The 2010 TOUR

Questions about QCD

- Confinement of color, or why are there no free quarks and gluons at a long distance?

  A very hard question to answer

Lets try to answer:

- What is the role of gluons and gluon self-interactions in nucleons and nuclei?
- What is the internal landscape of the nucleons?
  - What is the nature of the spin of the proton?
  - What is the three-dimensional spatial landscape of nucleons?
- What governs the transition of quarks and gluons into pions and nucleons?

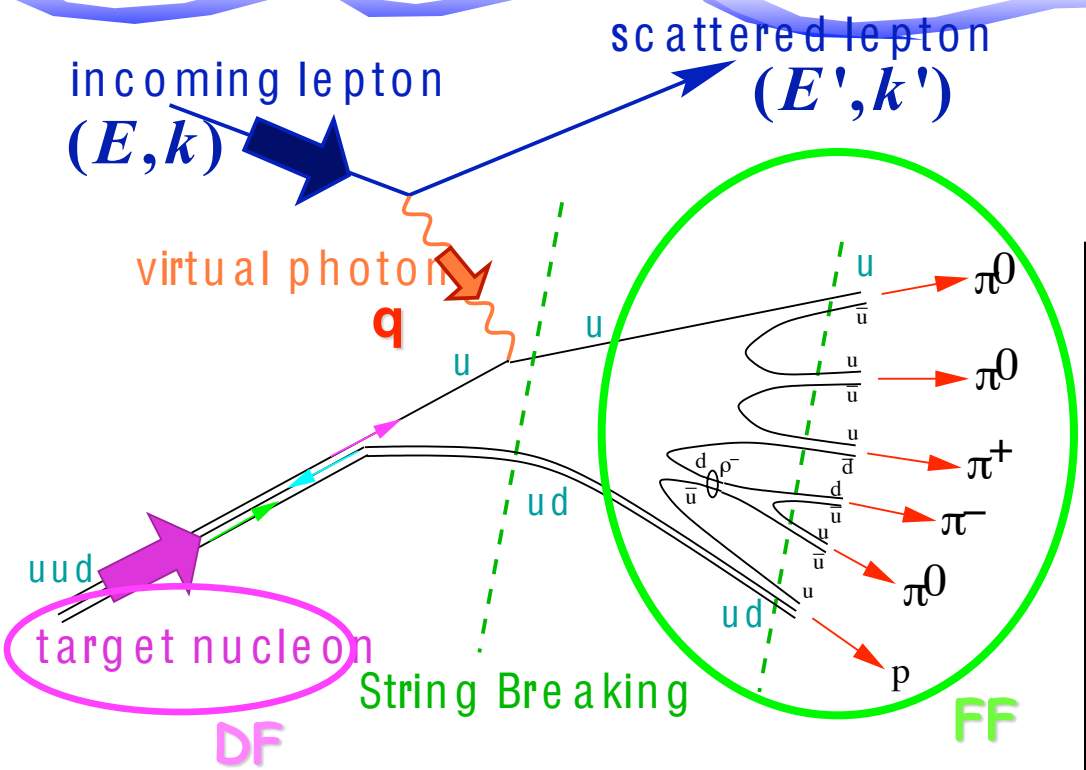
Hadrons are a composite particle of quarks and gluons

- What is the physics behind the QCD mass scale?

The key to the solution
The Gluon

- It represents the difference between QED and QCD
- Can't "see" it directly, but,
  it is behind the answers to all these questions

Deep Inelastic Scattering



Important kinematic variables:

Photon:

$$Q^2 = -q^2 = -(k-k')^2$$

$$\nu = E - E'$$

Quark: $x = \dfrac{Q^2}{2M\nu}$

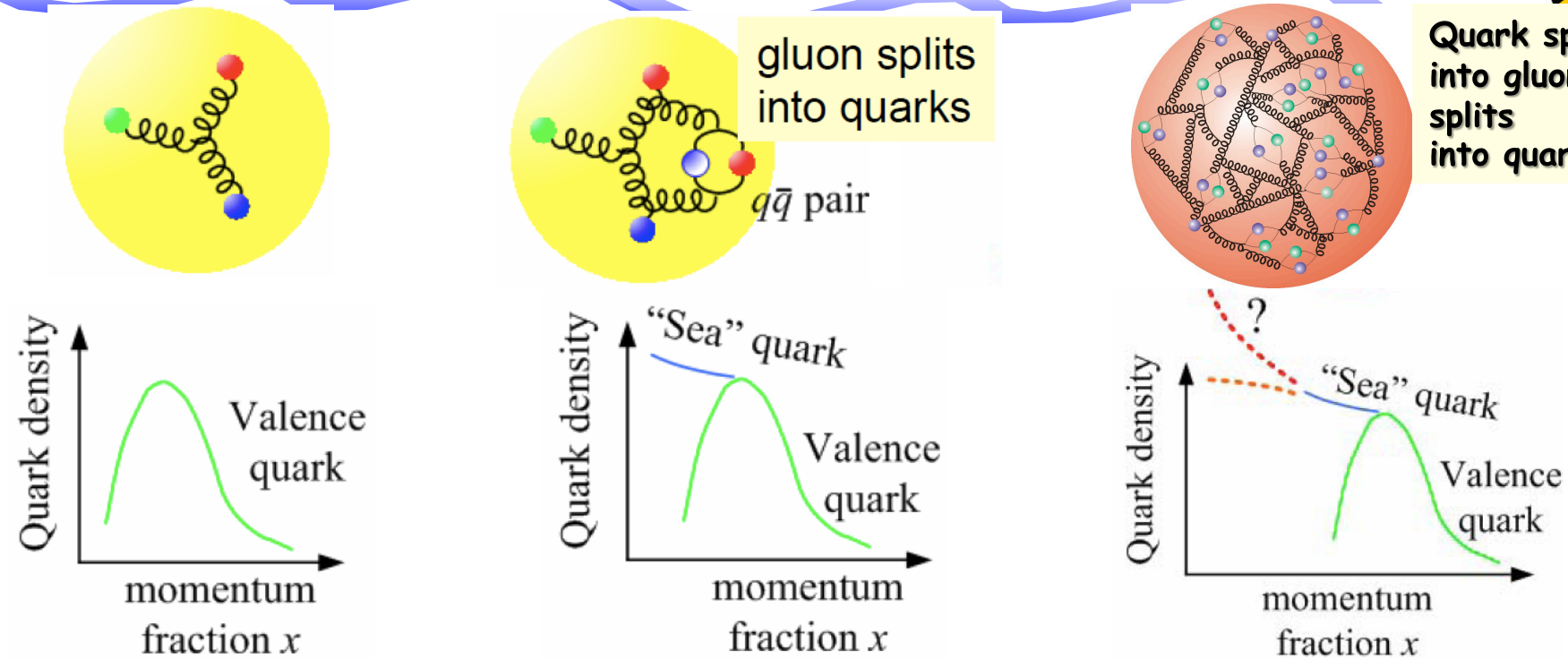
Hadron:

$$z = \frac{E_h}{\nu} \qquad p_t^2$$

cross section:

$$d\sigma^h(z) \sim \sum_f q_f(x) \otimes d\sigma_f \otimes D_f^h(z)$$

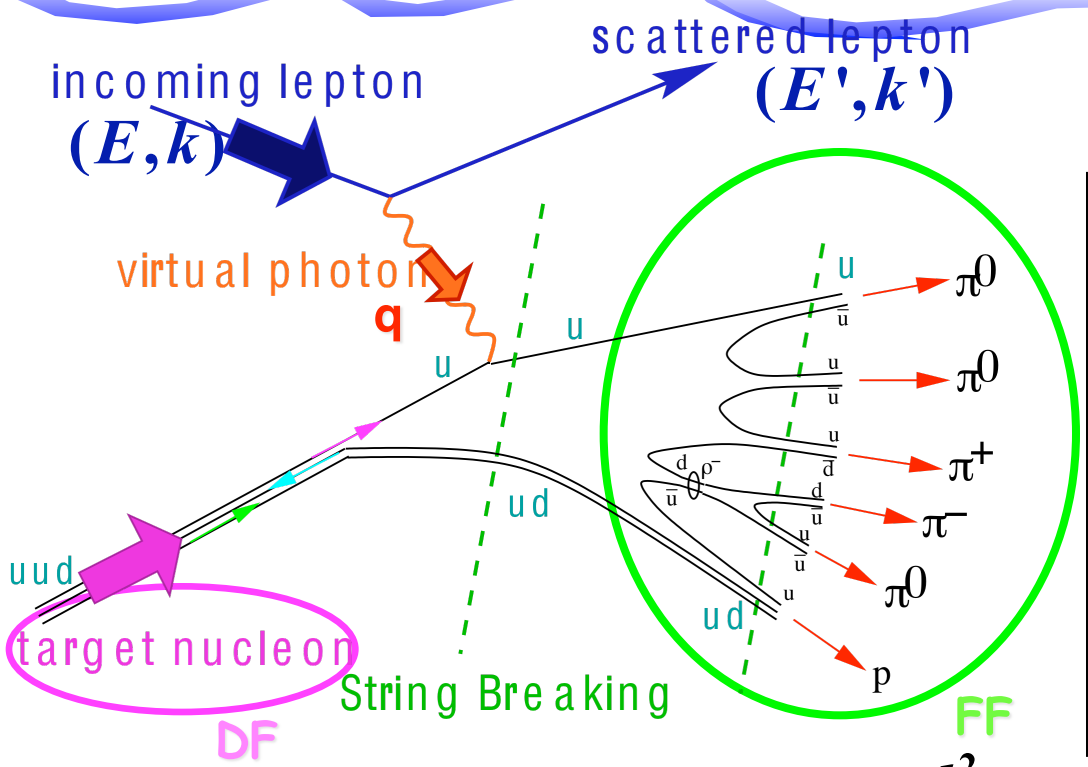
The structure of the proton – simple view



Increasing resolution (large angle scattering = large Q^2)

- **Increasing resolution: we see "small" partons**
- **How do the quarks behave at low-x**

Deep Inelastic Scattering



Important kinematic variables:

Collider:

Photon:

$$Q^2 = -q^2 = -(k-k')^2 = 2E_e E_e'(1+\cos\Theta_e)$$

$$\nu = E - E'$$

Quark: $x = \dfrac{Q^2}{sy}$

Hadron: $z = \dfrac{E_h}{\nu}$ $\quad p_t^2$

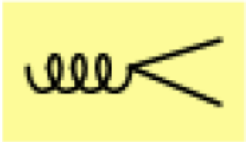
cross section: $\dfrac{d^2\sigma}{d\Omega dE'} \sim L_{\mu\nu} W^{\mu\nu}$

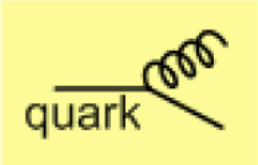
$$W^{\mu\nu} = -g^{\mu\nu} F_1 - \frac{p^\mu p^\nu}{\nu} F_2 + \frac{i}{\nu}\varepsilon^{\mu\nu\lambda\sigma} q^\lambda s^\sigma g_1 + \frac{i}{\nu^2}\varepsilon^{\mu\nu\lambda\sigma} q^\lambda (p\cdot q s^\sigma - s\cdot q p^\sigma) g_2$$

$$\underbrace{-r_{\mu\nu} b_1 + \frac{1}{6}(s_{\mu\nu} + t_{\mu\nu} + u_{\mu\nu}) b_2 + \frac{1}{2}(s_{\mu\nu} - u_{\mu\nu}) b_3 + \frac{1}{2}(s_{\mu\nu} - t_{\mu\nu}) b_4}_{\text{Spin 1}}$$

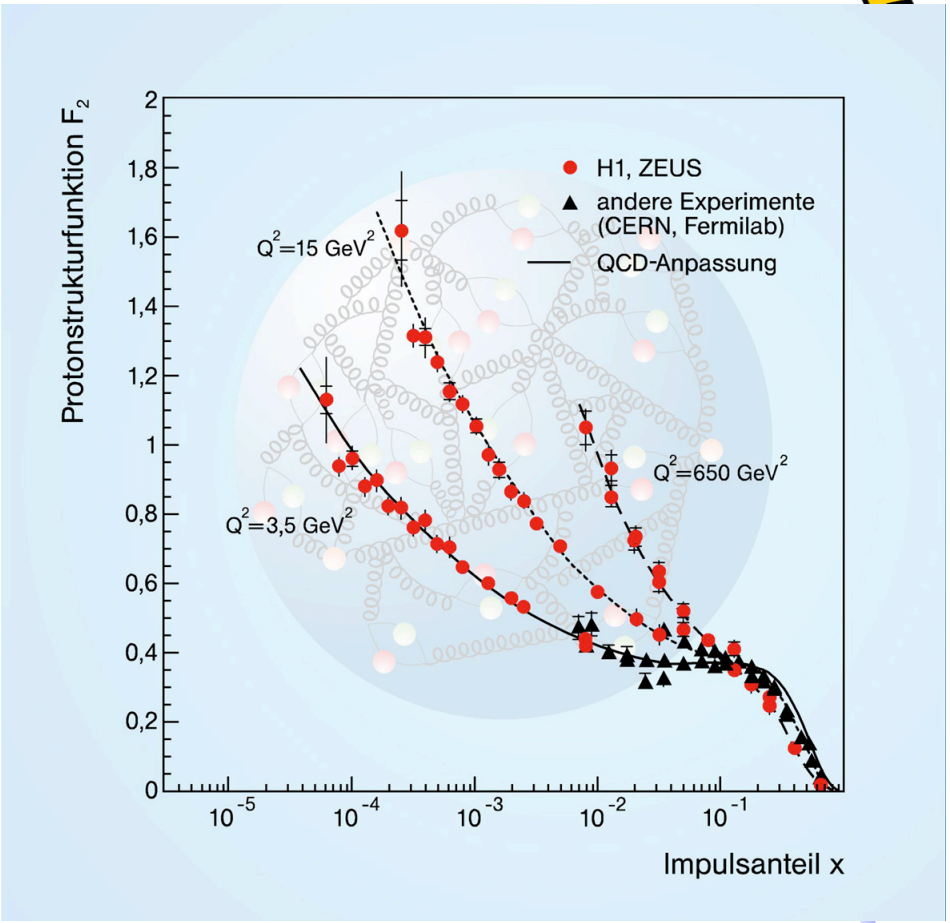
"Structure Function" & quark densities

- Strong increase of sea quarks towards low x
  - $F_2(x) = e^2 x(q(x) + \bar{q}(x))$
    quark density
- Density increases with Q^2
  - more partons by magnified view

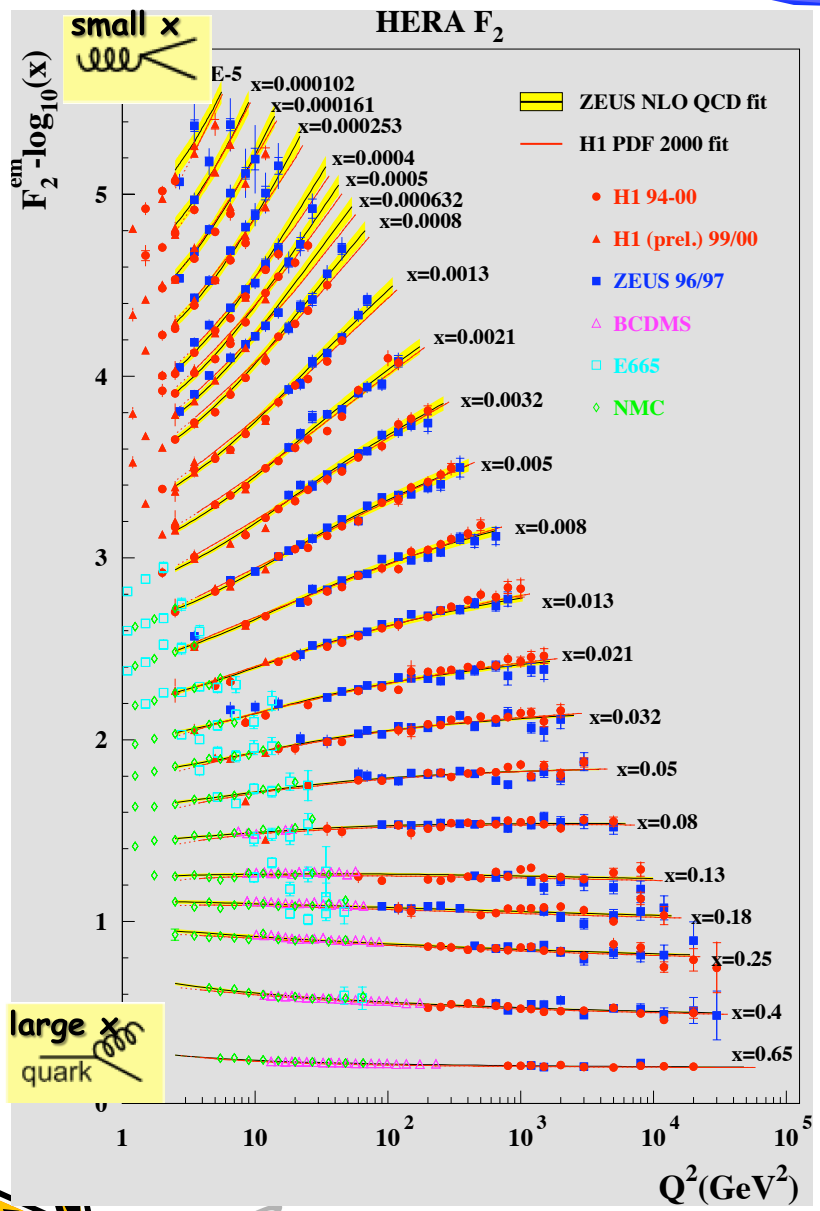




Dynamic creation of quarks at low x



Measure Glue through DIS

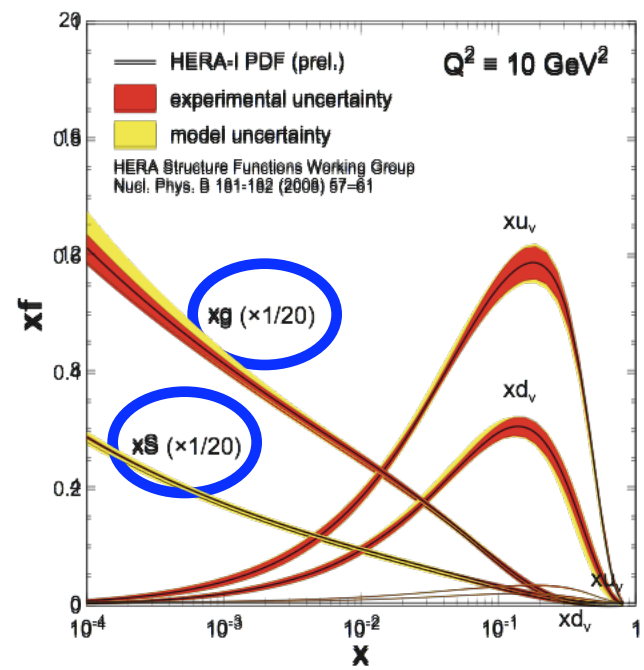


$$\frac{d^2\sigma^{NC}_{e^\mp p}}{dxdQ^2} = \frac{2\pi\alpha^2_{em}Y_+}{xQ^4}\left(F_2 - \frac{y^2}{Y_+}F_L \pm \frac{Y_-}{Y_+}xF_3\right)$$

$q(x,Q^2)+\bar{q}(x,Q^2)$ $\quad g(x,Q^2)$ $\quad q(x,Q^2)-\bar{q}(x,Q^2)$

Observation of large scaling violations

Gluon density dominates

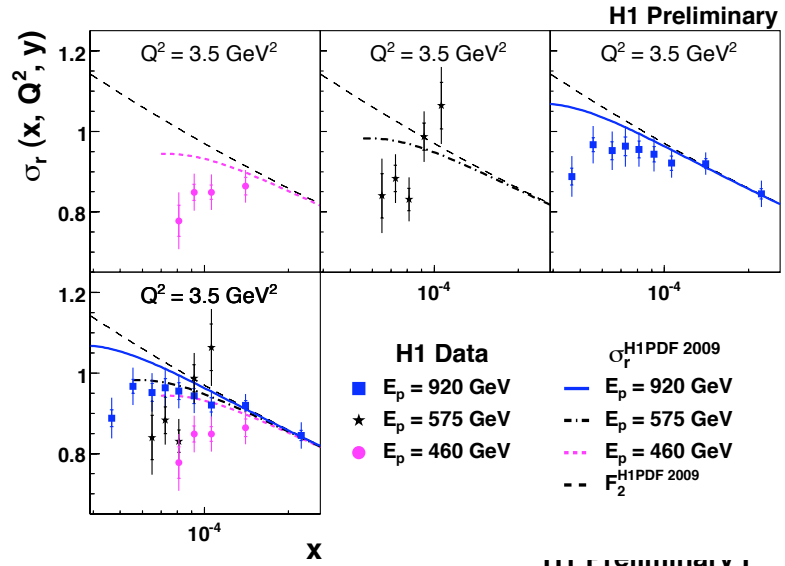


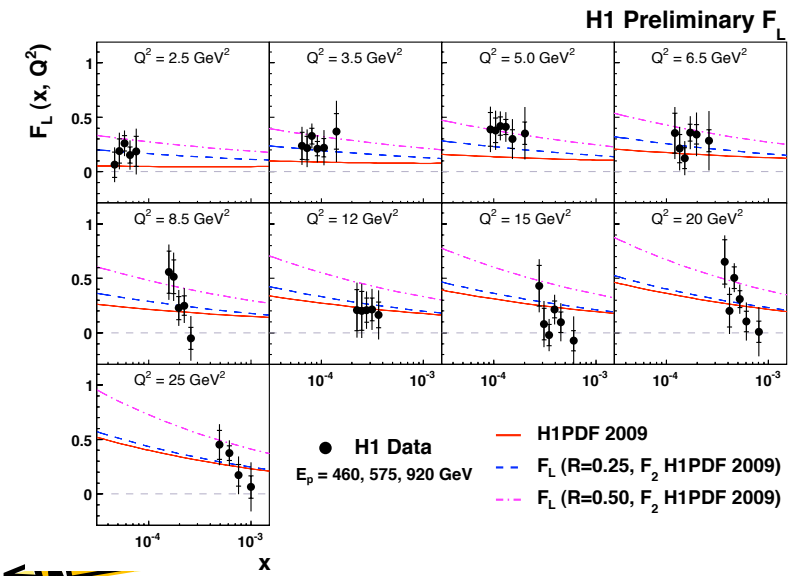
F_L: measures glue directly

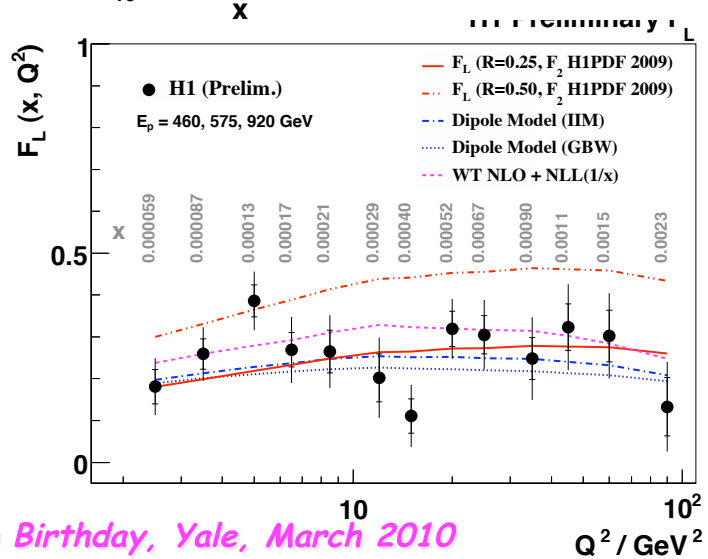
$$\frac{d^2\sigma^{NC}_{e^\mp p}}{dxdQ^2} = \frac{2\pi\alpha^2_{em}Y_+}{xQ^4}\left(F_2 - \frac{y^2}{Y_+}F_L \pm \frac{Y_-}{Y_+}xF_3\right)$$

