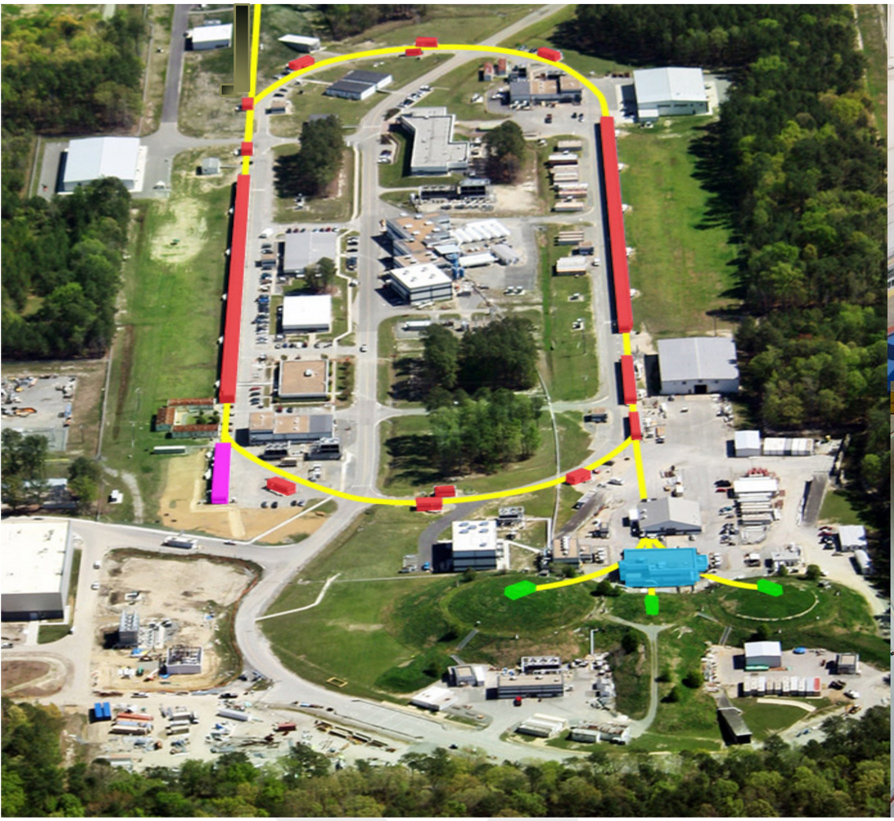
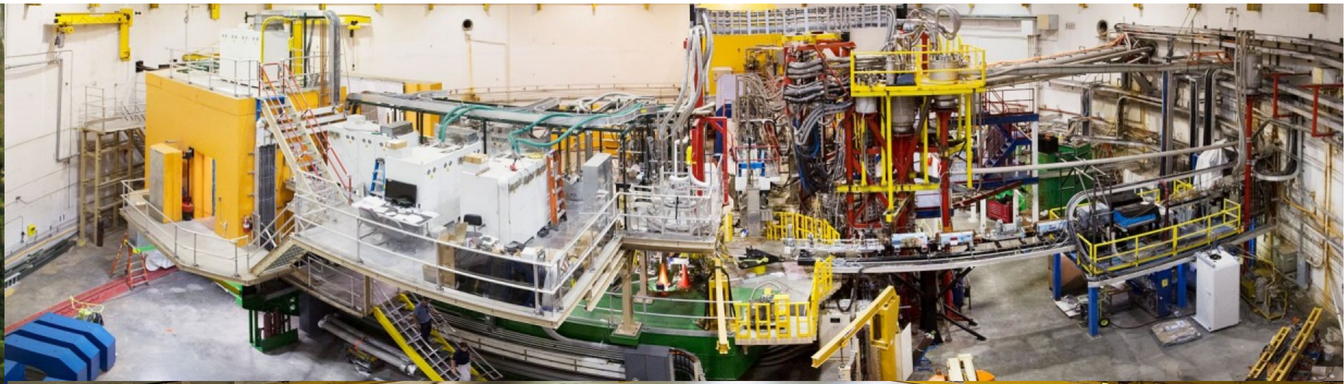
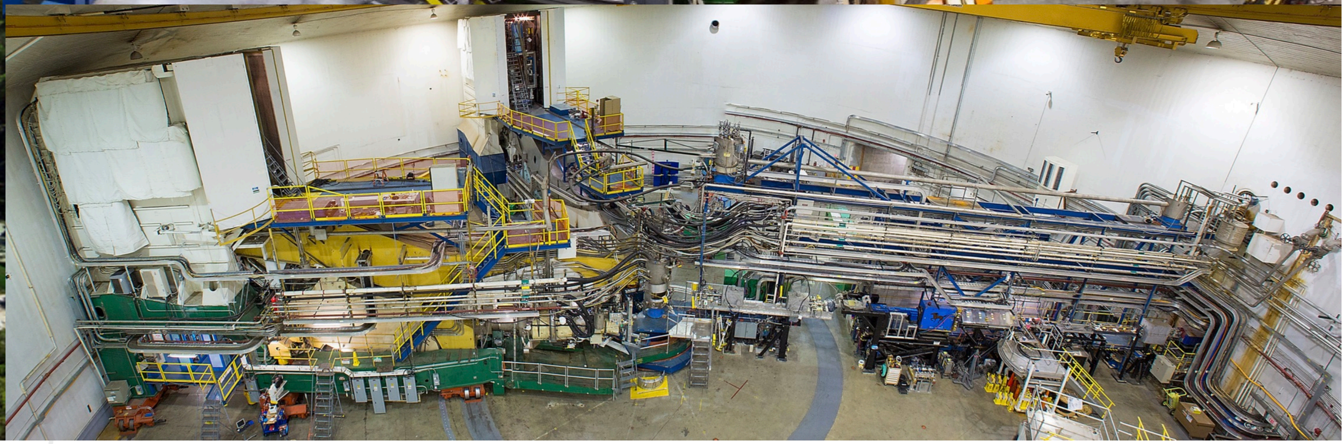
Tagged Deep Inelastic Scattering

Cynthia Keppel
Thomas Jefferson National Accelerator Facility







Exploring QCD with Light Nuclei at the EIC
Stony Brook University
January 2020

Jefferson Lab

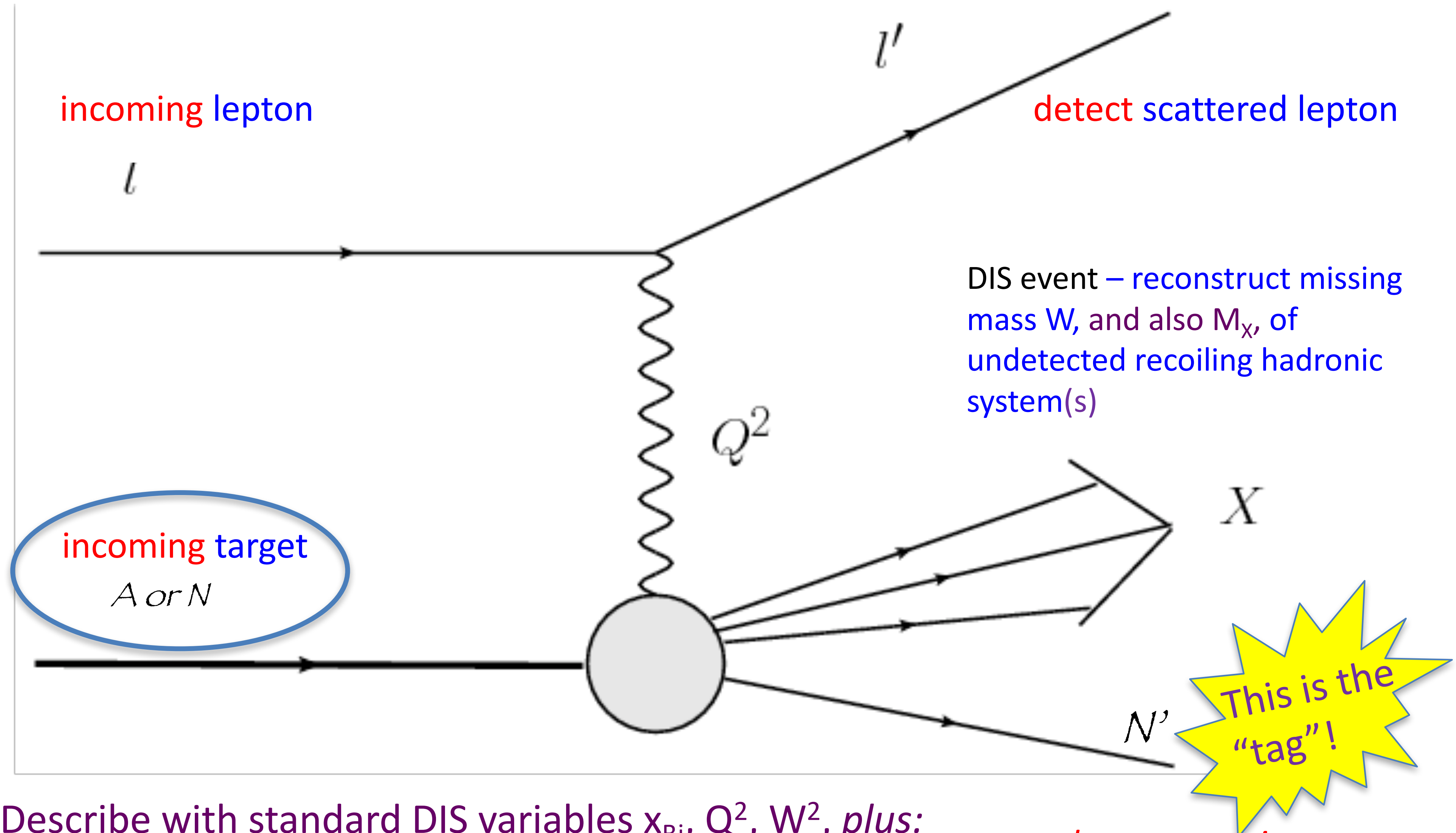
U.S. DEPARTMENT OF ENERGY | Office of Science

JSA

Tagged Deep Inelastic Scattering (TDIS)

- Semi-inclusive deep inelastic scattering technique
  - but *not* to access the current regime
- "Tagging" facilitates effective *targets* not readily found in nature
- Tagged DIS provides novel probe of partonic structure of these effective targets

Tagged Deep Inelastic Scattering:
Basic Experimental Approach



detect outgoing target nucleon

Describe with standard DIS variables x_{Bj}, Q^2, W^2, *plus:*

M_x = mass of system X

t = four-momentum transfer squared at the nucleon vertex

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- *Three examples:*
- Neutron
- Pion
- Kaon

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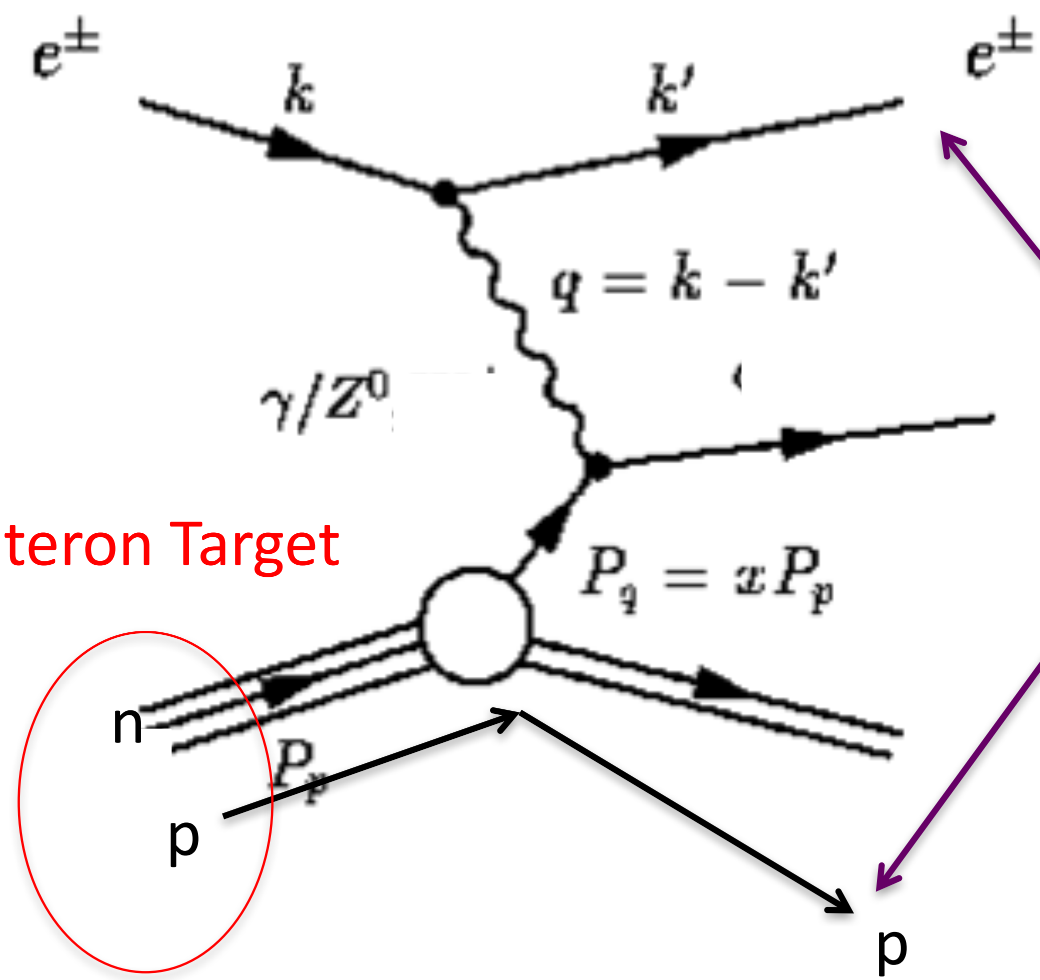
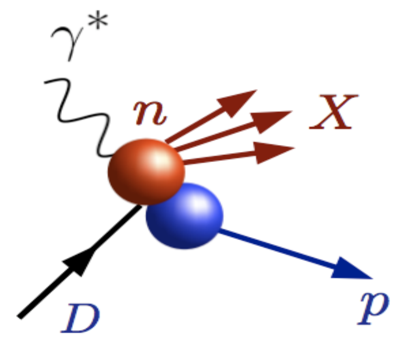
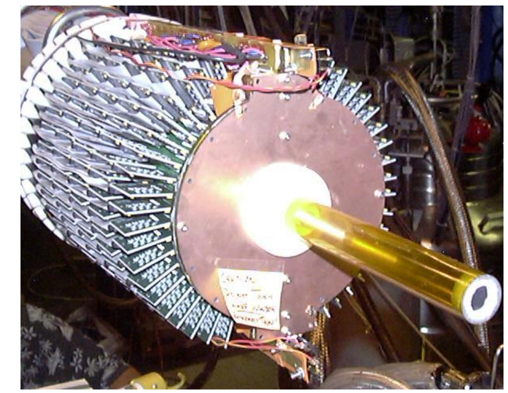
Example 1: TDIS to access neutron valence structure

"BONuS" Experiment at Jefferson Lab – use fixed target tagging to create an effective ***free neutron*** target

Deuteron Target



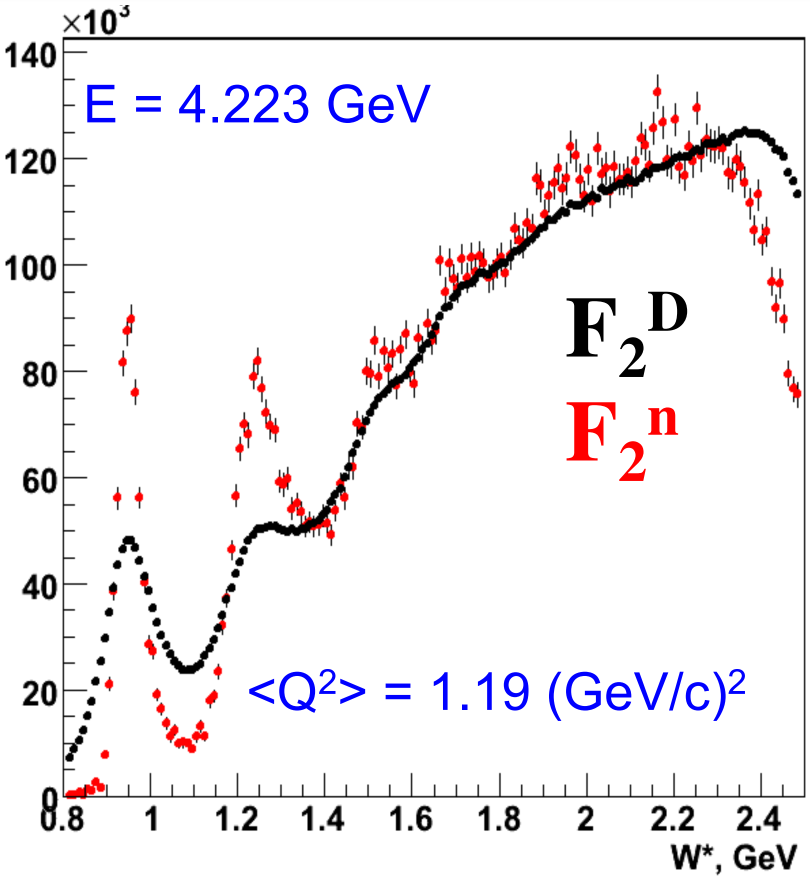




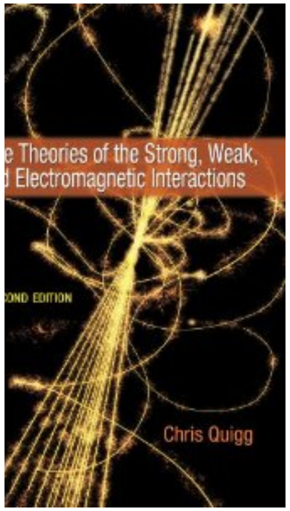
Measure DIS electron in coincidence with proton tag in novel GEM-based low mass detector

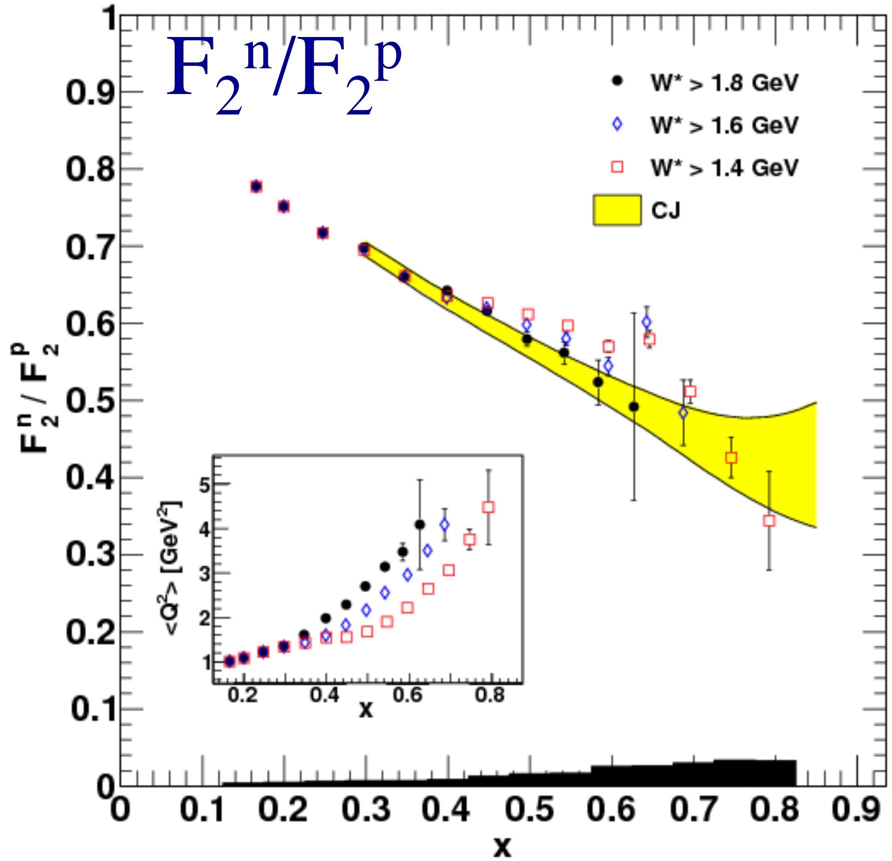
- Protons at ***low*** momentum
  - Optimize bound/free nucleon structure
  - *~70 MeV/c, challenging!*
- Protons at backward angle
  - Minimize final state interactions

Low momentum proton tagging *achieved*



Textbook Physics



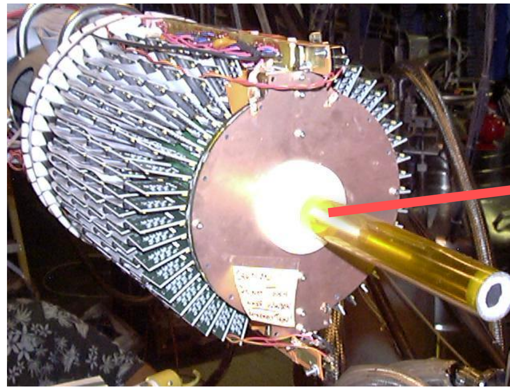


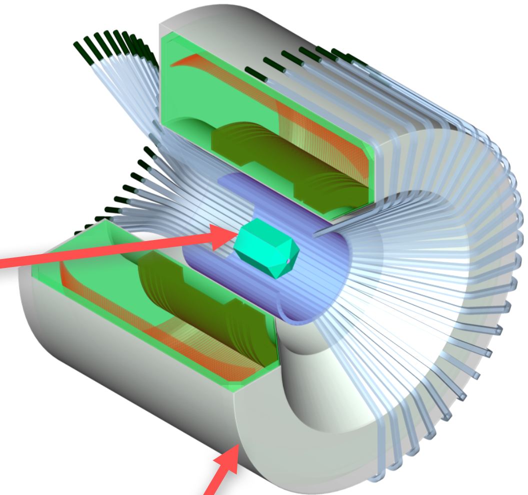
> 400 *neutron* data points!

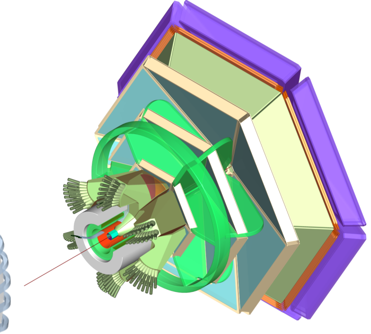
- Input for global PDF fits
- Measure EMC effect in deuterium
- Neutron duality studies
- Still lower W, Q^2 than desirable….

Nucl. Instrum. Meth. A592 (2008) 273-286
Phys. Rev. Lett. 108 (2012) 199902
Phys. Rev. C89 (2014) 045206 – editor's suggestion
Phys. Rev. C92 (2015) 1, 015211
Phys. Rev. C91 (2015) 5, 055206

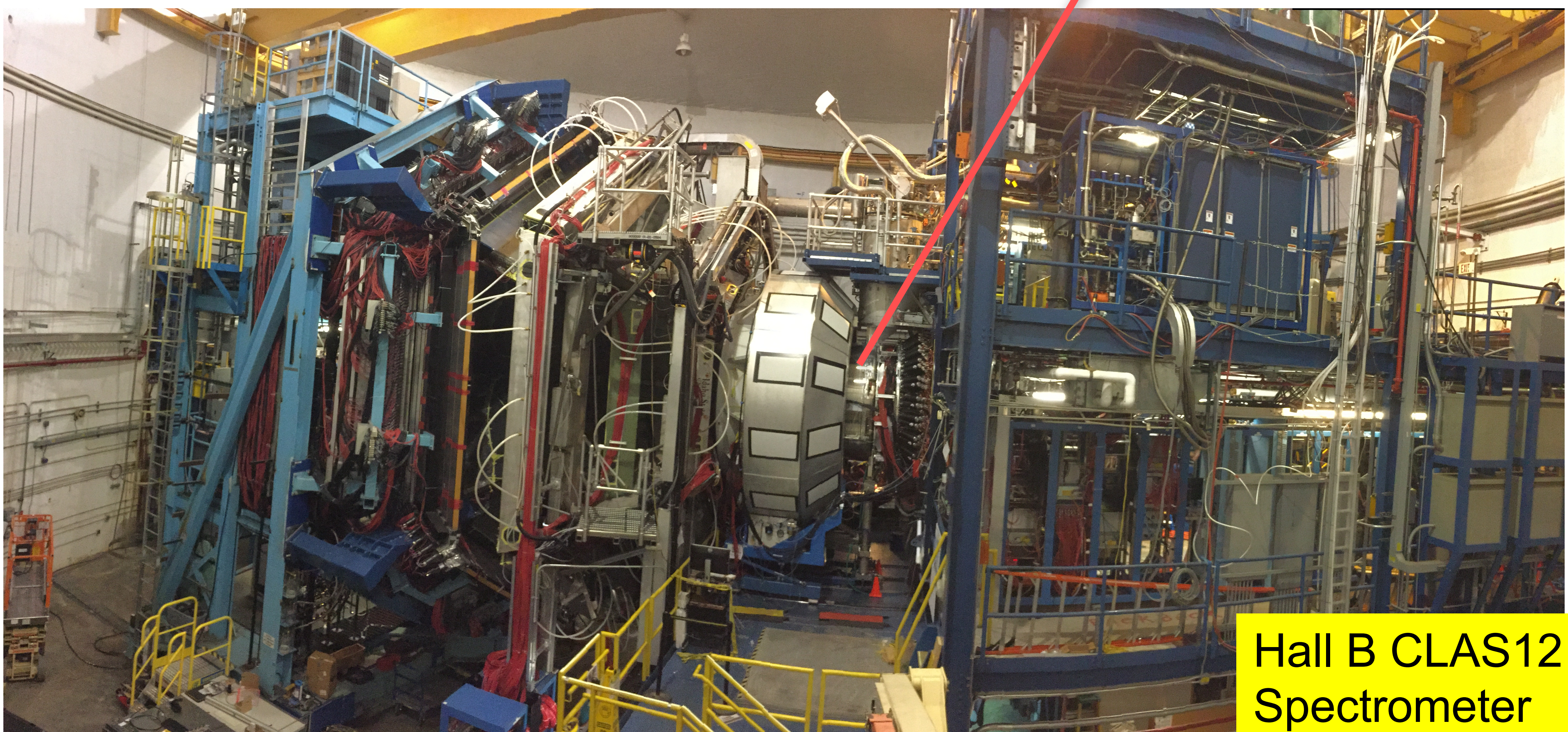
E12-06-113 "BONUS12": Larger x and higher Q^2







CLAS12 Central Detector



Hall B CLAS12 Spectrometer

RTPC UNDER CONSTRUCTION

Preparing for 2020 installation!

