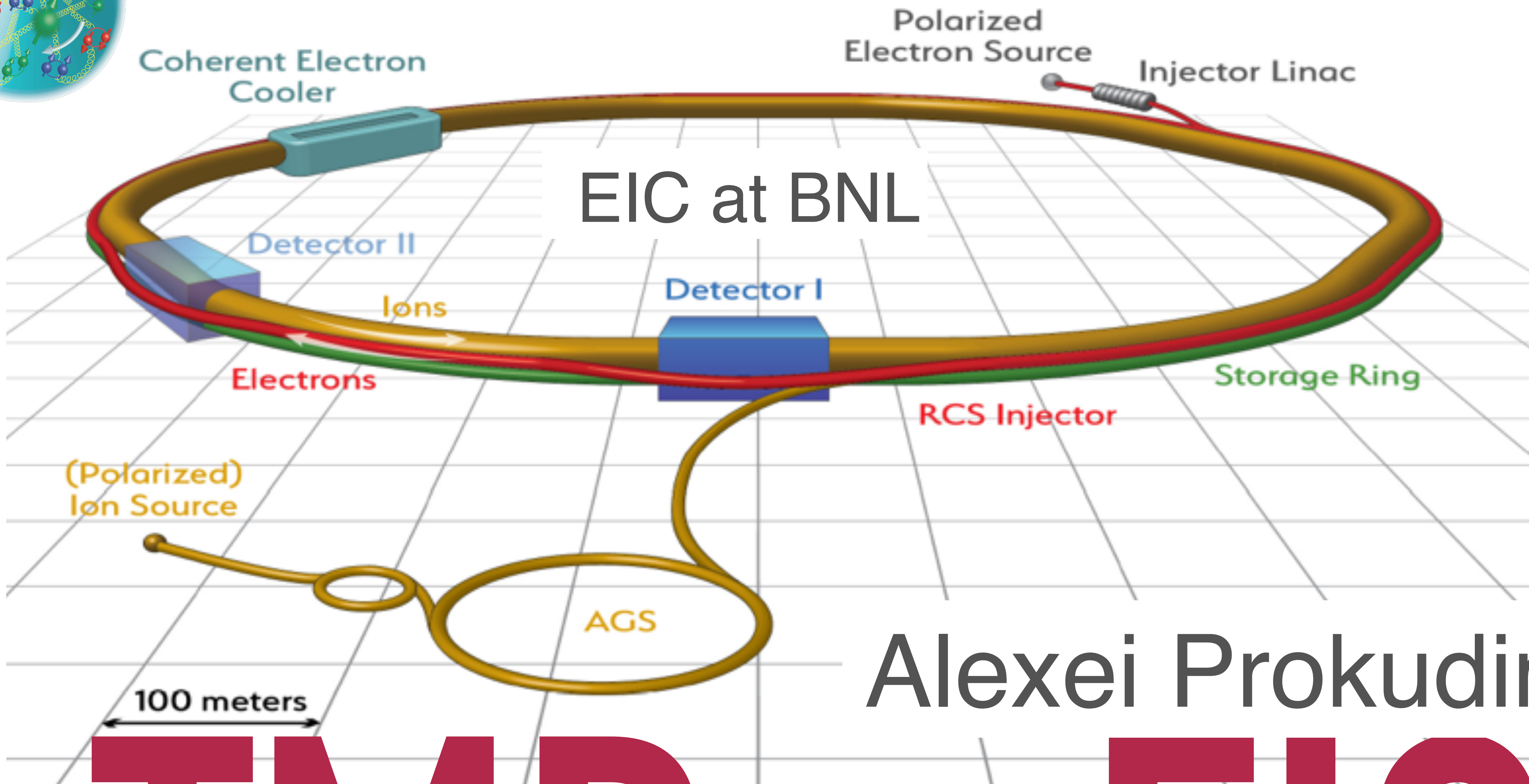
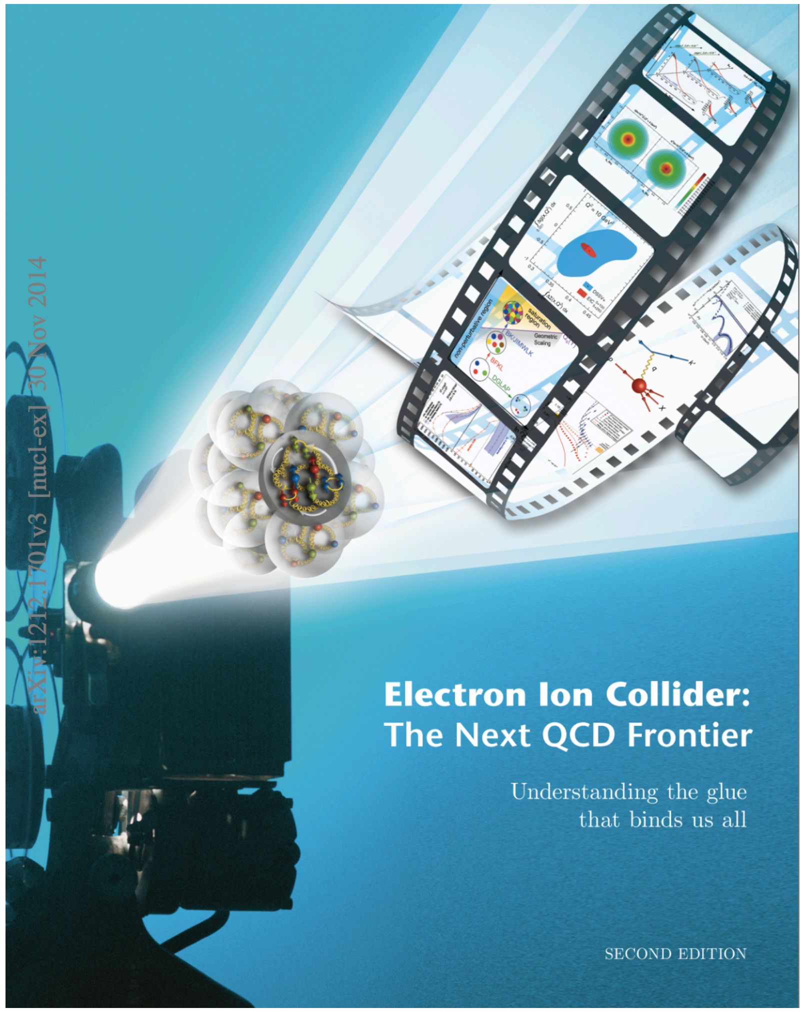