$\Rightarrow$ **$G(x,Q^2)$ with great precision**

$F_L \sim \alpha_s\, G(x,Q^2)$
requires $\sqrt{s}$ scan $Q^2/xs = y$

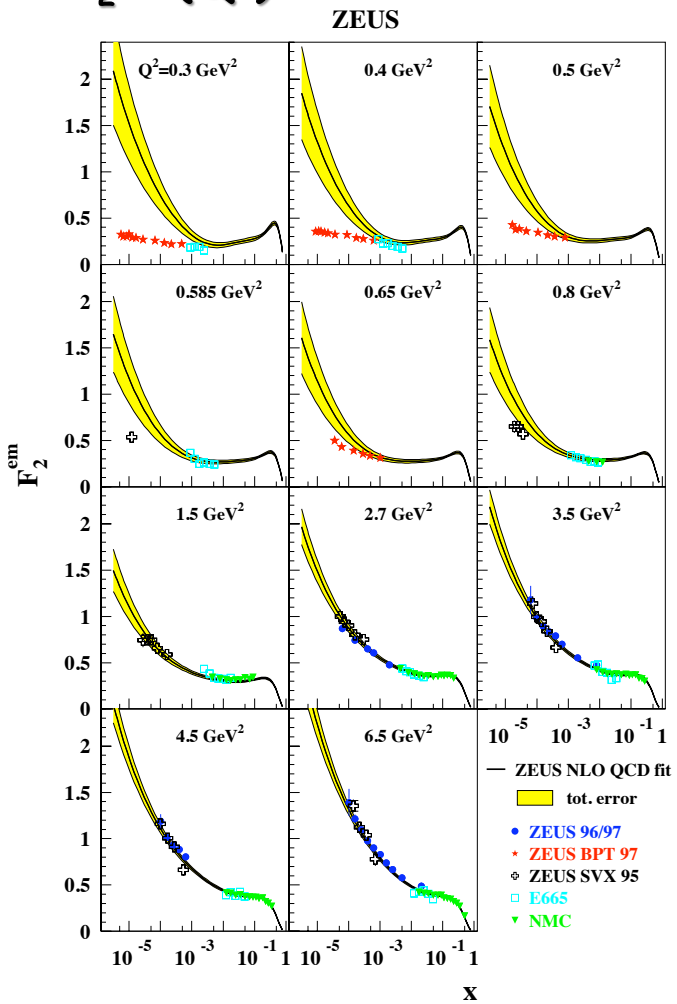






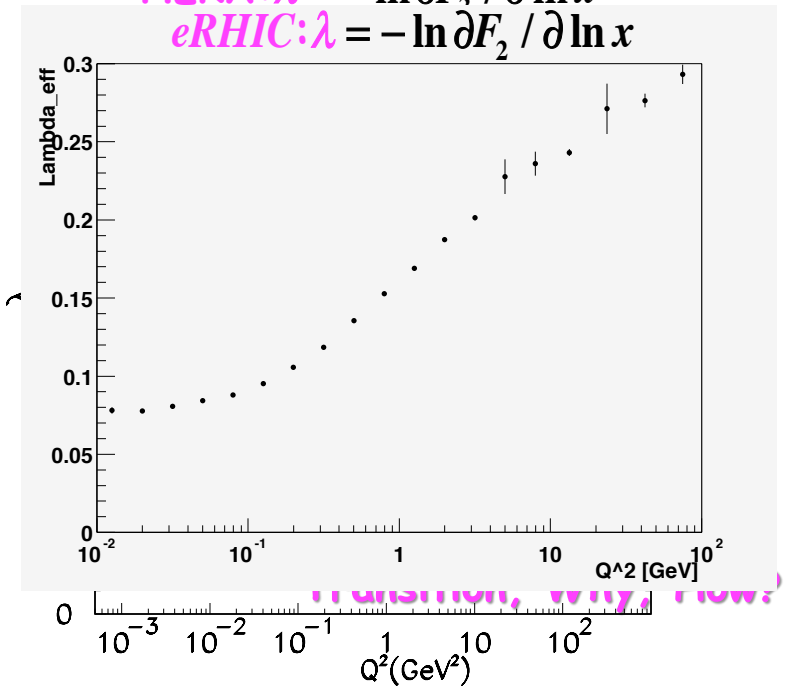
What do we know till know

$F_2 = C(Q^2)x^{-\lambda}$



Q^2 = 1GeV → 0.2fm
EM proton radius: 0.9fm

HERA: $\lambda = -\ln \partial F_2 / \partial \ln x$
eRHIC: $\lambda = -\ln \partial F_2 / \partial \ln x$

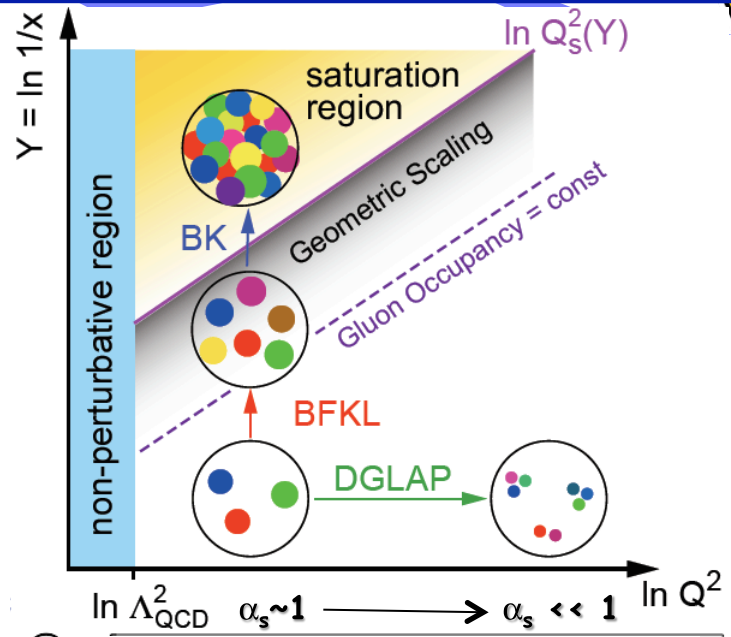


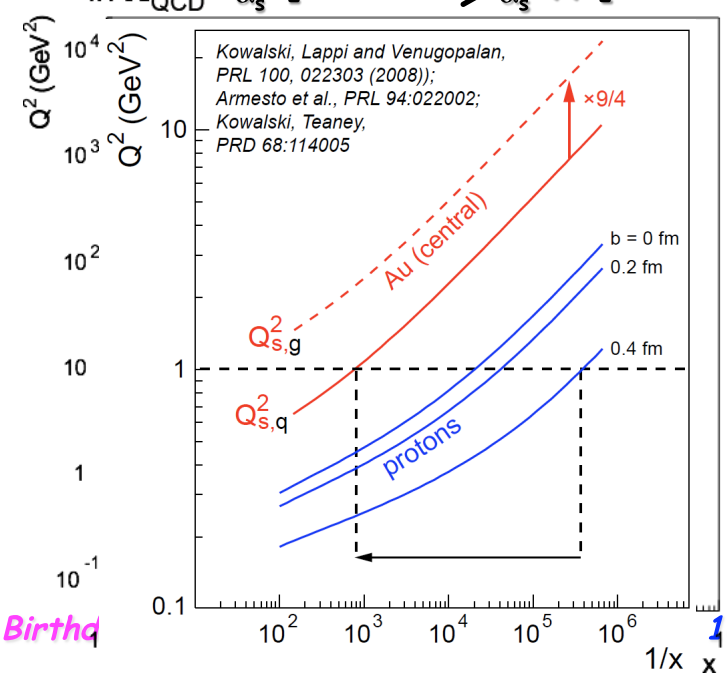
Does the rise of F_2 set in at the same Q^2 for nuclei?

Parton Saturation

- at small x linear evolution gives strongly rising g(x)
- BK/JIMWLK non-linear evolution includes recombination effects → saturation
  - Dynamically generated scale
    Saturation Scale: $Q^2_s(x)$
    - Increases with energy or decreasing x
  - Scale with $Q^2/Q^2_s(x)$ instead of x and Q^2 separately

Question:
What is the relation between saturation and the soft regime? Confinement?





EIC (eA):

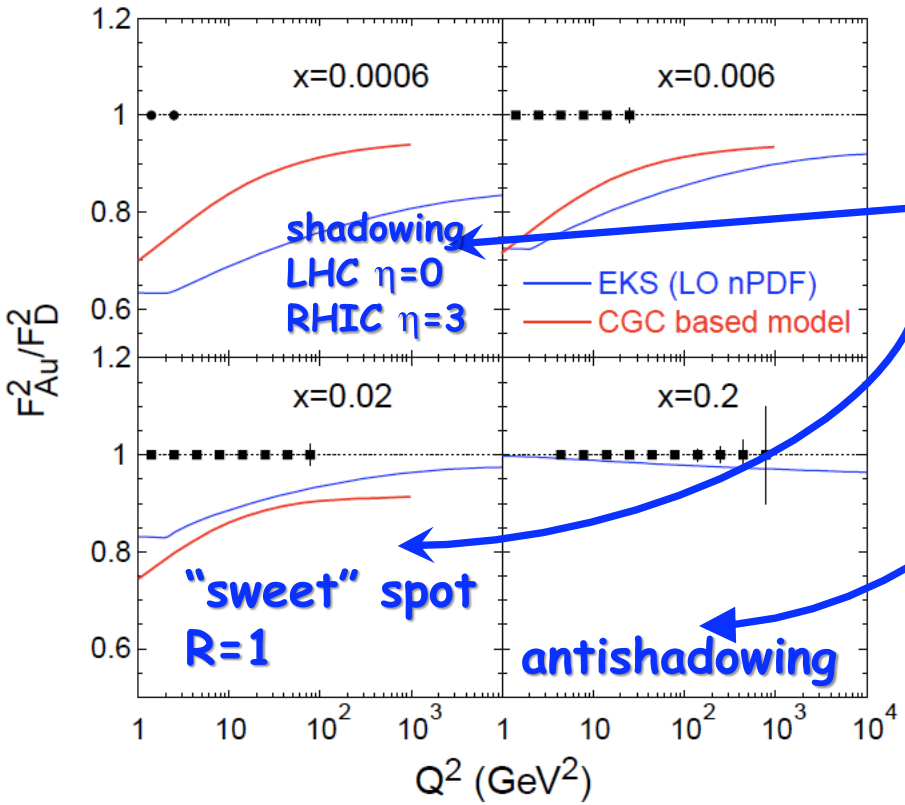
- Instead extending x, Q reach
  → increase Q_s
- Pocket formula for nuclei

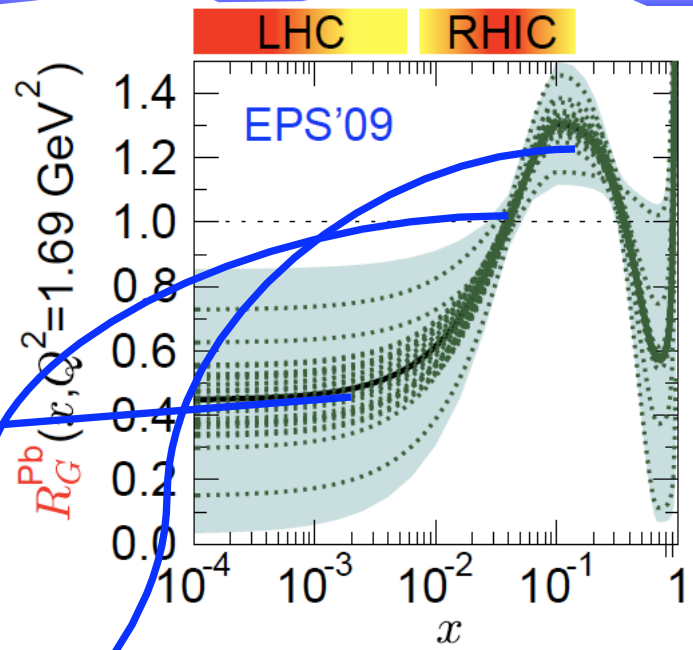
$$Q_s^2(x,A) \sim Q_0^2 \left(\frac{A}{X}\right)^{1/3}$$

- Remember: $Q^2 > Q_s^2 \Rightarrow \alpha_s = \alpha_s(Q^2)$
  $Q^2 < Q_s^2 \Rightarrow \alpha_s = \alpha_s(Q_s^2)$

F_2: for Nuclei

$$\frac{d^2\sigma^{NC}_{e^\mp p}}{dxdQ^2} = \frac{2\pi\alpha^2_{em}Y_+}{xQ^4}\left(F_2 - \frac{y^2}{Y_+}F_L \pm \frac{Y_-}{Y_+}xF_3\right)$$





Assumptions:

- 10GeV x 100GeV/n
  - $\sqrt{s}$=63GeV
- Ldt = 4/A fb^{-1}
  - equiv to 3.8 10^{33} cm^{-2}s^{-1}
  - T=4weeks; DC:50%
- Detector: 100% efficient
  - Q^2 up to kin. limit sx
- Statistical errors only
  - Note: L~1/A

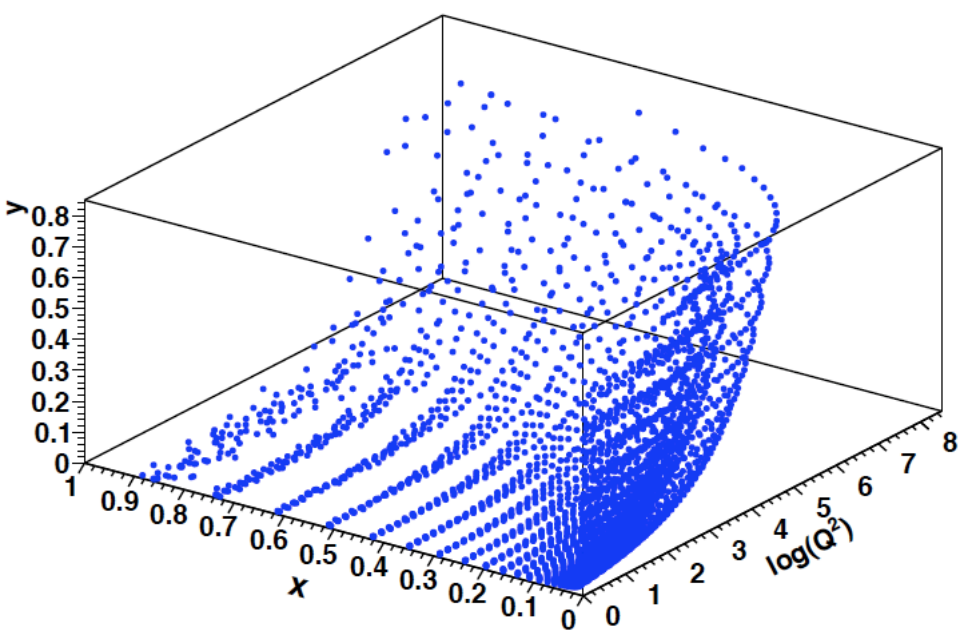
Measuring F_L with the EIC

$F_L \sim \alpha_s G(x,Q^2)$: the most "direct" way to $G(x,Q^2)$

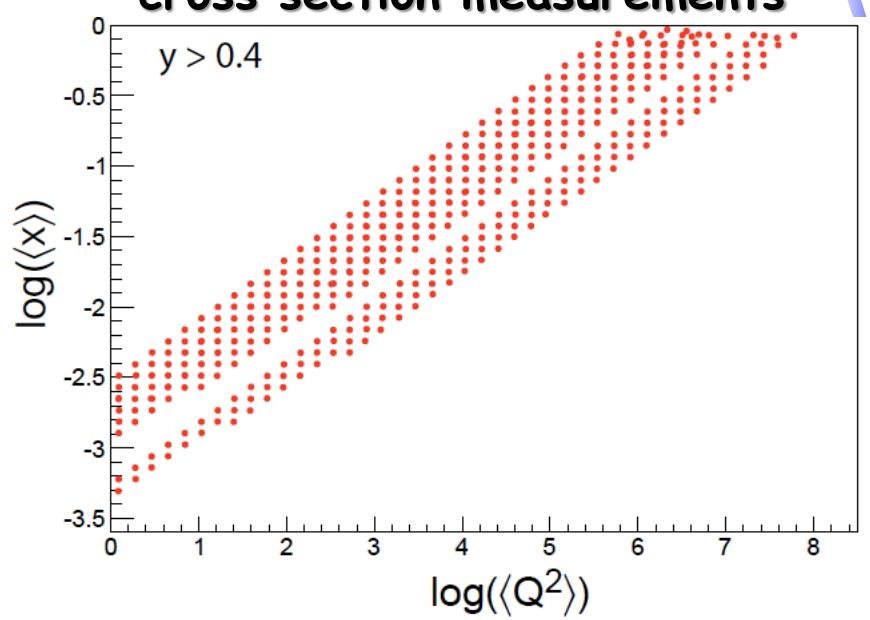
F_L needs various $\sqrt{s}$
→ longer program

$$\frac{d^2\sigma^{NC}_{e^\mp p}}{dxdQ^2} = \frac{2\pi\alpha^2_{em}Y_+}{xQ^4}\left(F_2 - \frac{y^2}{Y_+}F_L \pm \frac{Y_-}{Y_+}xF_3\right)$$

In order to extract F_L one needs at least two measurements of the inclusive cross section with a "wide" span in inelasticity parameter y (Q^2=sxy)



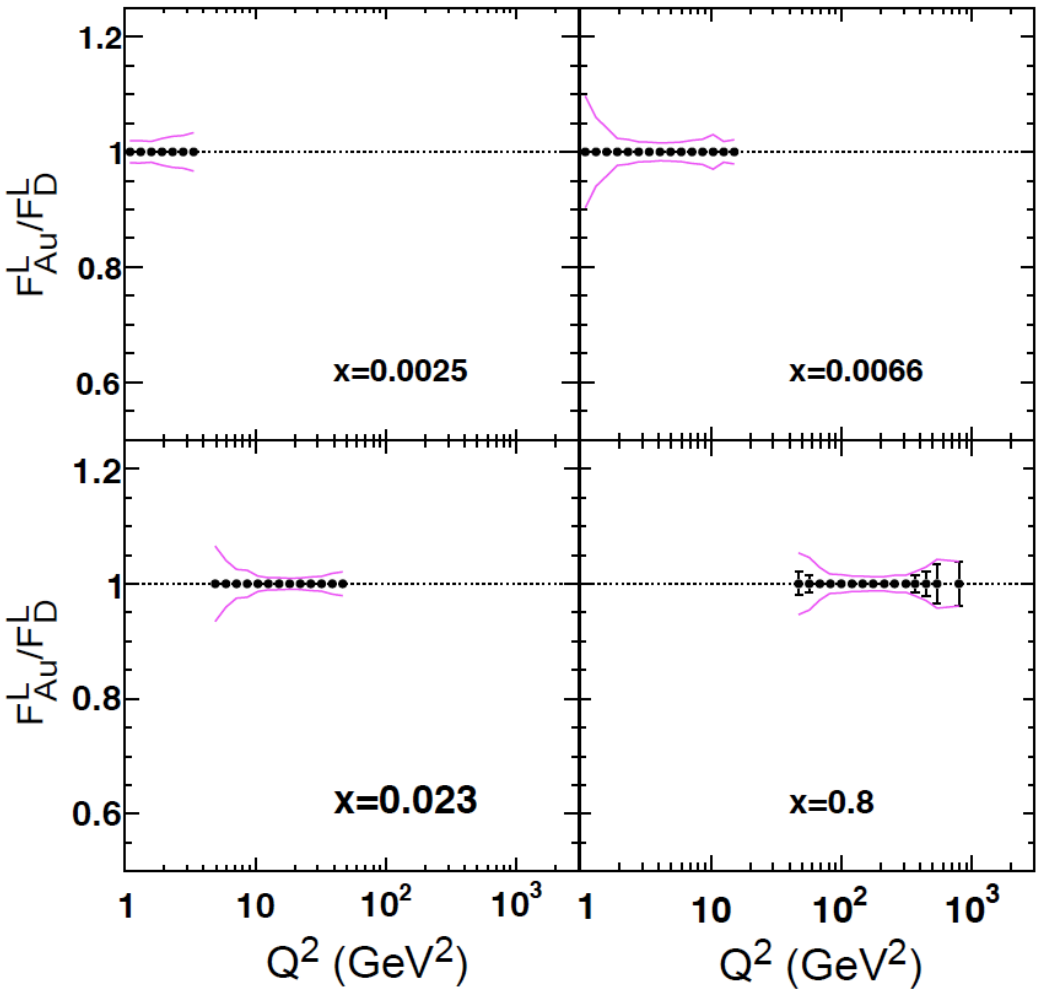
Coverage in x & Q^2 for inclusive cross section measurements



Plots for 4 GeV electrons on 50 – 250 GeV protons

Measuring F_L with the EIC

Lets get a feeling for systematic uncertainties
1% energy-to-energy normalization



Conclusion from this study

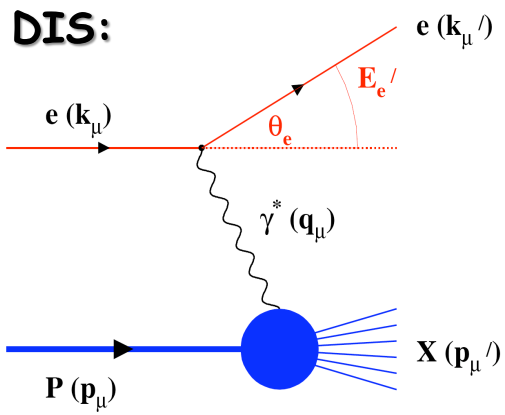
- Dominated by sys. uncertainties
  - → gives max. luminosity
  - → here: 4fb^{-1} / A
- Depending on x & Q^2 might be able to take a hit in luminosity
  - → need to include detector effects

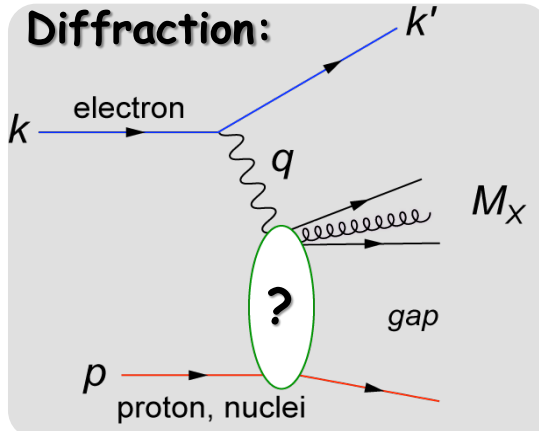
F_L for fixed electron energy (4GeV) and proton energies:
50, 70, 100, 250 GeV
Luminosity: 4fb^{-1} each setting

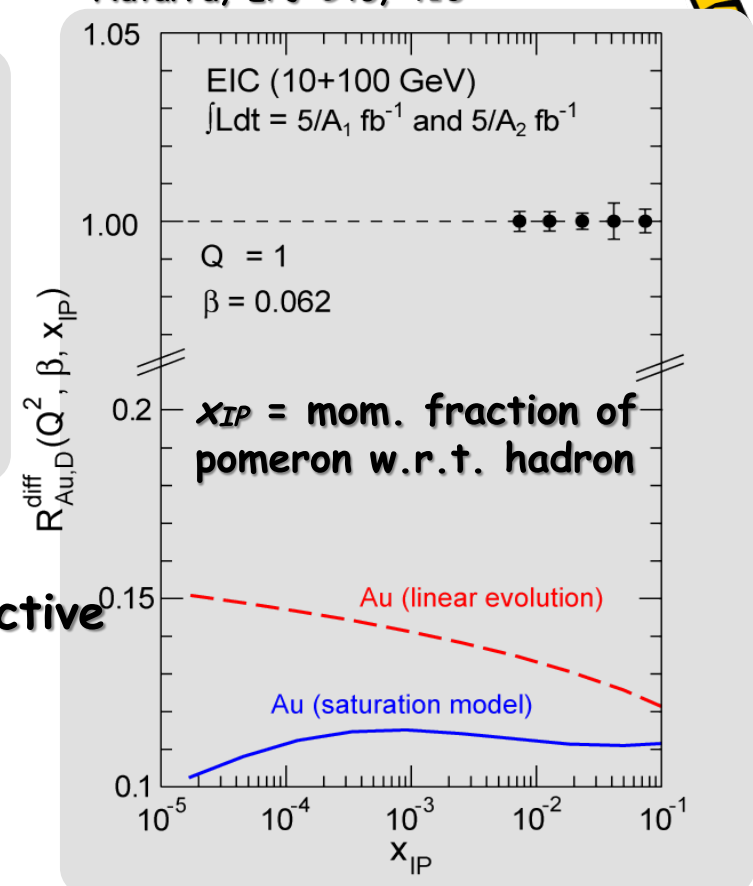
Diffractive physics: ep vs eA

$$\left.\frac{d\sigma}{dt}\right|_{t=0}(\gamma^* A \to M_x A) \sim \alpha^2 \left[G_A(x,Q^2)\right]^2$$

Curves: Kugeratski, Goncalves, Navarra, EPJ C46, 413

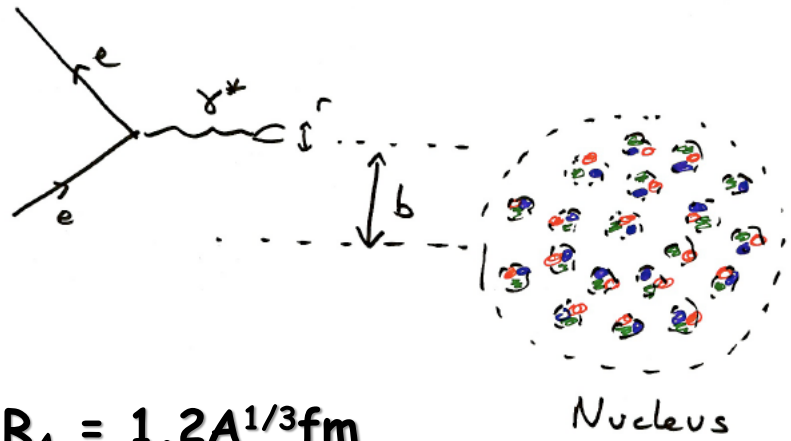






- HERA/ep: ~20% of all events are hard diffractive
- Diffractive cross-section $\sigma_{diff}/\sigma_{tot}$ in e+A ?
- Predictions: ~25-40%?
- Diffractive structure functions
  - F_L^D for nuclei and p extremely sensitive
- Exclusive Diffractive vector meson production: $d\sigma/dt \sim [xG(x,Q^2)]^2$!!
- Distinguish between linear evolution and saturation models

