DIS2008, University College London
April 7-11, 2008

"Future Facilities" Summary:
Fixed Target

Wally Melnitchouk
Jefferson Lab

Outline

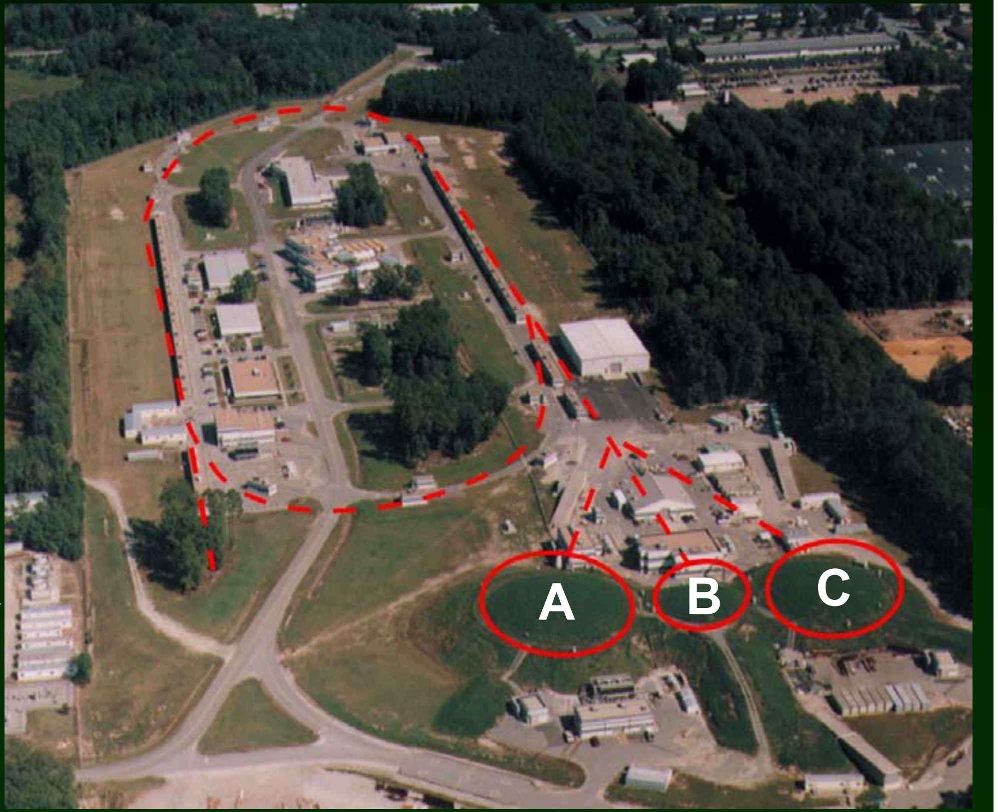
- electron beams: JLab at 12 GeV *Allison Lung*
  - → high luminosity, inclusive → exclusive reactions
  - → large x PDFs *Thia Keppel* , *Paul Souder* , *Ben Pecjak*
  - → SIDIS & TMDs *Peter Bosted* , *Feng Yuan*
  - → generalized parton distributions *Silvia Niccolai* , *Simonetta Liuti*

- neutrino beams: MINERvA, Project X *Heidi Schellman*
  - → high intensity beams
  - → parity-violating structure functions, nuclear dependence
  - → quasi-elastic, resonance production

- antiproton beams: PANDA @ FAIR *Bjoern Seitz*
  - → hydrogen, nuclear targets (polarized?)
  - → TMDs (Drell-Yan), time-like form factors

Jefferson Lab Today

2000 member international user community engaged in exploring quark-gluon structure of matter

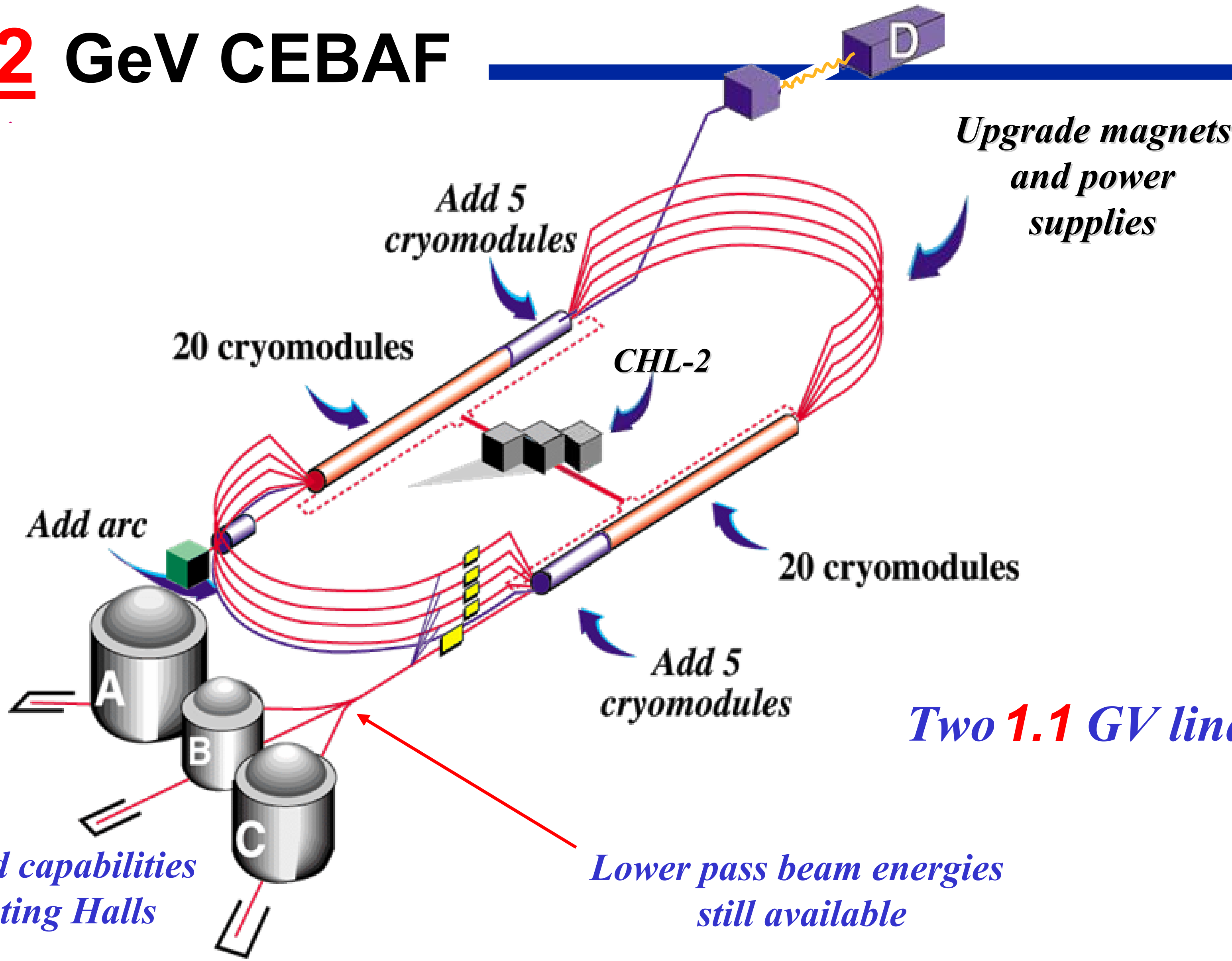


Superconducting accelerator provides 100% duty factor beams of unprecedented quality, with energies up to 6 GeV

CEBAF's innovative design allows delivery of beam with unique properties to three experimental halls simultaneously

Each of the three halls offers complementary experimental capabilities and allows for large equipment installations to extend scientific reach

12 GeV CEBAF



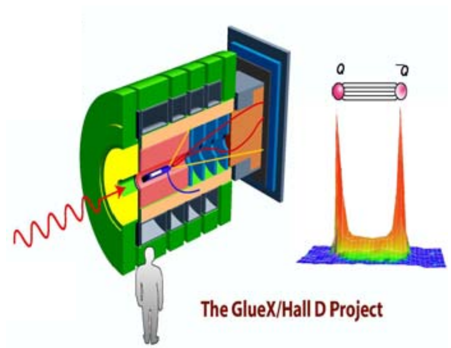
Two **1.1** *GV linacs*

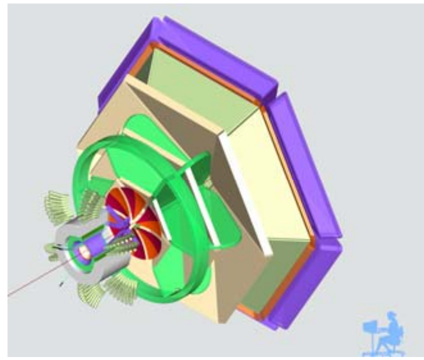
Enhanced capabilities in existing Halls

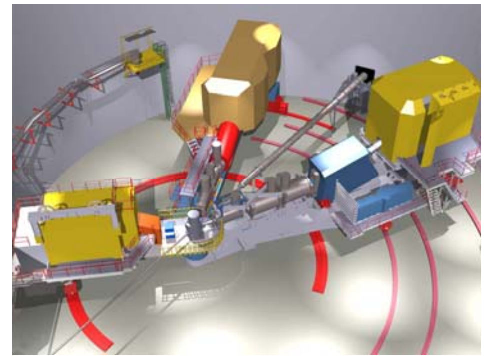
Lower pass beam energies still available

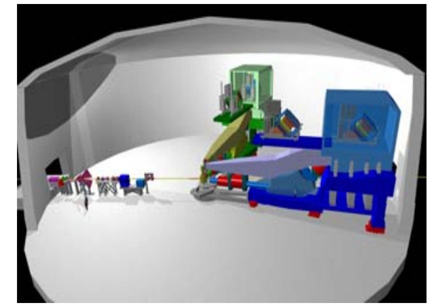
Allison Lung

Overview of Upgrade Technical Performance Requirements









<table>
<tr><th>Hall D</th><th>Hall B</th><th>Hall C</th><th>Hall A</th></tr>
<tr><td>excellent hermeticity</td><td>luminosity 10 x 10^{34}</td><td>energy reach</td><td>installation space</td></tr>
<tr><td>polarized photons</td><td>hermeticity</td><td>precision</td><td></td></tr>
<tr><td>E_γ~8.5–9 GeV</td><td colspan="3">11 GeV beamline</td></tr>
<tr><td>10^8 photons/s</td><td colspan="3">target flexibility</td></tr>
<tr><td colspan="2">good momentum/angle resolution</td><td colspan="2">excellent momentum resolution</td></tr>
<tr><td colspan="2">high multiplicity reconstruction</td><td colspan="2">luminosity up to 10^{38}</td></tr>
<tr><td colspan="4">particle ID</td></tr>
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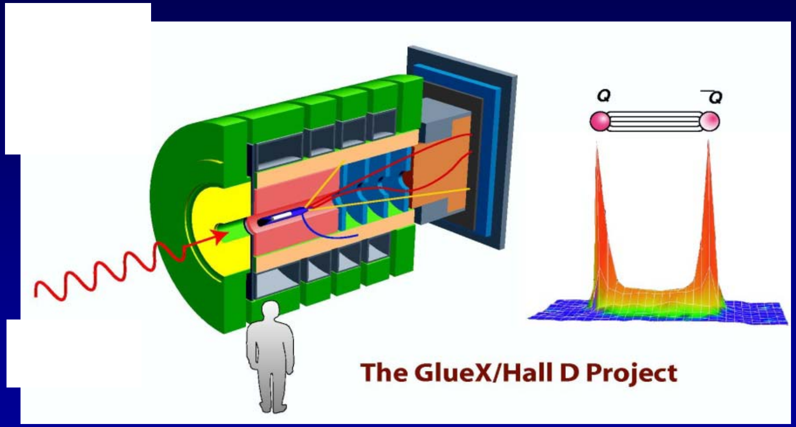
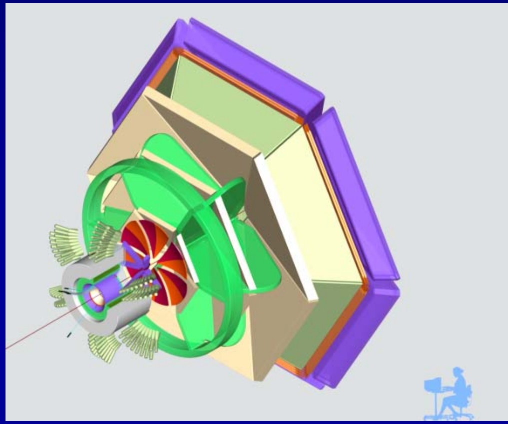
12 GeV Capabilities

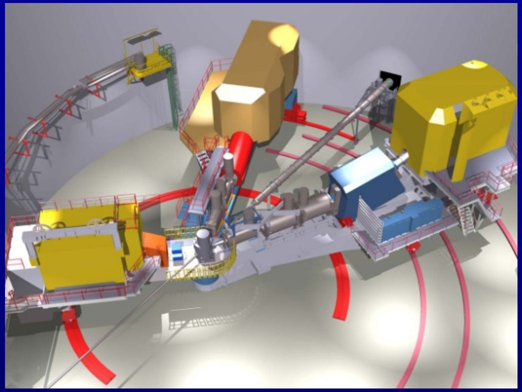
Hall D – exploring origin of confinement by studying exotic mesons

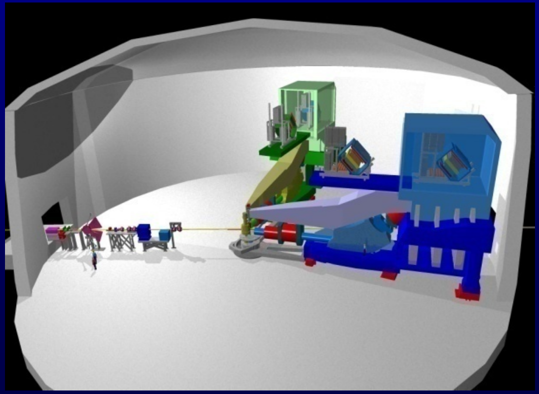




Hall B – understanding nucleon structure via generalized parton distributions

Hall C – precision determination of valence quark properties in nucleons and nuclei





Hall A – short range correlations, form factors, hyper-nuclear physics, future new experiments

Highlights of the 12 GeV Science Program

- New and revolutionary access to the structure of the proton and neutron

⇒ particularly at large x

⇒ PDFs, TMDs, GPDs

- Discovering the quark structure of nuclei

⇒ polarized EMC effect

⇒ EMC effect in deuterium, light nuclei

- High precision tests of the Standard Model

⇒ parity-violating DIS

Thia Keppel

12 GeV Upgrade Provides Substantially Enhanced Access to the DIS Regime

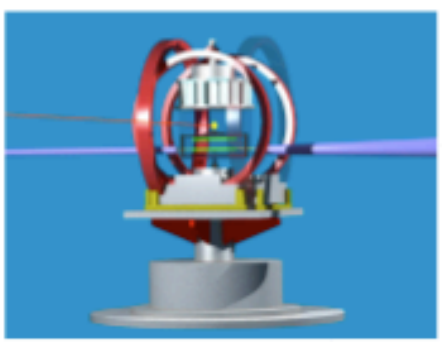
Access to very large x > 0.4

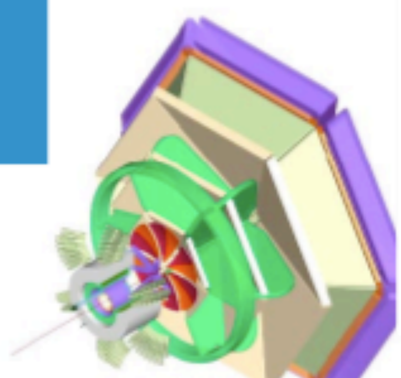
Clean region

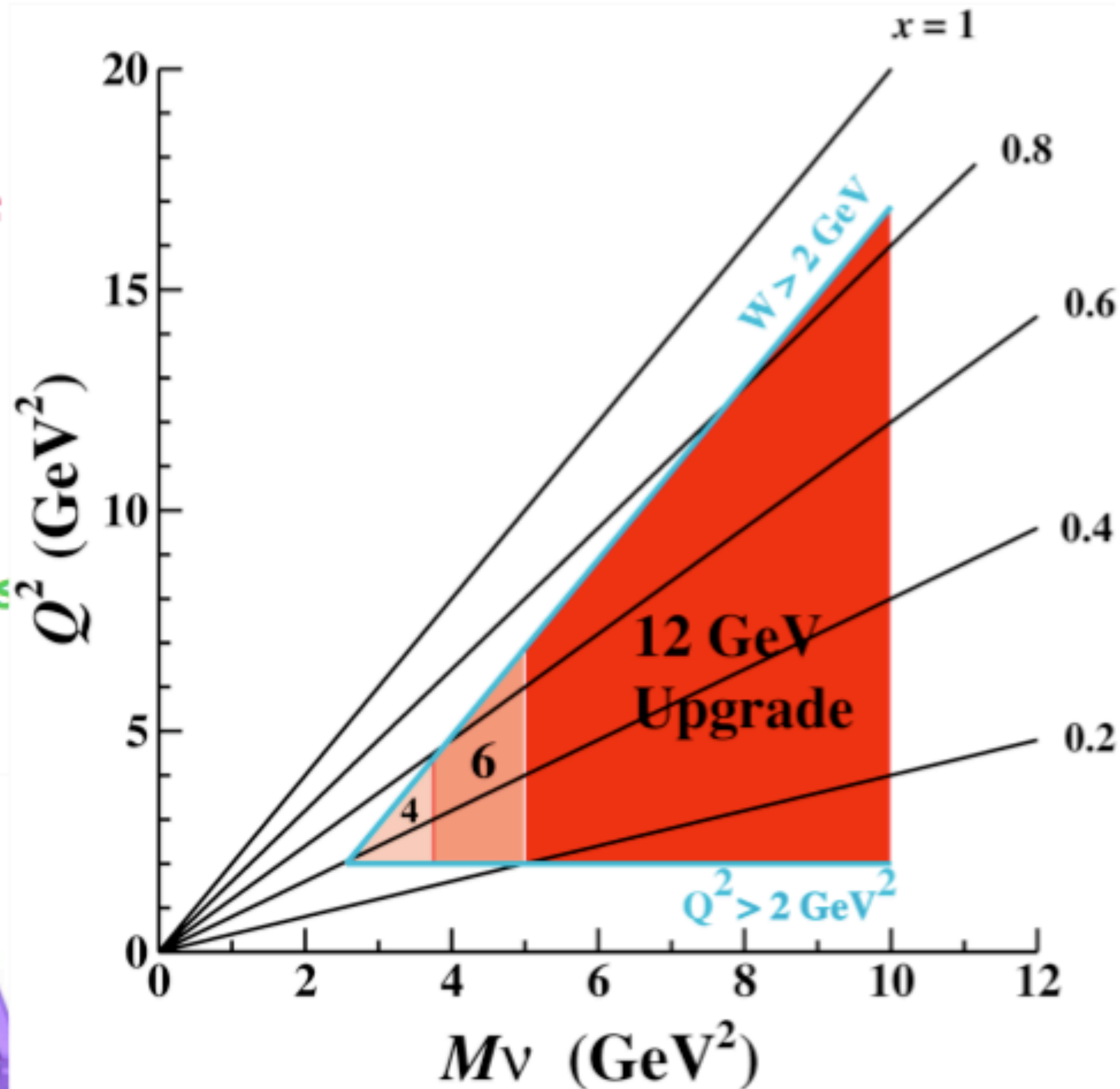
No strange sea effects

No explicit hard gluons to be included

Need also high luminosity, polarized targets, high momentum and large acceptance spectrometers







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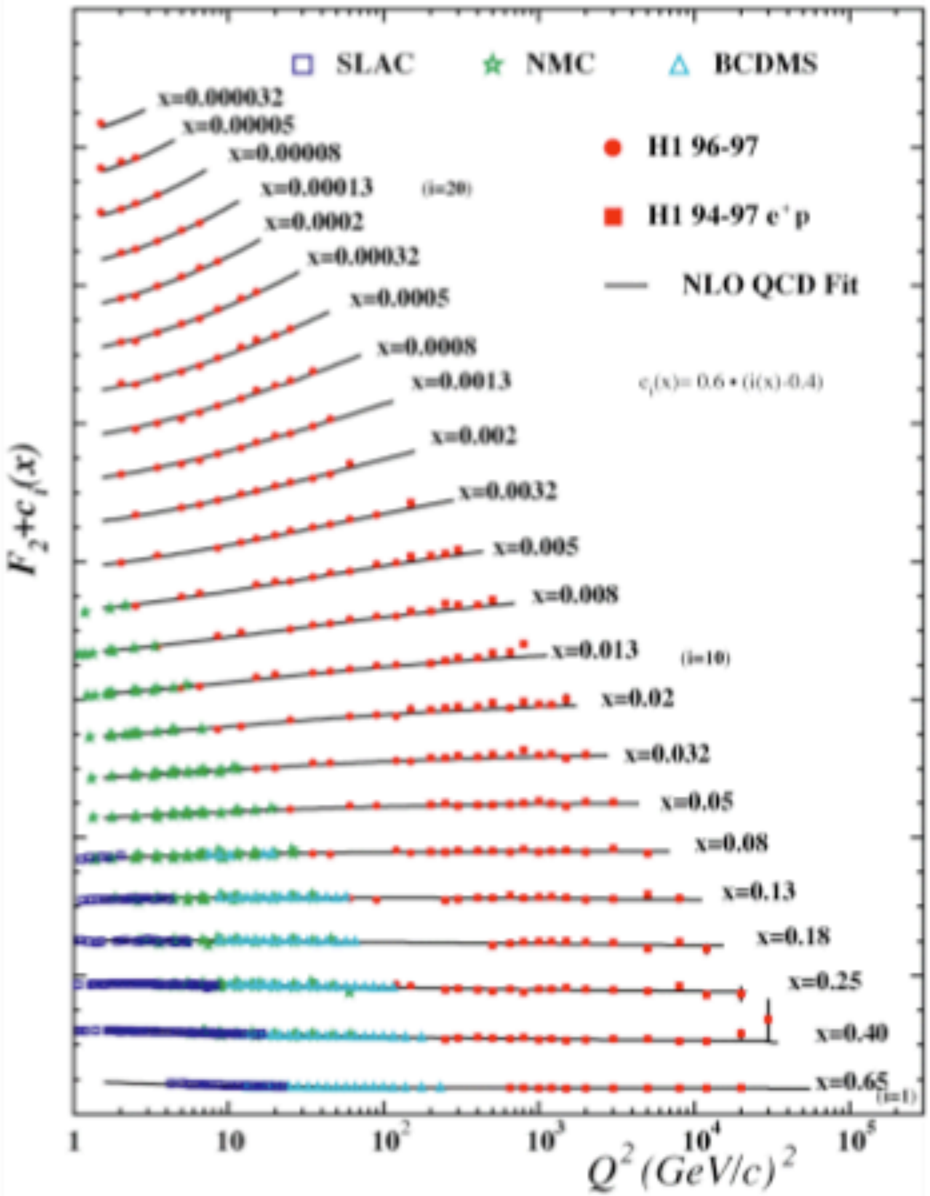
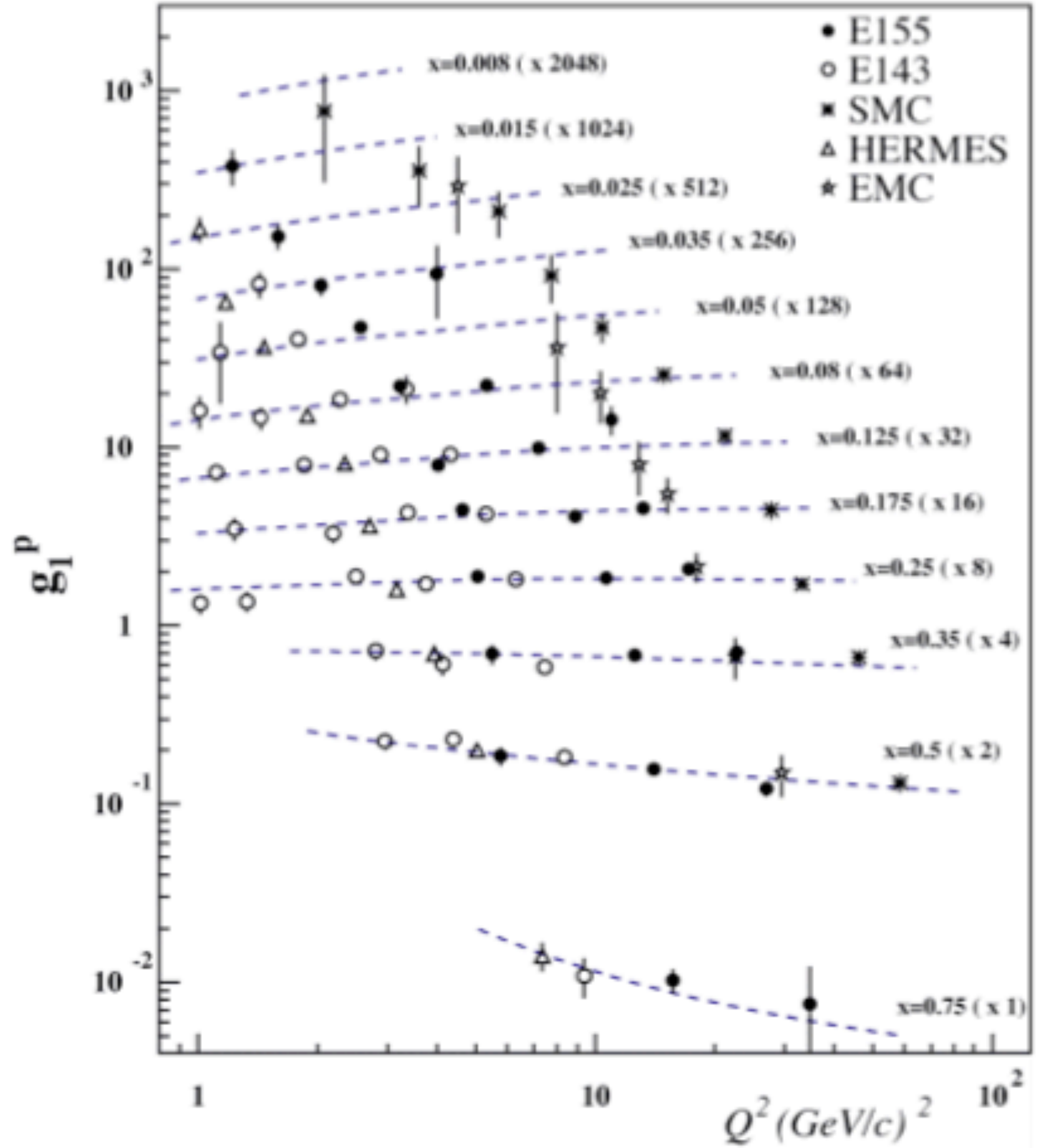
World data on F_2^p



World data on g_1^p



Some things we know pretty well….

