The glue that binds us all:

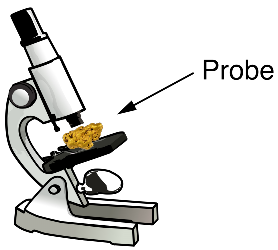
Imaging matter below 10^{-15} m with an Electron-Ion Co

Raju Venugopalan
Brookhaven National Laboratory

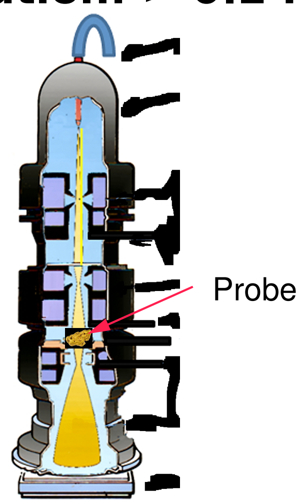
FSU, Nuclear Physics Seminar
November 10, 2017

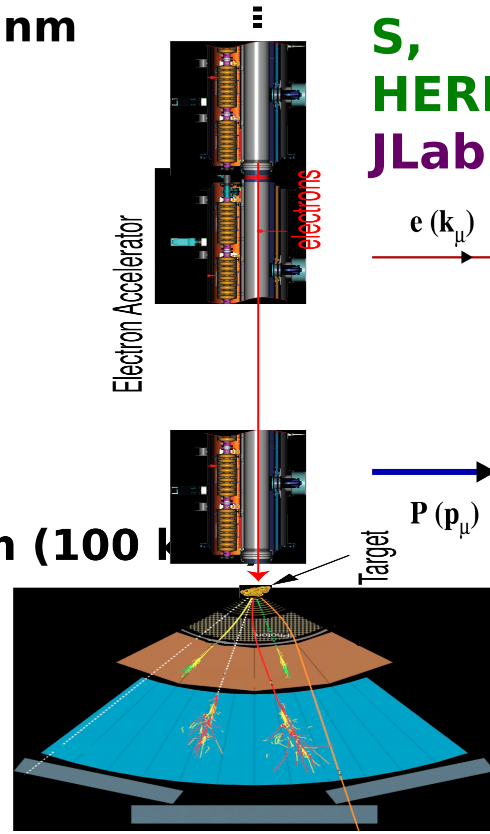
cture of matter: Microscopes to Femtosc

Light Microscope
Wave length: 380-740 nm
Resolution: > 200 nm



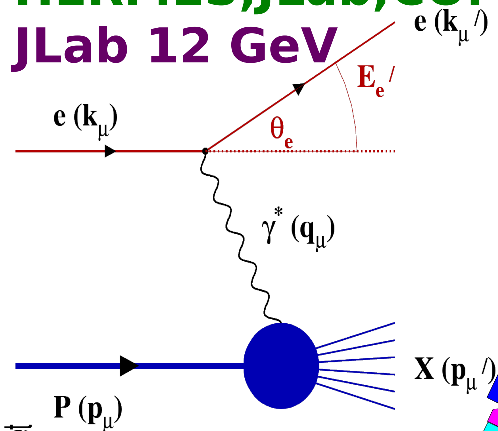
Electron Microscope
Wave length: 0.002 nm (100 k
Resolution: > 0.2 nm

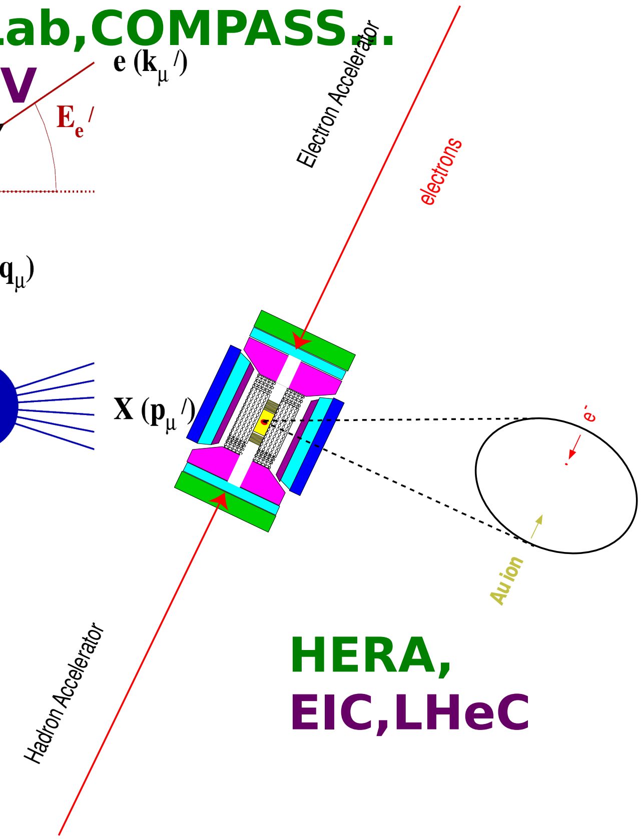




Fixed Target Particle Accelerator Experiments
Wave length: 0.01 fm (20 GeV)
Resolution: ~ 0.1 fm

SLAC,EMC,NMC,E665,BCDMS, HERMES,JLab,COMPASS,..
JLab 12 GeV

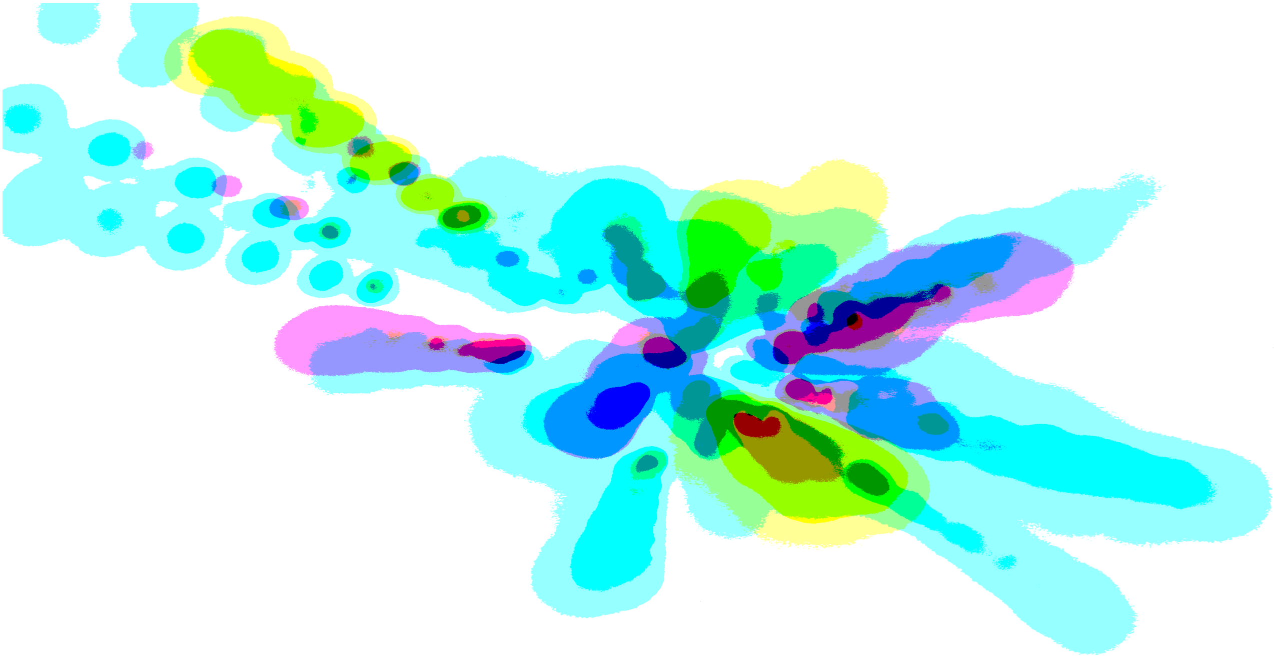




HERA,
EIC,LHeC

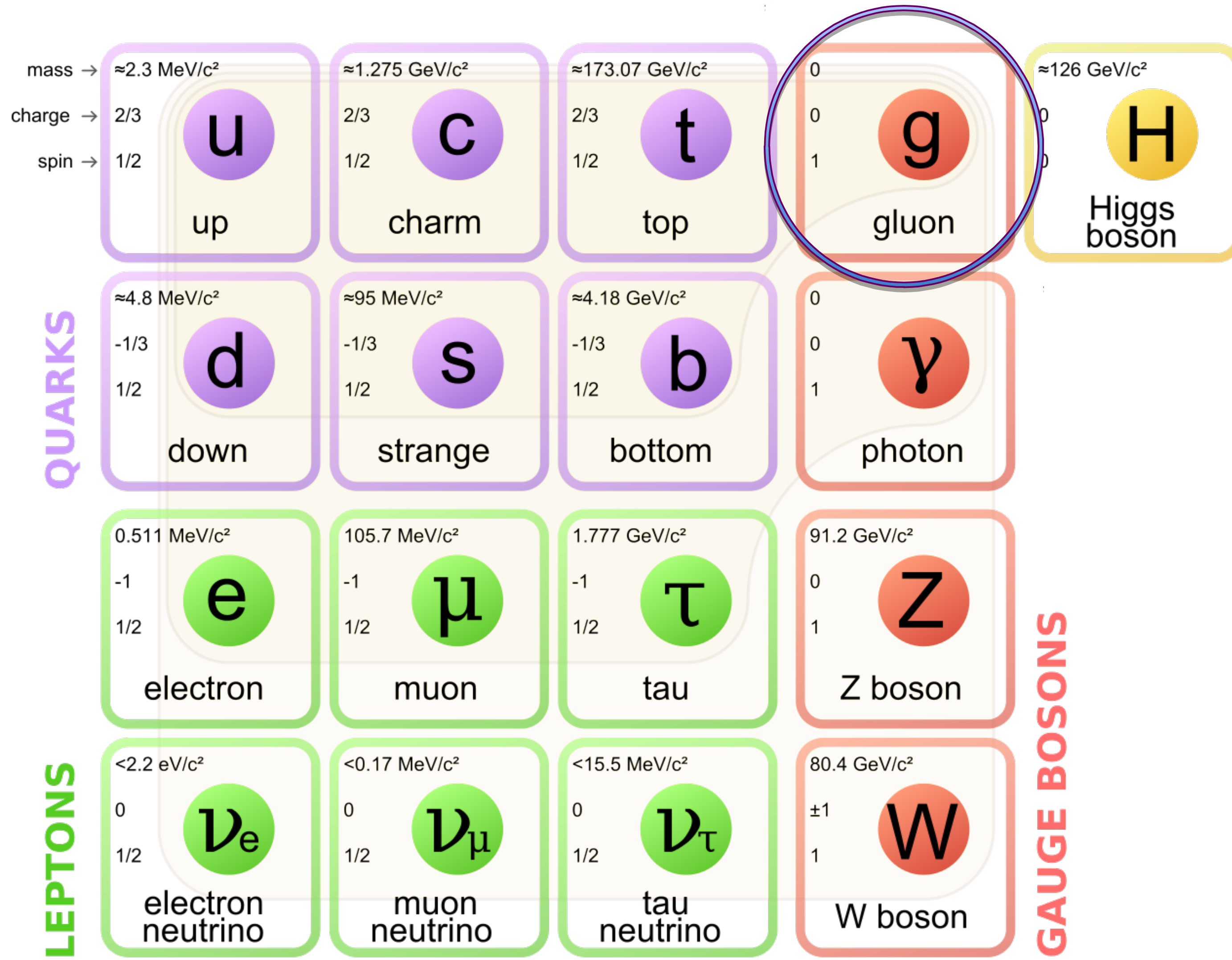
Collider Experiments
Wave Length: 0.0001 fm
(10 GeV + 100 GeV)
Resolution: 0.01-0.001

Science case for an EIC



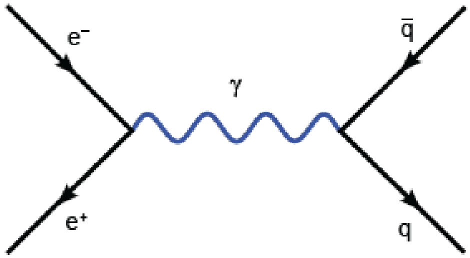
A study of origins in four acts:
the essential mystery, what we know,
what we would like to know, and...how to get there

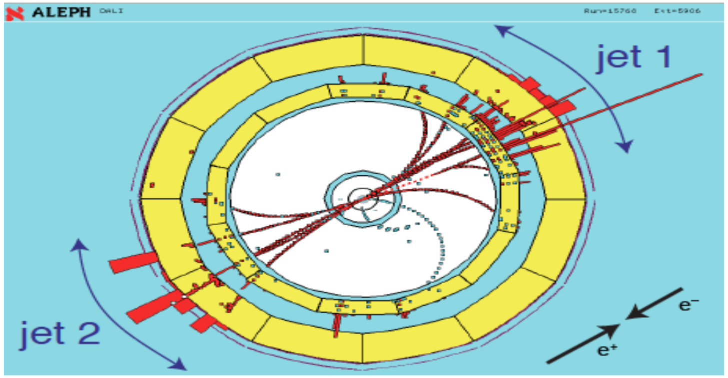
Act 1: The mysterious gluon

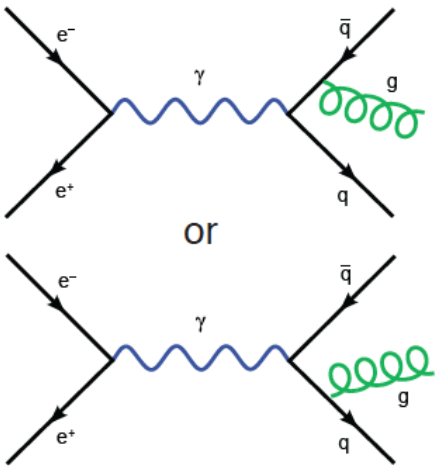


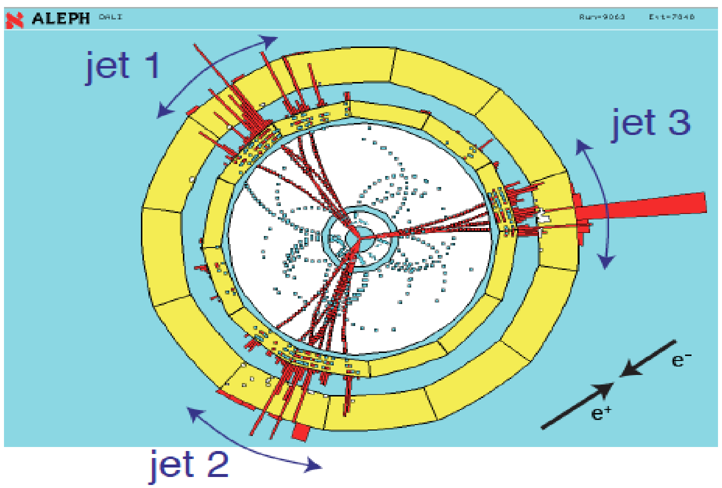
Gluons, the force carriers of the strong force,
are a fundamental building block of the standard model

Discovery of the gluon





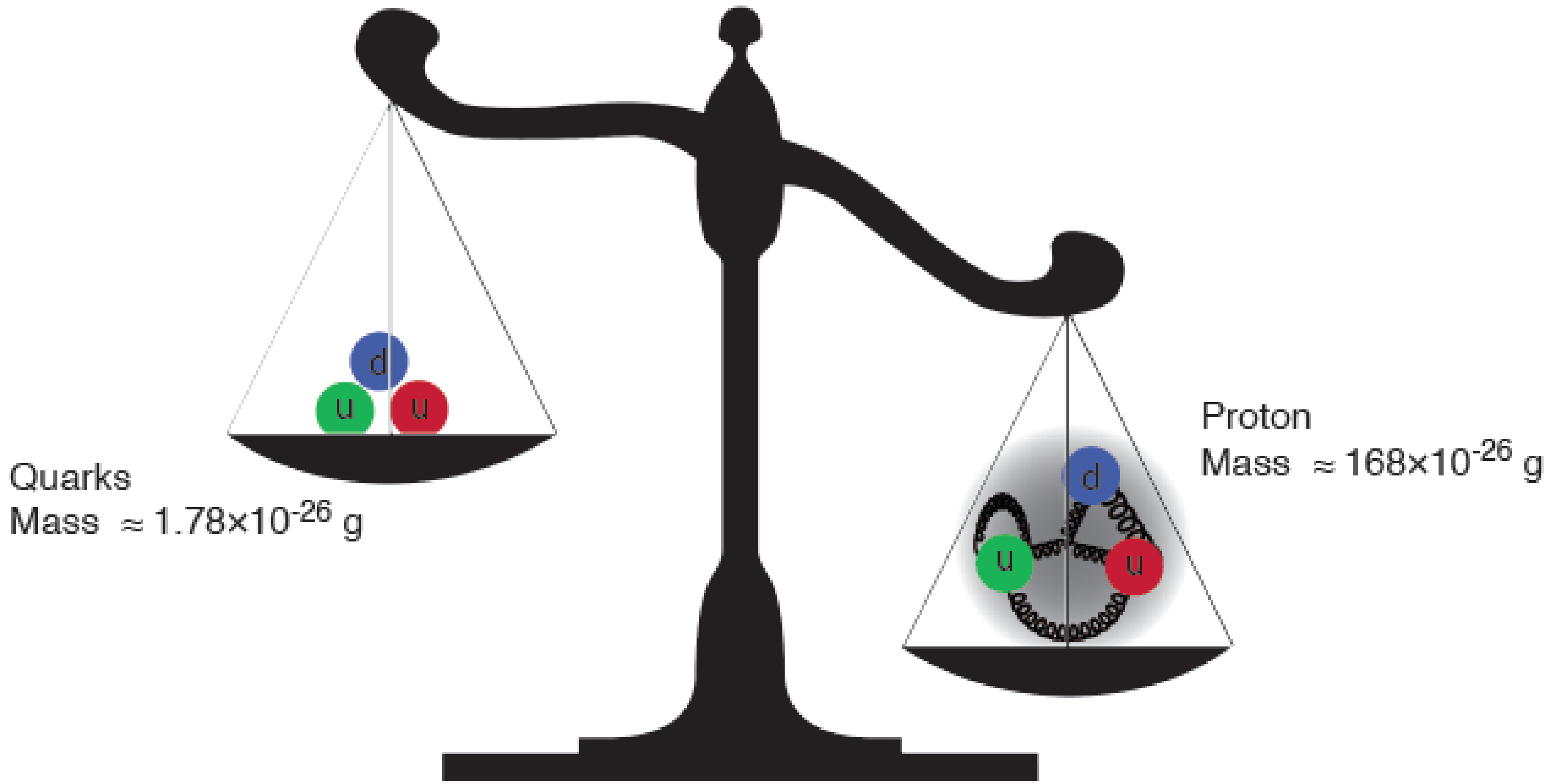




EVIDENCE FOR A SPIN-1 GLUON IN THREE-JET EVENTS

High-energy e^+e^--annihilation events obtained in the TASSO detector at PETRA have been used to determine the spin of the gluon in the reaction $e^+e^- \rightarrow q\bar{q}g$. We analysed angular correlations between the three jet axes. While vector gluons are consistent with the data (55% confidence limit), scalar gluons are disfavoured by 3.8 standard deviations, corresponding to a confidence level of about 10^{-4}. Our conclusion is free of possible biases due to uncertainties in the fragmentation process or in determining the $q\bar{q}g$ kinematics from the observed hadrons.

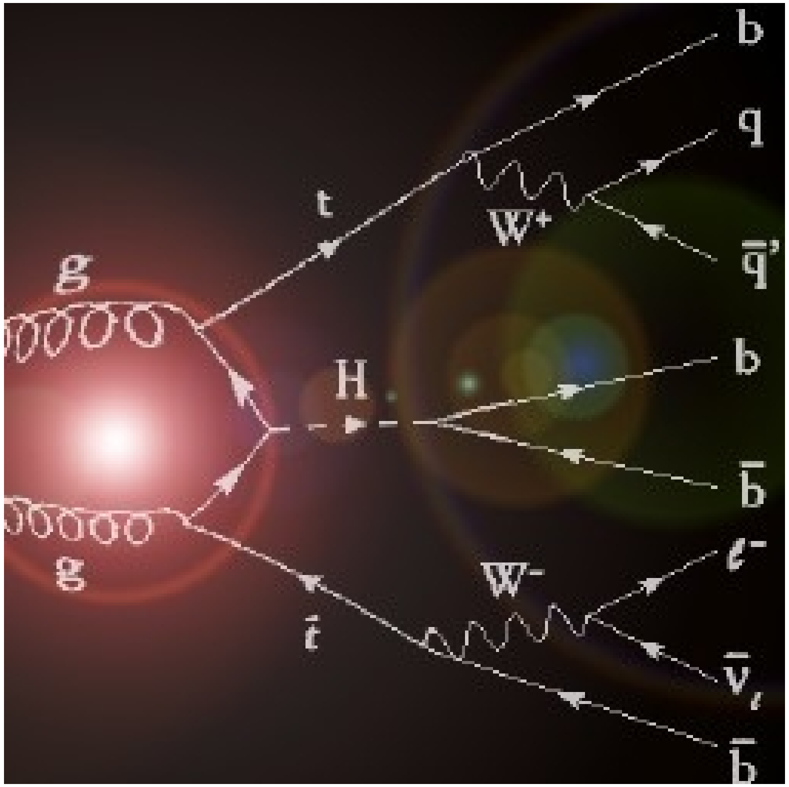
Physics Letters B, 15 December 19



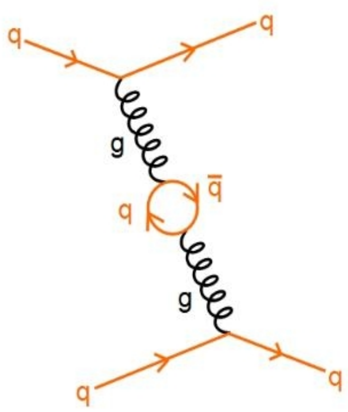
Gluons are massless…yet their dynamics is responsible for (nearly all) the mass of visible matter

The Higgs "God particle" is responsible for quark masses ~ 1-2% of the proton mass.

