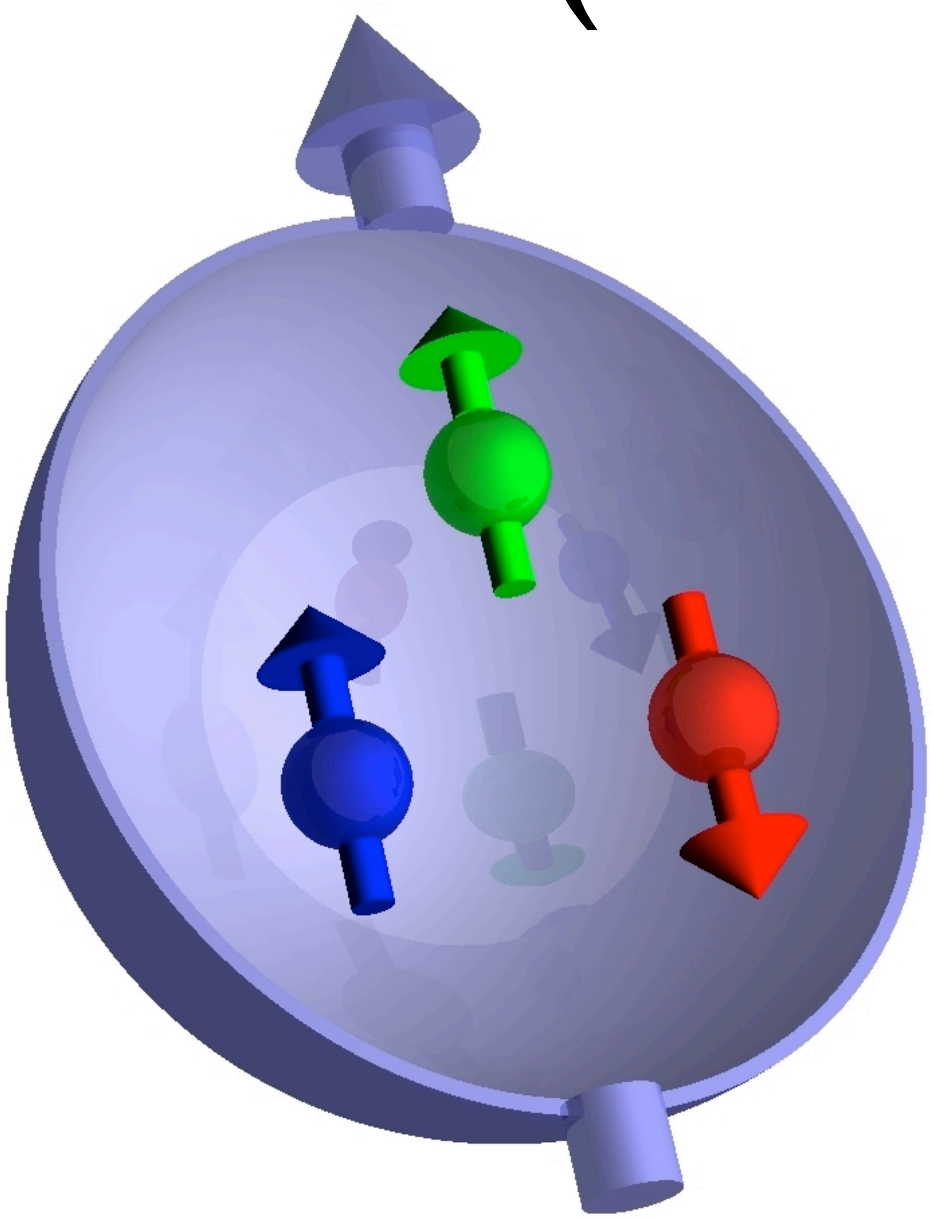
The Structure of the Nucleon
(with a HERMES bias)



Morgan J Murray, University of Glasgow

Overview

- History of the Field
- Notable Results
- Future Highlights

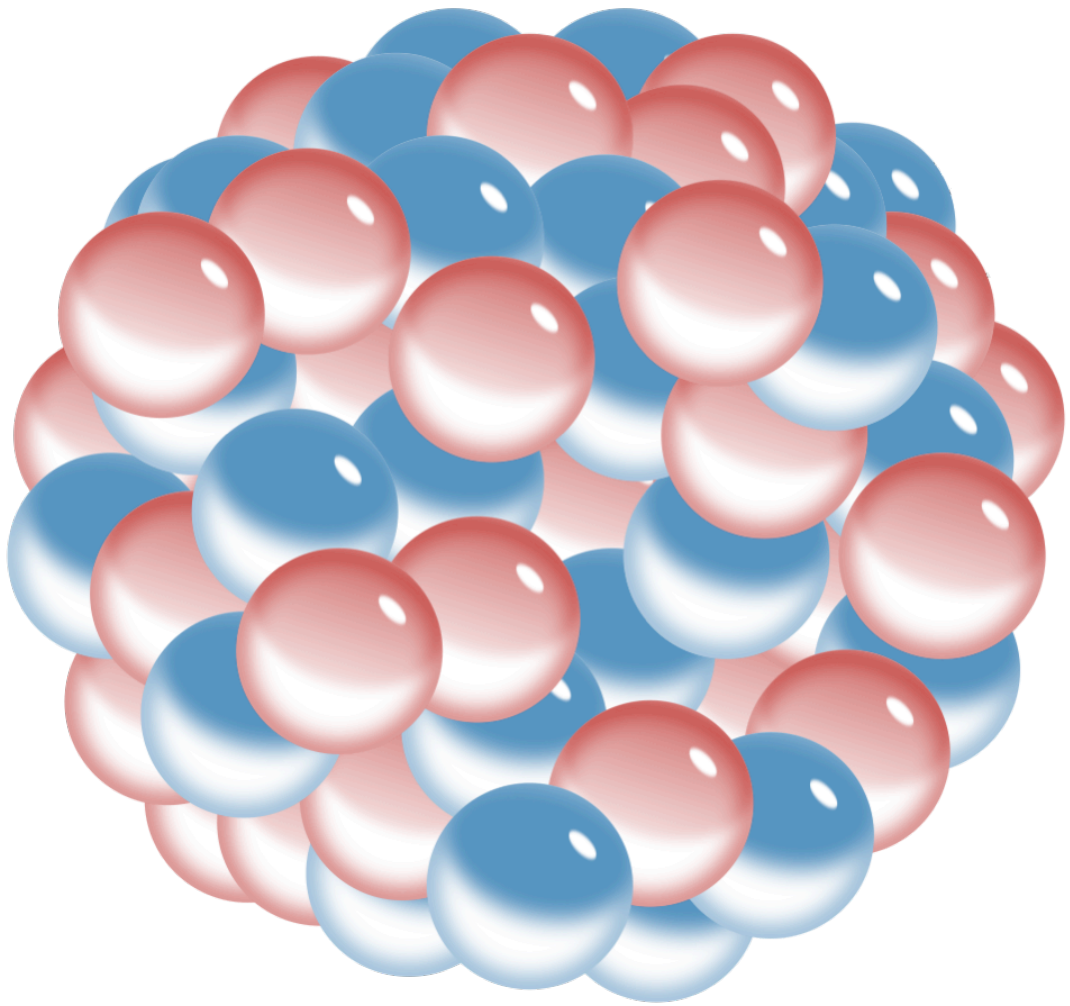
Where were we?

Where are we?

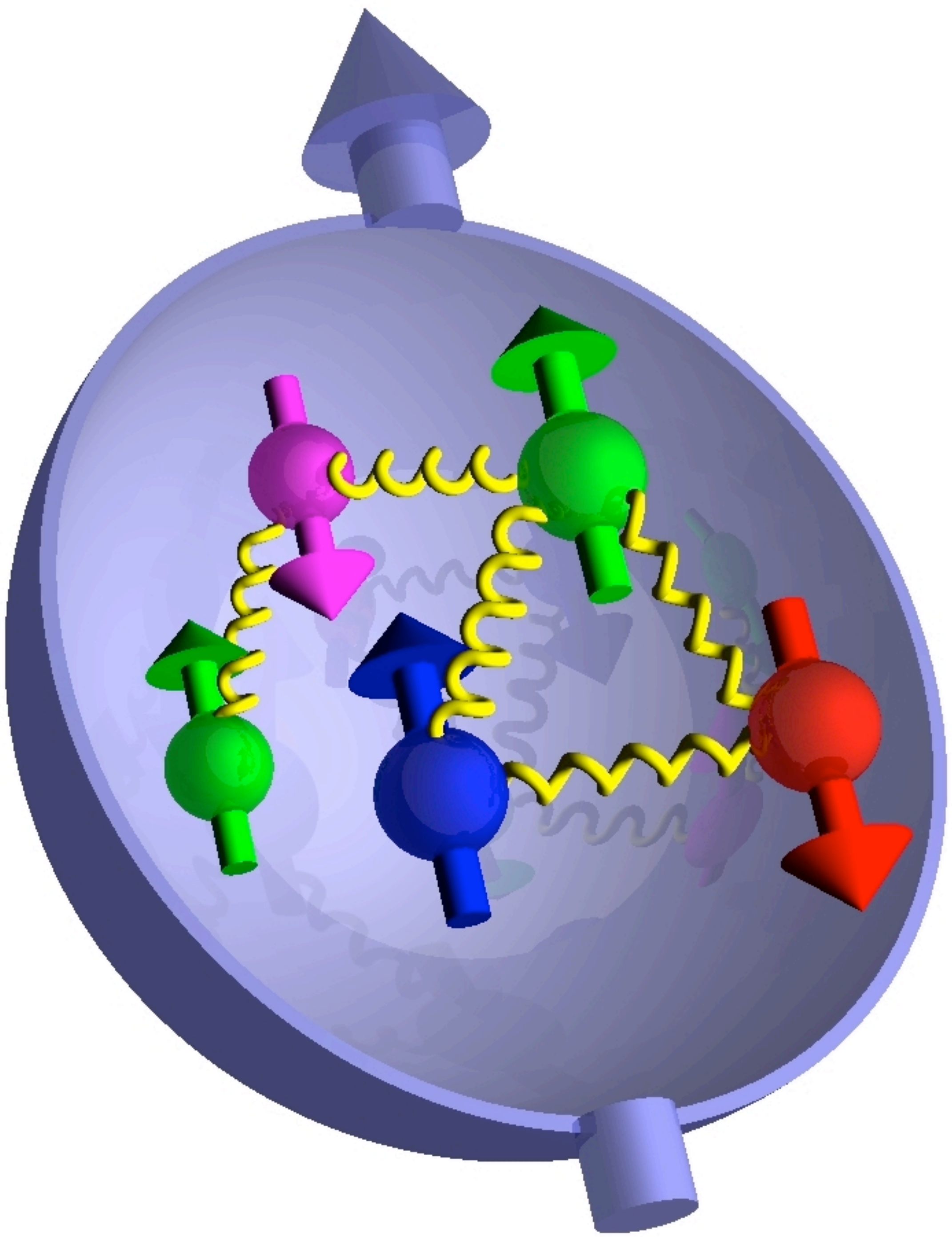
Where are we going?

Nucleons

- All matter made of atoms; subatomic structure is nucleons
- Protons and Neutrons
- Look at form factors to determine electric and magnetic distribution inside the nucleon



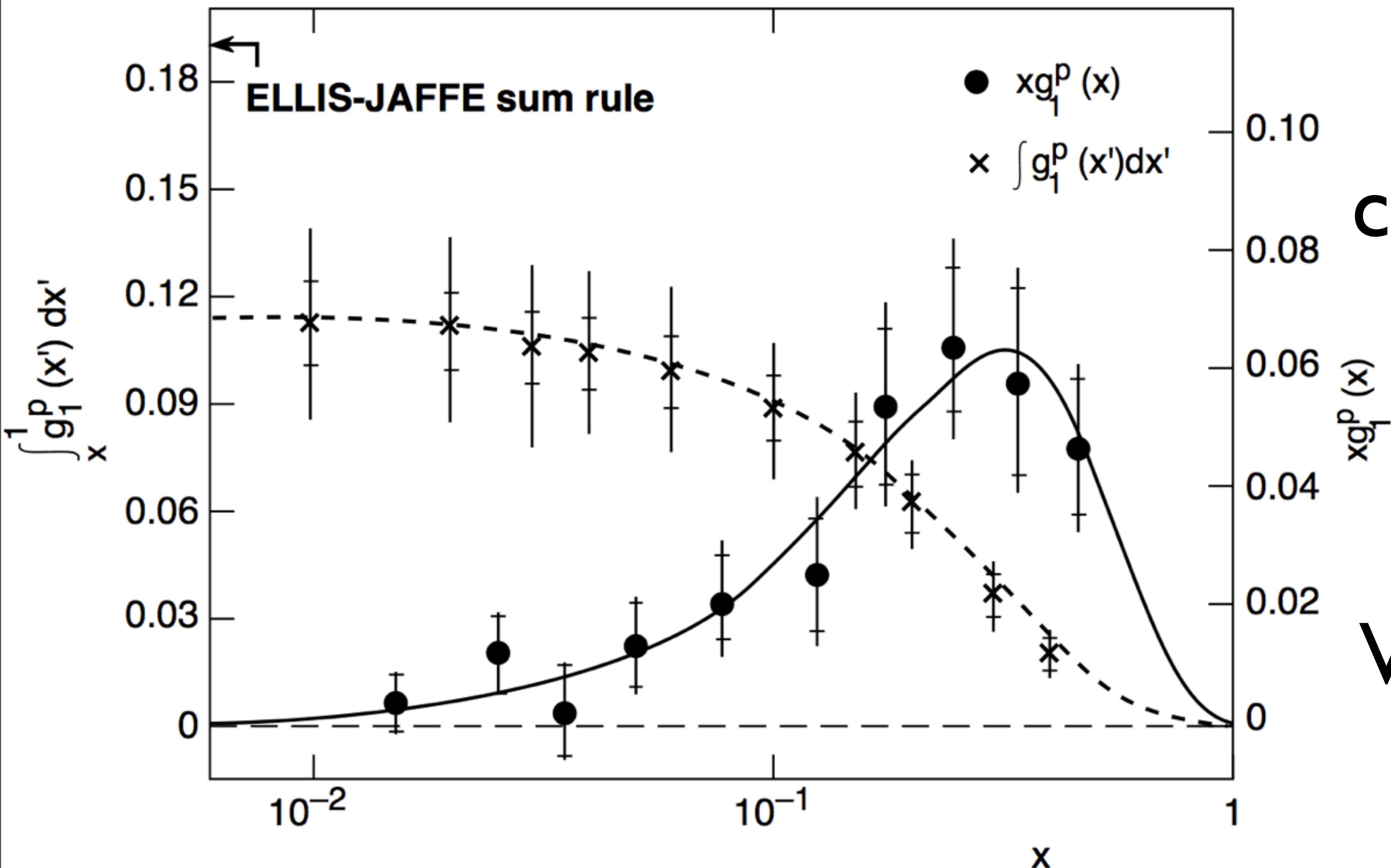
Quarks and Gluons



- Division between quarks and gluons
- Division between sea and valence quarks
- Concerned only with up, down and strange

Exploration

The Motivation



Expected that the nucleon's spin is carried by the quarks:

½ + ½ - ½ = ½

Via the Ellis-Jaffe sum rule, EMC said NO!

Spin Crisis!!!

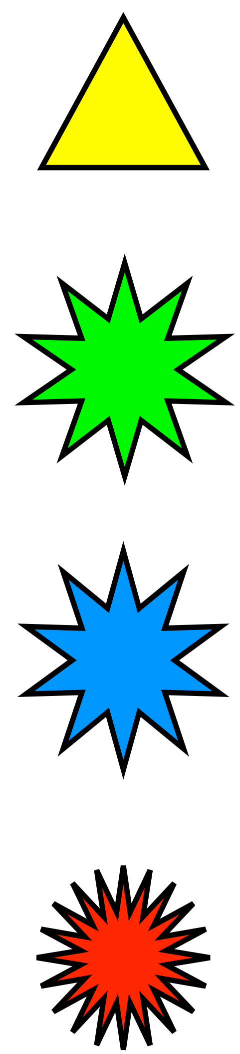
How do we explain the EMC result?

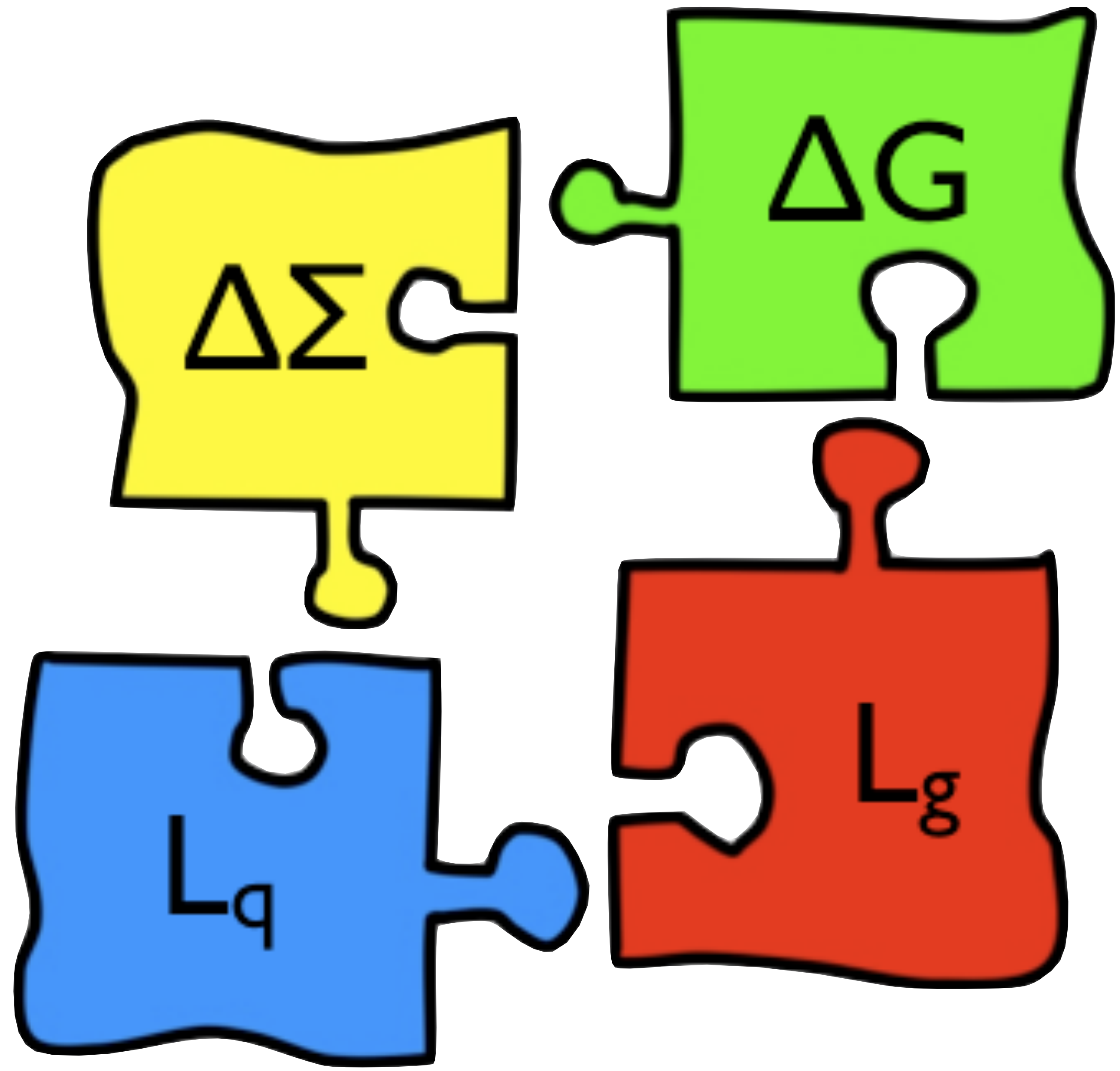
Quark spin

Gluon spin

Quark Orbital Angular Momentum

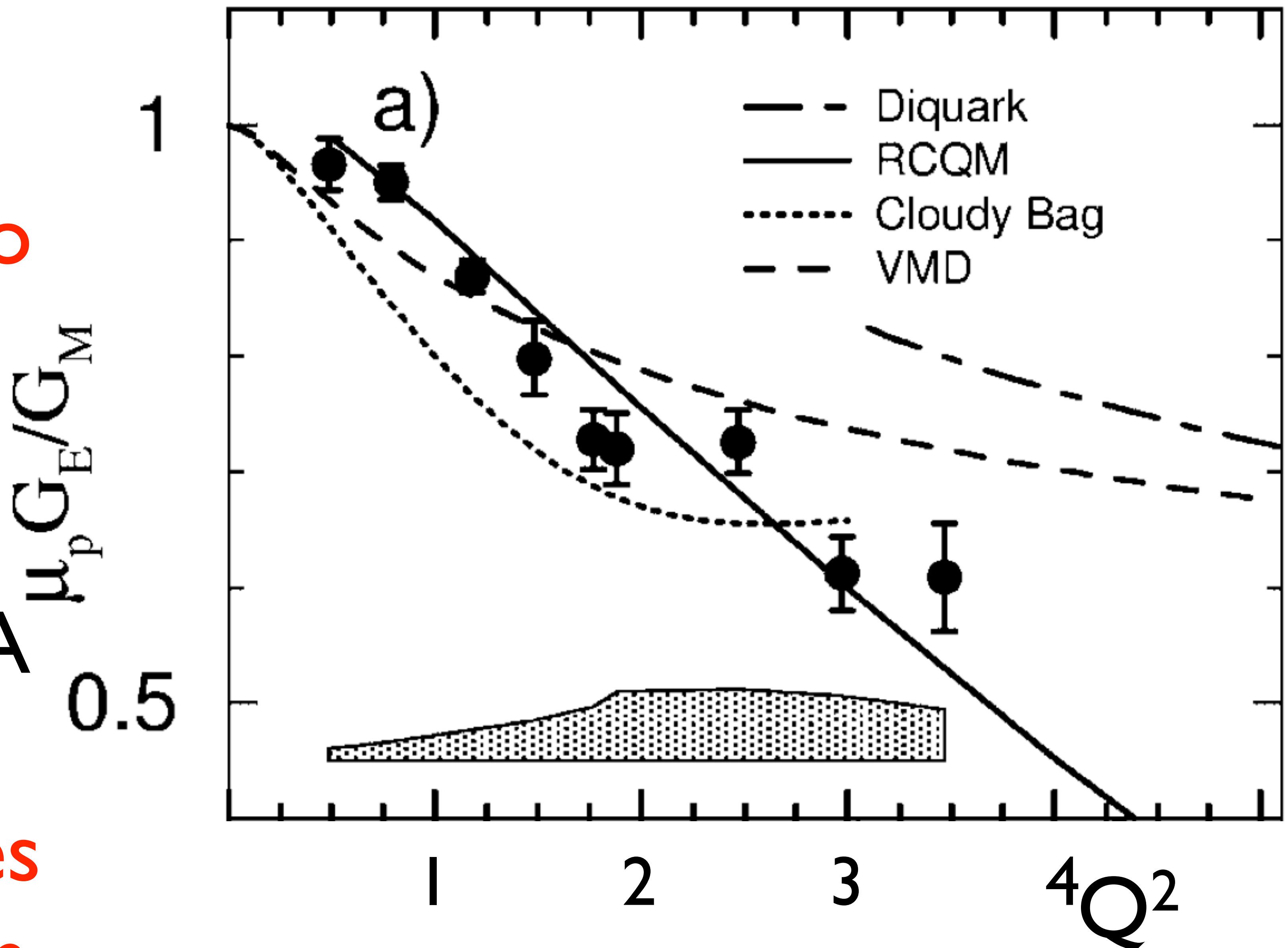
Gluon Orbital Angular Momentum





The Motivation

Single-photon exchange predicts a constant GE/GM ratio



Indicators from Hall A in 2000 are that this doesn't hold - requires (at least!) two-photon exchange.

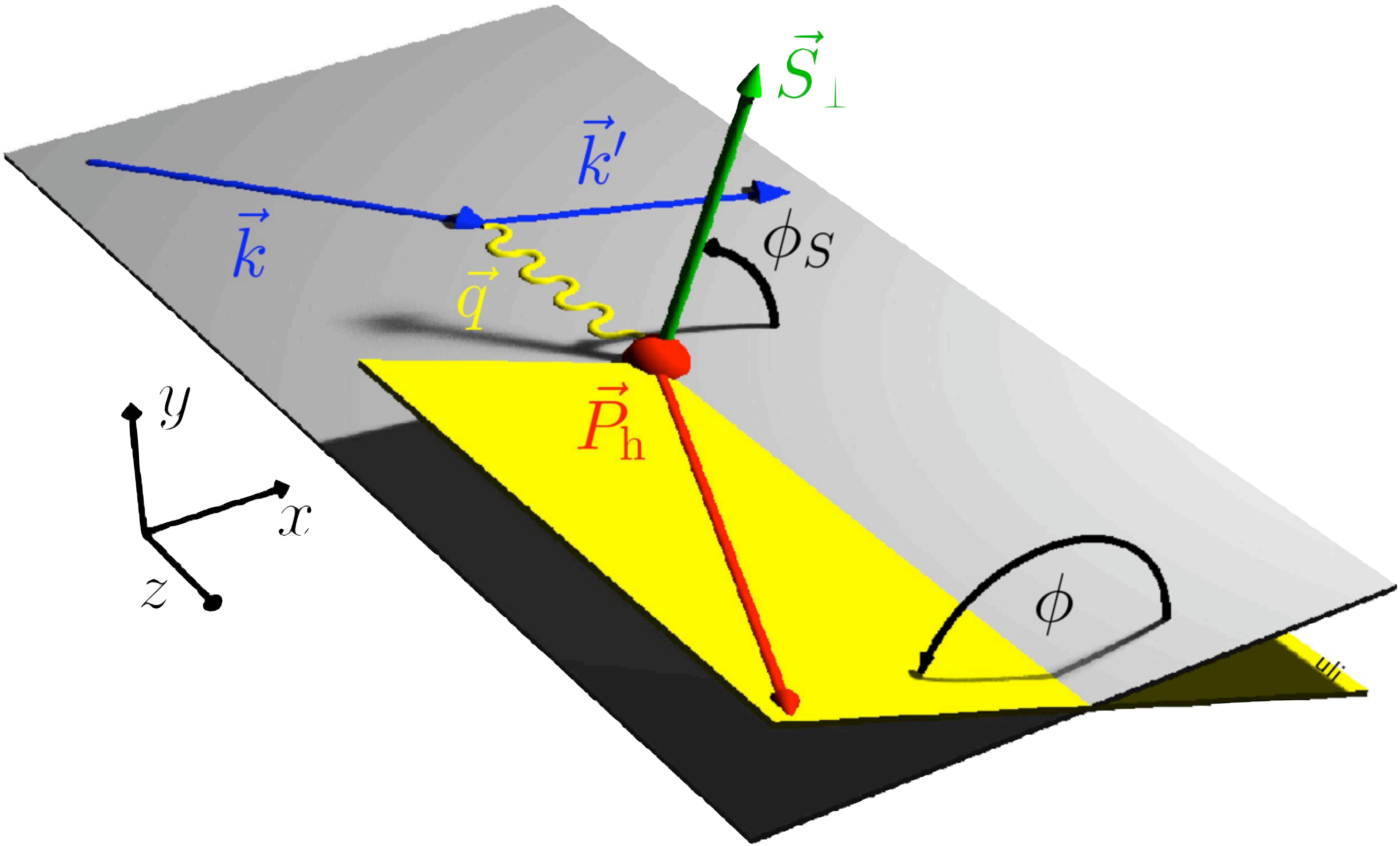
Consolidation

Structure Functions & TMDs

Quark Polarization

Nucleon Polarization

	U	L	T
U	f_1		$h_1^{\perp}$
L		g_{1L}	$h_{1L}^{\perp}$
T	$f_{1T}^{\perp}$	g_{1T}	$h_1, h_{1T}^{\perp}$


$\vec{S}_\perp$
$\vec{k}'$
$\vec{k}$
ϕ_S
$\vec{q}$
$\vec{P}_\mathrm{h}$
y
x
z
ϕ

Semi-Inclusive DIS

cos-phi moments

$$d\sigma = d\sigma^0_{\mathrm{UU}} + d\sigma^1_{\mathrm{UU}}\cos(2\phi) + \frac{1}{Q}\left(d\sigma^2_{\mathrm{UU}}\cos\phi + \lambda_e d\sigma^3_{\mathrm{LU}}\sin\phi\right)$$

$$+S_L\left\{d\sigma^4_{\mathrm{UL}} + \frac{1}{Q}\left(d\sigma^5_{\mathrm{UL}}\sin + \lambda_e\left[Q d\sigma^6_{\mathrm{LL}} + d\sigma^7_{\mathrm{UL}}\cos\phi\right]\right)\right\}$$

Sivers Function

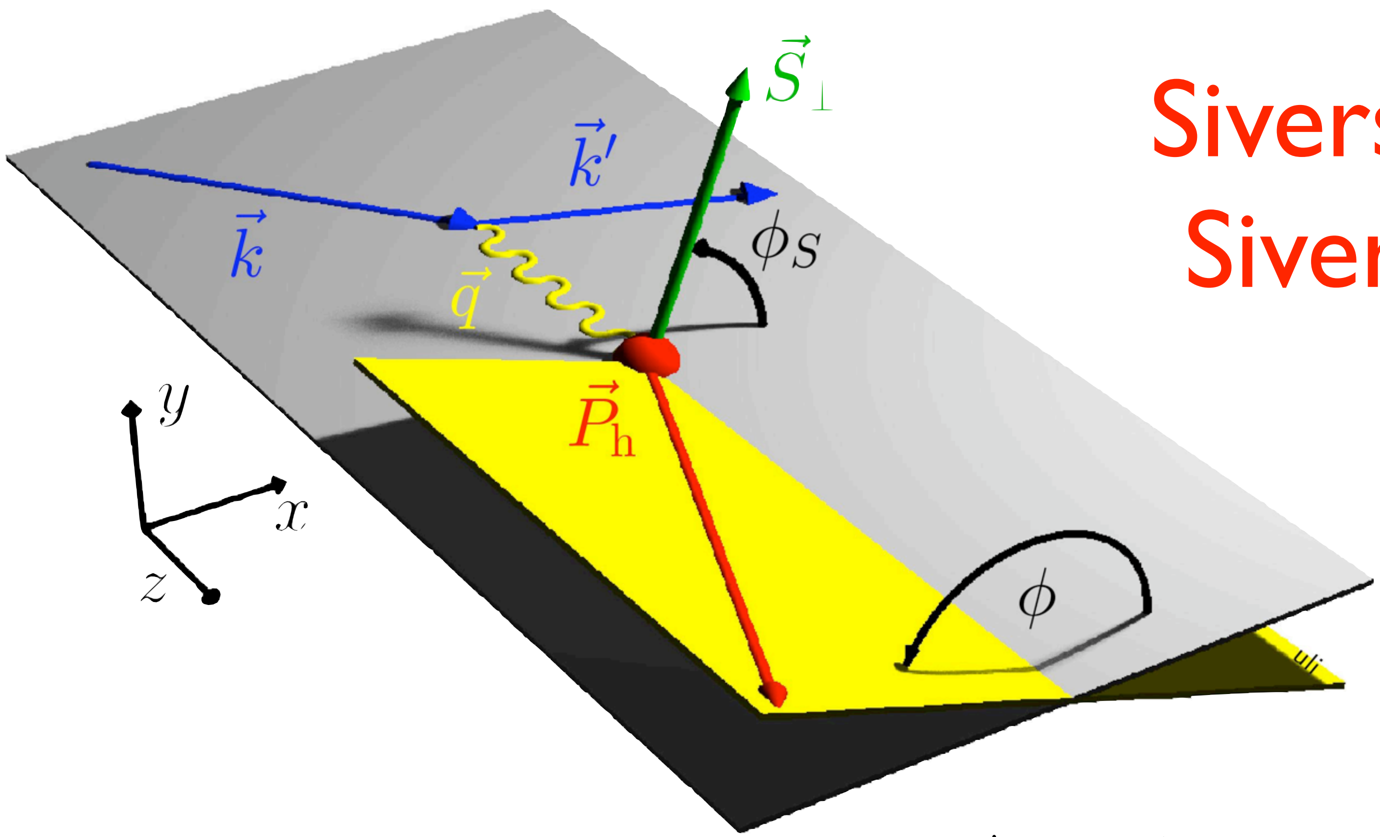
Collins Effect

$$S_T\left\{d\sigma^8_{\mathrm{UT}}\sin(\phi - \phi_s) + d\sigma^9_{\mathrm{UT}}\sin(\phi + \phi_S) + d\sigma^{10}_{\mathrm{UT}}\sin(3\phi - \phi_S)\right.$$

$$+\frac{1}{Q}\left[d\sigma^{11}_{\mathrm{UT}}\sin(2\phi - \phi_S) + d\sigma^{12}_{\mathrm{UT}}\sin\phi_S\right]$$

$$\left.+\lambda_e\left[d\sigma^{13}_{\mathrm{LT}}\cos(\phi - \phi_S) + \frac{1}{Q}d\sigma^{14}_{\mathrm{LT}}\cos\phi_S + \frac{1}{Q}d\sigma^{15}_{\mathrm{LT}}\cos(2\phi - \phi_S)\right]\right\}$$

