INT Program Overview

Markus Diehl
Deutsches Elektronen-Synchroton DESY

EIC Advisory Committee Meeting
Jefferson Lab, 10 April 2011

Program "Gluons and the quark sea at high energies: distributions, polarization, tomography

- INT, University of Washington, 13 Sept to 19 Nov 2010
- overall aim: help develop and sharpen science case for an EIC
- organizers:

  D. Boer, M. Diehl, R. Milner, R. Venugopalan, W. Vogelsang

  assisted by 12 physics coordinators (→ next slide)

- program website:

  http://www.int.washington.edu/PROGRAMS/10-3

  - ★ transparencies of talks (plus podcasts in some cases)
  - ★ links to wiki pages of working groups
  - ★ proceedings (hopefully soon)

Working groups and physics coordinators

- The origin of nucleon spin

  D. Hasch, M. Stratmann, F. Yuan

- The spatial structure of QCD matter

  M. Burkardt, V. Guzey, F. Sabatié

- QCD matter under extreme conditions

  A. Accardi, M. Lamont, C. Marquet

- Beyond the Standard Model / Electroweak physics

  K. Kumar, Y. Li, W. Marciano

- tasks:
  - ★ contact with participants, timetable of talks
  - ★ lead discussion sessions
  - ★ collect and edit proceedings contributions
- thanks already now for their work

Topics and timetable

Gluons and the quark sea at high energies

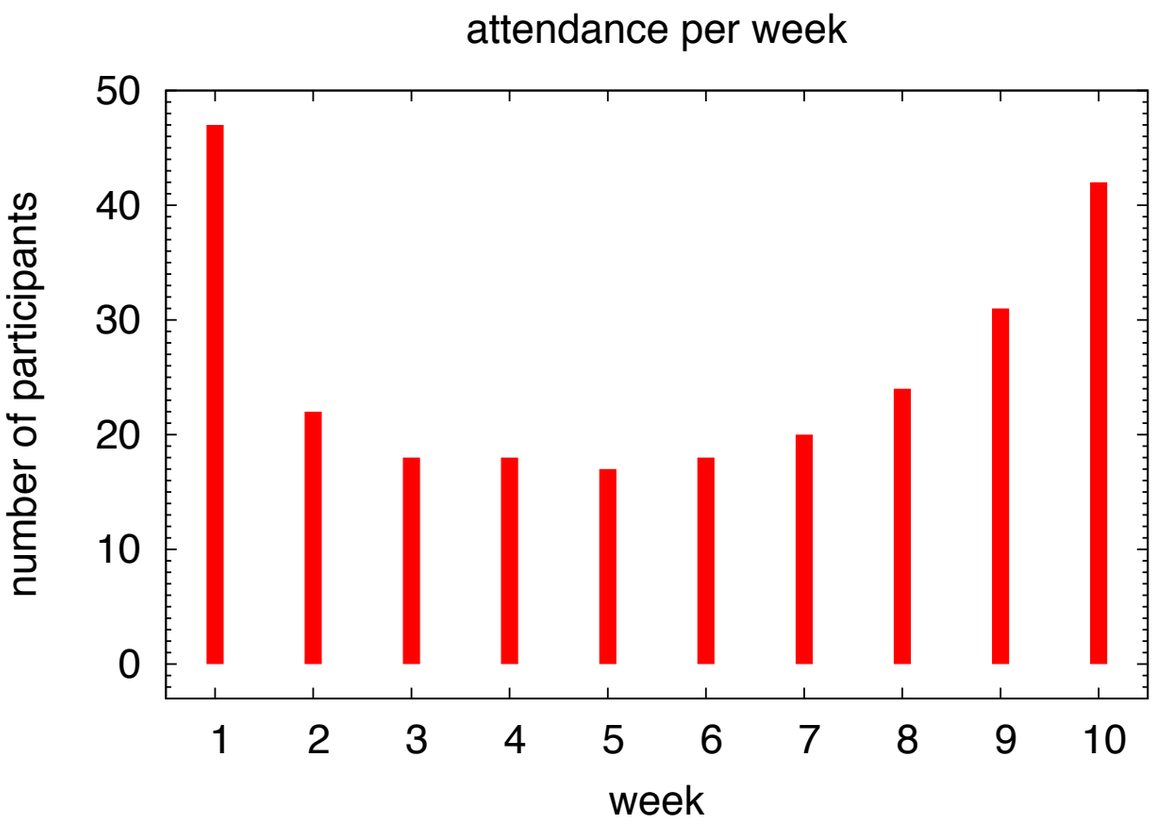
http://www.int.washington.edu/PROGRAMS/10-3/

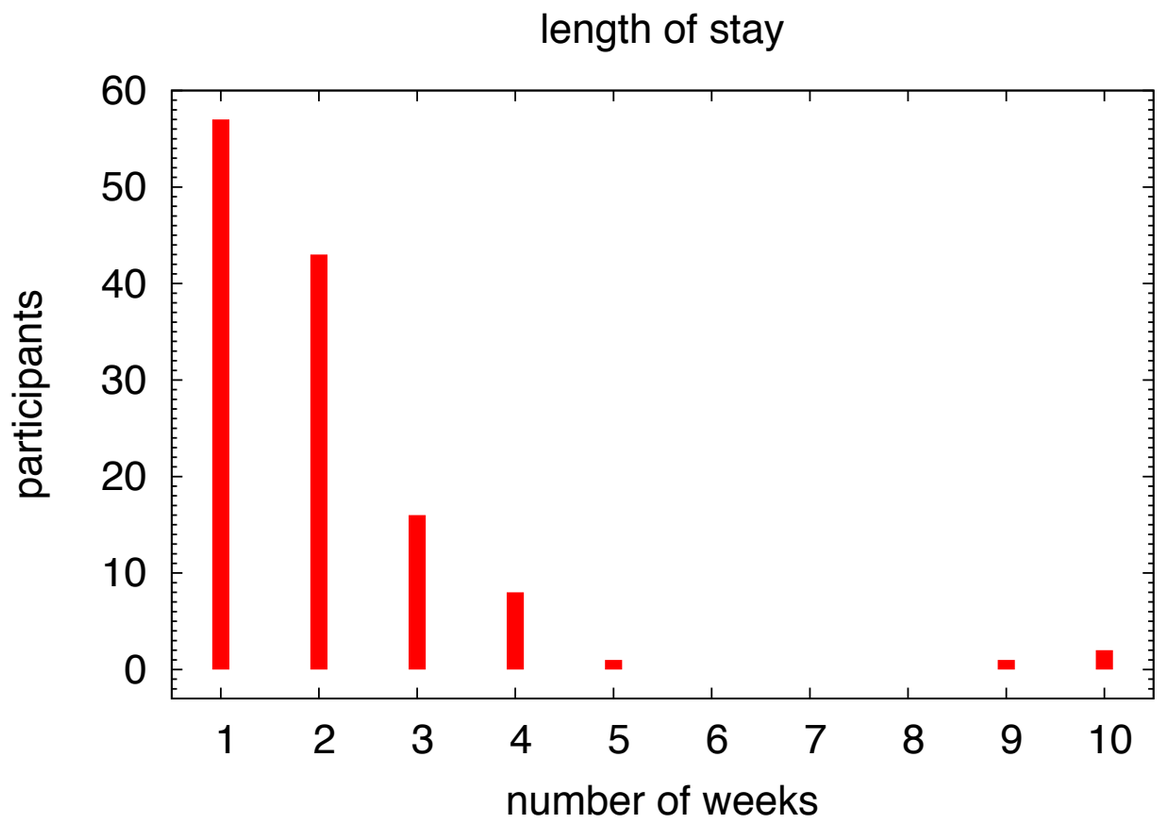
Gluons and the quark sea at high ...

