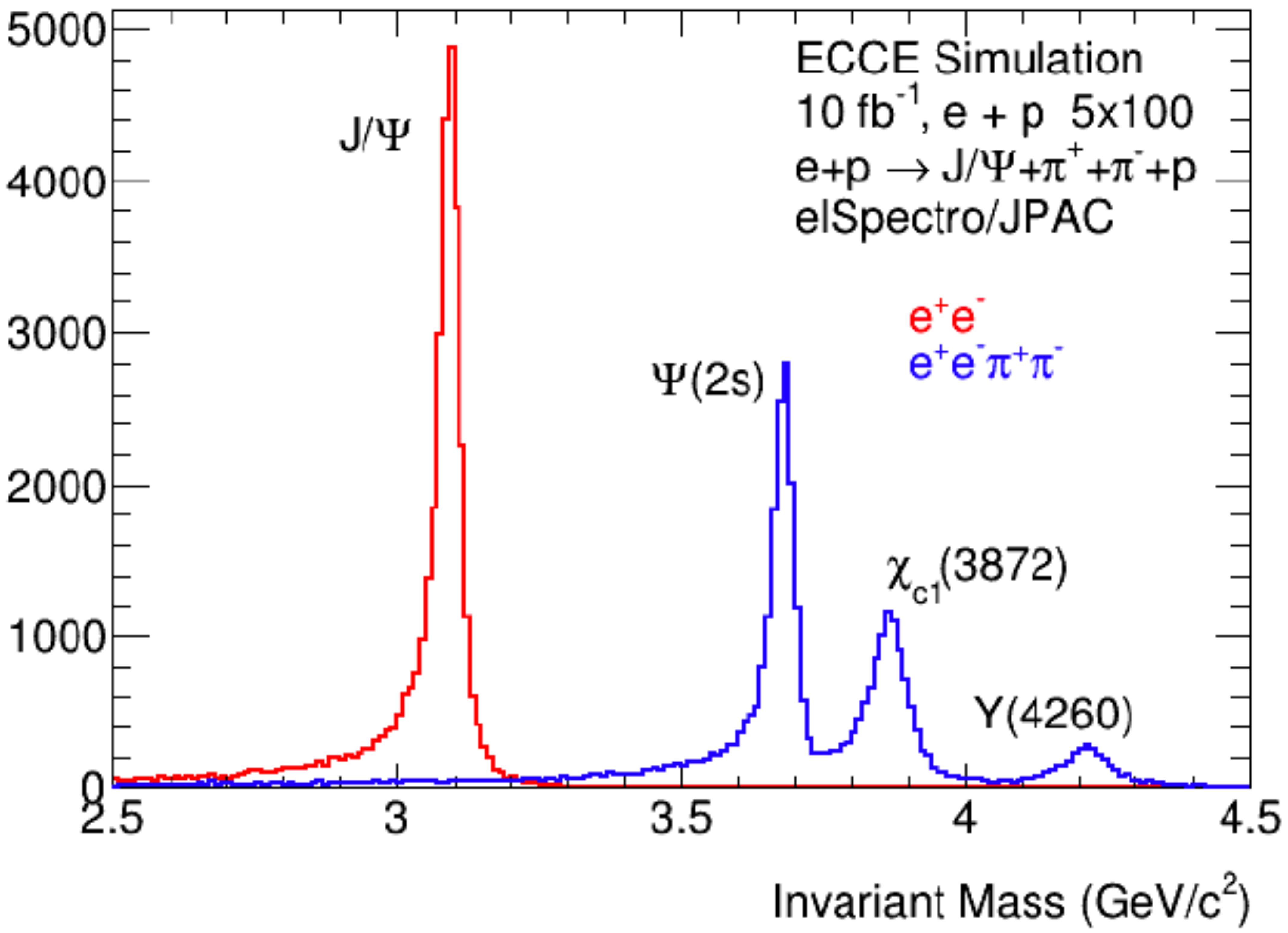


- Heavy quark threshold production (eg Y or J/psi) - insight into generation of mass in vacuum through trace anomaly

- Shown top: Q^2 and t dependence of J/Psi production at threshold, as well as the W and Q^2 dependence of the resulting trace anomaly

