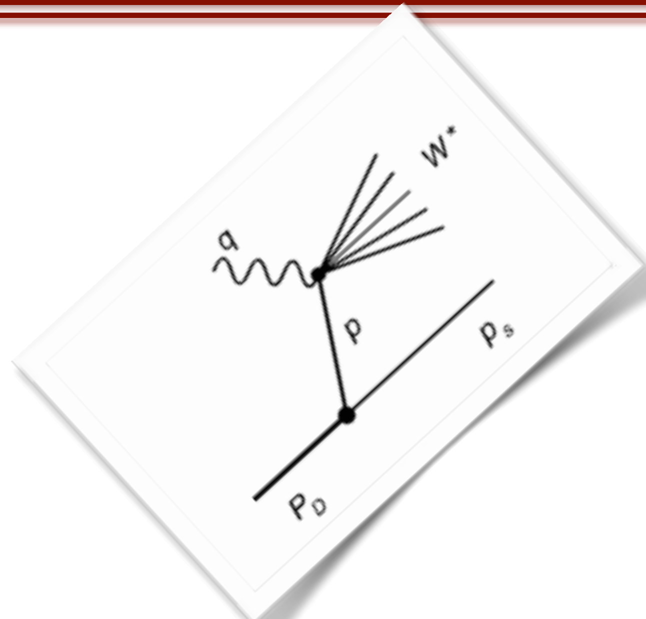
Tagged Deep Inelastic Scattering:
Exploring the Meson Cloud of the Nucleon

Dipangkar Dutta
Mississippi State University

Next generation nuclear physics with JLab12 and EIC
FIU, Feb 10-13, 2016

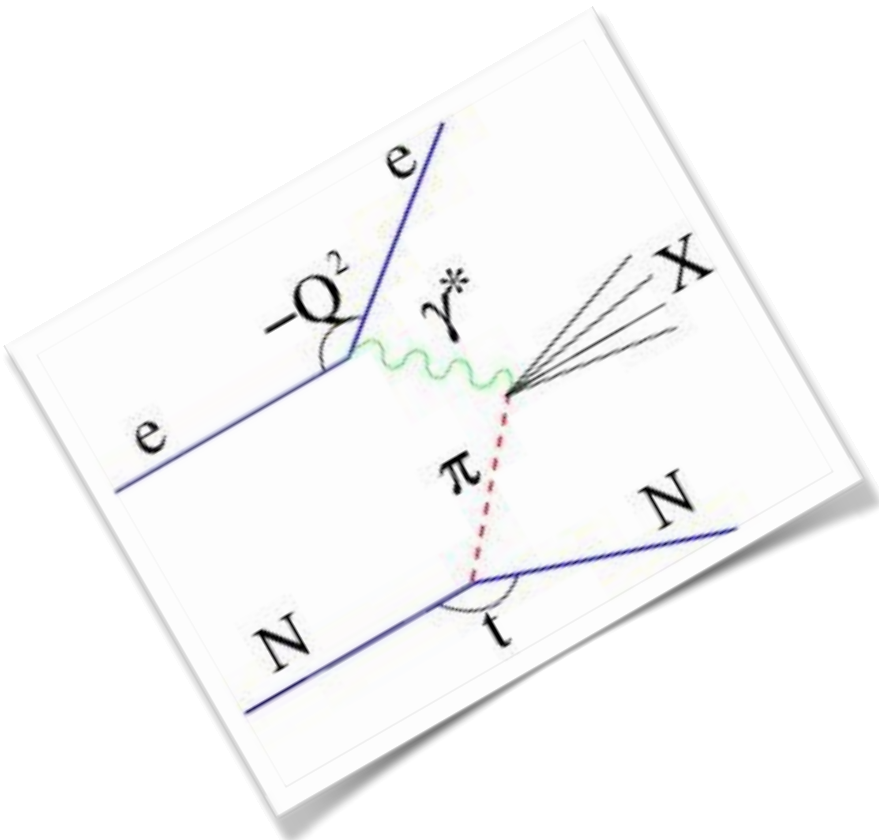
Outline

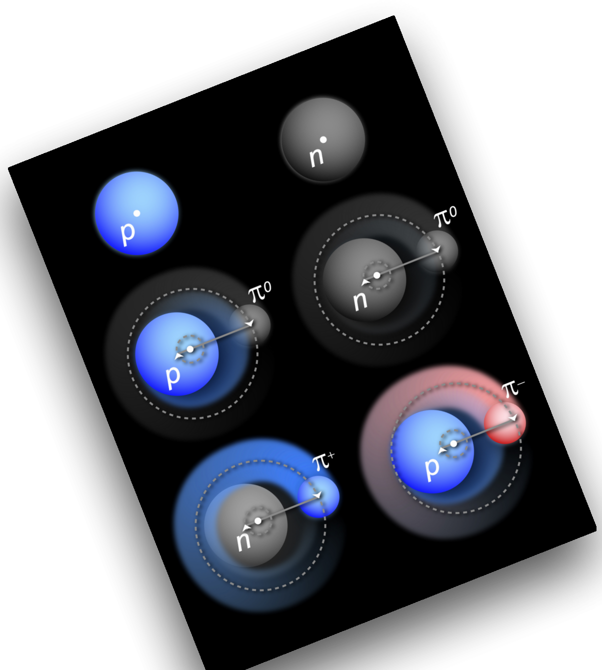
1. Introduction
   - Mesonic content of nucleons
2. Tagged structure functions
   - Sullivan process and access to meson cloud of nucleon
   - New experiment at JLab12



3. Tagged DIS at an EIC

3. Summary





There is ample evidence that nucleons have *some* mesonic content in them.

PHYSICAL REVIEW VOLUME 72, NUMBER 12 DECEMBER 15, 1947

On the Interaction Between Neutrons and Electrons*

E. FERMI AND L. MARSHALL

Argonne National Laboratory and ~~Institute for Nuclear Studies~~, University of Chicago, Chicago, Illinois

(Received September 2, 1947)

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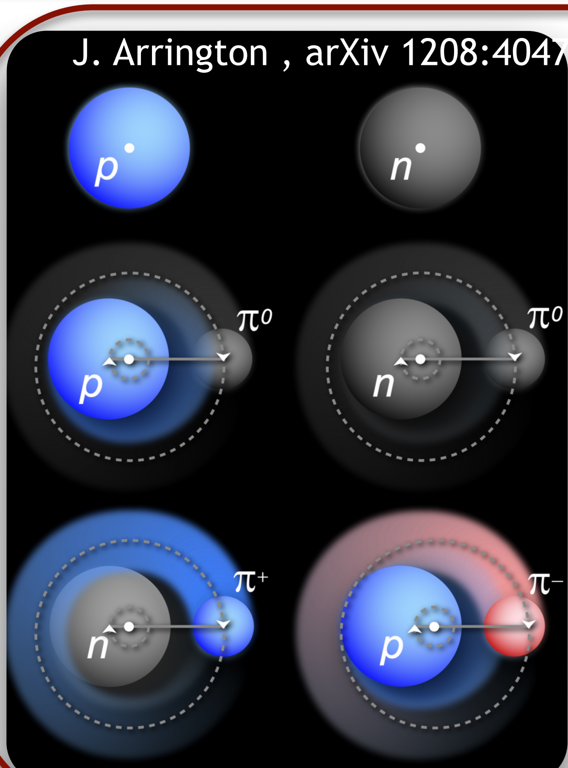

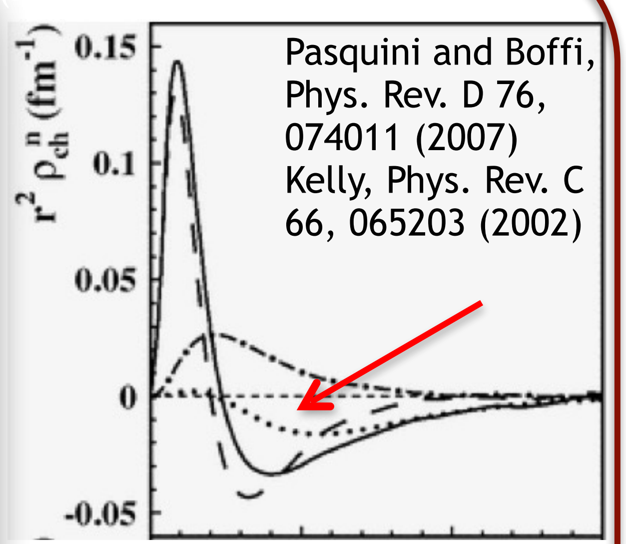

Proton & Neutron Charge Distribution

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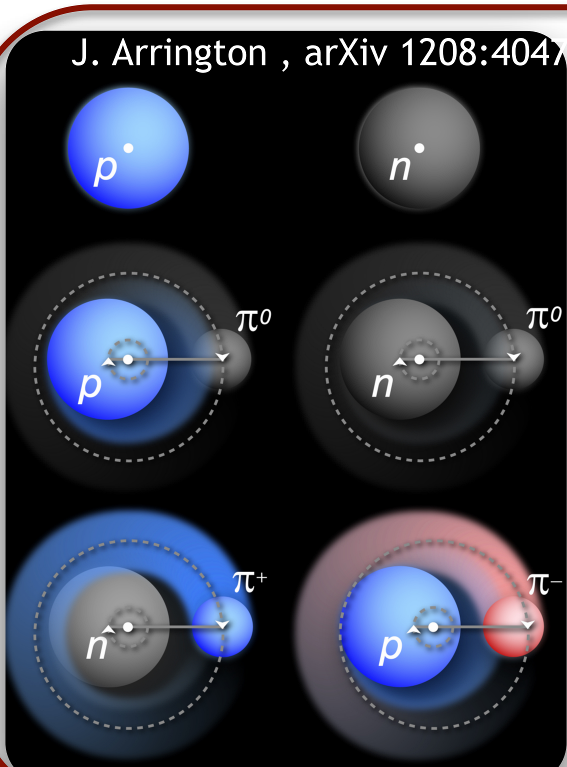

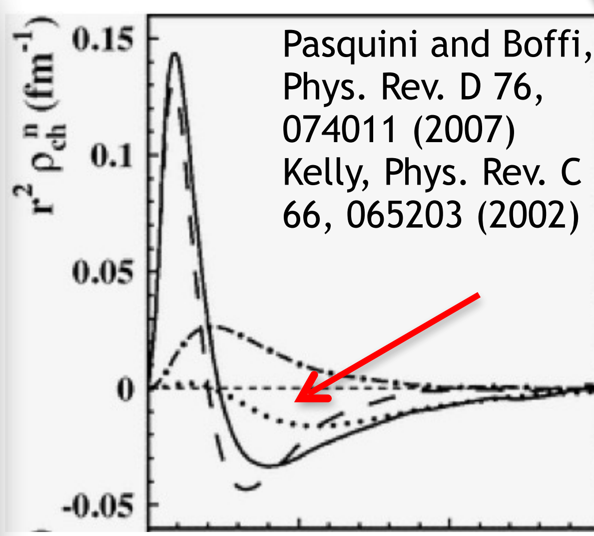

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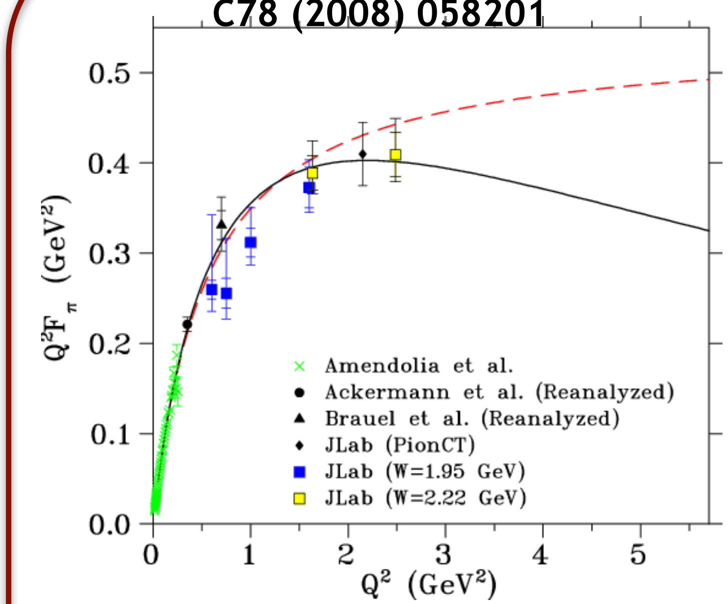
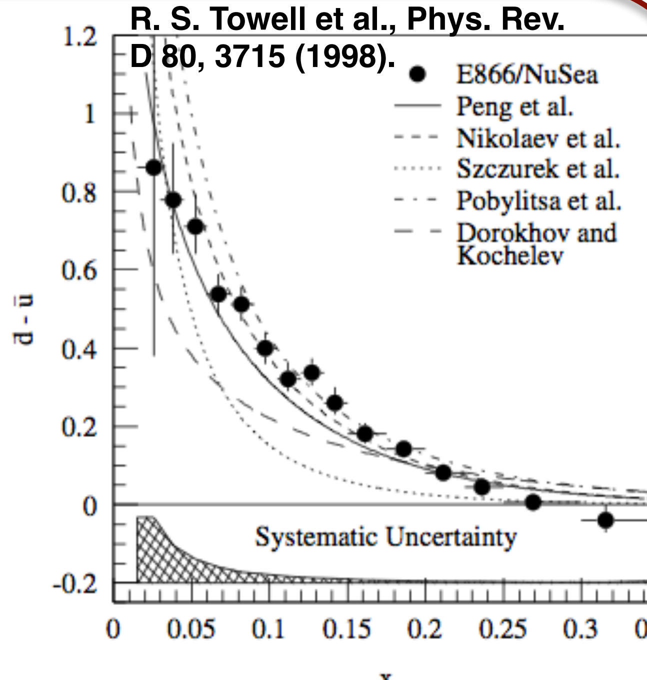
Horn et al., Phys.Rev. C78 (2008) 058201



Pion Form Factor

R. S. Towell et al., Phys. Rev. D 80, 3715 (1998).



up/down sea-antiquark flavor asymmetry

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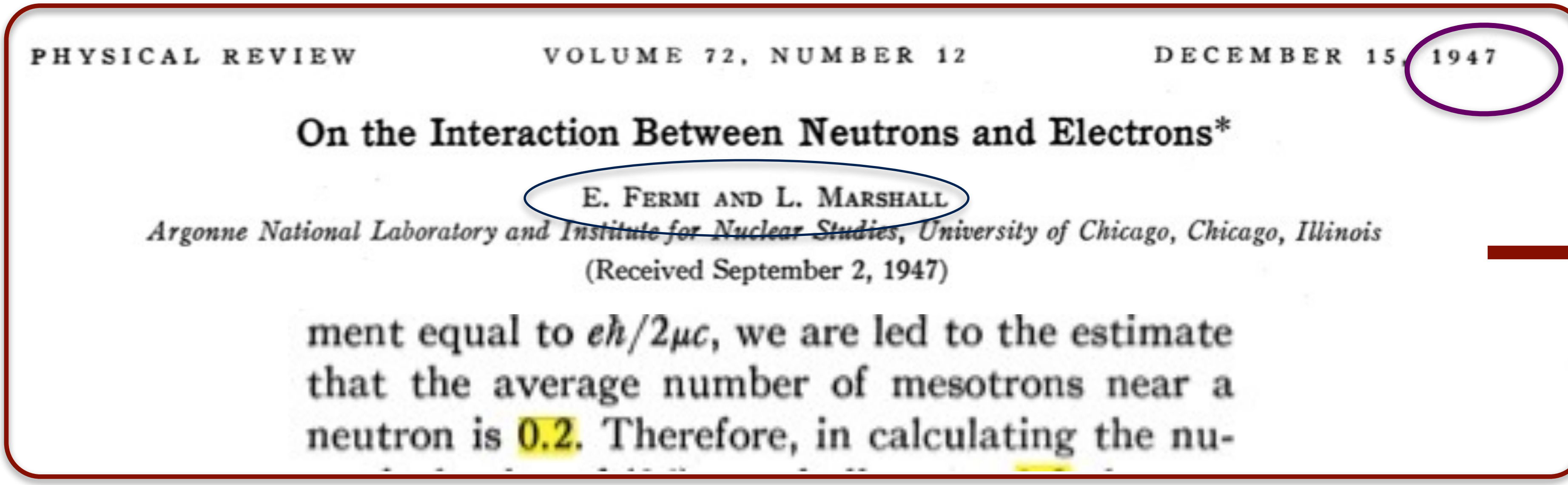
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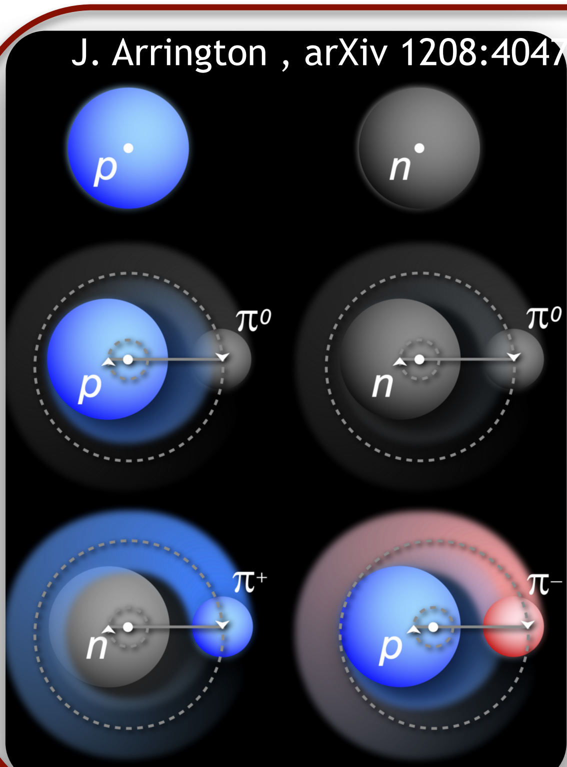

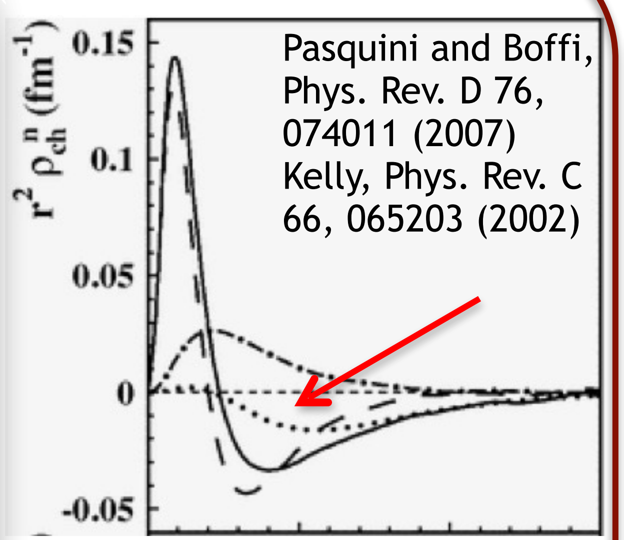

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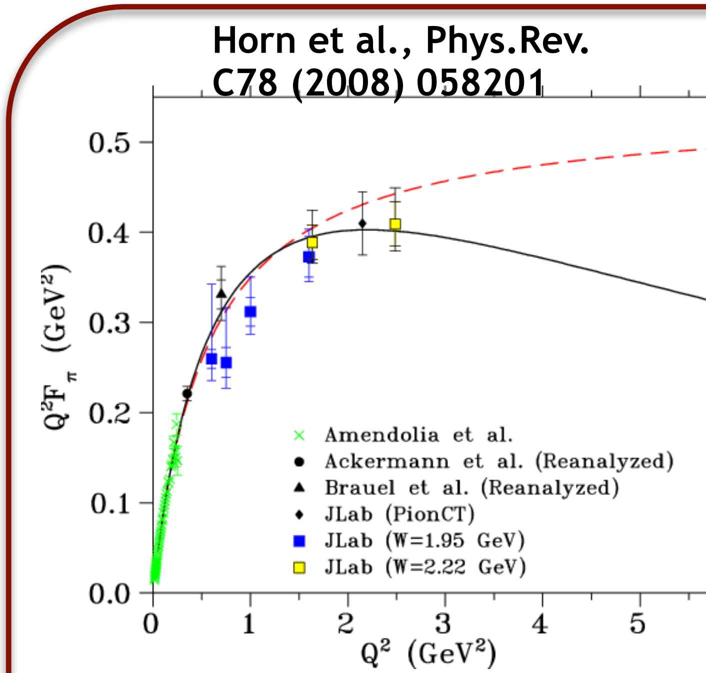