Measure the Gluon Form Factor



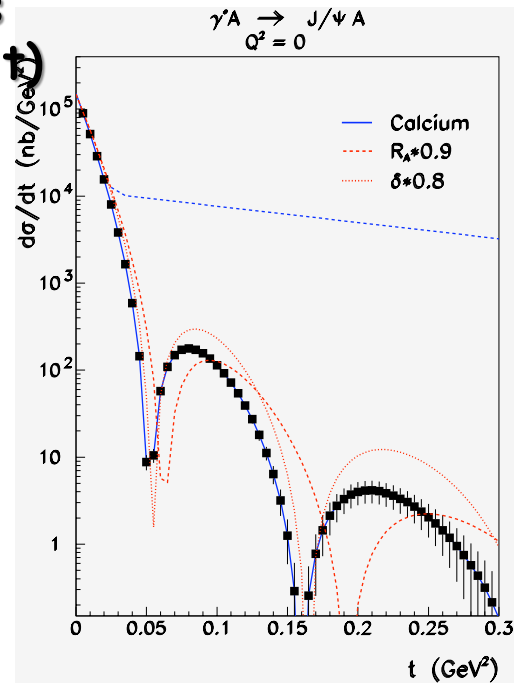
Basic Idea:
Studying diffractive exclusive J/ψ production at Q2~0

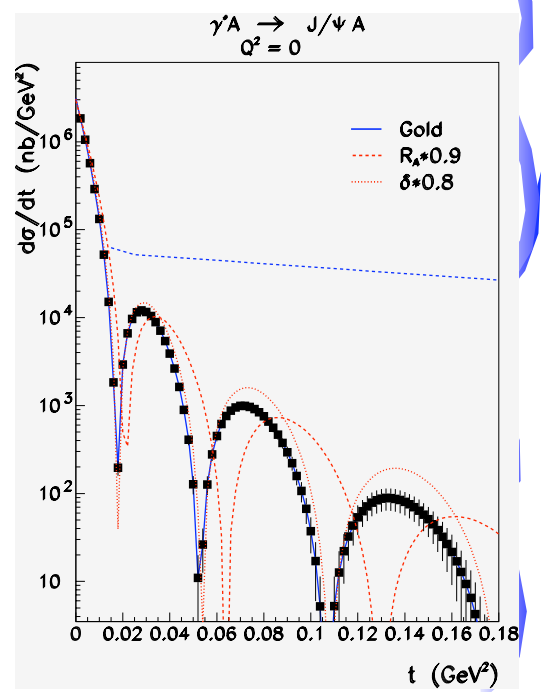
Ideal Probe:
large photo-production cross section
t can be derived from e,e' and J/ψ 4-momentum

$R_A = 1.2A^{1/3}$fm
Elastic scattering on full nucleus
→ long wavelength gluons (small t)

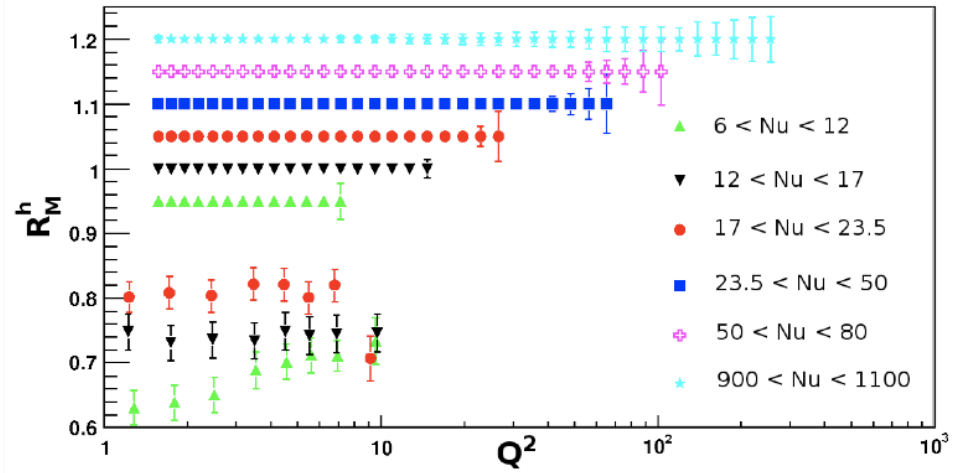
Expectation for 1M J/ψ

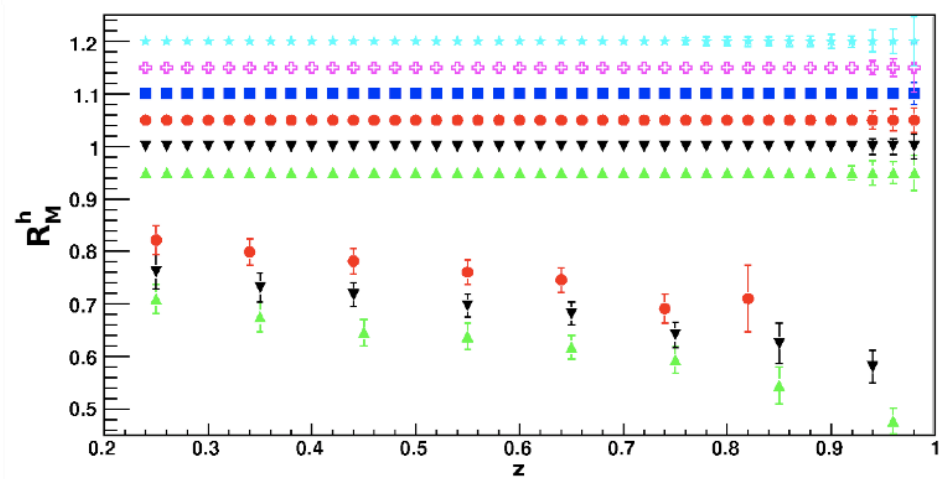
Requirement:
Momentum resolution < 10MeV
great *t* resolution
Need to detect nuclei break-up products
detect e' in FED

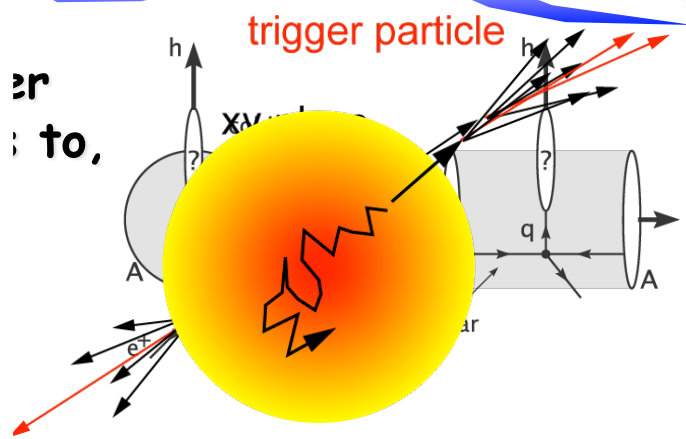


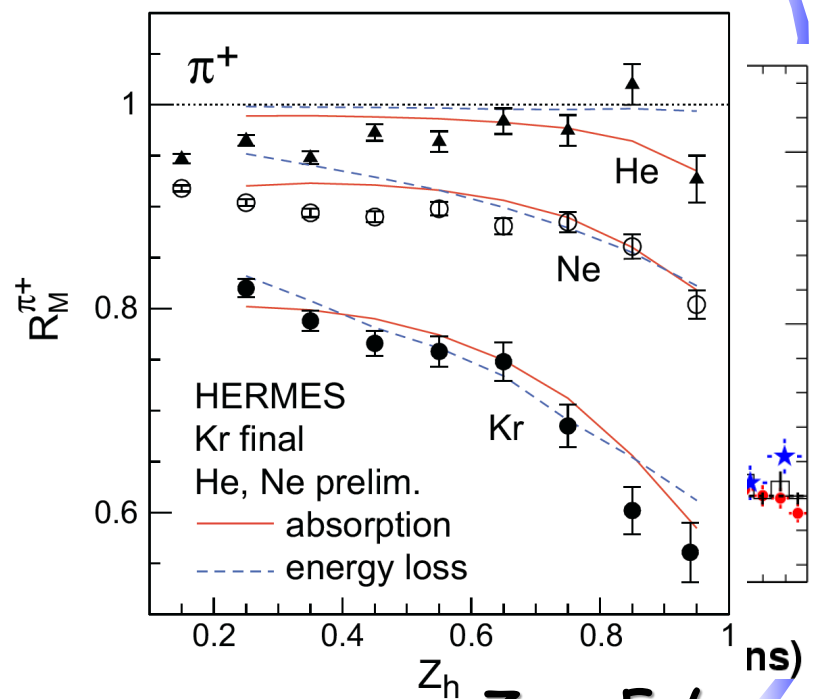


Interaction of fast probes with gluonic medium





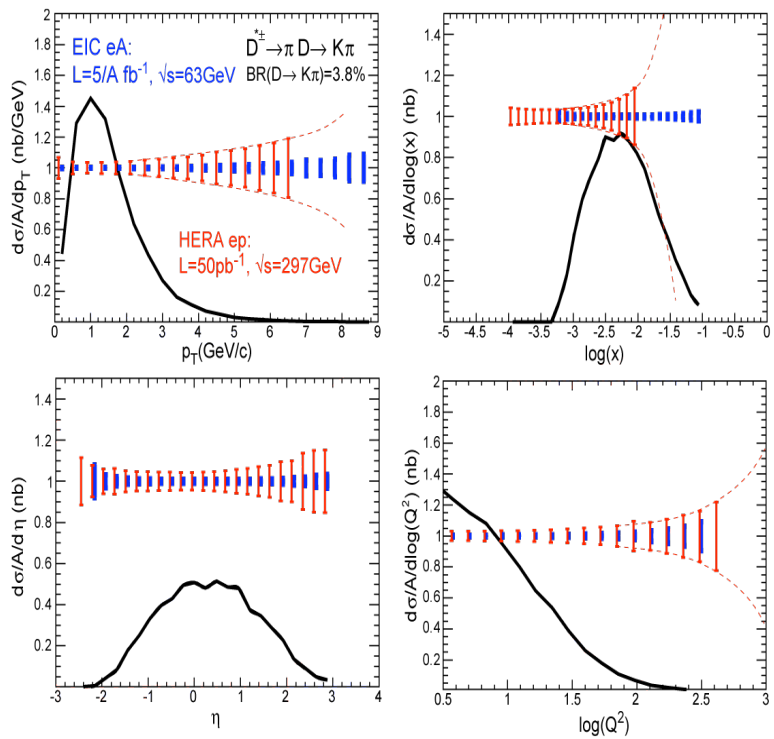


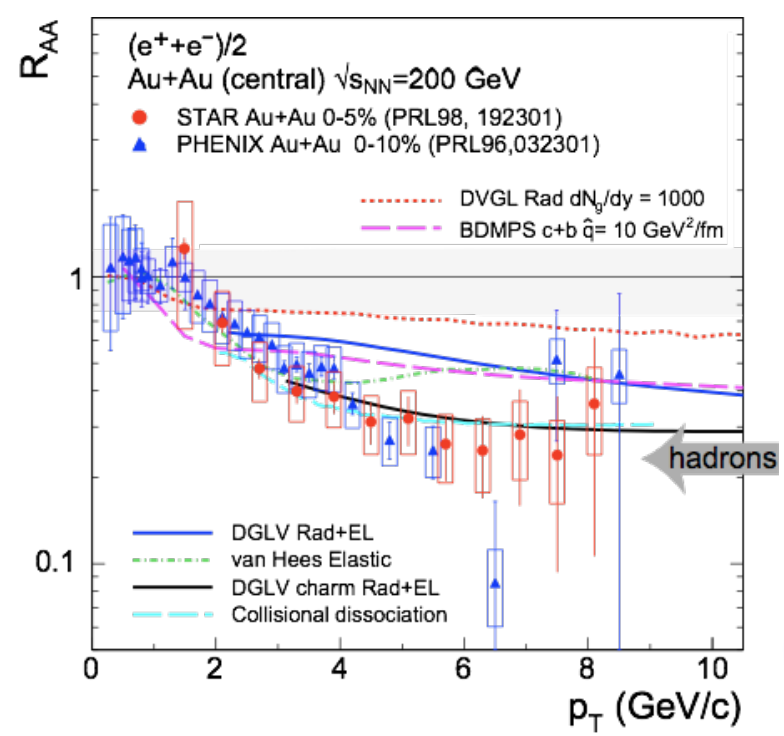


$Z_h = E_h/\nu$

Charm measurements at an EIC

Charm also suppressed at RHIC - above and beyond model predictions

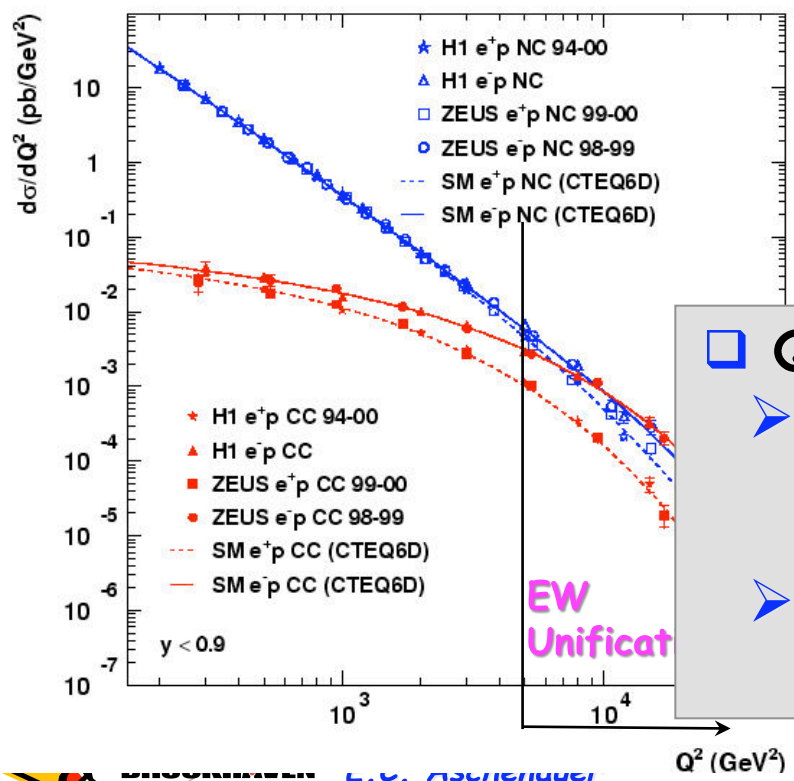




- EIC: allows multi-differential measurements of heavy flavour
- Covers and extends energy range of SLAC, EMC, HERA, and JLab allowing for the study of wide range of formation lengths

Unification

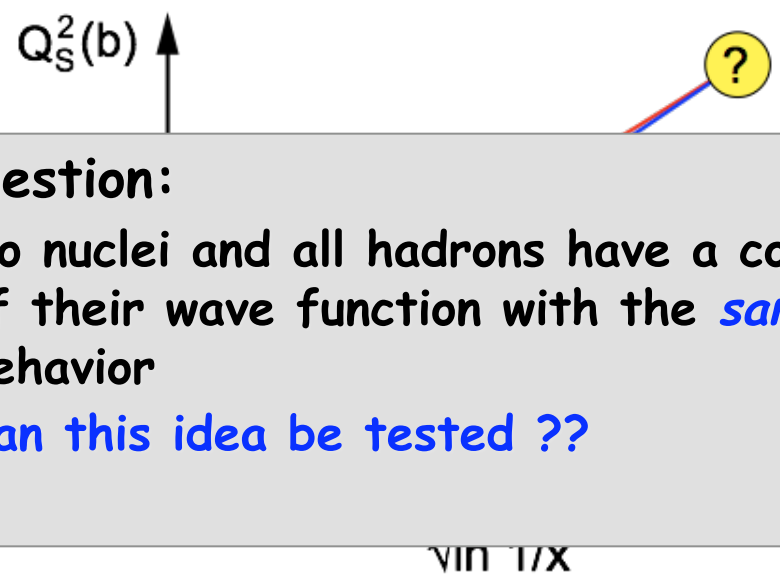
- From DIS at HERA:
  - At small-medium Q^2, $\sigma(NC) >> \sigma(CC)$
  - For $Q^2 > M_Z^2$ and M_W^2, $\sigma(NC) \sim \sigma(CC)$
    - ✓ EW Unification
- Already a textbook figure ...



What about on the parton scale?

Small-x running-coupling BFKL QCD evolution predicts:

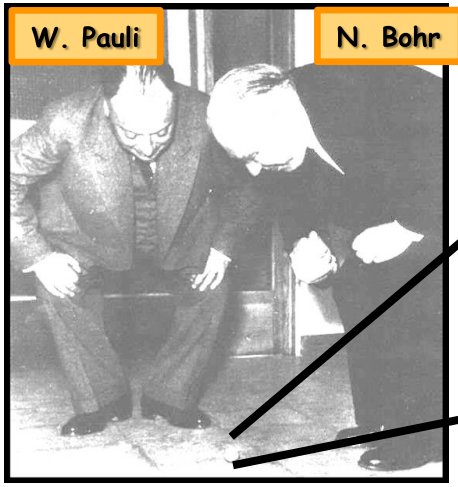
- Q_S approaches universal behaviour for all hadrons and nuclei
- No dependence on A!!
- Not only functional form $f(Q_S)$ universal, but even Q_S itself becomes universal

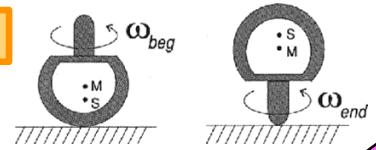


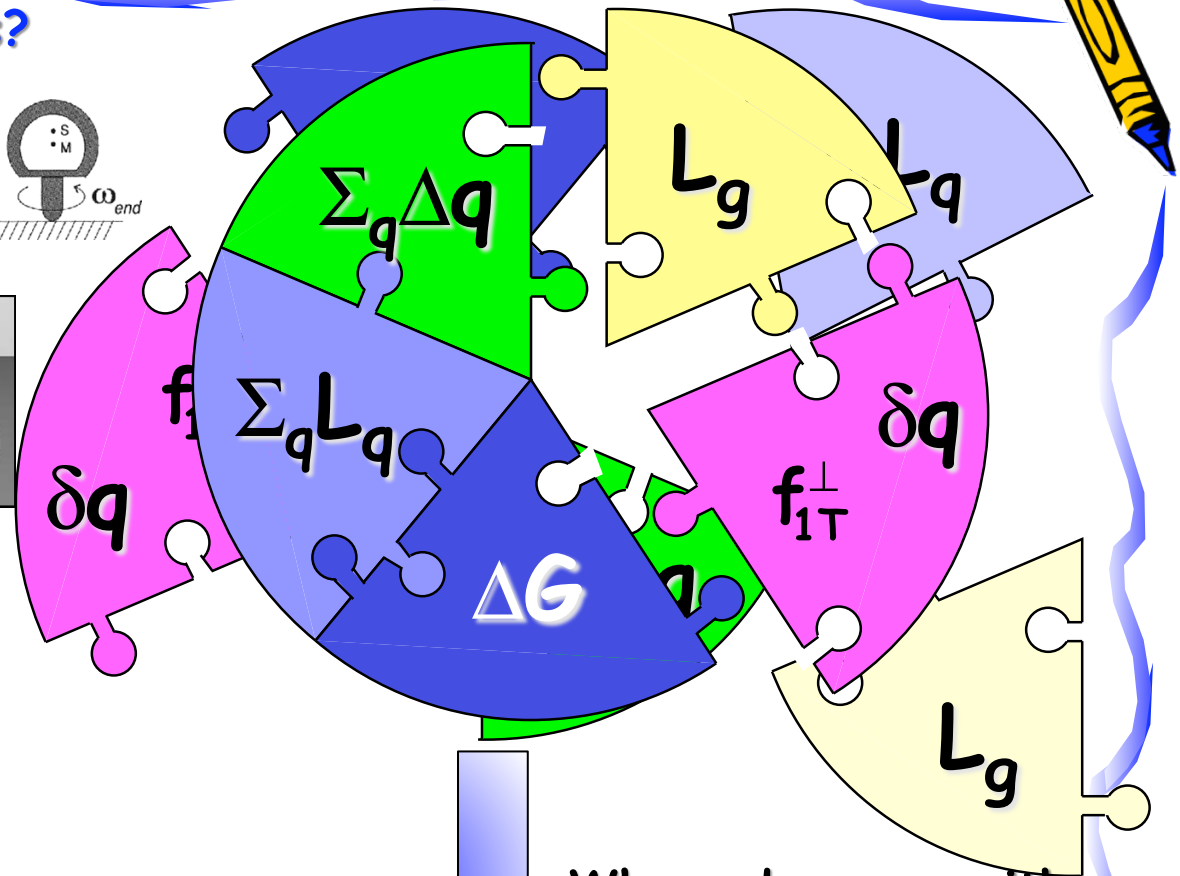
- Question:
  - Do nuclei and all hadrons have a component of their wave function with the *same* behavior
  - Can this idea be tested ??

Important to understand hadron structure: Spin

Is the proton spinning like this?





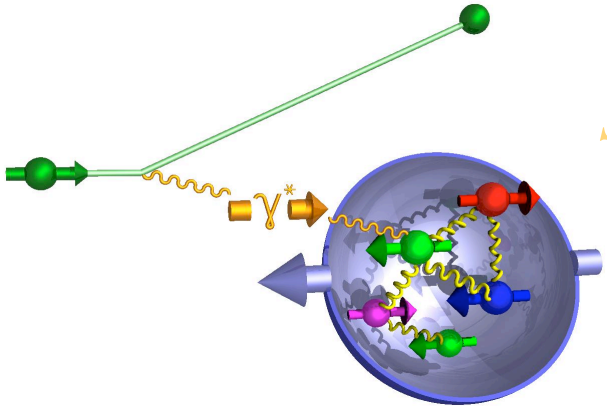


"Helicity sum rule"

$$\frac{1}{2}\hbar = \left\langle P,\frac{1}{2}\middle| J^z_{QCD} \middle| P,\frac{1}{2}\right\rangle = \underbrace{\sum_q \frac{1}{2} S^z_q}_{\text{total u+d+s quark spin}} + \overbrace{S^z_g}^{\text{gluon spin}} + \underbrace{\sum_q L^z_q + L^z_g}_{\text{angular momentum}}$$

Where do we go with solving the "spin puzzle" ?

