Tagged DIS in the JLab22 era

Carlos Ayerbe Gayoso (W&M), Dipangkar Dutta (MSU), Rachel Montgomery (UG), Tanja Horn (CUA),Cynthia Keppel (JLab), Paul King (OU), Rolf Ent (JLab)
With huge contribution from Patrick Barry (JLab)

Hall C Winter Collaboration Meeting, 13 January 2023

Motivation

Pions are the lightest QCD bound system $q\bar{q}$

Even so, its partonic structure is not well understood as is for the proton

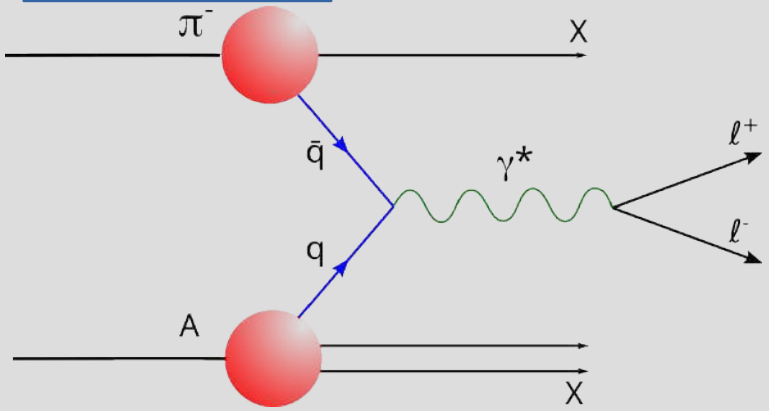
In principle, the pion PDF is easier to compute in Lattice QCD and effective models, precisely due to its simple quark-antiquark composition.

Experimental data is necessary to validate the calculations.

There are no ‘free’ pion targets… how to access them?

Probe pion structure

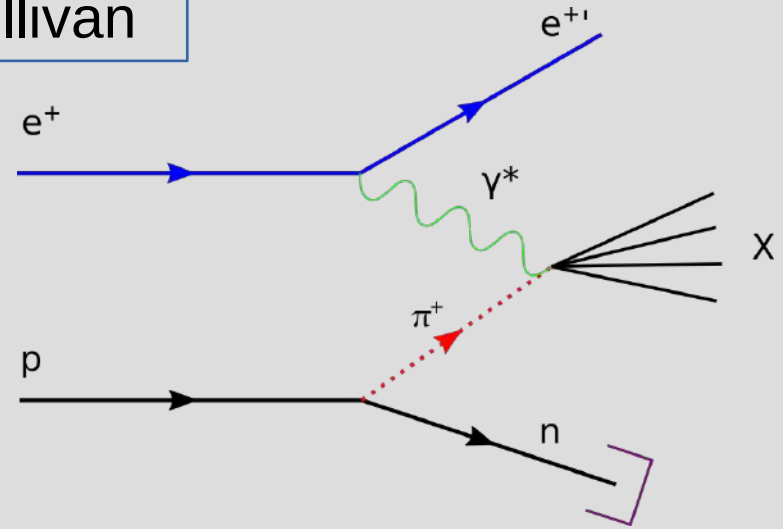
Drell-Yan



Fermilab and CERN

Medium to large x_π range

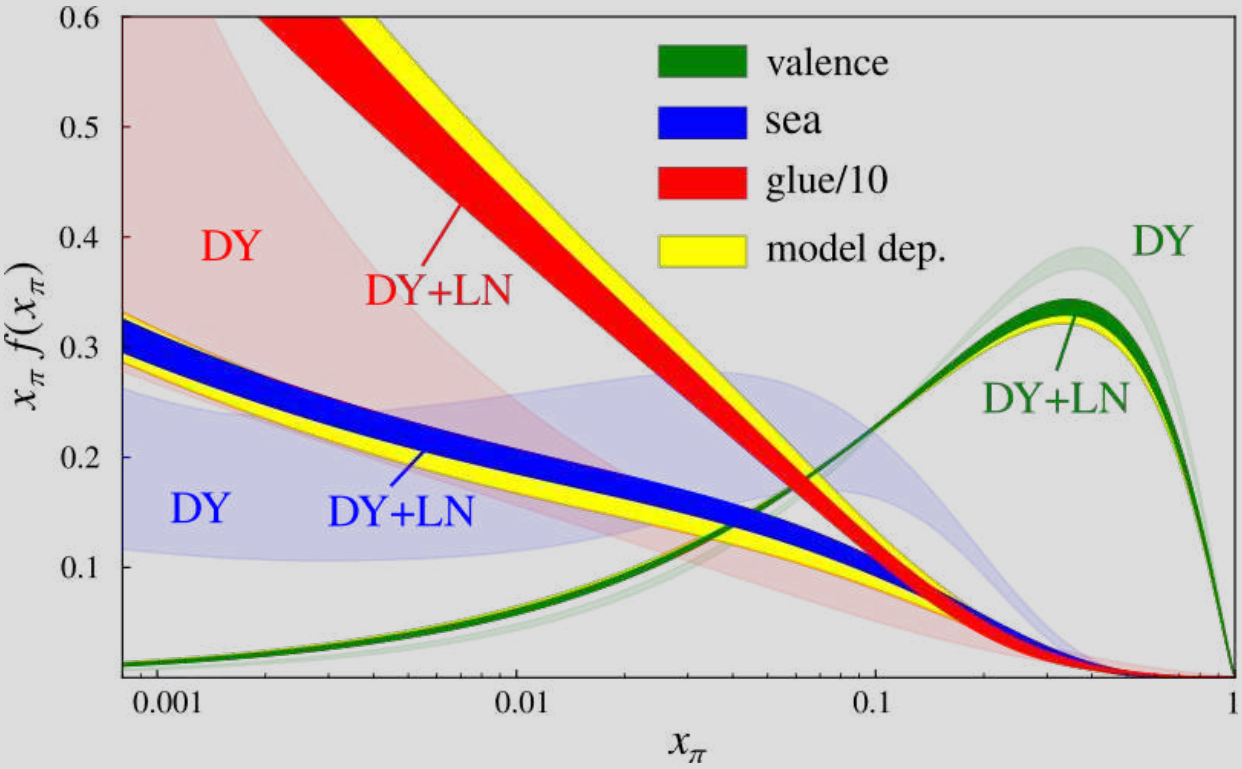
Sullivan



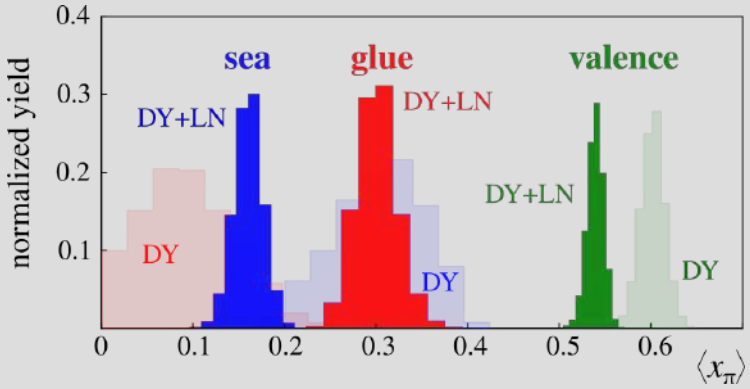
HERA (DESY)

Small x_π range

Pion PDFs in JAM



Resulting tensions between DY and LN require constrains at medium x_π



Adding the LN data to the global fit analysis, changes drastically the role of the sea and glue contribution to the pion momentum

