The German perspectice on the EIC

Andreas Schäfer (Regensburg University)

Disclaimer: I am not authorized to speak for the German community beyond the EICUG !!

SFB/ TR 55

HRT

BMBF Forschungsschwerpunkt ALICE Experiment 202

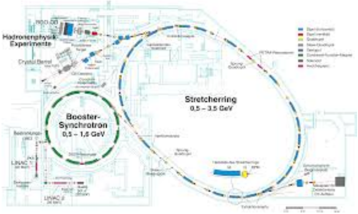
ALICE

EuroPLEx

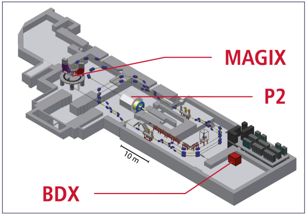
H2020

Germany has a long and very successful history in $e + p/A$ physics

Hera, Hamburg (1990-2007)



ELSA, Bonn



MESA, Mainz

COMPASS, CERN

However, $e + p/A$ physics is uncomfortably situated between the “Hadron and Nucleus” and the “High Energy” communities and funding agencies

- There are the KHuK (hadrons and nuclei) and KET (particle physics) committees competing for federal attention and funding
- COMPASS was funded by particle physics, Hermes by hadron physics, H1 and Zeus by particle physics, MAMI, MESA and ELSA by the States and DFG, ...
- At present both communities try hard to honor extremely expensive commitments: FAIR and HL-LHC
- For the European Long Range Plan 2020 KET and KHuK tried to produce a joint paper but in the end filed independent ones

Still, there is a dedicated community which keeps trying:

ELSEVIER

Nuclear Physics A622 (1997) 46c–49c

NUCLEAR PHYSICS A

The Electron-Nucleus Collider Project

Dietrich von Harrach [a], Volker Metag [b] and Andreas Schäfer [c]

[a] *Institut für Kernphysik, Universität Mainz, D-55099 Mainz, Germany*

[b] *GSI, Planckstr.1, D-64291 Darmstadt, Germany*

[c] *Institut für Theoretische Physik, Universität Frankfurt, D-60054 Frankfurt, Germany*

Abstract

In the context of the discussion about the future physics program of the GSI laboratory the physics potential of an electron-nucleus collider at about $s = 1000 GeV^2$ is being explored.

The KHuK input to the Long Range Plan (contact person Frank Maas, Mainz):

...

Future Projects

1. The full completion of the ESFRI Flagship FAIR with its additional storage rings is of highest priority and strongly recommended.

2. The second highest priority of the European hadron physics community is to participate significantly in the EIC (Electron Ion Collider) program.

...

Note: On the federal level the decision process is fully democratic (KHuK, KET) $\Rightarrow$ It is dominated by the big labs with very many users

In the end the EIC was positively mentionned (twice!) in the European Strategy Update of the CERN Council June,19 2020.

European Strategy Update

2020 Strategy Statements

4. Other essential scientific activities for particle physics

Diverse science at low energy: exploration of dark matter and flavour puzzle

- Change of paradigm for dark matter particles - could be as light as 10^{-22} eV to as heavy as primordial black holes of $10 \times M_{\odot}$
- Observed pattern of masses and mixings of quarks and leptons, remains a puzzle
- Physics Beyond Colliders study identified many high impact options with modest investment
- Larger scale new facilities such a the Beam Dump Facility, and later LHeC option at CERN, difficult to resource within the CERN budget, considering the other recommendations of this Strategy
- Improvements in the knowledge of the proton structure needed to fully exploit the potential of present and future hadron colliders - added value from fixed target experiments and from Electron Ion Collider (CD0) in BNL
- Given the challenges faced by CERN in preparing for the future collider, the role of the National Laboratories in advancing the exploration of the lower energy regime cannot be over-emphasised (ex. axions at DESY, rare muon decays in PSI, dark photon in Frascati)

a) The quest for dark matter and the exploration of flavour and fundamental symmetries are crucial components of the search for new physics. This search can be done in many ways, for example through precision measurements of flavour physics and electric or magnetic dipole moments, and searches for axions, dark sector candidates and feebly interacting particles. There are many options to address such physics topics including energy-frontier colliders, accelerator and non-accelerator experiments. A diverse programme that is complementary to the energy frontier is an essential part of the European particle physics Strategy. *Experiments in such diverse areas that offer potential high-impact particle physics programmes at laboratories in Europe should be supported, as well as participation in such experiments in other regions of the world.*

19/06/2020 CERN Council Open Session 21

All of this is better than nothing but less than what you would hope for.