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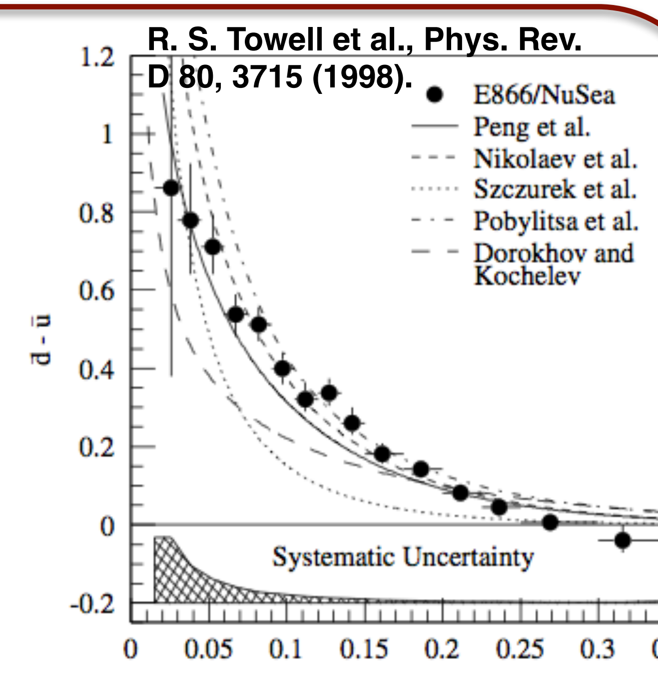
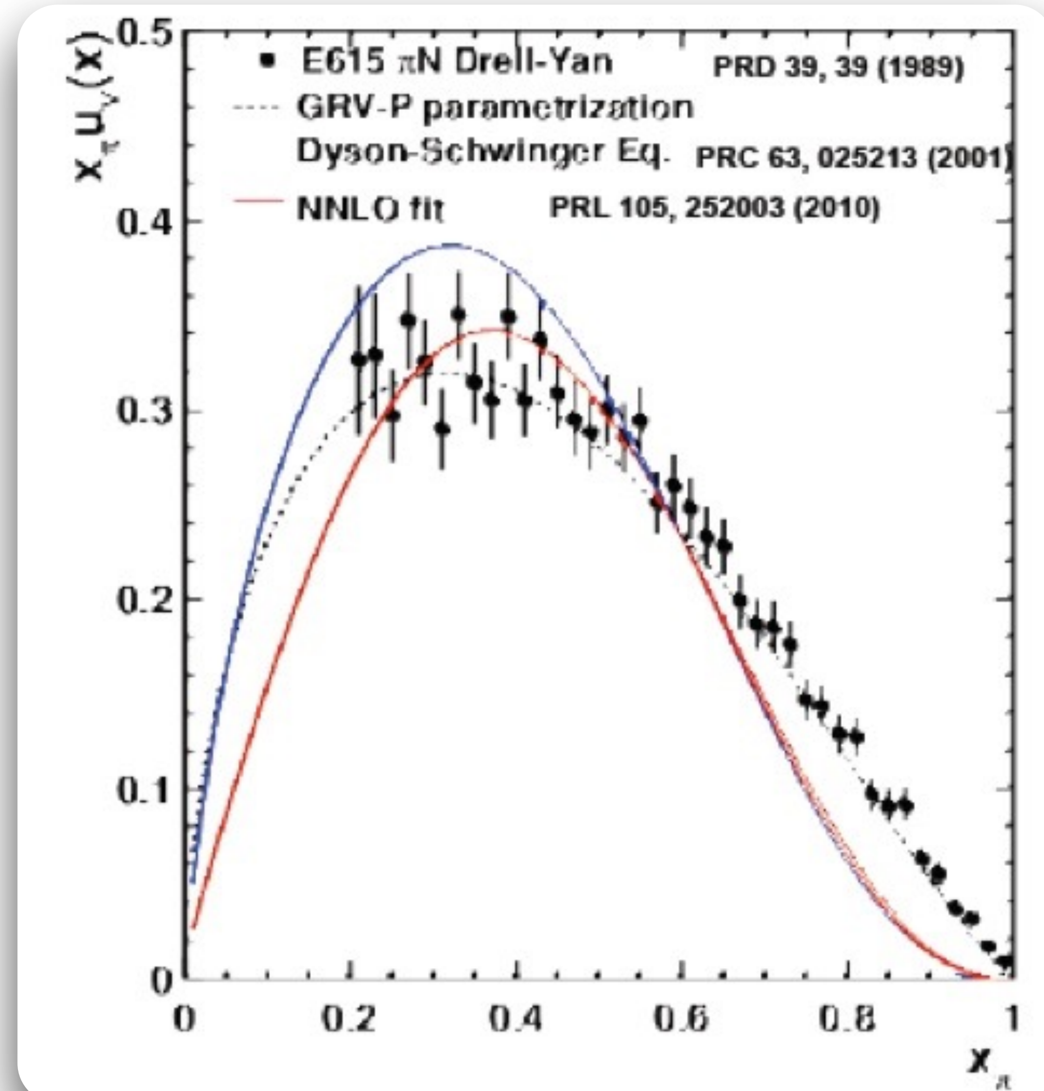


up/down sea-antiquark flavor asymmetry

Substantial theoretical developments, but…

There is no direct measurement of magnitude of mesonic content of nucleons.



In the valance region data comes from pionic Drell-Yan experiments

Pion structure function extracted from data disagree with calculations.

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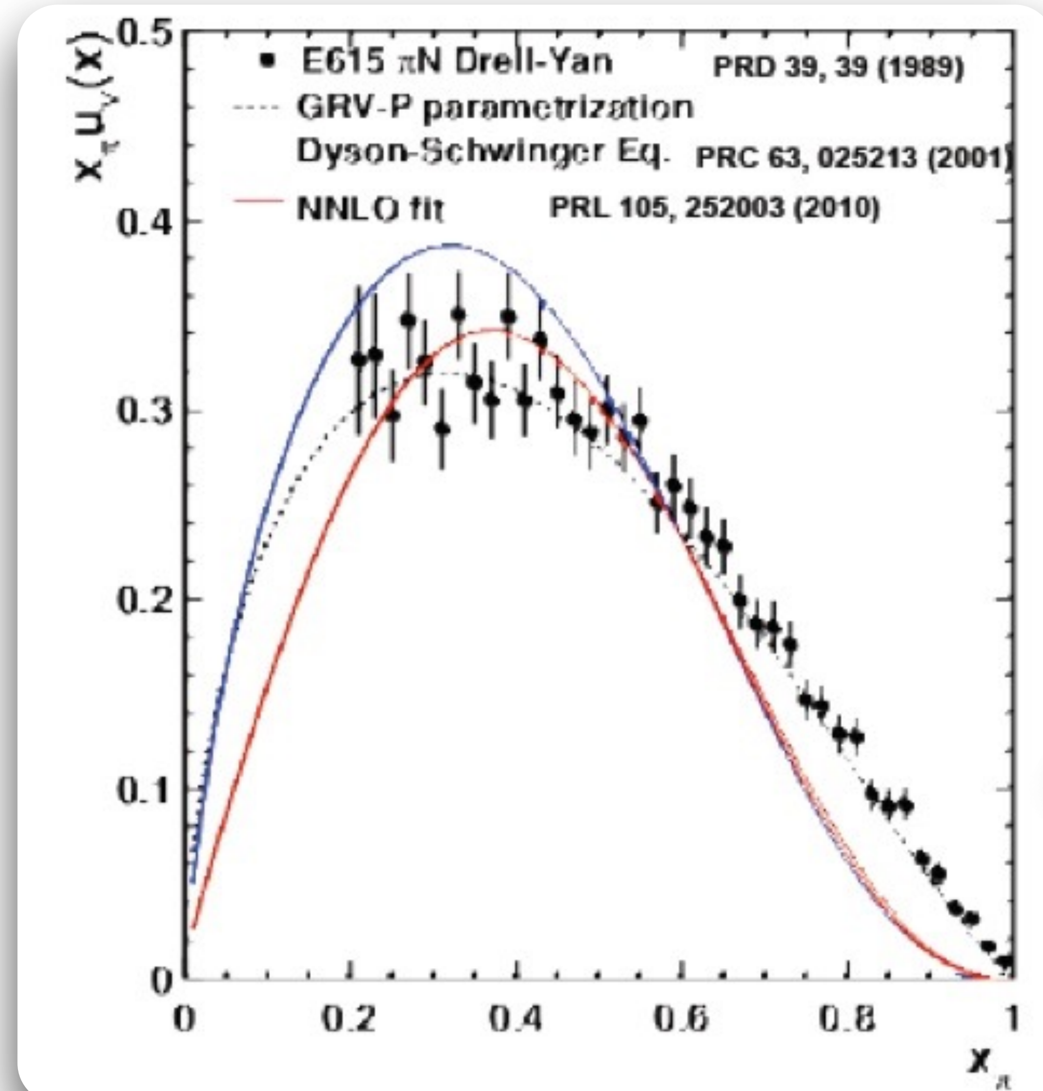

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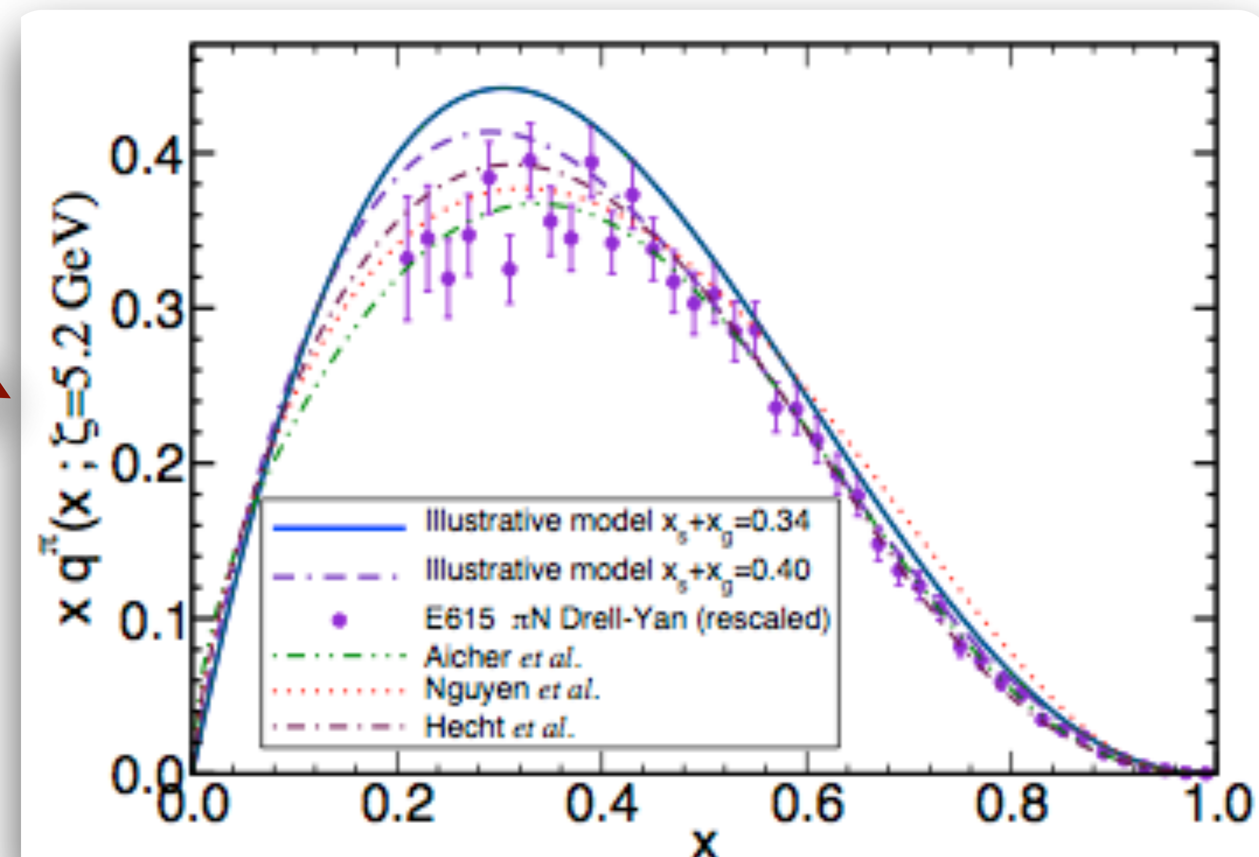
re-analysis

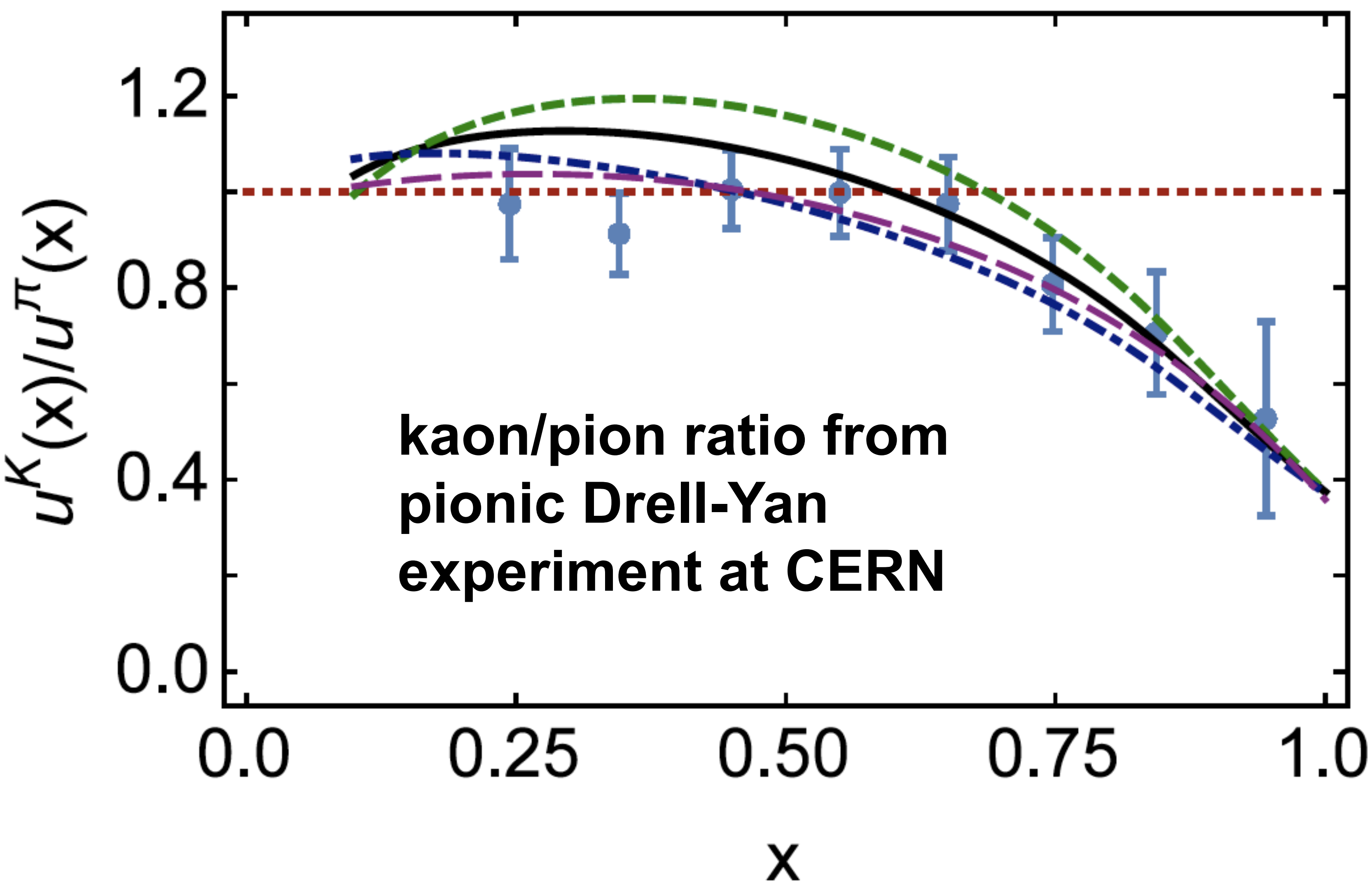


Re-analysis after including the gluonic contributions,

L. Chang, C. Mexrag, H. Moutarde, C. D. Roberts, J. Rodriguez-Quintero, P. C. Tandy, Phys. Lett. B420, 267 (2014)

Gluonic contribution also needed to explain the drop in koan/pion ratio at large x.

Same Dyson-Schwinger Eq. based calculations with the gluonic contributions can explain the kaon/pion ratio from pionic Drell-Yan experiment.



Points to the need for more precise data

C. Chen, L. Chang, C. D. Roberts, S. Wan and H.-S. Zong, in preparation (2016).

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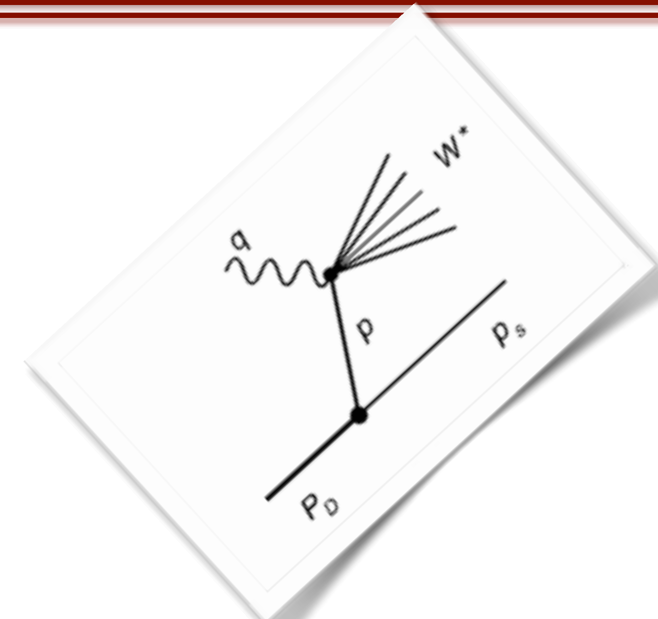

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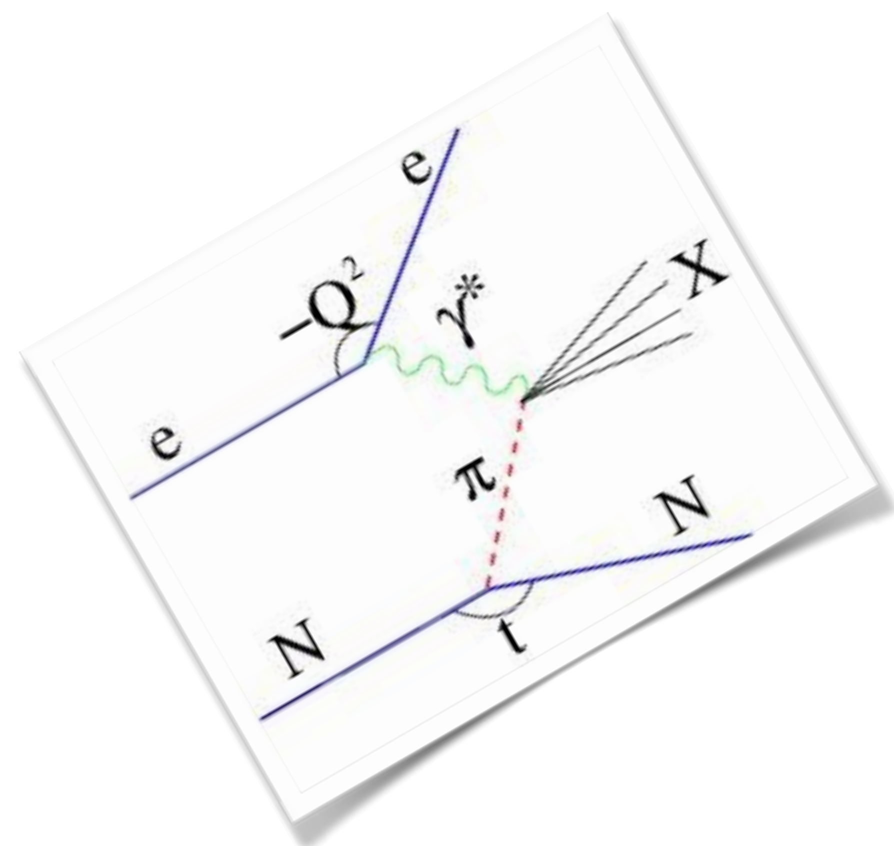
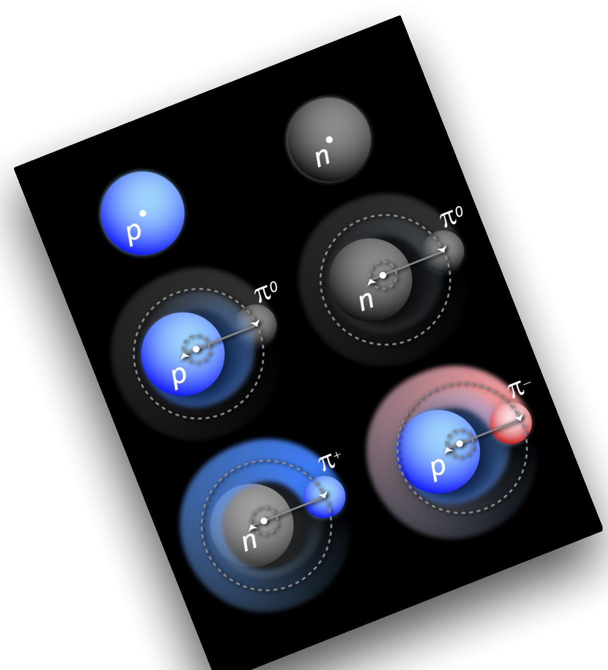
   - Sullivan process and access to meson cloud of nucleon
   - New experiment at JLab12