- Mapping t and Q2 dependence will provide data to theory for probing trace anomaly contribution to nucleon mass and its model dependent extraction

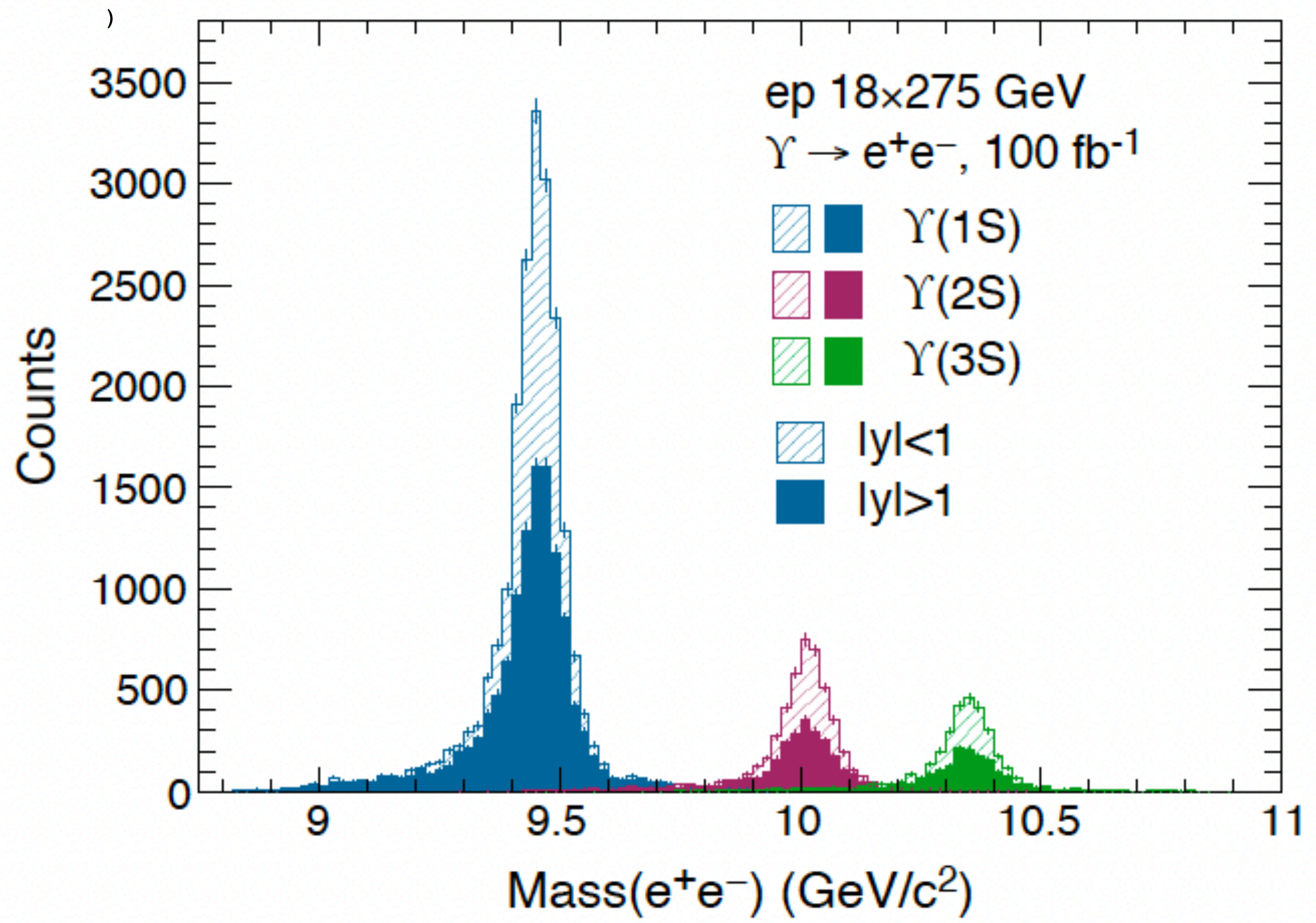
- Shown left: projected uncertainty of total and differential x-sec of near threshold Y photoproduction (Q^2<1GeV^2) and electroproduction (Q^2>1GeV^2) and trace anomaly composition contribution to proton mass in Ji's decomposition arXiv:2208.14575v2 [physics.ins-det] ECCE (D. Glazier)

