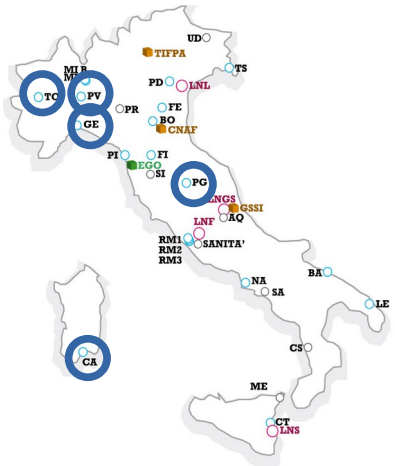
NINPHA

NINPHA nodes



- Cagliari
- Genova
- Pavia
- Perugia
- Torino

NINPHA coordinators

National Coordinator: Mariaelena Boglione (Torino)

Local Coordinators: Francesco Murgia (Cagliari)

Elena Santopinto (Genova)

Marco Radici (Pavia)

Sergio Scopetta (Perugia)

NINPHA goals

- Achieve a complete description of the internal hadron structure in terms of quarks and gluons, in a 3D momentum and coordinate space.
- This is an innovative way to look at the nucleon, which opens our understanding of its structure to new dimensions and reveals properties otherwise inaccessible.
- It offers an original methodology to study the problem of nucleon spin and orbital angular momentum.
- All NINPHA play a fundamental role in their area of expertise and can achieve the highest quality in their results.

NINPHA – Torino: members

NINPHA Torino - staff members

- Barone Vincenzo (Associate professor, PO University)
- Boglione Mariaelena (Associate professor, Torino University)
- Gonzalez-Hernandez J. Osvaldo (Researcher, Torino University)
- Nocera Emanuele Roberto (Researcher, Tenure,Torino University)
- Ratcliffe Philip (Associate Professor, Insubria University)
- Signori Andrea (Researcher, Tenure, Torino University)

NINPHA Torino - staff members

- Flore Carlo (Post-doc, Torino University)
- Sharma Tanishq (Ph.D student, Torino University)
- Yushkevych Tetiana (Ph.D student, Torino University)