3. **Tagged DIS at an EIC**

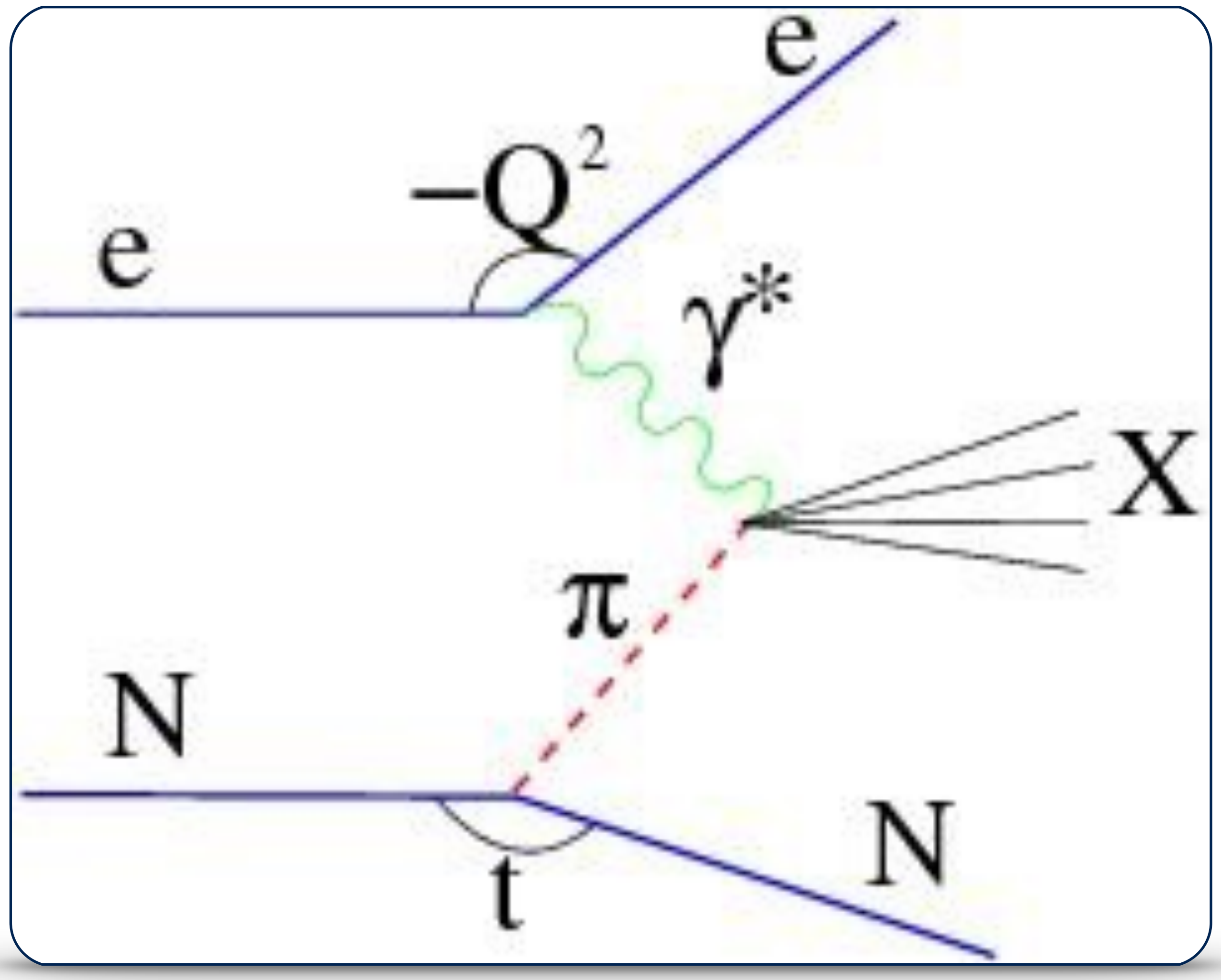


3. **Summary**



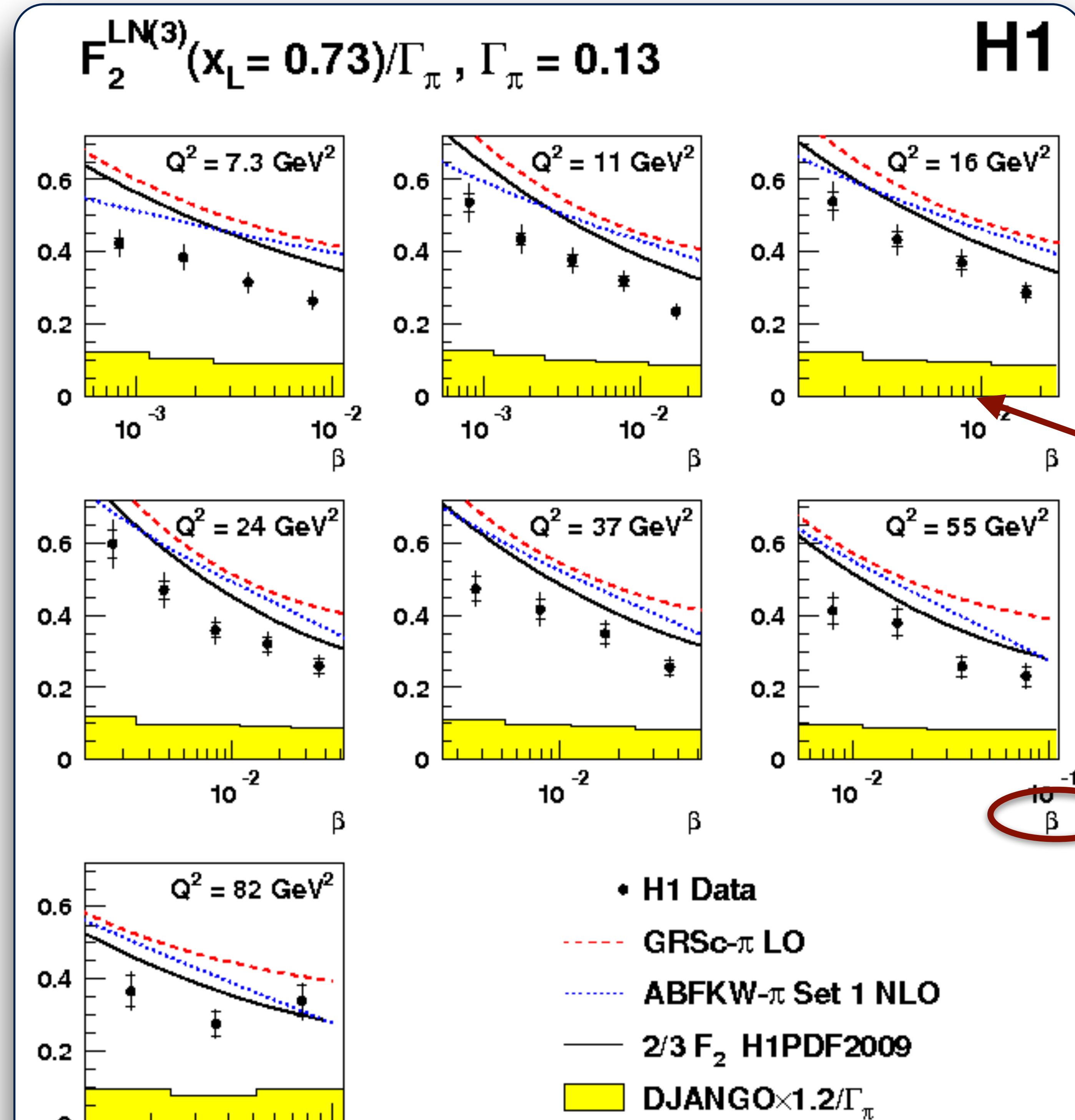
Deep-inelastic Scattering off a virtual-meson cloud is possible experimental technique.

The Sullivan process



Measuring the contribution to DIS from the Sullivan process is a direct measurement of the mesonic content of the nucleon

Scattering off a virtual-pion target was used to measure the pion structure function at low-x.



Forward neutron data

= x_{pi}

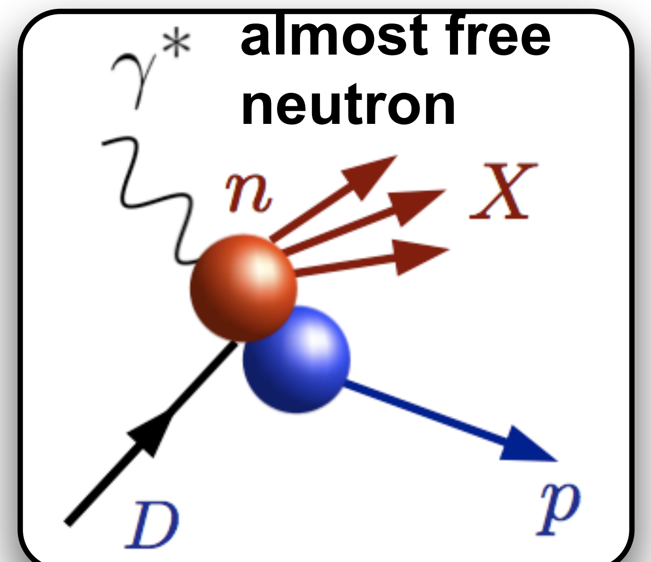
In the sea region only data from HERA, no independent confirmation.

DIS events with forward going neutrons in coincidence were found to be dominated by pion exchange; extracted pion F_2 < 2/3 of proton F_2

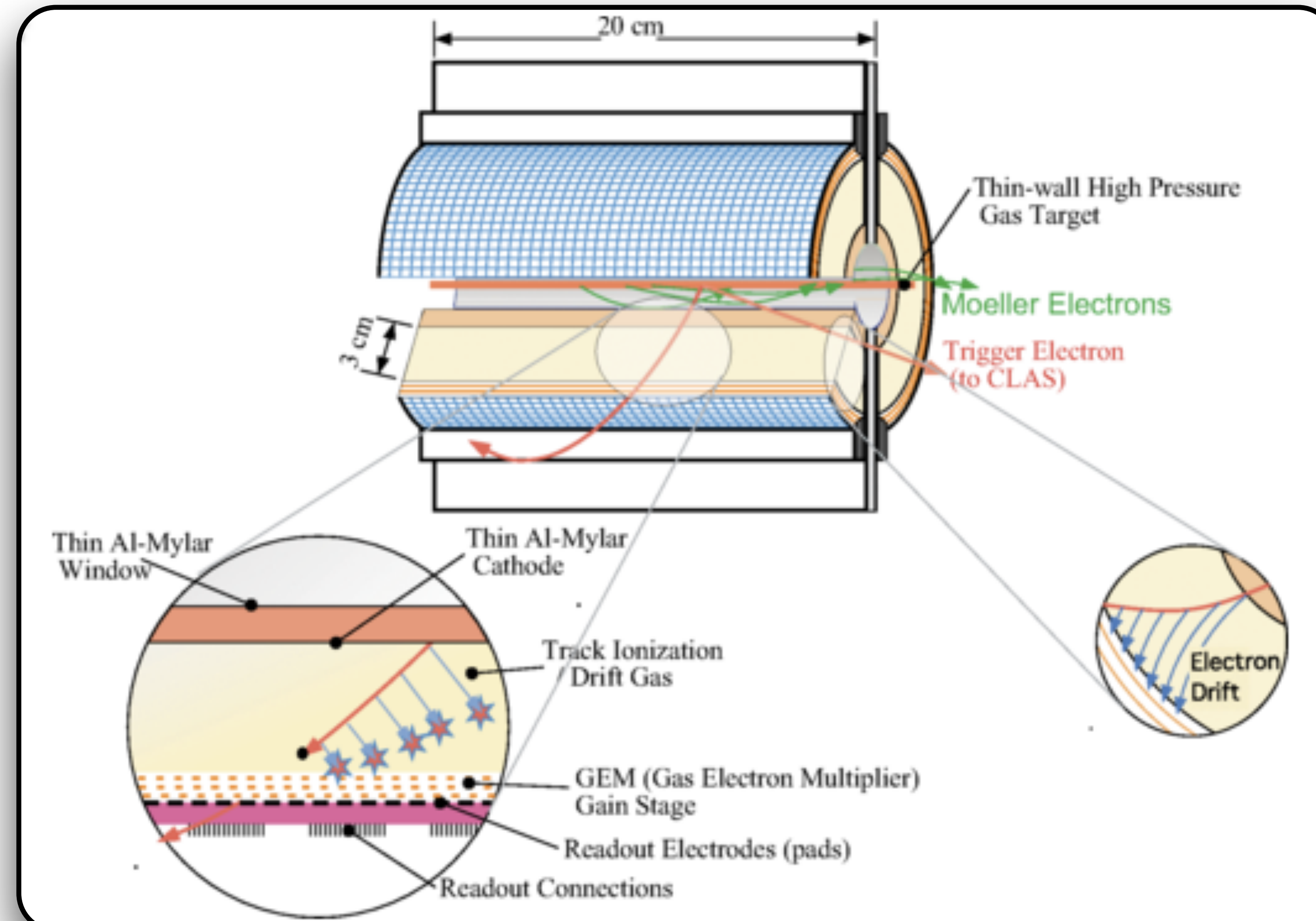
Forward proton data dominated by other resonances and hence could not be used to extract pion structure function

Spectator Tagging can be used to tag the "meson cloud" target.

Spectator tagging is now an established technique



Deuteron **Spectator proton (backward going slow proton)**



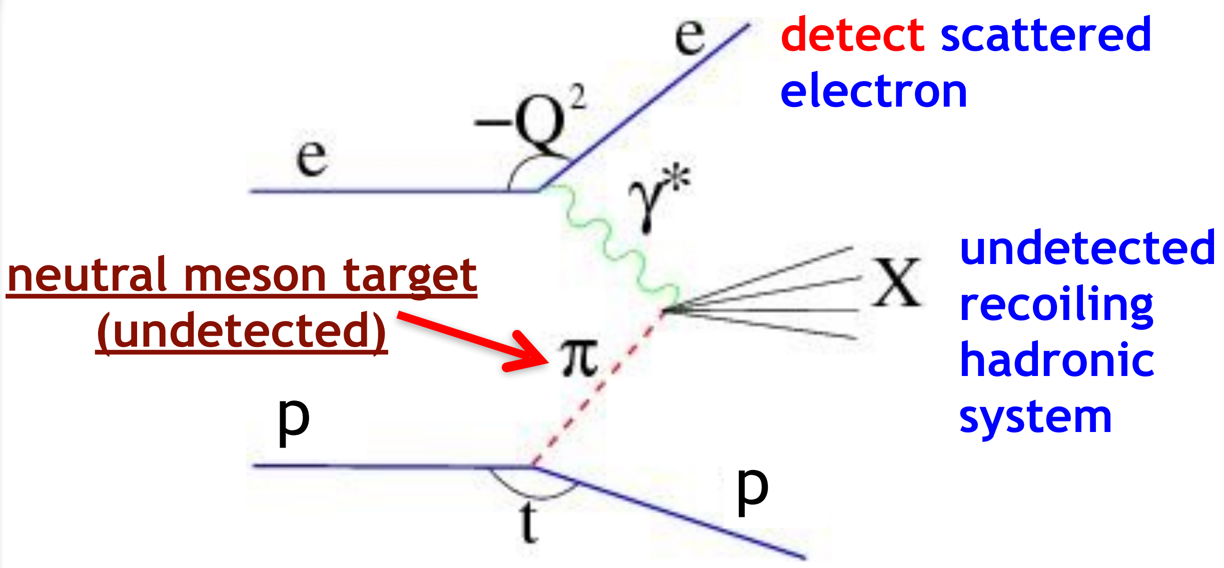
Almost-free neutron structure function studied with spectator tagging, technique successfully used by BoNuS

PRL 108, 142001 (2012); PRC 89, 045206 (2014)

Spectator Tagging can be used to tag the "meson cloud" target.

e.g. the Sullivan Process

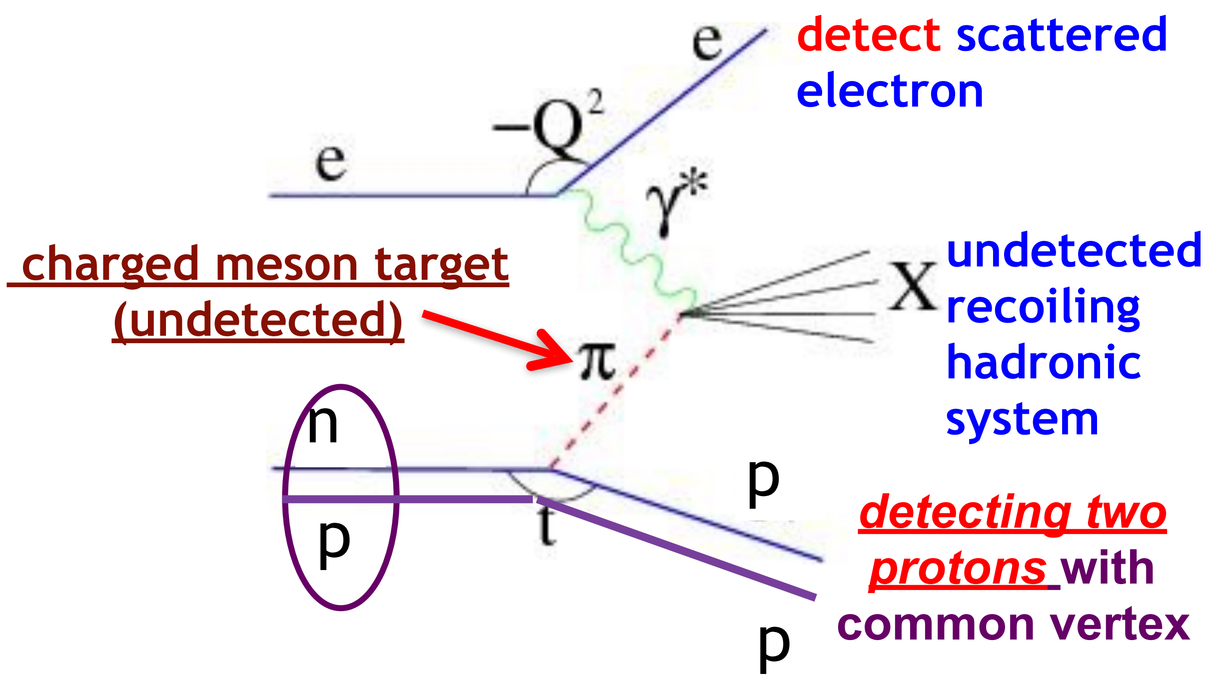
Hydrogen Target



Spectator proton

(backward going slow proton)

