Nucleon Structure and Helicity

- Hierarchy of EIC Physics goals presented in the White Paper
- Sensitivity Projections (mostly from EIC White Paper)
  - ➔ Gluon Spin
  - ➔ Light quark sea
  - ➔ strangeness
  - ➔ charged current
- So what ?
- What we might contribute from this meeting …

Hierarchy of EIC Goals: Top level

(I) Determine the spatial and momentum distribution of quarks, anti-quarks and gluons inside the nucleon and the correlation of theirs spins to the proton spin.

(II) Determine the impact of the nuclear environment on the distributions of quarks and gluons and their interactions.

(III) Explore the onset of gluon saturation

⇨ Quantitative understanding of the free and bound nucleon in terms of QCD, the field theory of the strong interaction.

Achieving Top Level Physics Goals Requires a Collider with Capability for Polarized e-p and e-A

- A collider is needed to provide kinematic reach well into the gluon-dominated regime;
- Electron beams are needed to bring to bear the unmatched precision of the electromagnetic interaction as a probe;
- Polarized nucleon beams are needed to determine the correlations of sea quark and gluon distributions with the nucleon spin;
- Heavy ion beams are needed to provide precocious access to the regime of saturated gluon densities and offer a precise dial in the study of propagation-length for color charges in nuclear matter.

⇨ **Quantitative understanding of the free and bound nucleon in terms of QCD, the field theory of the strong interaction, <u>requires a polarized e-p and e-A collider !</u>**

Hierarchy of EIC Goals: Nucleon Spin

(I) Explore the dynamical origin of sea quarks and gluons inside the proton.

(II) Determine the origin of the proton spin at the microscopic level.

(III) Determine the impact of chiral symmetry and its breaking on hadron structure.

(VI) Explore the role of confinement in hadron structure

Hierarchy of EIC Goals: Helicity Structure

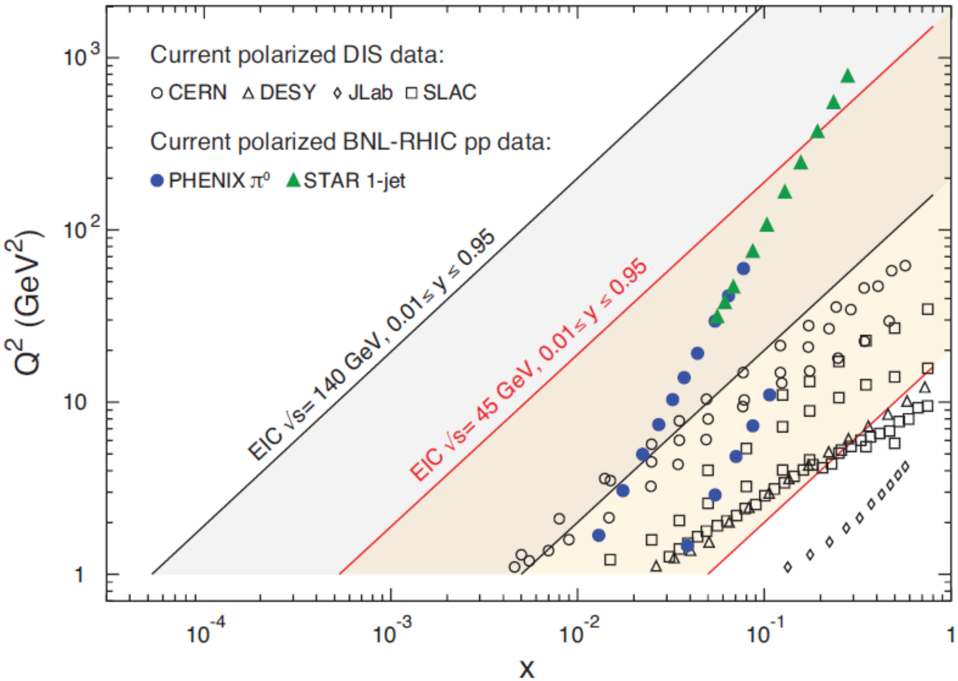
(I) Determine the gluon spin contribution to the nucleon spin.

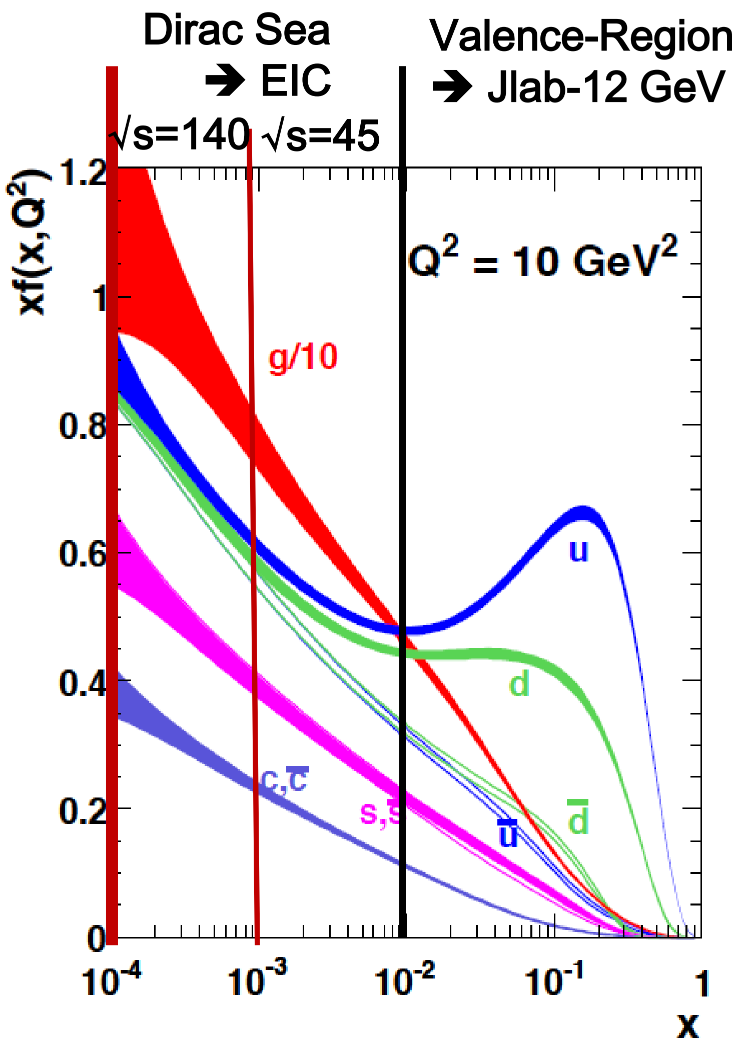
(II) Determine the polarization of the light sea.

(III) Explore the role of strange quarks in nucleon spin structure.