Removal of glued capton cylinder using puller mechanism

Self aligning puller assembly

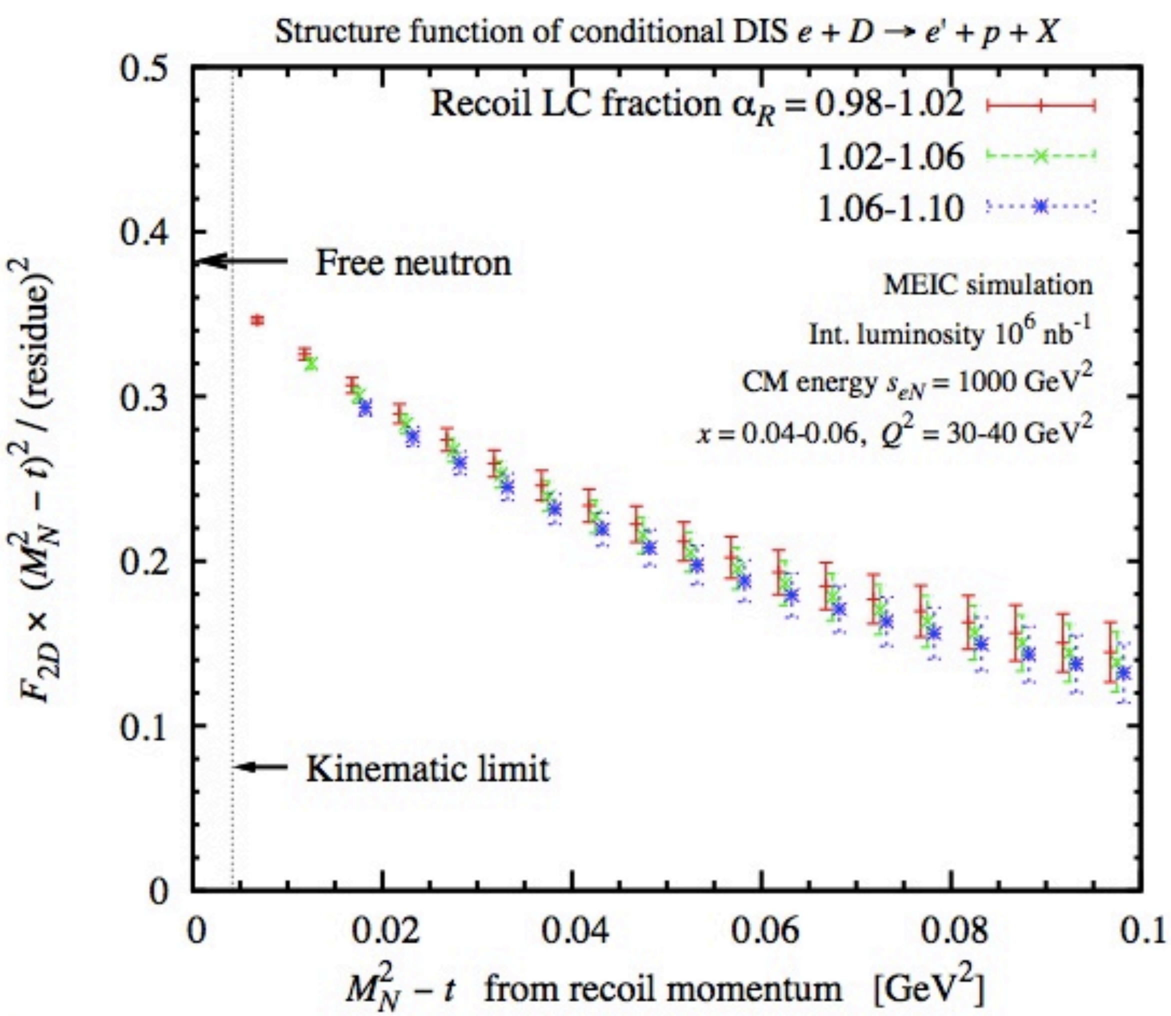
Tagged Neutron Structure at an Electron Ion Collider

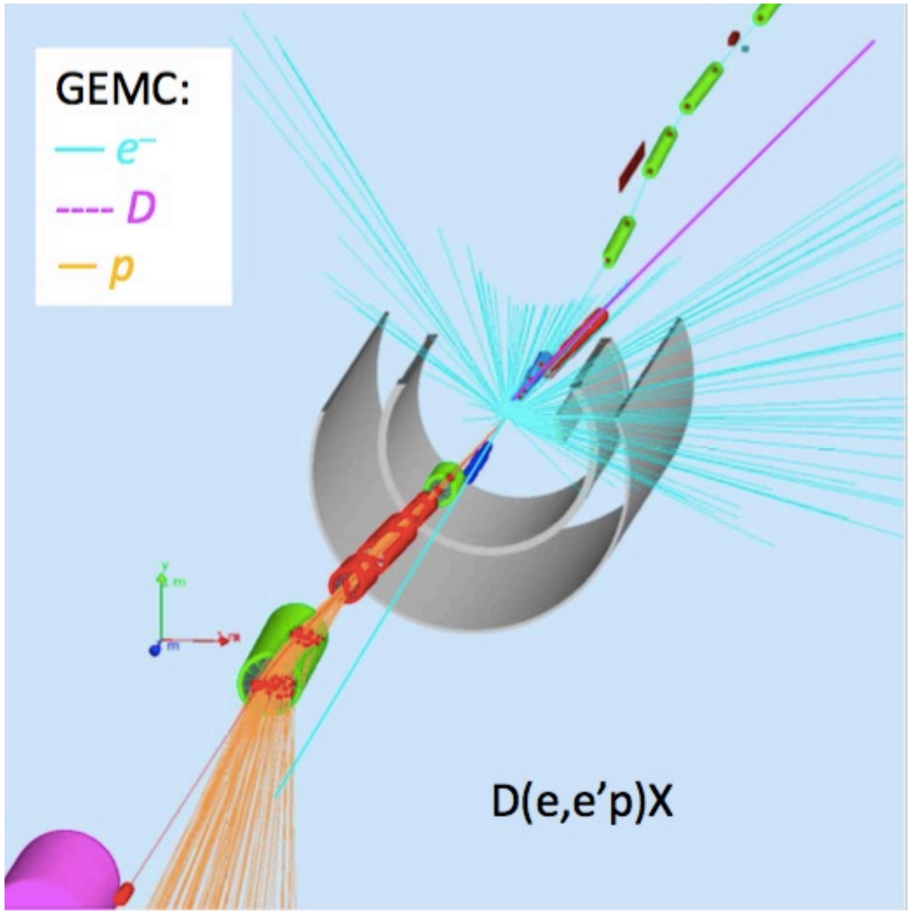
The TDIS technique is better suited to colliders: no target material absorbing low-momentum nucleons, forward acceptance only! Need:

- good momentum resolution (ΔpT ~20 MeV, < Fermi momentum)
- small intrinsic momentum spread in the ion beam for accurate reconstruction

EIC being designed with this physics in mind – neutron structure functions at high Q^2

e + D → e' + p + X *a la BONUS*





See Spectator Tagging Project at https://www.jlab.org/theory/tag/

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Abundant Evidence for *Some* Mesonic Content of the Nucleon

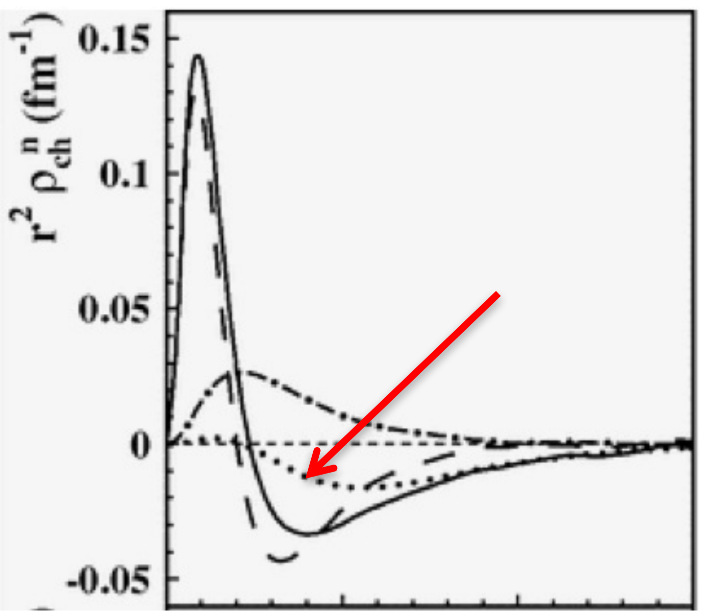
PHYSICAL REVIEW VOLUME 72, NUMBER 12 DECEMBER 15, 1947

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)

ment equal to $e\hbar/2\mu c$, we are led to the estimate that the average number of mesotrons near a neutron is 0.2. Therefore, in calculating the nu-

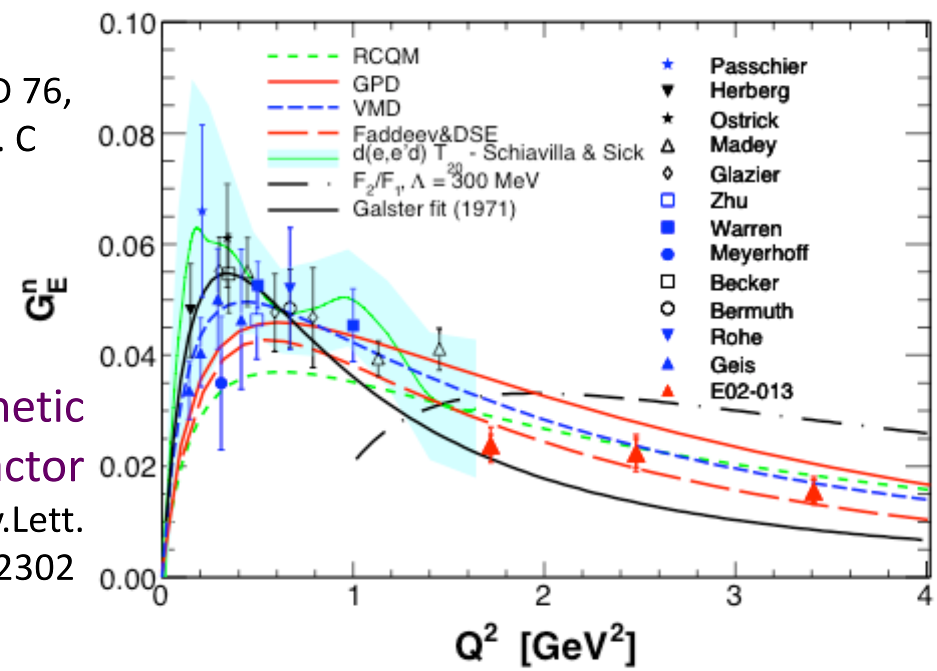


Neutron Charge Density

Pasquini and Boffi, Phys. Rev. D 76, 074011 (2007) Kelly, Phys. Rev. C 66, 065203 (2002)

Neutron Electromagnetic Form Factor

S. Riordan et al., Phys.Rev.Lett. 105 (2010) 262302



Neutron has no charge, but it **does** have a charge distribution:

$$n = p + \pi^-$$

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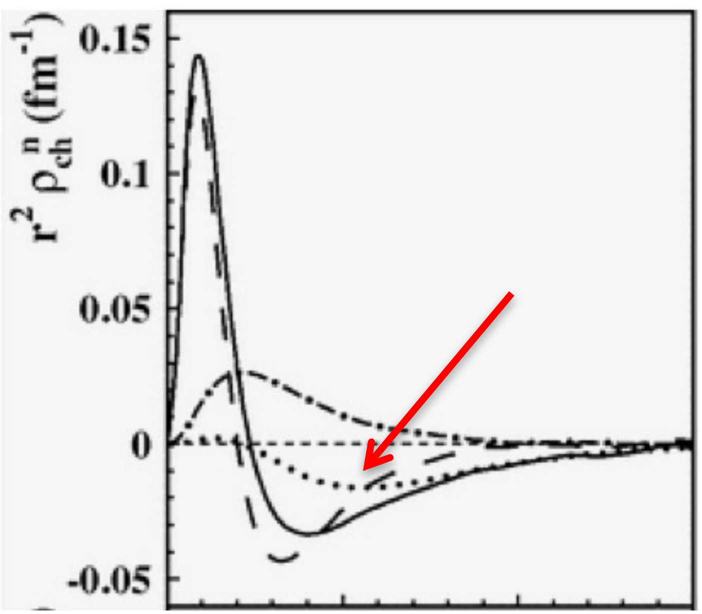

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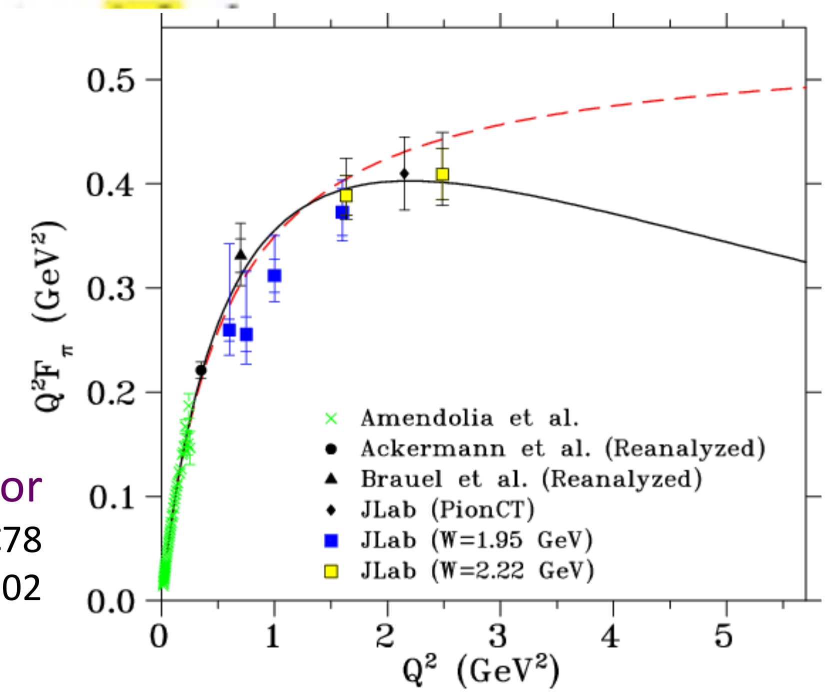
Blok et al., Phys.Rev. C78 (2008) 045202



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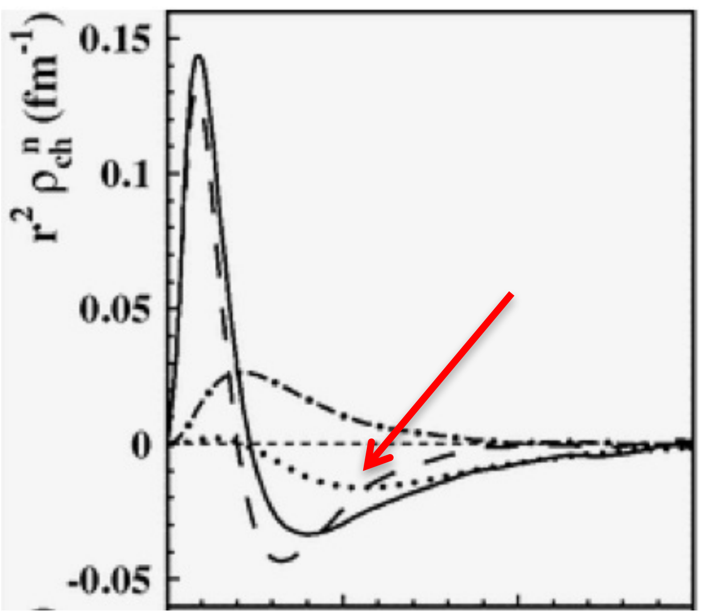

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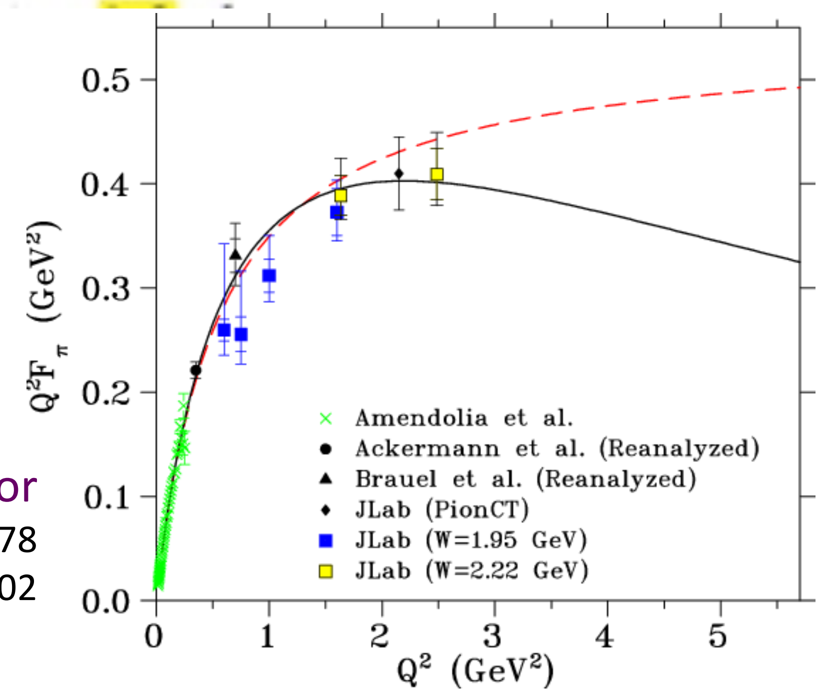
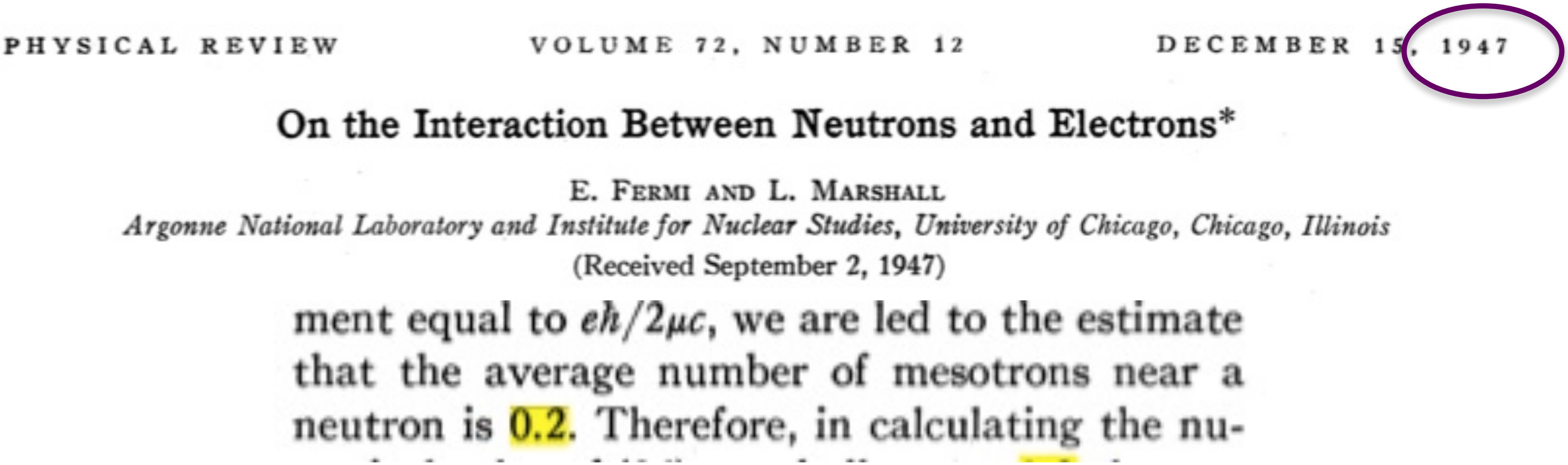


- Partially conserved axial current, chiral quark models, vector meson dominance models - ***substantial, successful theory development***

Abundant Evidence for *Some* Mesonic Content of the Nucleon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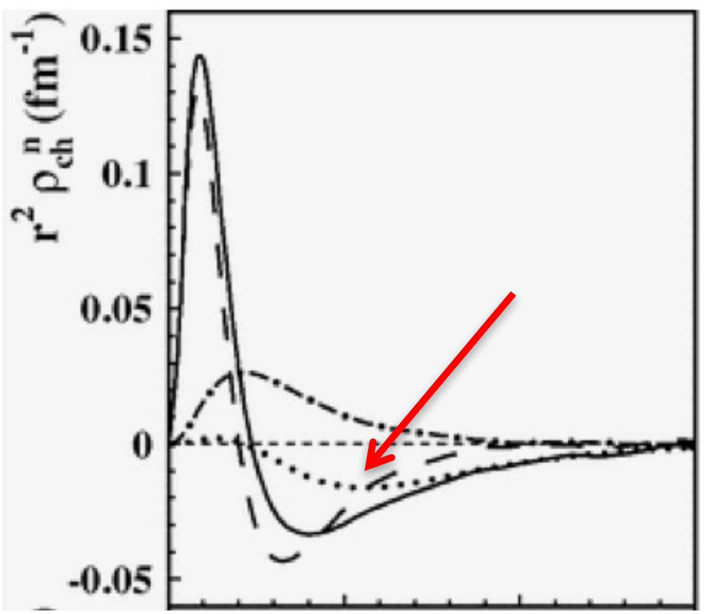

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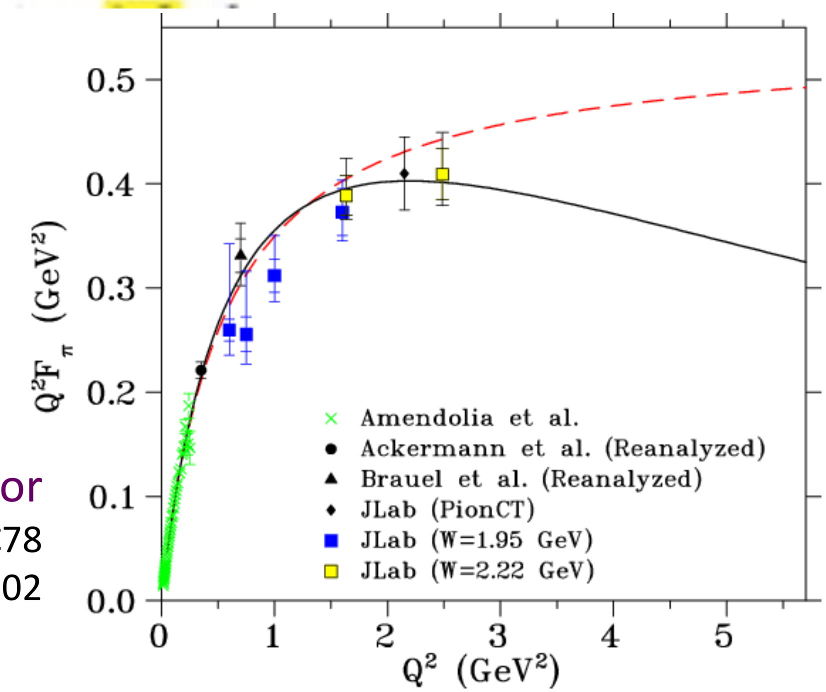


- Partially conserved axial current, chiral quark models, vector meson dominance models - ***substantial, successful theory development***
- ***In contrast, scant experimental data*** – do not know magnitude of mesonic content

Why are we interested in the pion?

The pion is *fundamental.*

- Plays a key role in nucleon and nuclear structure
- Dual role....

Viewed one way, the pion is the simplest hadron with only two valence quarks.

- Should be (relatively) easy to model, a test bed for predictions

Viewed another way, it is highly complex.

`

- Dressed quark-antiquark bound state
- QCD's Nambu-Goldstone boson, associated with dynamic chiral symmetry breaking

Critical role in long-range nucleon-nucleon interaction

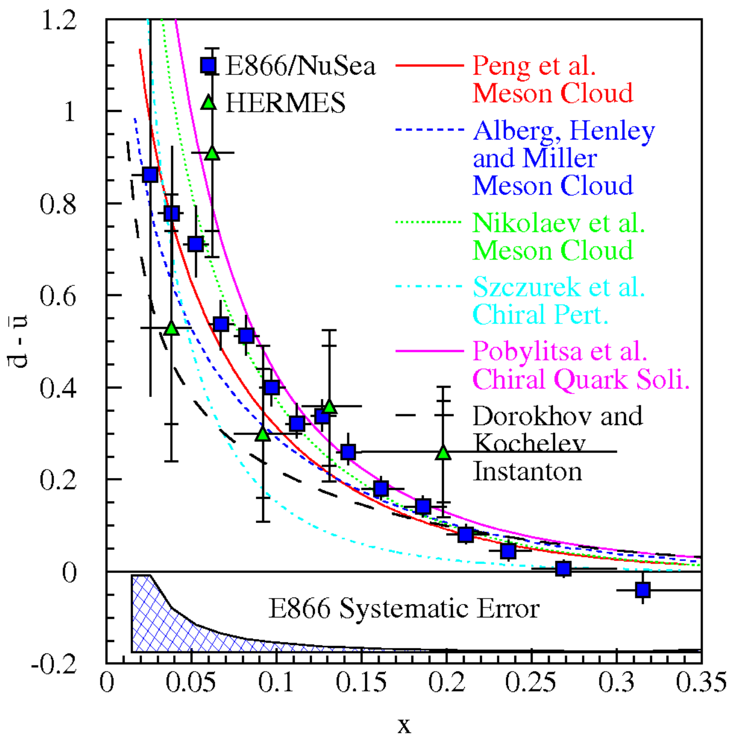
- Yukawa particles of the nuclear force – but no evidence for excess of nuclear pions or anti-quarks

Could be the origin of the nucleon d(bar) – u(bar) flavor asymmetry

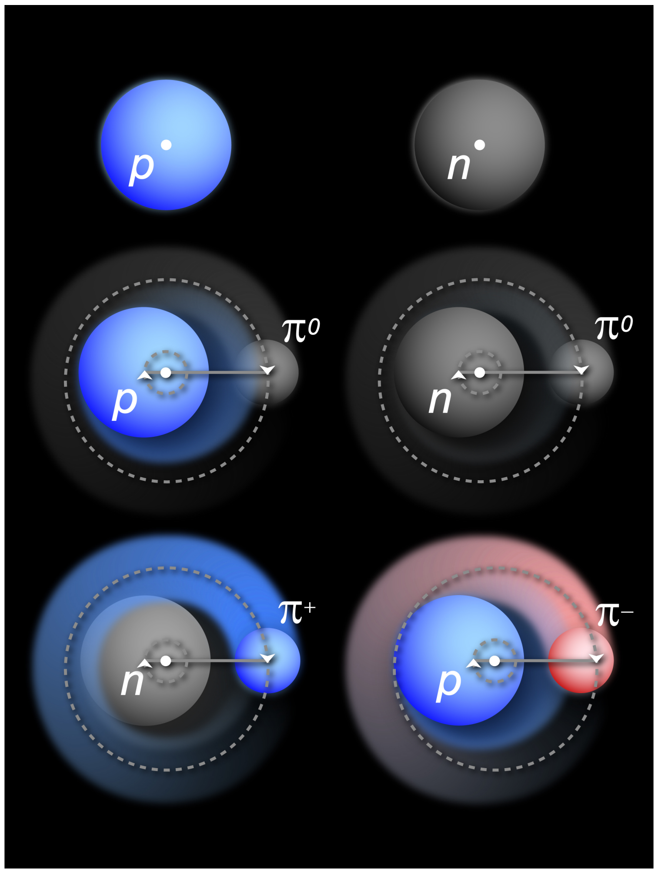
Pion parton distributions play a role in nucleon and nuclear parton distributions

- QCD tells us how the parton distributions evolve, but need measurements to obtain PDFs.