week	dates	topics
1	13–17 Sept	**Workshop** on "Perturbative and Non-Perturbative Aspects of QCD at Collider Energies" Agenda
2	20–24 Sept	open conceptual issues: factorization and universality, spin and flavor structure, distributions and correlations Agenda
3–5	27 Sept –15 Oct	small x, saturation, diffraction, nuclear effects; connections to p+A and A+A physics; fragmentation/hadronization in vacuum and in medium Agenda for week 3 Agenda for week 4 Agenda for week 5
6–7	18–29 Oct	parton densities (unpolarized and polarized), fragmentation functions, electroweak physics Agenda for week 6 Agenda for week 7
8–9	1–12 Nov	longitudinal and transverse nucleon structure; spin and orbital effects (GPDs, TMDs, and all that) Agenda for week 8 Agenda for week 9
10	16–19 Nov	**Workshop** on "The Science Case for an EIC" Agenda for week 10

- opening and closing workshops
- 8 program weeks: 2 to 3 talks per day, discussions, weekly "wrapups"

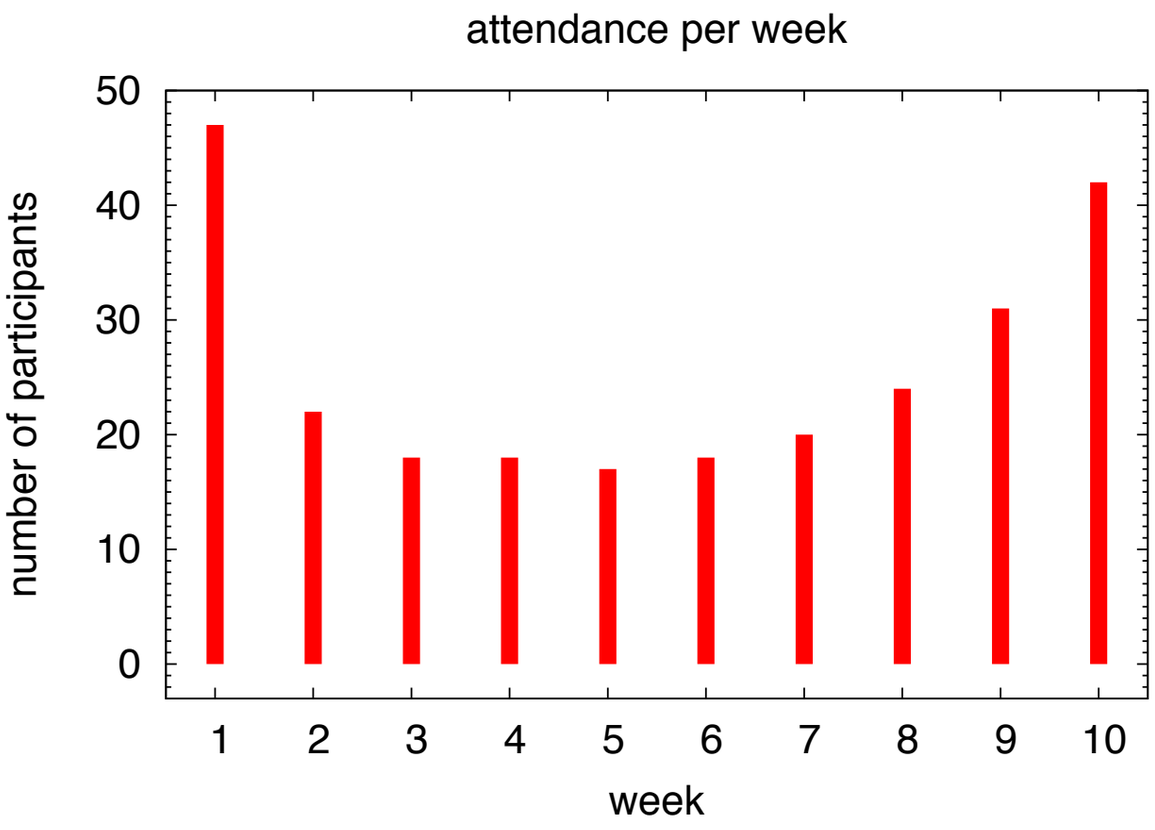
Attendance

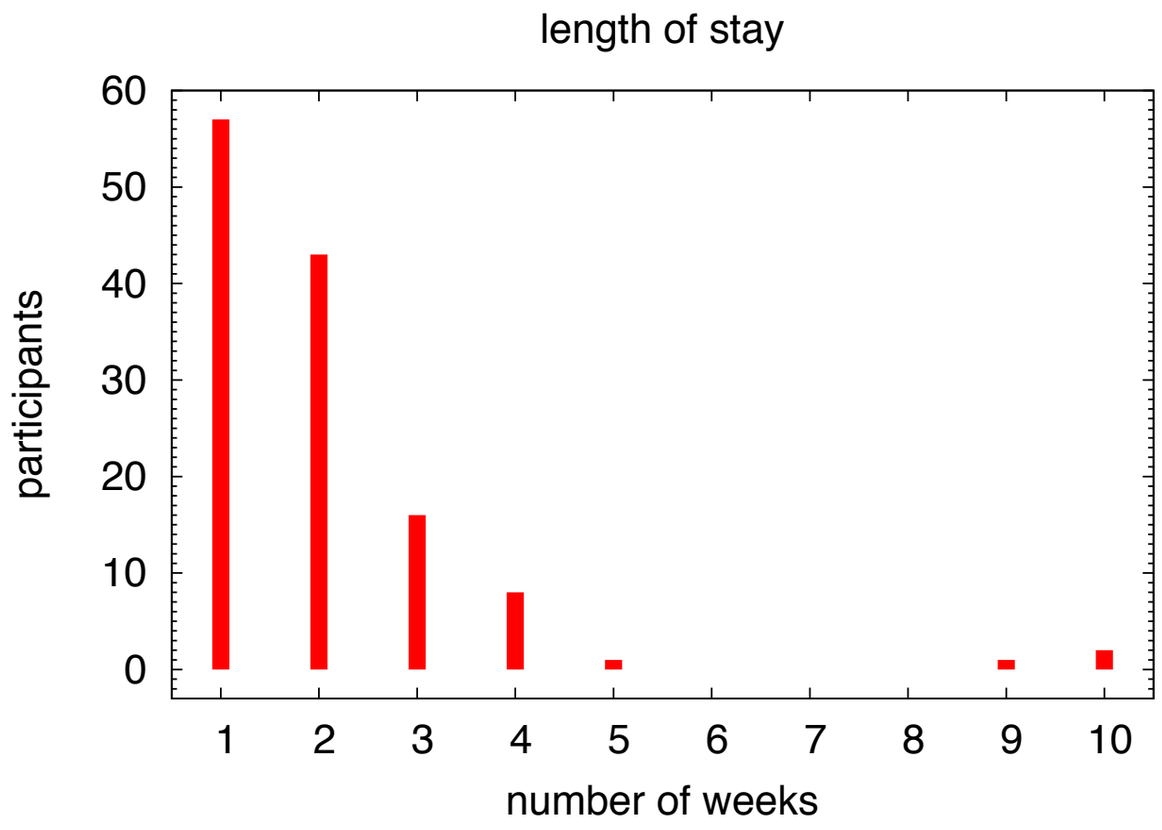




- 128 participants, 31 came to Seattle twice or more
  - ➡ significant interest and willingness to contribute
  - ➡ extraordinary effort by INT staff: thanks
  - ➡ thanks to BNL and JLab for supporting their own participants

