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FORMAL REPORT

Proceedings of RIKEN BNL Research Center Workshop Volume 90

PHENIX Spinfest School 2008 at BNL

August 04 – August 08, 2008

Organizers:

Christine Aidala, Yuji Goto, Kensuke Okada,

RIKEN BNL Research Center

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DISCLAIMER

Preface to the Series

The RIKEN BNL Research Center (RBRC) was established in April 1997 at Brookhaven National Laboratory. It is funded by the "Rikagaku Kenkyusho" (RIKEN, The Institute of Physical and Chemical Research) of Japan. The Center is dedicated to the study of strong interactions, including spin physics, lattice QCD, and RHIC physics through the nurturing of a new generation of young physicists.

The RBRC has both a theory and experimental component. The RBRC Theory Group and the RBRC Experimental Group consists of a total of 25-30 researchers. Positions include the following: full time RBRC Fellow, half-time RHIC Physics Fellow, and full-time, post-doctoral Research Associate. The RHIC Physics Fellows hold joint appointments with RBRC and other institutions and have tenure track positions at their respective universities or BNL. To date, RBRC has ~50 graduates of which 14 theorists and 6 experimenters have attained tenure positions at major institutions worldwide.

Beginning in 2001 a new RIKEN Spin Program (RSP) category was implemented at RBRC. These appointments are joint positions of RBRC and RIKEN and include the following positions in theory and experiment: RSP Researchers, RSP Research Associates, and Young Researchers, who are mentored by senior RBRC Scientists. A number of RIKEN Jr. Research Associates and Visiting Scientists also contribute to the physics program at the Center.

RBRC has an active workshop program on strong interaction physics with each workshop focused on a specific physics problem. In most cases all the talks are made available on the RBRC website. In addition, highlights to each speaker's presentation are collected to form proceedings which can therefore be made available within a short time after the workshop. Today there are ninety proceeding volumes available.

A 10 teraflops RBRC QCDOC computer funded by RIKEN, Japan, was unveiled at a dedication ceremony at BNL on May 26, 2005. This supercomputer was designed and built by individuals from Columbia University, IBM, BNL, RBRC, and the University of Edinburgh, with the U.S. D.O.E. Office of Science providing infrastructure support at BNL. Physics results were reported at the RBRC QCDOC Symposium following the dedication. QCDSP, a 0.6 teraflops parallel processor, dedicated to lattice QCD, was begun at the Center on February 19, 1998, was completed on August 28, 1998 and was decommissioned in 2006. It was awarded the Gordon Bell Prize for price performance in 1998.

N. P. Samios, Director
March 2007

*Work performed under the auspices of U.S.D.O.E. Contract No. DE-AC02-98CH10886.

CONTENTS

INTRODUCTION

Fourth Annual PHENIX Spinfest and School

Since 2005, the PHENIX Spin Physics Working Group has set aside several weeks each summer for the purposes of training and integrating recent members of the working group as well as coordinating and making rapid progress on support tasks and data analysis. One week is dedicated to more formal didactic lectures by outside speakers. The location has so far alternated between BNL and the RIKEN campus in Wako, Japan, with support provided by RBRC and LANL. This year's PHENIX Spinfest School will take place the mornings of August 4-8 in the Small Seminar Room. All are welcome.

The Organizers
August 2008

Introduction to Pertrubative QCD

(An Introduction/Historical Review)

George Sterman, YITP, Stony Brook

Phenix summer school, Aug. 4, 2008

Brookhaven National Laboratory

OUTLINE

- 1. Introduction: From the quark model to QCD
- 2. Self-consistency: antiquarks in hadron-hadron scattering
- 3. Factorization and Evolution
- 4. How we get away with pQCD: IR safety, factorize, evolve, resum
- 5. Inclusive annihilation in pQCD
- 6. Using pQCD Corrections
- 7. Getting PDFs from the data
- 8. Using resummation: the Q_T distribution
- 9. Putting it all together: pions and jets in hadronic collisions

1. INTRODUCTION: FROM QUARKS TO QCD

- **Spectroscopy and the quark model**
  - The discovery of quarks: qqq and $\bar{q}q$ with $q = u, d, s$ generate observed spectrum of baryons and mesons
  - Decay of $\bar{s}s$ states to K, $\bar{K}$ states (OZI rule) indicates continuity of quark lines
  - Non-relativistic wave functions predict ratios of magnetic moments μ_n/μ_p etc.

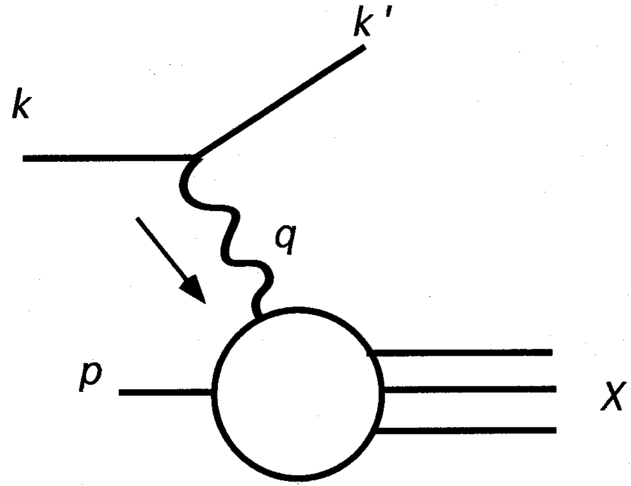
- **Dynamical evidence: form factors & structure functions**
  - **Form factors: ep $\rightarrow$ ep elastic** $(\tau = Q^2/4m_N^2)$

$$\frac{d\sigma}{d\Omega_e} = \left[\frac{\alpha_{\rm EM}^2 \cos^2(\theta/2)}{4E^2 \sin^4(\theta/2)}\right] \frac{E'}{E} \left(\frac{|G_E(Q)|^2 + \tau |G_M(Q)|^2}{1+\tau} + 2\tau |G_M(Q)|^2 \tan^2 \theta/2 \right)$$

  - **schematically:**

$$\frac{d\sigma_{\rm ep\rightarrow ep}(Q)}{dQ^2} \sim \frac{d\sigma_{\rm ee\rightarrow ee}(Q)}{dQ^2} \times G(Q) \quad \text{with} \quad G(Q) \sim \frac{1}{\left(1+\frac{Q^2}{\mu_0^2}\right)^2}$$

– Structure functions: ep inclusive, unpolarized, p rest frame



$$\frac{d\sigma}{dE'\,d\Omega} = \left[\frac{\alpha_{\rm EM}^2}{2SE\sin^4(\theta/2)}\right]\left(2\sin^2(\theta/2)F_1(x,Q^2)+\frac{m\cos^2(\theta/2)}{E-E'}F_2(x,Q^2)\right)$$

$$\text{with} \quad x = \frac{Q^2}{2p_N\cdot q}$$

– **More generally, with spin,** $\sigma \sim (leptonic)_{\mu\nu} W^{\mu\nu}$**,**

$$W^{\mu\nu} \;=\; \frac{1}{4\pi}\int d^4z\, e^{iq\cdot z}\;\langle P,S\,|\,J^\mu(z)J^\nu(0)\,|\,P,S\rangle$$

$$= \left(-g^{\mu\nu}+\frac{q^\mu q^\nu}{q^2}\right)\; F_1(x,Q^2)$$

$$+\left(P^\mu - q^\mu\,\frac{P\cdot q}{q^2}\right)\left(P^\nu - q^\nu\,\frac{P\cdot q}{q^2}\right)F_2(x,Q^2)$$

$$+\; iM_N\,\epsilon^{\mu\nu\rho\sigma}q_\sigma\left[\frac{S_\sigma}{P\cdot q}\,g_1(x,Q^2)+\frac{S_\sigma(P\cdot q)-P_\sigma(S\cdot q)}{(P\cdot q)^2}\,g_2(x,Q^2)\right]$$

- **Scaling:** $F_2(x, Q^2) \sim F_2(x) \Rightarrow$ **Point-like, quasi-free scattering**
- $F_2 \sim 2xF_1$: **Spin-1/2**
- **Parton model structure functions**

$$\begin{aligned} F_{2,N}(x) &= \sum_q e_q^2\, x\, q_N(x) \\ g_{1,N}(x) &= \frac{1}{2}\sum_q e_q^2\, \left(\Delta q_N(x) + \Delta \bar{q}_N(x)\right) \end{aligned}$$

- **Notation:** $f_{q/N}(x) = q_N(x)$ **etc. Probability for struck quark** q **to have momentum fraction** x**.**
- **Notation:** $\Delta q_N = q_N^+ \; - \; q_N^-$ **with** $q^{\pm}(x)$ **probability for struck quark** q **to have momentum fraction** x **and helicity with (+) or against (-)** N **helicity.**

- **At the same time, a quark model paradox ⇒ color**
  - **First of all, nobody had** *seen* **a quark (confinement), but also**
  - **A problem with the quark model: quarks have spin-$1/2$ but nucleon quark model wave function was symmetric**
- **But spin-$1/2$ particles are all fermions – right?**
- **Fast-forward resolution:**
  - **Han, Nambu 1965: quarks come in 3 triplets of colors**
  - **Quarks in baryons are antisymmetric in quantum number of the group SU(3)**

- **The birth of QCD: SU(3)**
  - **A nonabelian gauge theory built on color** ($q = q_1 q_2 q_3$)**:**

$$\mathcal{L}_{QCD} = \sum_q \bar{q}\,(i\not{\partial} - g_s \not{A} + m_q\,)\,q - \frac{1}{4} F^2_{\mu\nu}[A]$$

  - **Think of:** $\mathcal{L}_{EM} = K_\mathrm{e} + J_{EM} \cdot A + (E^2 - B^2)$
  - **The Yang-Mills gauge theory of quarks (q) and gluons (A) Gluons: like "charged photons". The field a source for itself.**
  - **Just the right currents to couple to EM and Weak AND . . .**

- **Just the right kind of forces: QCD charge is "antishielded" and** *grows* **with distance**

$b_0 = 11 - 2n_{\text{quarks}}/3$ **we get:**

$$\alpha_s(\mu') = \frac{g_s^2}{4\pi} = \frac{\alpha_s(\mu)}{1 + b_0 \frac{\alpha_s(\mu)}{4\pi} \ln\left(\frac{\mu'}{\mu}\right)^2} = \frac{4\pi}{b_0 \ln \frac{\mu'^2}{\Lambda^2_{\text{QCD}}}}$$

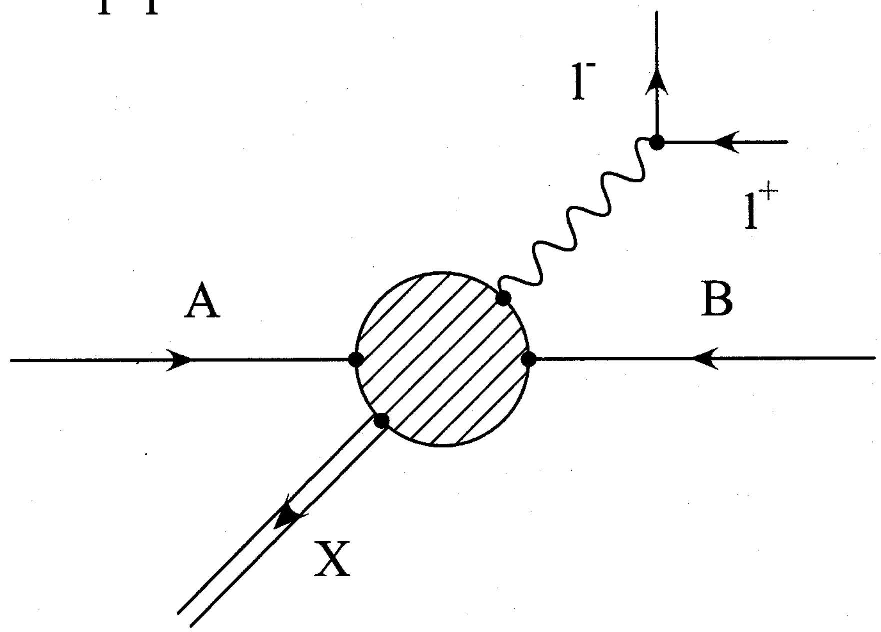
Quantum field theory: every state with the same quantum nos. as uud **in the proton . . . is present at least some of the time**

So antiquarks are in the nucleon: $uudd\bar{d}$**, etc.**

What it means: $q\bar{q}$ **annihilation processes in** NN **collisions as** d, u **from one nucleon collides with** $\bar{d}, \bar{u}$ **from another**

Annihilation into what? Back to quarks, & gluons, yes, but also

$l^+ l^-$



γ, **W, Z, H . . .**

Which brings us to . . .