Semi-Inclusive DIS



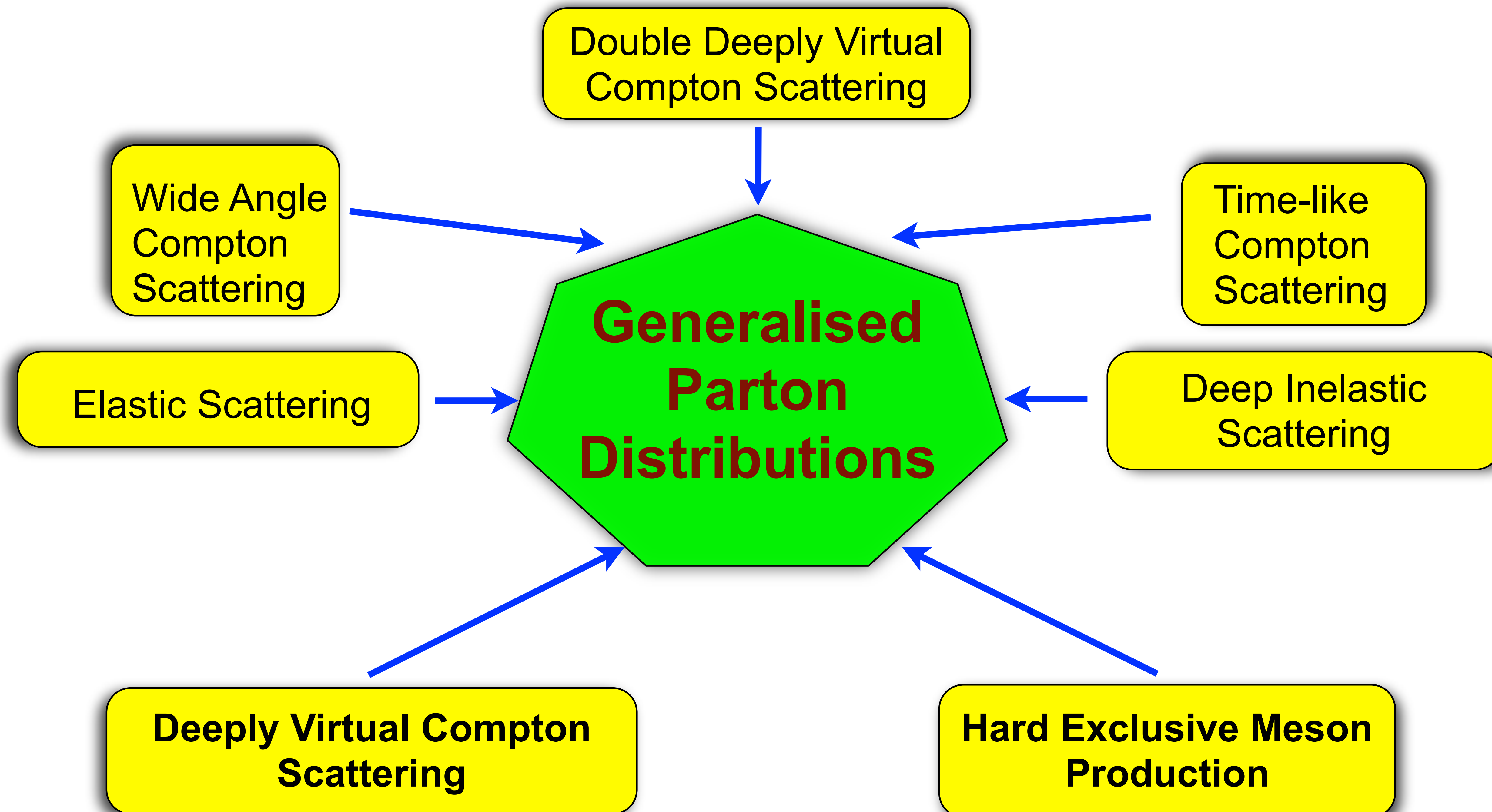
Sivers moment allows access to Sivers function ⇒ quark OAM

Collins moment allows extraction of transversity

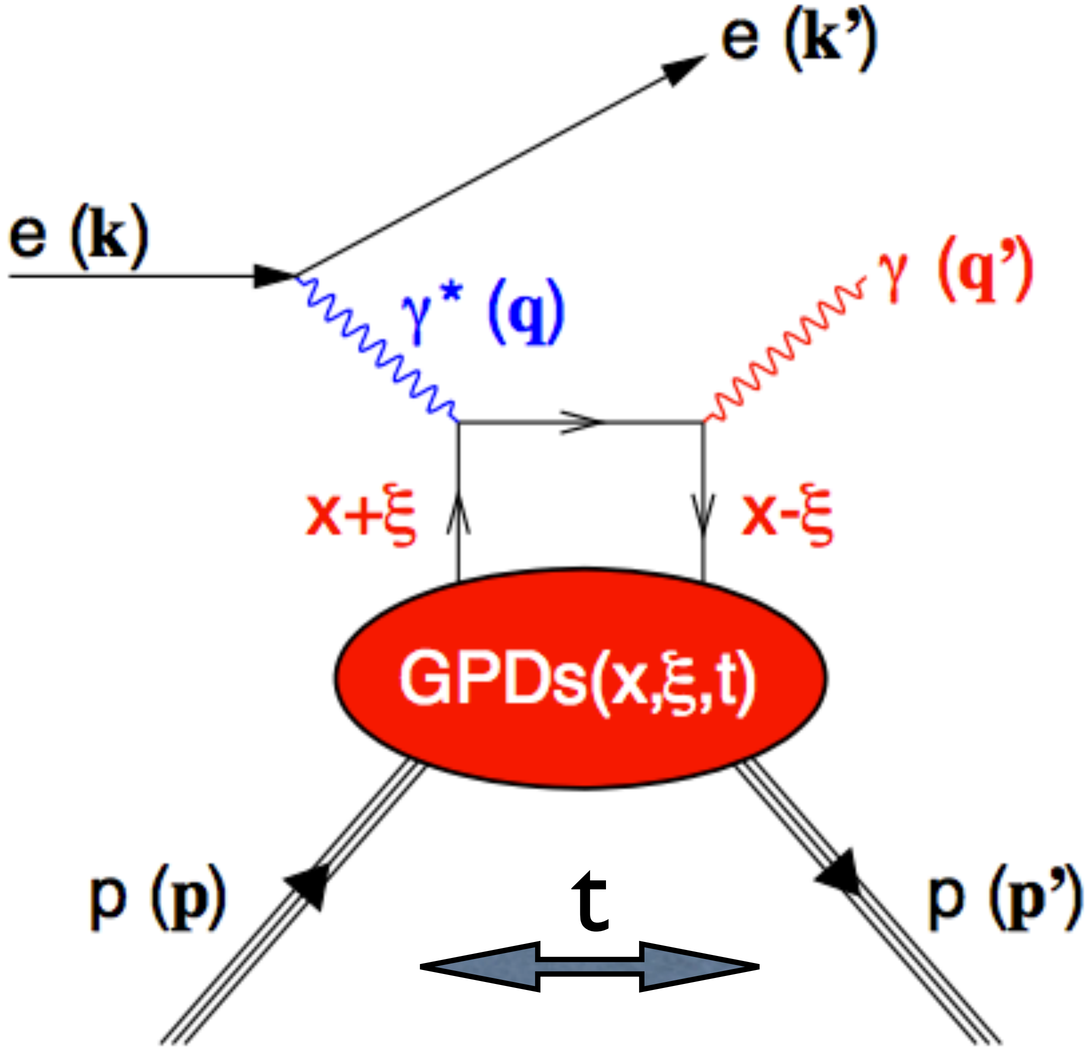
$$\mathrm{d}\sigma^{8}_{UT} \propto |S_T| \left[\frac{\vec{P}_T \cdot \hat{P}_{h,\perp}}{M_h} f_{1T}^{\perp q}(x, p_T^2) * D_1^q(z, k_T^2) \right]$$

$$\mathrm{d}\sigma^{9}_{UT} \propto |S_T| \left[\frac{\vec{k}_T \cdot \hat{P}_{h,\perp}}{M_h} h_1(x, p_T^2) * H_1^{\perp q}(z, k_T^2) \right]$$

Generalised Parton Distributions



GPDs



t - Mandelstam variable (squared momentum transfer to nucleon)

x - Fraction of nucleon's longitudinal momentum carried by active quark

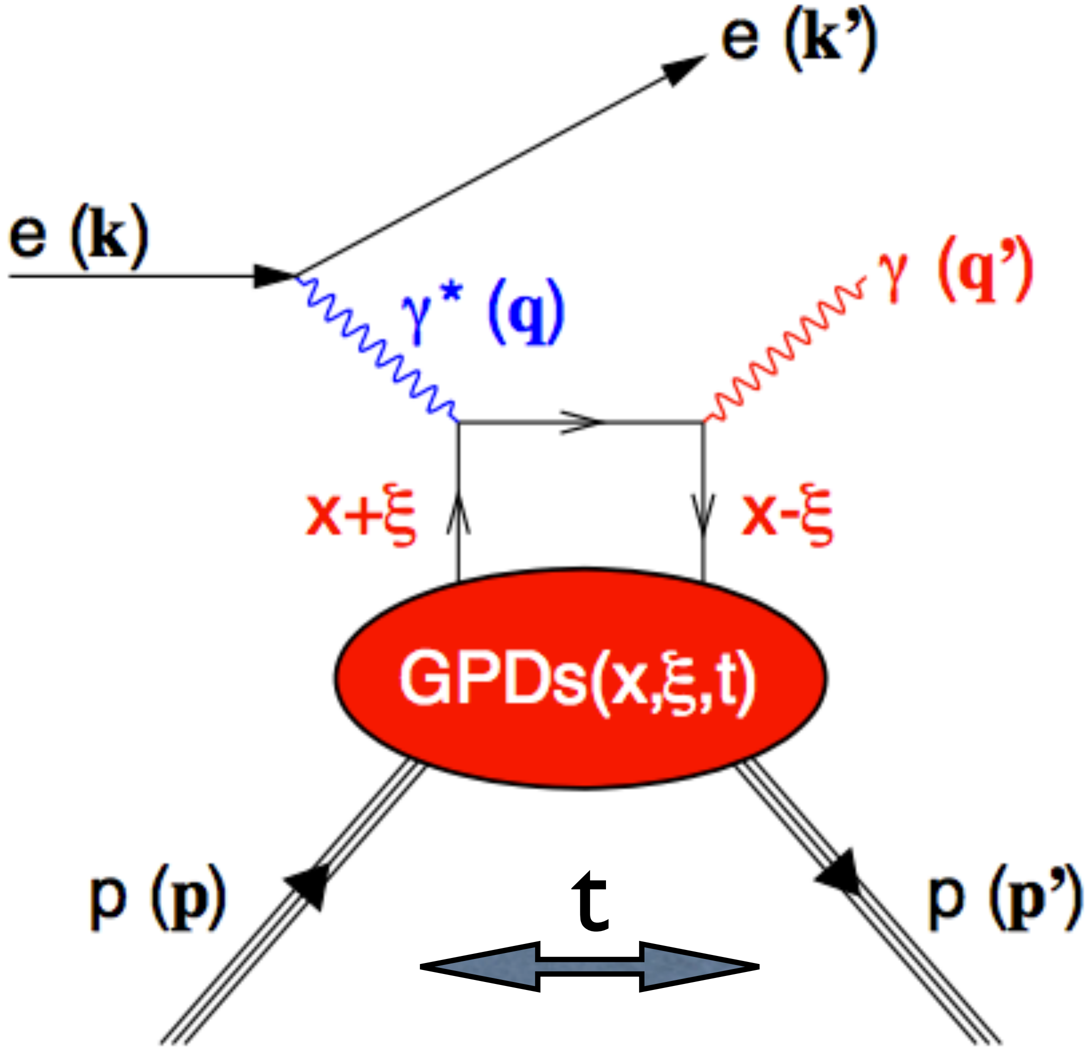
ξ - half the change in the longitudinal momentum of the active quark.

"Ji's Relation"

$$\Delta\Sigma + \mathrm{L_Q} = \mathrm{J_Q} = \frac{1}{2} \lim_{t\to 0} \int_{-1}^{1} \left[\mathrm{H}(x,\xi,t) + \mathrm{E}(x,\xi,t)\right] x \, \mathrm{d}x$$

Phys. Rev. Lett. 78:610, 1997

GPDs



Four GPDs: H, $\widetilde{\text{H}}$, E, $\widetilde{\text{E}}$

Constrained by PDFs and Form Factors

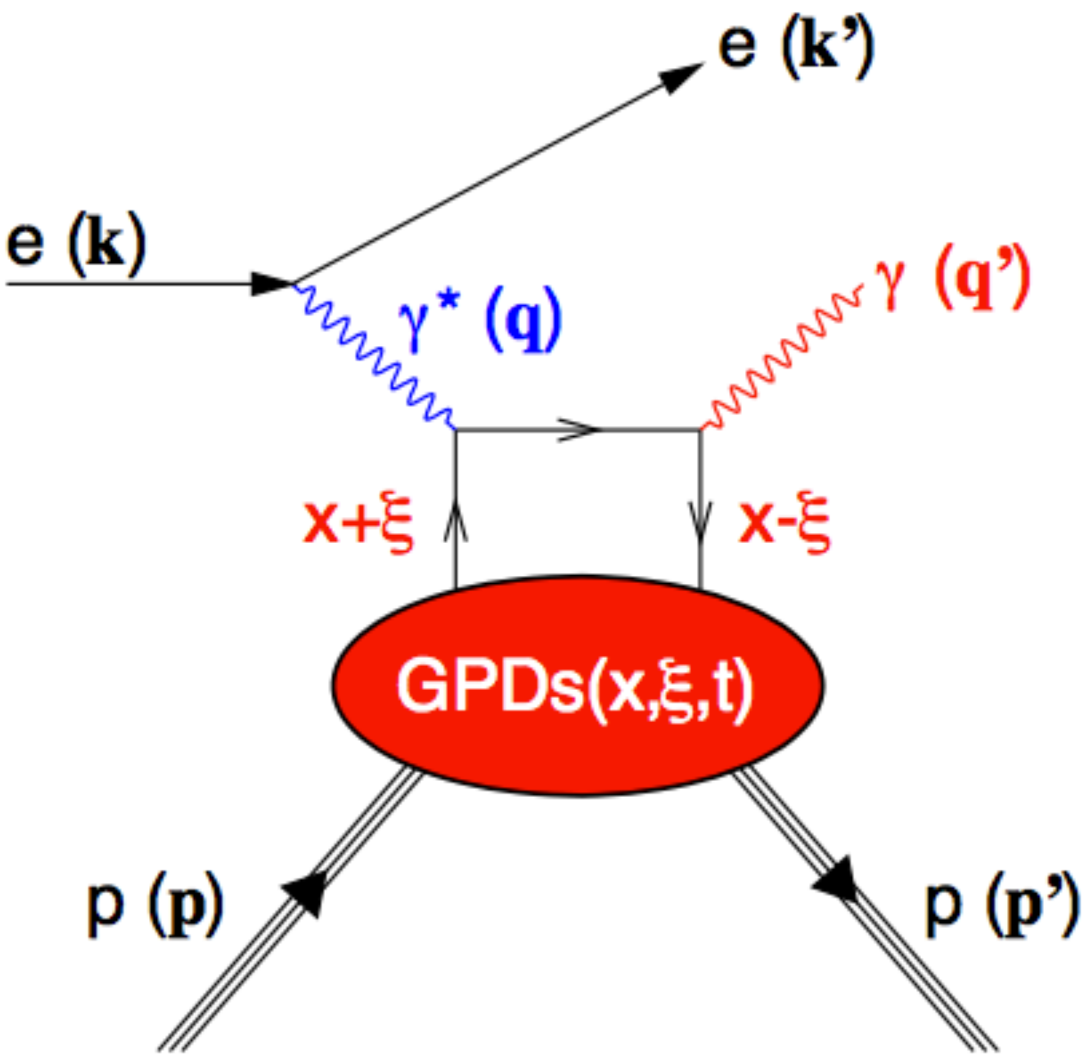
Offer a possible solution to the spin crisis!

"Ji's Relation"

$$\Delta\Sigma + \mathrm{L_Q} = \mathrm{J_Q} = \frac{1}{2}\lim_{t\to 0}\int_{-1}^{1}\left[\mathrm{H}(x,\xi,t) + \mathrm{E}(x,\xi,t)\right] x\,\mathrm{d}x$$

Phys. Rev. Lett. 78:610, 1997

Exclusive Physics



$$\frac{d\sigma}{dx_B\, dQ^2\, d|t|\, d\phi} = \frac{x_B\, e^6\, |\tau|^2}{32(2\pi)^4\, Q^4\, \sqrt{1+\epsilon^2}}$$

$$|\tau|^2 = |\tau_{BH}|^2 + |\tau_{DVCS}|^2 + \overbrace{\tau_{BH}\tau^*_{DVCS} + \tau^*_{BH}\tau_{DVCS}}^{\mathcal{I}}$$

$$\mathcal{A}_C(\phi) \equiv \frac{d\sigma^+(\phi) - d\sigma^-(\phi)}{d\sigma^+(\phi) + d\sigma^-(\phi)}$$

$$\mathcal{A}_{LU}(\phi) \equiv \frac{[\sigma^{\rightarrow\Leftarrow}(\phi) + \sigma^{\rightarrow\Rightarrow}(\phi)] - [\sigma^{\leftarrow\Leftarrow}(\phi) + \sigma^{\leftarrow\Rightarrow}(\phi)]}{[\sigma^{\rightarrow\Leftarrow}(\phi) + \sigma^{\rightarrow\Rightarrow}(\phi)] + [\sigma^{\leftarrow\Leftarrow}(\phi) + \sigma^{\leftarrow\Rightarrow}(\phi)]}$$

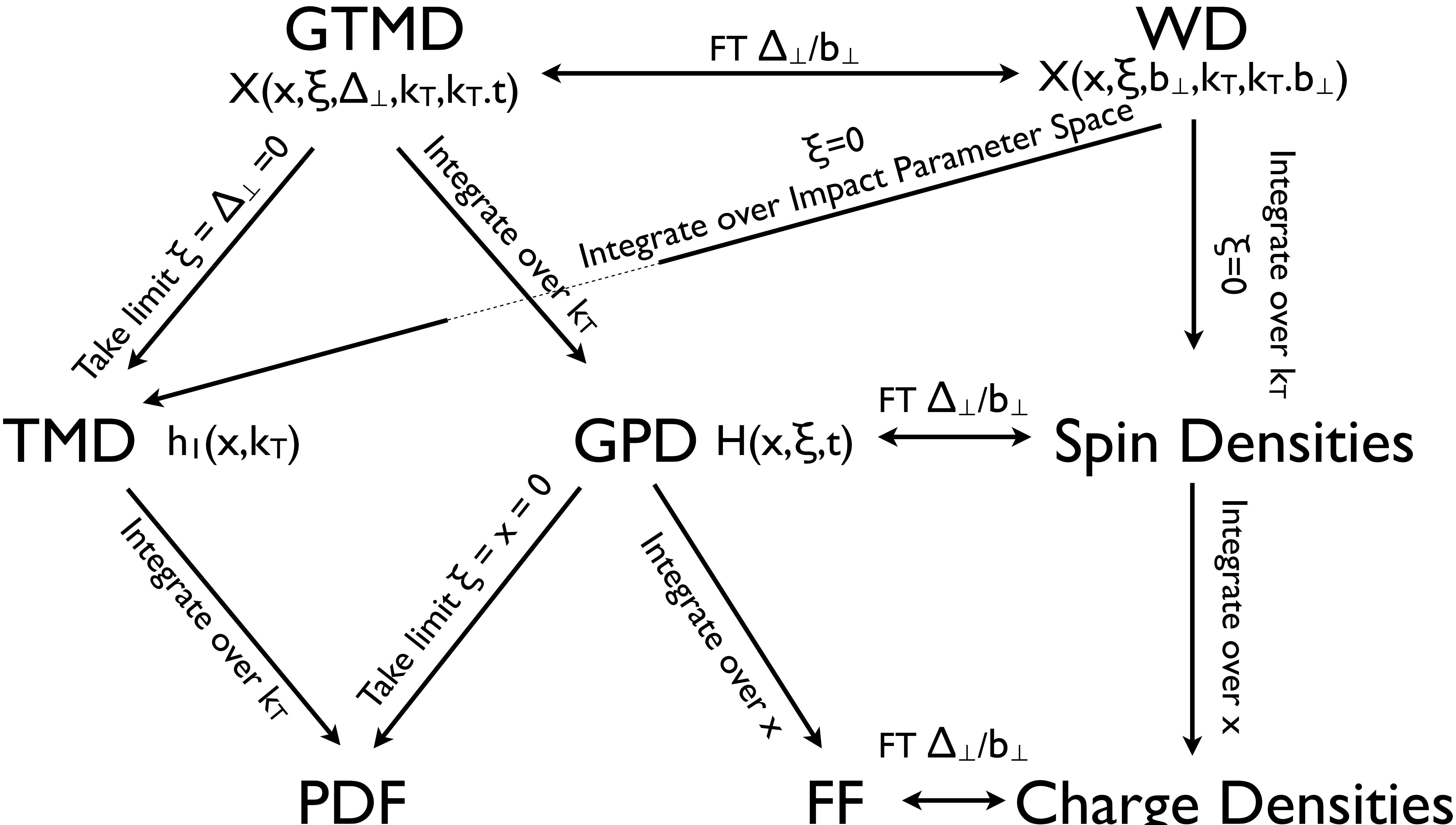
$$\mathcal{A}_{UL}(\phi) \equiv \frac{[\sigma^{\leftarrow\Rightarrow}(\phi) + \sigma^{\rightarrow\Rightarrow}(\phi)] - [\sigma^{\leftarrow\Leftarrow}(\phi) + \sigma^{\rightarrow\Leftarrow}(\phi)]}{[\sigma^{\leftarrow\Rightarrow}(\phi) + \sigma^{\rightarrow\Rightarrow}(\phi)] + [\sigma^{\leftarrow\Leftarrow}(\phi) + \sigma^{\rightarrow\Leftarrow}(\phi)]}$$

$$\mathcal{A}_{LL}(\phi) \equiv \frac{[\sigma^{\rightarrow\Rightarrow}(\phi) + \sigma^{\leftarrow\Leftarrow}(\phi)] - [\sigma^{\leftarrow\Rightarrow}(\phi) + \sigma^{\rightarrow\Leftarrow}(\phi)]}{[\sigma^{\rightarrow\Rightarrow}(\phi) + \sigma^{\leftarrow\Leftarrow}(\phi)] + [\sigma^{\leftarrow\Rightarrow}(\phi) + \sigma^{\rightarrow\Leftarrow}(\phi)]}$$

Wigner Distributions & GTMDs

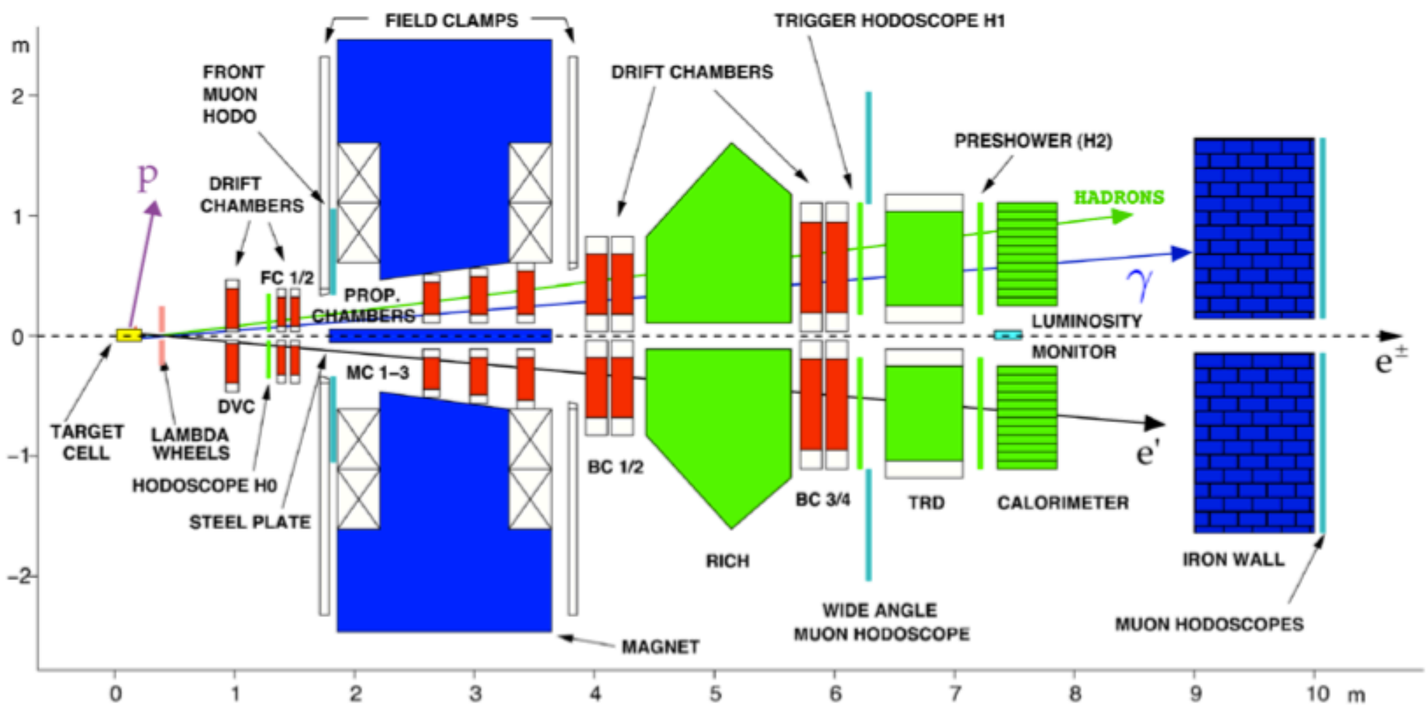
- Holy grail is WDs and GTMDs; not currently accessible through experiment
- Can access TMDs and GPDs experimentally
- WDs and GTMDs reduce to ‘ordinary distributions’ as limits and moments