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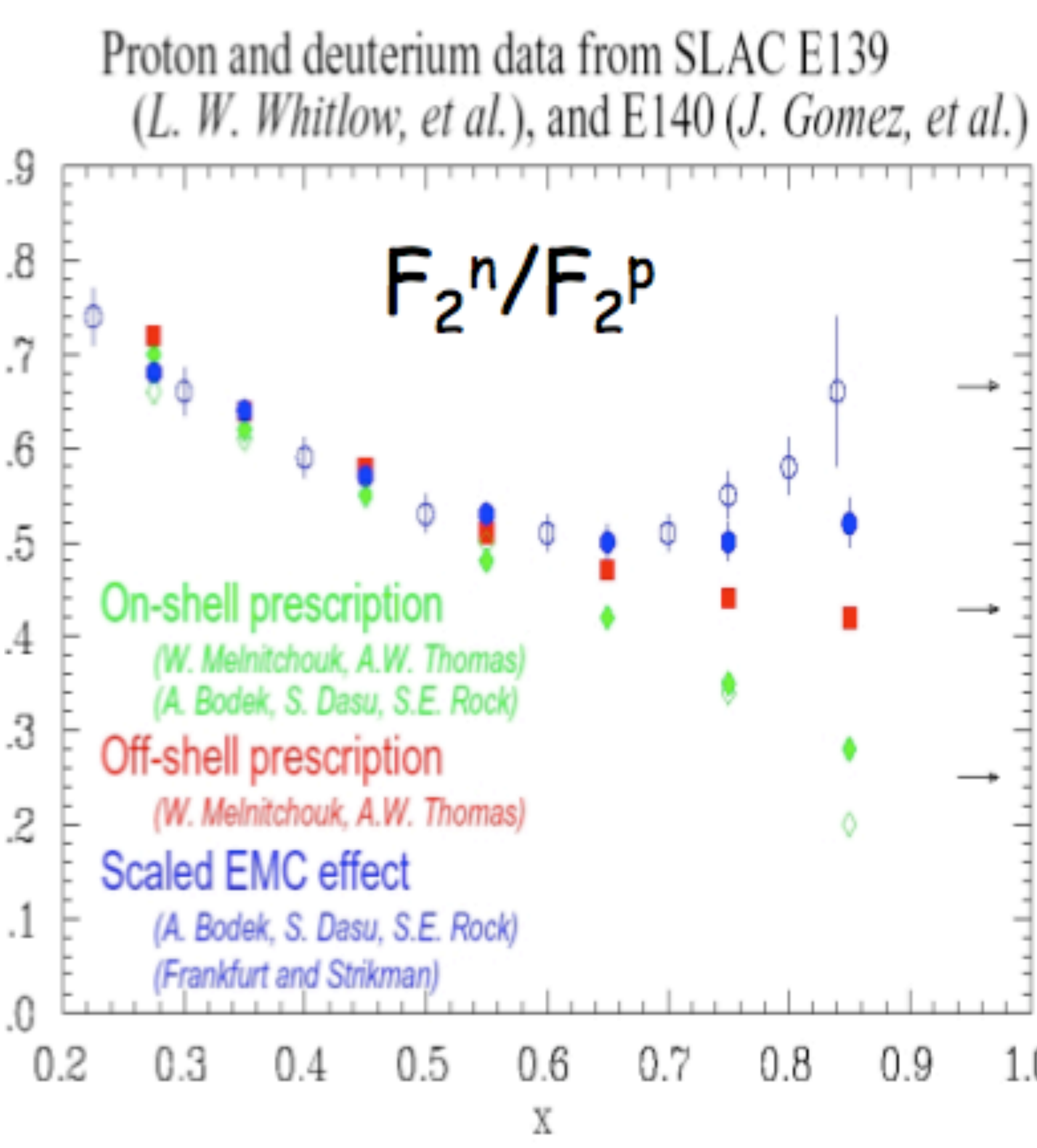
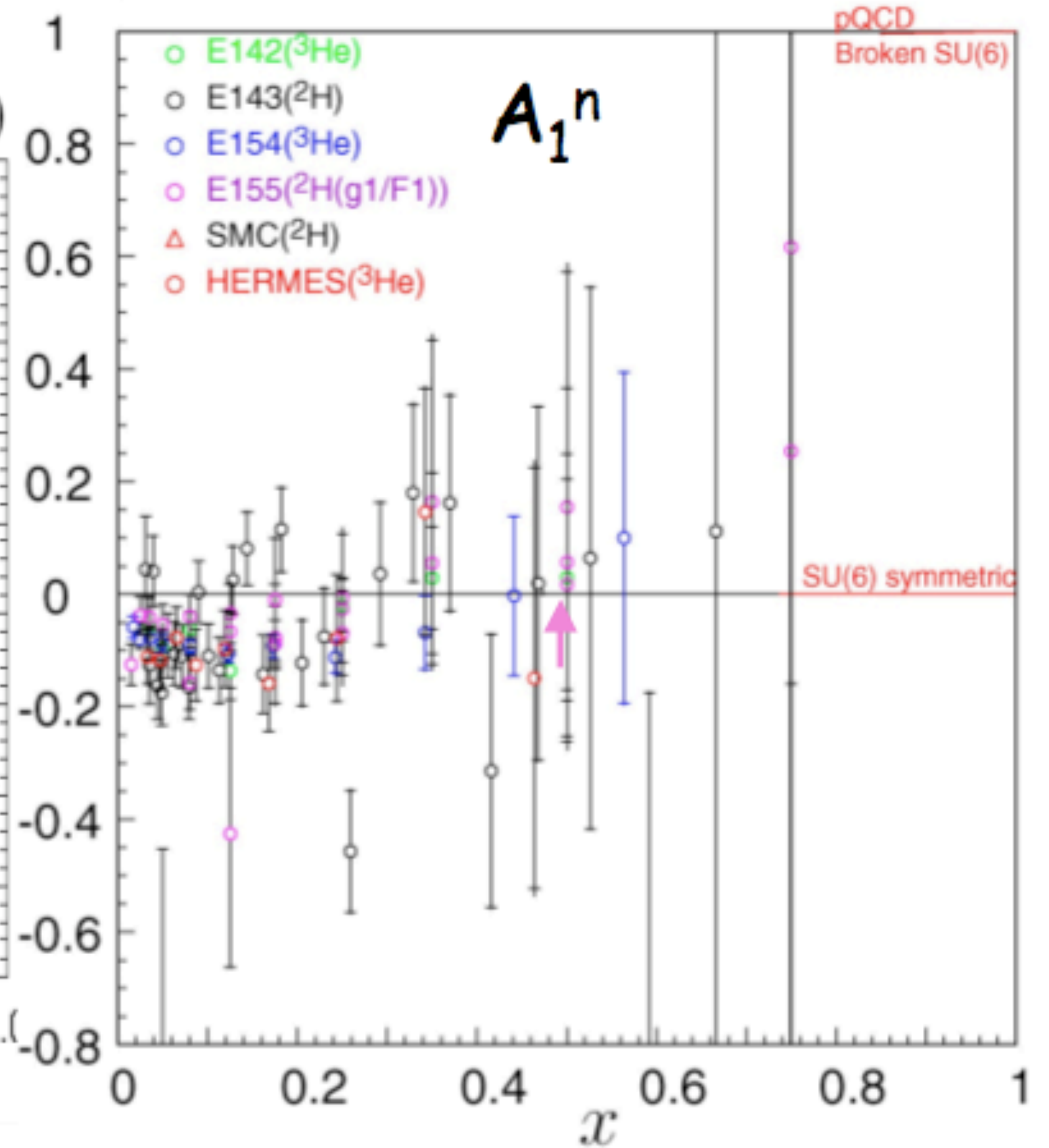
…and some things we don't.

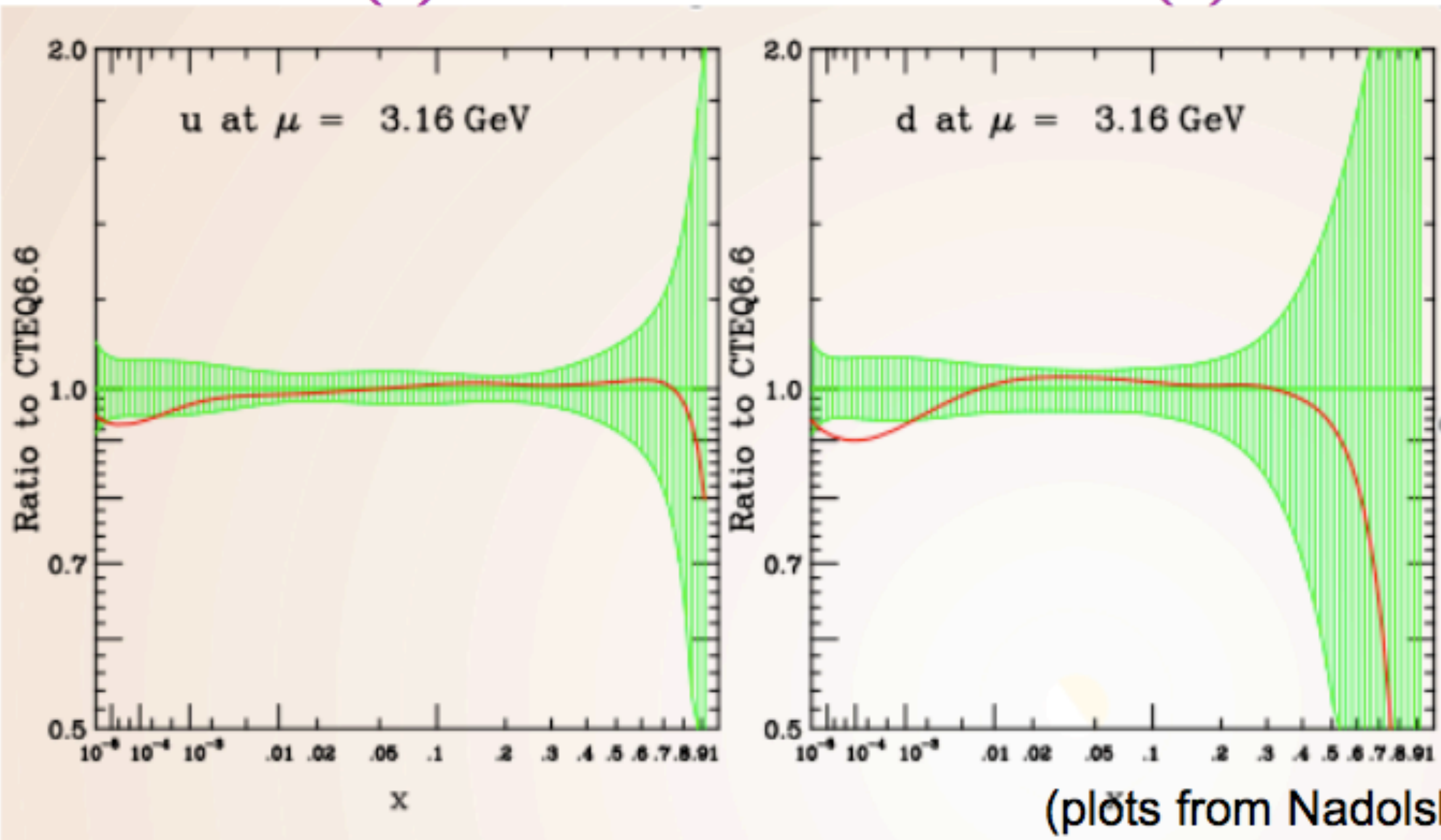
d-quarks at large x



and spin dependence at large x



u(x) **d(x)**



(plots from Nadolskys talk)

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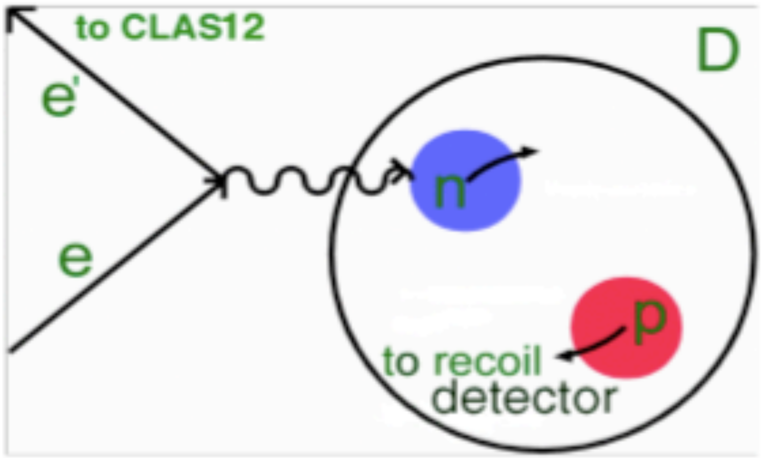
Unpolarized Neutron to Proton Ratio

Spectator tagging

- Nearly free neutron target by tagging low-momentum proton from deuteron at backward angles



- Small p (70-100 MeV/c)

  Minimize on-shell extrapolation (neutron only 7 MeV off-shell)
- Backward angles ($\theta_{pq} > 110^o$)

  Minimize final state interactions

DIS from A=3 Nuclei

- Mirror symmetry of A=3 nuclei

  Extract F_2^n/F_2^p from ratio of $^3He/^3H$ structure functions

$$\frac{F_2^n}{F_2^p} = \frac{2\mathcal{R} - F_2^{^3He}/F_2^{^3H}}{2F_2^{^3He}/F_2^{^3H} - \mathcal{R}}$$

Super ratio

$\mathcal{R}$ = ratio of "EMC ratios" for ^3He and ^3H Calculated to within 1%

- Most systematic and theoretical uncertainties cancel

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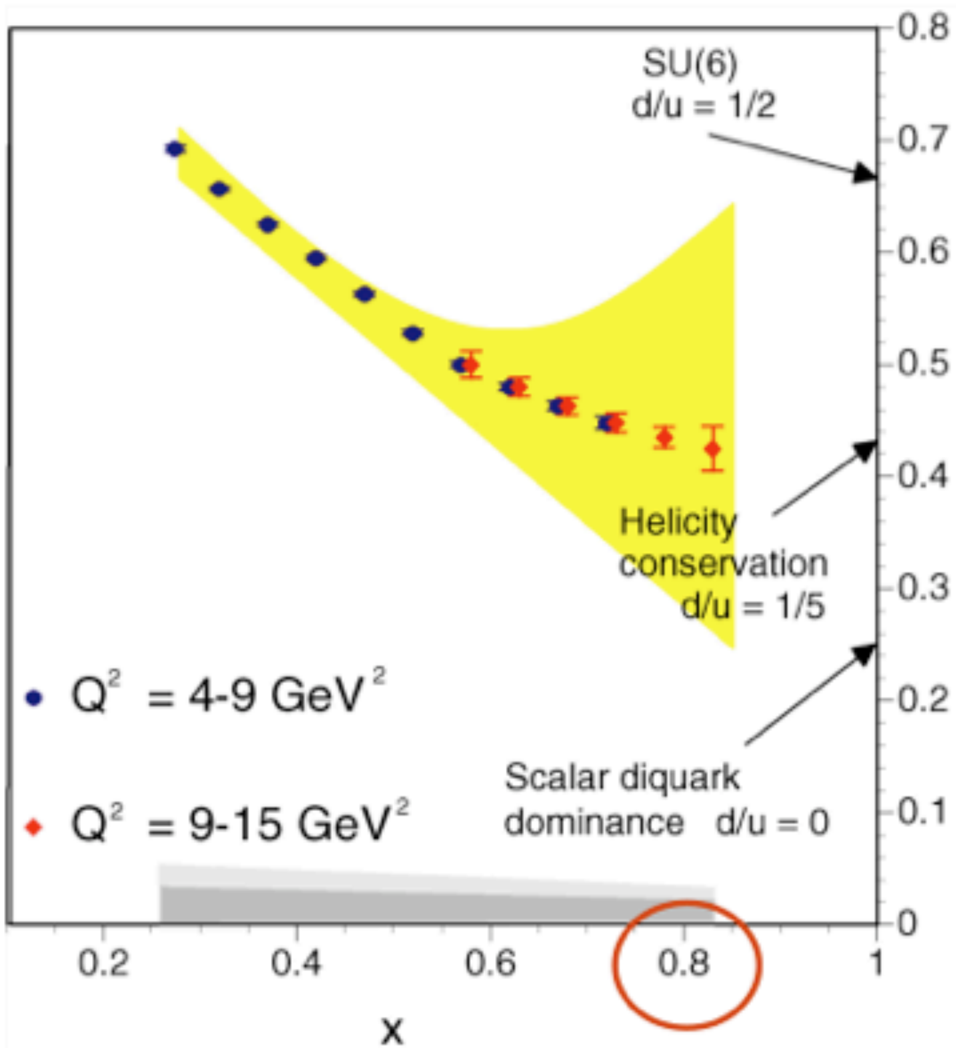
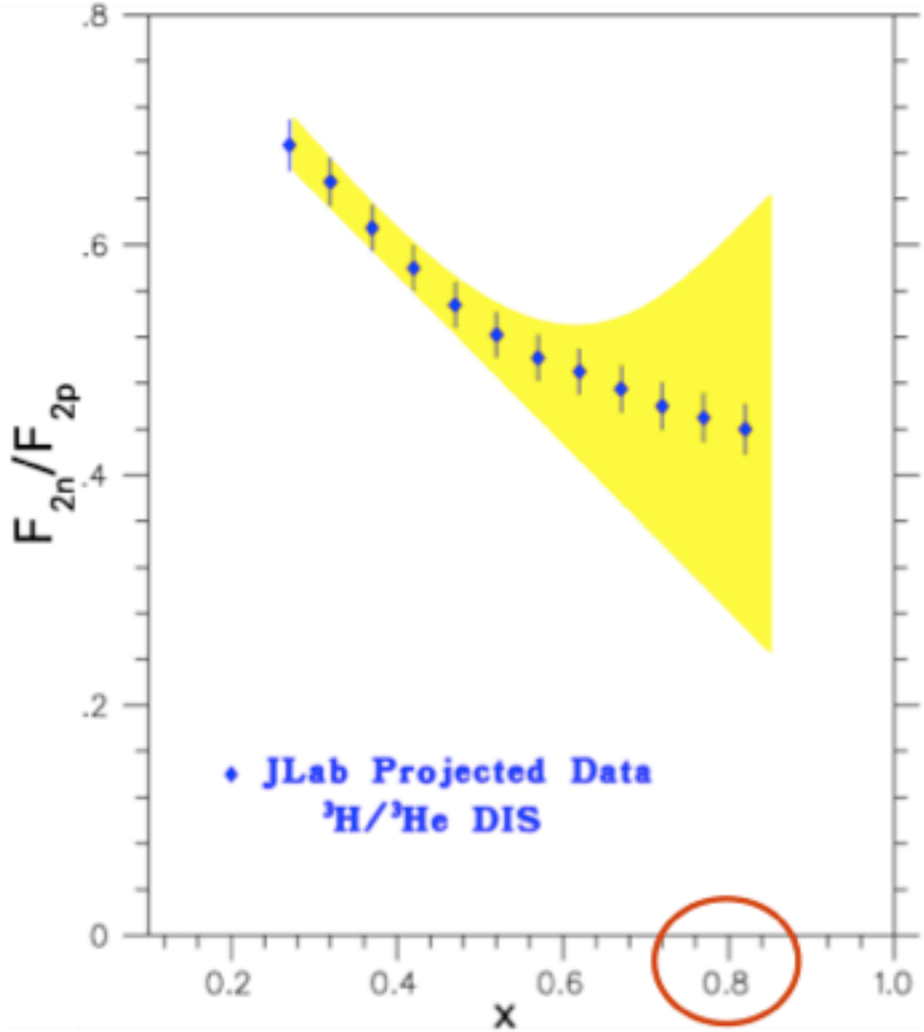
Unpolarized Neutron to Proton Ratio

BONUS in Hall B 11 GeV with CLAS12



Hall A 11 GeV with HRS



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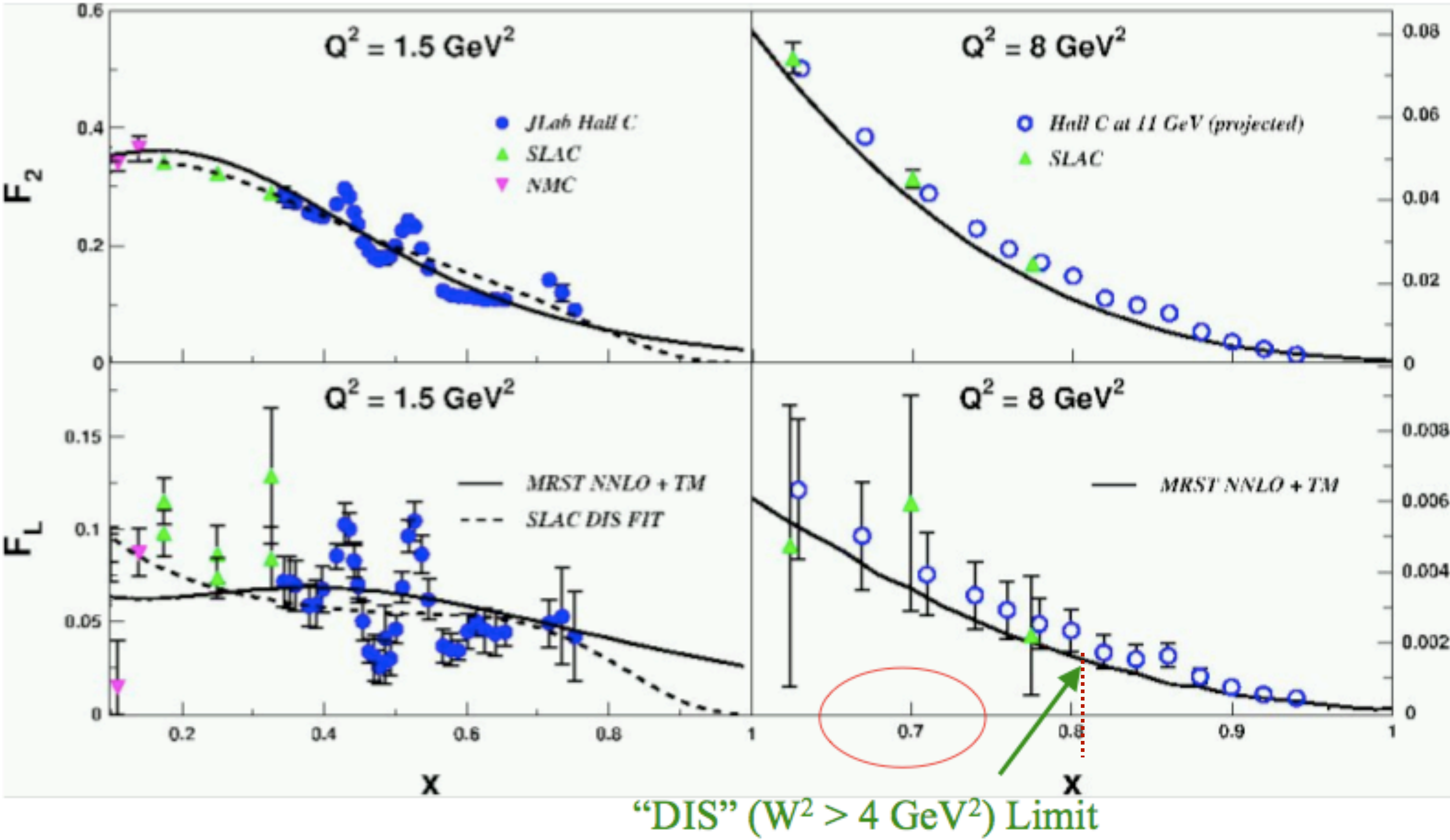
Rosenbluth Separations up to $Q^2 \sim 12$ GeV^2 → $R = \sigma_L/\sigma_T$, F_L