Essentially only two Pion Structure Function measurements exist to date....



Example 2: TDIS to access pion structure function
- use Sullivan process scattering from nucleon-pion fluctuation

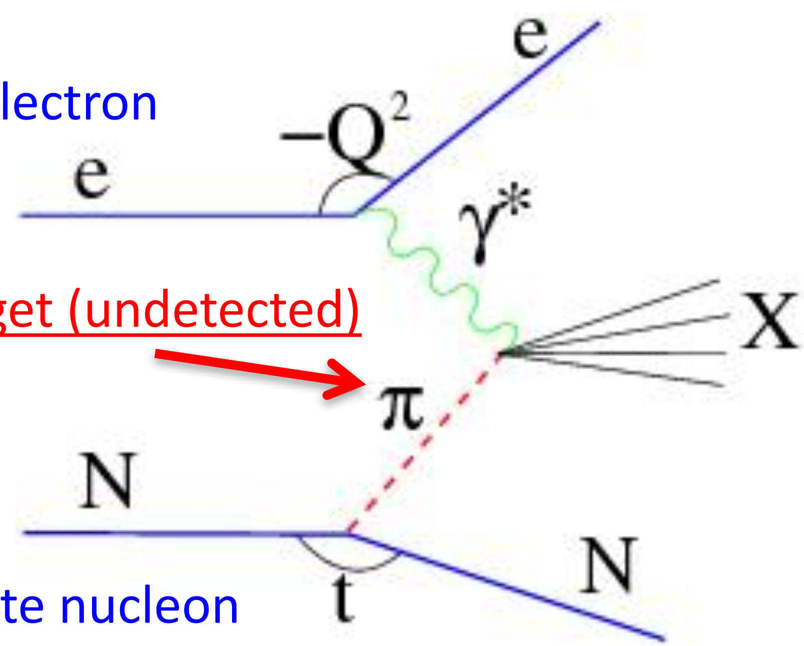


Proton can be
$p + \pi^0$ or $n + \pi^-$

detect scattered electron

incoming electron

pion target (undetected)



Initial state nucleon

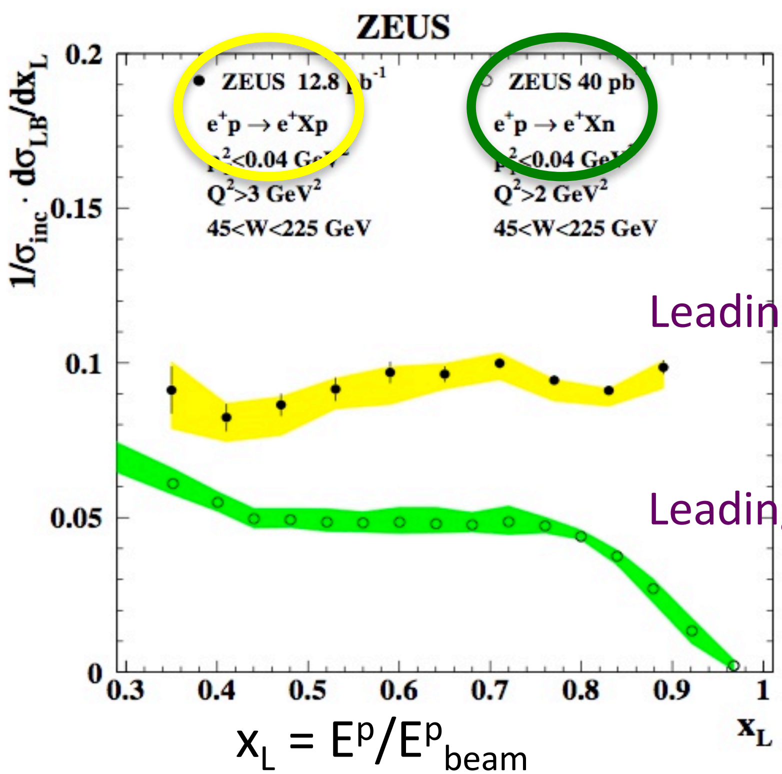
tagged outgoing target nucleon

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

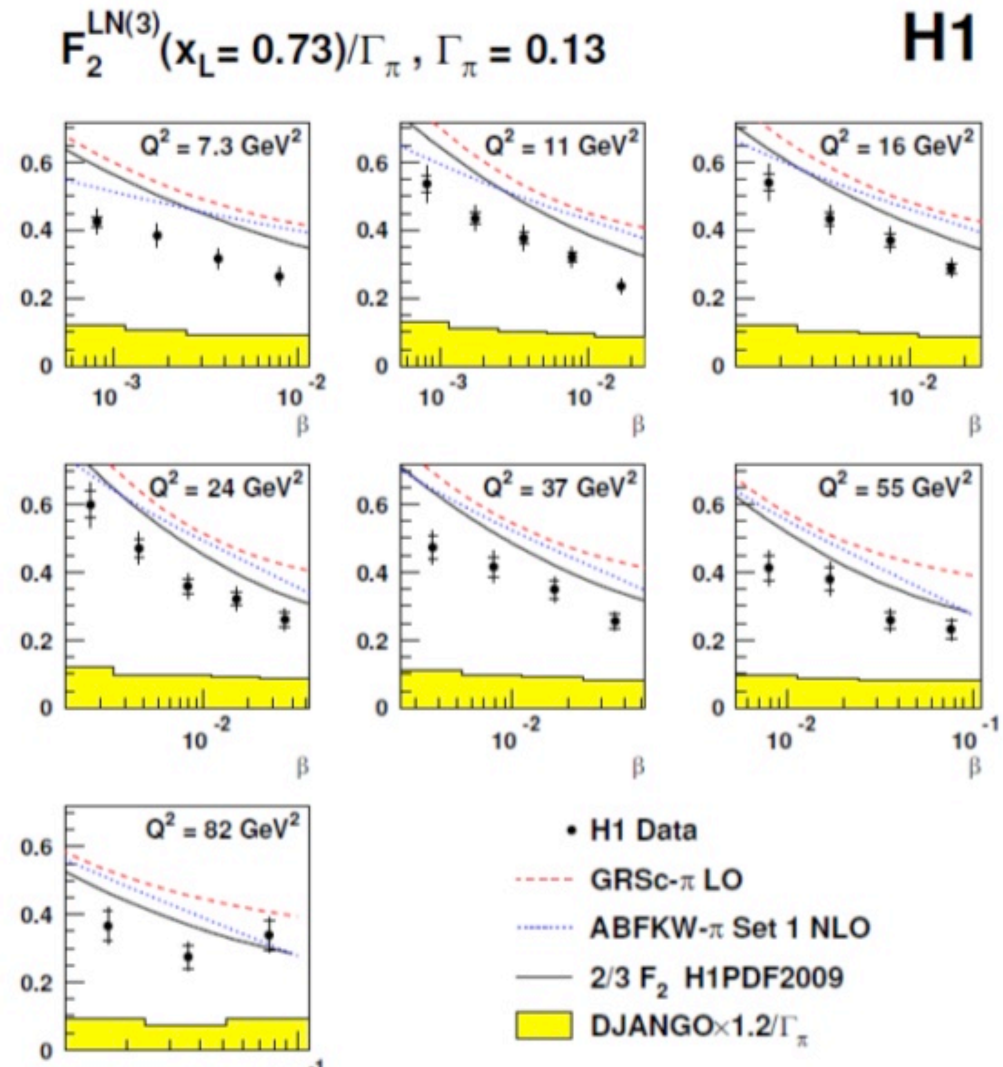
- t = four-momentum transfer squared at the nucleon vertex

Pion Structure Function from TDIS Measurements at HERA

Total yield for $0.35<x_L<0.9$



$x_L = E^p/E^p_{beam}$



Pure isovector exchange

⇒ Lp= ½ Ln (isospin Clebsch-Gordon)

Data: Lp ≈ 2Ln

⇒ additional isoscalar exchanges for Lp

Proton isoscalar events include diffractive scattering – *the neutral pion is buried*

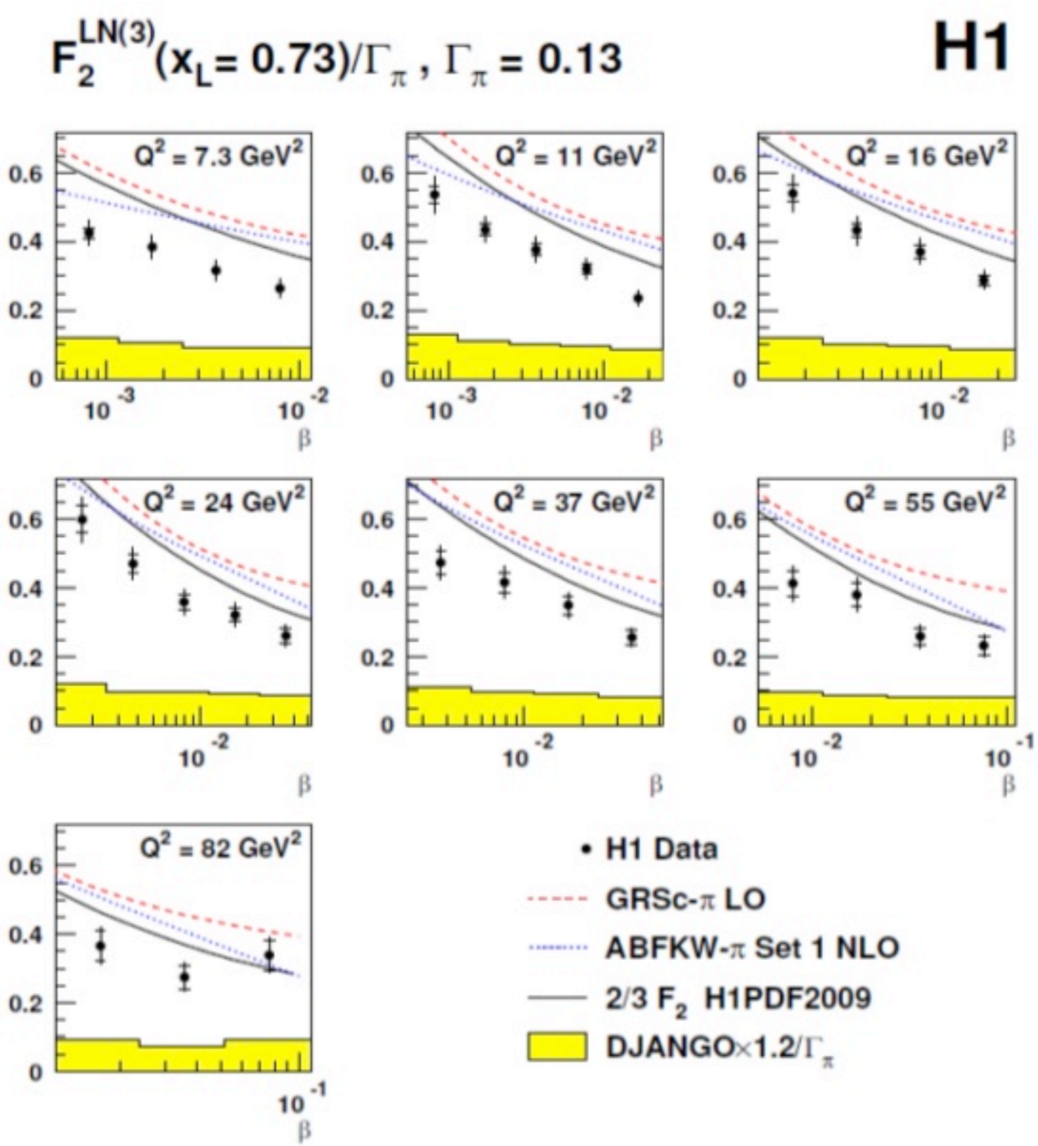
Leading neutron events isovector only, charged pions dominate →

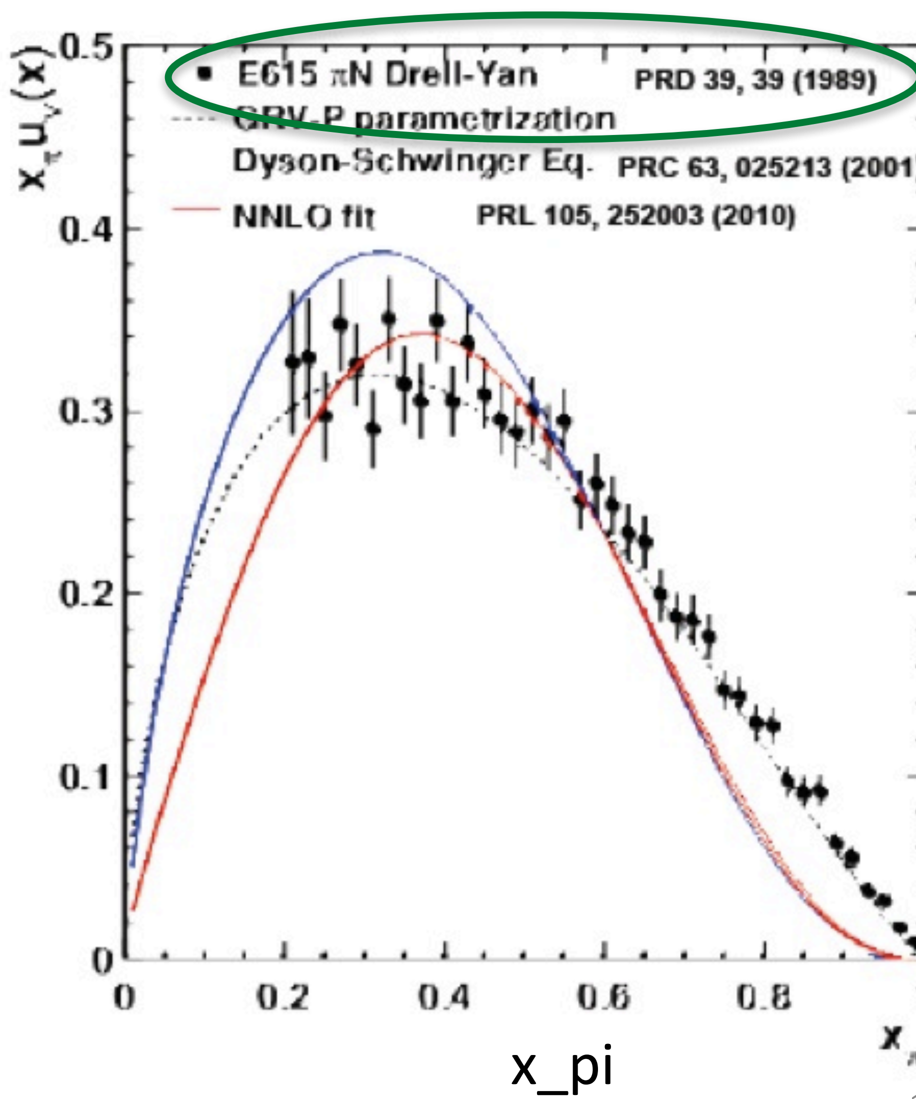
- *One pion exchange is the dominant mechanism.*
- *Can extract pion structure function*
- *Fine print disclaimer! Oversimplified (rescattering, absorption,…), requires in-depth model and kinematic studies*

DESY 08-176 JHEP06 (2009) 74

Pion Structure Function Measurements

- Knowledge of the pion structure function is ***very limited:***
  - HERA TDIS data - at low x
  - Pionic Drell-Yan from nucleons in nuclei - at large x



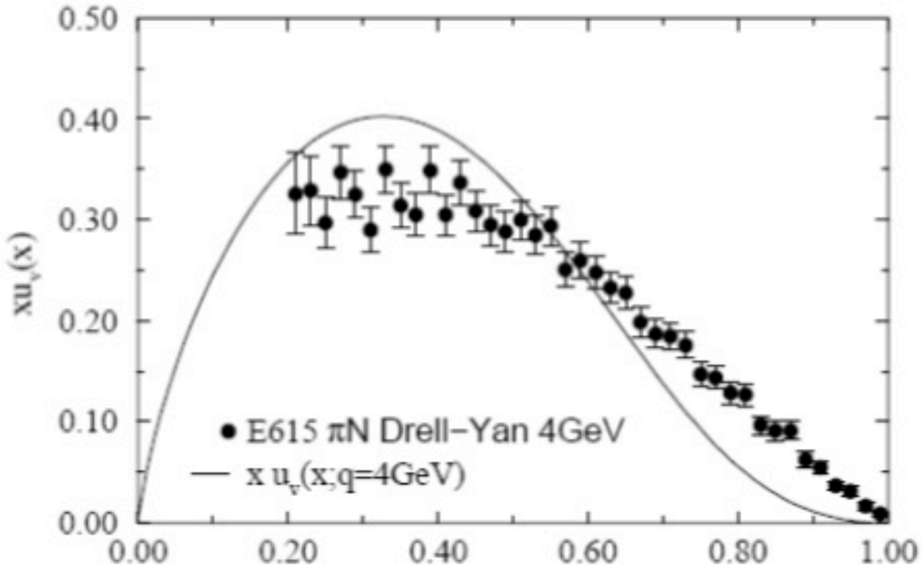


Pion Structure Function from Drell-Yan: Large x Concerns

Large x Structure of the Pion

Initial observations:

- PDF ~ $(1-x_\pi)$ as $x_\pi \to 1$
- Agrees with structureless model
- Differs from pQCD prediction of $(1-x_\pi)^2$

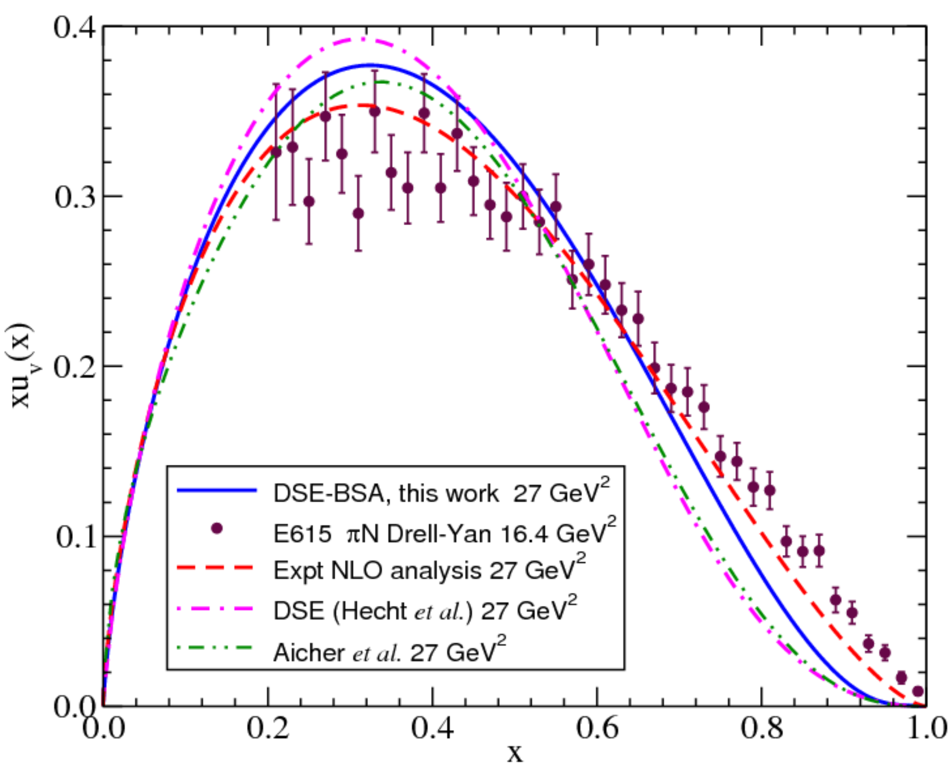


x_π

FNAL E615, CERN NA3,10

$$\pi^- W \rightarrow \mu^+ \mu^- X$$

$$\sigma \propto \bar{u}(x_{\pi^-}) u(x_N)$$



- Data do not agree with pQCD, Dyson-Schwinger, Light Front, Instanton,….*numerous models!*
- Problem with data analysis?
  - NLO fit
  - Improved proton PDFs
  - Sea quark contribution
  - More flexible extractions of PDFs
- Nuclear corrections needed?
- Soft gluon resummation shows "convex" shape (Aicher, Schäfer, Vogelsang, Phys. Rev. Lett. 105, 252003 (2010))

C.D. Roberts, IRMA Lect. Math. Theor.P hys. 21 (2015) 355-458 arXiv:1203.5341 [nucl-th]

Web-based Self-Serve Pion PDF: More Large x Concern

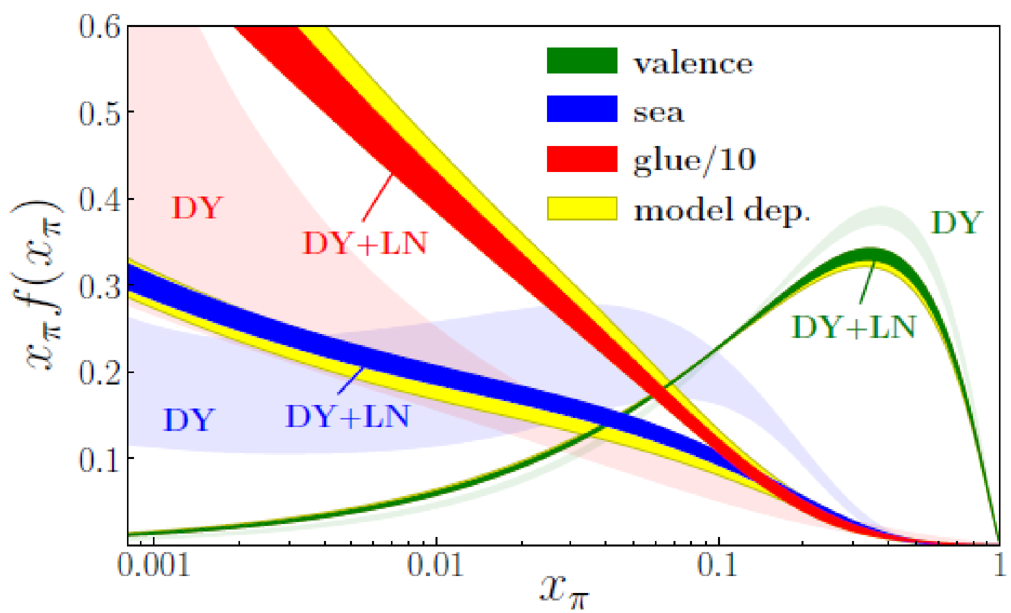
From combined HERA TDIS Leading-Neutron and Drell-Yan analysis…

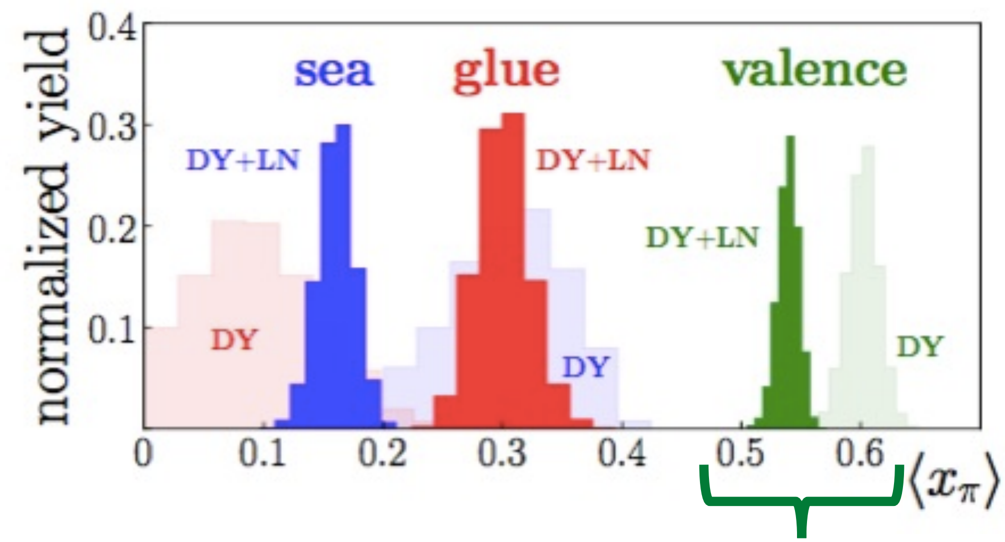
Web-based self-server performs a combined data analysis – can test sensitivity to new data

Github: https://github.com/JeffersonLab/jamfitter

Jupyter notebook: https://jupyter.jlab.org/

P.C. Barry, **N. Sato**, W. Melnitchouk, C-R Ji, Phys. Rev. Lett. 121 (2018) no.15, 152001

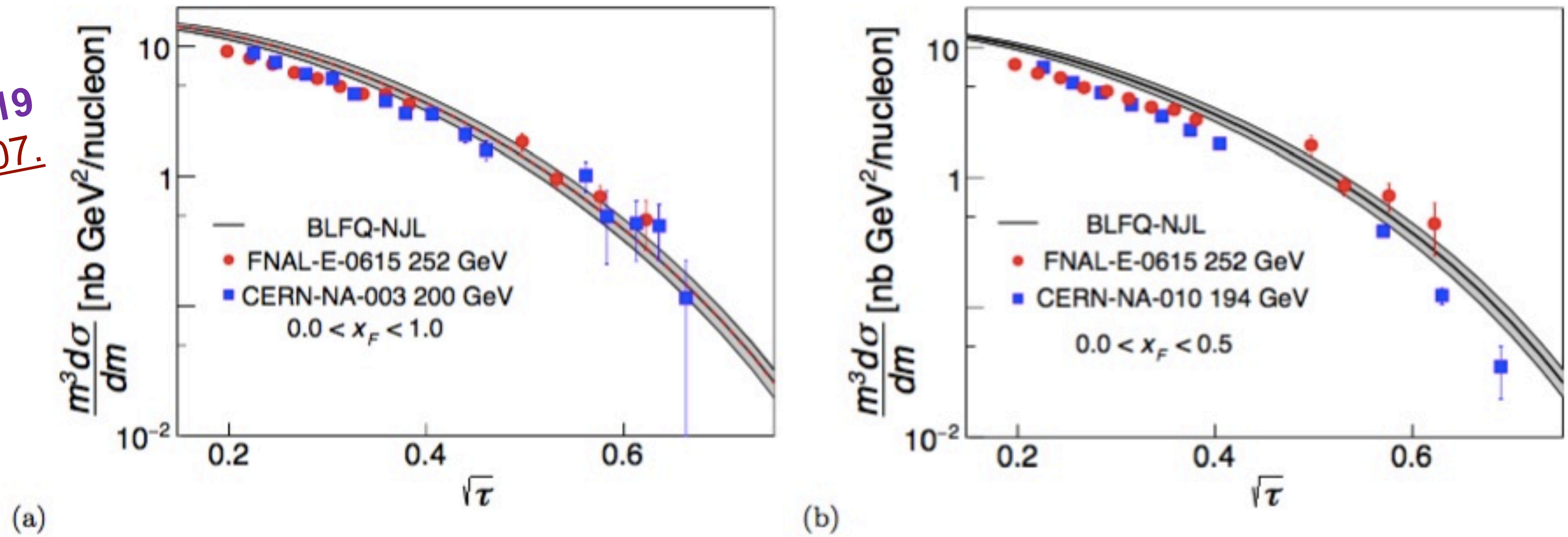




Tension at large x!
Need new data!

