Some EF06 highlights - SEC perspective

Maria Vittoria Garzelli,

with input from

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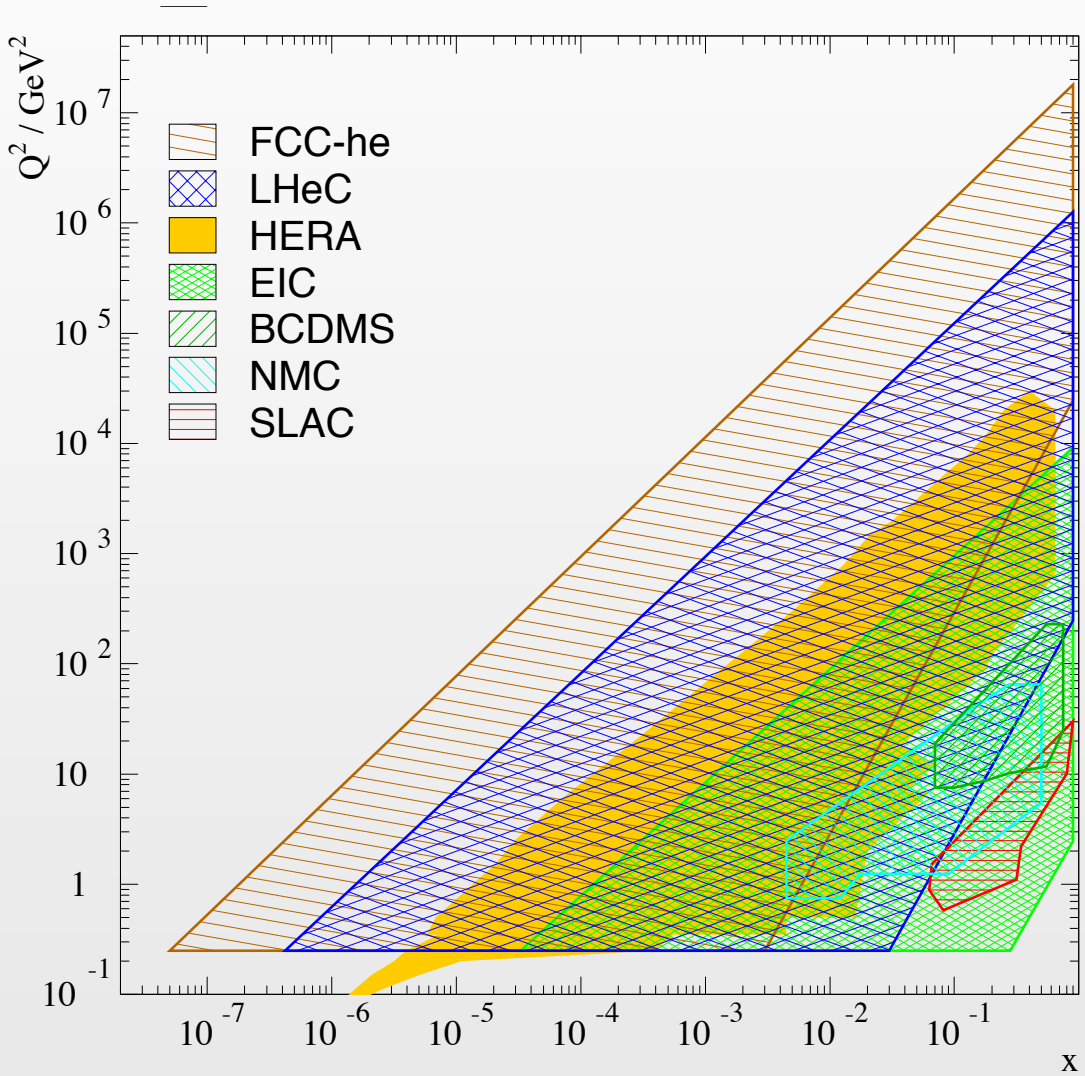
Hamburg Universität, II Institut für Theoretische Physik

on the basis of (recently published works + work in progress)

Snowmass day

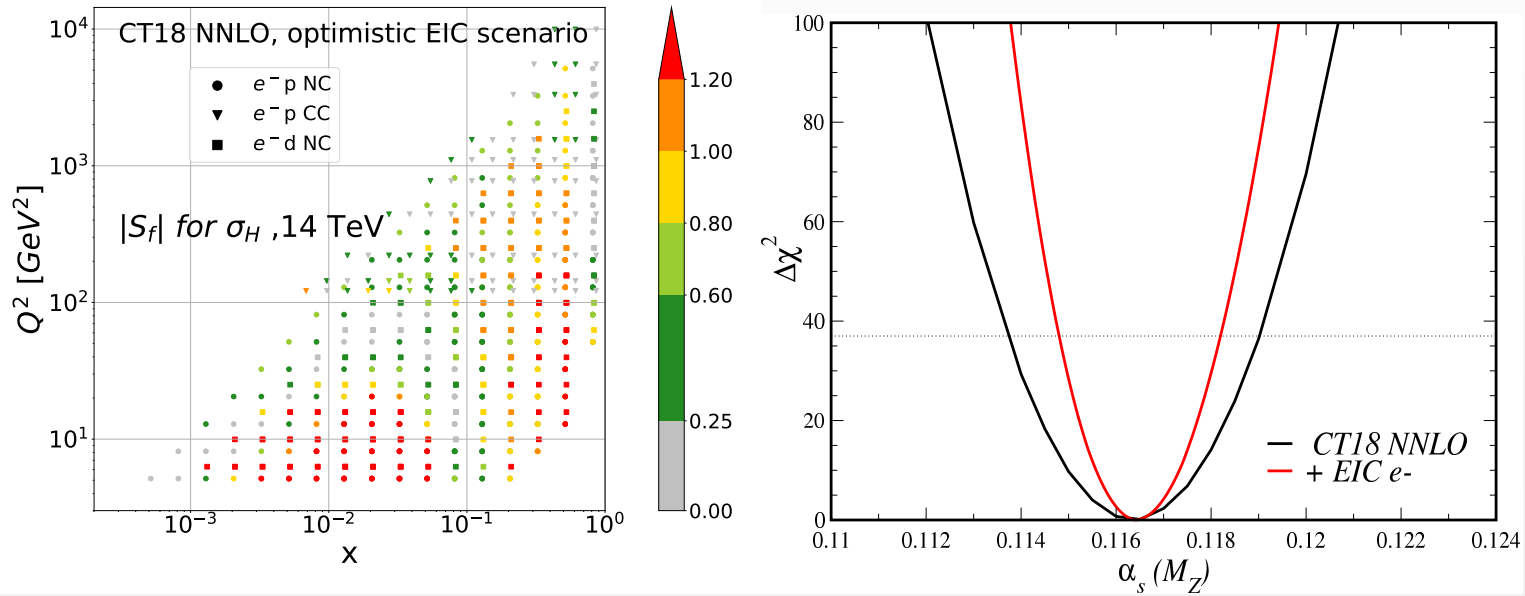
September 24th, 2021

Complementarity between EIC, LHeC and FCC-he DIS in constraining the proton structure



from the LHeC Report, [arXiv:2007.14491]

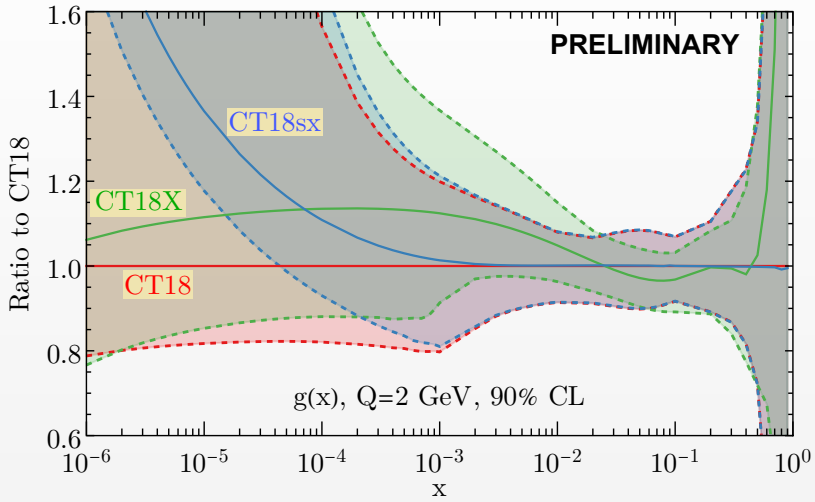
PDF sensitivity of 100 fb^{-1} EIC pseudodata and constraints on α_S