There is much interest, also from experiment, e.g. Iris Abt, Allen Caldwell, Frank Maas, but there are only very limited resources. Hadron physis: The flagship is FAIR

At present and in the mid-term future only a large scale DFG theory effort is realistic.

DFG funding comes on different levels:

- normal projects
- Research Units
- Cooperative Research Centers

Since last fall we (V. Braun (spokesperson), M. Diehl, S. Moch, W. Vogelsang etc.) have a joint Research Unit: "Next Generation Perturbative QCD for Hadron Structure: Preparing for the EIC"

Our present CRC "Hadron Physics from Lattice QCD" runs out end of the year. We are presently working on the preproposal for a new CRC "High Precision Hadron Physics: The EIC and Beyond"

We work towards a network encompassing everybody working on EIC theory in Germany (e.g. also Michael Klasen)

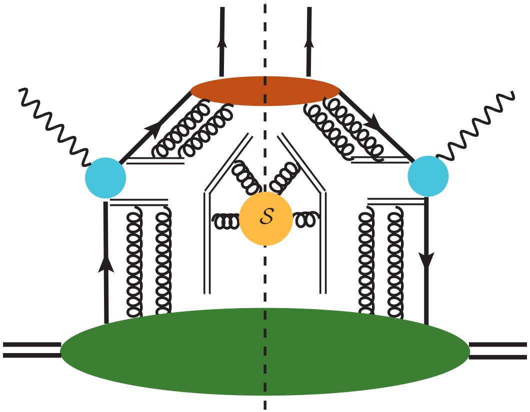
So, what can we offer ?

The idea is to focus on pQCD, LQCD and AI input to the EIC.

Make full usage of the high EIC luminosity requires tight control of all systemaic uncertainties. This requires an organic combination of pQCD+LQCD with experiment.

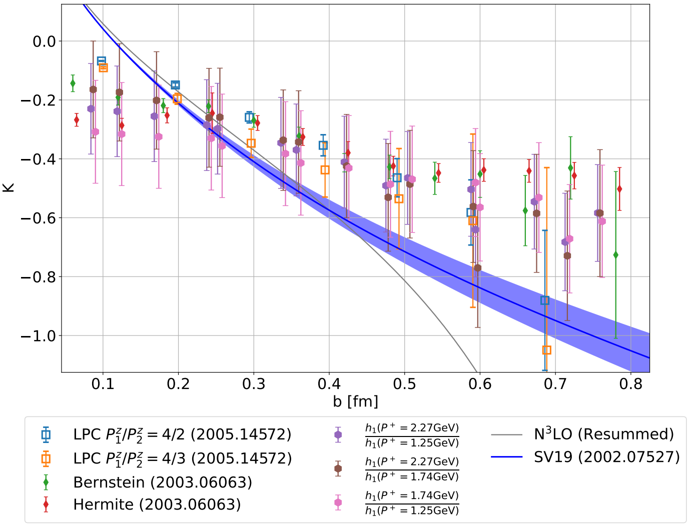
One recent example: The Collins-Soper kernel for rapidity evolution of TMDs (certainly of prime importance for the EIC)