→ moments of F_2 and F_L → moments of G

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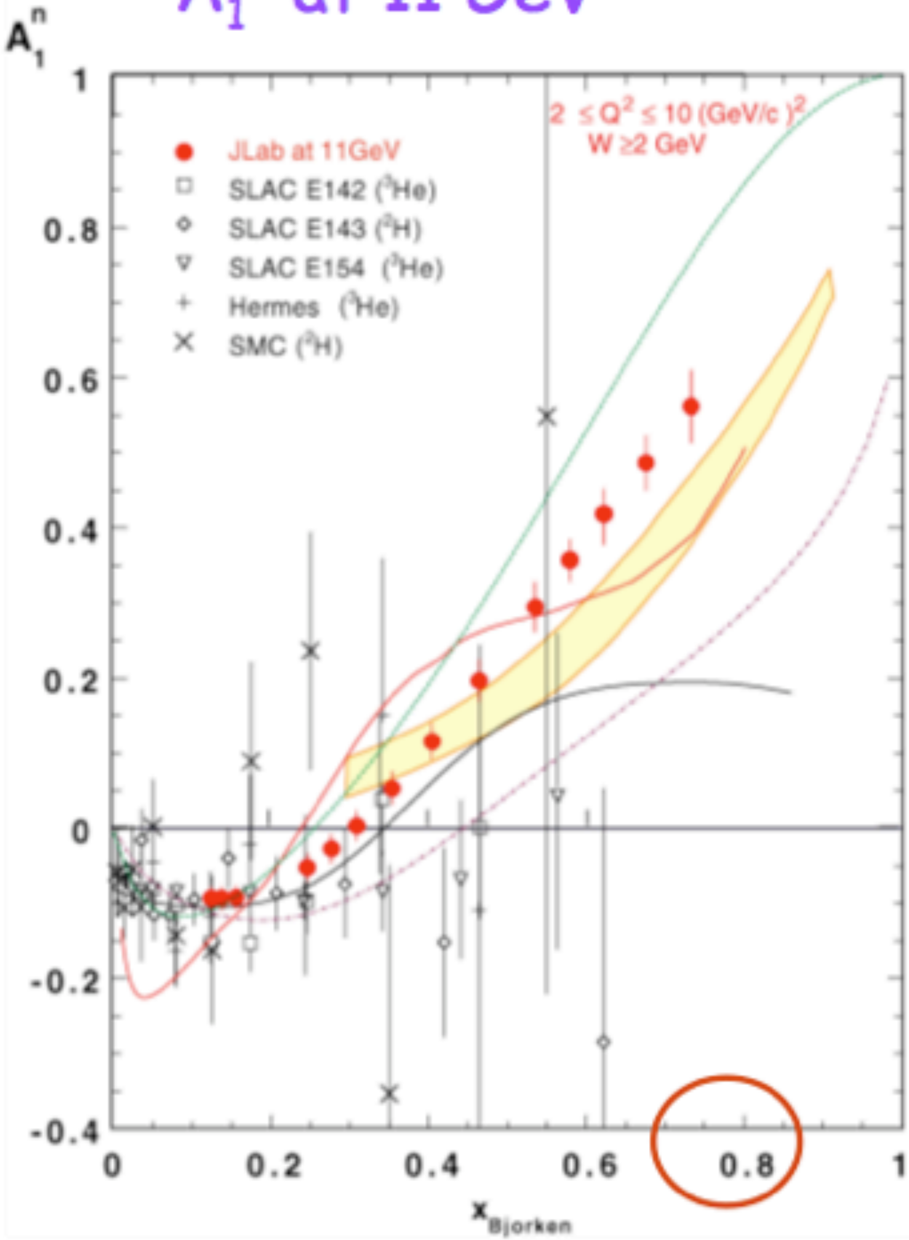
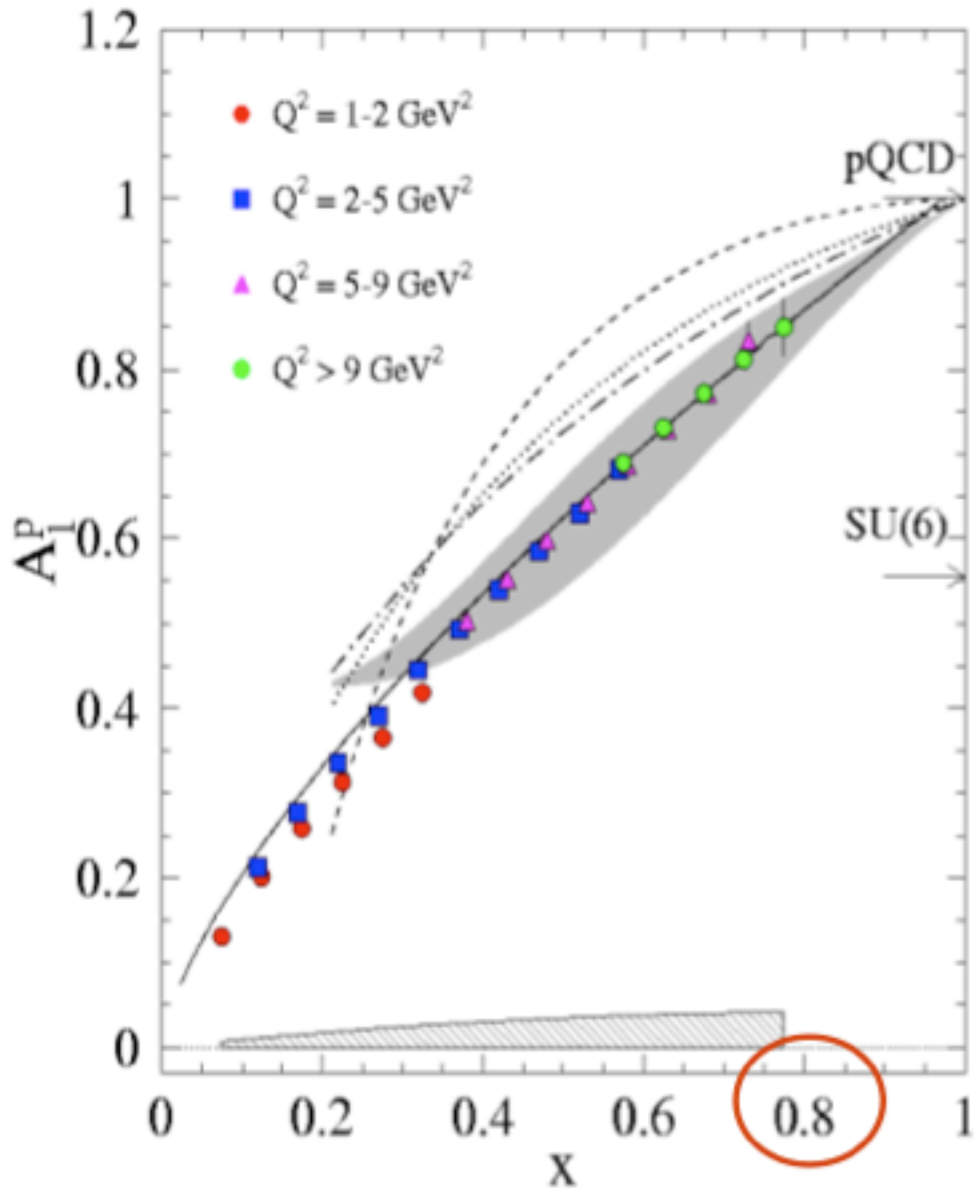
Spin Structure Function Projections for JLab at 11 GeV

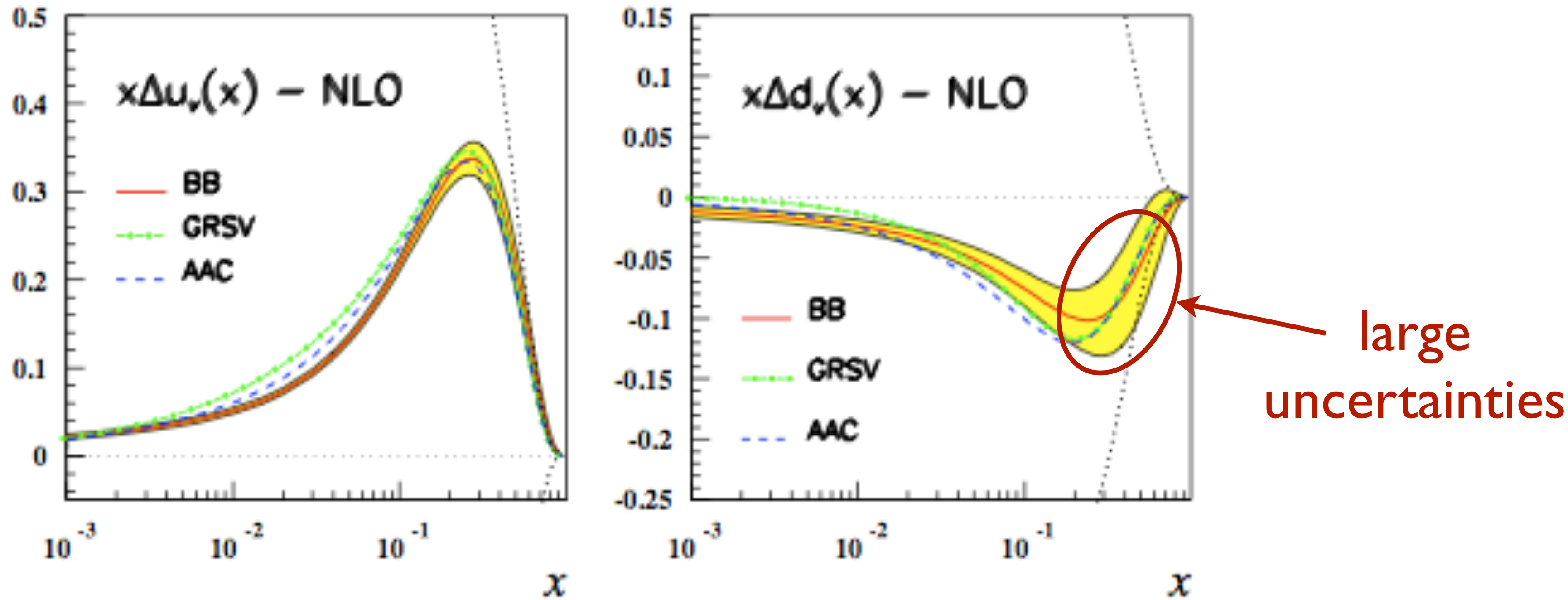
A_1^n at 11 GeV



A_1^p at 11 GeV



Polarized Parton Densities at Present



JB, H. Böttcher (2002)

Moments of Polarized Parton Densities

	Moment	BB, NLO
Δu_v	0	0.926
	1	0.163 ± 0.014
	2	0.055 ± 0.006
Δd_v	0	-0.341
	1	-0.047 ± 0.021
	2	-0.015 ± 0.009
$\Delta u_v - \Delta d_v$	0	1.267
	1	0.210 ± 0.025
	2	0.070 ± 0.011

More Lattice Results: upcoming; different (dynamical) fermion-types studied.
Low values of m_π crucial.
m_π 270 MeV at present.

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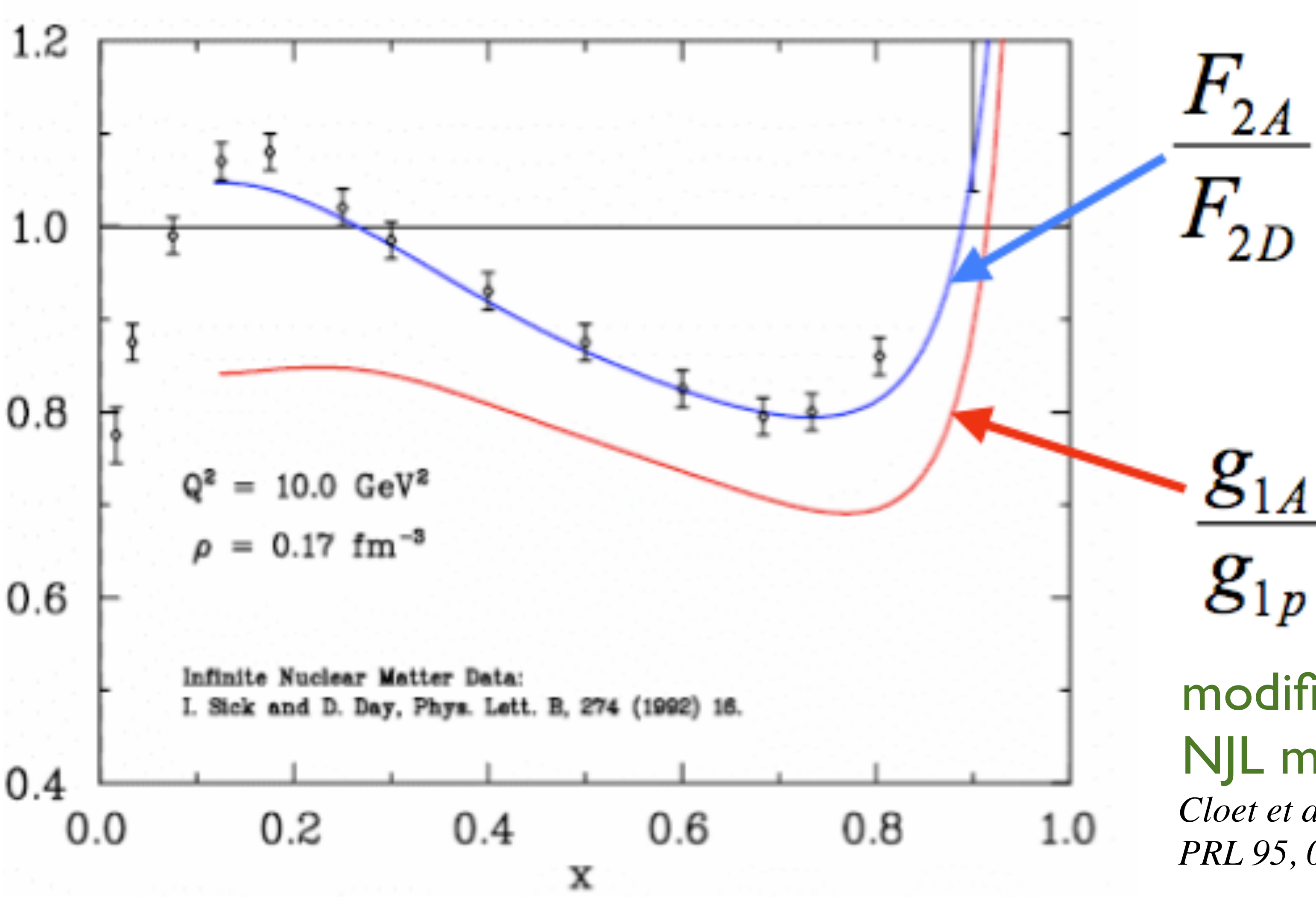
$g_1(A)$ – "Polarized EMC Effect"



modified NJL model

Cloet et al.
PRL 95, 052302 (2005)

Twice as large as unpolarized EMC effect!

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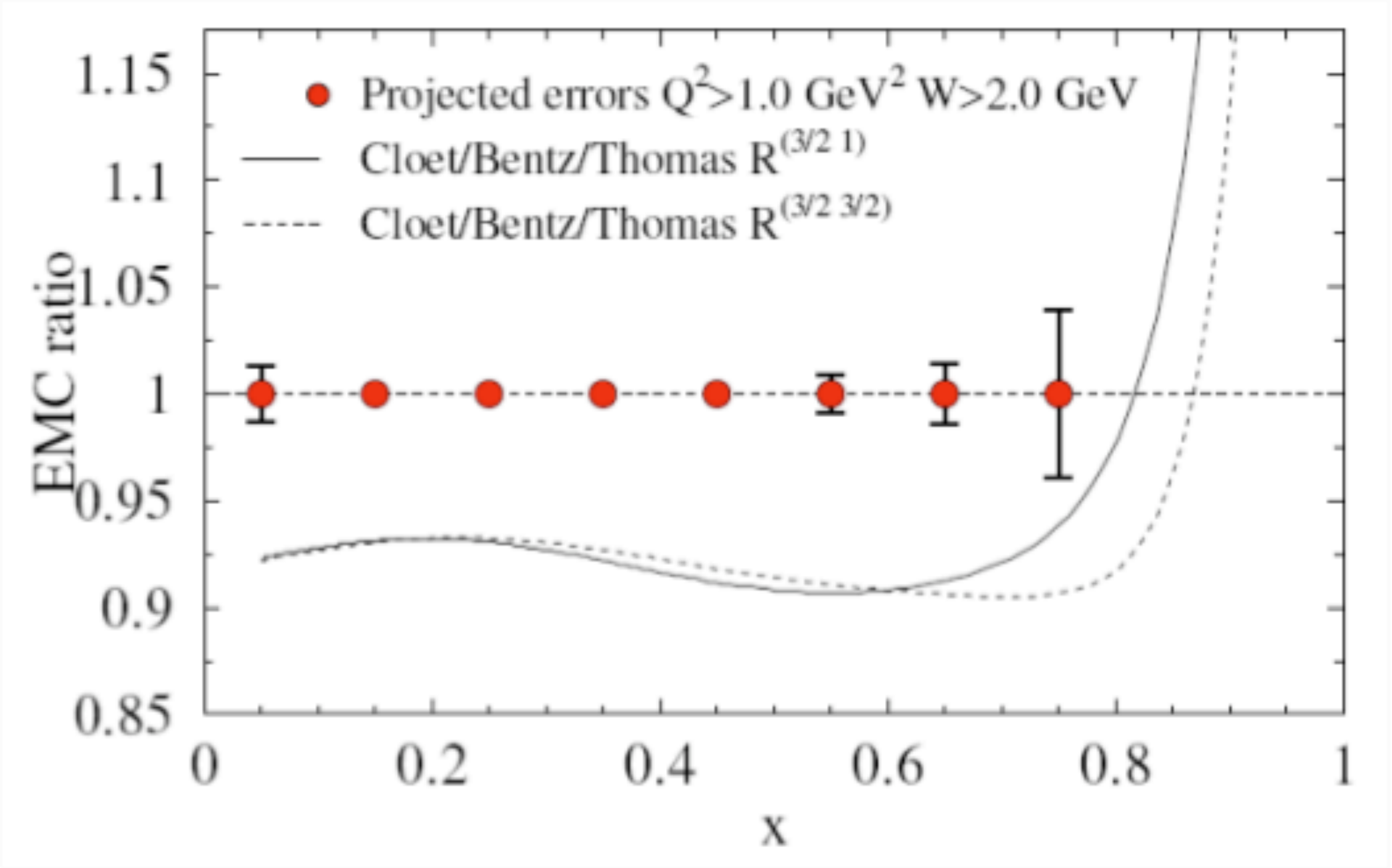
$g_1(A)$ – "Polarized EMC Effect"

- $\frac{g_{1A}(^7Li)}{g_{1p}}$



Expected errors with 11 GeV beam

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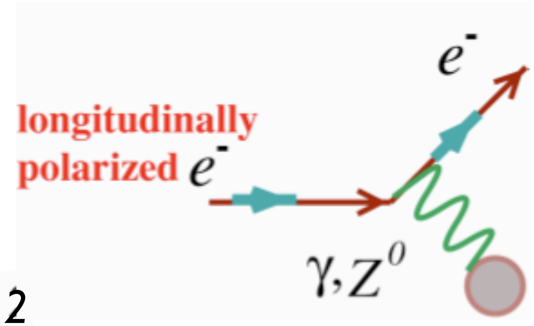
PV Asymmetries

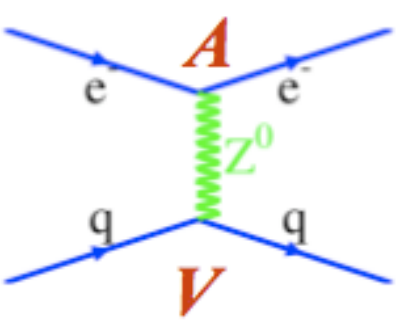
Weak Neutral Current (WNC) Interactions at $Q^2 \ll M_Z^2$

Longitudinally Polarized
Electron Scattering off
Unpolarized Fixed Targets

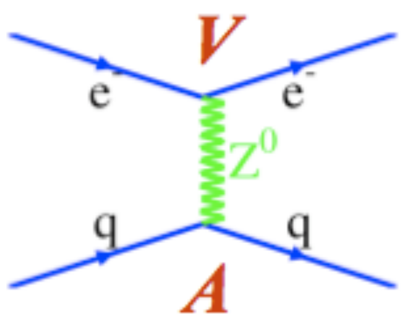


$$\sigma \;\propto\; |A_\gamma + A_{weak}|^2$$

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



$$C_{1i} \equiv 2 g_A^e g_V^i$$



$$C_{2i} \equiv 2 g_V^e g_A^i$$

$$C_{1u} = -\tfrac{1}{2} + \tfrac{4}{3}\sin^2(\theta_W) \approx -0.19$$
$$C_{1d} = \tfrac{1}{2} - \tfrac{2}{3}\sin^2(\theta_W) \approx 0.35$$
$$C_{2u} = -\tfrac{1}{2} + 2\sin^2(\theta_W) \approx -0.04$$
$$C_{2d} = \tfrac{1}{2} - 2\sin^2(\theta_W) \approx 0.04.$$

in DIS →

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

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

- ***For an isoscalar target like ^2H, structure functions largely cancel in the ratio:***

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

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

→ At high x, A_{PV} becomes independent of x, W

→ Sensitive to new physics at the TeV scale

- Exploratory measurements at 2% precision will be made at 6 GeV (2009)

Michaels, Reimer Zheng et al.