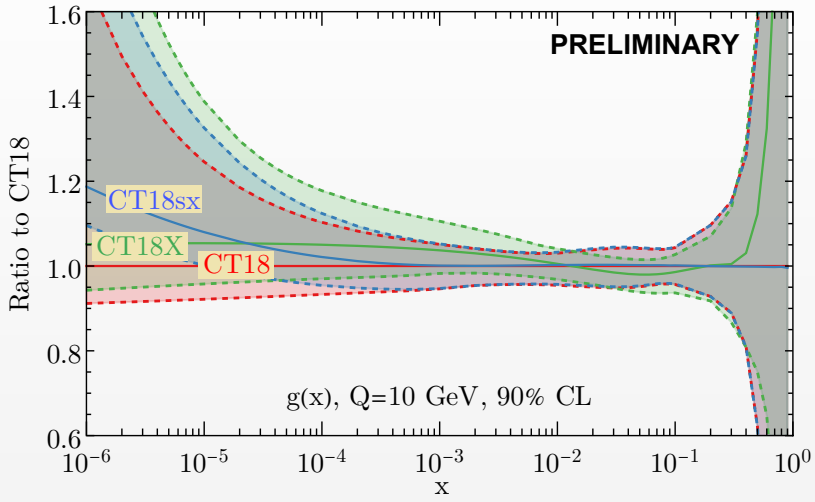


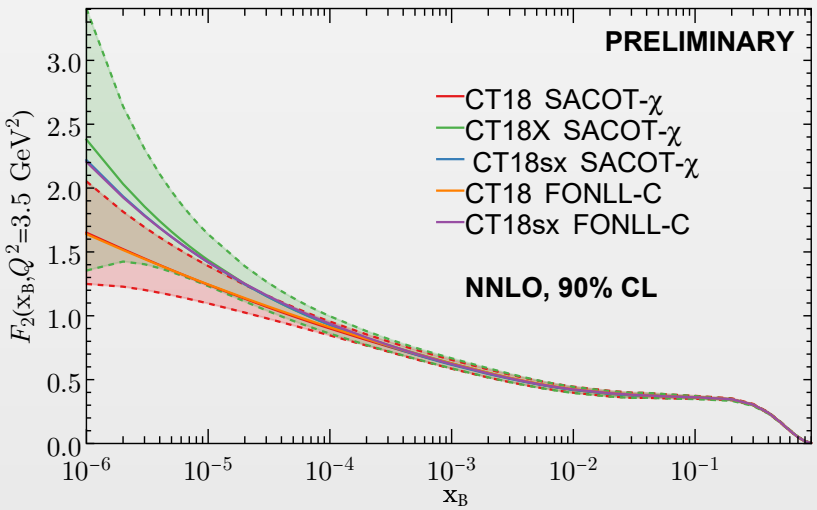
* point-by-point PDF sensitivity of EIC pseudodata generated in the EIC YR studies to the σ_H
  $\Rightarrow$ constraints for LHC phenomenology
* impact of 100^{-1} fb of EIC inclusive pseudodata on α_s uncertainties.
  $\Rightarrow$ EIC as a precision QCD facility
* PDFsense: tools for fast assessment of data impact on QCD analyses [PRD98 (2018) 094030].

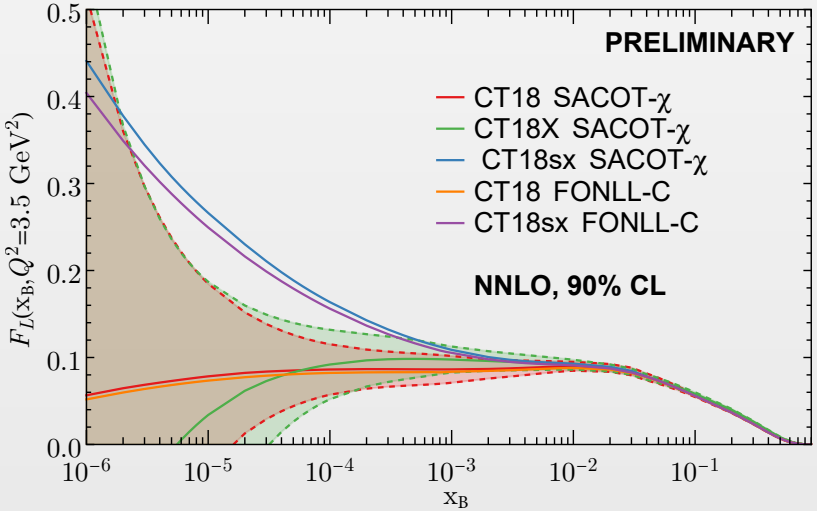
T. Hobbs et al., EIC Yellow Report and DIS2021 Proceedings

Small-x PDFs and implications for F_2 and F_L structure functions





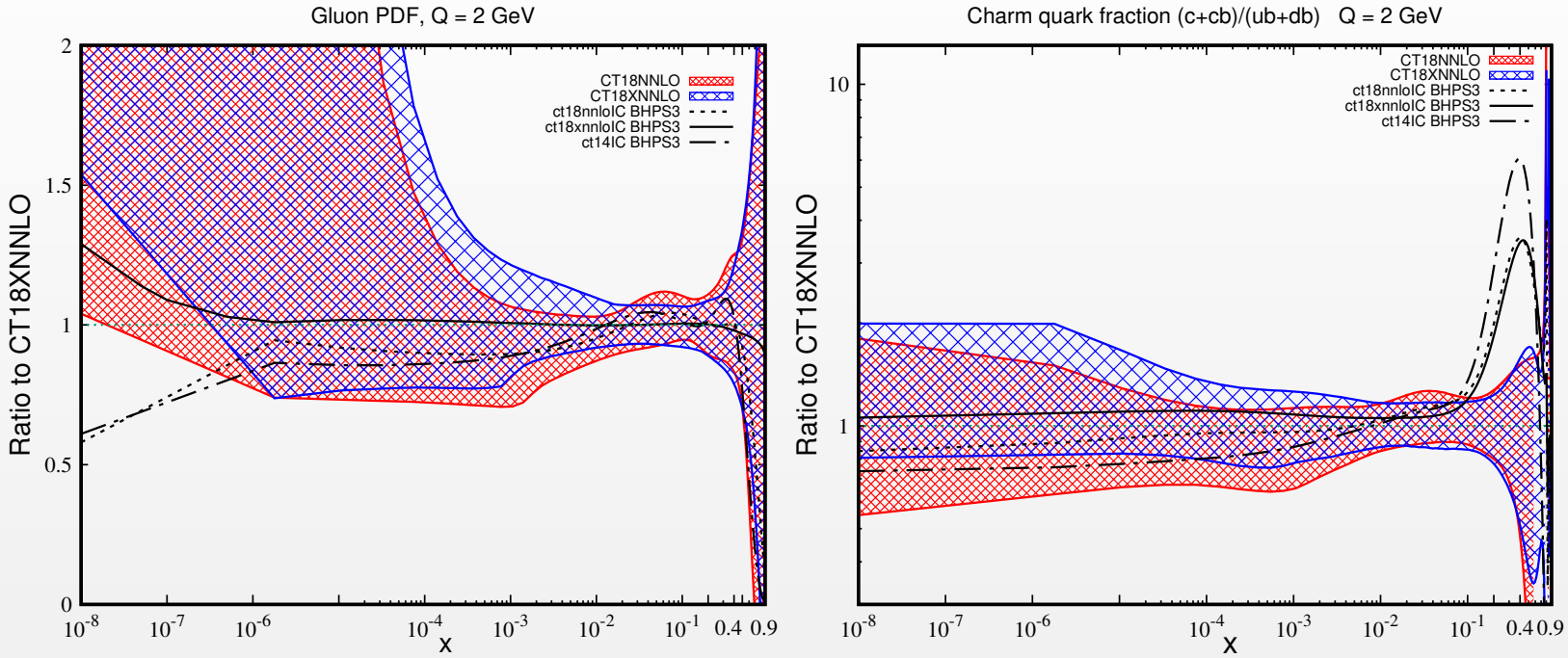




PDF fits differing for the small-x theory treatment (BFKL NLL $ln(1/x)$ resummation / saturation through effective $\mu_{F,DIS}$)