OR NOT?

Jul 2, 2019
arXiv:1907.01509



Pion and kaon parton distribution functions from basis light front quantization and QCD evolution

Jiangshan Lan,[1,2,3,*] Chandan Mondal,[1,†] Shaoyang Jia,[4,‡] Xingbo Zhao,[1,2,§] and James P. Vary[4,¶]
(BLFQ Collaboration)

Find agreement of both Drell-Yan and DESY-HERA (although some higher twist needed…) within BLFQ-NJL model

30+ years of proton DIS teaches us we need more than a couple data sets to unambiguously extract parton distribution functions…..

TDIS+BONUS Technique Provides Potential for HERA-type Experiments at JLab

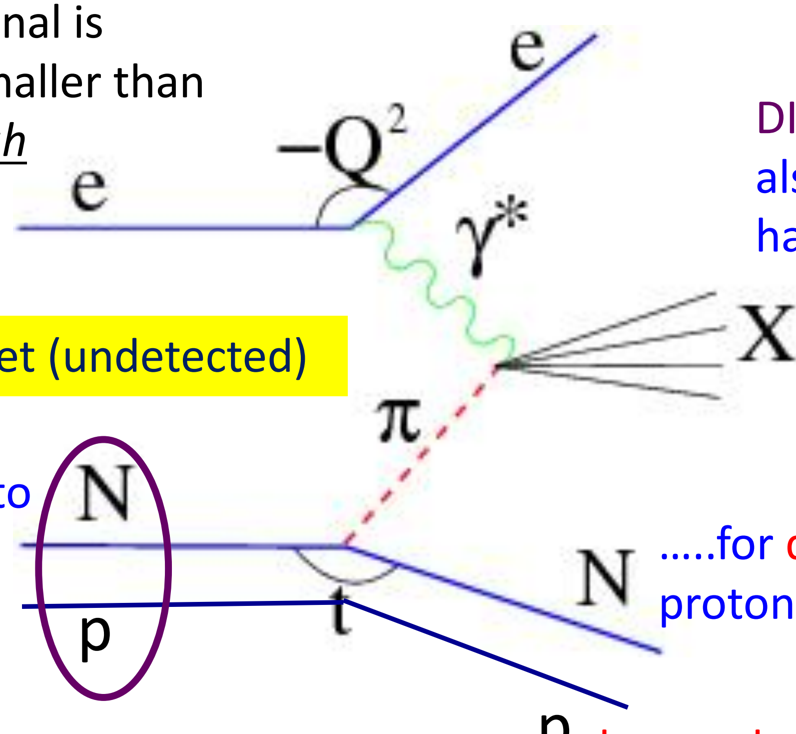
Sullivan Process scattering from neutron-pion fluctuation

detect scattered electron –
large acceptance a plus

Incoming electron – Signal is orders of magnitude smaller than inclusive DIS – *need high luminosity*

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

Want *charged* pion target (undetected)



need fluctuating nucleon to be a neutron.......

.....for detected nucleon to be a proton

neutron in deuteron target

detected spectator proton tags neutron target (BONUS experiment technique)

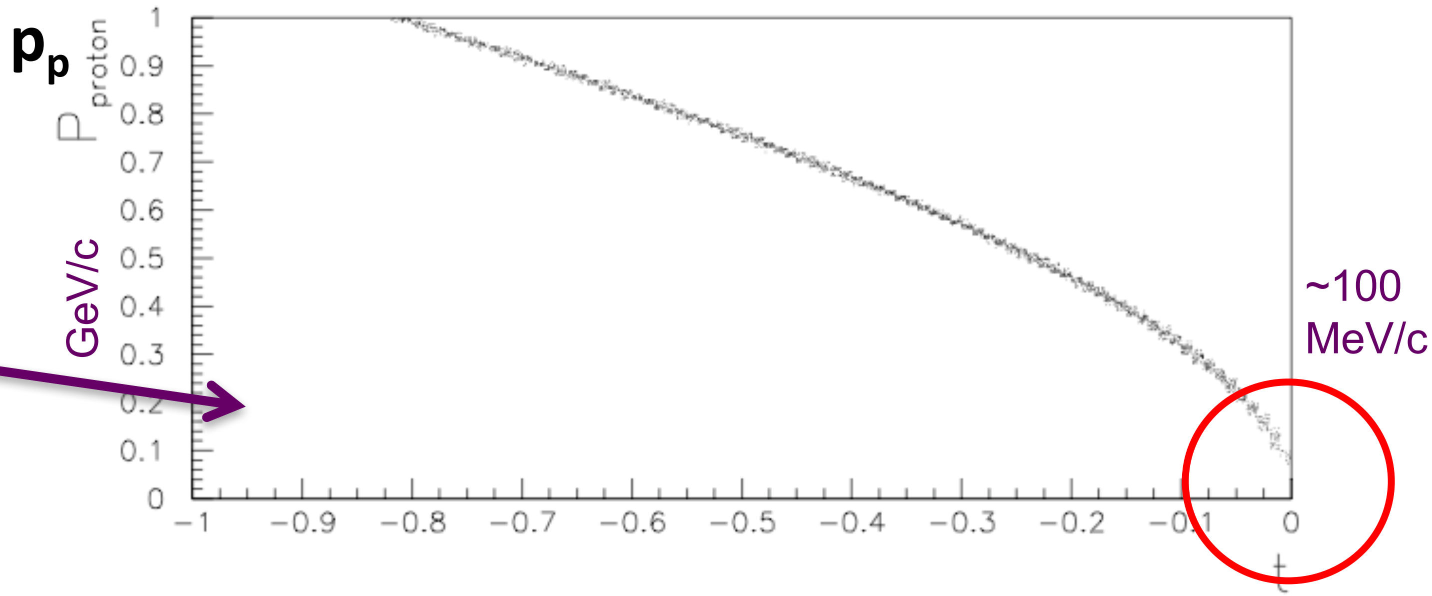
Detected protons need to be *low* momentum

- Tag target hadron
- Extrapolate to pole
- Barely off-shell neutron

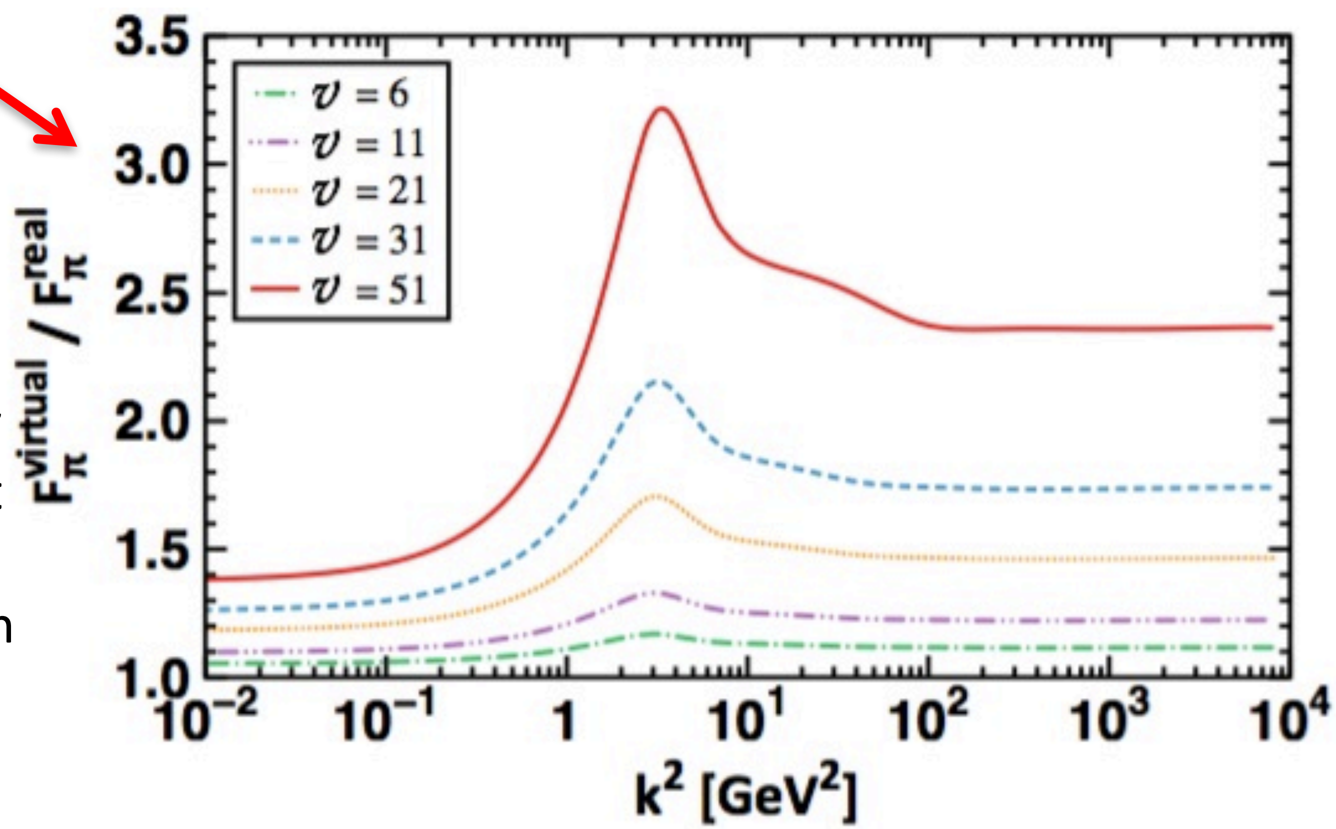
detecting two protons with common vertex in coincidence tags "pion" target!
Note: only need one p for hydrogen target – will do this too!

Extrapolation to the pole

Need range of low momentum protons



The ratio of off-shell to on-shell pion electromagnetic form factor



Si-Xue Qin, Chen Chen, Cedric Mezrag, Craig D. Roberts
Phys.Rev. C97 (2018) no.1

"…we demonstrated that for $v < v_S$ ~ 31, which corresponds to −t < ~0.6 GeV^2….the off-shell correlation serves as a valid pion target."

JLab TDIS kinematics best at lowest t values

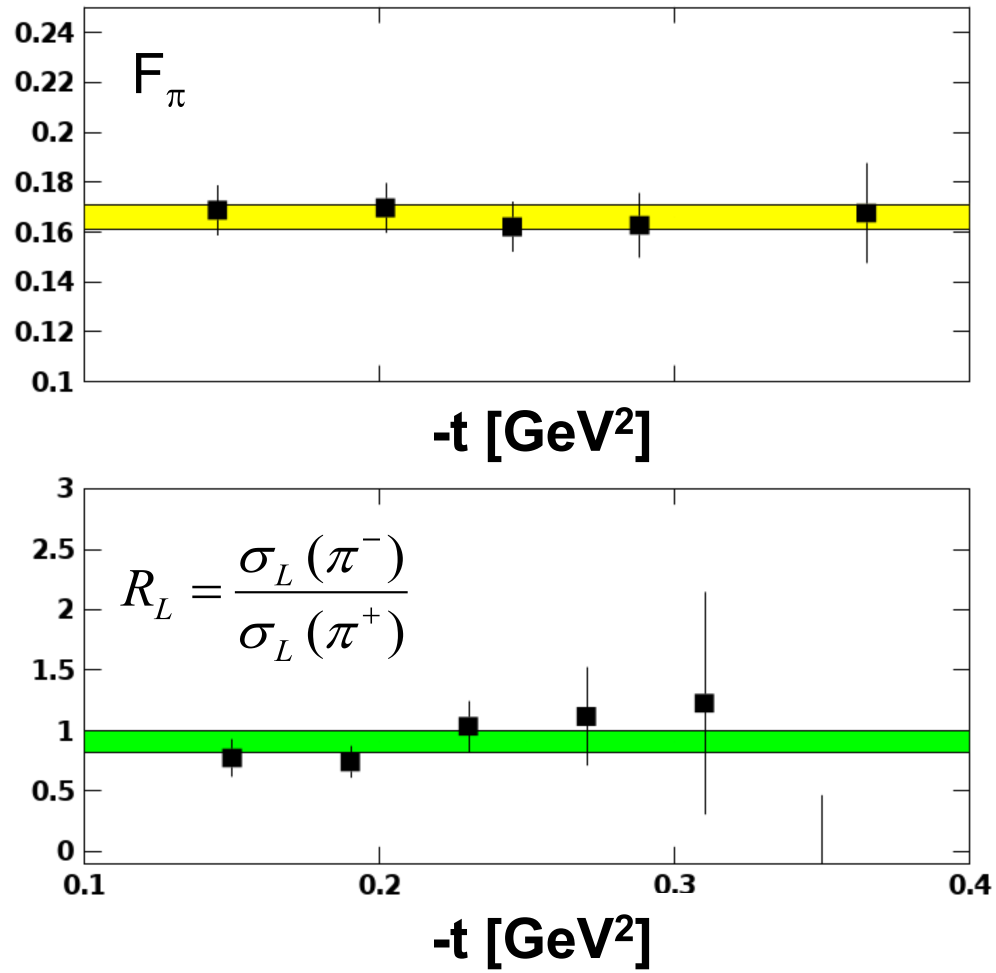
Like BONUS, a challenging low p proton tag experiment – one low mass detector to rule them all

Experimental Validation (Pion Form Factor example)

Experimental studies over the last decade have given *confidence* in the electroproduction method yielding the physical pion form factor

Experimental studies include:

- Take data covering a range in –t and compare with theoretical expectation
  - F_π values do not depend on -t – confidence in applicability of model to the (JLab 6 GeV) kinematic regime of the data
- Verify that the pion pole diagram is the dominant contribution in the reaction mechanism
  - R_L (= $\sigma_L(\pi^-)/\sigma_L(\pi^+)$) approaches the pion charge ratio, consistent with pion pole dominance

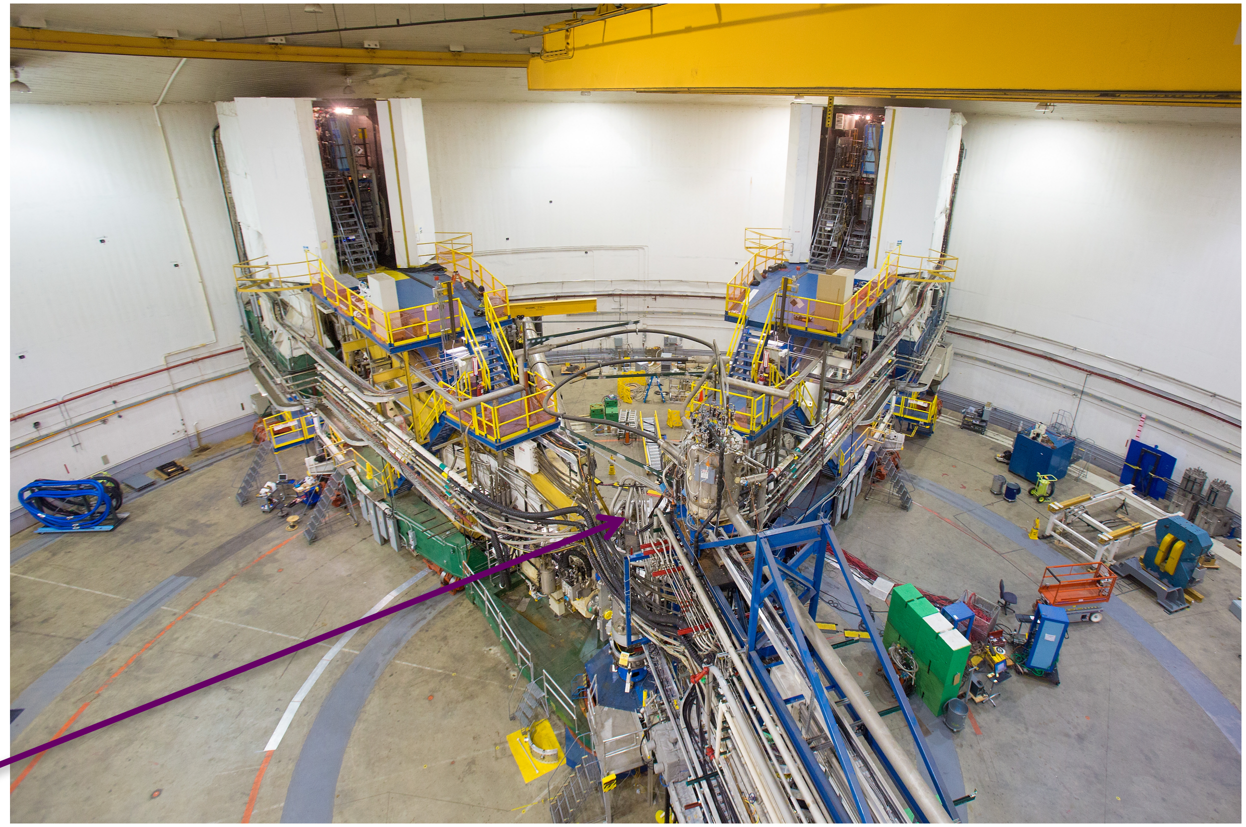


*[G. Huber et al, PRL**112** (**2014**)182501]*

[R. J. Perry et al., arXiV:1811.09356 (2019).]

*[T. Horn, C.D. Roberts, J. Phys. G**43** (**2016**) no.7, 073001]*

JLab Hall A TDIS Experiment



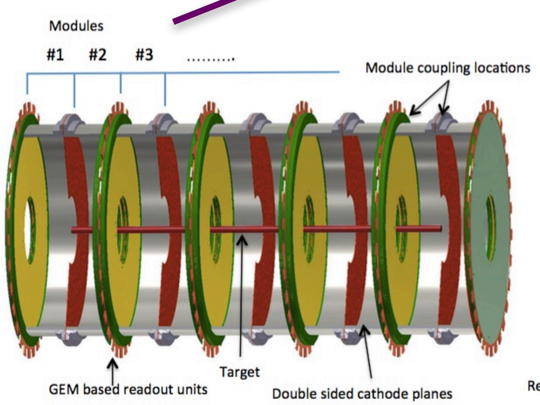
Hall A with SBS:

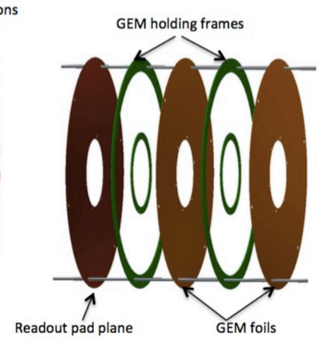
- ✓High luminosity,
  50 μAmp,
  $\mathcal{L}$ = 3x10^{36}/cm^2 s
- ✓Large acceptance
  ~70 msr

Important for small cross sections

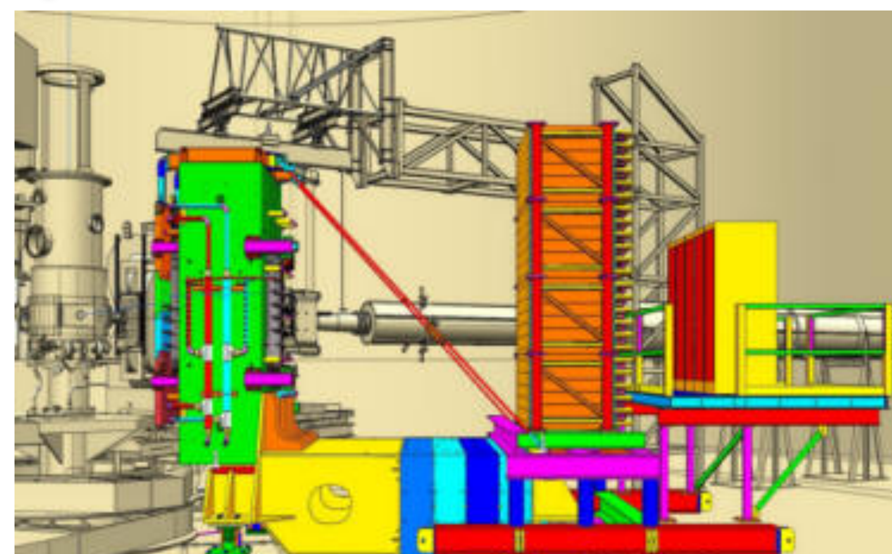
proton tag detection in GEM-based mTPC at pivot

e- beam





mTPC inside superconducting solenoid



Scattered electron detection in new Super Bigbite Spectrometer (SBS) – Installation 2020

Streaming/High Rate GEM Readout Development

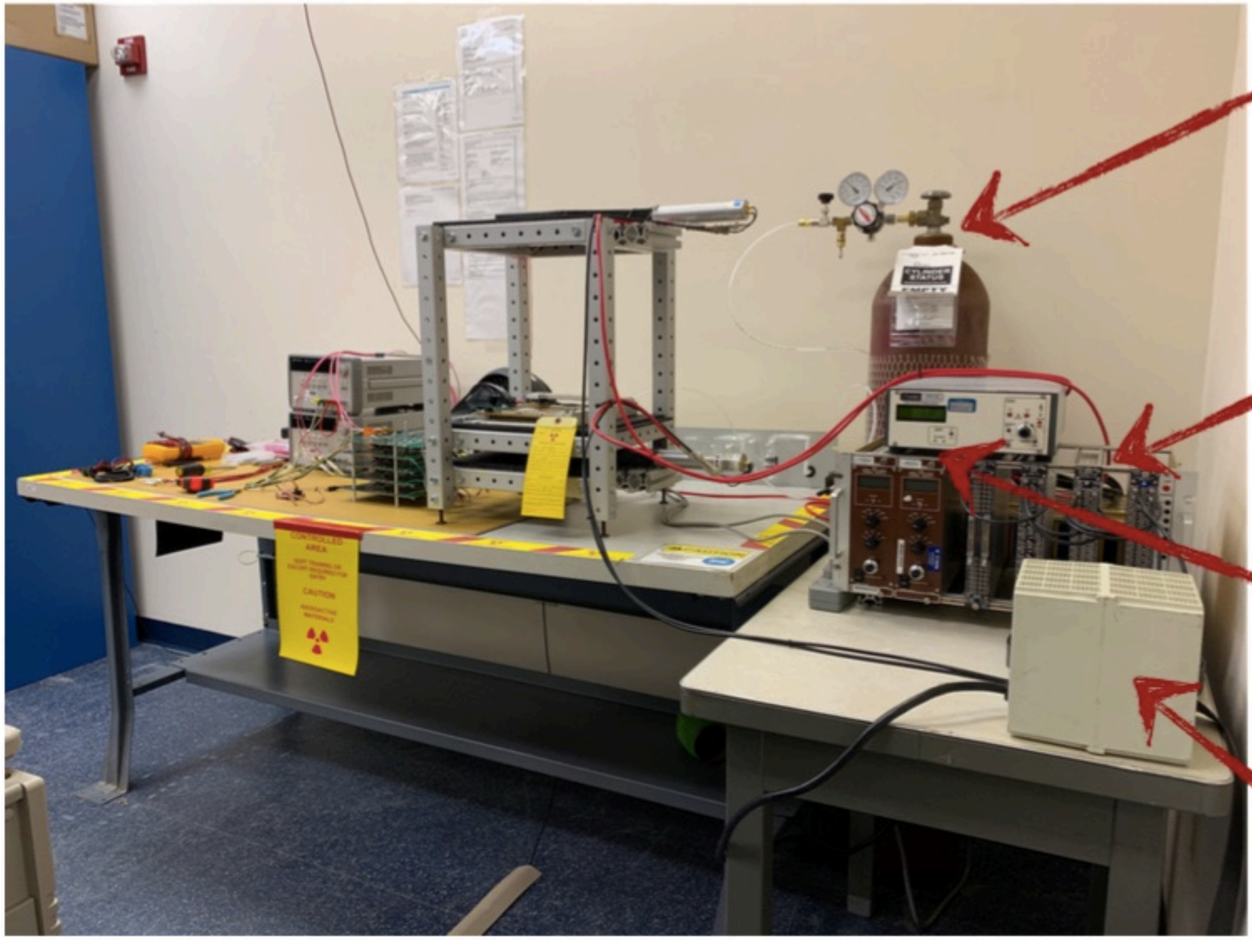
ALICE collaboration (CERN) is currently upgrading their TPC with a GEM based detection system that is read out continuously

- Streaming readout (SRO)
- Continuous time ordered sequences of detector system readout
- ~1 TB/s post zero-suppression

Novel front-end ASIC was developed specifically for this purpose ➛ SAMPA

TDIS (and SoLID and EIC and beyond…) high rate GEM test stand

- GEM ➛ x and y plane (324 channels each)
- TRORC ➛ ALICE/ATLAS readout receiver card with GBT serialization protocol
- FEC➛ALICE front end card (JLab version) – 5 SAMPA chips (160 channels)