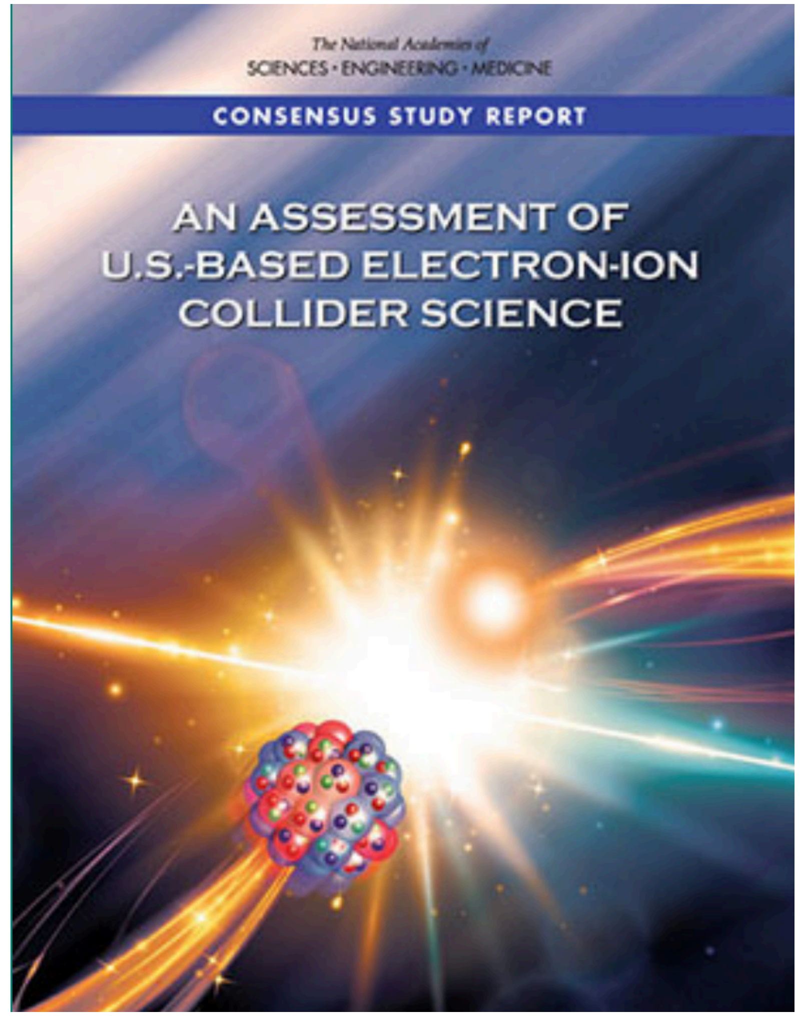
Alexei Prokudin

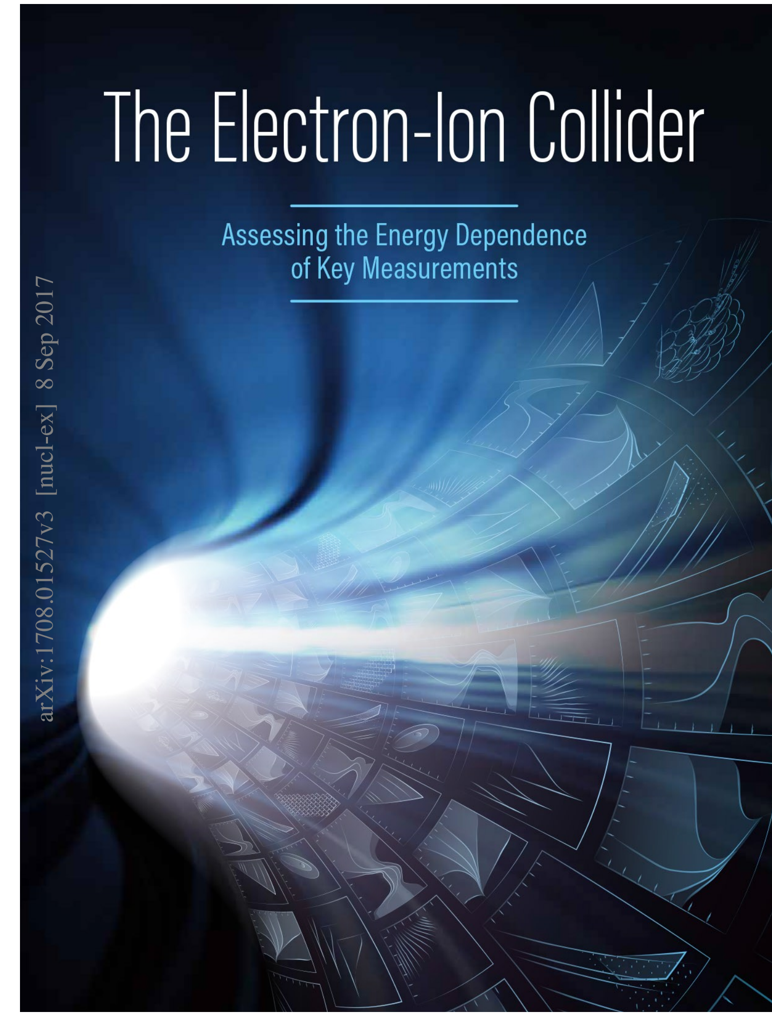
TMDs at the EIC

https://www.bnl.gov/eic/science.php

THE ELECTRON-ION COLLIDER: RELEVANT DOCUMENTS







White Paper (2012)
Accardi et al, arXiv:1212:1701

NSAC Study (2018)

BNL Report (2017)
Aschenauer at el, arXiv:1708.01527

Yellow Paper (2016)
Accardi et al, Eur. Phys. J. A
(2016) 52: 268

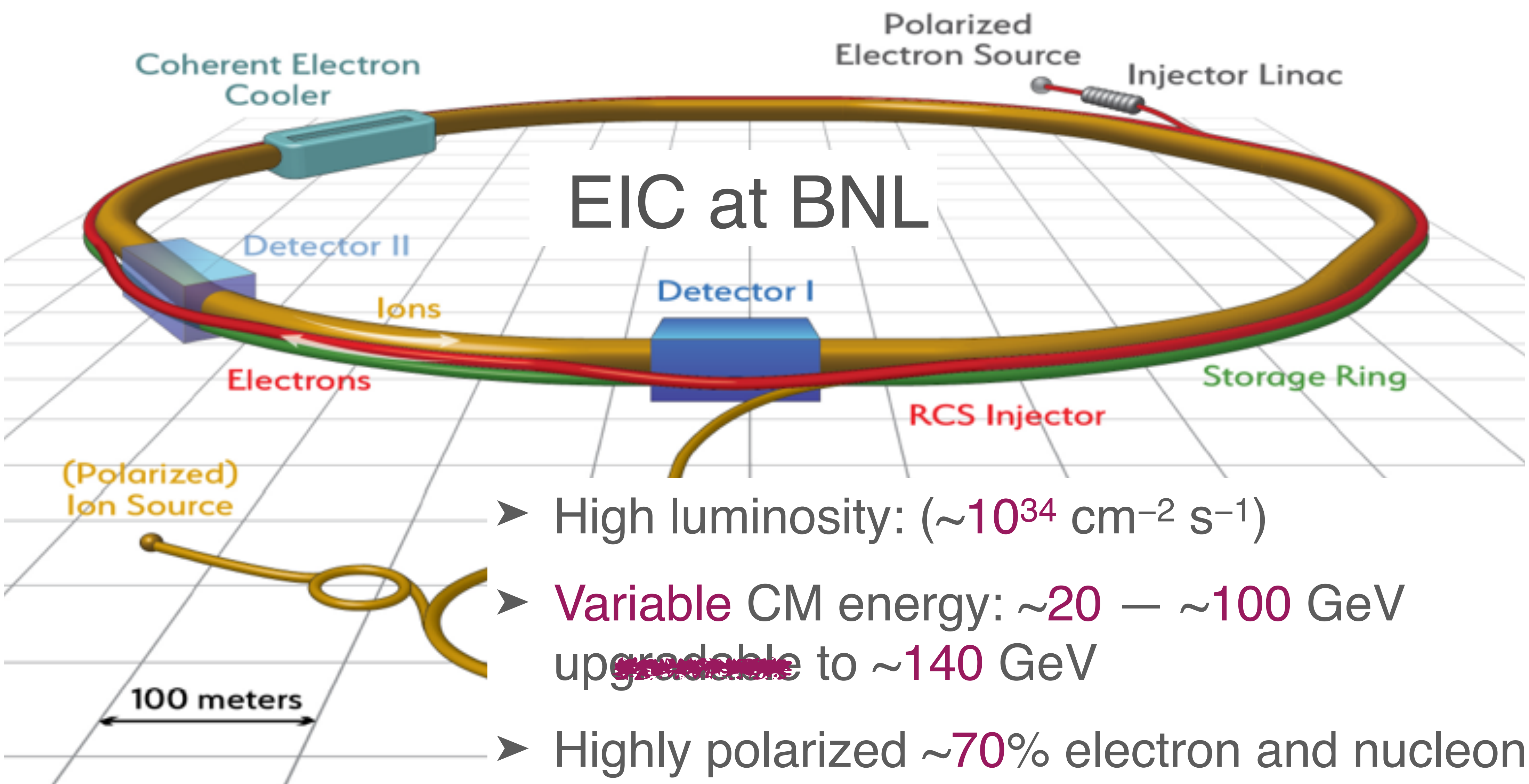
PHYSICS GOALS

THE ELECTRON-ION COLLIDER: SCIENTIFIC QUESTIONS

White Paper (2012)
Accardi et al, arXiv:1212:1701

- How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?
- Where does the saturation of gluon densities set in?
- How does the nuclear environment affect the distribution of quarks and gluons and their interactions in nuclei?

THE ELECTRON-ION COLLIDER @ BNL



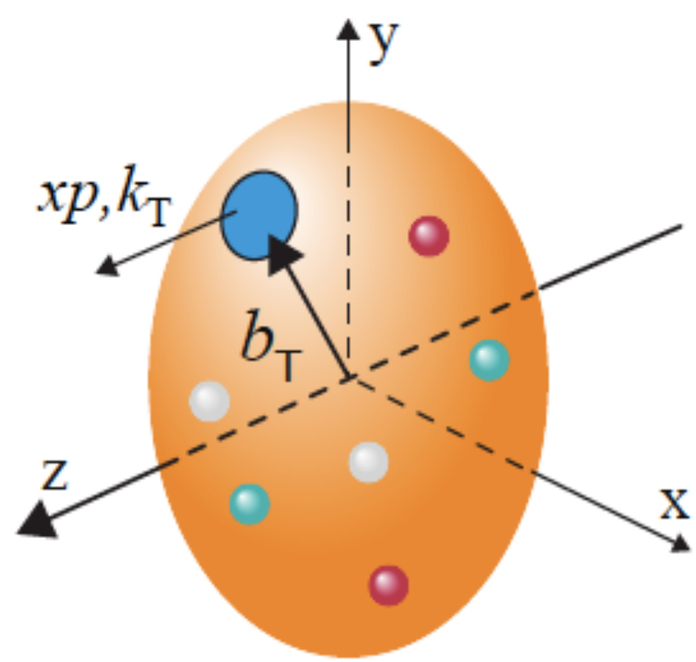
- High luminosity: (~10^{34} cm^{-2} s^{-1})
- Variable CM energy: ~20 — ~100 GeV upgradable to ~140 GeV
- Highly polarized ~70% electron and nucleon beams
- Protons and other nuclei
- Possibility of more than one interaction region

White Paper (2012)
Accardi et al, arXiv:1212:1701

OVERARCHING TMD QUESTIONS

What is the 2D confined transverse motion of quarks and gluons inside a proton?

How to identify universal proton structure properties from measured k_T-dependence?