K. Xie et al., DIS2021 proceedings

PDFs with intrinsic charm



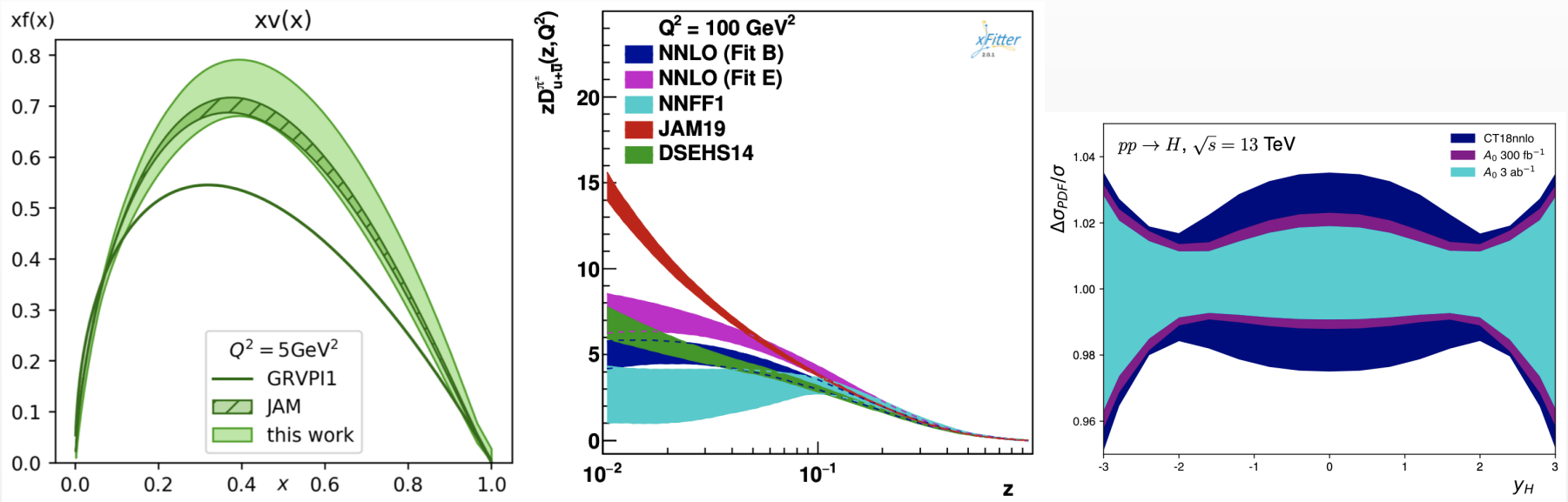
∗ non-perturbative contribution from power-suppressed scattering processes in DIS.

∗ IC introduced as phenomenological parameterization, determined in a global QCD analysis.

∗ Impact on forward heavy-flavour production → astroparticle physics

M. Guzzi et al., DIS2021 Proceedings and 1st FPF manuscript

xFitter recent developments



* extraction of pion PDFs [arXiv:2002.02902]
* extraction of pion FFs [arXiv:2105.11306]
  see also recent independent work by Abduh-Kalek et al. [arXiv:2105.08725]
* PDF profiling with A_0 pseudodata and constraints on σ_H [arXiv:2012.10298]

F. Giuli, O. Zenaiev et al.

Towards N3LO PDFs....

∗ Huge Snowmass EF06 effort

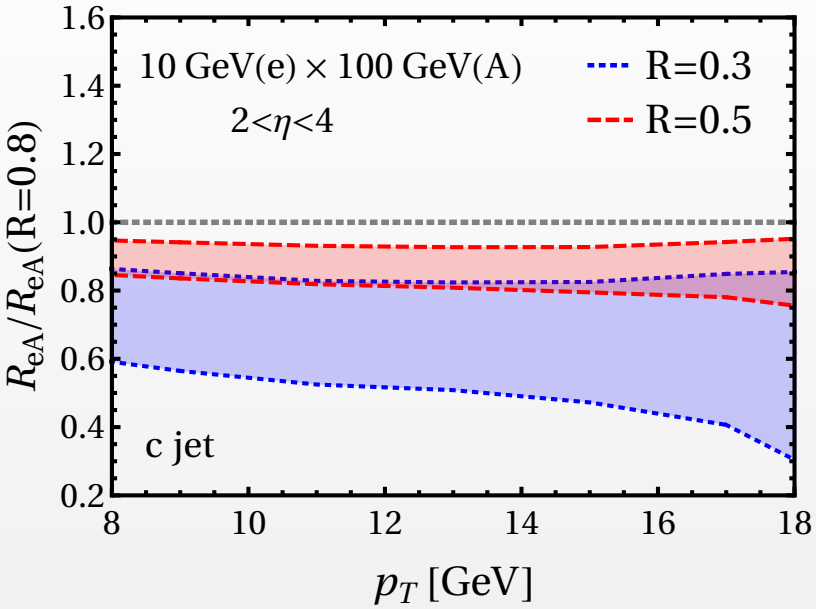
∗ 4-loop non-singlet splitting functions in the planar limit and beyond in [arXiv:1707.08315]

∗ Non-singlet structure functions in DIS at 4-loop: paper in preparation....expected to be published this year.

∗ 4-loop singlet splitting functions: work in progress....

B. Ruijl et al.

Heavy-flavour jets at the EIC



Ratio of nuclear modification factor R_{eA} for jets with R=0.3 and R=0.5 w.r.t. $R_{eA}(R = 0.8)$.

∗ The modification can be large - close to a factor ~ 2, especially for small jet radii.

∗ Significant modification of *c*-jet in *eA* w.r.t. *ep*.

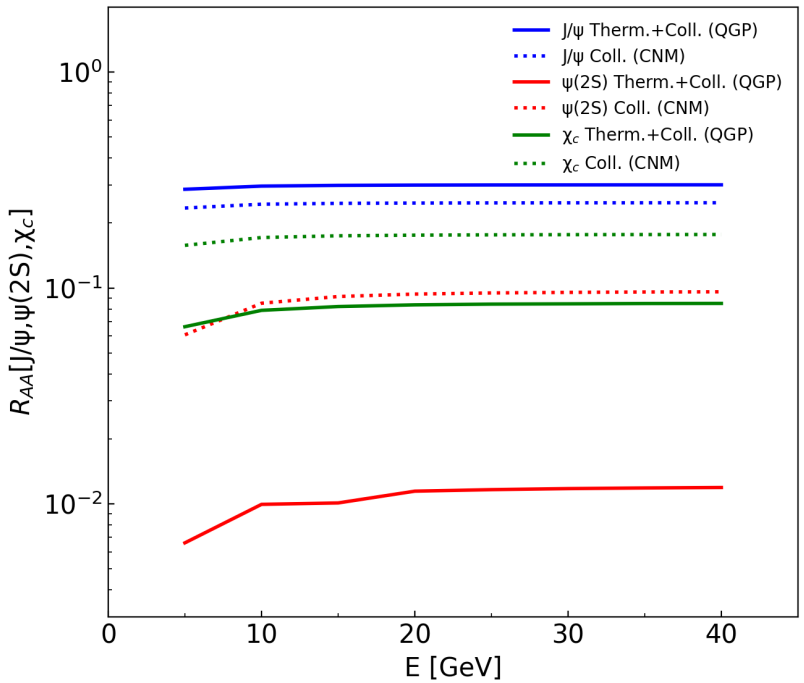
∗ initial and final-state effects can be separated: the ratio plotted here is sensitive to FSI effects

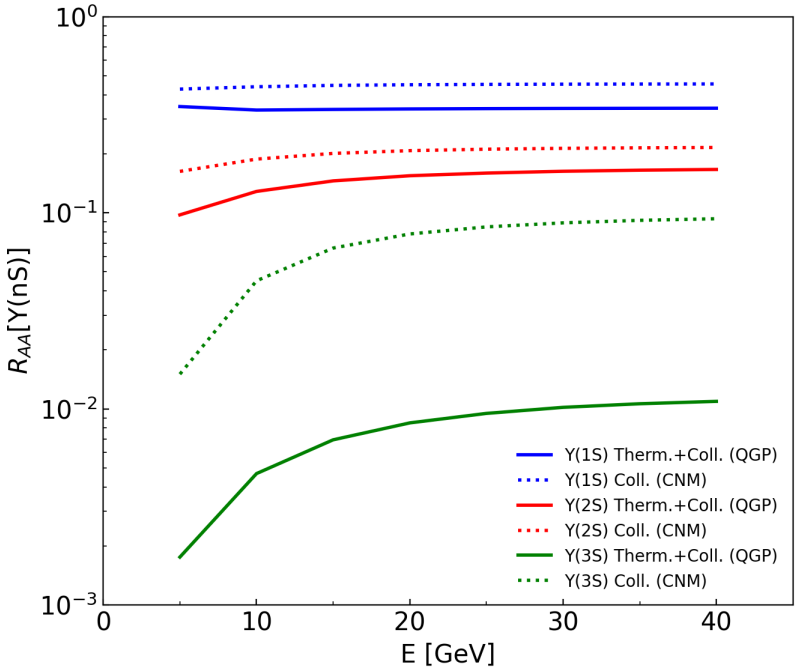
∗ c-jet production has also a large sensitivity to *g* distribution

∗ Small-*R* heavy-flavour jet suppression increases with increasing rapidity.