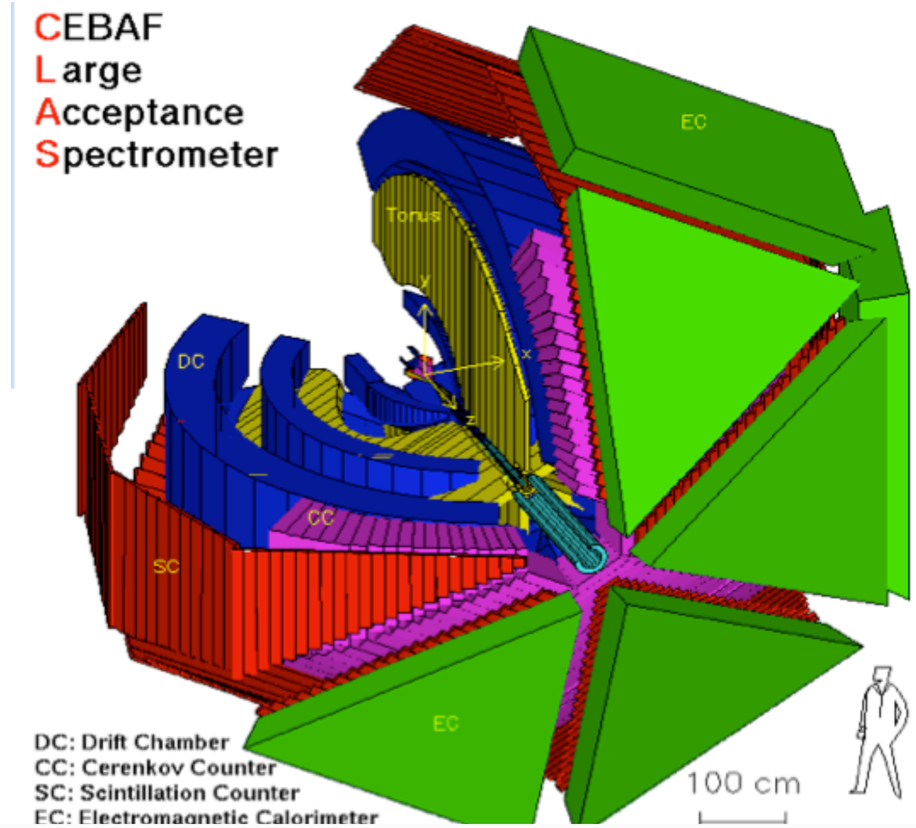
Distribution Graph

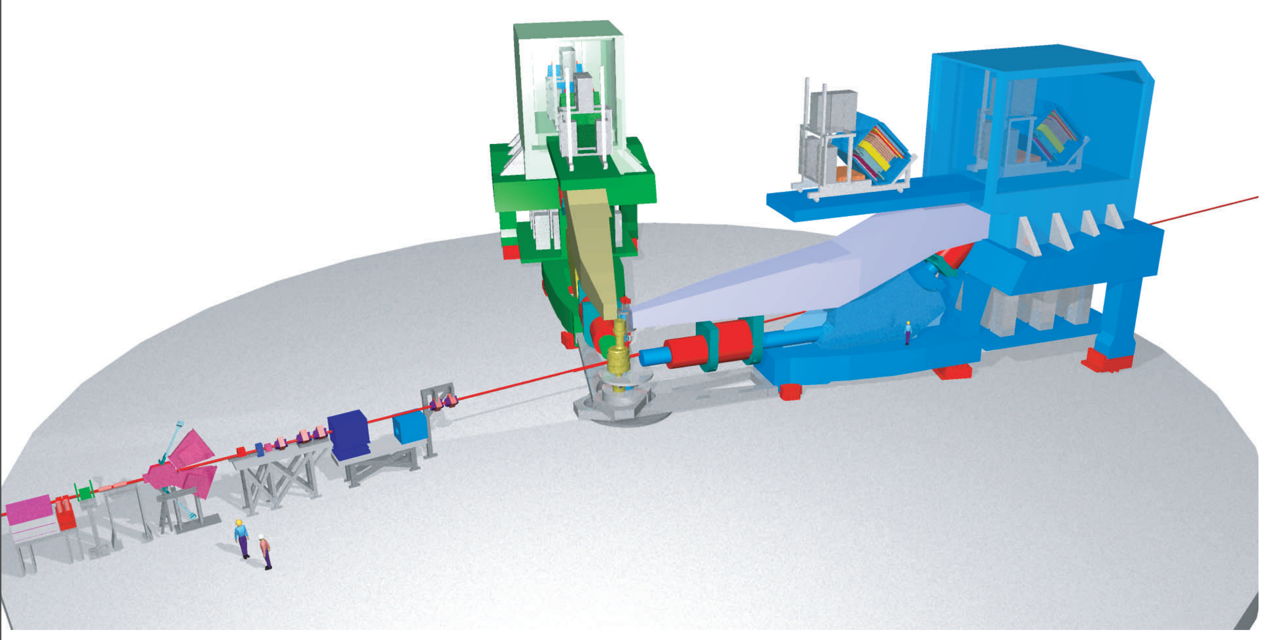


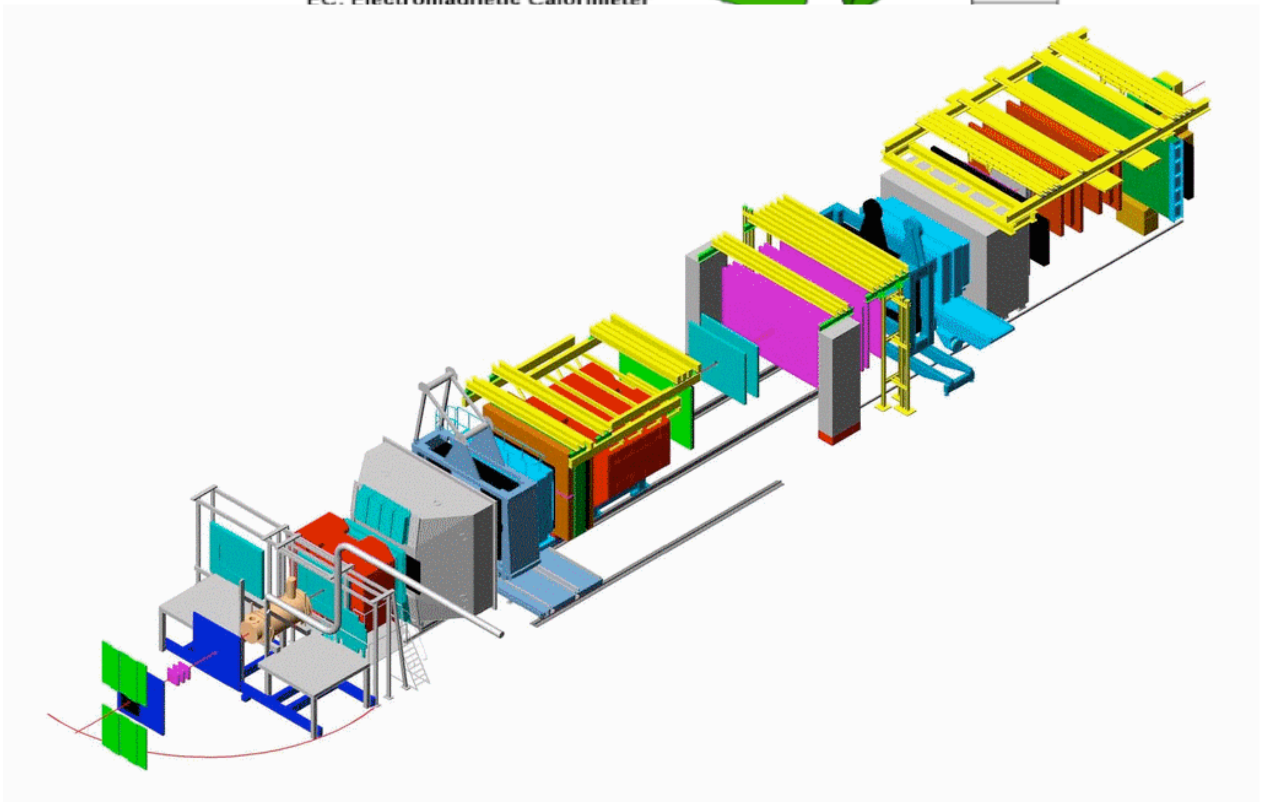
Experimental Access

“Current” Experiments

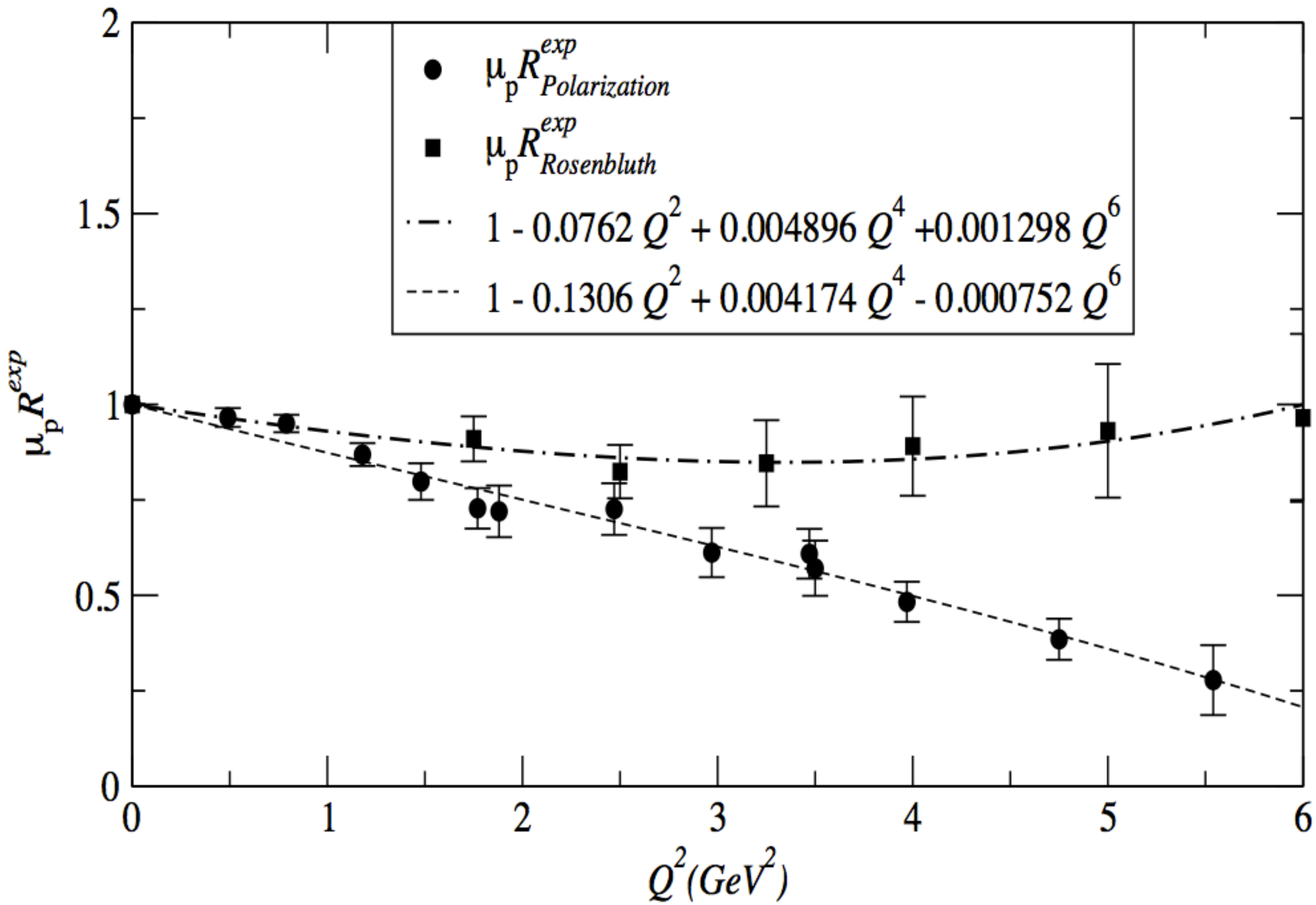








Form Factors

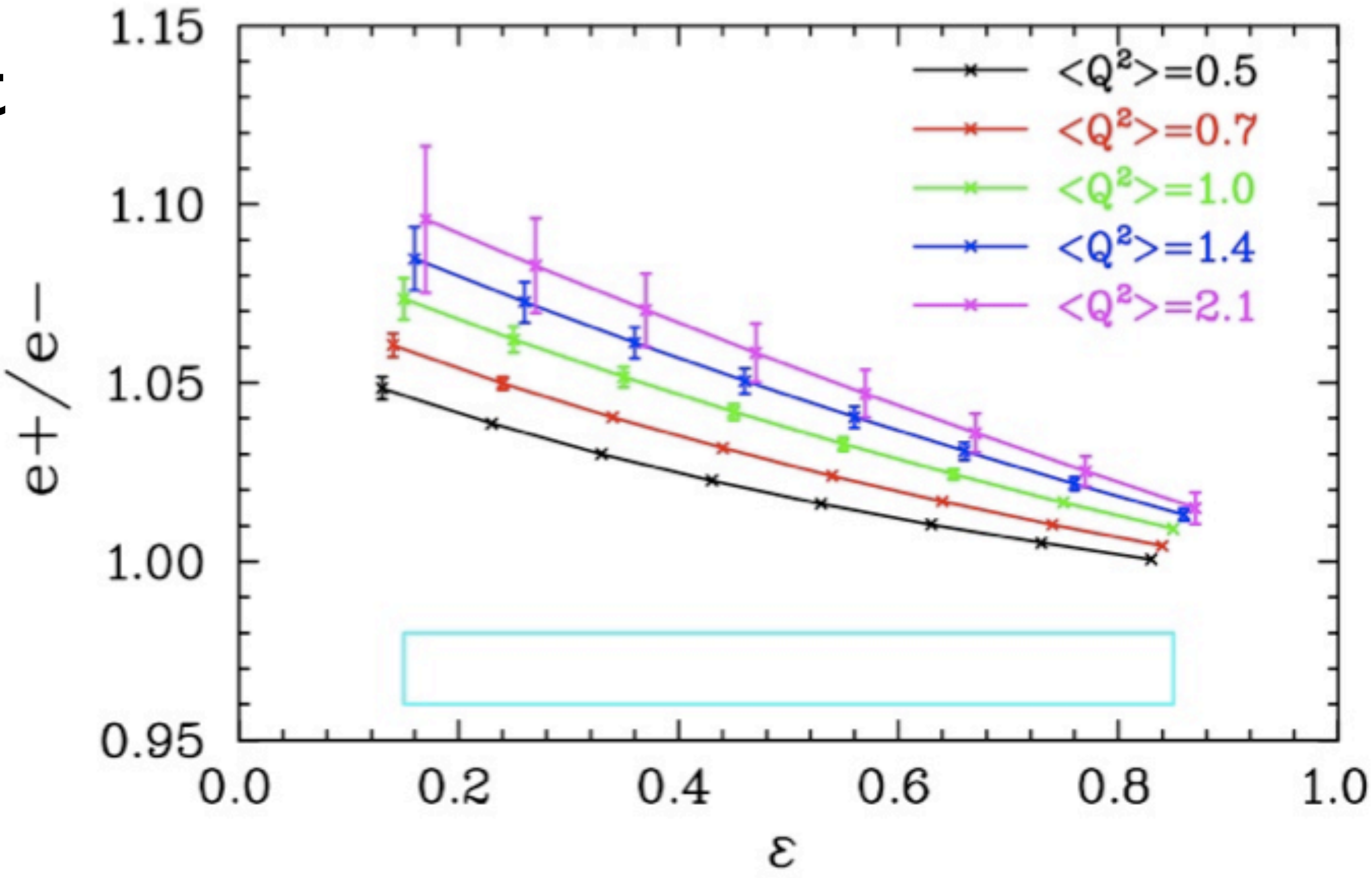


Can a 2γ-exchange correction explain the difference between Rosenbluth and Polarization transfer methods?

Race to check the calculations with data!

Form Factors

"Dirty" e^+/e^- beam at CLAS has high statistical precision across many bins



Novel beam technique presents challenges to the calculation of systematic errors

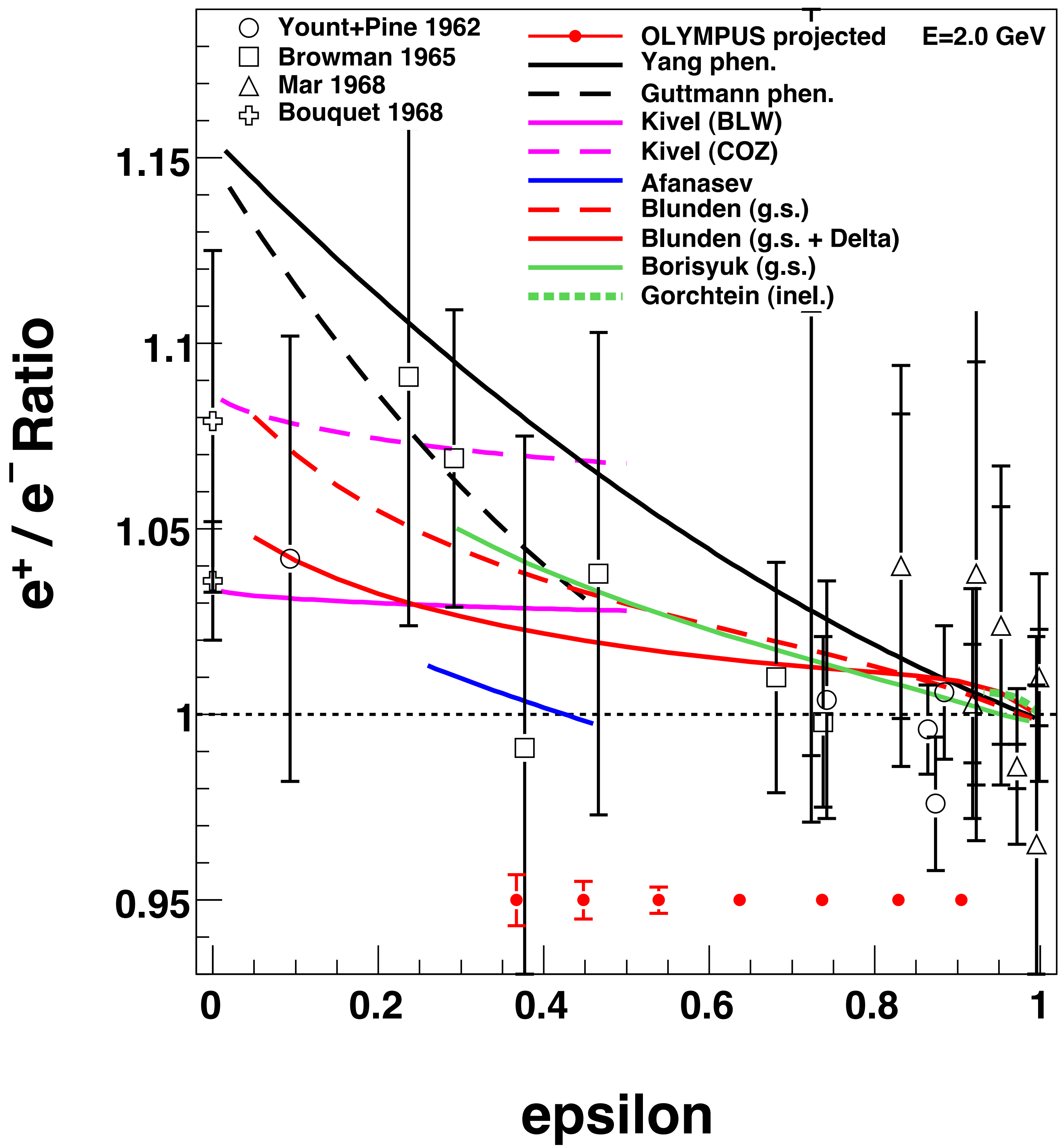
Data taken and currently undergoing analysis!

Form Factors

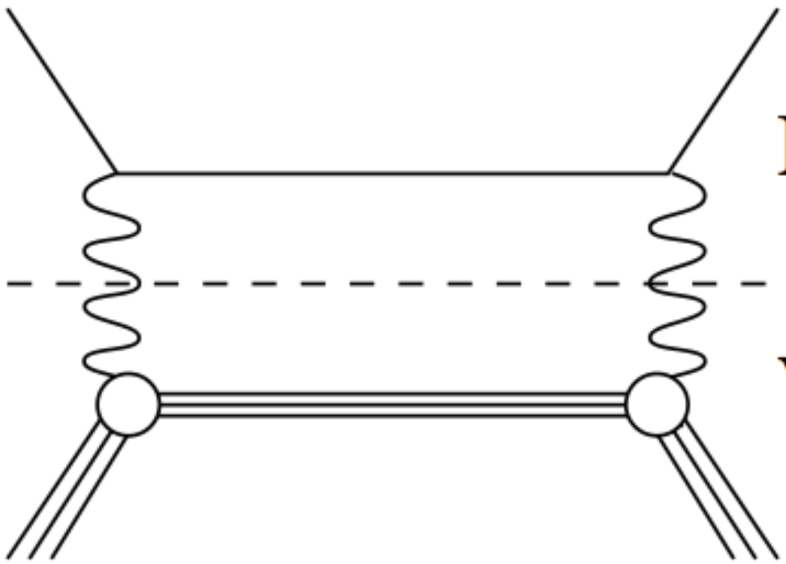
OLYMPUS transported BLAST to DORIS@DESY and plan to take data next year

Reuse of understood equipment ⇒ quick

analysis and simple uncertainty calculations



Structure Functions



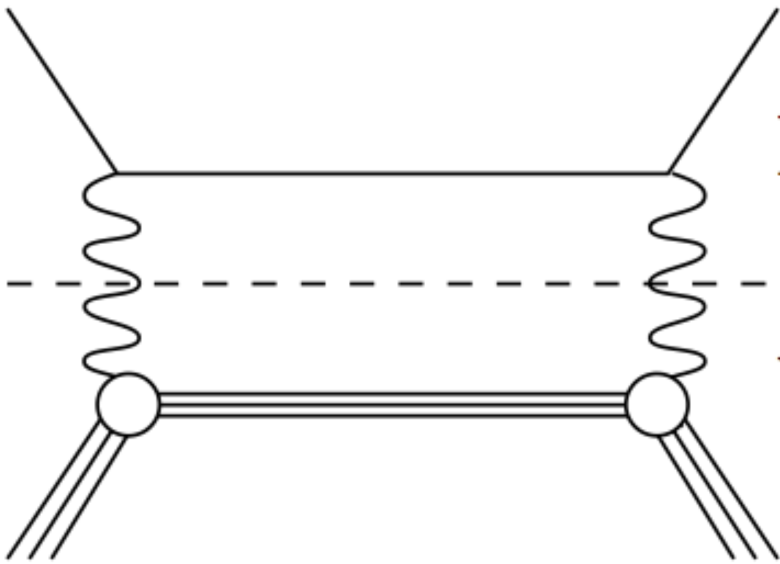
Deep Inelastic Scattering (DIS)

$$\frac{d^2\sigma}{d\Omega\, dE'} = \frac{\alpha^2}{2MQ^4}\frac{E'}{E}L_{\mu\nu}W^{\mu\nu}$$

$$L_{\mu\nu} = 2[k_\mu k'_\nu + k'_\mu k_\nu - g_{\mu\nu}(k\cdot k' - m^2) - i\epsilon_{\mu\nu\alpha\beta}s_l^\alpha q^\beta]$$

$$W_{\mu\nu} = F_1(-g_{\mu\nu} + \frac{q_\mu q_\nu}{p\cdot q}) + \frac{F_2}{p\cdot q}(p_\mu - \frac{p\cdot q\, q_\mu}{q^2})(p_\nu - \frac{p\cdot q\, q_\mu}{q^2})$$
$$+ \frac{i\, g_1}{p\cdot q}\epsilon_{\mu\nu\lambda\sigma}q^\lambda s_h^\sigma + \frac{i\, g_2}{(f\cdot q)^2}\epsilon_{\mu\nu\lambda\sigma}q^\lambda(p\cdot q s_h^\sigma - s_h\cdot q\, p^\sigma)$$

Structure Functions



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$$\begin{aligned} W_{\mu\nu} &= F_1(-g_{\mu\nu} + \frac{q_\mu q_\nu}{p\cdot q}) + \frac{F_2}{p\cdot q}(p_\mu - \frac{p\cdot q\, q_\mu}{q^2})(p_\nu - \frac{p\cdot q\, q_\mu}{q^2}) \\ &+ \frac{i\, g_1}{p\cdot q}\epsilon_{\mu\nu\lambda\sigma}q^\lambda s_h^\sigma + \frac{i\, g_2}{(f\cdot q)^2}\epsilon_{\mu\nu\lambda\sigma}q^\lambda(p\cdot q s_h^\sigma - s_h\cdot q\, p^\sigma) \end{aligned}$$

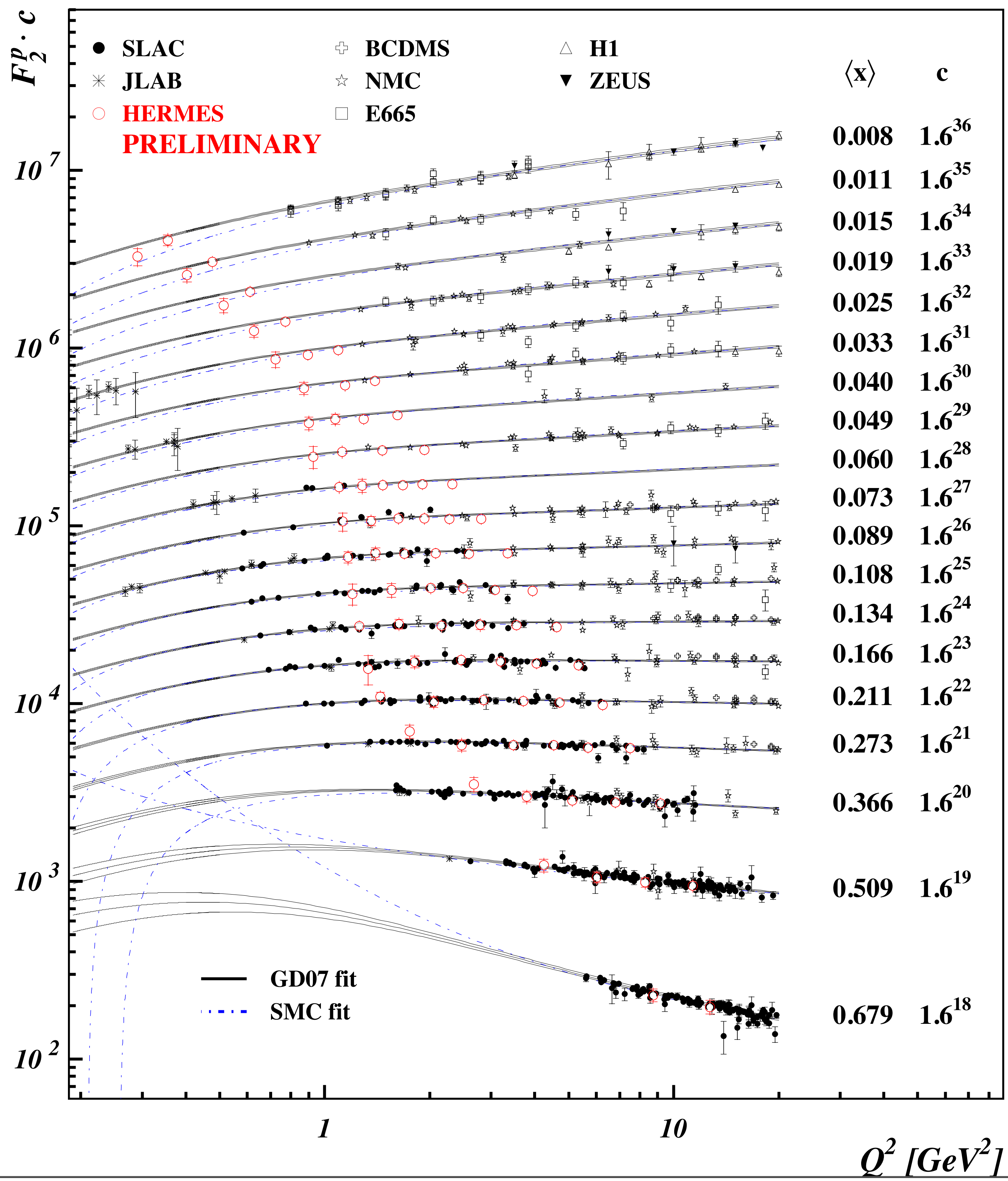
Structure Functions

Quark Polarization

Nucleon Polarization

	U	L	T
U	f_1		$h_1^{\perp}$
L		g_{1L}	$h_{1L}^{\perp}$
T	$f_{1T}^{\perp}$	g_{1T}	$h_1, h_{1T}^{\perp}$

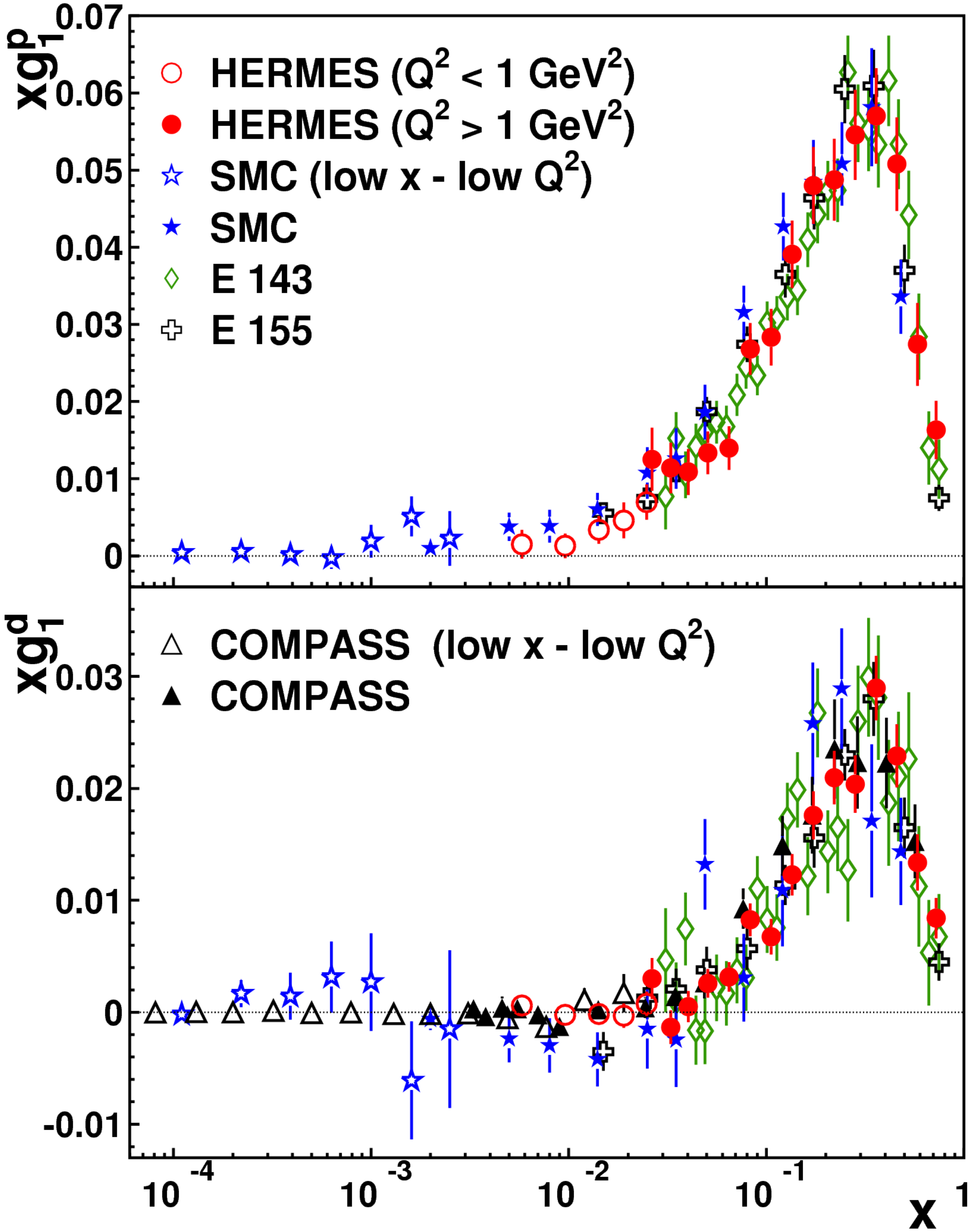
f_2



f_2 is well mapped-out at a large x-range by fixed-target and collider experiments

f_2 is easily the best understood structure function!