Attendance





- 128 participants, 31 came to Seattle twice or more
  - ➡ but: most participants have many other commitments
  - ➡ a number of studies would gain from increased manpower
  - ➡ this is not a time to "sit back and relax"

Proceedings

- will be pubished jointly by BNL, INT and JLab
- hardcopies and online version (to be put on the arXiv, INT website, etc.)
- status:
  - have 90% to 95% of contributions
  - several studies initiated at INT, completed for proceedings
  - coordinators are editing (shorten document to ~ 500 pages)
  - hope to have online version ready by beginning of May
- individual contributions combined into coherent chapters (not a collection of all program talks)

Proceedings outline

- chapters on the main physics topics:
  - The spin and flavor structure of the nucleon
    (polarized and unpolarized parton densities)
  - Three-dimensional structure of the nucleon and nuclei:
    transverse-momentum distributions
  - Three-dimensional structure of the nucleon and nuclei:
    spatial imaging (exclusive processes, GPDs)
  - QCD matter under extreme conditions
    (saturation, parton distributions and hadronization in nuclei)
  - electroweak physics (weak mixing angle, $e \to \tau$ conversion)
- shorter chapters on
  - input from lattice QCD
  - experimental aspects: accelarator and detector designs
    interplay between key mesurements, kinematics, detectors, IP design

Making the case for an EIC

- what are the main physics questions we want to study?
  how do they fit into a broader context? → interest
- how can they be studied with the proposed facility? → performance
- why not elsewhere (HERA, pp, AA, ...) → uniqueness

two aspects, in my view complementary:

- broad physics program, many different aspects → golden topics
  - attract and unite a large community
  - make best use of proposed facility
- select a few measurements as "flagships" → golden measurements
  - make physics case concrete, easy to grasp
  - driving requirements for accelerator and detector
  - document that are experimentally feasible (studies deserving priority)

Some physics highlights

(a personal selection)

more in the following talks

Small x and saturation

- physics dominated by gluon self-coupling:
  "essence" of non-Abelian gauge theory

- highest gluon density → saturation scale Q_S large
  → saturation at weak coupling (but stronly non-linear)

- golden measurement: F_L for heavy nuclei

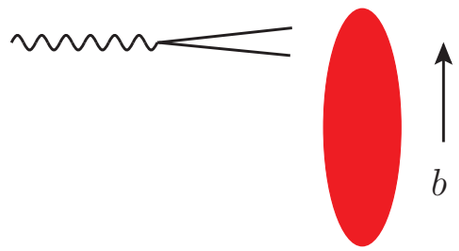
  - among simplest observables, benchmark for theory

  - precision: higher-order corrections known in DGLAP approach, should be known for BFKL/BK by time of EIC

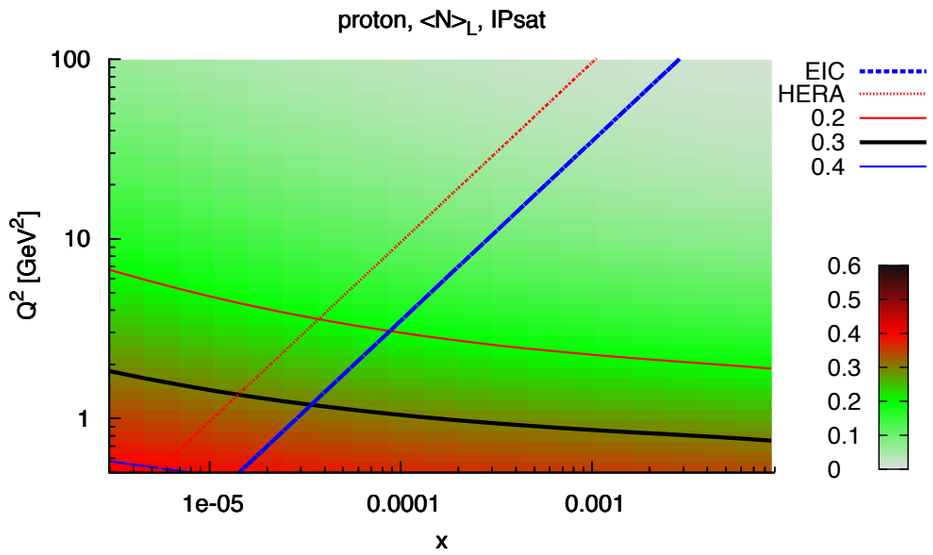
  - how sensitive to saturation?

    ★ calc. average dipole scattering amplitude $\langle \mathcal{N} \rangle$ in F_L and in F_2 (for comparison)

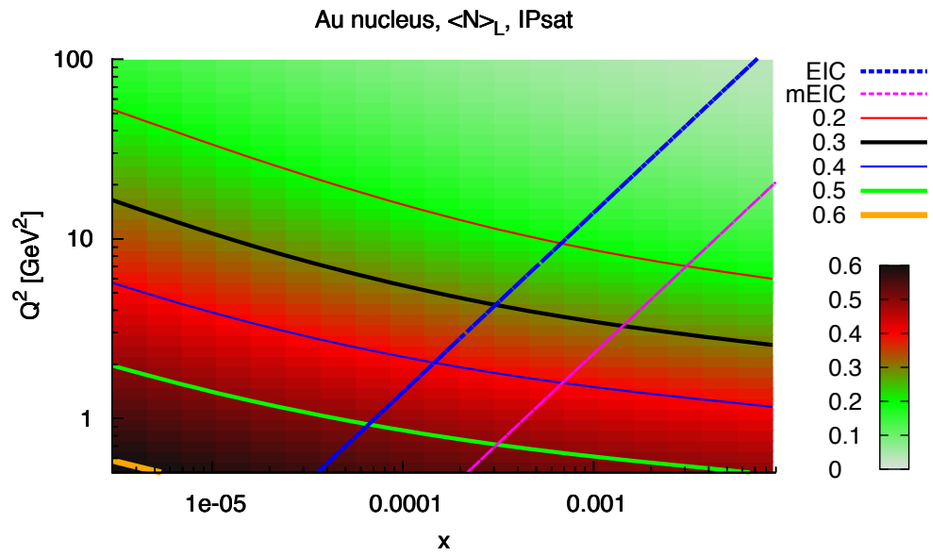
    ★ limited to $\langle \mathcal{N} \rangle < 0.5$ for Gaussian b space profile, to $\langle \mathcal{N} \rangle < 0.75$ for hard sphere