Z. Liu et al. [arXiv:2108.07809]

Nuclear modification factors for J/ψ and Υ states

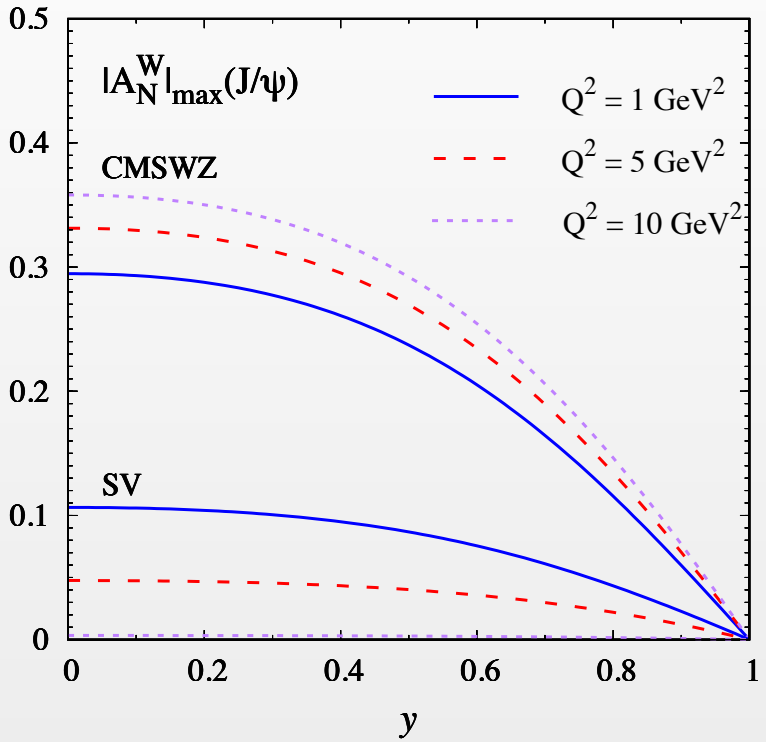


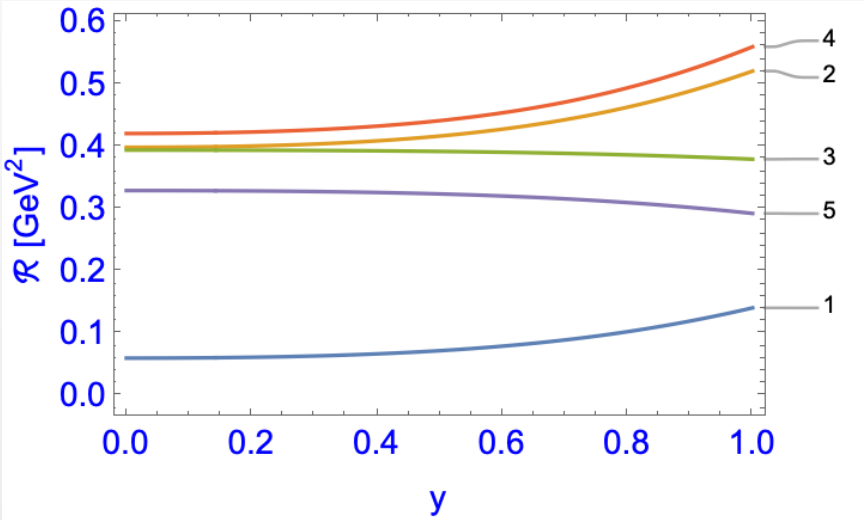


I. Olivant et al. (2021)

* Different sources of suppression (CNM and QGP effects)
* Promising program at the EIC.....

Probing SIDIS gluon TMDs with Quarkonium and $c\bar{c}$ jet production in SIDIS at EIC ?





* Extraction of gluon TMDs hampered by our poor knowledge of quarkonia LDMEs, fitted at large k_T.

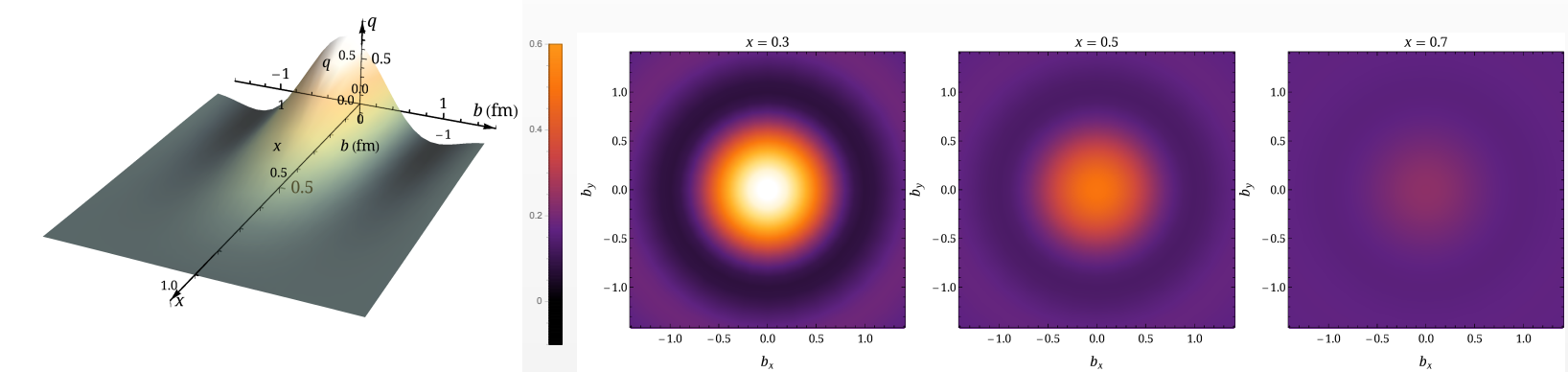
* LDMEs generalized to k_T-dependent shape functions in low-k_T regime, whose k_T dependence is calculated from the matching of collinear and TMD calculations.

* Knowing TMDs from other processes it is possible to use maxima of properly defined asymmetries to constrain LDME.

* Ratios between partially integrated cross-sections for quarkonium and open $c + \bar{c}$-jets production do not depend on TMDs (at least at LO) and might allow to extract the shape functions.

P. Taels et al. [arXiv:1809.02056], [arXiv:2102.00003]

Nucleon tomography from GPDs



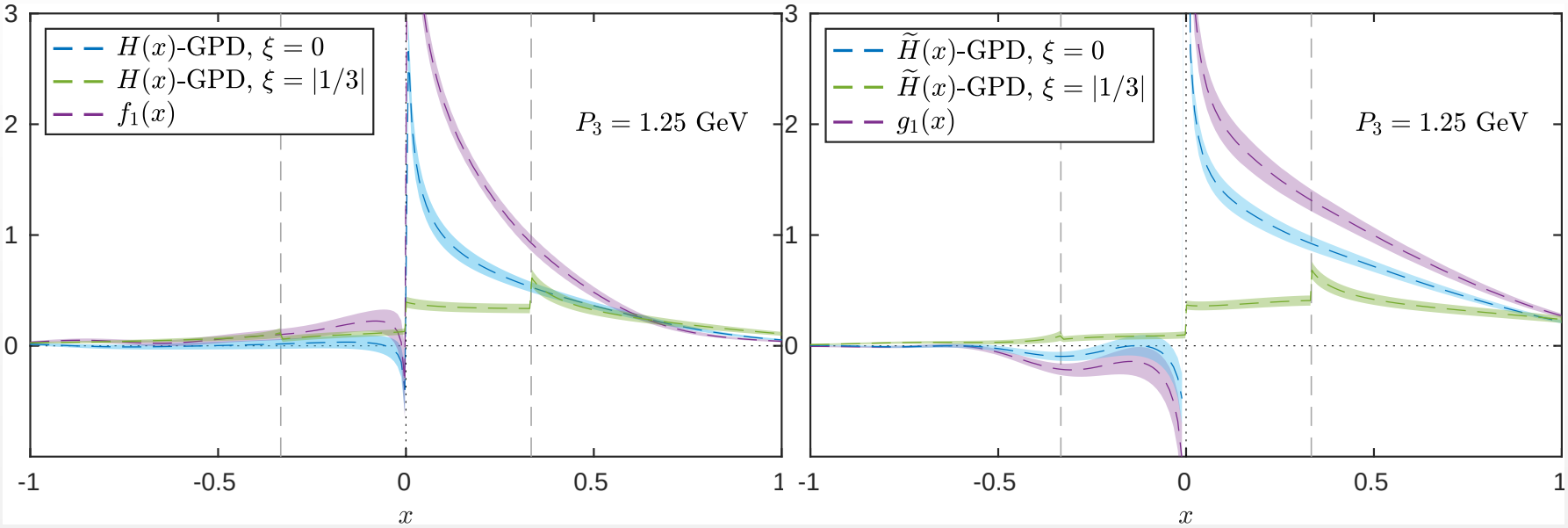
∗ Nucleon tomography: three-dimensional impact parameter–dependent parton distribution as a function of x and b from F.T. of lattice H at physical pion mass.

∗ The two-dimensional impact-parameter–dependent distribution $q(x, b)$ at fixed $x = 0.3$, 0.5 and 0.7: at large x distribution shrinks.