75/25 Ar/CO_2 Gas System

NIM Cosmic Trigger

HV Power Supplies

Isolation Transformer

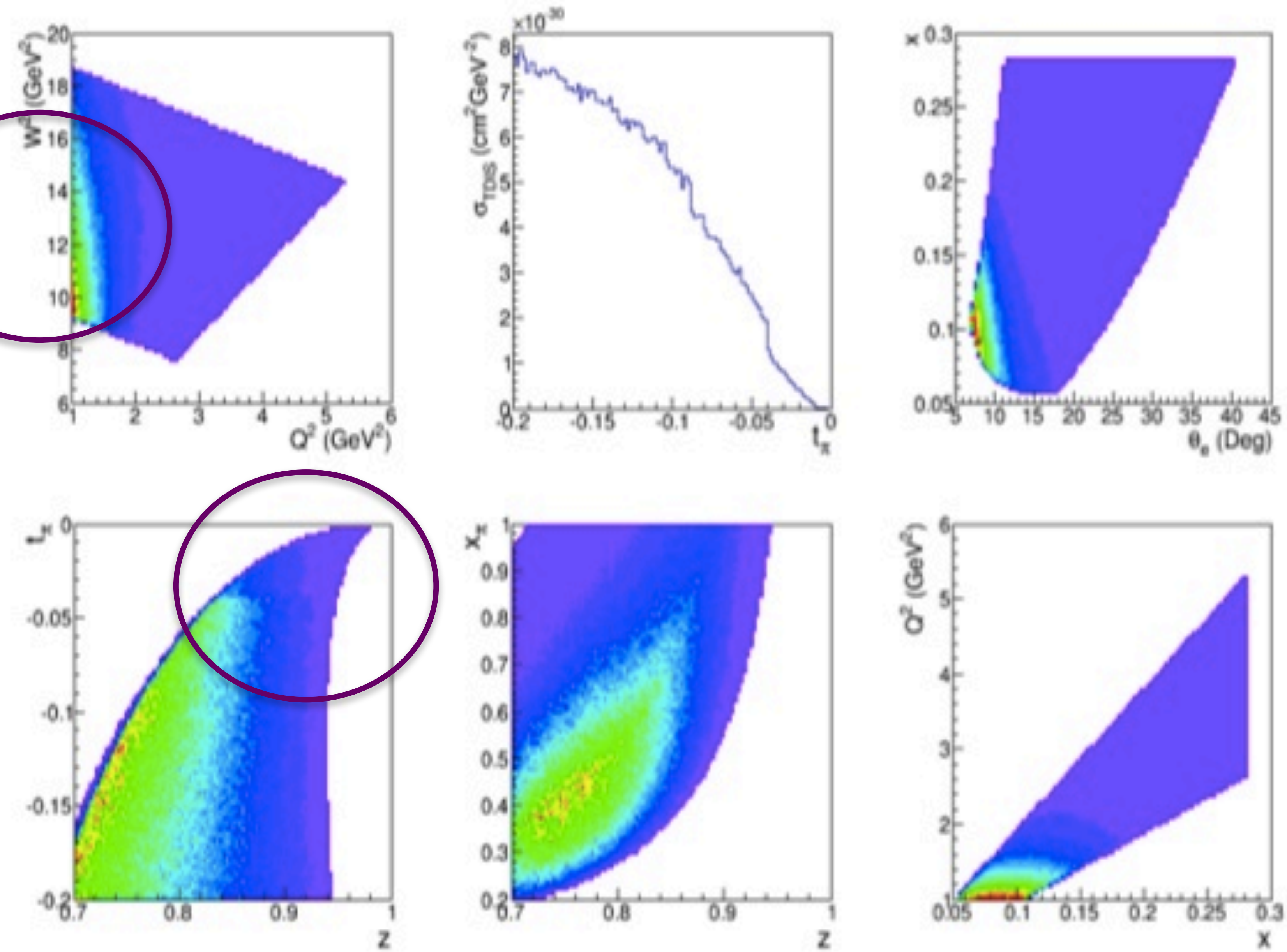
G. Heyes, E. Jastrzembski, E. Pooser

Jefferson Lab

TDIS Kinematics – *optimized for meson cloud*

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

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

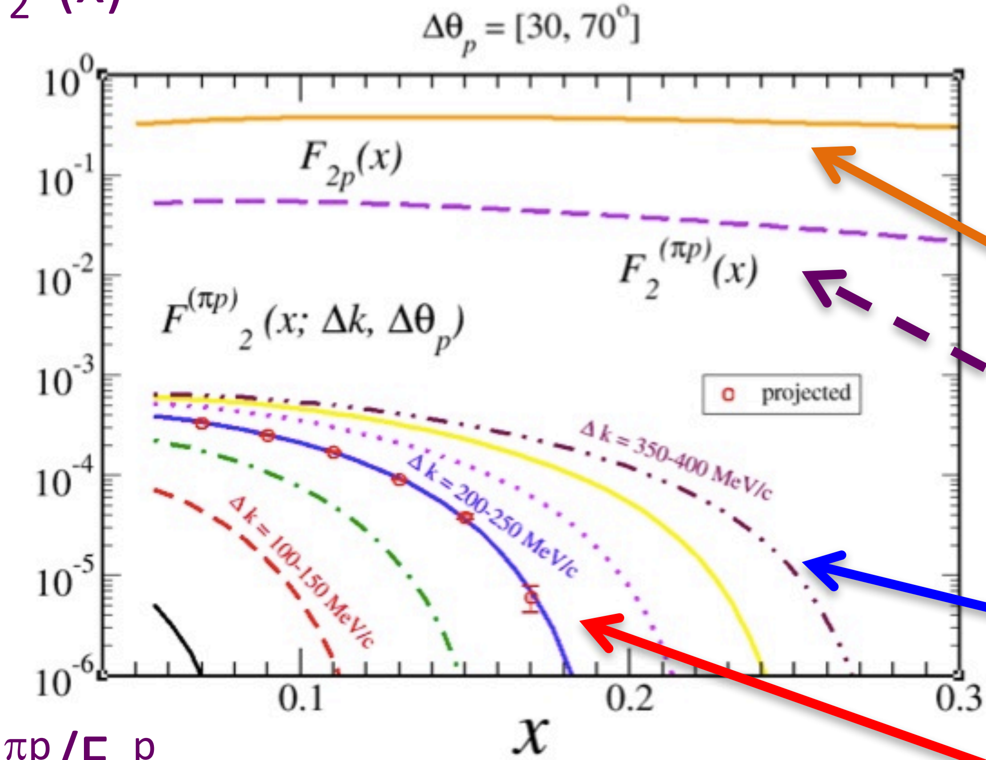


Low t, high (1-z)

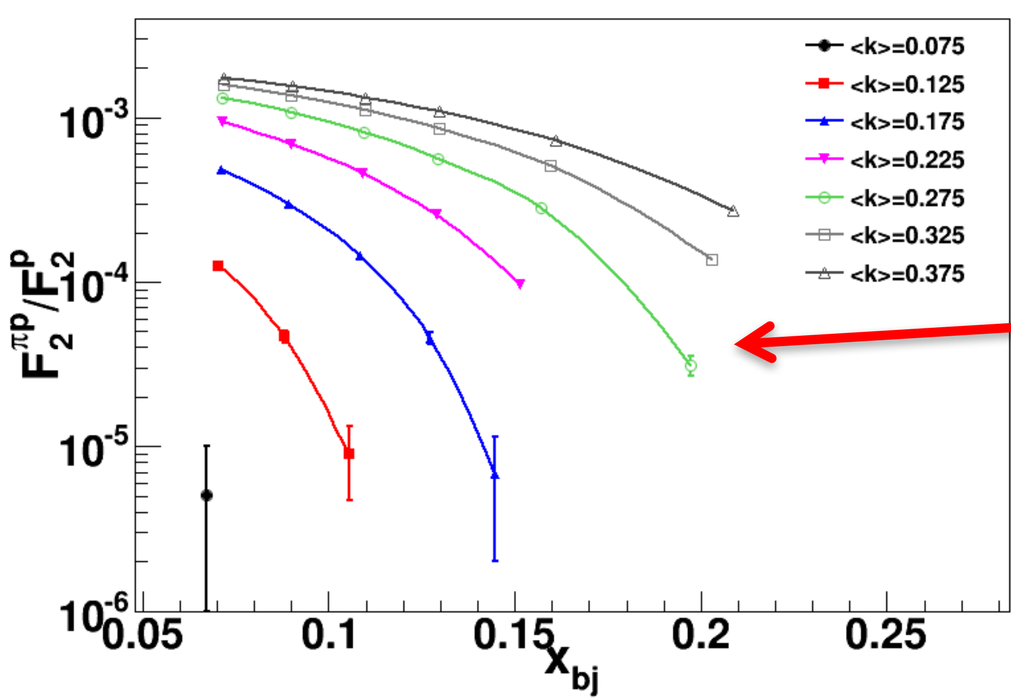
x range ~ 0.1

Projected Results I - proton

$F_2^p(x)$



$F_2^{\pi p}/F_2^p$



$F_2^p(x)$ is well-known inclusive DIS

$F_2^{(\pi p)}(x)$ is total pion contribution to structure function

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

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

- will have multiple momentum bins

Full data set shown here

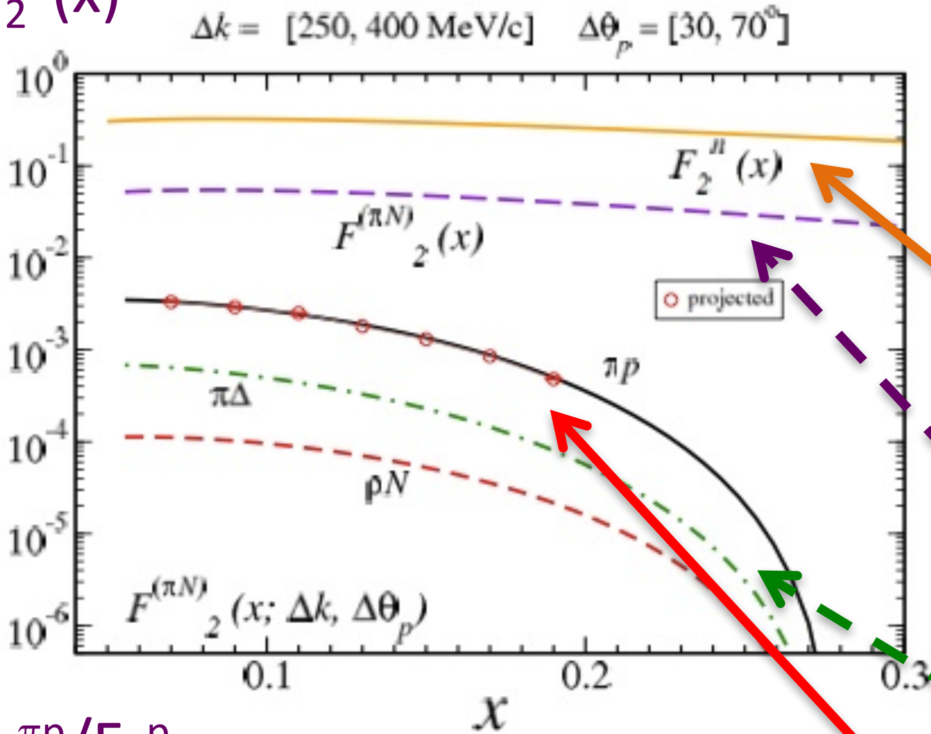
- all momentum bins in MeV/c

Error bars largest at highest x points – less statistics

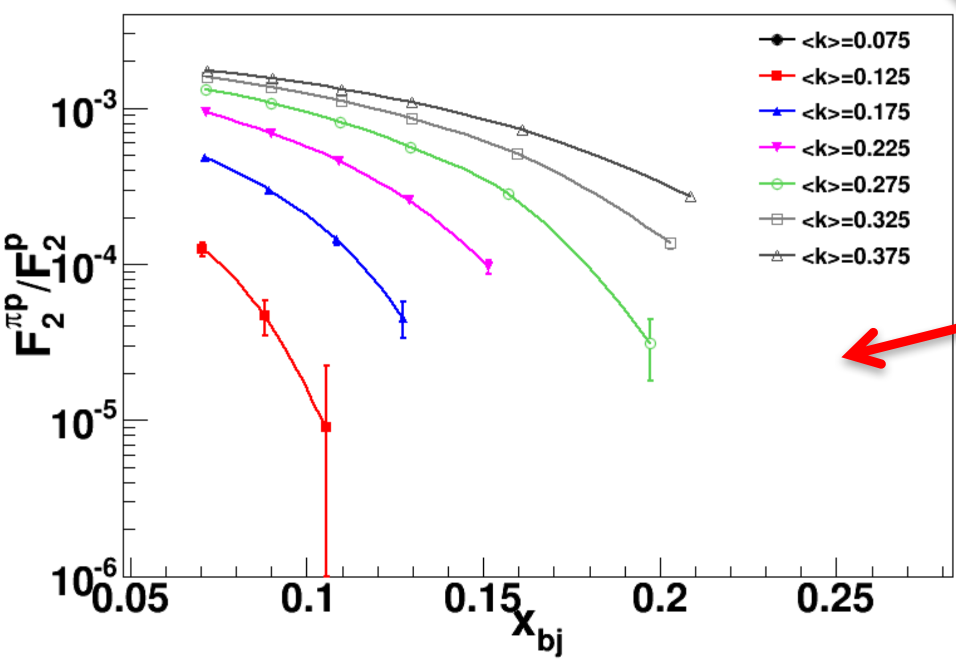
- at fixed x, these are the lowest t values

Projected Results II - neutron

$F_2^n(x)$



$F_2^{\pi p}/F_2^p$



$F_2^n(x)$ is inclusive DIS – tagged by additional low momentum, backward angle p as in BONUS

$F_2^{(\pi N)}(x)$ is total *pion* contribution to structure function

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

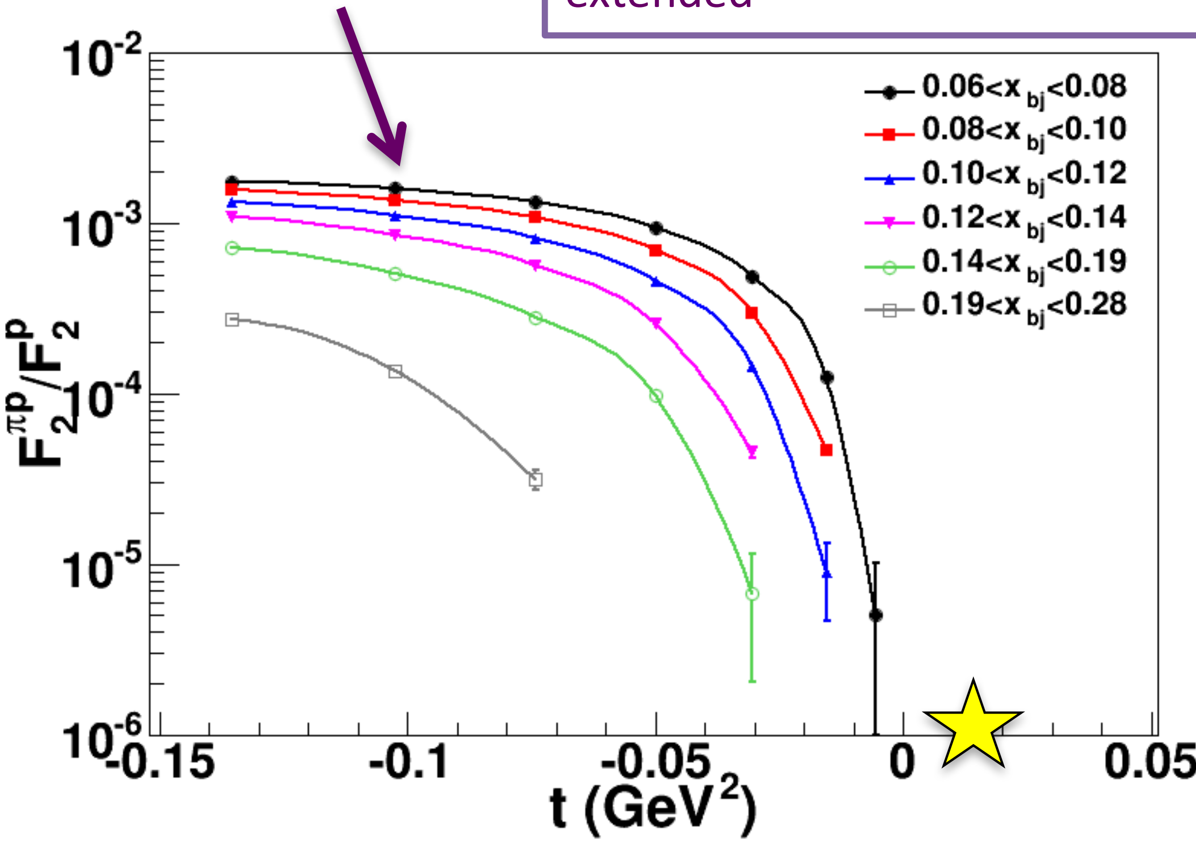
Full data set shown here
- all momentum bins in MeV/c

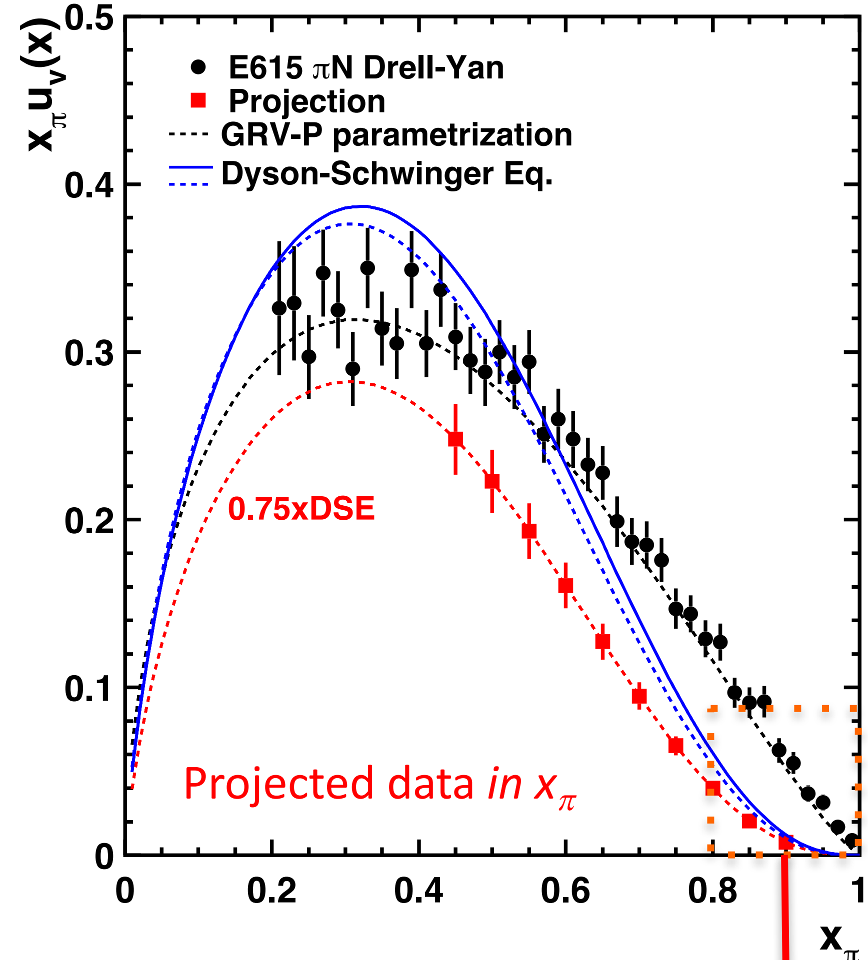
Do not show lowest momentum <x> = 0.075 data
- run lower luminosity due to larger background

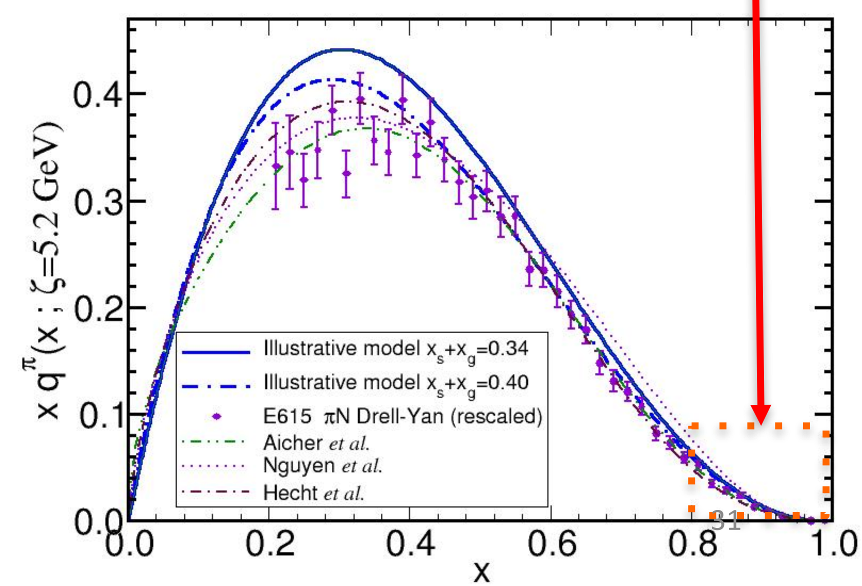
Projected Results – Pion Structure Function from TDIS at JLab

- 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
- Kinematic range for PDF fitting extended

- Low t extrapolation to the pion pole
- Proton p determines t



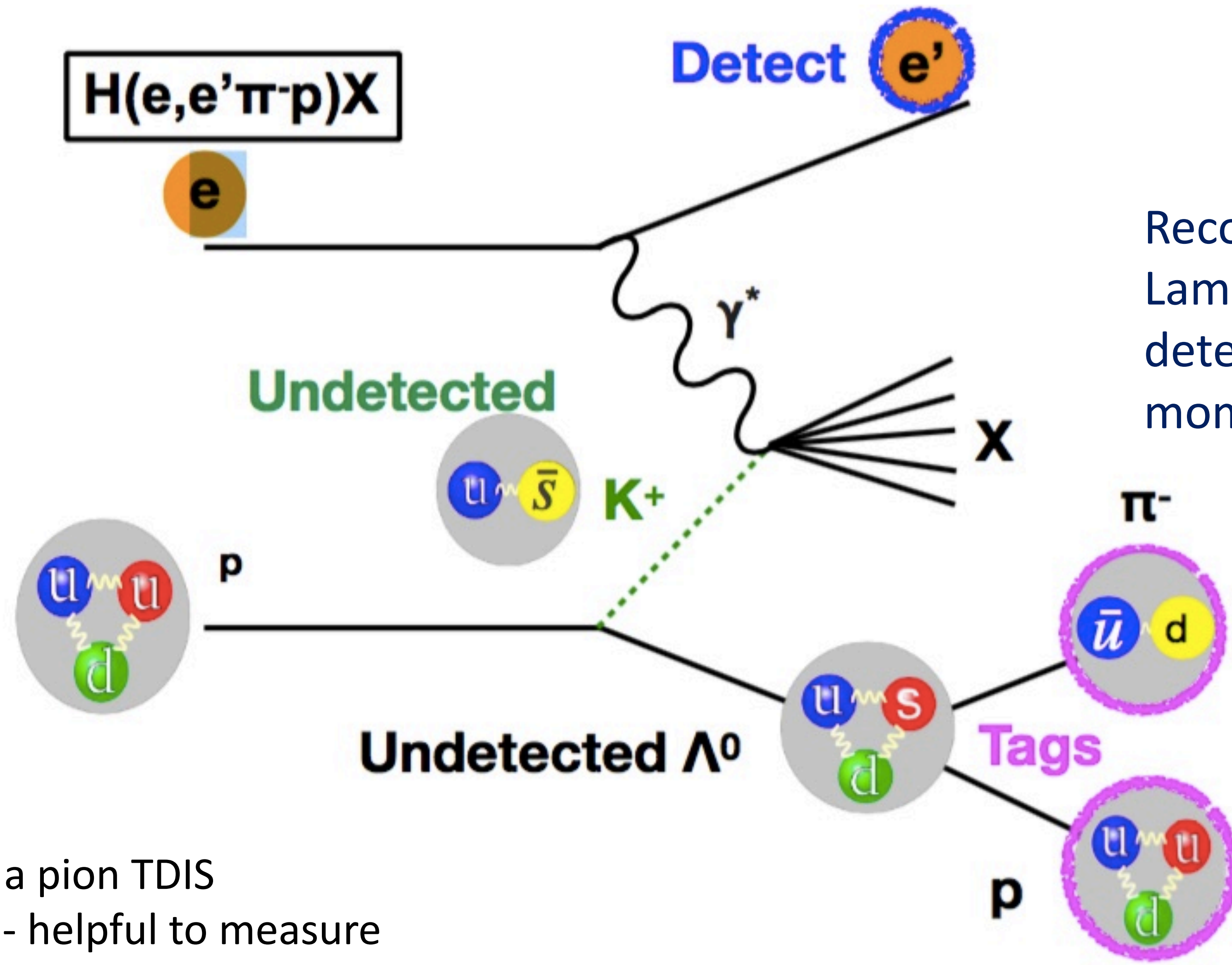




Will also measure n, p (π^-, π^0) difference
- look for isospin dependence
- very different backgrounds

But wait, there's more…!…. (***Example 3:*** **TDIS to access kaon structure function**)

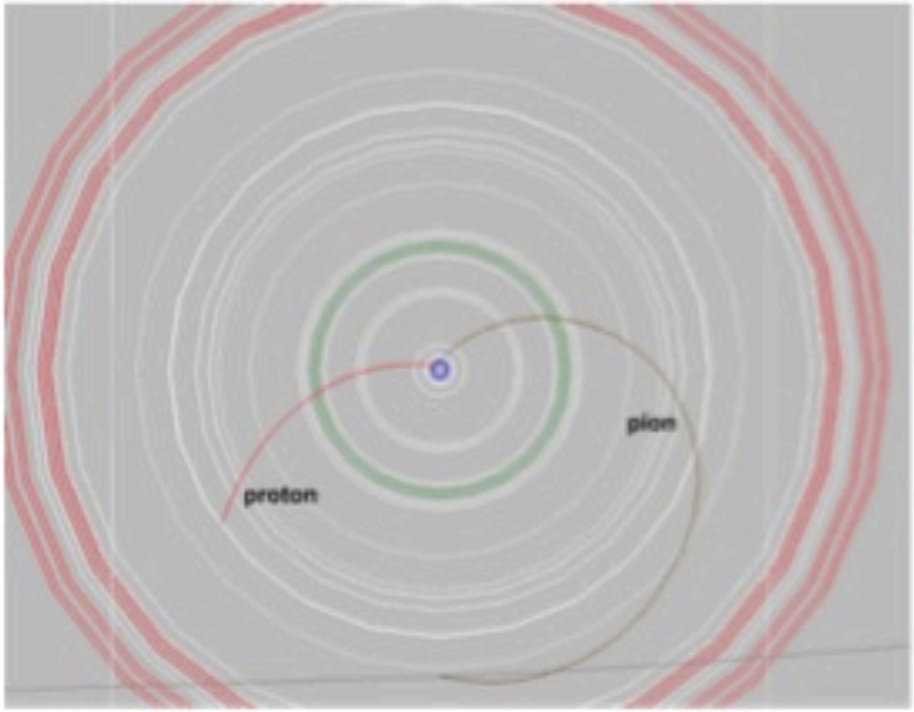
Approved TDIS "rungroup" experiment
– Get "for free"
- Very difficult
- *A first preliminary look*, en -> (eKΛ)