Featured in Physics Open Access

First Monte Carlo Global QCD Analysis of Pion Parton Distributions

P. C. Barry, N. Sato, W. Melnitchouk, and Chueng-Ryong Ji (Jefferson Lab Angular Momentum (JAM) Collaboration)

Phys. Rev. Lett. **121**, 152001 – Published 10 October 2018

Physics See Synopsis: More Gluons in the Pion

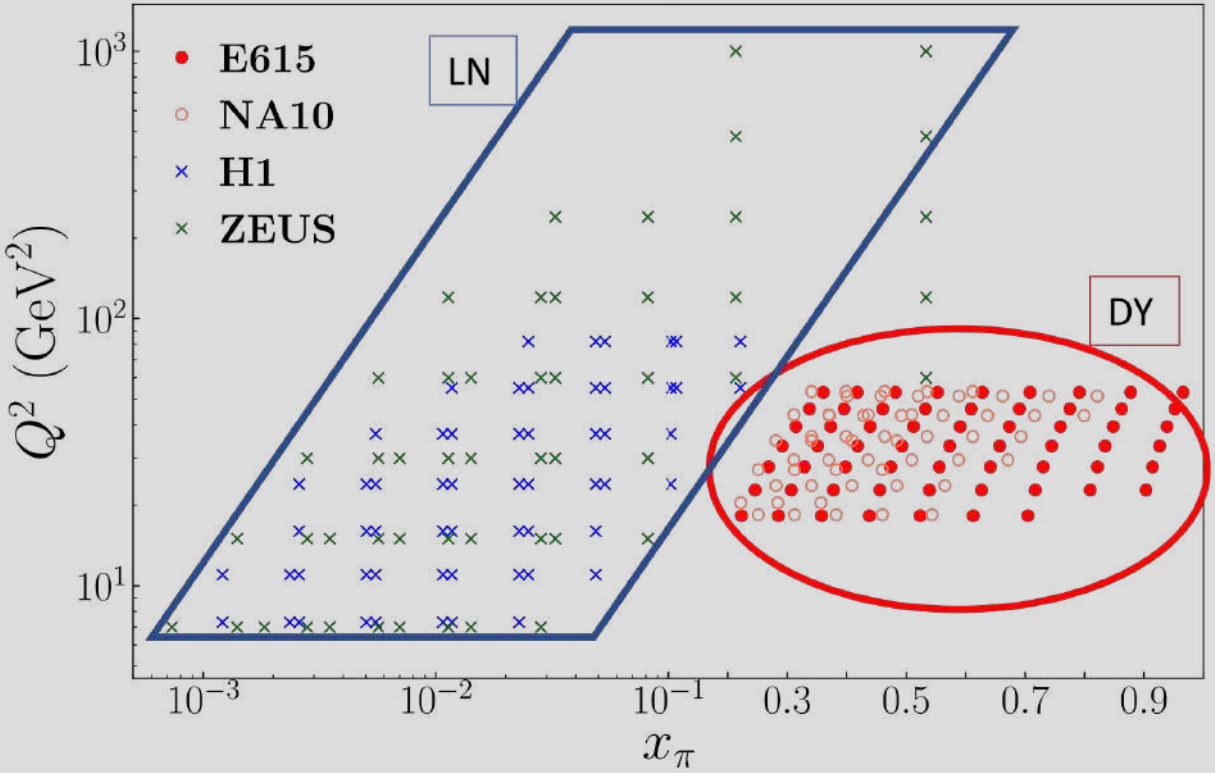
Datasets kinematics

- Large x_π – Drell-Yan (DY)
- Small x_π – Leading Neutron (LN)
- Not much data overlap
- In DY:

$$x_\pi = \frac{1}{2}\left(x_F + \sqrt{x_F^2 + 4\tau}\right)$$

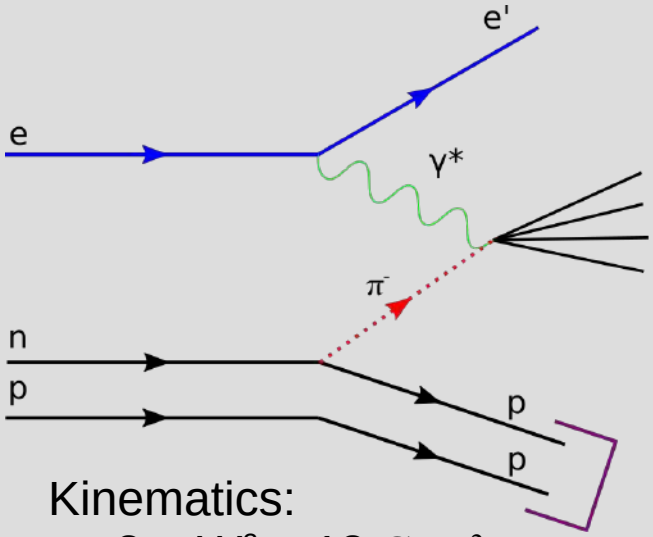
- In LN:

$$x_\pi = x_{Bj} / \bar{x}_L$$



Slide from Patrick Barry
Light Cone 2021

TDIS at Hall A



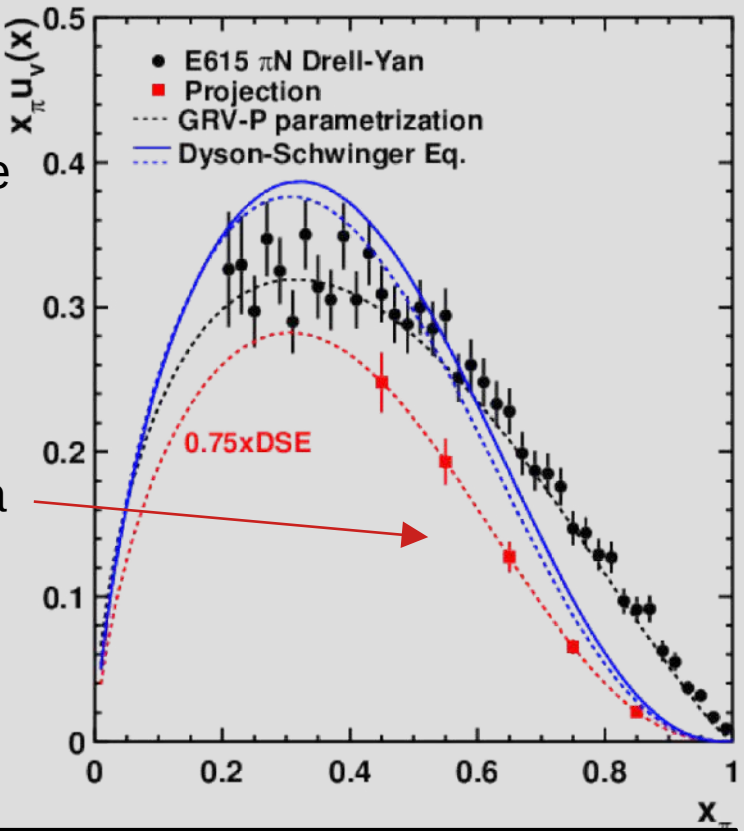
Kinematics:

$8 < W^2 < 18\ \mathrm{GeV}^2$

$1 < Q^2 < 3\ (\mathrm{GeV/c})^2$

$0.05 < x < 0.2$

- Measurement of the mesonic content of the nucleon through the Sullivan Process
- Similar to LN but with fix target
  - Larger x, overlapping DY data
  - **D2: π^-**

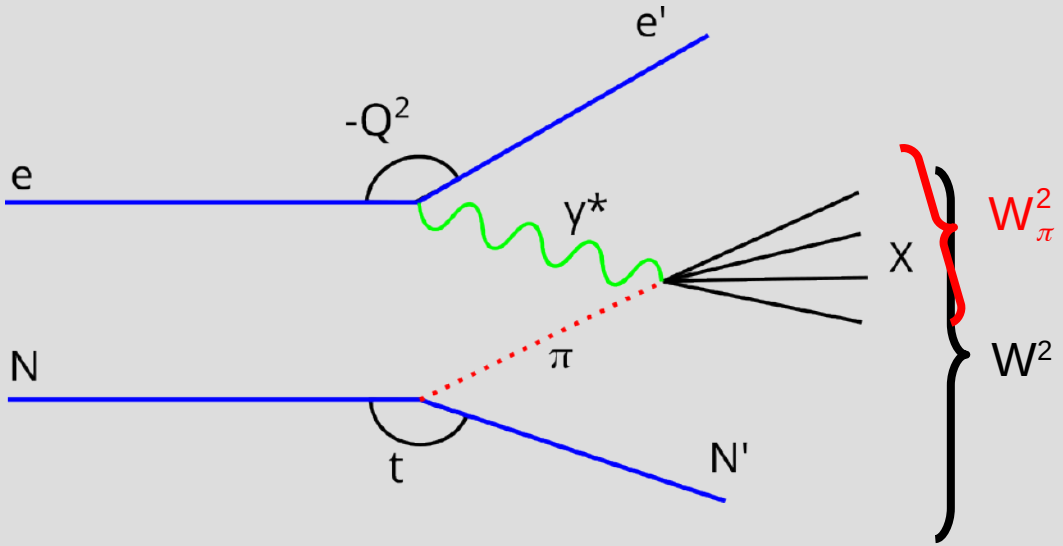


Measurement of the Tagged Deep Inelastic Scattering (TDIS) JLab PAC 43

Larger project:
- TDIS-K (Kaon SF)
- TDIS-n (neutron SF)