Paul Souder

in DIS →

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

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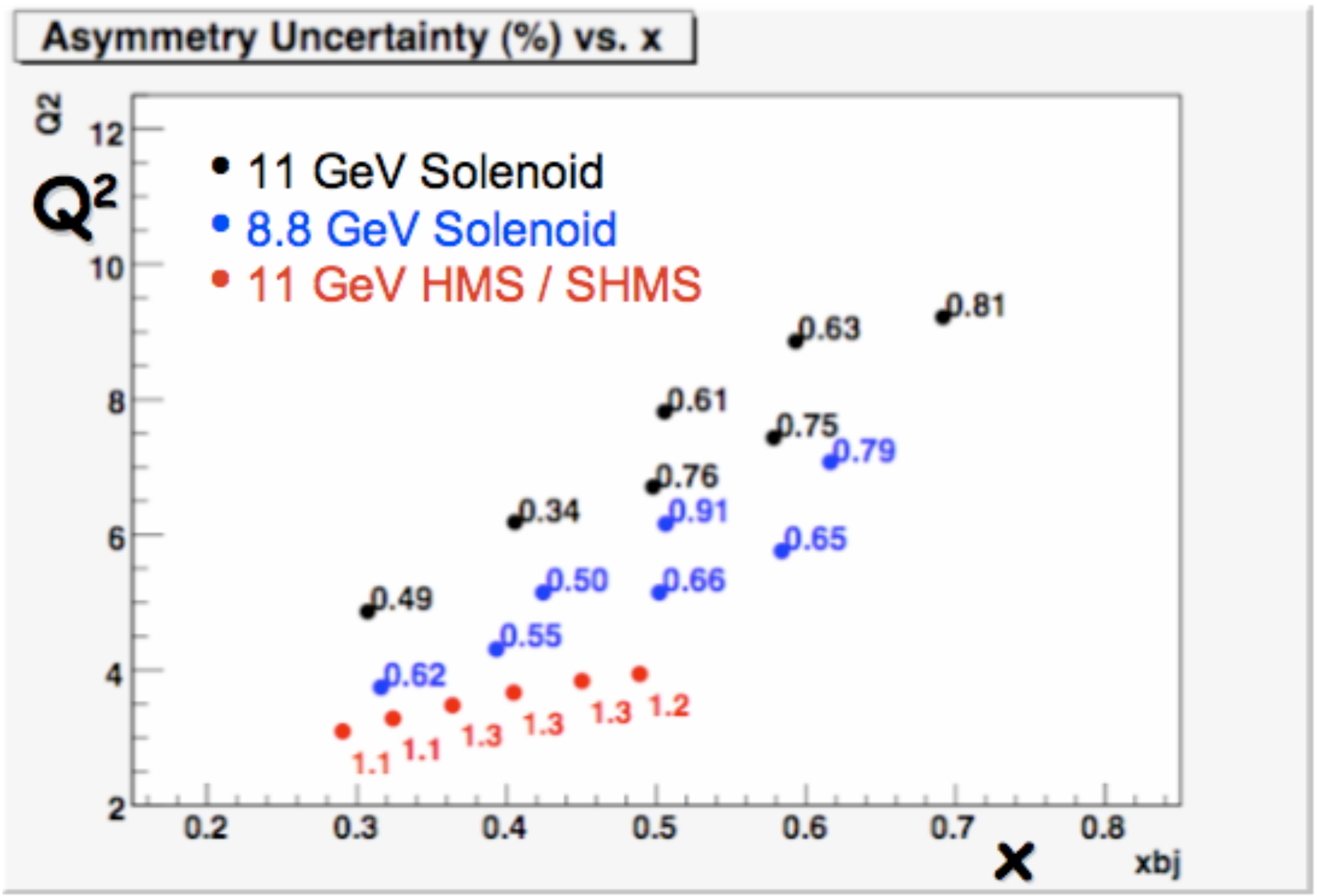


A Design for Precision PV DIS Physics

Paul Souder

High Luminosity on LH_2 & LD_2 Cryotargets

Better than 1% errors

- It is unlikely that any effects are larger than 5-6%

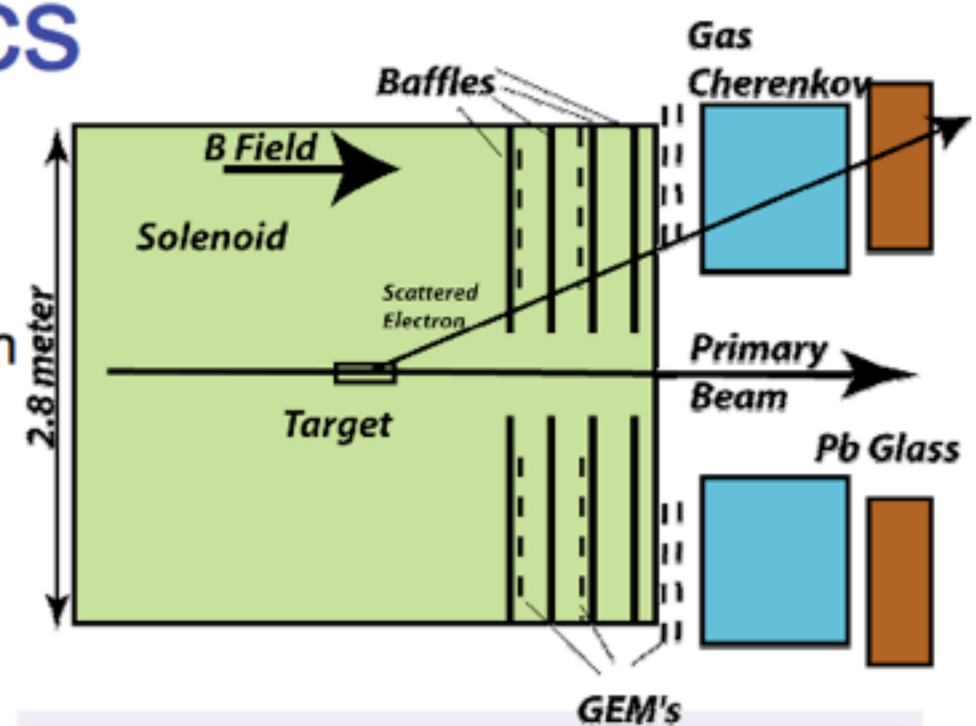
x-range 0.25-0.75

W^2 well over 4 GeV^2

Q^2 range a factor of 2 for each x

- (Except x~0.75)

Moderate running times



Existing solenoids which may fit

Experiment	B, T	Bore D, m	Length, m	MJ	X_0
BaBar	1.5	2.80	3.46	27	<1.4
Cleo-II	1.5	2.90	3.80	25	2.5

- *Need BaBar, CDF or CLEOII Solenoid*
- *state-of-the art fast tracking, particle ID and "parity" counting electronics*
- *precision polarimetry (-> 0.5%)*
- *diverse physics topics addressed*

  Standard Model test, CSV, d/u, nuclear EMC effect, semi-inclusive physics, detailed studies of spin structure functions…

Paul Souder

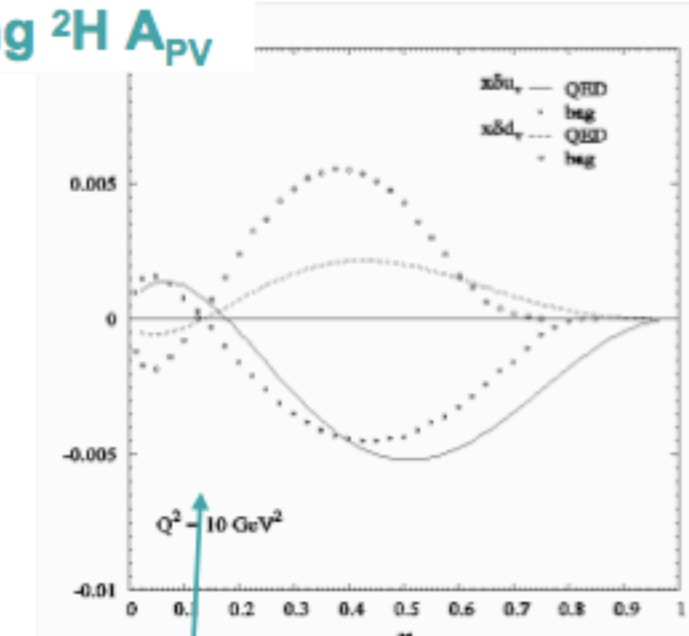
Charge Symmetry

Parton-level charge symmetry assumed in deriving ^2H A_{PV}

Charge Symmetry Violation

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

- u,d quark mass difference
- electromagnetic effects



- *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*

Analytic calculation similar to global fit

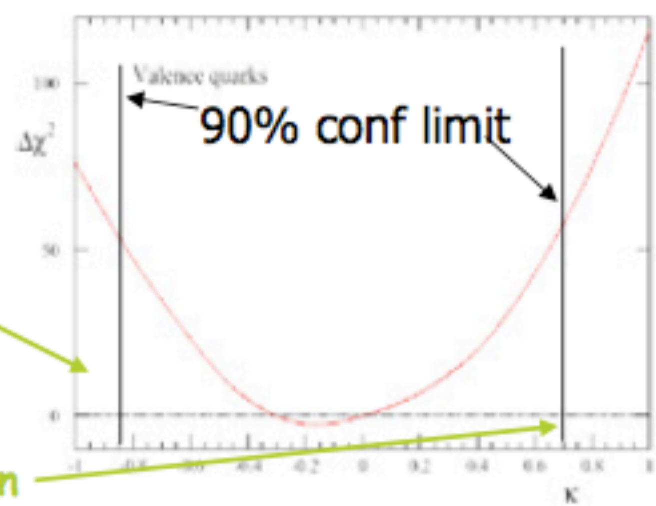
MRST PDF global with fit of CSV

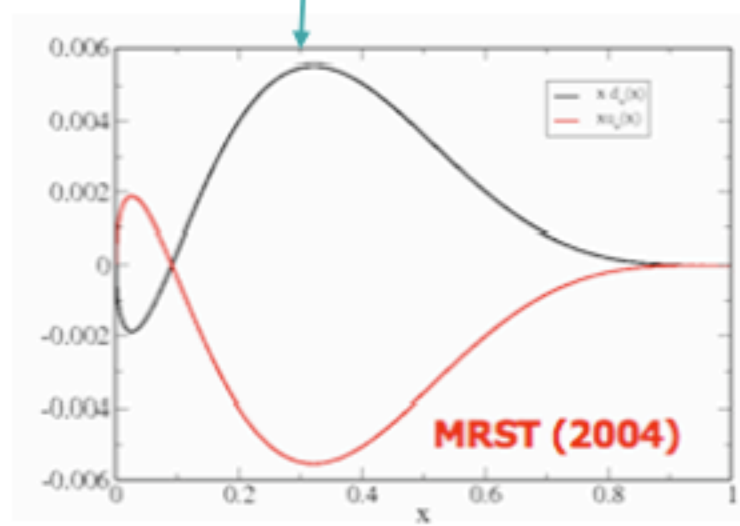
Martin, Roberts, Stirling, Thorne [Eur Phys J C**35**, 325 (04)]:

Broad minimum (90% C.L.)

fully explains NuTeV

doubles NuTeV deviation

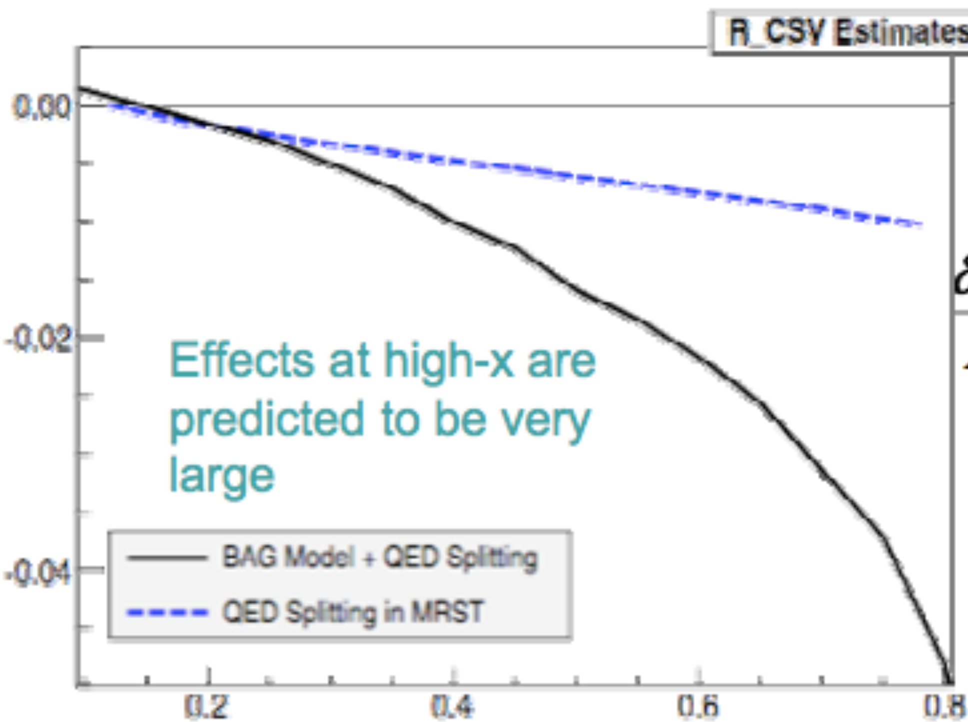


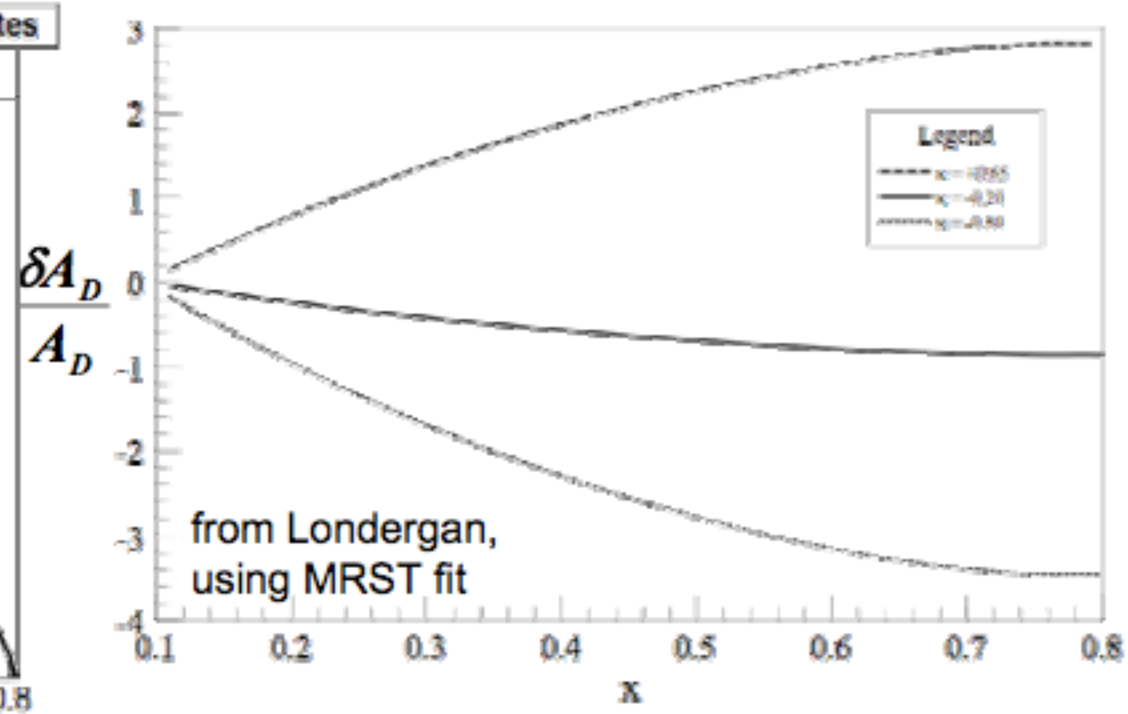


For PV-DIS from ^{2}H:

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

Sensitivity will be enhanced if u+d falls off more rapidly than δu - δd as x → 1



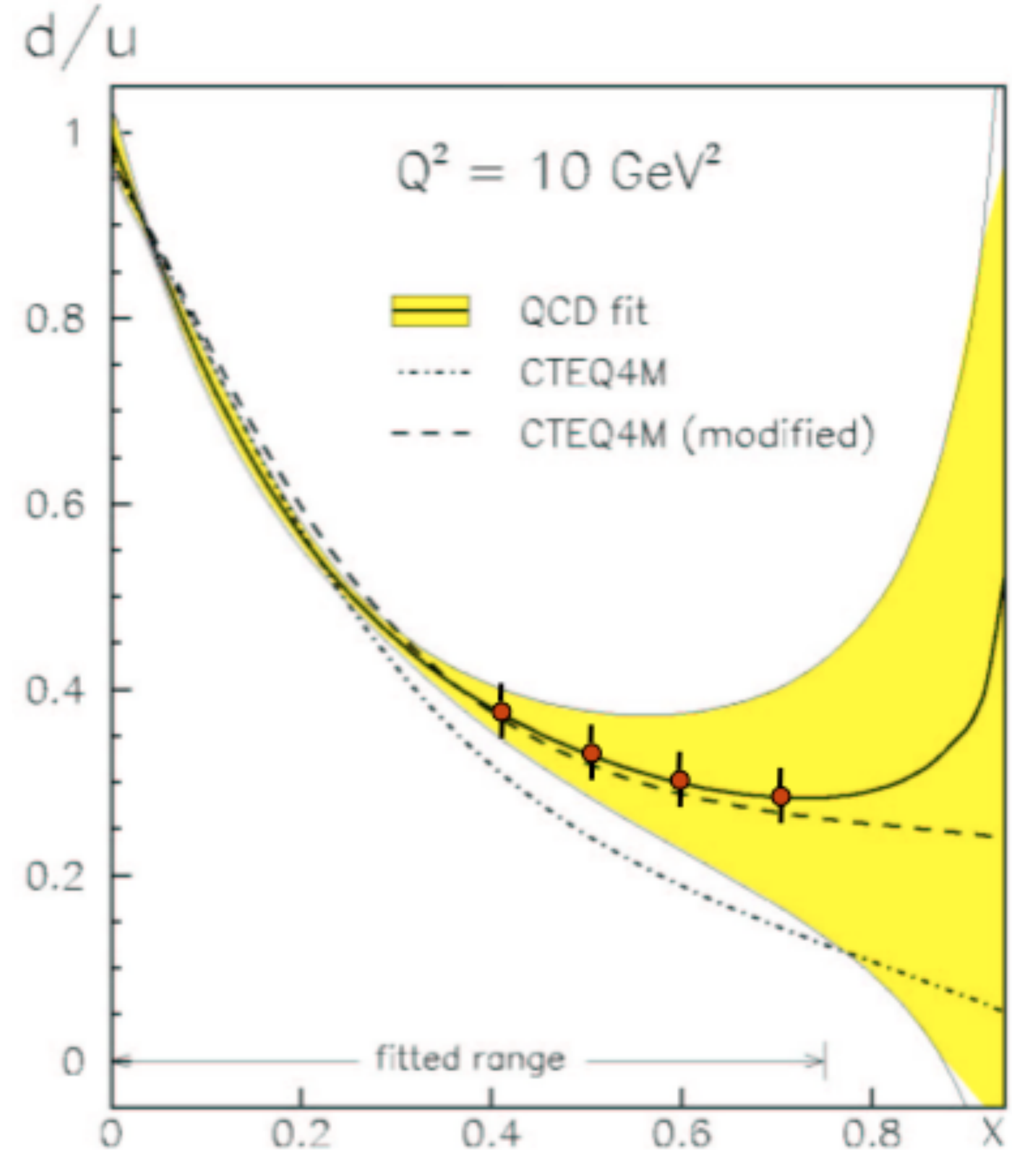


Proton target

Deuteron analysis has nuclear corrections

A_{PV} for the proton has no such corrections

Must simultaneously constrain higher twist effects



statistical and systematic errors ~ 2%

Complications at large x

Factorization formula for structure function F_2:

$$F_2(x, Q^2) = C(Q^2, M_X^2, \mu) \otimes \phi_q(\mu)$$

Straightforward for generic x: $M_X^2 \sim Q^2$

- C is calculated as an expansion in $\alpha_s(Q)$
- Non-perturbative effects in ϕ_q

Problematic at large x: $M_X^2 \ll Q^2$

- C contains large "threshold" logarithms $\alpha_s^n \ln^{2n}(Q^2/M_X^2)$
- Scale in coupling: $\alpha_s(Q)$ or $\alpha_s(M_X)$?

Need factorization and resummation for $x \to 1$

Factorization formula for $x \to 1$

(Sterman '87, Catani and Trentadue '89, SCET '03-'06)

$$F_2(x, Q^2)\big|_{x\to 1} \;=\; H(Q^2, \mu)\, J(M_X^2, \mu) \otimes \phi_q(\mu)$$

Each function depends only on one scale:

- H is a "hard function" depending on hard scale Q^2
- J is a "jet function" depending on jet scale M_X^2
- ϕ_q is the parton distribution function in $\xi \to 1$ limit

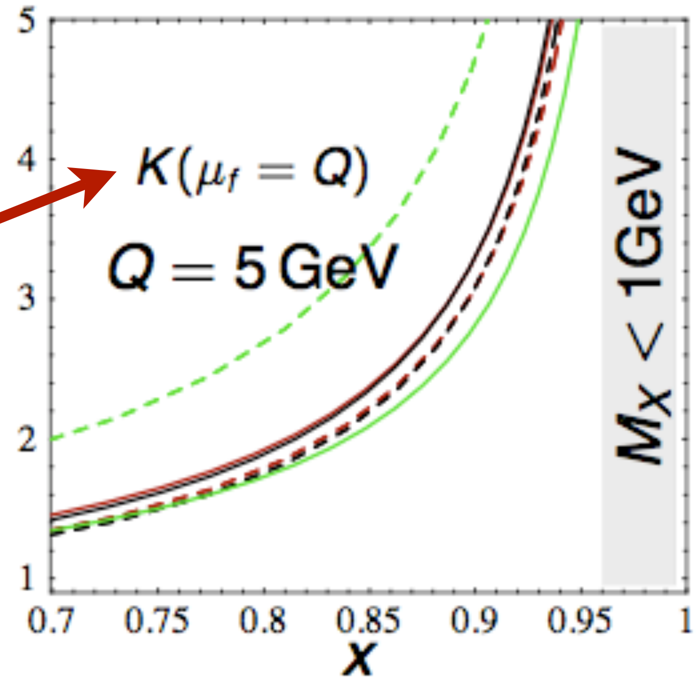
Scales are separated **but**

- No choice of μ eliminates large logs in Q^2/M_X^2

Also need resummation

Comparison between SCET and standard results

$$K(\mu_f) = \frac{F_2^{\rm ns}(x, Q^2)}{\sum_q e_q^2\, x\, \phi_q^{\rm ns}(x, \mu_f)}$$



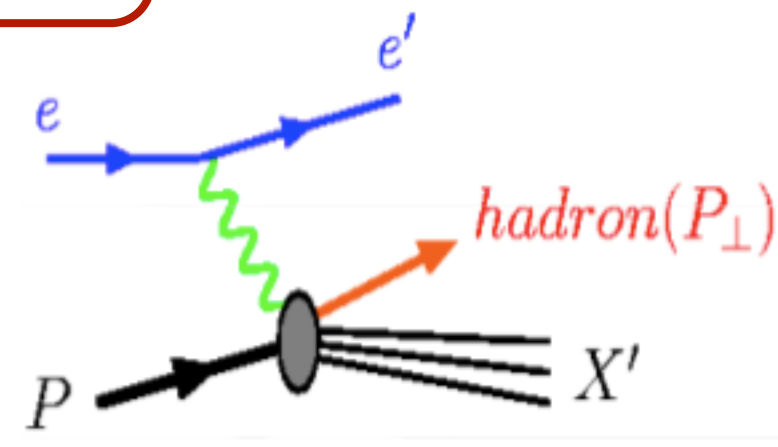
- Solid = SCET results in momentum space
- Dashed = Mellin-inverted moment space results
- green = LO, red = NLO, black = NNLO

Numerical differences very small at NLO and NNLO

SIDIS and TMDs (Semi-Inclusive DIS and Transverse Momentum-Dependent Distribtuions at 12-GeV Jefferson Lab)

Peter Bosted
Feng Yuan

- Flavor decomposition of PDFs



- Spin Sum Rule implies significant angular momentum of quarks and gluons in nucleon
  → Quark Orbital Motion

- Should lead to observable differences in TMD of up and down quarks.

TMD Physics

- A way to measure Transversity Distribution, the last unkown **leading twist** distribution

  Collins 1993

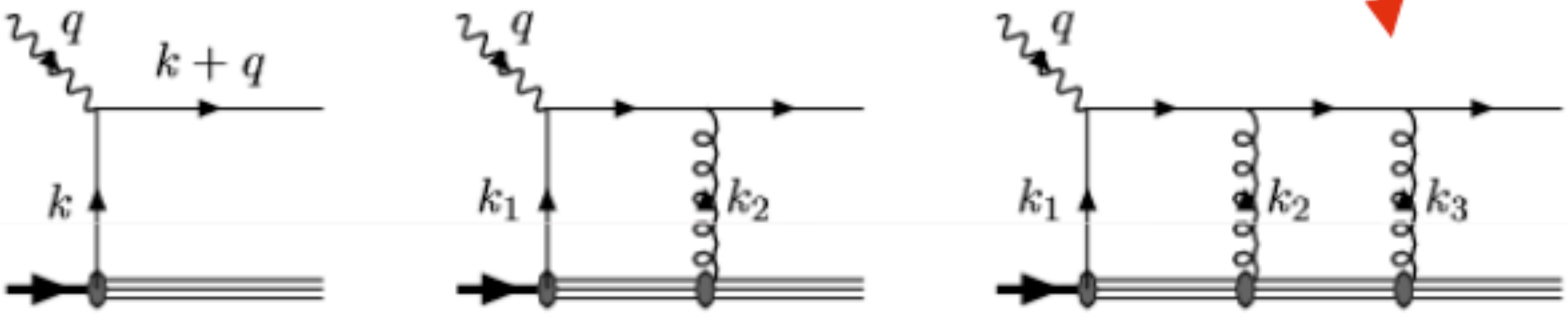
- The Novel Single Spin Asymmetries
- Connections with GPDs, and Quantum Phase Space Wigner distributions
- Quark Orbital Angular Momentum and

  Many others …

TMD Distribution: the definition

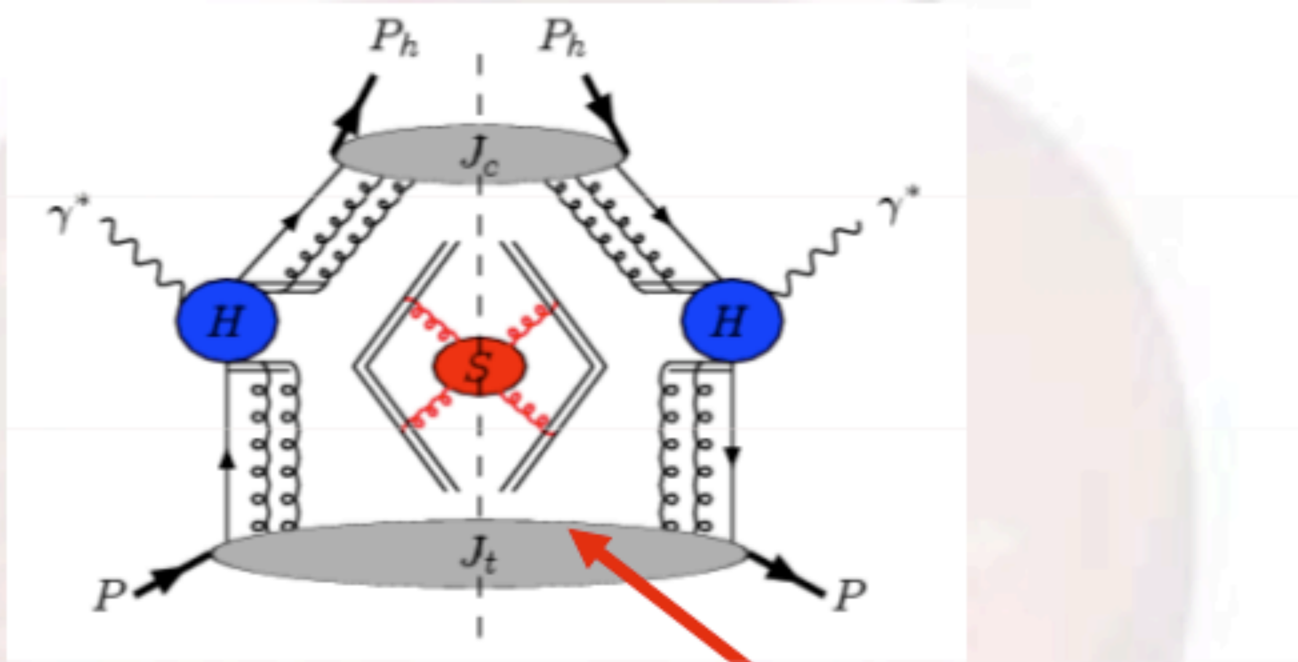
$$Q(x,k_\perp,\mu,x\zeta) = \frac{1}{2}\int\frac{d\xi^-}{2\pi}e^{-ix\xi^-P^+}\int\frac{d^2\vec{b}_\perp}{(2\pi)^2}e^{i\vec{b}_\perp\cdot\vec{k}_\perp} \times \left\langle P\left|\overline{\psi}_q(\xi^-,0,\vec{b}_\perp)\mathcal{L}_v^\dagger(\infty;\xi^-,0,\vec{b}_\perp)\gamma^+\mathcal{L}_v(\infty;0)\psi_q(0)\right|P\right\rangle$$