Deuterium Target



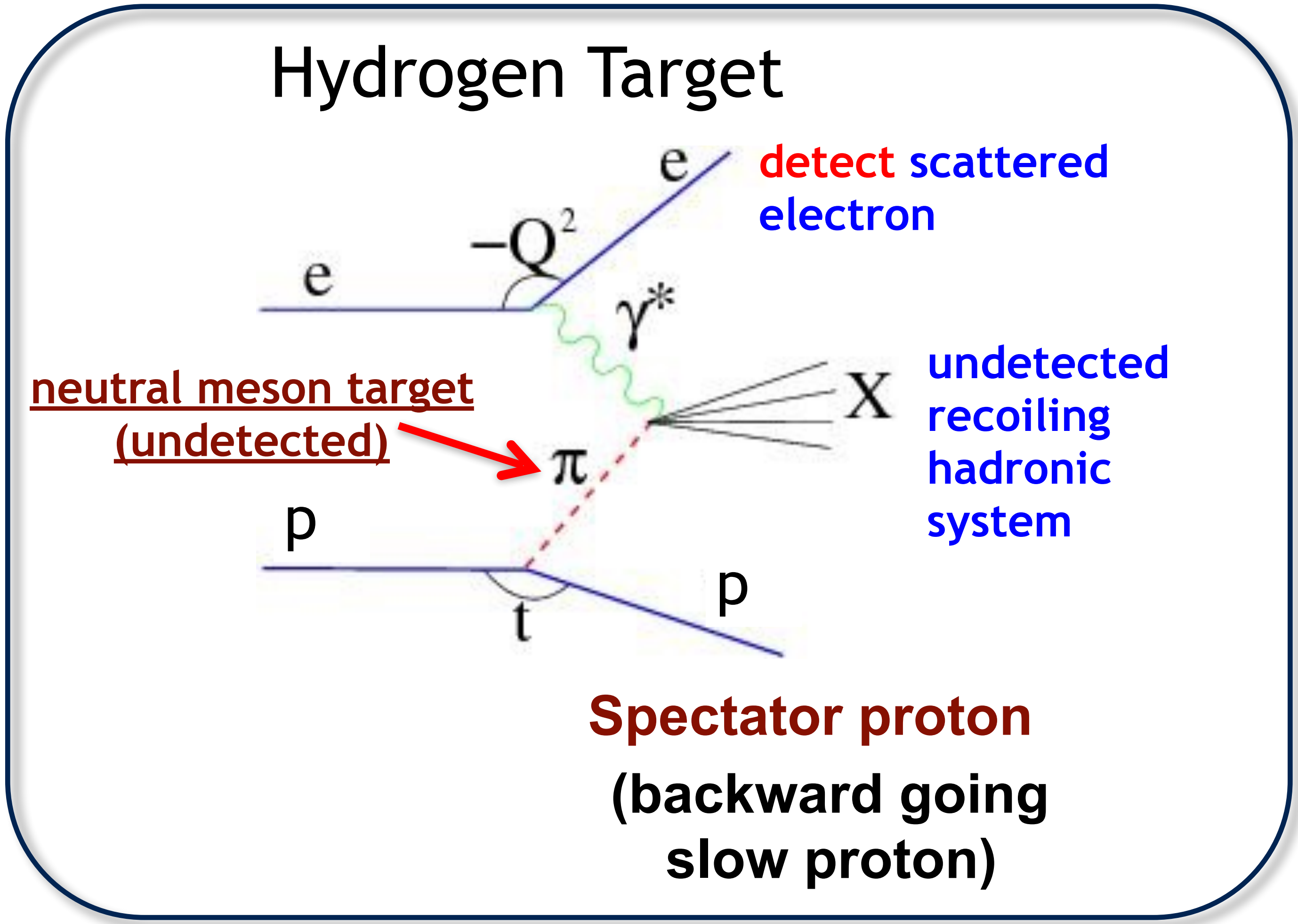
Spectator proton

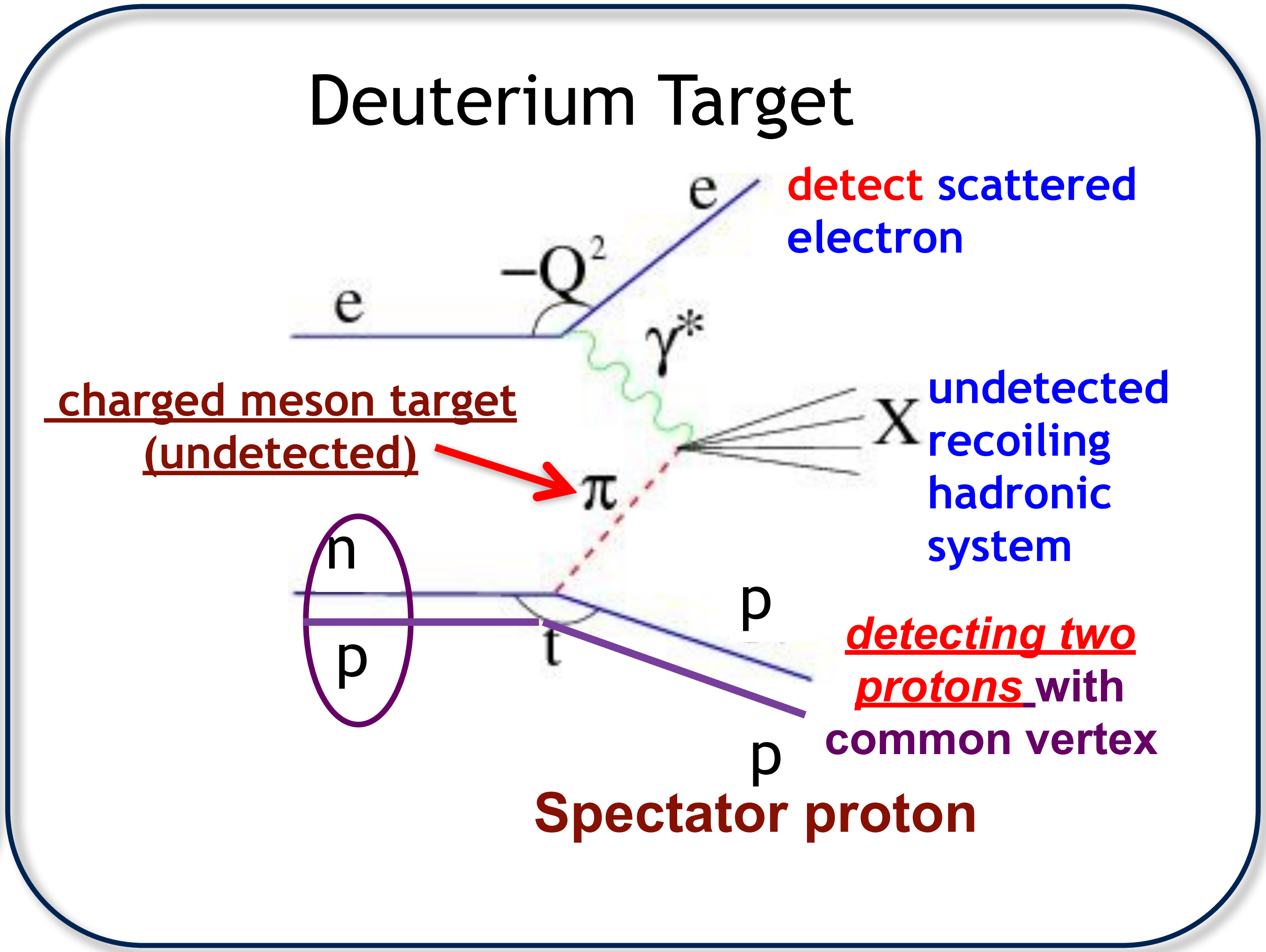
DIS event – reconstruct x, Q^2, W^2, also M_X of recoiling hadronic system

$$R^T = \frac{d^4\sigma(ep \to e'Xp')}{dxdQ^2dzdt} \Big/ \frac{d^2\sigma(ep \to e'X)}{dxdQ^2} \Delta z \Delta t \sim \frac{F_2^T(x,Q^2,z,t)}{F_2^p(x,Q^2)} \Delta z \Delta t.$$

Spectator Tagging will provide the first measurement of tagged structure functions.

e.g. the Sullivan Process

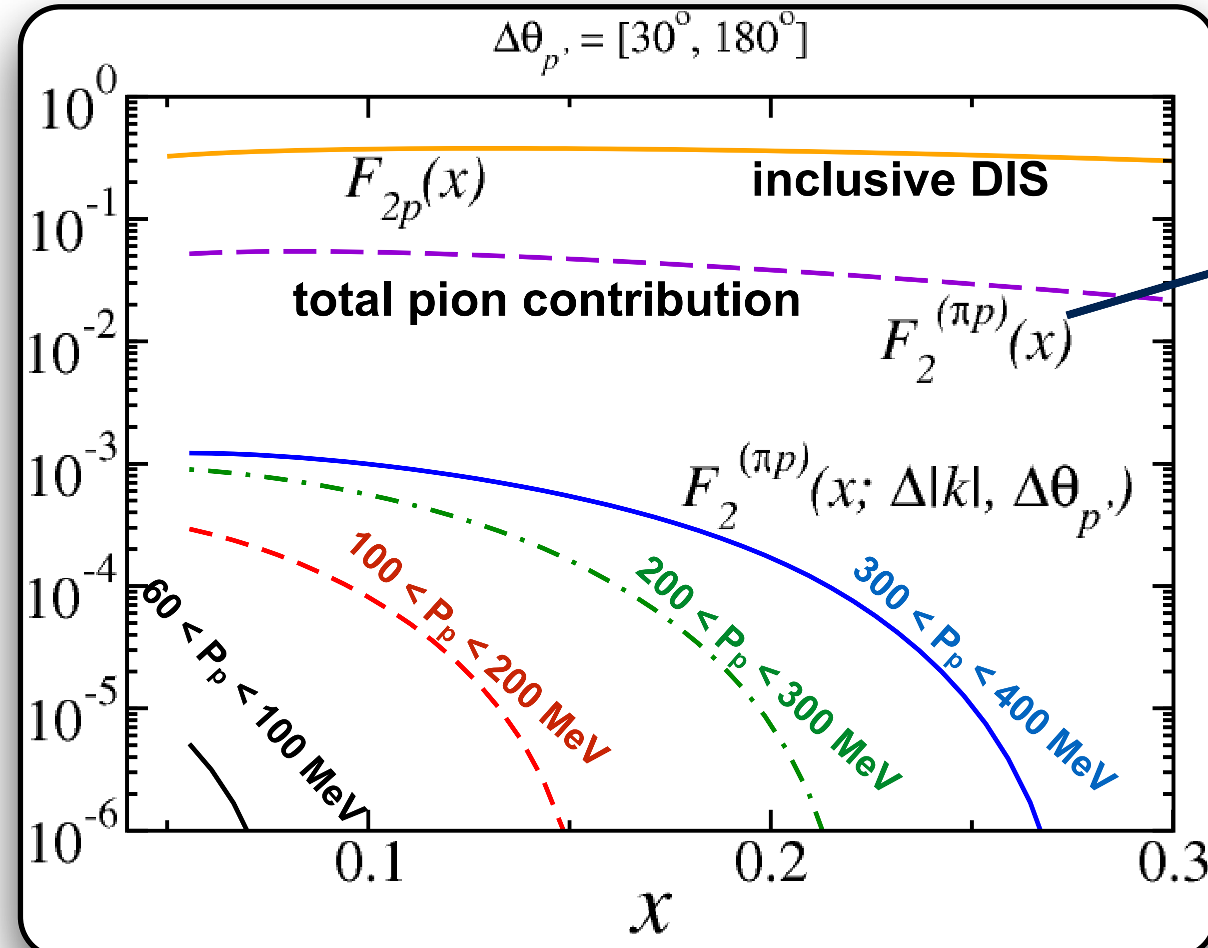




DIS event – reconstruct x, Q^2, W^2, also M_X of recoiling hadronic system

$$F_2^T(x, Q^2, z, t) = \frac{R^T}{\Delta z \Delta t} F_2^p(x, Q^2).$$

Phenomenological models can be used to interpret the measured tagged structure function.



$$F_2^{(\pi N)}(x) = \int_x^1 dz\, f_{\pi N}(z)\, F_{2\pi}\left(\frac{x}{z}\right),$$

$$f_{\pi N}(z) = \frac{1}{M^2}\int_0^\infty dk_\perp^2\, f_{\pi N}(z, k_\perp^2).$$

$$f_{\pi N}(z) = c_I \frac{g_{\pi NN}^2}{16\pi^2}\int_0^\infty \frac{dk_\perp^2}{(1-z)}\frac{G_{\pi N}^2}{z\,(M^2 - s_{\pi N})^2}\left(\frac{k_\perp^2 + z^2 M^2}{1-z}\right),$$

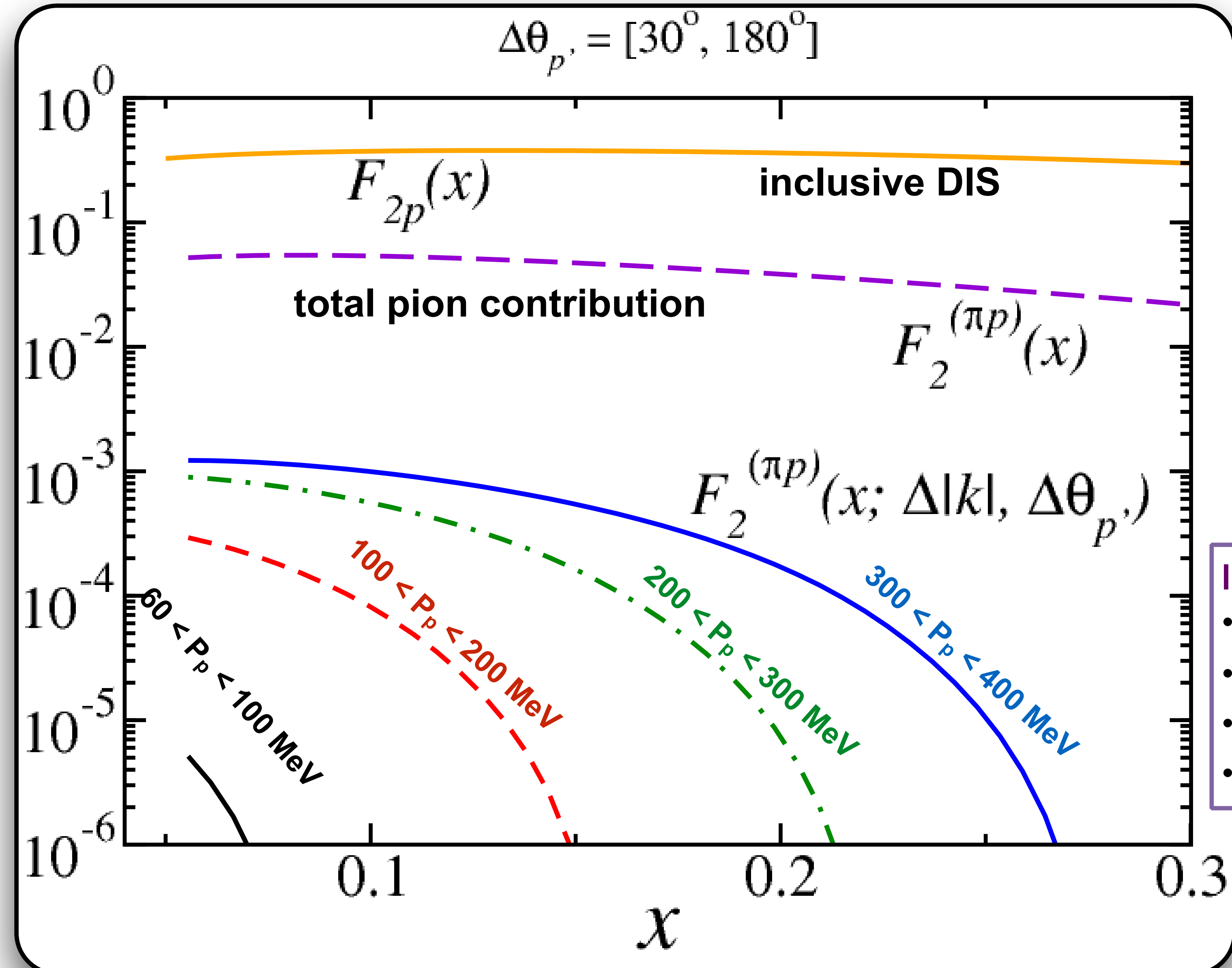
light cone momentum distribution of pions in the nucleon, $G_{\pi N}$ is the parametrization of the momentum dependence of the πNN vertex function

$$F_2^{(\pi N)}(x, z, k_\perp) = f_{\pi N}(z, k_\perp)\, F_{2\pi}\left(\frac{x}{z}\right)$$

Tagged SF — **pion "flux"** — **Pion SF**

T. J. Hobbs, T. Londergan, W. Melnitchouk, et al. (2014, in preparation);
H. Holtmann, A. Szczurek and J. Speth, Nucl. Phys. A 596, 631 (1996);
W. Melnitchouk and A. W. Thomas, Z. Phys. A 353, 311 (1995)

The tagged structure functions can provide the magnitude of the mesonic content of the nucleon.



Pion contribution dominates at JLab kinematic

Important to note - kinematic limits:
- $z < |k|/M$, where k is π 3-momentum = -p'
- 150 < k < 400 MeV/c corresponds to z < ~0.2
- Also, x < z!
- Low x, high W at 11 GeV means Q^2 ~2 GeV^2

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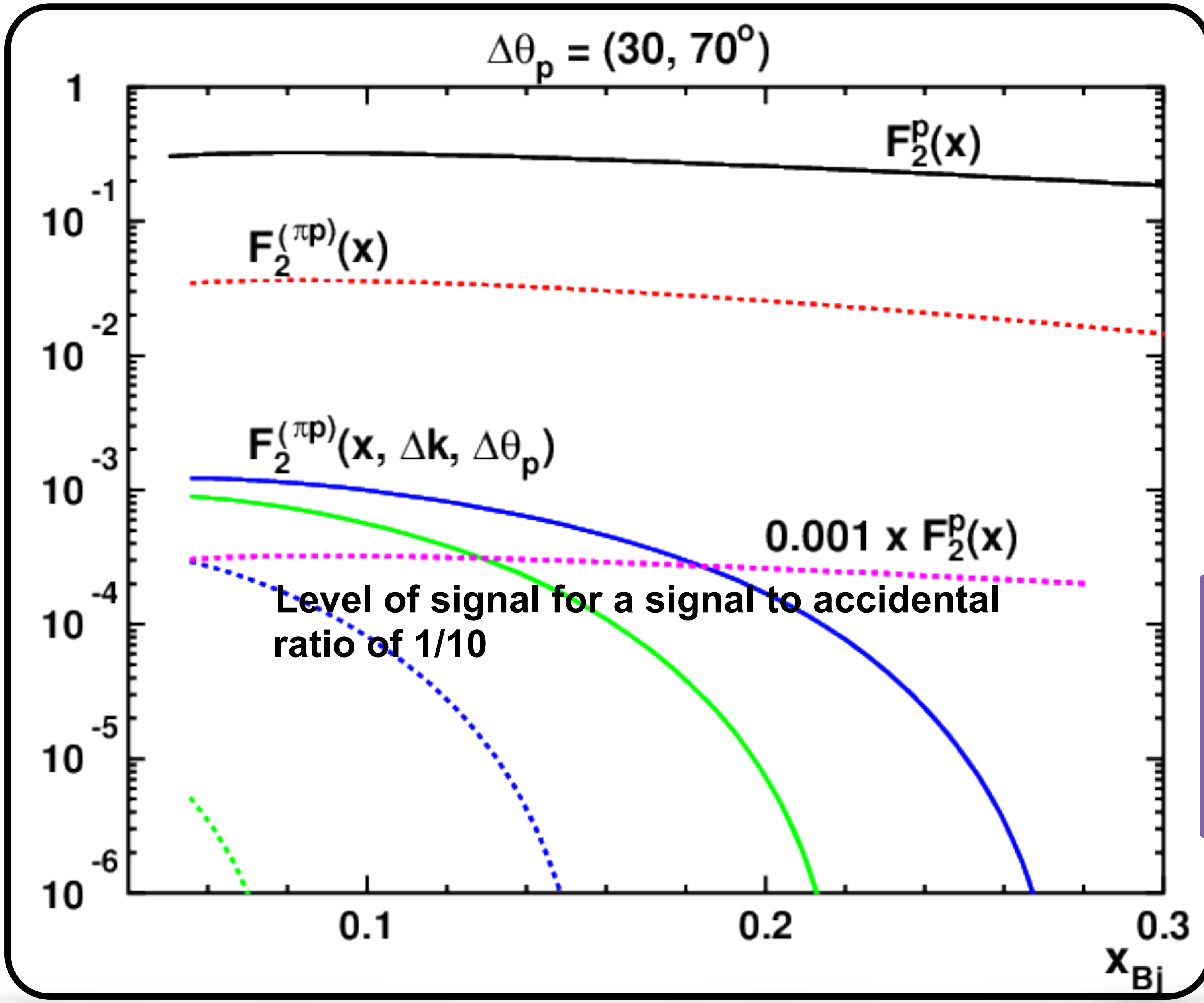
For a signal to accidental ratio of 1/10 we can measure the mesonic content by tagging 150 - 400 MeV/c protons.