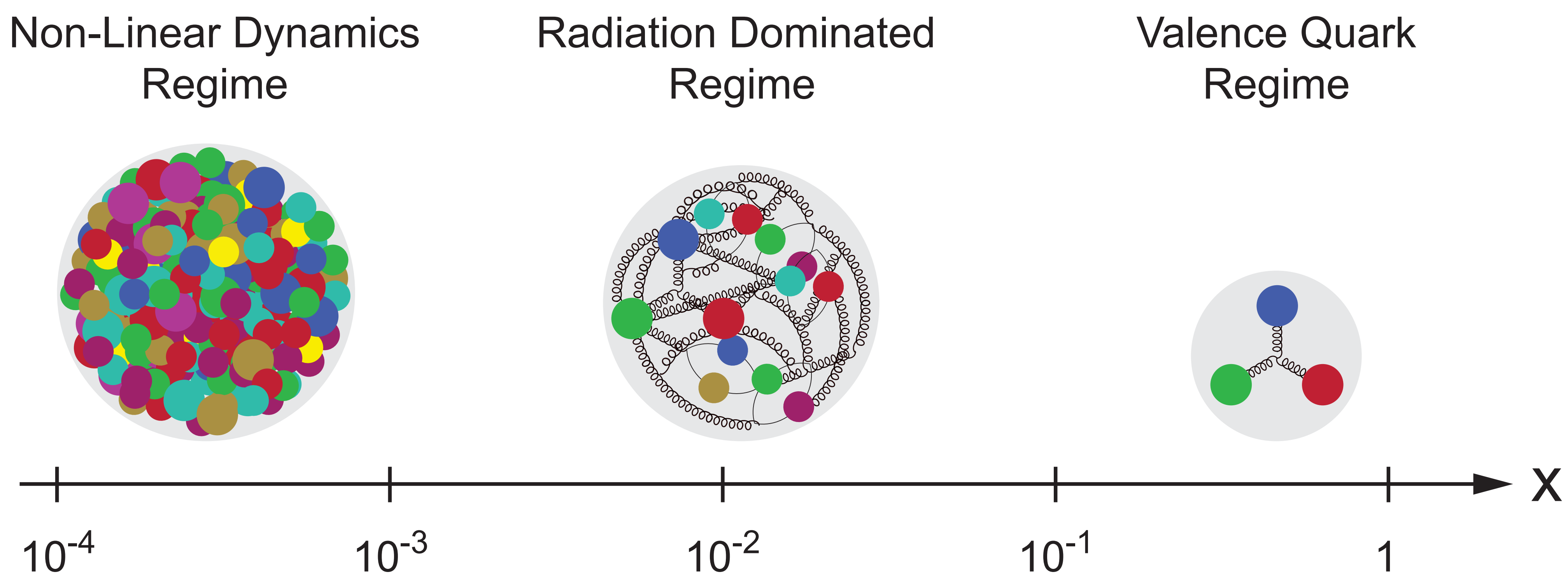
How does the confined motion change along with probing x, Q^2?

Can we extract QCD color force responsible for the confined motion?

How is the motion correlated with macroscopic proton properties, as well as microscopic parton properties,
such as the spin?

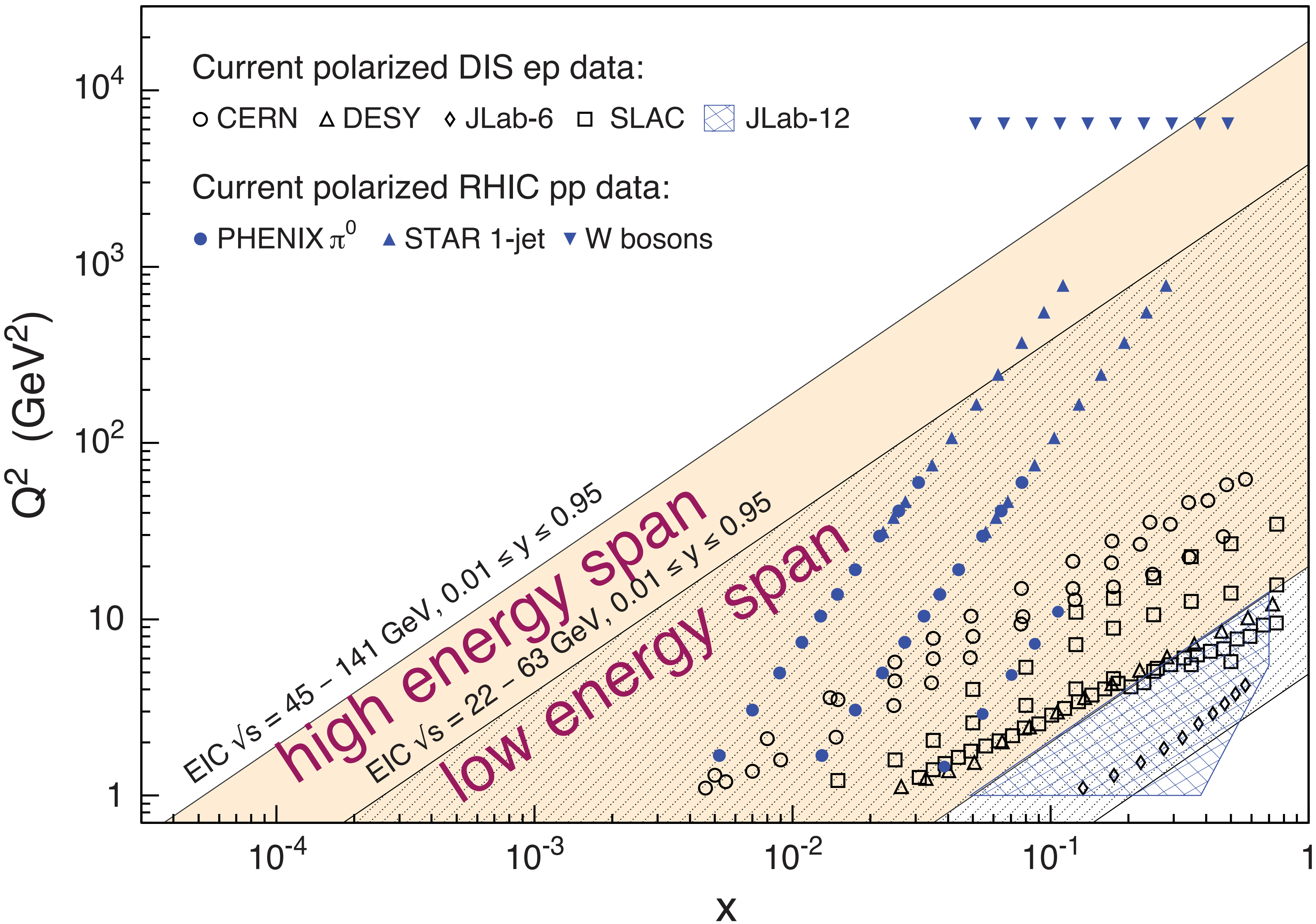
KINEMATICS

THE ELECTRON-ION COLLIDER: KINEMATICS



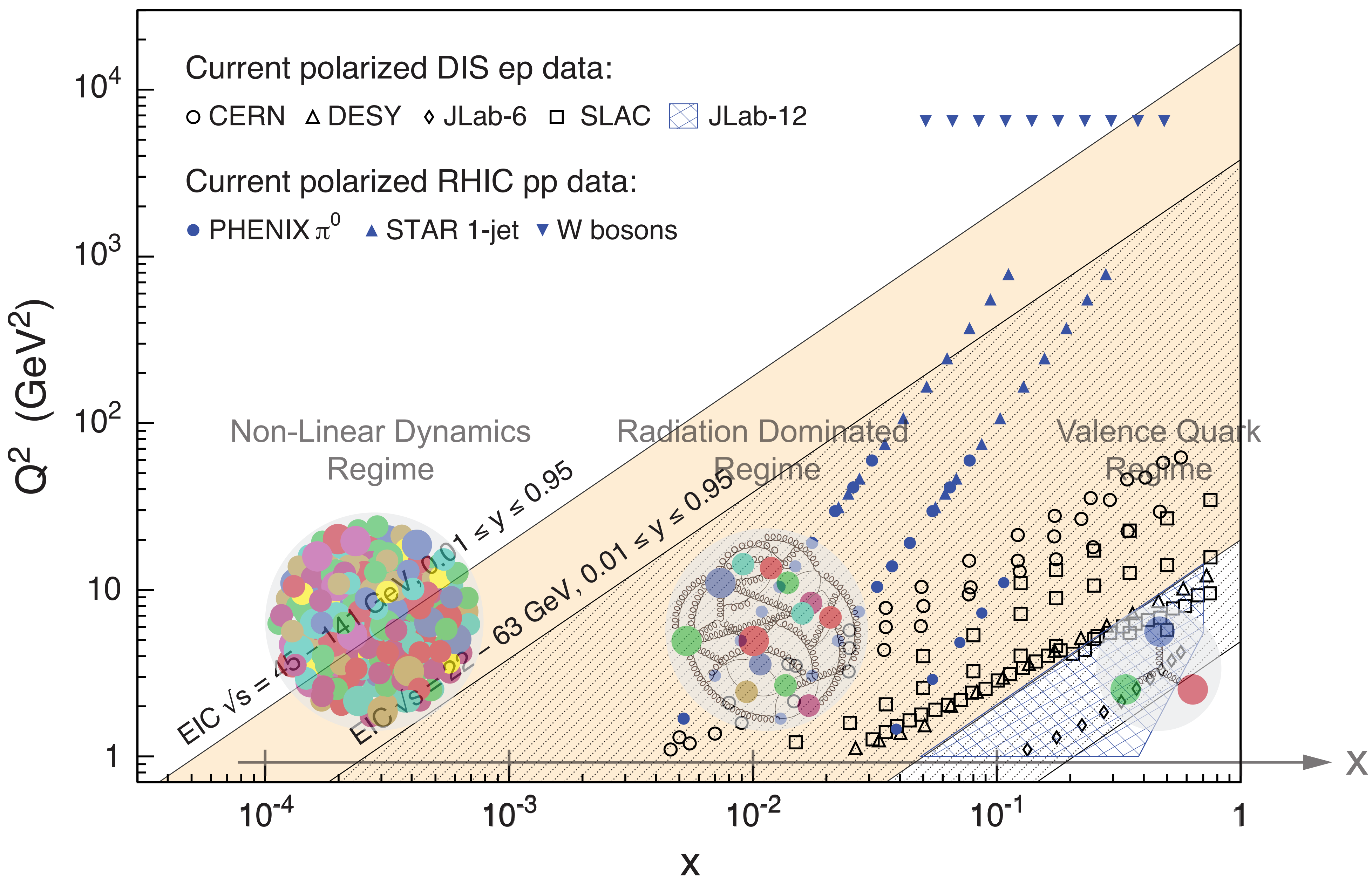
BNL Report (2017)
Aschenauer at el, arXiv:1708.01527