Gauge Invariance requires the Gauge Link



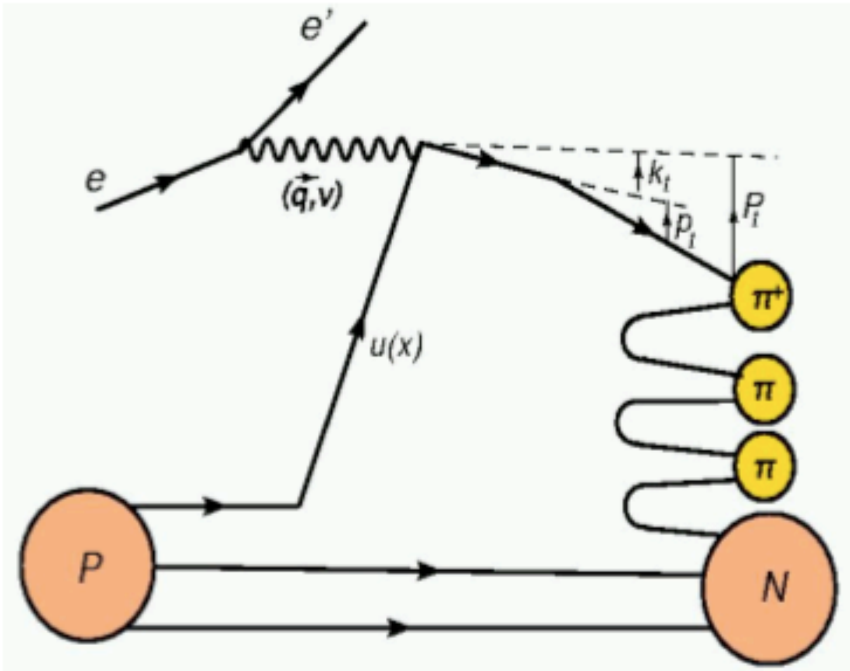
This definition is consistent with QCD factorization

Factorization



$$F(x_B, z_h, P_{h\perp}, Q^2) = \sum_{q=u,d,s,\dots} e_q^2 \int d^2\vec{k}_\perp d^2\vec{p}_\perp d^2\vec{\ell}_\perp \times q\left(x_B, k_\perp, \mu^2, x_B\zeta, \rho\right) \hat{q}_h\left(z_h, p_\perp, \mu^2, \hat{\zeta}/z_h, \rho\right) S(\vec{\ell}_\perp, \mu^2, \rho) \times H\left(Q^2, \mu^2, \rho\right) \delta^2(z_h\vec{k}_\perp + \vec{p}_\perp + \vec{\ell}_\perp - \vec{P}_{h\perp})$$

k_T-dependent SIDIS

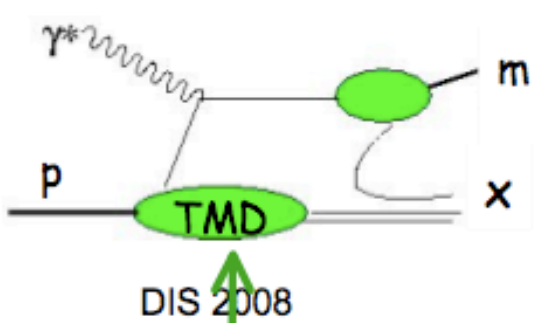


Final transverse momentum of the detected pion P_t arises from convolution of the struck quark transverse momentum k_t with the transverse momentum generated during the fragmentation p_t.

$$p_t = P_t - z\,k_t + O(k_t^2/Q^2)$$

Linked to framework of Transverse Momentum Dependent Parton Distributions

$$\sum e_q^2\, q(x)\, D_{q\to M}(z)$$



$\mathrm{TMD}^u(x,k_T)$

$f_1, g_1, f_{1T}^{\perp}, g_{1T}^{\perp}$

$h_1, h_{1T}^{\perp}, h_{1L}^{\perp}, h_1^{\perp}$

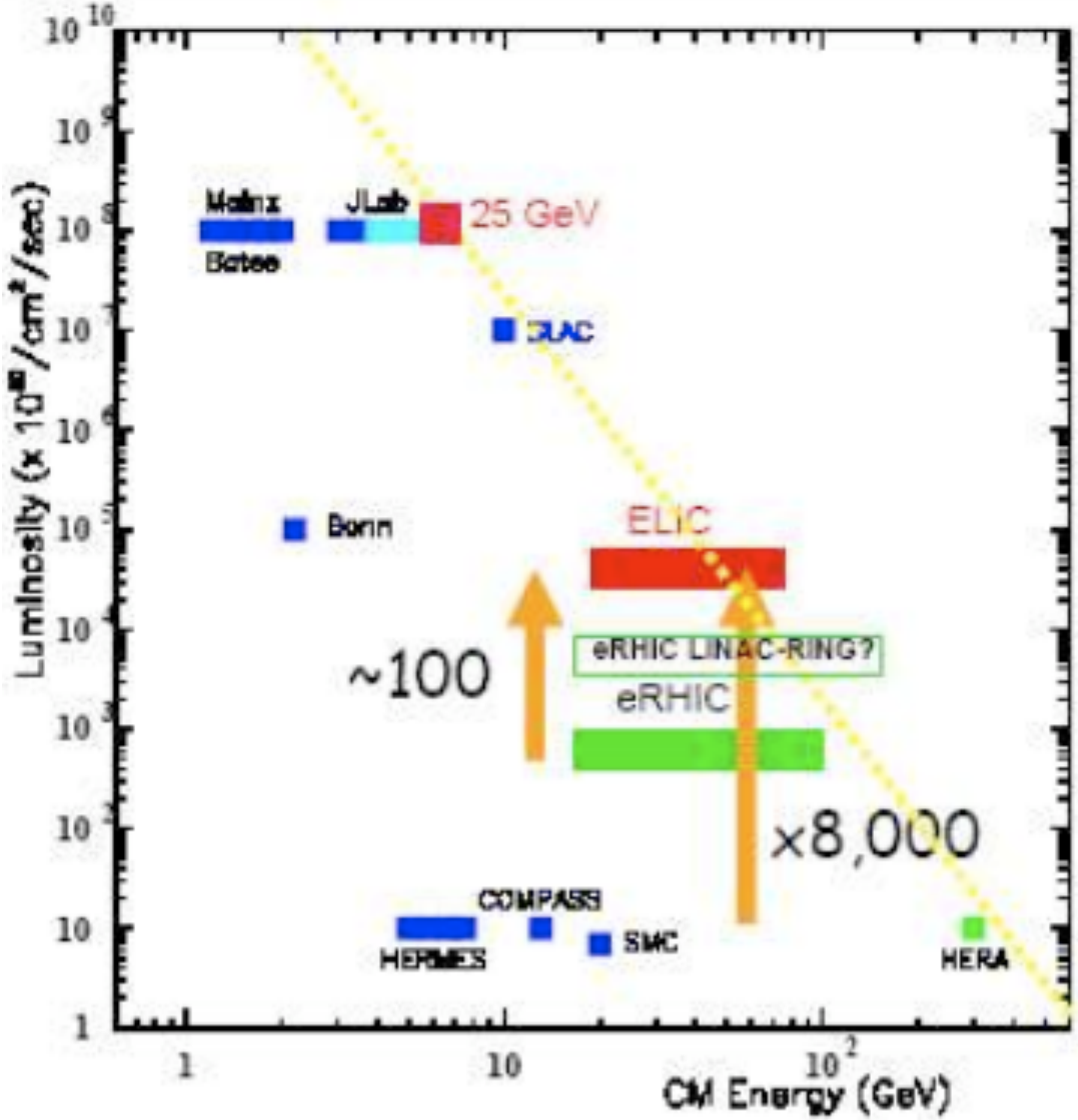
e.g. T-odd Sivers function, Collins effect, etc.

WHAT IS NEEDED

- **Much more data in many bins in z, Q^2, x, P_t, ε, and azimuthal angle**
- **Need study of diffractive ρ contribution, dependence on missing mass M_x, …**
- **Some already taken with Jlab CLAS 6 GeV**
- **Much more posible with 12 GeV upgrade, espeically with CLAS 12 (Halll B).**

WHAT IS PLANNED

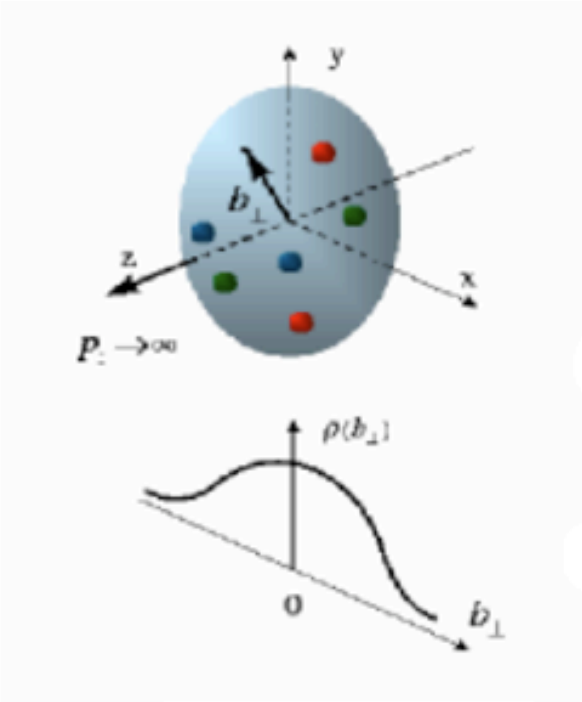
- **Accurate neutron/proton ratios for SIDIS pion and kaons with CLAS in many bins**
- **Extentise data with longitudinally and transversly polarized protons and deuterons uwing CLAS6 and CLAS12 (maybe HD)**
- **Accurate π^+/π^- (and K^+/K^-) ratios for proton and deuteron using spectrometers Hall C**
- **ε-depdendence using spectrometers Hall C**



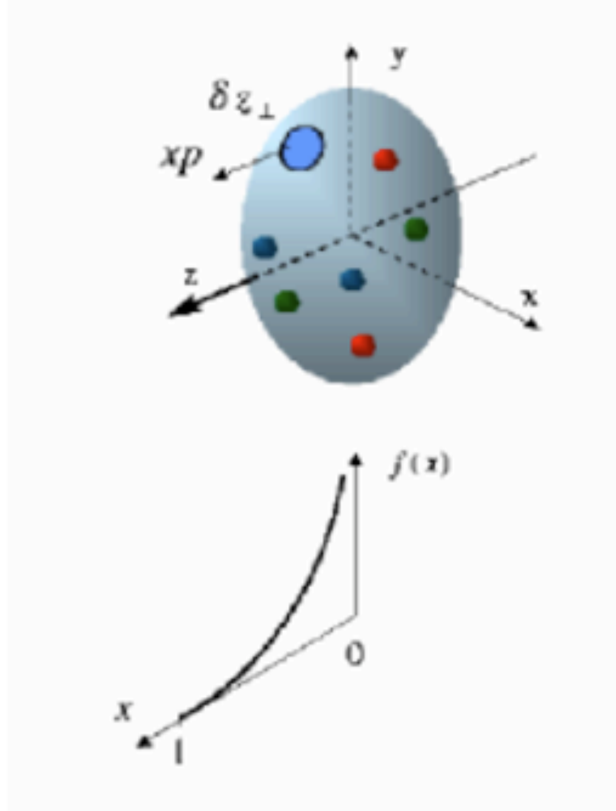
Luminosity (x 10^33/cm^2/sec)
CM Energy (GeV)
Mainz
Bates
JLab
25 GeV
Bonn
ELIC
eRHIC LINAC-RING?
eRHIC
~100
×8,000
COMPASS
HERMES
SMC
HERA

Silvia Niccolai
Simonetta Liuti

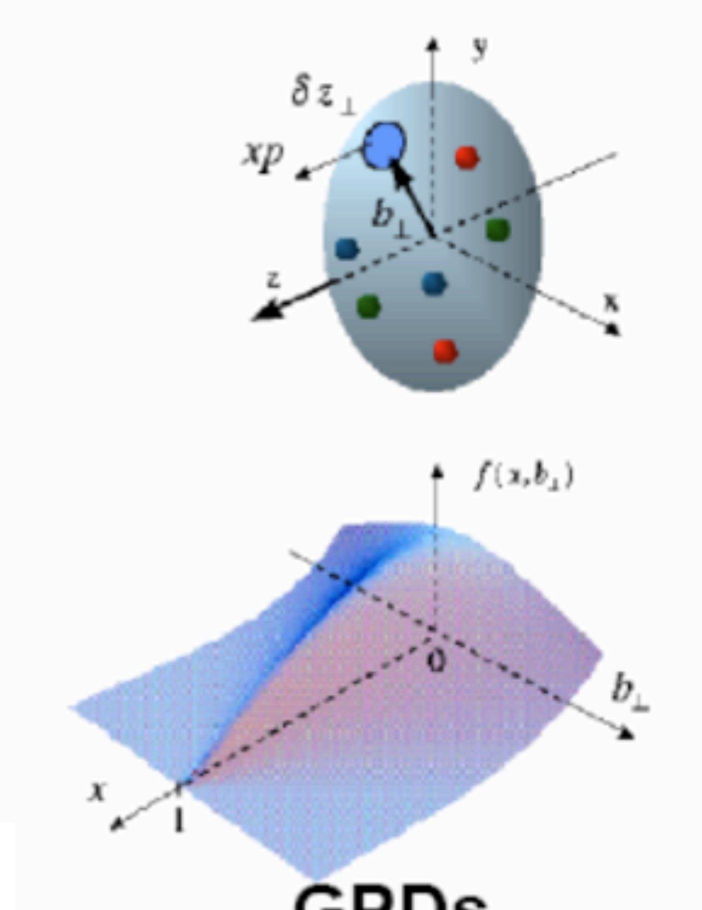
New, comprehensive view of hadronic structure



Elastic Scattering
transverse quark distribution in Coordinate space



DIS
longitudinal quark distribution in momentum space



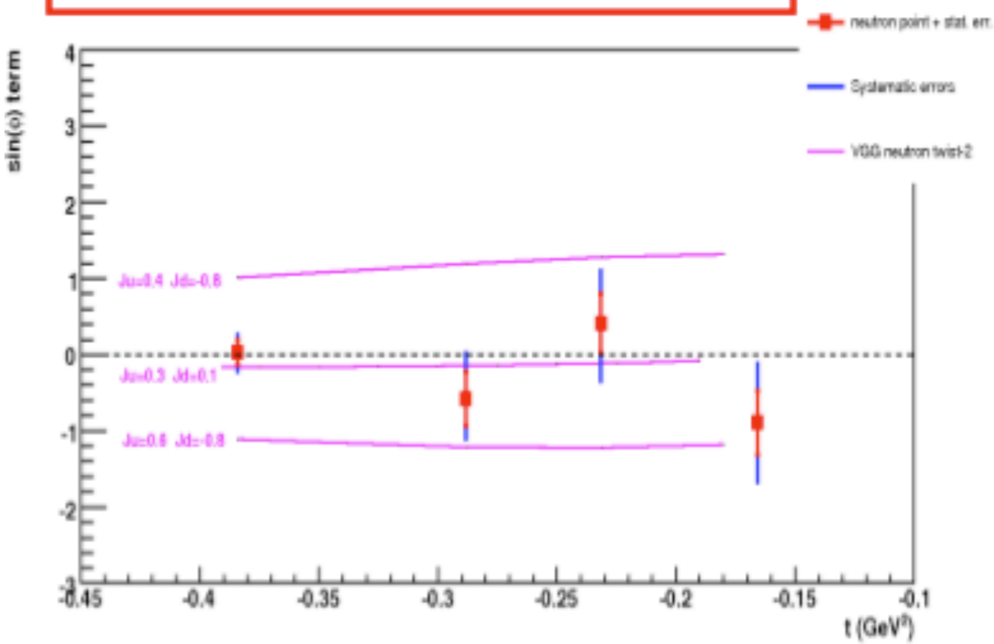
GPDs
The fully-correlated Quark distribution in both coordinate and momentum space

Silvia Niccolai

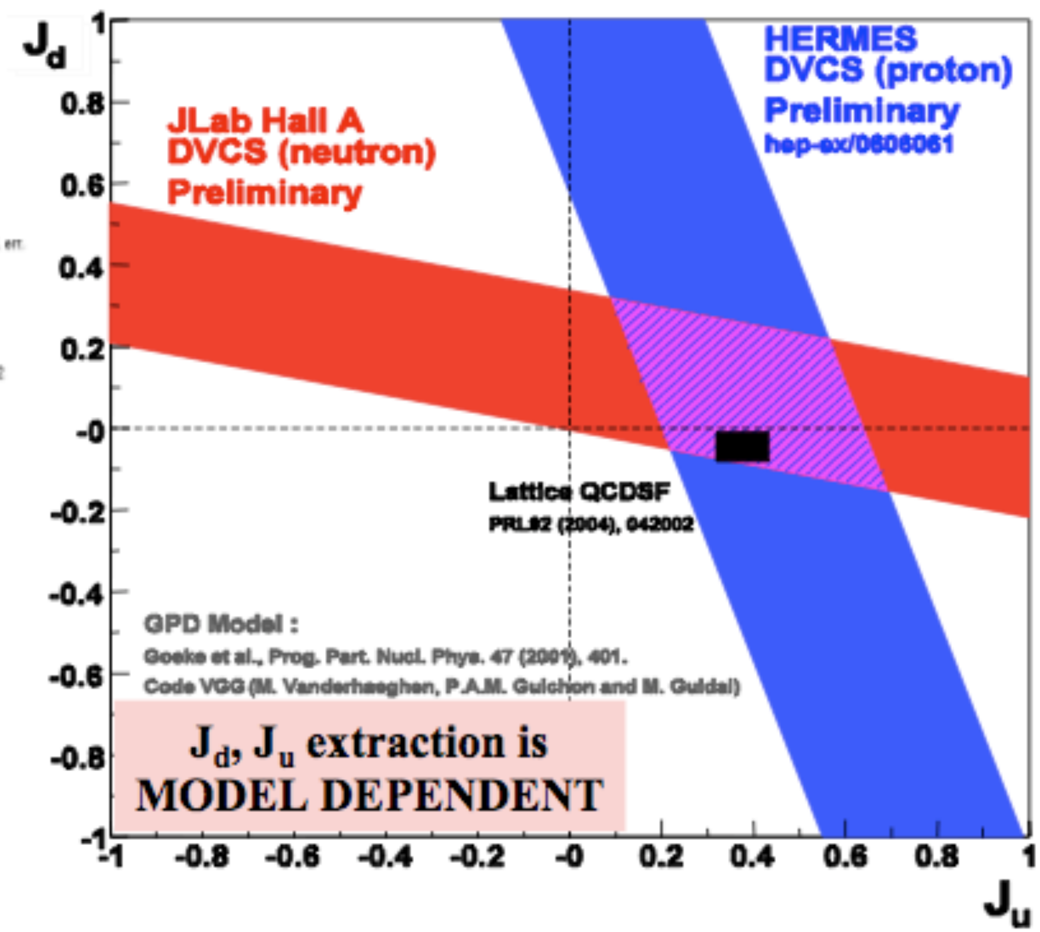
GPDs: where we stand, where we are going

- Pioneering dedicated experiments on **DVCS** (Hall A, CLAS), show evidence for **handbag (twist-2) dominance** (asymmetry ~sinϕ) and **unexpected scaling** at **$Q^2 \sim 2$ GeV^2** (Hall A)
- GPD models **fail** to reproduce consistently the **DVCS cross section and asymmetry** data
- **DVMP** experiments at CLAS (ρ, ω, π^0) and Hall A (π^0) hint that either **scaling cannot be reached** for Q^2 as low as for DVCS or **something is missing** in GPDs parameterizations
- Hall A's first attempt to measure **nDVCS** showed the importance of this channel for **Ji's sum rule** and the extraction of **J_q**

n-DVCS: access to E, the least known and constrained GPD



PhD thesis of M. Mazouz

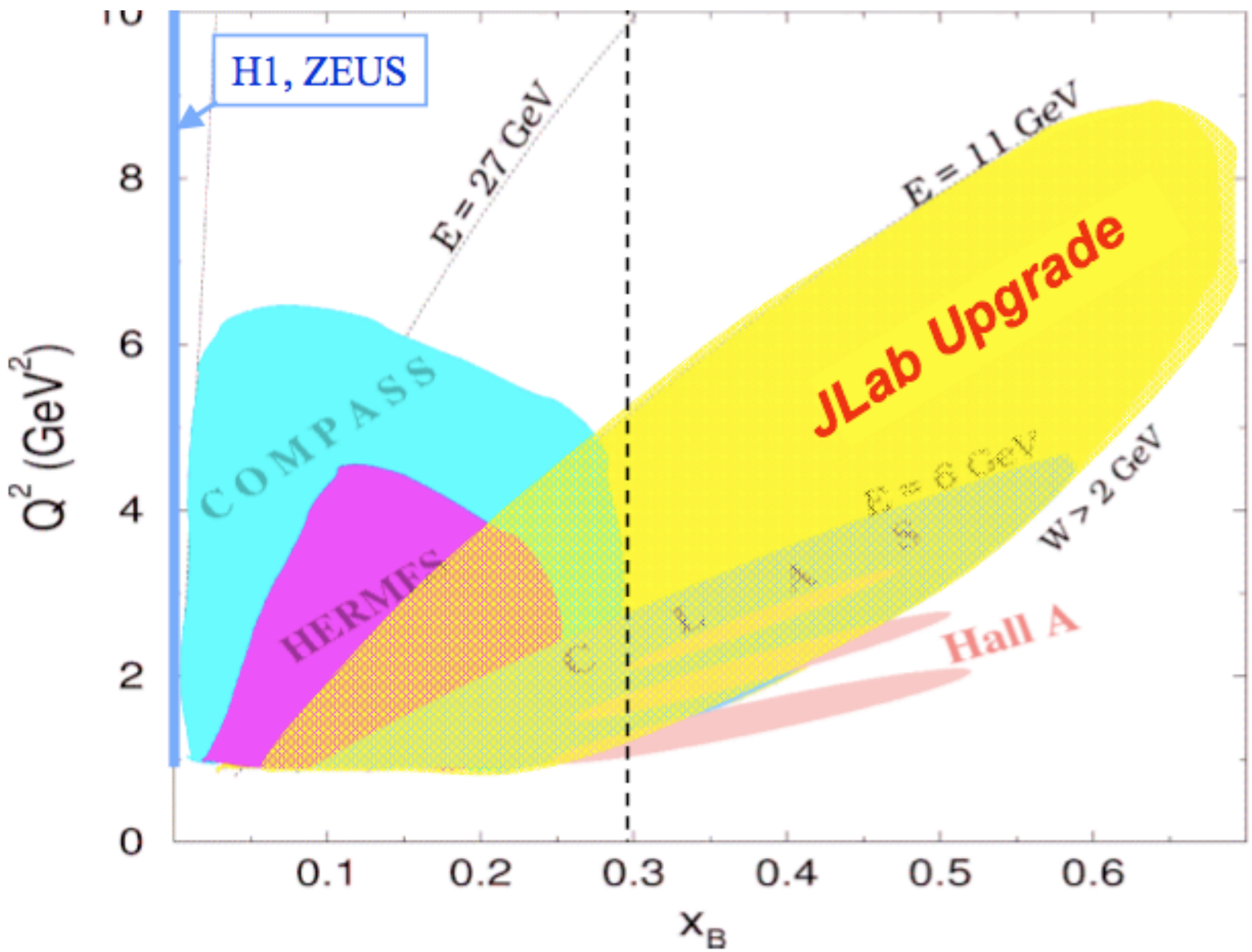


Silvia Niccolai

More data needed on DVCS and DVMP:

- **High Q^2 to verify scaling for DVCS on a wider Q^2 range, and to approach GPD validity regime for DVMP**
- **Wide x_B coverage**
- **High accuracy on measured observables to test models (high luminosity required)**
- **Measurements of spin-asymmetries AND cross sections**

JLab @ 12 GeV will be the optimal facility for these goals



What goes into a theoretically motivated parametrization...?