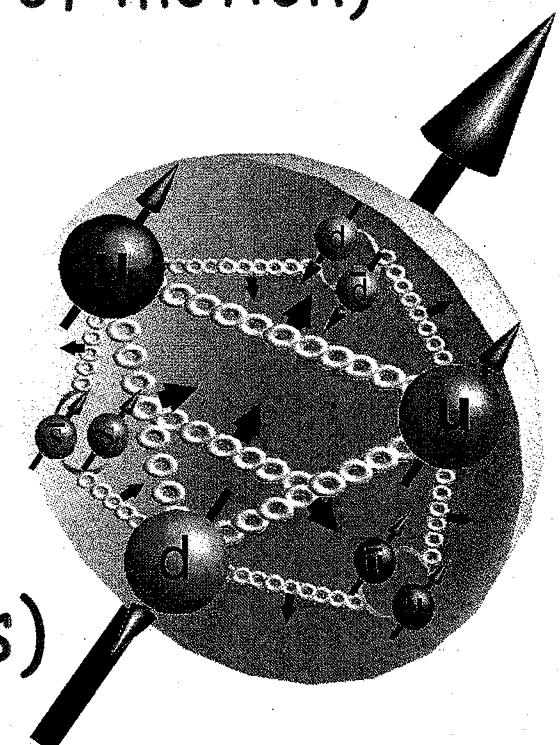
Mauro Anselmino: **The transverse spin structure of the nucleon - I**

Central object of investigation: the proton transverse internal structure, that is the quark transverse spin and transverse motion (with respect to the direction of motion)

Why transverse? How?

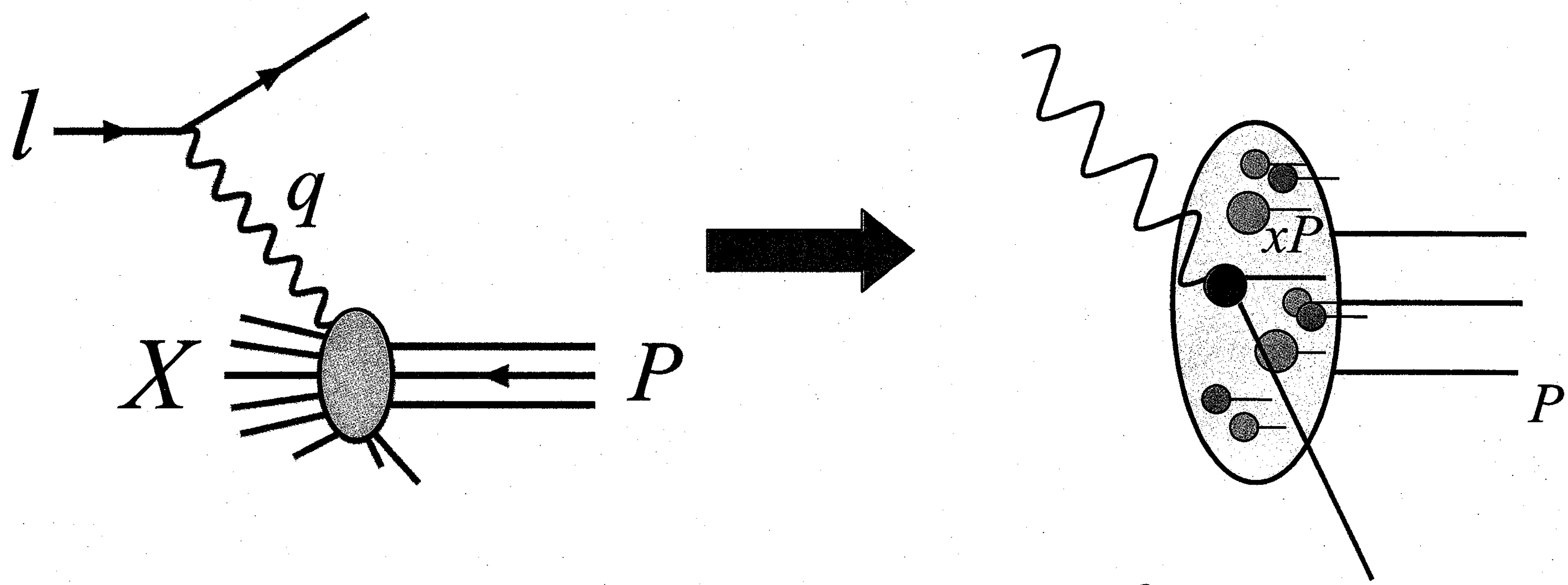
Single Spin Asymmetries

Transverse Momentum Dependent distribution and fragmentation functions (TMDs)



Combining all together and learning...

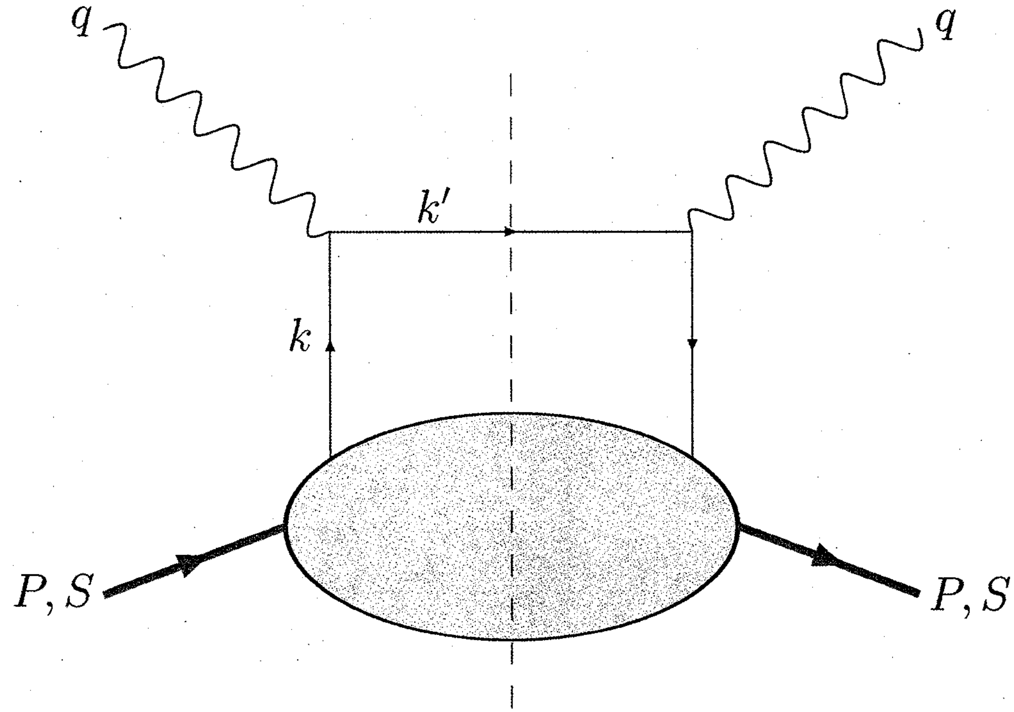
How and what do we know about the longitudinal proton structure?



$$\text{DIS}: \ \ell\, p \to \ell\, X \qquad Q^2 = -q^2 \qquad x = \frac{Q^2}{2P\cdot q} \qquad y = \frac{P\cdot\ell}{P\cdot q}$$

Naive parton model: $$\frac{\mathrm{d}\sigma^{\ell p\to\ell X}}{\mathrm{d}x\,\mathrm{d}Q^2} = \sum_q e_q^2\, q(x)\, \frac{\mathrm{d}\hat{\sigma}^{\ell q\to\ell q}}{\mathrm{d}Q^2}$$

Total cross section for $\gamma^* p \to X$ process
= imaginary part of forward scattering amplitude

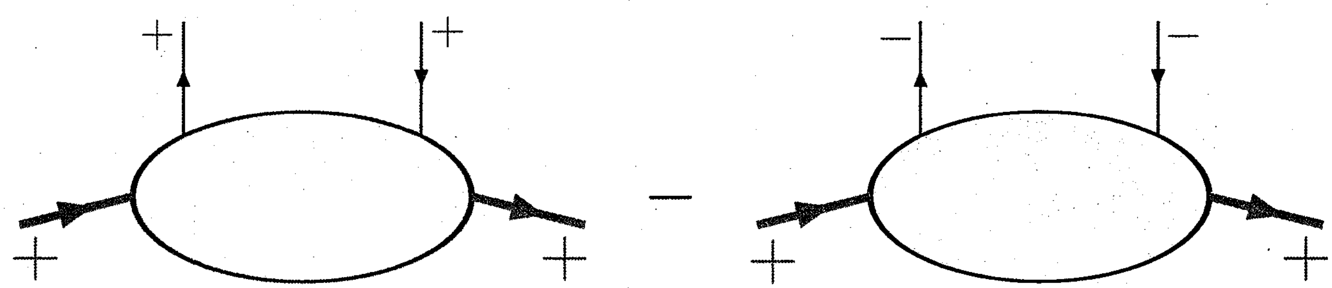


handbag diagram

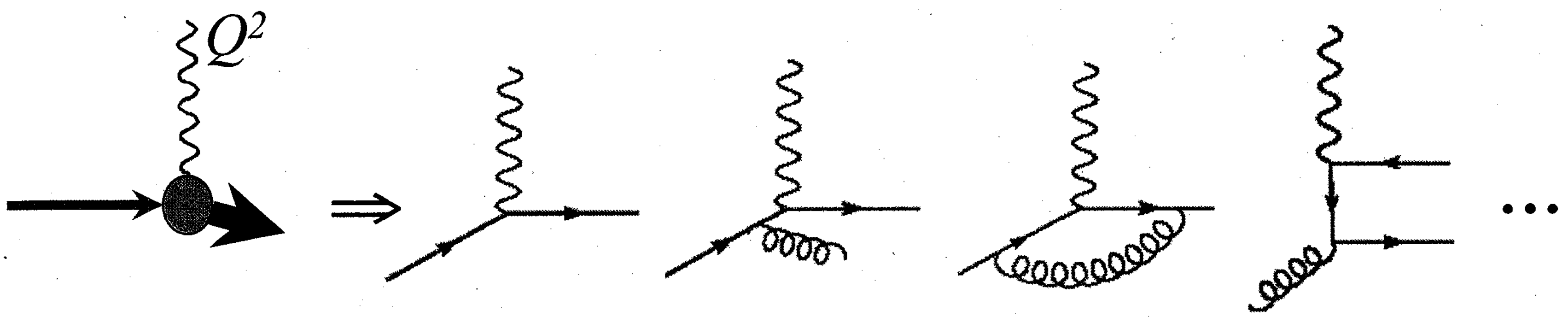
Longitudinally polarized DIS gives information on the helicity distributions of quarks (and, indirectly, of gluons)