Extended description: Hall A collaboration meeting. 27 Jan 2023 - 13:30h

Adding more constrains

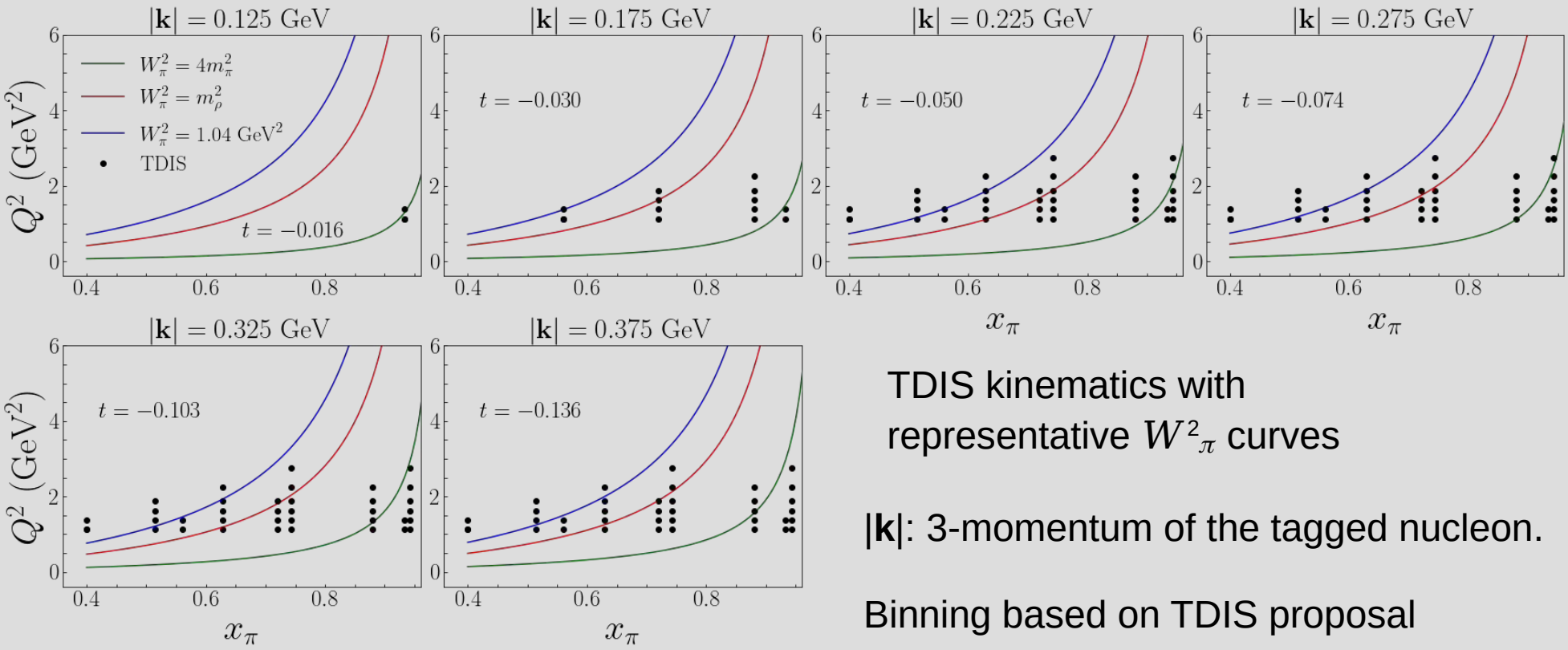


$$W_{\pi}^{2} = t - Q^{2}\left(1 - \frac{\bar{x}_L}{x}\right)$$

$$\bar{x}_L = 1 - z$$

- Adding a new constrain in the kinematics opens the possibility to study π resonances
- HERA did not measure the low-$W^2{}_{\pi}$ region, so the strength of various resonances in this process in unknown
- Kinematic coverage in TDIS will be a great use to measure this resonance region

11 GeV TDIS Kinematics



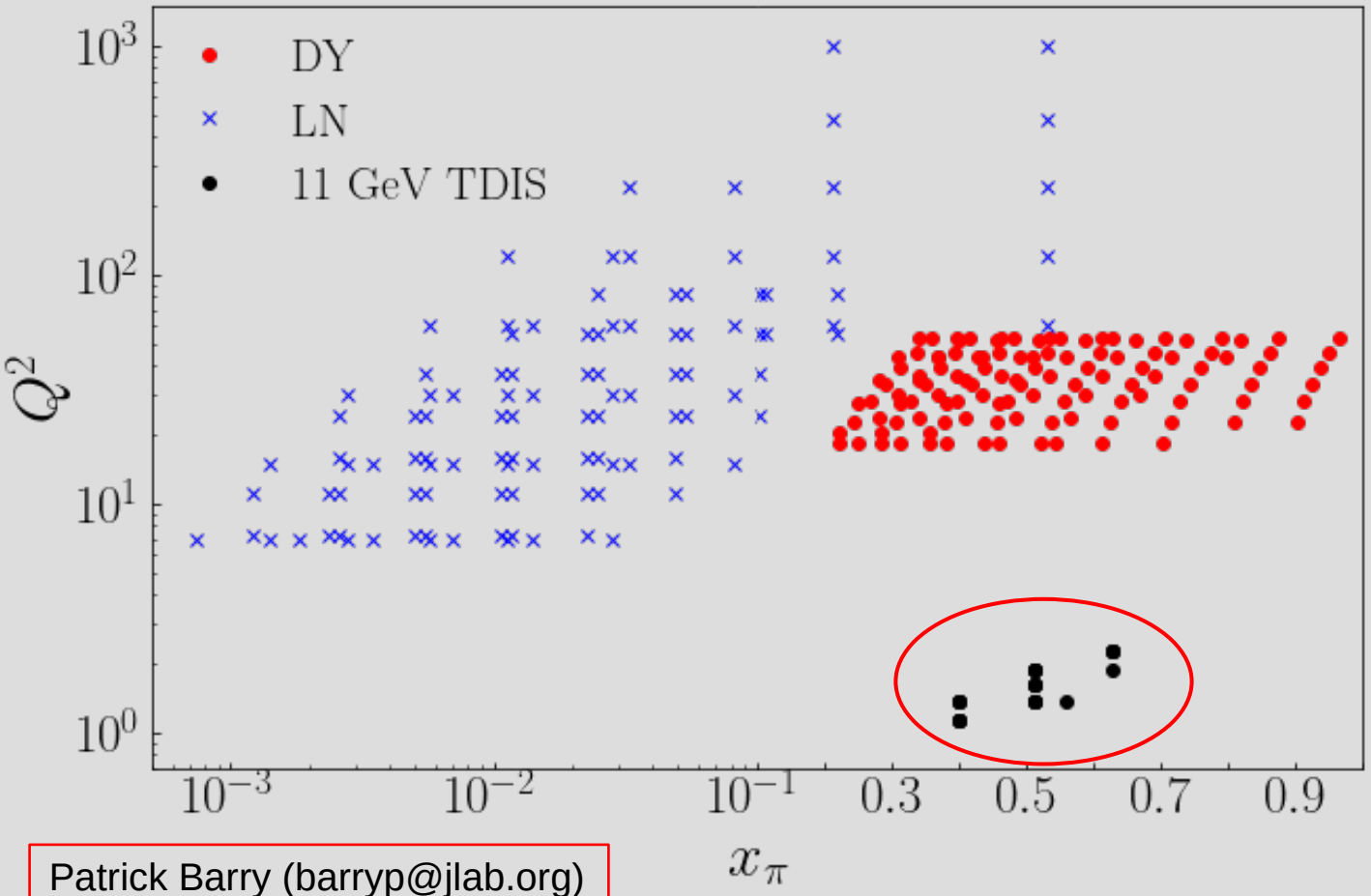
TDIS kinematics with representative W^2_π curves

|k|: 3-momentum of the tagged nucleon.

Binning based on TDIS proposal

Patrick Barry (barryp@jlab.org)

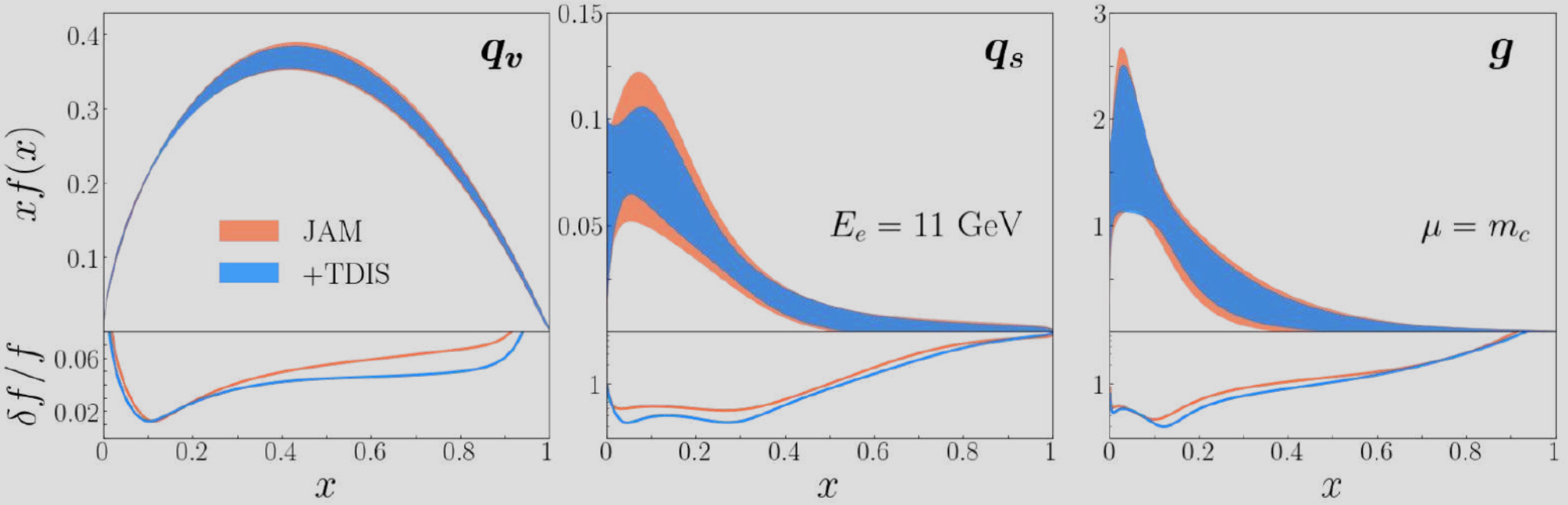
Total pion kinematics



Choosing $W^2_{\pi,\max}$ = 1.04 GeV²
left just 26 data points

Patrick Barry (barryp@jlab.org)