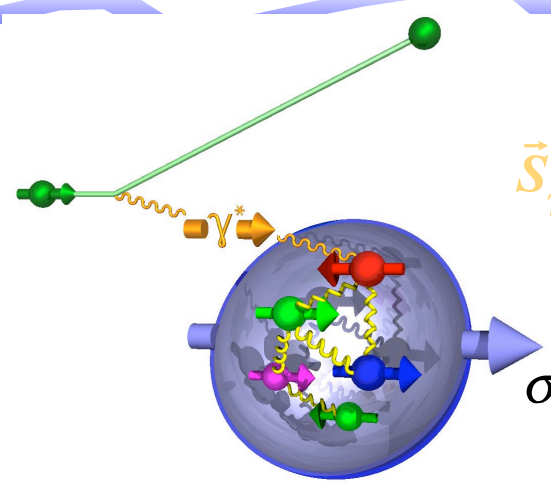
How to measure Quark Polarizations



$$\vec{S}_{\gamma^*} + \vec{S}_N = \frac{1}{2}$$

$$\vec{S}_N = \vec{S}_q$$

$$\sigma_{1/2} \sim q^+(x)$$



$$\vec{S}_{\gamma^*} + \vec{S}_N = \frac{3}{2}$$

$$\vec{S}_N = -\vec{S}_q$$

$$\sigma_{3/2} \sim q^-(x)$$

- Virtual photon γ^* can only couple to quarks of opposite helicity
- Select $q^+(x)$ or $q^-(x)$ by changing the orientation of target nucleon spin or helicity of incident lepton beam

$$\Delta q = q^+ - q^-$$

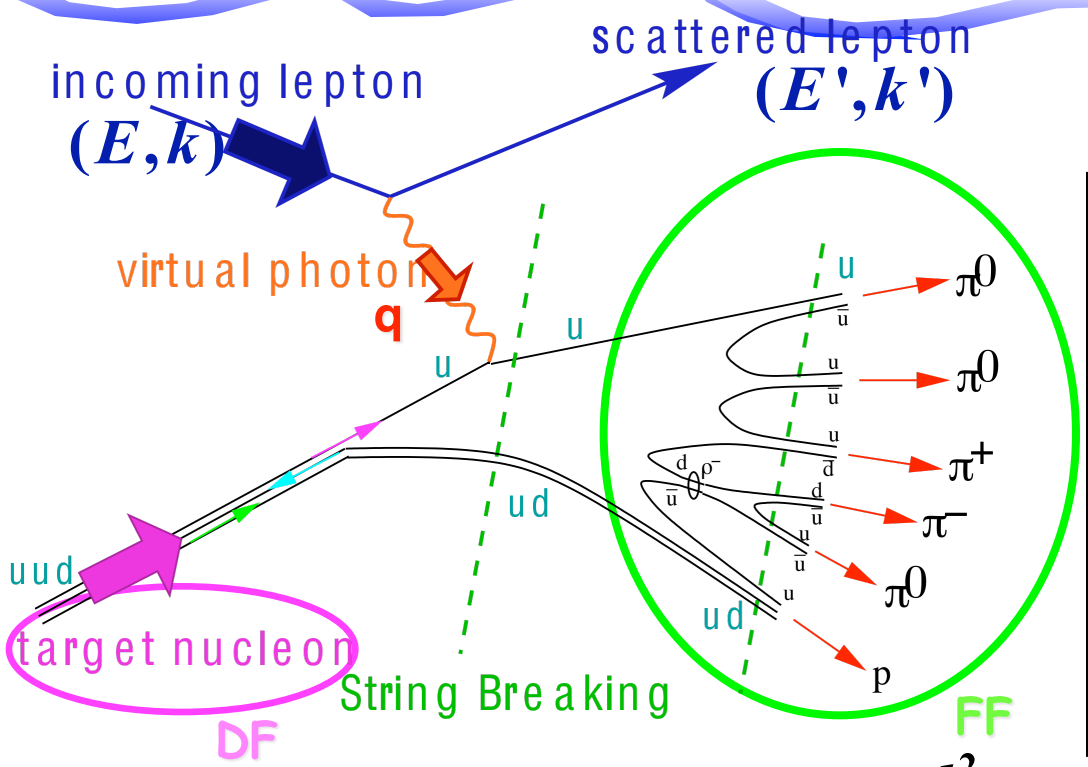
Asymmetry definition:

$$A_{\parallel}^{e',h} \sim \frac{\sigma_{1/2}^{e',h} - \sigma_{3/2}^{e',h}}{\sigma_{1/2}^{e',h} + \sigma_{3/2}^{e',h}} \qquad A_{\parallel}^{e'h} = \frac{1}{\langle P_B P_T \rangle} \frac{N_{e',h}^{\rightleftarrows} L^{\rightrightarrows} - N_{e',h}^{\rightrightarrows} L^{\rightleftarrows}}{N_{e',h}^{\rightleftarrows} L^{\rightrightarrows} + N_{e'h}^{\rightrightarrows} L^{\rightleftarrows}}$$

inclusive DIS: only e' info used

semi-inclusive DIS: e'+h info used

Deep Inelastic Scattering



Important kinematic variables:

Collider:

Photon:

$$Q^2 = -q^2 = -(k-k')^2 = 2E_e E_e'(1+\cos\Theta_e)$$

$$\nu = E - E'$$

Quark: $x = \dfrac{Q^2}{sy}$

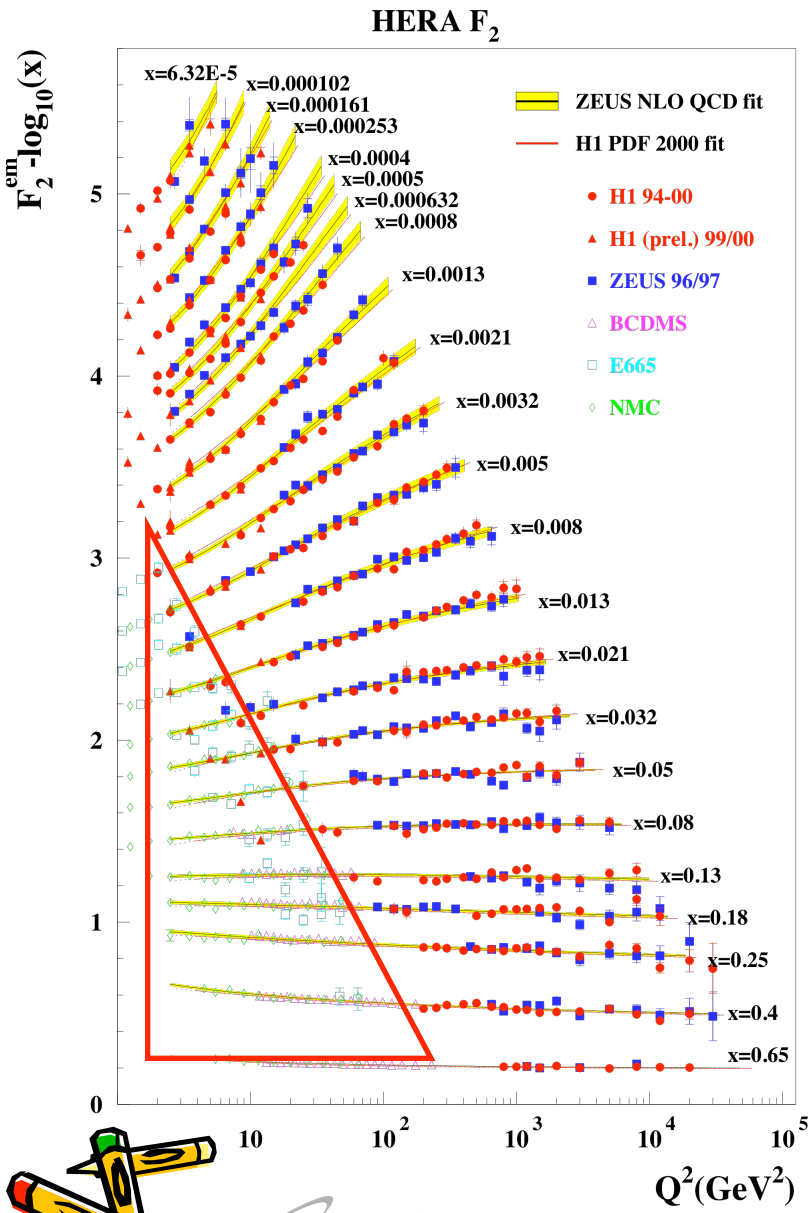
Hadron: $z = \dfrac{E_h}{\nu}$ $\quad p_t^2$

cross section: $\dfrac{d^2\sigma}{d\Omega dE'} \sim L_{\mu\nu} W^{\mu\nu}$

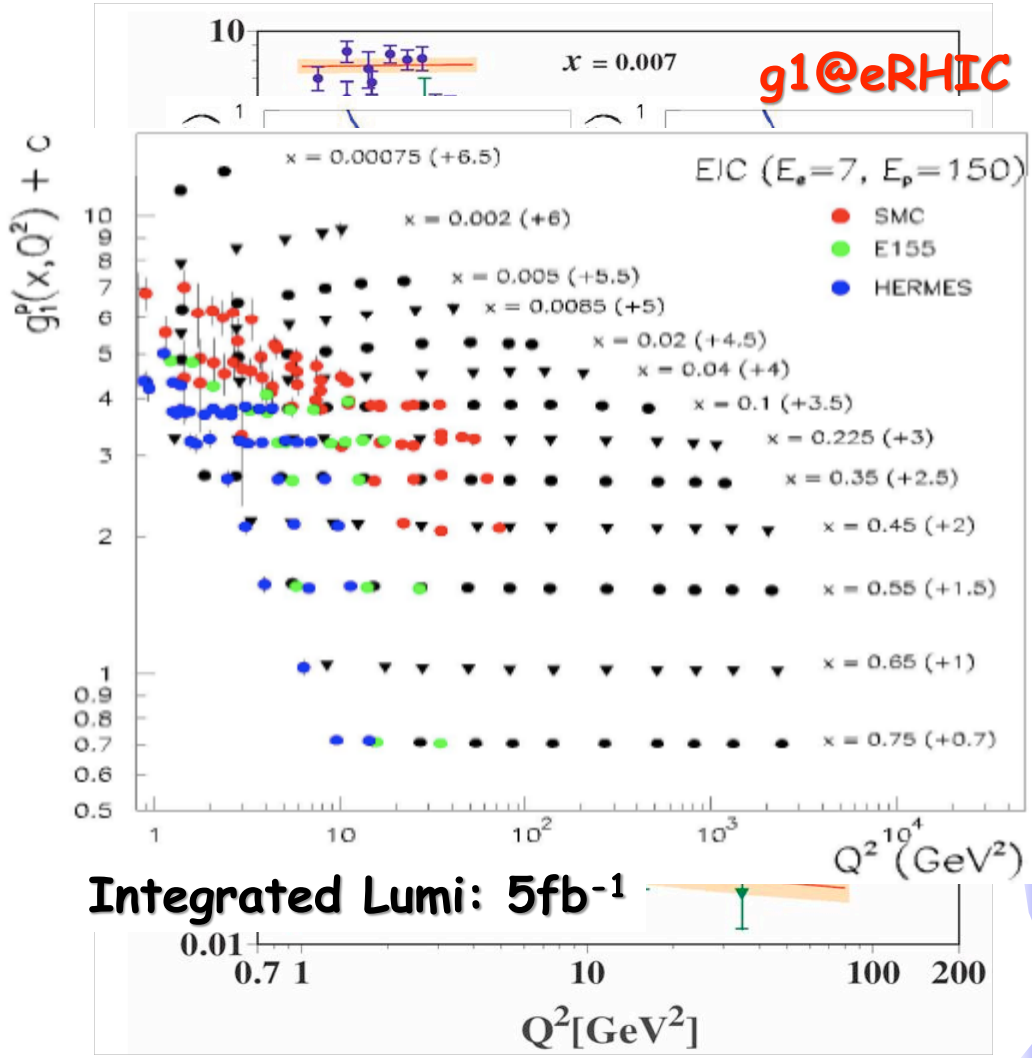
$$W^{\mu\nu} = -g^{\mu\nu} F_1 - \frac{p^\mu p^\nu}{\nu} F_2 + \frac{i}{\nu}\varepsilon^{\mu\nu\lambda\sigma} q^\lambda s^\sigma g_1 + \frac{i}{\nu^2}\varepsilon^{\mu\nu\lambda\sigma} q^\lambda (p\cdot q s^\sigma - s\cdot q p^\sigma) g_2$$

$$\underbrace{-r_{\mu\nu} b_1 + \frac{1}{6}(s_{\mu\nu} + t_{\mu\nu} + u_{\mu\nu}) b_2 + \frac{1}{2}(s_{\mu\nu} - u_{\mu\nu}) b_3 + \frac{1}{2}(s_{\mu\nu} - t_{\mu\nu}) b_4}_{\text{Spin 1}}$$

How to measure ΔS and ΔG



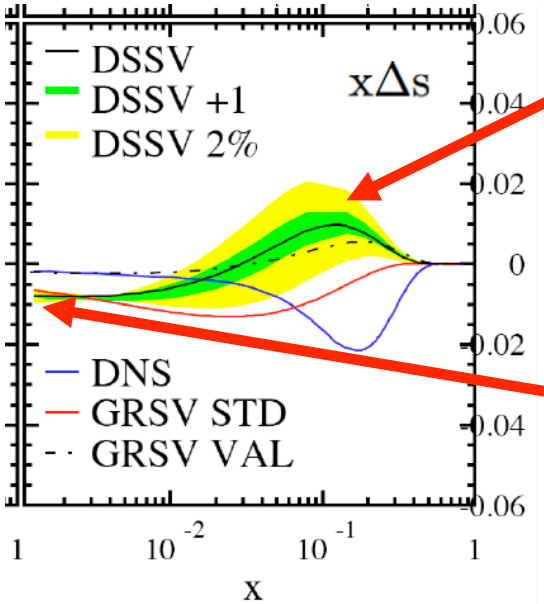
- ΔG: Indirect from scaling violation



Integrated Lumi: 5fb^{-1}

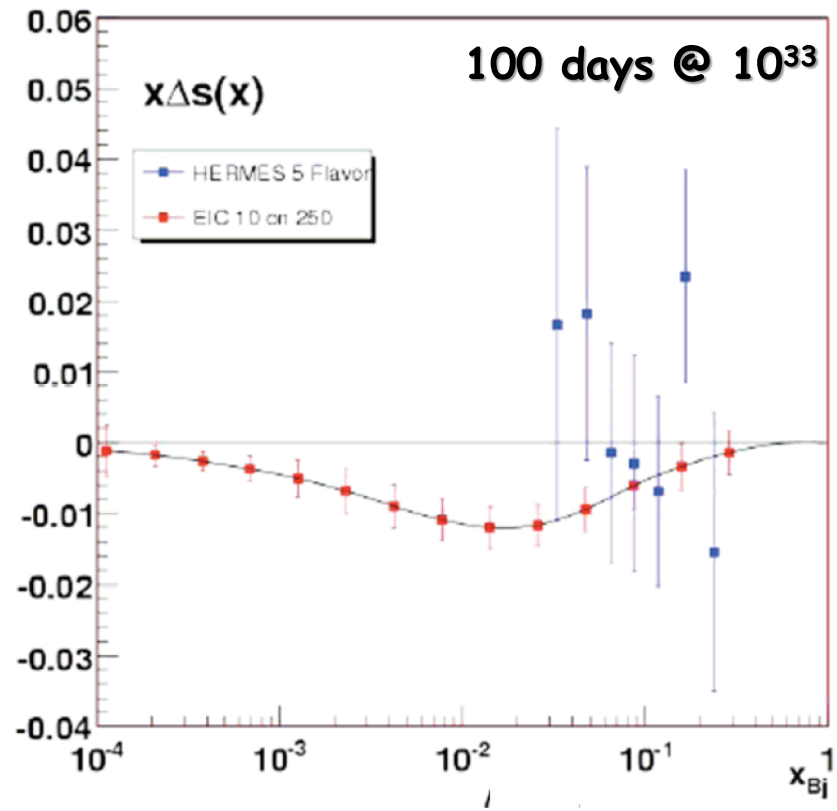
Polarized Strangeness

Knowledge Today:



Driven by SIDIS
K-Asymmetries
K-FF
dominated by hermes

Driven by
SU(3): (3F-D)



Δs(x) always thought to be negative from inclusive DIS data

striking result, but relies on:

- kaon fragmentation fct. – how reliable
- unpolarised PDFs-how well do we know s(x)?
- SU(3) breaking uncertainties – sizeable?

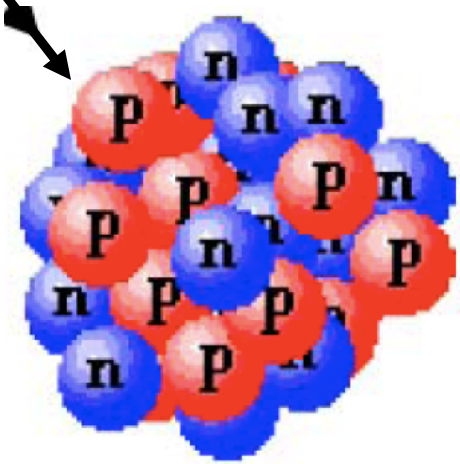
Why is Δs interesting

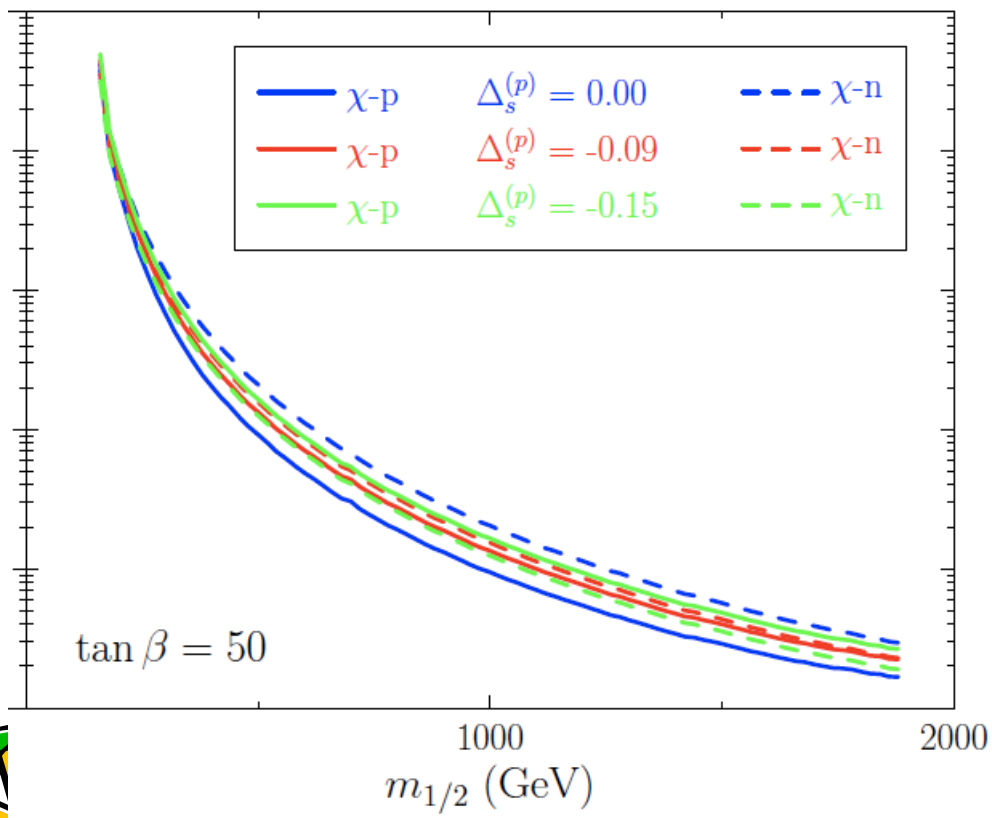
e.g. elastic scattering of SUSY dark matter

$$\mathcal{L} = \alpha_i(\overline{\chi}\chi)(\overline{q_i}q_i) + \beta_i(\overline{\chi}\gamma^\nu\gamma^5\chi)(\overline{q_i}\gamma_\nu\gamma^5 q_i)$$

gives spin-dep. cross sec.

neutralino χ



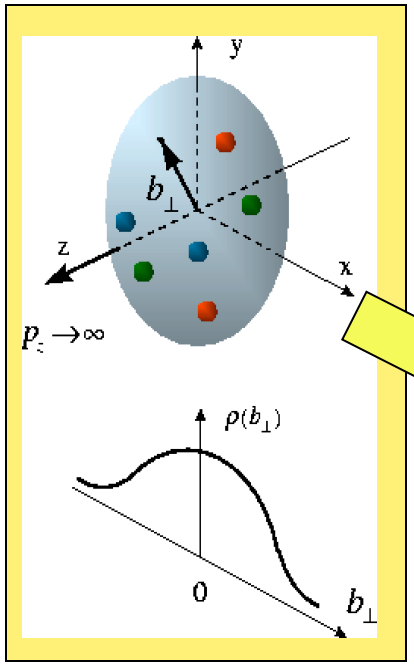


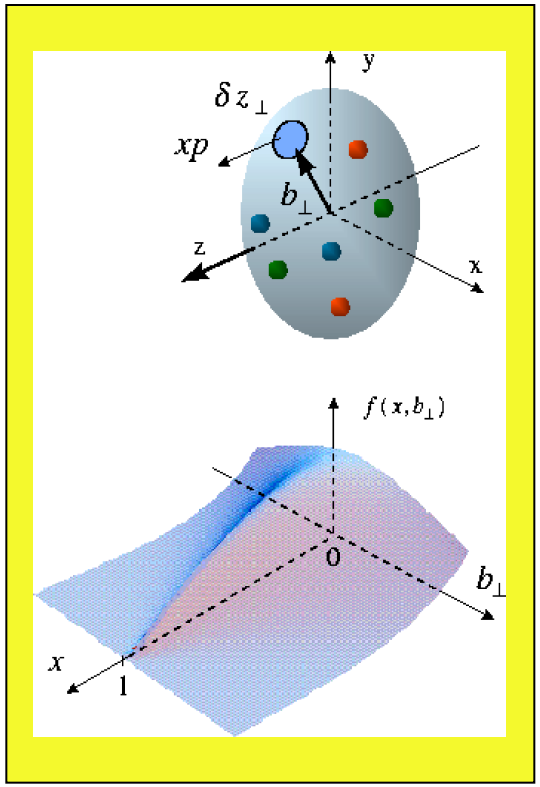
Ellis et al.
arXiv: 0801.3656

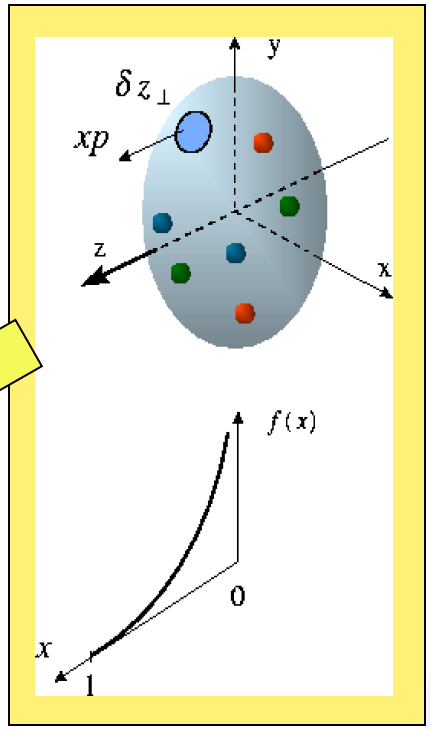
Beyond form factors and quark distributions

Generalized Parton Distributions

X. Ji, D. Mueller, A. Radyushkin (1994-1997)





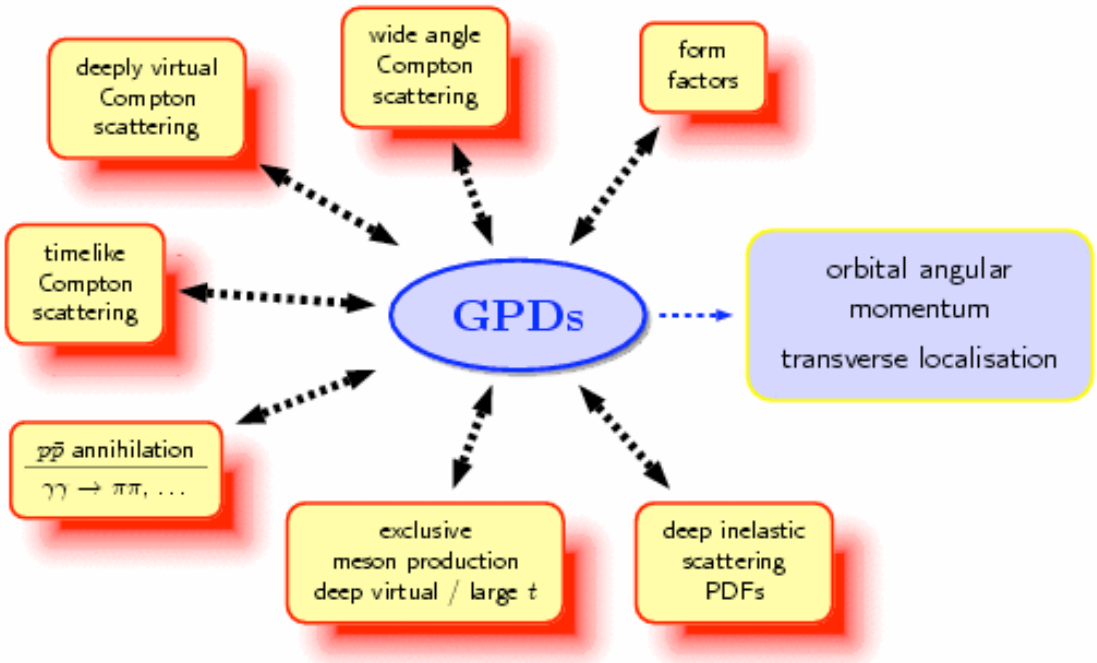


Proton form factors, transverse charge & current densities

Correlated quark momentum and helicity distributions in transverse space - GPDs

Structure functions, quark longitudinal momentum & helicity distributions

How to access GPDs?



$$\frac{1}{2} = J_q^z + J_g^z = \frac{1}{2}\sum_q \Delta q + \sum_q \mathcal{L}_q^z + J_g^z$$

$$J_q^z = \frac{1}{2}\sum_q \Delta q + \sum_q \mathcal{L}_q^z$$

$$J_q^z = \frac{1}{2}\left(\int_{-1}^{1} x\,dx\left(H^q + E^q\right)\right)_{t\to 0}$$