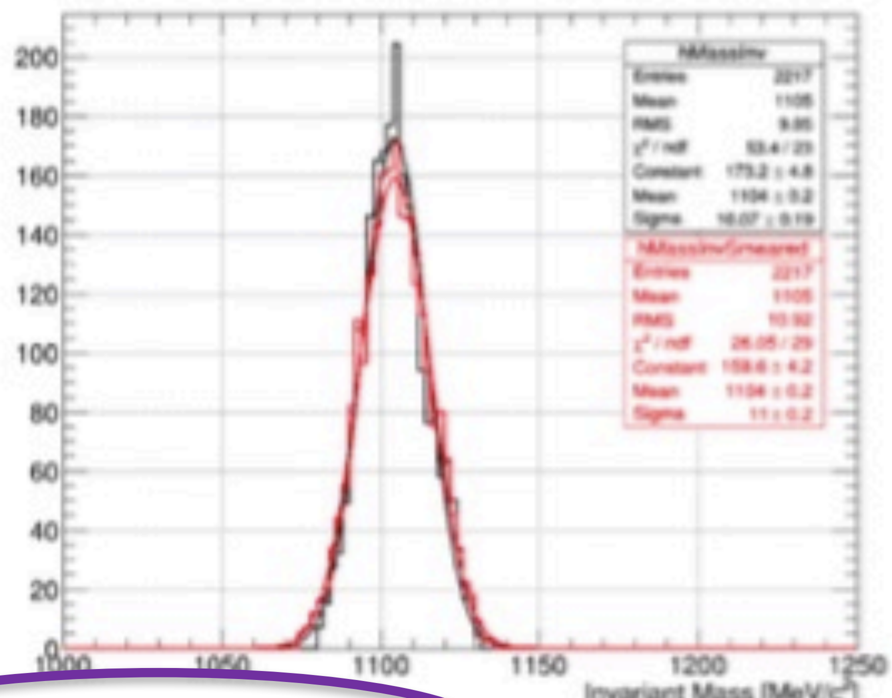


Reconstruct Lambda from detected (low momentum) p + π

Actually, it's a pion TDIS background - helpful to measure

Kaon TDIS Measurement





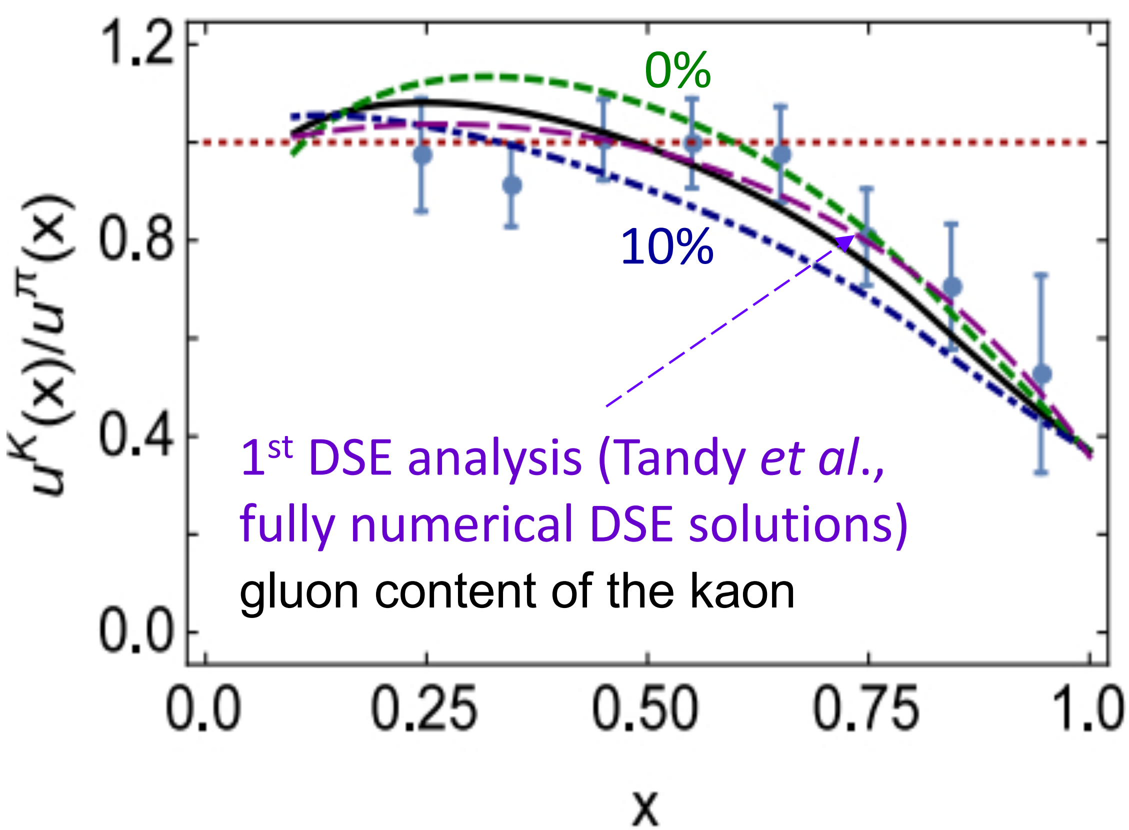
- $p\pi^-$ decay angle in CMS back to back with common decay/displaced vertex
- Λ^0 reconstructed from $p\pi^-$ invariant mass

Kaon structure functions – gluon pdfs

Based on Lattice QCD calculations and DSE calculations:

- ➢Valence quarks carry 52% of the pion's momentum at the light front, at the scale used for Lattice QCD calculations, or ~65% at the perturbative hadronic scale

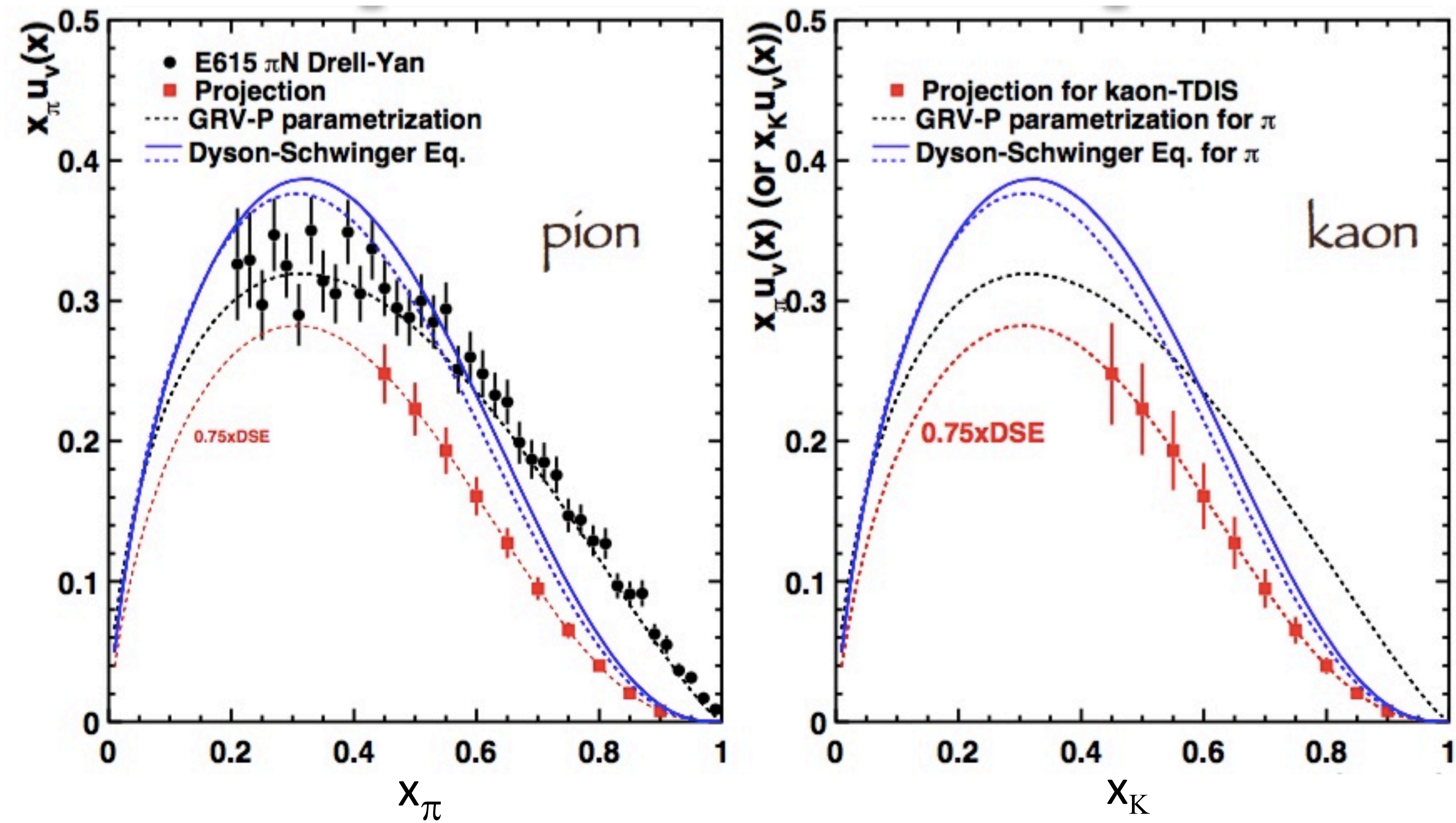
- ➢At the same scale, valence-quarks carry ⅔ of the kaon's light-front momentum, or roughly 95% at the perturbative hadronic scale



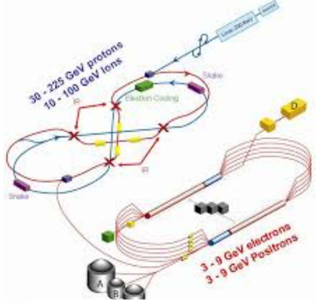
Thus, at a given scale, there is far **less glue in the kaon than in the pion**:

- ❑heavier quarks radiate less readily than lighter quarks
- ❑heavier quarks radiate softer gluons than do lighter quarks
- ❑Landau-Pomeranchuk effect: softer gluons have longer wavelength and multiple scatterings are suppressed by interference.
- ❑Momentum conservation communicates these effects to the kaon's u-quark.

Projected JLab TDIS Results for π, K Structure Functions



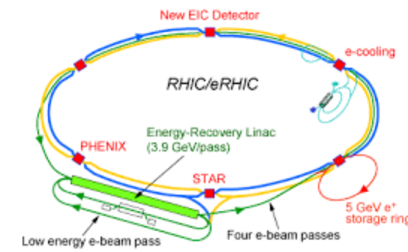
Essentially no data currently – *first ever direct kaon structure function extraction*



Meson Structure Functions at the EIC

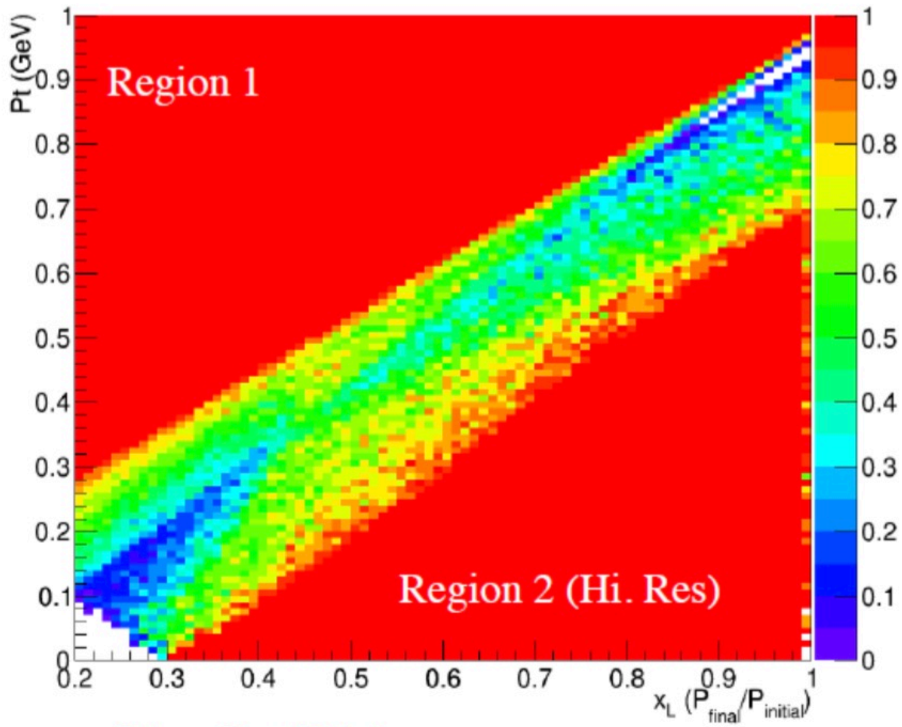
Good Acceptance for TDIS-type Physics!

Low momentum nucleons ***easier*** to measure!



Example: acceptance for p' in e + p → e' + p' + X

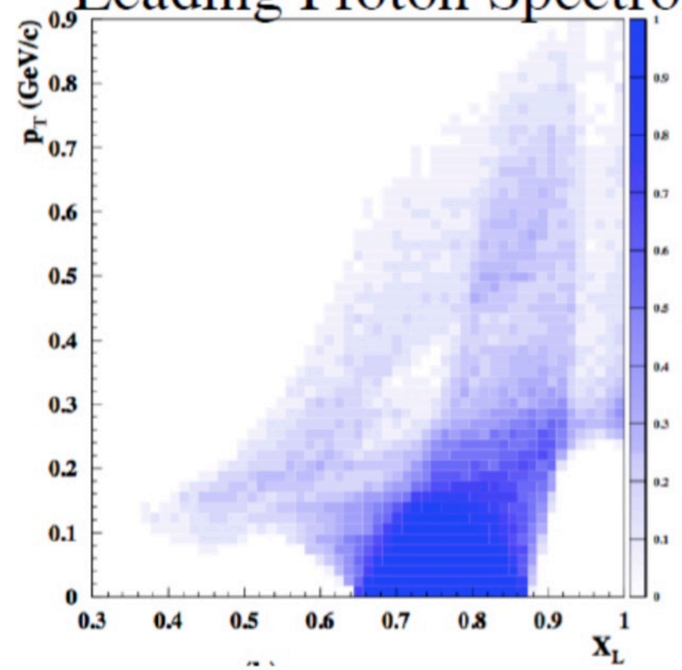
JLEIC acceptance



Zhiwen Zhao (Duke)

ZEUS

Leading Proton Spectrometer



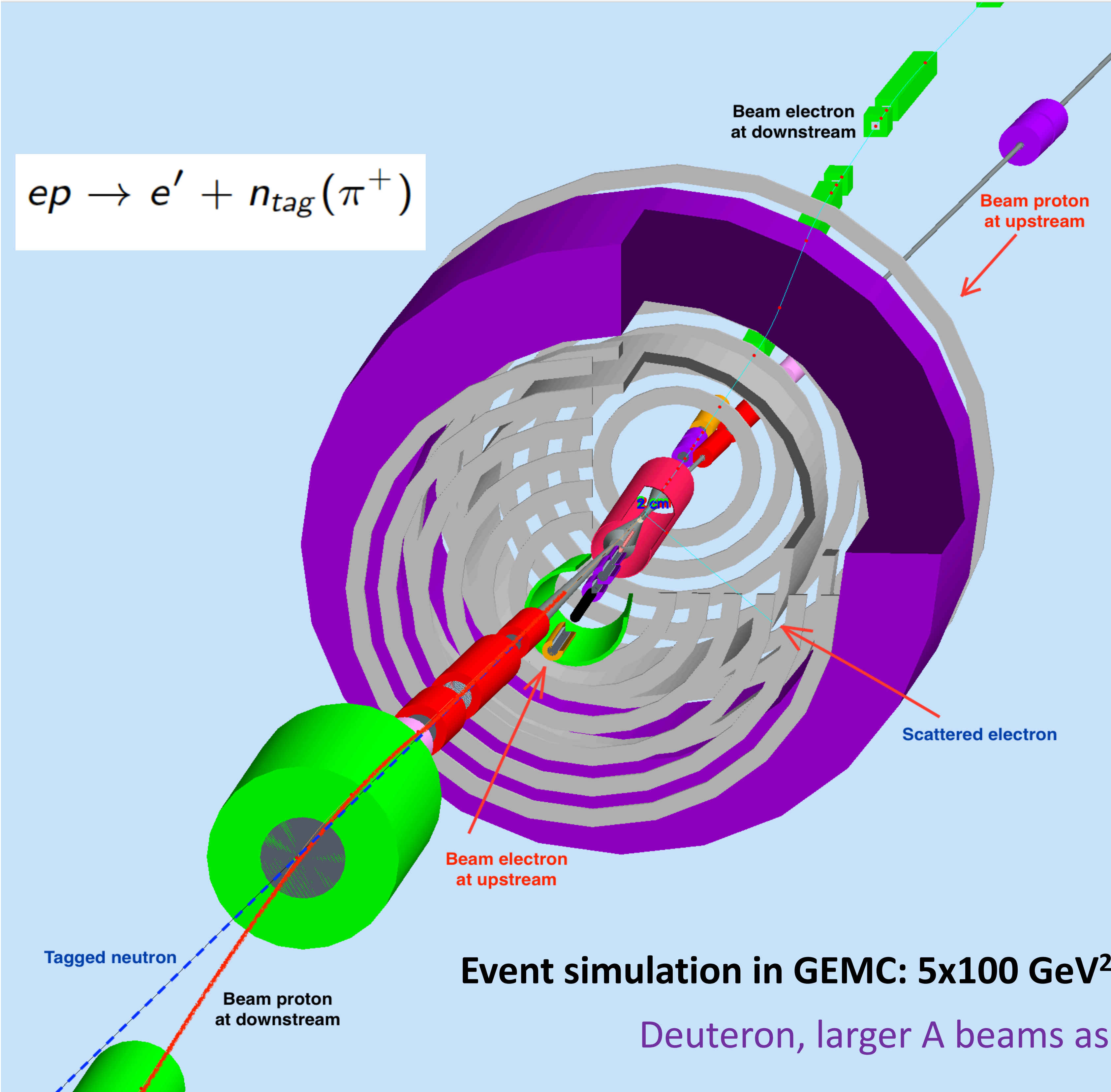
Acceptance in diffractive peak (X_L>~.98)

ZEUS: ~2%

JLEIC: ~100% (also covers much higher X_L than ZEUS)

Huge gain in acceptance for forward tagging….

$$ep \rightarrow e' + n_{tag}(\pi^+)$$

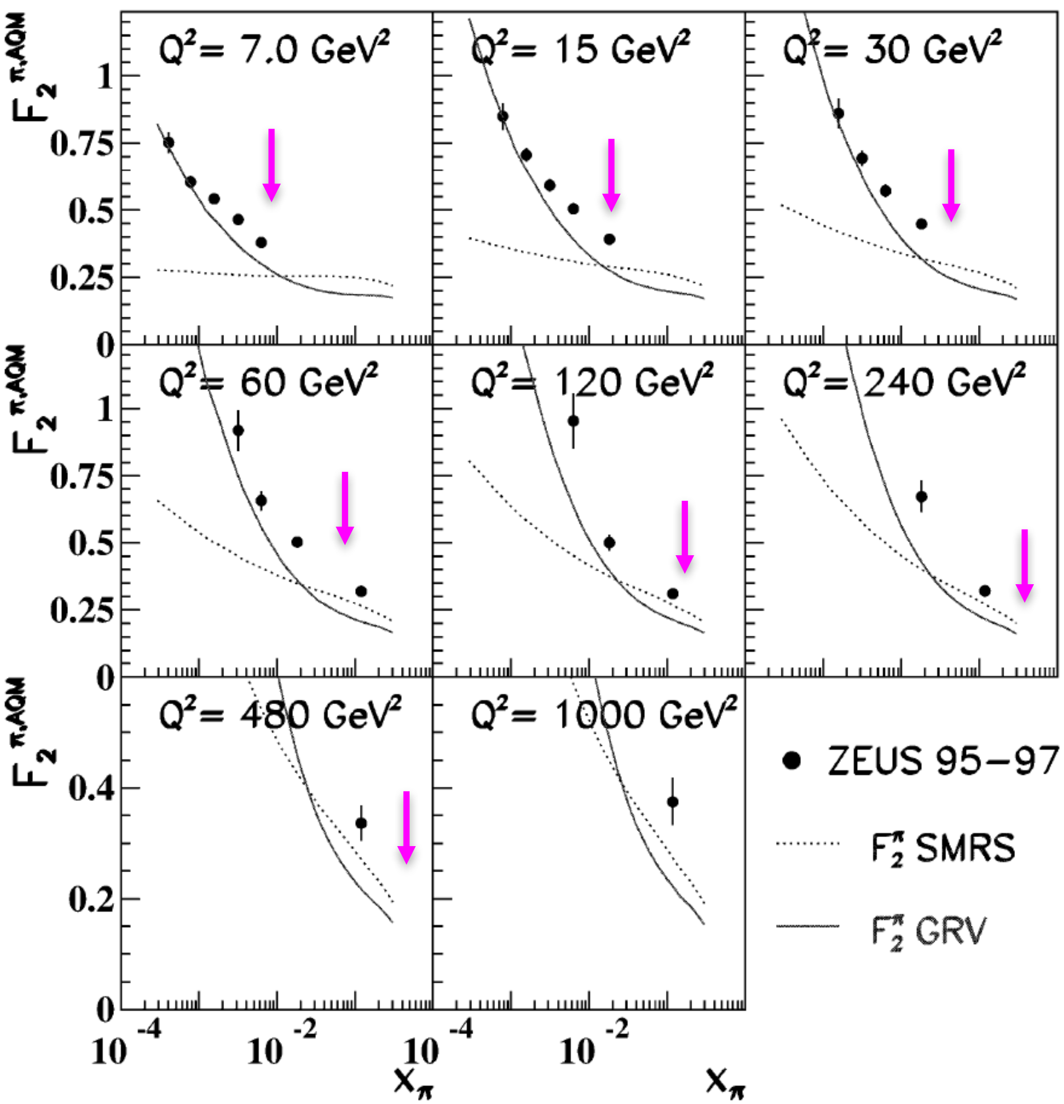


Event simulation in GEMC: 5x100 GeV^2, e/p beams

Deuteron, larger A beams as well

World TDIS Data on Pion Structure Function F_2^{π}

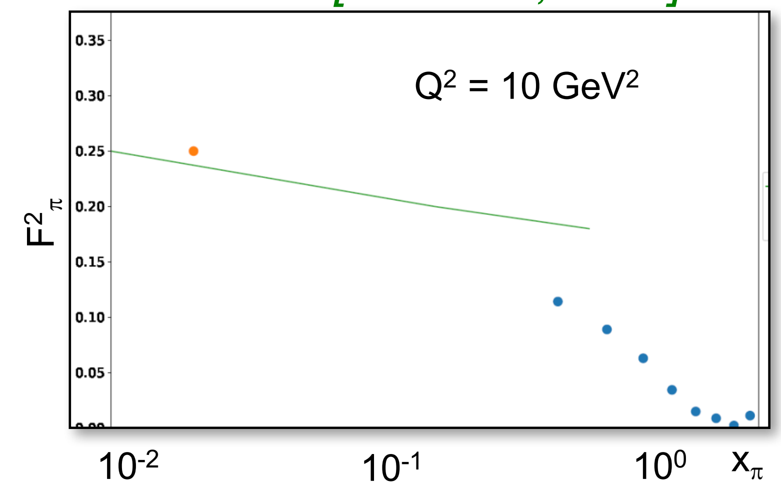
HERA ↓ ~x_{min} for EIC

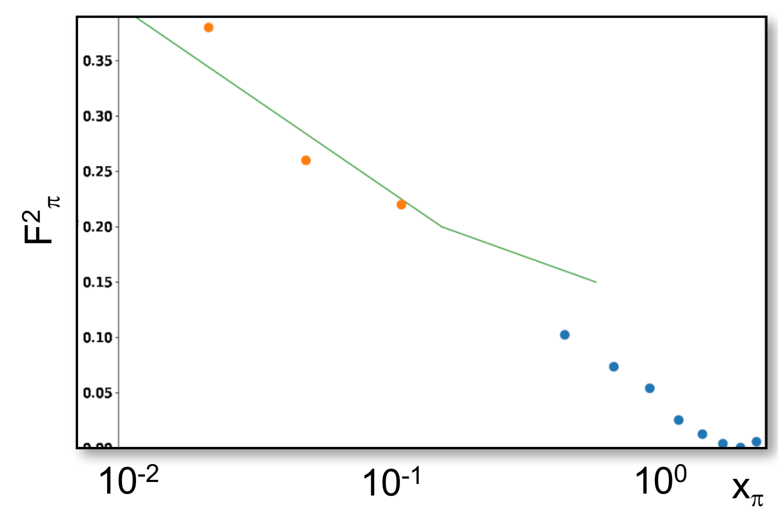


EIC

Here example for 5 GeV e⁻ and 100 GeV p

[R. Trotta, CUA]





- ❑ **EIC kinematic reach down to a x = few 10^{-3}**
- ❑ **Lowest x constrained by HERA**

Kaon structure functions – gluon pdfs

T. Horn, C. Roberts, R. Ent

Based on Lattice QCD calculations and DSE calculations:

- Valence quarks carry 52% of the pion's momentum at the light front, at the scale used for Lattice QCD calculations, or ~65% at the perturbative hadronic scale

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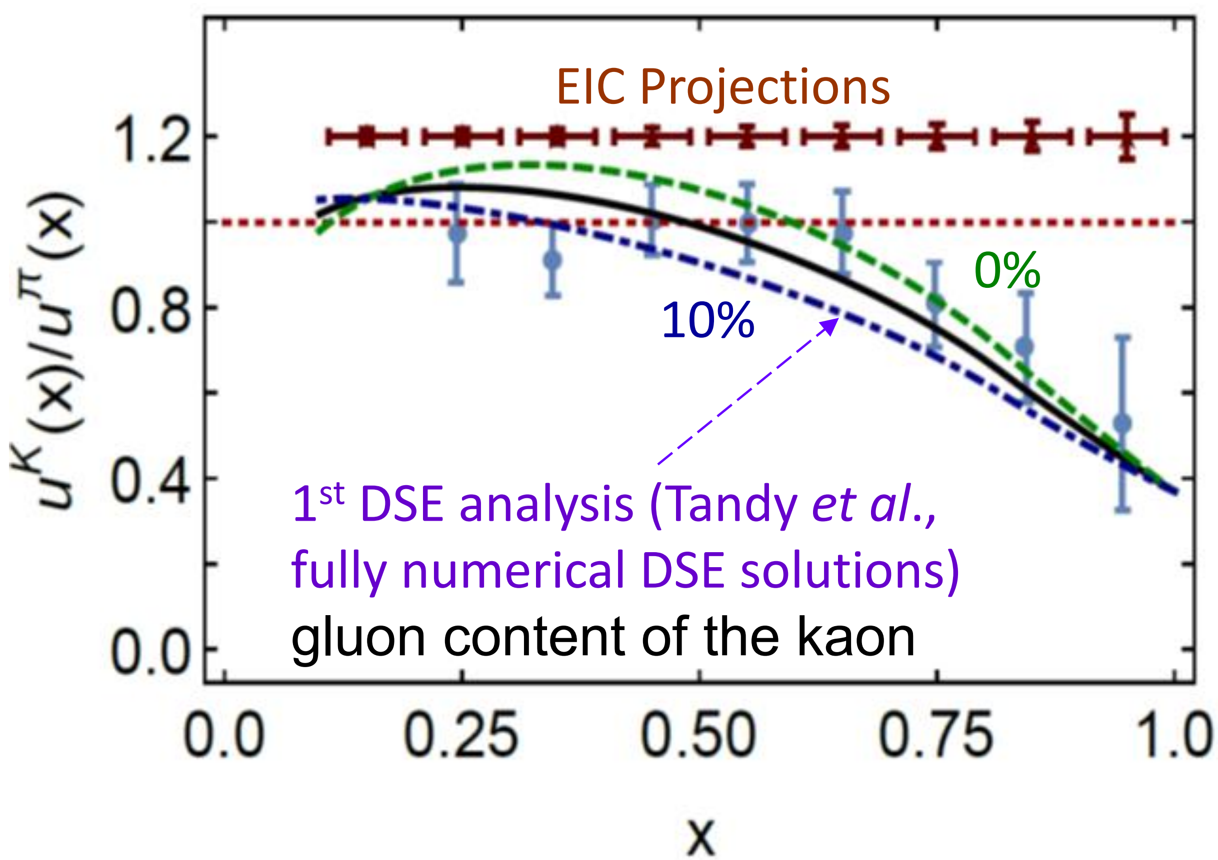

Thus, at a given scale, there is far **less glue in the kaon than in the pion**:

- heavier quarks radiate less readily than lighter quarks
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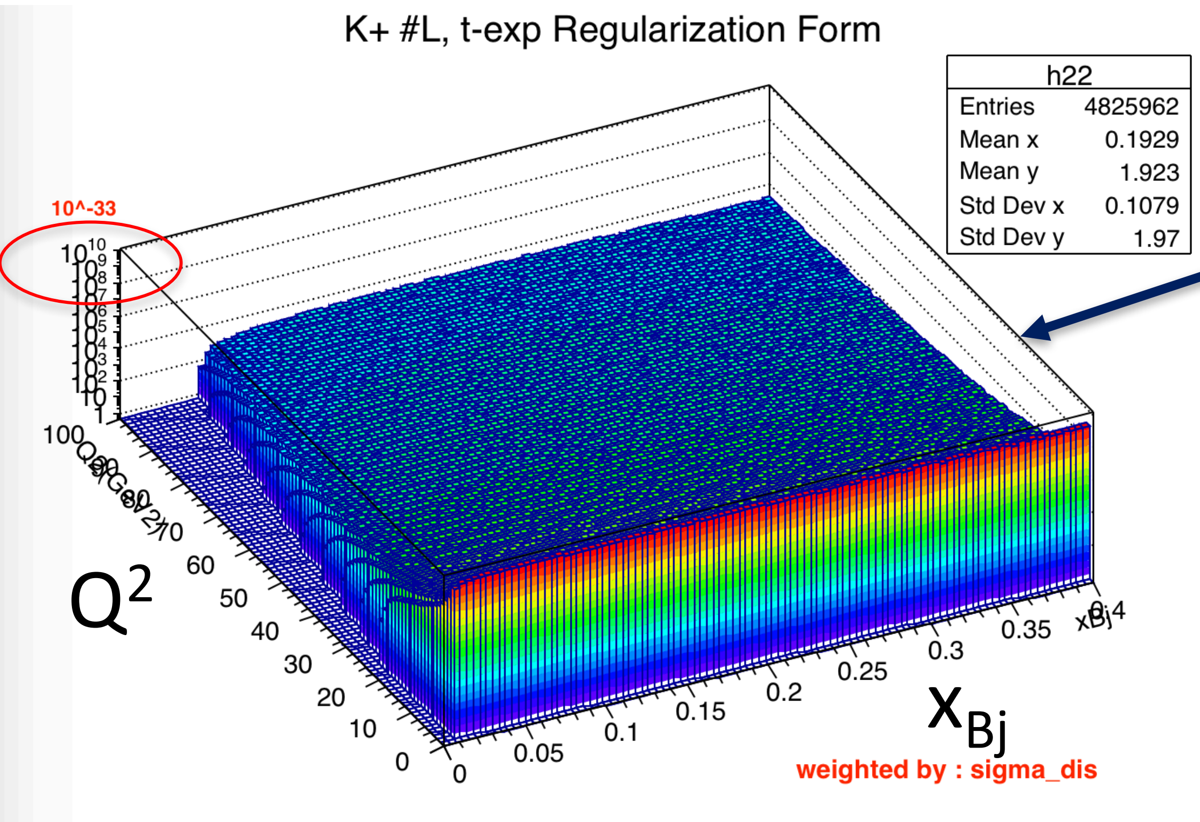
- Momentum conservation communicates these effects to the kaon's u-quark.