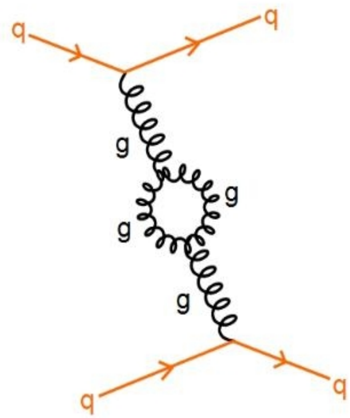
Higgs from Gluon fusion



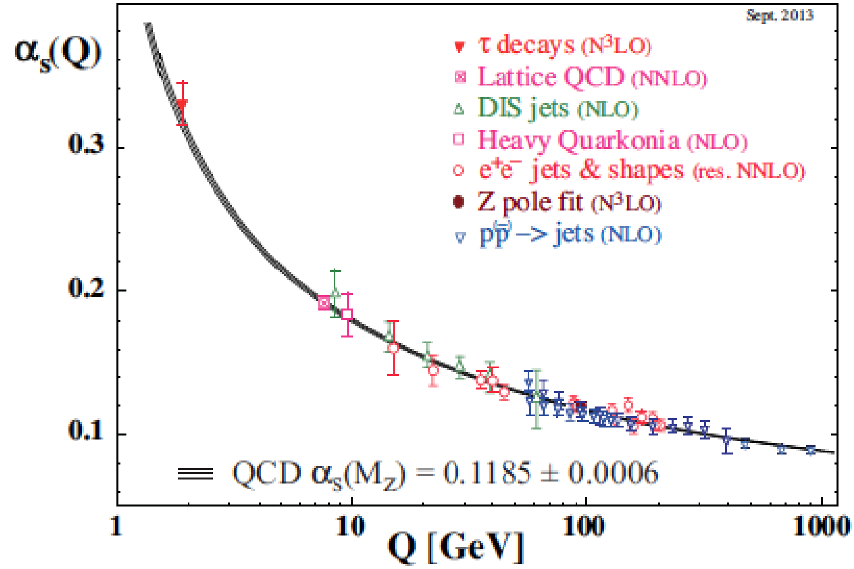
Asymptotic freedom: the role of glue

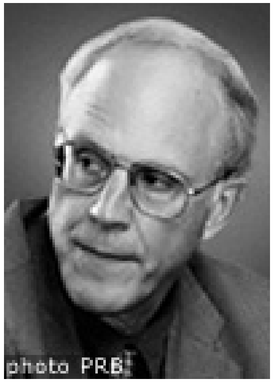


screening correction



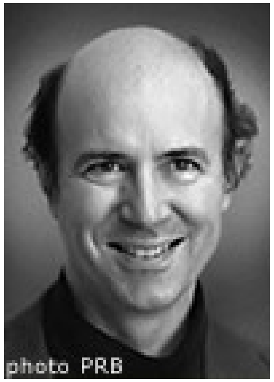
antiscreening correction





David Gross

David Politzer

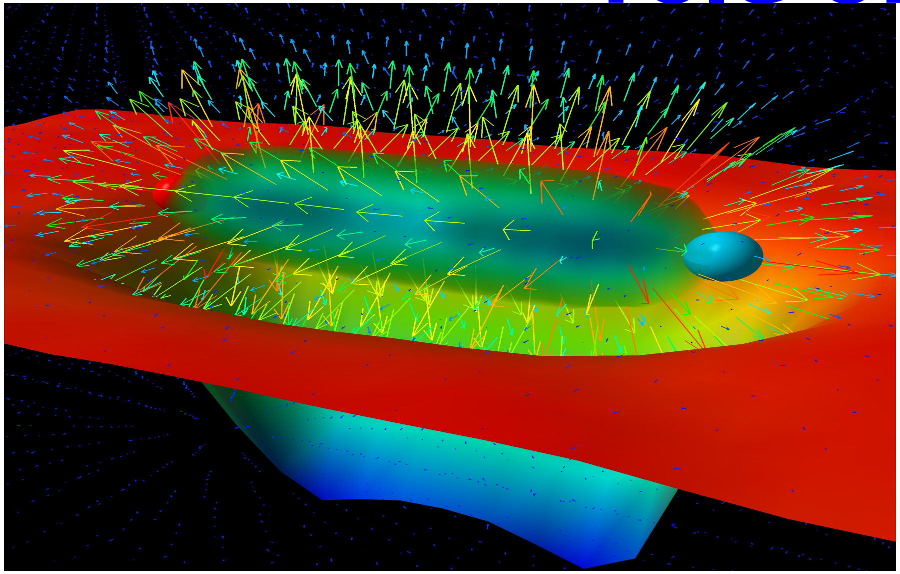


Frank Wilczek

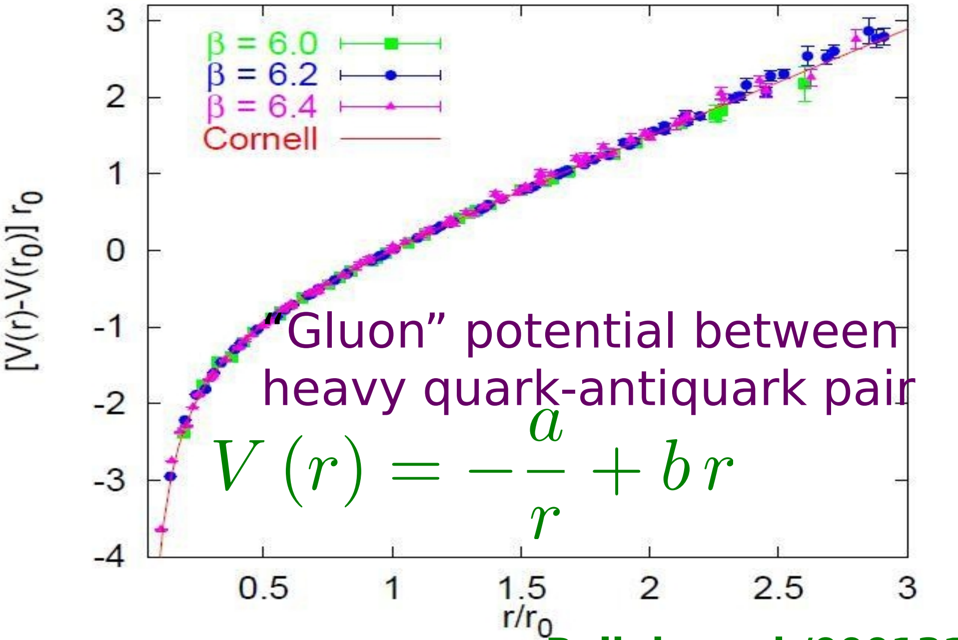
2004

elf-interaction (of color charged) gluons is fundamentally responsible fo
symptotic freedom of quarks and gluons in Quantum Chromodynamics (

Quark (and Gluon) confinement: the role of glue ?

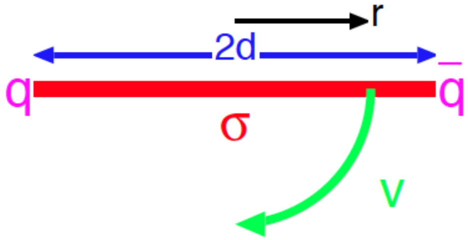


uarks experience force of 16 tons at
istances of ~ 1 Fermi (10^{-15} m)

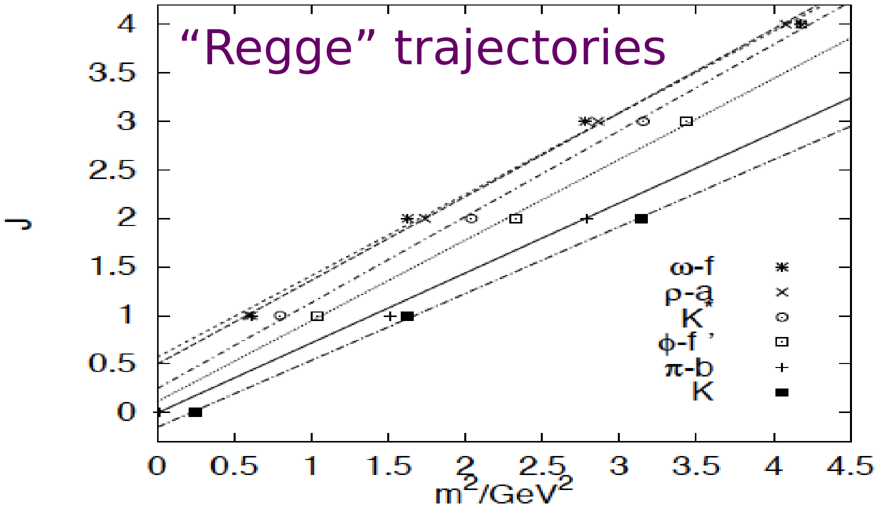


$$V(r) = -\frac{a}{r} + b\,r$$

Bali, hep-ph/000131



Intuitive picture of quark confinement and stringy pictures of mesons



The essential mystery

- (Nearly) all visible matter is made up of quarks and gluons

- But quarks and gluons are not visible

- All strongly interacting matter is an emergent consequence of many-body quark-gluon dynamics.

  Example: Mass from massless gluons and (nearly) massless quarks

- There is an elegance and simplicity to nature's strongest force we do not understand

- Understanding the origins of matter demands we

  develop a *deep and varied knowledge* of this emergent dynamics

Act 2. Quantum Chromodynamics: The Power and the Glory

New Quantum Numbers
The Eightfold Way / Unitary Symmetry
Mesons ~ $\underset{\sim}{8}$ Baryons ~ $\underset{\sim}{8} + \underset{\sim}{10}$
Fundamental Representation Absent

The Quarks: Fractional Charge Triplets
Are They Real? (Constituents of Hadrons)
Are They Just a Mathematical Shorthand?
Relationship to Weak Currents?

Thinking About Real Quarks –
Spin/Statistics Problem → Parafermions
Color (New SU(3)!) – More Shorthand?
Still No Dynamics; Confinement a Mystery

Asymptotic Freedom → Quarks = Partons
Promotion of Color to the Essence of
Strong Dynamics; Gluons a Color $\underset{\sim}{8}$
QCD the Theory of Strong Interactions

From Gell-Mann's 8-fold way to QCD: A lepidopteral metaphor

Quantum Chromodynamics (QCD)

QCD - "nearly perfect" fundamental quantum theory of quark and gluon fields **F.Wilczek, hep-ph/9907340**

- Theory is rich in symmetries: **"Symmetries dictate interactions" – C.N Yang**

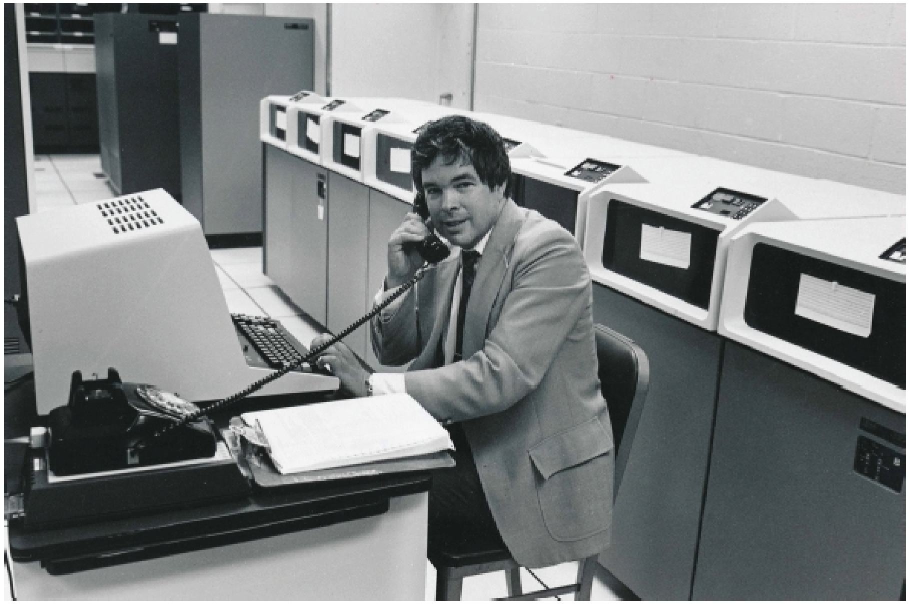
$$\underbrace{SU(3)_c}_{\textbf{i}} \times \underbrace{SU(3)_L \times SU(3)_R}_{\textbf{ii}} \times \underbrace{U(1)_A \times U(1)_B}_{\textbf{iii}}$$

i) Gauge "color" symmetry: unbroken but confined
ii) Global "chiral" symmetry: exact for massless quarks
iii) Baryon number and axial charge (m=0) are conserved
iv) Scale invariance of quark (m=0) and gluon fields
v) Discrete C,P & T symmetries

- Chiral, Axial, Scale and (in principle) P &T broken by vacuum/quantum effects - "emergent" phenomena

- Inherent in QCD are the deepest aspects of relativistic Quantum Field Theories (confinement, asymptotic freedom, anomalies, spontaneous breaking of chiral symmetry)

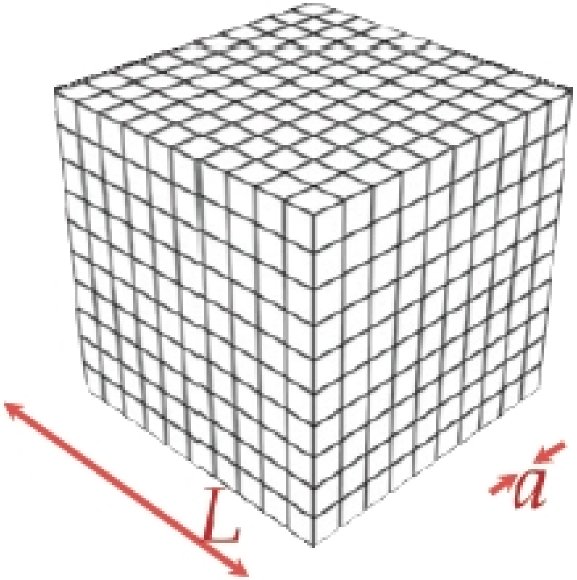
Numerical realization: Lattice QCD



Kenneth G. Wilson

(1982)

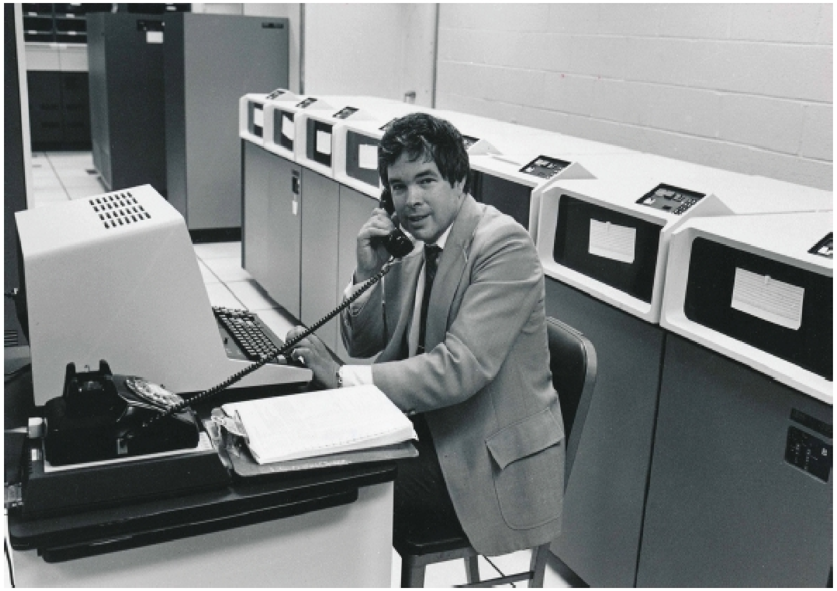
CUBIC LATTICE



attice regularization (UV&IR) of QCD

rst principles treatment of static
roperties of QCD: masses, moments,
hermodynamics at finite T (& μ_B ?)

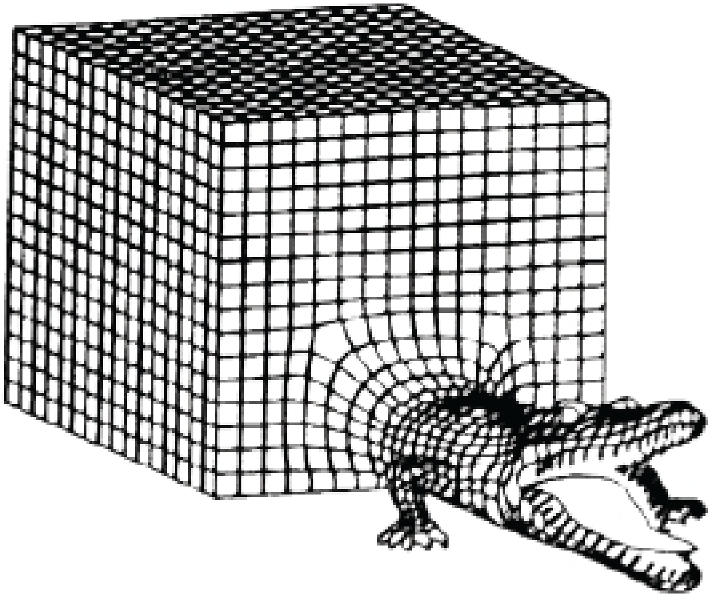
Numerical realization: Lattice QCD



Kenneth G. Wilson

(1982)

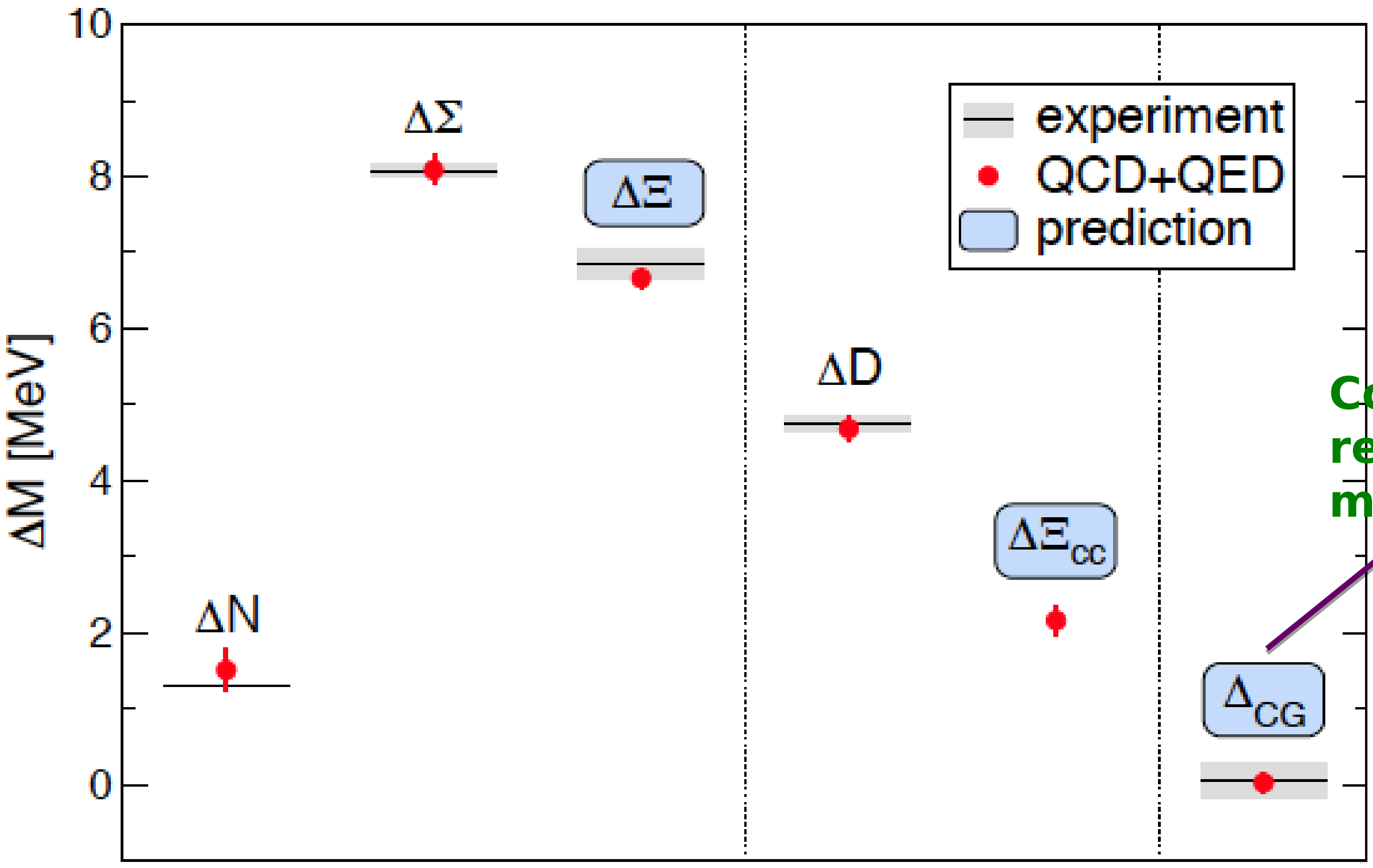
CUBIC LATTICE



Formidable computational problem

Very challenging for *dynamical processes*...