⇨ Helicity goals require extension of the kinematic region from the valence region covered at HERMES, COMPASS, RHIC, and Jlab 6&12 to low x where gluon and sea-quark densities are large.

EIC Kinematic: Collider to explore spin structure and nuclear effects for sea quarks and gluons !



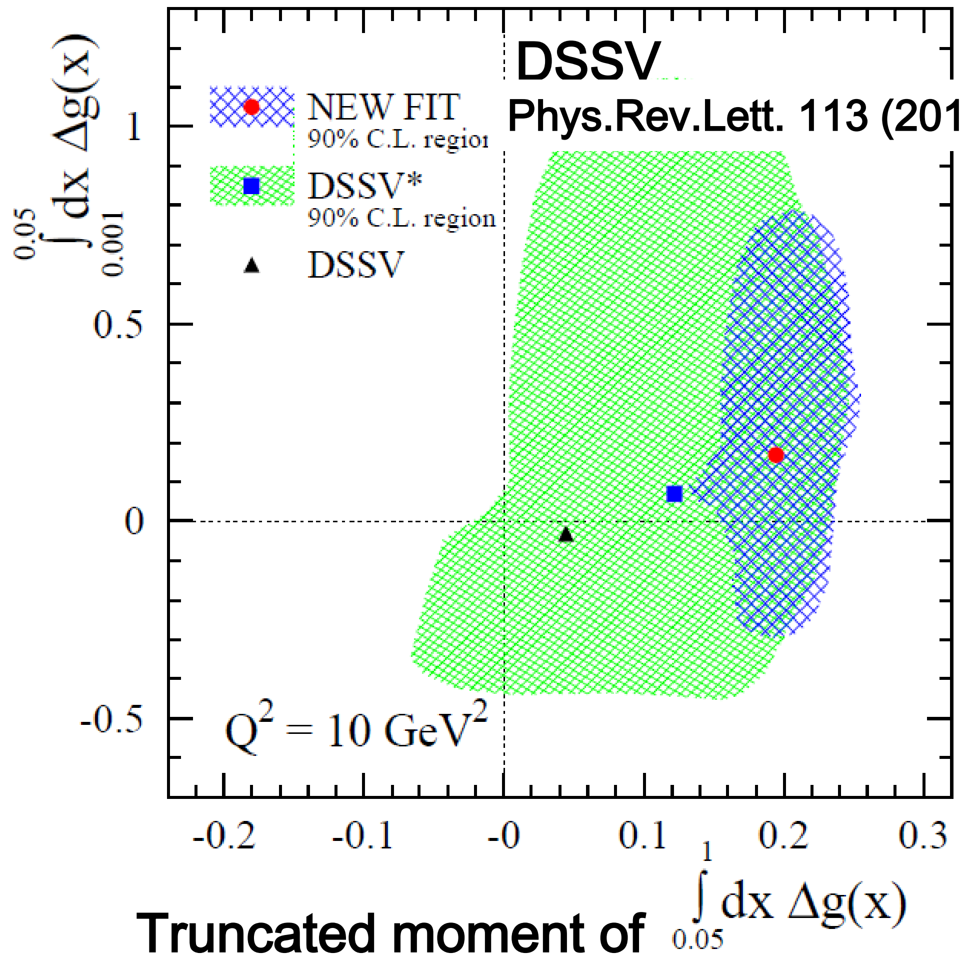


Present + Jlab 12 : $x > 0.01$

EIC, $\sqrt{s}$ = 45 GeV: $x > 0.001$
ECI, $\sqrt{s}$ = 140 GeV: $x > 0.0001$

Example: Knowledge of Truncated Moments of ΔG in Valence- and Sea-Regions

Truncated moment of ΔG(x) for sea between 0.001 < x < 0.05



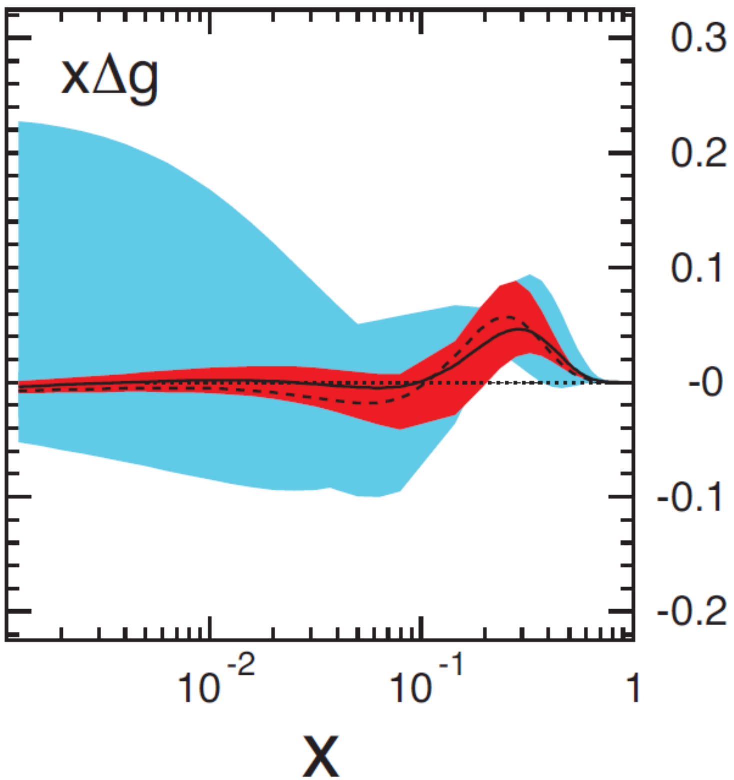
DSSV
Phys.Rev.Lett. 113 (2014) 012001

Truncated moment of ΔG(x) for valence region 0.05 < x < 1

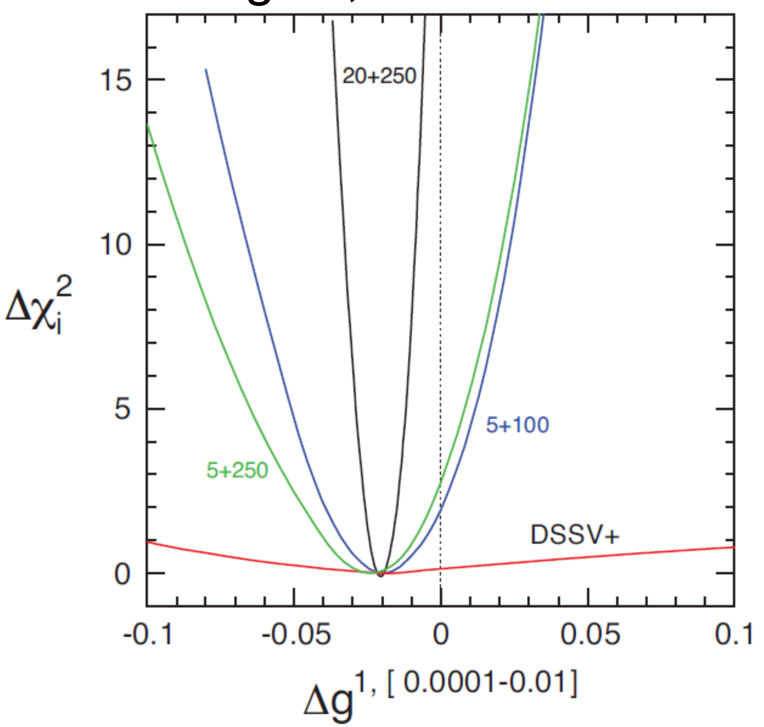
For gluon spin the sea is terra incognita with possibly large spin contributions!