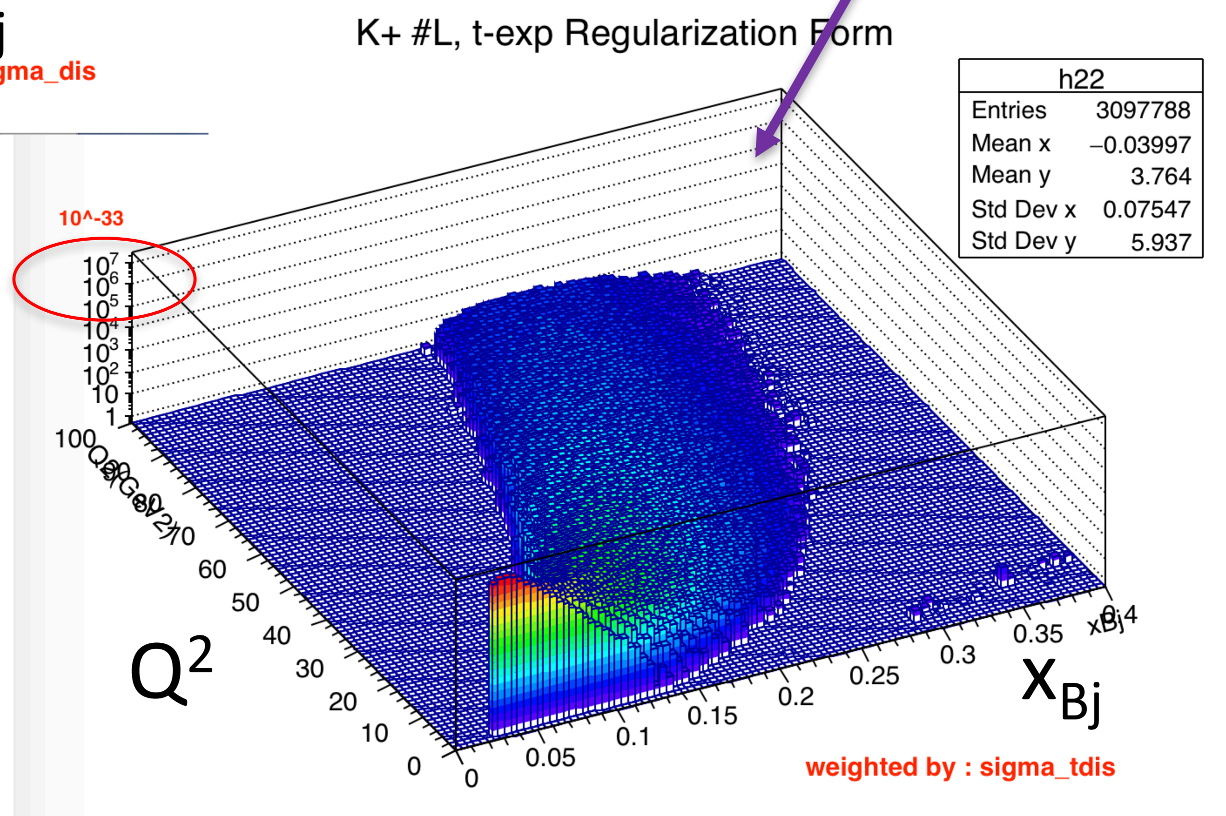
EIC TDIS events weighted by cross-section



Monte Carlo events weighted by DIS e-p cross section

Monte Carlo events weighted by tagged DIS e-p cross section

~3 orders of magnitude smaller ***- luminosity critical***

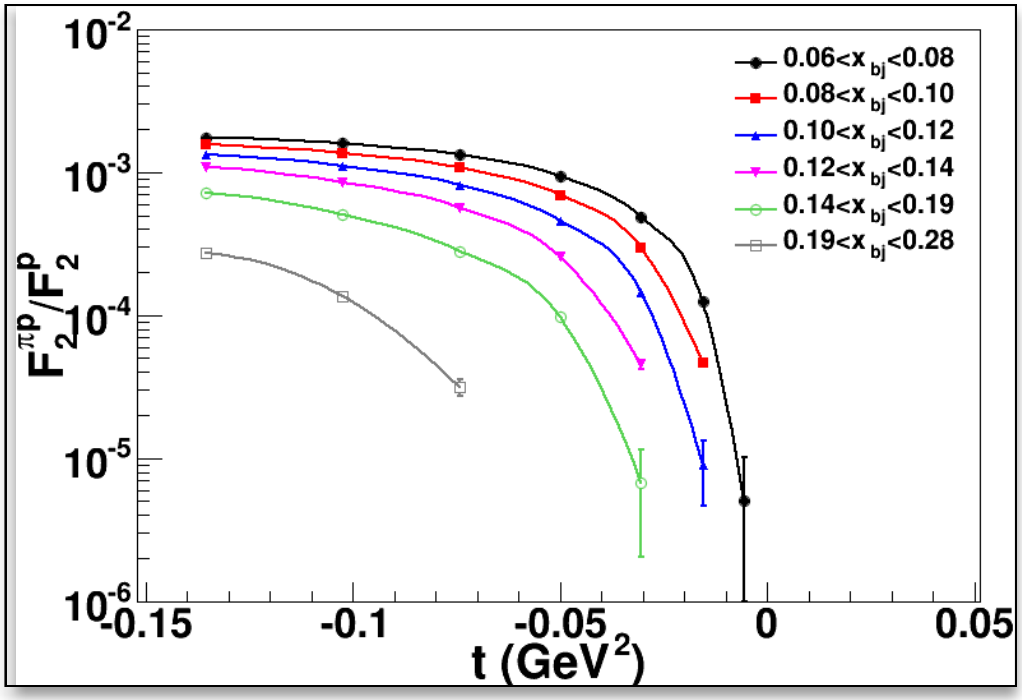


J. R. McKenney, et al., Phys. Rev. D93 (2016), 054011

T. J. Hobbs et al, Few Body Syst. 56 (2015) no.6-9

EIC – Luminosity is Key

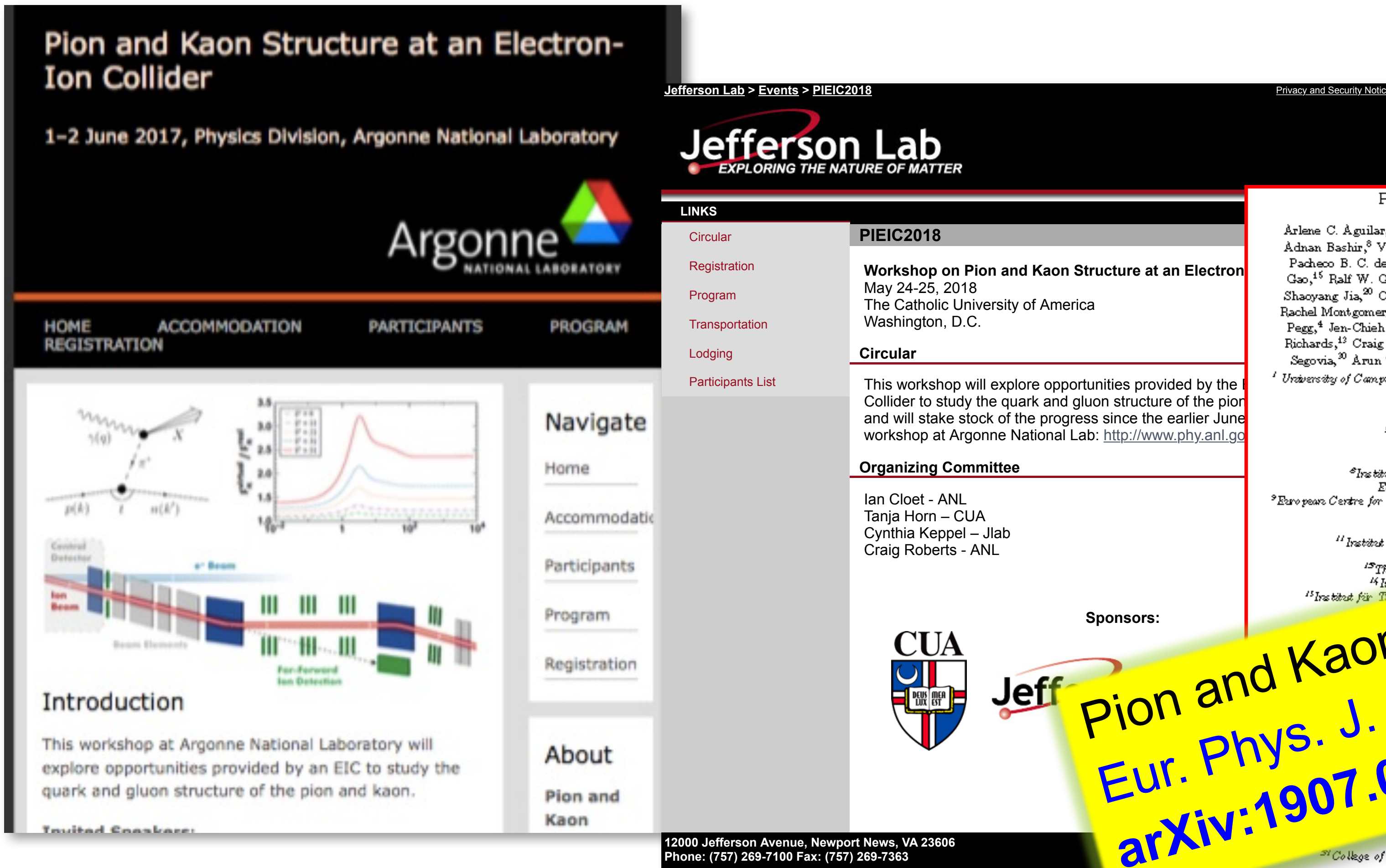
- $L_{EIC} = 10^{34} = 1000 \times L_{HERA}$
  - Detection fraction @ EIC in general much higher than at HERA
- Fraction of proton wave function related to pion Sullivan process is roughly 10^{-3} for a small –t bin (0.02).
- Hence, pion data @ EIC should be comparable or better than the proton data @ HERA, or the 3D nucleon structure data @ COMPASS
- If we can convince ourselves we can map pion (kaon) structure for –t < 0.6 (0.9) GeV2, we gain at least a decade as compared to HERA/COMPASS.

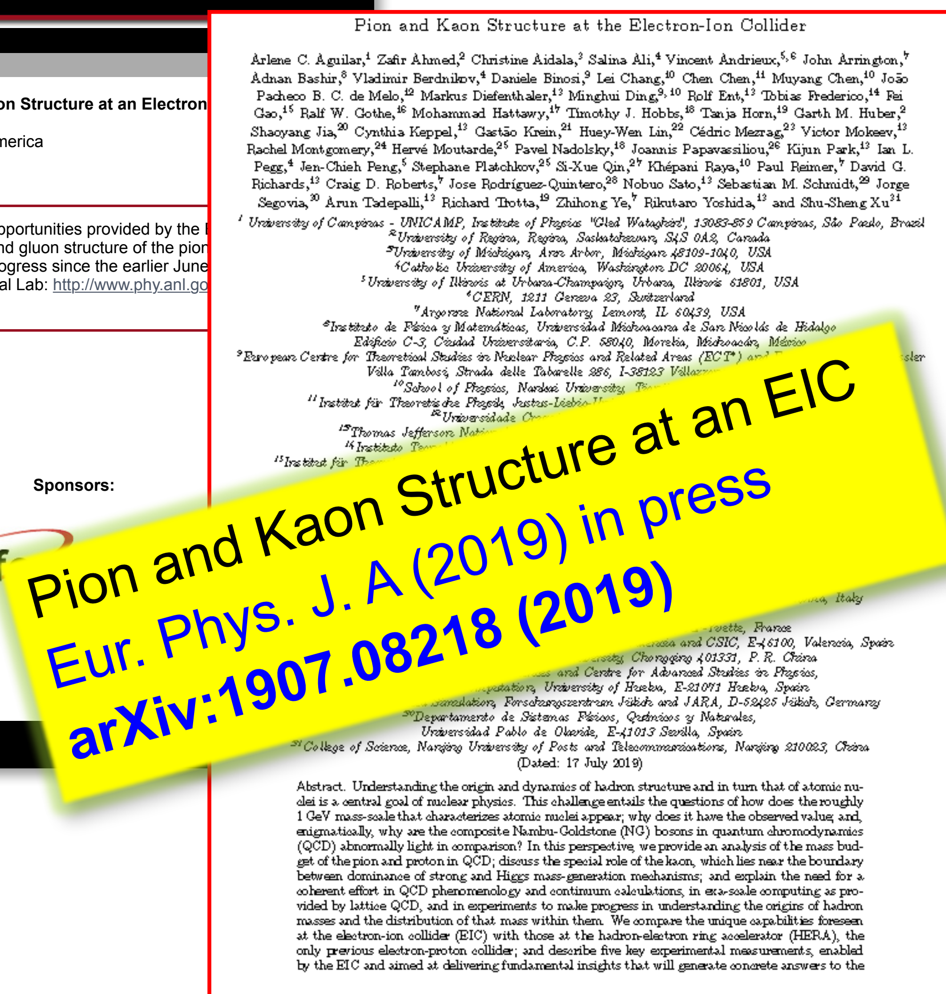


JLab 12 GeV Hall A TDIS projections

Some shameless advertisement…

- ❑ PIEIC Workshops hosted at ANL (2017) and CUA (2018)
- ❑ Also ECT* workshop on Emergent Mass and its Consequences (2018)





- ❑ PIEIC White Paper (2019)
  - Yellow paper en route

universite PARIS-SACLAY (/fr)

More shameless advertisement!

Exploring QCD with Tagged Processes

PARTAGER

From the 14th of September to the 23rd of October 2020

The workshop 'Exploring QCD with Tagged Processes' will be held at Institut Pascal of the University Paris-Saclay from the 14th of September to the 23rd of October 2020.

The topics to be discussed will cover a wide field including all high energy nuclear reactions where nuclear fragments are detected, both with hadronic and leptonic probes. The goal of this program is to elicit detailed discussion on various aspects of the field, from the detector technologies to the theoretical treatment of the tagged processes. It will include discussions about key issues such as the few-body and many-body break-ups of the nucleus, the mesonic content of nuclei and nucleons, development of models describing final state interactions in semi-inclusive (deep) inelastic processes, incorporating the description of the short-range structure of the nucleus with the calculation of high energy scattering processes, as well as modeling hadronization processes that can be studied with tagging.

The 6-week program is intended for a relatively light schedule allowing much discussion and work time in the weeks 1, 3, 4 and 6. Two topical workshops with denser schedules are planned for weeks 2 and 5. The intended topics for the different weeks are as follows:

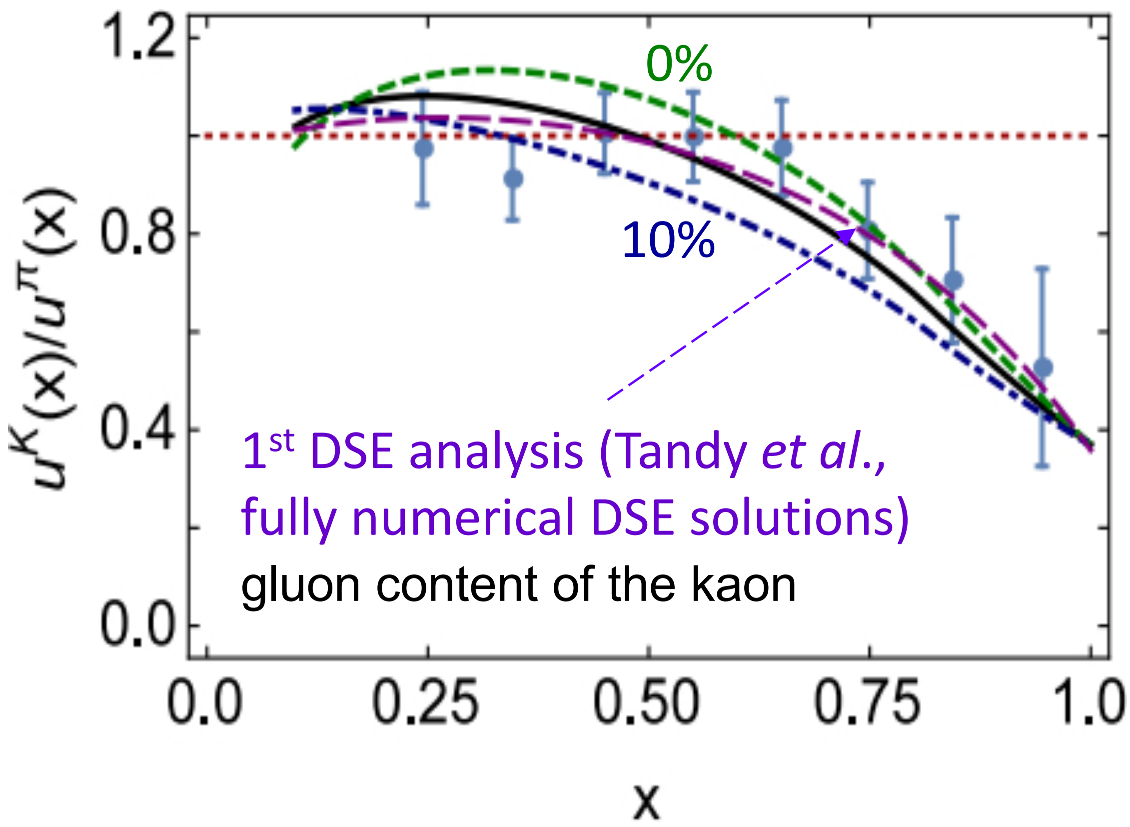
- 14 to 18 Sept. 2020 (Week 1): Many body tagging, hadronization and measuring centrality in AA, pA and eA
- 21 to 25 Sept. 2020 (Week 2): Experimental progress to measure tagged processes, in fixed target and collider settings
- 28 Sept to 2 Oct. 2020 (Week 3): Tagging light nuclei to understand nuclear effects
- 5 to 9 Oct. 2020 (Week 4): Tagging light nuclei to access pion, kaon and neutron structure
- 12 to 16 Oct 2020 (Week 5): The future of tagging in fixed and collider kinematics
- 19 to 23 Oct 2020 (Week 6): Treating final state interactions in tagged processes

Summary

- TDIS provides unique access to targets not otherwise found in nature
  - *Critical, fundamental hadron structure measurements!*
- TDIS can directly probe the meson cloud of the nucleon
  - Direct measurement of nucleon-meson fluctuation
  - Access pion and kaon structure functions
- The structure functions of pions, kaons and protons at large-x should be different
  - Confirming these would be textbook material.
- ***Very*** few experiments to date
  - JLab12 TDIS at large x, low Q – ***pion***eering
  - EIC will open up a new TDIS era

Thanks

Kaons at Large x



1[st] DSE analysis (Tandy *et al.*, fully numerical DSE solutions)

gluon content of the kaon

1. At high x, the shapes of valence u quark distributions in pion, kaon and proton are different, and so are their asymptotic x→1 limits

S-S Xu, L. Chang, C.D. Roberts, H-S Zong, Phys. Rev. D 97 (2018) no.9, 094014

3. Kaon exchange is related to the ΛN interaction – correlated with the Equation of State and astrophysical observations

Proton: Mass ~ 940 MeV
preliminary LQCD results on mass budget, or view as mass acquisition by DχSB

Kaon: Mass ~ 490 MeV
at a given scale, less gluons than in pion

Pion: Mass ~ 140 MeV
mass enigma – gluons vs Goldstone boson

2. Based on Lattice QCD and DSE:

- Valence quarks carry ~52% of the pion's momentum at the light front, at the scale used for LQCD calculations, or ~65% at the perturbative hadronic scale
- At the same scale, valence-quarks carry ⅔ of the kaon's light-front momentum, or roughly 95% at the perturbative hadronic scale
- **Less glue in the kaon than in the pion**

TDIS Hall A Status

C2 approval – both experiments (π and k) form a run group

- Physics rating, days approved – no need to return to PAC
- *Full approval requires passing internal technical review*

Thin wall target *(D. Dutta)*

High rate data acquisition and tracking

- New detector design *(K. Gnanvo, N. Liyanage)*
- Simulation *(E. Fuchey, R. Montgomery, A. Tadepalli)*
- Fast GEM data acquisition *(G. Heyes, E. Jastrzembski, E. Pooser)*
- Tracking *(R. Montgomery, A. Tadepalli, S. Wood)*

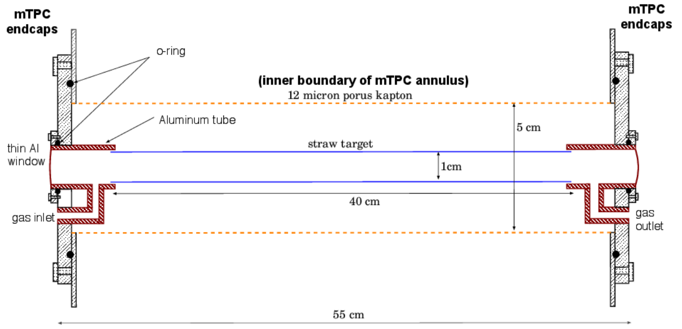
Calorimeter refurbishment *(D. Dutta, S. Malace)*

Cerenkov refurbishment *(E. Fuchey, A. Puckett)*

…..and more!

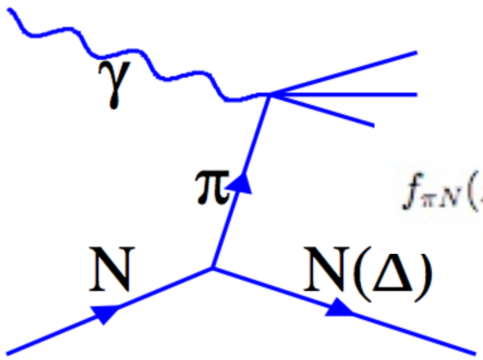
TDIS Target design

Target design adapted to the new mTPC detector design



How to estimate rates?