$$\frac{\mathrm{d}\sigma^{\overbrace{+,+}^{\lambda_l\,\lambda_p}}}{\mathrm{d}x\,\mathrm{d}y} - \frac{\mathrm{d}\sigma^{+,-}}{\mathrm{d}x\,\mathrm{d}y} = \sum_q e_q^2\,\Delta q(x)\left[\frac{\mathrm{d}\hat{\sigma}^{\overbrace{+,+}^{\lambda_l\,\lambda_q}}}{\mathrm{d}y} - \frac{\mathrm{d}\hat{\sigma}^{+,-}}{\mathrm{d}y}\right]$$

$$\Delta q(x) = q_+^+(x) - q_-^+(x)$$



QCD interactions induce a well known Q^2 dependence



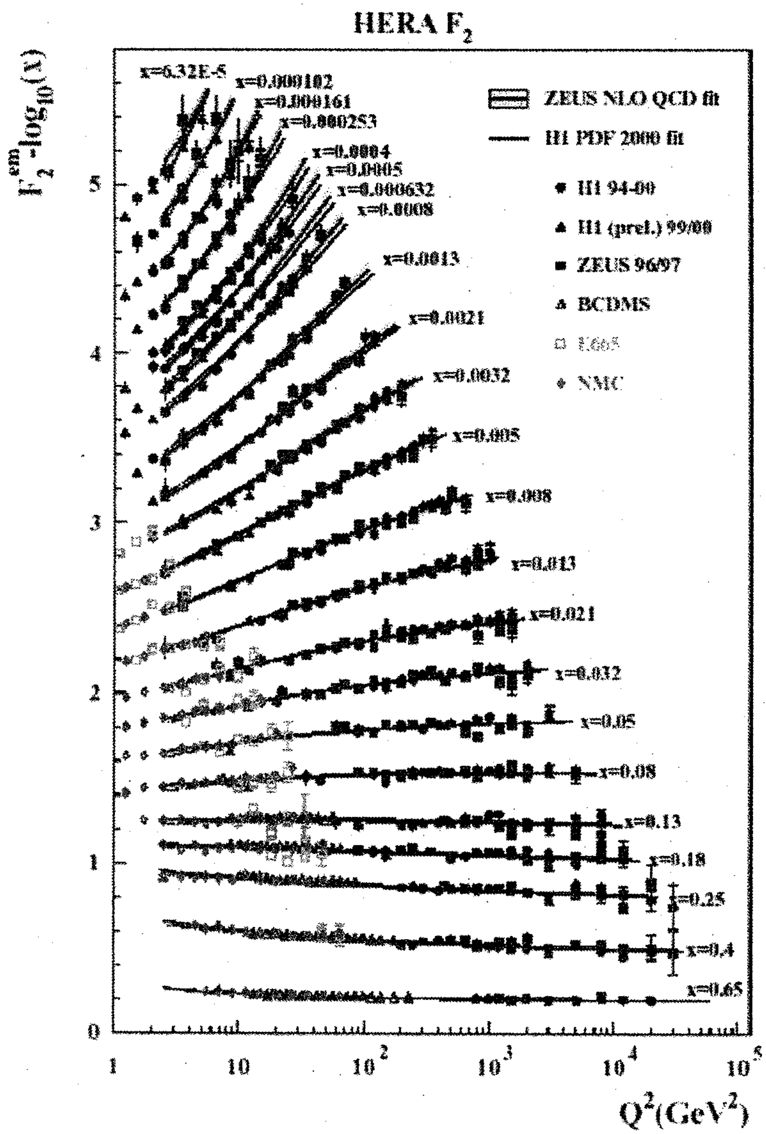
$$\text{DIS} - \text{pQCD}: \quad q(x) \Rightarrow q(x, Q^2)$$

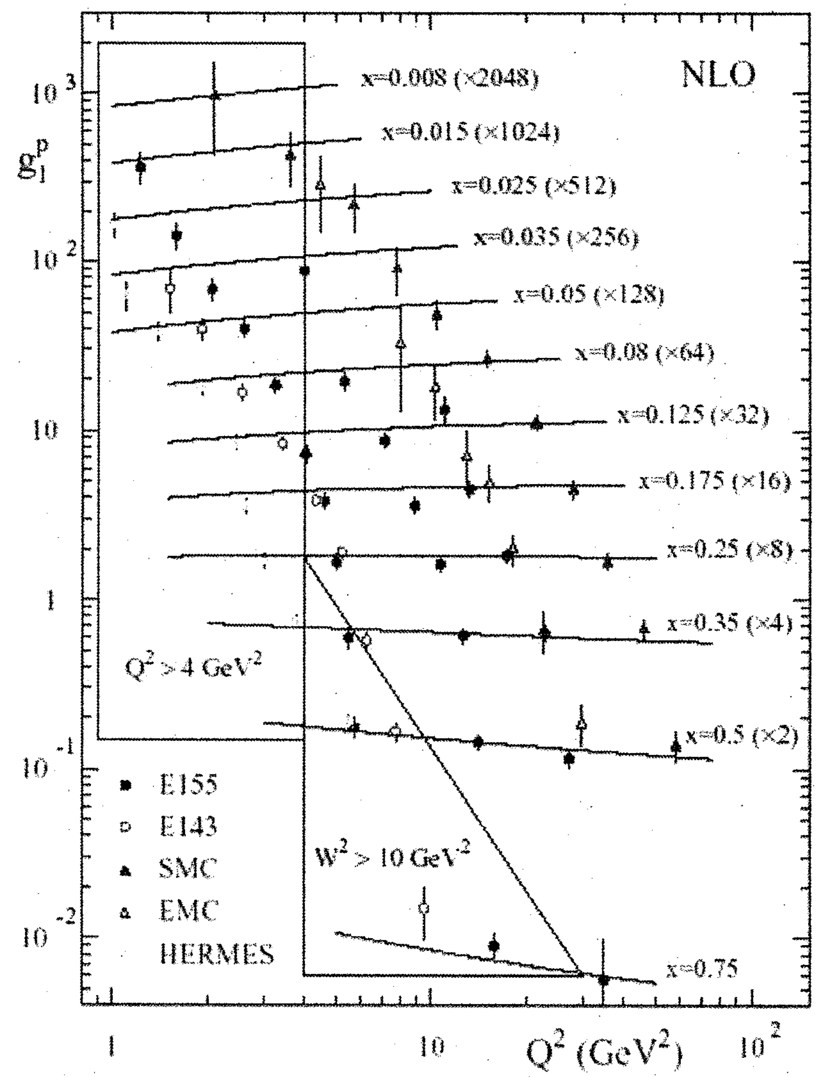
factorization:

$$\frac{d\sigma^{\ell p \to \ell X}}{dx\, dQ^2} = \sum_q e_q^2\, q(x, Q^2)\, \frac{d\hat{\sigma}^{\ell q \to \ell q}}{dQ^2}$$

universality: same $q(x,Q^2)$ measured in DIS can be used in other processes

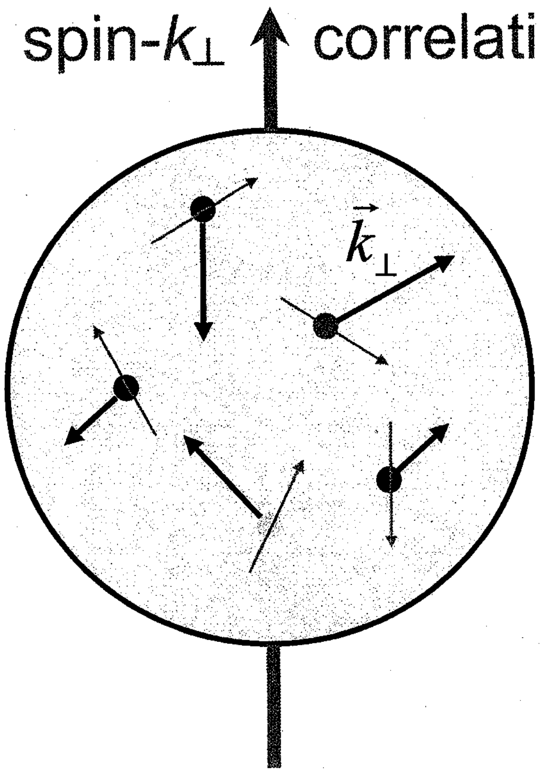
essentially x and Q^2 degrees of freedom ….





The transverse structure is much more interesting and less studied

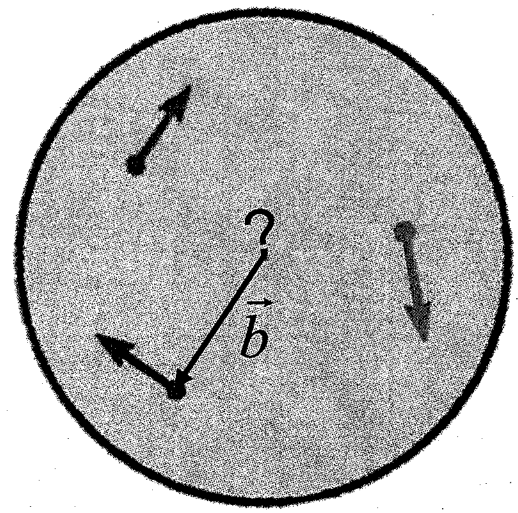
spin-$k_\perp$ correlations?



Transverse Momentum Dependent distribution functions

$$q(x,\boldsymbol{k}_\perp;Q^2)$$

orbiting quarks?