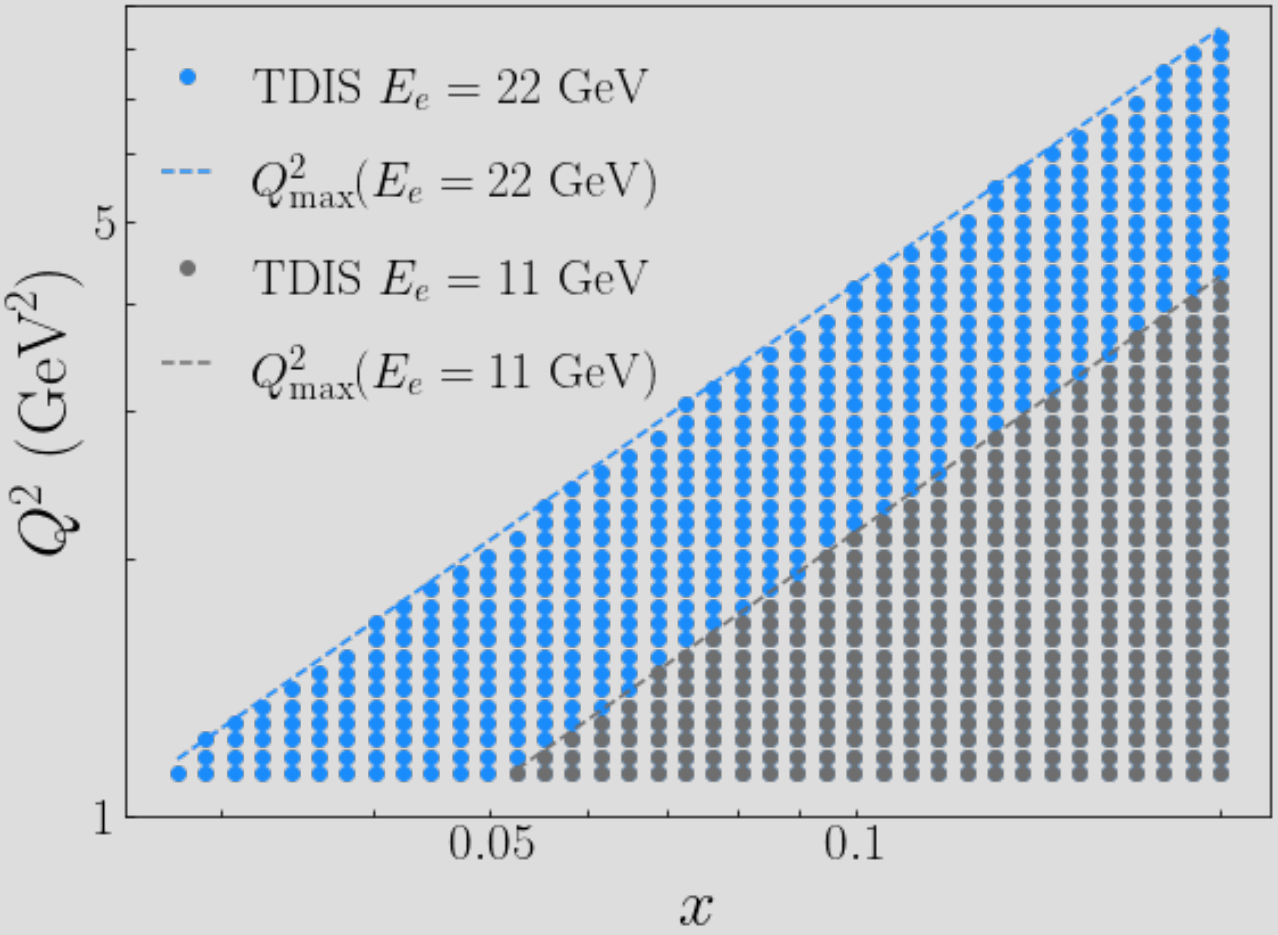
JAM global analysis impact



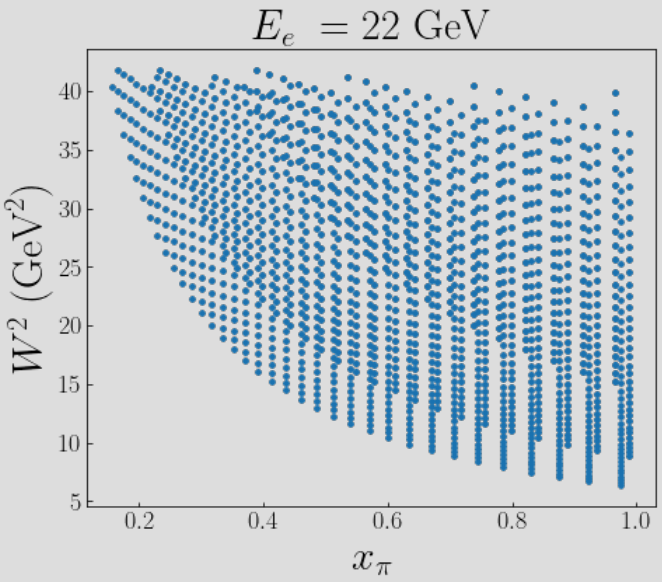
From these points, JAM has created pseudodata and performed global analysis with existing experimental data.

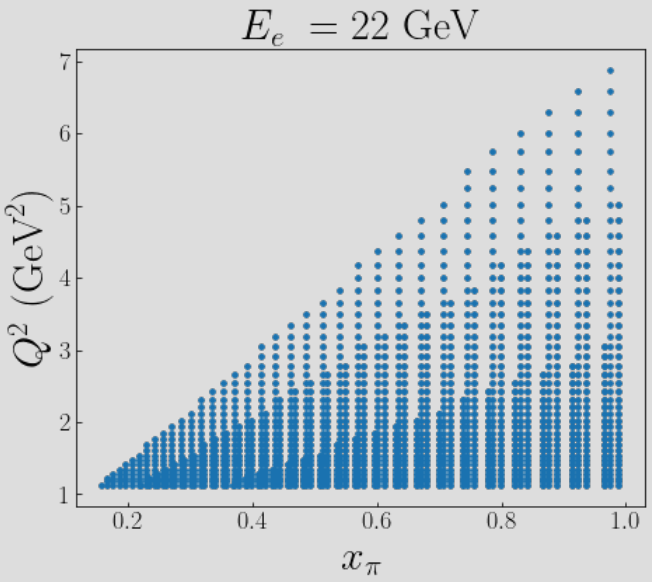
Patrick Barry (barryp@jlab.org)

TDIS @ 22 GeV


TDIS $E_e = 22$ GeV
$Q^2_{\max}(E_e = 22$ GeV$)$
TDIS $E_e = 11$ GeV
$Q^2_{\max}(E_e = 11$ GeV$)$
Q^2 (GeV^2)
5
1
0.05
0.1
x

Phase space @ 22 GeV

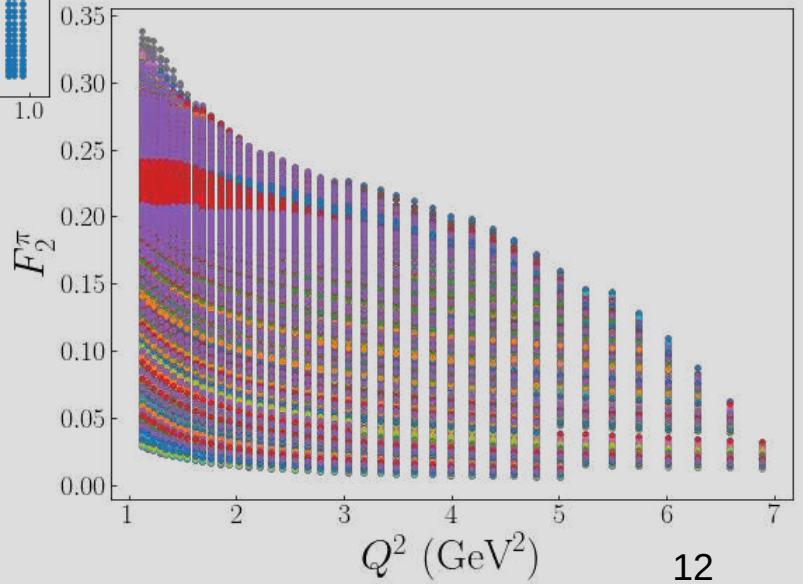




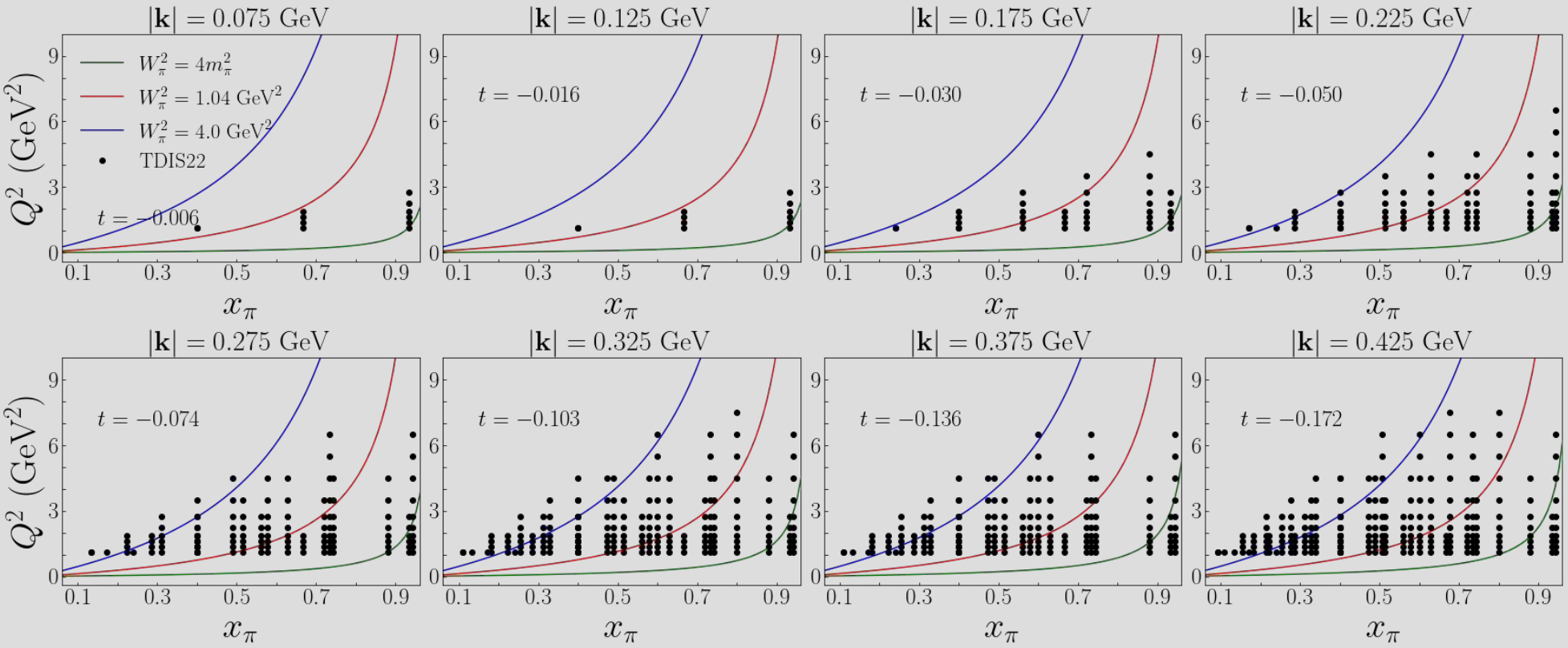
F^2_π projections based on Hobbs et al. and JAM PDFs