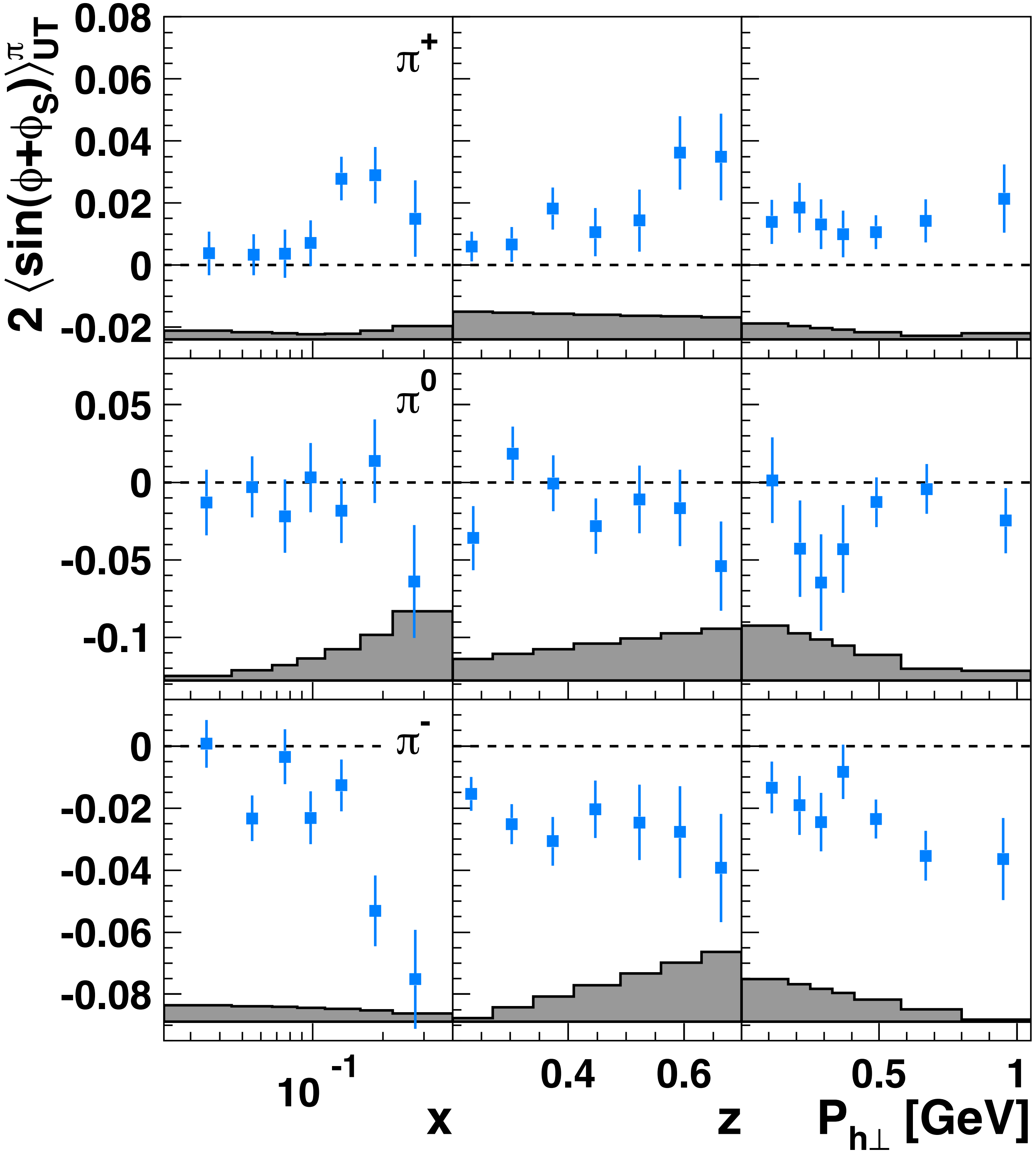
g_1



$g_1(x)$ measured in the valence region and into the sea

Measurements imply an unpolarized sea

Results from HERMES

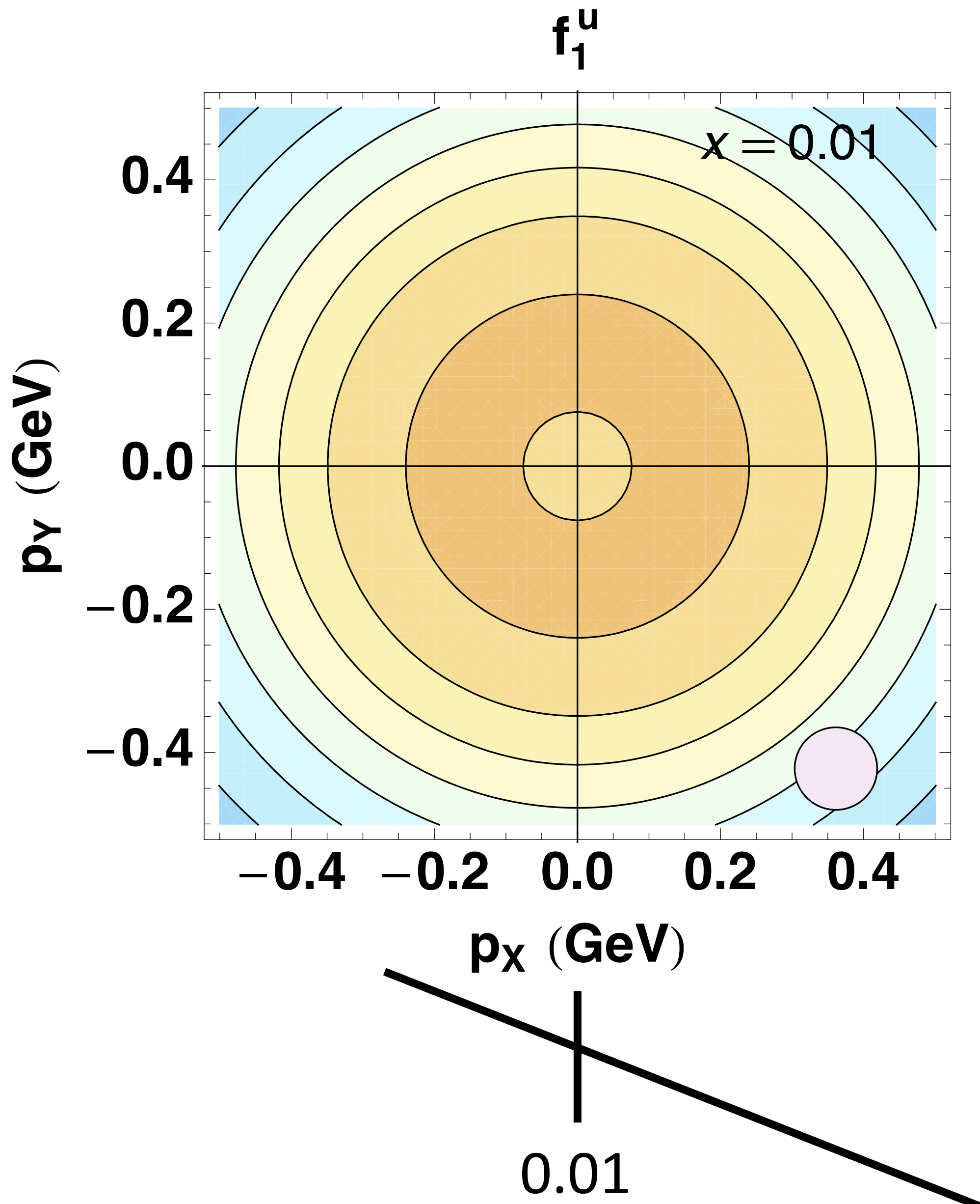


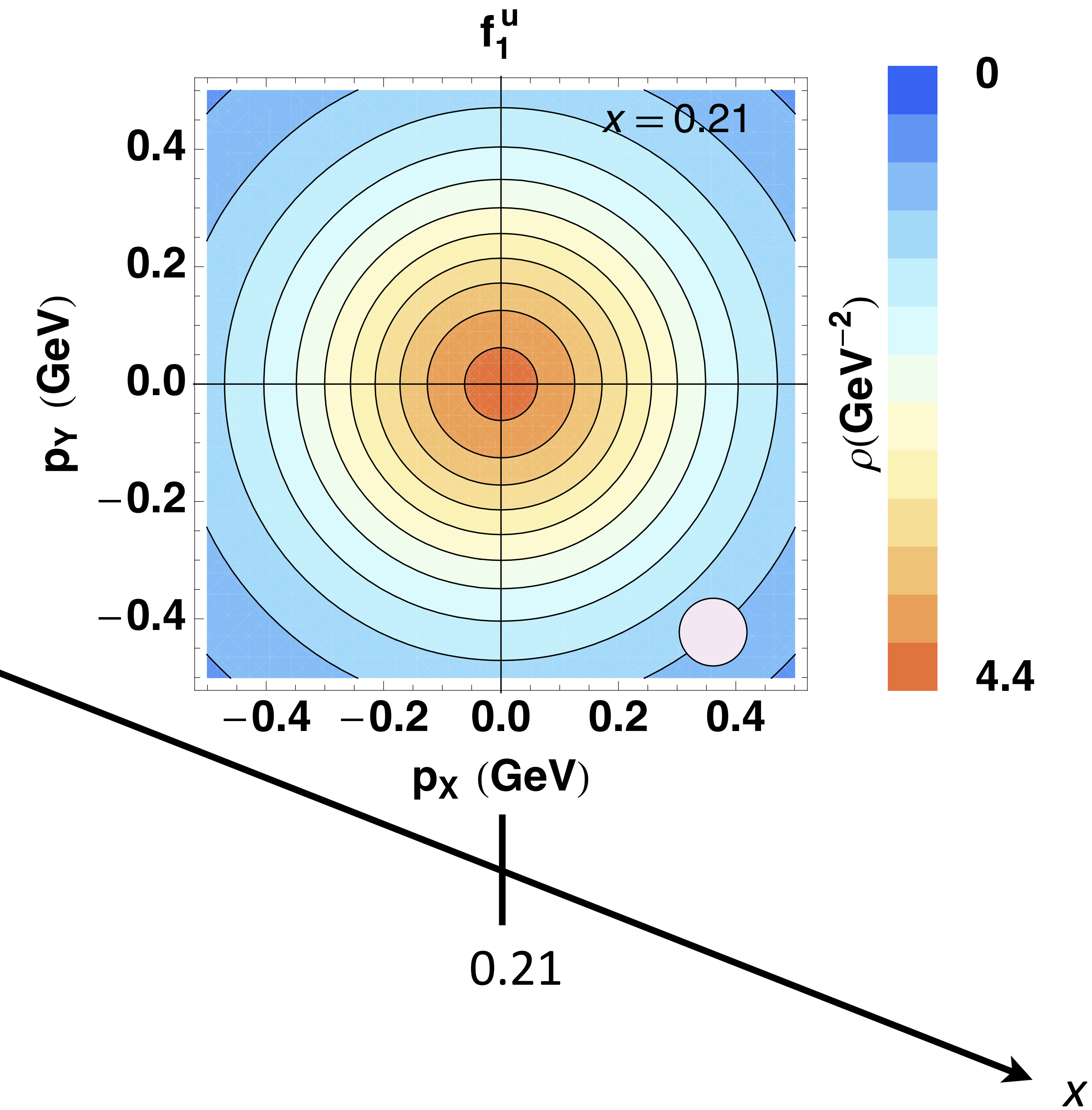
Collins moments for pions allows access to h_1

Use meson charges as quark flavor filters!

Significant differences between quark flavors shows that $h_{1(u)} != h_{1(d)}$

TMDs: tomography in momentum space





Based on model calculation
A.B., Conti, Guagnelli, Radici, arXiv:1003.1328

TMDs

Quark Polarization

Nucleon Polarization

	U	L	T
U	f_1		$h_1^{\perp}$
L		g_{1L}	$h_{1L}^{\perp}$
T	$f_{1T}^{\perp}$	g_{1T}	$h_1, h_{1T}^{\perp}$

TMDs

Quark Polarization

Nucleon Polarization

	U	L	T
U	f_1		$h_1^{\perp}$
L		g_{1L}	$h_{1L}^{\perp}$
T	$f_{1T}^{\perp}$	g_{1T}	$h_1, h_{1T}^{\perp}$

Unpolarized, helicity, transversity and Sivers distributions are familiar to most!

TMDs

Quark Polarization

Nucleon Polarization	U	L	T
U	f_1		$h_1^{\perp}$
L		g_{1L}	$h_{1L}^{\perp}$
T	$f_{1T}^{\perp}$	g_{1T}	$h_1, h_{1T}^{\perp}$

Indications of Boer-Mulders from unpolarized lepton-nucleon scattering

TMDs

Quark Polarization

Nucleon Polarization

	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$h_1, h_{1T}^\perp$

The *x*-dependence may be known, but the k_T-dependence almost never is!

Results from HERMES

Semi-Inclusive Deep Inelastic Scattering

- Sivers moment ⇒ quark OAM
- Different meson-types provide a flavor-filter

Results from HERMES

Positive!

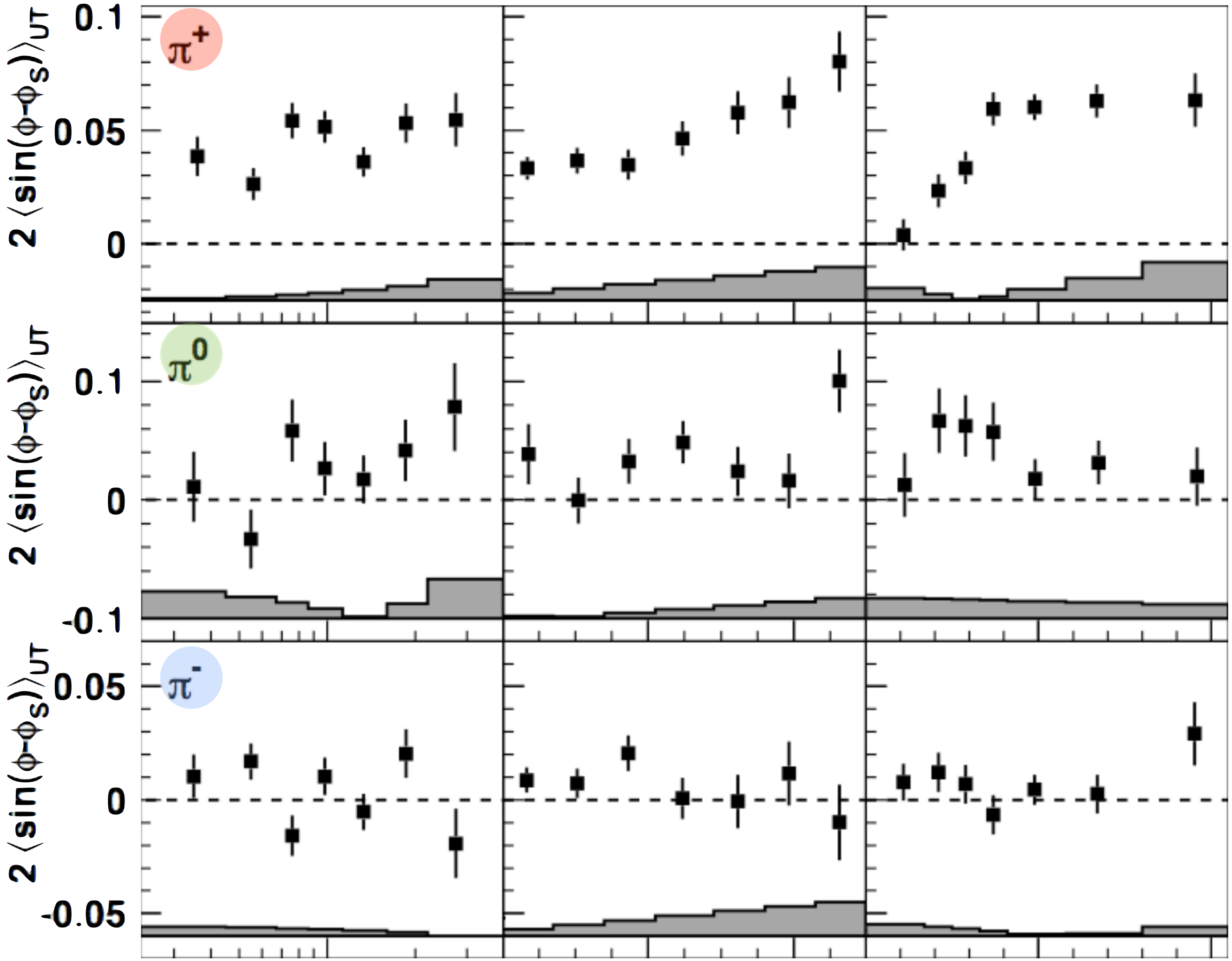
$u\bar{d}$

Positive?

uu or dd

Zero!

$d\bar{u}$



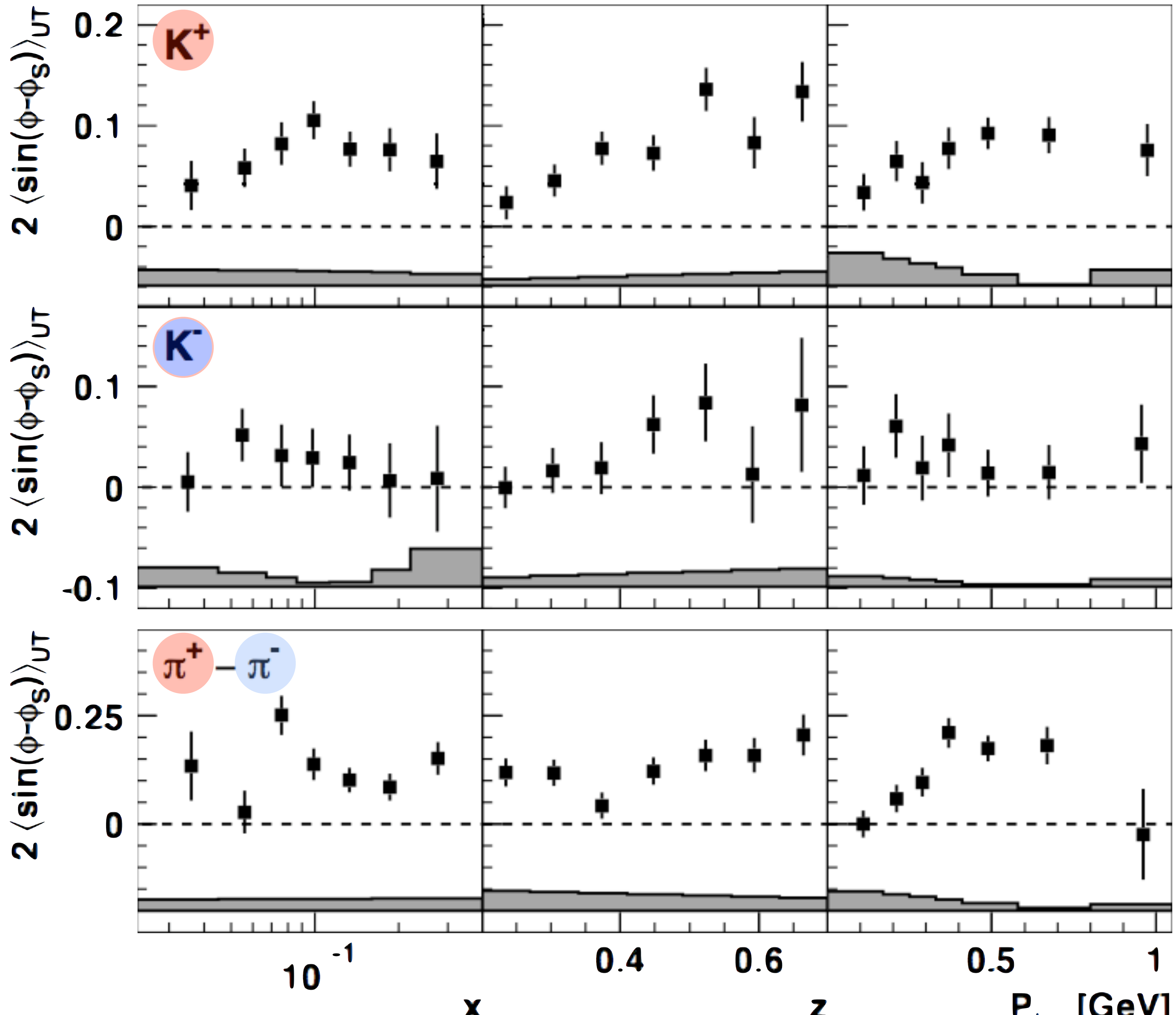
Results from HERMES

Sivers Moments

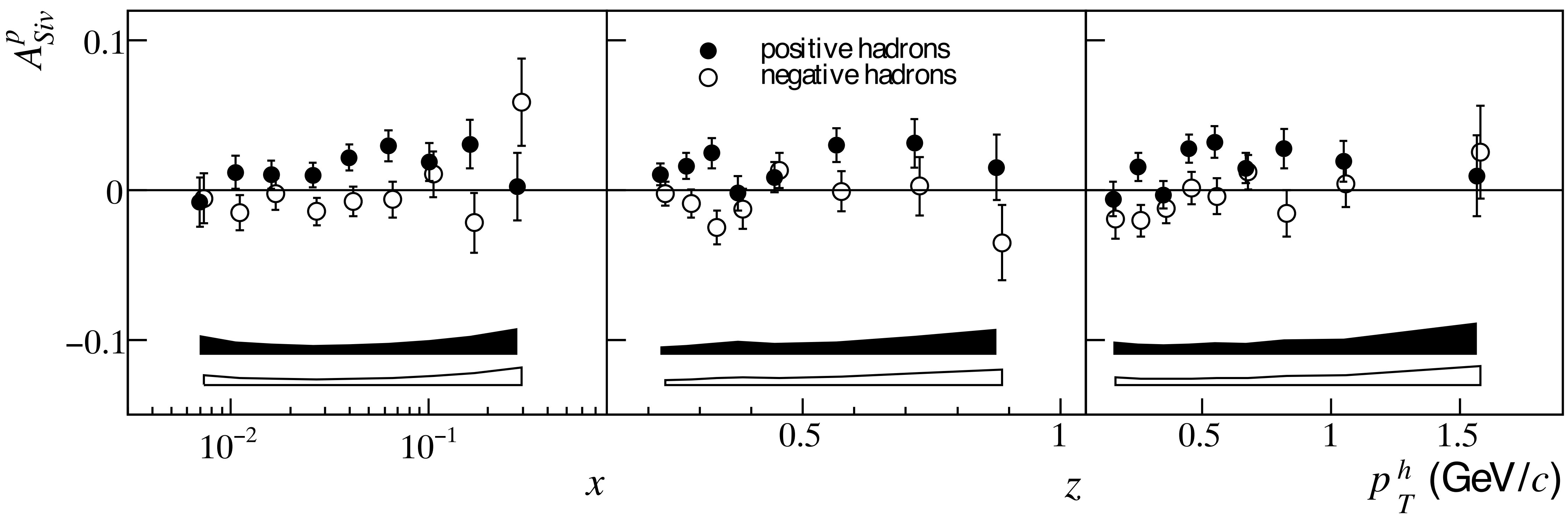
Positive!
$u\bar{s}$

Positive?
$s\bar{u}$

Valence



Results from COMPASS

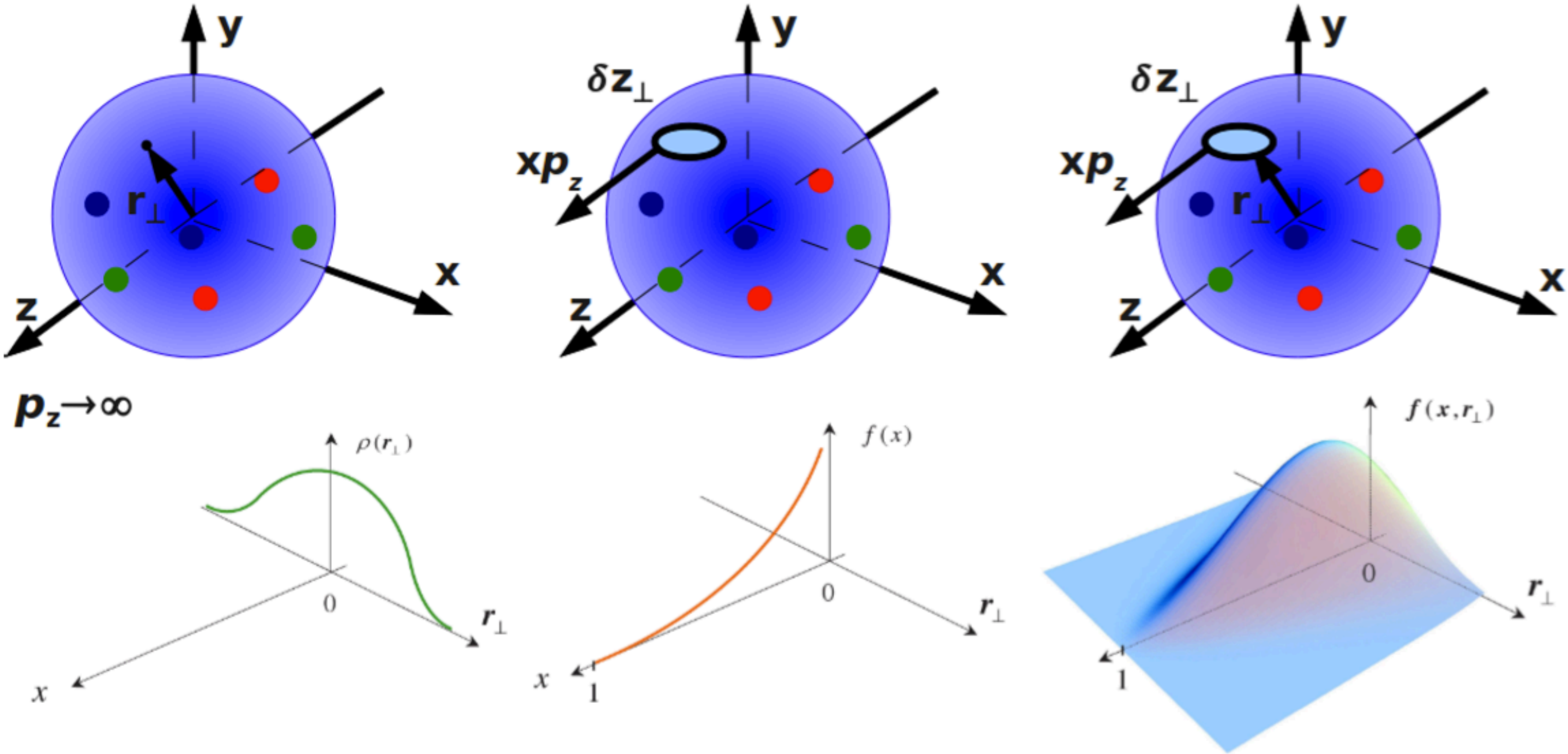


Results from COMPASS confirm HERMES observations

SIDIS

- Results indicate that $h_{1u}(x) \neq h_{1d}(x)$ and $f_{1\perp}(x,k_T) \neq 0$ for up-quarks or sea quarks
- Gives rise to a picture of the nucleon as having up quarks with transverse momentum but "stationary" down quarks
- Results are not thorough: cannot extract a picture of nucleon structure (valence, sea and glue) from these alone!

GPDs

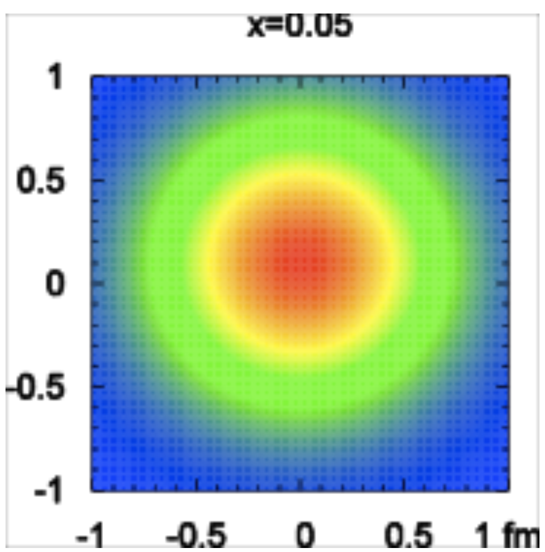


Form Factors (FFs)

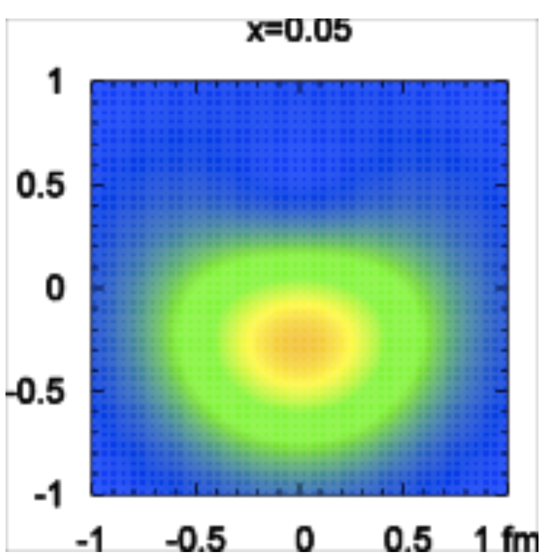
Parton Distribution Functions (PDFs)

Generalised Parton Distributions (GPDs)

GPDs



Up Quarks



Down Quarks

"Hadron Tomography" is the phrase du jour

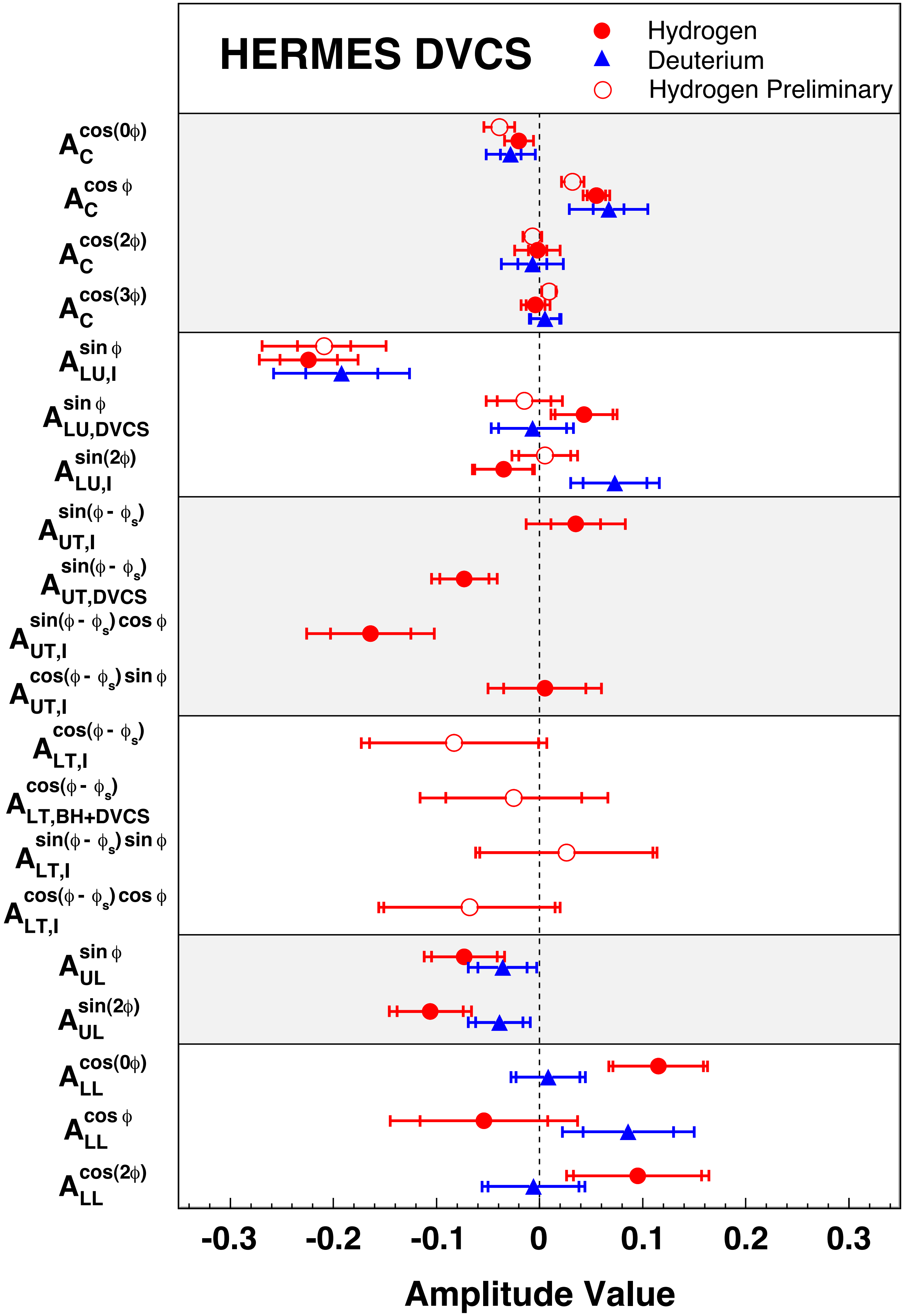
Simple models trained with meson data already illustrate the intuitive picture offered by GPDs

Not simple to get to GPD information: go through CFFs first!

Results from HERMES

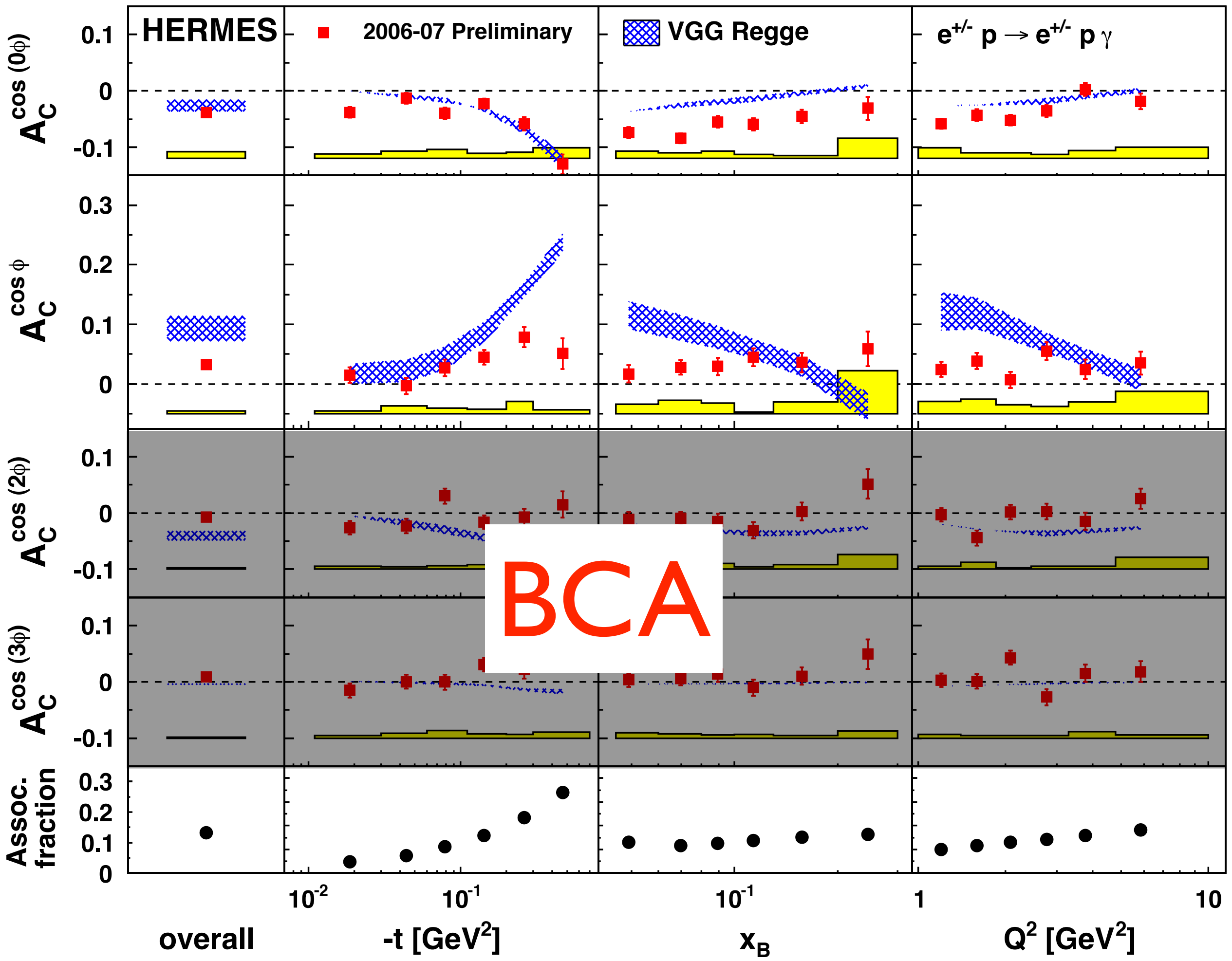
Exclusive Physics Results

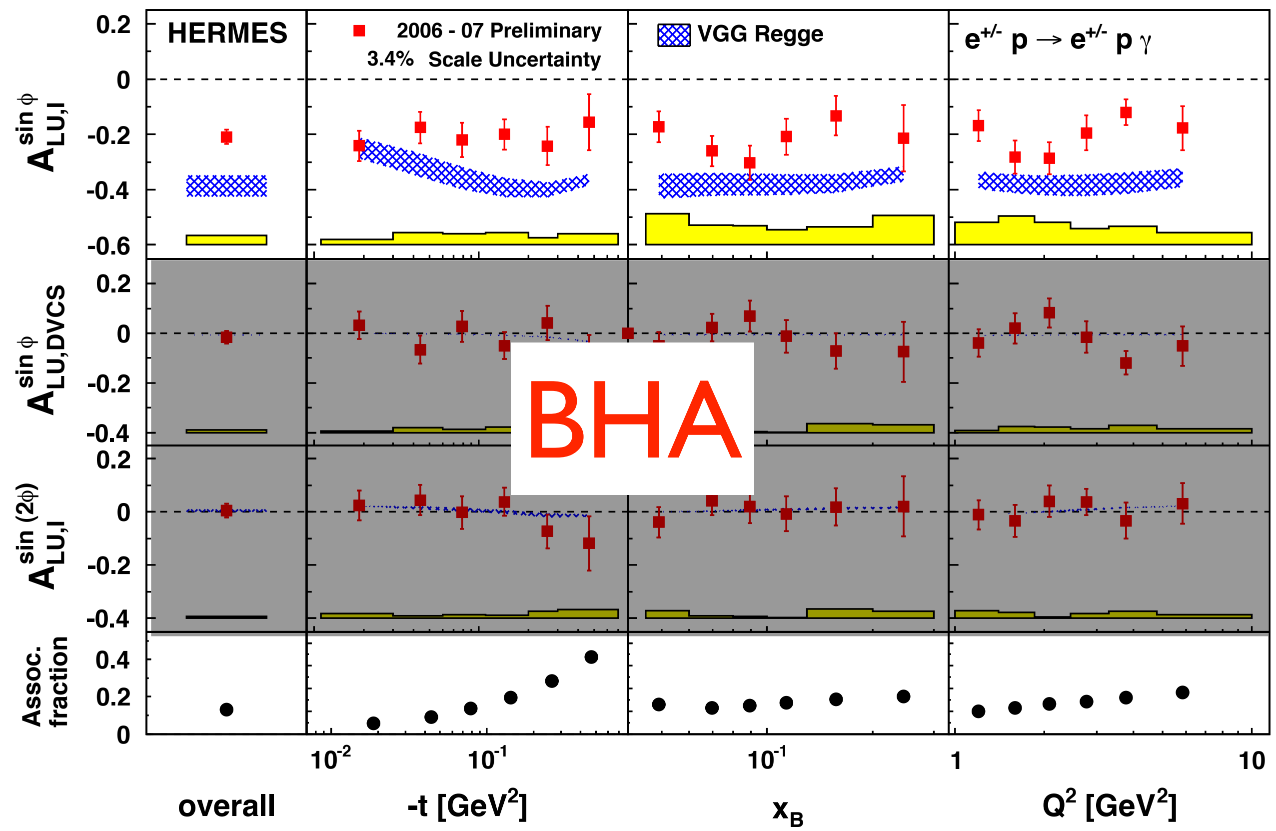
- DVCS allows the cleanest access to GPDs
- Mesons allow access to GPDs that would otherwise be difficult to access through DVCS
- HERMES has the most diverse set of DVCS measurements in the world