Very Large Improvement from EIC on the Knowledge of ΔG(x) for 0.001 < x < 0.1

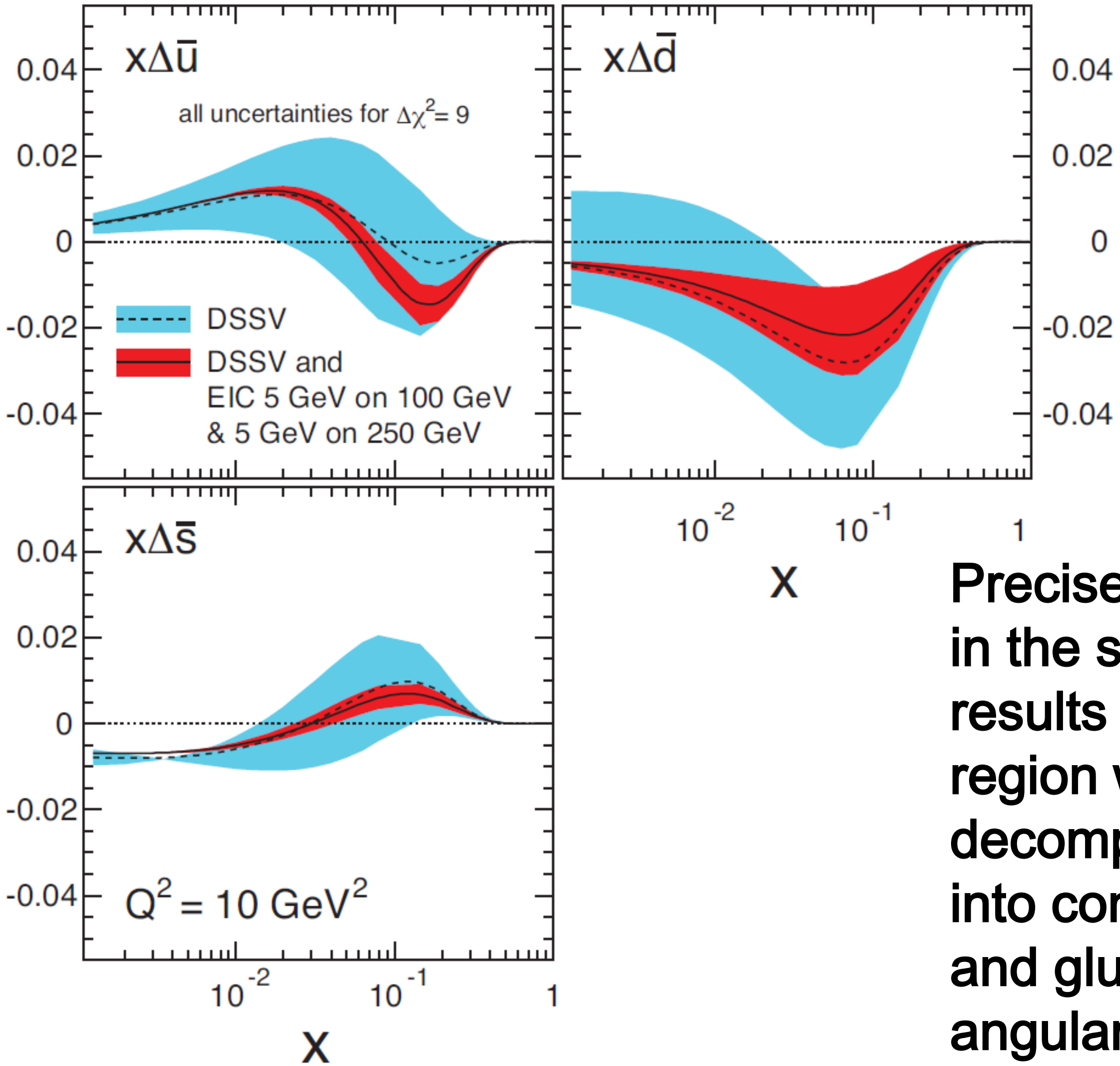
ΔG(x) for x> 0.001



Truncated moment ΔG(x) in sea region, for 0.0001 < x < 0.01

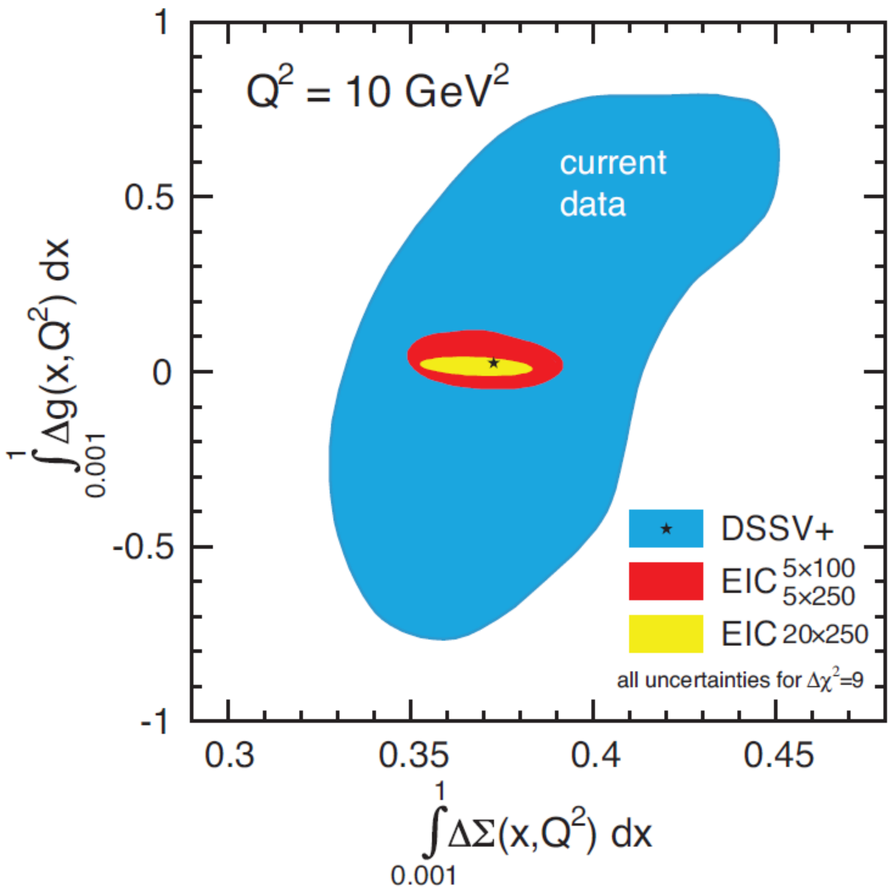


Impact of EIC on Helicity Structure of Light Quark Sea & Strangeness



Precise measurements in the sea region ! Combined results from valence- and sea-region will make it possible to decompose the proton spin into contributions from quark- and gluon-spin and orbital angular momentum !

