PVDIS: 12 GeV at JLab

For the SOLID Collaboration

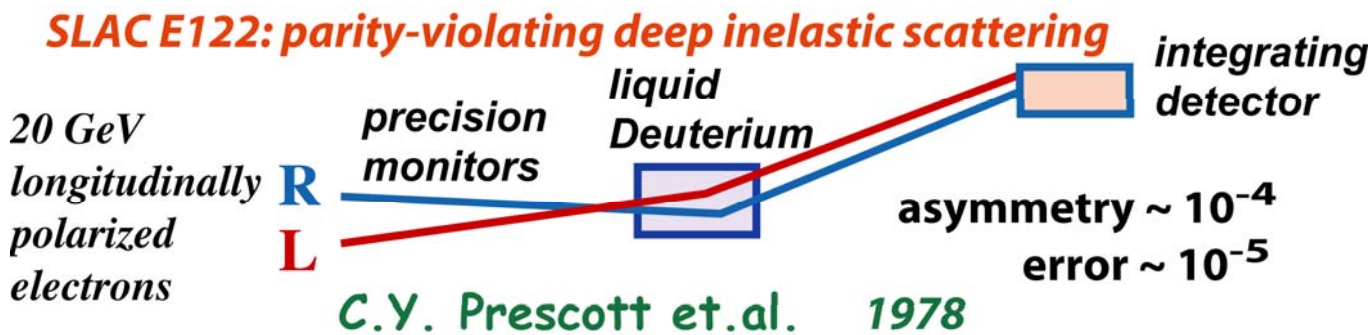
OUTLINE

- PVDIS
- Physics Potential
  - Electroweak couplings
  - CSV
  - Higher Twist
- Apparatus
- Conclusions

First Electron Parity Experiment

It was realized independently in the mid 70s at SLAC:

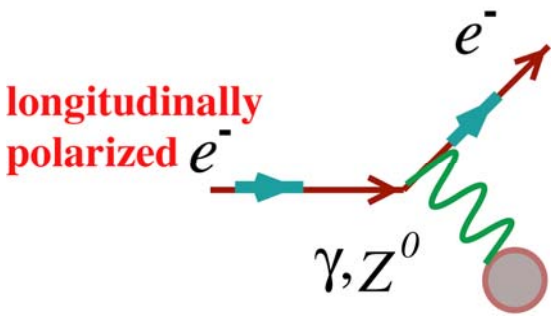
A_{PV} in Deep Inelastic Scattering off liquid Deuterium: $Q^2 \sim 1\ (\mathrm{GeV})^2$



$$A_{PV} \sim 10^{-4} \cdot Q^2\ (\mathrm{GeV}^2)$$

This experiment convinced the world that the Z-boson violated parity

PV Asymmetries: Any Target

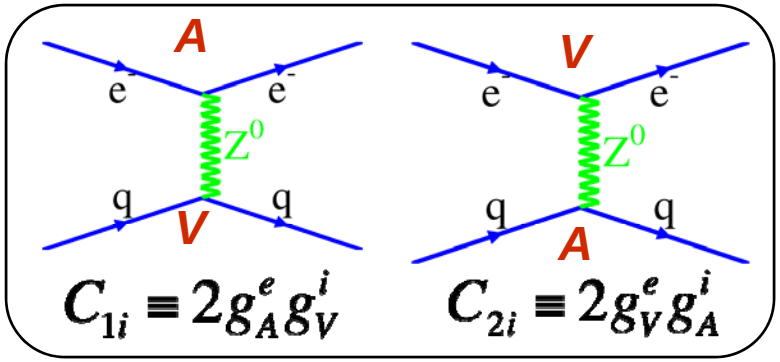


$$\sigma \;\; \alpha \, | A_\gamma + A_{weak} |^2$$

$$-A_{LR} = A_{PV} = \frac{\sigma_{\uparrow} - \sigma_{\downarrow}}{\sigma_{\uparrow} + \sigma_{\downarrow}} \sim \frac{A_{weak}}{A_\gamma} \sim \frac{G_F Q^2}{4 \pi \alpha} (g_A{}^e g_V{}^T + \beta \, g_V{}^e g_A{}^T)$$

- ***The couplings g depend on electroweak physics as well as on the weak vector and axial-vector hadronic current***
- ***Both new physics at high energy scales as well as interesting features of hadronic structure come into play***
- ***A program with many targets and a broad kinematic range can untangle the physics***

Electron-Quark Phenomenology



$$C_{1u} = -\tfrac{1}{2} + \tfrac{4}{3}\sin^2(\theta_W) + \delta C_{1u} \approx -0.19$$
$$C_{1d} = \tfrac{1}{2} - \tfrac{2}{3}\sin^2(\theta_W) + \delta C_{1d} \approx 0.35$$
$$C_{2u} = -\tfrac{1}{2} + 2\sin^2(\theta_W) + \delta C_{2u} \approx -0.030$$
$$C_{2d} = \tfrac{1}{2} - 2\sin^2(\theta_W) + \delta C_{2d} \approx 0.025$$

Moller PV is insensitive to the C_{ij}

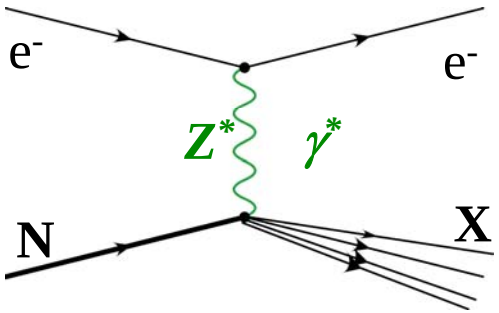
C_{1u} and C_{1d} will be determined to high precision by Q_{weak}, APV Cs

C_{2u} and C_{2d} are small and poorly known:
one combination can be accessed in PV DIS

New physics such as compositeness, leptoquarks:

Deviations to C_{2u} and C_{2d} might be fractionally large

Deep Inelastic Scattering



$$A_{PV} = \frac{G_F Q^2}{\sqrt{2}\pi\alpha}\left[\mathbf{a}(x) + Y(y)\,\mathbf{b}(x)\right]$$

a(x) and **b**(x) contain quark distribution functions $f_i(x)$

$$x \equiv x_{Bjorken}$$

$$y \equiv 1 - E'/E$$

$$f_i^{\pm} \equiv f_i \pm \overline{f}_i$$

$$\boldsymbol{a}(x) = \frac{\sum_i \boldsymbol{C_{1i}} Q_i f_i^{+}(x)}{\sum_i Q_i^2 f_i^{+}(x)} \qquad \boldsymbol{b}(x) = \frac{\sum_i \boldsymbol{C_{2i}} Q_i f_i^{-}(x)}{\sum_i Q_i^2 f_i^{+}(x)}$$

For an isoscalar target like ^{2}H, structure functions largely cancel in the ratio at high x

at high x

$$\boldsymbol{a}(x) = \frac{3}{10}(2C_{1u} - C_{1d})\left(1 + \frac{0.6\, s^+}{u^+ + d^+}\right) \rightarrow \mathbf{0}$$

$$\boldsymbol{b}(x) = \frac{3}{10}(2C_{2u} - C_{2d})\left(\frac{u_v + d_v}{u^+ + d^+}\right) + \cdots \rightarrow \mathbf{1}$$

At high x, A_{PV} becomes independent of x, W, with well-defined SM prediction for Q^2 and y

C_{2q} inaccessible in elastic scattering

DIS at high x (Approved)

$$\frac{2C_{2u} - C_{2d}}{2C_{1u} - C_{1d}} \sim 0.14$$

0.5% fractional precision on the asymmetry is needed!

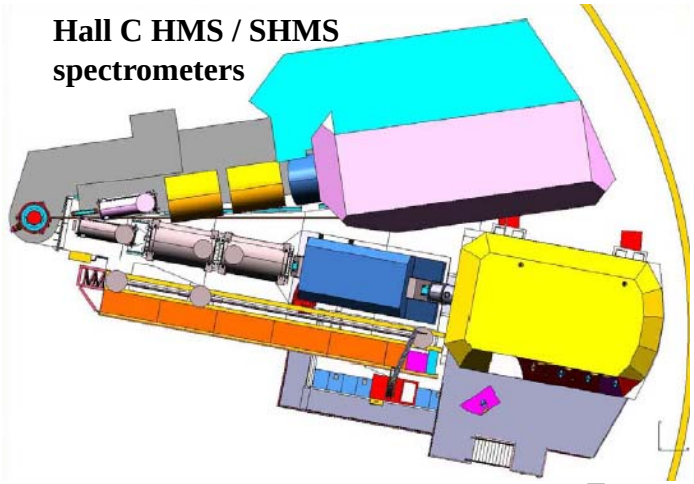
$$\frac{\delta(A_{PV})}{A_{PV}} \sim 0.5\% \qquad \frac{\delta(2C_{2u} - C_{2d})}{(2C_{2u} - C_{2d})} \sim 5\%$$

Feasible (in narrow kinematics) with existing JLab spectrometers.

JLab 11 GeV proposal: Conditional approval

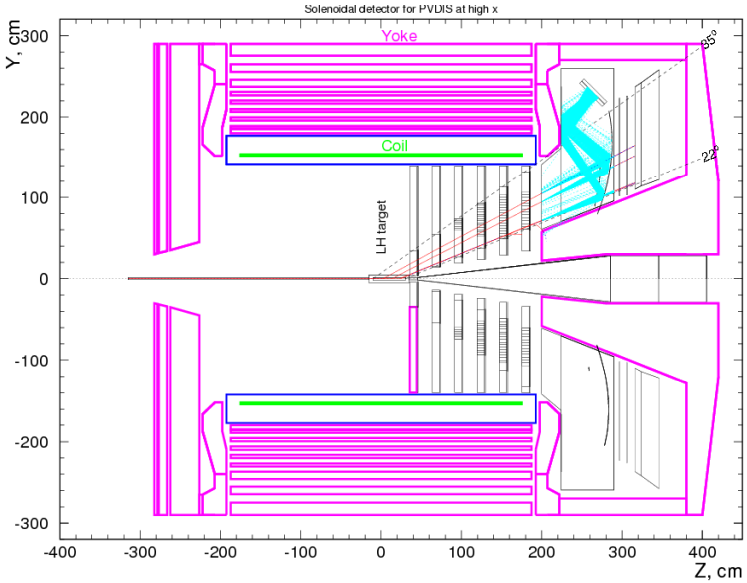
Paschke, Reimer, Zheng et al.