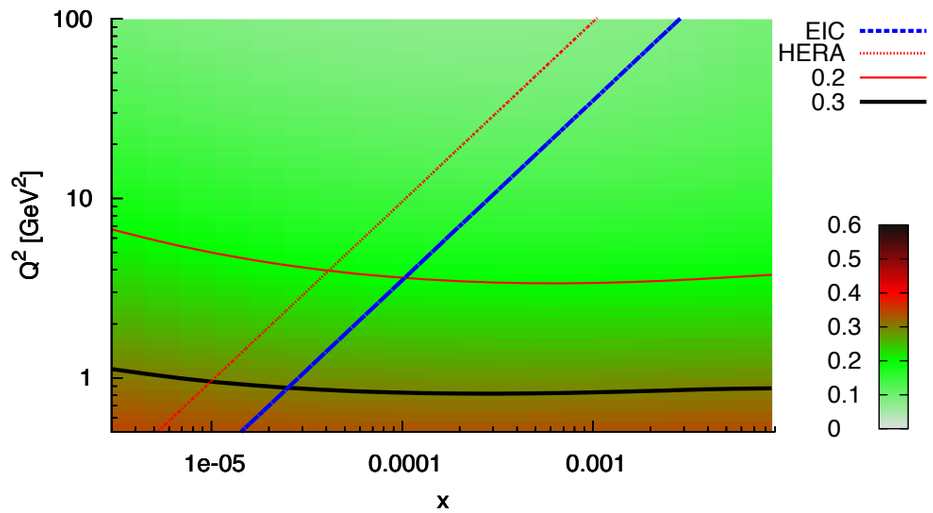


Small x and saturation

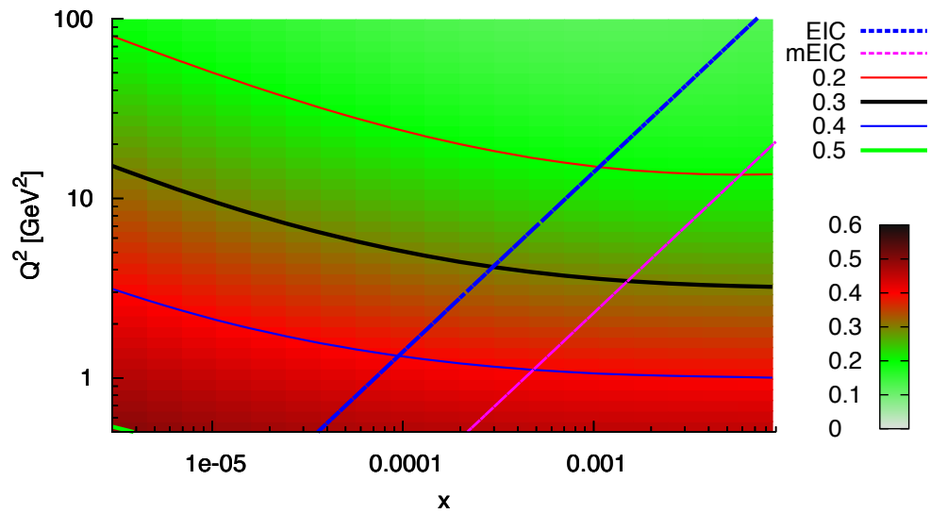


F_L





F_2



plots: T. Lappi

- EIC: E_p = 300 GeV, E_A = 130 GeV/nucleon, E_e = 30 GeV
- mEIC: E_A = 130 GeV/nucleon, E_e = 5 GeV
- always cut $y < 0.9$

Small x and saturation

- F_L measurement not for free:

  ★ different sets of beam energies, lever arm in y

  ★ QED radiative corrections: at high y huge for heavy nuclei
  (from elastic eA scattering with radiation of extra photon)
  → need suitable cuts, implications for detector design
  → work in progress E. Aschenauer and H. Spiesberger

- detailed study of saturation → more measurements

  ★ k_T distribution of gluons ↔ saturation scale Q_S

  ➡ dihadron production $eA \to e\, h_1\, h_2 + X$
  azimuth between h_1 and h_2 ↔ gluon k_T → talk C. Marquet

  ★ diffraction: $eA \to e\, J/\Psi + A$ (coherent) or $\to e\, J/\Psi + X$ (incoherent)

  - coherent part very difficult to measure for heavy A
    no consensus yet whether physics gain high enough

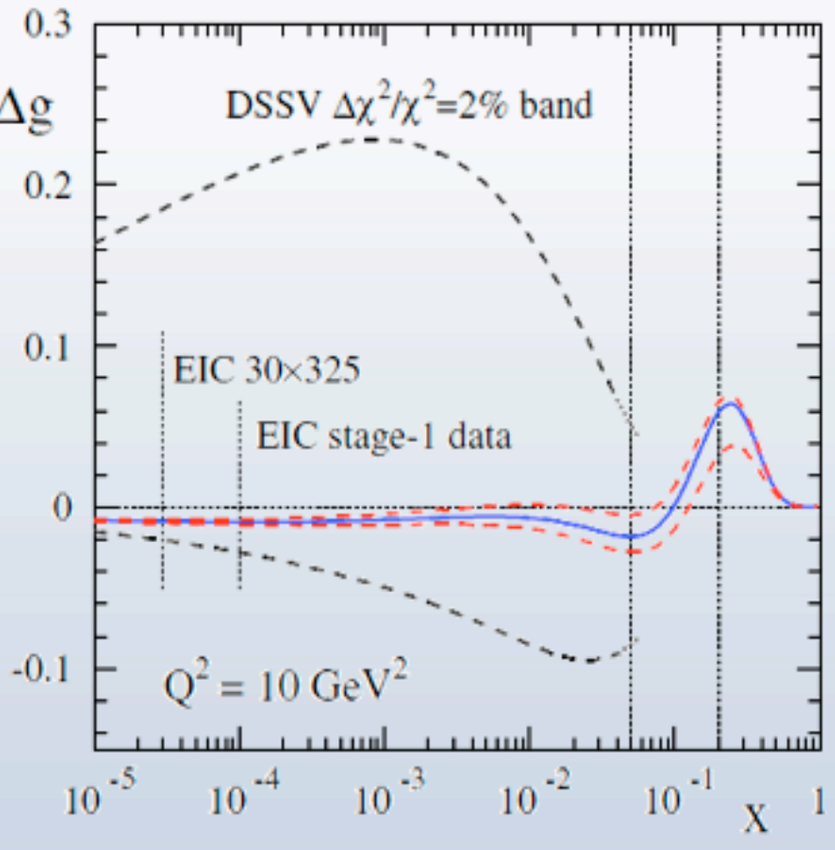
Parton distributions

- golden measurement for spin physics:
  Δg from scaling violation of g_1

what can be achieved for Δg? – cont'd

what about the uncertainties on the x-shape …

Sassot, MS



… wow – cool!

- even with flexible DSSV x-shape we can now determine $\int_0^1 dx\, \Delta g(x, Q^2)$ up to ± 0.07
- work in progress: try weird x-shapes below x = 10^{-4} to improve/check error estimate