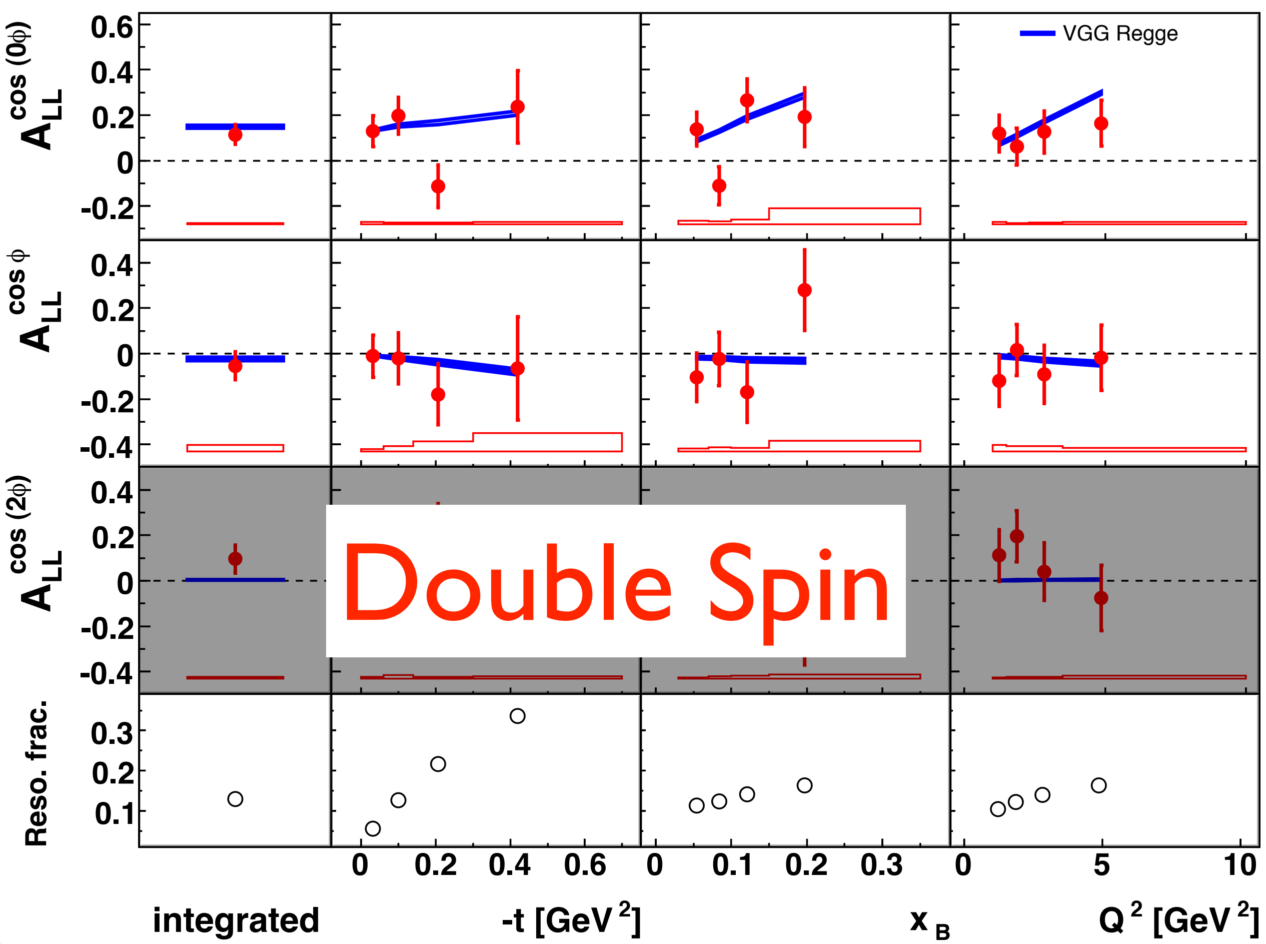


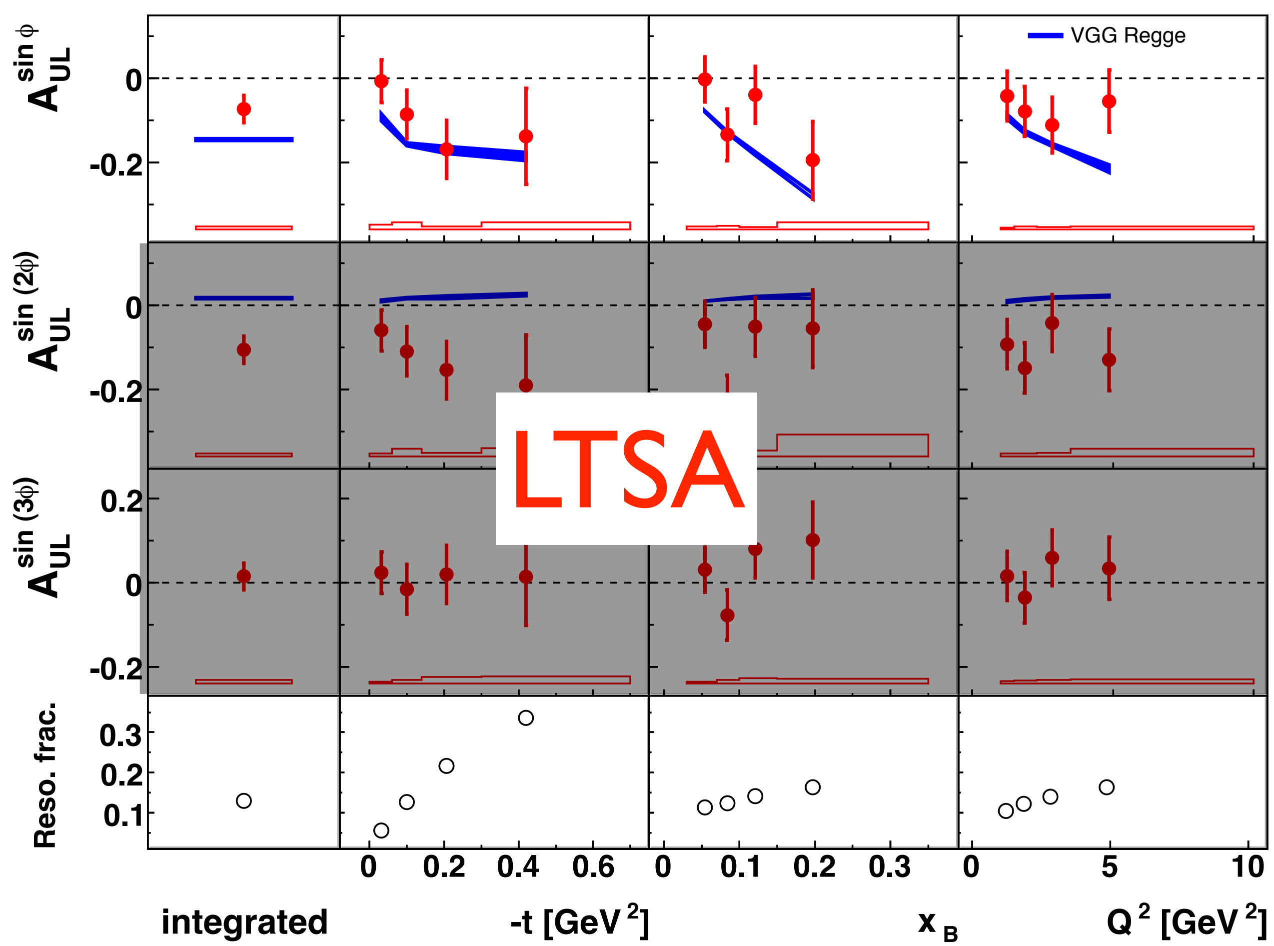
Both beam charges allows access to both the interference and DVCS terms of the amplitudes

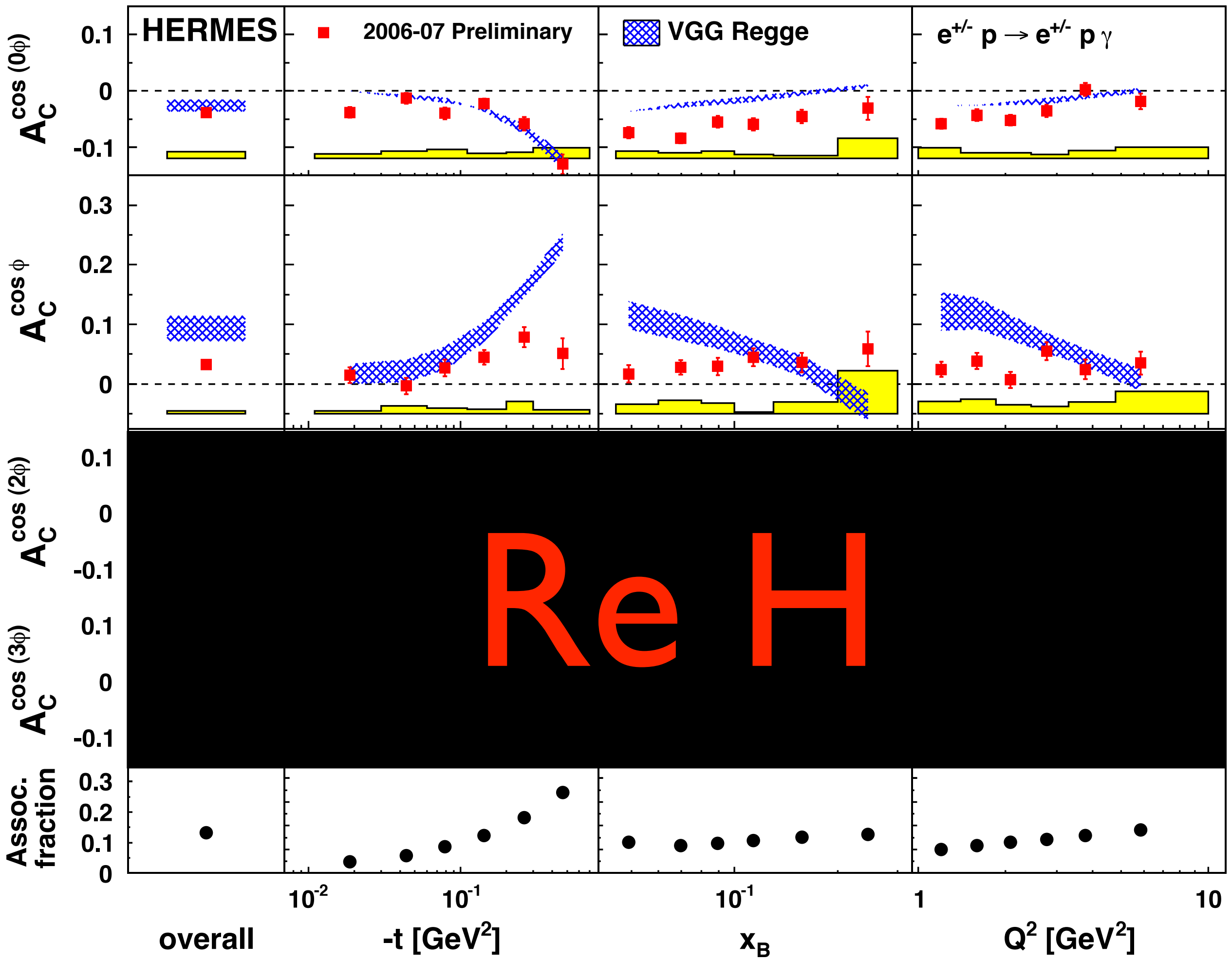
Polarized targets are very important: allow access to both real and imaginary parts of 3 out of 4 CFFs

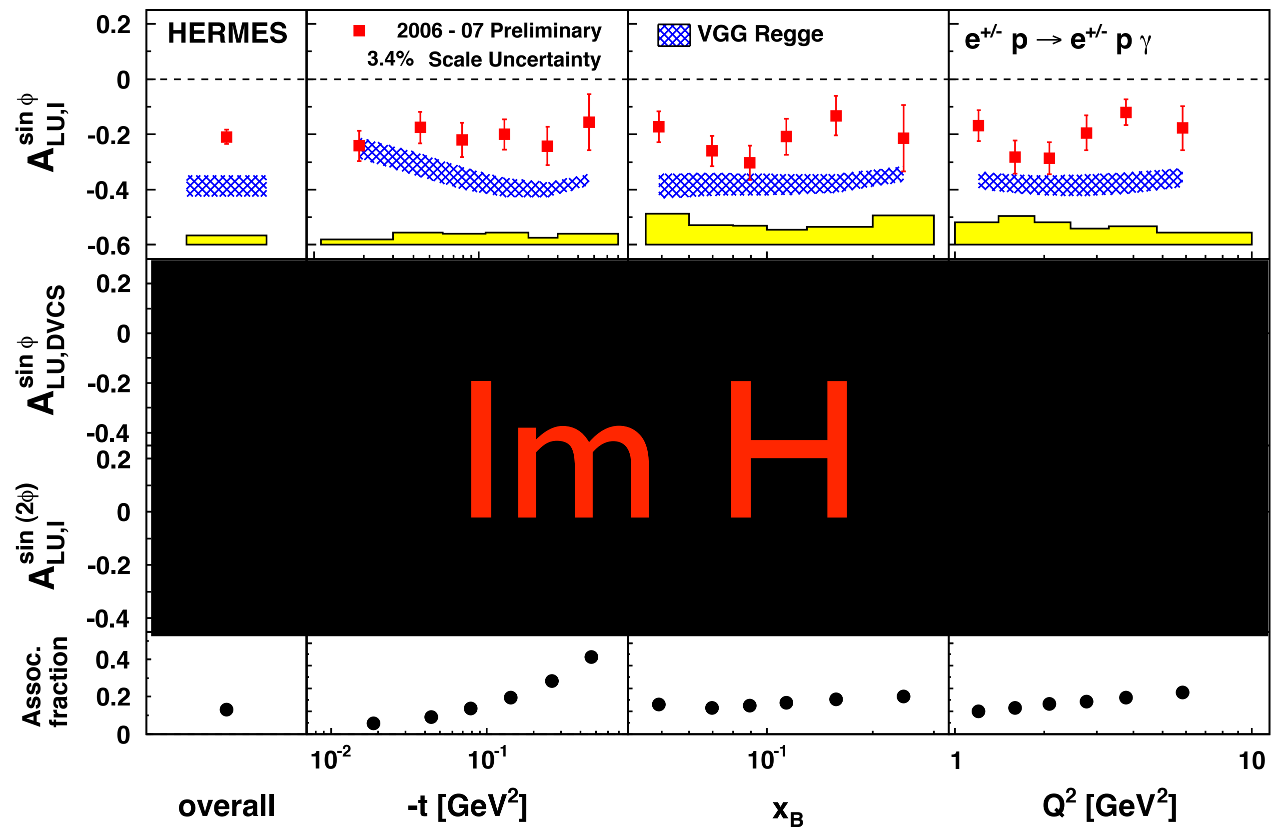

HERMES
2006-07 Preliminary
VGG Regge
$e^{+/-} p \rightarrow e^{+/-} p \gamma$
$A_C^{\cos(0\phi)}$
$A_C^{\cos\phi}$
$A_C^{\cos(2\phi)}$
$A_C^{\cos(3\phi)}$
Assoc. fraction
overall
-t [GeV^2]
x_B
Q^2 [GeV^2]
BCA

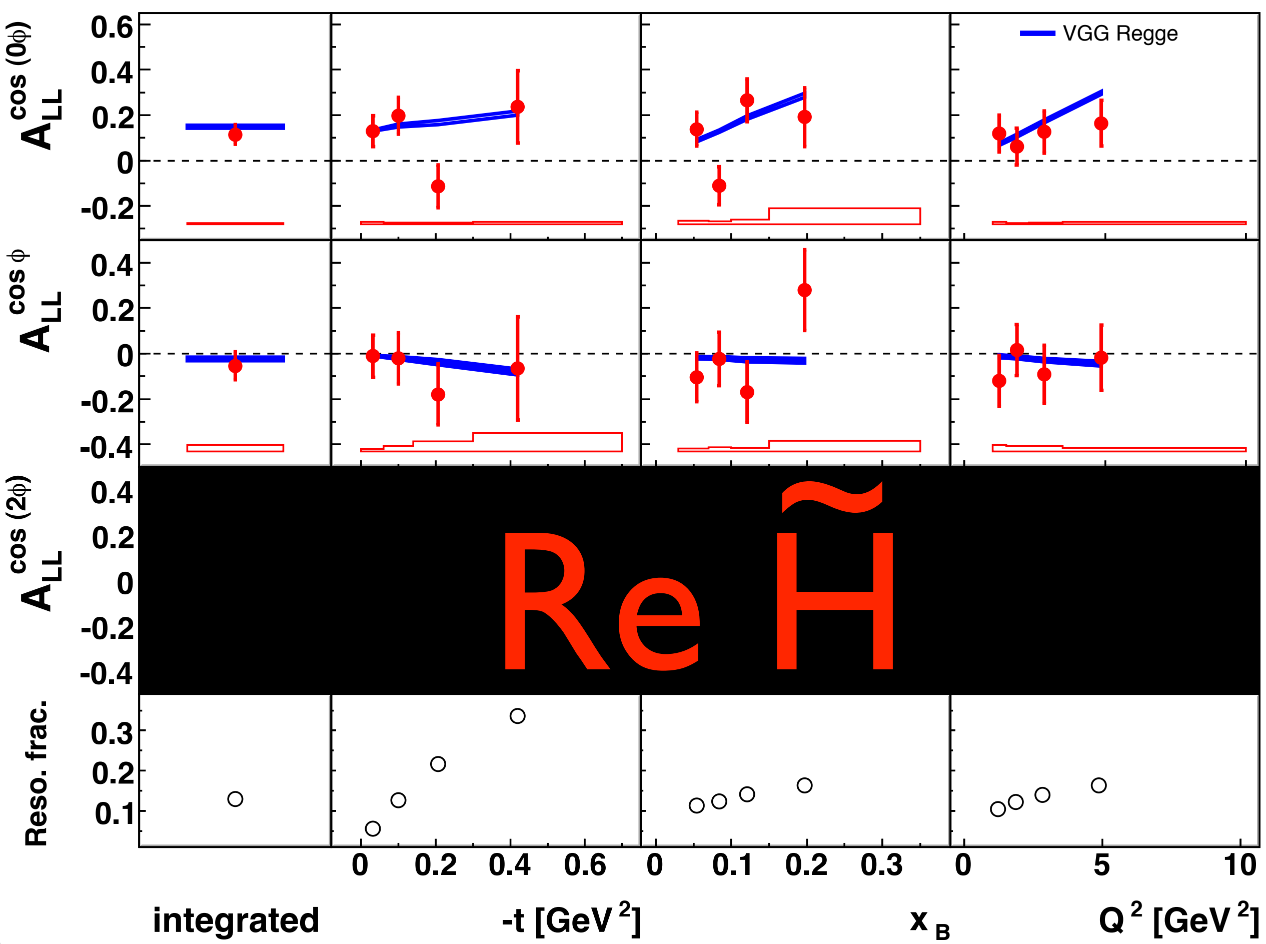

HERMES
2006 - 07 Preliminary
3.4% Scale Uncertainty
VGG Regge
$e^{+/-} p \rightarrow e^{+/-} p \gamma$
$A_{LU,I}^{\sin\phi}$
$A_{LU,DVCS}^{\sin\phi}$
$A_{LU,I}^{\sin(2\phi)}$
Assoc. fraction
overall
-t [GeV^2]
x_B
Q^2 [GeV^2]
BHA

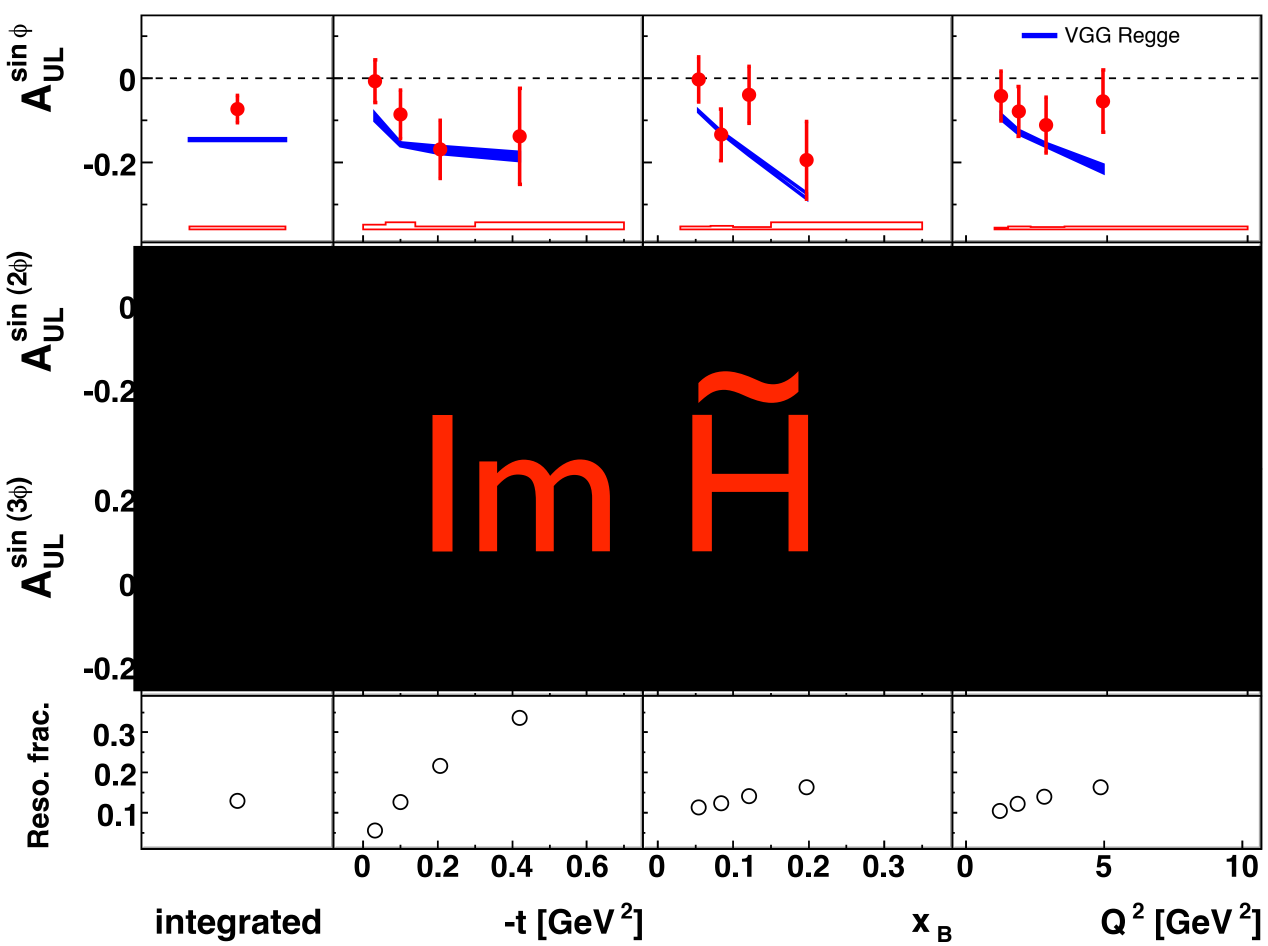

VGG Regge
$A_{LL}^{\cos(0\phi)}$
$A_{LL}^{\cos\phi}$
$A_{LL}^{\cos(2\phi)}$
Reso. frac.
integrated
-t [GeV^2]
x_B
Q^2 [GeV^2]
Double Spin


VGG Regge
$A_{UL}^{\sin\phi}$
$A_{UL}^{\sin(2\phi)}$
$A_{UL}^{\sin(3\phi)}$
Reso. frac.
integrated
-t [GeV^2]
x_B
Q^2 [GeV^2]
LTSA

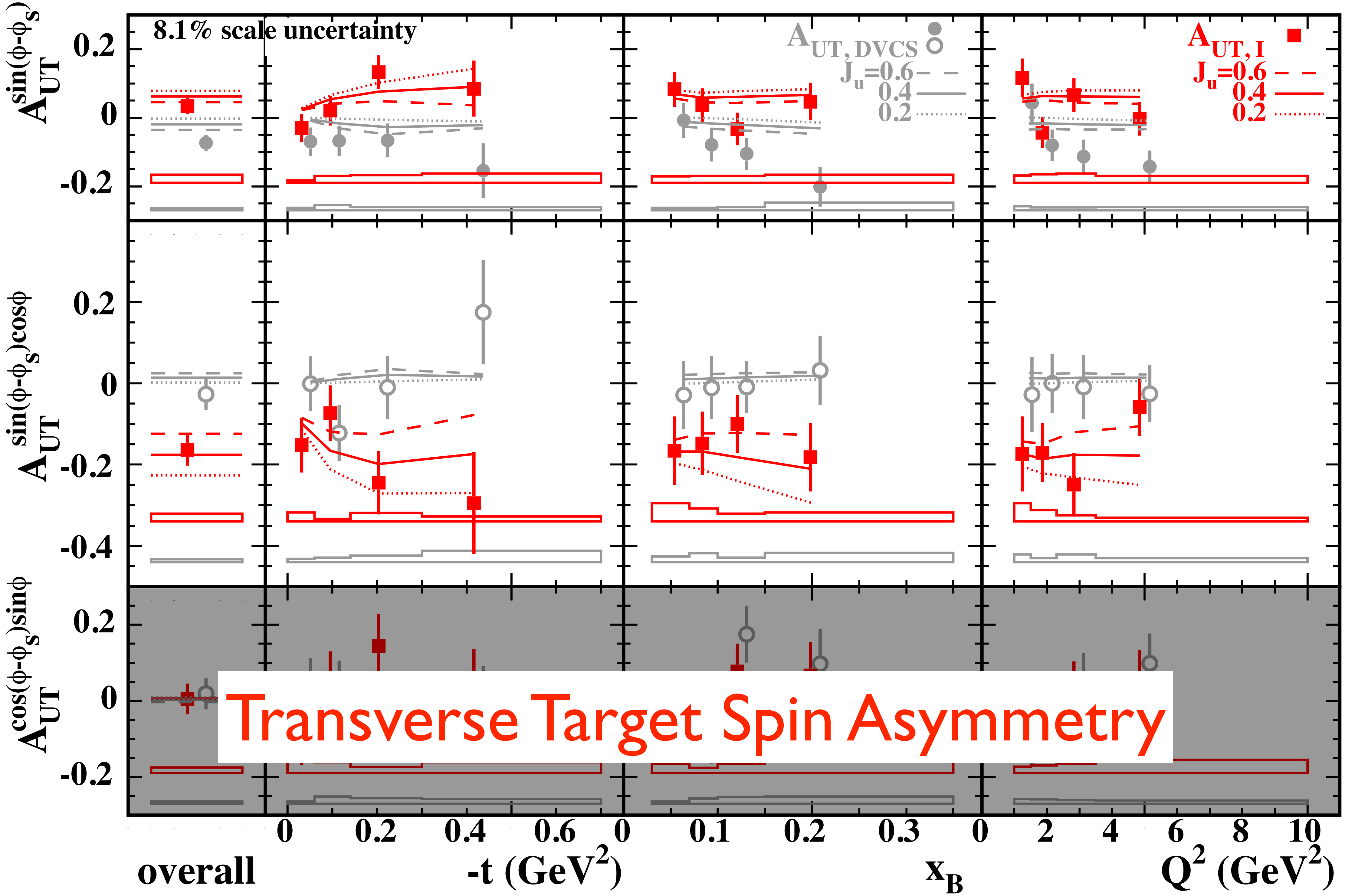

HERMES
2006-07 Preliminary
VGG Regge
$e^{+/-} p \to e^{+/-} p \gamma$
$A_C^{\cos(0\phi)}$
$A_C^{\cos\phi}$
$A_C^{\cos(2\phi)}$
$A_C^{\cos(3\phi)}$
Assoc. fraction
Re H
overall
-t [GeV^2]
x_B
Q^2 [GeV^2]


HERMES
2006 - 07 Preliminary
3.4% Scale Uncertainty
VGG Regge
$e^{+/-} p \to e^{+/-} p \gamma$
$A_{LU,I}^{\sin\phi}$
$A_{LU,DVCS}^{\sin\phi}$
$A_{LU,I}^{\sin(2\phi)}$
Assoc. fraction
Im H
overall
-t [GeV^2]
x_B
Q^2 [GeV^2]