- Experimental systematic errors challenging
- Averaged over large Q^2, W, and x range



PVDIS with SOLID

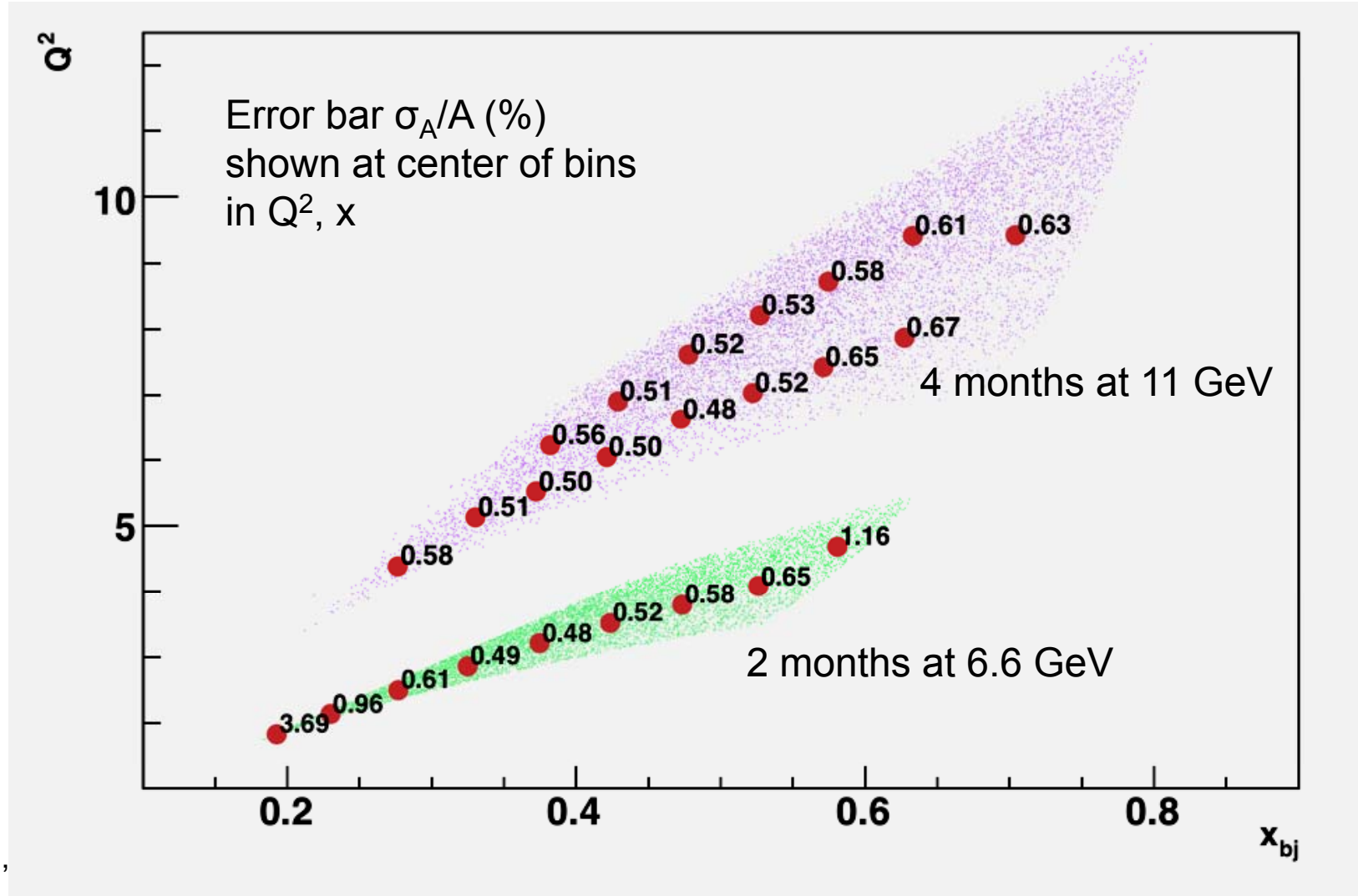
- *Solenoid (from BaBar, CDF or CLEOII) contains low energy backgrounds (Moller, pions, etc) trajectories measured after baffles*
- *Fast tracking, particle ID, calorimetry,*
- *and pipeline electronics*
- *Precision polarimetry (0.4%)*



- ***High Luminosity on LH_2 & LD_2***
- ***Better than 1% errors for small bins***
- ***x-range 0.25-0.75***
- ***W^2 > 4 GeV^2***
- ***Q^2 range a factor of 2 for each***
- ***Moderate running times***

Statistical Errors (%) vs Kinematics

For SOLID Spectrometer



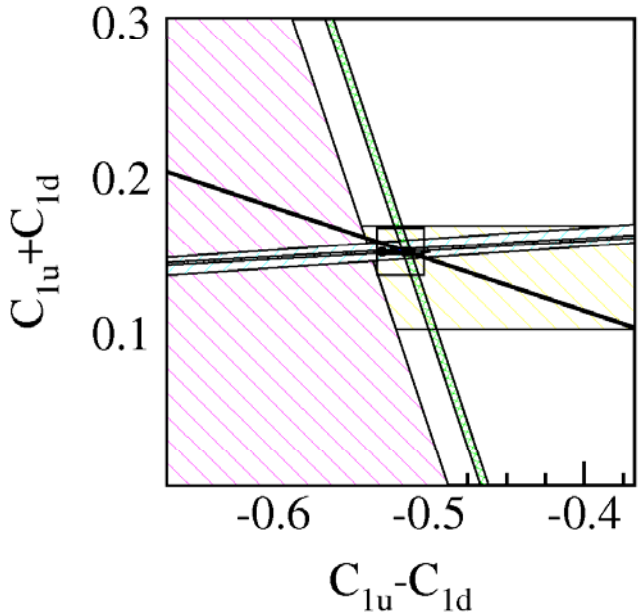
Why do we need so many data points?

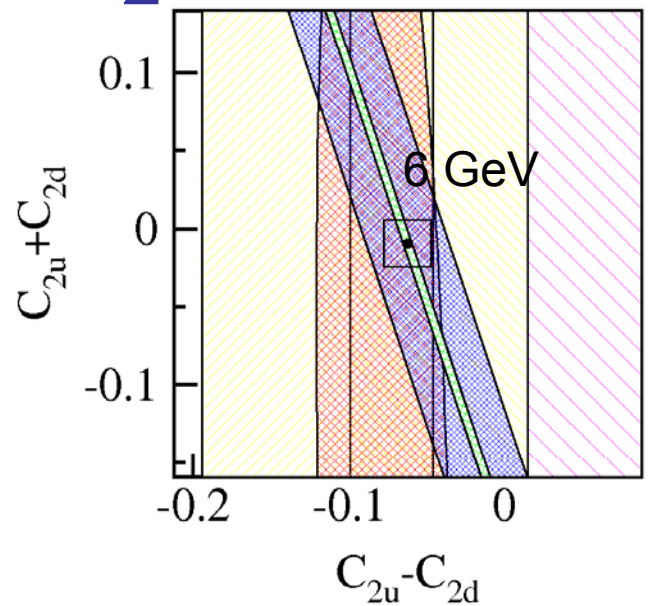
- Possible new physics
  - New interactions
  - Charge symmetry violation (CSV)
  - Higher twist effects

Like neutron beta decay experiments:
many diverse physics topics

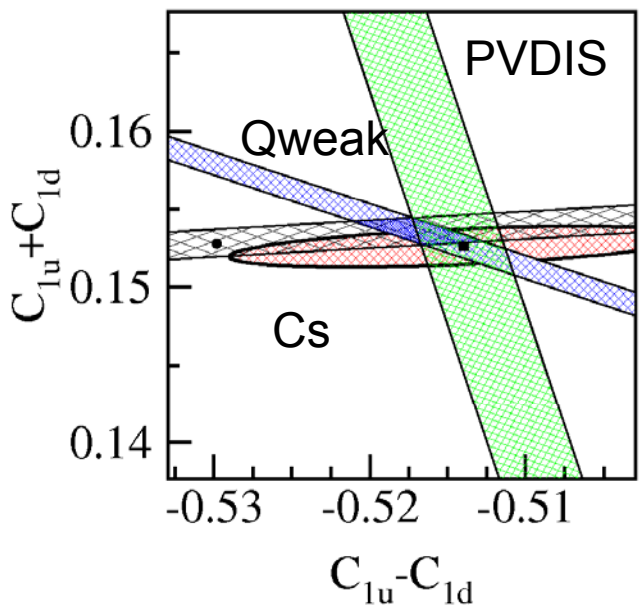
Sensitivity: C_1 and C_2 Plots

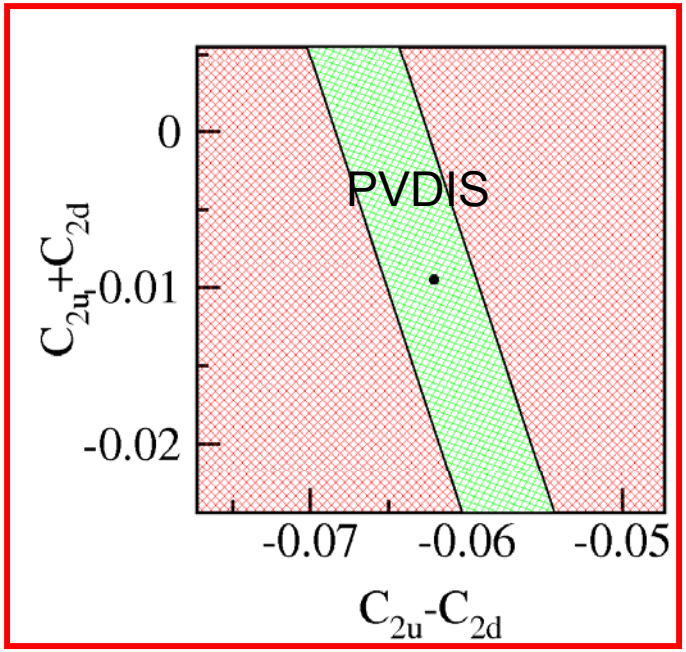
World's data





Precision Data





Search for CSV in PV DIS

$u^p(x) = d^n(x)?$

$d^p(x) = u^n(x)?$

- u-d mass difference
- electromagnetic effects

$\delta u(x) = u^p(x) - d^n(x)$

$\delta d(x) = d^p(x) - u^n(x)$

- *Direct observation of parton-level CSV would be very exciting!*
- *Important implications for high energy collider pdfs*
- *Could explain significant portion of the NuTeV anomaly*