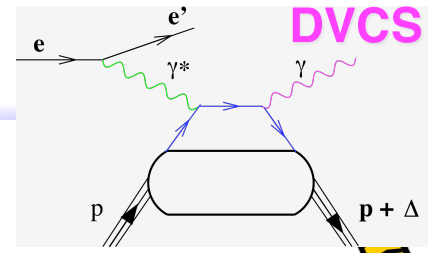
quantum number of final state selects different GPDs:

- **theoretically very clean**
  DVCS (γ): H, E, $\tilde{H}$, $\tilde{E}$
- **VM** (ρ, ω, ϕ): H E
- **info on quark flavors**
  PS mesons (π, η): $\tilde{H}$ $\tilde{E}$

π^0	$2\Delta u+\Delta d$
η	$2\Delta u-\Delta d$

ρ^0	$2u+d$, $9g/4$
ω	$2u-d$, $3g/4$
ϕ	s, g
ρ^+	$u-d$
J/ψ	g

Proton Tomography



p + Δ

[M. Burkardt, M. Diehl 2002]

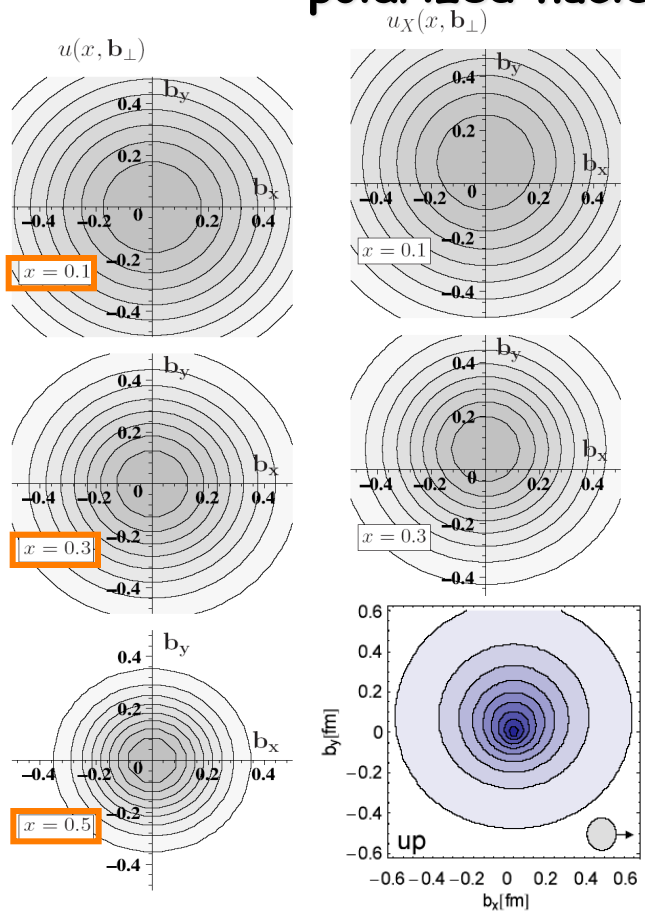
FT (GPD) : momentum space → impact parameter space:

probing partons with specified long. momentum @transverse position $b_\perp$

polarized nucleon:

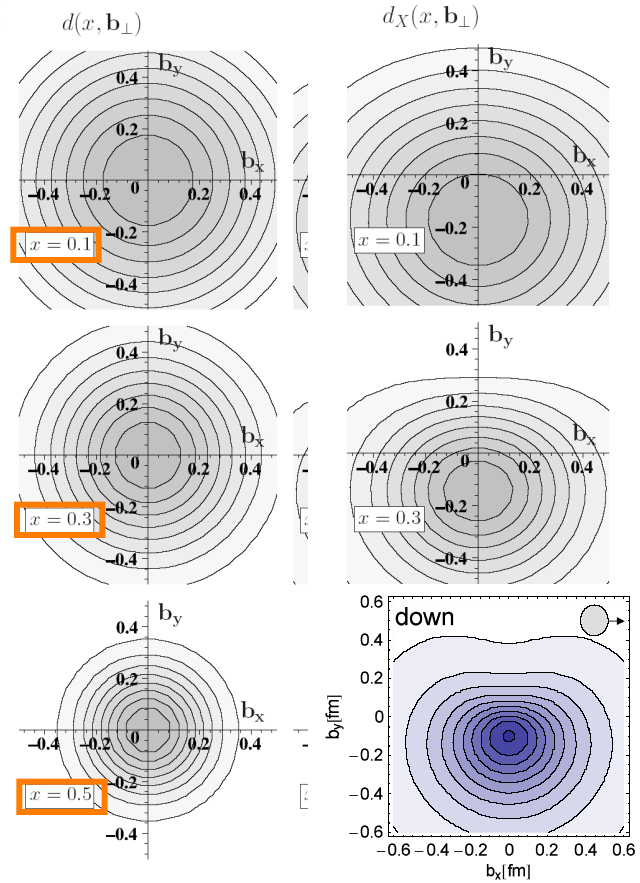
u-quark

[ξ=0]



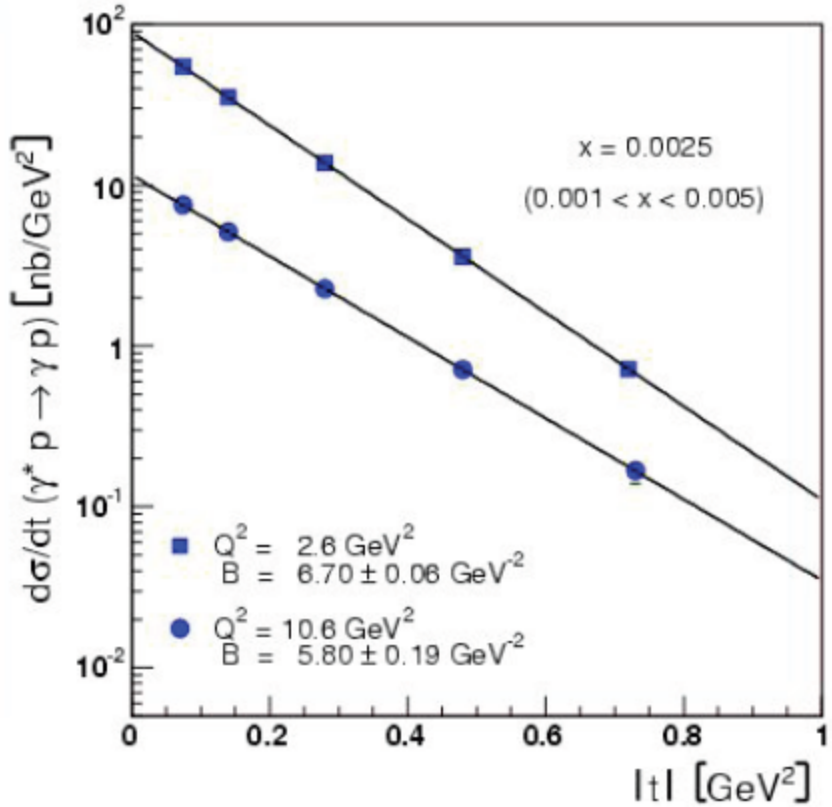
from lattice

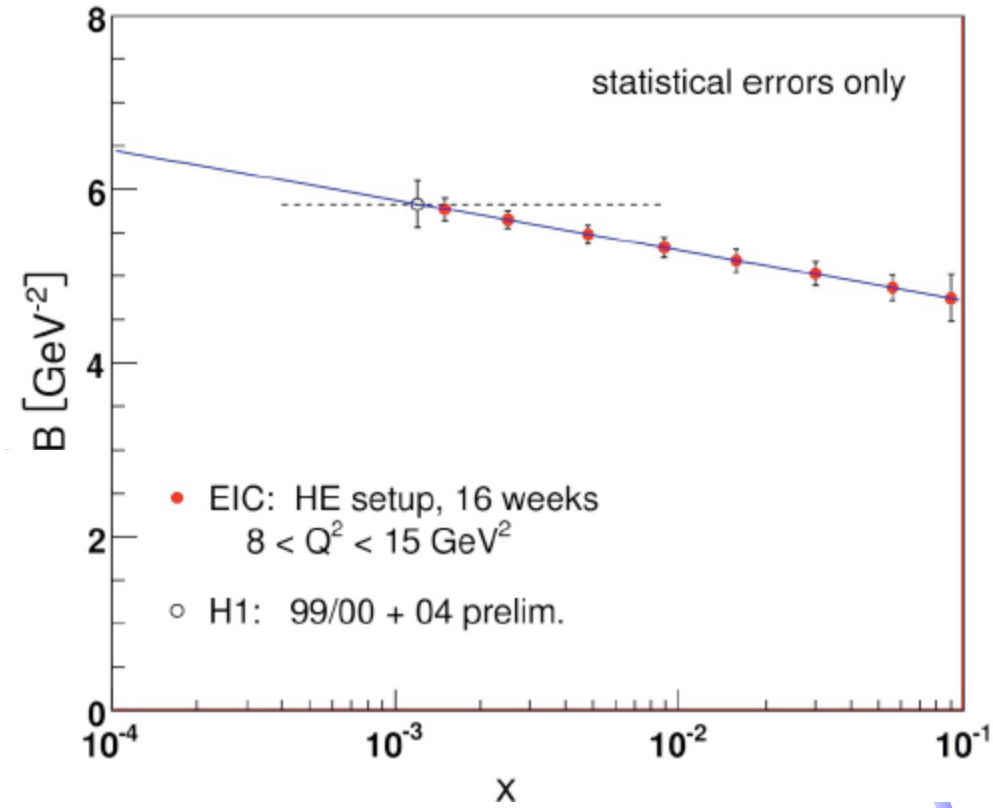
d-quark



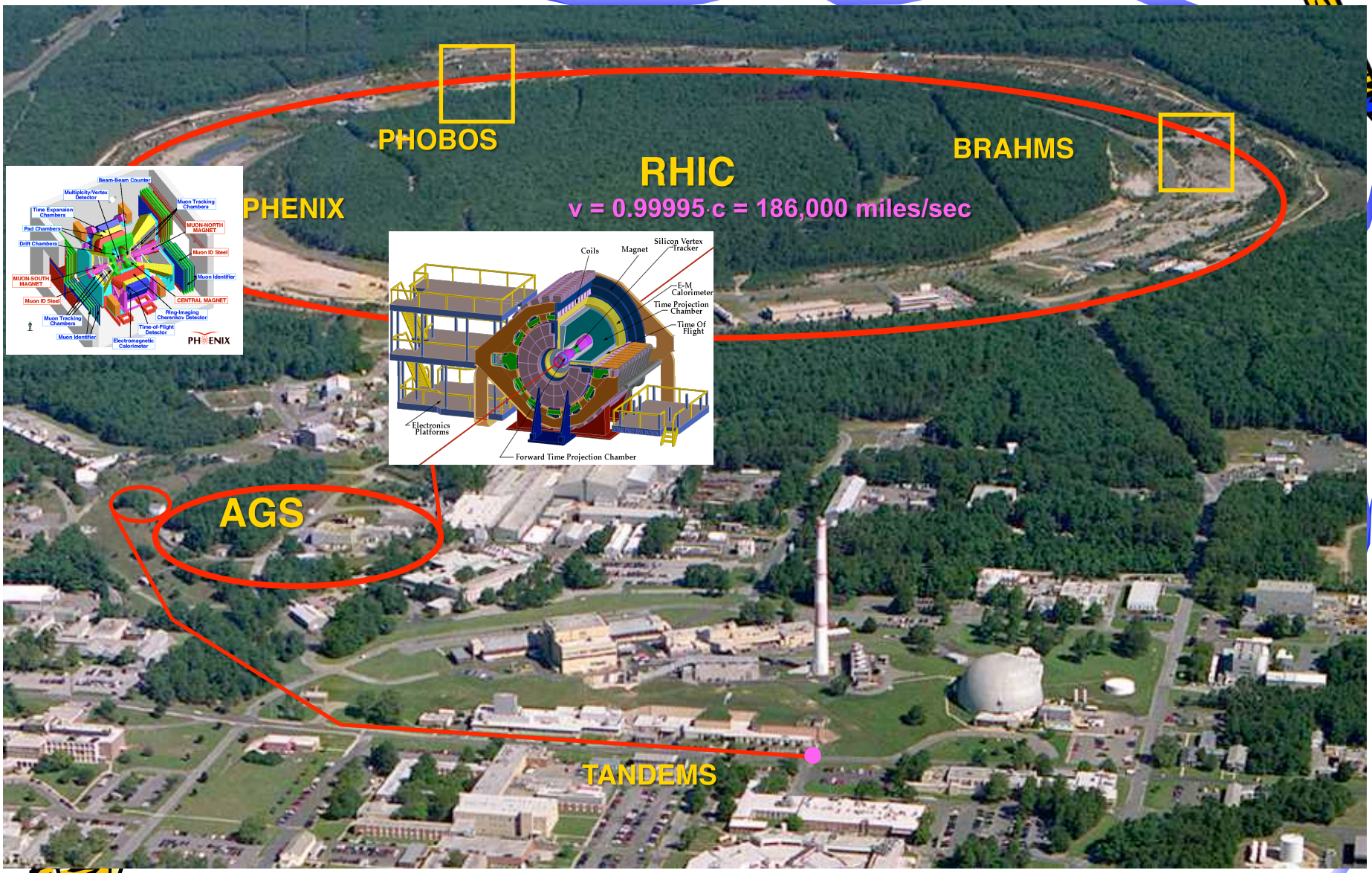
DVCS @ eRHIC

- dominated by gluon contributions
- Need wide x and Q^2 range to extract GPDs
- Need sufficient luminosity to bin in multi-dimensions





The Relativistic Heavy-Ion Collider @ BNL



EIC: one solution eRHIC @ BNL

	MeRHIC		eRHIC with CeC	
	p (A)	e	p (A)	e
Energy, GeV	250 (100)	4	325 (125)	20 <30>
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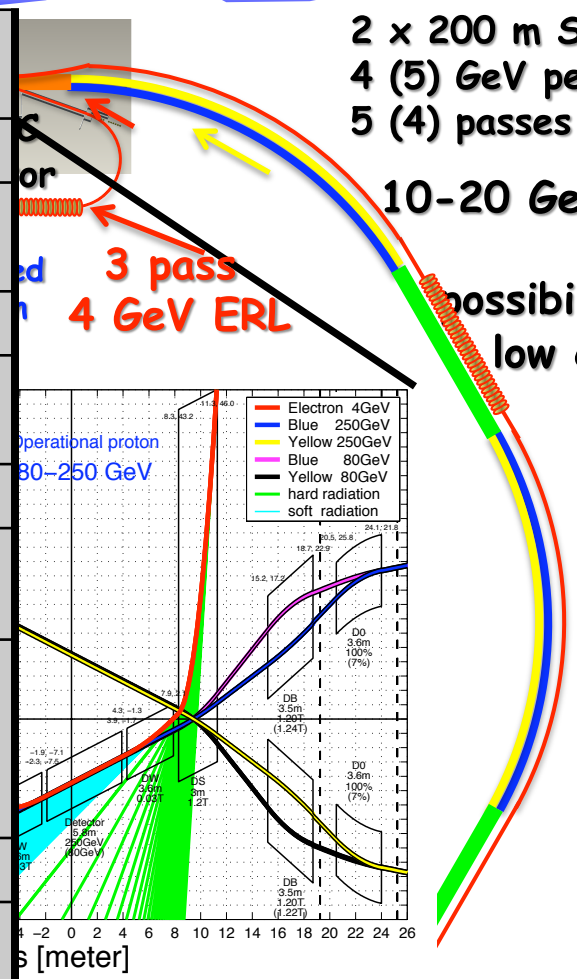
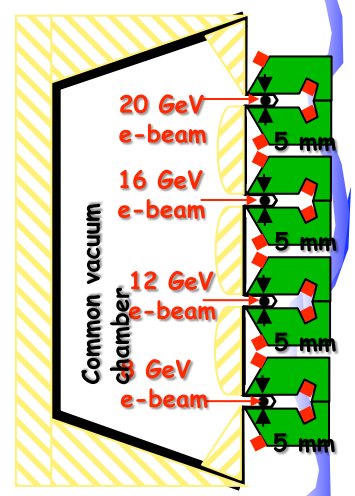
Beam current, mA	320	50	420	50 <10>
Normalized emittance, 1e-6 m, 95% for p / rms for e	15	73	1.2	25
Polarization, %	70	80	70	80
rms bunch length, cm	20	0.2	4.9	0.2
β*, cm	50	50	25	25
Luminosity, x 10^{33}, $cm^{-2}s^{-1}$	0.1 -> 1 with CeC		2.8	



2 x 200 m SRF linac
4 (5) GeV per pass
5 (4) passes

10-20 GeV e x 325 GeV p
130 GeV/u Au
possibility of 30 GeV @ low current operation

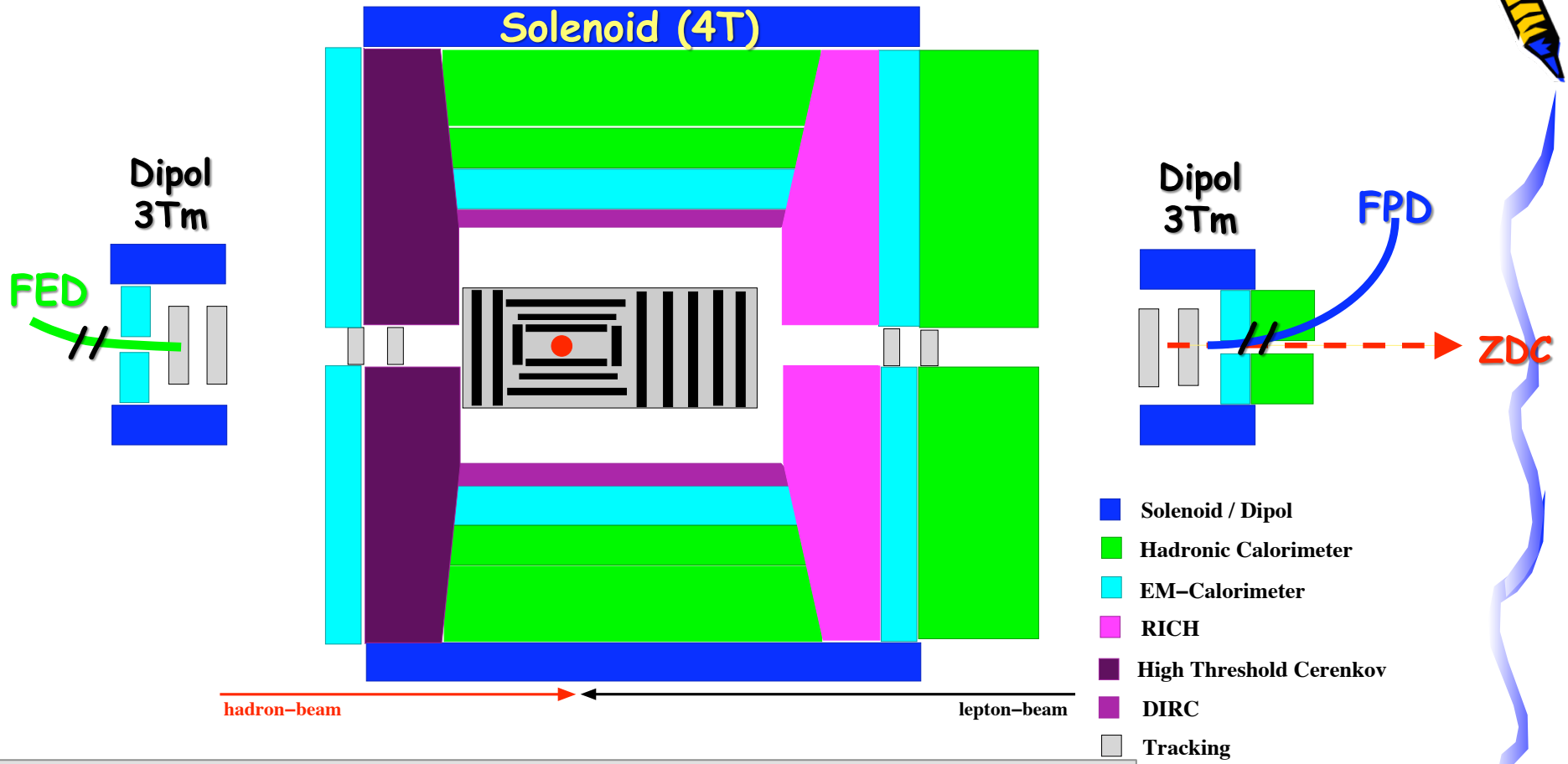


4 to 5 vertically separated recirculating passes

Detector Requirements from Physics

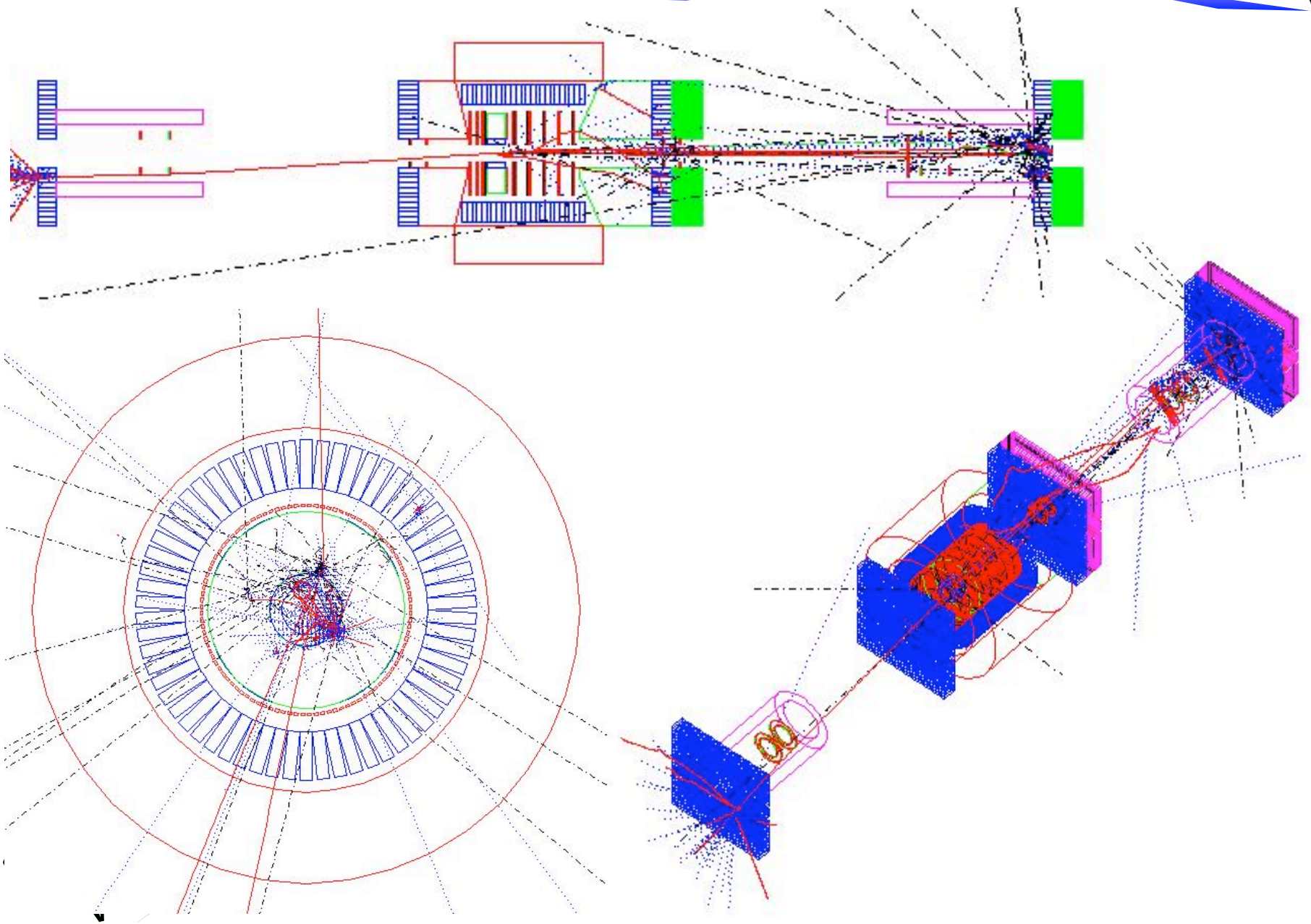
- Detector must be multi-purpose
  - Need the same detector for inclusive (ep -> e'X), semi-inclusive (ep -> e'hadron(s)X), exclusive (ep -> e'πp) reactions and eA interactions
  - Able to run for different energies (and ep/A kinematics) to reduce systematic errors
  - Ability to tag the struck nucleus in exclusive and diffractive eA reactions
- Needs to have large acceptance
  - Cover both mid- and forward-rapidity
  - particle detection to very low scattering angle; around 1° in e and p/A direction
- particle identification is crucial
  - e, π, K, p, n over wide momentum range and scattering angle
  - excellent secondary vertex resolution (charm)
- small systematic uncertainty for e,p-beam polarization and luminosity measurement