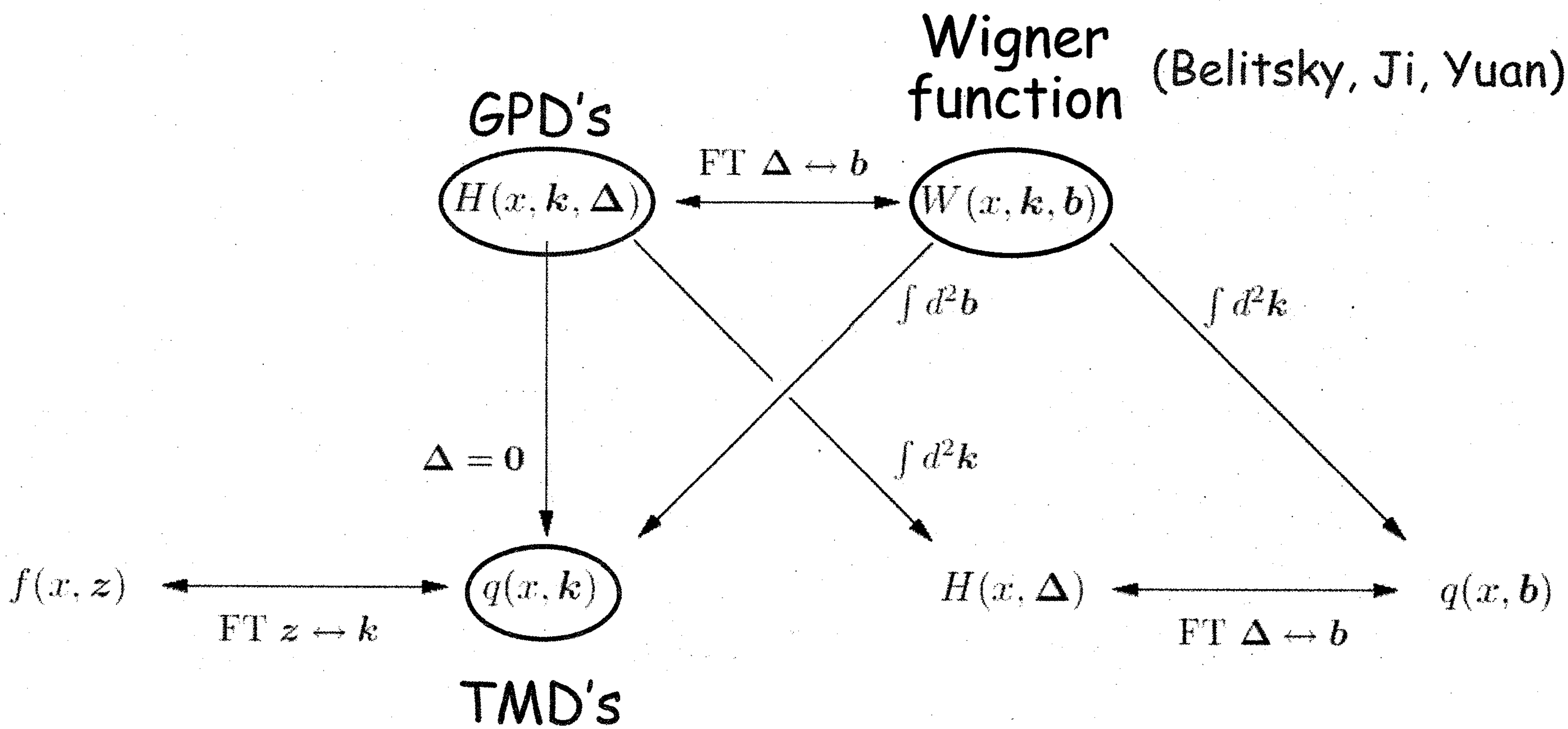


Space dependent distribution functions

$$q(x,\boldsymbol{b};Q^2)$$

The mother of all functions

M. Diehl, Trento workshop, June 07



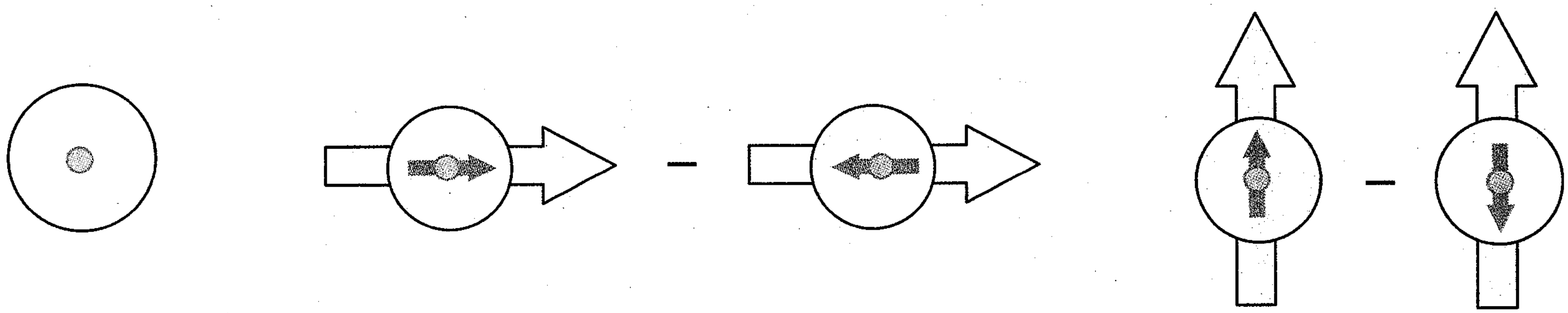
Transversity distribution

$$\Delta_T q(x) = q^{\uparrow}_{\uparrow}(x) - q^{\uparrow}_{\downarrow}(x)$$

$\Delta_T q$ also denoted as h_{1q} or δq

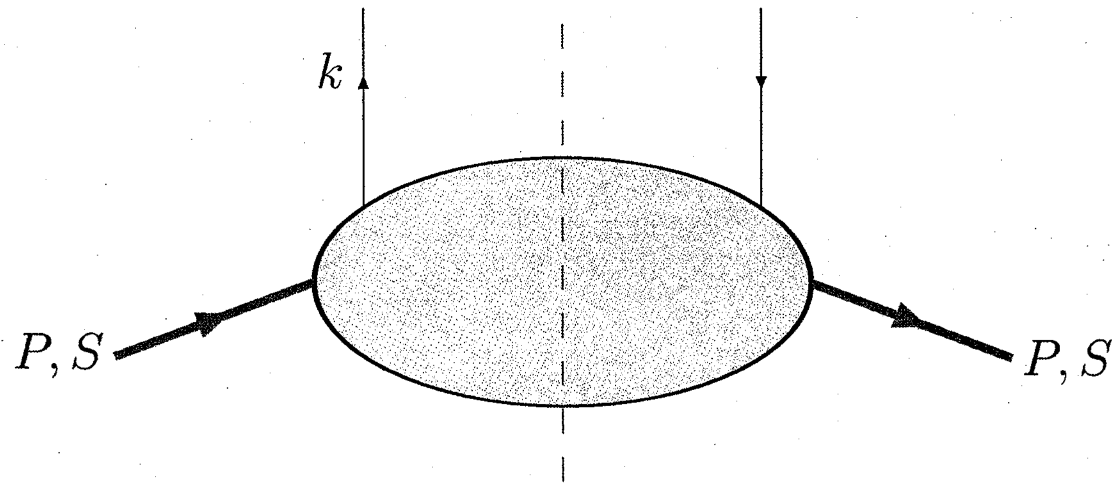
$q(x, Q^2)$, $\Delta q(x, Q^2)$ and $\Delta_T q(x, Q^2)$

are all fundamental, and different, leading-twist quark distributions, equally important



$\Delta_T q = \Delta q$ only for a proton at rest

The correlator



$$\Phi_{ij}(k;P,S) = \sum_X \int \frac{d^3 \boldsymbol{P}_X}{(2\pi)^3\, 2E_X} (2\pi)^4 \, \delta^4(P-k-P_X) \langle PS|\overline{\Psi}_j(0)|X\rangle\langle X|\Psi_i(0)|PS\rangle$$

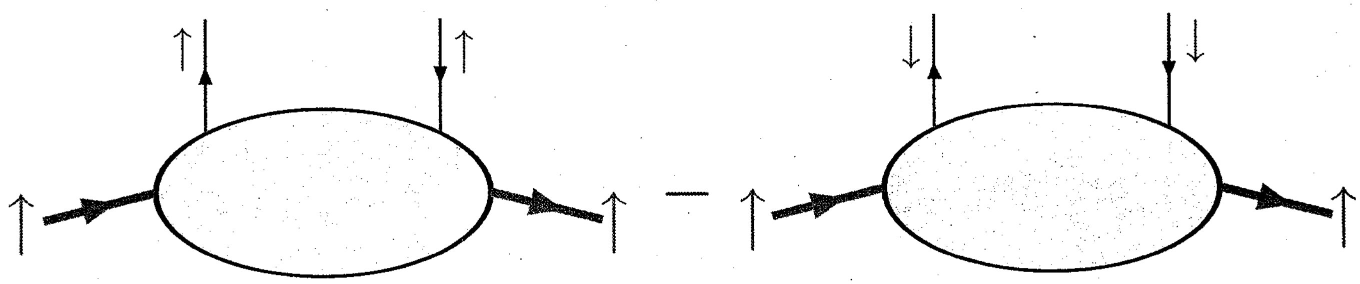
$$= \int d^4\xi \, e^{ik\cdot\xi} \langle PS|\overline{\Psi}_j(0)\Psi_(\xi)|PS\rangle$$

at leading twist, in collinear configuration:

$$\Phi(x,S) = \frac{1}{2}\,[\underbrace{f_1(x)}_{q}\, \not{n}_+ + S_L \underbrace{g_{1L}(x)}_{\Delta q}\, \gamma^5\, \not{n}_+ + \underbrace{h_{1T}}_{\Delta_T q}\, i\sigma_{\mu\nu}\gamma^5 n_+^\mu S_T^\nu]$$

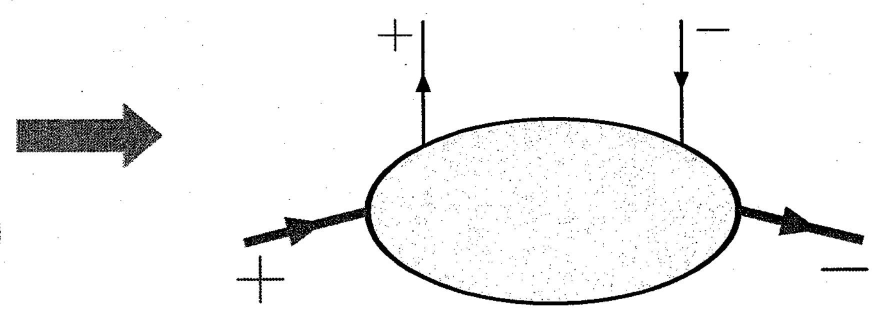
Does transversally polarized DIS give information on the transversity distributions of quarks? No!

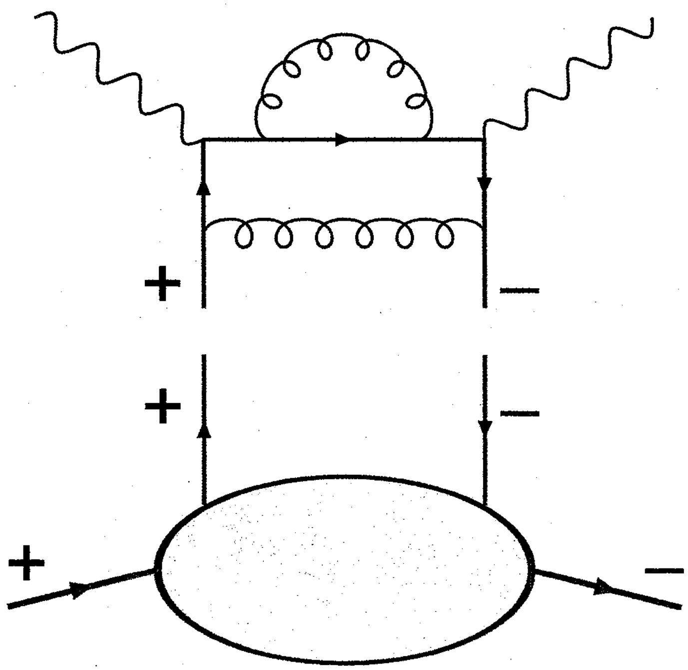
$$\frac{d\sigma^{\uparrow,\uparrow}}{dx\,dy} - \frac{d\sigma^{\uparrow,\downarrow}}{dx\,dy} = \sum_q e_q^2\, \Delta_T q(x) \underbrace{\left[\frac{d\hat{\sigma}^{\uparrow,\uparrow}}{dy} - \frac{d\hat{\sigma}^{\uparrow,\downarrow}}{dy}\right]}_{O(m_q/E_q)}$$



in helicity basis:

$$|\uparrow,\downarrow\rangle = \frac{1}{\sqrt{2}}(|+\rangle \pm i|-\rangle)$$





no h_1 in DIS

QED and QCD interations
(and SM weak interactions)
conserve helicity:
h_1 decouples from DIS