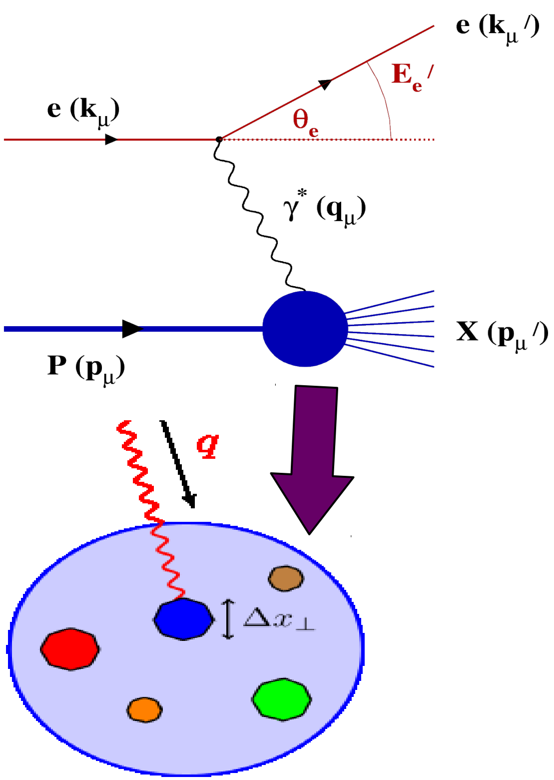
Precision QCD on the lattice



Coleman-Glashow relation among mass splittings

Budapest-Marseille-Wuppertal (BMW) Coll., arXiv:1406.4

The deeply inelastic scattering (DIS) femtoscope



$$Q^2 = -q^2 = -(k_\mu - k_\mu')^2$$

$$Q^2 = 4E_e E_e' \sin^2\left(\frac{\theta_e'}{2}\right)$$

Measure of resolution power

$$y = \frac{pq}{pk} = 1 - \frac{E_e'}{E_e}\cos^2\left(\frac{\theta_e'}{2}\right)$$

Measure of inelasticity

$$x = \frac{Q^2}{2pq} = \frac{Q^2}{sy}$$

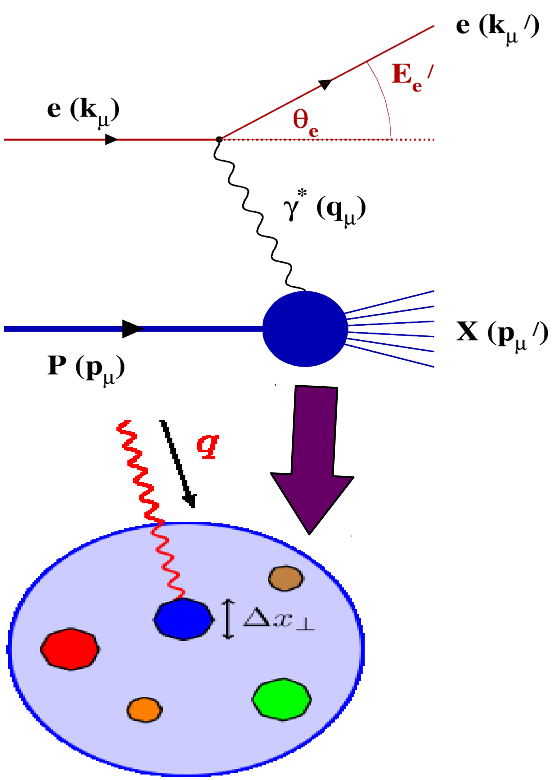
Bjorken variable: Measure of momentum fraction of struck quark

$$\frac{d^2\sigma^{eh\to eX}}{dx dQ^2} = \frac{4\pi\alpha_{em}^2}{xQ^4}\left[\left(1 - y + \frac{y^2}{2}\right)F_2(x,Q^2) - \frac{y^2}{2}F_L(x,Q^2)\right]$$

quark+anti-quark momentum distributions

gluon momentum distribution

The deeply inelastic scattering (DIS) femtoscope



$$Q^2 = -q^2 = -(k_\mu - k'_\mu)^2$$

$$Q^2 = 4 E_e E'_e \sin^2\left(\frac{\theta'_e}{2}\right)$$

Measure of resolution power

$$y = \frac{pq}{pk} = 1 - \frac{E'_e}{E_e}\cos^2\left(\frac{\theta'_e}{2}\right)$$

Measure of inelasticity

$$x = \frac{Q^2}{2\,pq} = \frac{Q^2}{sy}$$

Bjorken variable: Measure of momentum fraction of struck quark

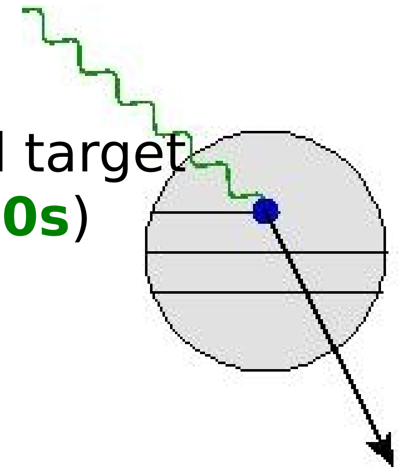
$$\frac{d^2\sigma^{eh\to eX}}{dx\,dQ^2} = \frac{4\pi\alpha_{em}^2}{xQ^4}\left[\left(1 - y + \frac{y^2}{2}\right)F_2(x,Q^2) - \frac{y^2}{2}F_L(x,Q^2)\right]$$

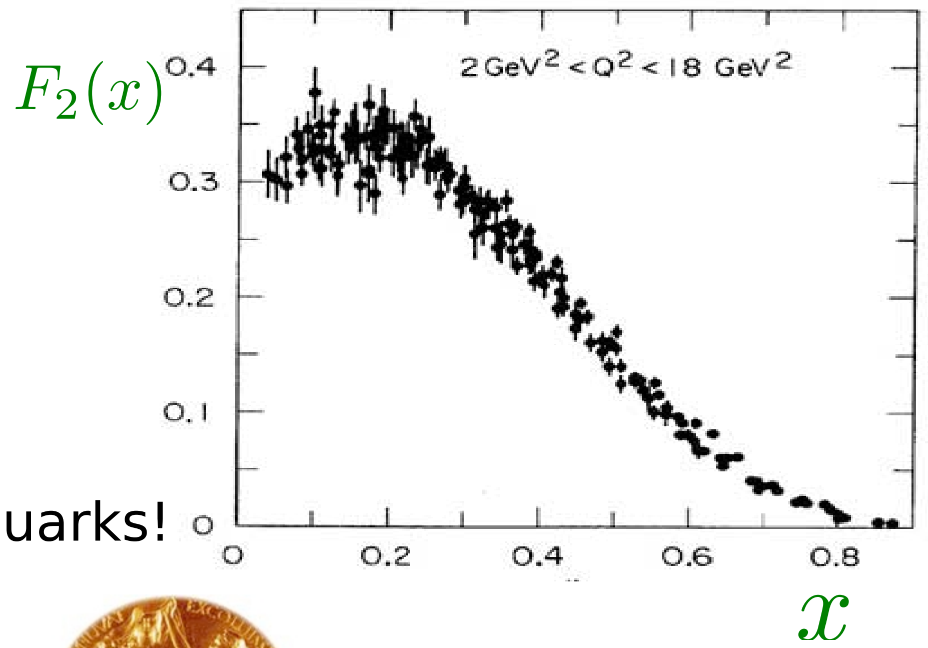
quark+anti-quark momentum distributions

gluon momentum distribution

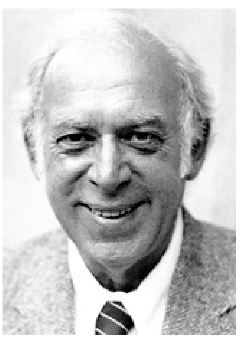
The deeply inelastic scattering (DIS) femtoscope

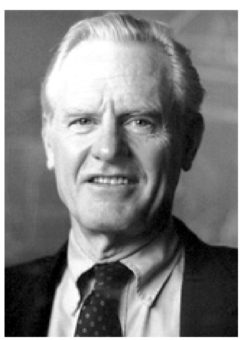
From SLAC fixed target DIS… (**late 1960s**)

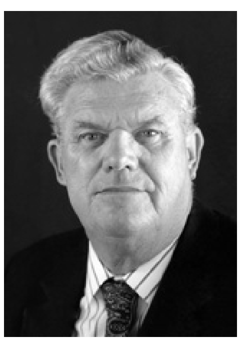




Discovery of quasi-free point-like quarks!





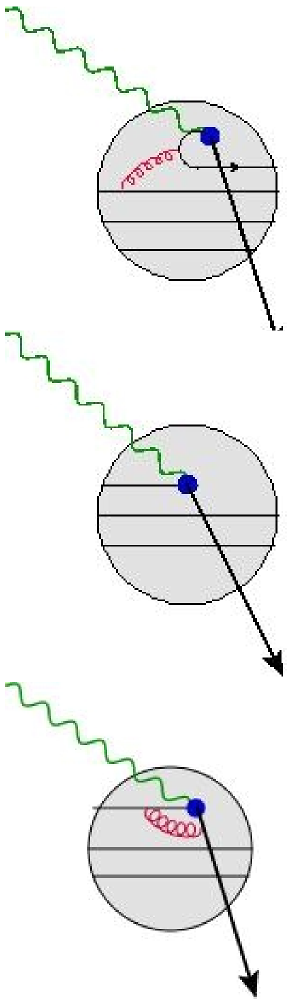


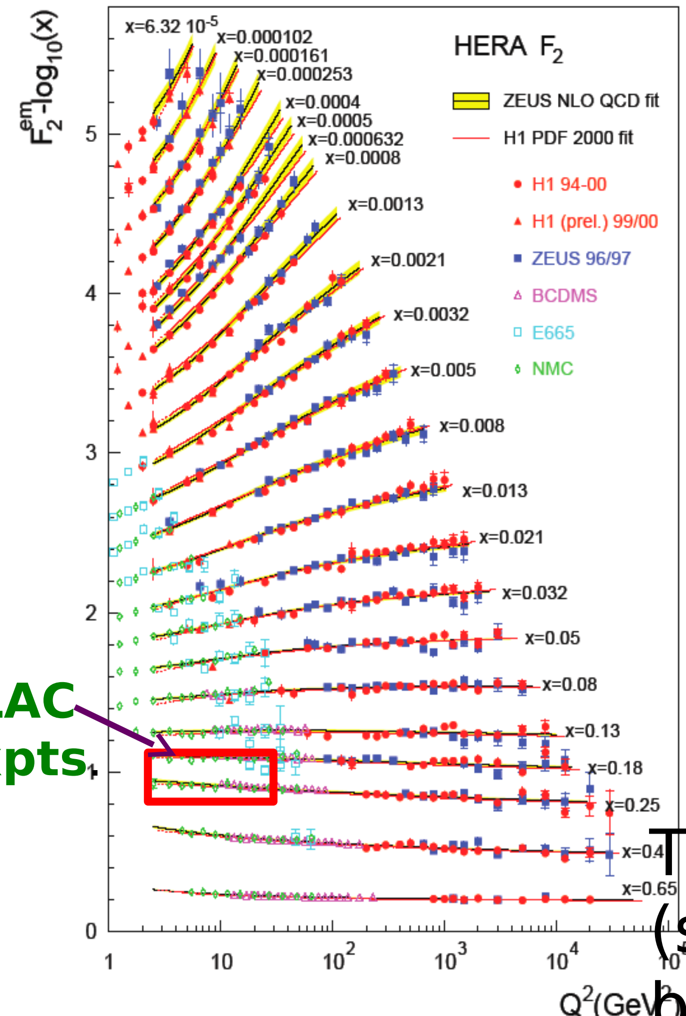
Friedman **Kendall** **Taylor**

(**1990**)

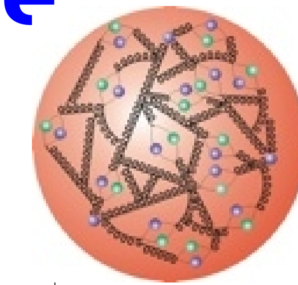
The deeply inelastic scattering (DIS) femtoscope

...to the HERA DIS collider (1990s)

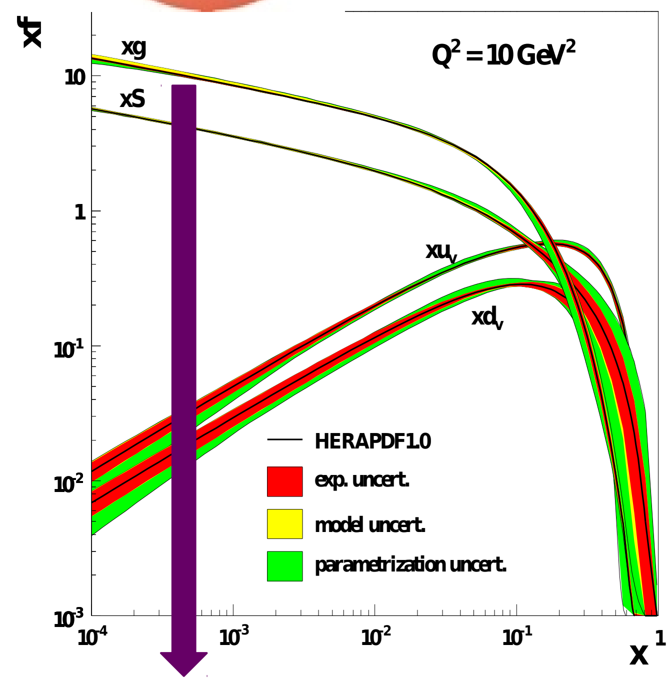




SLAC expts



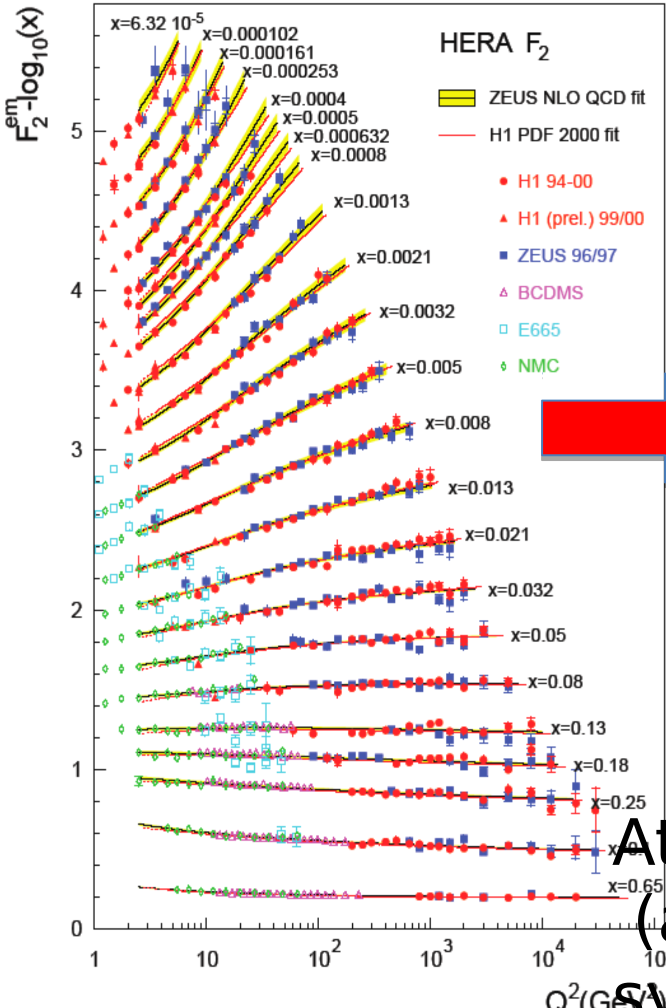
Gluons and “sea” quarks



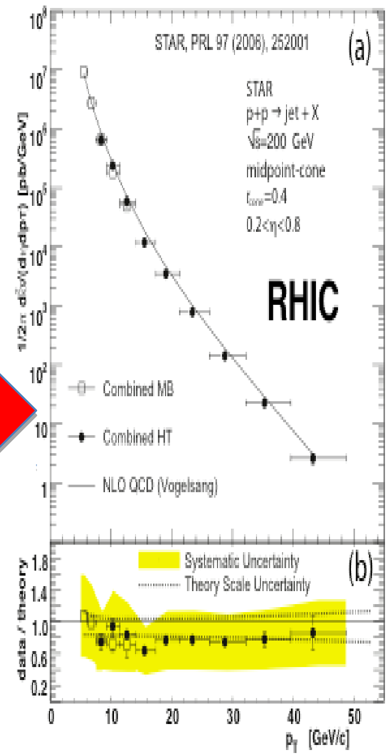
The proton at high energie
(small x) is dominated
by glue!

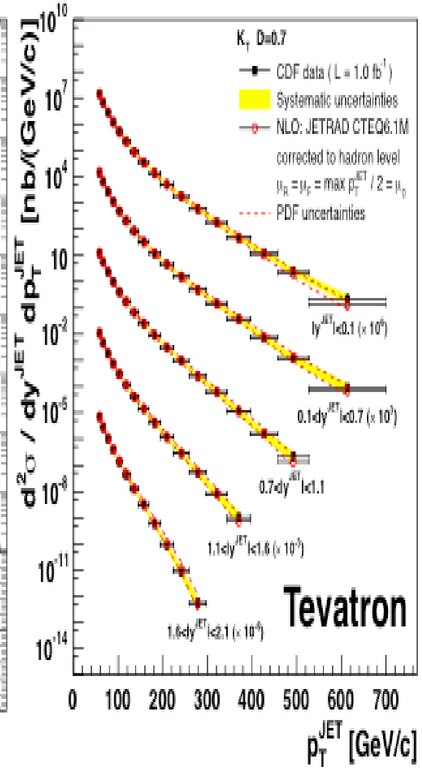
Perturbative QCD: now benchmark for new physics

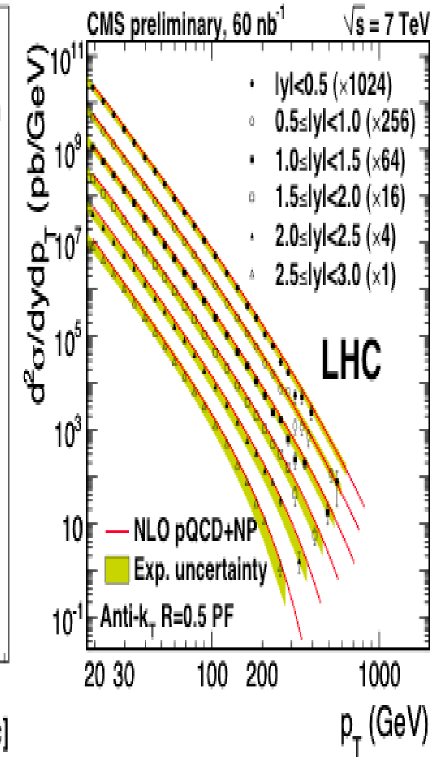
**ructure functions measured at
ERA electron-proton collider**



**Jet cross-sections: proton-proton collisions (RHIC
and proton-antiproton collisions at Fermilab**







At large momenta, the weak QCD couplin
(asymptotic freedom!) enables
systematic computations

The study of the strong interactions is now a mature subject - we have a theory of the fundamentals* (QCD) that is correct* and complete*.