THE ELECTRON-ION COLLIDER: KINEMATICS



BNL Report (2017)
Aschenauer at el, arXiv:1708.01527

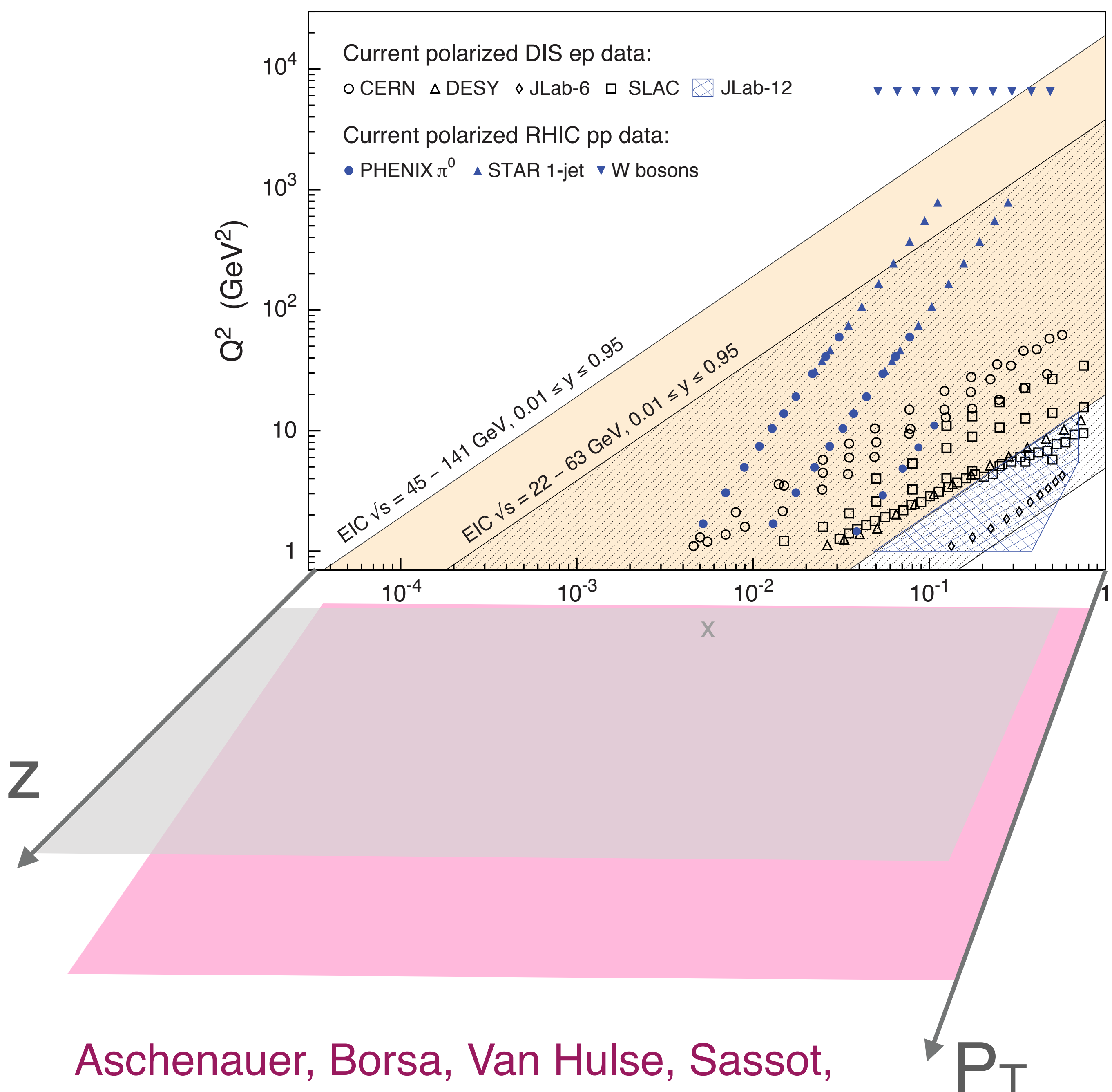
THE ELECTRON-ION COLLIDER: KINEMATICS



BNL Report (2017)
Aschenauer at el, arXiv:1708.01527

THE ELECTRON-ION COLLIDER: KINEMATICS

BNL Report (2017)
Aschenauer at el, arXiv:1708.01527



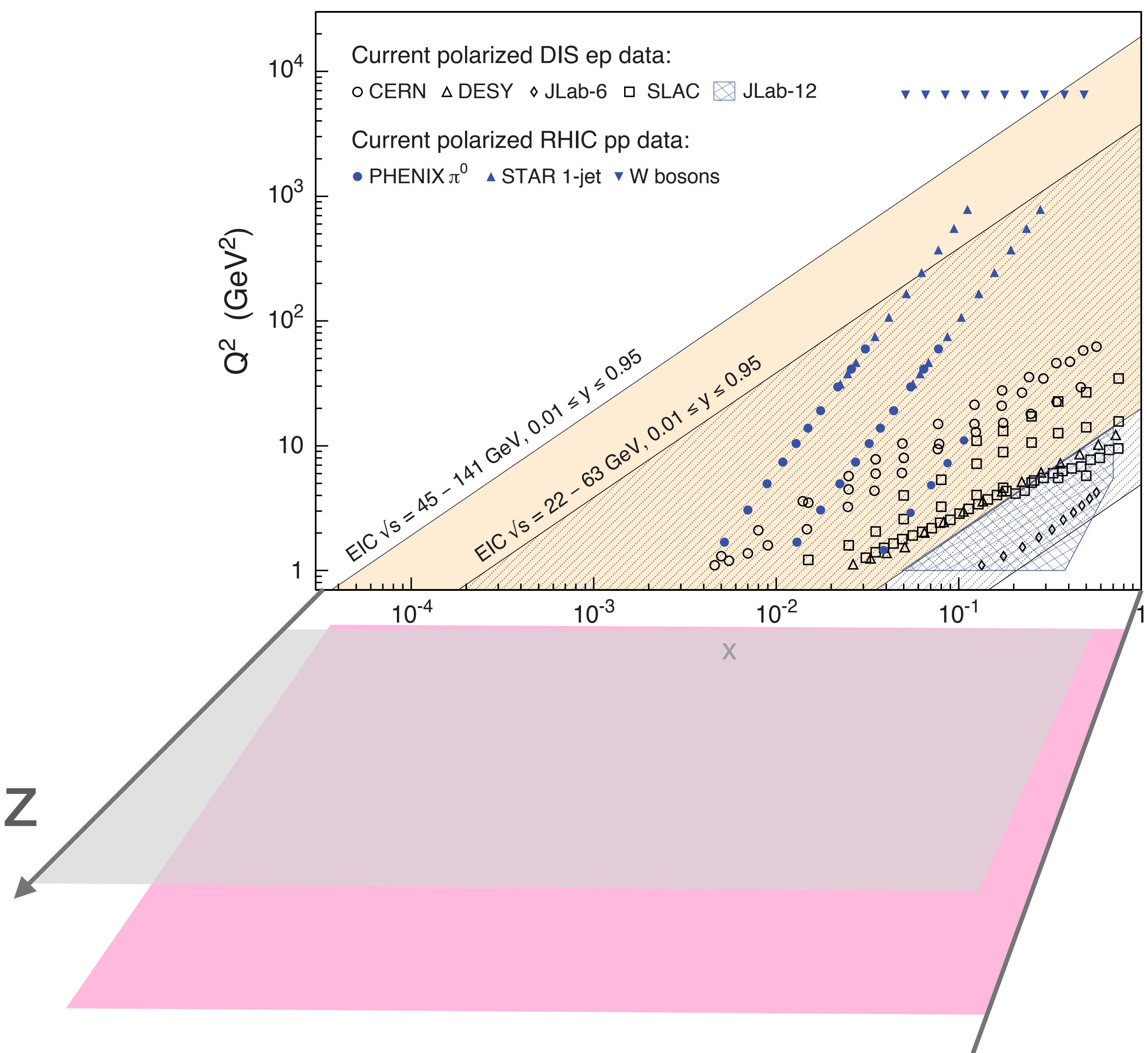
Aschenauer, Borsa, Van Hulse, Sassot, arXiv:1902.10663

- SIDIS measurements add two more dimensions: z and P_T
- The ranges $[z_{min}, z_{max}]$, $[P_{T\,min}, P_{T\,max}]$ should be tested in impact studies along side with detector simulations
- TMD factorization has a variable $q_T = P_T/z$ that allows to test applicability of TMD factorization
- It is important that EIC probes transition from TMD to collinear factorization regime. As such EIC is the unique facility to allow for such a study, from $q_T \ll Q$ to $q_T \sim Q$