First ideas for a detector concept



- Dipoles needed to have good forward momentum resolution
  - Solenoid no magnetic field @ r ~ 0
- DIRC, RICH hadron identification → π, K, p
- high-threshold Cerenkov → fast trigger for scattered lepton
- radiation length very critical → low lepton energies

MeRHIC Detector in Geant-3



Outlook and Summary

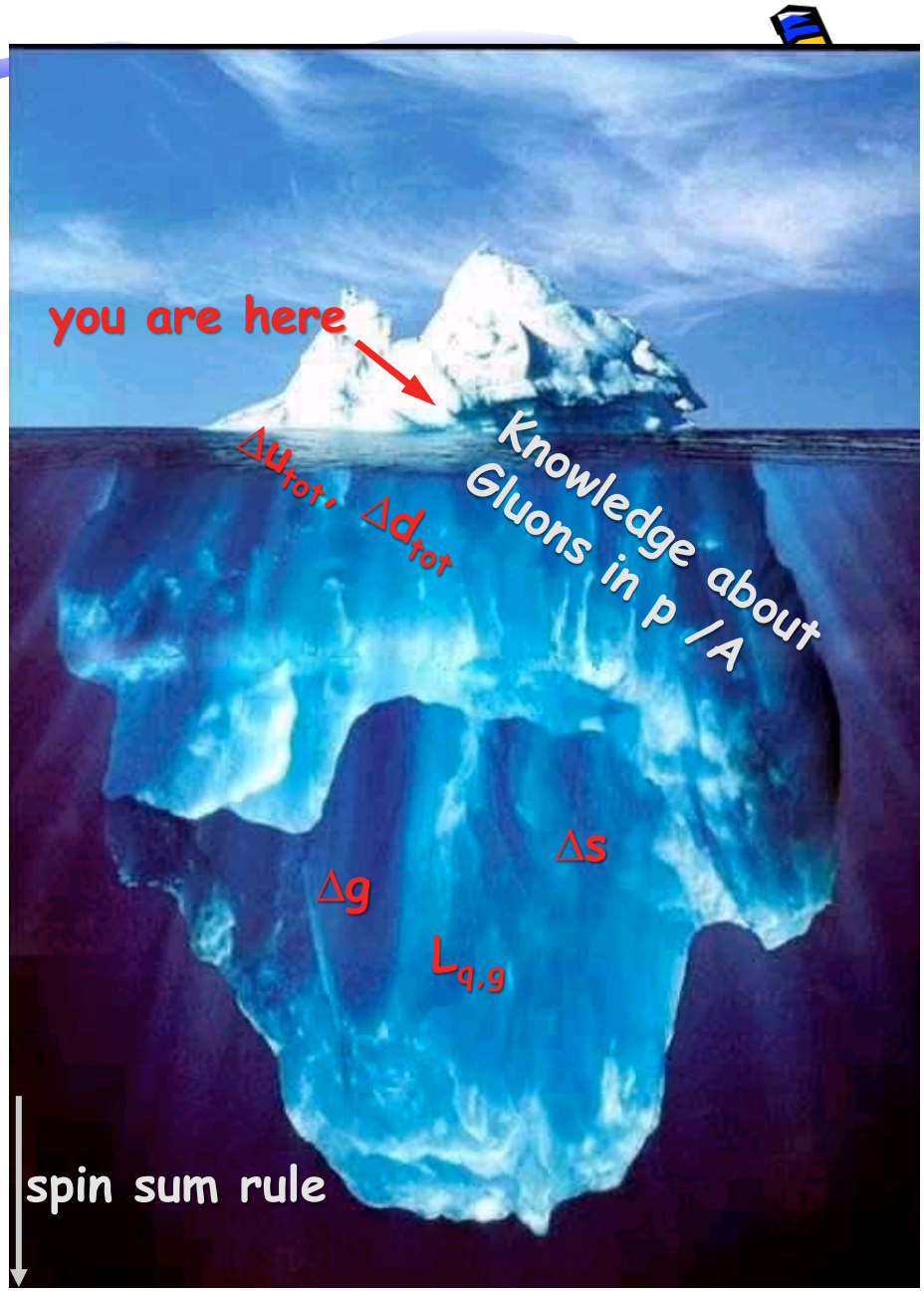
we have just explored the tip of the iceberg

EIC

many avenues for further important measurements and theoretical developments

Come and join us

The BNL EIC Taskforce

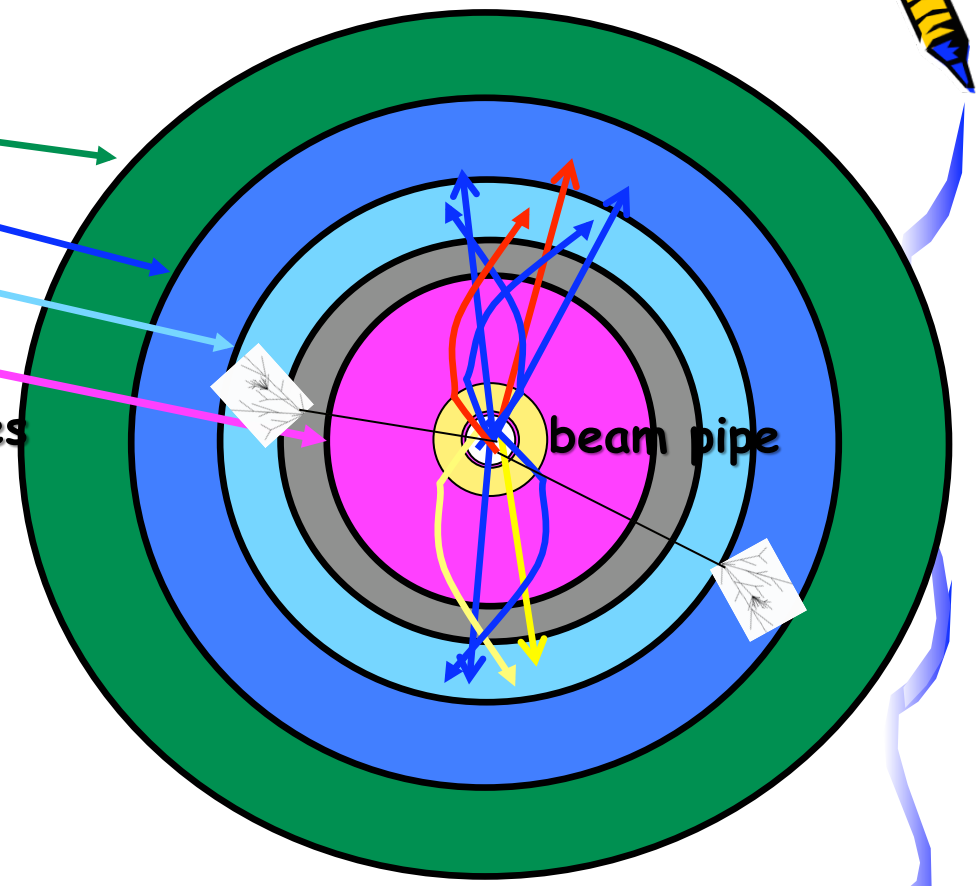


BACKUP

A typical High Energy Detector

Particle types:

- neutrinos (missing energy)
- muons μ
- hadrons π, K, p
  - quarks, gluons → jets
- electrons, photons, π^0
- charged particles



Rough Classification

- track detectors for charged particles
  - "massless" detectors
    - gas detectors
    - solid state detectors
- magnet coil
  (solenoid, field || beam axis)

Calorimeter for energy measurement

- electromagnetic
  - high Z material (Pb-glas)
- hadronic
  - heavy medium (Fe, Cu, U)
    + active material
- absorber (mostly Fe)
  - flux return yoke + active material

The Standard Model

BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.4	−1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

ν_τ t n 2/3

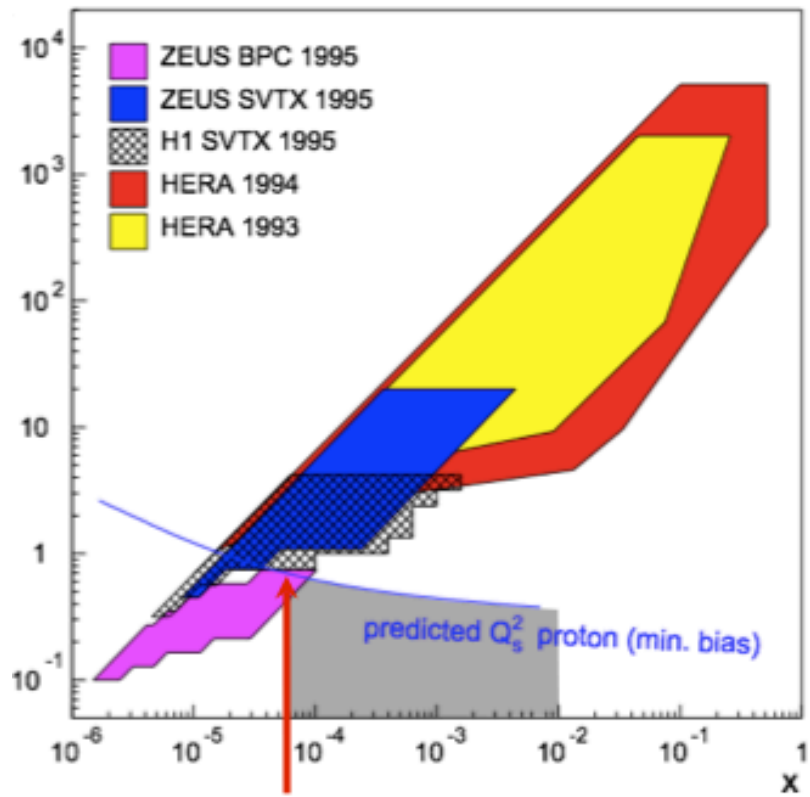
τ t 1/3

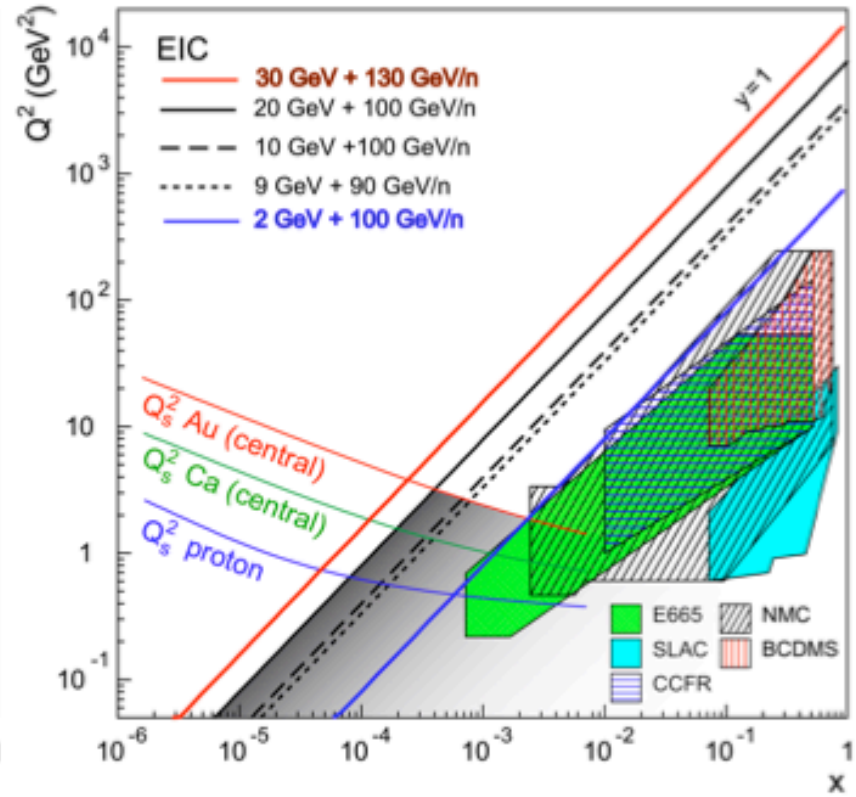
QED: Theory of the Electromagnetic Interaction
QCD: Theory of the Strong Interaction

Quarks and gluons

- No free quarks and gluons seen in the detector
- Quarks and Gluons "live" in the world of strong interaction
- Quarks "talk" to outside world via their fractional electric charge
- Gluons do not directly interact with anyone else
  - no gravity and beyond standard model here
- We "see" quarks directly via electromagnetic probes and "produce" them in pairs
- We "feel" gluons' existence via the scale dependence of inclusive cross sections
  - "see" their trace from the jet events
- "measure" them quantitatively from global QCD analysis of cross sections and parton distribution functions

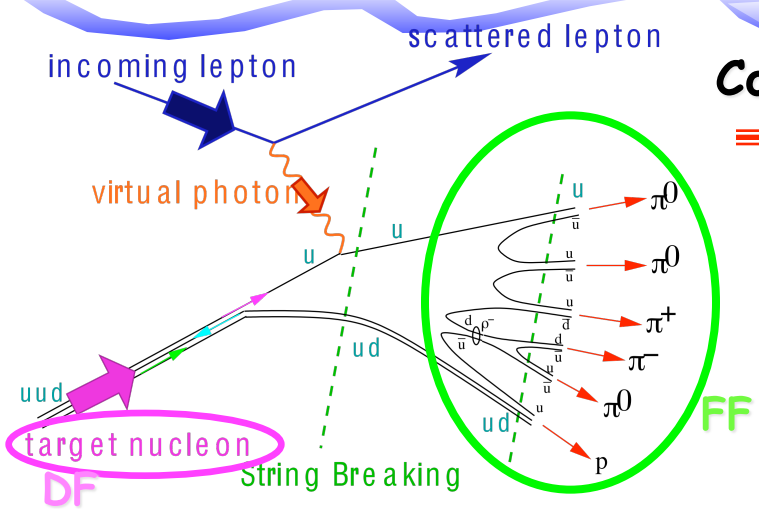
Probing Saturation regime





- HERA (ep) energy range higher $G(x,Q^2)$ very limited reach of the saturation regime
- eRHIC (eA) will probe deeply into the saturation region

Polarised quark distributions



$$d\sigma^h(z) \sim \sum_f \Delta q_f(x) \otimes d\Delta\sigma_f \otimes D_f^h(z)$$

Correlation between detected hadron and struck q_f

⟹ "Flavor - Separation"

Inclusive DIS:

$$\Delta\Sigma = (\Delta u + \Delta d + \Delta\bar{u} + \Delta\bar{d} + \Delta s + \Delta\bar{s})$$

Semi-inclusive DIS:

$$(\Delta u, \Delta d, \Delta\bar{u}, \Delta\bar{d}, \Delta s, \Delta\bar{s})$$

In LO-QCD:

$$A_1^h(x,Q^2,z) = \frac{\sigma_{1/2}^h - \sigma_{3/2}^h}{\sigma_{1/2}^h + \sigma_{3/2}^h} \sim C \sum_q \underbrace{\frac{e_q^2 q(x,Q^2) D_q^h(z,Q^2)}{\sum_{q'} e_{q'}^2 q'(x,Q^2) D_{q'}^h(z,Q^2)}}_{P_q^h(x,Q^2,z)} \frac{\Delta q(x,Q^2)}{q(x,Q^2)}$$

$P_q^h(x,Q^2,z)$ ⟸ MC

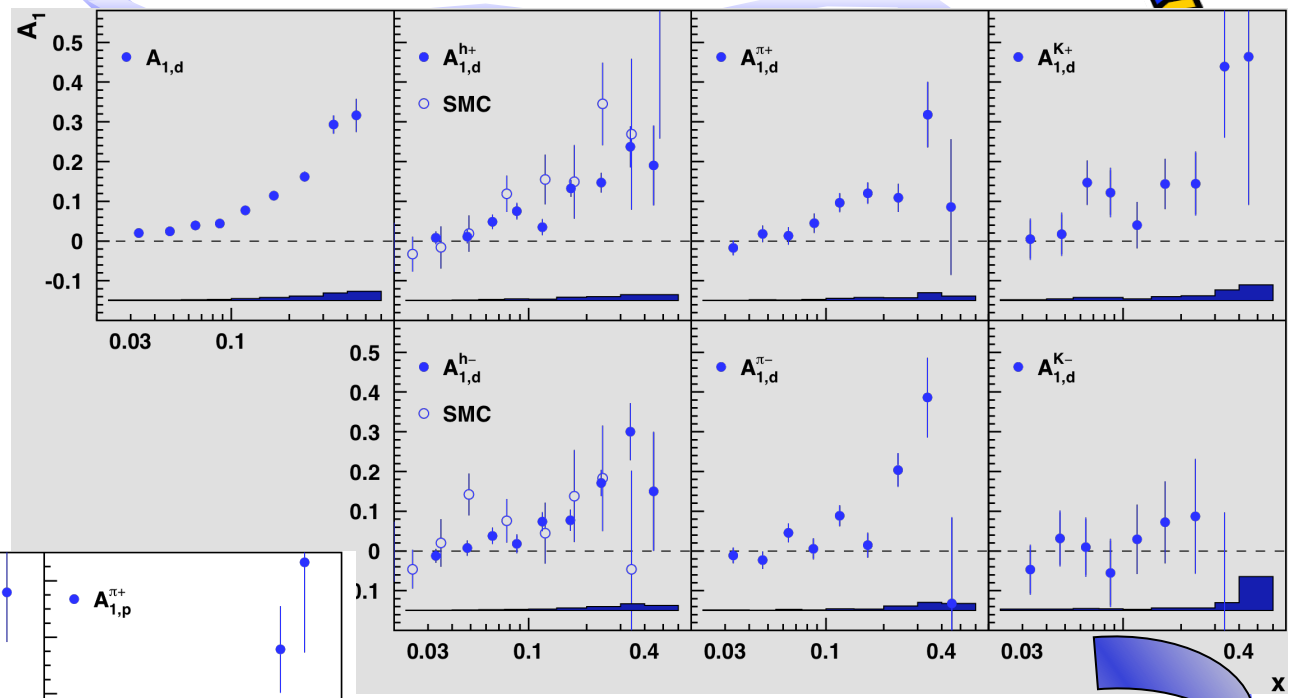
Extract Δq by solving:

$$\vec{A} = P\vec{Q}$$

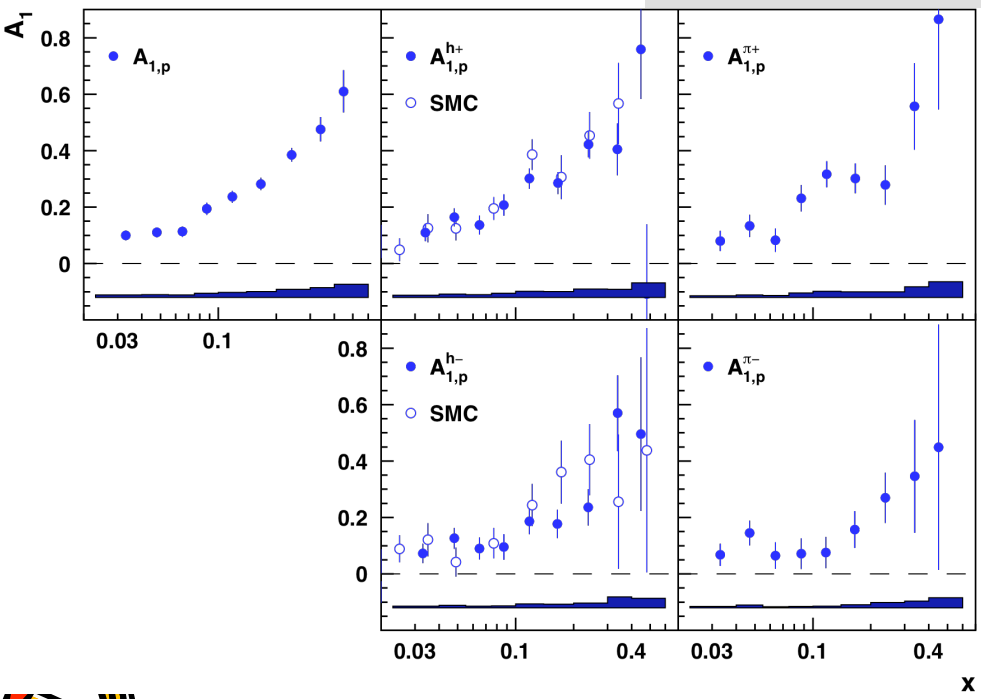
$$\vec{A} = (A_{1,p}(x), A_{1,p}^{\pi\pm}(x), A_{1,d}(x), A_{1,d}^{\pi\pm}(x), A_{1,d}^{K\pm}(x)) \qquad \vec{Q} = \left(\frac{\Delta u}{u}, \frac{\Delta d}{d}, \frac{\Delta\bar{u}}{\bar{u}}, \frac{\Delta\bar{d}}{\bar{d}}, \frac{\Delta s}{s}, \frac{\Delta\bar{s}}{\bar{s}} = 0\right)$$

Measured Asymmetries

Deuterium



Proton

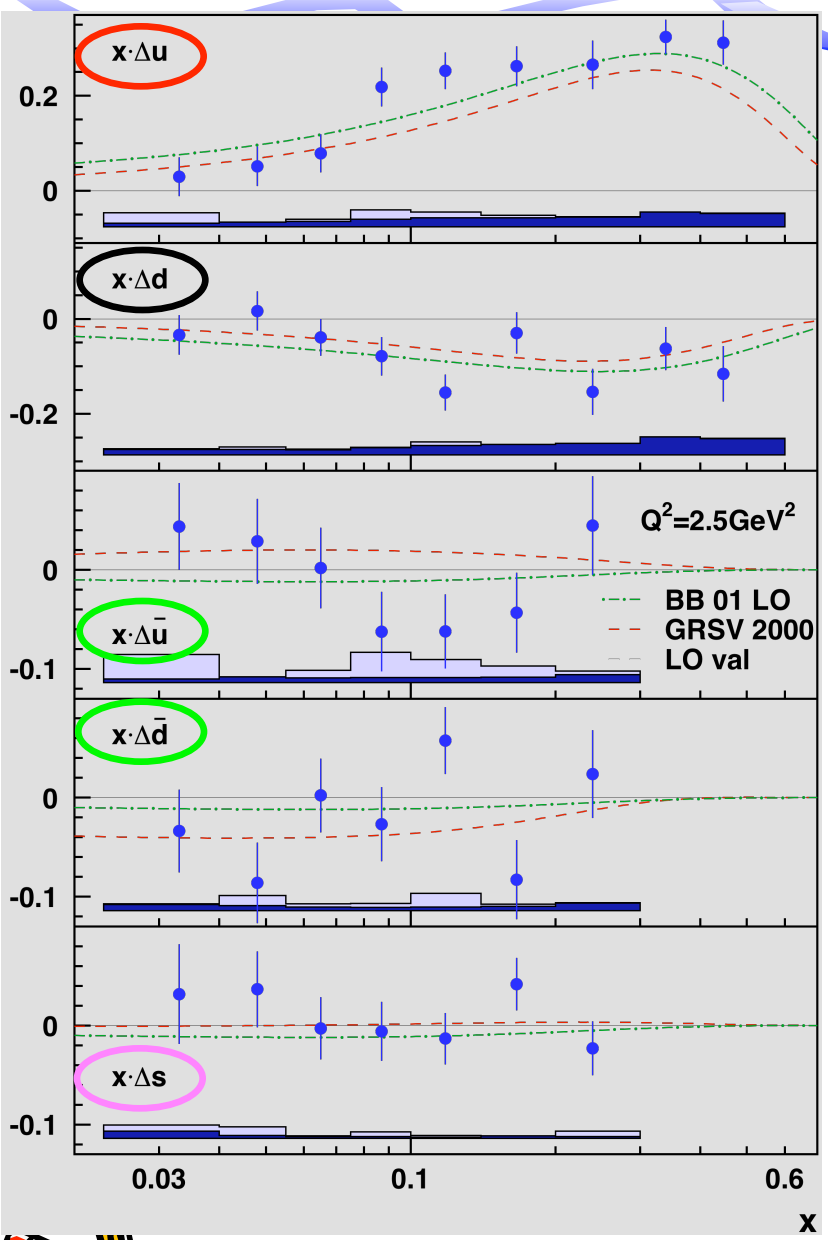


$$A_1^{K^-} \sim 0 \Rightarrow K^- = (\bar{u}s)$$

- statistics sufficient for 5 parameter fit

$$\vec{Q} = \left(\frac{\Delta u}{u}, \frac{\Delta d}{d}, \frac{\Delta \bar{u}}{\bar{u}}, \frac{\Delta \bar{d}}{\bar{d}}, \frac{\Delta s}{s}, \frac{\Delta \bar{s}}{\bar{s}} = 0\right)$$