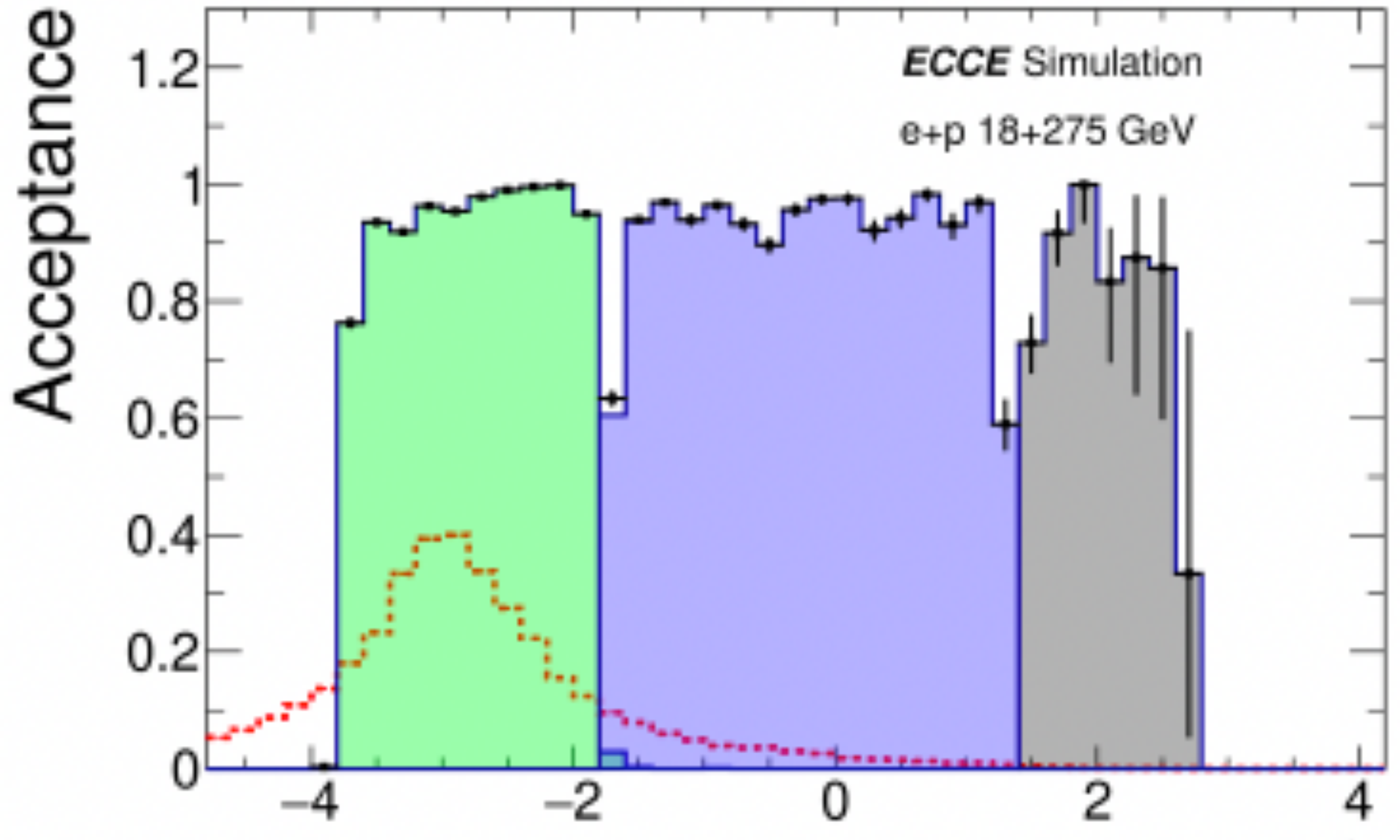


- Spectroscopy of mesons with charm quarks
- Unexpected widths compared to tests of quark model predictions
- Enough resolution to separate states