NINPHA – Torino: Meet the team

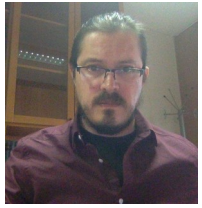
Staff members

Mariaelena Boglione

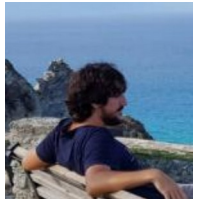
Emanuele Nocera

Andrea Signori

Former members

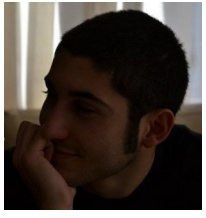


Osvaldo Gonzalez



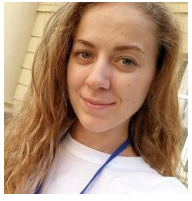
Andrea Simonelli

Post Doc and Phd students



Carlo Flore

Tanishq Sharma



Tetiana Yushkevych

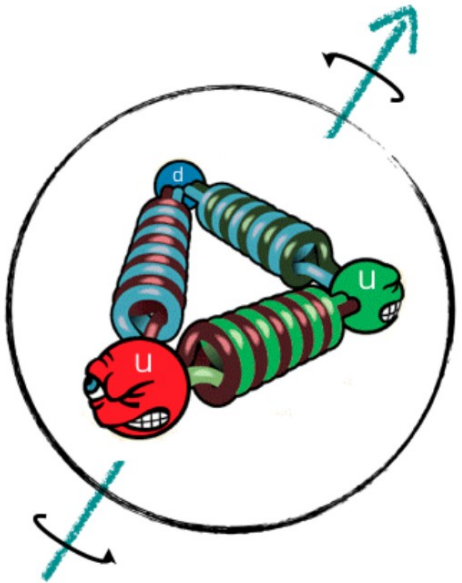
Master Students

Kamil Laurent

Patrizio Pucci

Amedeo Chiefa

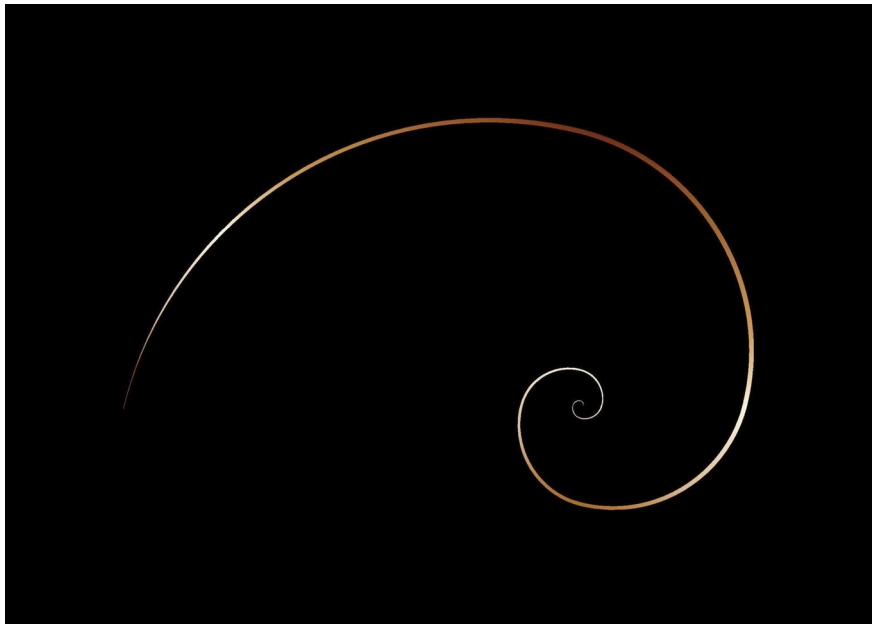
NINPHA – Torino: research interests



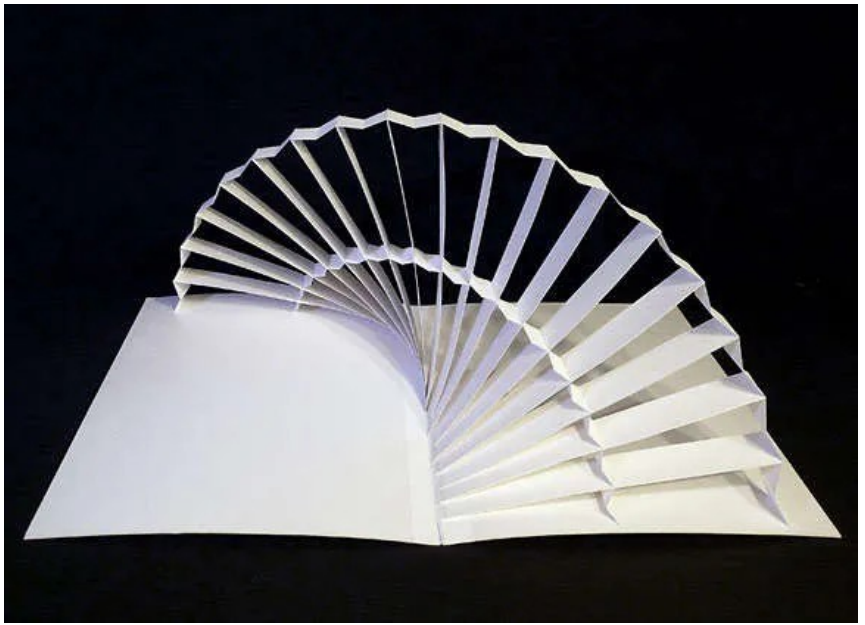
- Our research interests focus on the study of the strong interaction, which is the force that shapes protons, neutrons and the like and keeps atomic nuclei together. It is the fundamental glue which binds us all.
- The field theory that describes the strong force is called Quantum Chromodynamics (QCD). It is the mathematical tool to understand the emergence of matter from quarks and gluons, the elementary degrees of freedom of the theory.
- There are several research directions that address a combination of theoretical aspects of QCD, the interpretation of experimental data collected by high-energy and nuclear physics facilities, and advanced computing techniques. Our group has strong ties with several institutions around the world (see below).