THE ELECTRON-ION COLLIDER: KINEMATICS

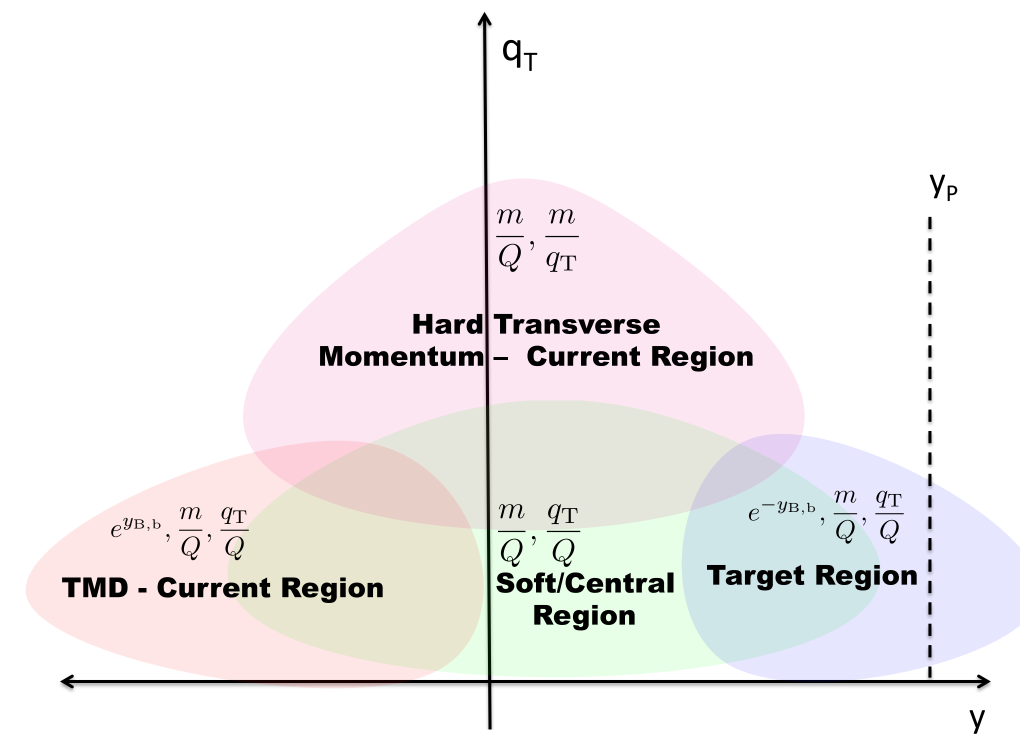
➤ Not to understate, the EIC is uniquely shaped to study both current and target fragmentation regions

BNL Report (2017)
Aschenauer at el, arXiv:1708.01527

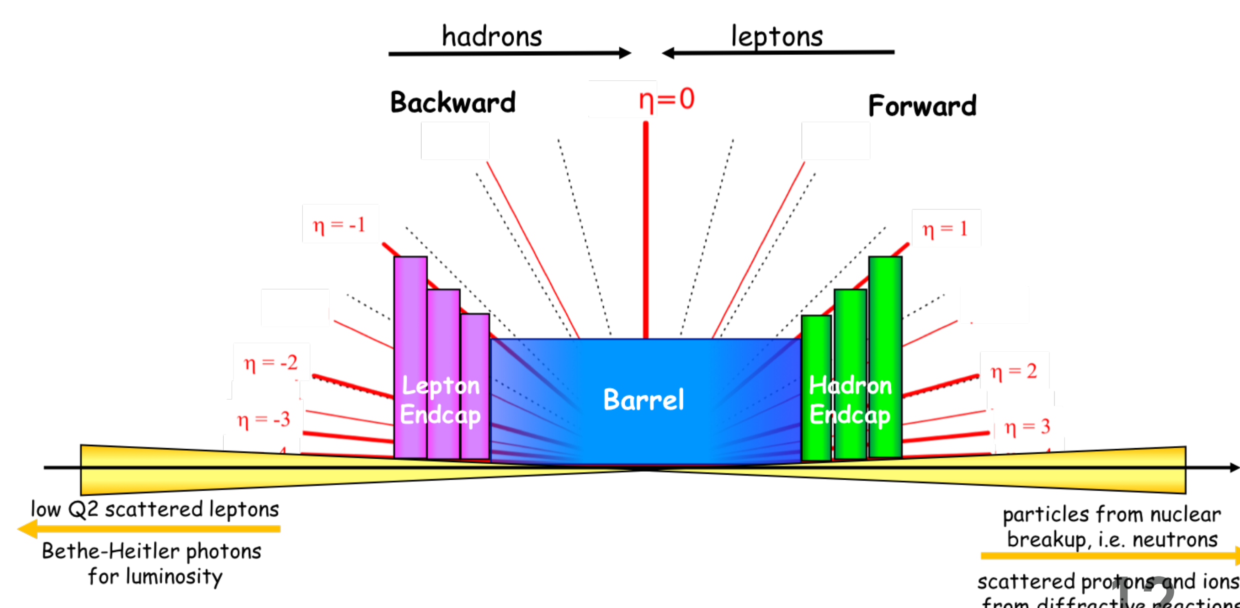


P_T

Aschenauer, Borsa, Van Hulse, Sassot,
arXiv:1902.10663



Boglione et al, JHEP 1910 (2019) 122



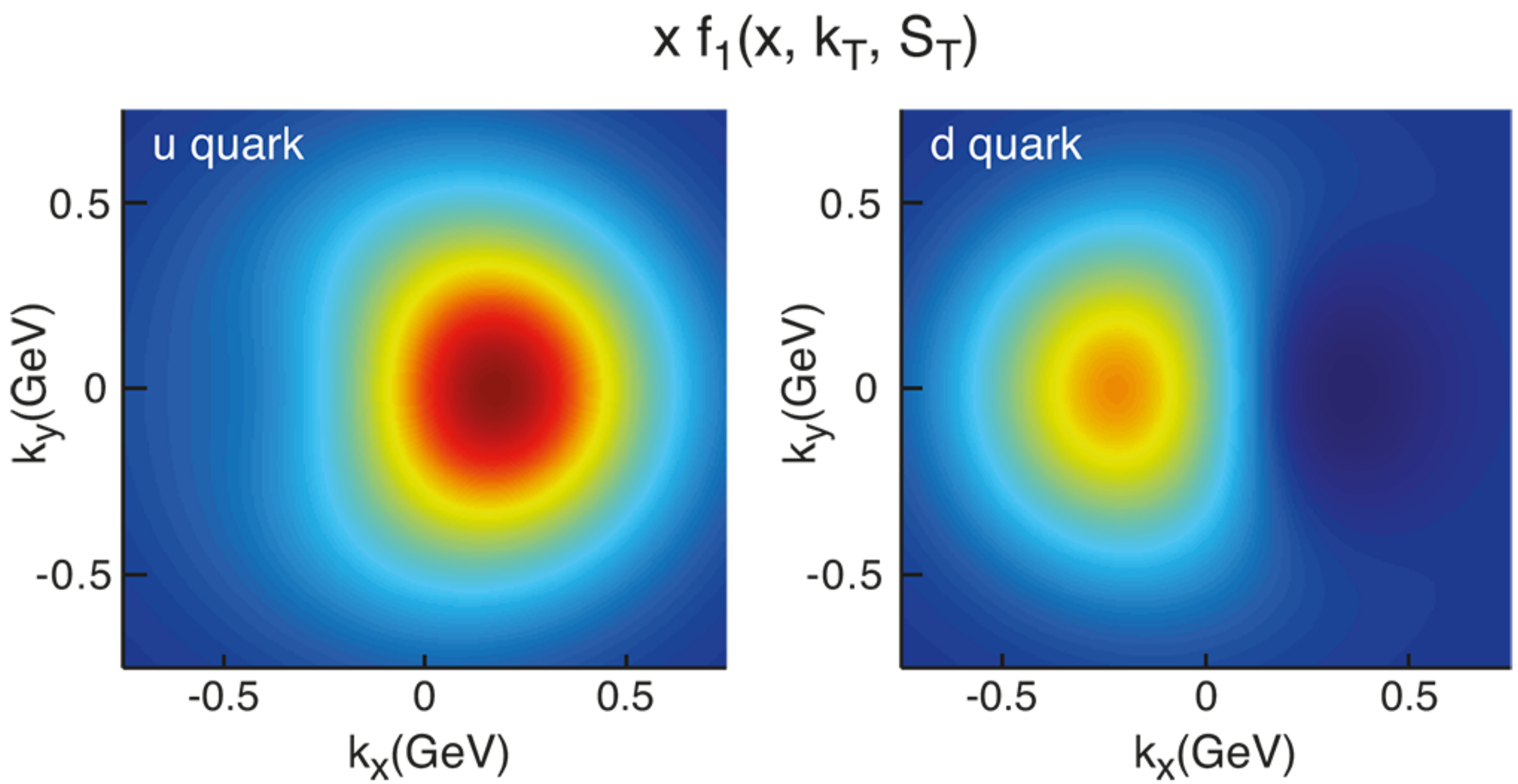
MONEY PLOTS

THE ELECTRON-ION COLLIDER: TMD MEASUREMENTS

“Golden”