The name of the game: Devise a form combining essential dynamical elements with a flexible model that allows for a fully quantitative analysis constrained by the data

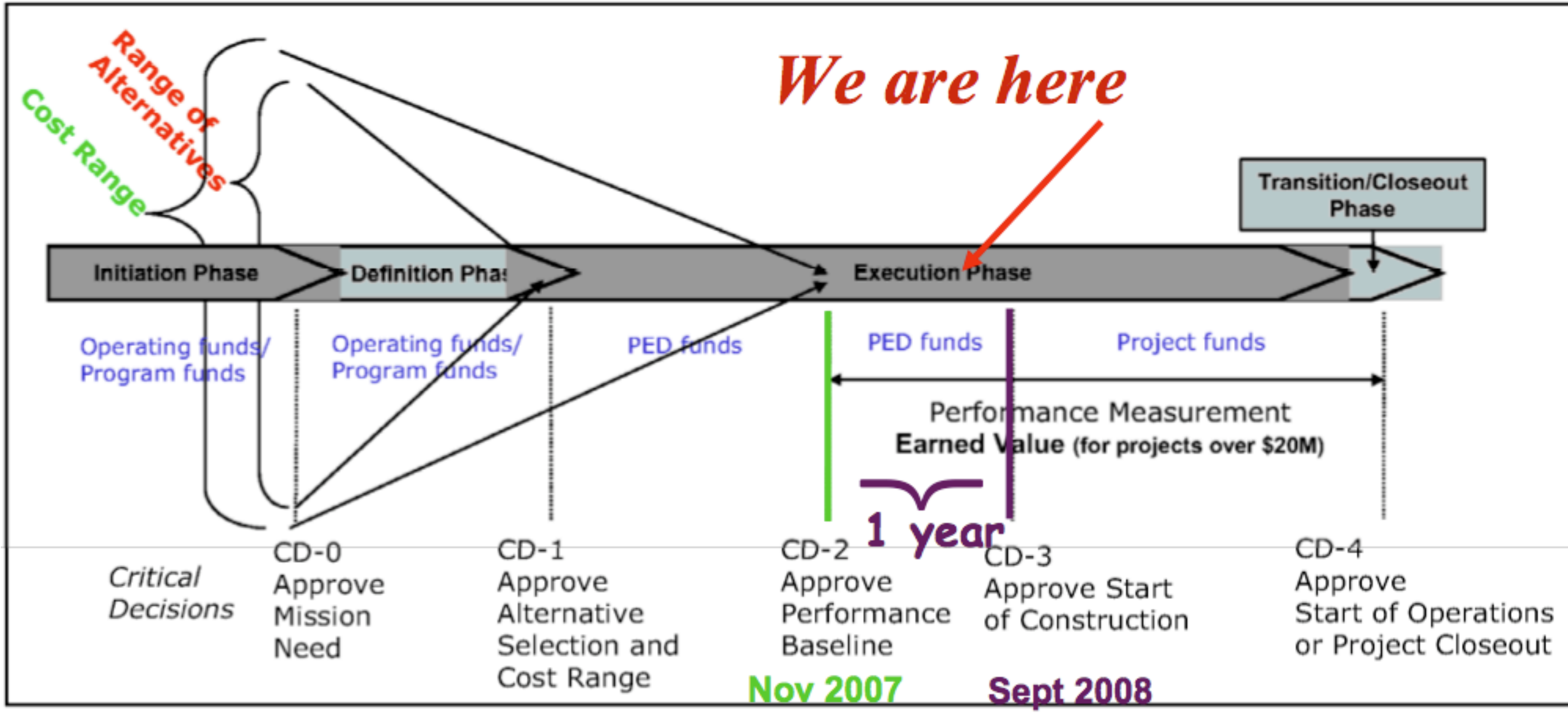
$$H_q(X,t)=R(X,t)\,G(X,t)$$

"Regge"

Quark-Diquark

Q^2 Evolution is an essential element!!

DOE Generic Project Timeline

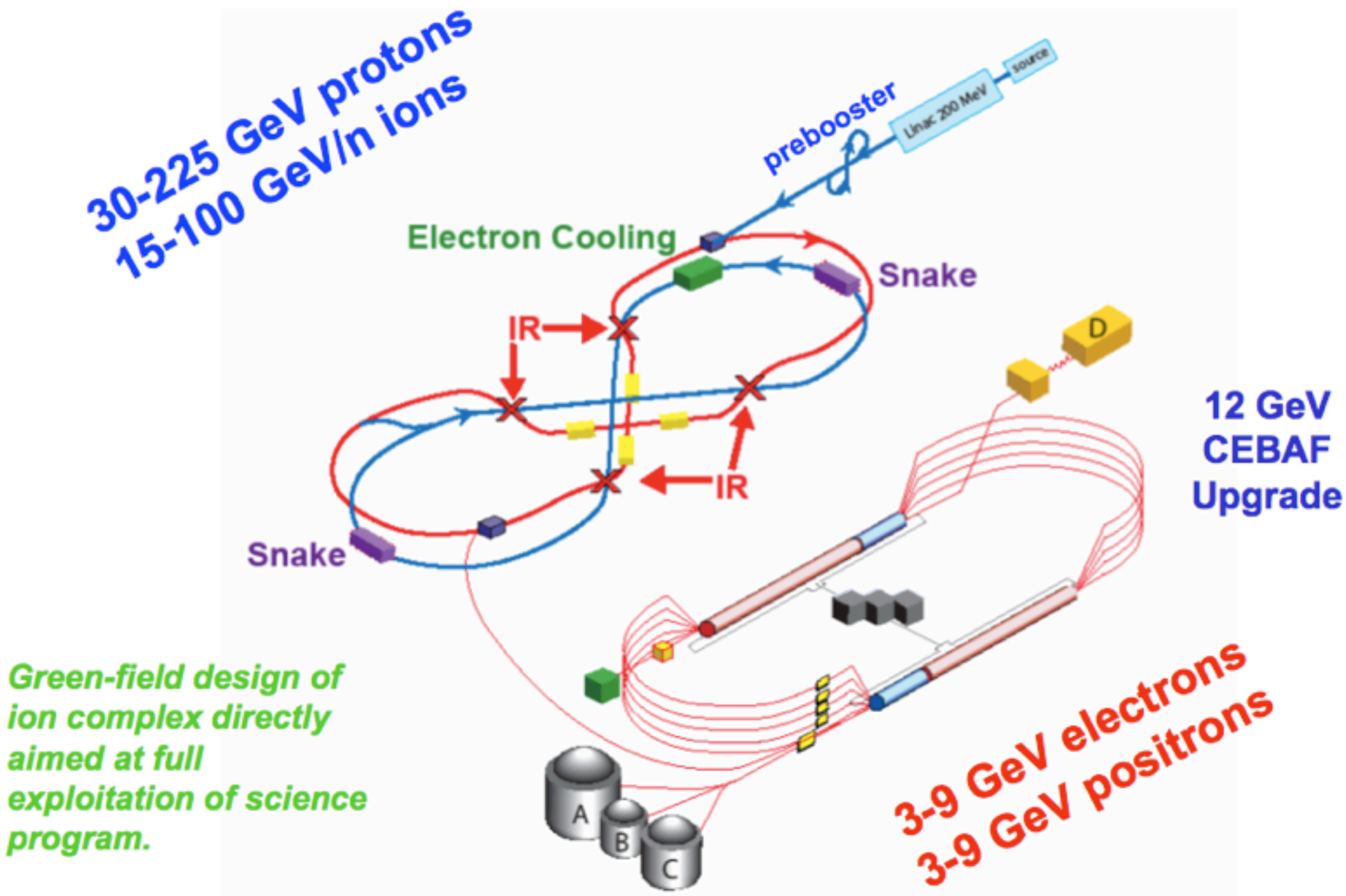


12 GeV Upgrade: Phases and Schedule

- 2004-2005 Conceptual Design (CDR) - ***finished***
- 2004-2008 Research and Development (R&D) - ***ongoing***
- 2006 Advanced Conceptual Design (ACD) - ***finished***
- 2006-2009 Project Engineering & Design (PED) - ***ongoing***

- 2009-2013 Construction – ***starts in ~ 6-9 months!***
  - ***Parasitic machine shutdown – May 2011 through Oct 2011 (6 months)***
  - ***Accelerator shutdown start mid-May 2012***
  - ***Accelerator commissioning mid-May 2013***
- 2013-2015 Pre-Ops (beam commissioning)
  - ***Hall A commissioning start ~October 2013***
  - ***Hall D commissioning start ~April 2014***
  - ***Halls B and C commissioning start ~October 2014***

ELIC Conceptual Design

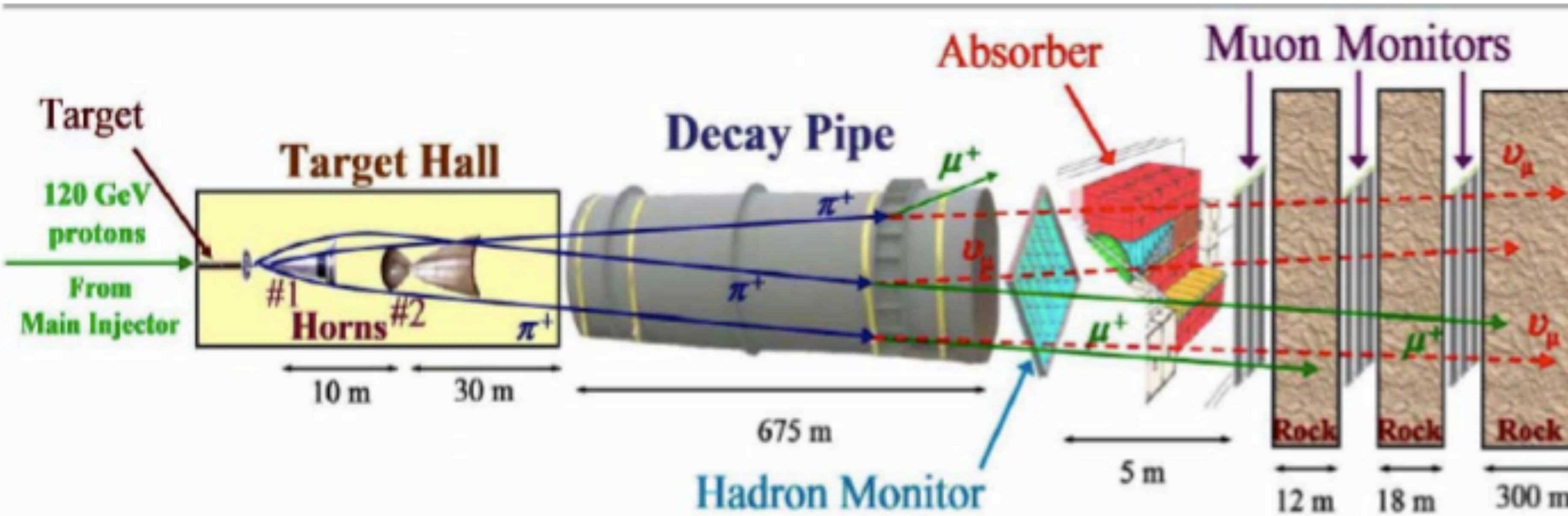


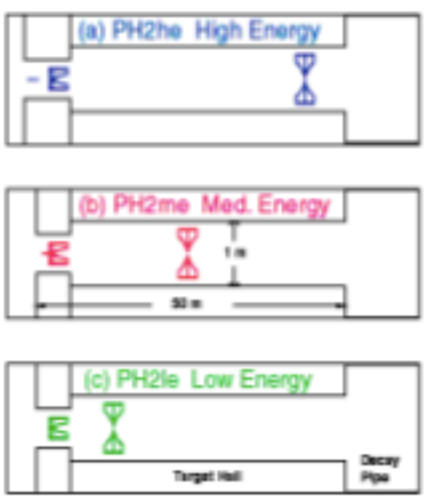
- *Simultaneous* operation of collider and CEBAF fixed target program

The MINERνA Experiment

Heidi Schellman for the MINERνA collaboration

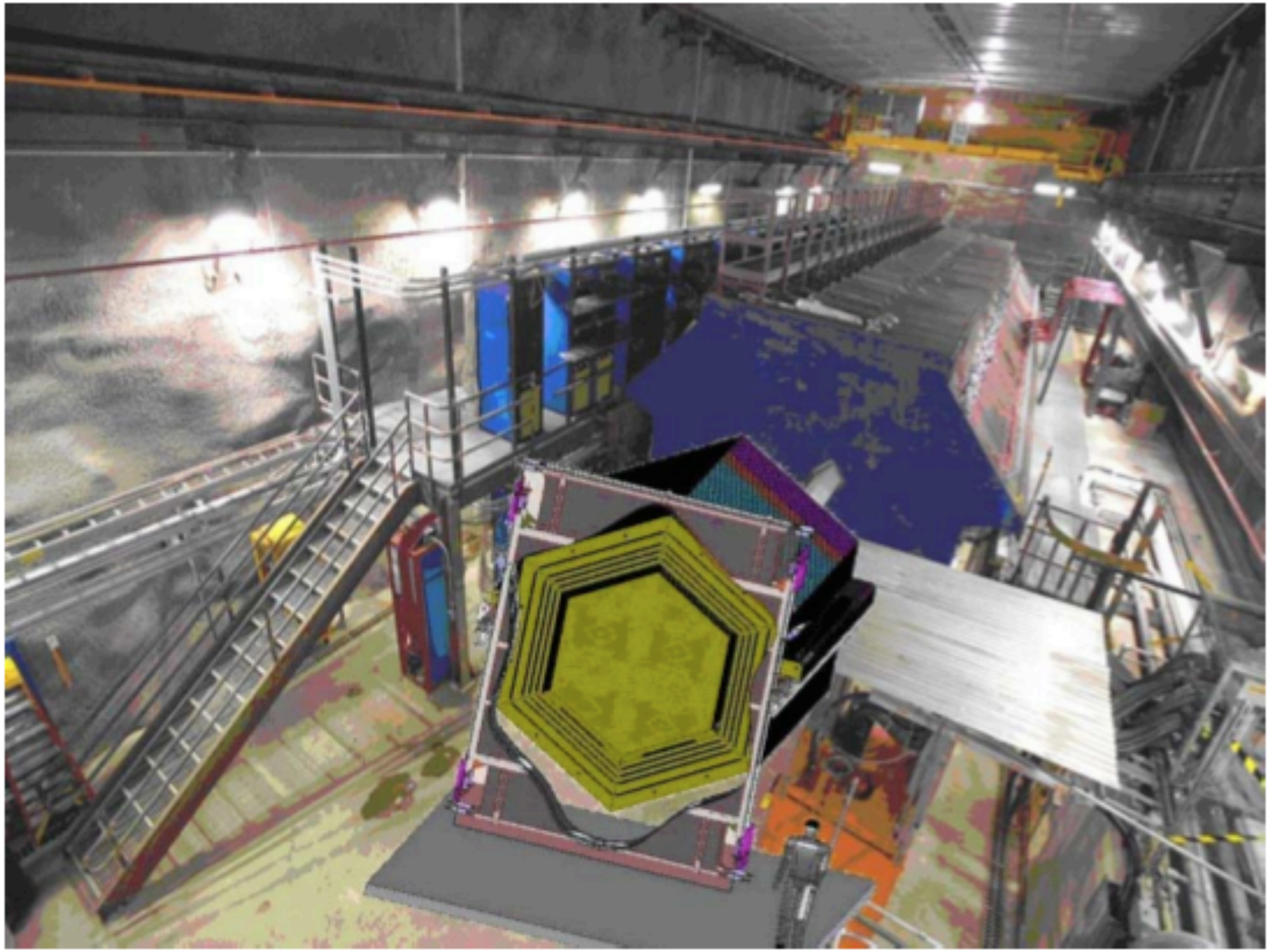
The NuMI Beam Configurations.





- For MINOS, the majority of the running will be in the "low-energy" (LE) configuration.
- Post-MINOS: NOvA would use the ME beam,
- MINERvA would prefer LE (≥ one year) and ME beam

“MINERvA” in the NUMI beamline



MINERvA Physics Goals

- Axial form factor of the nucleon
  - **Accurately measured over a wide Q2 range.**
- Resonance production in both NC & CC neutrino interactions
  - **Study of "duality" with neutrinos**
- Coherent pion production
- Strange particle production
- Parton distribution functions (DIS) at high x
- Generalized parton distributions
- Nuclear dependence of all of these
  - **Expect some significant differences for ν-A vs e/μ-A nuclear effects**

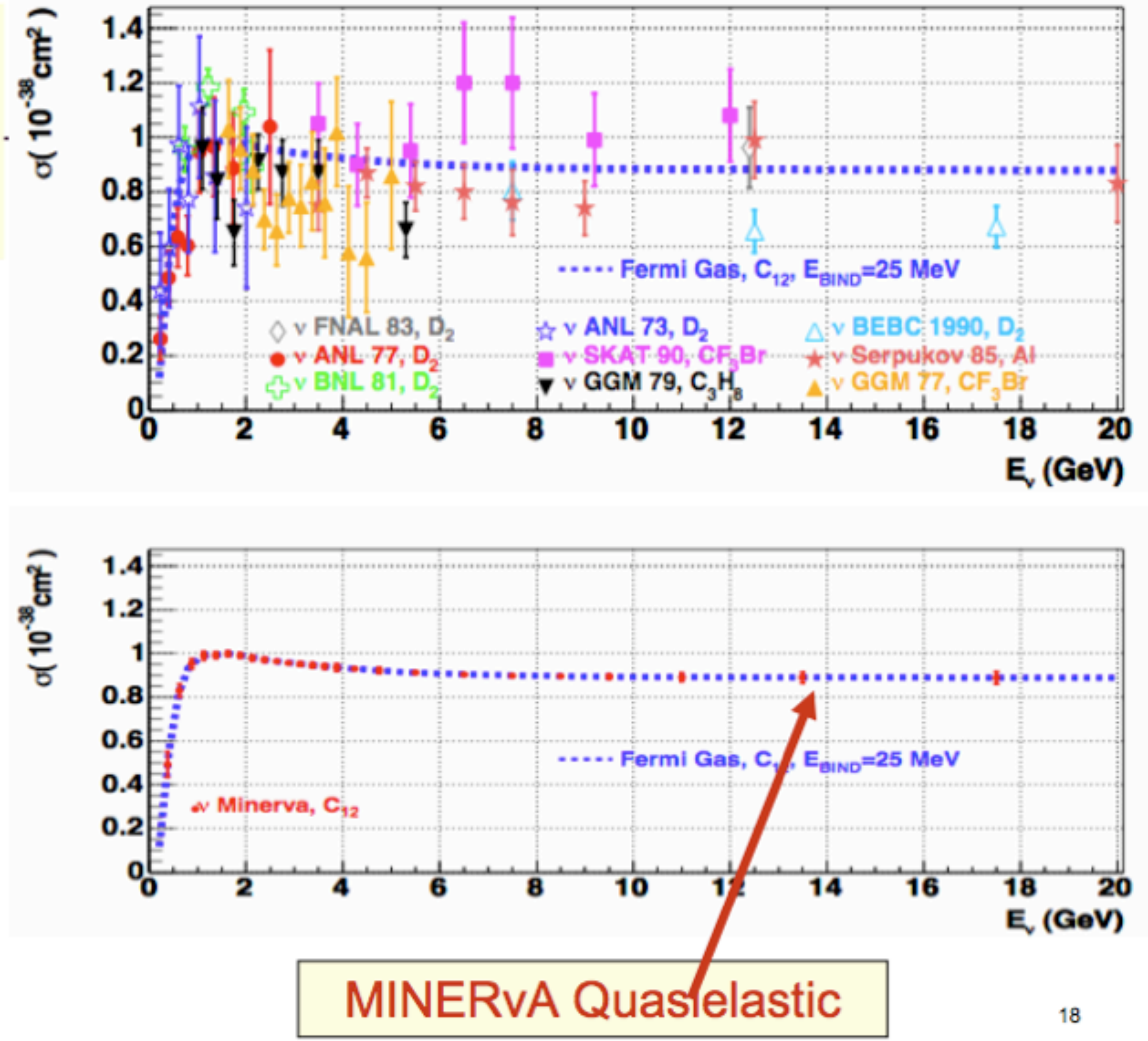
MINERvA measurements

Main CC Physics Topics (Statistics in active target only - CH)

- **Quasi-elastic** — **0.8 M events**
- **Resonance Production** — **1.7 M total**
- **Transition: Resonance to DIS** — **2.1 M events**
- **DIS, Structure Funcs. and high-x PDFs** — **4.3 M DIS events**
- **Coherent Pion Production** — **89 K CC / 44 K NC**
- **Strange and Charm Particle Production** — **> 240 K fully reconstructed events**
- **Generalized Parton Distributions** — **~ 10 K events**

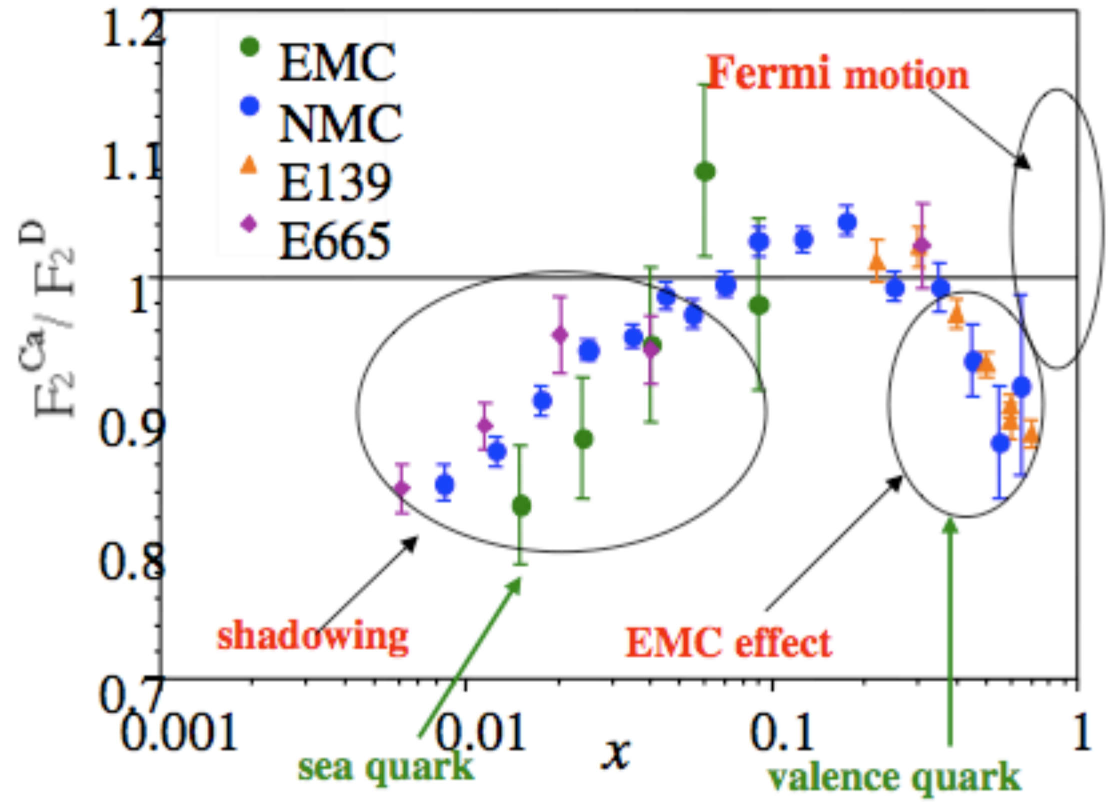
All absolute cross section
results will be limited by the flux normalization (~5%)

Precision Quasi Elastic



A-dependence in ν scattering

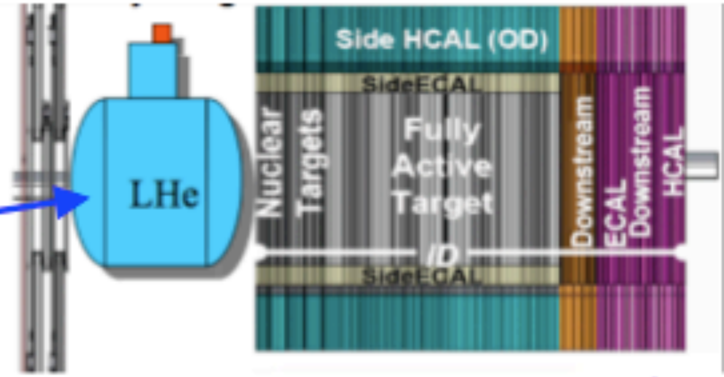
- A dependence observed in e/μ DIS
- Could be different for neutrinos
  - Presence of axial-vector current.
  - Different nuclear effects for valence and sea
  - leads to different shadowing for xF_3 compared to F_2.



If we understand at 10-20 GeV
Will that help at 100 GeV?
Comparing with JLAB will help.