$$\bar{u}_{\lambda_q}(q)\underbrace{\gamma\cdots\gamma}u_{\lambda'_q}(q') \propto \delta_{\lambda_q,\lambda'_q} + \mathcal{O}\left(\frac{m_q}{E_q}\right)\delta_{\lambda_q,-\lambda'_q}$$

odd numbers of
gamma matrices

Accelerating Polarized Protons

Mei Bai

Collider Accelerator Department
Brookhaven National Laboratory

Outline

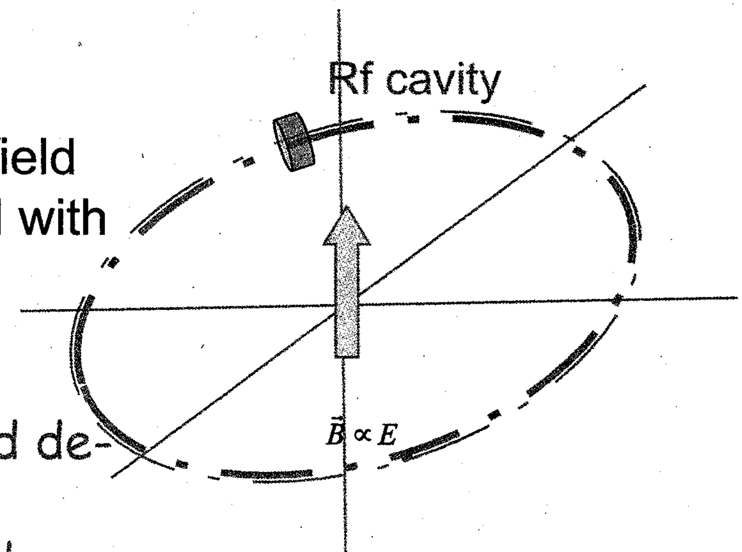
- **General introduction of**
  - accelerator physics
  - spin dynamics
- **Accelerating polarized protons to high energy**
  - Depolarizing mechanism
  - Techniques for preserving polarization
    - RHIC pp complex: the first polarized proton collider
- **Other topics**
  - Spin flipper
- **Summary**

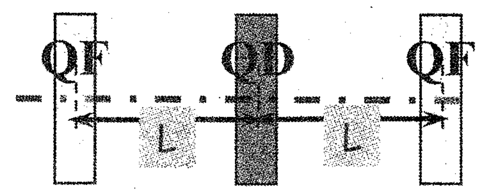
Suggested topics from Christine

- Basic accelerator physics
- Basics of polarized proton acceleration
- RHIC pp complex
- Is there any fundamental site requirements for polarized colliders. What should be considered if we can build from scratch?
- Why HERA didn't work
- Other than pp, what are the other species we can get in RHIC
- What are the required expertise for designing/ operating high energy colliders
- ....

Synchrotron

- The acceleration comes from the electric field with an oscillating frequency synchronized with the particle's revolution frequency
- Alternating gradient
  - *A proper combination of focusing and de-focusing quadrupoles yields a net focusing force in both horizontal and vertical planes*
- FODO cell: most popular building block for synchrotrons





$$\begin{pmatrix} x \\ x' \end{pmatrix}_2 = \begin{pmatrix} 1 & 0 \\ \frac{1}{-2f} & 1 \end{pmatrix} \begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ \frac{1}{f} & 1 \end{pmatrix} \begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ \frac{1}{-2f} & 1 \end{pmatrix} \begin{pmatrix} x \\ x' \end{pmatrix}_1$$

Beam motion in a circular accelerator

- Closed orbit
  - A particle trajectory remains constant from one orbital revolution to the next
  - Closed orbit distortion: deviation from the center of the beam pipe

- Betatron oscillation
  - An oscillatory motion around the closed orbit from turn to turn

$$\frac{d^2x}{ds^2} + K_x(s)x = 0 \Longrightarrow x(s) = \sqrt{2\beta_x J}\cos(2\pi Q_x \theta(s) + \chi_x)$$

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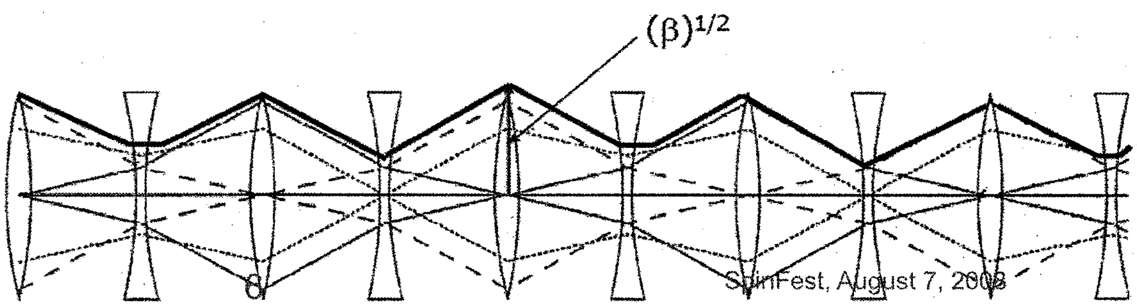
Particle motion in a synchrotron

- Betatron oscillation:

$$x(s) = \sqrt{2\beta_x J}\cos(2\pi Q_x \theta(s) + \chi_x)$$

- Betatron tune: number of betatron oscillations in one orbital revolution
- Beta function: the envelope of the particle's trajectory along the machine



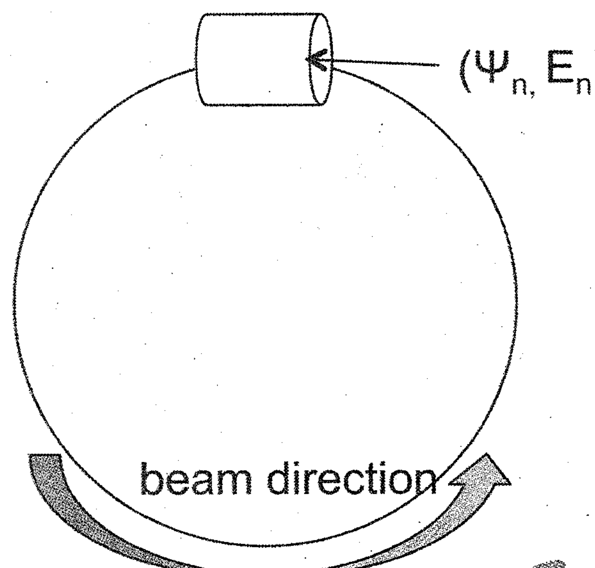
RF cavity

- Provide an oscillating electrical field to
  - accelerate the charged particles
  - keep the particles longitudinally bunched, i.e. focused

- A metallic cavity
  - resonating at a frequency integer multiples of the particle's revolution frequency

$$E_z(r,t) = E(r)e^{i2\pi f_{rf}t}$$

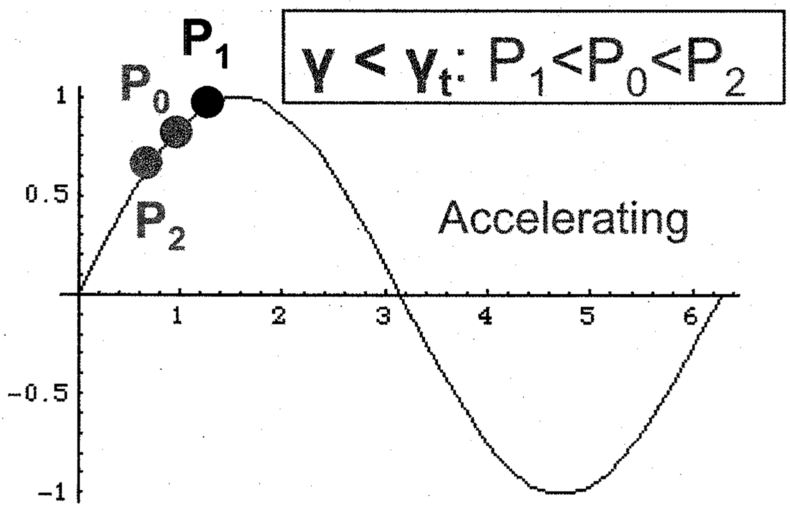
$$B_\theta(r,t) = B(r)e^{i2\pi f_{rf}t}$$

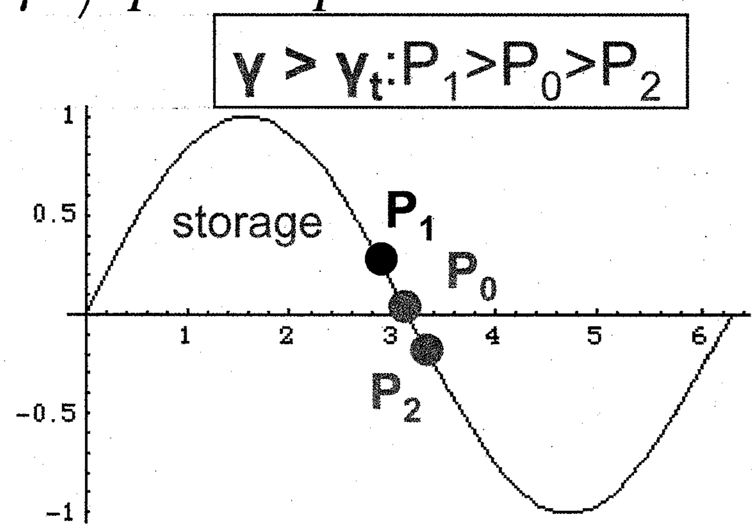


Longitudinal motion

- Synchronous particle: particle always arrive at the same phase of the oscillating electrical field
- Non-synchronous particle: particle which has different energy than the synchronous particle's

$$\frac{\Delta T}{T} = \frac{\Delta L}{L} - \frac{\Delta v}{v} = \left(\frac{1}{\gamma_t^2} - \frac{1}{\gamma^2}\right)\frac{\Delta p}{p} = \eta\frac{\Delta p}{p}$$





Synchrotron motion

- Transition energy γ_t
  - When the particles are getting more and more relativistic, there is an energy when particles with different energies spend the same time to travel along the ring
  - Pre-determined by the optical structure of the accelerator
  - Synchronous phase has to jump 180° before and after the transition to keep the longitudinal stability

- Synchrotron oscillation

$$\phi_{n+1} = \phi_n + \frac{2\pi h \eta}{\beta_s^2 E} \Delta E_{n+1}$$

$$\Delta E_{n+1} = \Delta E_n + eV(\sin\phi_n - \sin\phi_s)$$

Spin motion: Thomas BMT Equation

$$\frac{d\vec{S}}{dt} = \vec{\Omega} \times \vec{S} = -\frac{e}{\gamma m}\left[(1+G\gamma)\vec{B}_{\perp} + (1+G)\vec{B}_{//}\right] \times \vec{S}$$

Spin vector in particle's rest frame

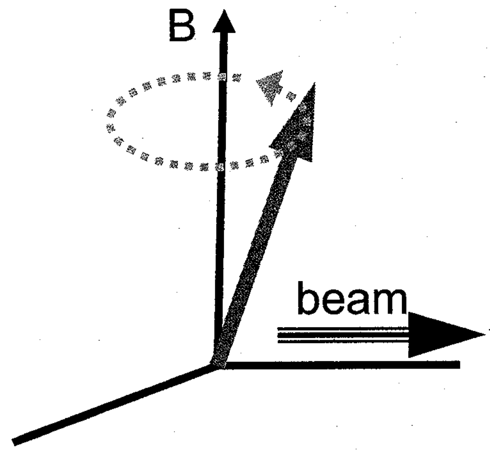
Magnetic field along the direction of the particle's velocity