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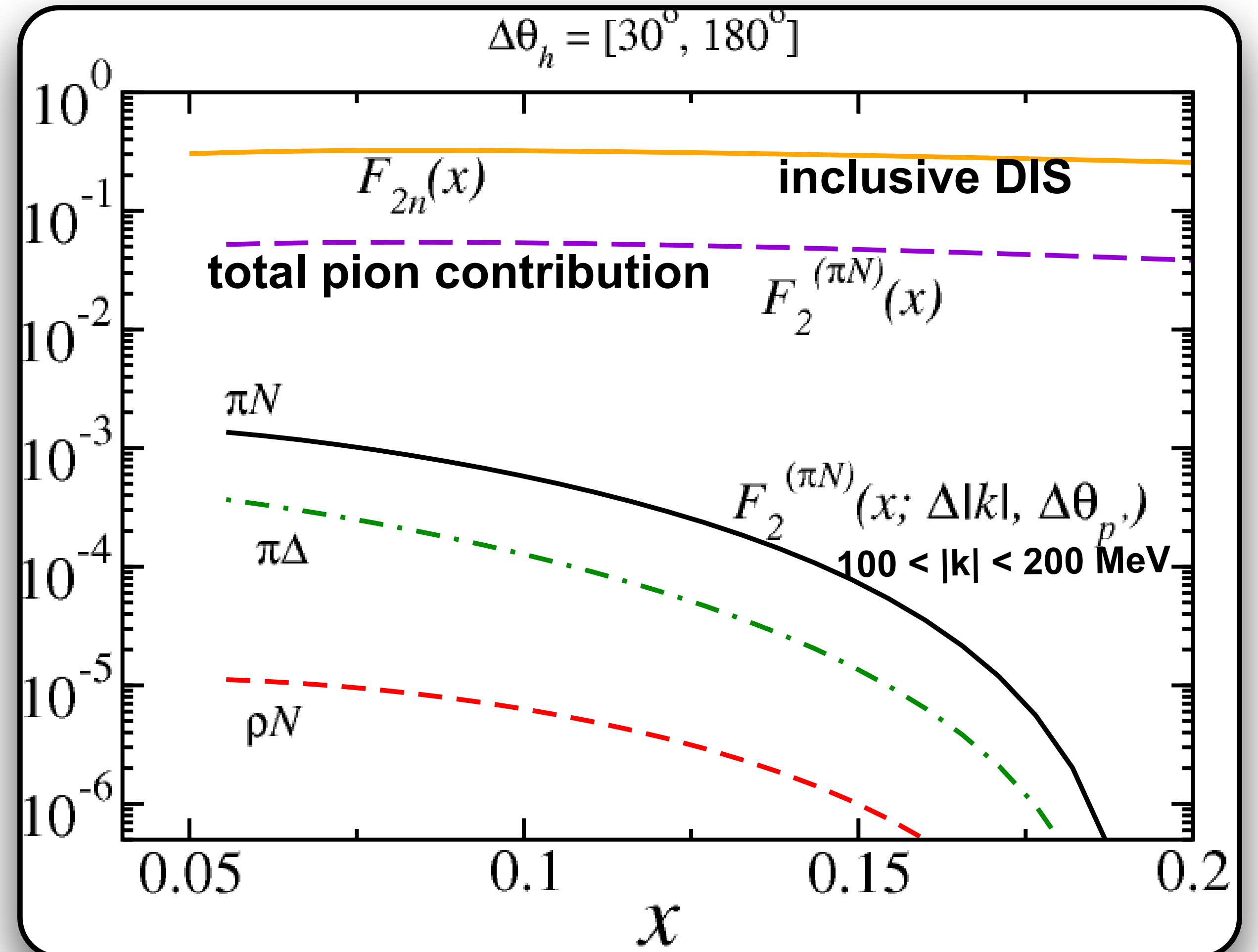

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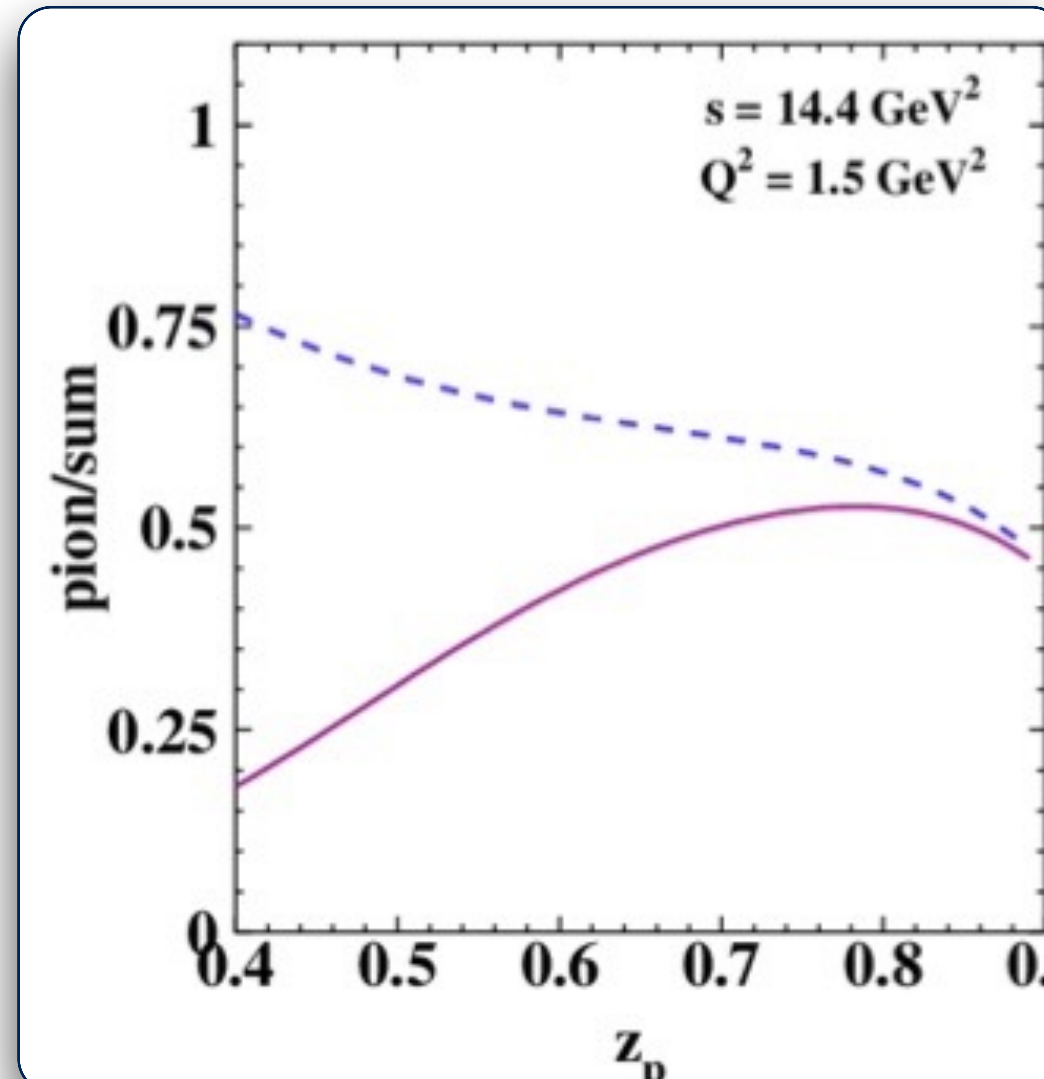
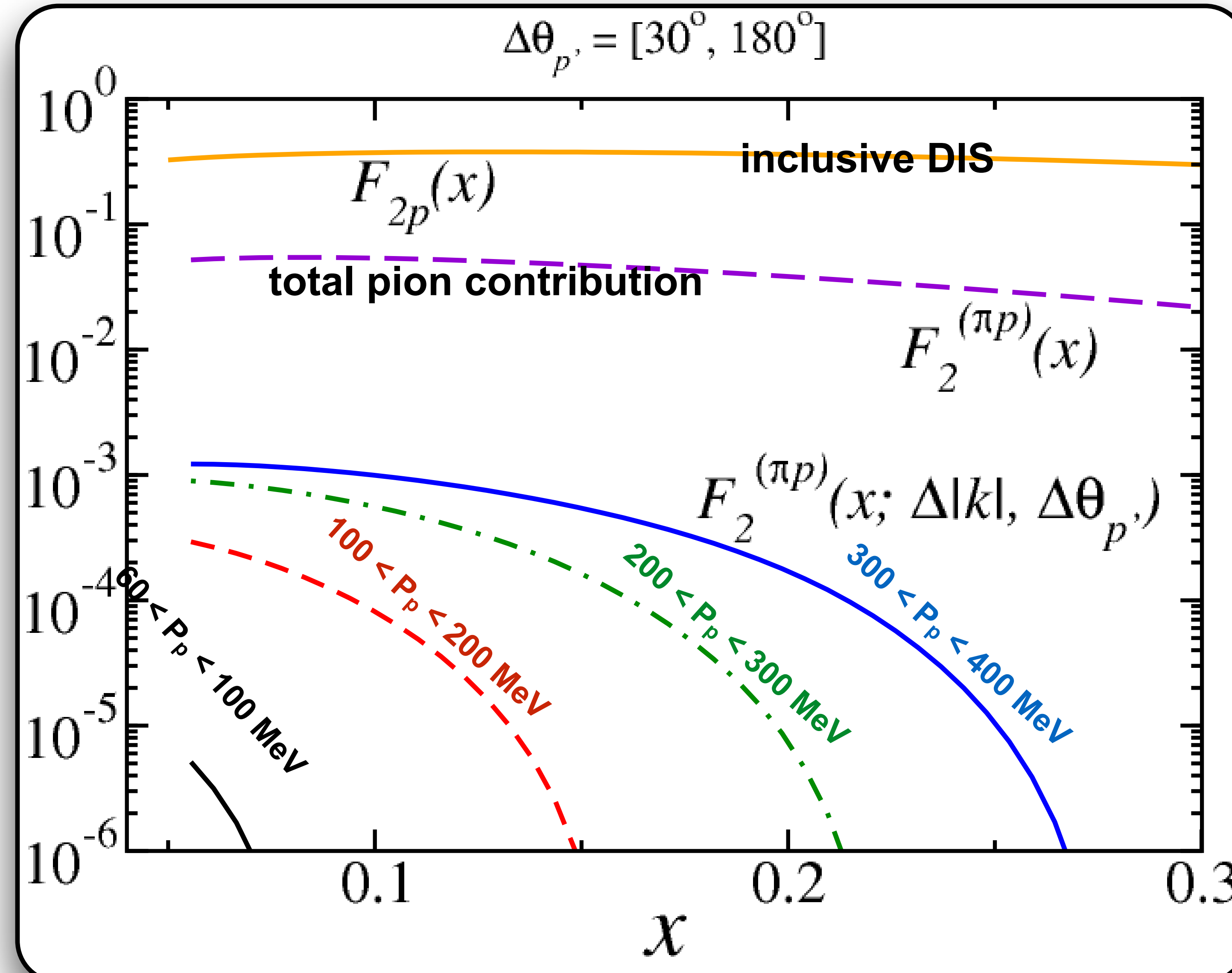


B. Kopeliovich, I. Potashnikova (2015), Rho, Regge

Tagged structure functions can also be used to extract the pion structure function.



$$F_2^{(\pi N)}(x, z, k_\perp) = f_{\pi N}(z, k_\perp)\, F_{2\pi}\left(\frac{x}{z}\right)$$

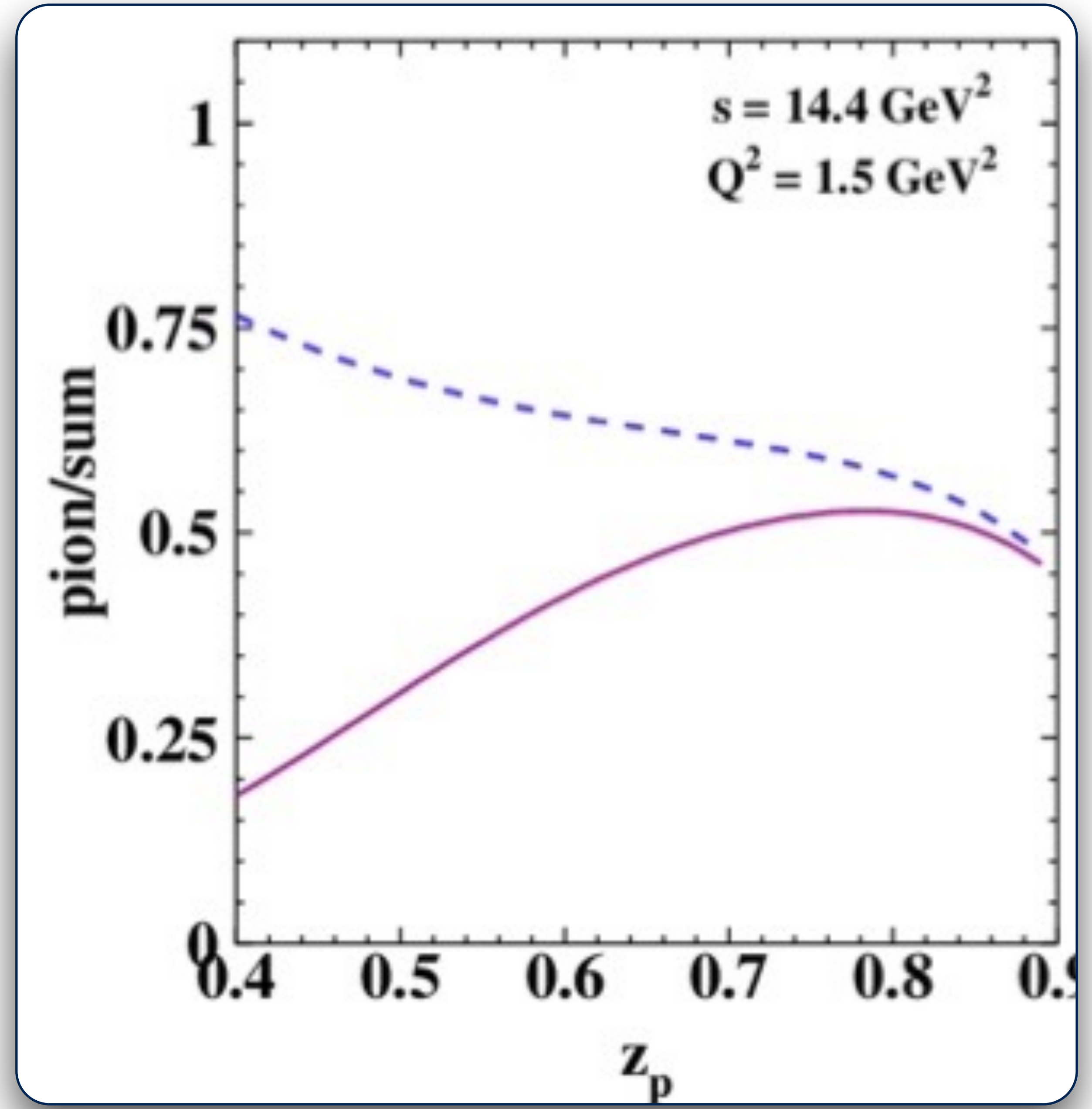
Tagged SF (from spectator tagging)

pion "flux"

Pion SF

Tagged structure functions can also be used to extract the pion structure function.

Pion flux is largest uncertainty, ~10-20%



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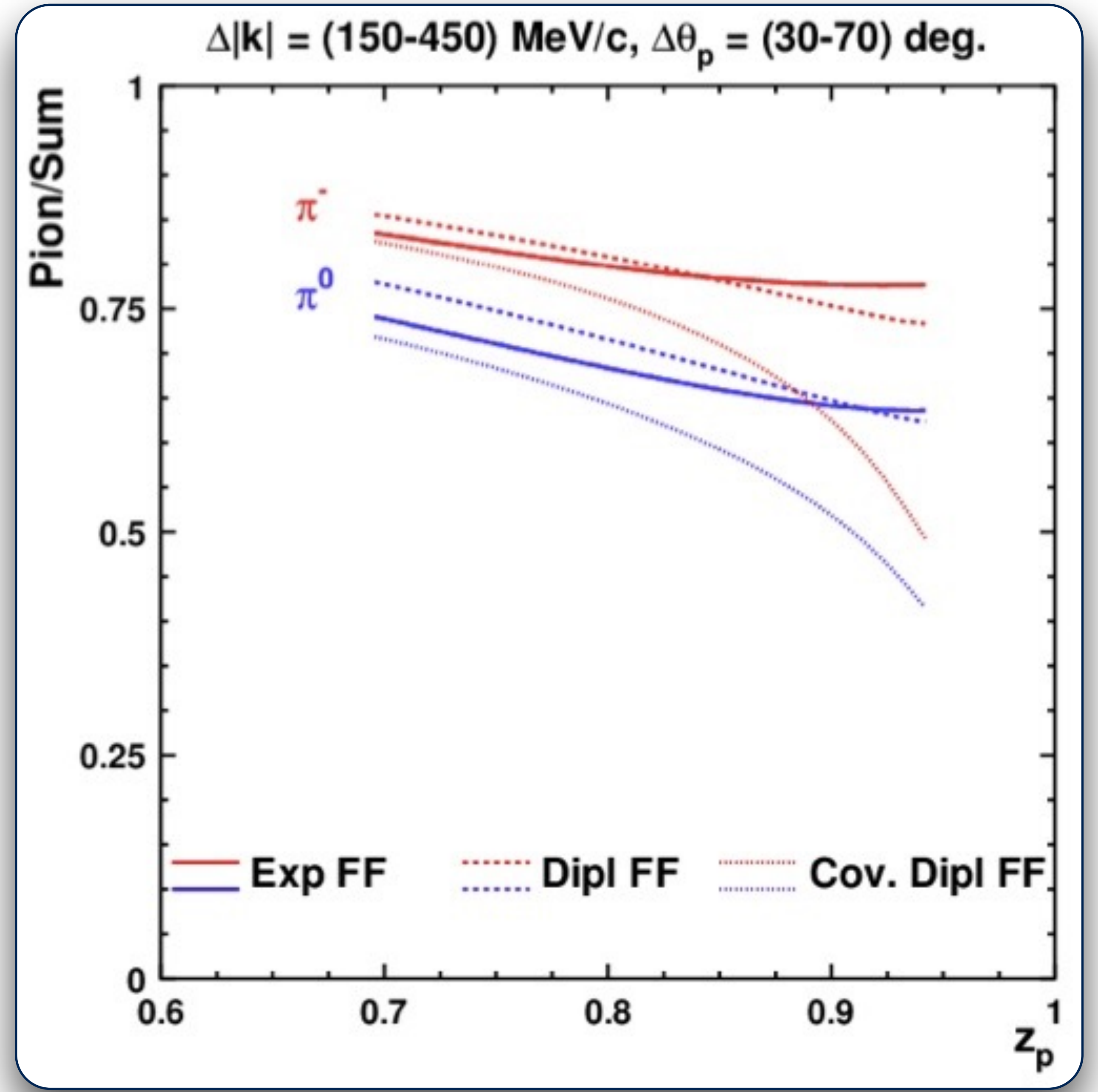


T. Hobbs, W. Melnitchouk, T. Londergan (2014), Rho, Delta

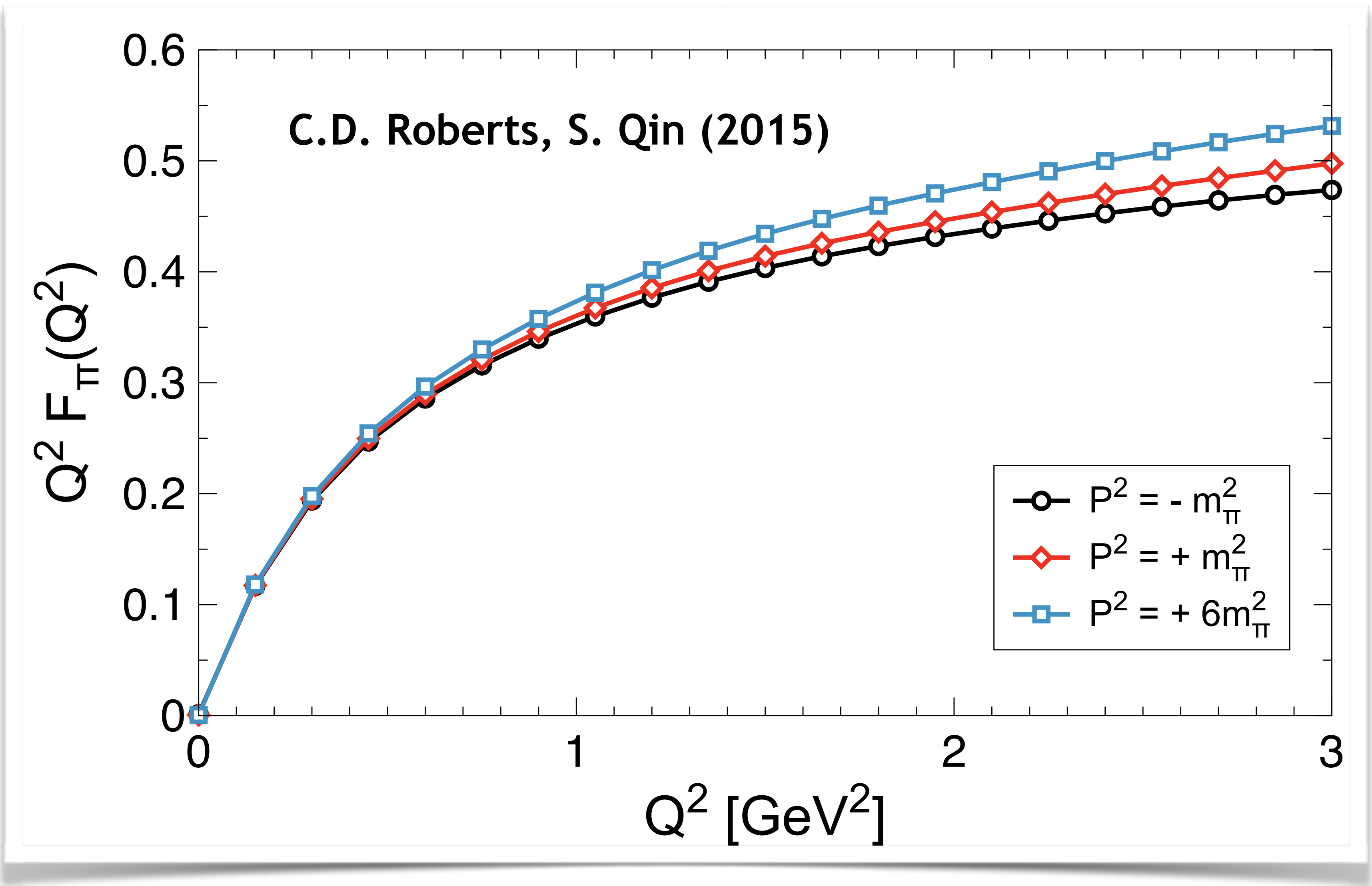
But can also be normalize to Drell-Yan data (5% uncertainty)….