For A_{PV} in electron-^{2}H DIS:

$$\frac{\delta A_{PV}}{A_{PV}} = 0.28 \frac{\delta u - \delta d}{u + d}$$

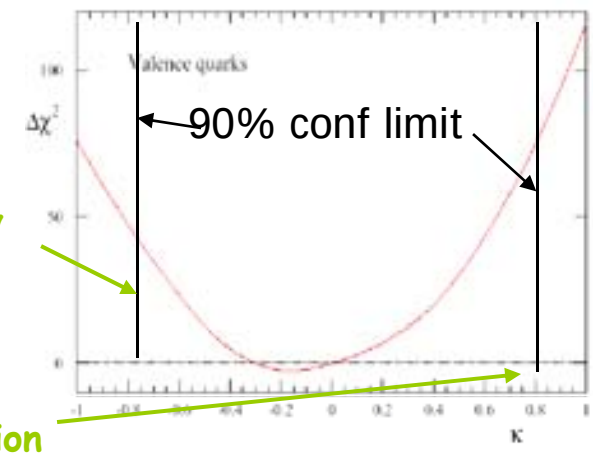
Sensitivity will be further enhanced if u+d falls off more rapidly than δu-δd as $x \to 1$

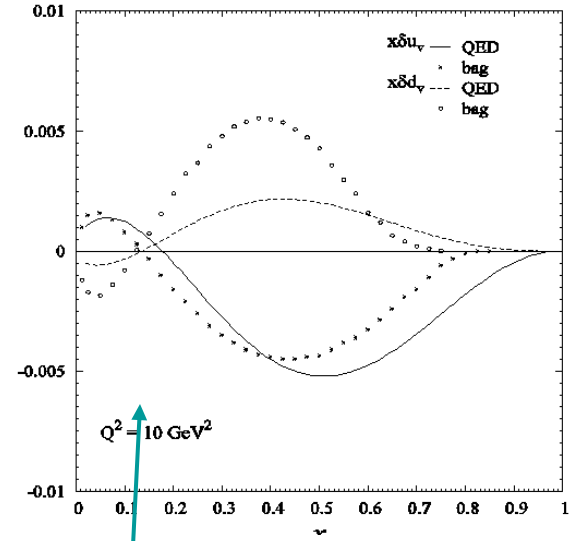
CSV Theory and Data

Broad minimum
(90% C.L.)

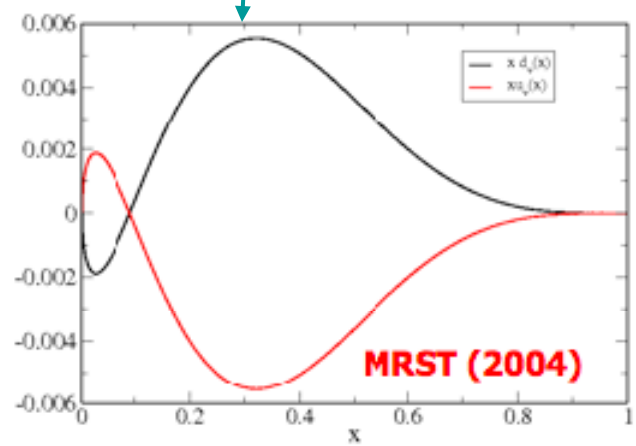
fully explains NuTeV

doubles NuTeV deviation





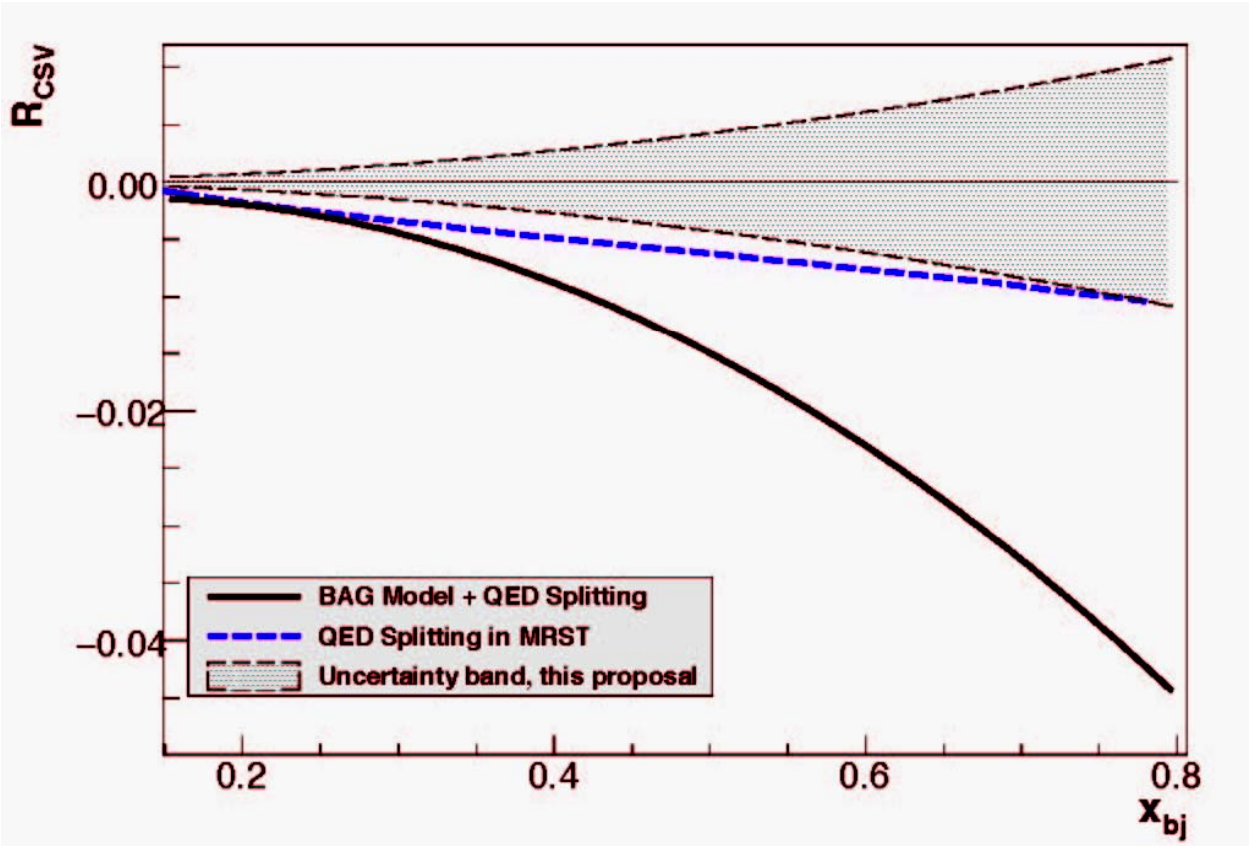
Analytic calculation
similar to global fit



MRST PDF global with fit of CSV

Martin, Roberts, Stirling, Thorne [Eur Phys J C**35**, 325 (04)]:

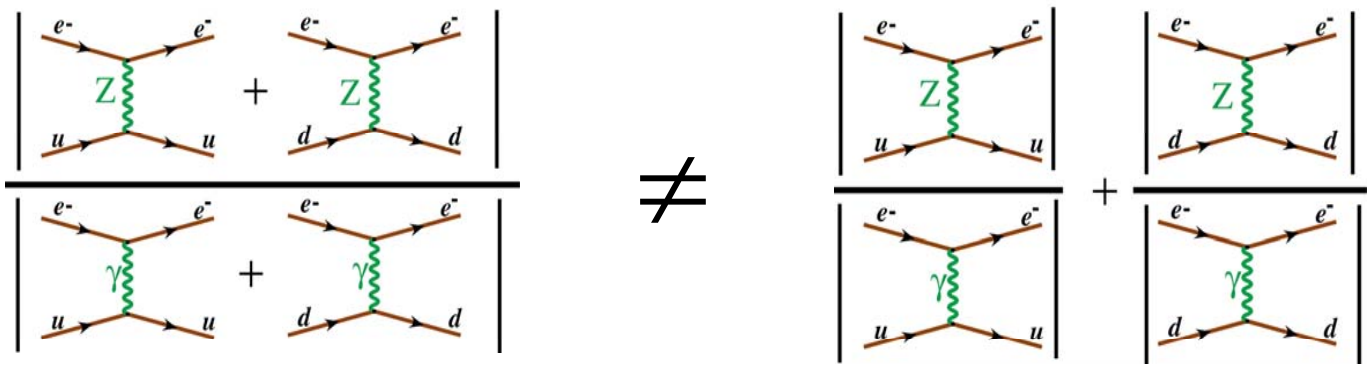
Sensitivity with PVDIS



$$R_{CSV} = \frac{\delta A_{PV}(x)}{A_{PV}(x)} = 0.28\,\frac{\delta u(x) - \delta d(x)}{u(x) + d(x)}$$

Higher Twist

Subject of recent workshop at Madison, Wisconsin



- A_{PV} sensitive to diquarks: ratio of weak to electromagnetic charge depends on amount of coherence (elastic He vs PVDIS)
- Do diquarks have twice the x of single quarks?
- If Spin 0 diquarks dominate, likely only $1/Q^4$ effects