Phase space based on Patrick Barry's code

Different colors represent different values of x_π



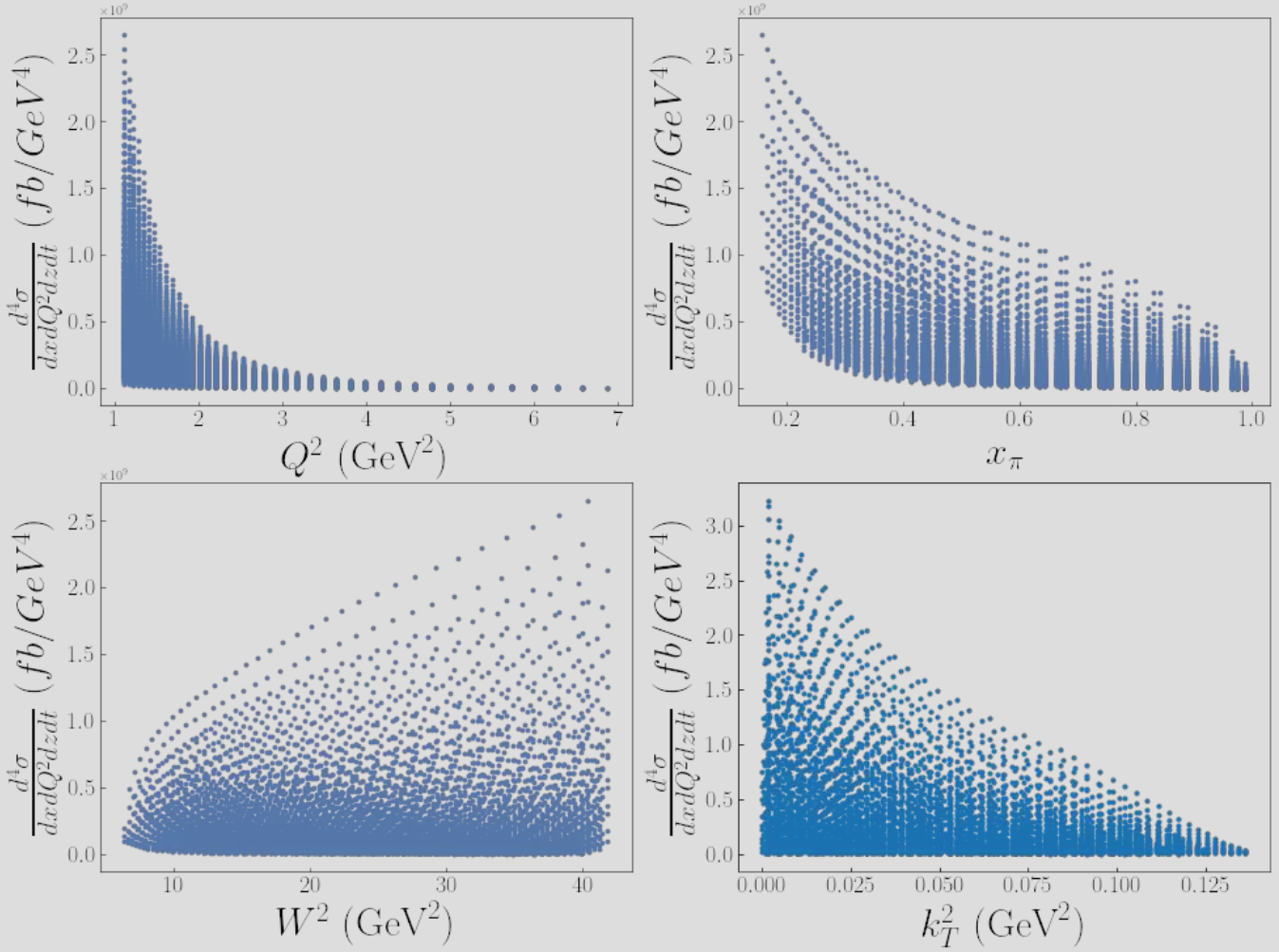
22 GeV TDIS Kinematics



Dipangkar Dutta
(ddutta@jlab.org)

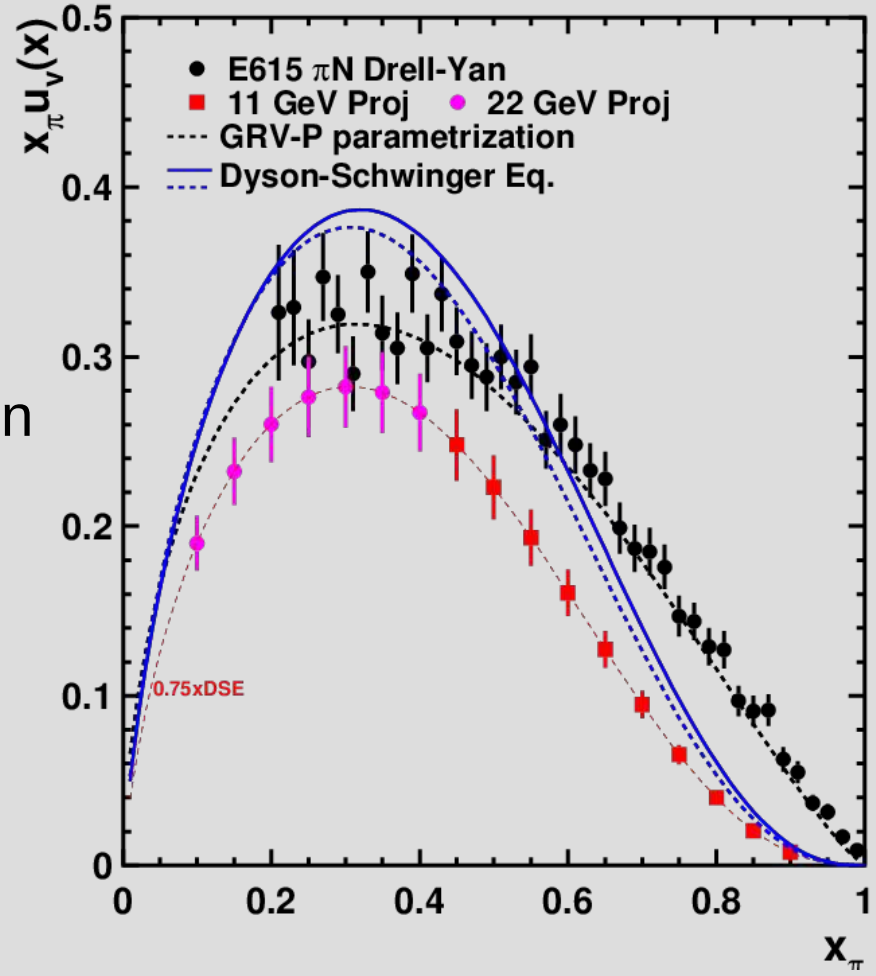
Massive increase of available data points $W^2{}_\pi > 1.04\text{GeV}^2$