Tagged structure functions can also be used to extract the pion structure function.

It requires extrapolation to the pion pole

low momentum protons helps cover a range of low |t|

Ratio of off-shell to on-shell pion EM form factors

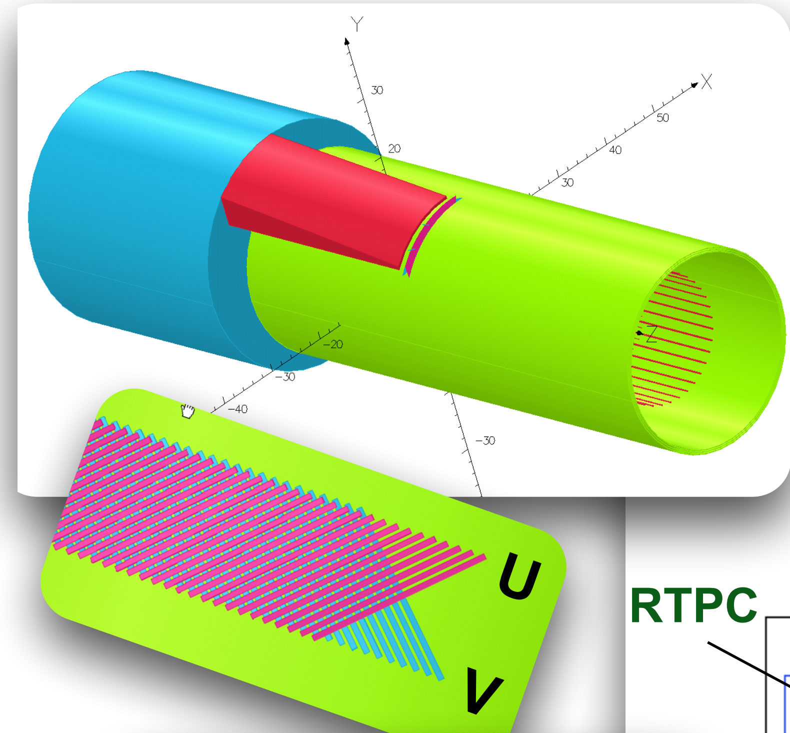


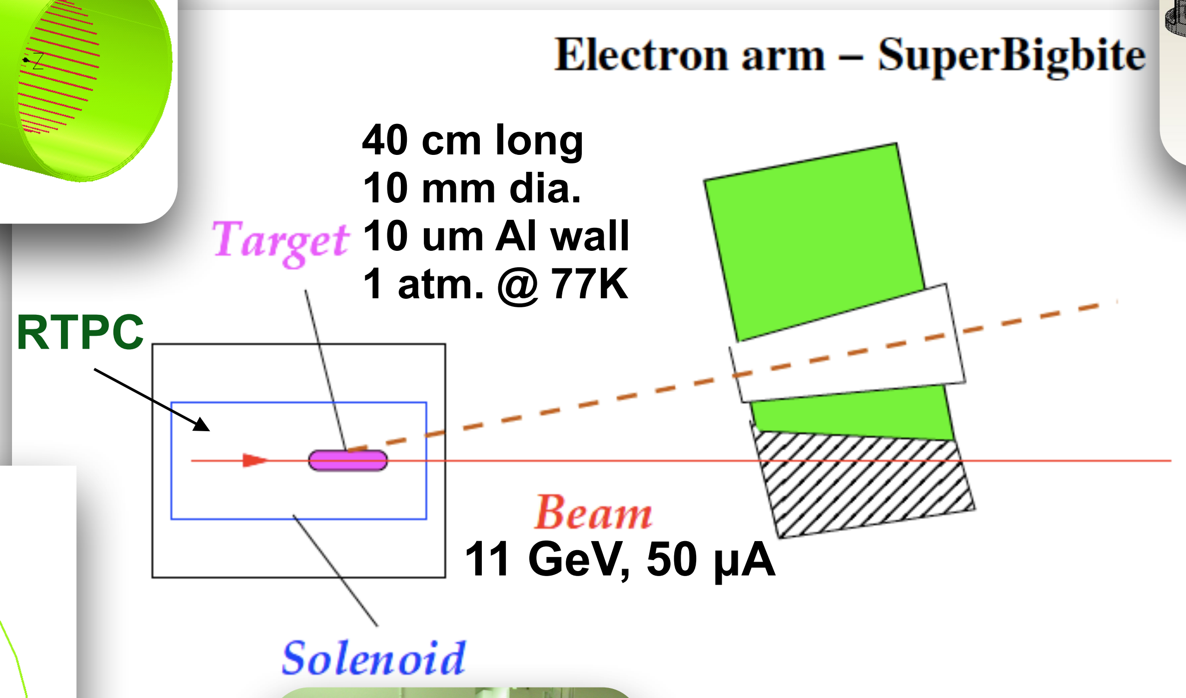
Pion's valence-quark GPDs in unified Dyson-Schwinger Equation framework:

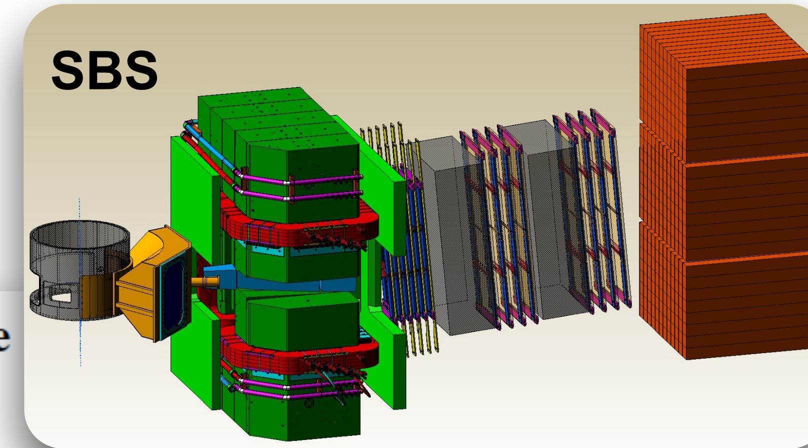
virtuality-independent form factor implies virtuality-independent pion structure function

This ensures small uncertainty in extrapolation to the pion pole -within ~5% at JLab kinematics

TDIS is a new experiment to probe the mesonic content of the nucleon.

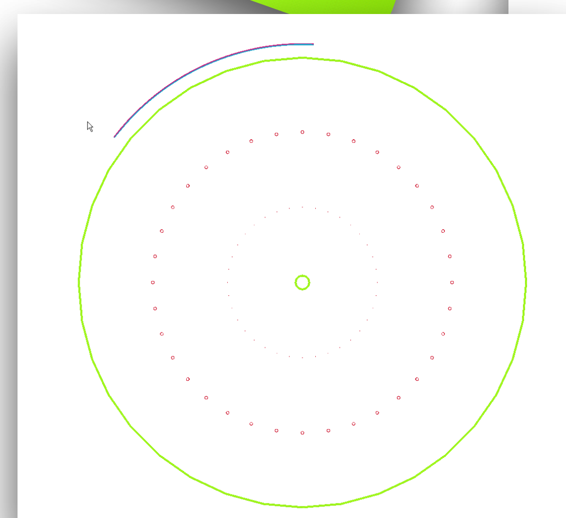






1. Tracker: 5 GEM planes
2. Add calorimeter (LAC from CLAS)
3. RICH or threshold gas Cherenkov
4. PID for trigger level 2: LAC + Cherenkov

hadron calorimeter (HCAL) for quasi-elastic neutron calibration



RTPC

5 cm radius of inner electrical wire grid
10 cm radius of middle electrical wire grid
15 cm radius of GEM foil
15.6 cm radius of U&V readout strips

40 cm bore, 5T super conduction solenoid

Proposal approved for Jlab Hall A:

√High luminosity,
   50 μAmp, $\mathcal{L}$ = 3 x $10^{36}/cm^2$ s
√Large acceptance
   Super Bigbite ~70 msr, hadron spectrometer
√HCAL will be used in RTPC calibration

Need to…
   Add BONUS-type RTPC, requires solenoidal field
   Modify SBS for electron detection

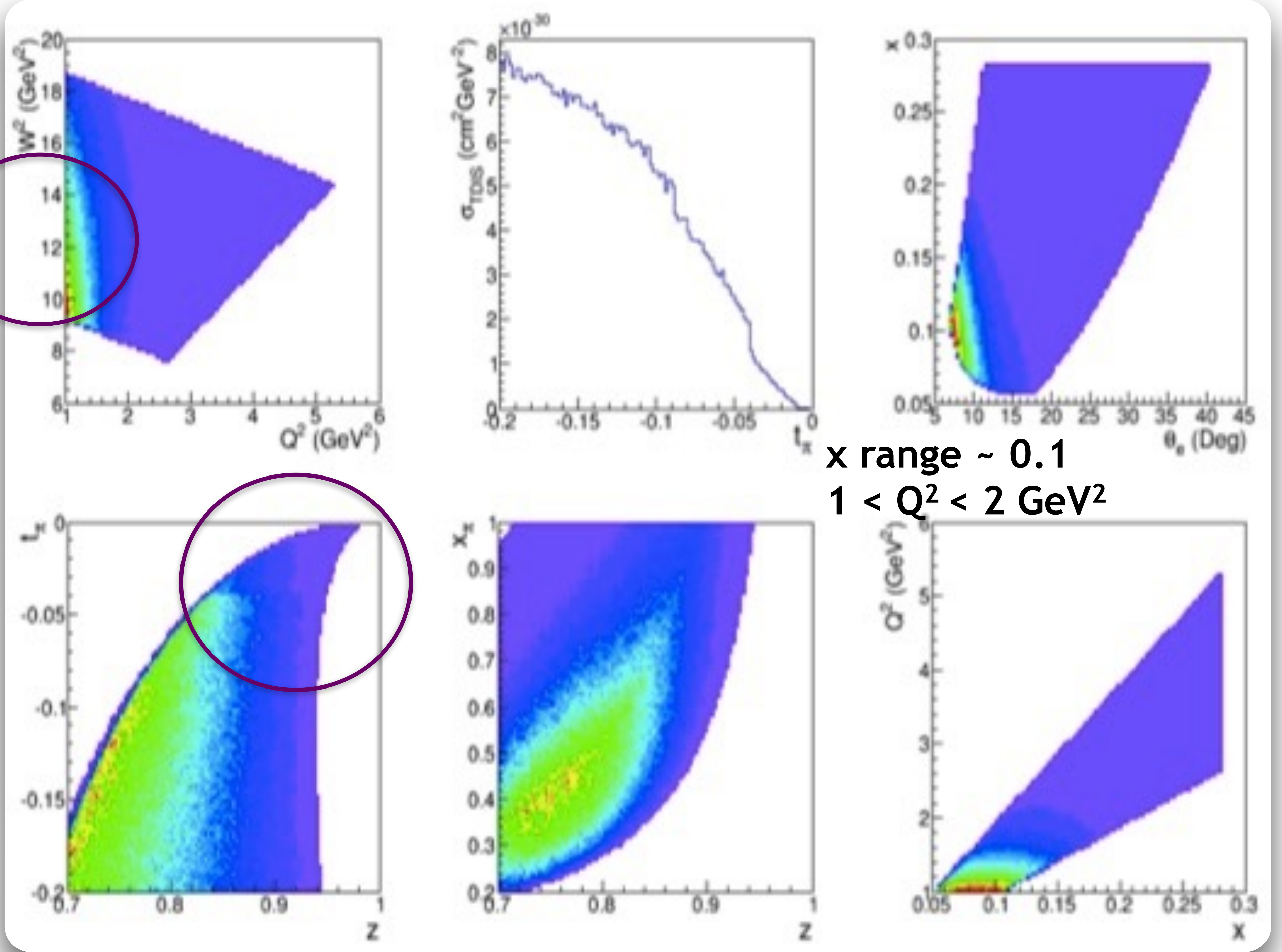
TDIS is a new experiment to probe the mesonic content of the nucleon.

TDIS kinematics - optimized for isolating meson cloud

High W^2
- High M_x^2
- DIS!

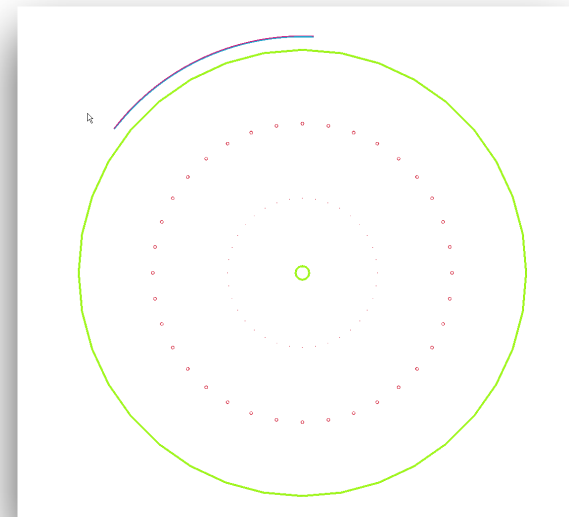
Low t, high z

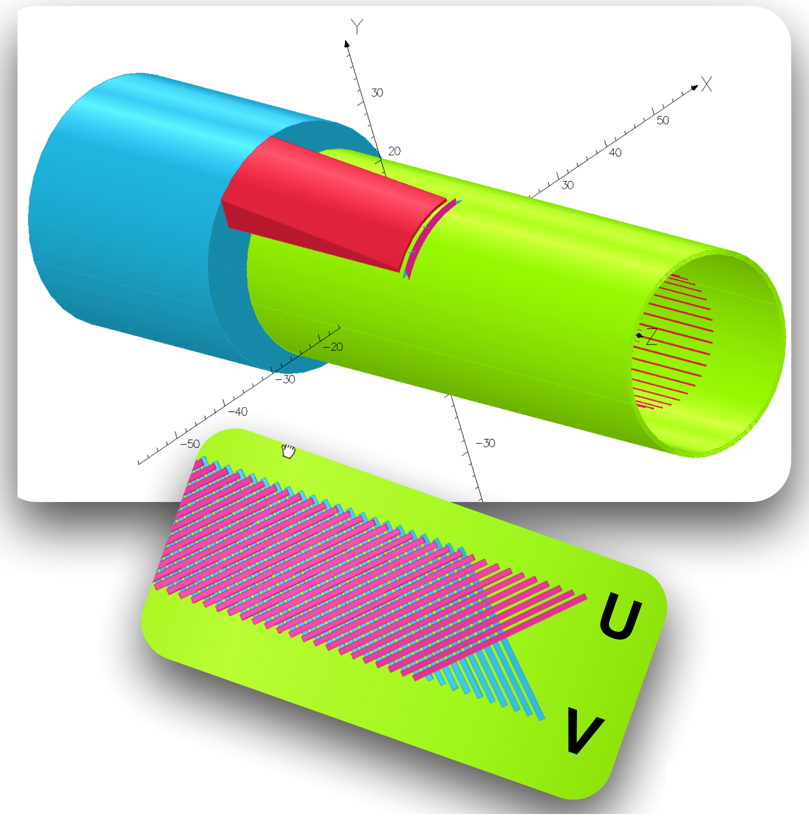
All data obtained *simultaneously* at one E = 11 GeV setting, only a target change – will run hydrogen and deuterium (neutron)



x range ~ 0.1
$1 < Q^2 < 2$ GeV^2

The conceptual design for a radial TPC has been optimized for the TDIS experiment.



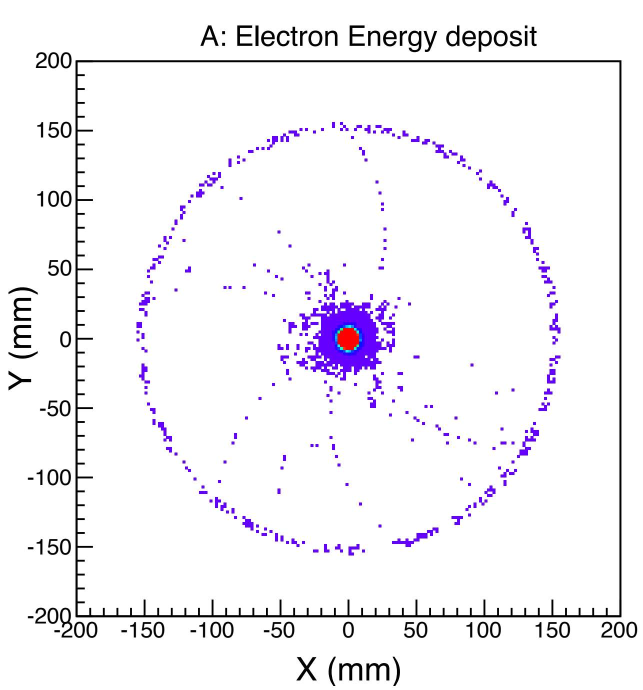


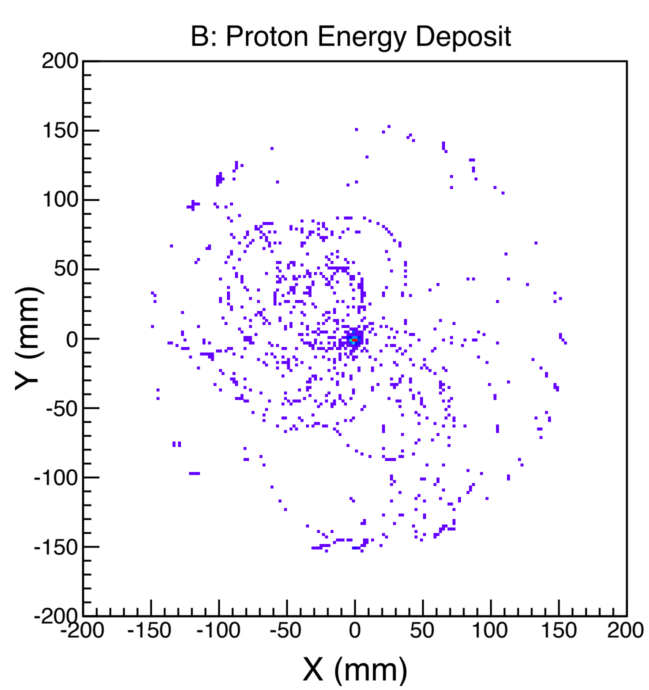
RTPC

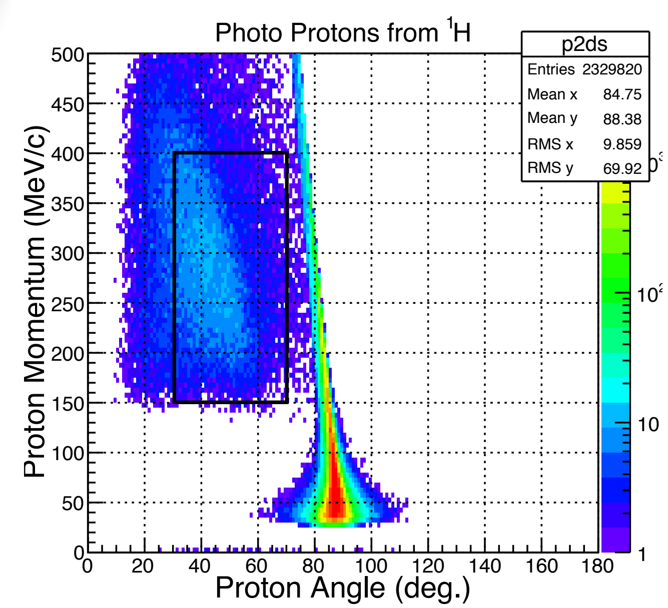
40 cm long
5 cm radius of inner electrical wire grid
10 cm radius of middle electrical wire grid
15 cm radius of GEM foil
15.6 cm radius of U&V readout strips
(1mm x 21.25 mm, with 1mm pitch)