Impact of EIC on Gluon- and Quark-Spin Contributions.



Can constrain orbital contribution:

$$L_Z = \frac{1}{2} - \frac{1}{2}\Delta\Sigma - \Delta G$$

Helicity from SIDIS at EIC

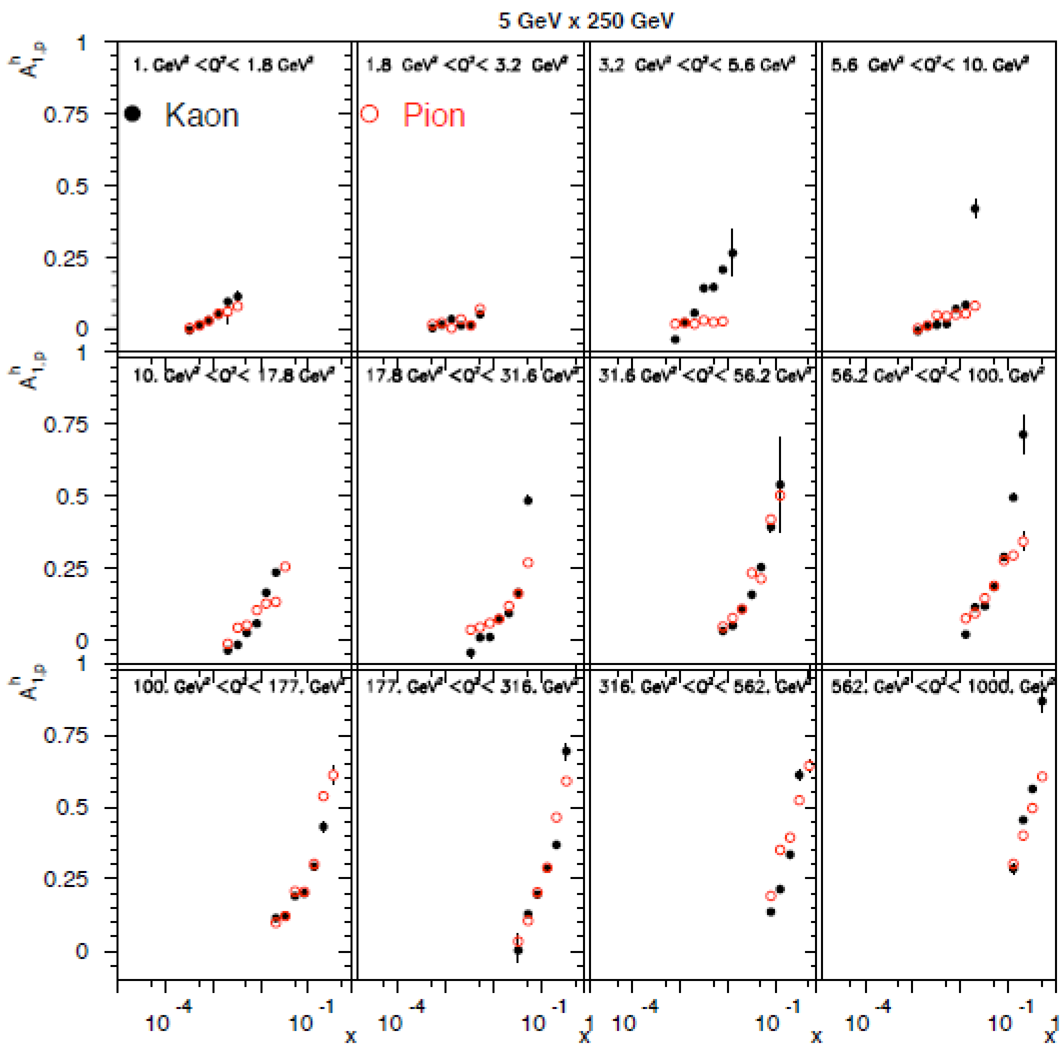
A_{LL} for semi inclusive Hadronen

(from Elke Aschenhauer & Marco Stratmann)

Excellent statistical resolution for all quark and anti-quark helicity distributions.

In the whitepaper SIDIS is discussed in context of TMDs (good decision!)

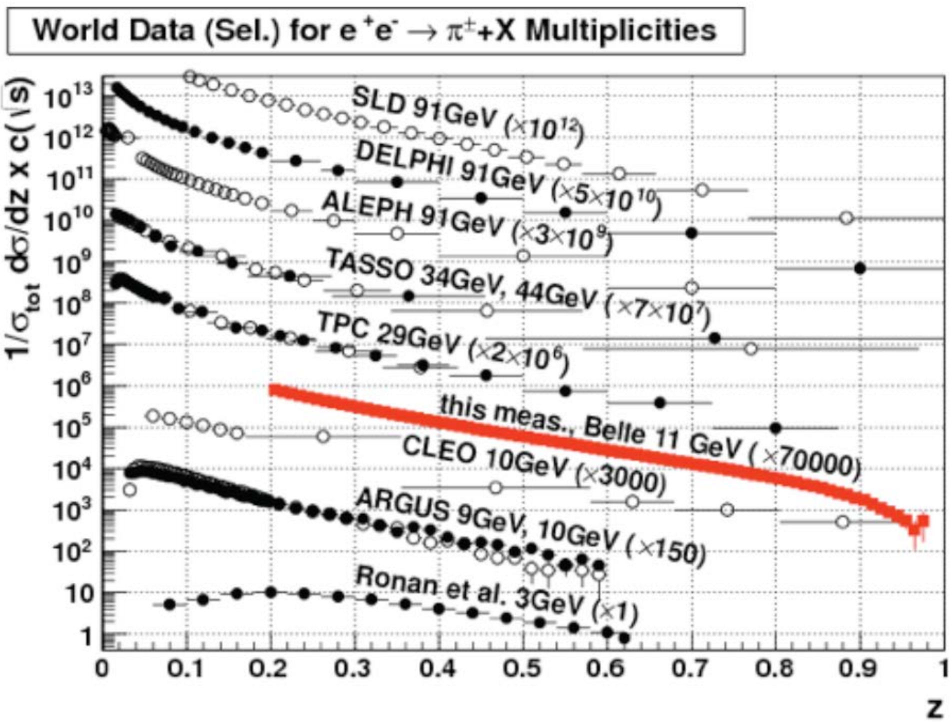
Fragmentation functions?