TDIS cross section @ 22 GeV



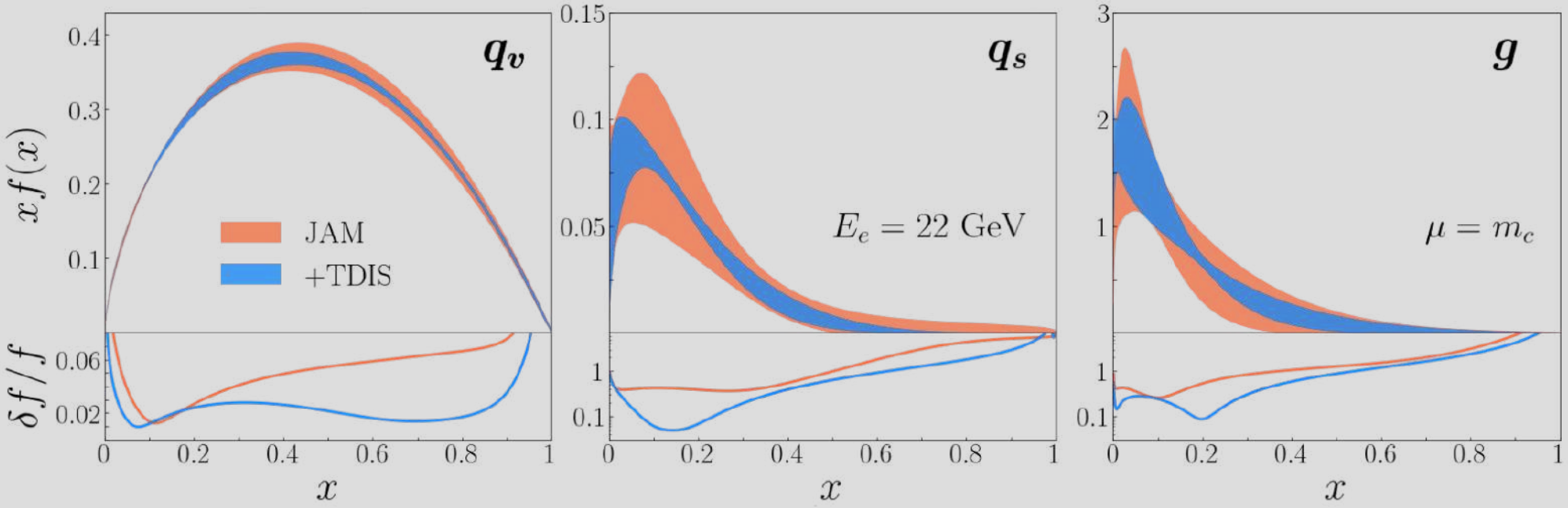
Pion SF projections @ 22GeV

Projections based on 50 days of beam time (TDIS12 will be 10 days on H2 and 10 days on D2)



Courtesy Dipangkar Dutta (ddutta@jlab.org)

JAM global analysis impact



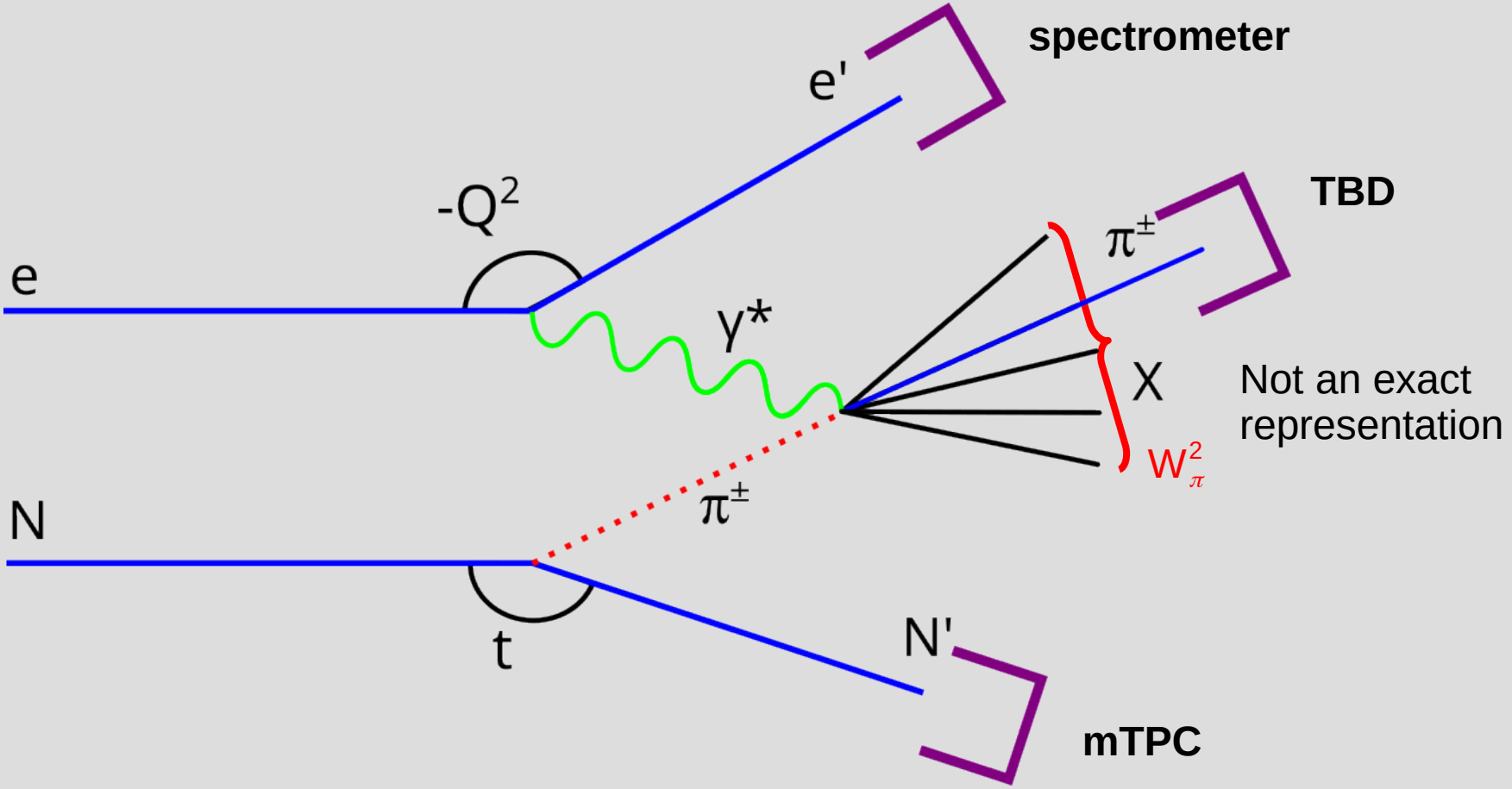
Similarly to the 11 GeV case, JAM estimated the impact of the 22 GeV pseudo-data from the kinematic points*

Strong improvement of the knowledge of the pion PDFs

*not the data presented in this talk, but same approach

Patrick Barry (barryp@jlab.org)

SIDIS from a pion target @ 22GeV



SIDIS @22 GeV (work in progress)

Considering W^2_π:[1.04, 4.0] GeV^2, which is the DIS debris energy available in the reaction.

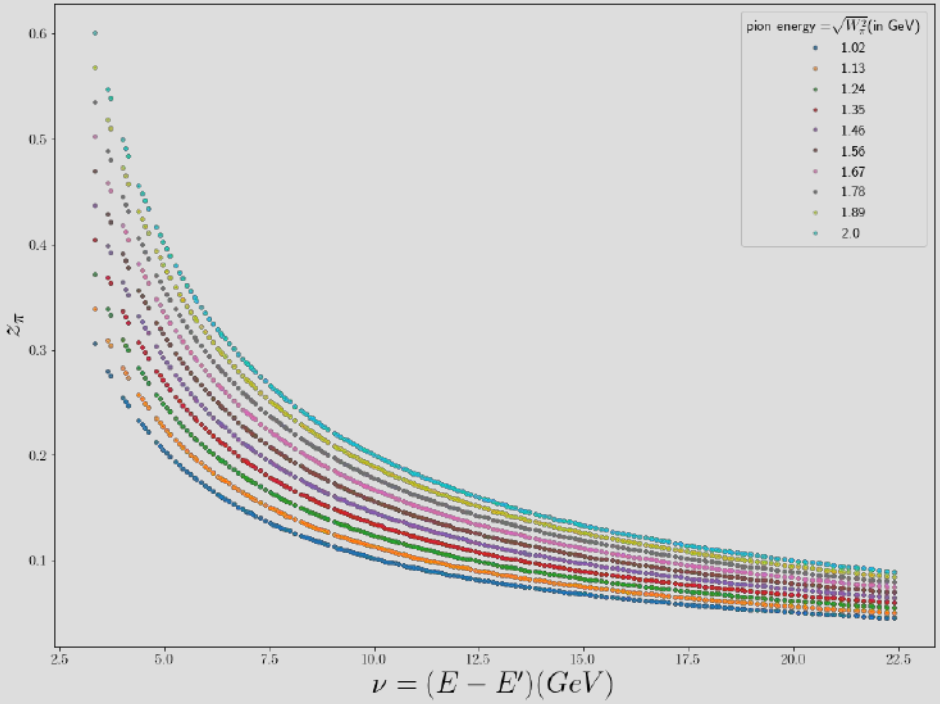
If all of this energy goes to produce a pion (the SIDIS one), we can estimate the momentum of the SIDIS pion in the range:

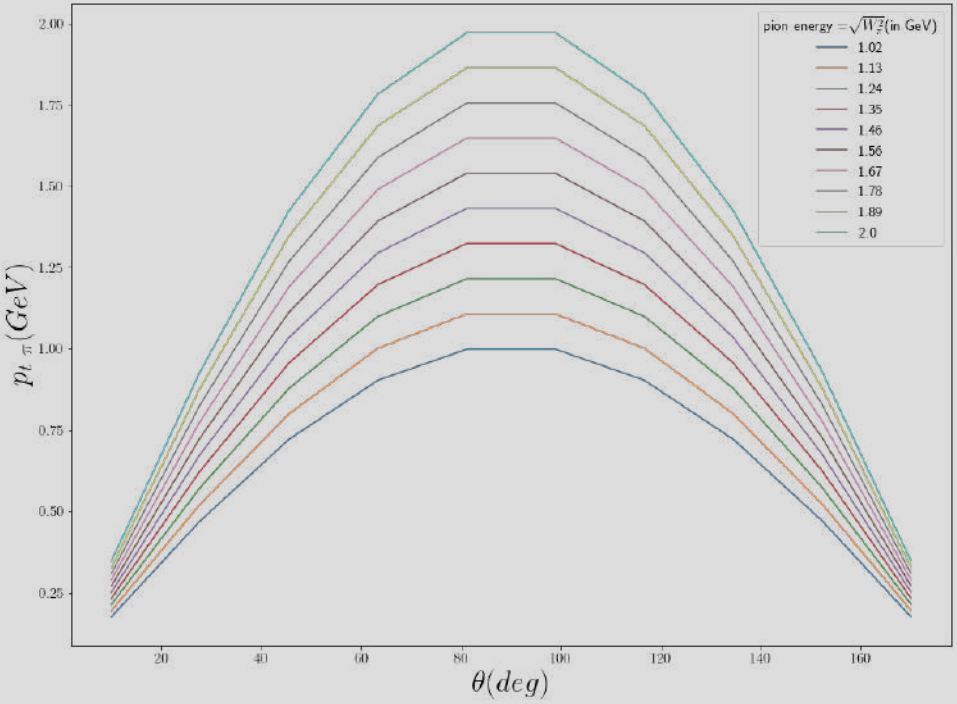
$$1.04\,GeV^2 < \left(m_\pi^2 + p_\pi^2\right) < 4\,GeV^2 \Rightarrow$$

$$1\,GeV < |p_\pi| < 2\,GeV$$

Some assumptions from TDIS22 could be realized upon a more detailed analysis from our colleagues of the Theory Center (IN PROGRESS)

SIDIS @ 22 GeV estimations

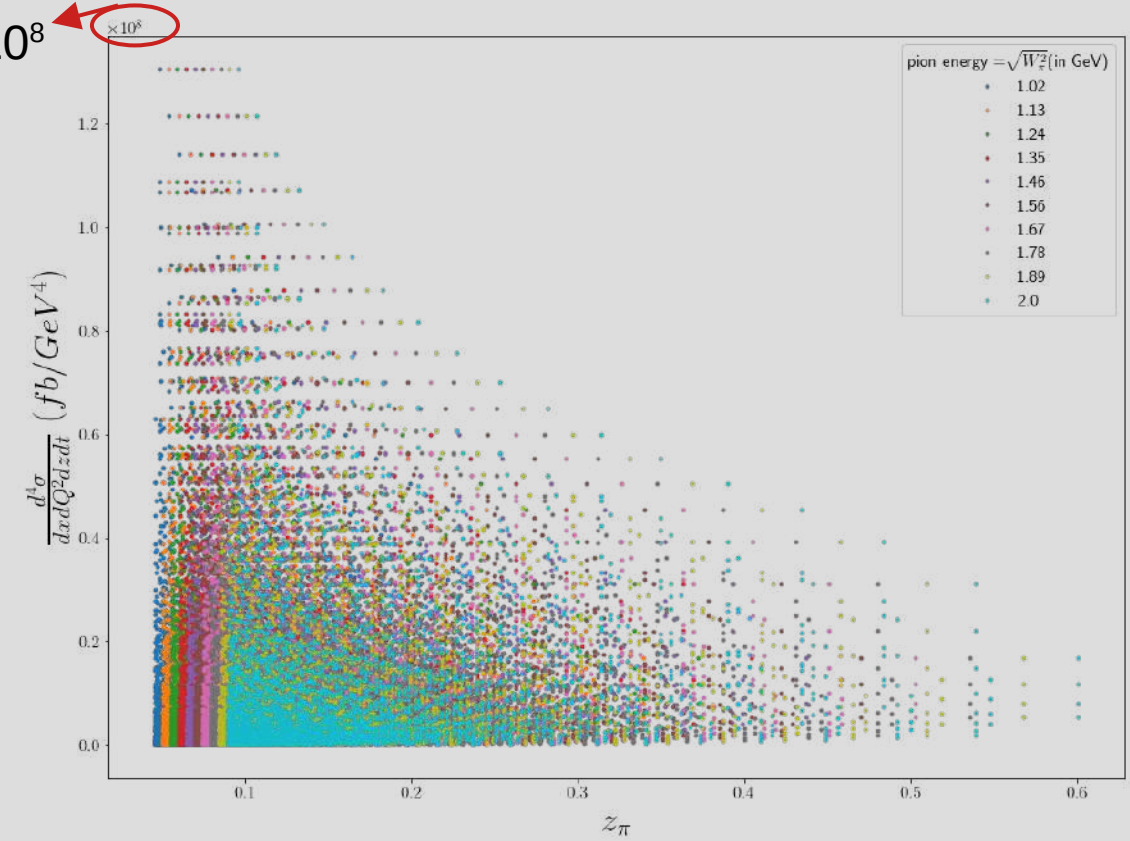




$P_{t\,\pi}$ ranges from: 0.25 (@20deg) to ~2 GeV (@90deg)

SIDIS @ 22 GeV estimations

x10^8



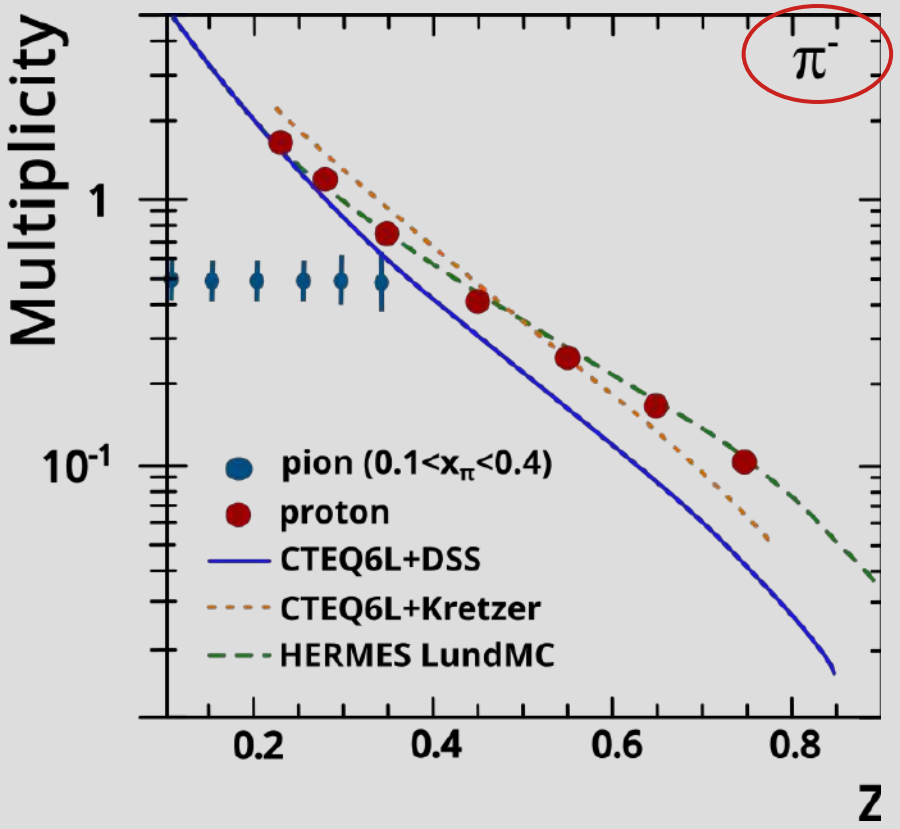
"(...)the average Q^2 at 22 GeV goes up by a factor of 2-3 so that the rates go down by a factor of ~10. We need to detect an additional pion assuming an acceptance and efficiency factor of 0.4 (same as for the protons), this brings the rates down to about 4% of the TDIS @ 11 GeV. The Hermes and Compass average multiplicities at around z=0.3 and in the x range covered by TDIS @ 22 GeV is ~1, this means that if the SIDIS on pion rates are similar to SIDIS on proton we should get rates that are about 4% of TDIS @11 GeV rates."

Dipangkar Dutta, Internal communication

TDIS 22 cross section scaled x0.04 vs z_{SIDIS} as a function of the SIDIS pion energy

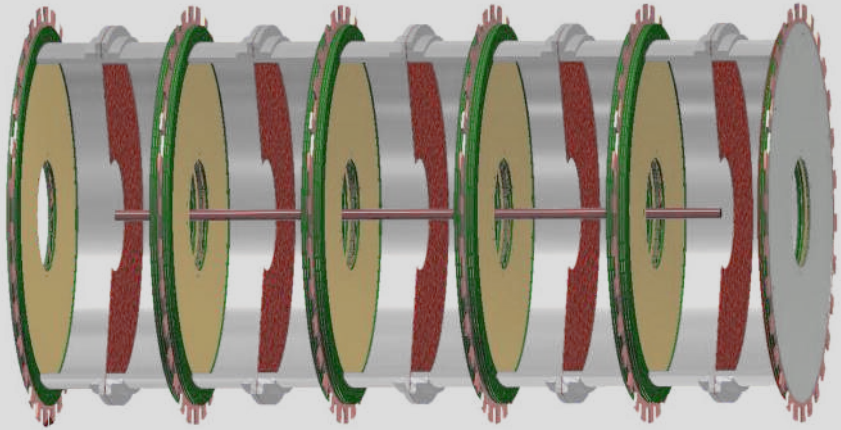
SIDIS @22 GeV (work in progress)