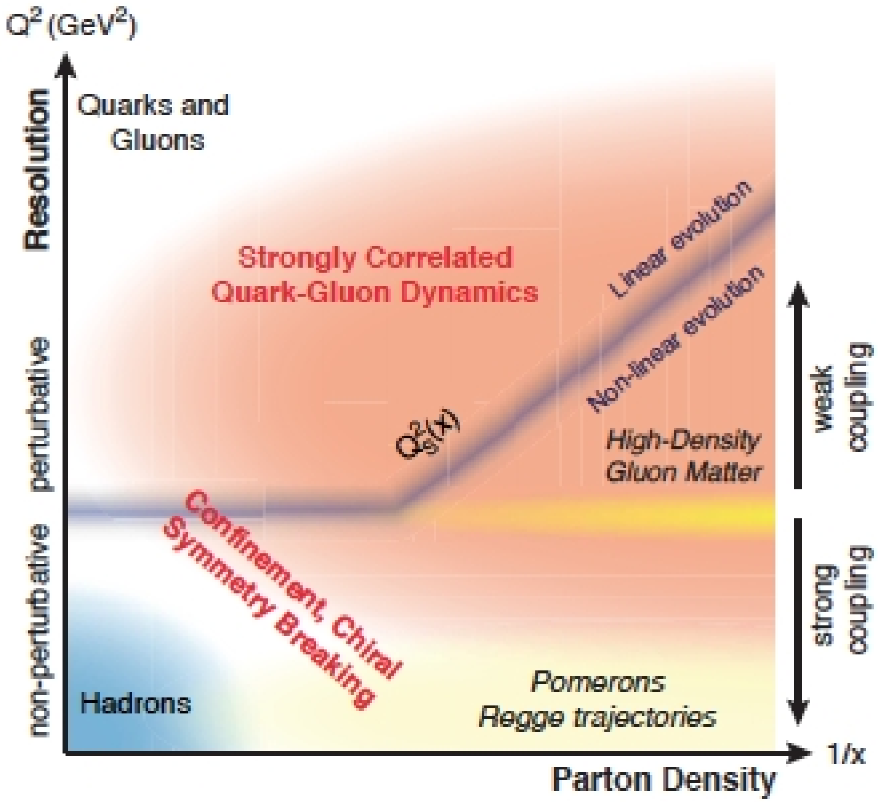
In that sense, it is akin to atomic physics, condensed matter physics, or chemistry. The important questions involve emergent phenomena and “applications”.

F. Wilczek , “Quarks (and Glue) at the Frontiers of Knowledge”
Talk at Quark Matter 2014

Are we done ?

Act 3. Frontiers of our ignorance

Scattering in the strong interactions



arXiv:1708.01527

Perturbative QCD describes only a small part of the total cross-section

Lattice QCD is of very limited utility in describing scattering

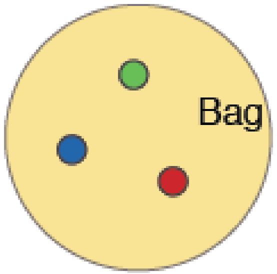
Effective theories: how do quark and gluon degrees organize themselv
to describe the bulk of the cross-section ?

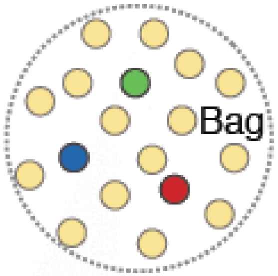
What does the proton look like ?

Static pictures | **Glue dominated boosted proton**

Bag model:

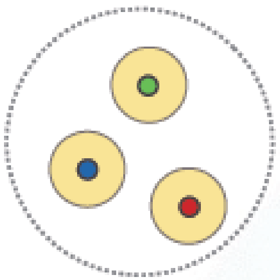
- Field energy distribution is wider than the distribution of fast moving light quarks

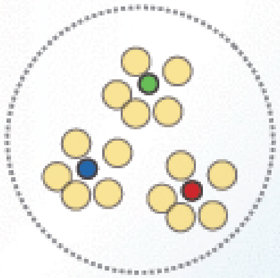




Constituent quark model:

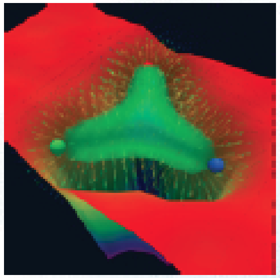
- Gluons and sea quarks "hide" inside massive quarks
- Sea parton distribution similar to valence quark distribution

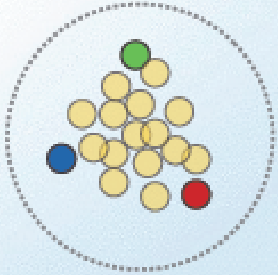




Lattice gauge theory:

- (with slow moving quarks)
- gluons are more concentrated than quarks

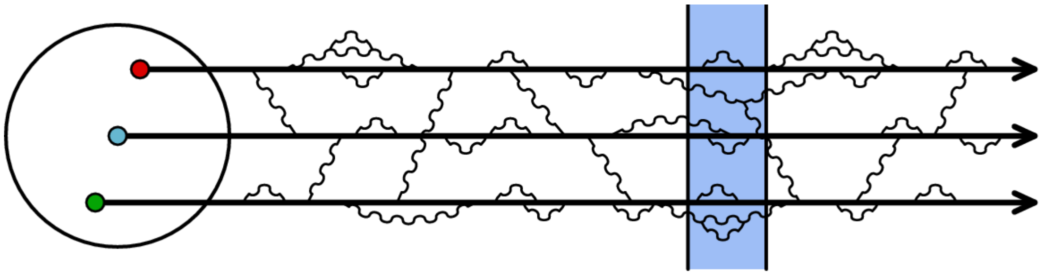




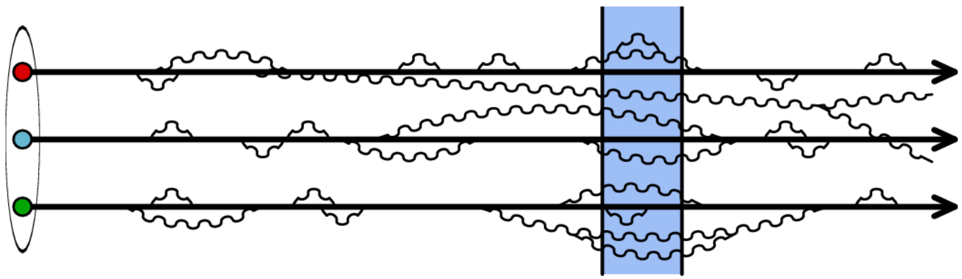
The boosted proton

QCD, the proton is made up of quanta that fluctuate in and out of existe

Low Energy or large x



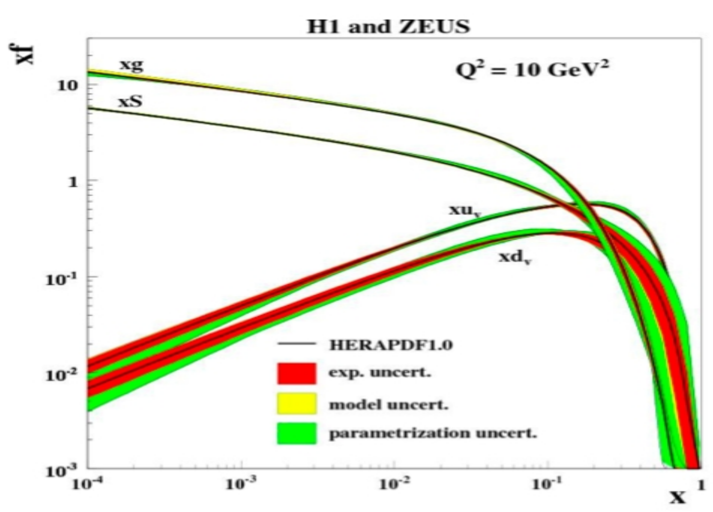
High Energy or small x



Wee parton fluctuations time dilated on strong interaction time scales

Long lived gluons can radiate further small x gluons…

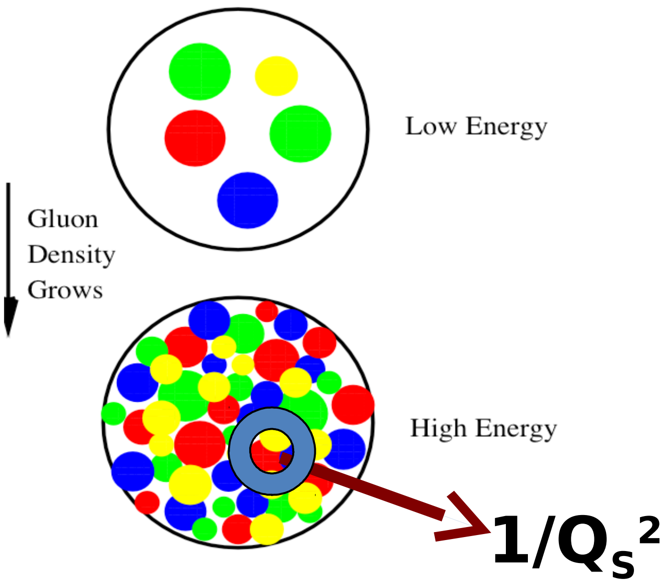
Is the proton a runaway popcorn machine at high



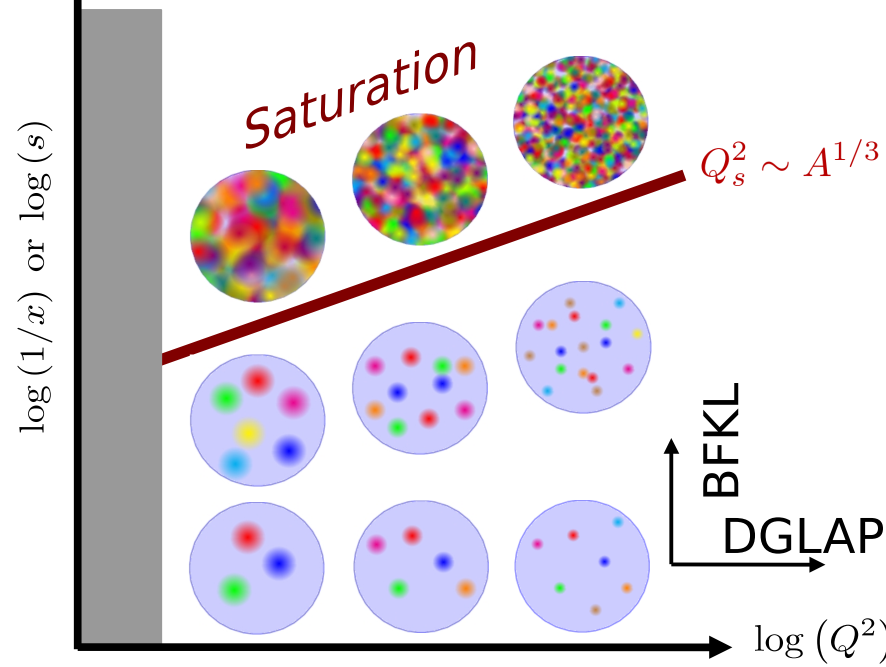
The boosted proton

Boosted protons: classical coherence from quantum fluctuations

nergent dynamical saturation
ale grows with energy

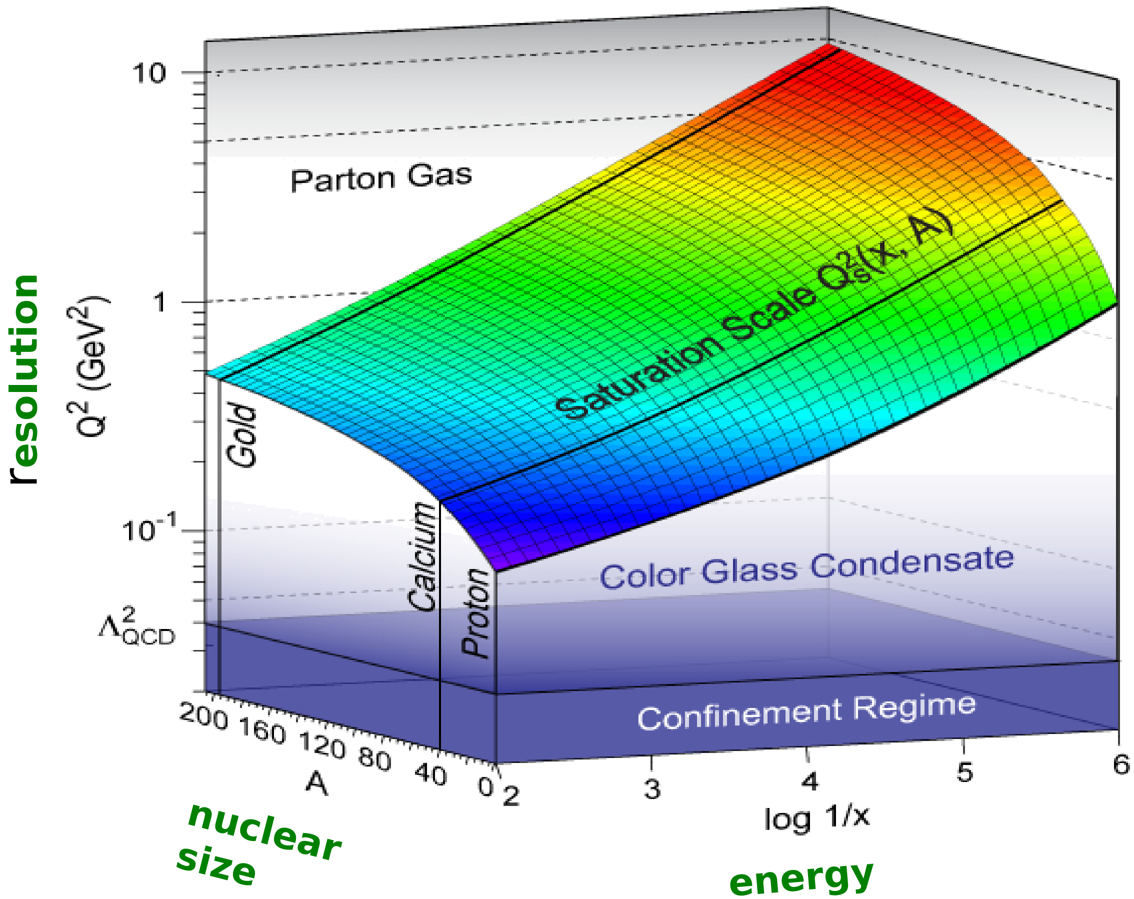


Powerful ``Wilsonian" RG equati
describe evolution in this landsc

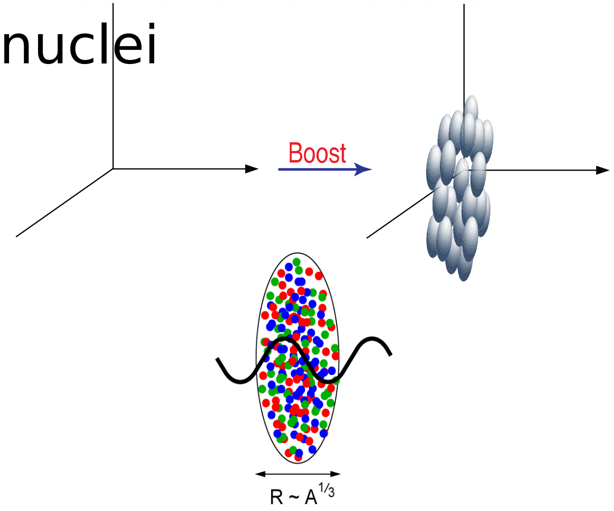


- How does this happen? What are the right degrees of freedom?
- How do correlation functions of these evolve?
- Is there a universal fixed point for RG evolution? Does the coupling run with Q_s^2?

Many-body high energy QCD: a new frontier



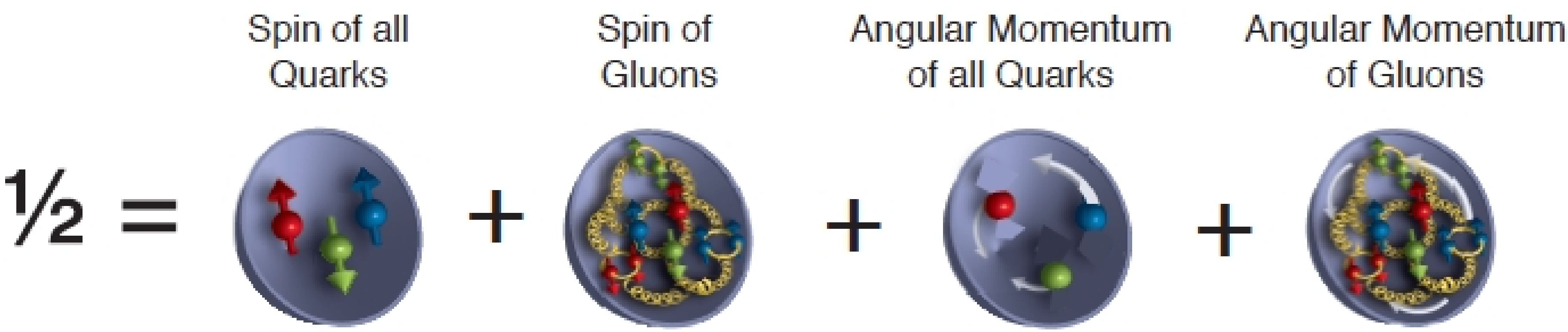
$A^{1/3}$ enhancement of saturation scale in nuclei



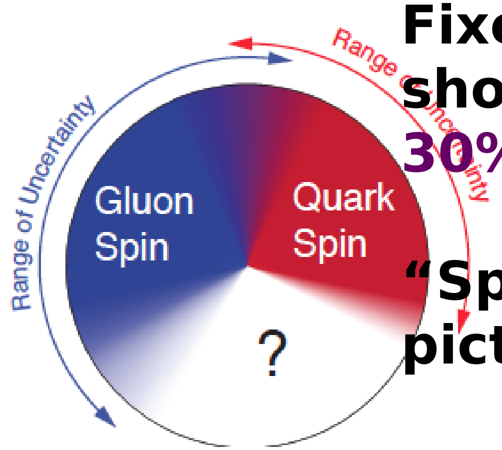
$$Q^2_{S,A} \approx A^{1/3} Q^2_{S,p}$$

Dynamically generated semi-hard "saturation scale" opens window for
systematic weak coupling study of non-perturbative dynamics

The proton’s spin puzzle



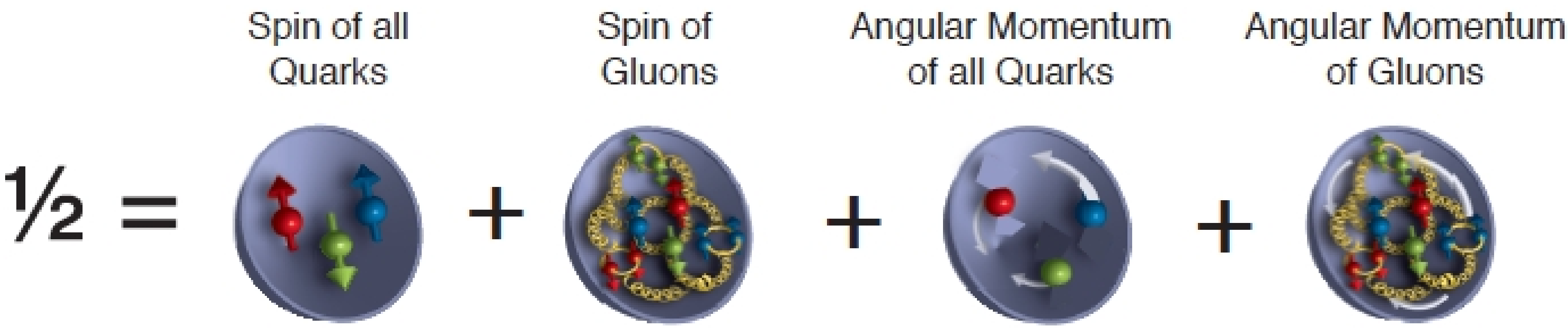
Approximate Current Contributions to the Proton Spin

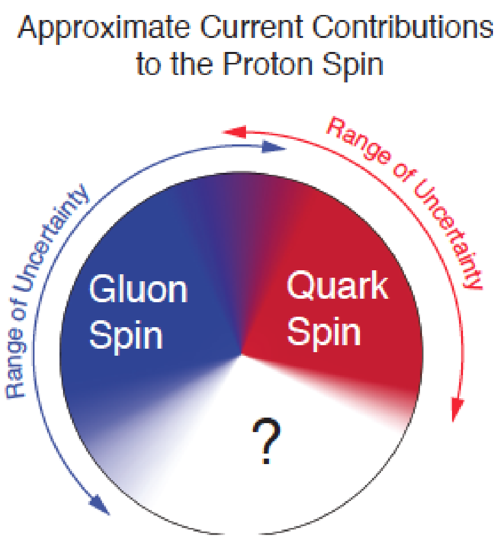


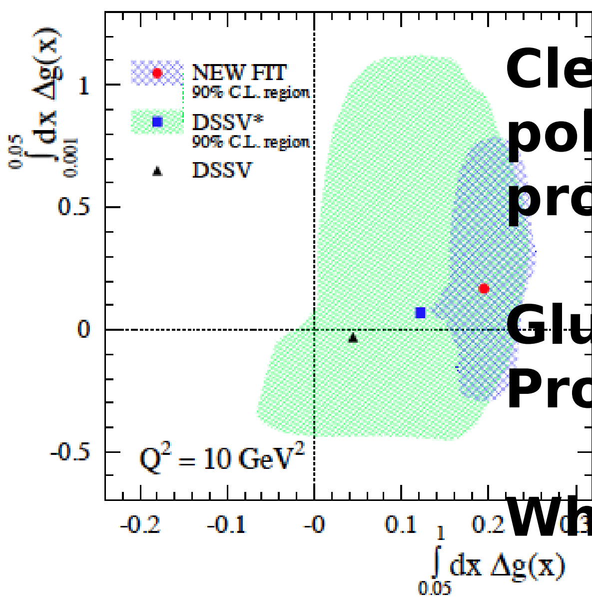
Fixed target deep inelastic scattering experiments showed that quarks carry only about 30% of the proton’s spin

“Spin crisis” – a failure of the quark model picture of three relativistic “constituent” quarks

The proton’s spin puzzle







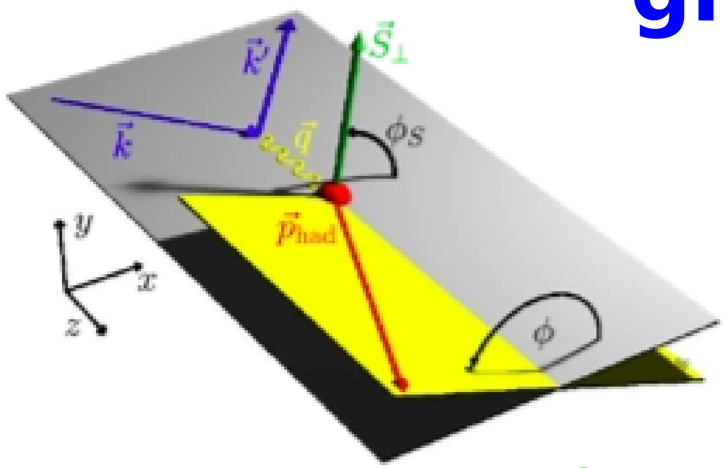
Clear evidence for gluon polarization from RHIC polar proton-proton data

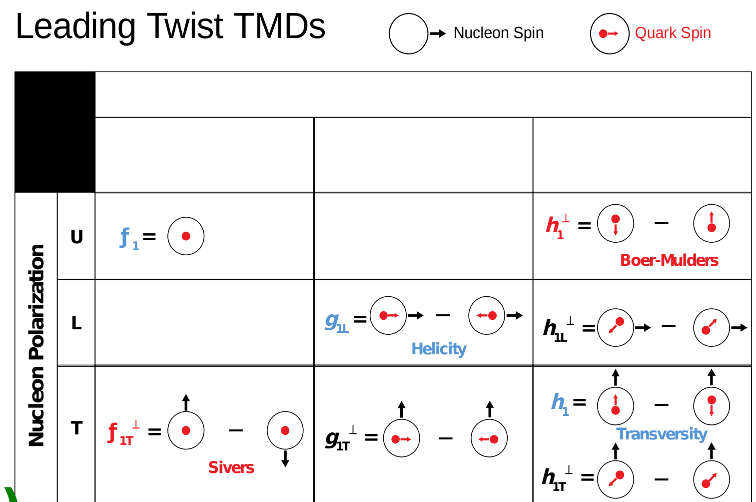
Gluons carry ~ 20-40 % of th Proton spin

Where’s the rest ?