Magnetic field perpendicular to the particle's velocity

- G is the anomoulous g- factor, for proton,
  G=1.7928474
- γ: Lorenz factor

Spin motion in a circular accelerator

- In a perfect accelerator, spin vector precesses around its guiding field along the vertical direction

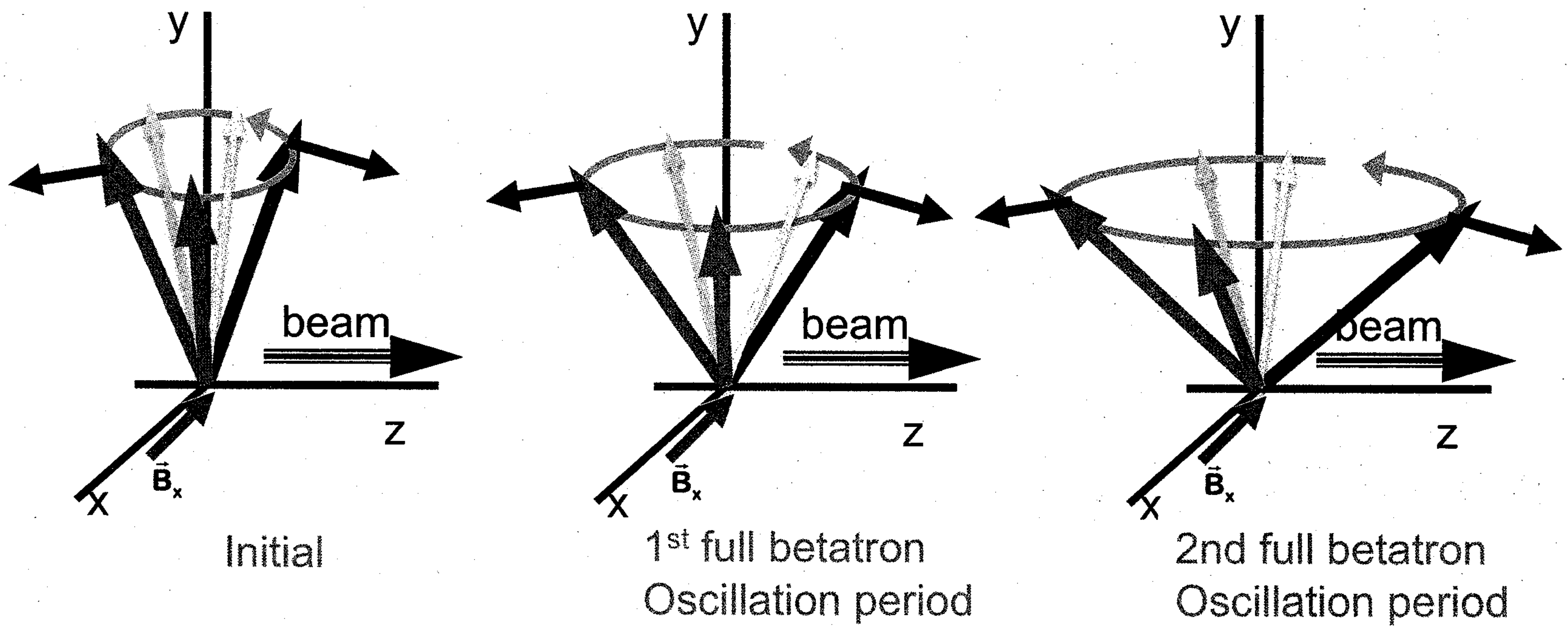


- Spin tune Q_s: number of precessions in one orbital revolution. In general,

$$Q_s = G\gamma$$

Depolarizing mechanism in a synchrotron

- **horizontal field kicks the spin vector away from its vertical direction, and can lead to polarization loss**
  - dipole errors, misaligned qadrupoles, imperfect orbits
  - betatron oscillations
  - other multipole magnetic fields
  - other sources



Nucleon Structure and Lattice QCD

J. W. Negele

PHENIX Spin Fest 2008

BNL August 8, 2008

Collaborators

MIT
- B. Bistrovic
- J. Bratt
- D. Dolgov
- O. Jahn
- M. F. Lin
- H. Meyer
- A. Pochinsky
- D. Sigaev
- S. Syritsyn

JLab
- R. Edwards
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- D. Richards

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- Ph. Leontiou

Athens
- A. Tsapalis

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- Ph. de Forcrand

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- Th. Lippert

Wuppertal
- K. Schilling

Outline

- Introduction
  - QCD
  - Lattice Field Theory
  - Computers for lattice QCD
  - Lattice highlights
- Understanding hadron structure
  - Deep inelastic scattering
  - Lattice calculation of nucleon matrix elements
  - Quark distributions
  - Form factors and generalized form factors
  - Transverse structure
  - Origin of nucleon spin
  - Baryon shapes
- Insight into how QCD works
- Summary and future challenges

QCD

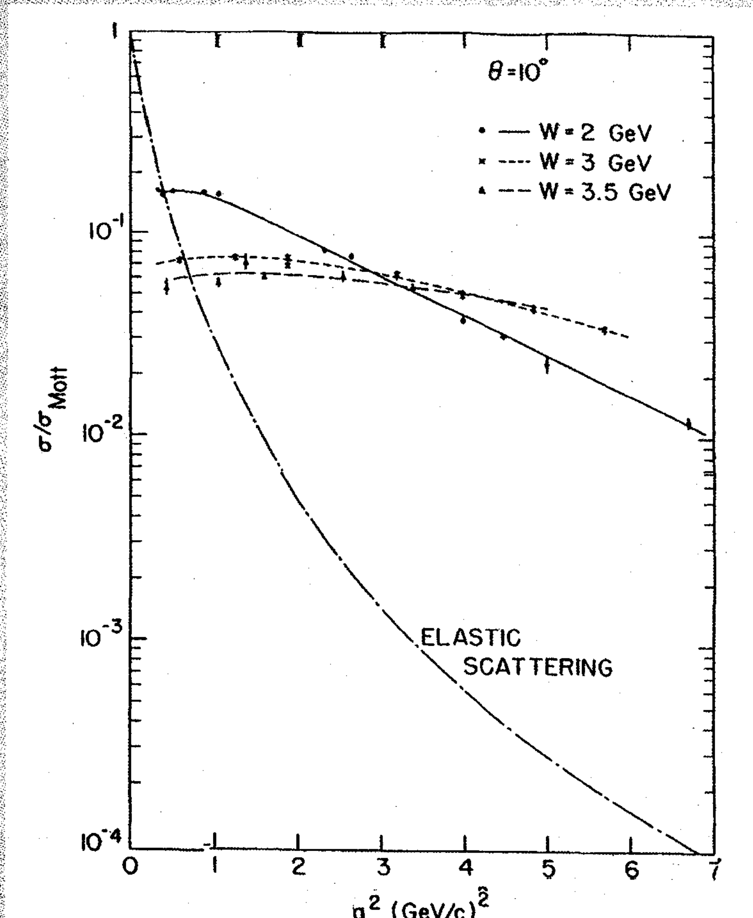
Introduction - Fundamental Question

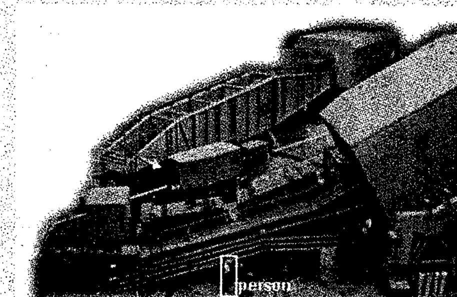
- Hadrons - protons, neutrons and other strongly interacting particles - make up most of the mass of the visible universe

- How do we understand the properties and interactions of these basic building blocks of matter from first principles?