Scope - Detector

2022 JINST 17 P10019 ATHENA (Y. Ji)





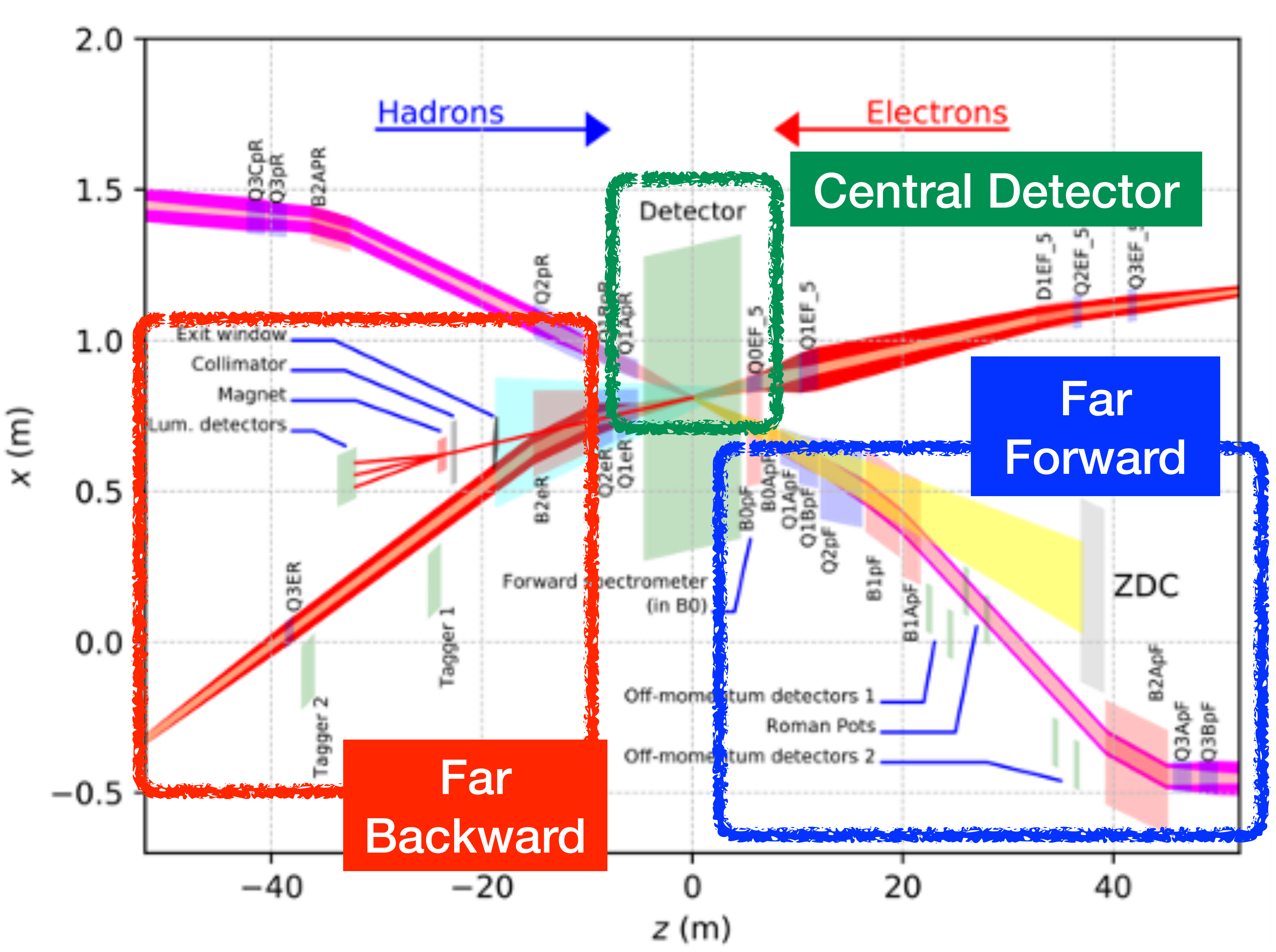
arXiv:2208.14575v2 [physics.ins-det] ECCE (I. Korover)