Need Full Phenomenology

$$\left[\frac{d^2\sigma}{dxdy}\right]_{EM} \propto 2xyF_1^{\gamma} + \frac{2}{y}(1-y-\frac{xyM}{2E})F_2^{\gamma}$$

$$F_1^{\gamma} = F_2^{\gamma}(1+R) \rightarrow R = \frac{\sigma_L}{\sigma_T}$$

$$\left[\frac{d^2\sigma}{dxdy}\right]_{\gamma Z}^{V} \propto \frac{G}{2\sqrt{2\pi\alpha}}[-g_A\{2xyF_1^{\gamma Z} + \frac{2}{y}(1-y-\frac{xyM}{2E})F_2^{\gamma Z}\}]$$

$$\left[\frac{d^2\sigma}{dxdy}\right]_{\gamma Z}^{A} \propto \frac{G}{2\sqrt{2\pi\alpha}}[-g_V x(2-y)F_3^{\gamma Z}]$$

There are 5 relevant structure functions

$$A_B^{PV} = \frac{\sigma_{\gamma Z}^{V} + \sigma_{\gamma Z}^{A}}{\sigma_{EM}}$$

$$a(x) = \frac{\sigma_{\gamma Z}^{V}}{\sigma_{EM}}$$

BIG

$$f(y)b(x) = \frac{\sigma_{\gamma Z}^{A}}{\sigma_{EM}}$$

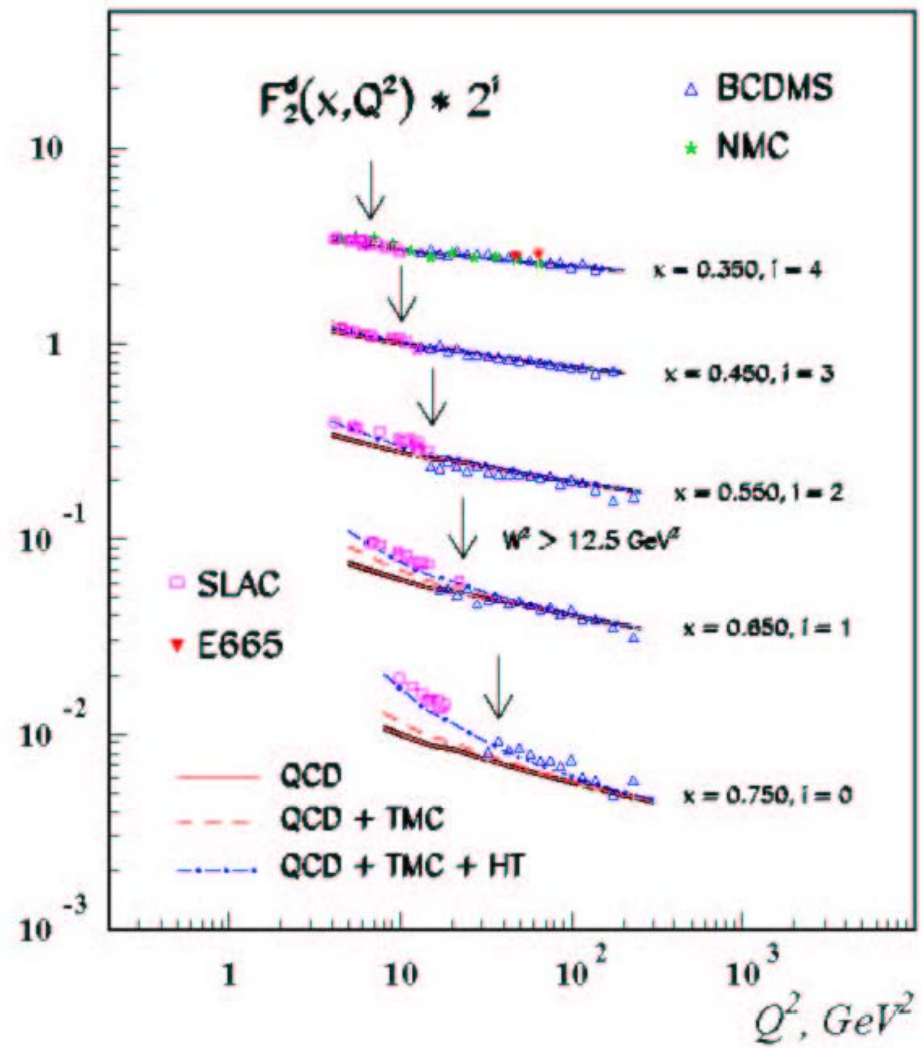
Small; use ν data (Higher twist workshop at Madison, Wisconsin)

Best HT Data

F_2 dominates the cross section

Higher twist is clearly seen at the PVDIS kinematics. What can we add?

Analysis of Blumlein and Botcher



MRST Fits

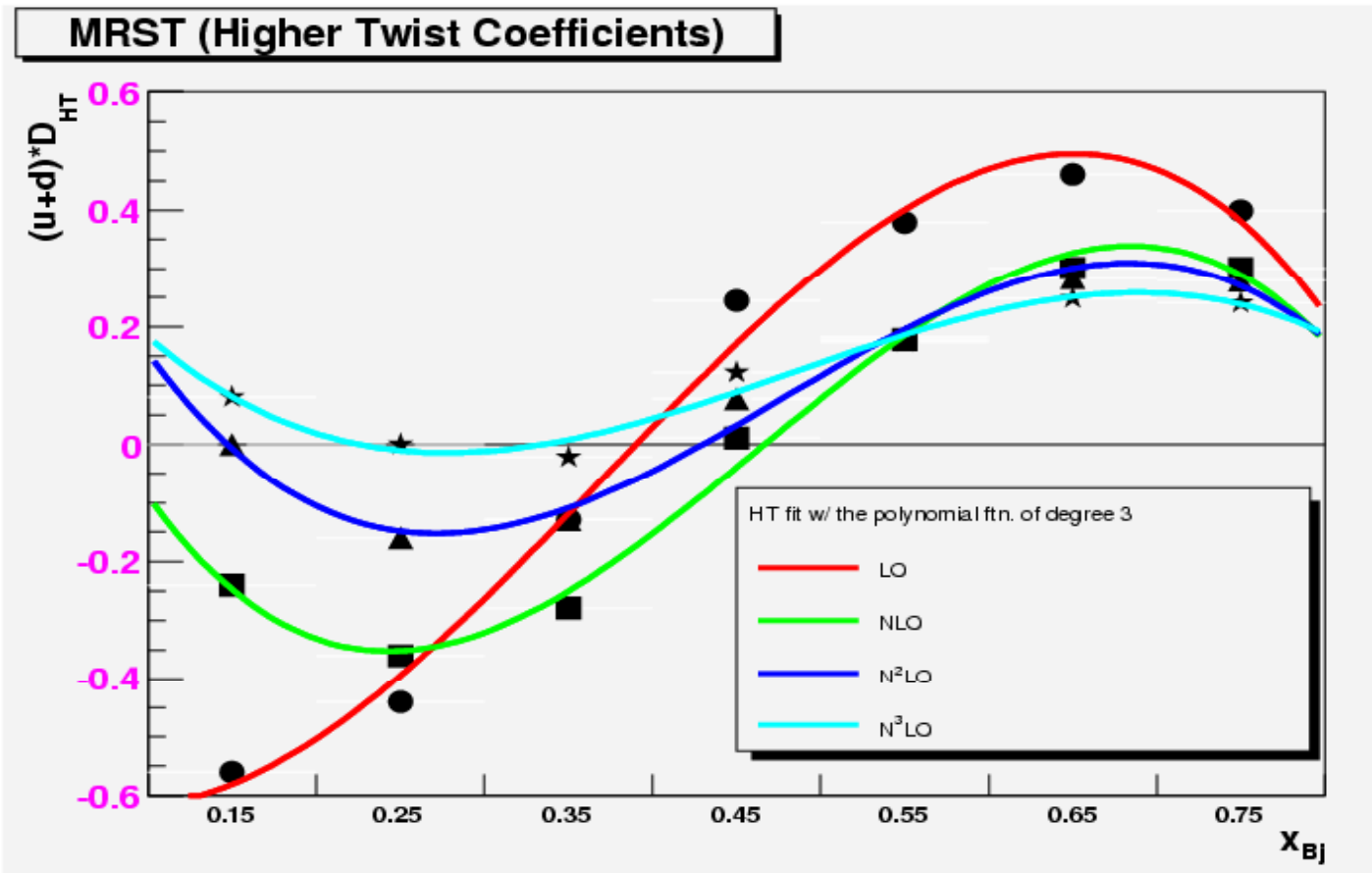
$F_2(x,Q^2)=F_2(x)(1+D(x)/Q^2)$ $Q^2=(W^2-M^2)/(1/x-1)$ $Q^2_{min}=Q^2(W=2)$

MRST, PLB582, 222 (04)

x	D(x)	D(x)	Q^2_{min}	D/Q^2_{min}(%)	D/Q^2_{min}(%)
	LO	NNNLO		LO	NNNLO
0.1-0.2	-.007	0.001	0.5	-14	2
0.2-0.3	-.11	0.003	1.0	-11	0.0
0.3-0.4	-.06	-0.001	1.7	-3.5	-0.5
0.4-0.5	.22	0.11	2.6	8	4
0.5-0.6	.85	0.39	3.8	22	10
0.6-0.7	2.6	1.4	5.8	45	24
0.7-0.8	7.3	4.4	9.4	78	47