M.Stratmann
INT week 10

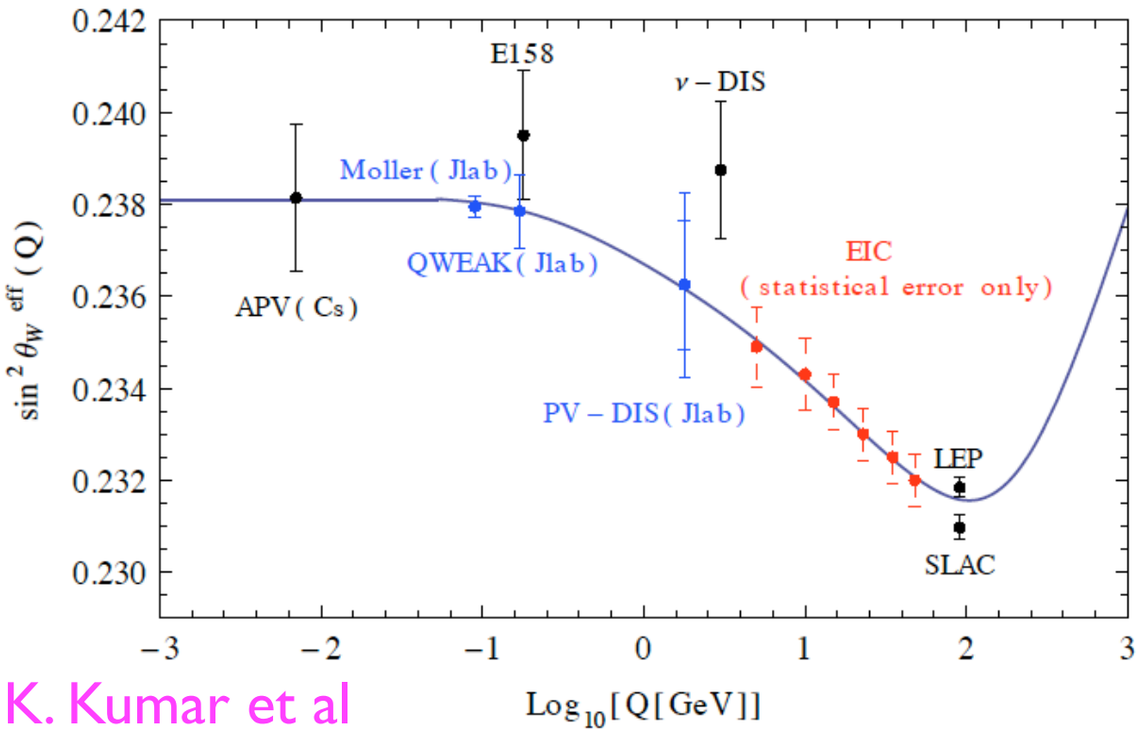
Parton distributions

- SIDIS with kaons: s and $\overline{s}$ in nucleon → talk M. Stratmann
  - least known part of proton flavor structure
  - unpolarized: relevant for W, Z, $H^{\pm}$ prod'n at LHC
  - polarized: spin sum rule w/o assuming flavor $SU(3)$
- nuclear quark and gluon distributions → F_2 and F_L
  - poorly or not known in large part of (x, Q^2) plane → kinematic reach of EIC
  - input for heavy-ion physics
- some may not be golden but rather silver measurments: significantly enrich physics scope of EIC

Electroweak DIS

studies at INT → disadvantage from lower Q^2 than HERA
more than compensated by gain in luminosity

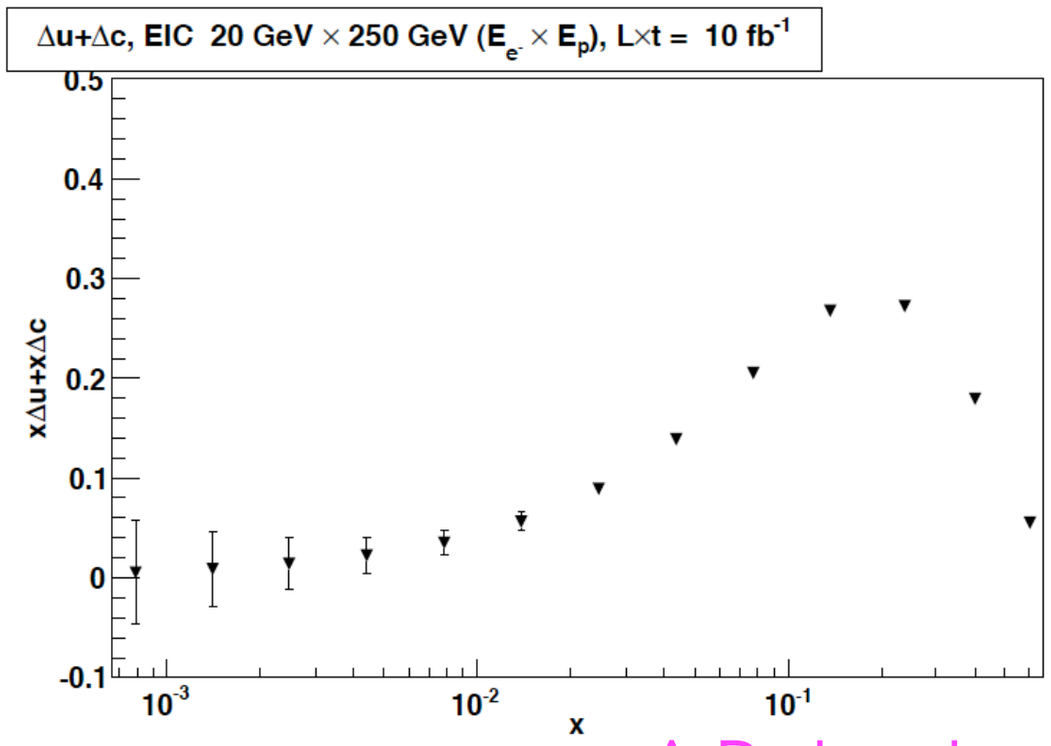
- beam spin asymmetry in DIS → $sin^2\vartheta_W$



K. Kumar et al

- for $\sqrt{s}$ = 140 GeV and 200 fb^{-1}
- stat. errors ~ 0.25%
  sytematics remain to be studied

- polarized p → alternative access to helicity distributions

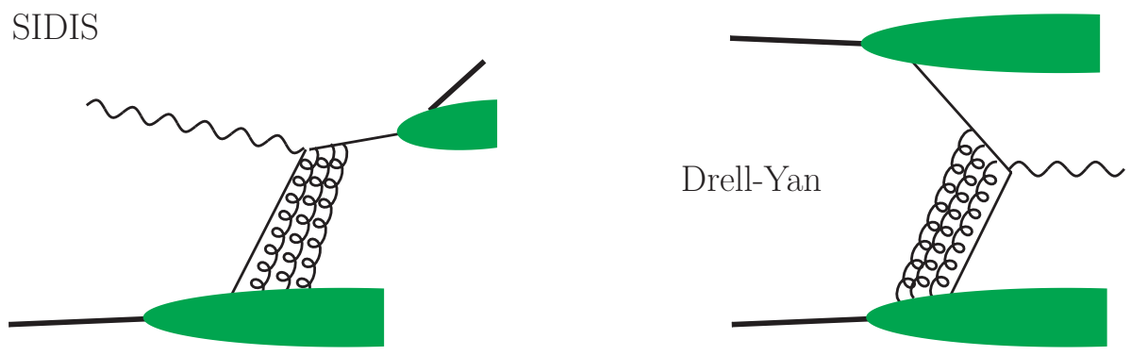


A. Deshpande et al

- find CC more promising than NC
- stat. errors only, syst. to be studied

Three-dimensional structure: transverse momentum

- transverse momentum of quarks and gluons:
  - influences momenta in final state → practical relevance
  - fundamental aspect of hadron structure
  - correlations with flavor structure largely unexplored
- correlation of k_T with polarization reveals deep properties of QCD:
  Sivers effect as a golden measurement