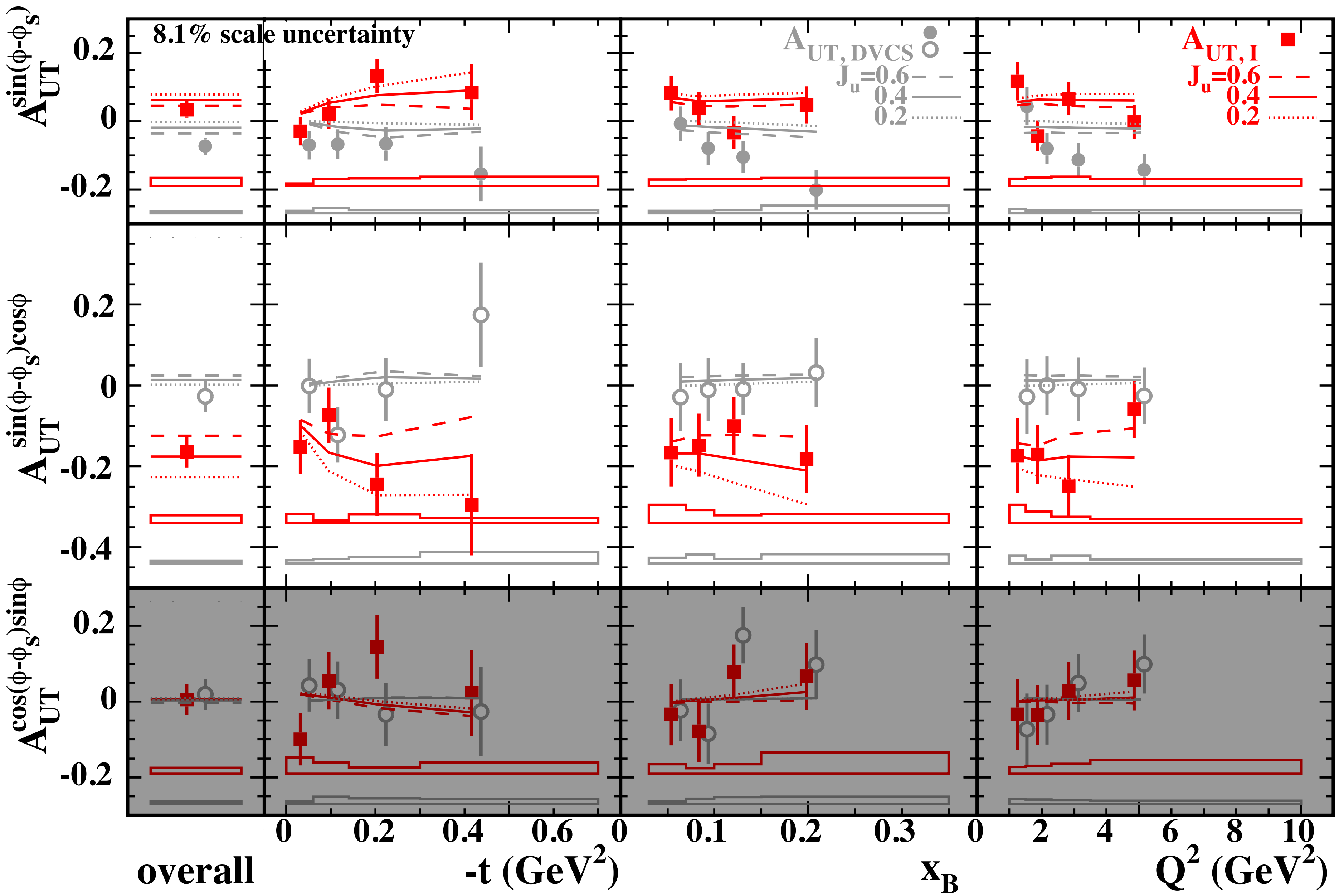

VGG Regge
$A_{LL}^{\cos(0\phi)}$
$A_{LL}^{\cos\phi}$
$A_{LL}^{\cos(2\phi)}$
Reso. frac.
Re $\tilde{H}$
integrated
-t [GeV^2]
x_B
Q^2 [GeV^2]


VGG Regge
$A_{UL}^{\sin\phi}$
$A_{UL}^{\sin(2\phi)}$
$A_{UL}^{\sin(3\phi)}$
Reso. frac.
Im $\tilde{H}$
integrated
-t [GeV^2]
x_B
Q^2 [GeV^2]

Results from HERMES



Results from HERMES



Data lacks the precision to differentiate between model flavours

Sensitivity to Im(*E*)

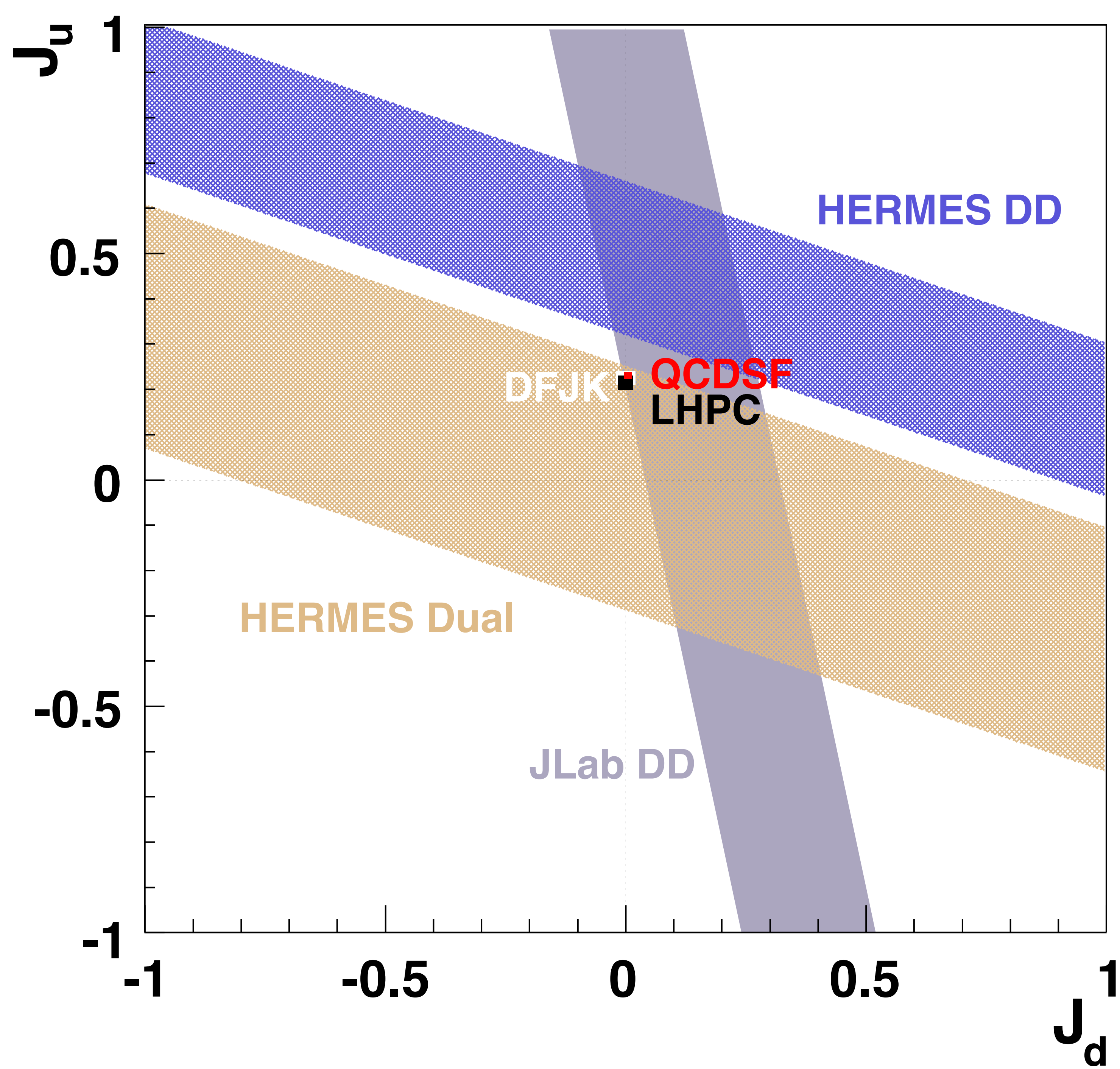
Sensitivity to Re(*E*)

Where is the next measurement coming from?

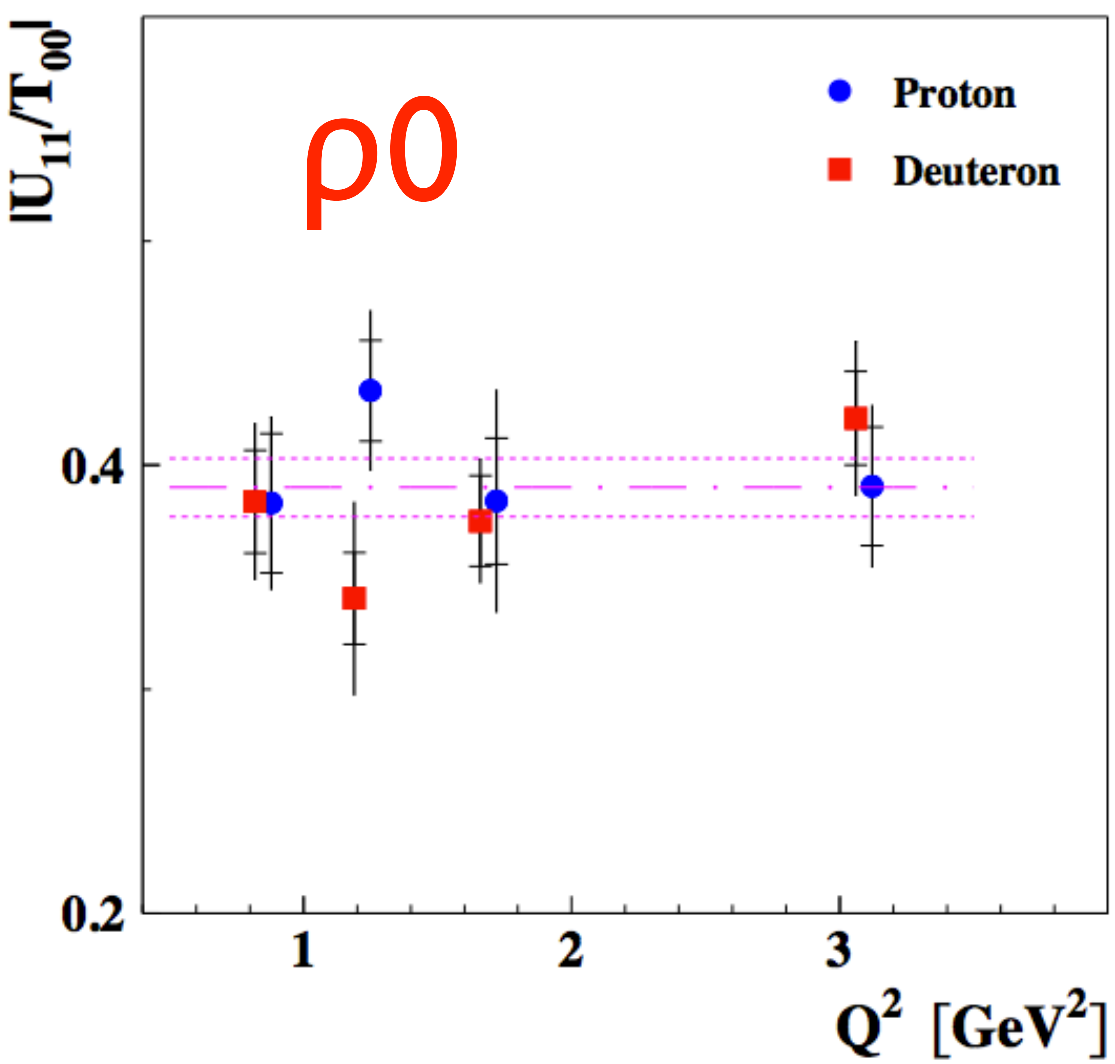
Results from HERMES

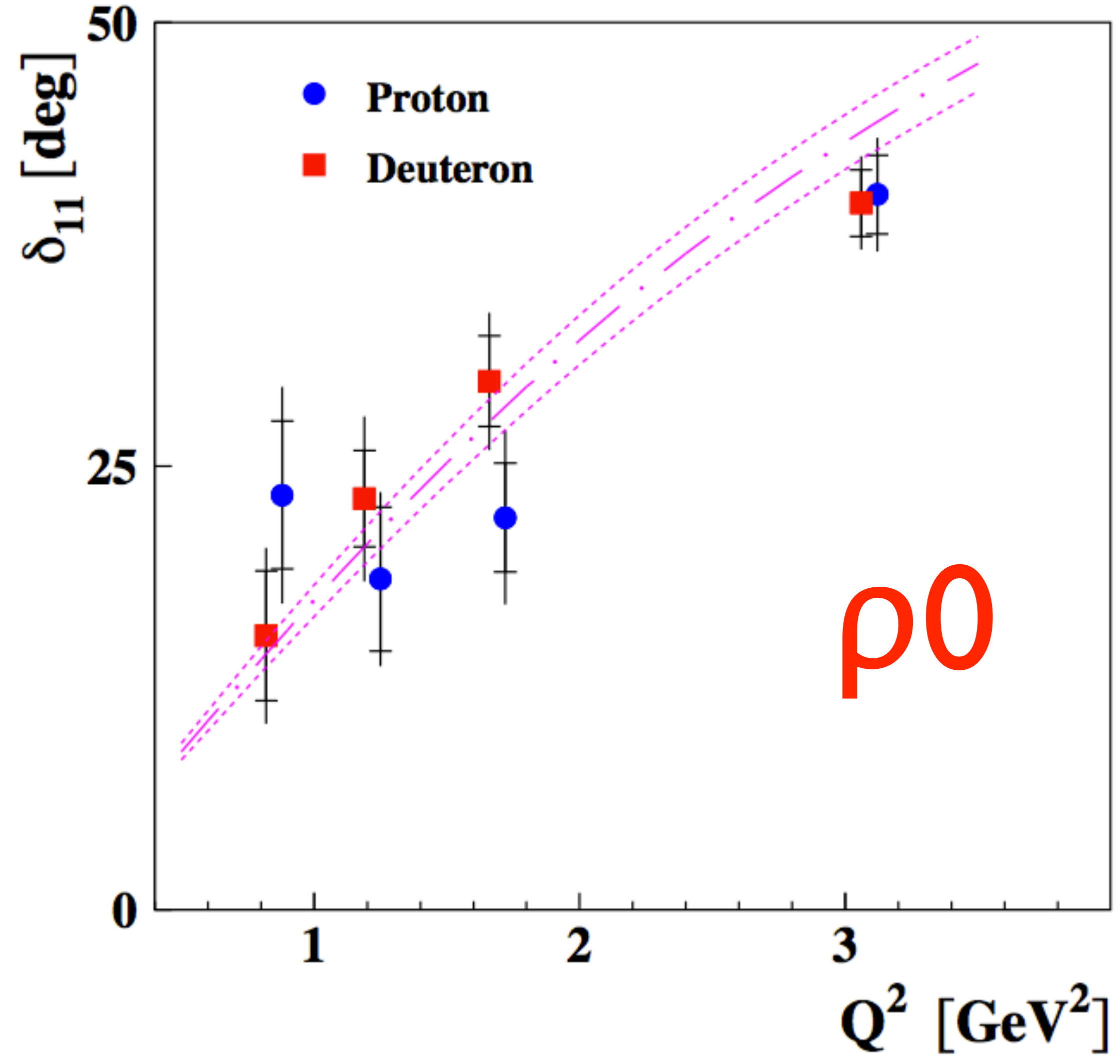
Access to E gives access to Ju for CQSM parameterisation

Opens the door to model-dependent constraints!



Results from HERMES

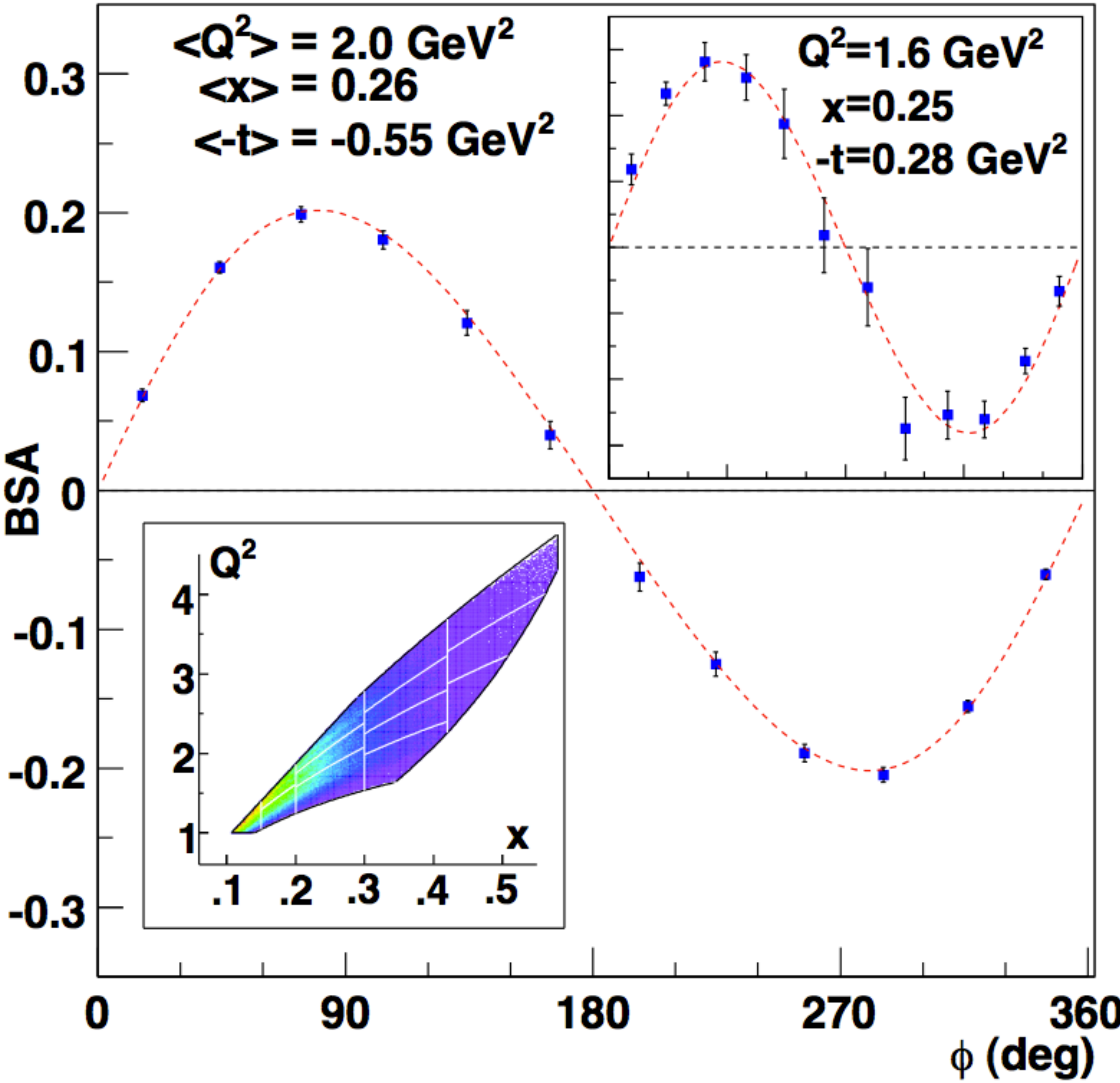




Evidence of UPE for ρ^0 mesons @ HERMES

Contradiction to GPD-based models!

Results from CLAS

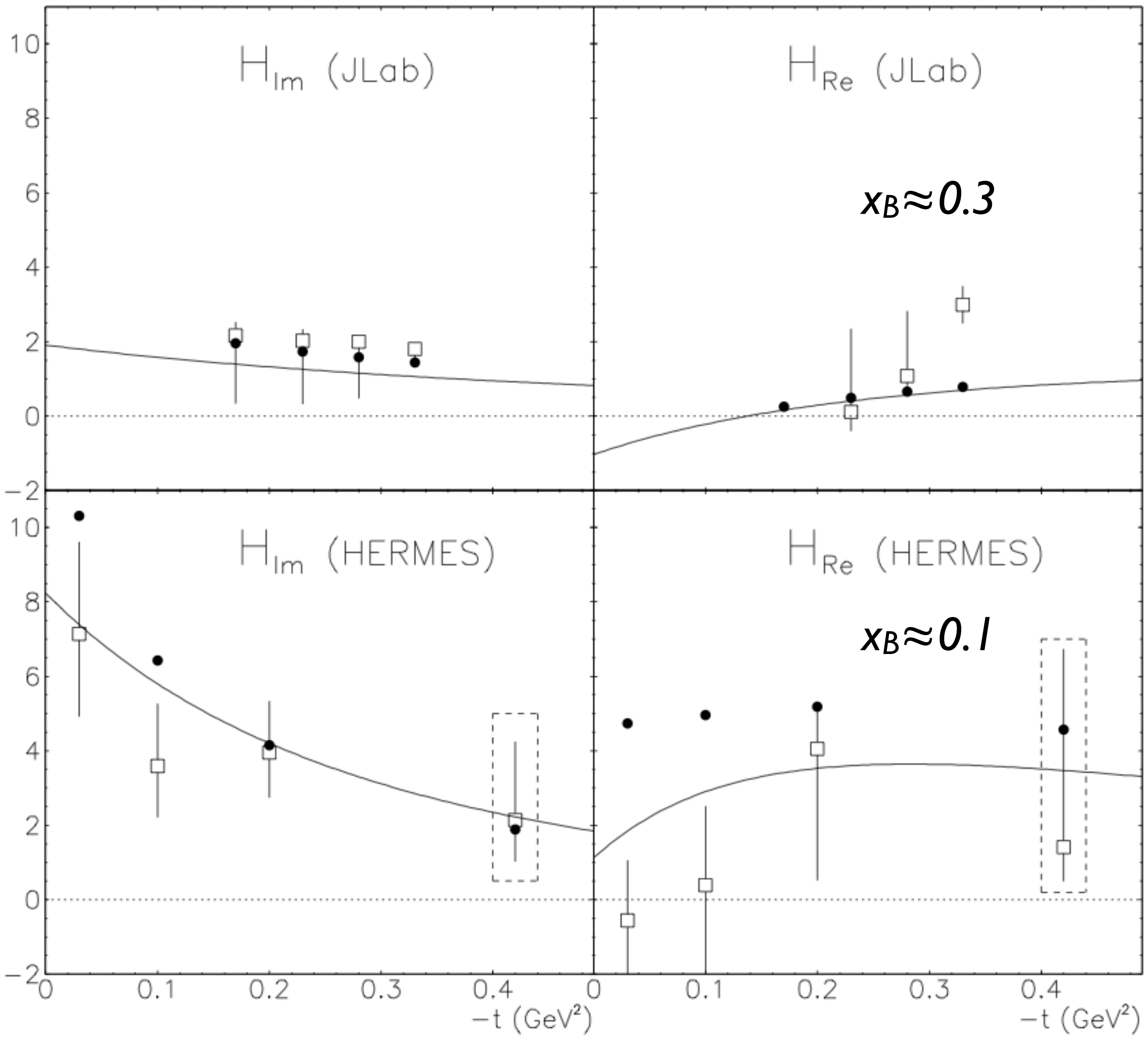


DVCS A_{LU} asymmetries measured in bins of x_B & Q^2

Very precise measurements over a wide range in x_B

GPDs

M. Guidal

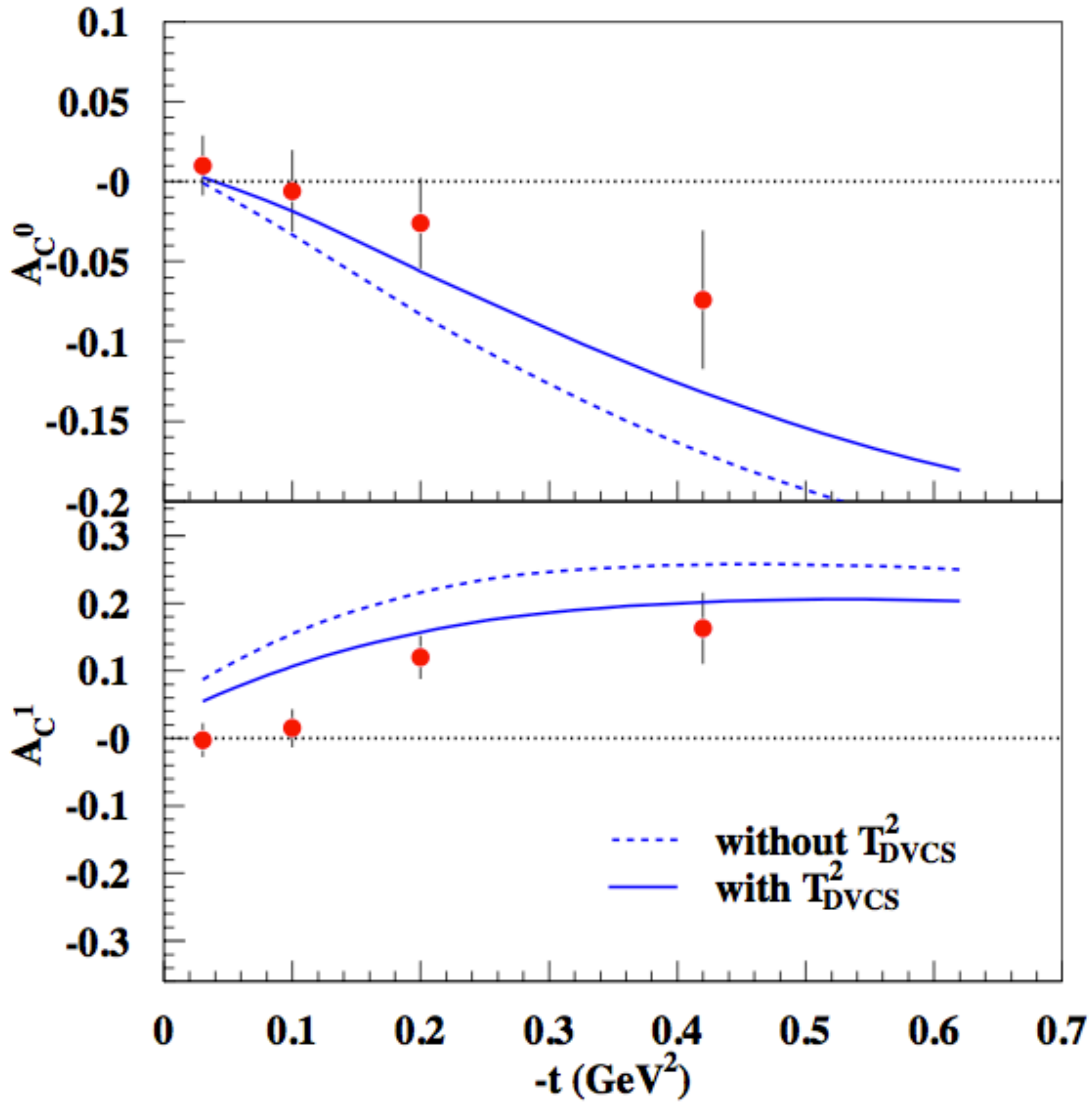


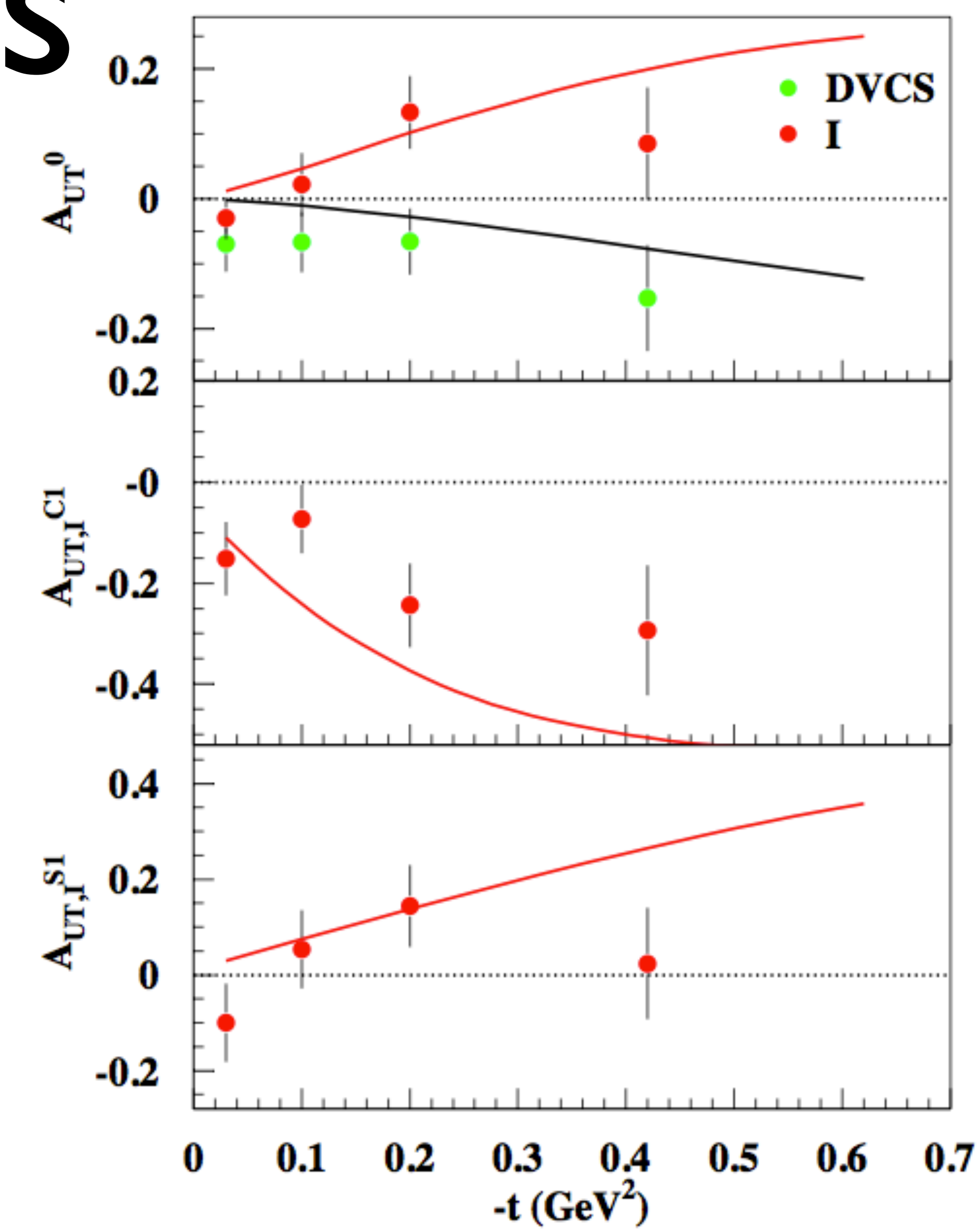
- Previous input to models

□ Extracted from fits to fixed-target data

Already we see that the previous input to models was good, but not right!

GPDs

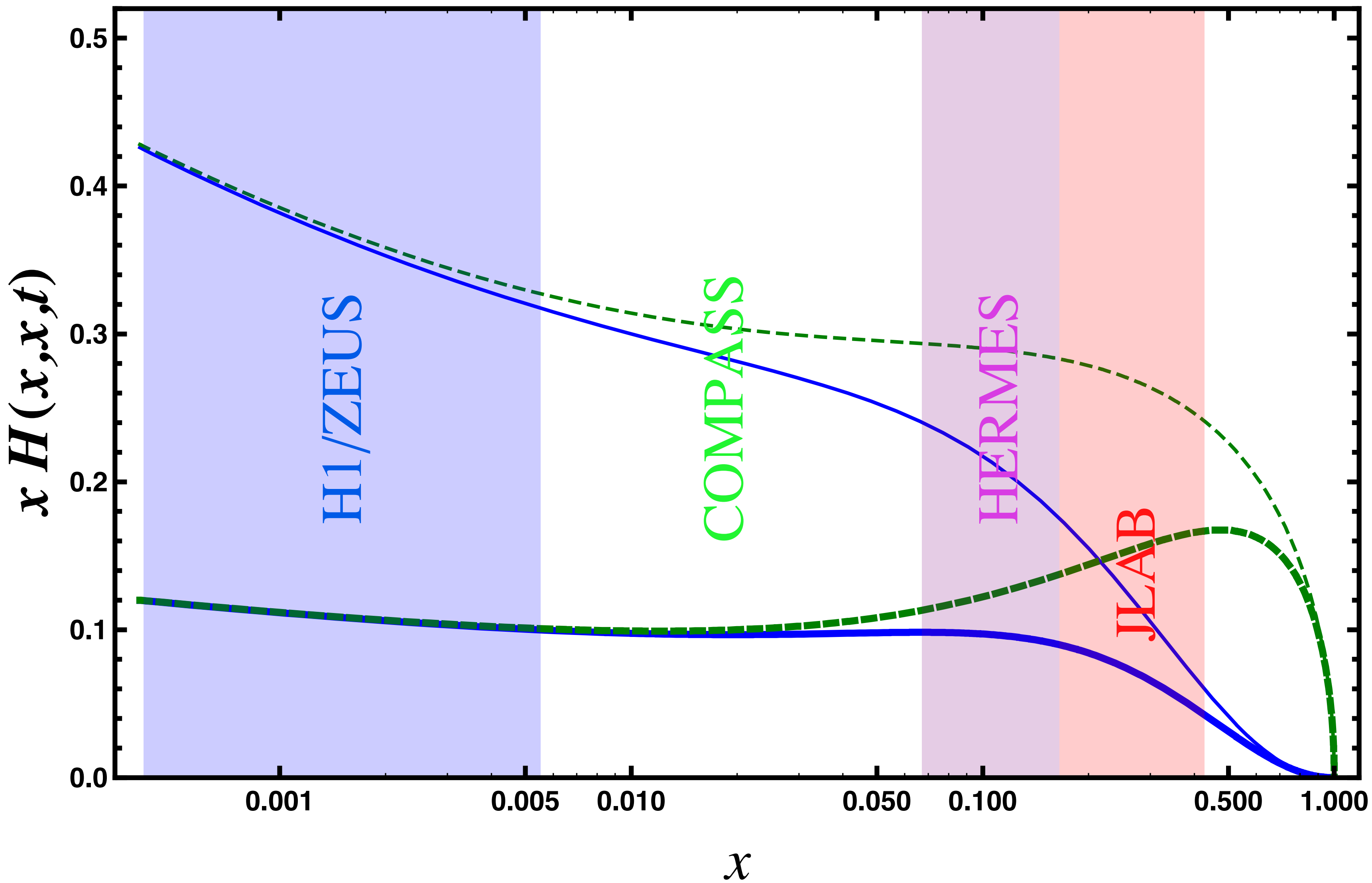




Models trained on JLab data (Liuti, Goldstein & Hernandez) have predictive power for HERMES asymmetry amplitudes!