D. De Florian, R. Sassot, M. Stratmann, W. Vogelsang, PRL 113 (2014)

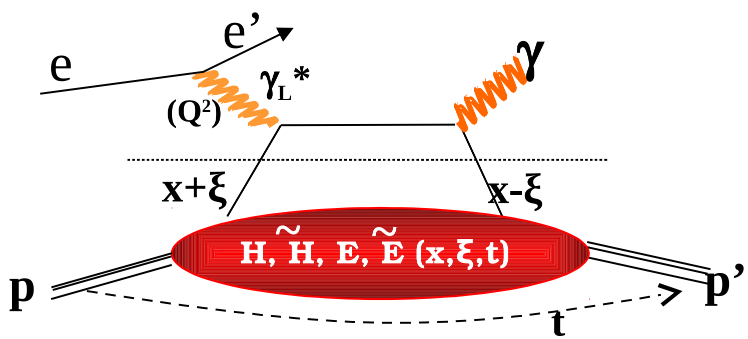
Imaging distributions of quarks and gluons ?

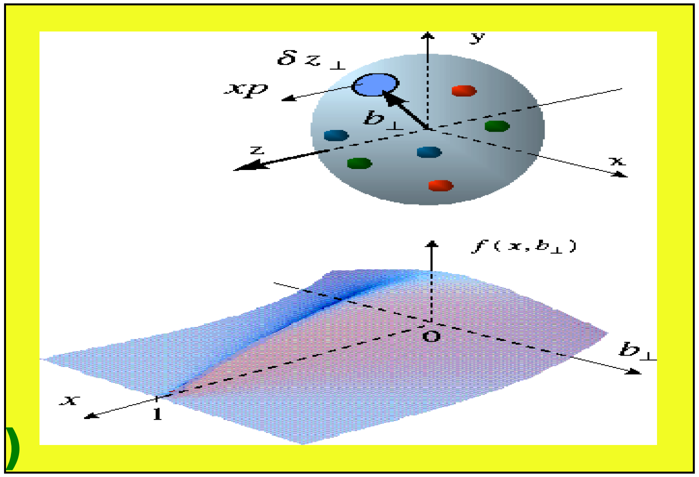




Similar for gluons

Transverse momentum dependent (TMD) distributions

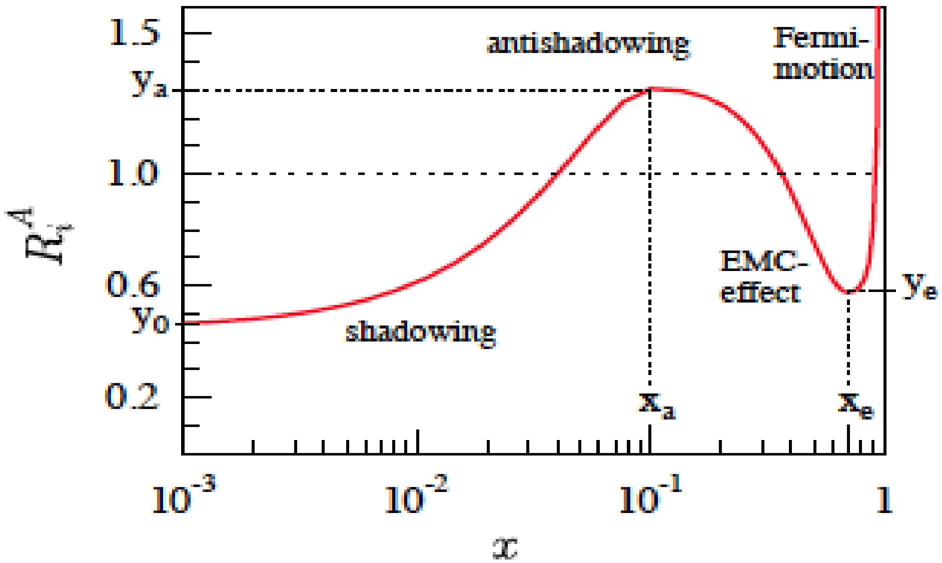


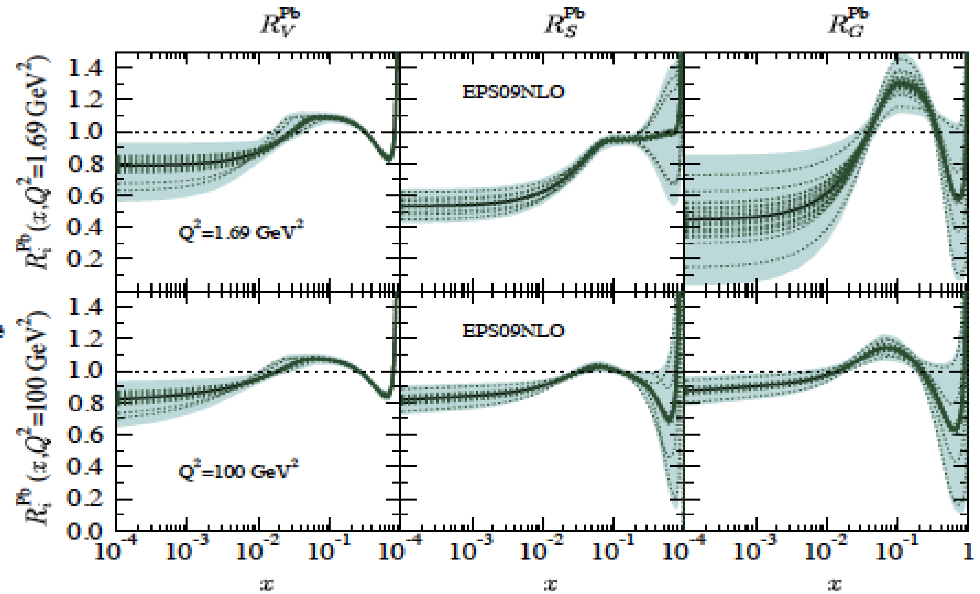


Generalized parton distributions (GPDs)

- Differential images correlating the spin, momentum and spatial distributions will provide fundamental insight into quark-gluon dynamics in nucleon structure

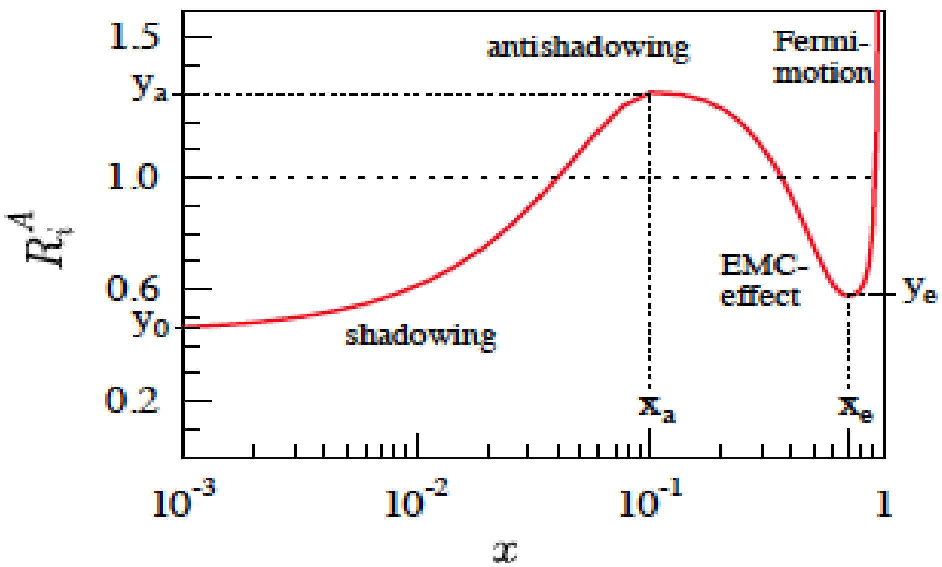
Nuclear glue: terra incognita

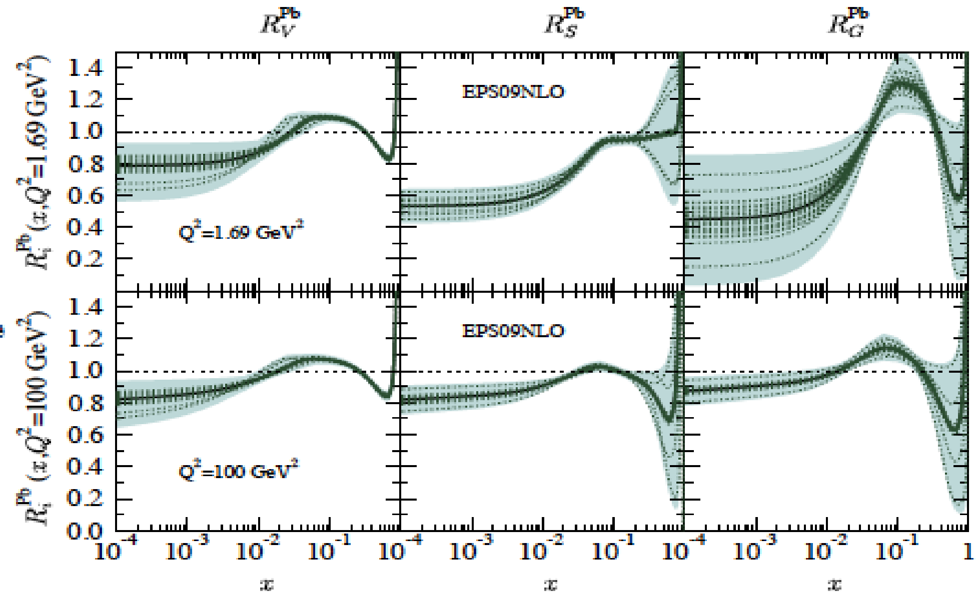




Quark (Gluon) distributions in nuclei- ***not simple superpositions***
of nucleon Quark (Gluon) distributions

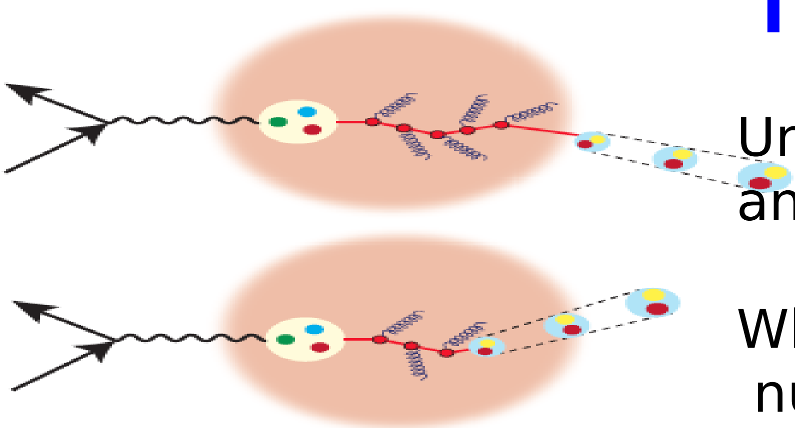
Nuclear glue: terra incognita





Quark (Gluon) distributions in nuclei- ***not simple superpositions*** **of nucleon Quark (Gluon) distributions**

The nucleus as a QCD laborator



Understand how quarks and gluons fragme and hadronize in and out of the medium

What is the quark-gluon nature of nuclear short-range correlations ?

Act 4. EIC: the ultimate QCD machine?

e world's **first** polarized electron-polarized proton col

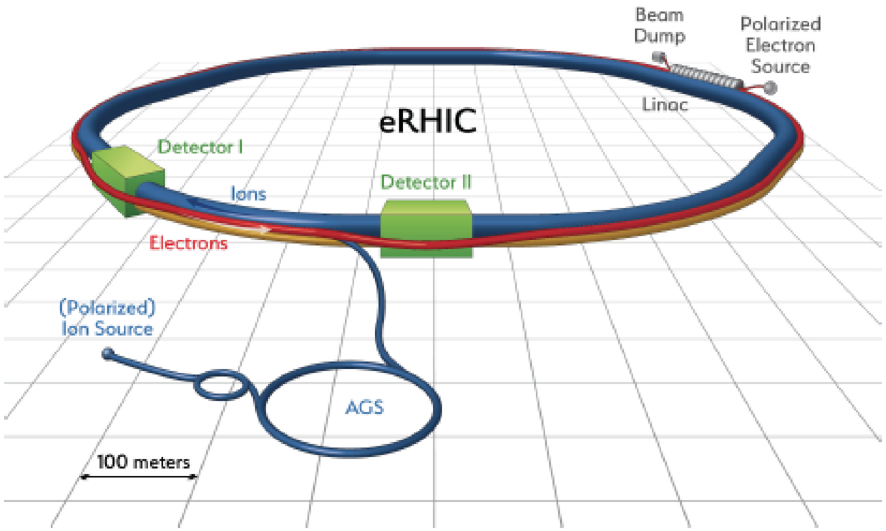
e world's **first** electron-heavy ion collider

minosities: a hundred to up to a thousand times HERA

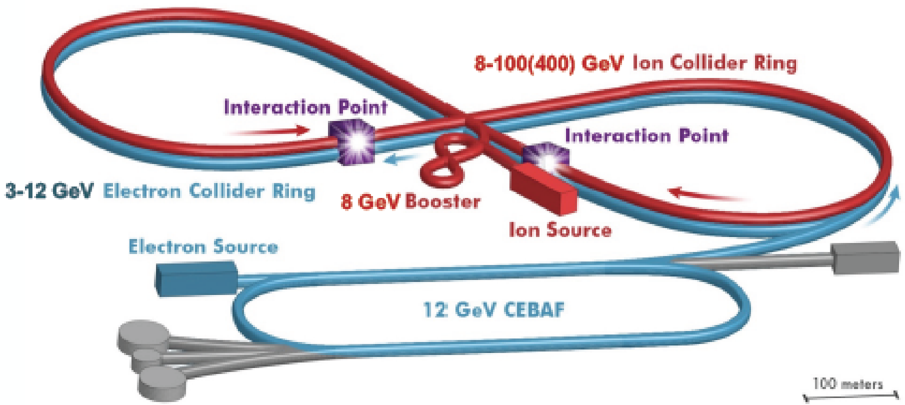
ne resolution inside proton down to 10^{-18} meters

Electron-Ion Colliders: accelerator desi

- **eRHIC (BNL)**
  - Add e Rings to RHIC facility: Ring-Ring (alt. recirculating Linac-Ring)
  - Electrons up to 18 GeV
  - Protons up to 275 GeV
  - $\sqrt{s}$=30-140 $\sqrt{(Z/A)}$ GeV
  - L ≈ 1×10^{34} $cm^{-2}s^{-1}$ at $\sqrt{s}$=105 GeV



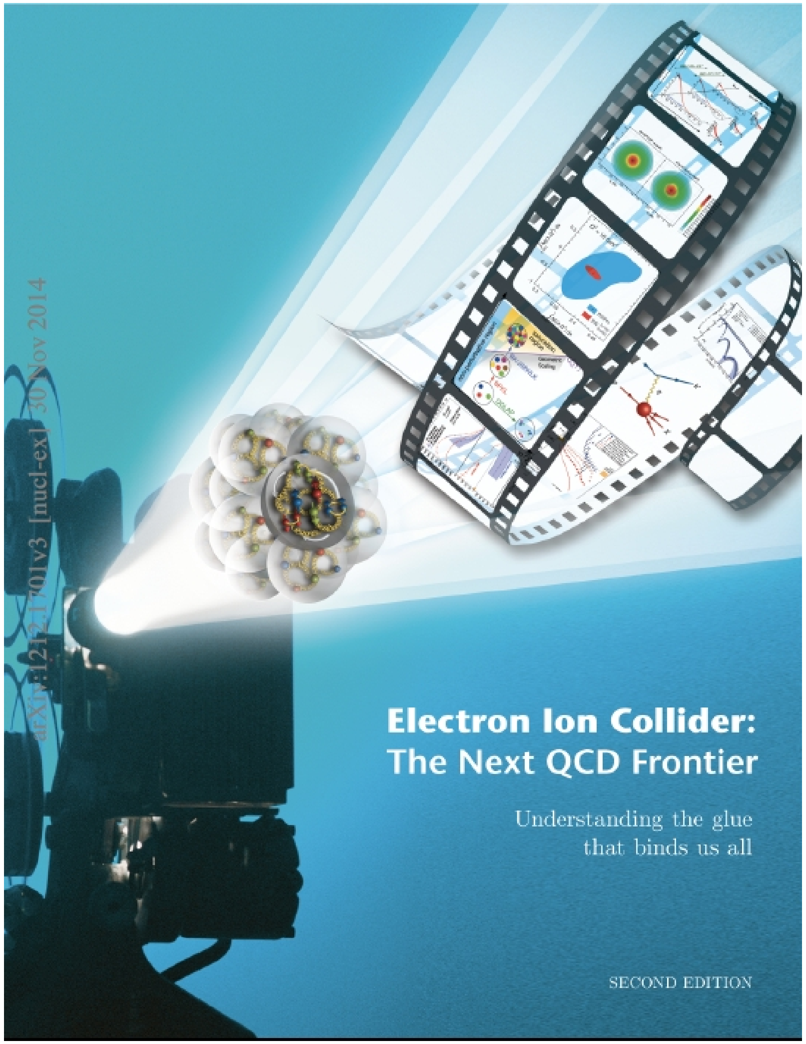
- **JLEIC (JLab)**
  - Figure-8 Ring-Ring Collider, use of CEBAF as injector
  - Electrons 3-10 GeV
  - Protons 20-100 GeV
  - e+A up to $\sqrt{s}$=40 GeV/u
  - e+p up to $\sqrt{s}$= 64 GeV
  - L ≈ 2×10^{34} cm^{-2} s^{-1} at $\sqrt{s}$=45 GeV