Thia Keppel

Large x pdfs from ν - p Scattering (He designed for H,D)



(Harris)

$$F_2^{\nu p} = 2x\,(d + \bar{u} + s)$$

$$F_2^{\bar{\nu} p} = 2x\,(\bar{d} + u + \bar{s})$$

At high x →

$$\frac{F_2^{\nu p}}{F_2^{\bar{\nu} p}} = \frac{d}{u}$$

Add in…

$$xF_3^{\nu p} = 2x\,(d - \bar{u} + s)$$

$$xF_3^{\bar{\nu} p} = 2x\,(-\bar{d} + u - \bar{s})$$

→

$$F_2^{\nu p} - xF_3^{\nu p} = 4x\bar{u}$$

$$F_2^{\bar{\nu} p} + xF_3^{\bar{\nu} p} = 4xu$$

Unprecedented valence / sea separation

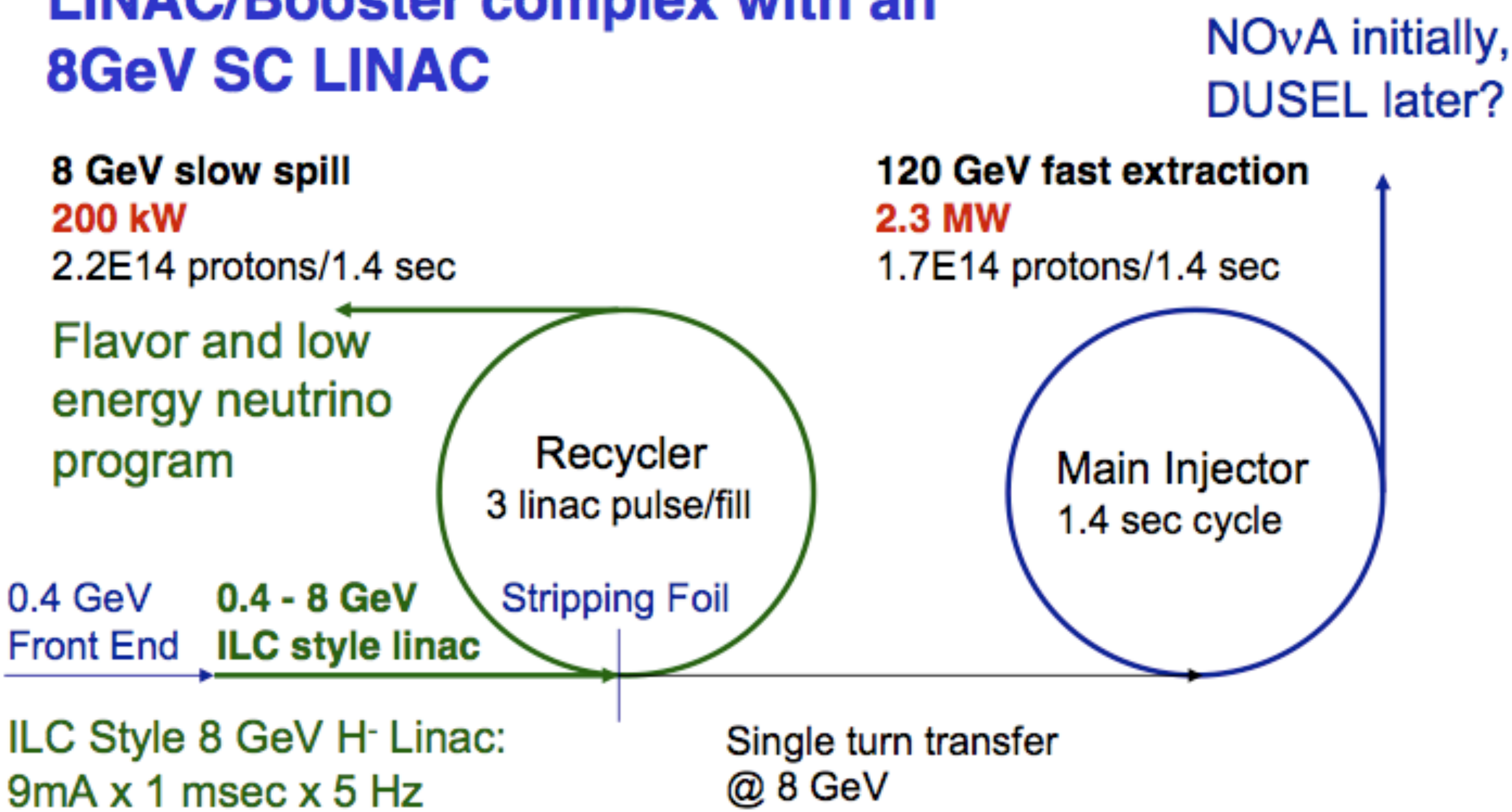
MINERvA schedule

- MINERvA received DOE critical decision (CD) 3a approval Spring 07
  - Authorization for advanced purchases
  - Beginning purchases for PMT's, WLS fiber, Clear fiber, PMT box components, steel and lead
- Approved for full construction authorization (CD 3b) Fall 07
  - Included in FY08 Presidential Budget for Department of Energy
  - Construction is beginning
- Detector installation and commissioning in 2009

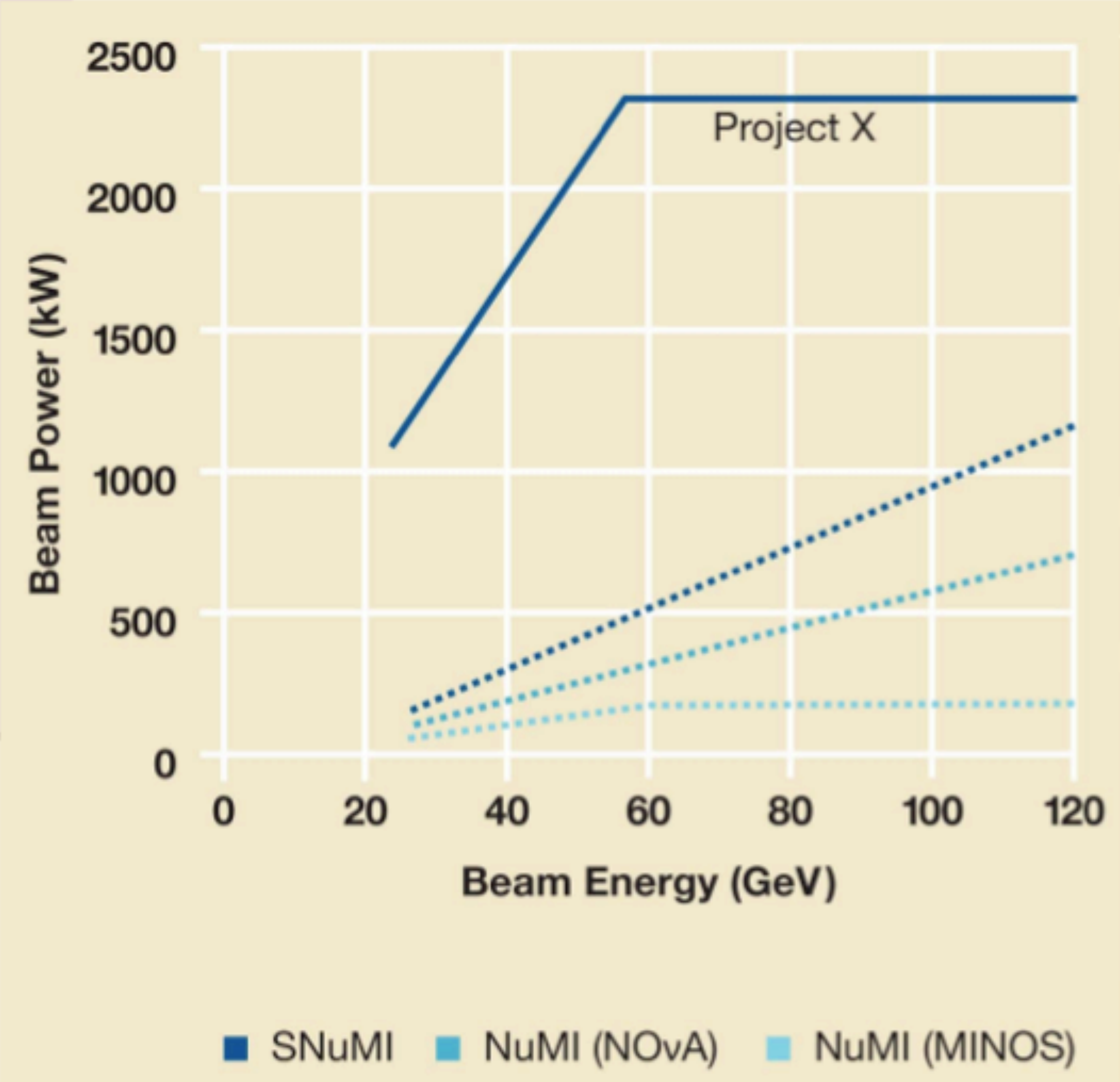
We'll bring results to DIS 2010

Project X

Replace the 35 year old LINAC/Booster complex with an 8GeV SC LINAC



The future: Beam power vs Energy



- NuMI(MINOS)
  - what we have now
- NuMI(NOvA)
  - near term upgrades
- SNuMI
  - big upgrades
- **Project X**
  - replace the whole injection system with an 8 GeV Linac

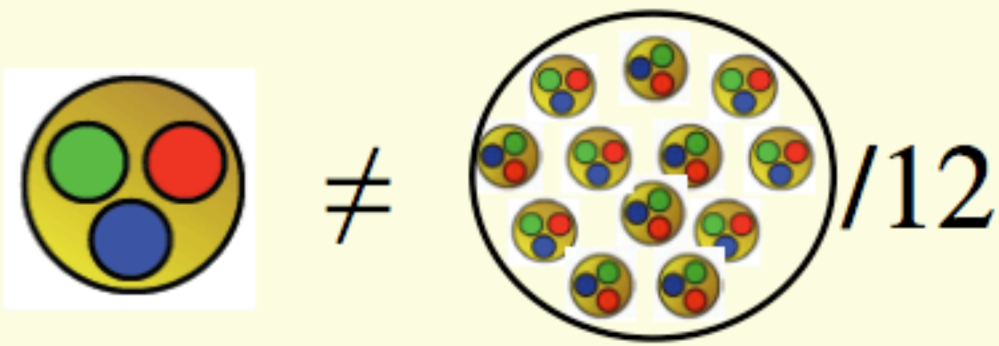
MINERνA with Hydrogen and Deuterium

- Nucleon structure - PDF's, especially high-x behavior, can be cleanly studied with ν/ $\bar{\nu}$ H.

$$F_2^{\nu p} = 2x\,(d + \bar{u} + s)$$

$$F_2^{\bar{\nu} p} = 2x\,(u + \bar{d} + \bar{s})$$

At high x → $$\frac{F_2^{\nu p}}{F_2^{\bar{\nu} p}} = \frac{d}{u}$$



- Combine with other MINERνA measurements (νHe, νC, νFe, νPb) to determine neutrino induced nuclear effects.

MINERνA I
Expected CC event samples:
9.0 M ν events in 3 tons of CH
0.6 M ν events in He

MINERνA X
Project X Event rates:

Assume 32.0x10^{20} protons in ME beam (2 years, 4 years?)

0.6 M ν events in H

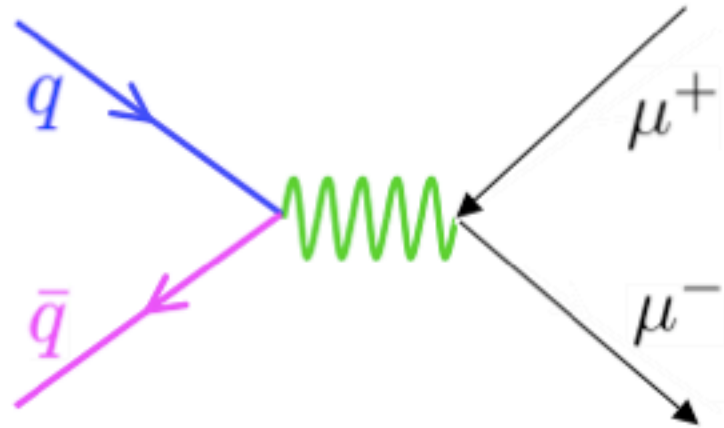
1.2 M ν events in D

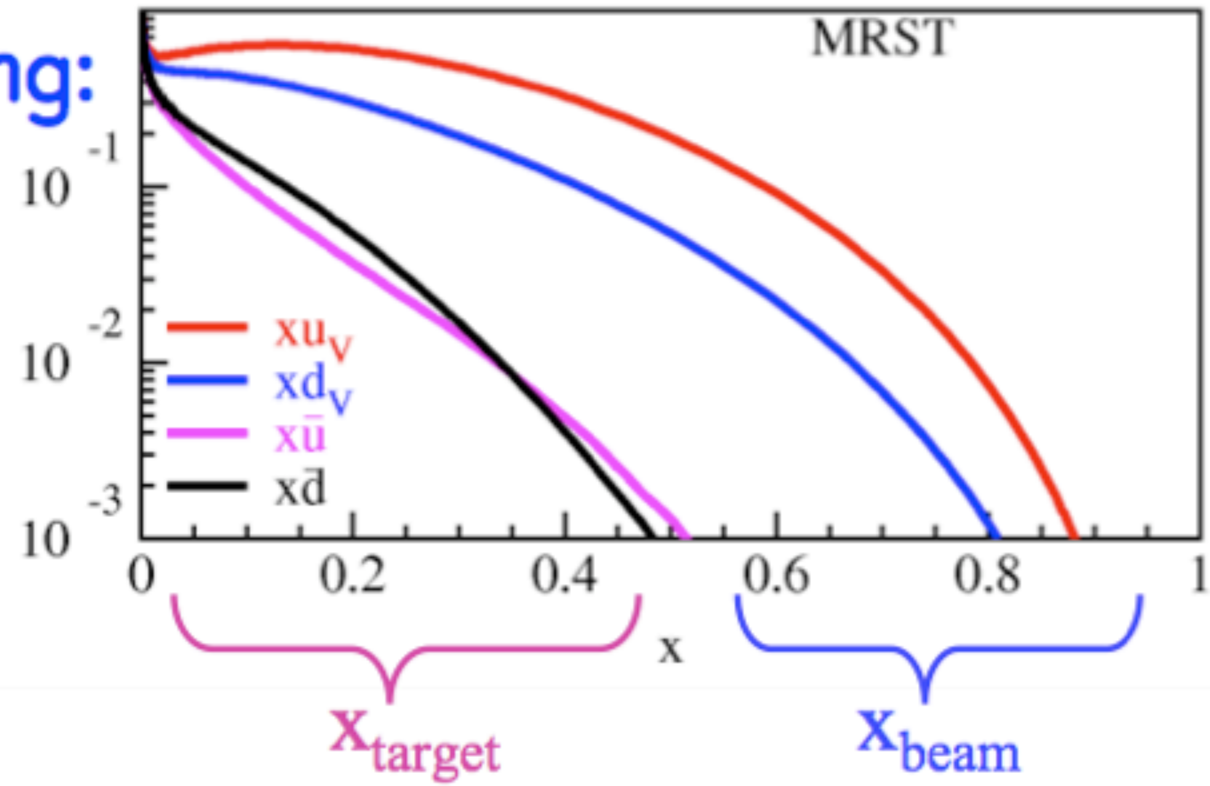
Conventional neutrino experiments @FNAL

	Fiducial mass	Energy	POT, x	Technology	Status	Goal
DONuT	0.3 T	20-300 GeV	0.03	Emulsion	complete	τ neutrino
NuTeV	680 T	20-300 GeV	0.03	Iron/Scint	complete	θ_W, DIS, charm
MiniBooNE	440 T	0.3-2 GeV	10	Mineral Oil	running	σ, anomaly
SciBooNE	10 T	0.3-2 GeV	2	Scintillator	running	σ, QE, Coh
MINOS near	100 T	1-20 GeV	25	Iron/Scint.	running	σ, QE, Coh, DIS
Minerva	5T	1-20 GeV	15	Scintillator	2010	σ, QE, Coh, excl., A dep., DIS
MicroBoone	50 T	0.3-2 GeV	6	Liquid Argon	Proposal	σ, QE, Coh, low E excess
HiResMNu	7.4T	1-20 GeV	120	magnetic tracker	LOI	θ_W, σ, excl.
NuSonG	3000 T	20-300 GeV	2	Glass	EOI	θ_W, DIS, A dep.

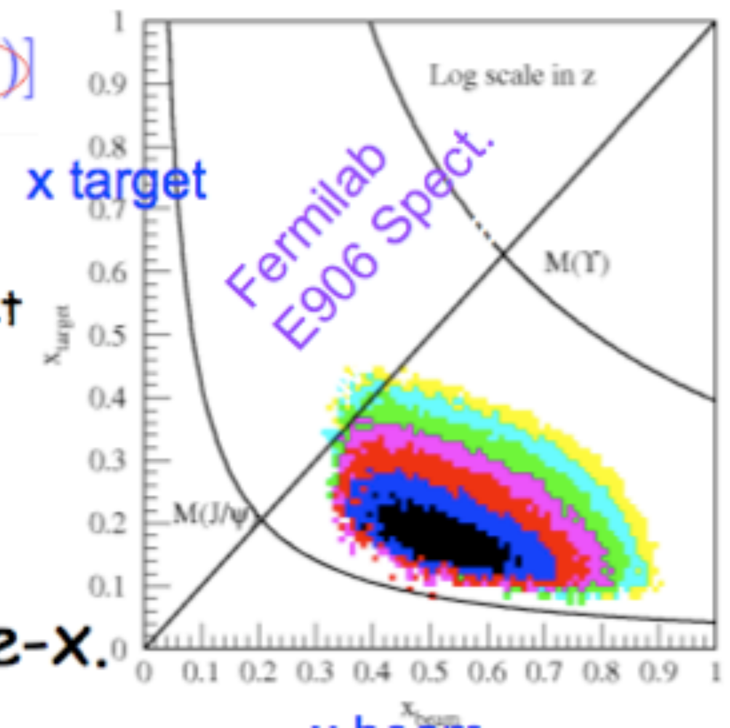
Thia Keppel

Drell-Yan scattering: FNAL E906





$$\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9x_1x_2}\frac{1}{s}\sum e^2\left[\bar{q}_t(x_t)q_b(x_b) + q_t(x_t)\bar{q}_b(x_b)\right]$$



E906 Detector acceptance chooses x_{target} and x_{beam}.

- Fixed target high $x_F = x_{beam} - x_{target}$
- Valence Beam quarks at high-x.
- Sea Target quarks at low/intermediate-x.

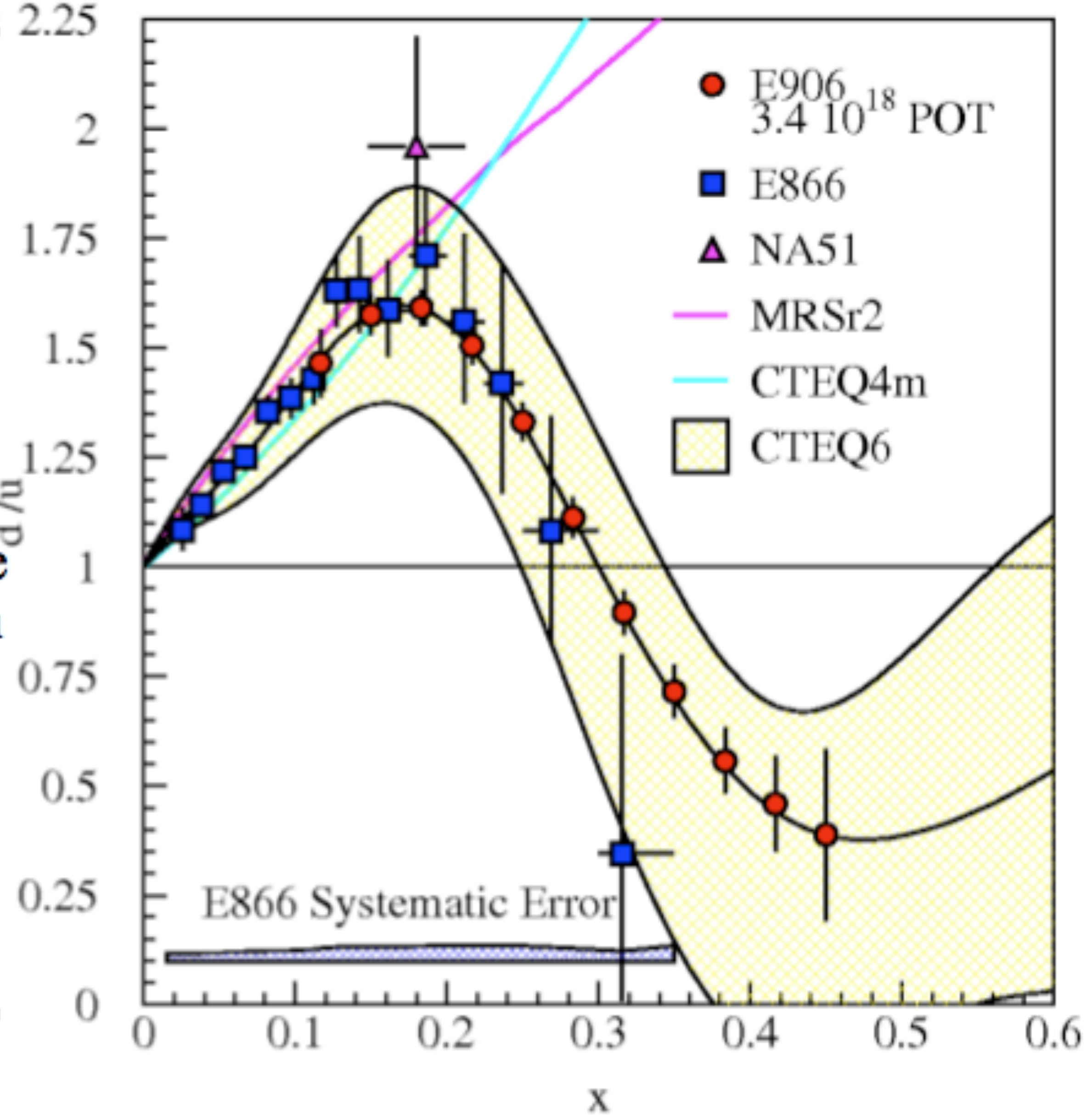
Extracting $\overline{d}/\overline{u}$ from Drell-Yan Scattering

Ratio of p,d Drell-Yan cross sections

$$\left.\frac{\sigma^{pd}}{2\sigma^{pp}}\right|_{x_b \gg x_t} \approx \frac{1}{2}\left[1 + \frac{\bar{d}(x_t)}{\bar{u}(x_t)}\right]$$

(Approximation in Leading Order. Data analysis and parton distribution fits confirmed in NLO)

- Global NLO PDF fits which include E866 cross section ratios agree with E866 results
- Fermilab E906/Drell-Yan will extend these measurements and reduce statistical uncertainty.
- E906 expects systematic uncertainty to remain at approx. 1% in cross section ratio.