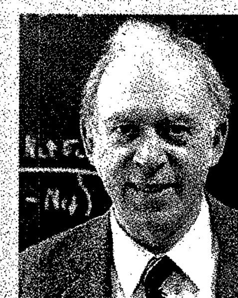
Discovery of Quarks at SLAC

Deep Inelastic electron scattering





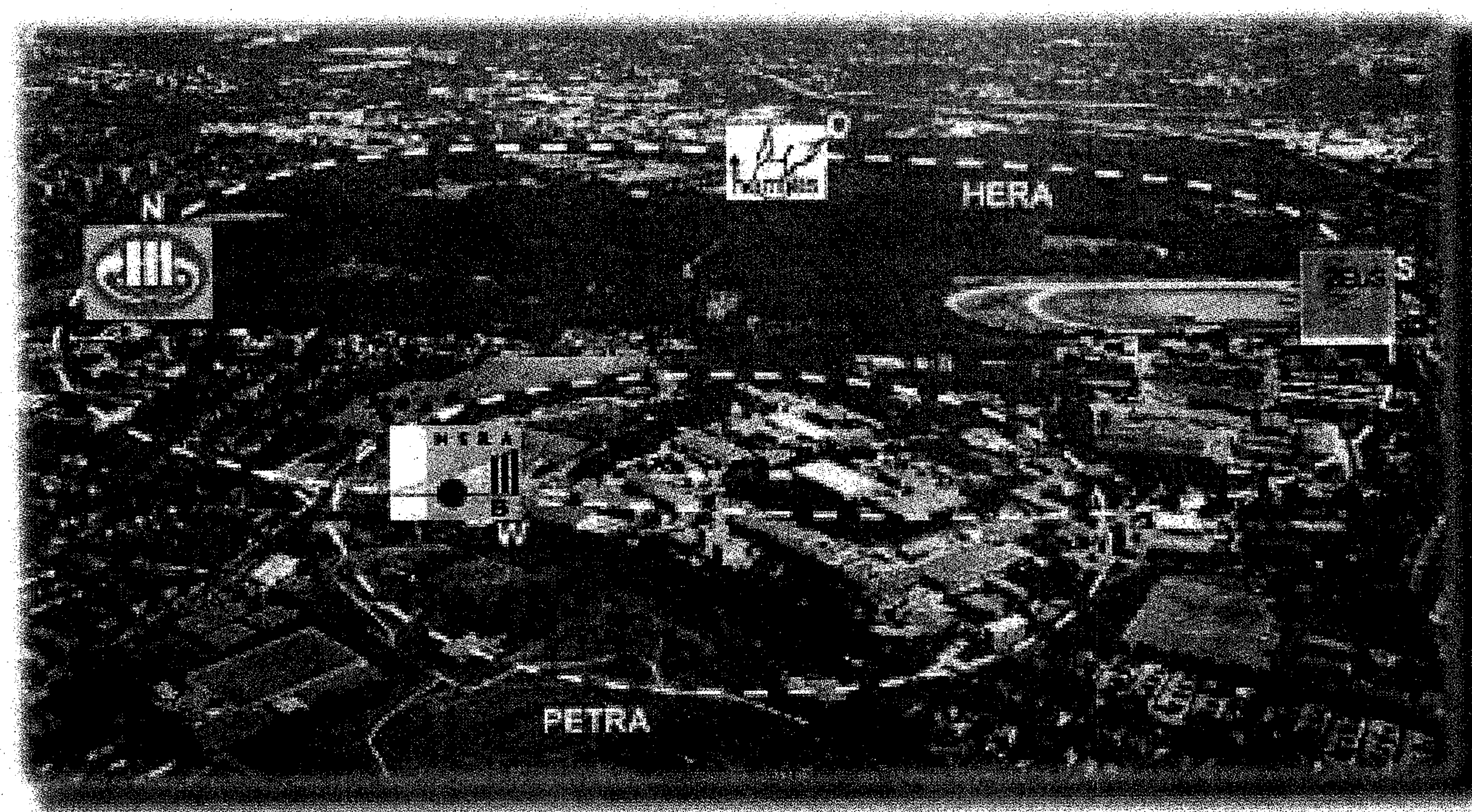
1990 Nobel Prize



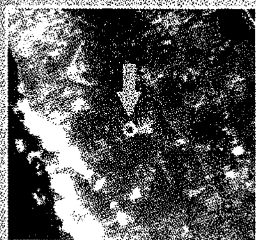
DESY

HERA 27.5 GeV electrons on 920 GeV protons

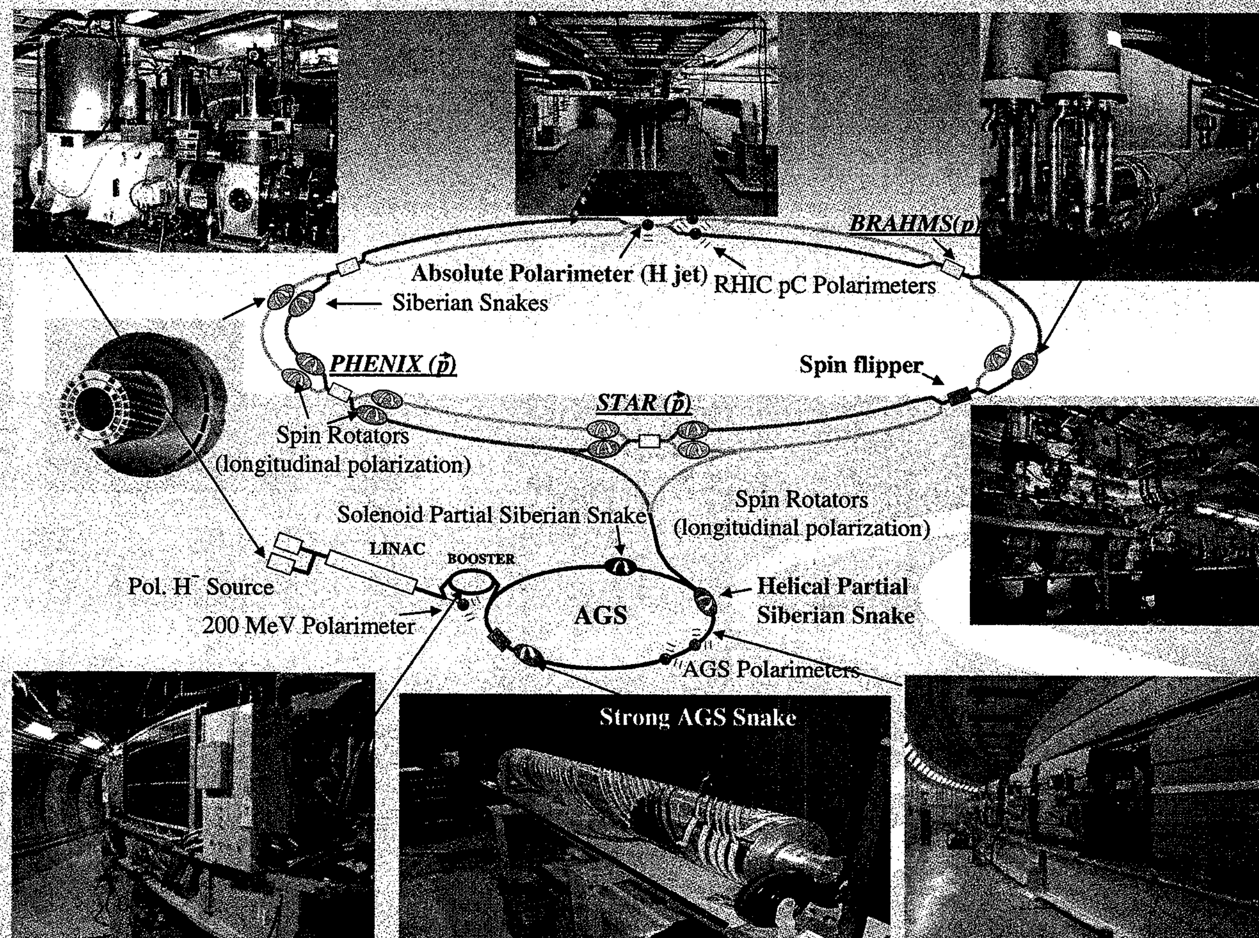
HERMES 27.5 GeV electrons on gas target - Polarization



RHIC - Spin

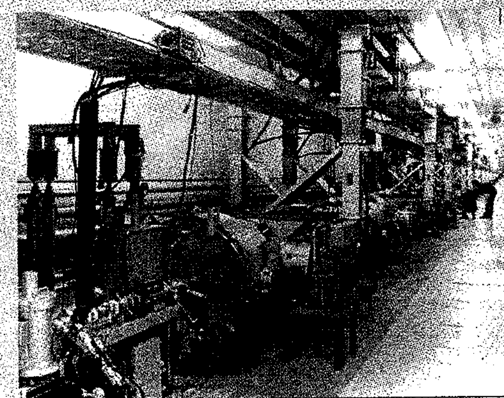


250 + 250 GeV polarized protons



Jefferson Lab Electron Accelerator

Scatter 6 GeV electrons from nucleons
12 GeV upgrade planned



Fundamental Question

- How do hadrons arise from QCD?
- Lagrangian constrained by Lorentz invariance, gauge invariance and renormalizability:

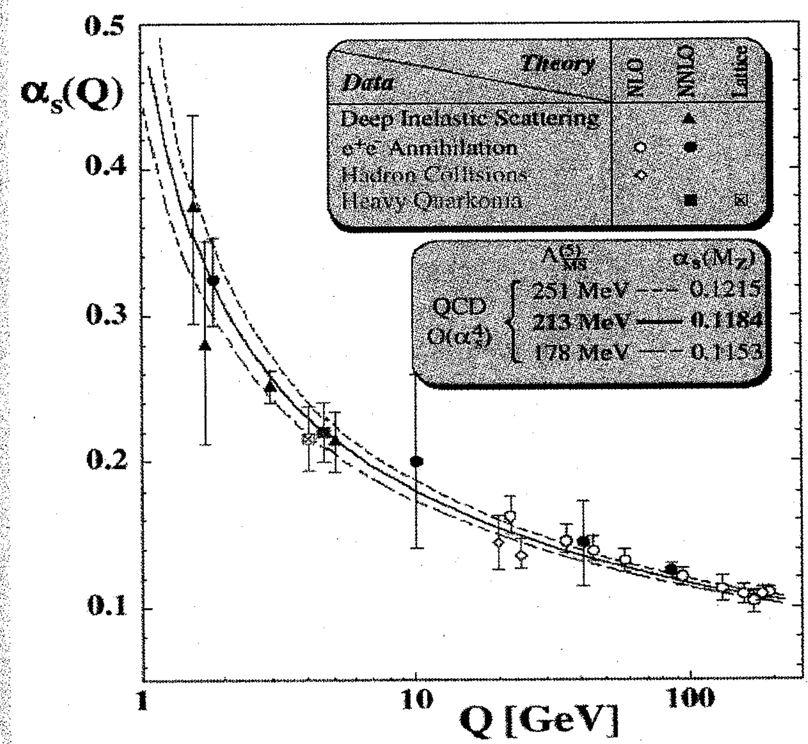
$$\mathcal{L} = \bar{\psi}(i\gamma^{\mu} D_{\mu} - m)\psi - \frac{1}{4}F_{\mu\nu}^{2}$$

$$D_{\mu} = \partial_{\mu} - igA_{\mu} \qquad F_{\mu\nu} = \frac{i}{g}[D_{\mu}, D_{\nu}]$$

- Deceptively simple Lagrangian produces amazingly rich and complex structure of strongly interacting matter in our universe

QCD and Asymptotic Freedom

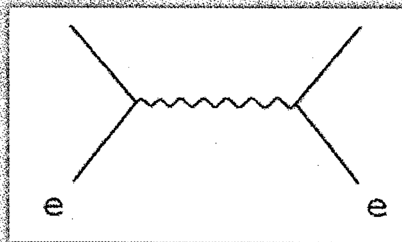
David J. Gross	**H. David Politzer**	**Frank Wilczek**
Kavli Institute for Theoretical Physics University of California, Santa Barbara, USA	California Institute of Technology (Caltech), Pasadena, USA	Massachusetts Institute of Technology (MIT), Cambridge, USA



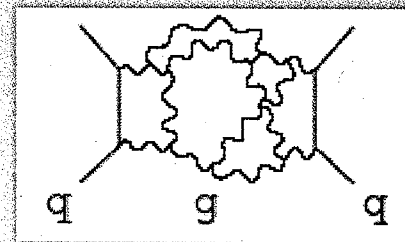
The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics for 2004 "for the discovery of asymptotic freedom in the theory of the strong interaction" jointly to David J. Gross, H. David Politzer and Frank Wilczek

Nonperturbative QCD

QED



QCD



- Fundamental differences relative to QED
  - Self-interacting: highly nonlinear
  - Interaction increases at large distance: Confinement
  - Interaction decreases at small distance: Asymptotic Freedom
  - Strong coupling: $\alpha_s \gg \alpha_{em}$
  - Topological excitations
- Solution of nonperturbative QCD
  - Present analytical techniques inadequate
  - Numerical evaluation of path integral on space-time lattice

Profound differences between hadrons and other many-body systems

- Atoms, molecules, nuclei,...
  - Constituents can be removed
  - Exchanged boson generating interaction may be subsumed into static potential
    - photons → Coulomb potential
    - Mesons → N-N potential
  - Most of mass from fermion constituents
- Nucleons
  - Quarks are confined
  - Gluons are essential degrees of freedom
    - Carry half of momentum
    - Nonperturbative topological excitations
  - Most of mass generated by interactions

Goals

- Quantitative calculation of hadron observables from first principles
  - Agreement with experiment
  - Credibility for predictions and guiding experiment
- Insight into how QCD works
  - Mechanisms
    - Origin of nucleon spin and mass
    - Paths that dominate action - instantons
    - Variational wave functions
    - Diquark correlations
  - Dependence on parameters
    - N_c, N_f , gauge group, m_q

How to solve QCD

- Analytic methods
  - Perturbation theory
  - Chiral Perturbation theory / Effective field theory
  - String theory techniques to solve somewhat similar theories
- Nonperturbative regime
  - Numerical solution of path integral on space-time lattice

Lattice Field Theory

PHENIX SPIN FEST SCHOOL 2008 AT BNL

Physics Bldg. 510 small and large conference rooms

Agenda

Monday Morning, Aug. 04	**Chair – Christine Aidala**
Small Conference Room	**Speaker: George Sterman**, Stony Brook
09:00 - 12:00	Introduction to Pertrubative QCD
Tuesday Morning, August 05	**Chair – Christine Aidala**
Large Conference Room	**Speaker: George Sterman, Stony Brook**
09:00 - 12:00	Introduction to Pertrubative QCD
Wednesday Morning, August 06	**Chair - Christine Aidala**
Small Conference Room	**Speaker: Mauro Anselmino, INFN/Torino Italy**
09:00 - 10:30	The Transverse Spin Structure of the Nucleon - I
Thursday Morning, August 07	**Chair - Christine Aidala**
Small Conference Room	
09:00 – 10:30	**Speaker: Mauro Anselmino, INFN/Torino Italy**
	The Transverse Spin Structure of the Nucleon - I
10:30 – 12:00	**Speaker: Mei Bai, BNL**
	Acceleration of Polarized Protons
Friday Morning, August 08	**Chair - Christine Aidala**
Small Conference Room	
09:00 – 12:00	**Speaker: John Negele, MIT**
	Nucleon Structure and Lattice QCD

PHENIX SpinFest 2008

The 4th annual PHENIX Spinfest will take place at BNL July 21 through August 8. Since 2005, the PHENIX Spin Physics Working Group has set aside several weeks each summer for the purposes of training and integrating recent members of the working group as well as coordinating and making rapid progress on support tasks and data analysis. One week is dedicated to more formal didactic lectures by outside speakers. The location has so far alternated between BNL and the RIKEN campus in Wako, Japan, with support provided by RBRC and LANL. This year's PHENIX Spinfest School will take place the mornings of August 4-8. All are welcome. Lectures will be in the Small Seminar Room all days except Tuesday, on which the lecture will instead be held in the Large Seminar Room.