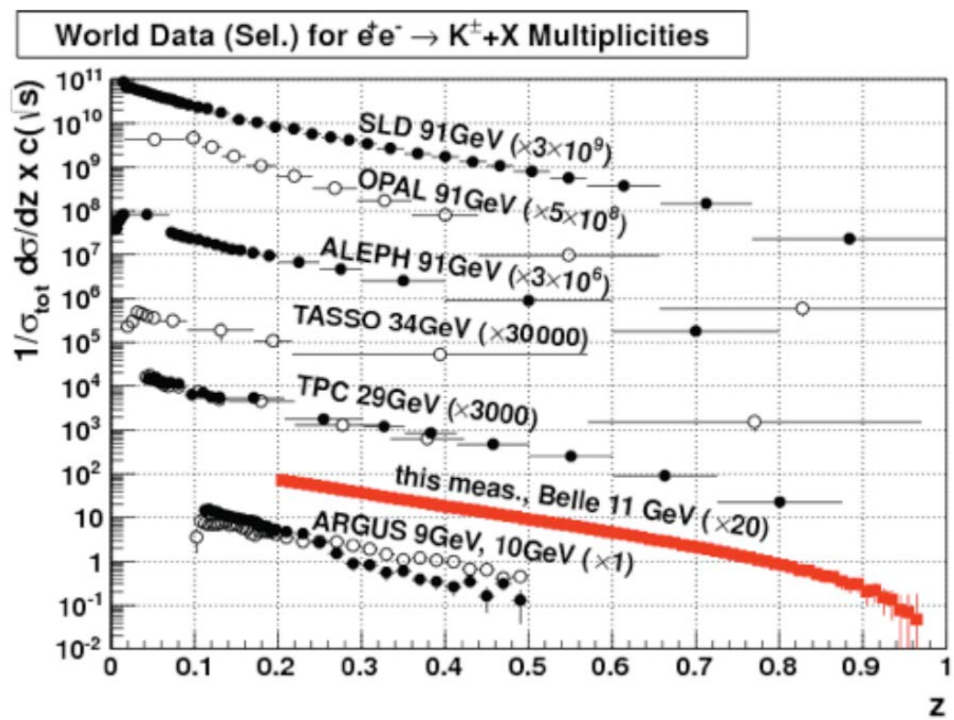
Knowledge of FFs will come from Combined Analysis of Current Data Sets with future Data from Super Belle, LHC, and EIC SIDIS

New Belle and Babar data have been integrated into DSS global FF analysis

Pions



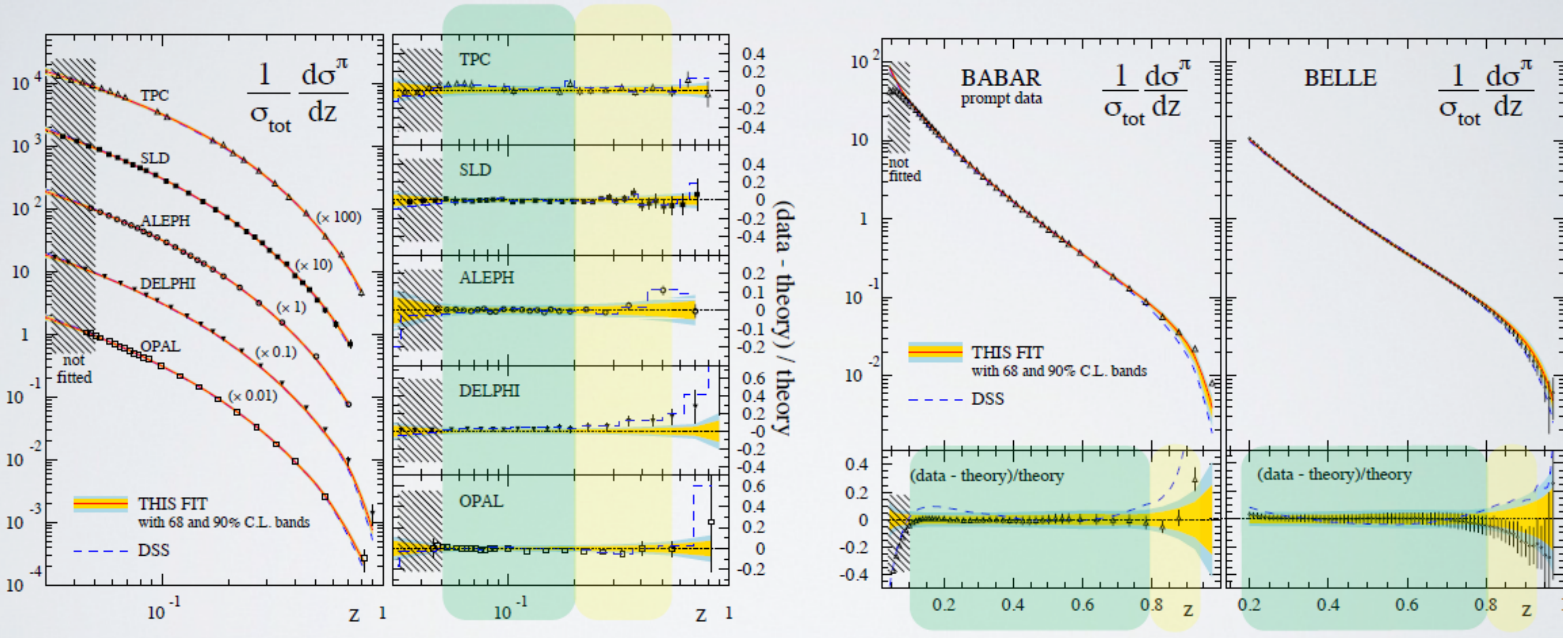
Kaons



BaBar and Belle Data in DSS Analysis

new Belle and BaBar (large z, lower Q)