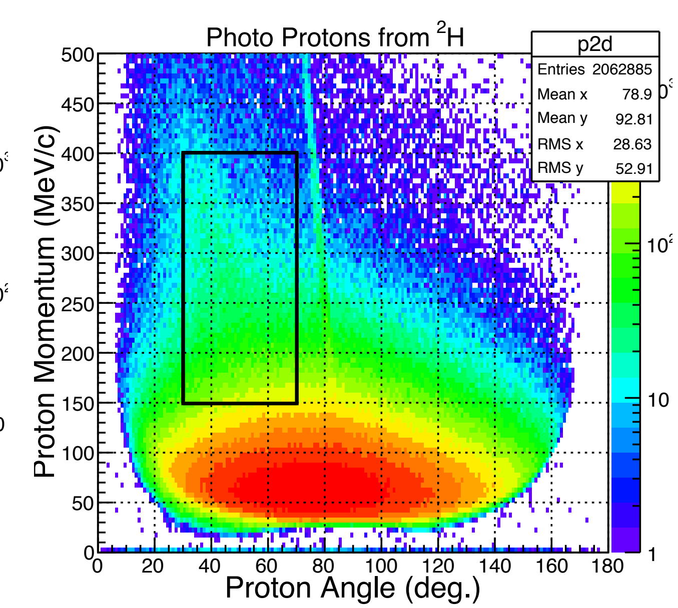
Expected resolution ~ 300um,

Readout electronics at the end(s) of the detector

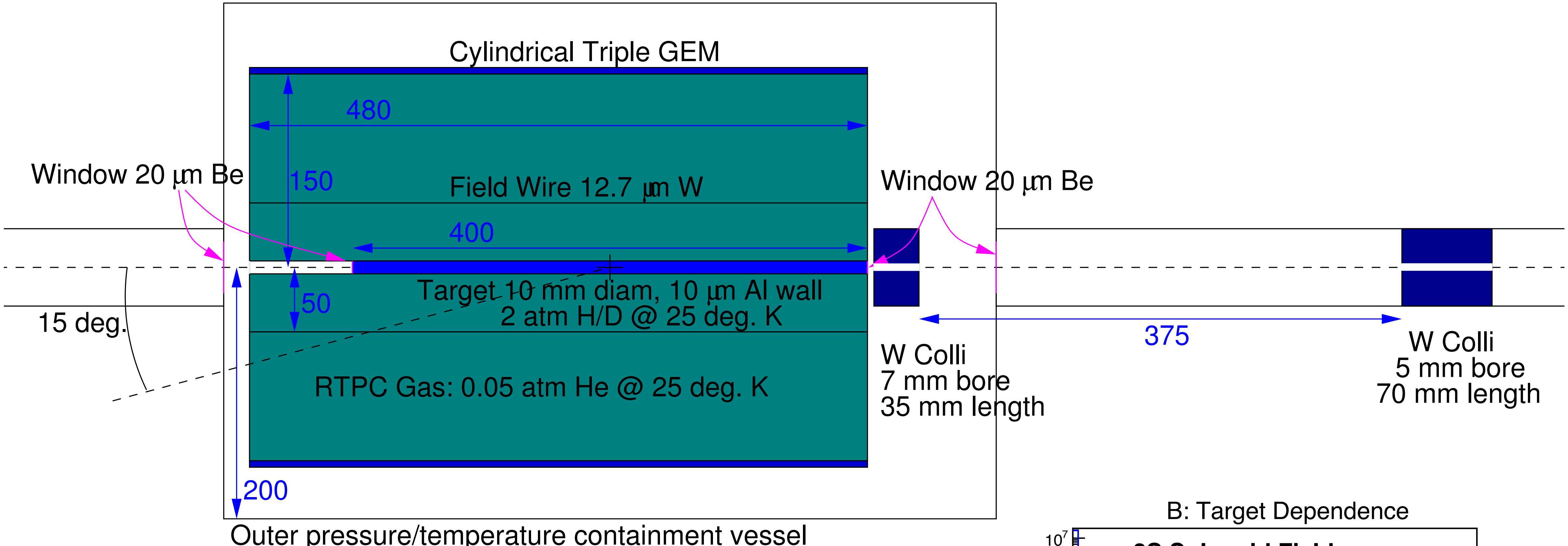








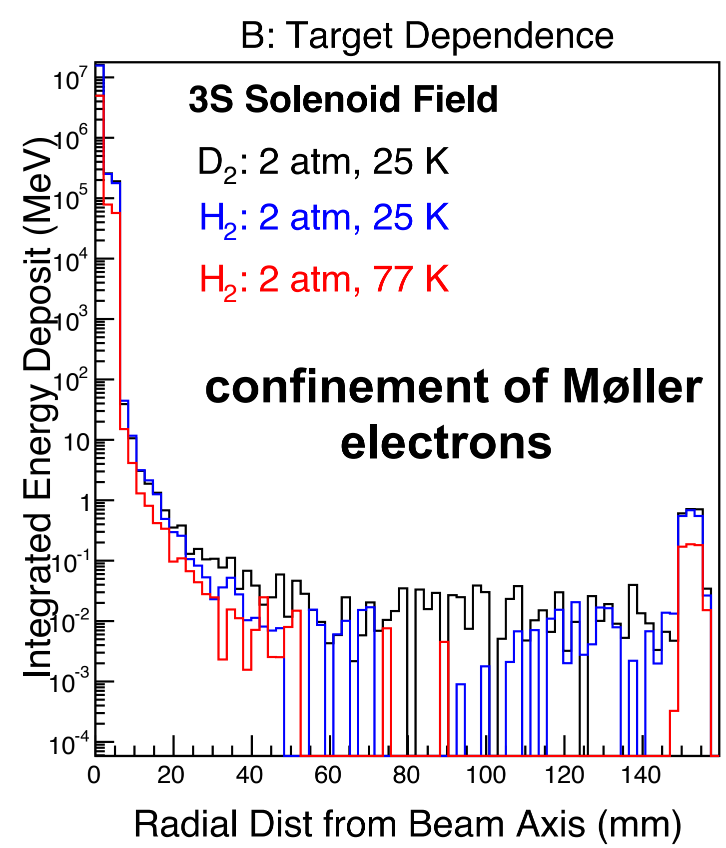
The conceptual design for a radial TPC has been optimized for the TDIS experiment.



The protons of interest have large transverse momentum and can be separated from background electrons using the solenoidal magnet.

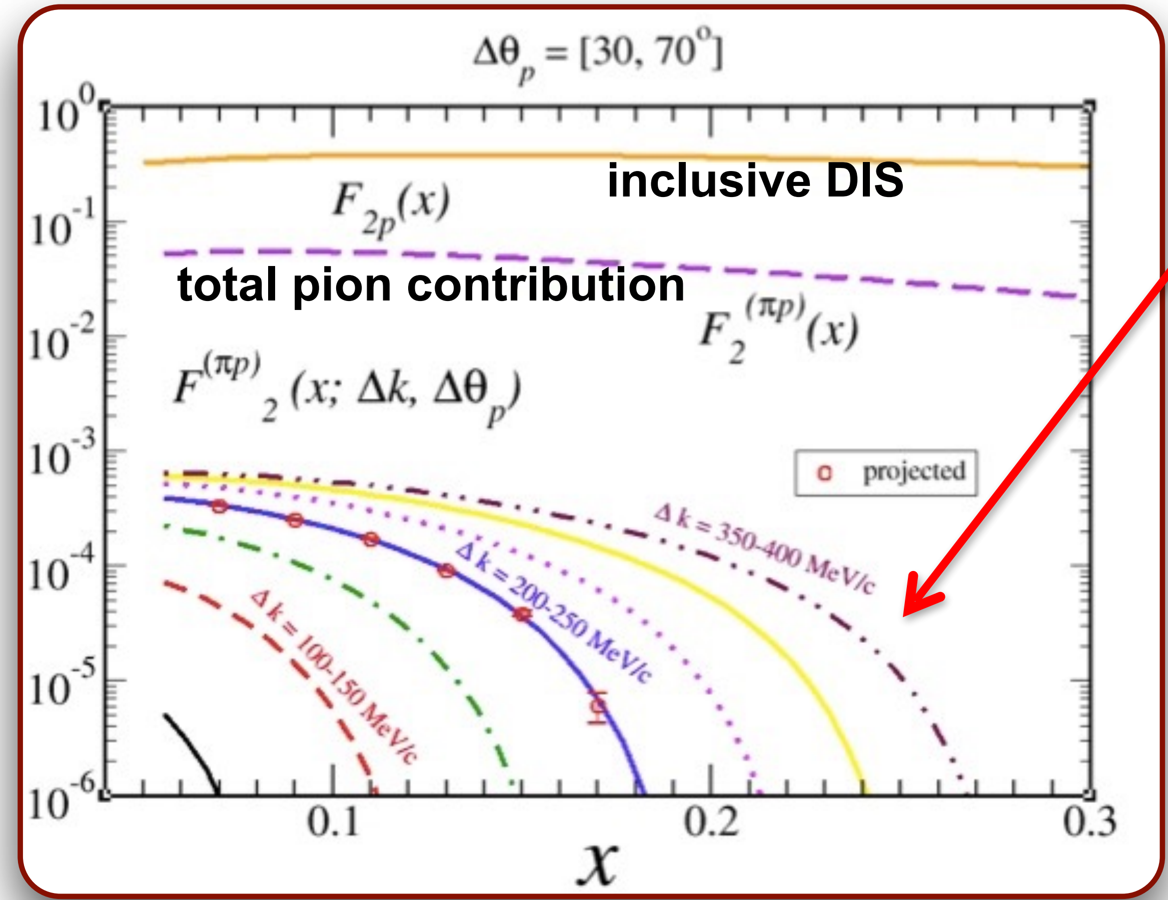
The proton of interest can be separated from accidentals using vertex reconstruction.

Will require a level-3 trigger or a streaming DAQ



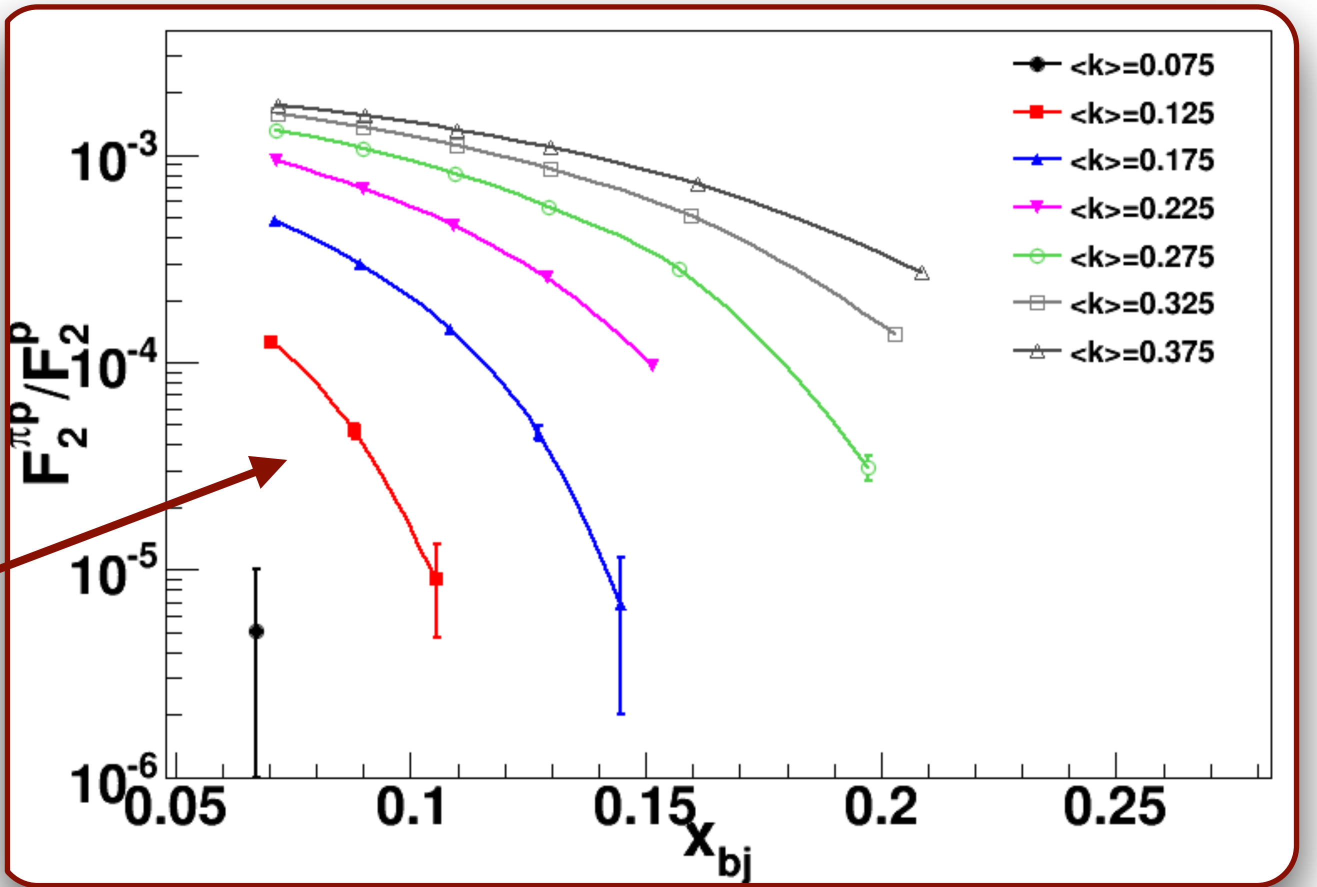
The TDIS experiment will measure tagged structure functions for protons and neutrons

proton target



Colored lines are pion contribution for different bins in p_{proton}

Data for 200 < p_{proton} <250 MeV/c are representative to show uncertainty



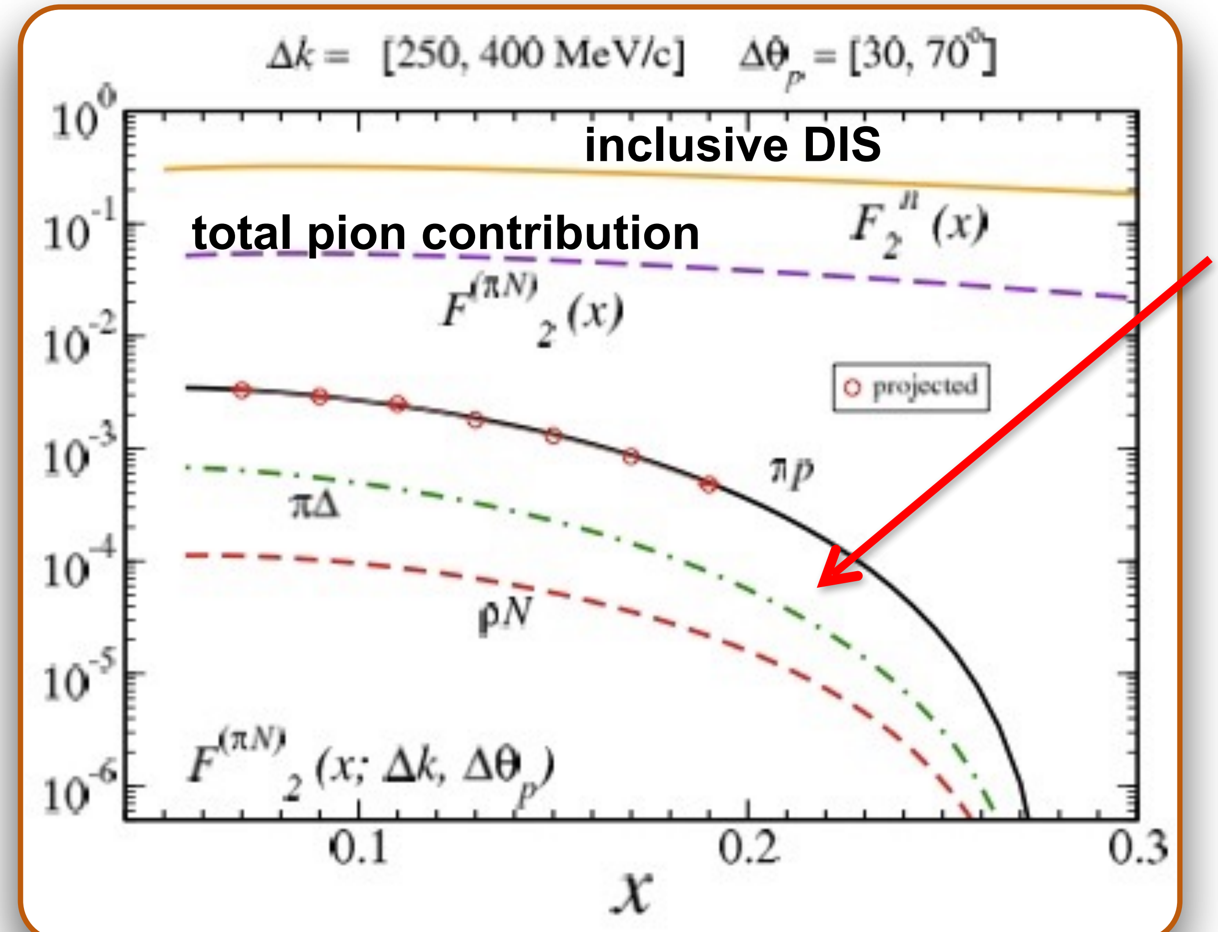
Full momentum range (collected simultaneously)

- all momentum bins in MeV/c

Error bars largest at highest x points

- at fixed x, these are the lowest t values

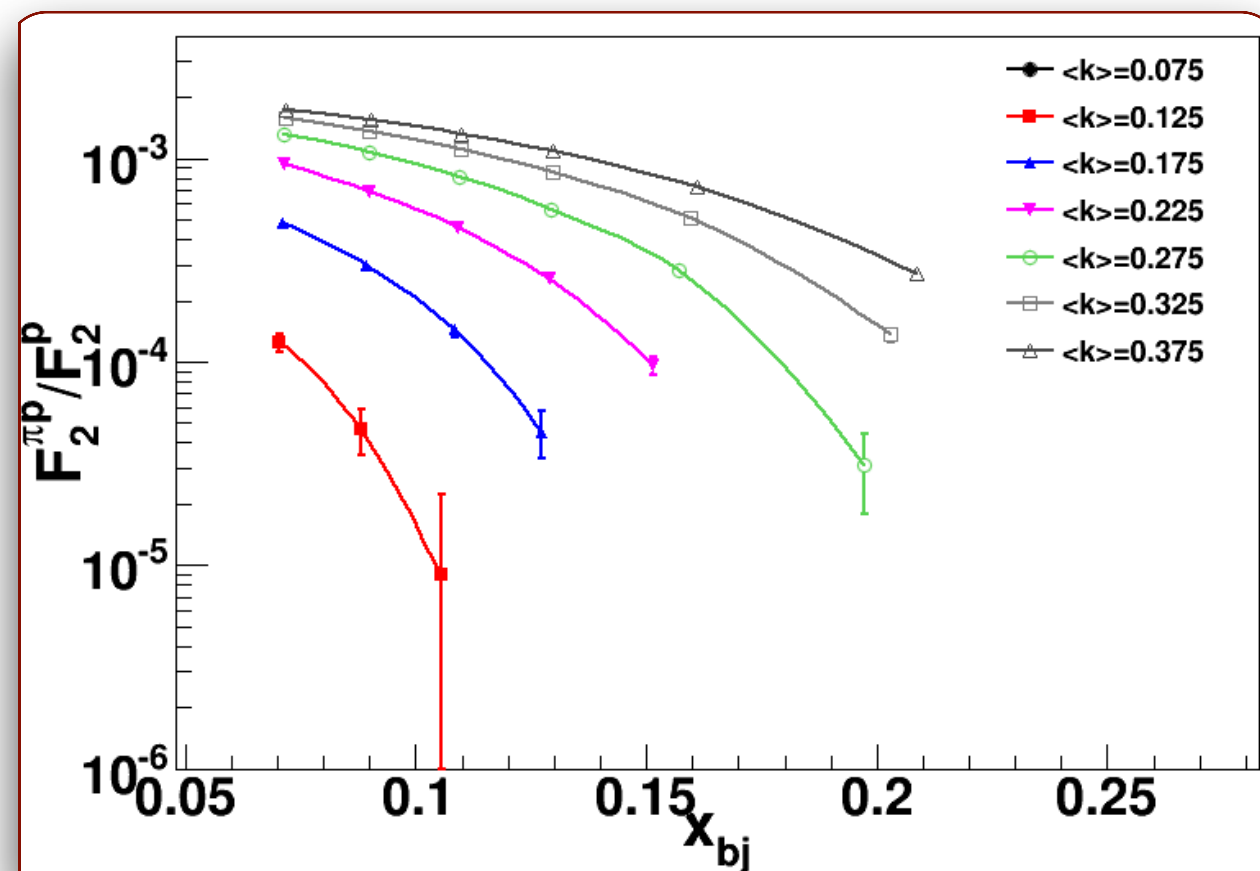
The TDIS experiment will measure tagged structure functions for protons and neutrons



neutron target

Colored lines are expected *total* Delta and rho contribution for 250 < p_{proton} < 400 MeV/c.