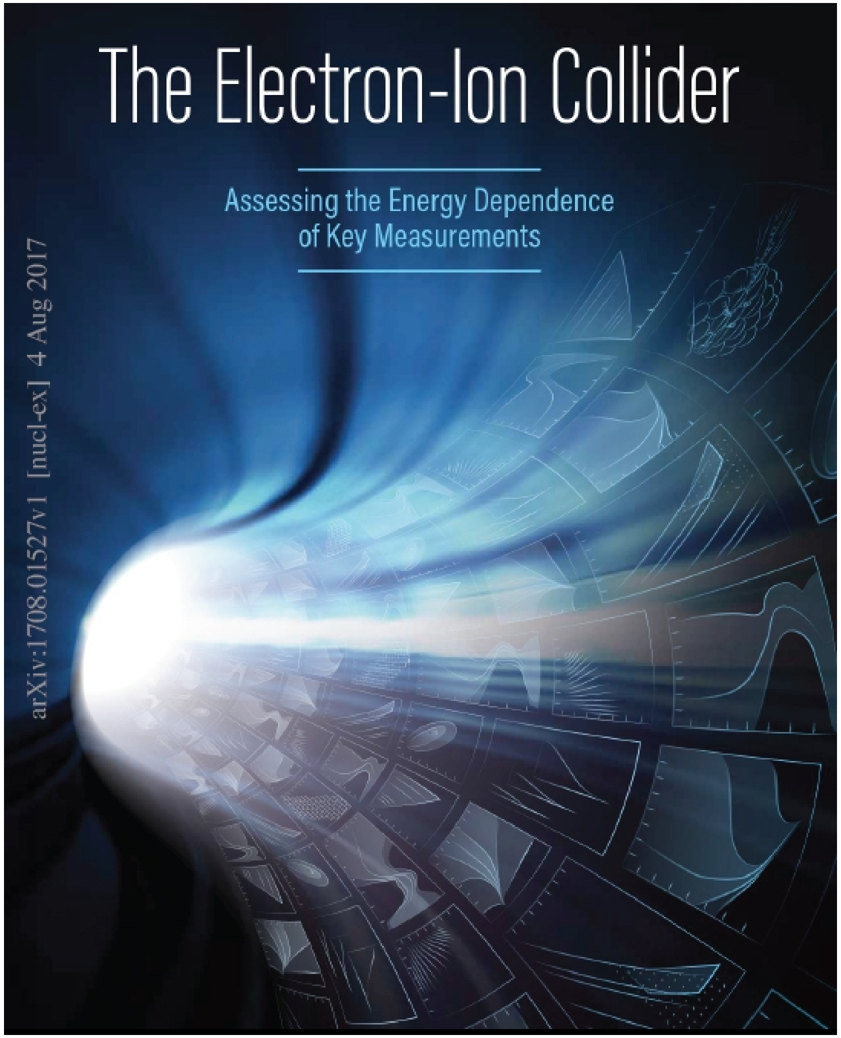
eRHIC: arXiv:1409.1633, JLEIC: arXiv:1504.07961

eC at CERN – center-of-mass energies of 1.2 TeV (4 times HERA)
electron-ion collisions; no polarized protons

Select measurements

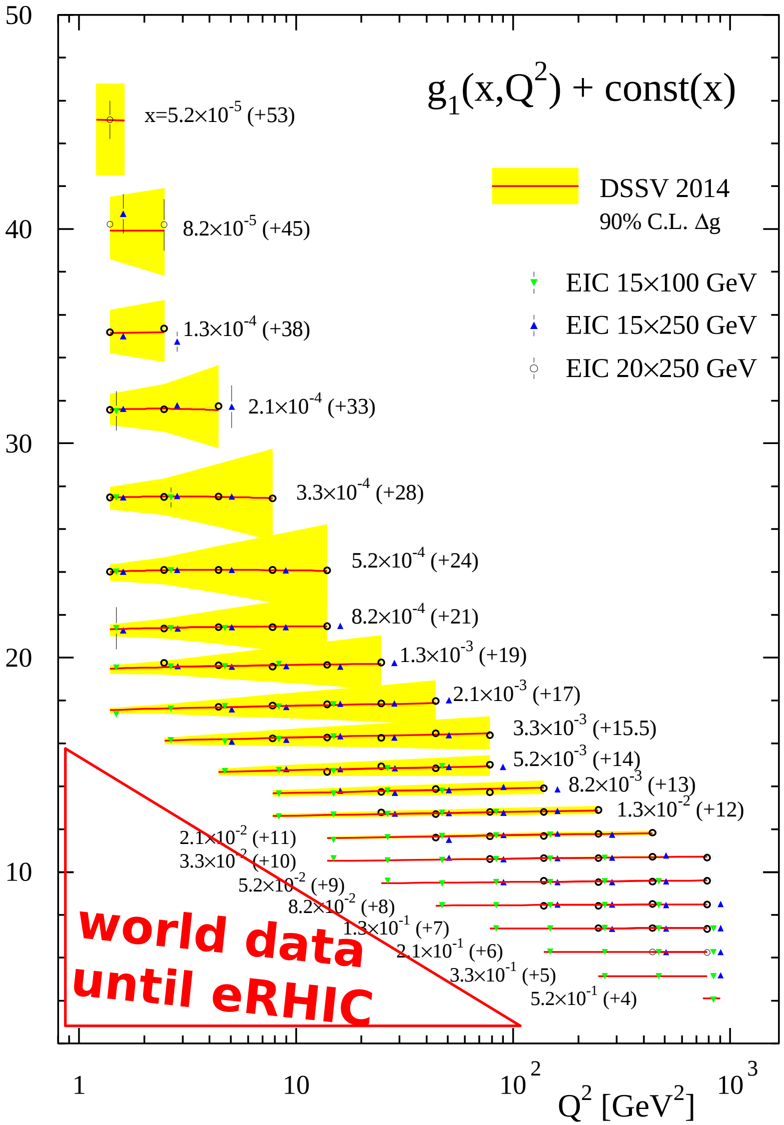


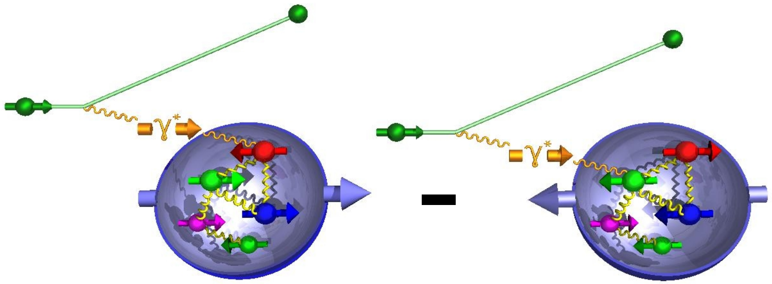
arXiv:1212.1701v3



arXiv:1708.01527

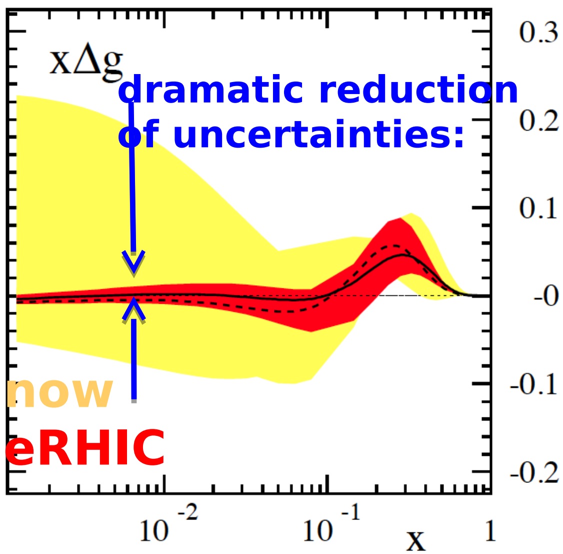
Resolving the proton's spin puzzle



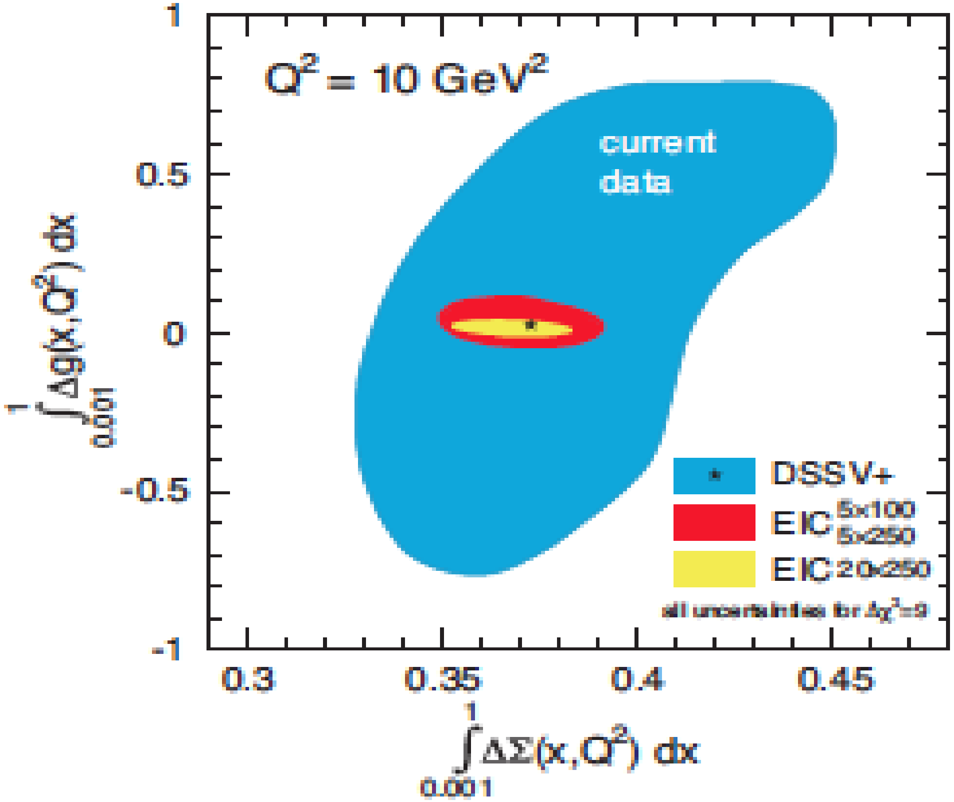


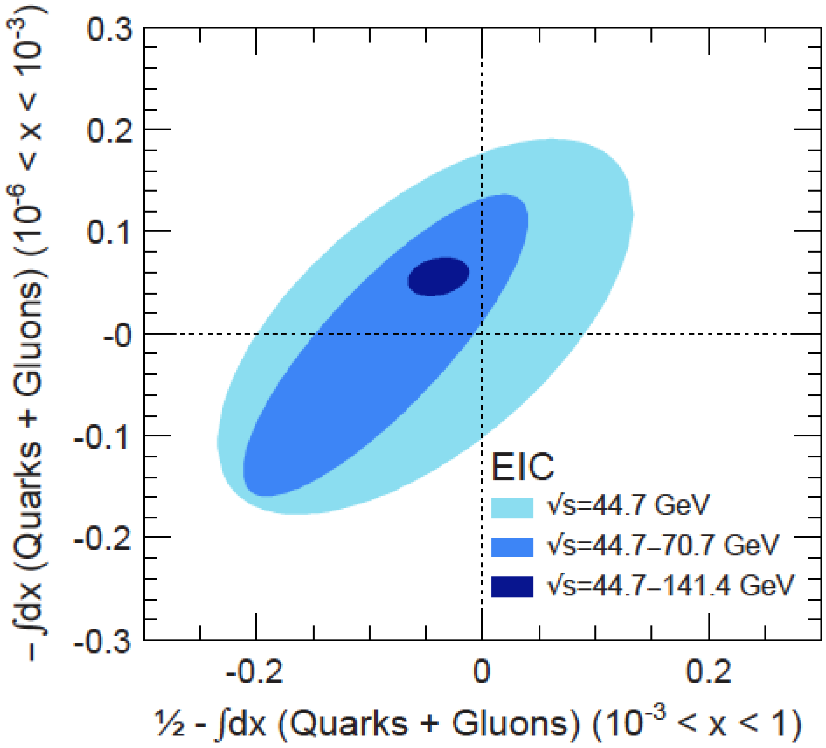
$$\Delta\Sigma(Q^2) = \int_0^1 g_1(x,Q^2)\,dx = \int_0^1 \Delta q_f(x,Q^2)\,dx \rightarrow \textbf{quark contr.}$$

$$\frac{dg_1}{d\log(Q^2)} \sim -\Delta g(x,Q^2) \rightarrow \textbf{gluon contr.}$$



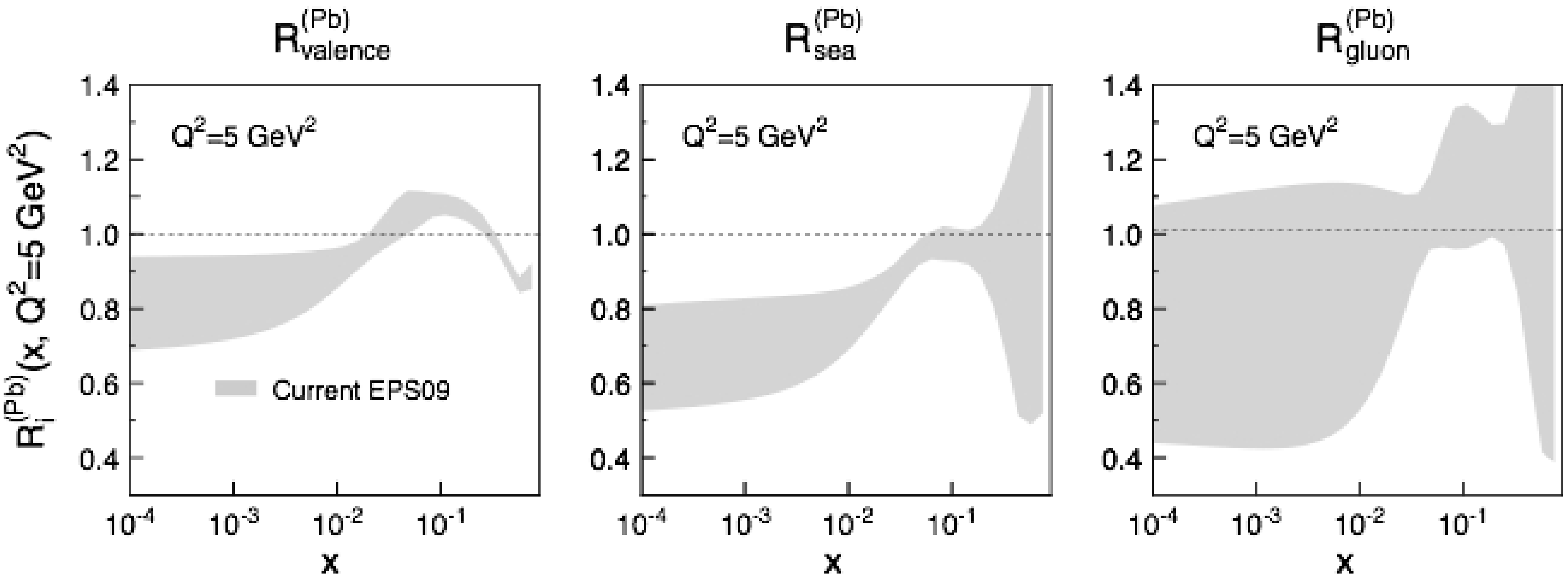
Money plot





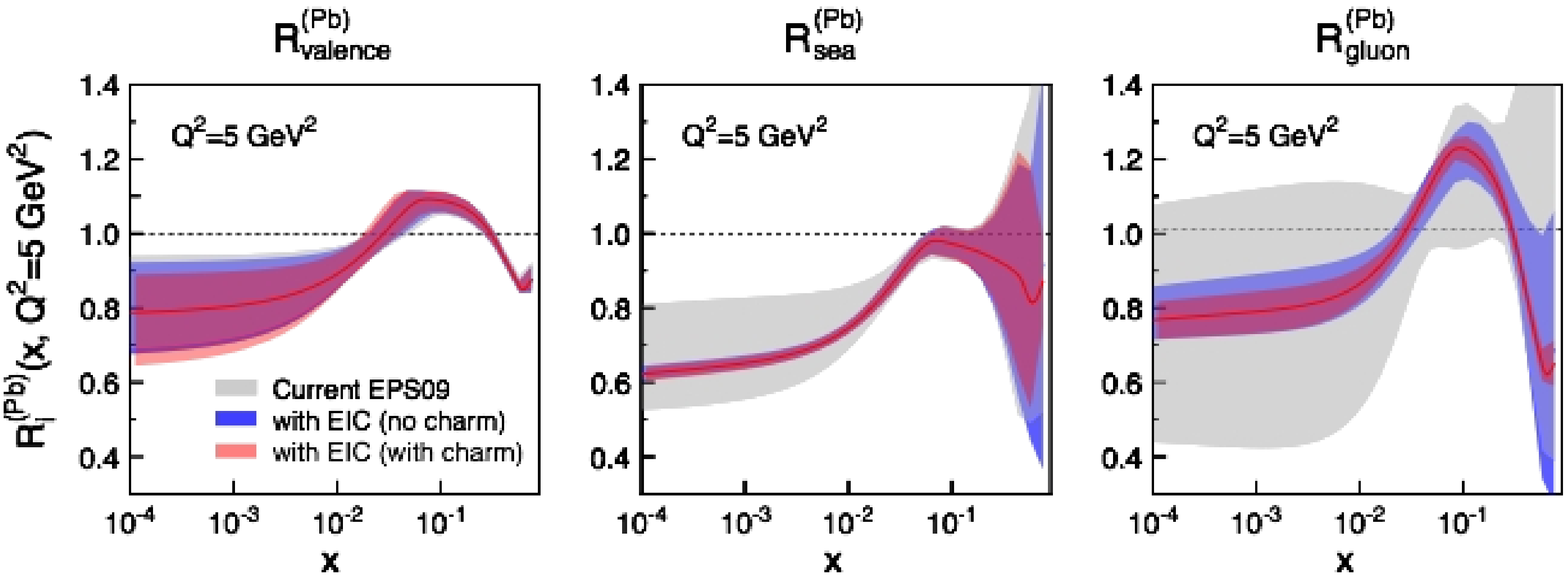
- Nail down the valence, sea quark, gluon ***and orbital*** contributions to the proton’s spin

Entering terra-incognita in nuclei



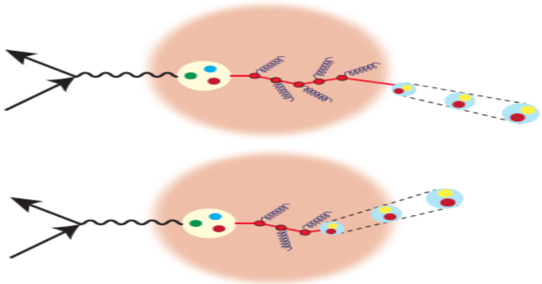
Current knowledge on distributions of quarks and gluons in nuc

Entering terra-incognita in nuclei

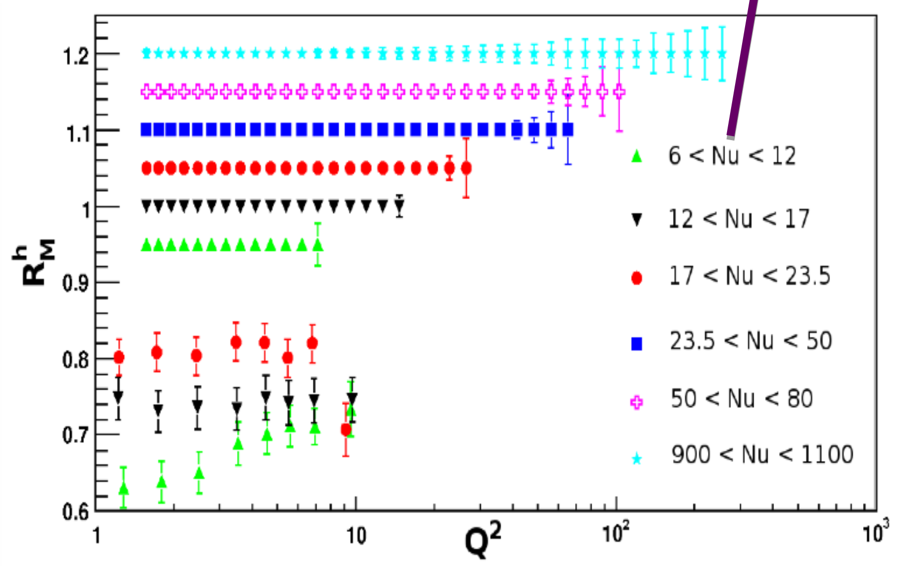


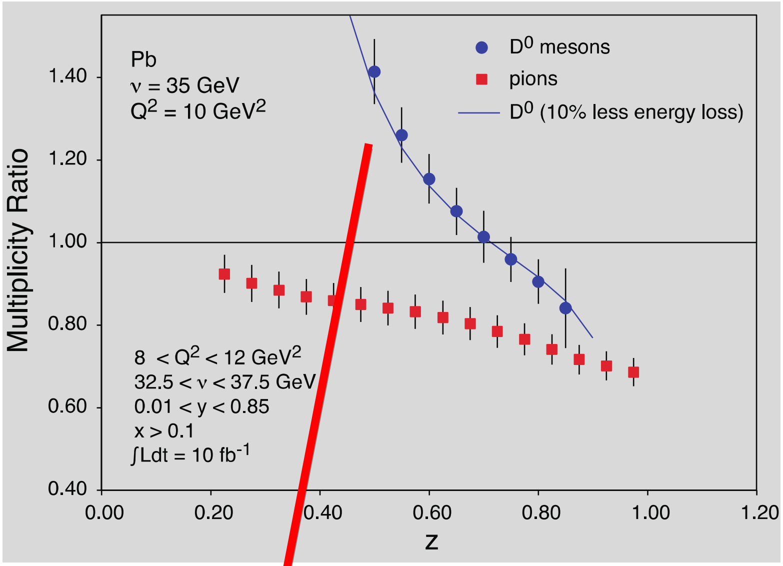
- **Dramatic improvement in precision extraction of nuclear gluons and sea quarks**
  - factors of 4 – 8 reduction in present uncertainties…