from Rodolfo Sassot



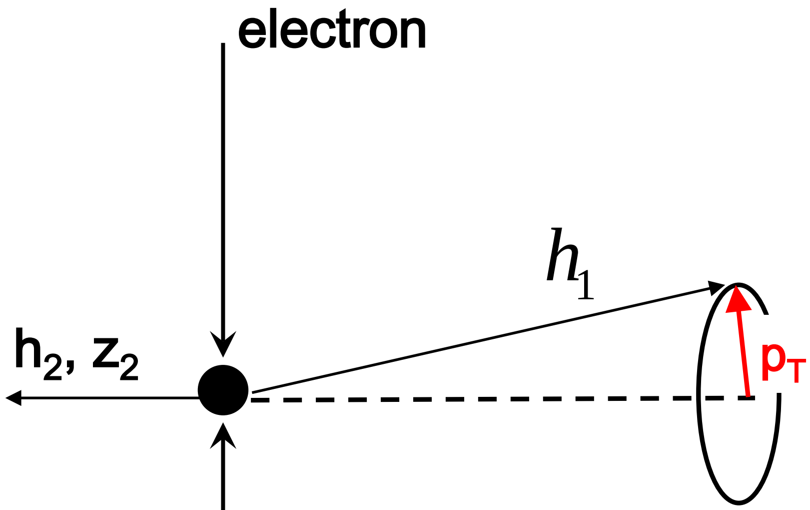
z~0.05-0.2 z>0.2

Q~Mz

very precise up to z~0.8

Q~10 GeV

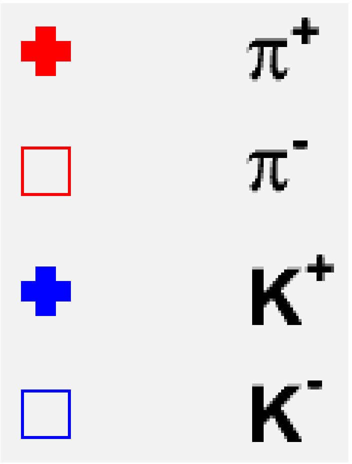
Super Belle: Precise Measurement of p_T Dependence of Hadron Yields for e^+e^- Annihilation



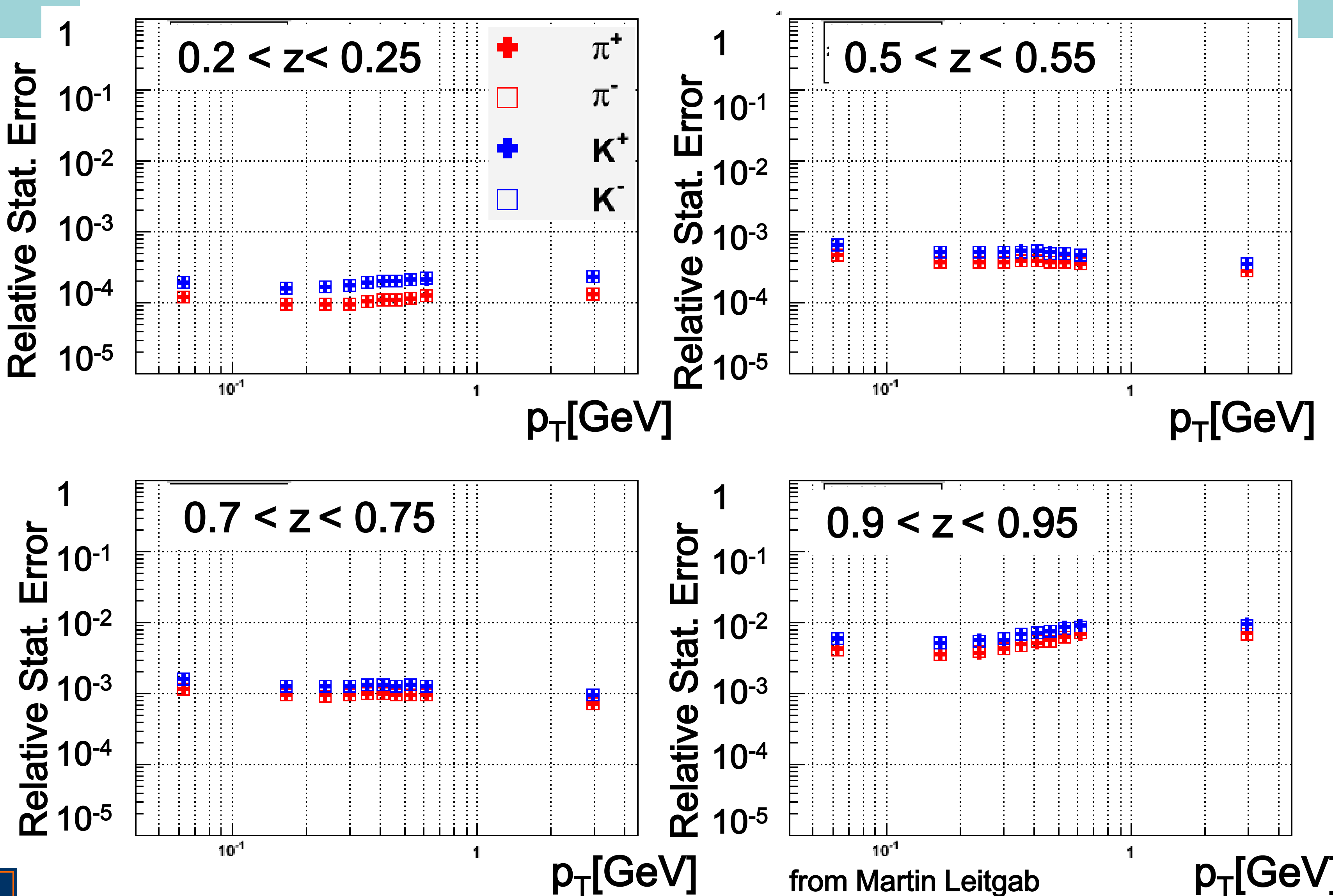
z relative hadron momenta

Constrain p_T-dependence of fragmentation functions

Combinations:



Statistical Errors for $e^+e^- \rightarrow h(z,p_T)+X$ with $\int Ld = 5ab^{-1}$ for Super Belle → Precise Measurement of k_T-dep.