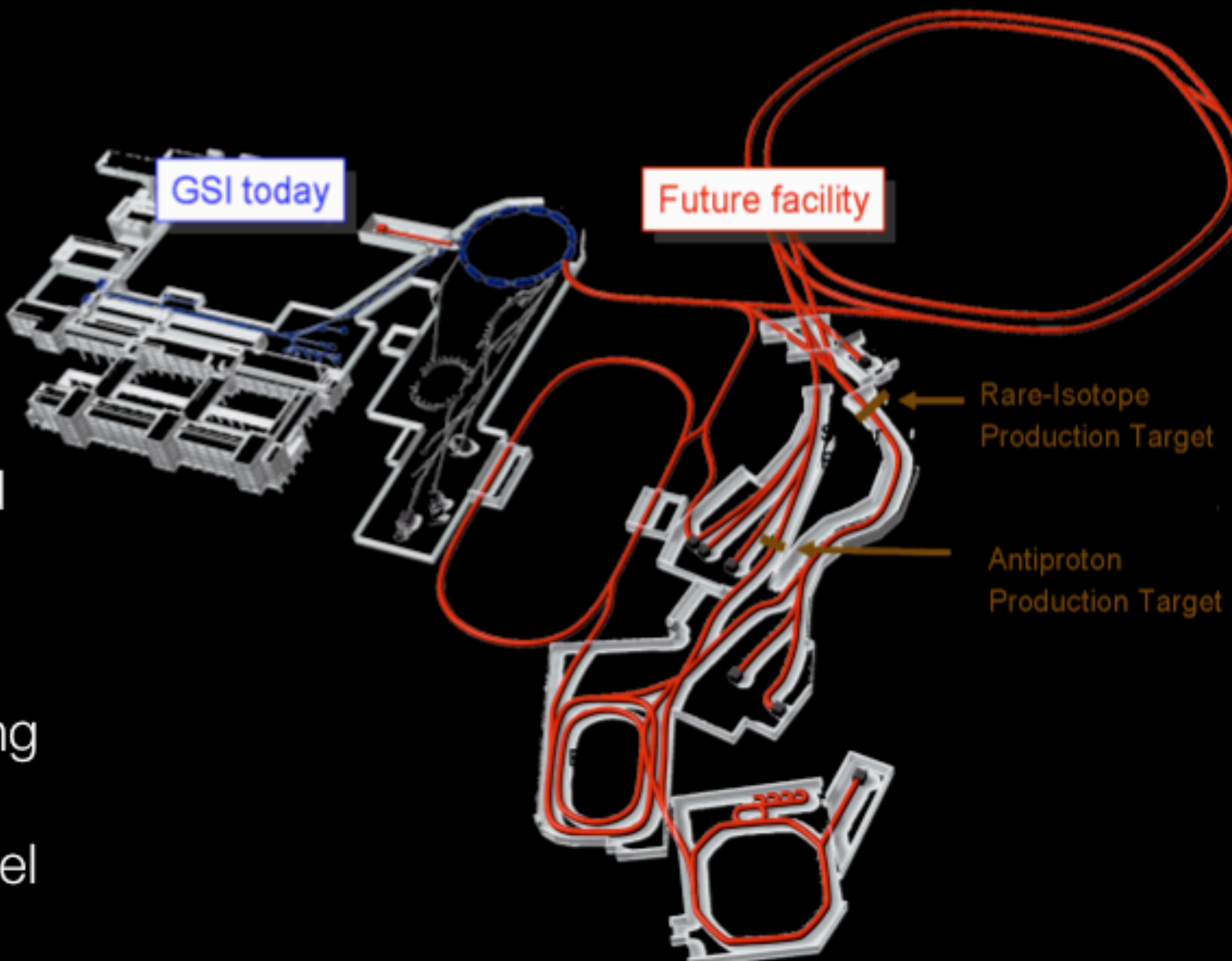


Bjoern Seitz

PANDA @ FAIR

Antiproton Annihilation at Darmstadt @ Facility for Antiproton and Ion Research

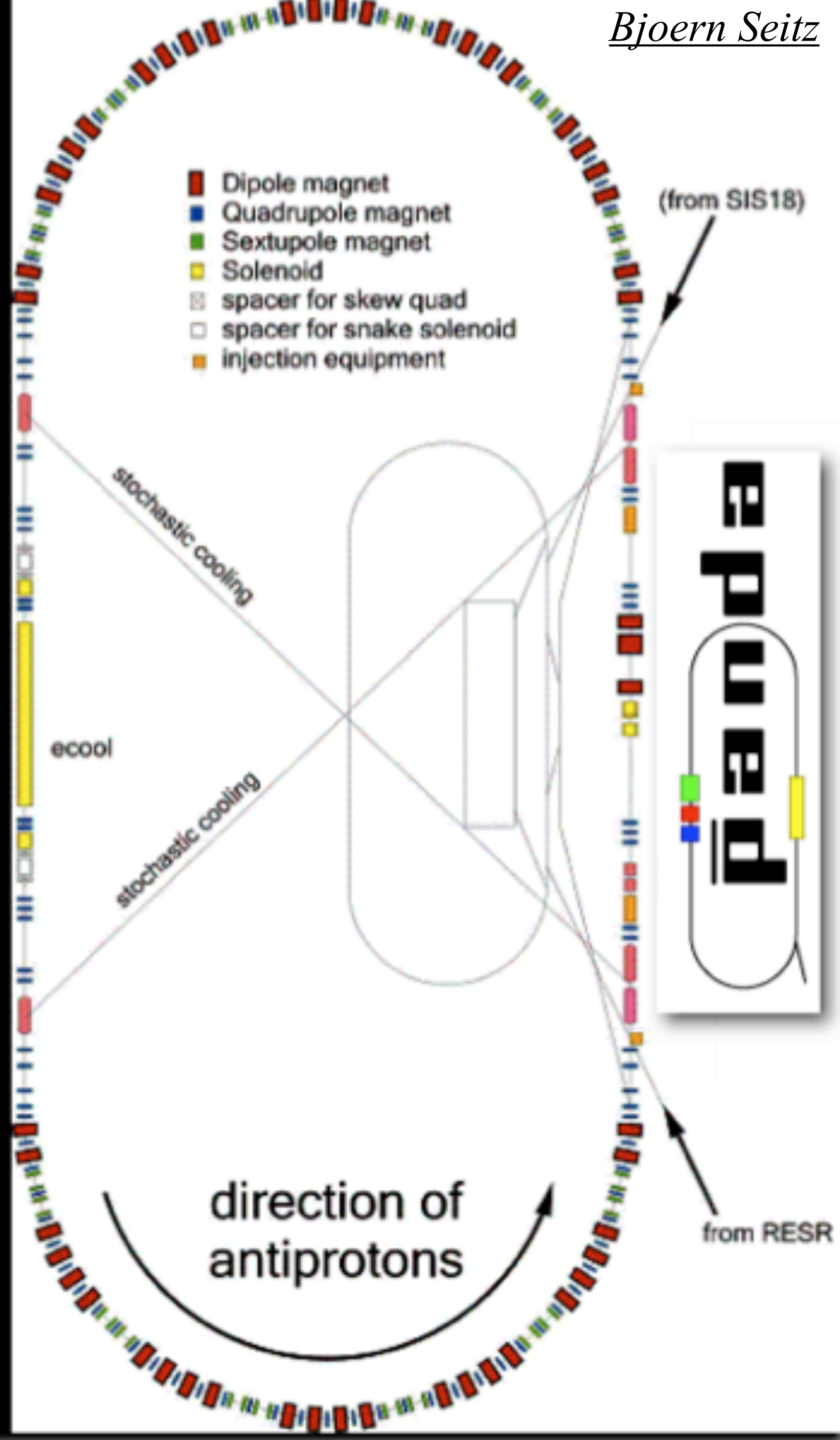
- High intensity are Isotope beam
- up 45 GeV/u heavy ion beams for QCD studies
- 15 GeV/c cooled and stored antiproton beam
- Versatile facility serving a multitude of user communities in parallel

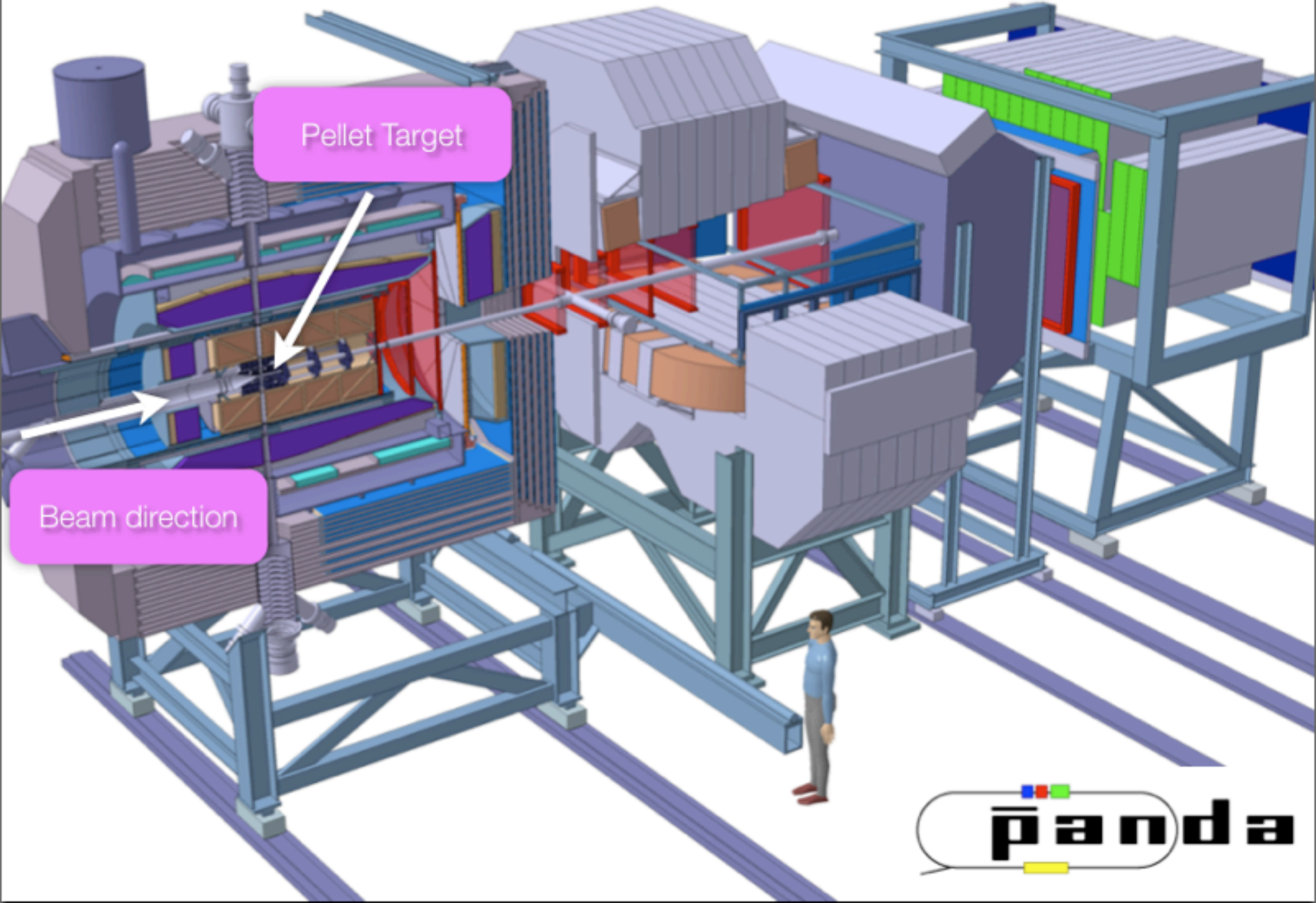


Bjoern Seitz

High Energy Storage Ring

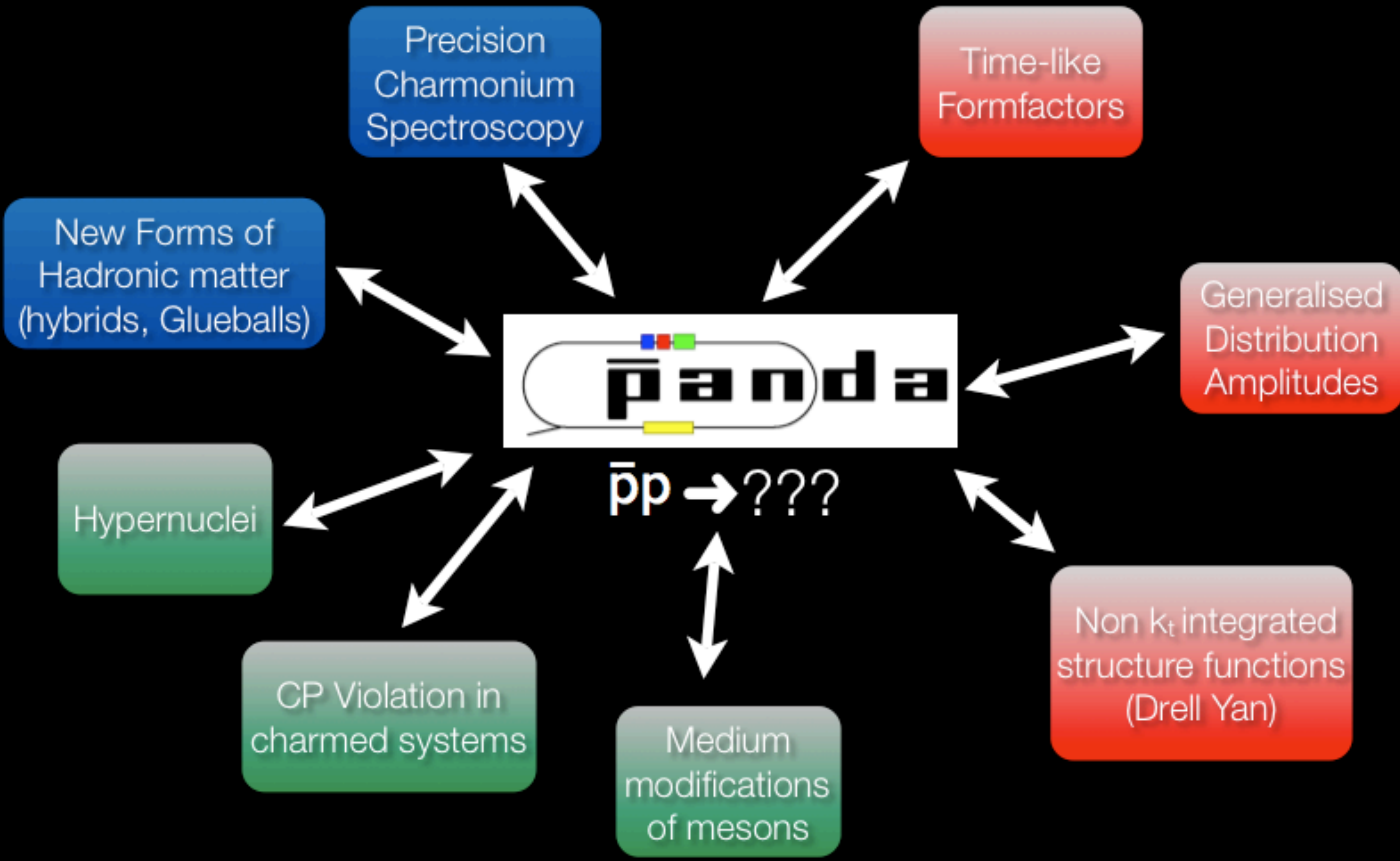
- antiproton momentum 1.5 GeV/c < p < 15 GeV/c
- Stochastic and electron cooling: $\Delta p/p < 10^{-5}$
- Luminosity > $10^{31} cm^{-2} s^{-1}$
- Hydrogen pellet or jet target, polarised Hydrogen under study
- Variety of nuclear targets




Pellet Target
Beam direction
panda

Bjoern Seitz

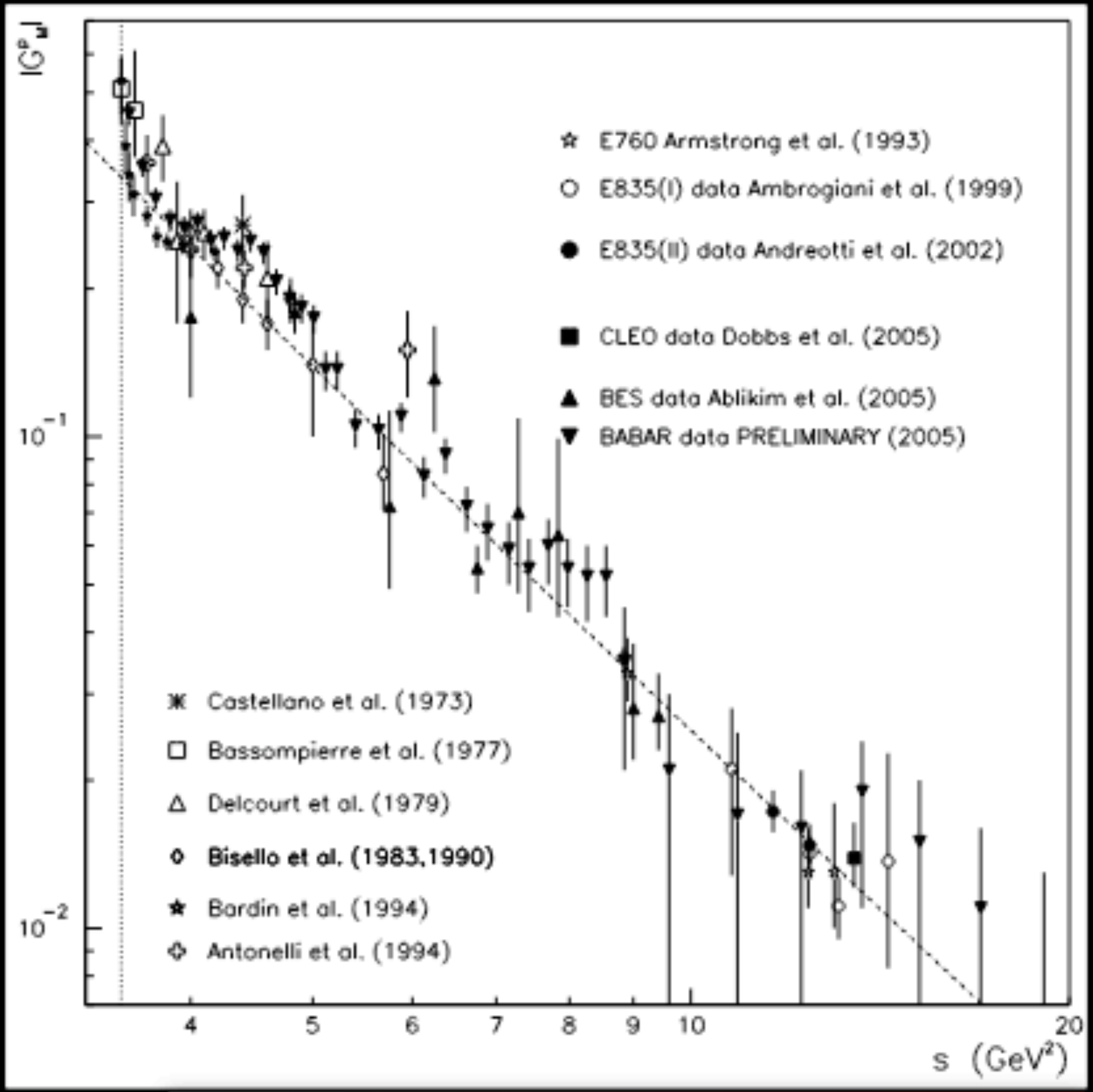
Physics at PANDA



Bjoern Seitz

Time-like Formfactors

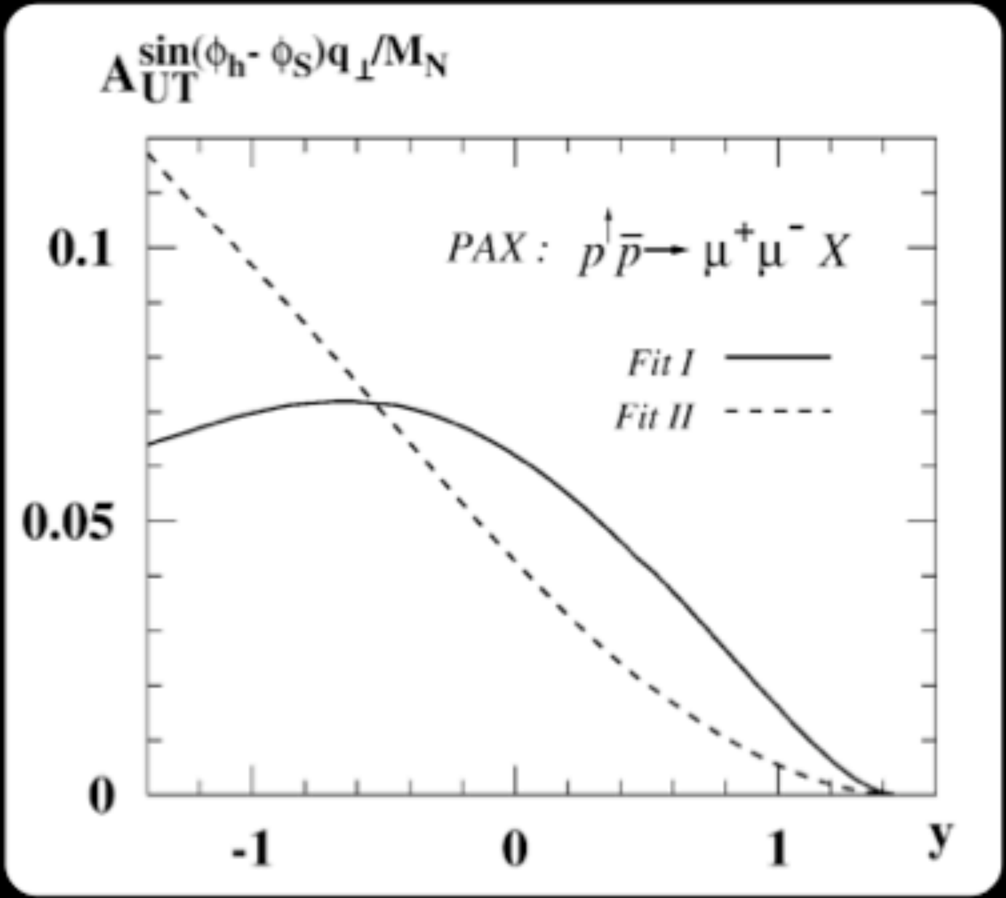
- All existing data measure absolute cross section $G_E = G_M$
- PANDA will provide independent measurements of G_E and G_M
- widest kinematic range in a single experiment
- Time-like form factors are complex
- precision experiments will reveal these structures



PANDA range

Measurement of Sivers Function

- Single polarised transverse target provides measurement of Sivers function
- Sign provides crucial test for QCD and factorisation
- Model predictions based on HERMES data look promising



Efremov et al PLB 612 (2005)233

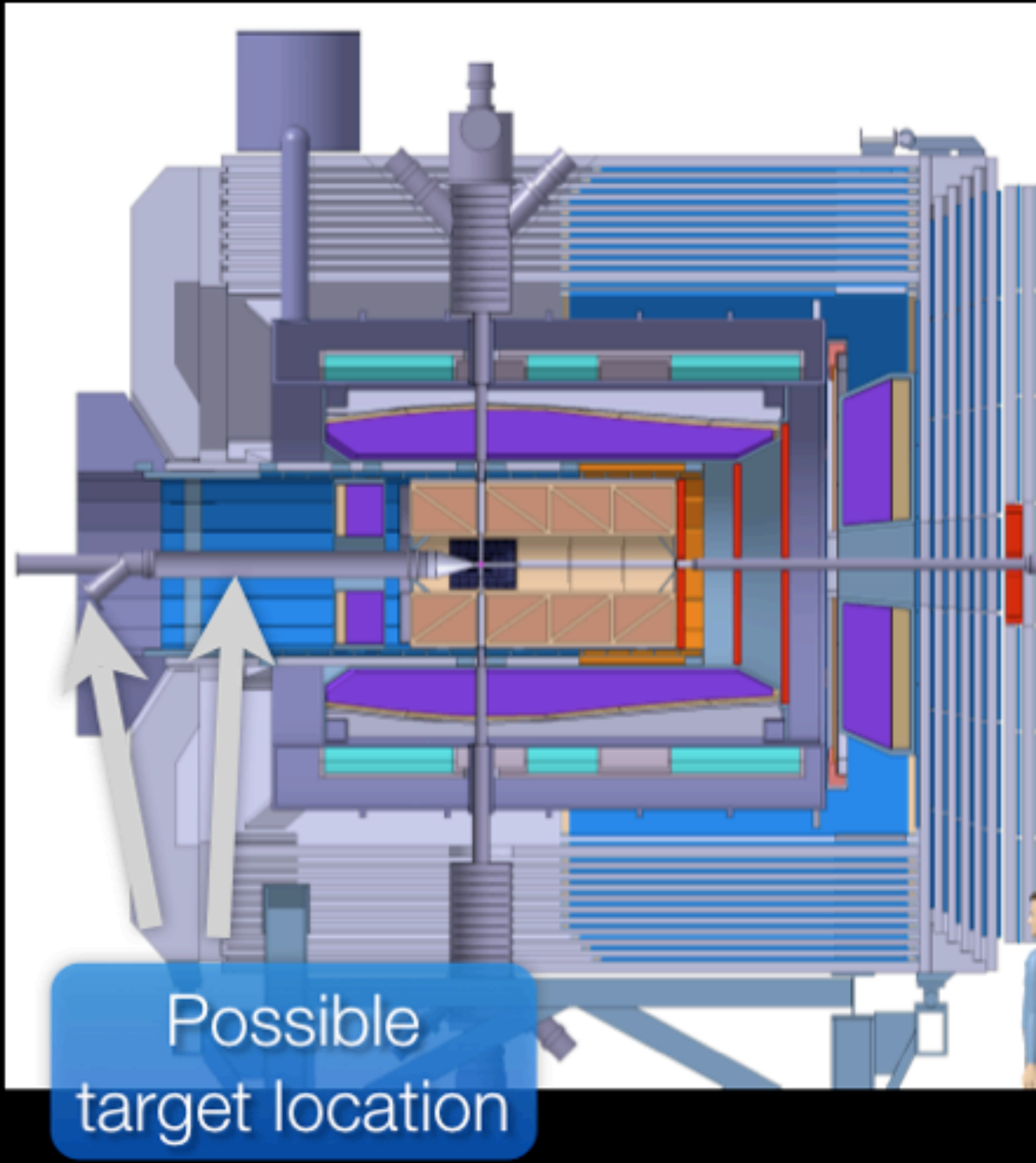
$$(f_{1T}^{\perp})_{DY} = -(f_{1T}^{\perp})_{DIS}$$

$$A_N^{DY} \propto f_{1T}^{\perp}(x_1, k_{1\perp}) \otimes f(x_2)$$

Bjoern Seitz

Polarised Physics at PANDA

- Transversely polarised protons increase PANDA physics potential
  - SSA in Drell Yan
  - Phase difference between G_E and G_M
- Polarised target inside solenoid very difficult
- Exploit modular upstream design for polarised target with storage cell



In short ...

- Jefferson Lab at 12 GeV
  - → unique access to large-x region
  - → PDFs $(d/u, \Delta d)$, TMDs , GPDs (J_u, J_d) , EMC effect
  - → CD-3 (start of construction) expected Sep. 2008
- MINERvA, Project X at Fermilab
  - → PDFs at high x, neutrino-nucleus cross sections, neutrino GPDs
  - → construction beginning, detector installation 2009
- PANDA at FAIR
  - → time-like form factors, TMDs in Drell-Yan
  - → experiments from 2014

Thank you
to speakers,
organisers!