∗ Under study: lattice systematics

Huey-Wen Lin, [arXiv:2008.12474]

unpolarized and helicity GPDs



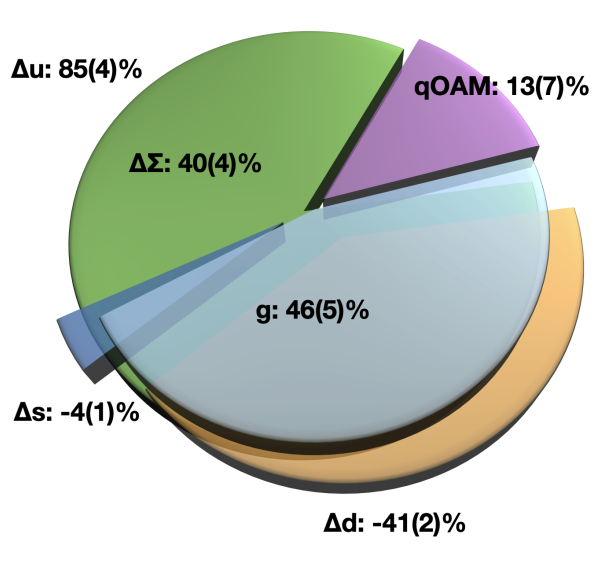
∗ Comparison between the PDFs and the GPDs at zero and non-zero skewness for GPD H and $\tilde{H}$. The nucleon momentum boost is 1.25 GeV.

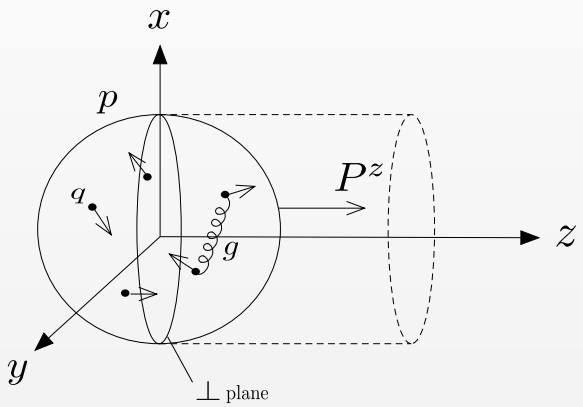
∗ For GPDs at nonzero ξ an ERBL region ($|\xi| < 1/3$ in our case) appears, differentiating it from the DGLAP region ($|\xi| > 1/3$).

∗ The behavior of the GPDs as a function of t for a fixed x is as expected, i.e. increasing $-t$ suppresses the GPDs.

ETMC Collaboration, PRL 125 (2020), 262000

Proton spin decomposition and transverse spin





∗ proton spin decomposition on the basis of lattice calculation of χQCD collaboration PRD 98 (2018) 074505 (+ G. Wang, in preparation)

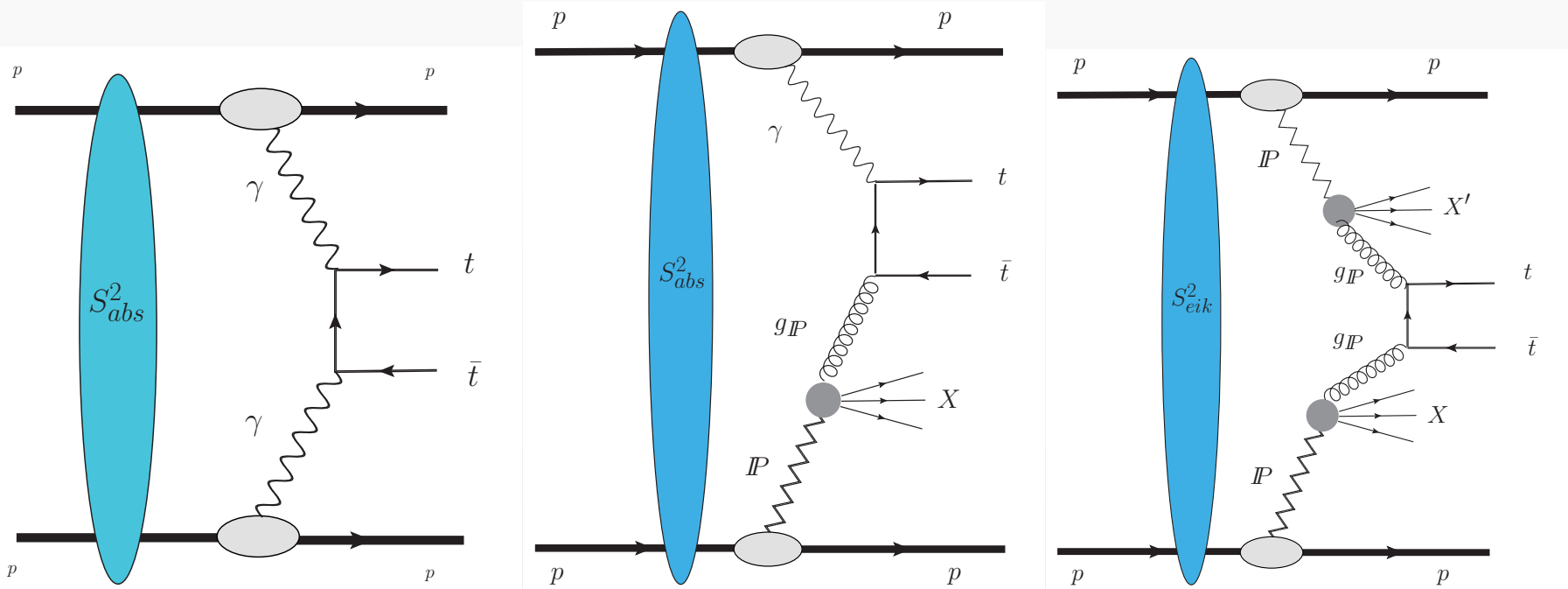
∗ Ongoing evaluation of systematics (excited state contaminations - non-pert. renormalization - lattice volume/spacing)

∗ New twist-3 partonic sum rule for the p transverse spin in Y. Guo et al., NPB 969 (2021) 115440, complementing the Manohar and Jeffe one already existing for the longitudinal spin.

∗ Partonic canonical angular momentum densities related to a new class of twist-3 GPDs measurable in deeply-virtual exclusive processes

Y. Zhao et al.

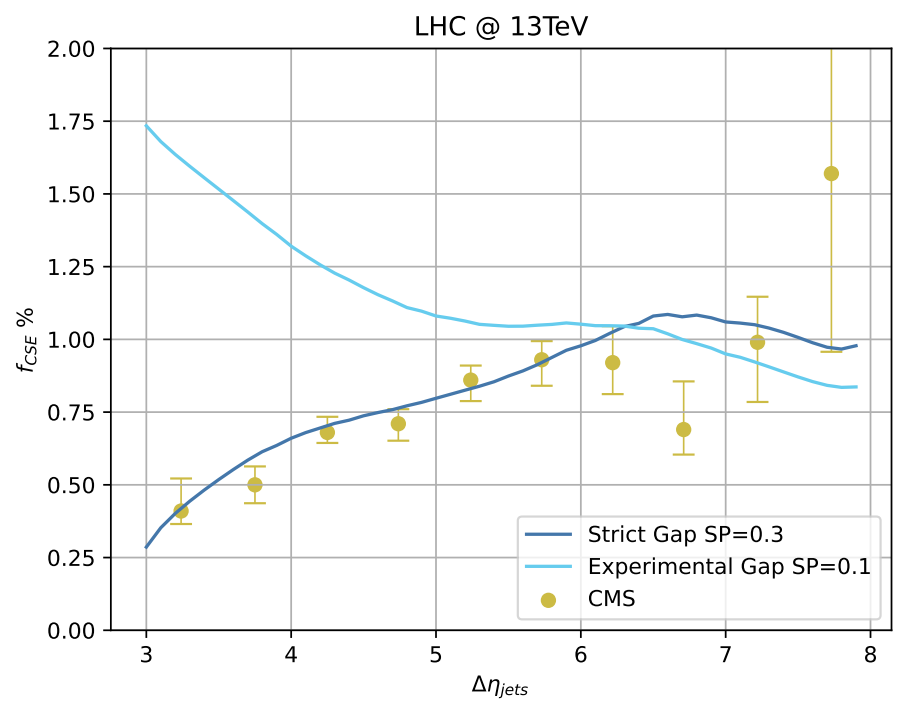
$t\bar{t}$ pair production in exclusive and semi-exclusive processes at the LHC