$A_{PV}=A_{PV}(1+C(x)/Q^2)$

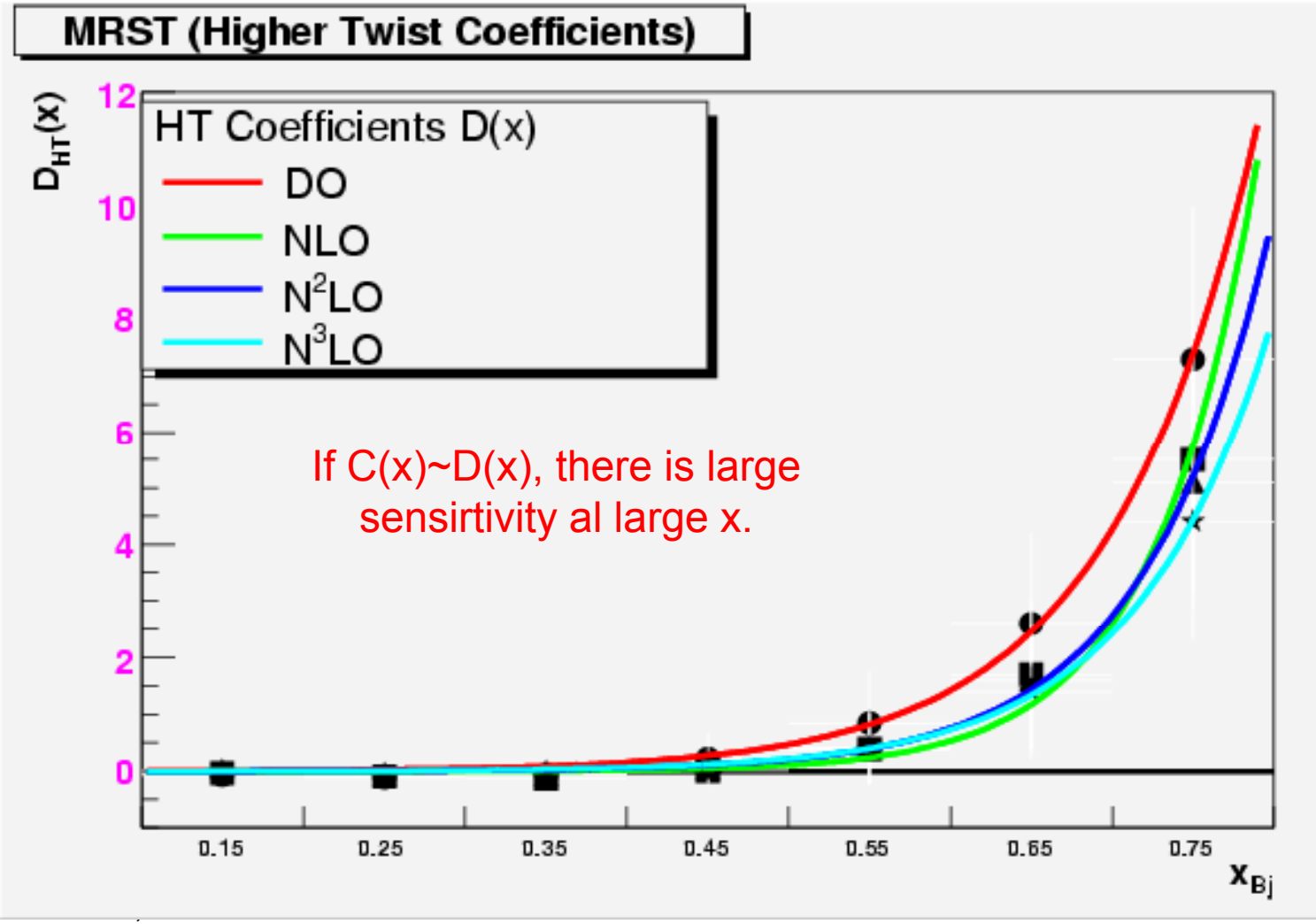
$F_2D(x)$: All x on Same Scale



Order of DGLAP influences size of HT

Higher twist falls slowly compared to PDF's at large x.

D(x) versus x


MRST (Higher Twist Coefficients)
HT Coefficients D(x)
DO
NLO
N2LO
N3LO
If C(x)~D(x), there is large sensirtivity al large x.
DHT(x)
12
10
8
6
4
2
0
0.15
0.25
0.35
0.45
0.55
0.65
0.75
xBj

Why HT in PVDIS is Special

Bjorken,
PRD 18, 3239 (78)

Wolfenstein,
NPB146, 477 (78)

$$A \propto \frac{l_{\mu\nu}\int \langle D \,|\, j^{\mu}(x) J^{\nu}(0) + J^{\mu}(x) j^{\nu}(0) \,|\, D \rangle e^{iq\cdot x} d^4x}{l_{\mu\nu}\int \langle D \,|\, j^{\mu}(x) j^{\nu}(0) \,|\, D \rangle e^{iq\cdot x} d^4}$$

$$V_{\mu} = \left(\bar{u}\gamma_{\mu}u - \bar{d}\gamma_{\mu}d\right) \Leftrightarrow S_{\mu} = \left(\bar{u}\gamma_{\mu}u + \bar{d}\gamma_{\mu}d\right)$$

$$\langle VV \rangle = l_{\mu\nu}\int \langle D \,|\, V^{\mu}(x) V^{\nu}(0) \,|\, D \rangle e^{iq\cdot x} d^4x$$

Isospin decomposition
before using PDF's

$$A = \frac{(C_{1u} - C_{1d})\langle VV \rangle + \frac{1}{3}(C_{1u} + C_{1d})\langle SS \rangle}{\langle VV \rangle + \frac{1}{3}\langle SS \rangle}$$

Zero in QPM

$$\langle VV \rangle - \langle SS \rangle = \langle (V - S)(V + S) \rangle \propto \boxed{l_{\mu\nu}\int \langle D \,|\, \bar{u}(x)\gamma^{\mu}u(x)\bar{d}(0)\gamma^{\nu}d(0) \rangle e^{iq\cdot x} d^4x}$$

HT in F_2 may be dominated
by quark-gluon correlations

Higher-Twist valance
quark-quark correlations

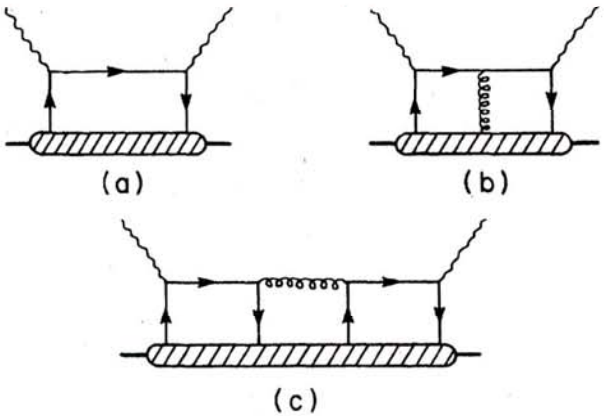
Vector-hadronic piece only

Use v data for small b(x) term.

Quark-Quark vs Quark-Gluon

Parton Model
or
leading twist

Quark-gluon
diagram



Di-quarks

What is a true
quark-gluon
operator?

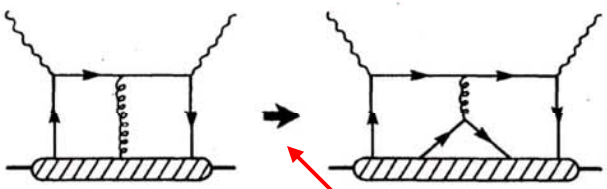


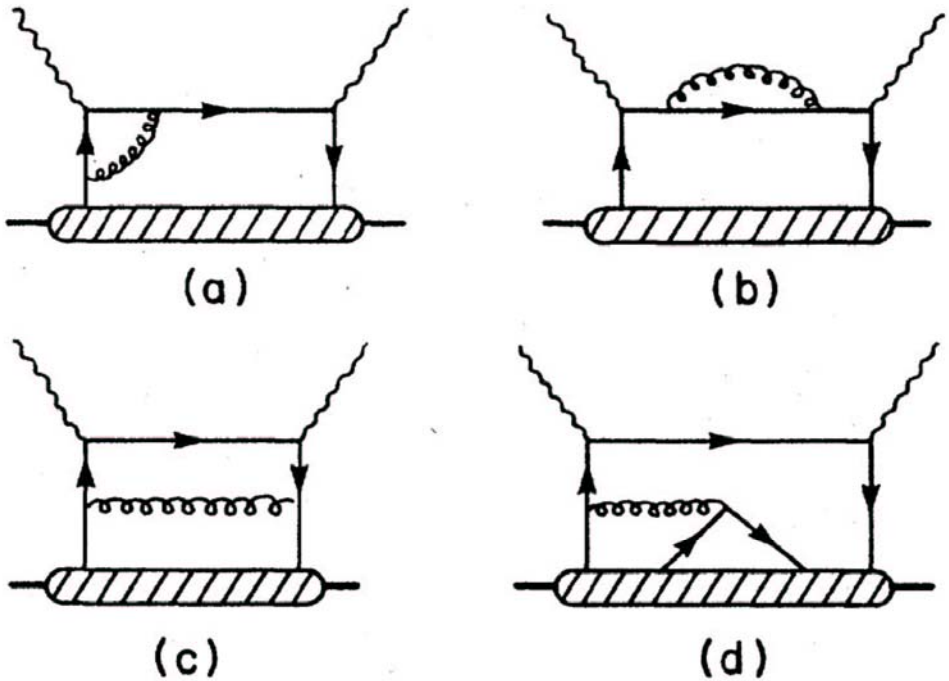
FIG. 3. The only gluon operator that we keep is the operator O^9, which can be expressed as a four-quark operator using the equations of motion.