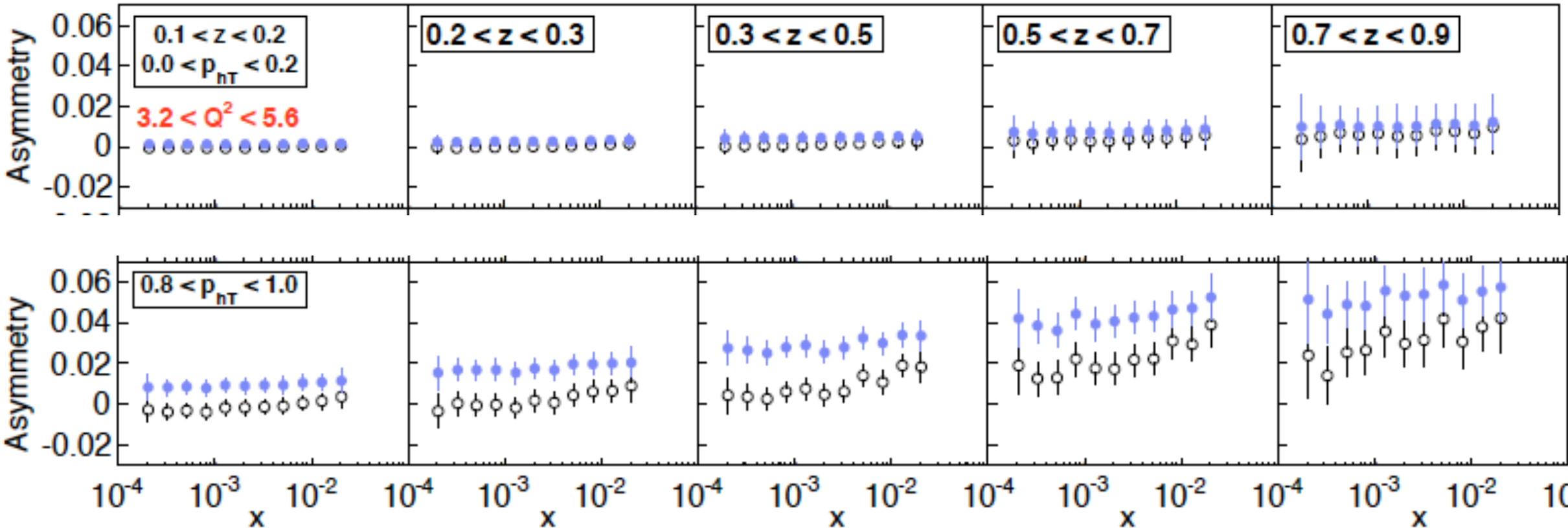


  - partons are not isolated but embedded in environment of gluons
  - Sivers distribution = indicator for this effect
    changes sign between SIDIS and DY (RHIC measurements)
  - Sivers distribution essentially unknown for sea quarks and gluons

Transverse parton momentum

- luminosity and kinematic reach at EIC → explore effects as fct of x, z, Q^2 and p_T

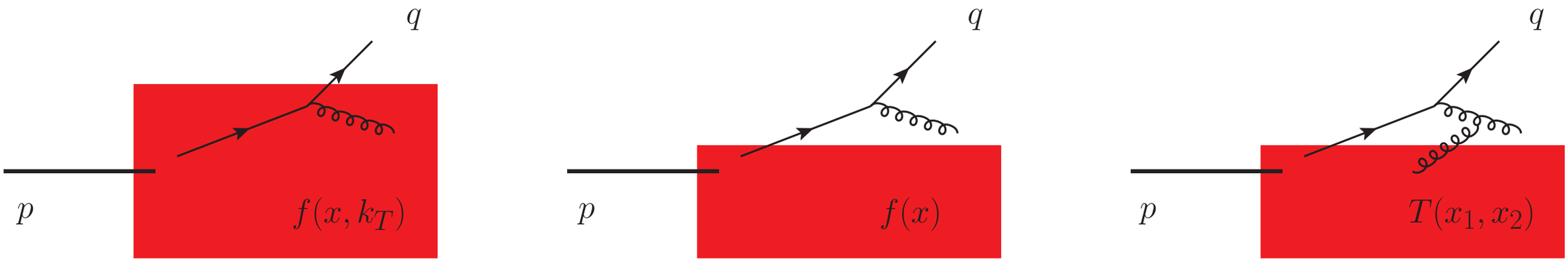
T. Burton et al



- blue (white) dots for (non)zero Sivers function
- stat. errors for $\sqrt{s}$ = 140 GeV and 4 fb^{-1}

Transverse parton momentum

- higher p_T → transverse momentum generated perturbatively have smooth transition between "intrinsic" and "radiative" k_T



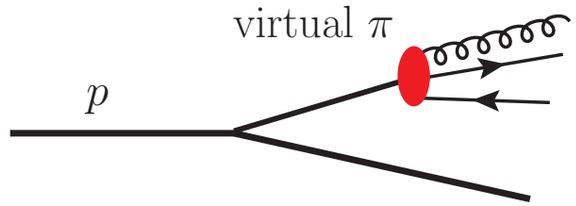
  - need kinematic reach and rates of an EIC to explore
  - Sivers effect at high p_T → twist-three distributions
- Sivers effect is one of several spin/angular asymmetries, each with characteristic physics → silver measurements
  - in particular: chiral-odd distributions, i.e. transverse quark polarization → talk H. Gao

Three-dimensional structure: parton imaging

- transverse mom. transfer Δ_T in hard exclusive processes

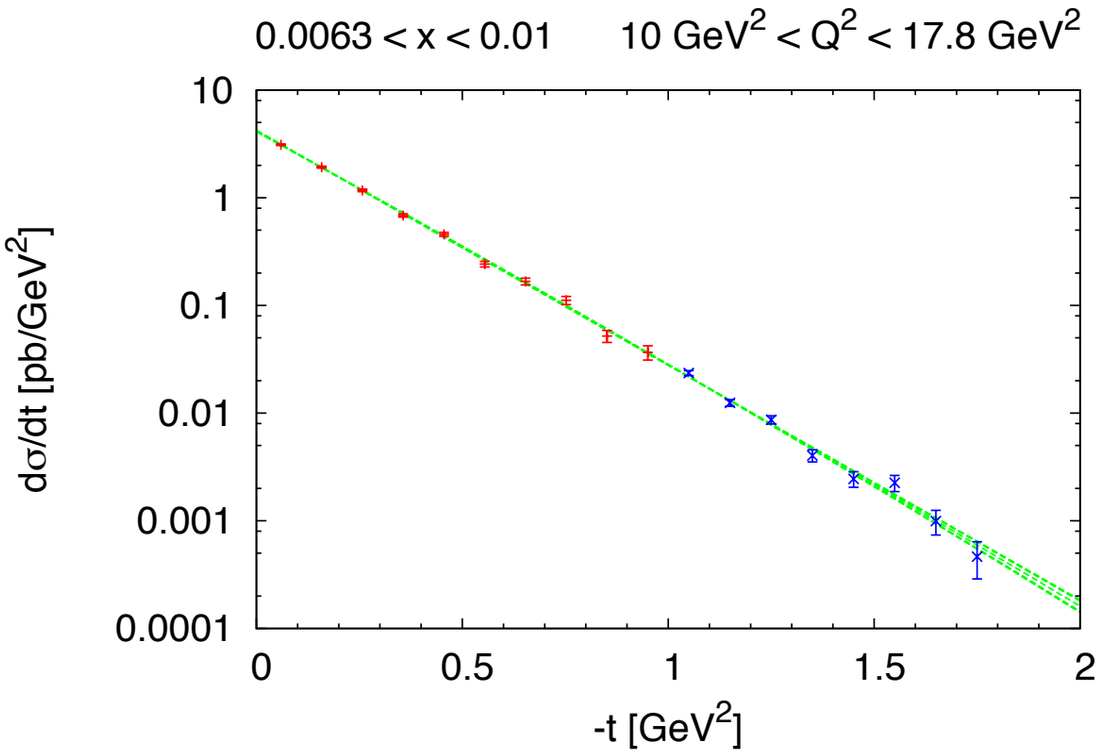
  ➡ transverse position b of parton (via Fourier transform)