A_L in Charged Current DIS

Aschenauer, Burton, Martini, Spiesberger, Stratmann Phys.Rev. D88 (2013) 114025

Measurement of longitudinal single spin asymmetry in CC-DIS provides independent access to quark distributions

$$A_L^{W^-,N} \equiv \frac{d^2\Delta\sigma^{W^-,N}/dxdy}{d^2\sigma^{W^-,N}/dxdy}$$

$$\frac{d^2\Delta\sigma^{W^-,N}}{dxdy} = \frac{2\pi\alpha_{em}^2}{xyQ^2}\eta\left[2Y_- x g_1^{W^-,N} - Y_+ g_4^{W^-,N} + y^2 g_L^{W^-,N}\right]$$

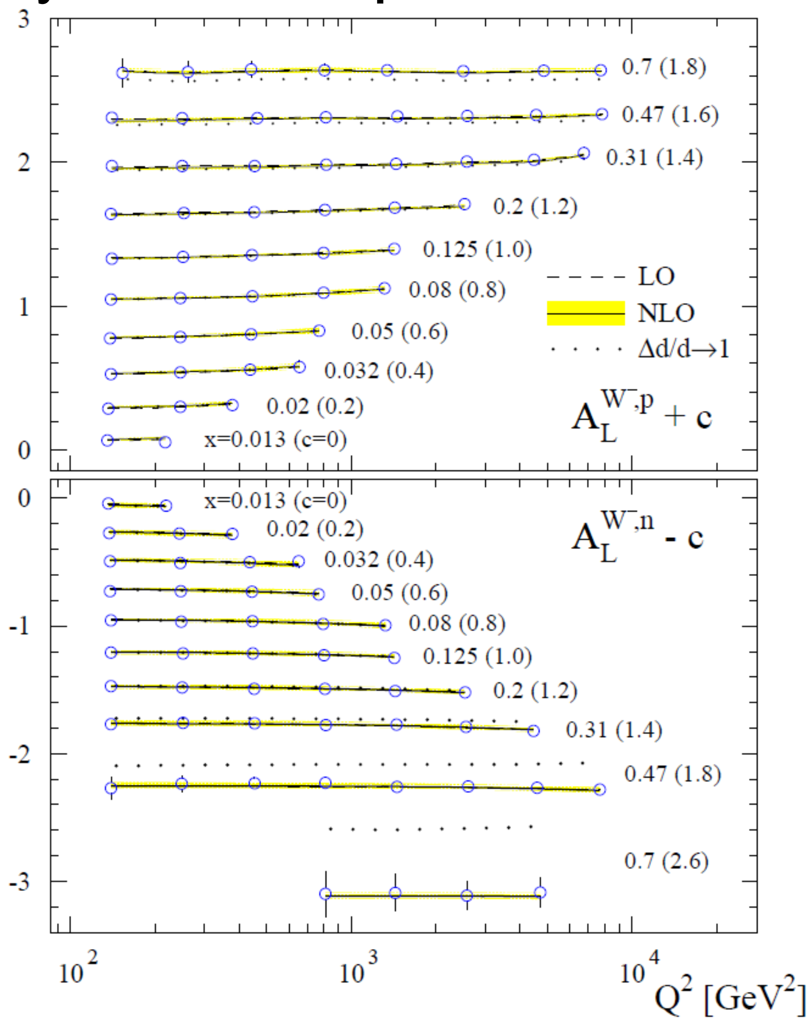
$$g_L \equiv g_4 - 2xg_5$$

$$g_1^{W^-,p}(x) = \Delta u(x) + \Delta\bar{d}(x) + \Delta c(x) + \Delta\bar{s}(x) ,$$
$$g_5^{W^-,p}(x) = -\Delta u(x) + \Delta\bar{d}(x) - \Delta c(x) + \Delta\bar{s}(x)$$

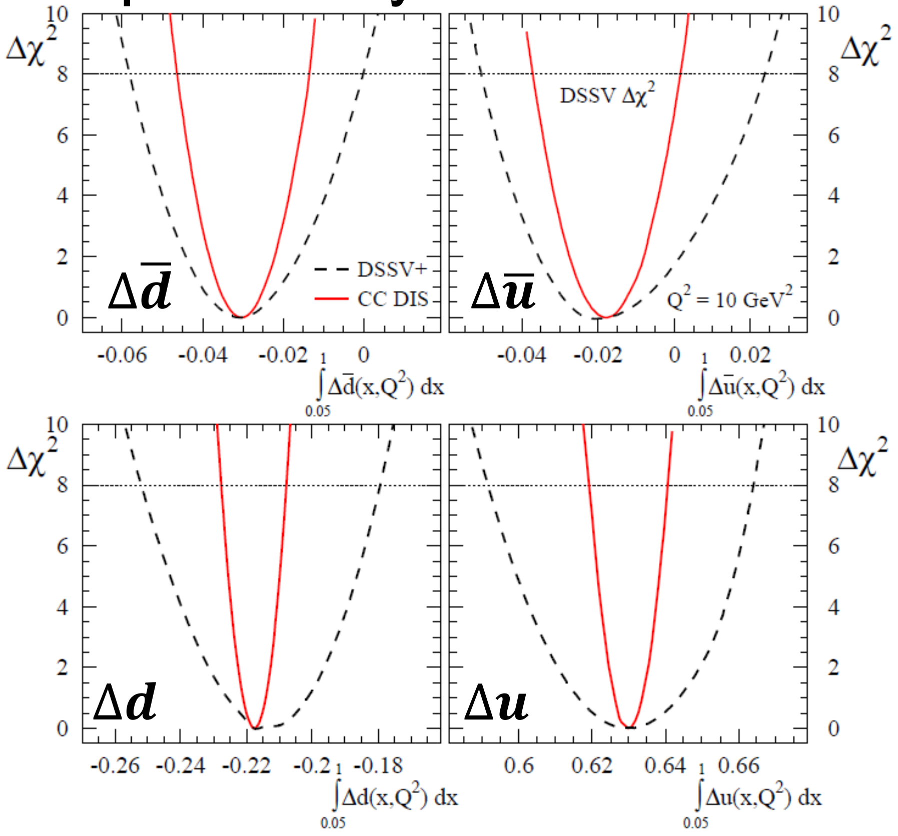
Projected Results for $\int L dt = 10 fb^{-1}$, $p_e = 20$ GeV, $p_p = 250$ GeV

Aschenauer, Burton, Martini, Spiesberger, Stratmann Phys.Rev. D88 (2013) 114025

Asymmetries for p and n (p tagged ^{3}He)