Quark-gluon operators
correspond to
transverse momentum

QCD equations
of motion

Test Questions

1. Which diagram is HT?
2. Is the HT diagram qq or qg?



DGLAP Evolution

Diagrams (a)-(c) cancel in A_{PV}

Coherent Program of PVDIS Study

Strategy: requires precise kinematics and broad range

Fit data to: $$A = A\left[1 + \beta_{HT}\frac{1}{(1-x)^3 Q^2} + \beta_{CSV} x^2\right]$$

$C(x)=\beta_{HT}/(1-x)^3$

- Measure A_D in NARROW bins of x, Q^2 with 0.5% precision
- Cover broad Q^2 range for x in [0.3,0.6] to constrain HT
- Search for CSV with x dependence of A_D at high x
- Use x>0.4, high Q^2, and to measure a combination of the C_{iq}'s

	x	y	Q^2
New Physics	no	yes	no
CSV	yes	no	no
Higher Twist	yes	no	yes

Other Targets

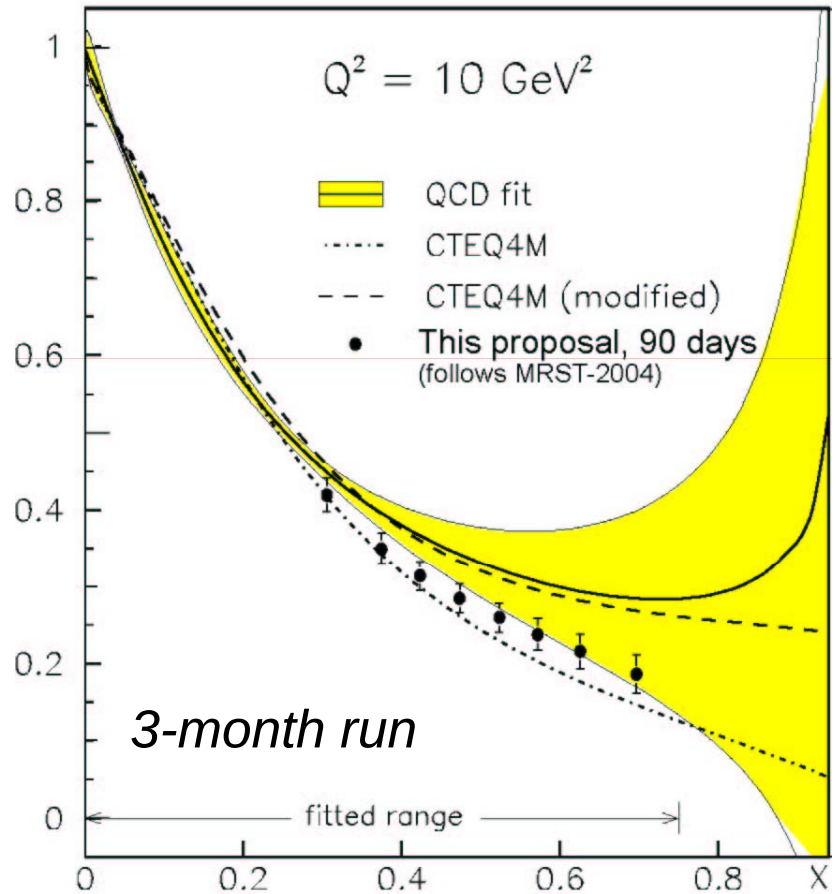
- Hydrogen: d/u
- EMC effect
- N≠Z nuclei

PVDIS on the Proton: d/u at High x

$$a^P(x) \approx \frac{u(x) + 0.91d(x)}{u(x) + 0.25d(x)}$$

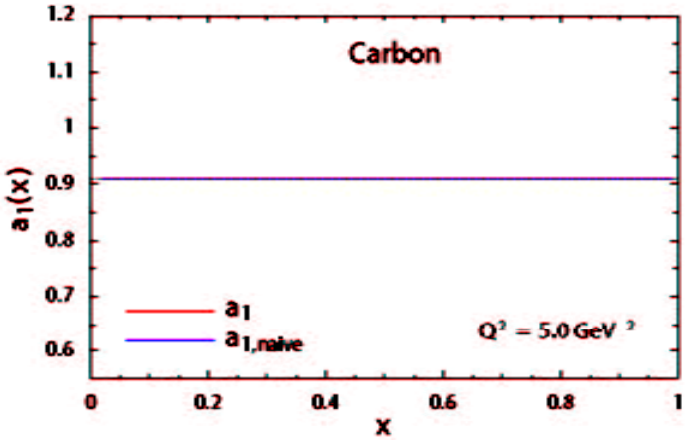
Deuteron analysis has large nuclear corrections (Yellow)

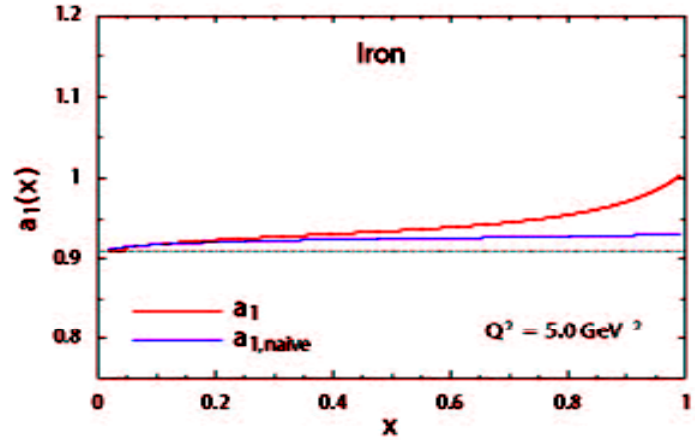
A_{PV} for the proton has no such corrections (complementary to BONUS)



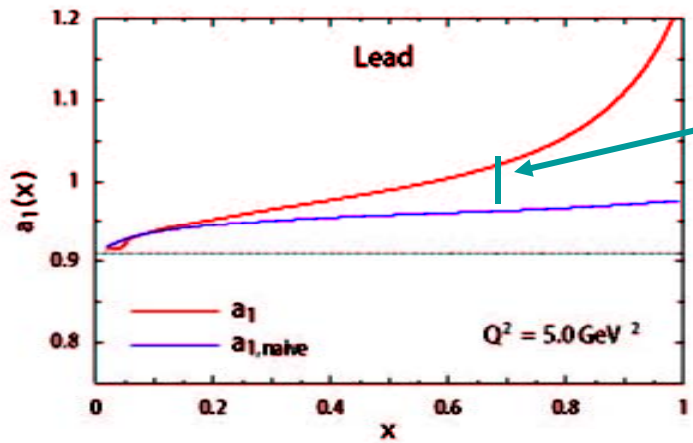
The challenge is to get statistical and systematic errors ~ 2%

CSV in Heavy Nuclei: EMC Effect





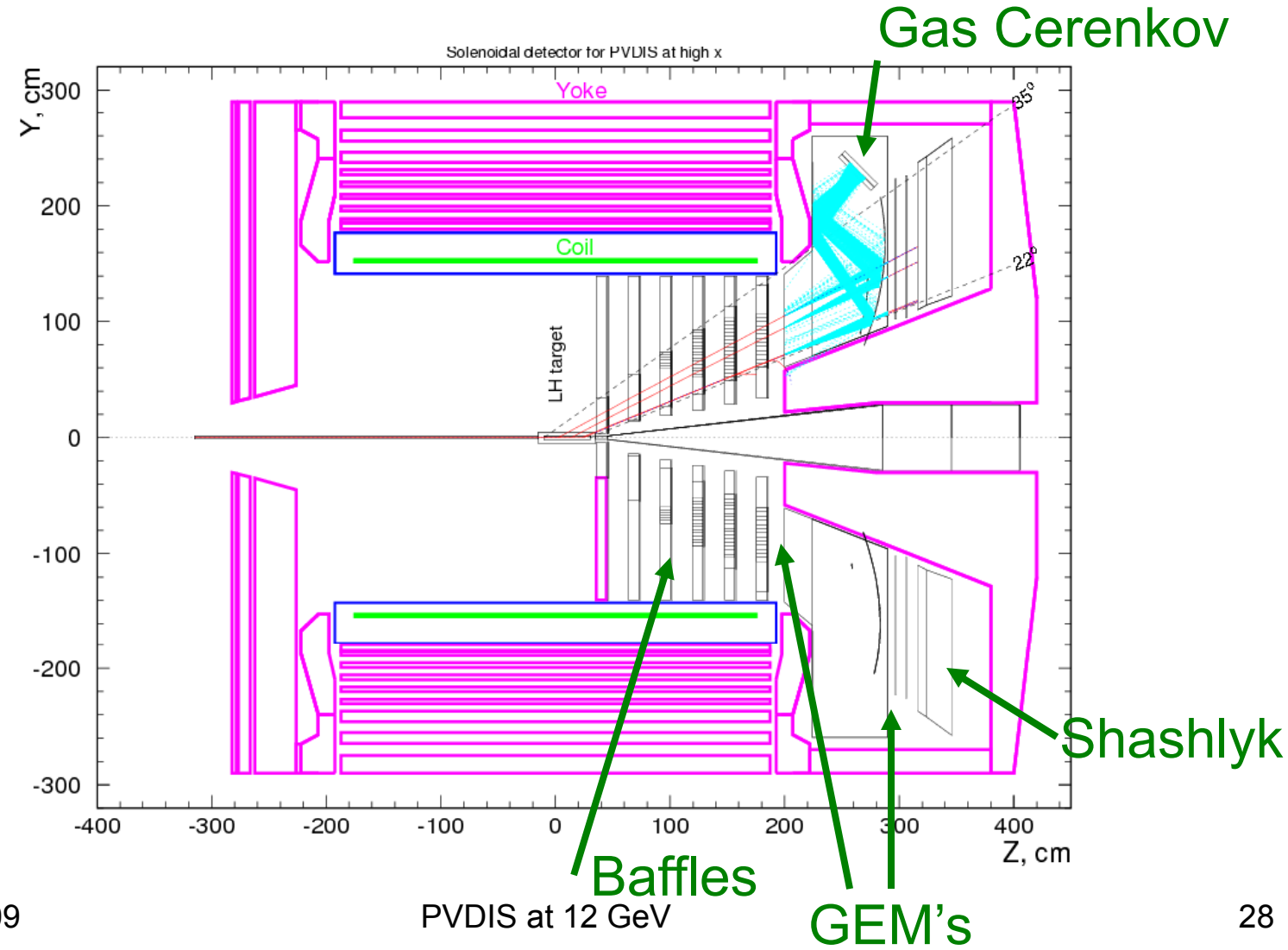
Additional possible application of SoLID



5%

Isovector-vector mean field. (Cloet, Bentz, and Thomas)