- August 4-5, 9 a.m.
  Introduction to pQCD
  George Sterman, Stony Brook

- August 6-7, 9 a.m.
  The Transverse Spin Structure of the Nucleon
  Lecture 1 Lecture 2 Lecture 3
  Mauro Anselmino, INFN and University of Torino

- August 7, 10:30 a.m.
  Acceleration of Polarized Protons
  Mei Bai, BNL

- August 8, 9 a.m.
  Nucleon Structure and Lattice QCD
  John Negele, MIT

PHENIX SPIN FEST

August 04 - 08, 2008

Bldg. 510A; RBRC Conference - Small Conference room

LIST OF PARTICIPANTS

NAME	AFFILIATION
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Murad Sarsour	Texas, A&M
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Feng Wei	ISU
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Gary Kyle	NMSU
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Itaru Nakagawa	RBRC/BNL
Sinya Aoki	Univ. of Tsukuba
Paul Kline	Stony Brook
Gabriele Carcassi	BNL
David Morrison	BNL
Anatoli Zelenski	BNL

RBRC Workshop Proceedings

Volume 89 - Understanding QGP through Spectral Functions and Euclidean Correlators, April 23-25, 2008 - BNL-81318-2008
Volume 88 - Hydrodynamics in Heavy Ion Collisions and QCD Equation of State, April 21-22, 2008 - BNL-81307-2008
Volume 87 - RBRC Scientific Review Committee Meeting – BNL-79570-2007
Volume 86 – Global Analysis of Polarized Parton Distributions in the RHIC Era, October 8, 2007 – BNL-79457-2007
Volume 85 – Parity Violating Spin Asymmetries at RHIC-BNL, April 26-27, 2007 – BNL – 79146-2007
Volume 84 – Domain Wall Fermions at Ten Years, March 15-17, 2007 - BNL-77857-2007
Volume 83 – QCD in Extreme Conditions, July 31-August 2, 2006 – BNL-76933-2006
Volume 82 – RHIC Physics in the Context of the Standard Model, June 18-23, 2006 – BNL-76863-2006
Volume 81 – Parton Orbital Angular Momentum (Joint RBRC/University of New Mexico Workshop) February 24-26, 2006 – BNL-75937-2006
Volume 80 – Can We Discover the QCD Critical Point at RHIC?, March 9-10, 2006 – BNL 75692-2006
Volume 79 – Strangeness in Collisions, February 16-17, 2006 – BNL-79763-2008
Volume 78 – Heavy Flavor Productions and Hot/Dense Quark Matter, December 12-14, 2005 – BNL-76915-2006
Volume 77 – RBRC Scientific Review Committee Meeting, October 10-12, 2005 – BNL-52649-2005
Volume 76 – Odderon Searches at RHIC, September 27-29, 2005 – BNL-75092-2005
Volume 75 – Single Spin Asymmetries, June 1-3, 2005 – BNL-74717-2005
Volume 74 – RBRC QCDPC Computer Dedication and Symposium on RBRC QCDOC, May 26, 2005 – BNL-74813-2005
Volume 73 - Jet Correlations at RHIC, March 10-11, 2005 - BNL-73910-2005
Volume 72 - RHIC Spin Collaboration Meetings XXXI (January 14, 2005), XXXII (February 10, 2005), XXXIII (March 11, 2005) - BNL-73866-2005
Volume 71 - Classical and Quantum Aspects of the Color Glass Condensate - BNL-73793-2005
Volume 70 - Stongly Coupled Plasmas: Electromagnetic, Nuclear & Atomic - BNL-73867-2005
Volume 69 - RBRC Scientific Review Committee Meeting - BNL-73546-2004
Volume 68 - Workshop on the Physics Programme of the RBRC and UKQCD QCDOC Machines - BNL-73604-2004
Volume 67 - High Performance Computing with BlueGene/L and QCDOC Architectures - BNL-
Volume 66 - RHIC Spin Collaboration Meeting XXIX, October 8-9, 2004, Torino, Italy - BNL-73534-2004
Volume 65 - RHIC Spin Collaboration Meetings XXVII (July 22, 2004), XXVIII (September 2, 2004) - BNL-73506-2004
Volume 64 - Theory Summer Program on RHIC Physics - BNL-73263-2004
Volume 63 - RHIC Spin Collaboration Meetings XXIV (05/21/04), XXV (05/27/04), XXVI (06/01/04) - BNL-72397-2004
Volume 62 - New Discoveries at RHIC, May 14-15, 2004 - BNL-72391-2004
Volume 61 - RIKEN-TODAI Mini Workshop on "Topics in Hadron Physics at RHIC", March 23-24, 2004 - BNL-72336-2004
Volume 60 - Lattice QCD at Finite Temperature and Density - BNL-72083-2004
Volume 59 - RHIC Spin Collaboration Meeting XXI, XXII, XXIII - BNL-72382-2004
Volume 58 - RHIC Spin Collaboration Meeting XX - BNL-71900-2004
Volume 57 - High pt Physics at RHIC, December 2-6, 2003 - BNL-72069-2004
Volume 56 - RBRC Scientific Review Committee Meeting - BNL-71899-2003

Volume 55 - Collective Flow and QGP Properties - BNL-71898-2003
Volume 54 – RHIC Spin Collaboration Meetings XVII, XVIII, XIX - BNL-71751-2003
Volume 53 – Theory Studies for Polarized *pp* Scattering - BNL-71747-2003
Volume 52 – RIKEN School on QCD, "Topics on the Proton" - BNL-71694-2003
Volume 51 – RHIC Spin Collaboration Meetings XV, XVI – BNL-71539-2003
Volume 50 – High Performance Computing with QCDOC and BlueGene – BNL-71147-2003
Volume 49 – RBRC Scientific Review Committee Meeting – BNL-52679
Volume 48 – RHIC Spin Collaboration Meeting XIV – BNL-71300-2003
Volume 47 – RHIC Spin Collaboration Meetings XII, XIII – BNL-71118-2003
Volume 46 – Large-Scale Computations in Nuclear Physics using the QCDOC – BNL-52678
Volume 45 – Summer Program: Current and Future Directions at RHIC – BNL-71035
Volume 44 – RHIC Spin Collaboration Meetings VIII, IX, X, XI – BNL-71117-2003
Volume 43 – RIKEN Winter School – Quark-Gluon Structure of the Nucleon and QCD – BNL-52672
Volume 42 – Baryon Dynamics at RHIC – BNL-52669
Volume 41 – Hadron Structure from Lattice QCD – BNL-52674
Volume 40 – Theory Studies for RHIC-Spin – BNL-52662
Volume 39 – RHIC Spin Collaboration Meeting VII – BNL-52659
Volume 38 – RBRC Scientific Review Committee Meeting – BNL-52649
Volume 37 – RHIC Spin Collaboration Meeting VI (Part 2) – BNL-52660
Volume 36 – RHIC Spin Collaboration Meeting VI – BNL-52642
Volume 35 – RIKEN Winter School – Quarks, Hadrons and Nuclei – QCD Hard Processes and the Nucleon Spin – BNL-52643
Volume 34 – High Energy QCD: Beyond the Pomeron – BNL-52641
Volume 33 – Spin Physics at RHIC in Year-1 and Beyond – BNL-52635
Volume 32 – RHIC Spin Physics V – BNL-52628
Volume 31 – RHIC Spin Physics III & IV Polarized Partons at High Q^2 Region – BNL 52617
Volume 30 – RBRC Scientific Review Committee Meeting – BNL-52603
Volume 29 – Future Transversity Measurements – BNL-52612
Volume 28 – Equilibrium & Non-Equilibrium Aspects of Hot, Dense QCD – BNL-52613
Volume 27 – Predictions and Uncertainties for RHIC Spin Physics & Event Generator for RHIC Spin Physics III – Towards Precision Spin Physics at RHIC – BNL-52596
Volume 26 – Circum-Pan-Pacific RIKEN Symposium on High Energy Spin Physics – BNL-52588
Volume 25 – RHIC Spin – BNL-52581
Volume 24 – Physics Society of Japan Biannual Meeting Symposium on QCD Physics at RIKEN BNL Research Center – BNL-52578
Volume 23 – Coulomb and Pion-Asymmetry Polarimetry and Hadronic Spin Dependence at RHIC Energies – BNL-52589
Volume 22 – OSCAR II: Predictions for RHIC – BNL-52591
Volume 21 – RBRC Scientific Review Committee Meeting – BNL-52568
Volume 20 – Gauge-Invariant Variables in Gauge Theories – BNL-52590
Volume 19 – Numerical Algorithms at Non-Zero Chemical Potential – BNL-52573
Volume 18 – Event Generator for RHIC Spin Physics – BNL-52571
Volume 17 – Hard Parton Physics in High-Energy Nuclear Collisions – BNL-52574
Volume 16 – RIKEN Winter School - Structure of Hadrons - Introduction to QCD Hard Processes – BNL-52569
Volume 15 – QCD Phase Transitions – BNL-52561
Volume 14 – Quantum Fields In and Out of Equilibrium – BNL-52560
Volume 13 – Physics of the 1 Teraflop RIKEN-BNL-Columbia QCD Project First Anniversary Celebration – BNL-66299
Volume 12 – Quarkonium Production in Relativistic Nuclear Collisions – BNL-52559
Volume 11 – Event Generator for RHIC Spin Physics – BNL-66116
Volume 10 – Physics of Polarimetry at RHIC – BNL-65926
Volume 9 – High Density Matter in AGS, SPS and RHIC Collisions – BNL-65762

Volume 8 – Fermion Frontiers in Vector Lattice Gauge Theories – BNL-65634
Volume 7 – RHIC Spin Physics – BNL-65615
Volume 6 – Quarks and Gluons in the Nucleon – BNL-65234
Volume 5 – Color Superconductivity, Instantons and Parity (Non?)-Conservation at High Baryon Density – BNL-65105
Volume 4 – Inauguration Ceremony, September 22 and Non -Equilibrium Many Body Dynamics –BNL-64912
Volume 3 – Hadron Spin-Flip at RHIC Energies – BNL-64724
Volume 2 – Perturbative QCD as a Probe of Hadron Structure – BNL-64723
Volume 1 – Open Standards for Cascade Models for RHIC – BNL-64722

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Complete talk: http://www.phenix.bnl.gov/WWW/physics/spin/spinfest/2008/

RIKEN BNL RESEARCH CENTER

PHENIX SpinFest School 2008 at BNL

August 04 – 08, 2008

Li Keran

Nuclei as heavy as bulls
Through collision
Generate new states of matter.
T.D. Lee

Speakers: Geroge Sterman, Stony Brook; Mei Bai, BNL; Mauro Anselmino, INFN/Torino, Italy; John Negele, MIT

Organizers: Christine Aidala, Yuji Goto, Kensuke Okada