Sensitivity to quark and anti-quark helicity distributions



$0.05 < x < 1$

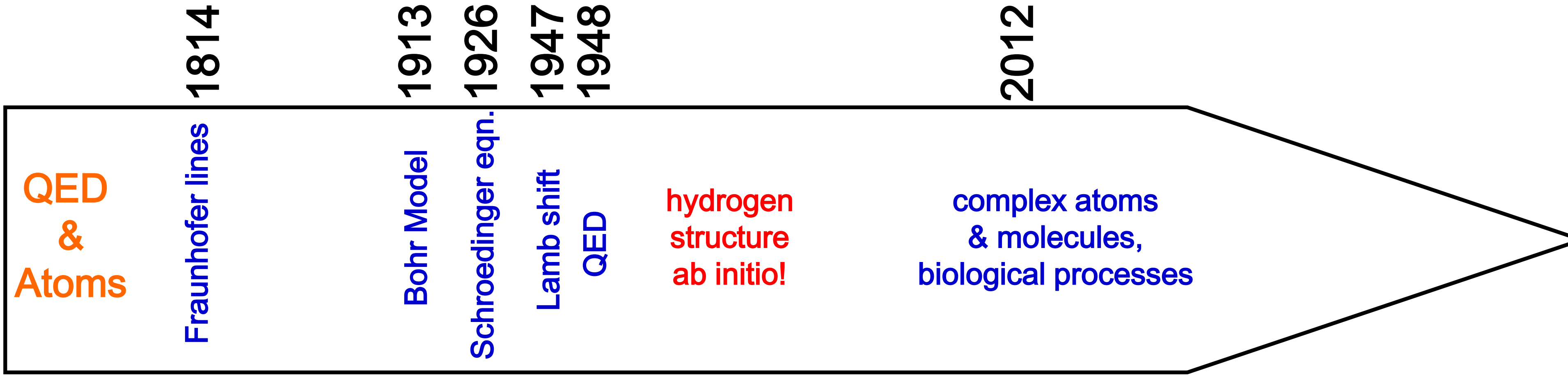
So What?

An EIC can improve the extraction of ΔG to much better precision. If we can measure ΔG up to 1% accuracy, what impact this would have in our understanding of the nucleon? What do we learn from that?

(1) Without a measurement of ΔG in the sea region, $x<0.01$,
it will be not possible to determine the total gluon spin contribution to the proton spin with the precision required to decompose the proton spin into contribution from quark and gluon helicty as well as orbital angular momentum.

(2) The nucleon is the fundamental bound state of the strong interaction.
A quantitative understanding of the nucleon in terms of QCD, will be not attainable without precise experimental information about its parton structure and spin structure in the sea region.

Example EM Force: from Hydrogen Structure to QED to Applications



Observation & Models

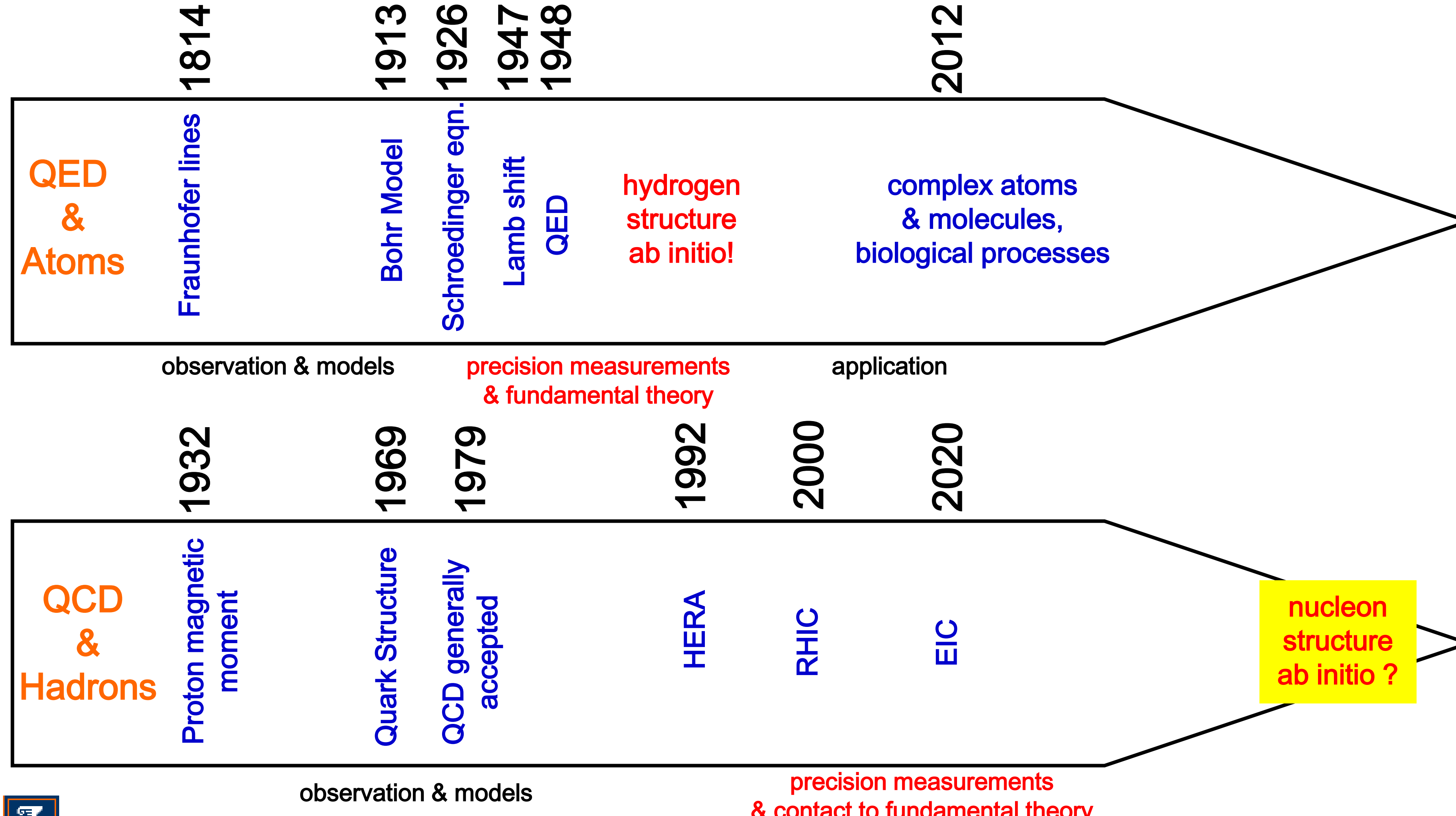
Precision measurements & contact with fundamental theory

Applications

Iterations of measurements with improved instrumentation and increasing precision and the confrontation of the results with theory were critical to the development of QED - Rabi school of physics !

~ 200 year process – many applications only 60 years after establishing QED

EIC: confront QCD with precise information on quark and gluon structure of the proton as input to the development of an ab initio description of the free and bound nucleon



What we might contribute from this meeting:

The white paper summarizes the physics case convincingly and much information on simulations and sensitivities is available.

For the consumption of colleagues taking part in the discussions leading to the new long range plan it might be useful to compose

- o a concise summary of the physics goals of the EIC as described in the white paper, starting from top and then branching into the different subfields.

- o for each important physics topic a set of 3-4 example slides explaining the physics and the impact EIC will have in an as clear as possible way.