The Transubstantiation of Quarks and Glue into mesons and baryons



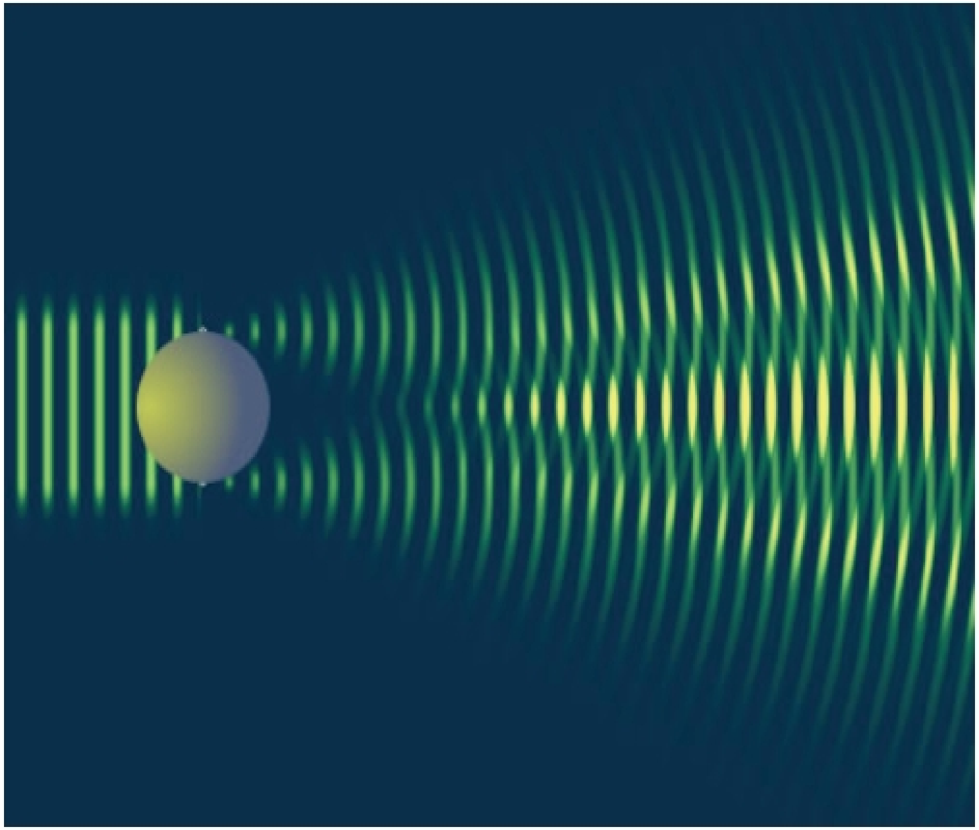
Nu is a coherence length. Dialing it determines whether quarks (gluons) fragment in or out of nucleus

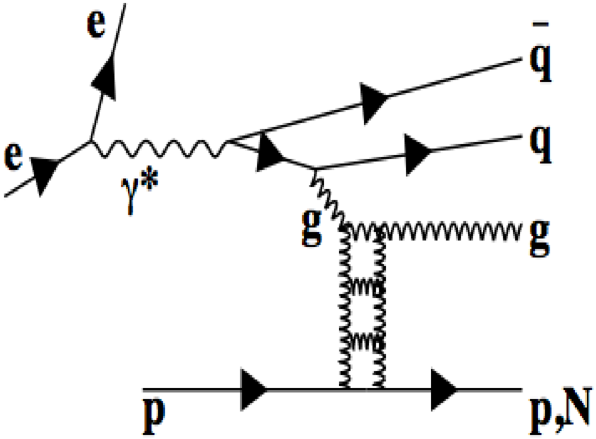




Novel sensitivity to heavy quark fragmentation

Diffraction for the 21st Century





Mx

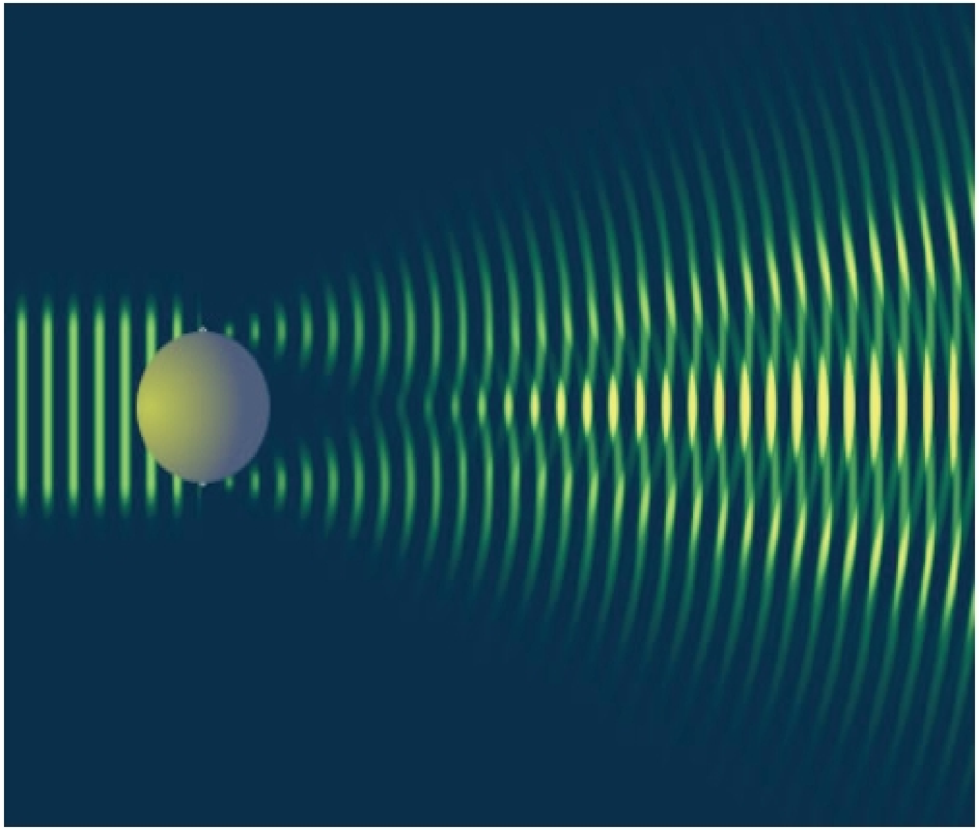
olorless
xchange

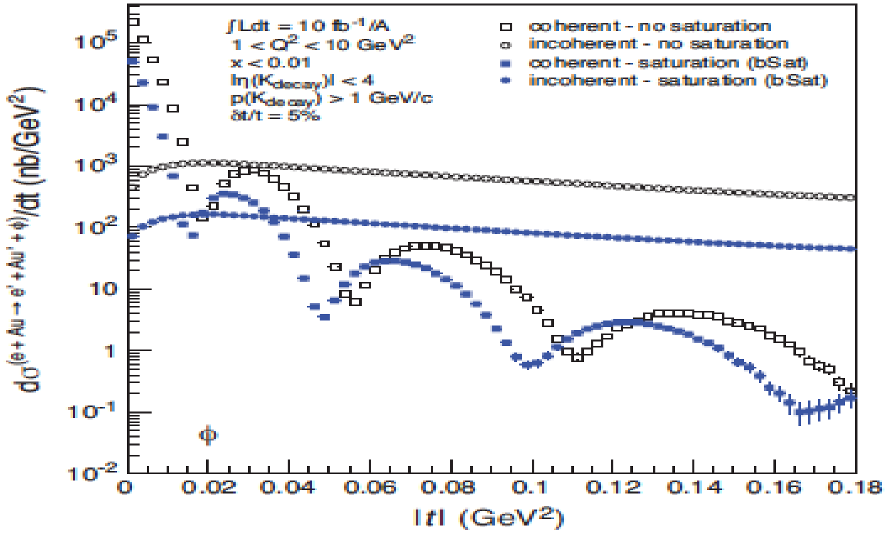
$$|e^-\rangle = |e_B\rangle + |e_B\,\gamma^*\rangle$$
$$+\, |e_B\,\gamma^*\,q\bar{q}\rangle + |e_B\,\gamma^*\,q\bar{q}\;g\rangle$$
$$+ \cdots$$

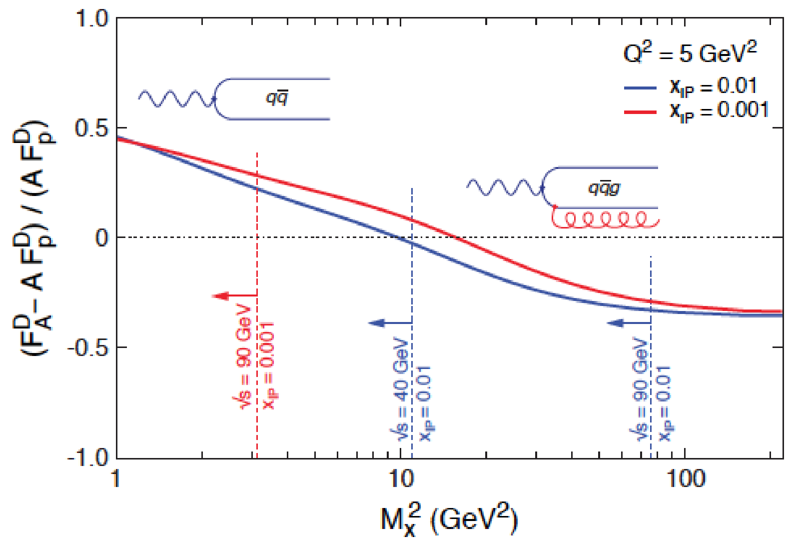
ectron hits a nucleus (binding energy of 8 MeV/nucleon)

1: prediction: nucleus remains intact in at least 1 in 5

Diffraction for the 21st Century







tron hits a nucleus with binding energy ~ 8 MeV/nucleon)

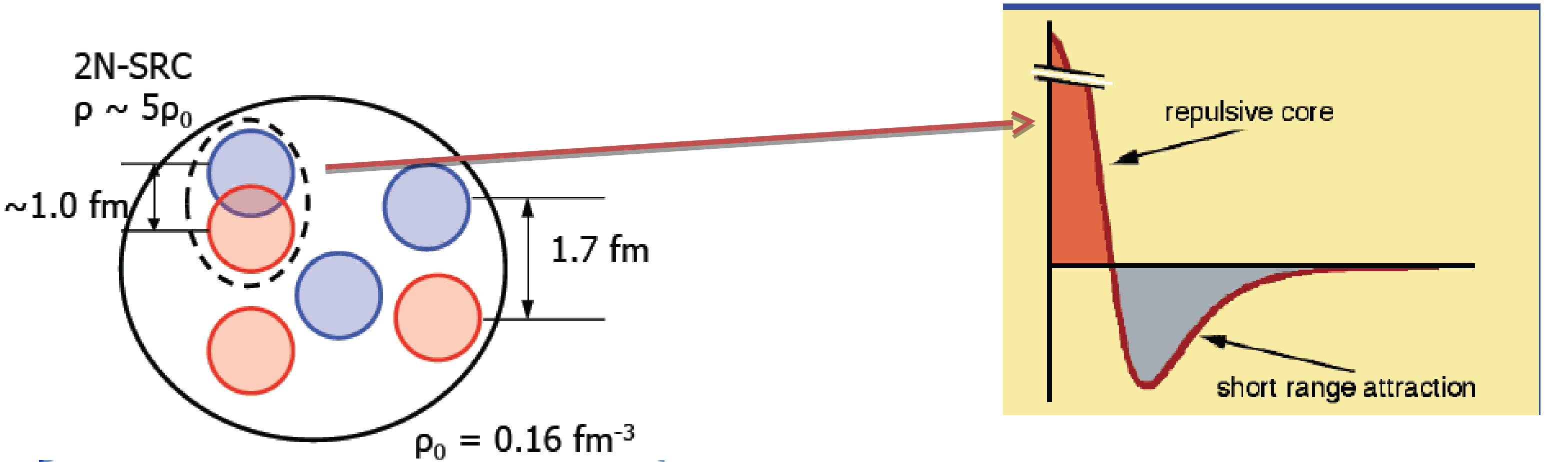
l: prediction: nucleus remains intact in at least 1 in 5

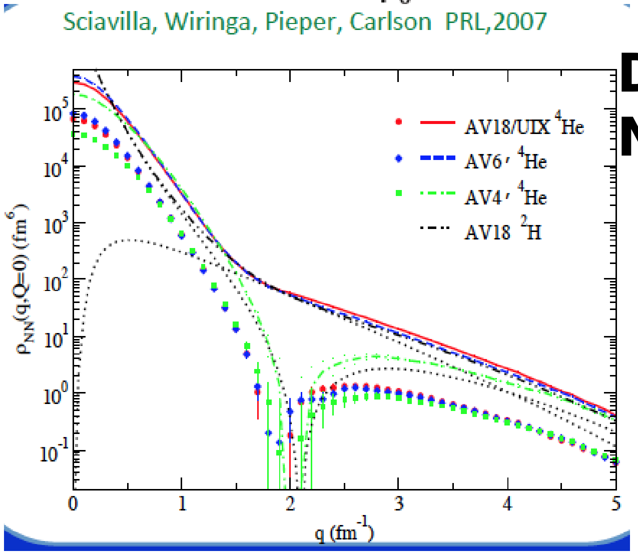

EIC whitepaper
New opportunities

Short-range nucleon-nucleon correlations

Topic of much interest:

ng data on p-n versus p-p and n-n correlations from Jlab



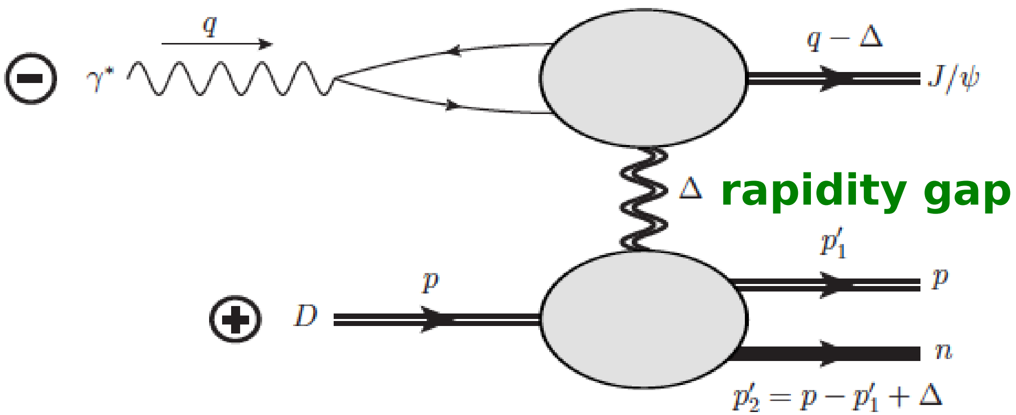


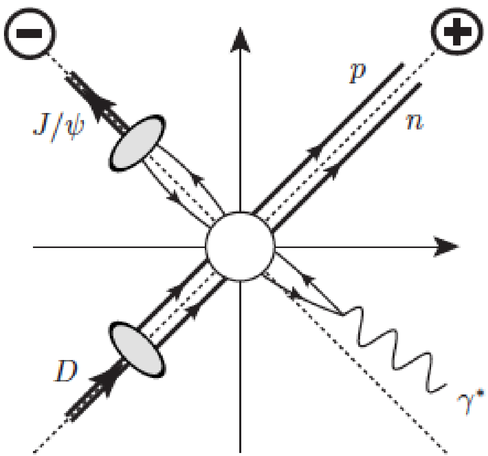
Dominance of tensor component of Nucleon-Nucleon potential?

Probing short-range NN interactions with EIC

Miller, Sievert, Venugopalan, PRC93 (2016), 04520

Exclusive process: $e + D \longrightarrow e + J/\Psi + n + p$



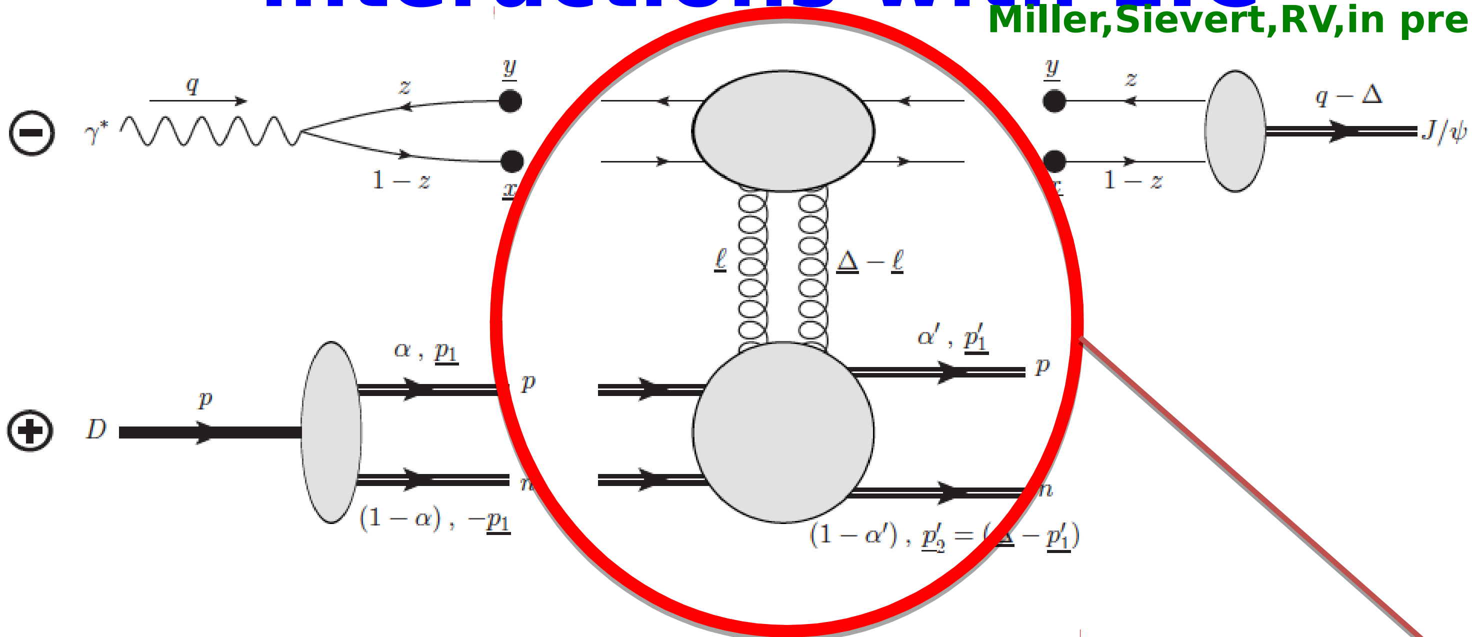


r on process with $T = \Delta^2 \approx -\Delta_T^2 \approx -\Lambda_{QCD}^2$ and $p'^2_T >> \Lambda_{QCD}^2$

n and neutron produced with large back to back transverse mon

Short-range nucleon-nucleon interactions with EIC

Miller,Sievert,RV,in preparation



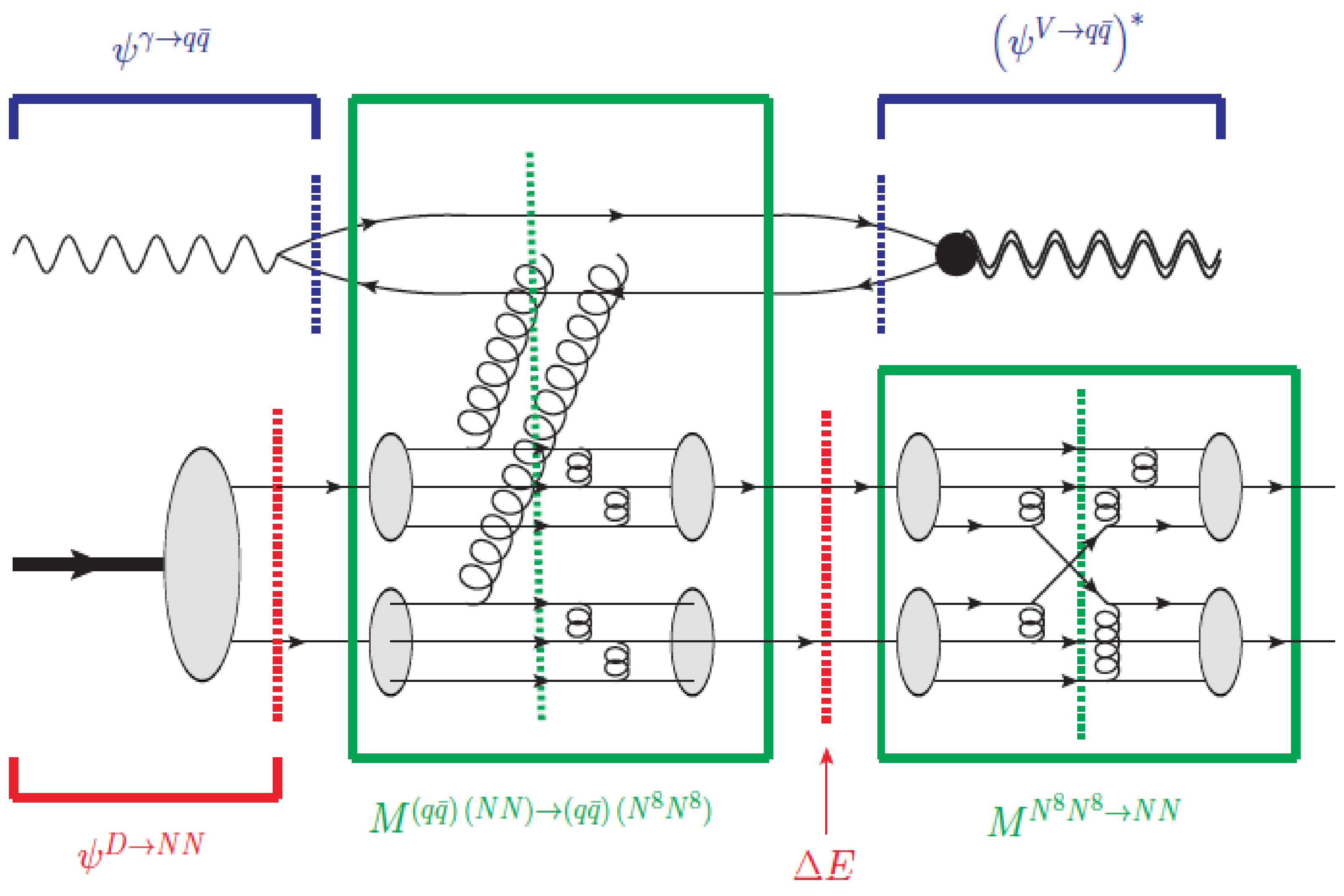
n separation of scales of upper vertex
e high energy ``Regge" limit:

$$\int \frac{d^2r\, dz}{4\pi z(1-z)} \left[\sum_{\sigma\sigma'} \psi^{\gamma}_{\lambda\sigma\sigma'}(\underline{r},z)\, \left(\psi^{V}_{\lambda'\sigma\sigma'}(\underline{r},z)\right)^*\right] \mathrm{Tr}_C\, A^{q\bar{q}D}(\underline{r},\underline{\Delta};\underline{p}_1',\alpha')$$

$$\frac{\Delta x^+_{q\bar{q}}}{p^+_{q\bar{q}}} \sim \mathcal{O}\left(\frac{1}{m_c^2}\right) \qquad \frac{\Delta x^+_{J}}{p^+_{J}} \sim \mathcal{O}\left(\frac{1}{M_J^2}\right) \qquad \frac{\Delta x^+_{Int}}{p^+_{tot}} \sim \mathcal{O}\left(\frac{1}{s}\right)$$

$$\Delta x^+_J\,,\ \Delta x^+_{q\bar{q}} \gg \Delta x^+_{Int},$$

$$\frac{d\sigma^D}{dT\, dt\, dy_1'} = \frac{1}{(4\pi)^3}\frac{\alpha'}{1-\alpha'}\int \frac{d\phi_\Delta}{2\pi}\frac{d\phi_1'}{2\pi}\left|A(\underline{\Delta},\underline{p}_1',\alpha')\right|^2$$



$\psi^{\gamma\to q\bar{q}}$
$\left(\psi^{V\to q\bar{q}}\right)^*$
$\psi^{D\to NN}$
$M^{(q\bar{q})\,(NN)\to(q\bar{q})\,(N^8N^8)}$
ΔE
$M^{N^8N^8\to NN}$

Short-range nucleon-nucleon interactions with EIC

$$\frac{d\sigma^D}{dT\,dt\,dy_1'} = \frac{1}{(4\pi)^3}\frac{\alpha'}{1-\alpha'}\left|\int \frac{d^2r\,dz}{4\pi z(1-z)}\left[\sum_{\sigma\sigma'}\psi^{\gamma}_{\lambda\sigma\sigma'}(\underline{r},z)\left(\psi^{V}_{\lambda'\sigma\sigma'}(\underline{r},z)\right)^*\right]\times\frac{\alpha_s\pi^2}{2}r_T^2\,\hat{H}^g_{(D)}(x,0,T;t)\right|^2$$

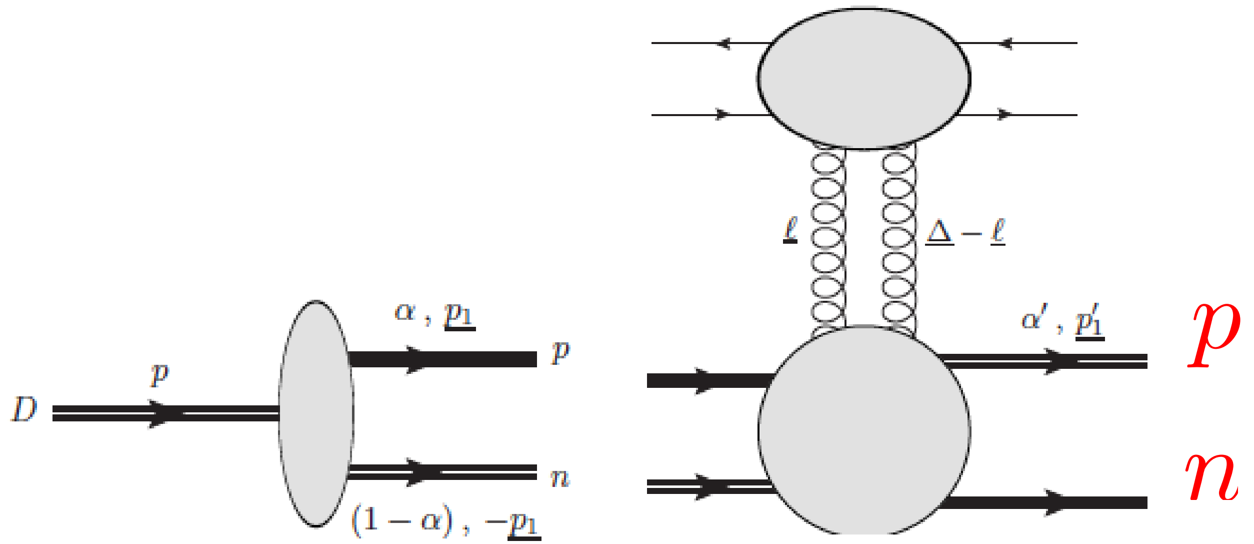
$$\alpha' \equiv p_1'^+/p^+$$

$$\hat{H}^g(x,0,T;t) \equiv \frac{g_{+-}}{2\pi p^+}\int dr^-\, e^{ixp^+g_{+-}r^-}$$

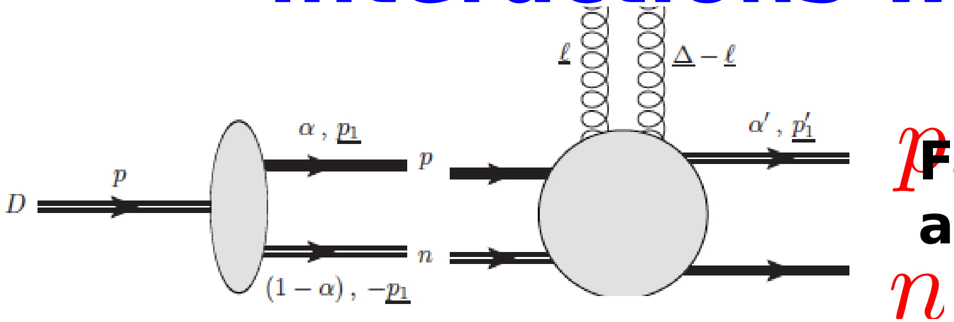
Transition Generalized Parton Dist.

$$\times\left\langle p(p_1')\,n(p+\Delta-p_1')\middle|F^{+ia}(-\tfrac{1}{2}r)F^{+ia}(+\tfrac{1}{2}r)\middle|D(p)\right\rangle$$

ider kinematics, T-GPD factorizes in the Light Front Framework



Short-range nucleon-nucleon interactions with EIC



Factorization of time scales also occurs for lower vertex

$$ {}_{out}\langle N\otimes N|\,[F^{+ia}F^{+ia}](0^+)\,|D\rangle_{in} = \sum\!\!\!\!\!\!\!\int d\Omega_{NN}\,\langle N\otimes N|\,\mathcal{U}[+\infty^+,0^+]\,[F^{+ia}F^{+ia}](0^+)\,|N\otimes N\,(\Omega_{NN})\rangle\,\psi^{D\to NN}(\Omega_{NN}) $$

Deuteron light fro wave function:

$$ \begin{aligned} \psi^{D\to NN} &= \langle N\otimes N|\,\mathcal{U}[0^+,-\infty^+]\,|D\rangle \\ &= \lim_{x^+\to-\infty^+}\langle N\otimes N|\,\exp[+i(\mathcal{H}^-_{QCD})g_{+-}x^+]\,\exp[-i(\mathcal{H}^-_0)g_{+-}x^-]\,|D\rangle \end{aligned} $$

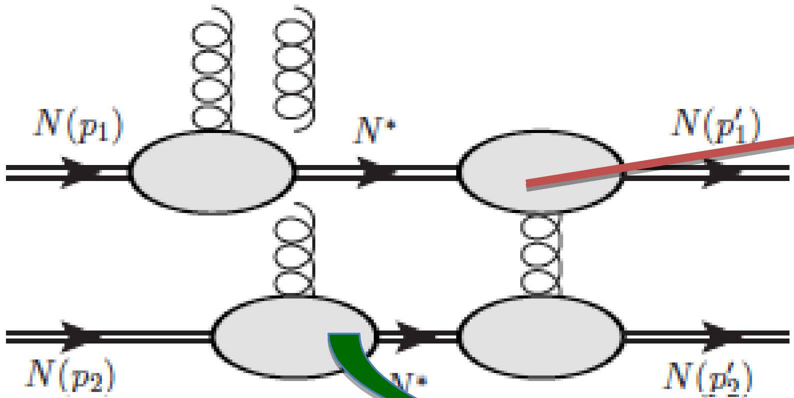
$$ \begin{aligned} \hat{H}^g_{(D)}(x,0,T;t) = \int \frac{d\alpha}{4\pi\alpha(1-\alpha)}\frac{d^2p_1}{(2\pi)^2}\sum_{\sigma_p\sigma_n}\psi^D_{\sigma_D;\sigma_p\sigma_n}(\underline{p_1},\alpha)\Bigg[\frac{g_{+-}}{2\pi p^+}\int dr^-\,e^{ixp^+g_{+-}r^-} \\ \times \boxed{\Big\langle p_{\sigma_p'}(p_1')\,n_{\sigma_n'}(p+\Delta-p_1')\Big|V_{NN}\Big|pn\Big\rangle}\frac{1}{\Delta E^-} \\ \times\Big\langle pn\Big|F^{+ia}(-\tfrac{1}{2}r)F^{+ia}(+\tfrac{1}{2}r)\Big|p_{\sigma_p}(p_1)\,n_{\sigma_n}(p-p_1)\Big\rangle\Bigg] \end{aligned} $$

Short-range nucleon-nucleon interactions with EIC

$$\hat{H}^g_{(D)}(x,0,T;t) = \int \frac{d\alpha}{4\pi\alpha(1-\alpha)} \frac{d^2 p_1}{(2\pi)^2} \sum_{\sigma_p \sigma_n} \psi^D_{\sigma_D;\sigma_p\sigma_n}(\underline{p_1},\alpha) \Bigg[\frac{g_{+-}}{2\pi p^+} \int dr^- \, e^{ixp^+ g_{+-} r^-}$$

$$\times \boxed{\left\langle p_{\sigma'_p}(p'_1)\, n_{\sigma'_n}(p+\Delta-p'_1) \middle| V_{NN} \middle| pn \right\rangle \frac{1}{\Delta E^-}}$$

$$\times \left\langle pn \middle| F^{+ia}(-\tfrac{1}{2}r) F^{+ia}(+\tfrac{1}{2}r) \middle| p_{\sigma_p}(p_1)\, n_{\sigma_n}(p-p_1) \right\rangle \Bigg]$$



relative transverse momenta, $p'^2_T >> \Lambda^2_{QCD}$, perturbative expans

The EIC can therefore provide information about the gluon structure of short range nuclear forces!

e: previous discussions of ``multi-pomeron" contributions to short range forces
d neutron star masses Rikjen et al. , arXiv: 1406.4332, 1308.2130

Concluding Thoughts

ur knowledge of the fundamental structure of matter is cloud
he vast fog of our ignorance
ough there are bright gems that shine through

the heart of the matter is the confining dynamics of QCD –
s many-body dynamics with gluons playing a lead role.

dressing this requires deep and varied knowledge
EIC enables unique and unprecedented measurements.
history of DIS informs us that surprises may be anticipated

cientific American
ay 2015 issue

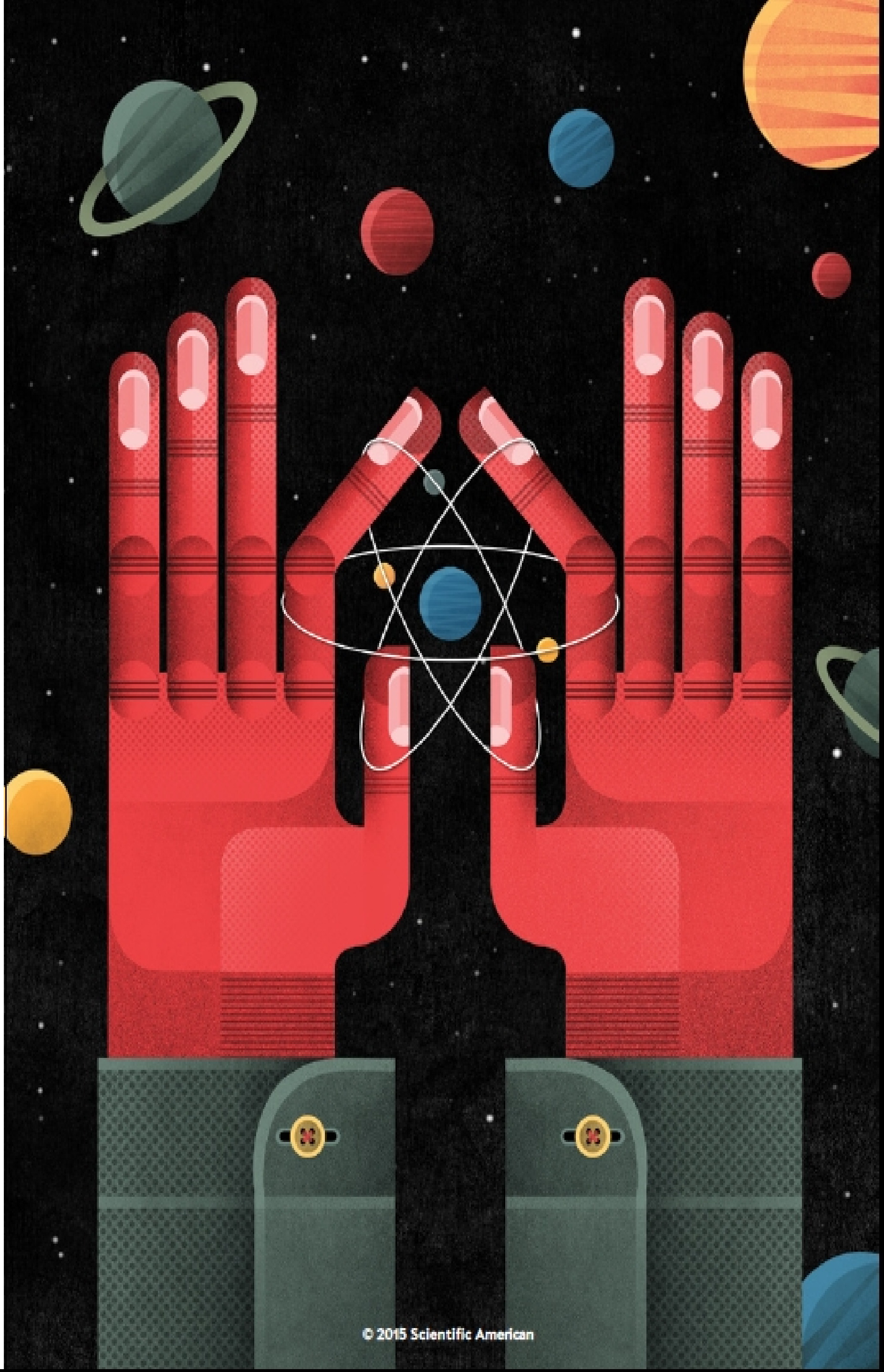
PARTICLE PHYSICS

the glue that binds us

Physicists have known for decades that particles called gluons keep protons and neutrons intact—and thereby hold the universe together. Yet the details of how gluons function remain surprisingly mysterious

By Rolf Ent, Thomas Ullrich and Raju Venugopalan

Illustration by Maria Corte



© 2015 Scientific American

EIC Project Status

2015: Long Range Plan of U.S. nuclear physics community recommends an EIC as the highest priority for new facility construction.

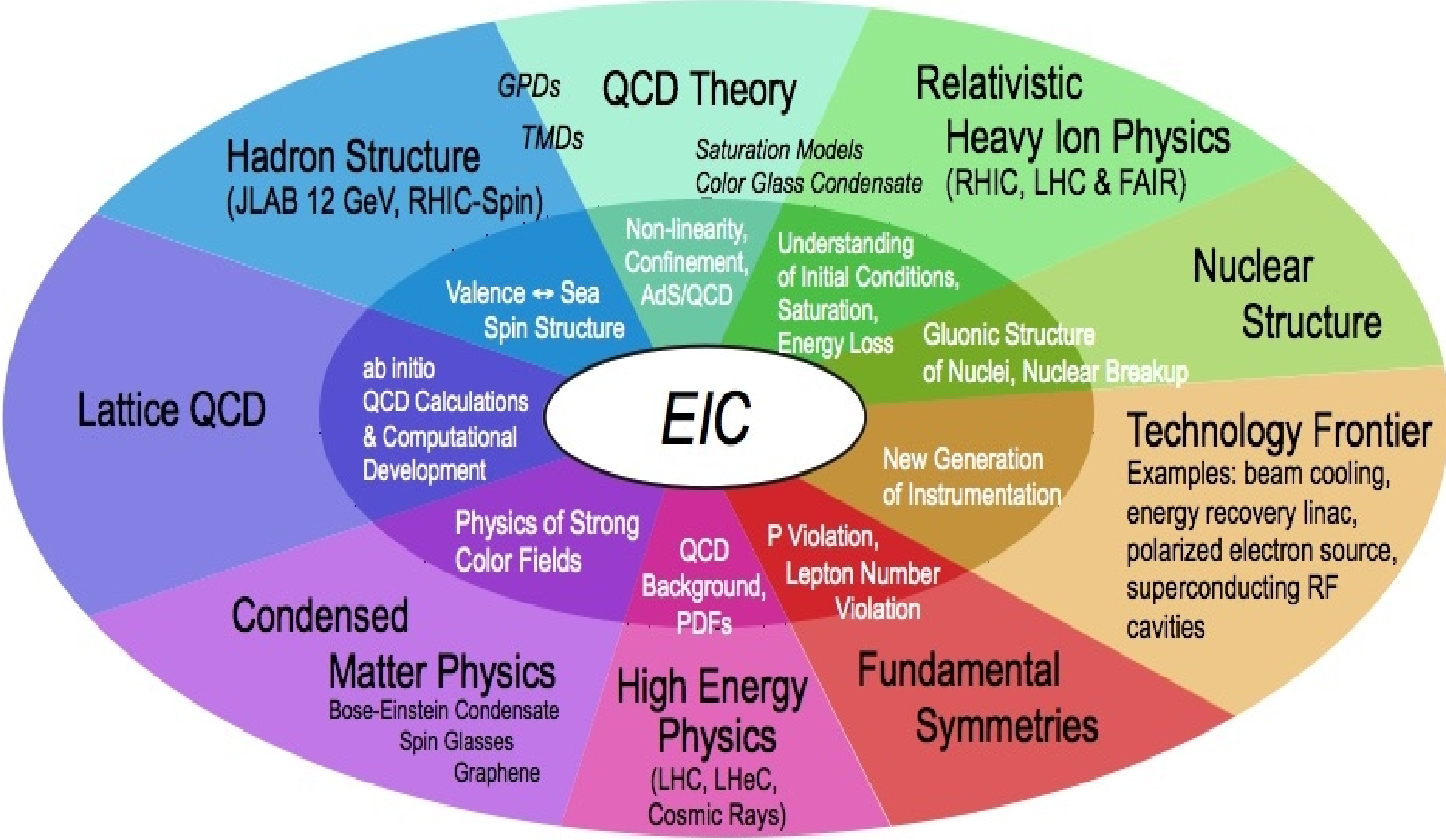
2016: Organize EIC Users Group (http://www.eicug.org)

2017: National Academy of Sciences Review of EIC

- Assess the scientific justification for a US EIC
- Expect report around March 2018

2018: CD-0*

- Indicated by T. Hallman, Associate Director for NP of the Office of Science at DOE at the EIC Users' Group Meeting in Trieste in July 2017



Slide by Thomas Ullrich