GPDs

Müller & Kumerički attempt to extract GPDs from LCWF models



Factorized *t*-dependence

Regge *t*-dependence

Hall A cross-sections make a large difference!

Future @ HERMES

Still 9 papers in draft status

Almost 20 analyses ongoing!

cos-phi moments

$$d\sigma = d\sigma^0_{\mathrm{UU}} + d\sigma^1_{\mathrm{UU}}\cos(2\phi) + \frac{1}{Q}\left(d\sigma^2_{\mathrm{UU}}\cos\phi + \lambda_e d\sigma^3_{\mathrm{LU}}\sin\phi\right)$$

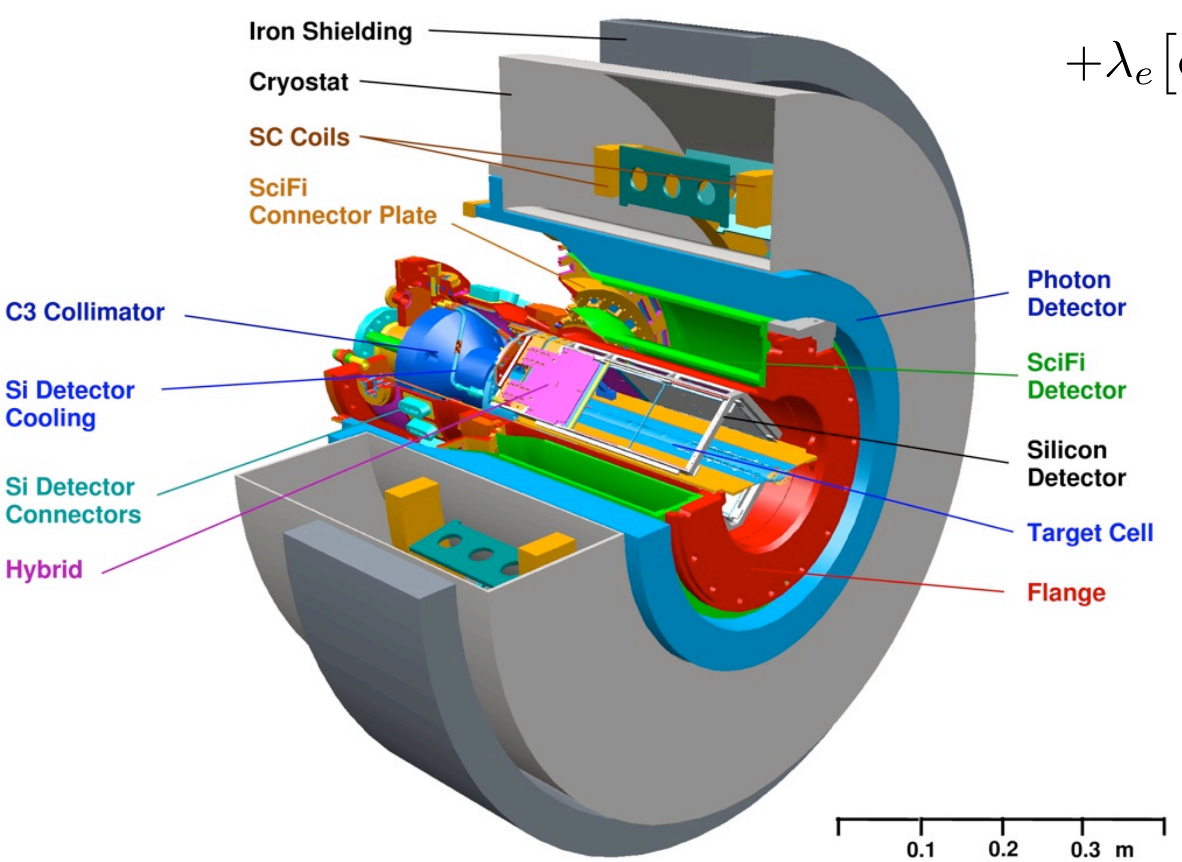
$$+S_L\left\{d\sigma^4_{\mathrm{UL}} + \frac{1}{Q}\left(d\sigma^5_{\mathrm{UL}}\sin + \lambda_e[Q d\sigma^6_{\mathrm{LL}} + d\sigma^7_{\mathrm{UL}}\cos\phi]\right)\right\}$$

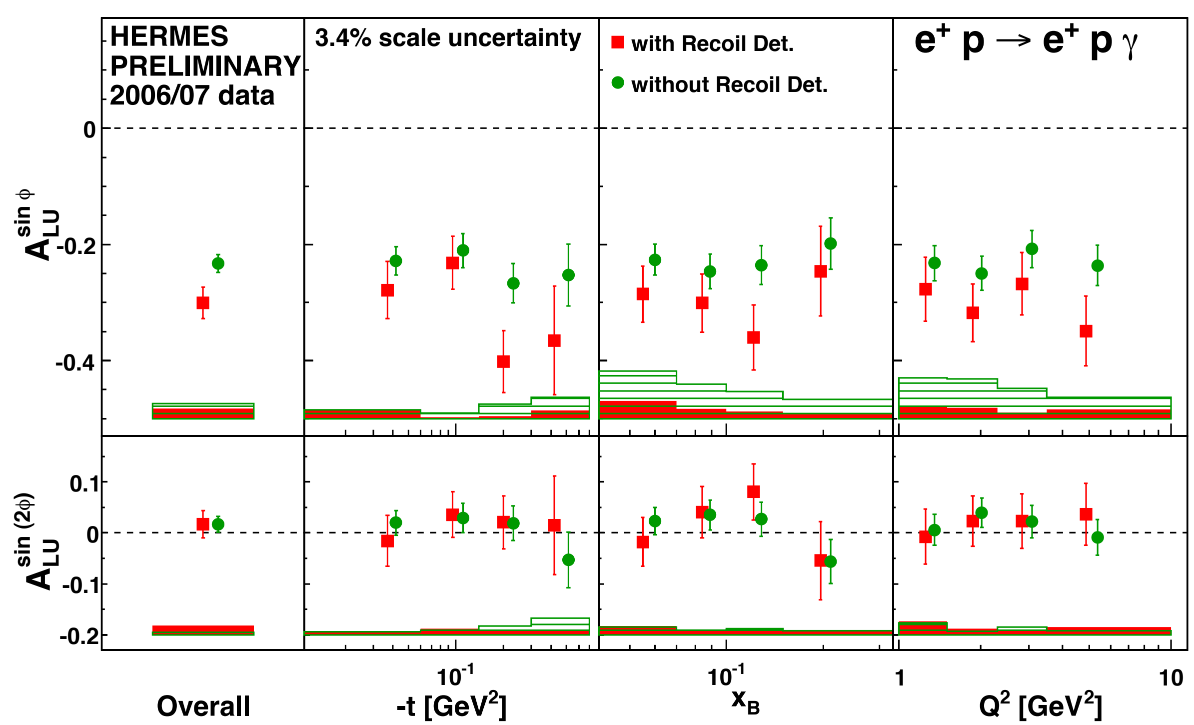
Sivers Function   Collins Effect

$$S_T\left\{d\sigma^8_{\mathrm{UT}}\sin(\phi-\phi_s) + d\sigma^9_{\mathrm{UT}}\sin(\phi+\phi_S) + d\sigma^{10}_{\mathrm{UT}}\sin(3\phi-\phi_S)\right.$$

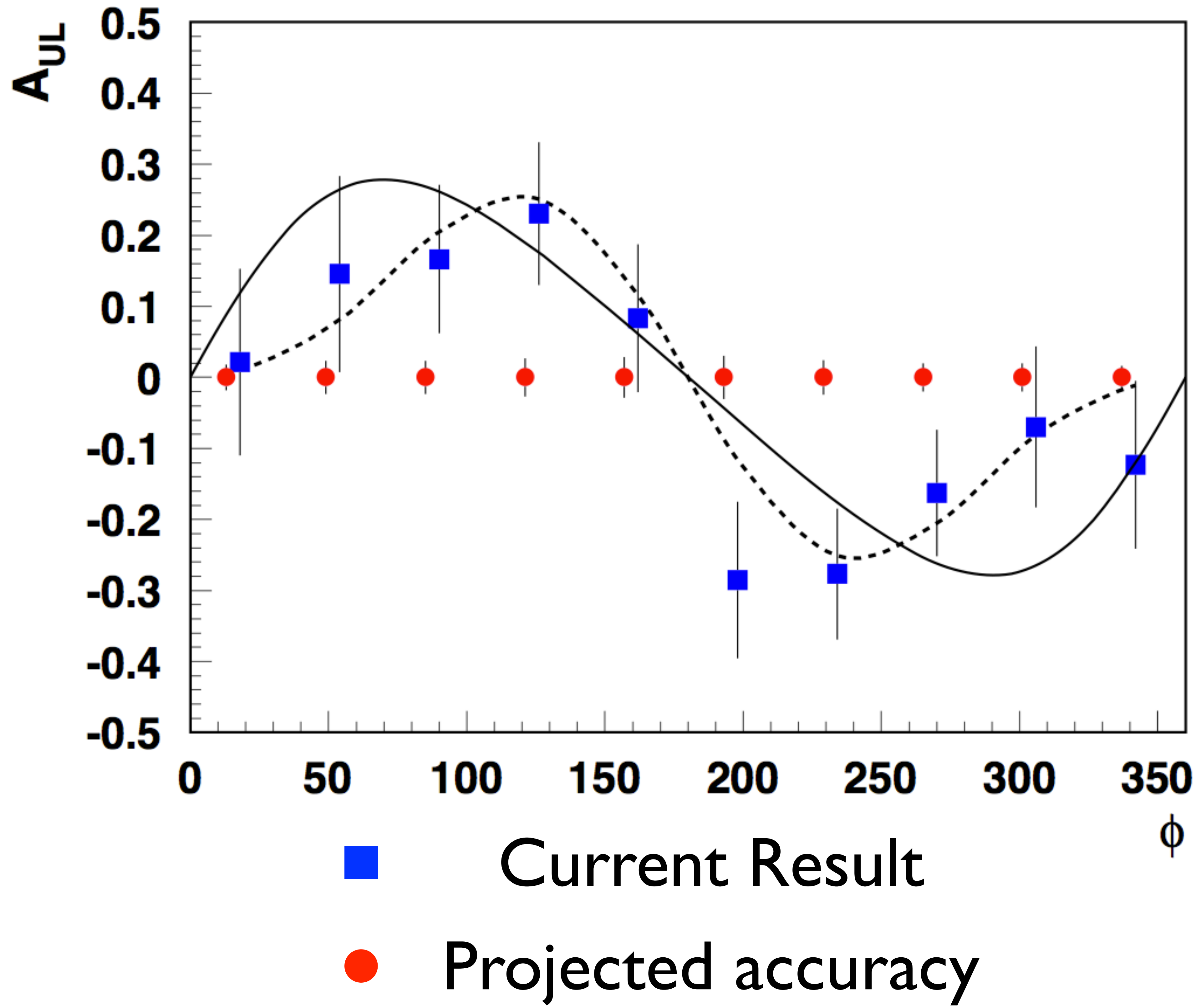
$$+\frac{1}{Q}\left[d\sigma^{11}_{\mathrm{UT}}\sin(2\phi-\phi_S) + d\sigma^{12}_{\mathrm{UT}}\sin\phi_S\right]$$

$$\left.+\lambda_e\left[d\sigma^{13}_{\mathrm{LT}}\cos(\phi-\phi_S) + \frac{1}{Q}d\sigma^{14}_{\mathrm{LT}}\cos\phi_S + \frac{1}{Q}d\sigma^{15}_{\mathrm{LT}}\cos(2\phi-\phi_S)\right]\right\}$$





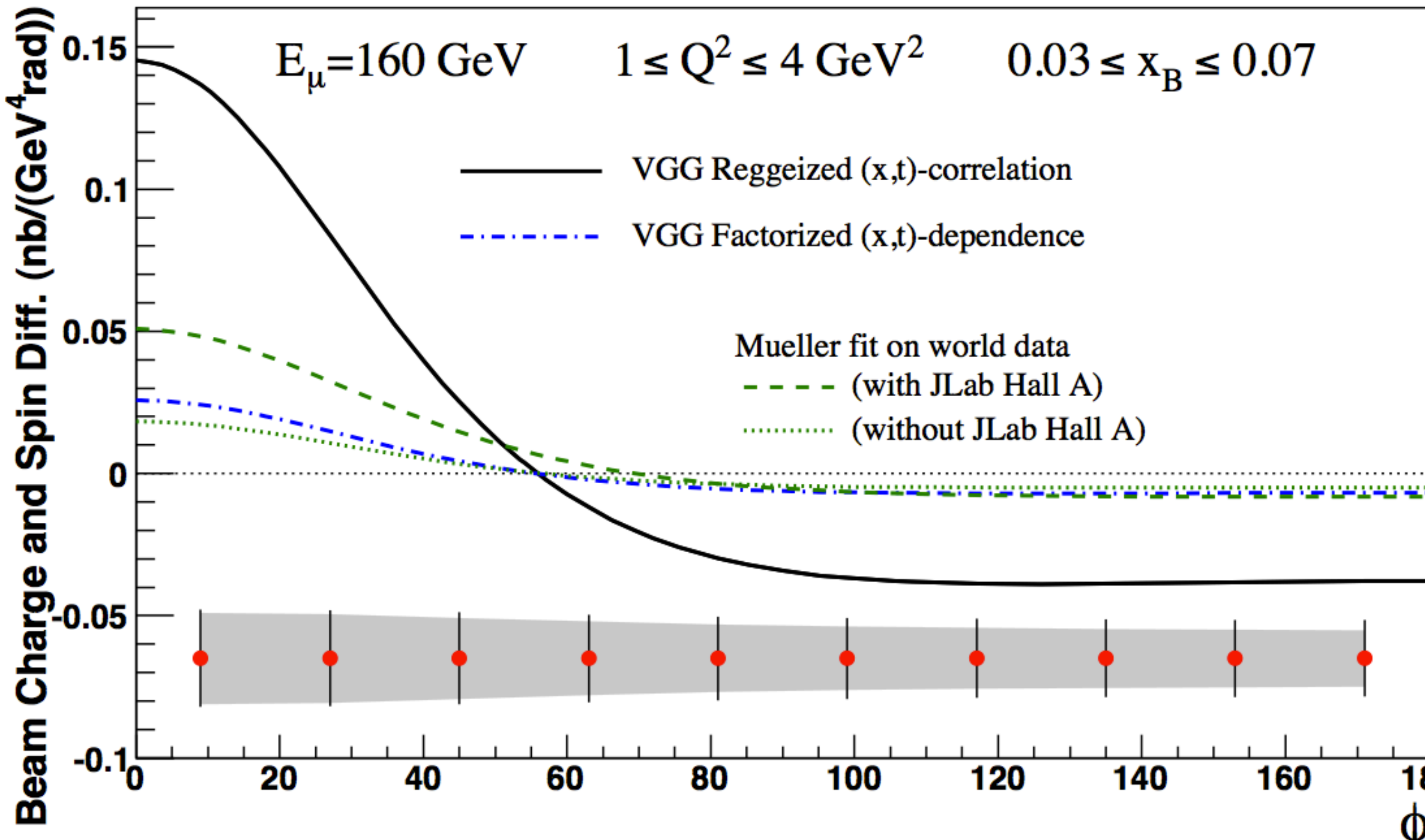
Future @ JLab

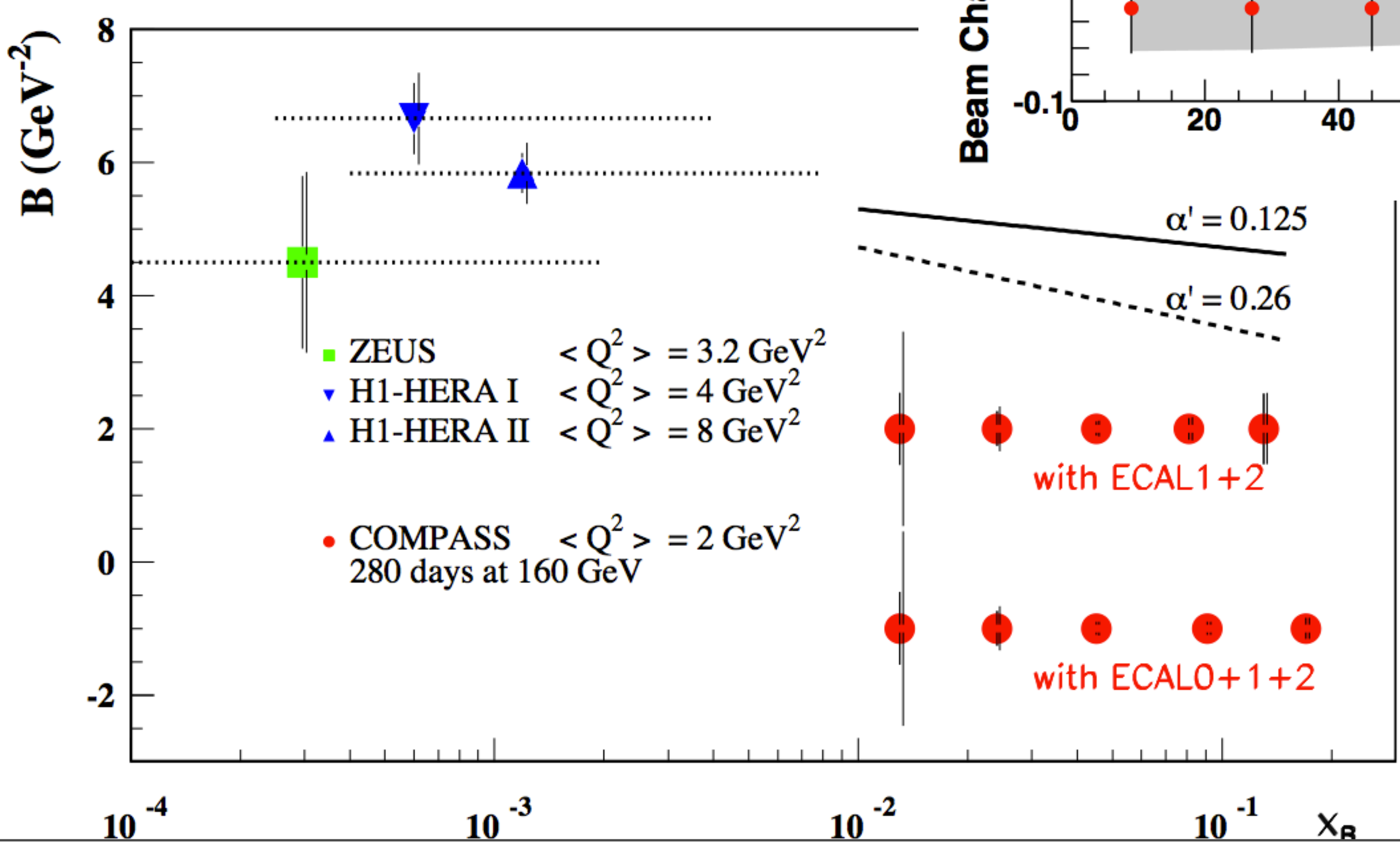


Experiment currently under analysis
should allow access to A_{LU}, A_{UL} and A_{LL}

Future @ COMPASS

COMPASS GPD Program aims to access Im(H) and Re(H)





Upcoming COMPASS data will determine the GPD t-dependence: Regge? Factorized? Something else?

Precision

WASHINGTON
ANNAPOLIS
MARYLAND
WEST VIRGINIA
CHARLESTON
RICHMOND
Chesapeake Bay
Appalachian Mountains
Allegheny Mountains
Blue Ridge
Shenandoah Mts
Massanutten Mt
Alexandria
Arlington
Manassas
Warrenton
Front Royal
Winchester
Leesburg
Rockville
Culpeper
Harrisonburg
Staunton
Charlottesville
Lexington
Covington
Bedford
Salem
Christiansburg
Pulaski
Wytheville
Marion
Abingdon
Martinsville
Farmville
Emporia
Williamsburg
Newport News
Hampton
Norfolk
Virginia Beach
Morgantown
Keyser
Fairmont
Grafton
Clarksburg
Parkersburg
Elkins
Buckhannon
Oak Hill
Beckley
Princeton
Moundsville
New Martinsville
Salisbury
La Plata
Cambridge
Elizabeth City
Edenton
Henderson
Roxboro
Oxford
Tarboro
Williamston
Winston-Salem
Greensboro
Boone
Mt Rogers
VIRGINIA
0 km 25 50 75 km
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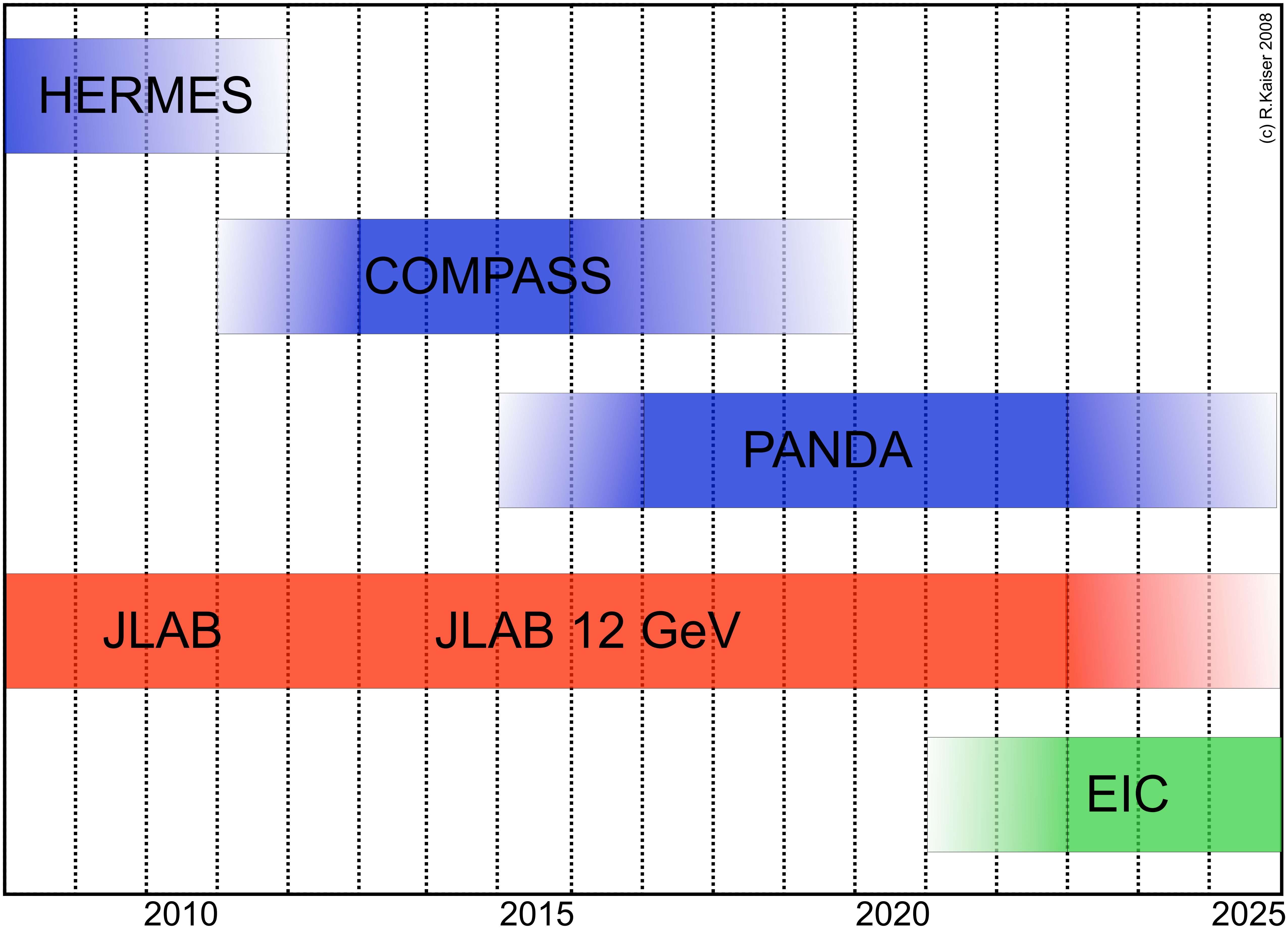
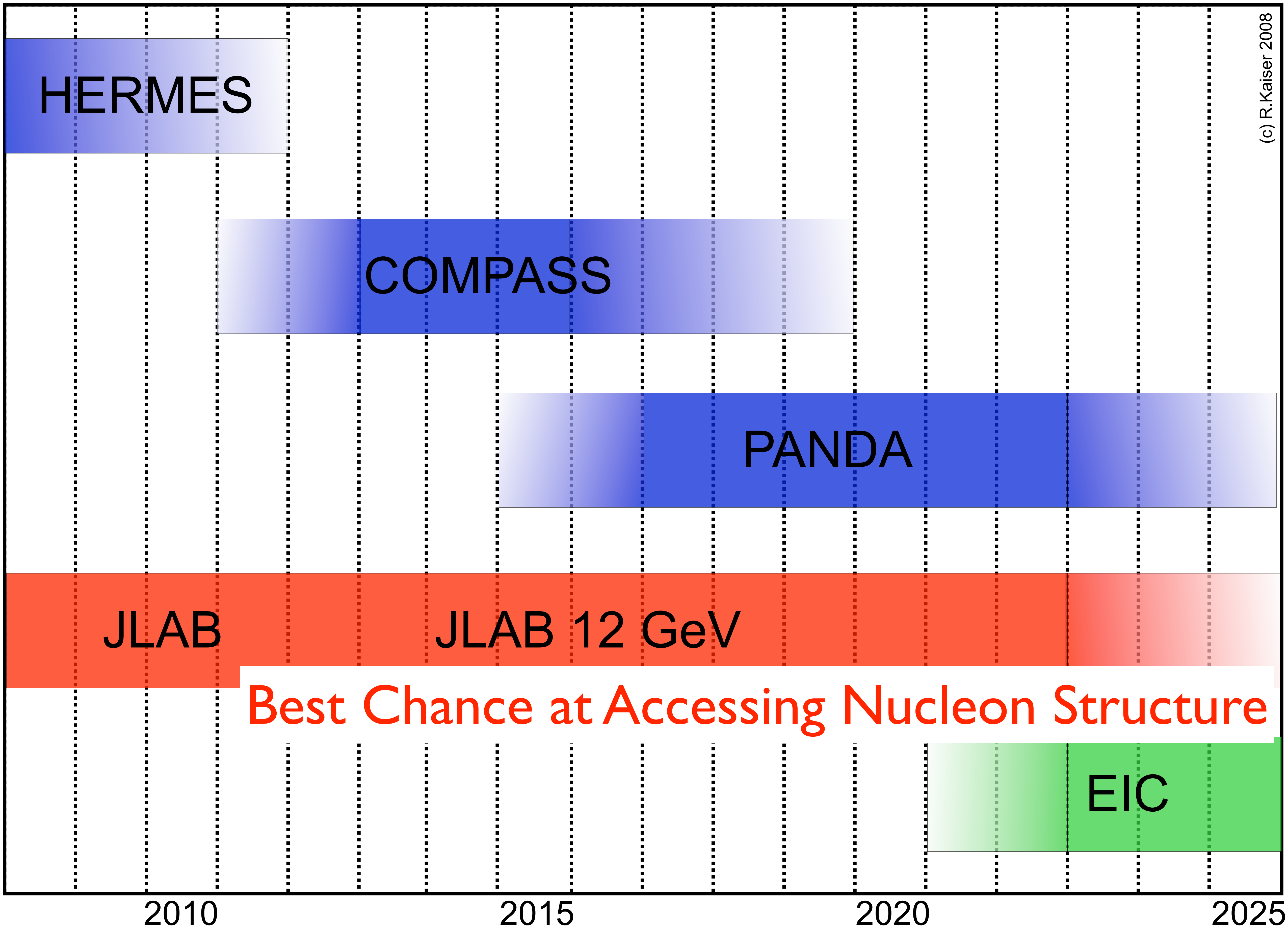
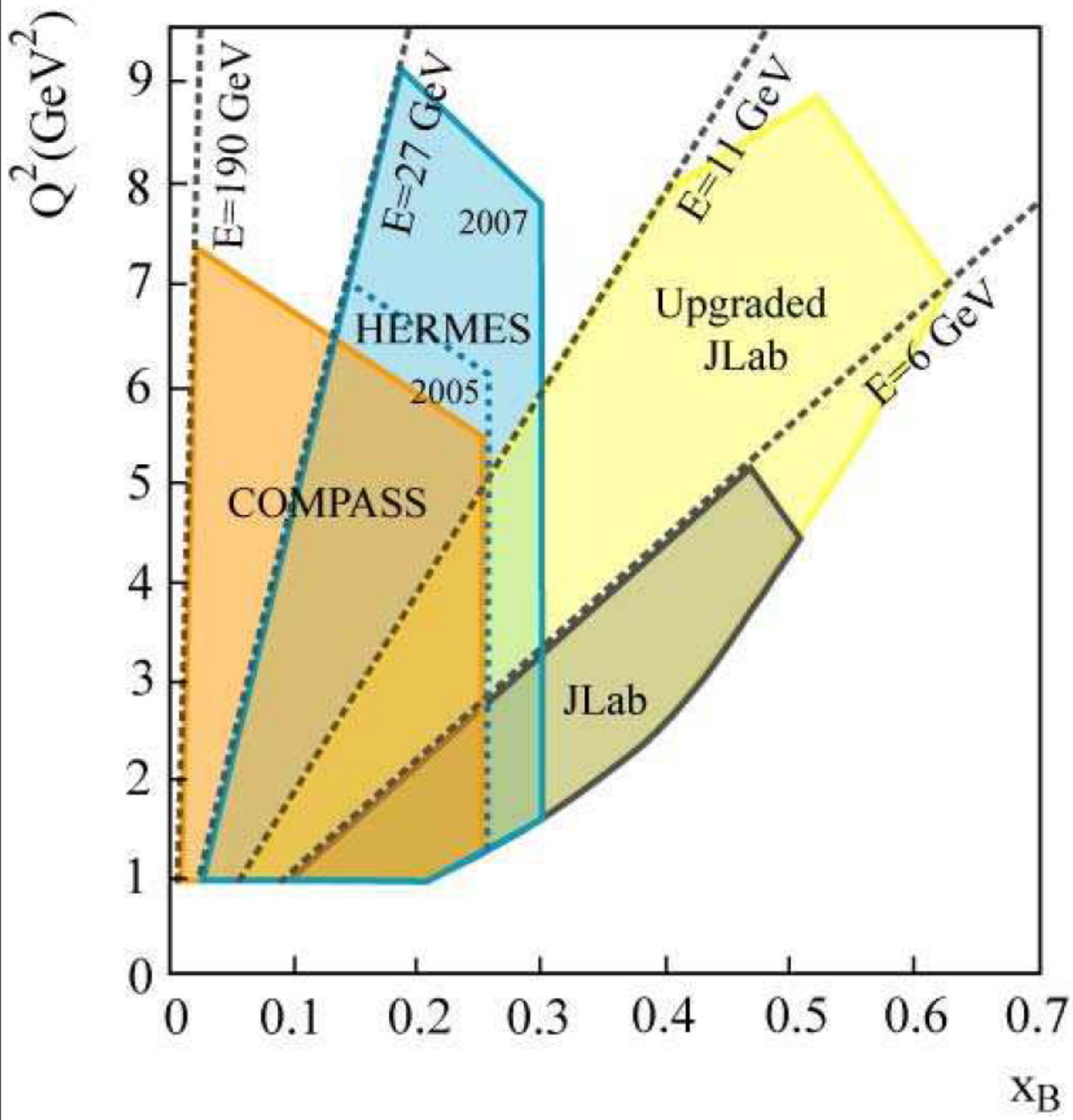

HERMES
COMPASS
PANDA
JLAB
JLAB 12 GeV
EIC
(c) R.Kaiser 2008
2010
2015
2020
2025



HERMES
COMPASS
PANDA
JLAB
JLAB 12 GeV
Best Chance at Accessing Nucleon Structure
EIC
2010
2015
2020
2025
(c) R.Kaiser 2008