Factorizing with a soft factor, which introduces a rapidity dependence



This results in two Renormalization Group Equations

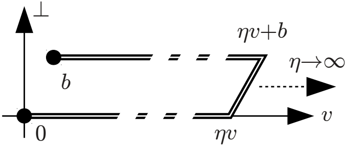
$$
\begin{aligned}
\mu \frac{d}{d\mu}\ f_i^{\mathrm{TMD}}(x, \vec{b}_T, \mu, \zeta) &= \gamma_\mu^i(\mu,\zeta) f_i^{\mathrm{TMD}}(x, \vec{b}_T, \mu, \zeta) \\
\zeta \frac{d}{d\zeta}\ f_i^{\mathrm{TMD}}(x, \vec{b}_T, \mu, \zeta) &= \frac{1}{2} K(\mu, b_T) f_i^{\mathrm{TMD}}(x, \vec{b}_T, \mu, \zeta) \\
\mu \frac{d}{d\mu} K(\mu, b_T) &= 2\zeta \frac{d}{d\zeta} K(\mu,\zeta) = -2\Gamma^i_{\mathrm{cusp}}[\alpha_s(\mu)] \\
f_i^{\mathrm{TMD}}(x, \vec{b}_T, \mu, \zeta) &= f_i^{\mathrm{TMD}}(x, \vec{b}_T, \mu_0, \zeta_0)\ \exp\left[\int_{\mu_0}^{\mu} \frac{d\mu'}{\mu'}\ \gamma_\mu^i(\mu', \zeta_0)\right] \\
&\times \quad \exp\left[\frac{1}{2} K(\mu, b_T) \ln \frac{\zeta}{\zeta_0}\right]
\end{aligned}
$$



Regensburg: ratios **preliminary** ; Bernstein, Hermite: The MIT method LPC: LaMET; SV19 a pQCD fit to data

The ratio method, A. Vladimirov et al. arXiv:2002.07527

B. Yoon *et al.* Phys. Rev. D **96** (2017) 094508;
arXiv:1706.03406 based on the assumption that soft factors as well as renormalization factors cancel in ratios.
various extrapolations are required



We simulate for spatial, not light-like separations, but the limit $\hat{\zeta} \to \infty$ of

$$\hat{\zeta} \; := \; \frac{v \cdot P}{\sqrt{v^2}\sqrt{P^2}}$$

reproduces the light-cone behavior.

We define moments and leading terms of a Taylor expansion in $\vec{k}_T$.

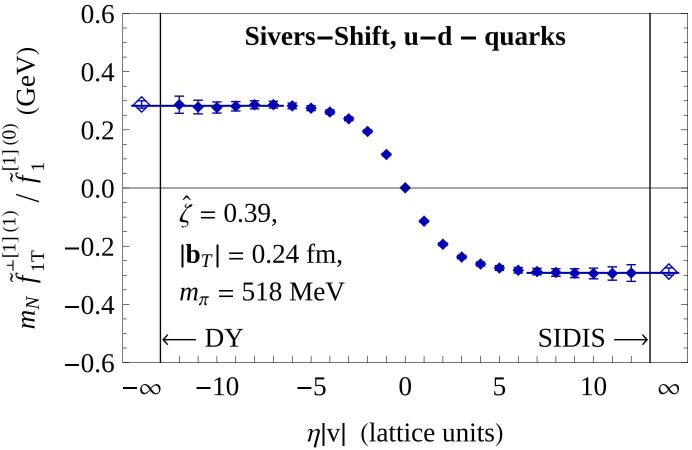
$$f[m](n)(...) = \int_{-1}^{1} dx\, x^{m-1} \int d^2k_T \left(\frac{\vec{k}_T^2}{2m_N^2}\right)^2 f(x, \vec{k}_T^2, ...)$$

and calculate "generalized shifts"

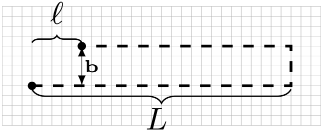
$$\begin{aligned}
\langle \vec{k}_y \rangle_{TU}(\vec{b}_T^2; \hat{\zeta}, \eta v \cdot P) &= m_N \frac{\tilde{f}_{1T}^{\perp[1](1)}(\vec{b}_T^2; \hat{\zeta}, \ldots, \eta v \cdot P)}{\tilde{f}_1^{[1](0)}(\vec{b}_T^2; \hat{\zeta}, \ldots, \eta v \cdot P)} \\
&= -m_N \frac{\widetilde{A}_{12B}(-\vec{b}_T^2, 0, 0, -1/(m_N\hat{\zeta})^2, \eta v \cdot P)}{\widetilde{A}_{2B}(-\vec{b}_T^2, 0, 0, -1/(m_N\hat{\zeta})^2, \eta v \cdot P)} \\
\overset{b_T \to 0}{\Longrightarrow} &\quad \left. \frac{\int dx \int d^2k_T\, k_y\, \Phi^{[\gamma^+]}(x, \vec{k}_T, P, S; \ldots)}{\int dx \int d^2k_T\, \Phi^{[\gamma^+]}(x, \vec{k}_T, P, S; \ldots)} \right|_{\vec{S}=(1,0)}
\end{aligned}$$