Polarized Quark Densities



- First complete separation of pol. PDFs without assumption on sea polarization
- $\Delta u(x) > 0$ $\Delta d(x) < 0$
  → good agreement with NLO-QCD
  → Polarised parallel to proton spin
- $\Delta\bar{u}(x), \Delta\bar{d}(x) \sim 0$
- No indication for $\Delta s(x) < 0$
- In measured range (0.023 – 0.6)

$$\int \Delta\bar{u} = -0.002 \pm 0.043$$

$$\int \Delta\bar{d} = -0.054 \pm 0.035$$

$$\int \Delta s = +0.028 \pm 0.034$$

Beyond collinear pQCD

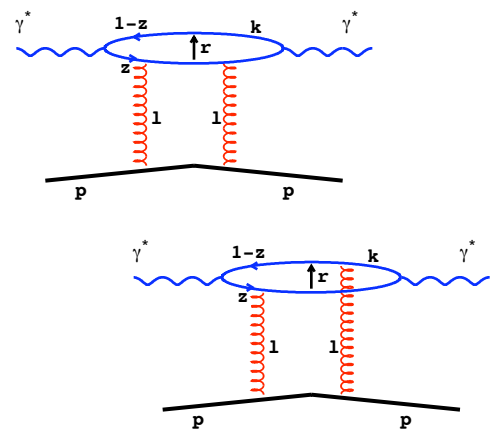
- Suppose we view DIS in rest frame of target
  - γ^* fluctuation into quark, anti-quark (dipole) frozen
  - w / radial separation r
  - Dipole interacts with proton/nuclei
- Then DIS cross-section

$$\sigma(x,Q^2) = \int dz \int d^2r \left|\Psi(r,z,Q^2)\right|^2 \hat{\sigma}(r,x)$$

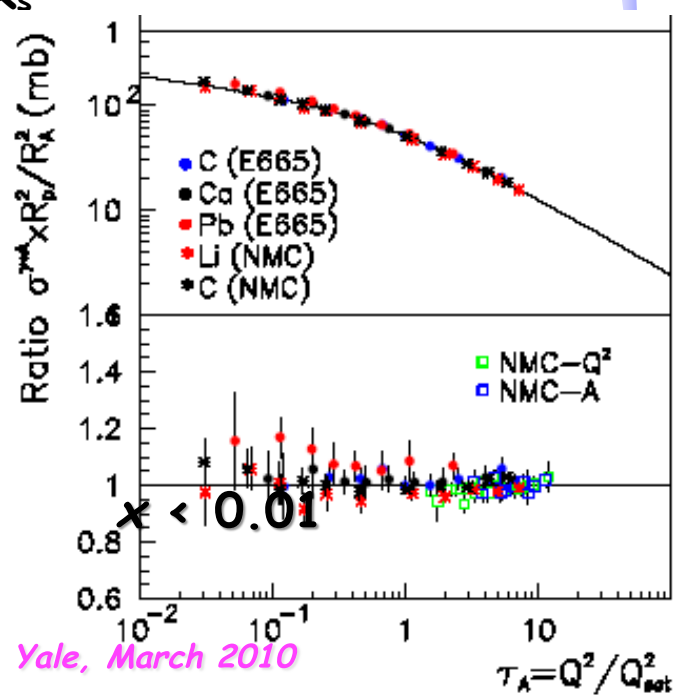
- Interesting physics in $\hat{\sigma}(r,x)$
- What happens @ large r ? $r \sim h/\sqrt{Q^2}$
- In dipole picture $\hat{\sigma}(r,x)$ saturates for $r > R_0 = 1/Q_s$

  assume: $\hat{\sigma}(r,x) = g(r,Q_s)$
- Use BFKL for x dependence of $Q_s(x) = Q_0 (\frac{x_0}{x})^{\lambda/2}$

$$Q_s^A(x) = Q_s^p (A \frac{R_p}{R_A})^{\lambda}$$



Geometric Scaling → works for proton and nuclei



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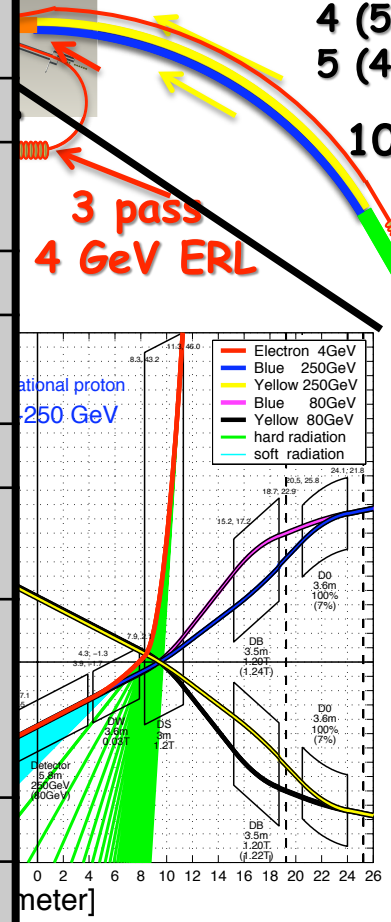

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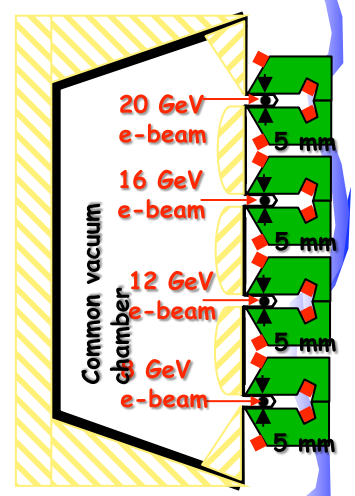
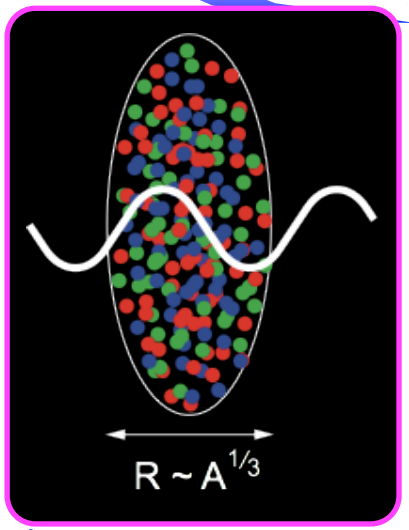
possibility of 30 GeV @
low current operation



4 to 5 vertically separated recirculating passes

The Nuclear Enhancement Factor

- Enhancing Saturation effects:
  - Probes interact over distances $L \sim (2m_n x)^{-1}$
  - For probes where $L > 2R_A$ ($\sim A^{1/3}$), cannot distinguish between nucleons in the front or back of of of the nucleus.
    - Probe interacts coherently with all nucleons.
- Probes with transverse resolution $1/Q^2$ ($\ll \Lambda^2_{QCD}$) ~ 1 fm^2 will see large colour charge fluctuations.
  - This kick experienced in a random walk is the resolution scale.



Simple geometric considerations lead to:

$$Q_s^2 \sim \frac{\alpha_s x G(x,Q_s^2)}{\pi R_A^2}$$

HERA: $xG \sim \frac{1}{x^{1/3}}$

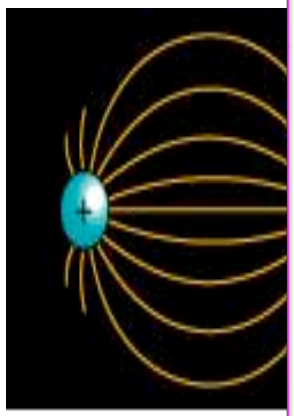
A-dependence: $xG_A \sim A$

Nuclear Enhancement Factor: $(Q_s^A)^2 \sim c Q_o^2 \left(\frac{A}{x}\right)^{1/3}$

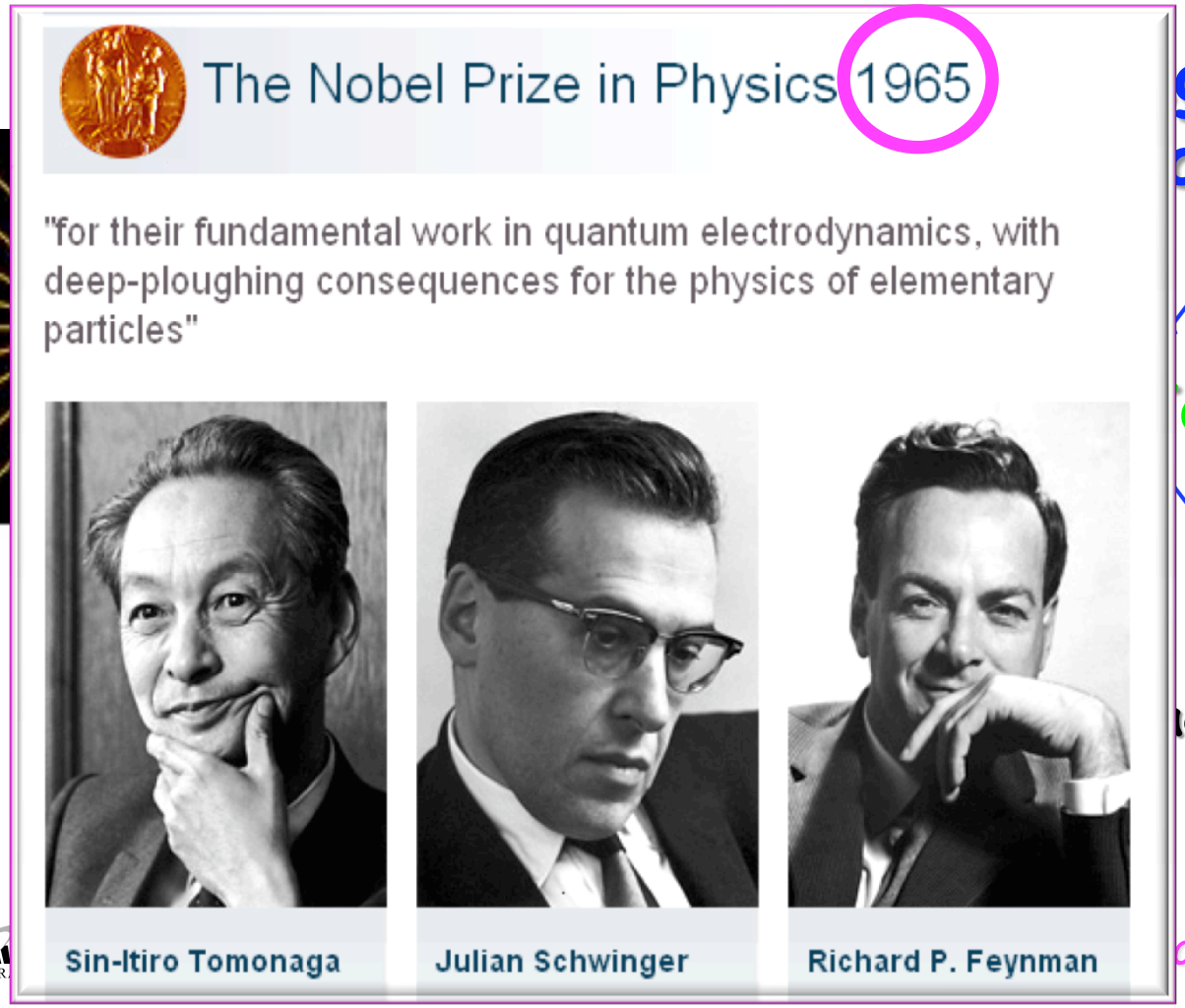
Enhancement of Q_s with A: $\Rightarrow$ non-linear QCD regime reached at significantly lower energy in e+A than in e+p

A reminder of Quantum Electro-Dynamics (QED)

- Theory of electromagnetic interactions
- Exchange particles (photons) do not carry electric charge
- Flux is not confined: $V(r) \sim 1/r$, $F(r) \sim 1/r^2$



$V_{em}(r)$



gram:
ation

μ^+

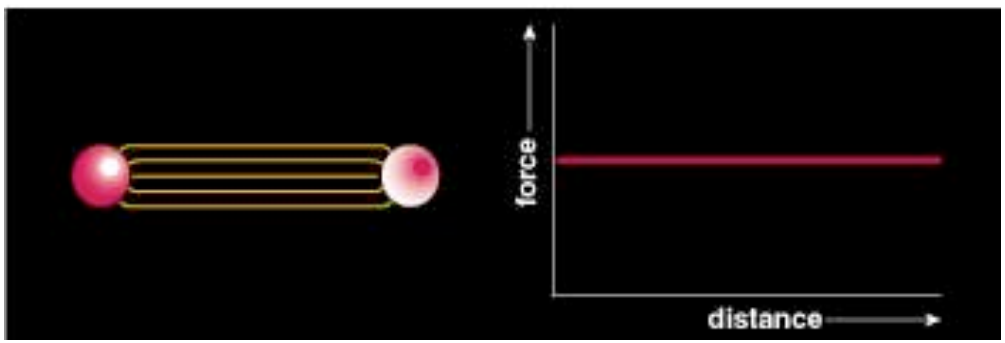
α

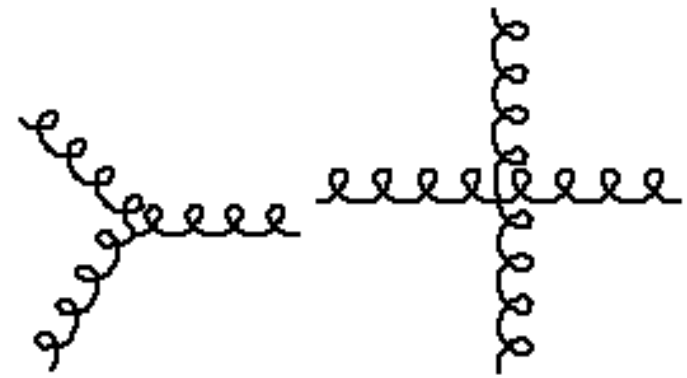
μ^-

ction Strength

Quantum Chromo-Dynamics (QCD) - 1973

- Theory of strong (nuclear) interactions
- Three colour charges: red, green and blue
- Exchange particles (gluons) carry colour charge and can self-interact
- Flux is confined: V(r) ~ r, F(r) ~ constant





~1/r at short range

$$V_s(r) = \frac{4}{3}\frac{\alpha_s}{r} + k_r$$

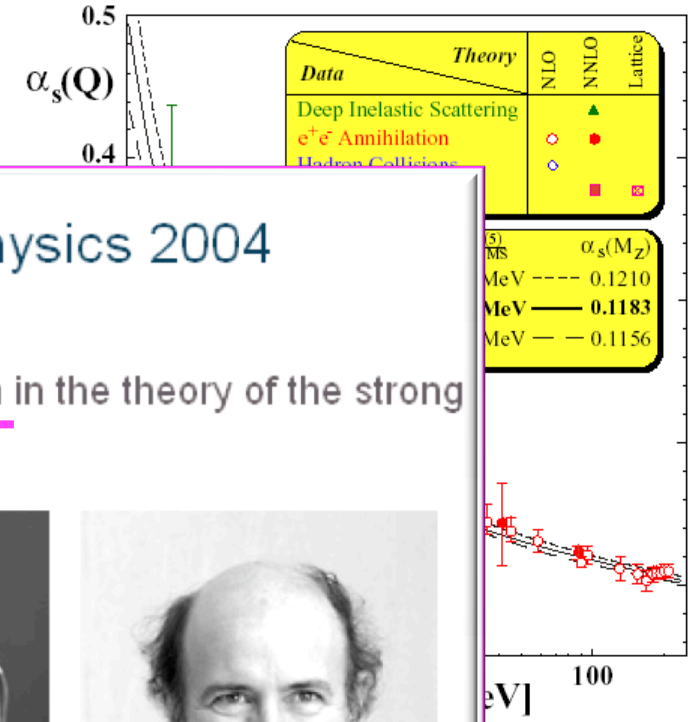
α_s = strong coupling constant ≈ 0.3

gluons can self-interact – more vertices are allowed

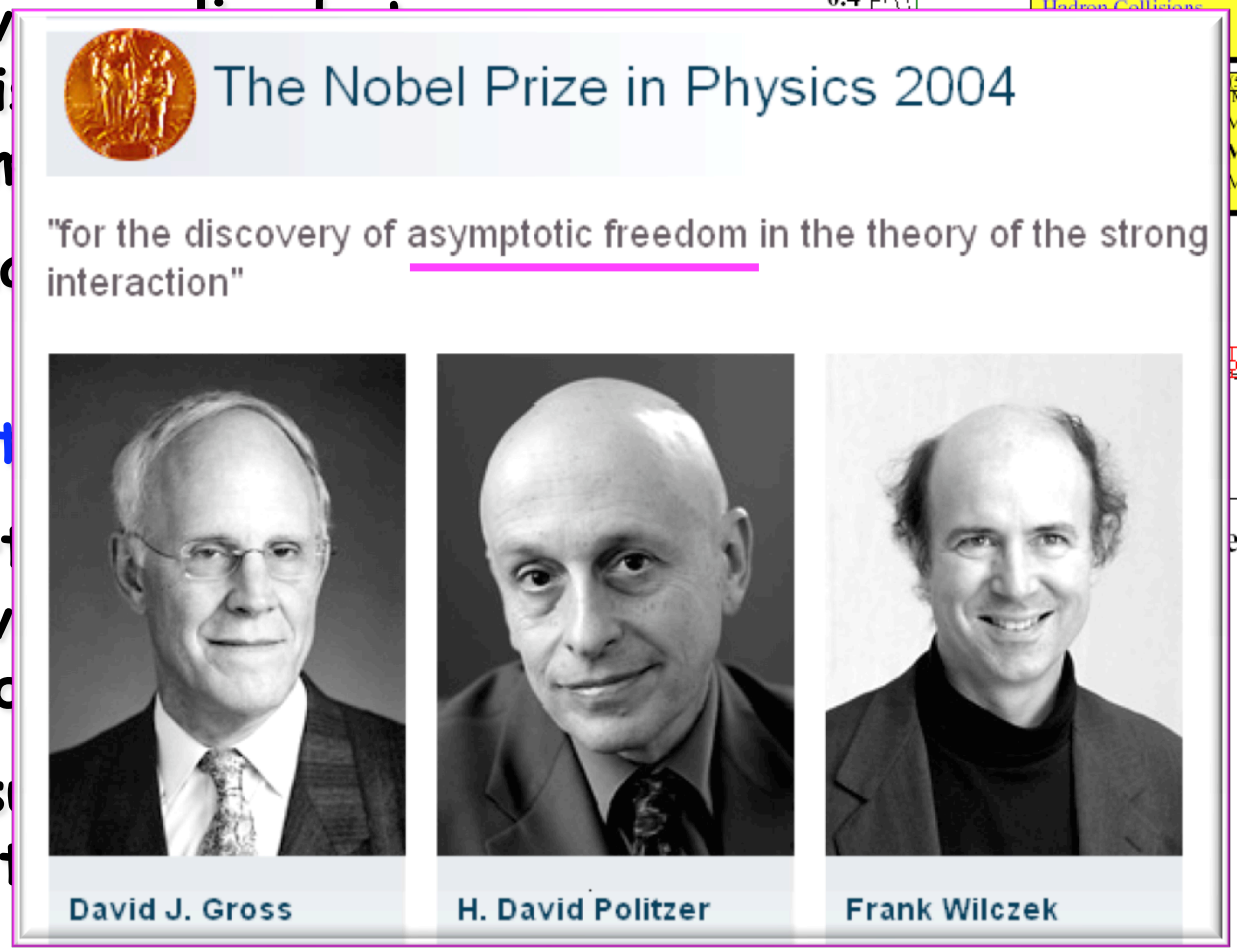
long range force ~ r

Features of Quantum Chromo-Dynamics

- Confinement
  - At large distances, the effectiv
    quarks i
    confinen
  - Free qu
    nature
- Asymptot
  - At short
    effectiv
    quarks c
  - Under s
    appear t



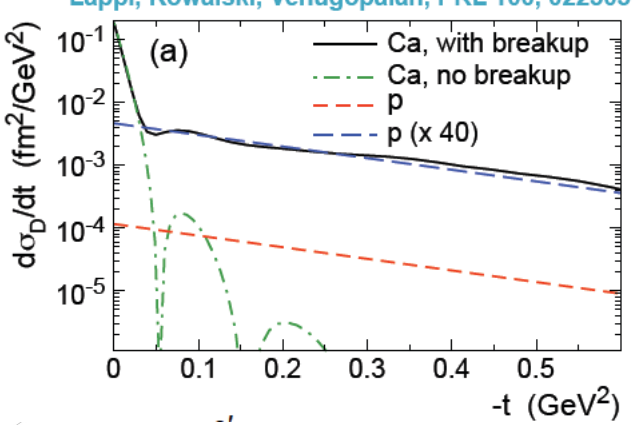
0.002 fm



How to measure coherent diffraction in e+A ?

- Beam angular divergence limits smallest outgoing Θ_{min} for p/A that can be measured
- Can measure the nucleus if it is separated from the beam in Si (Roman Pot) "beamline" detectors
  - $p_{Tmin} \sim pA\,\theta_{min}$
    - For beam energies = 100 GeV/n and θ_{min} = 0.08 mrad:
- These are large momentum kicks, much greater than the binding energy (~8MeV)
  - Therefore, for large A, coherently diffractive nucleus cannot be separated from beamline without breaking up

Lappi, Kowalski, Venugopalan, PRL 100, 022303



- Need to rely on rapidity gap method
  - simulations look good
  - high eff. high purity possible with gap alone
    - ~1% contamination
    - ~80% efficiency
  - depends critical on detector hermeticity
  - improve further by veto on B[illegible])
- Very critical
  - mandatory to detect nuclear fragments from breakup
  - n: Zero-Degree calorimeter
  - p, A frag: Forward Spectrometer
  - New idea: Use U instead of AU

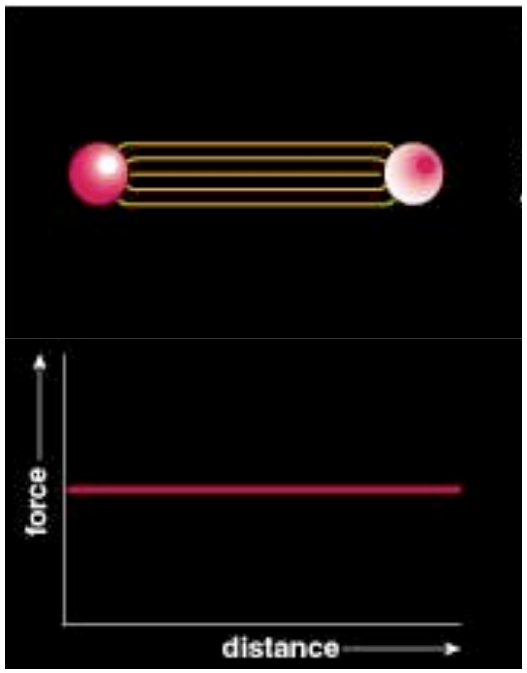
species (A)	p_{Tmin} (GeV/c)
d (2)	0.02
Si (28)	0.22
Cu (64)	0.51
In (115)	0.92
Au (197)	1.58
U (238)	1.90

QED vs QCD

- Potentials:

$$V_{em}(r) = -\frac{q_1 q_2}{4\pi\varepsilon_0 r} = \frac{\alpha_{em}}{r} \qquad V_s(r) = \frac{4}{3}\frac{\alpha_s}{r} + k_r$$

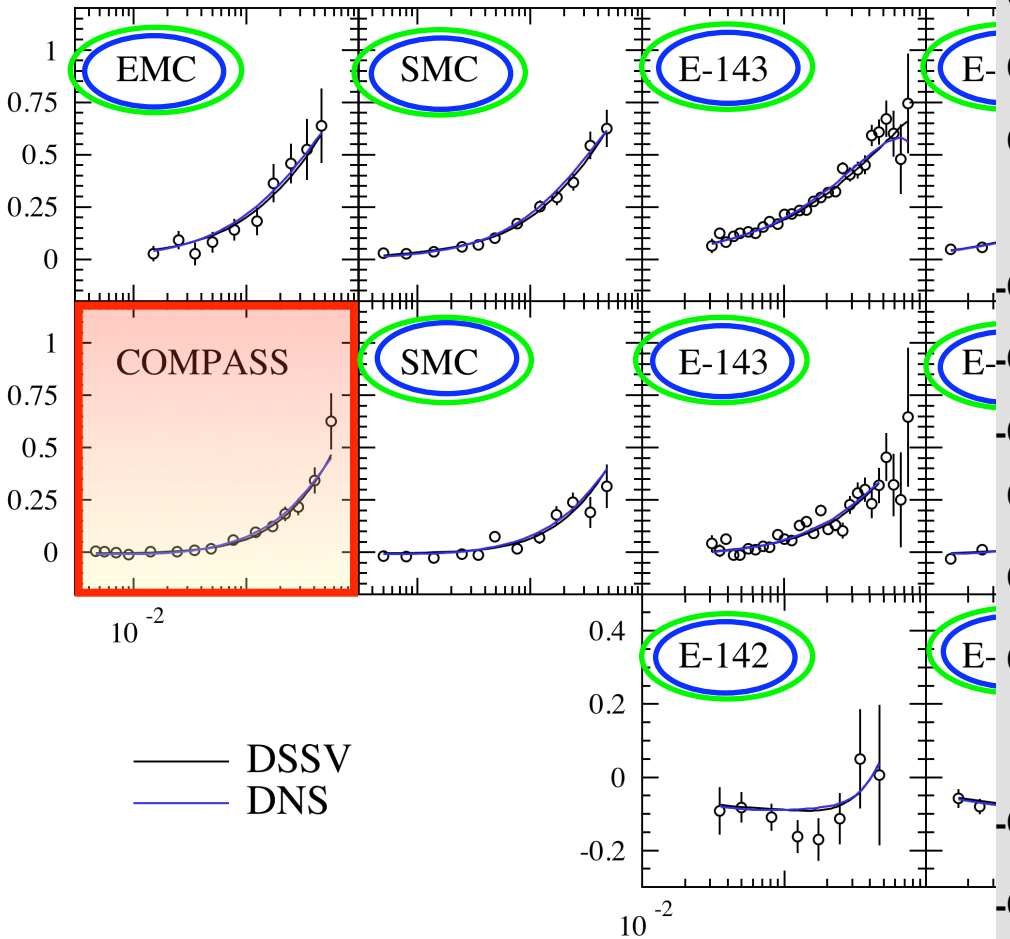
  - long range aspect of $V_s(r)$ leads to quark confinement and the existence of nucelons