Yellow Paper (2016) Accardi et al, Eur. Phys. J. A (2016) 52: 268

Unpolarised TMD measurements and Sivers function measurements



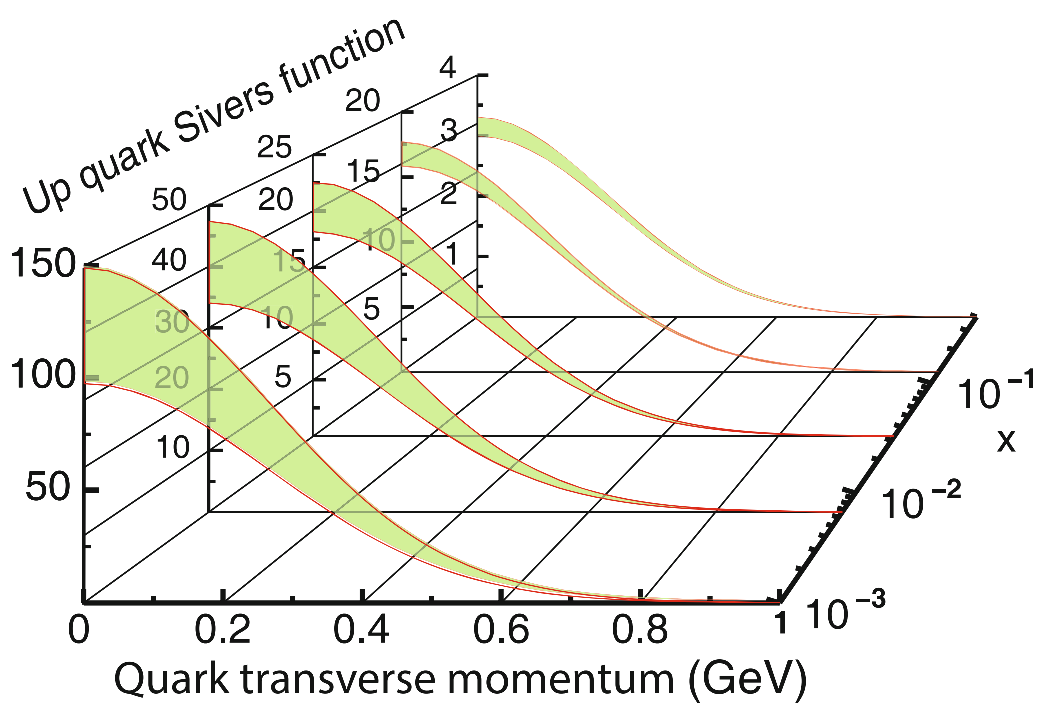
- The characteristic dipole deformation due to the Sivers effect
- Visually pleasing and intuitively comprehensive
- No suitable way to visualize the impact was found (by the author of the plot at least)

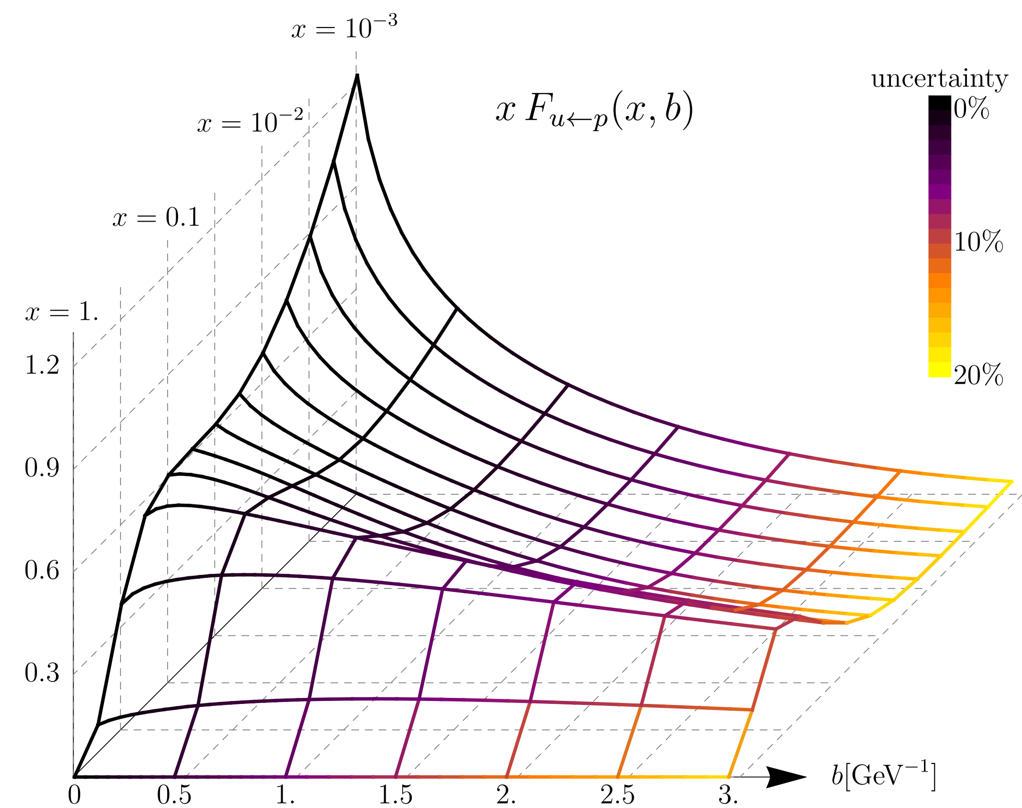
THE ELECTRON-ION COLLIDER: TMD MEASUREMENTS

"Golden"

Yellow Paper (2016) Accardi et al, Eur. Phys. J. A (2016) 52: 268

Unpolarised TMD measurements and Sivers function measurements





Scimemi, Vladimirov, arXiv:1912.06532

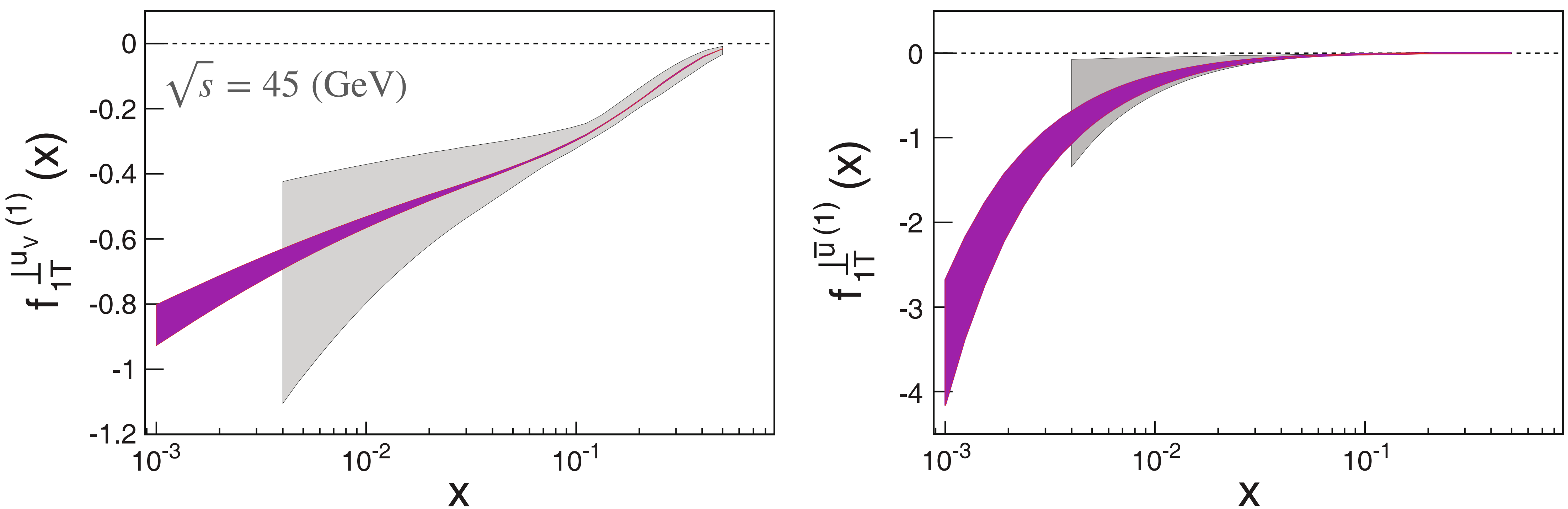
- P_T shape of the Sivers function
- Visually pleasing and intuitively comprehensive as a 3D structure
- There is a way to show the impact

THE ELECTRON-ION COLLIDER: TMD MEASUREMENTS

"Golden"