Projections based on 50 days of beam time



Courtesy Dipangkar Dutta
(ddutta@jlab.org)

SIDIS @22 GeV - Detection

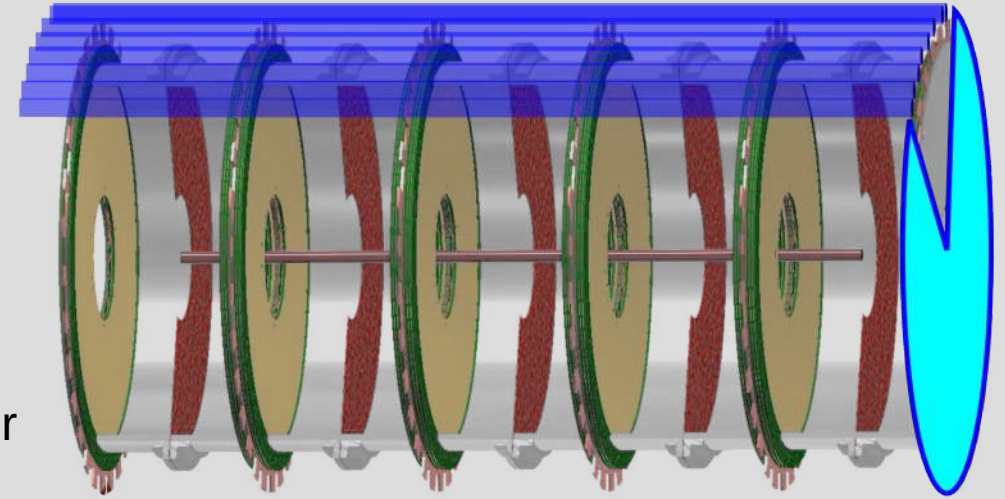


mTPC design for TDIS 11 → TDIS 22

The HERMES recoil detector (or similar)

Pure speculative work!!

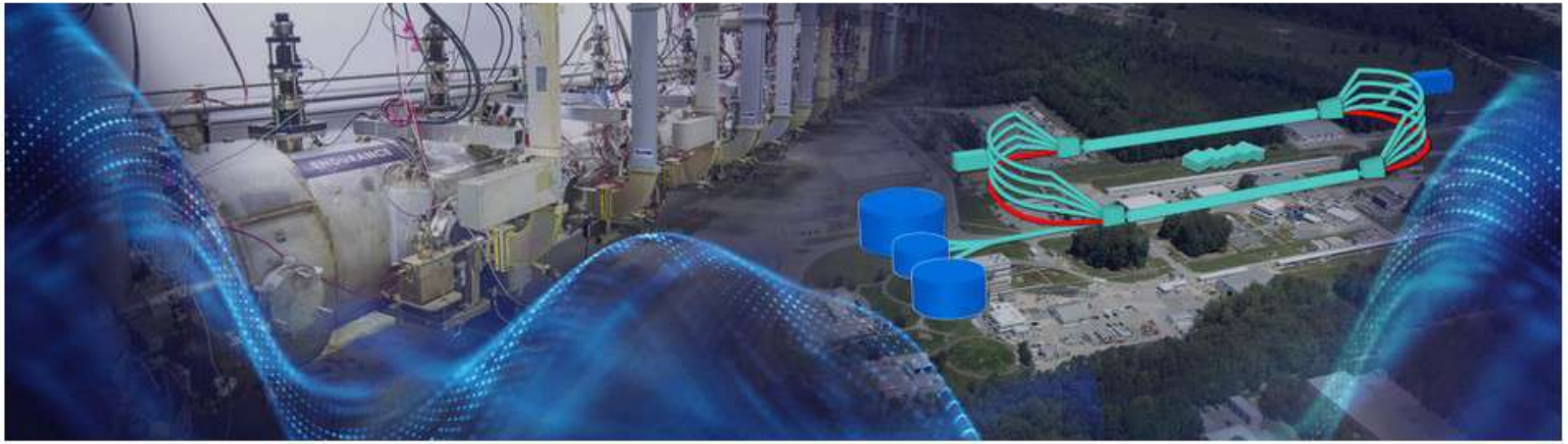
mTPC+ idea for SIDIS 22



Conclusions and Outlook

- TDIS @11GeV will test the impact on pion PDFs at large x_π, where it overlap DY data.
- TDIS @22GeV offer a great scenario to improve the partonic knowledge of mesons
  - A kinematic cut on W^2_π introduces constraints on pions resonances.
  - Our projections, based on JAM libraries, reach lower x_π ranges, complementing TDIS @11GeV projections.
  - Pseudo-data analysis shows a huge impact in the PDF knowledge, in particular in the valence and sea quark regions.
- SIDIS from pion target @22GeV is an open case based on extrapolations from TDIS@22GeV analysis and data from HERMES and COMPASS
  - In principle similar set-up as TDIS@22GeV, but requires extra instrumentation for an efficient pion detection.
  - Work in progress with the collaboration of the theory center.
- The nature of this kind of experiments would benefit the use of AI/ML techniques for data reduction and pattern recognition.

SCIENCE AT THE LUMINOSITY FRONTIER: JEFFERSON LAB AT 22 GEV



Conference Date

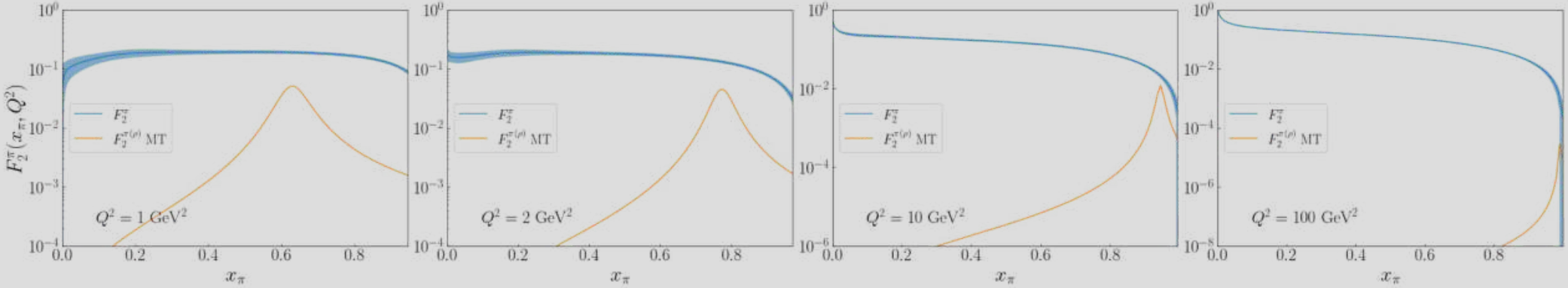
January 23, 2023 to January 25, 2023

Conference Location

CEBAF Center Auditorium. In-person attendance is strongly encouraged, but a Zoom link will be provided.

BACKUP SLIDES

Comparison with F^2_π from JAM

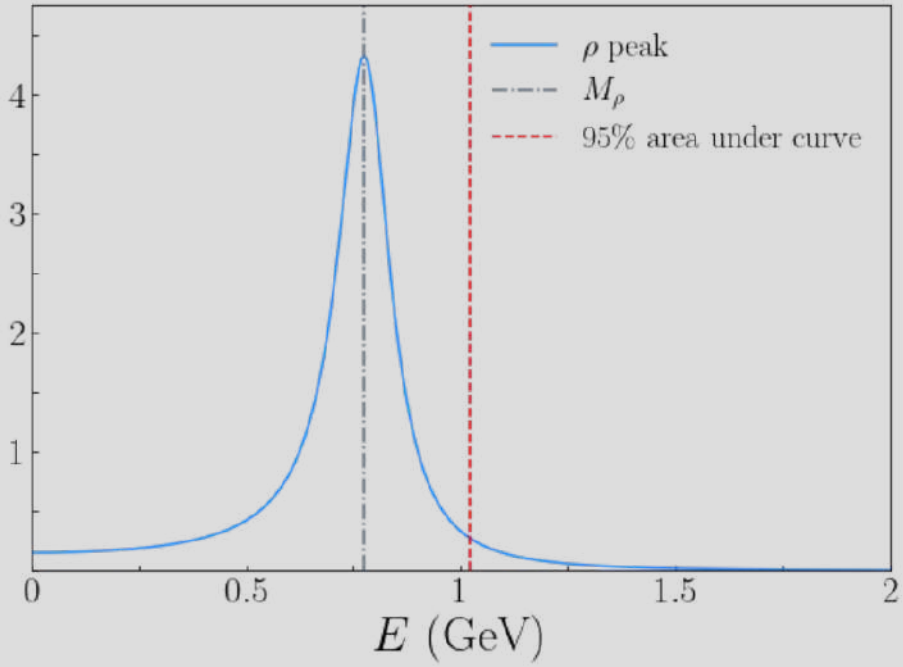


- Use our JAM pion PDFs extracted from data comparing with the model-dependent $F_2^{\pi(\rho)}$
- At low-Q^2 and intermediate-to-large x_π, the peak is about 2 times smaller than the partonic version
- May see some influence in the data – bumps as a function of x_π or W_π

Slide courtesy Patrick Barry
(barryp@jlab.org)
TDIS biweekly meeting

What to choose for W_π^2

- HERA did not measure the low-W_π^2 region
- Potentially largest resonance comes from the ρ-meson
- Must be well above the peak of the resonance
- Estimating the safe region to be an energy above 95% of the area under the curve



Patrick Barry (barryp@jlab.org)