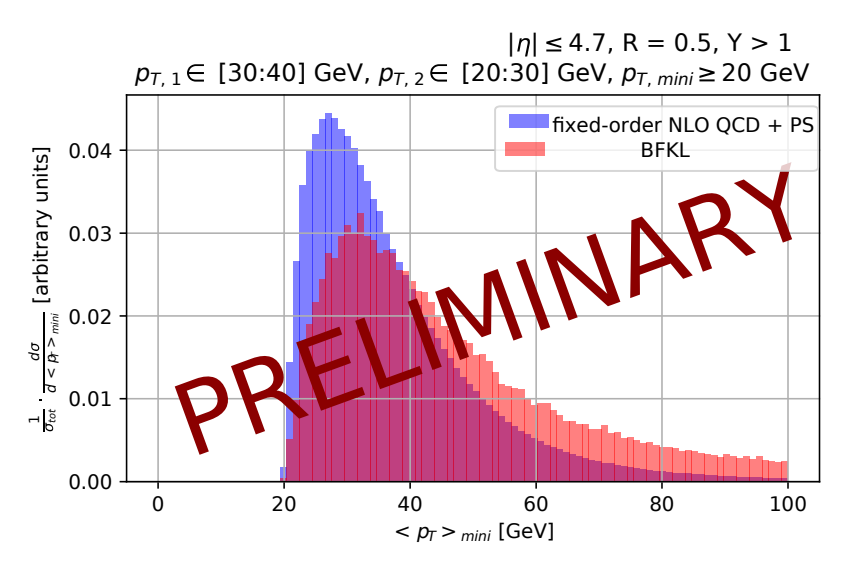


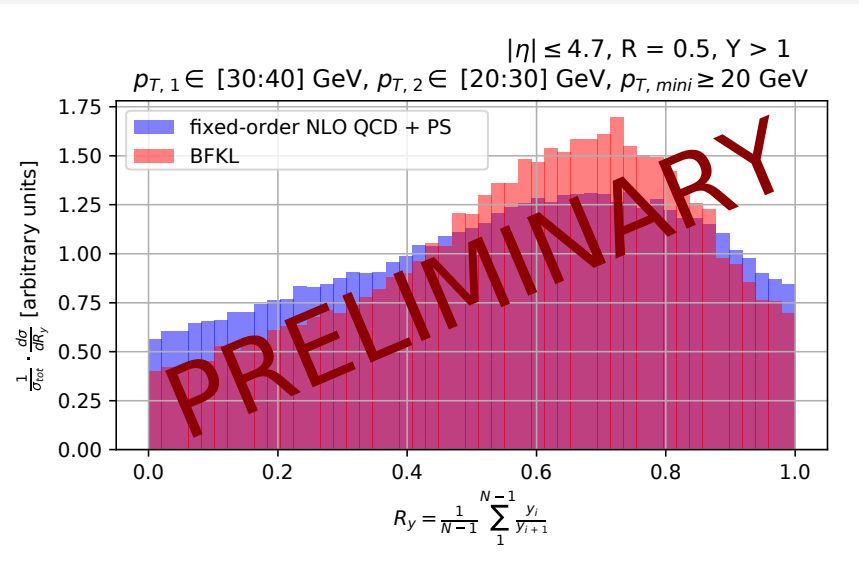
* Possibility of observing exclusive signal above background
* Not enough sensitivity for competitive m_t determinations

D. Martins et al. (2020)

Mueller-Tang and Mueller-Navelet jets

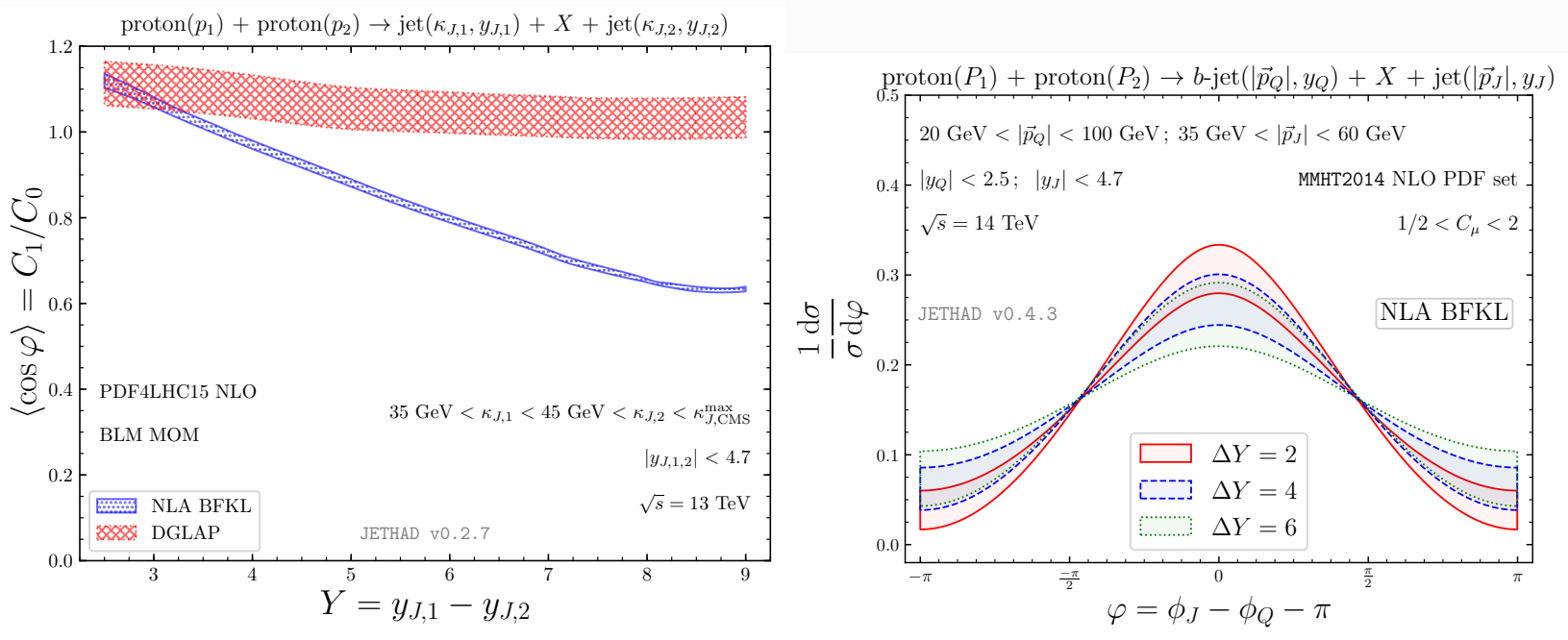






C. Baldenegro, F. Doganutti, P. Gonzalez, M. Kampshoff, J. Salomon et al.

Mueller-Navelet jets (light and heavy)



F. Celiberto, [arXiv : 2008.07378] *M. Fucilla et al.*

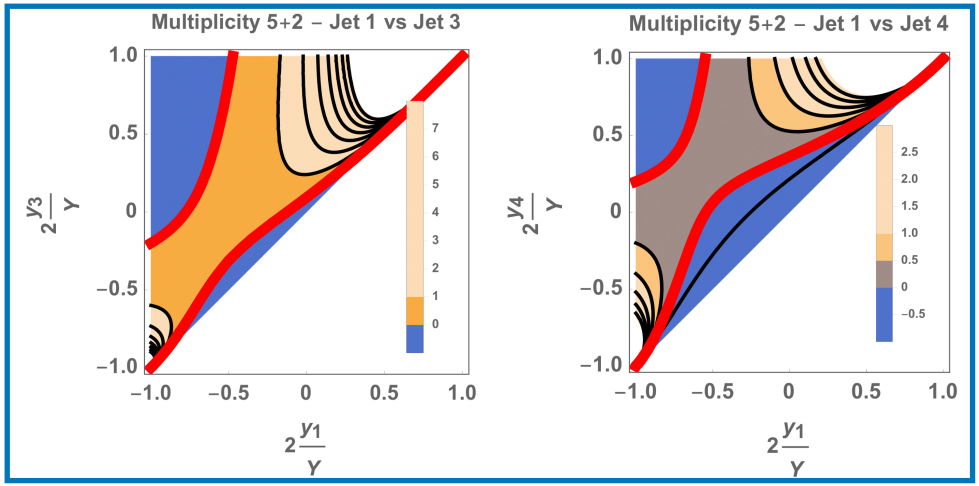
* Asymmetric cuts and discrimination BFKL/DGLAP: is the NLA approximation stable enough ?
* Loosing correlations at large rapidity due to increased phase-space for BFKL emissions.

Rapidity-rapidity correlations between jets: An old multiperipheral model vs pQCD

Multiperipheral Models were developed (Amati, Fubini, Chew, Pignotti, …) ~60 years ago to describe high energy scattering. “High energy” back then meant s ~ (few tens of GeVs.) A key idea was that particle production takes place in “**clusters**” and that there is decoupling of the longitudinal (rapidity) and transverse degrees of freedom.