Yellow Paper (2016) Accardi et al, Eur. Phys. J. A (2016) 52: 268

Unpolarised TMD measurements and Sivers function measurements



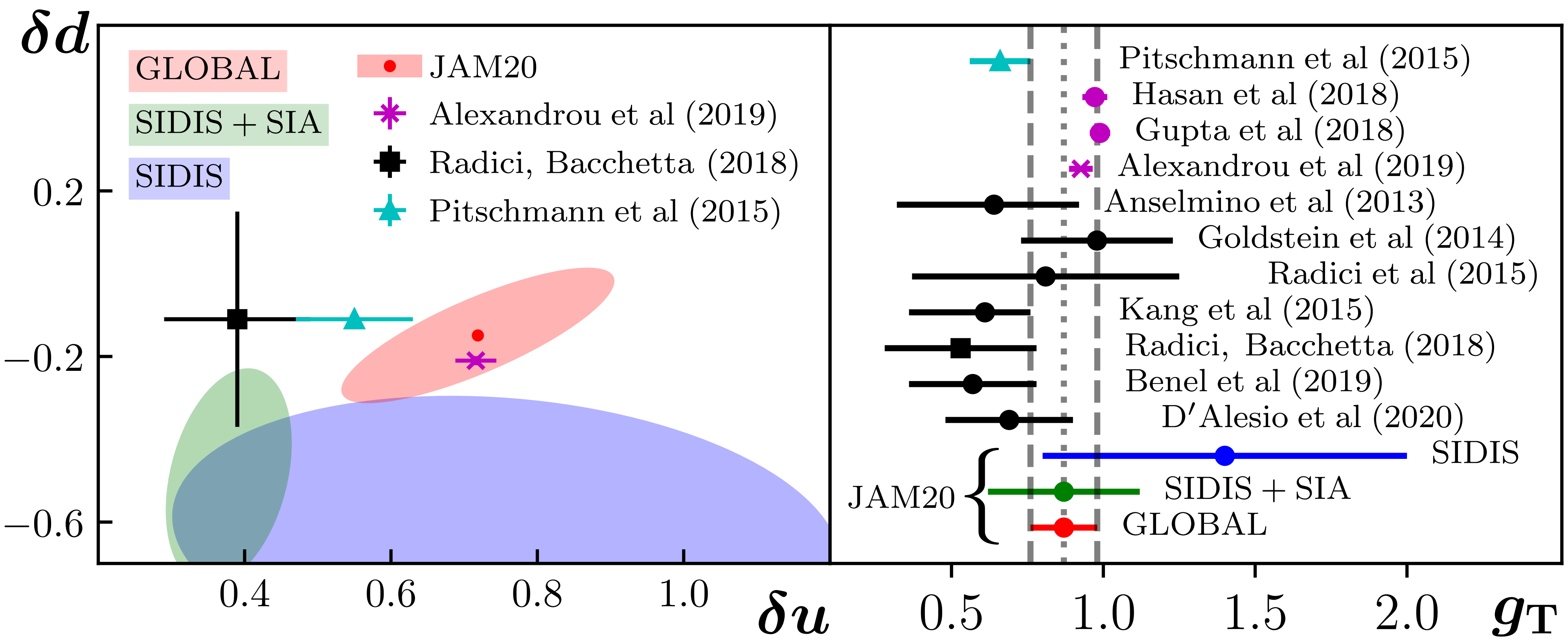
- First moment of Sivers function
- Visually comprehensive, but 1D
- There is a way to show the impact

THE ELECTRON-ION COLLIDER: TMD MEASUREMENTS

Yellow Paper (2016) Accardi et al, Eur. Phys. J. A (2016) 52: 268

"Silver"

Transversity and tensor charge measurements



Cammarota, Gamberg, Kang, Miller, Pitonyak, Prokudin, Rogers, Sato arXiv:2002.08384 (2020)

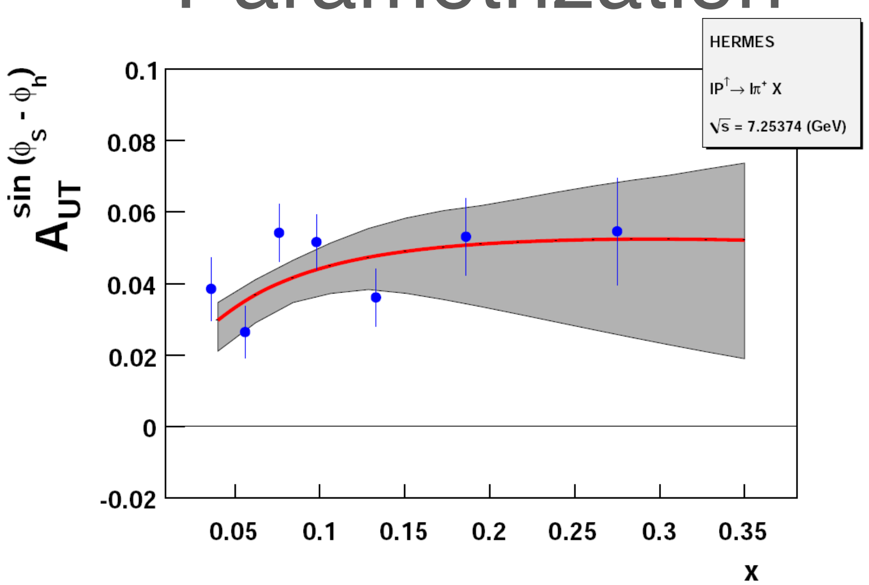
- No plots for EIC (that I found)
- A lot of physics and opportunities for impact study
- Tensor charge is important

DETAILS, PROBLEMS, PLANS

IMPACT STUDY

- ➤ Unpolarized cross sections are reliably simulated using Pythia
- ➤ There is no polarized SIDIS event generator that includes all correlations
- ➤ Current way is reweighing unpolarized events based of extracted parametrizations

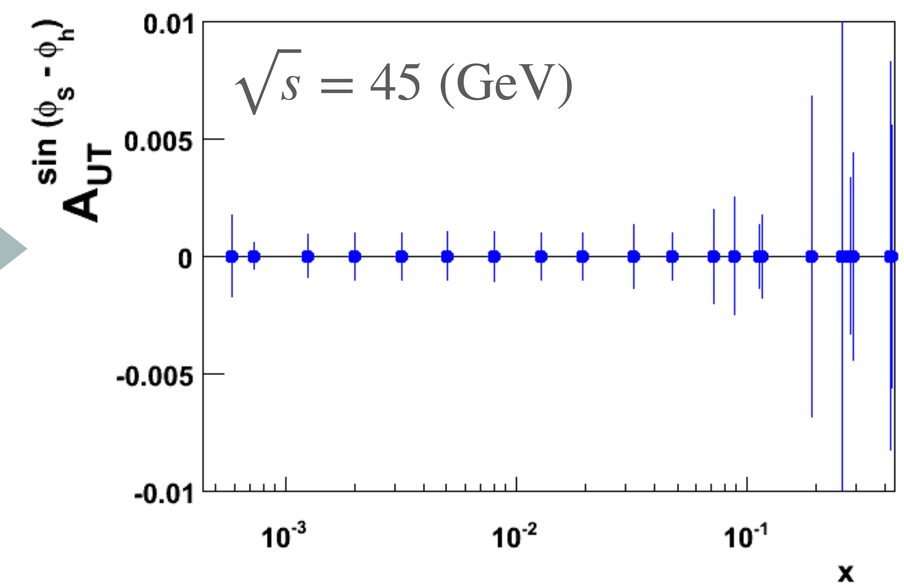
Parametrization



Anselmino et al (2009)

YR effort

Error estimate

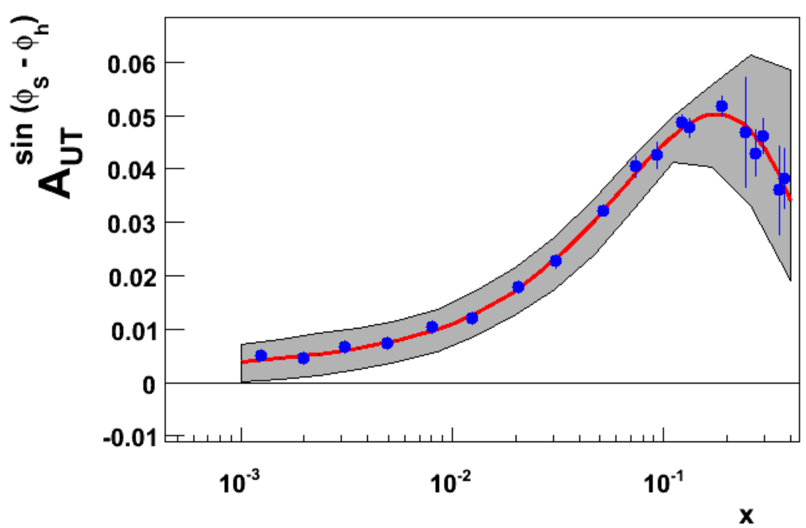


EIC estimate @ 10 fb^{-1}

- ➤ Database of both parametrizations and error estimates is highly needed
- ➤ Expertise exists in our and HEP community and other groups, cooperation is needed
- ➤ Manpower is needed