- physics aspects:
  - spatial extension of hadrons ↔ confinement
  - interplay between sea quarks and gluons
  - large b behavior ↔ chiral dynamics



- golden measurements:
  - DVCS (accurate theory for large number of asymmetries)
  - $ep \to e\, J/\Psi + p$ (selective to gluons)

DVCS

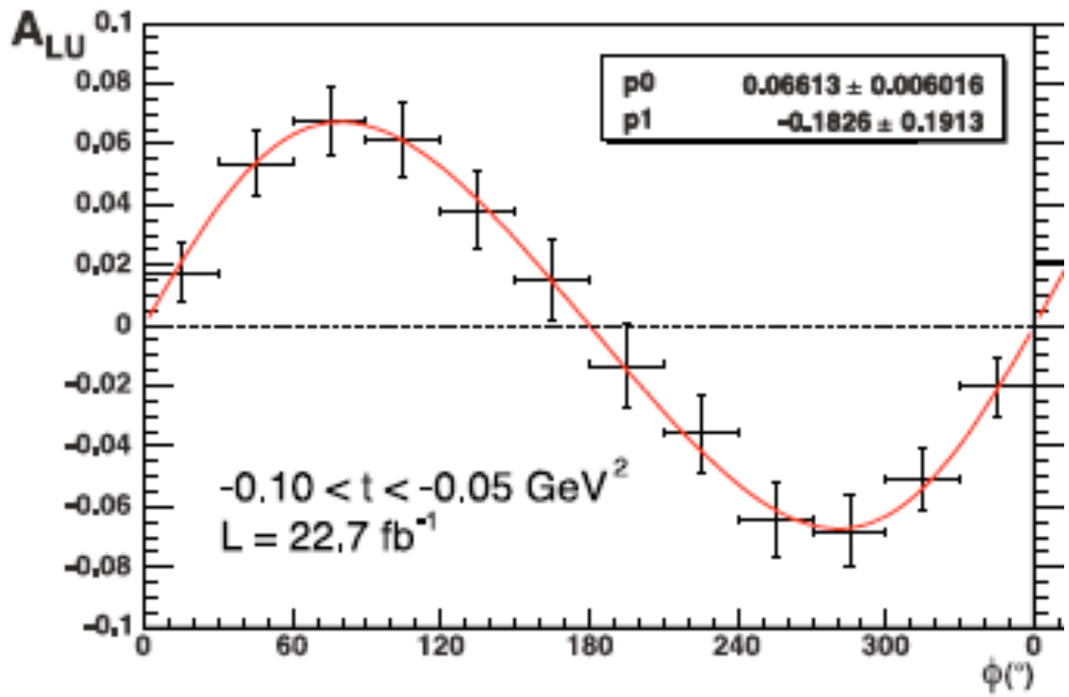


simulation S. Fazio

- stat. errors with

  12 fb^{-1} for $|t| < 1$ GeV^2

  150 fb^{-1} for $|t| > 1$ GeV^2



R. Géraud et al.

- beam spin asymmetry for

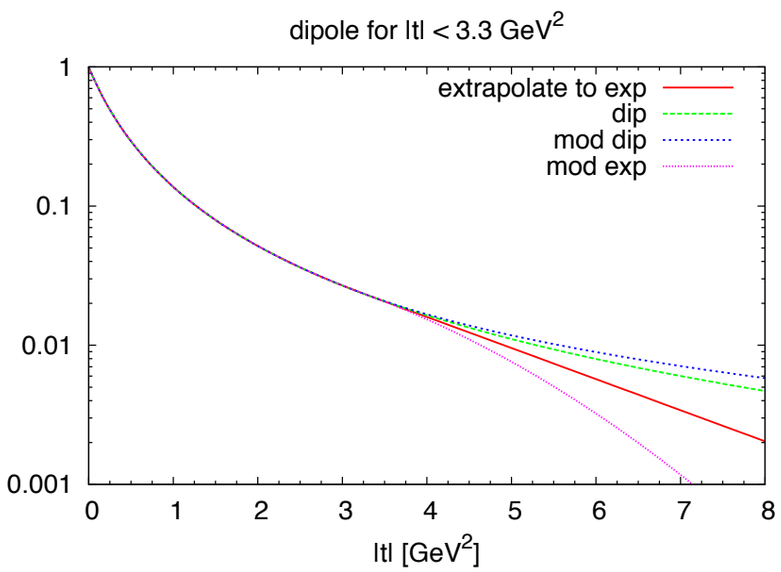
  $1.58 \times 10^{-3} < x_B < 2.51 \times 10^{-3}$