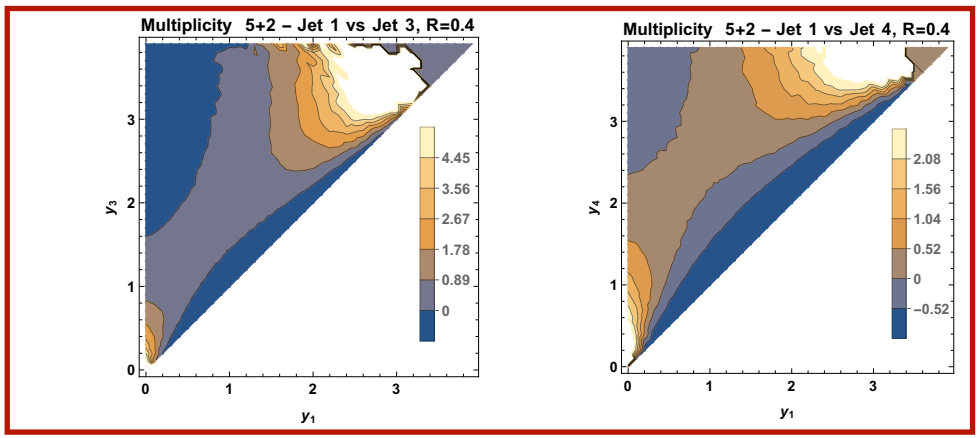
See G. F. Chew, A. Pignotti, Phys. Rev. 176, 2112-2119 (1968), C. E. DeTar, Phys. Rev. D 3, 128-144 (1971)

The Chew-Pignotti model was applied naively to multi-jet final states at the LHC. The rapidity-rapidity correlations, are shown in the plots to the right, the jet multiplicity was set to (5+2). 2 jets are the outermost jets in rapidity and 5 jets have rapidities in between. The correlations are studied for the 5 jets in between. Plotted correlations: jet_1 and jet_3 (left) and jet_1 and jet_4 (right).



The same rapidity-rapidity correlations were studied with **BFKLex**, a MC code that implements the BFKL dynamics. BFKL is a pQCD resummation program to all orders of large logarithms of the form (αs lns)^n relevant at the high energy limit. Plots layout same as for Chew-Pignotti. **The similarities are striking.**

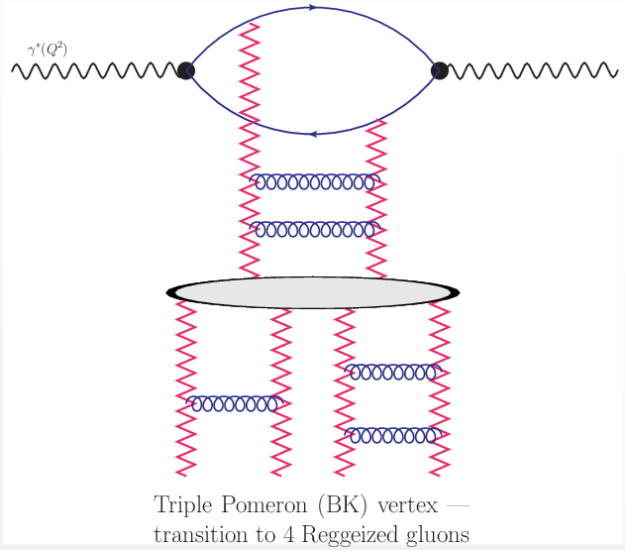
Nucl.Phys.B 971 (2021) 115518



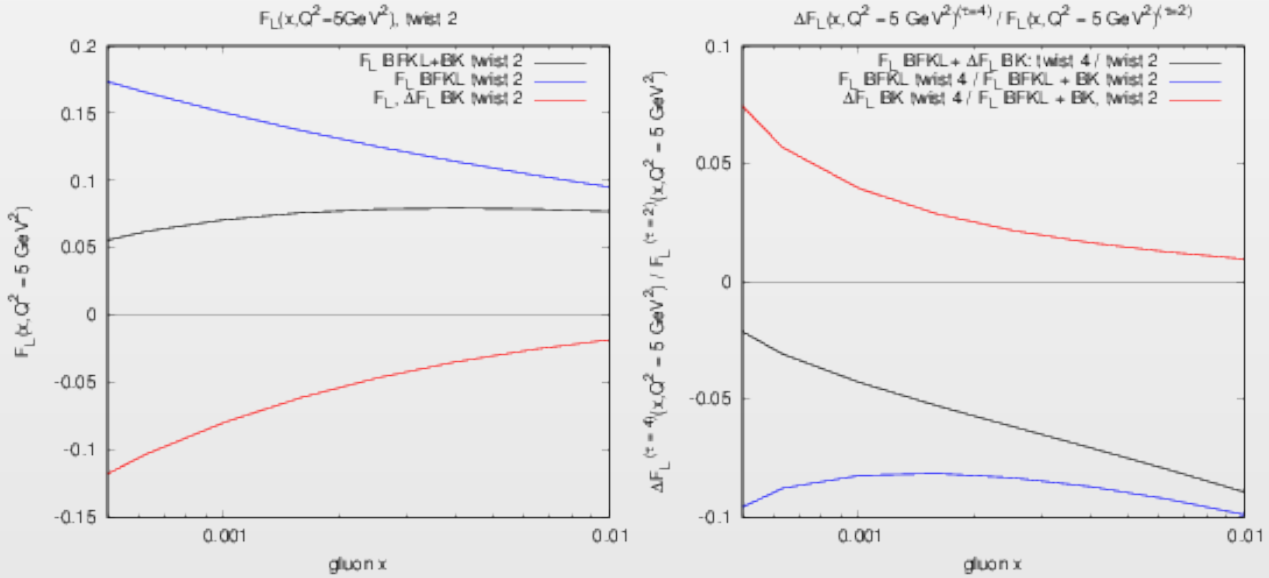
G. Chachamis et al.

Higher-twist effects in F_L structure functions at small x

* Non conclusive exp. data on HT effects
* Perturbative ev. of HT operators known, but unperturbative input not.
* Use various small-x models and ev. eq. to extract HT contributions at small x

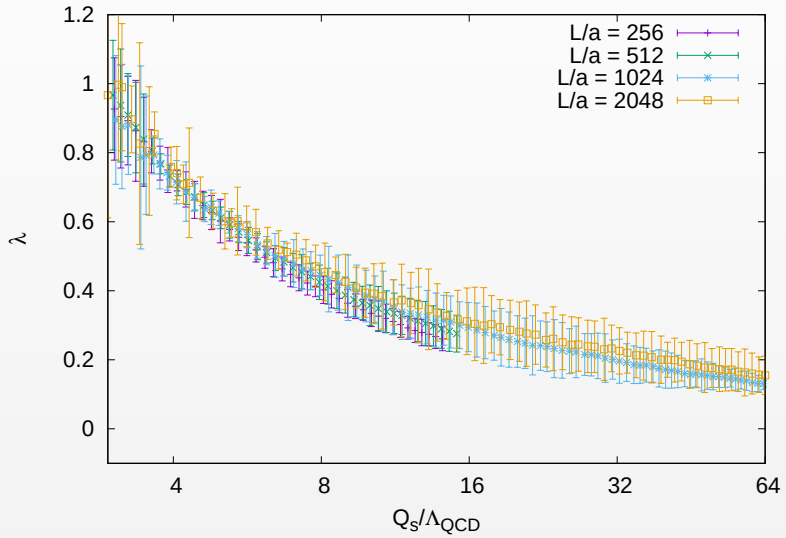


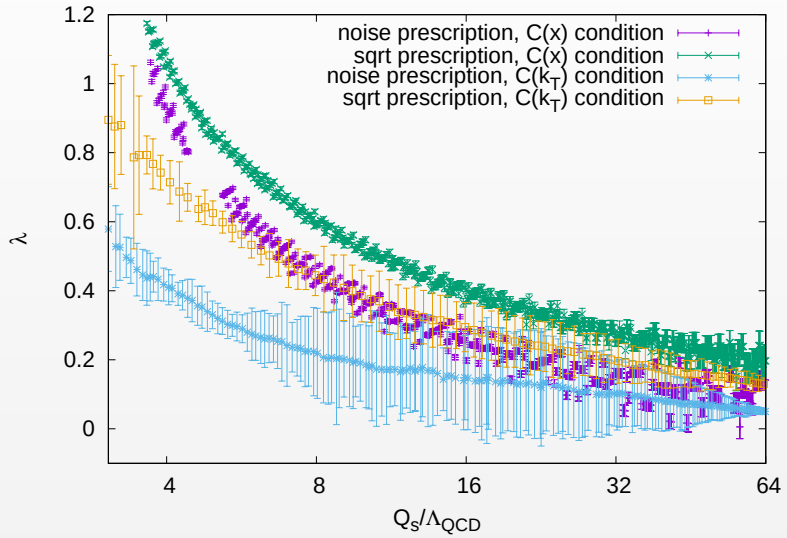
Triple Pomeron (BK) vertex — transition to 4 Reggeized gluons



M. Sadzikowski and L. Motyka, Low-x 2021 Workshop

Solution of JIMWLK equation





∗ BK equation valid in the mean-field approximation.

∗ Going beyond mean-field : JIMWLK eq., access to correlators more complex than the dipole case, useful e.g. for obtaining TMDs values in saturation regime.