Data for pion contribution are representative to show uncertainty



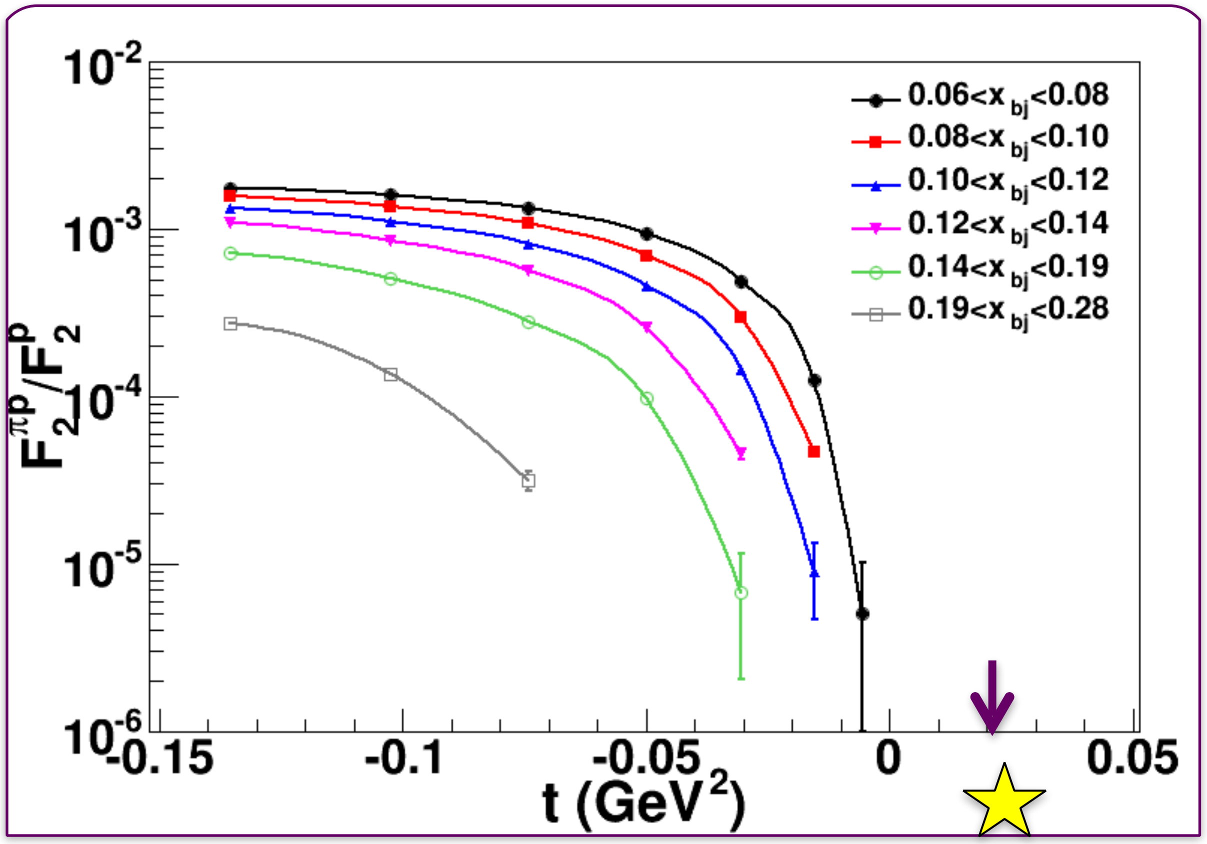
Full momentum range (collected simultaneously)
- all momentum bins in MeV/c

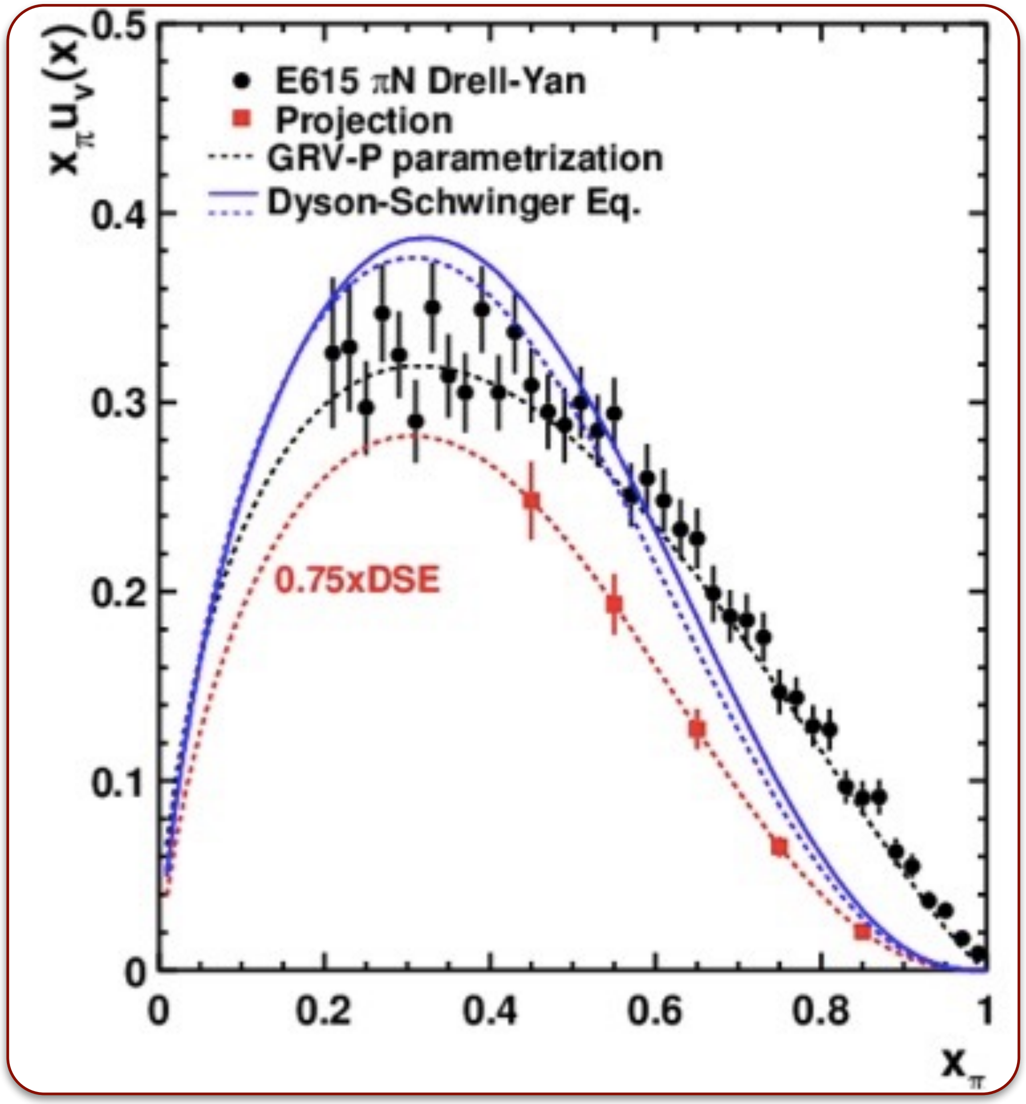
run at lower luminosity due to larger background

The TDIS experiment will also extract the pion structure function.

- Large x structure of the pion is of particular recent interest, verify resummed Drell-Yan results
- Q^2 range will check evolution
- Large x, low Q complementary to HERA low x, high Q

- Low t extrapolation to the pion pole

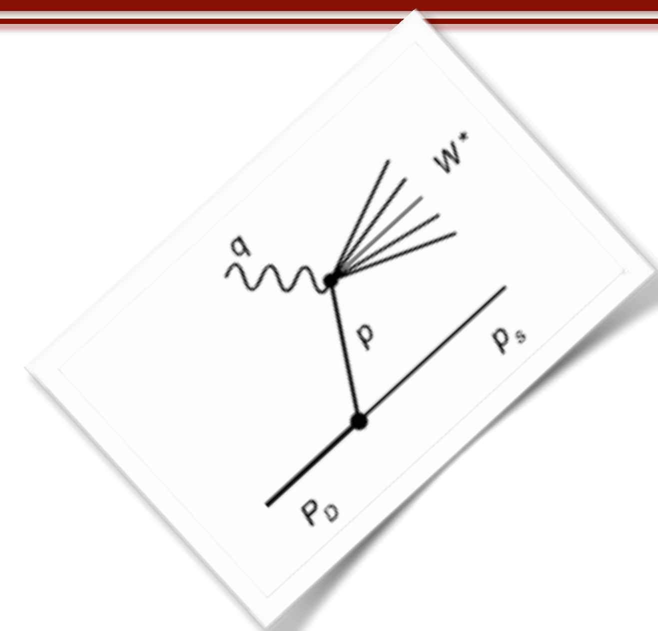




Will also measure n, p (π^-, π^0) difference
- look for isospin dependence

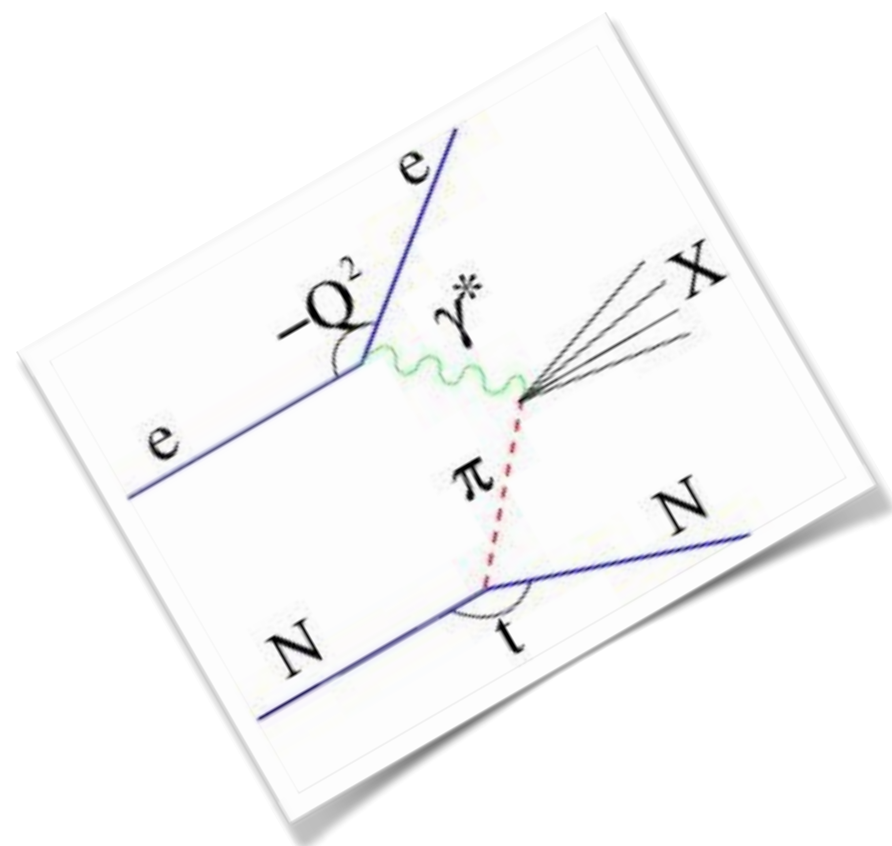
Outline

1. **Introduction**
   - Mesonic content of nucleons

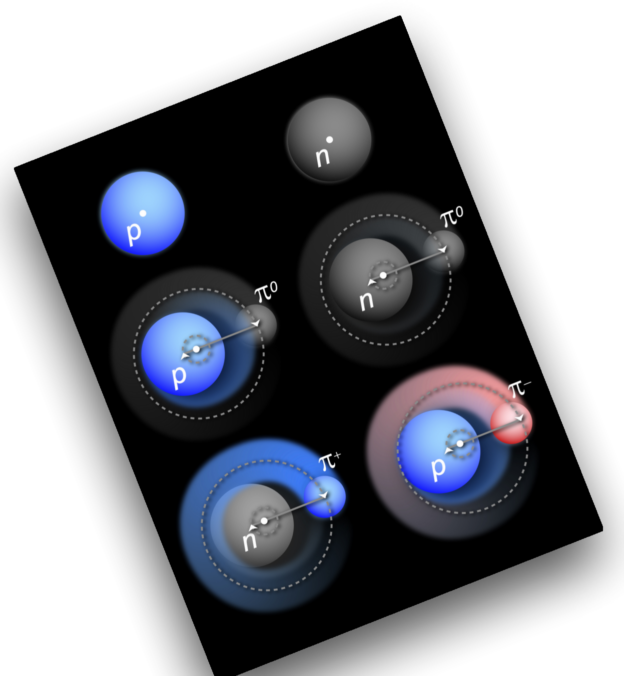


2. **Tagged structure functions**
   - Sullivan process and access to meson cloud of nucleon
   - New experiment at JLab12

3. **Tagged DIS at an EIC**



3. **Summary**

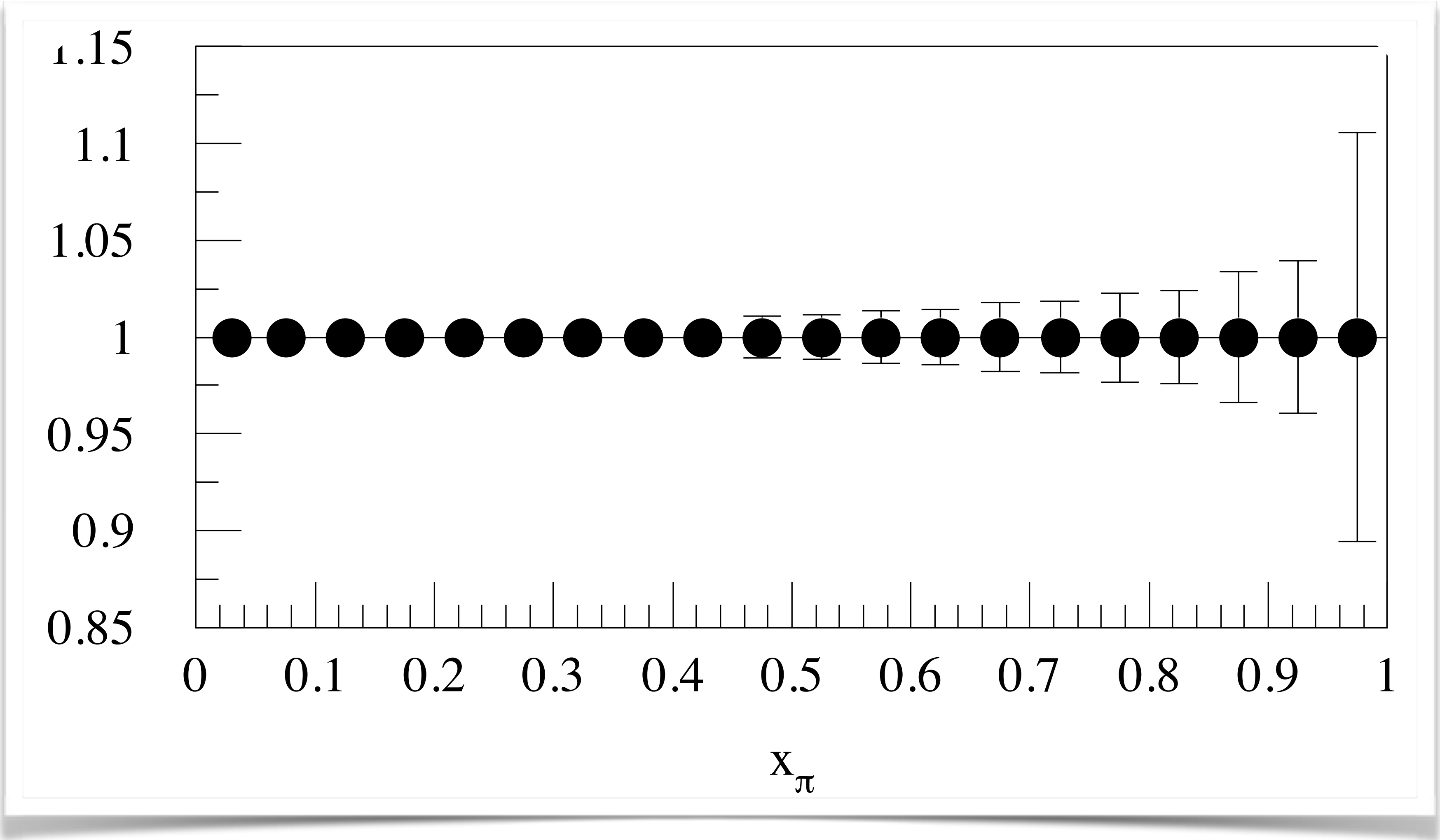


TDIS experiments at an EIC would cover a large kinematic range.

Simulated uncertainty for: 5 GeV e⁻ on 25 GeV p
spectator neutron tagging & luminosity = 10^{32} cm^{-2}s^{-1} (for 10^6 s)

Forward neutron angle < 50 mrad

Q^2 > 1 GeV^2



R. J. Holt & P. Reimer, AIP Conf. Proc. 588, 234 (2001)

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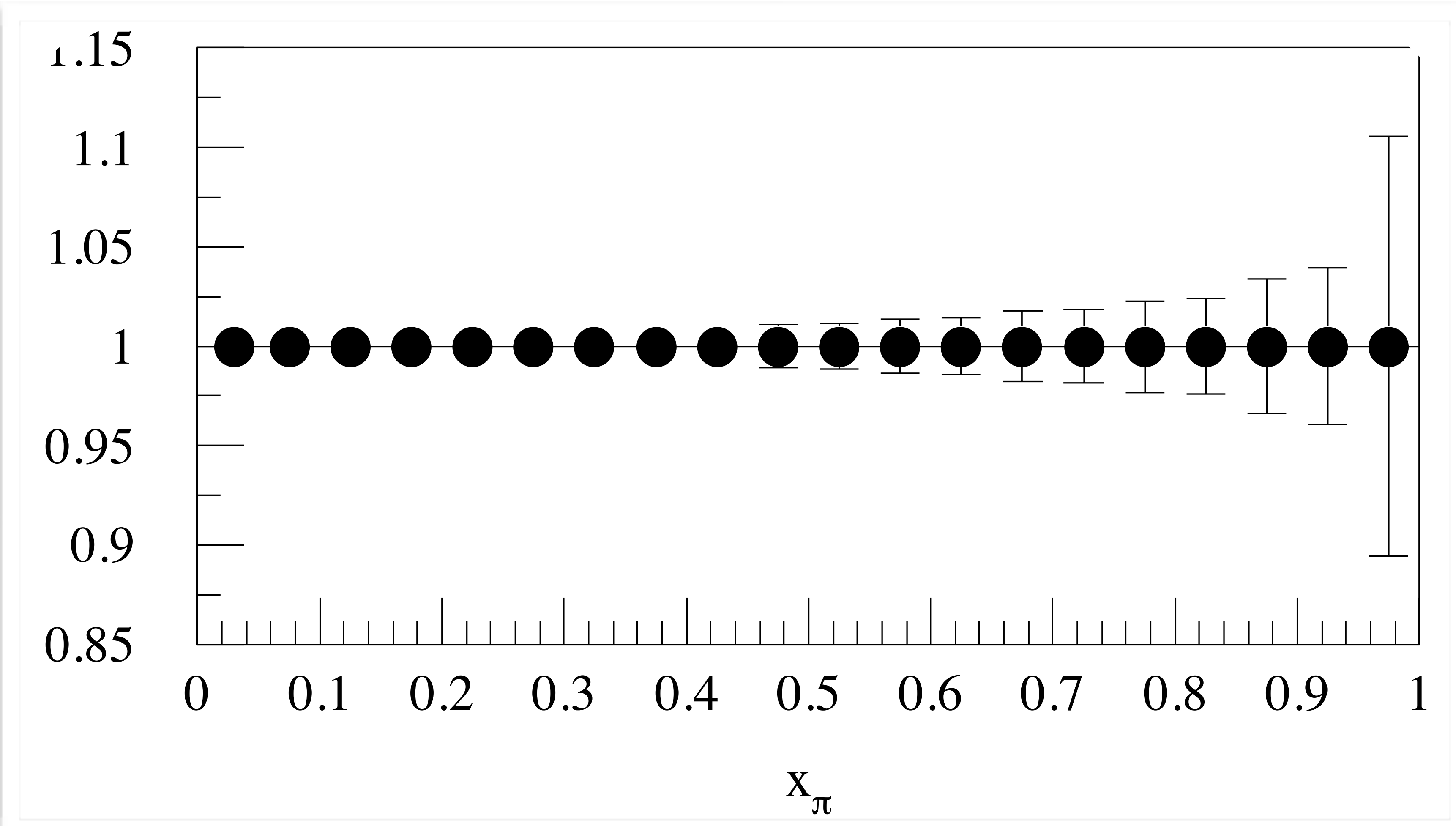

with forward protons detection kaon structure can be studied

with ^2H, ^4He beams, pion structure in nuclear medium can be studied.

K. Park working on simulation suite for tagged measurements at EIC

R. J. Holt & P. Reimer, AIP Conf. Proc. 588, 234 (2001)

Summary

1. Tagged DIS: Spectator tagging, provide new tools to study the structure of nucleons.

2. Spectator tagging can provide access to the mesonic content of the nucleon structure and the pion structure function.

3. A new experiments at JLab have been proposed to take advantage of these new avenues during the 12 GeV era.

4. These studies can be extended to a wide range of complimentary kinematics at an EIC.

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