SoLID Spectrometer



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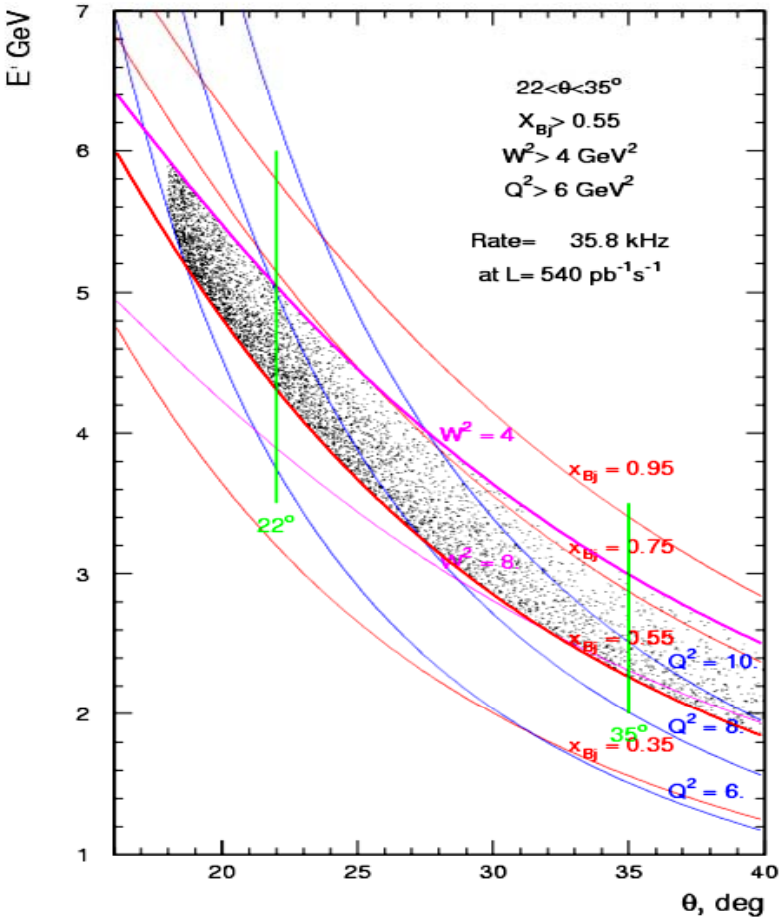
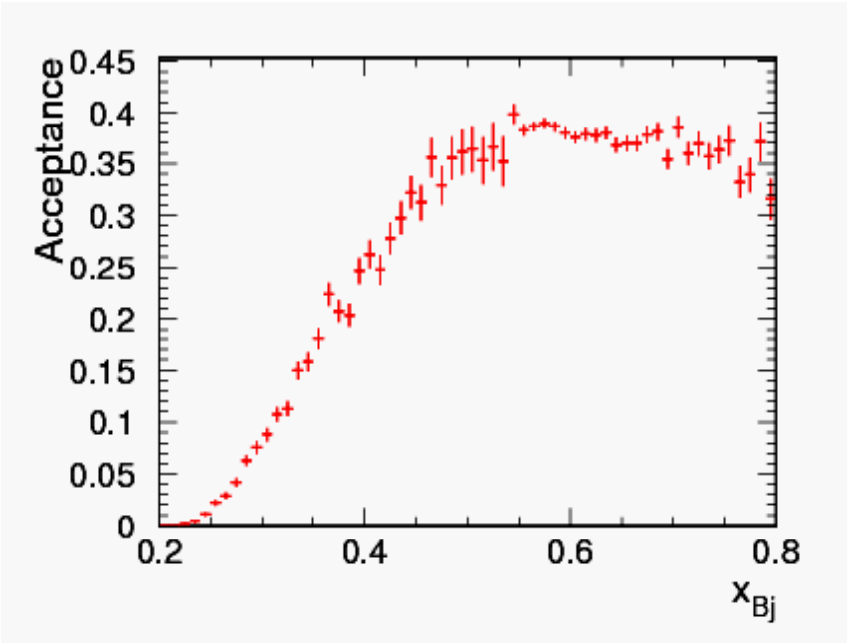
STATUS and PLANS

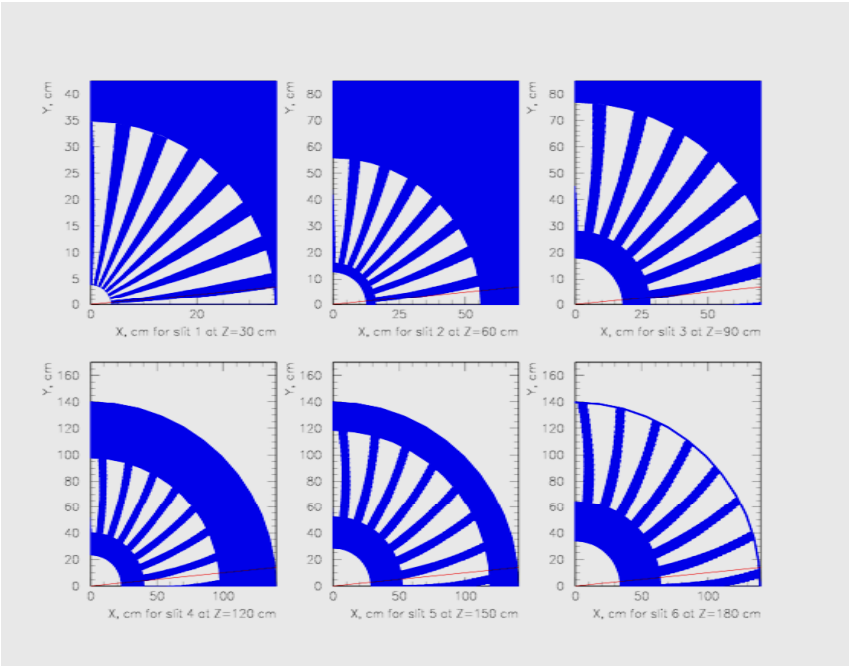
- Jan. 2009: Conditional approval
- Jan. 2010: Seek full approval
- Fall 2010: Director's review
- Spring 2011: Seek CD0