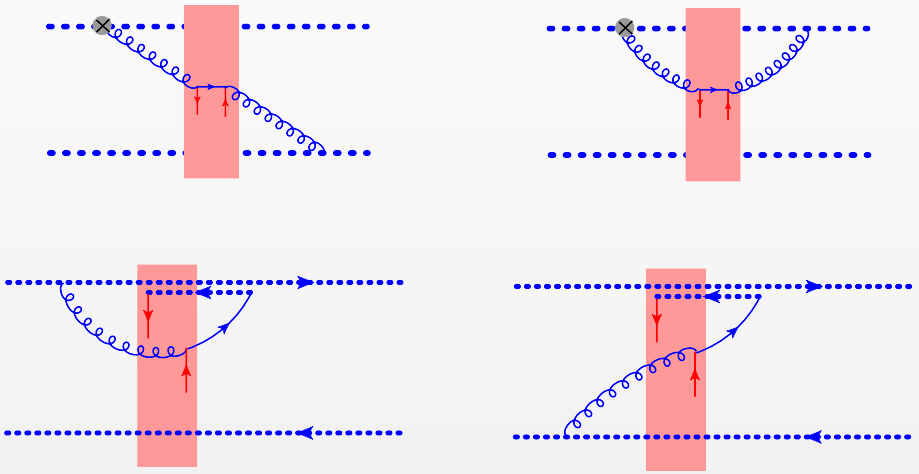
∗ Numerical solution, including LL(1/x) resummation effects.

∗ Next: use for evaluating higher-twist operators in proton at small x.

P. Korcyl et al. [arXiv:2009.02045, 2104.14254]

High-energy spin dynamics

Sample of diagrams with Wilson lines (dotted lines) and shock-wave (reddish band) background formalism.



- The operator product expansion (OPE) in Wilson line (eikonal approximation) operators is a well established formalism to study the behavior of unpolarized scattering processes at high-energy and high parton density.

- Extension of the high-energy OPE to include sub-eikonal Wilson line operators and Impact factors for polarized and unpolarized structure functions. New non-linear evolution equations and new quark and gluon distributions derived to study the spin dynamics at high energy and high parton density.

G. A. Chirilli JHEP 06 (2021) 096, JHEP 01 (2019) 118

Forward Physics Facility

∗ Forward energetic ν produced close to LHC IP, propagating $\sim$ 600 m along the tangent line and interacting with A in detectors using different technologies

∗ QCD opportunities:

- nuclear and proton PDF
- non-perturbative models in MC / tuning
- charm production at large y

$\Rightarrow$connections with high-energy CR astroparticle physics

∗ Many authors also involved in EF06.....

∗ 3rd FPF Meeting, October 25-26th:
`https://indico.cern.ch/event/1076733`
Registrations open

in arXiv since today:

BNL-222142-2021-FORE, CERN-PBC-Notes-2021-025, DESY-21-142, FERMILAB-CONF-21-452-AE-E-ND-PPD-T
KYUSHU-RCAPP-2021-01, LU TP 21-36, PITT-PACC-2118, SMU-HEP-21-10, UCI-TR-2021-22

**The Forward Physics Facility:
Sites, Experiments, and Physics Potential**

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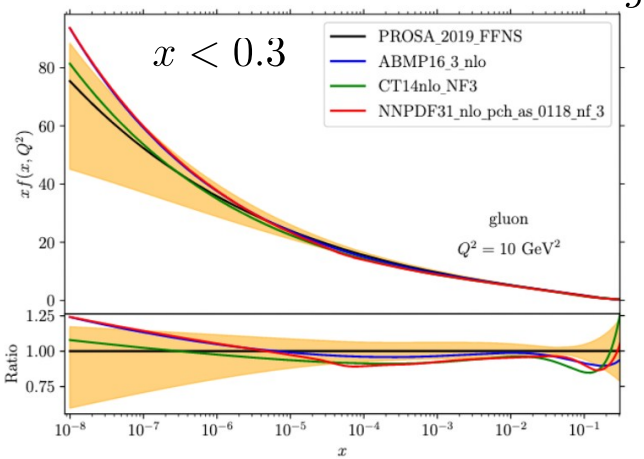
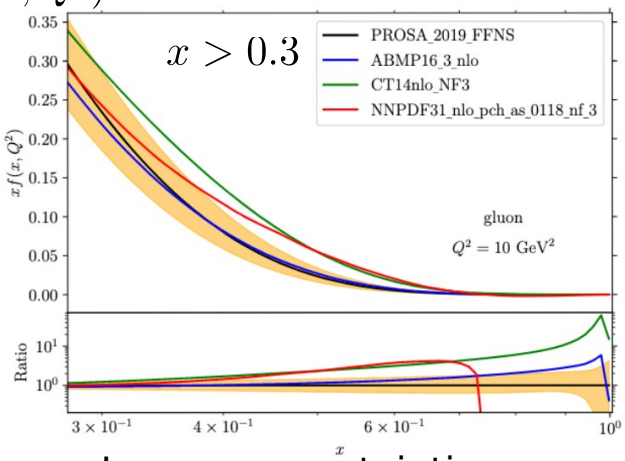
Neutrino production at Forward Physics Facility

$xg(x, Q^2)$



Small x extrapolations.



Large x uncertainties.

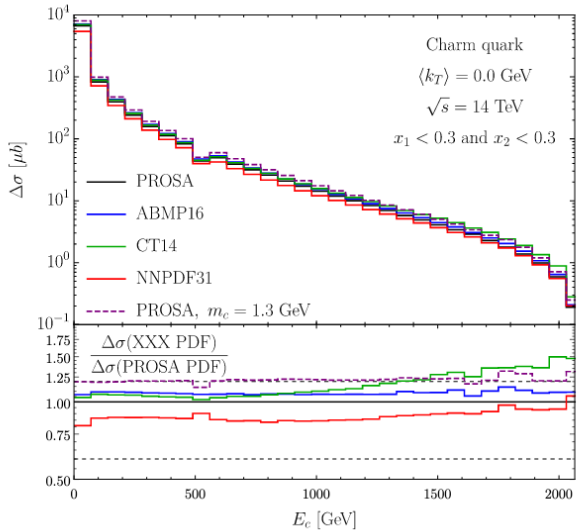
PDF uncertainties:
PROSA_2019 fit, model & parameterization;
ABMP16, CT14,NNPDF3.1

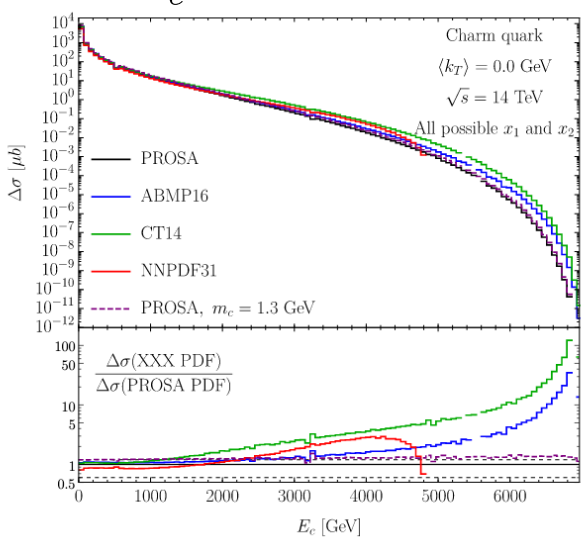
Large x uncertainties translate to large uncertainties at high E_c (E_D) → high E_ν at FPF.

- Additional large uncertainties due to scale dependence.
- Feature of NLO QCD at scale ~ m_c.

In preparation, Bai, Diwan, Garzelli, Jeong, Karan Kumar, Reno.

$\frac{d\sigma}{dE_c}$





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Conclusions

∗ EF06 developments and theory efforts boosted by a number of forthcoming experimental opportunities (HL-LHC, EIC, LHeC,...., maybe FPF.....).

∗ Great interest in connecting different kind of languages and physics perspectives (collinear factorization, BFKL log resummation, saturation, PDFs, TMDs, GPDs, lattice counterparts, ...): opportunity offered by Snowmass that might allow to increase knowledge of Early Career Scientists.

∗ 90% of the number of EF06 members that I contacted in view of this talk, answered and they were all actively providing material (without me needing to ask them twice) !

∗ The selection was a bit quick. I would have been happy to contact more authors, but I could not due to time constrain. Hope nobody feels too offended.

∗ To me EF06 looks like a great group of scientists, full of enthusiasm and capable of excellent and timely Snowmass reports.

∗ Natural synergies with the other EF groups, in particular EF05 and EF07, but also with other frontiers, e.g. CF and NF.

Thank you for your attention!

Additional link to the Cracow School of Theoretical Physics, organized by some of the EF06 participants, that last week was dedicated to EIC physics:

`http://th-www.if.uj.edu.pl/school/2021/`