- Use Sullivan process and pion cloud model



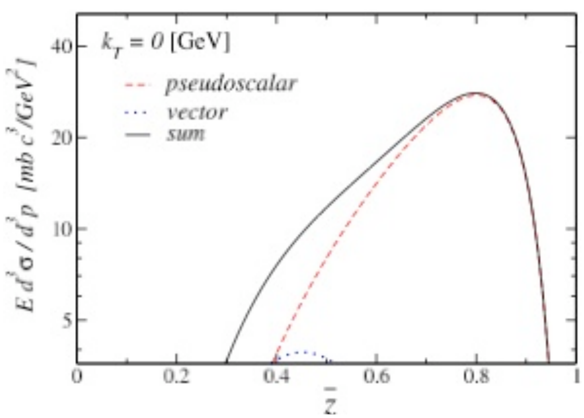
$$F_2^{(\pi N)}(x) = \int_x^1 dz\, f_{\pi N}(z)\, F_{2\pi}\left(\frac{x}{z}\right)$$

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

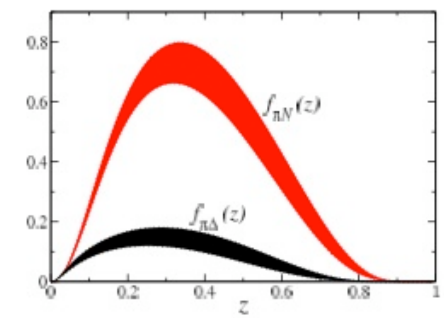
$F_2^{(\pi N)}$ = contribution to inclusive F_2 from scattering off of the virtual pion, *use for estimate*

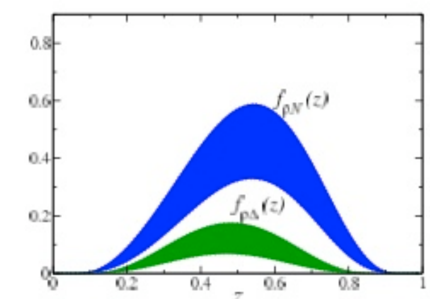
$F_{\pi N}(z)$ = light-cone momentum distribution of pions in the nucleon

Pion expected to be dominant – also estimated ρ, Δ

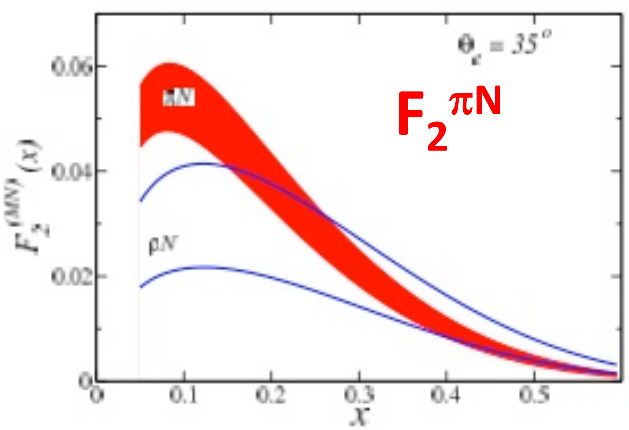


Form factor GπN constrained by comparing the meson cloud contributions with data on inclusive pp → nX scattering





Light-cone momentum distributions, fπ(ρ)N and fπ(ρ)Δ, as a function of the meson light-cone momentum fraction



Convolute the light-cone distributions with the structure function of the meson (from GRV)

Important to note – kinematic limits:
- z ~< |**k**|/M, where **k** is π 3-momentum = **-p'**
- 60 < **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

T. J. Hobbs et al, Few Body Syst. 56 (2015) no.6-9
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)

multiple Time Projection Chamber (mTPC)

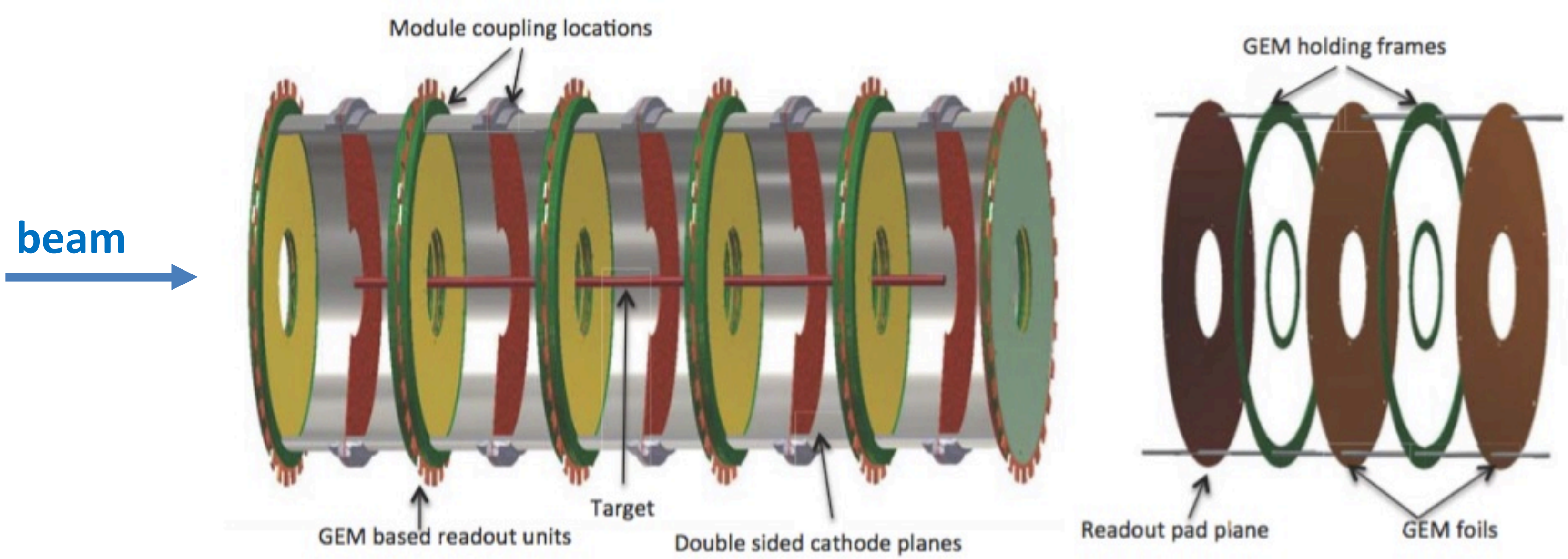
Device consists of multiple TPC modules instead of a single TPC detector

Cylindrical device optimized to detect low momentum particle tracks under extremely high background rate conditions (~10 MHz) - ten times higher than any previous TPC.

Placed within strong solenoidal magnetic field to confine background δ-electrons created in the target

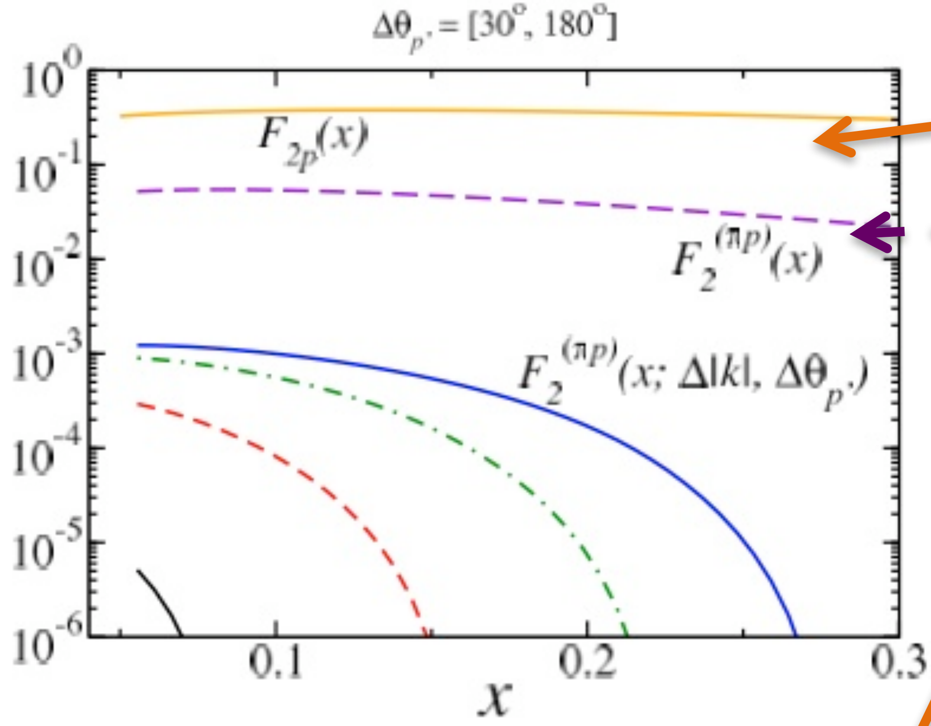
Drift electric field parallel to the solenoidal magnetic field, minimizes Lorentz force on drift electrons and leads to simplified track reconstruction and reduced drift times.

Drift distances ~5 cm, leading to maximum drift time ~1 μs, down by about a factor of 20-40 compared to a radial TPC of a similar size.

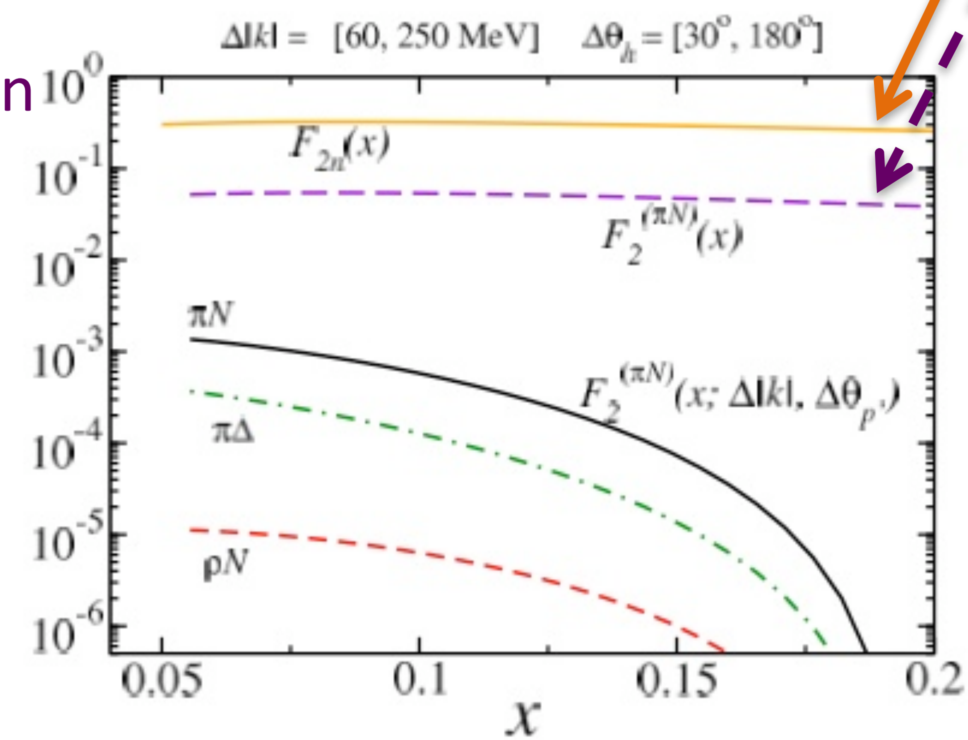


Rate estimations of TDIS physics signal

proton



neutron



Inclusive structure function $F_2(x)$

Contribution to F_2 from pions via Sullivan process

top:

- For different tagged p momenta ranges **Δk:** 60-100, 100-200, 200-300, 300-400 MeV
- Neutron will be similar

bottom:

- Neutron plot shows contributions from ρ, Δ
- Proton will be similar

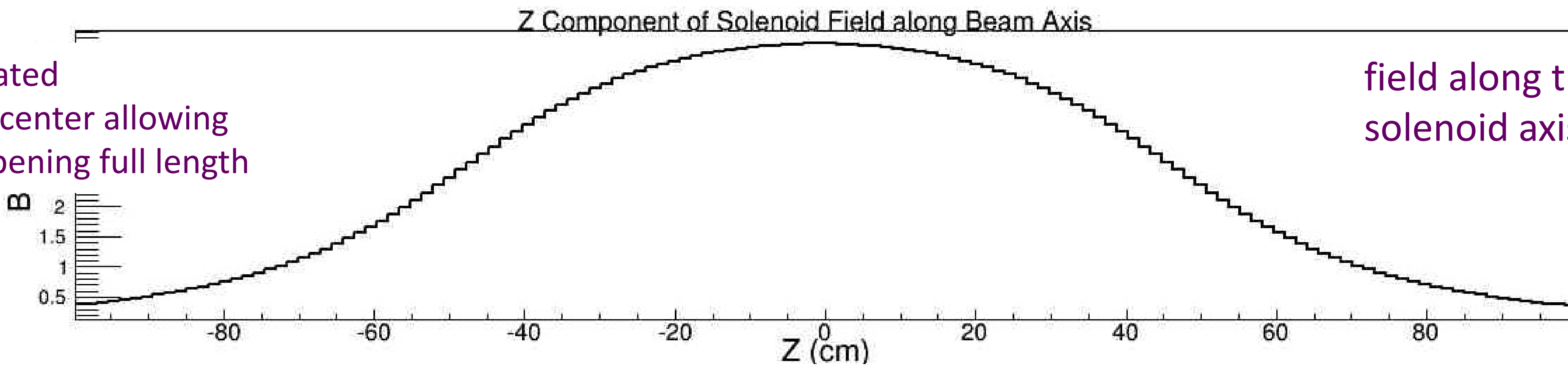
Signal is orders of magnitude smaller than inclusive DIS – *need high luminosity experiment*

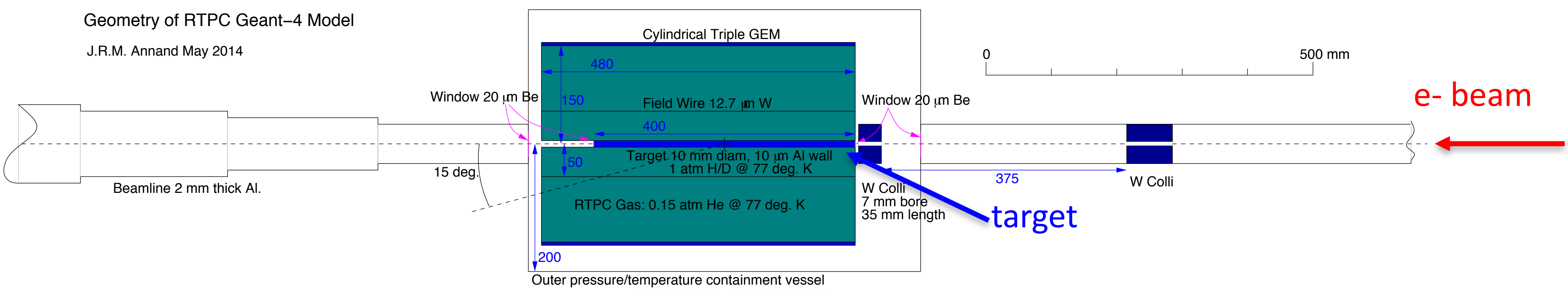
T.J. Hobbs, Few Body Syst. 56 (2015) no.6-9, 363-368

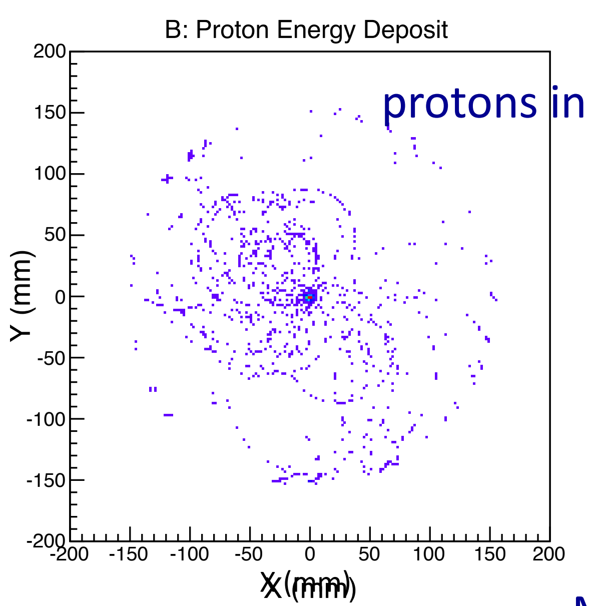
Radial TPC in Field for Monte Carlo Simulations

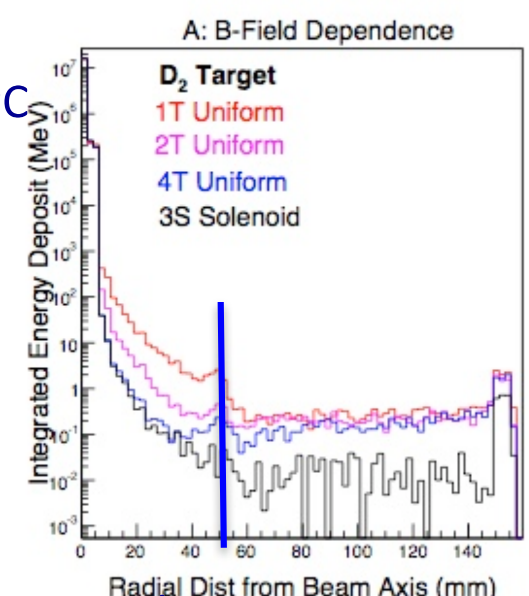
target located
20 cm off center allowing
15 deg. opening full length

field along the
solenoid axis









Moller containment

Monte Carlo simulates electromagnetic interactions

- Moller scattering, secondaries ~10 MHz
- photoproduction ~20 MHz

Includes deuteron photodisintegration

- ~20 MHz

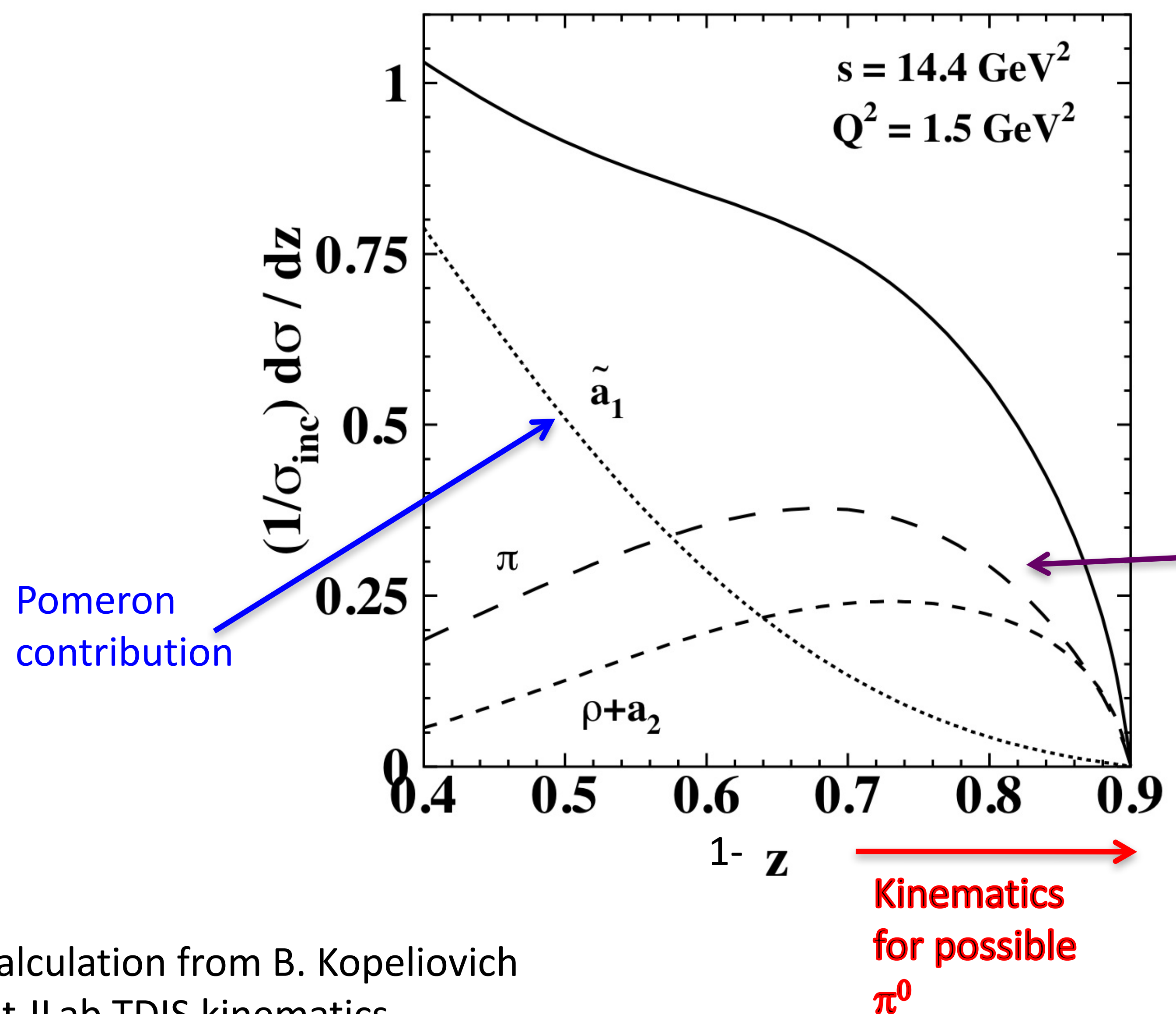
Elastic scattering by far largest

- direct calculation 170 MHz

5 MHz/cm^2 s - OK for GEMs

Developing the F_2^{π} case

hydrogen target, worst theoretical backgrounds



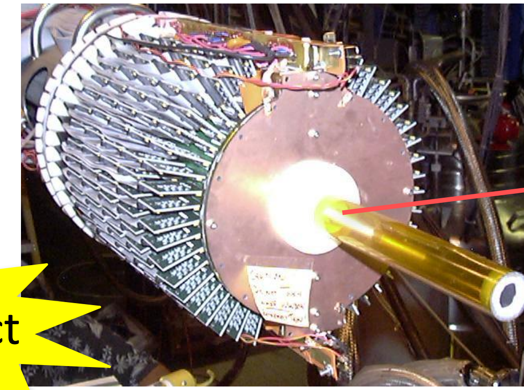
1-z = light-cone momentum fraction of hadron (proton tag)
In the target fragmentation region

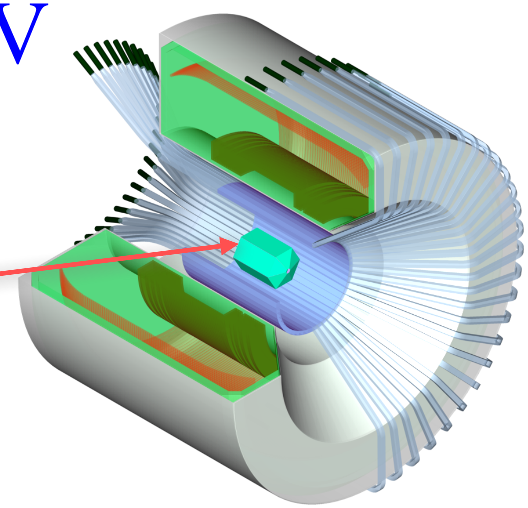
Calculation from B. Kopeliovich
at JLab TDIS kinematics

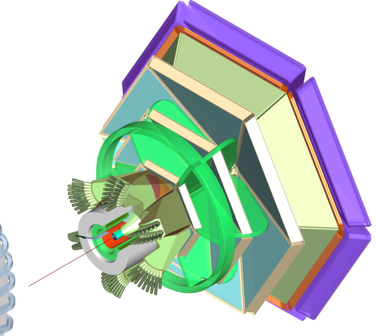
Approved for Jefferson Lab 12 GeV

E12-06-113
"BONUS12"

High Impact

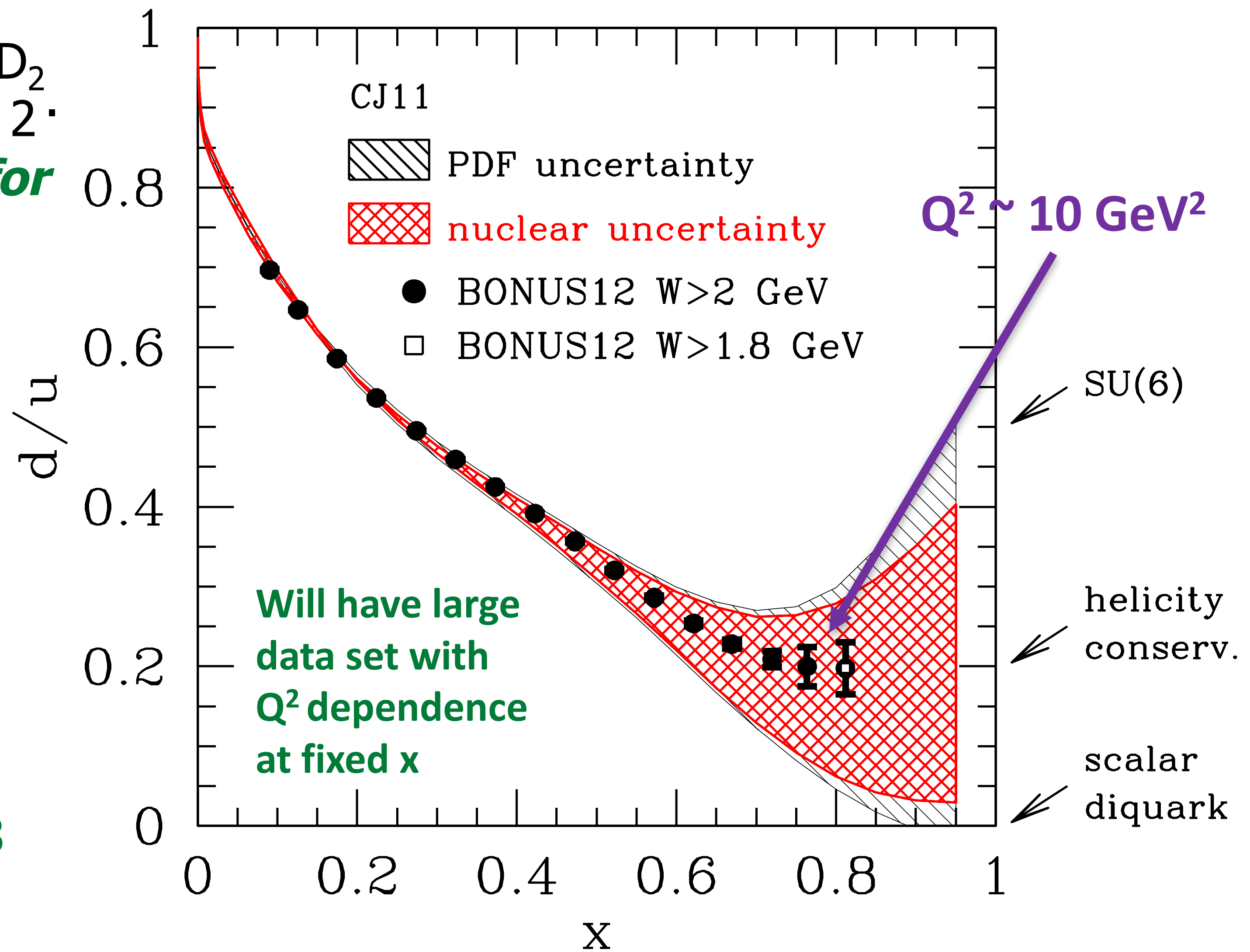






CLAS12
Central
Detector

- Data taking of 35 days on D_2 and 5 days on H_2 with $L = 2 \cdot 10^{34}$ cm^{-2} sec^{-1} ***planning for 2019 installation***
- BoNuS detector DAQ and trigger upgrade
- DIS region with
  - $Q^2 > 1$ GeV$^2/c^2$
  - $p_s < 100$ MeV/c
  - $\theta_{pq} > 110°$
- Largest value for $W^* > 1.8$ GeV gives max. $x^* = 0.83$



BONuS12 RTPC