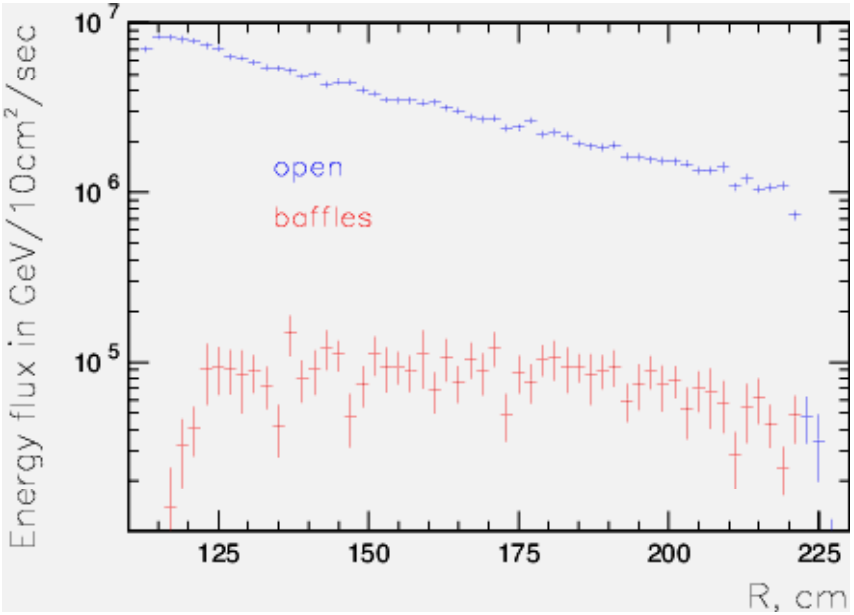
Kinematics at large x





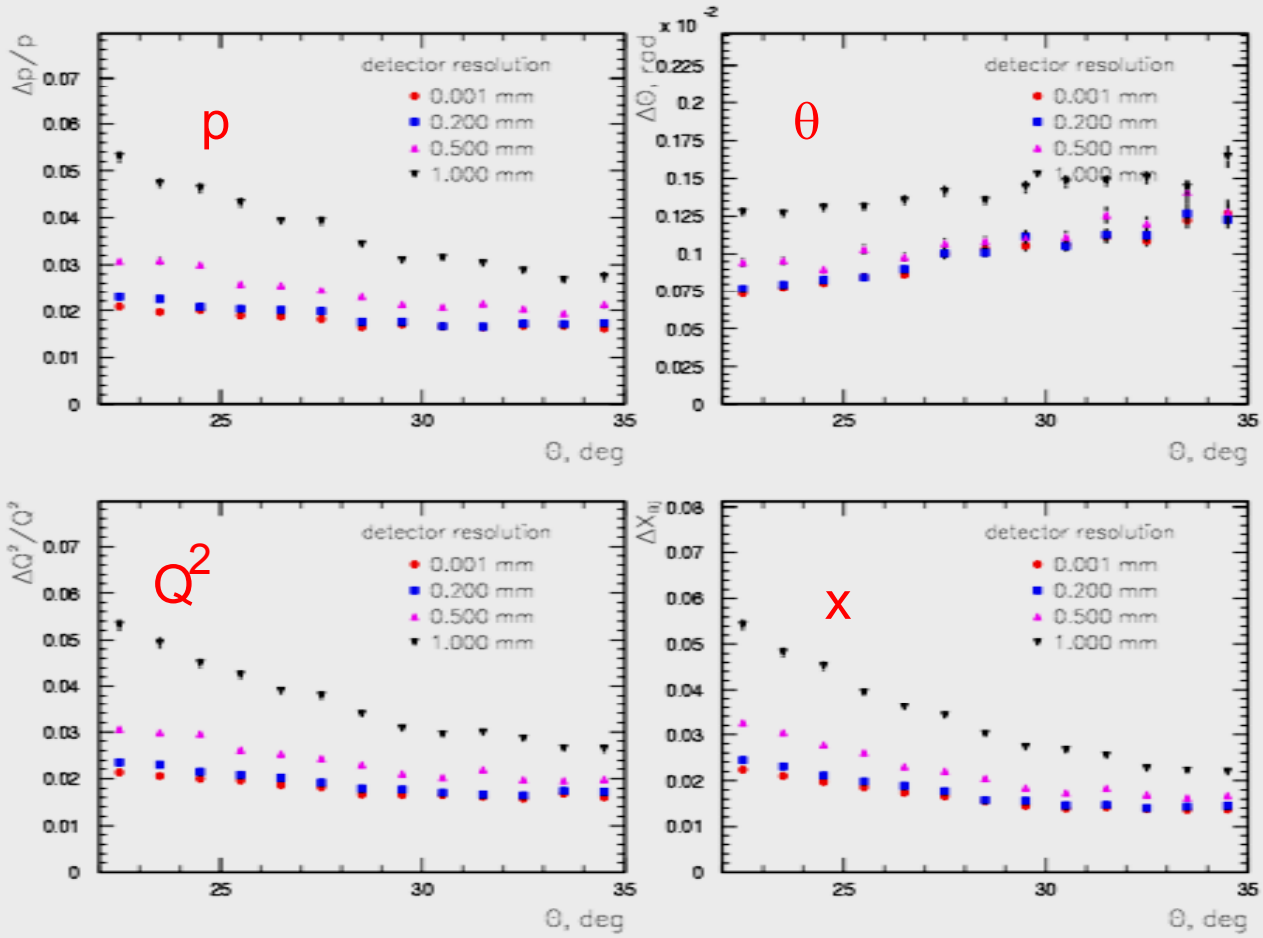
Baffles





Rates in detectors reduced by more than 10

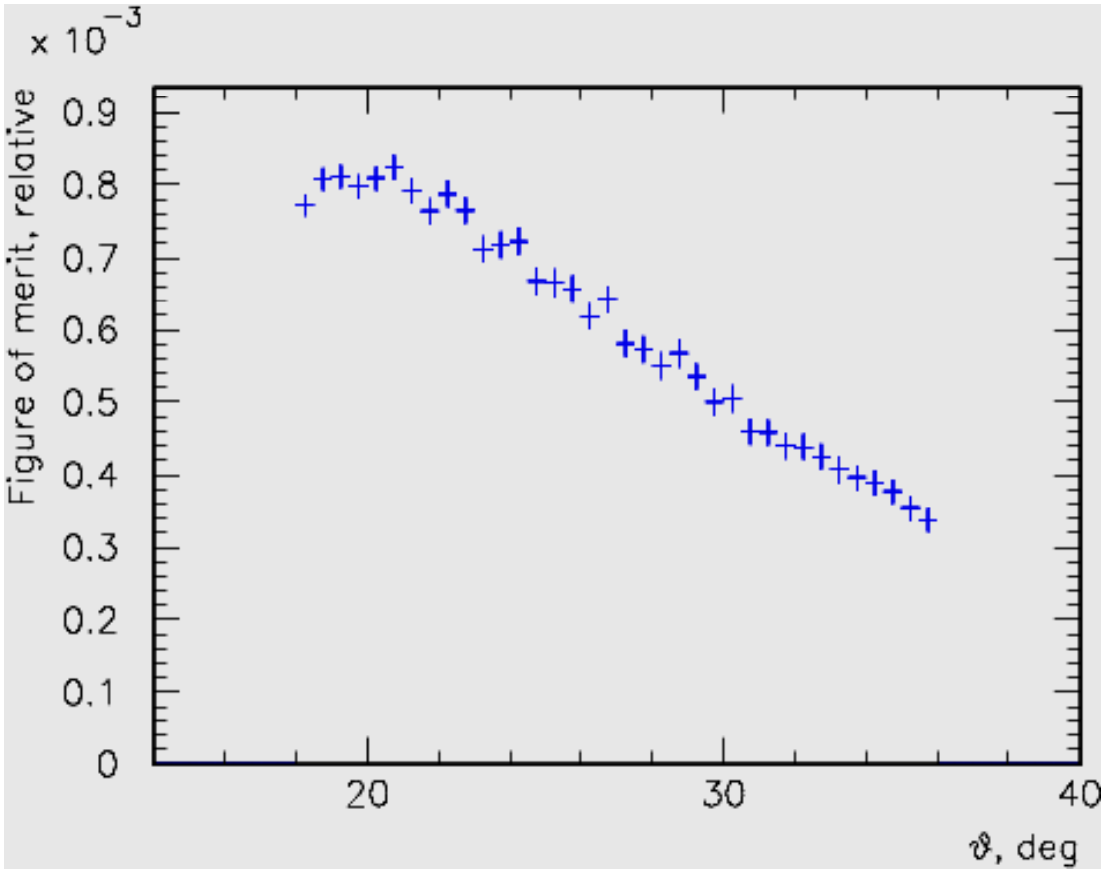
Physics Resolution (%) vs Detector Resolution and Angle



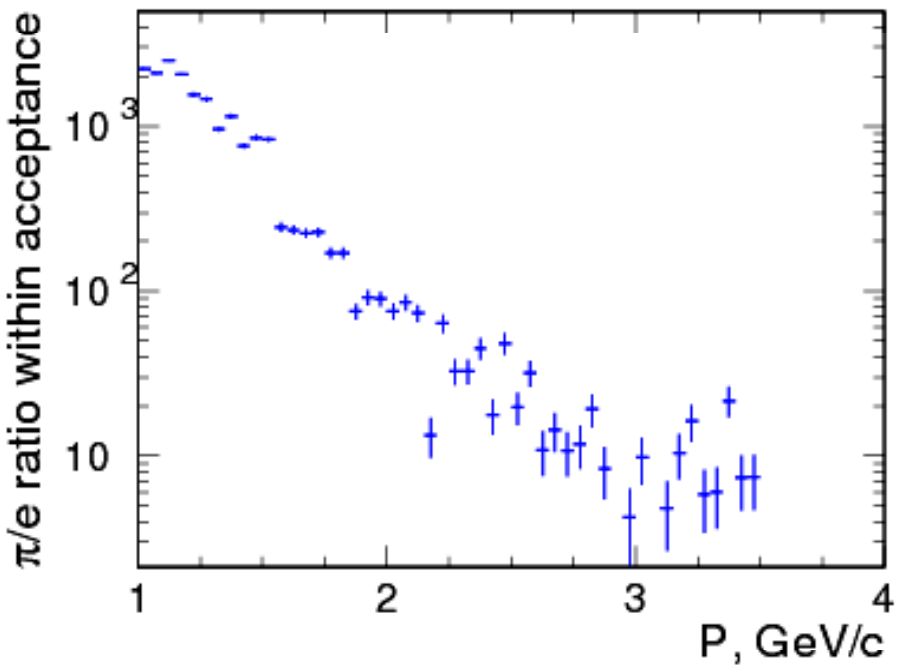
Conclusions

- PVDIS addresses many physics topics
  - Electroweak couplings
  - CSV at the quark level
  - Di-quarks
  - d/u for the proton
  - Nuclear-induced CSV
- SOLID spectrometer can deliver the physics

Figure of Merit vs Scattering Angle

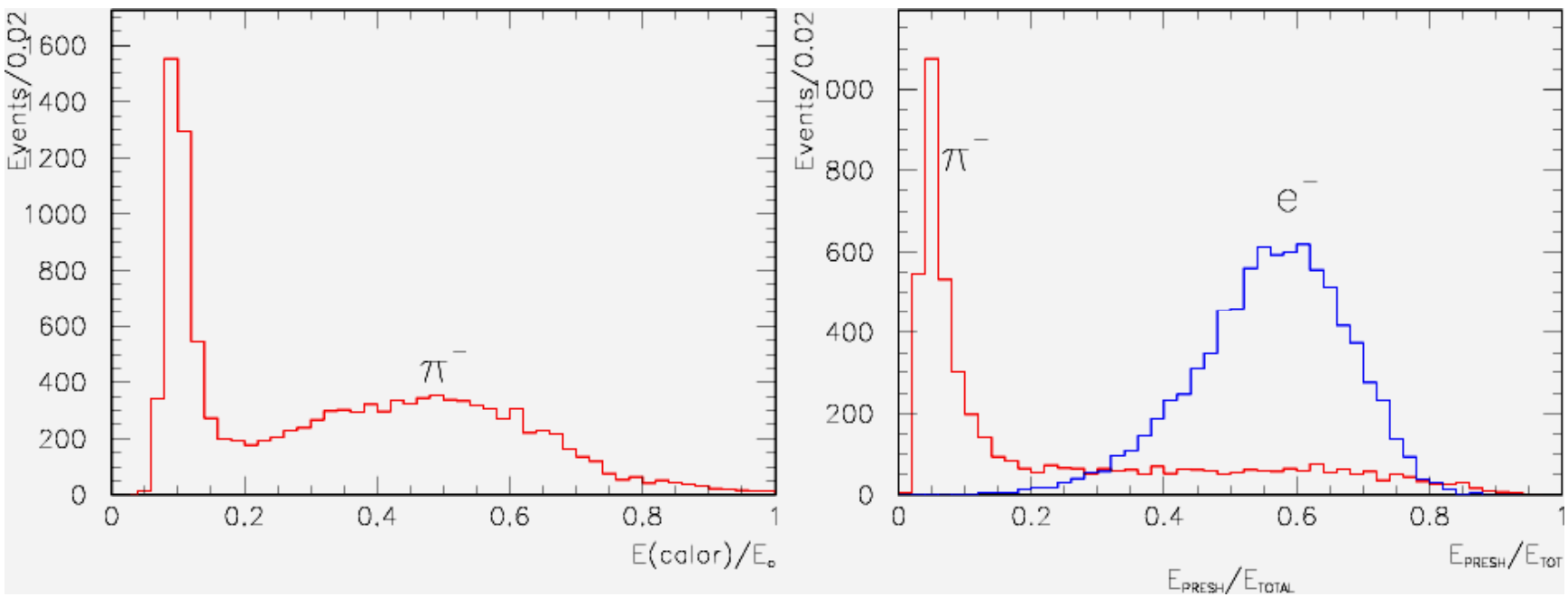


Lots of Pions at Low Energies



Need gas Cerenkov plus shower counter with preradiator

Pion Rejection: Shashlik Detector



Total Pion Signal

$E_{preshower}/E_{total}$