In leading twist: Shift in y direction in a nucleon polarized in x direction for two unpolarized quarks with separation $\vec{b}_T$

$\eta \to \pm\infty$



requires: $\eta \to \pm\infty$; and large ζ

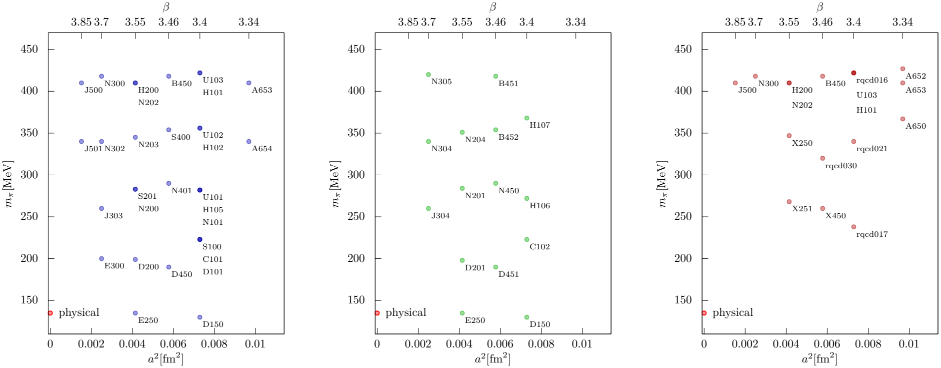


$$\mathbf{R}^{(n)} = \left(\frac{P_2^+}{P_1^+}\right)^{n-2} \frac{\partial_\ell^{n-1} W_{f\leftarrow h}^{[\Gamma]}(P_1)}{\partial_\ell^{n-1} W_{f\leftarrow h}^{[\Gamma]}(P_2)}\Bigg|_{\ell=0} = \left(\frac{P_2^+}{P_1^+}\right)^{-K(\mu,b)} \mathbf{r}^{(n)} + \mathcal{O}(\lambda)$$

$$\mathbf{r}^{(n)} = 1 + 4C_F \frac{\alpha_s(\mu)}{4\pi} \ln\left(\frac{P_1^+}{P_2^+}\right)\left[1 - \ln\left(\frac{4P_1^+ P_2^+ |v^-|^2}{\mu^2}\right) - 2\mathbf{M}_{\ln|x|}^{(n),\Gamma}(\mu, b)\right] + \mathcal{O}(\alpha_s^2)$$

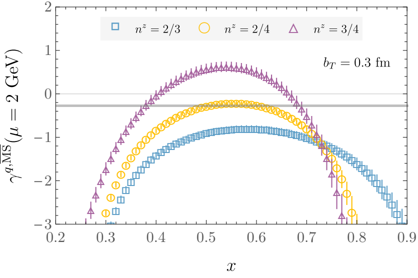
$$\mathbf{M}_{f(x)}^{(n),\Gamma}(\mu, b) = \frac{\int dx f(x)\, |x|^{K(\mu,b)+n-1} \Phi_{f\leftarrow h}^{[\Gamma]}(x, b; \mu, \zeta_0)}{\int dx |x|^{K(\mu,b)+n-1} \Phi_{f\leftarrow h}^{[\Gamma]}(x, b; \mu, \zeta_0)}$$

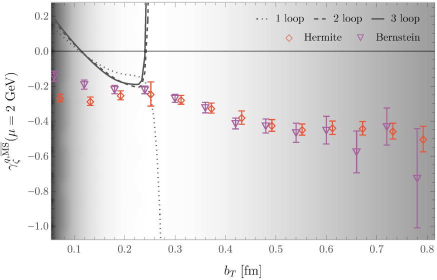
We used CLS ensembles



The MIT method arXiv:2003.06063

quenched, heavy valence quarks; the big numerical problem is the Discrete Fourier Transformation

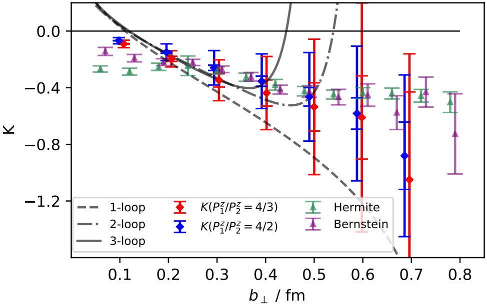




The trick is to first parameterize the beam function and then Fourier transform the resulting curve.