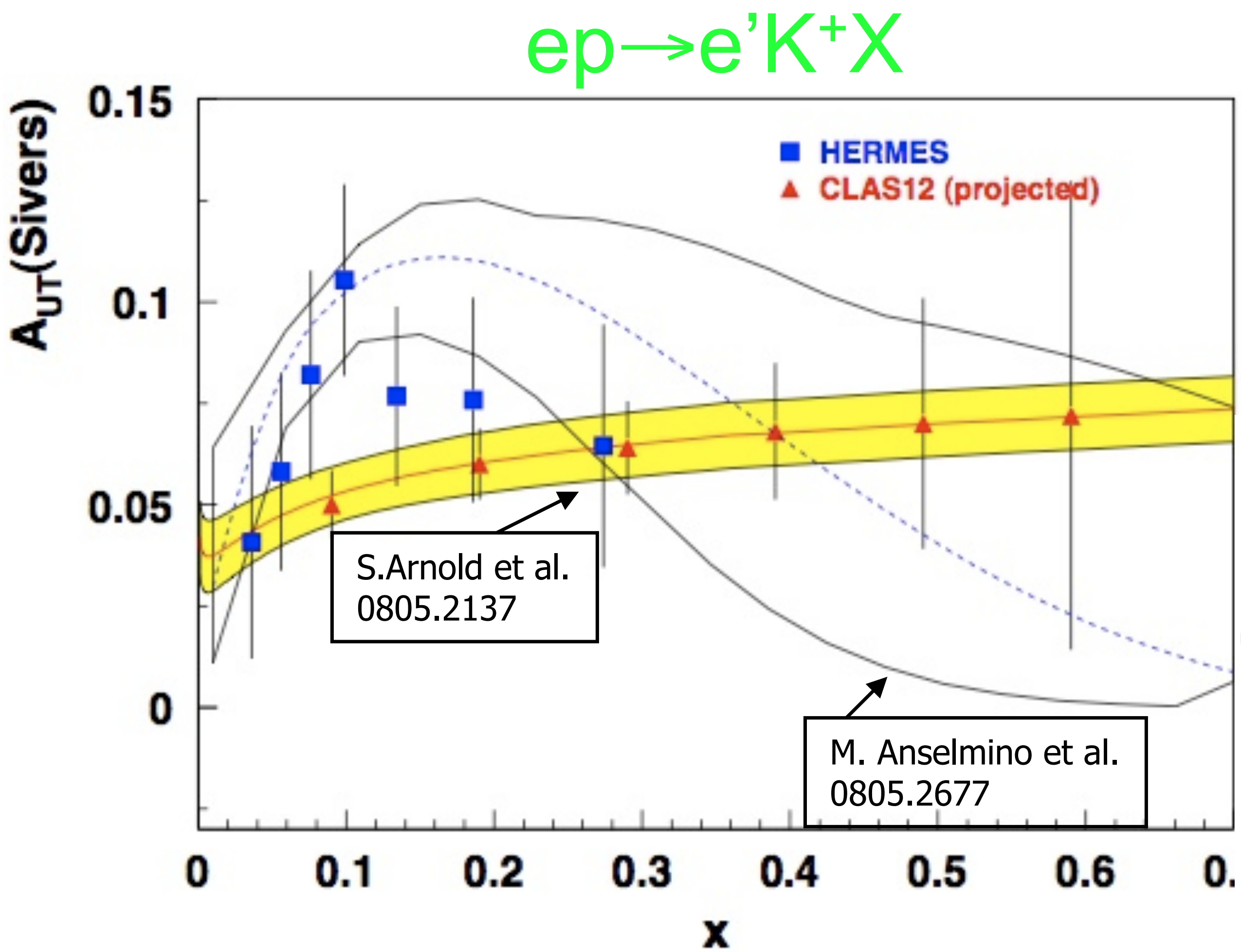
JLab @ 12 GeV



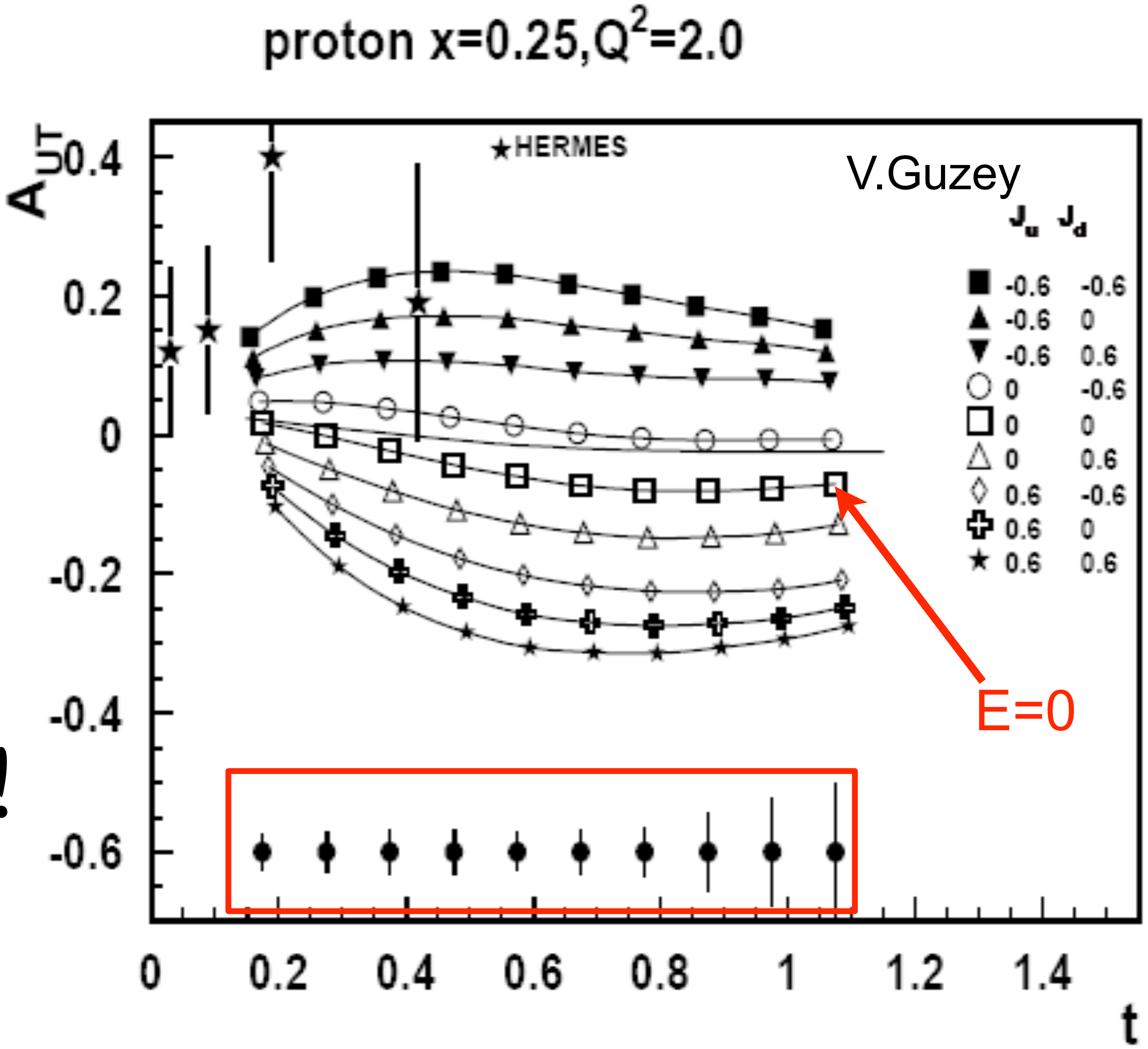
Expanded kinematic coverage allows expanded physics program

Ambitious plans to do DVCS on neutron at Halls A and B; help map out Sivers moments with precision enough to distinguish models

CLAS 12



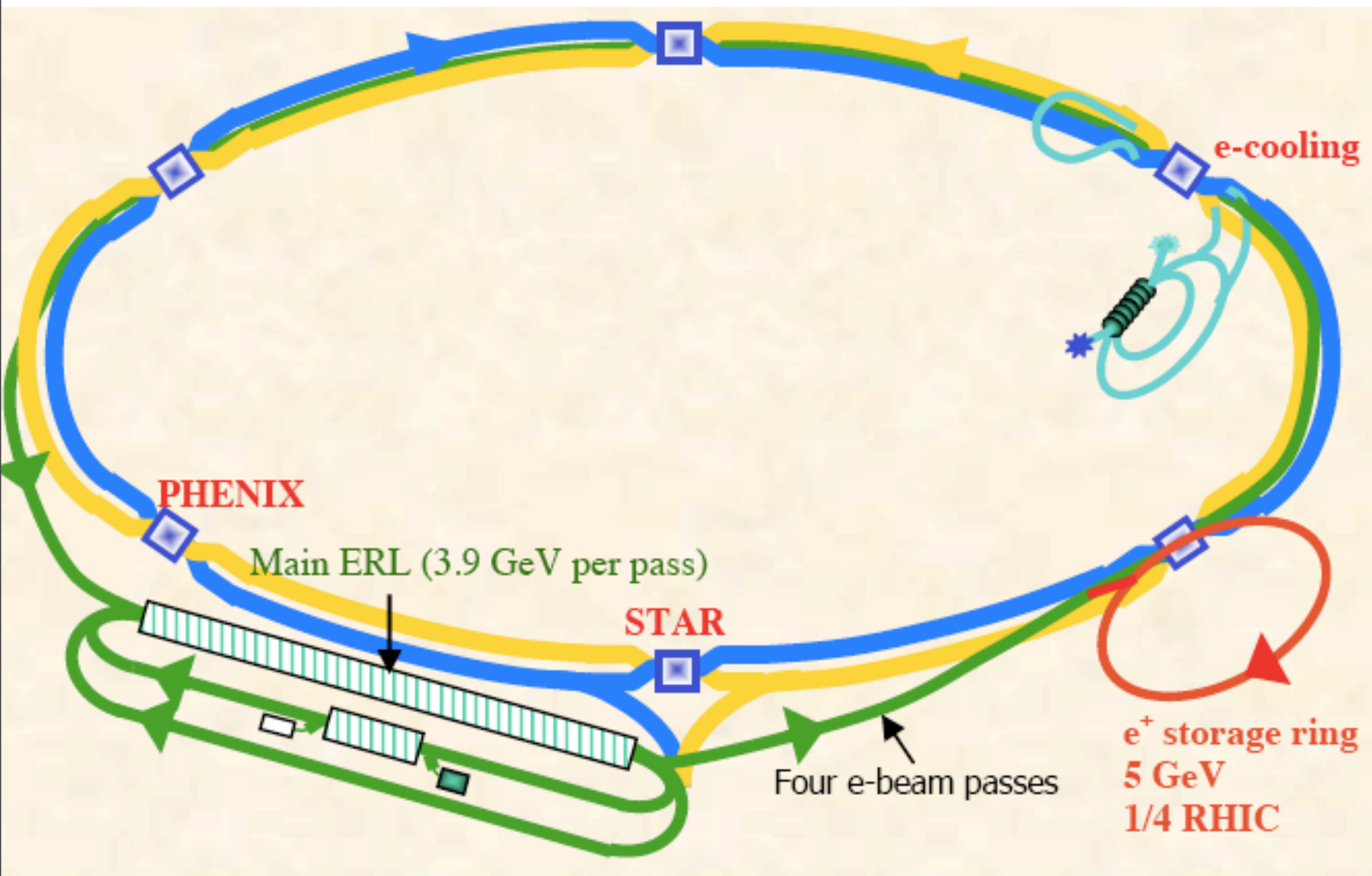
Sivers moment will help confirm Quark OAM



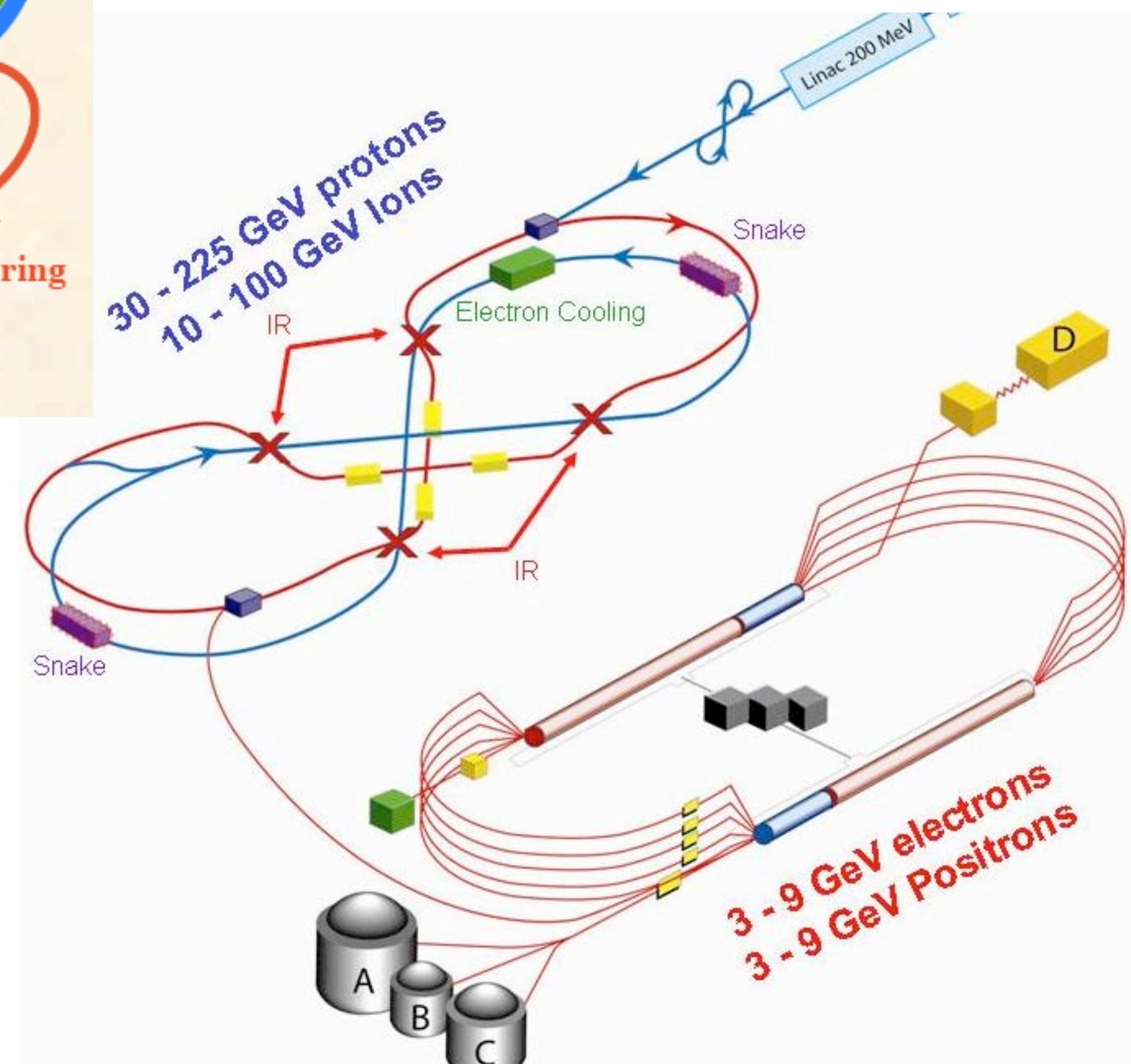
Measurement of TTSA in DVCS may help quantify it!

EIC

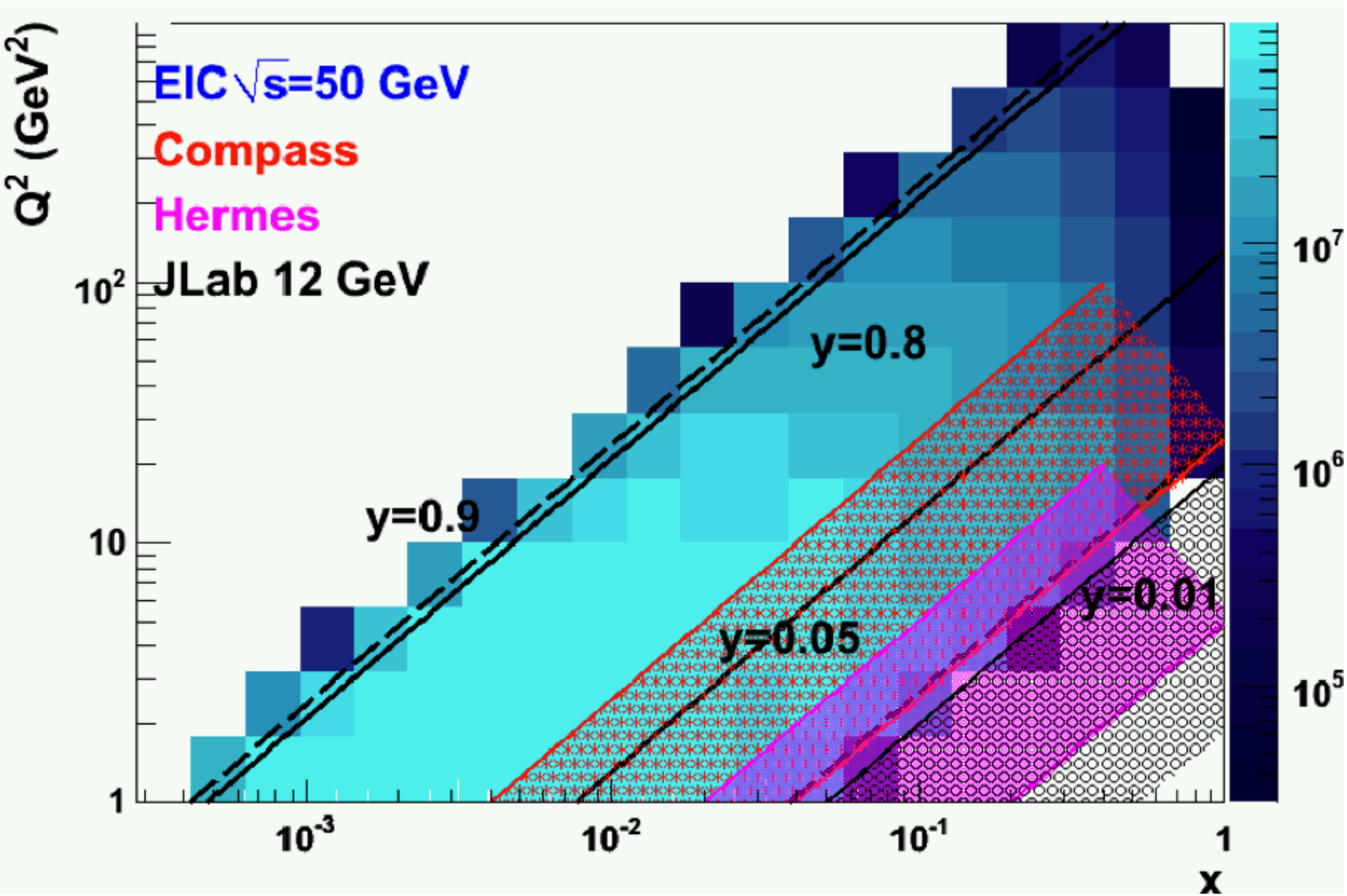
Two competing designs: the resultant choice will decide the precise physics coverage



Will be built as a machine to access sea quarks and gluons: map out distributions in heretofore unexplored areas!

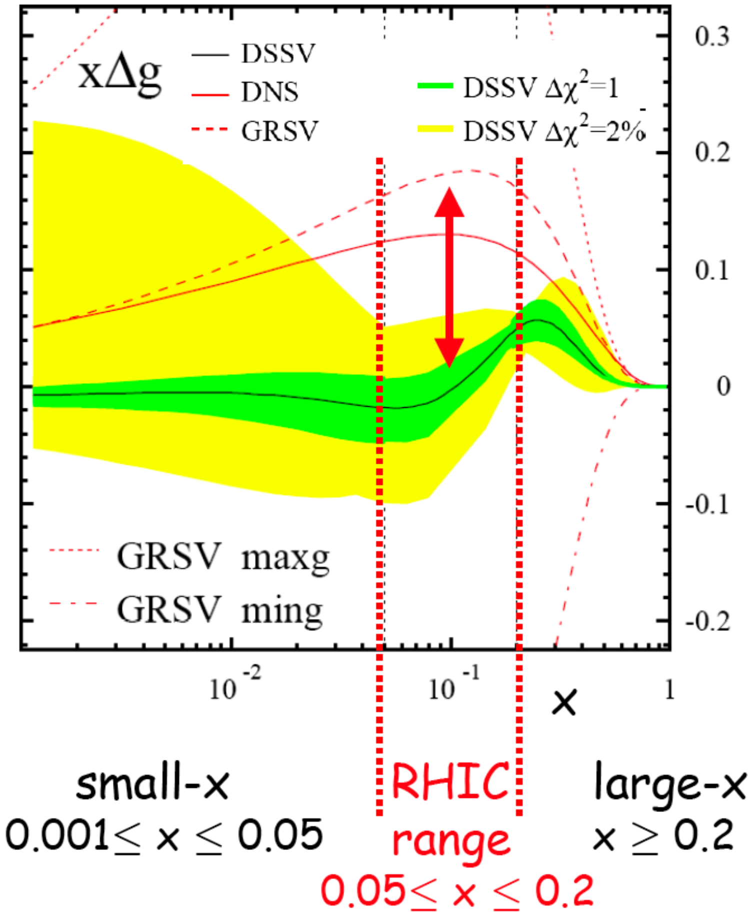


EIC

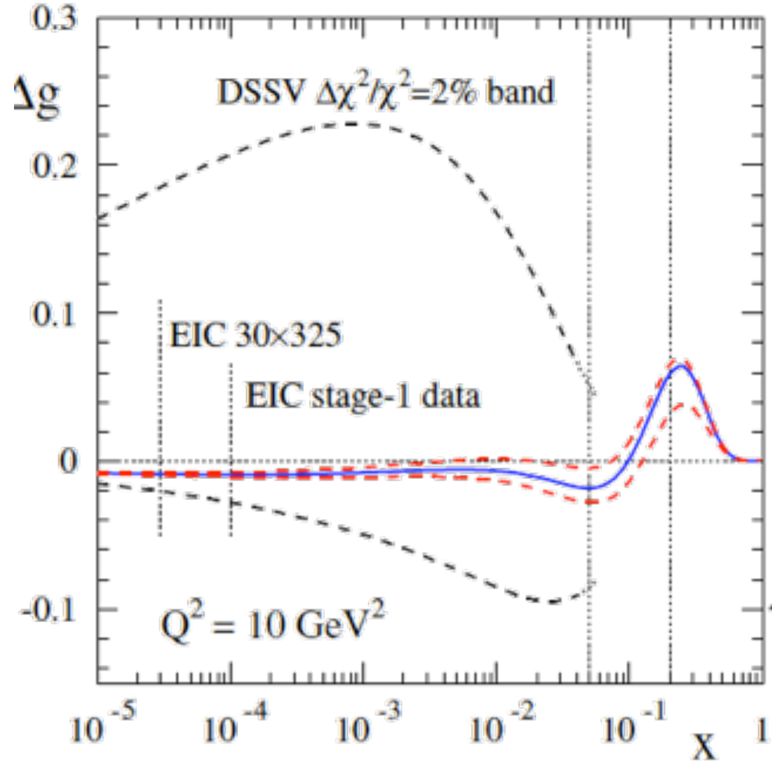


EIC √s=50 GeV
Compass
Hermes
JLab 12 GeV
Q² (GeV²)
y=0.9
y=0.8
y=0.05
y=0.01
10²
10
1
10⁻³
10⁻²
10⁻¹
1
x
10⁷
10⁶
10⁵

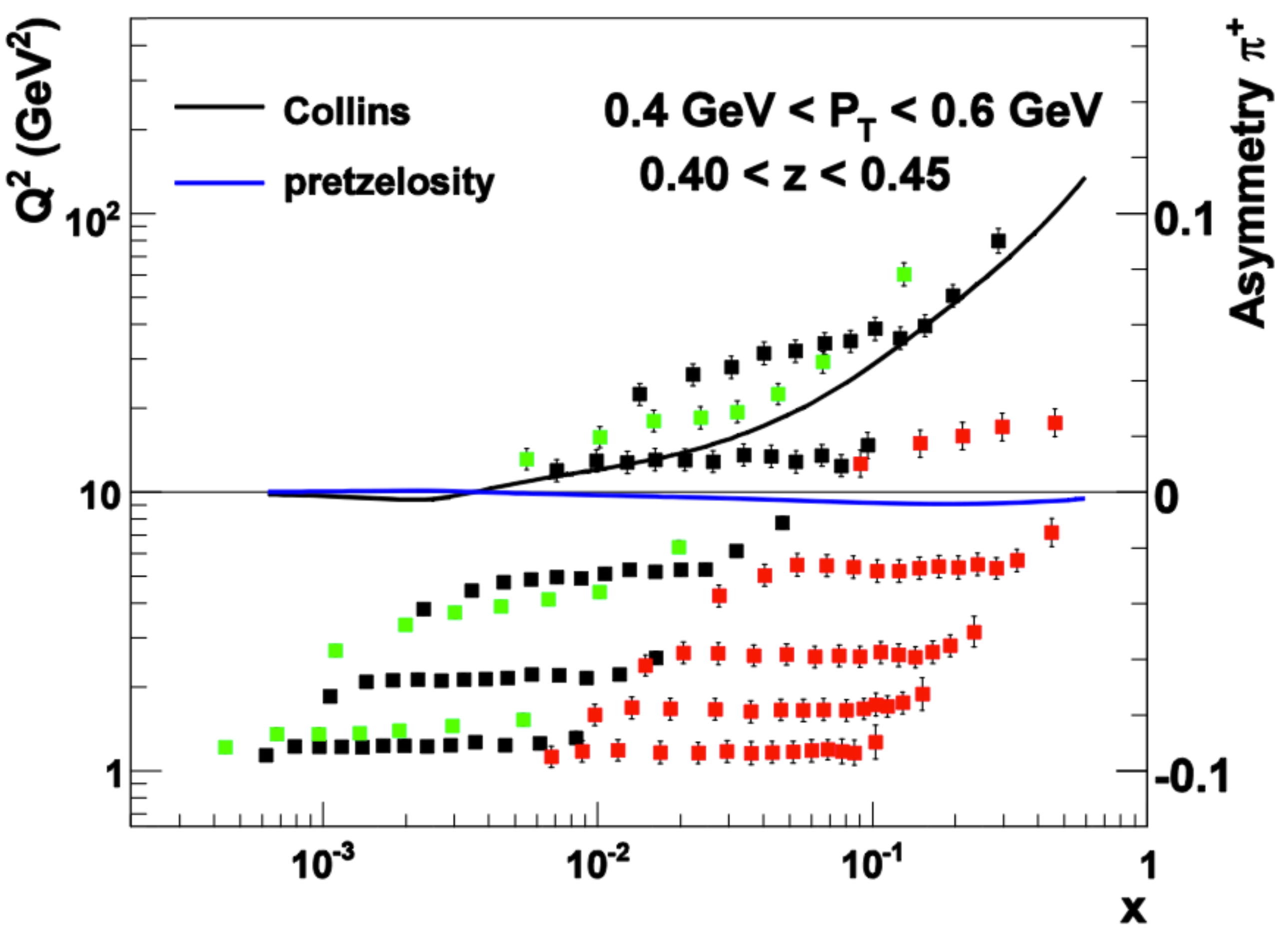
EIC



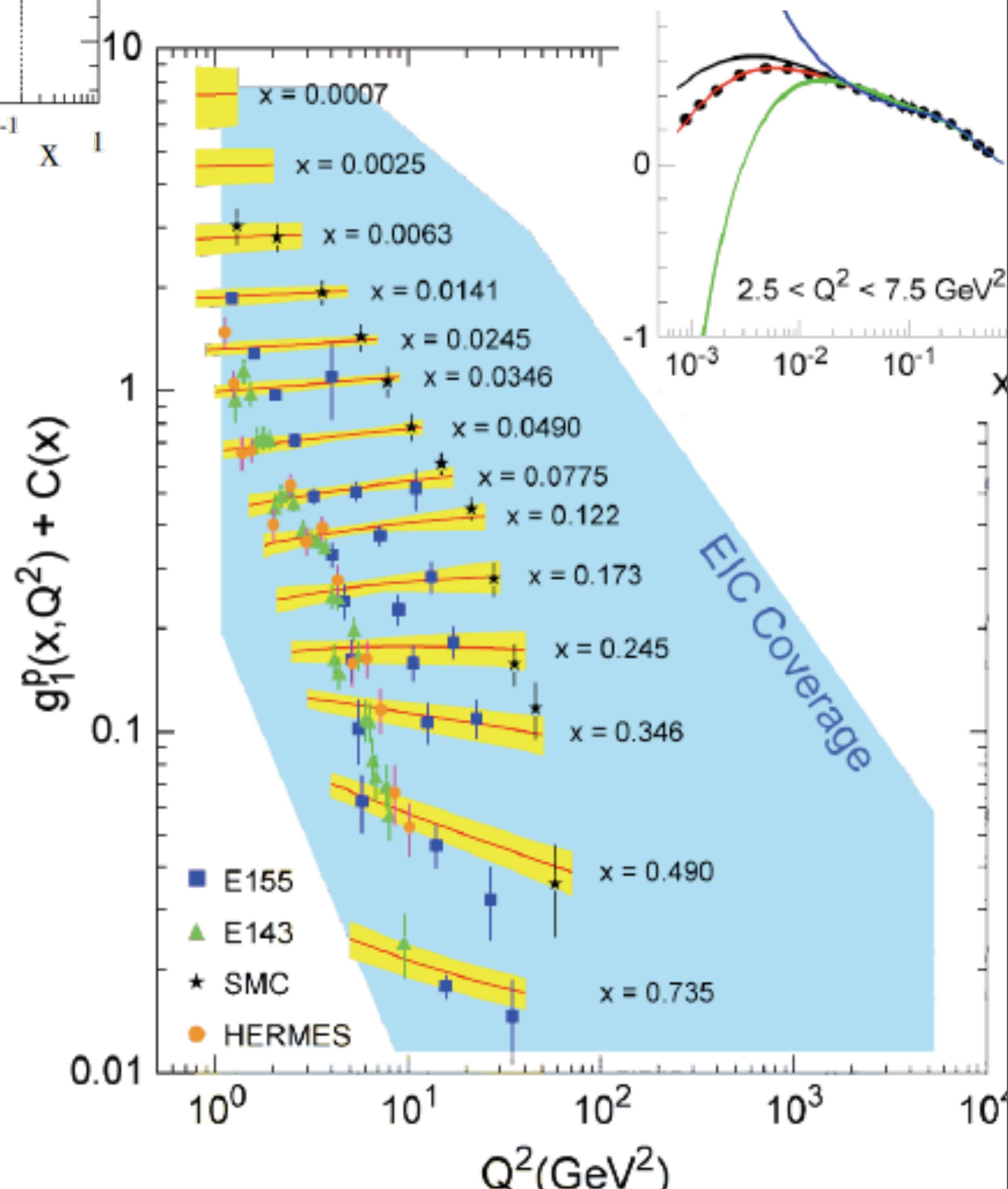
xΔg
DSSV
DNS
GRSV
DSSV Δχ²=1
DSSV Δχ²=2%
GRSV maxg
GRSV ming
x
small-x
0.001≤ x ≤ 0.05
RHIC range
0.05≤ x ≤ 0.2
large-x
x ≥ 0.2



Δg
DSSV Δχ²/χ²=2% band
EIC 30×325
EIC stage-1 data
Q² = 10 GeV²
x



Q² (GeV²)
Collins
pretzelosity
0.4 GeV < P_T < 0.6 GeV
0.40 < z < 0.45
Asymmetry π⁺
x



g₁ᵖ(x,Q²) + C(x)
x = 0.0007
x = 0.0025
x = 0.0063
x = 0.0141
x = 0.0245
x = 0.0346
x = 0.0490
x = 0.0775
x = 0.122
x = 0.173
x = 0.245
x = 0.346
x = 0.490
x = 0.735
EIC Coverage
E155
E143
SMC
HERMES
Q²(GeV²)
2.5 < Q² < 7.5 GeV²

Summary

- One message of nucleon structure physics is that the first thought is invariably incorrect
- Theoretical calculations from 15 years ago are still beyond the grasp of current experiments - but getting closer all the time!
- Two-way street: a lot of experimental data is not yet used by theorists either!

Summary

- TMDs and GPDs currently offer the best route to understanding nucleon structure
- We can access those through SIDIS and DVCS and DVMP
- Look to JLab@12GeV and EIC for precise measurements