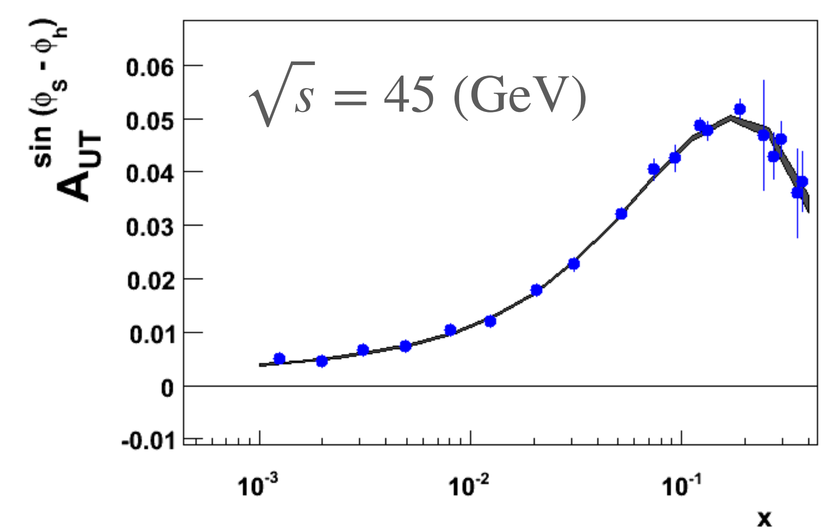
IMPACT STUDY

Pseudodata

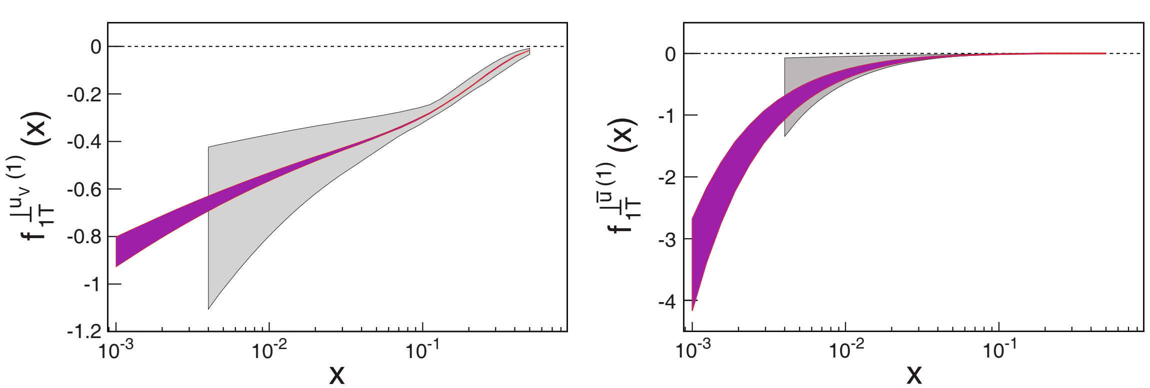


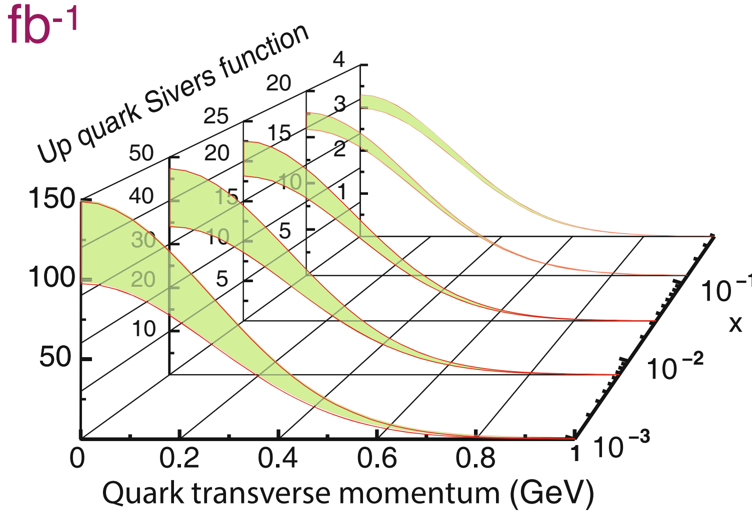
YR effort

Impact estimate



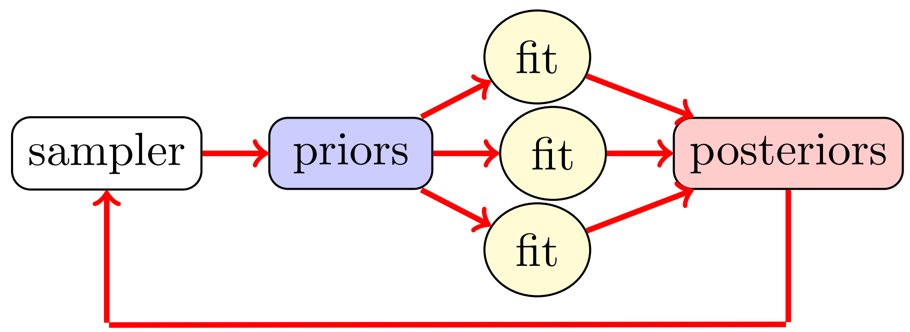
AP (2012) EIC estimate @ 10 fb^{-1}

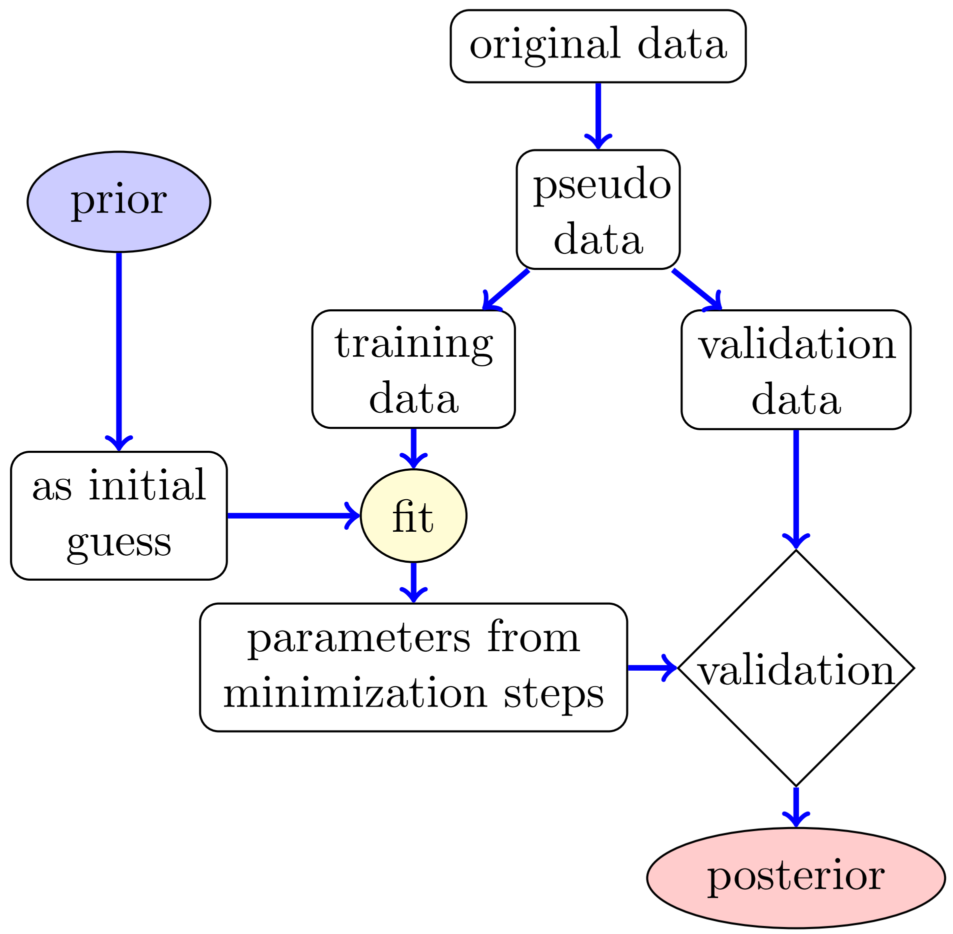




- Different ways on impact estimate are needed to cross-check
- Many groups should join and cooperate
- Manpower is needed

JAM FITTING METHODOLOGY





- Bayesian inference is used

$$E[\mathcal{O}] = \int d^n a \mathcal{P}(\vec{a}|data)\mathcal{O}(\vec{a})$$

- Iterative Monte Carlo is then used to perform the fit
- Large parameter space is sampled
- Data is partitioned in validation and training sets
- Training set is fitted via chi-square minimization
- Posteriors are used to feed the next iterations

Sato et al., P.R. D94 (16) 114004

JAM FITTING METHODOLOGY

Sato et al., P.R. D94 (16) 114004

- Jefferson Lab Angular Momentum Collaboration has developed a robust fitting/reweighting methodology based on Bayesian statistical methods and machine learning algorithms

- Such methodology may prove crucial and essential for our future endeavors in studies of the structure of the nucleon and beyond.

- Expectation value and variance estimates:

$$E[\mathcal{O}] = \int d^n a \mathcal{P}(\vec{a}|data)\mathcal{O}(\vec{a}) \qquad V[\mathcal{O}] = \int d^n a\, \mathcal{P}(\vec{a}|data)[\mathcal{O}(\vec{a}) - E[\mathcal{O}]]^2$$

- Bayes' theorem defines probability density $\mathcal{P}$ as

$$\mathcal{P}(\vec{a}|data) = \frac{1}{Z}\mathcal{L}(\vec{a}|data)\, \pi(\vec{a})$$

Evidence

Likelihood function

Prior

$$Z = \int d^n a\, \mathcal{L}(\vec{a}|data)\, \pi(\vec{a}) \qquad \mathcal{L}(\vec{a}|data) = \exp\left(-\frac{1}{2}\chi^2(\vec{a})\right)$$

PROGRESS

PROGRESS

- Several groups started working on impact study. Unpolarized cross sections impact study, the data are available from Charlotte Van Hulse, Elke Aschenauer.
- Database is at initial stage, mostly discussions. Some parametrizations are already available:

https://github.com/JeffersonLab/jam3dlib

https://github.com/prokudin/WW-SIDIS

https://github.com/VladimirovAlexey/artemide-public

https://github.com/vbertone/NangaParbat

http://tmdplotter.desy.de

SUGGESTIONS

- Identify benchmark for the impact
- Identify the format for the database, simulations, plots
- Perform the impact/detector study for at least two different energies $\sqrt{s} \simeq 50\ (\mathrm{GeV})$ and $\sqrt{s} \simeq 100\ (\mathrm{GeV})$
- Consider two different setups for detectors
- Collaborate closely with other WGs
- Involve more manpower