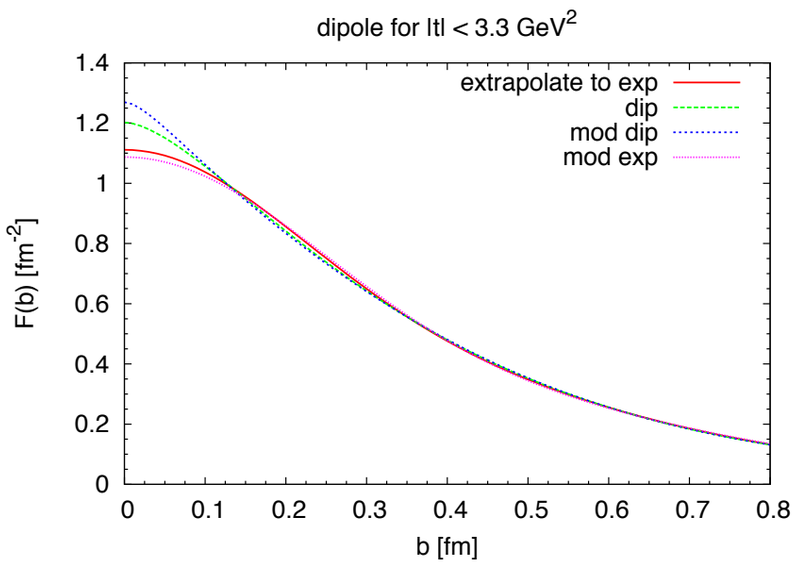
  $3.16 < Q^2 < 5.61$ GeV^2

→ multi-dimensional binning possible, also for asymmetries

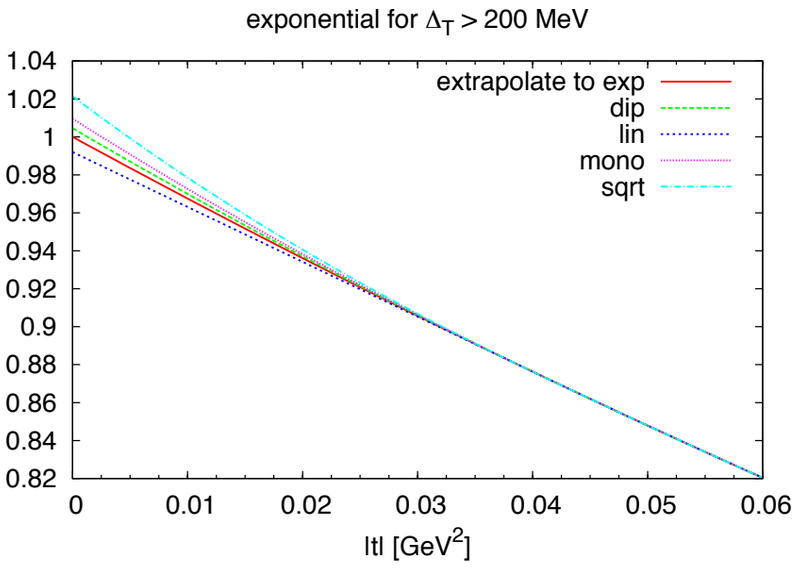
Transverse imaging

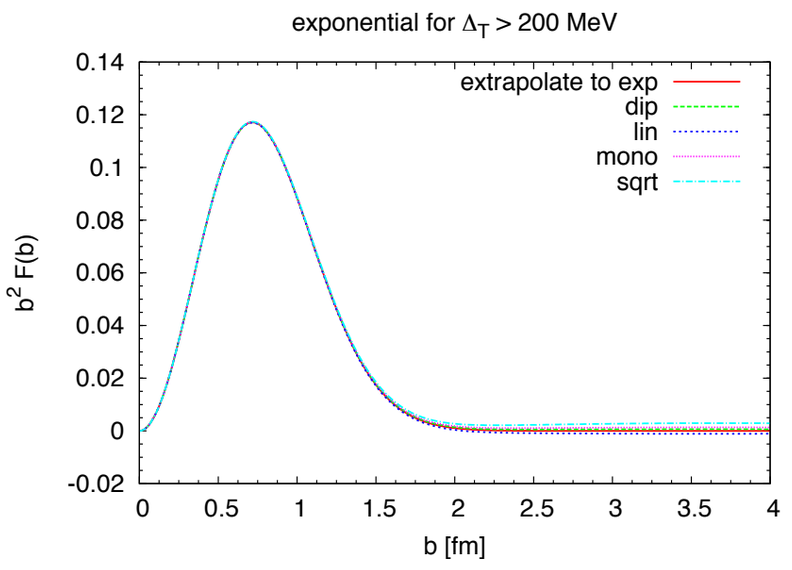
- estimate uncertainty in b space from incomplete measurement in Δ_T
  E. Aschenauer, M.D.





- measure p in Roman pots for $\Delta_{Tmin} < \Delta_T$ <1 GeV , in main detector for Δ_T > 1 GeV , extrapolate for unmeasured Δ_T





➡ implications for design of detectors and interaction point

Transverse imaging

- transverse proton polarization

  ➡ orbital angular momentum (Ji's sum rule)

  ➡ connection with Sivers effect (chromodynamic lensing)

  need more theory work and simulations, no conclusions yet

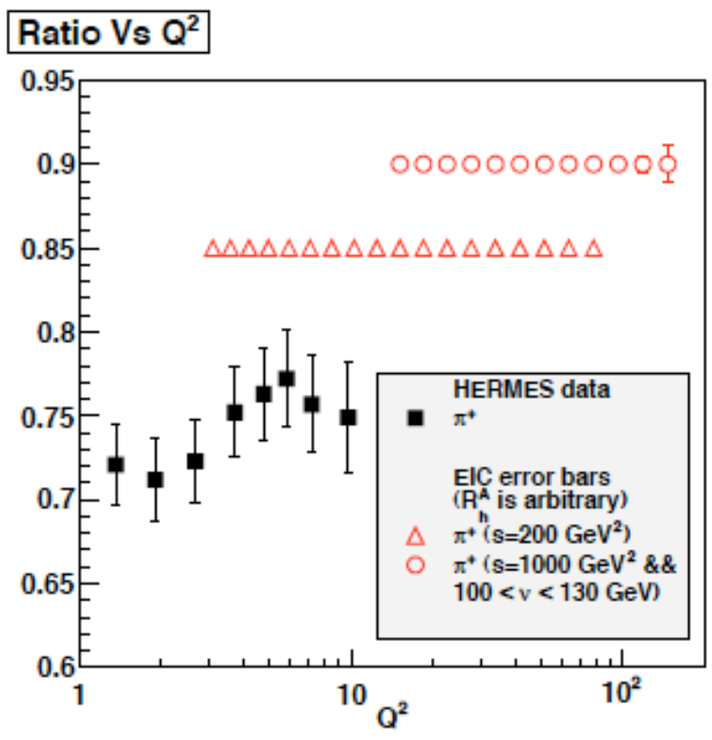
- silver measurements:

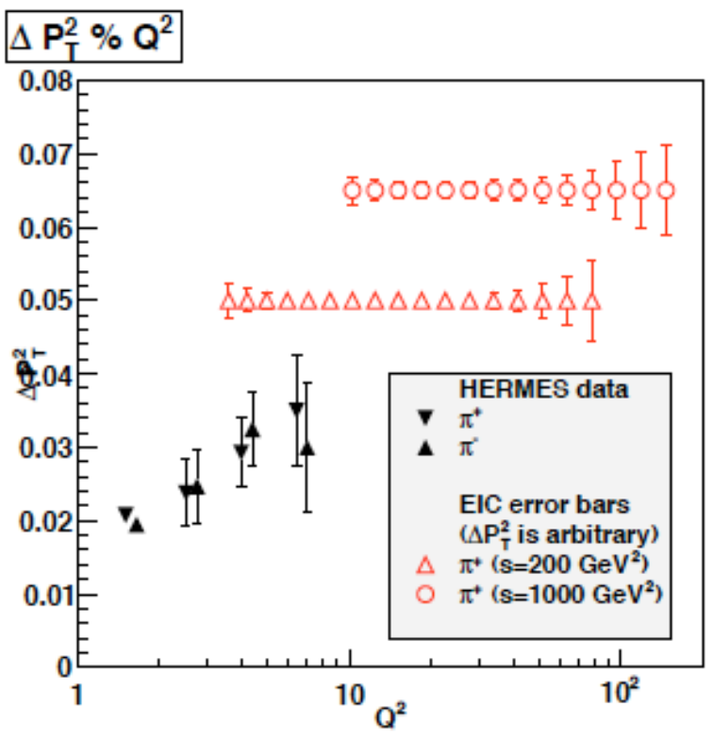
  production of light vector or pseudscalar mesons

  ➡ disentangle quark flavors and quarks vs. gluons

Hadronization in nuclei

- key observables:
  - attenuation ratio $R_A = \dfrac{N_A^{\mathrm{SIDIS}}/N_A^{\mathrm{DIS}}}{N_d^{\mathrm{SIDIS}}/N_d^{\mathrm{DIS}}}$
  - transverse-momentum broadening $\Delta\langle p_T^2\rangle = \langle p_T^2\rangle_A - \langle p_T^2\rangle_d$
- luminosity and kinematic reach at EIC → multidimensional studies, wide range in Q^2, p_T, ν





- stat. errors for 200 fb^{-1}

A. Accardi, R. Dupré

Summary

- for several topics identified golden measurement candidates
  - ★ clear physics interest
  - ★ performance studies initiated
- second tier of silver measurements
  - ★ broaden physics case, connect with other domains
- with luminosity and kinematics of current accelerator/detector designs
  - ★ many measurements possible with multi-dimensional binning including exclusive processes
  - ★ electroweak DIS possible
  - ★ many measurements will be systematics limited
    - ➡ detailed detector studies/simulations required
- open questions/to-do items identified

Thanks to all participants of the
INT program for their input

special thanks to E. Aschenauer, H. Gao, Y. Li, C. Marquet,
M. Stratmann, R. Venugopalan, B.-w. Xiao for discussions