- Check detector capabilities for reconstructing exclusive, diffractive and tagging reactions
  - E.g. M_{ee} shown for 3 states of Y
  - Also many detector acceptance plots shown
- Again, many many reactions
- Also, several beam types and energies
- → Numerous final state topologies
- Complete measurements
- Scattered lepton, scattered nucleon/nuclei (intact or dissociated), any other particles produced
- Acceptance, resolutions, PID → phase space, kinematic binning, background reduction, physics quantities and exclusivity cuts
- In addition to central detector, far forward and far backwards…

Scope - IR Layout

Broad range of exclusive final states rely on different combinations of Far Backward, Central Detector and - *critically* - Far Forward

- Far backward
- Absolute/Relative luminosity monitors
  - Precision eg asymmetries
- Low Q^2 electron tagging
  - extends kinematic range for electrons, or tag for quasi real photons
  - e.g. XYZ spectroscopy



- Far forward *essential* for EDT physics eg
- e.g. tagging at very forward rapidities (charged and neutral particles); diffraction; nuclear breakup and incoherent vetoing; t reconstruction over wide range
- Different instrumentation comes into play in different configurations
  - e.g. DVCS (ep→e'p'γ), p' in B0 for low beam energy, and in RP for high energies

Few Examples of References to Importance of FF/FB Systems in Proposals

- B0 - forward going hadrons and photons for exclusive reactions, including increasing detection fraction of two γ's (e.g. backwards DVCS and meson production)
- RP - diffractive processes (eg veto incoherent), and very small p_T hadrons, e.g. DVCS which produces protons with small p_T (ie only small separations from hadron beam). Inside beam pipe.
- OMD - outside beam pipe; compliment RP by measuring charged particles with smaller magnetic rigidity than hadron beam.
- ZDC - photons and neutrals. E.g. meson SF, demanding measuring forward going neutrons with 80-98% of proton beam momentum. Also pion FF measurements.
- Low Q^2 tagger - help measurements with small x-sec, e.g. TCS (e' gives measure of s-dependence and t reconstruction), or reactions with quasi-real photons
- Luminosity monitors - absolute accuracy 1% or better needed, driven by desired precision on asymmetries

See next talk for more info on FF/FB

Summary/Discussion

- EDT PWG encompasses an extremely broad, rich and exciting physics program
- These were just some glimpses, not an exhaustive summary
- Many topics remain to be studied
- We must press to recreate proposal/presentation quality plots for write up/TDR
- Many opportunities to get involved - if interested please ask/volunteer today (or reach out to us later)

- In discussions today - for planning our write up - here are some initial broader topics (not exhaustive), before moving to more detailed plot discussion session later…
  - Studies into as many reactions as possible spanning physics program are good, to demonstrate wide breadth of physics and to check entire detector design. e.g. the proposals did not cover all potential topics, anyone willing to work on other topics are more than welcome!
  - Restricted in people power for analyses for TDR purposes currently, should we prioritise efforts based on NAS topics? Based on demonstration of each of exclusive, diffractive, tagging capabilities? Based on detector regions?
  - Beam energy configurations? Are we restricted to standard for the monthly productions?
  - Backgrounds?

Contact Info/Coordinates

- Mailing List Sign Up: https://lists.bnl.gov/mailman/listinfo/eic-projdet-excldiff-l
- Mattermost channel: phys-exclusive-diffractive
- Emails: rachel.montgomery@glasgow.ac.uk and raphael.dupre@ijclab.in2p3.fr

Wiki: https://wiki.bnl.gov/EPIC/index.php?title=ExclusiveDiffractionTagging

- Meetings Mondays at noon
  - Indico page for meetings: https://indico.bnl.gov/category/419/

Link to our table after discussions

This slide has been added after the workfest for reference

- During the workfest we assigned names to each of these topics
- Each topic or new topic is welcome to more people and we are open to new topics
- https://docs.google.com/spreadsheets/d/1cYxuR3BICbTGzy_FPMkhtAhGdAeV6JeSpaG1RqgF3v8/edit#gid=0

We also had a discussion about the diffractive vector meson plots and achievable t-resolution

It would be good to think about different plots for these topics, eg integrated over t, or fig 1.6 in white paper

It could be good to start looking into diffractive pdfs too - we need to get generator set up