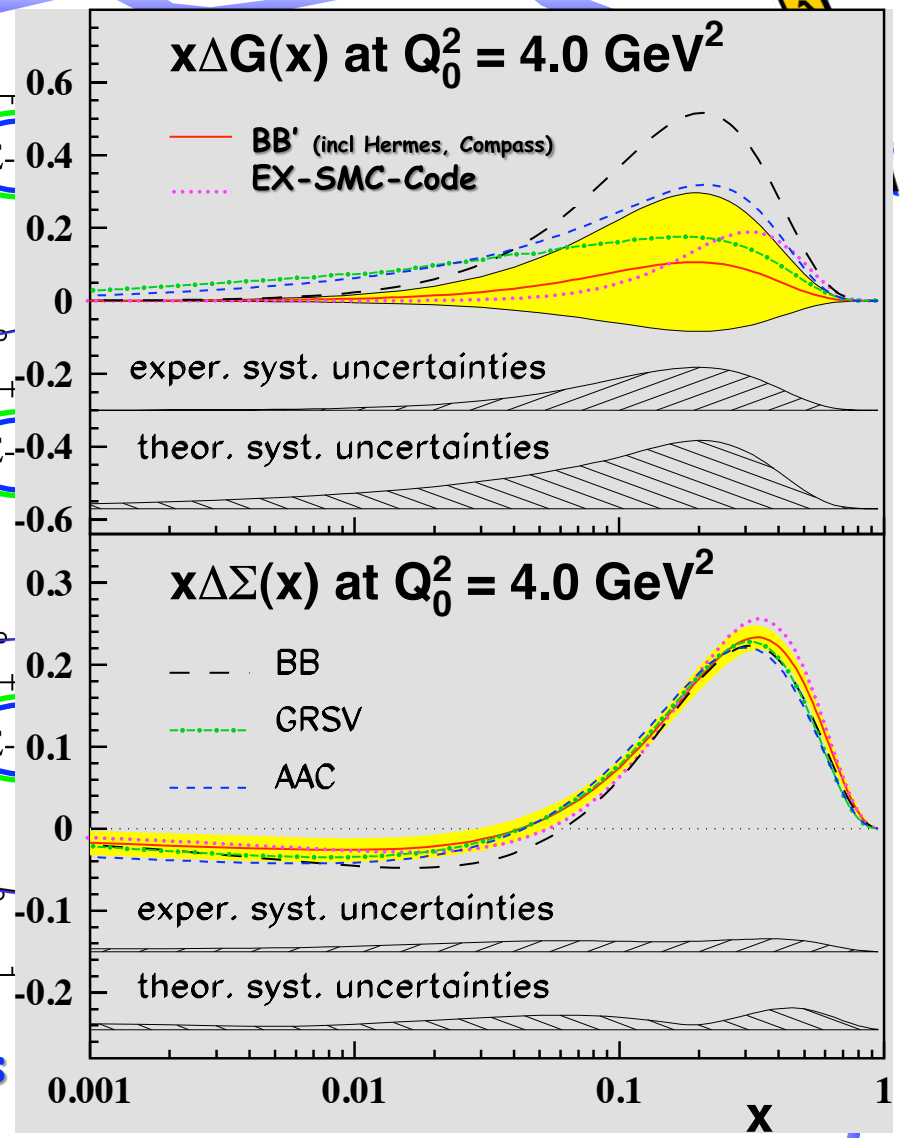


	QED	QCD
Charges	electric (2)	colour (3)
gauge bosons	γ	g (8)
charged?	no	yes
coupling strength	$\alpha_{em} = e^2/4\pi \approx 1/137$	$\alpha_s \approx 0.3$

Inclusive World data

- **Inclusive DIS-Data:**





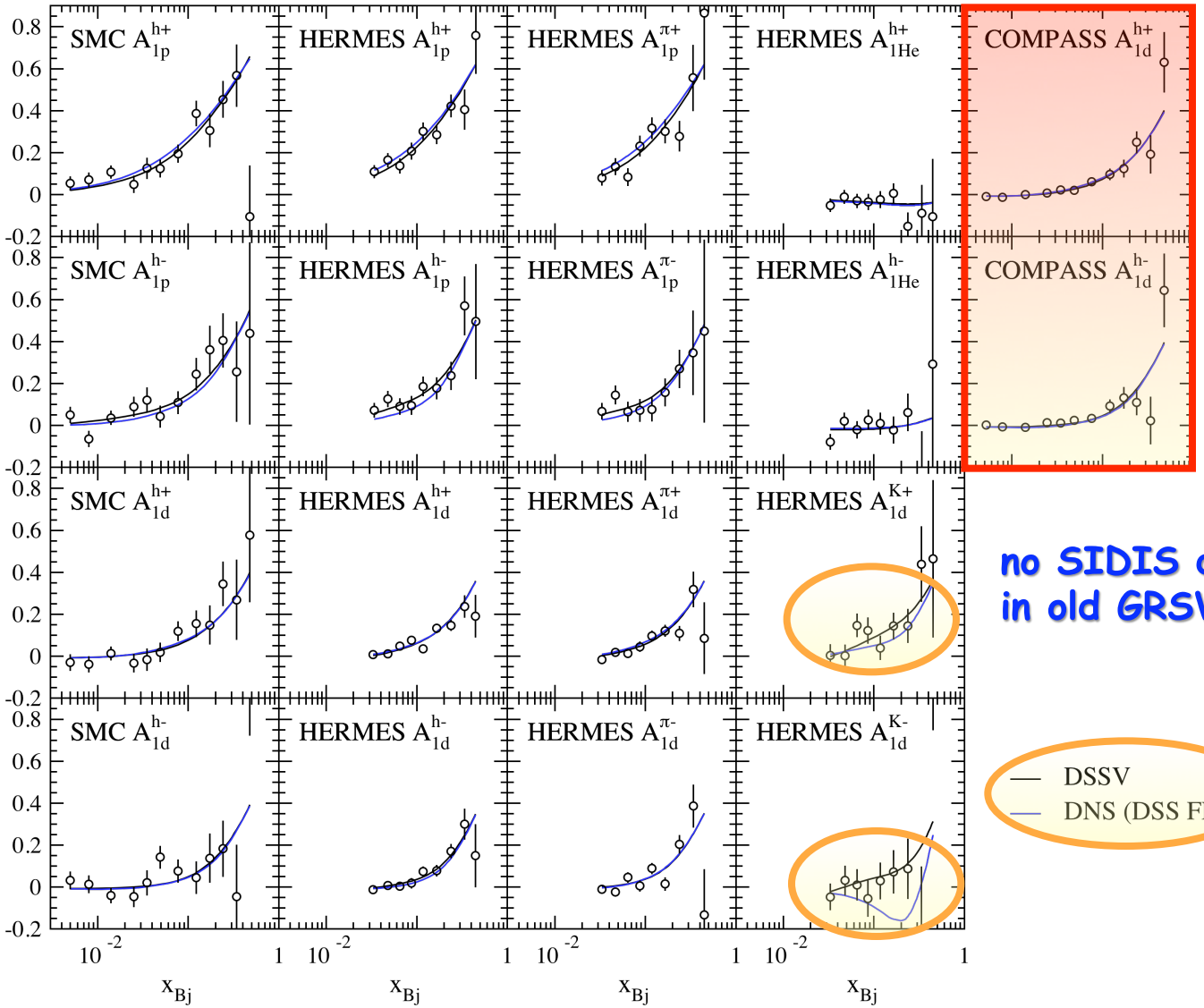
: input to the old GRSV-analysis

: input to the DIS & SIDIS – analysis by DNS

Semi-Inclusive World Data

- **Semi-inclusive DIS-Data:**

not in DNS



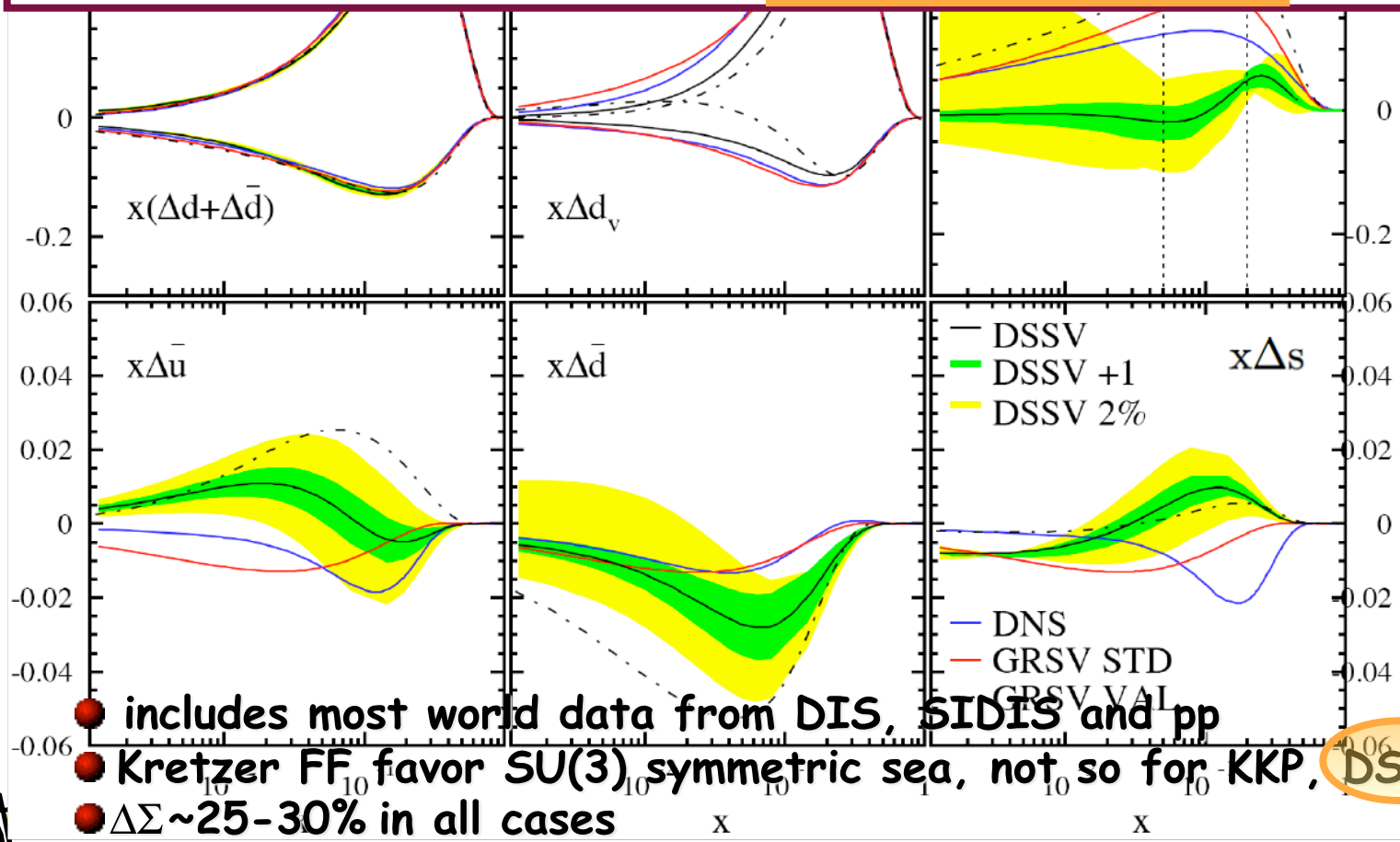
no SIDIS data included in old GRSV-analysis

DSSV
DNS (DSS FFs)

NLO Fit to World Data

D. De Florian et al. arXiv:0804.0422 NLO @ Q^2=10 GeV^2

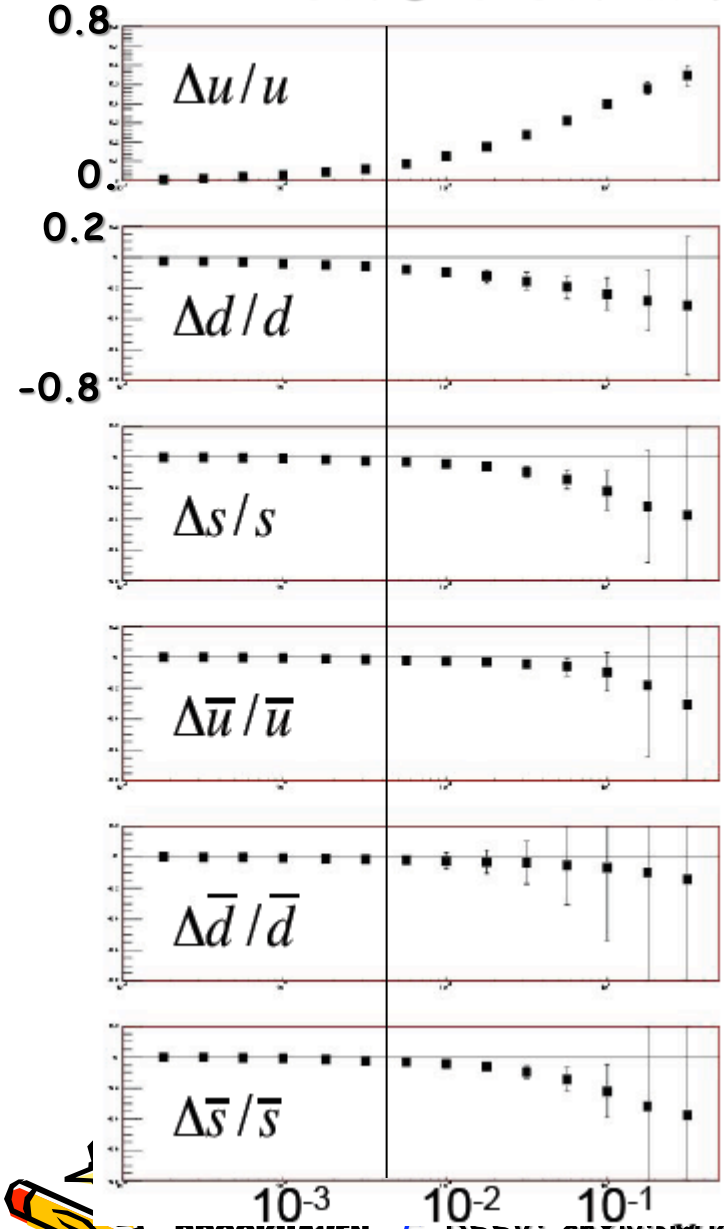
	χ^2_{DIS}	χ^2_{SIDIS}	Δu_v	Δd_v	$\Delta\bar{u}$	$\Delta\bar{d}$	Δs	Δg	$\Delta\Sigma$
Kretzer	206	225	0.94	−0.34	−0.049	−0.055	−0.051	0.68	0.28
KKP	206	231	0.70	−0.26	0.087	−0.11	−0.045	0.57	0.31
DSS			0.813	−0.458	0.036	−0.115	−0.057	−0.084	0.242

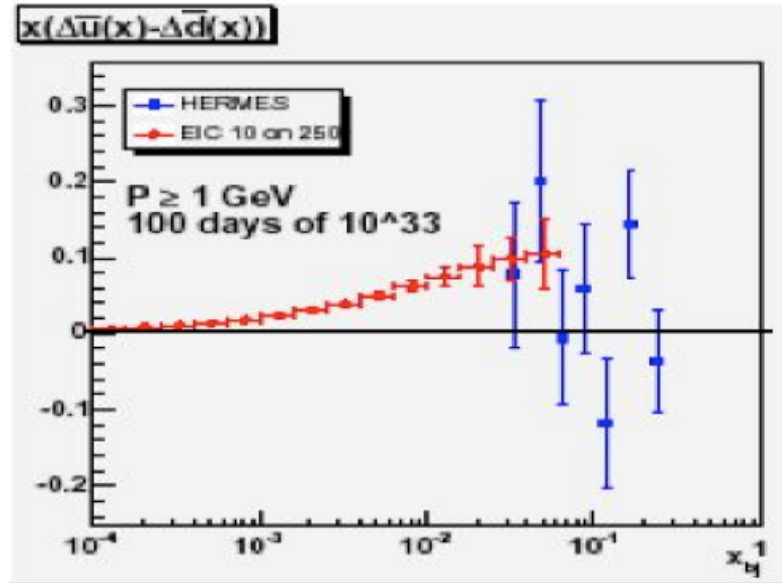


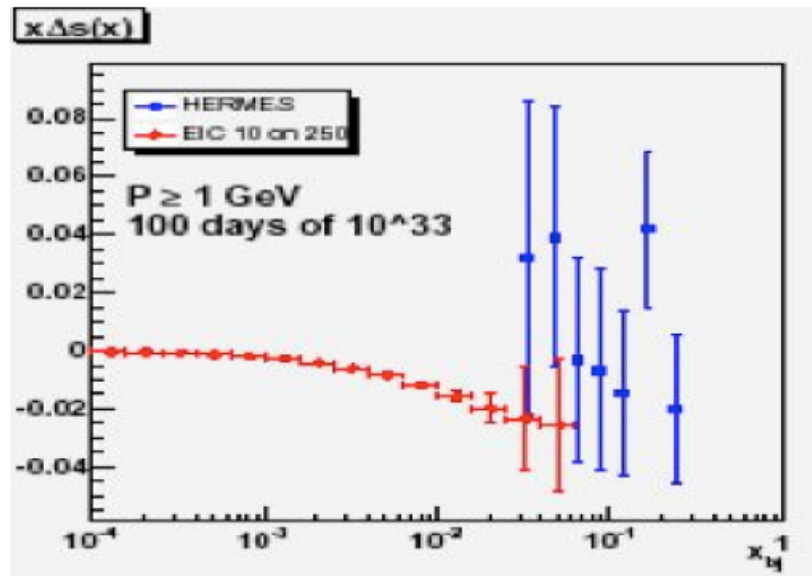
- includes most world data from DIS, SIDIS and pp
- Kretzer FF favor SU(3) symmetric sea, not so for KKP, DSS
- $\Delta\Sigma$~25-30% in all cases

Polarized Quark Distributions @ EIC

eRHIC: 10GeV@250GeV at 9 fb^{-1}

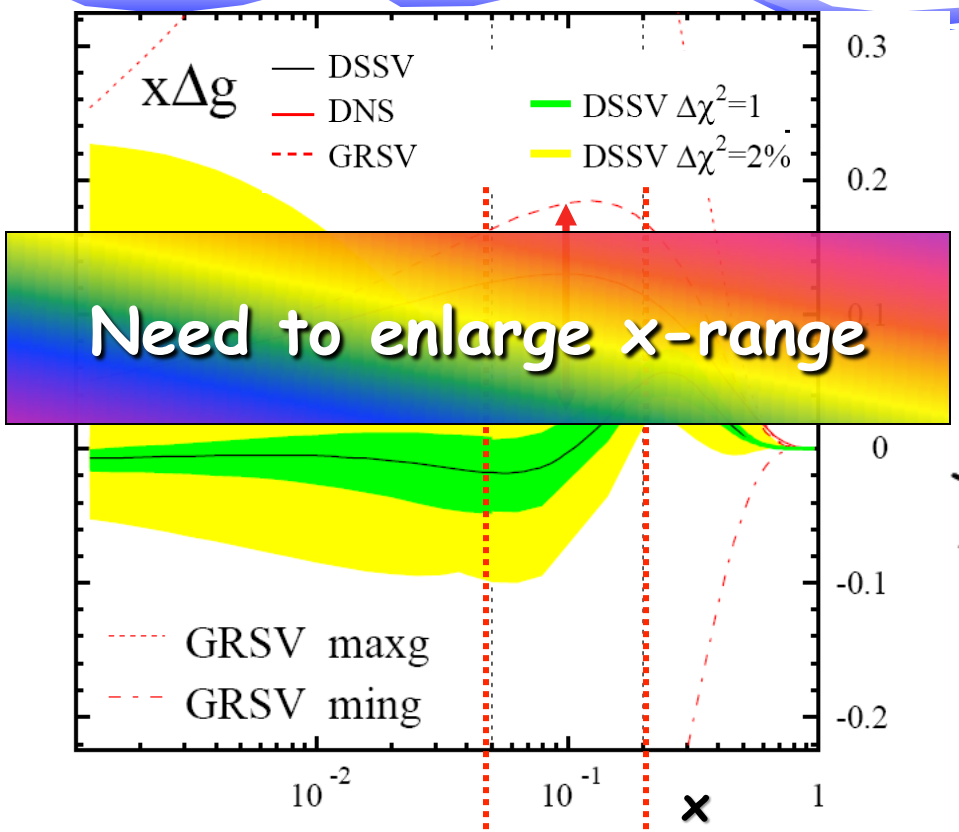






E. DSSV: arXiv:0904.3821

The Gluon Polarization



Need to enlarge x-range

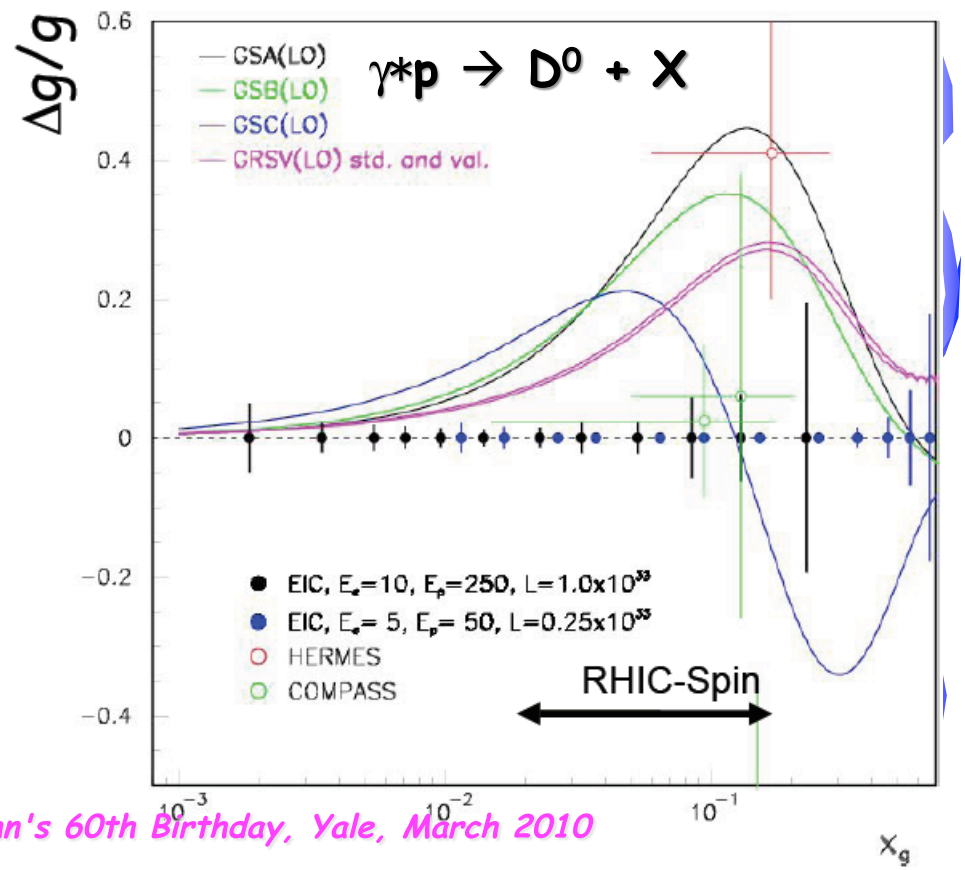
small-x
0.001< x < 0.05

RHIC range
0.05· x · 0.2

large-x
x > 0.2

can be extended a bit by changing √s to 64GeV & 500GeV

- Δg(x) very small at medium x
- best fit has a node at x ~ 0.1
- huge uncertainties at small x

Δg(x) small !?

$$\int^{1} \Delta g(x)\,dx = -0.084 @ 10GeV^2$$