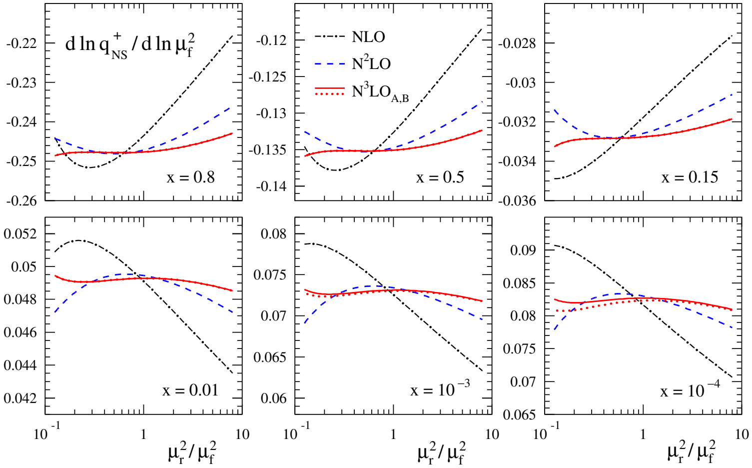
LaMET arXiv:2005.14572

as a side product of calculation the TMD soft factor one also gets the CS kernel. Statistical errors are small, but systematic ones (the imaginary part of the quasi-TMD should be zero) are large ⇒ lattice artefacts, smaller a is needed.



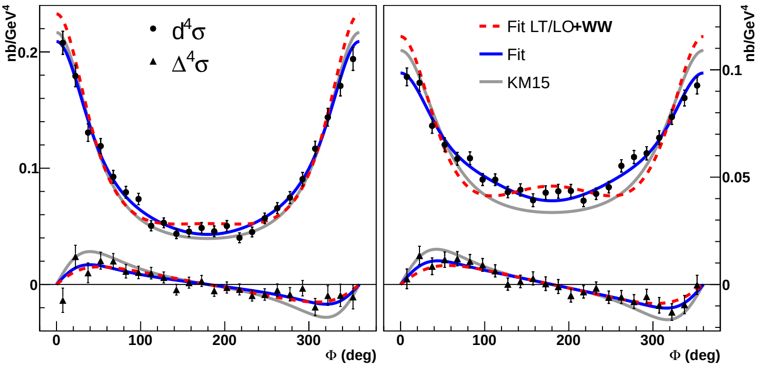
FOR 2926

- P1: QCD evolution at one percent precision Braun, Kniehl, Moch
- P2: Parton distributions and fragmentation functions Kniehl, Moch, Vogelsang
- P3: Multi-parton interactions and higher twist effects Braun, Diehl
- P4: Semi-inclusive reactions from low to high p_T Vladimirov, Vogelsang
- JRP: Theoretical and experimental interplay to optimize the EIC design Zurita



Moch, Ruijl, Ueda, Vermaseren, Vogt, arXiv:1707.08315

reduction of scale dependence with increasing order



Braun, Manashov, Müller and Pirnay, arXiv:1401.7621

Higher Twist corrections to DVCS, Hall A; beam energy $E_{\rm beam} = 4.455$ GeV (left) and $E_{\rm beam} = 5.55$ GeV (right); $Q^2 = 1.75\,{\rm GeV}^2$; $x_B = 0.36$; $t = -0.30\,{\rm GeV}^2$

We also build computers and develop specialized software.

QPACE 3 (1.8 PFlop/s in Jülich)

Summary

- In Germany there is great interest but little free money
- Right now theory is probably the only feasible option for an EIC initiative
- A significant group has already come together (Bali, Braun, S. Collins, Diehl, Jäger, Kniehl, Lehner, Moch, Pleiter, Stratmann, Vladimirov, Vogelsang, Wettig ...) and is trying to extend.
- We can offer a pretty unique combination of high precision pQCD, LQCD and sophisticated computer developments. (Presently, University of Regensburg creates a faculty for Computer Sciences.)
- Institutionalized links to the US are of key importance.