From collinear approximation … to 3D nucleon structure

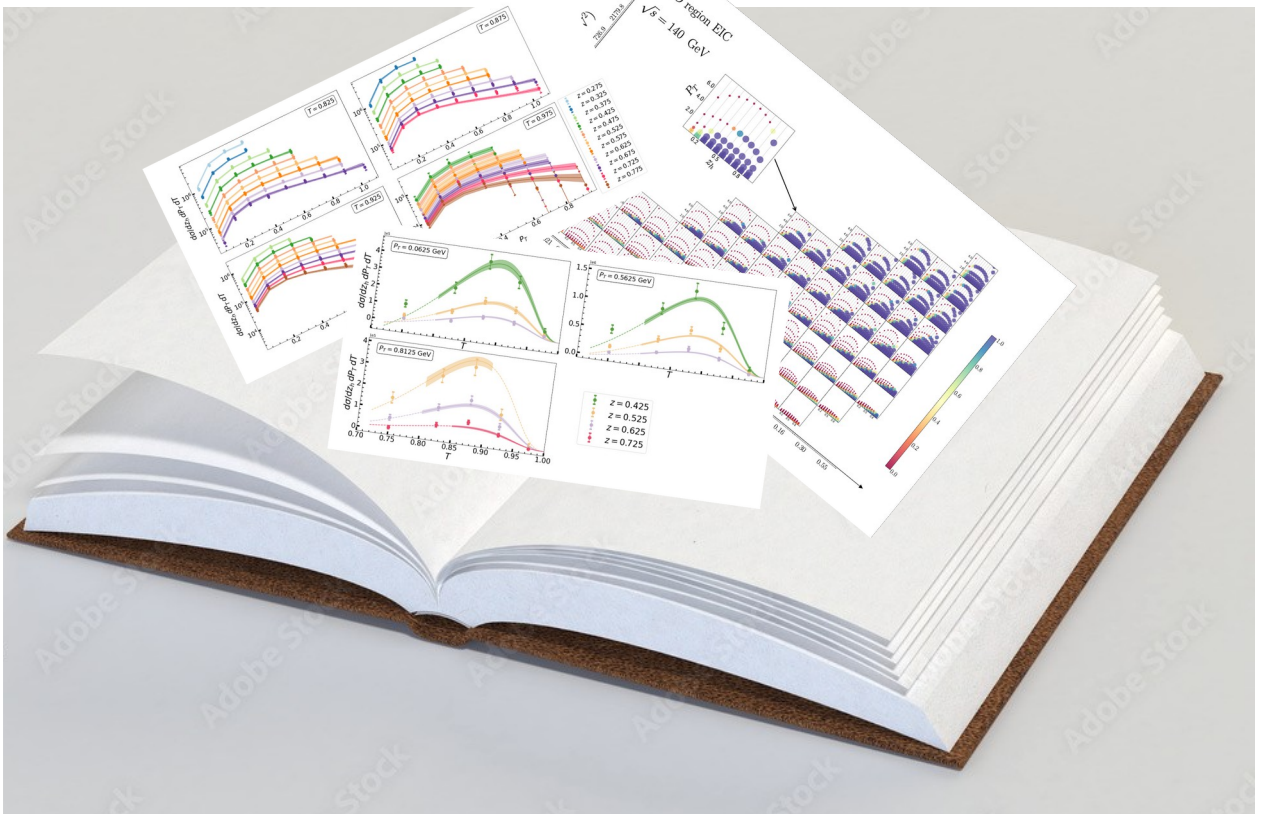
Collinear approximation



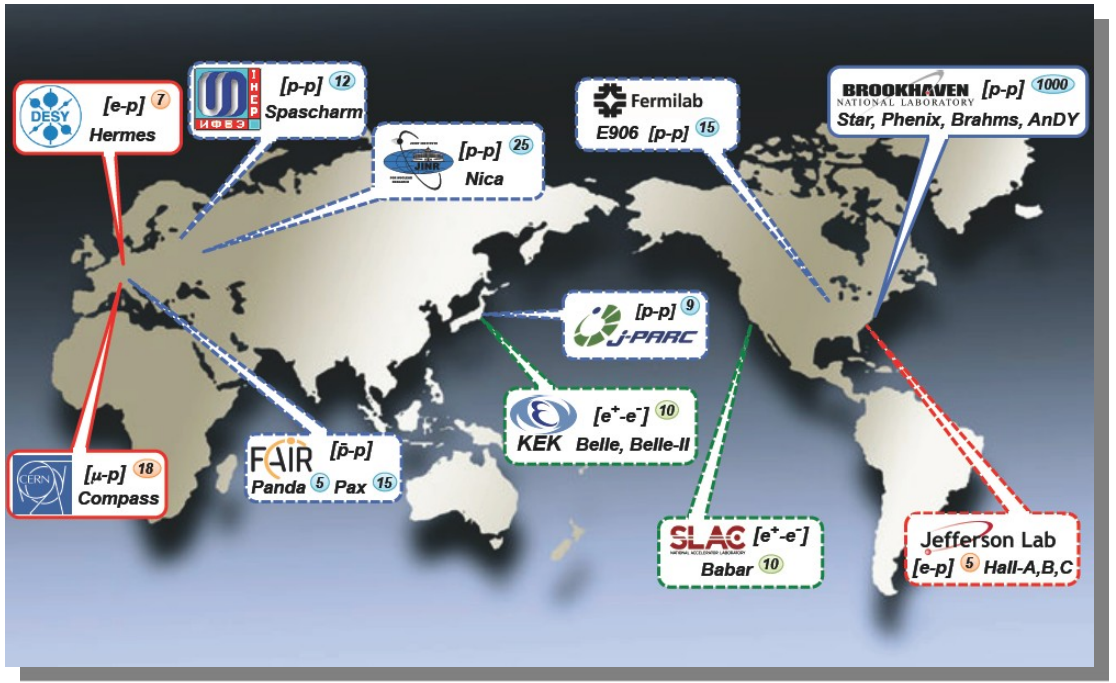
3D structure



Data analyses have much to say about the 3D dynamical inner structure of nucleons!



NINPHA – Torino: Experiment Connections



- Brookhaven National Labs (RHIC and EIC)
- CERN (Compass – LHC)
- Jefferson Lab (Hall A,B,C)
- KEK (Belle)
- BES III
- DESY (ZEUS, H0, HERMES)
- Fermi Lab (CDF, C0, SeaQuest, SpinQuest)
- **BNL Electron Ion Collider (future facility)**

NINPHA – Torino: PHENOMENOLOGY

THEORY
- Perturbative QCD
- Factorization theorems
- Resummation
- ...

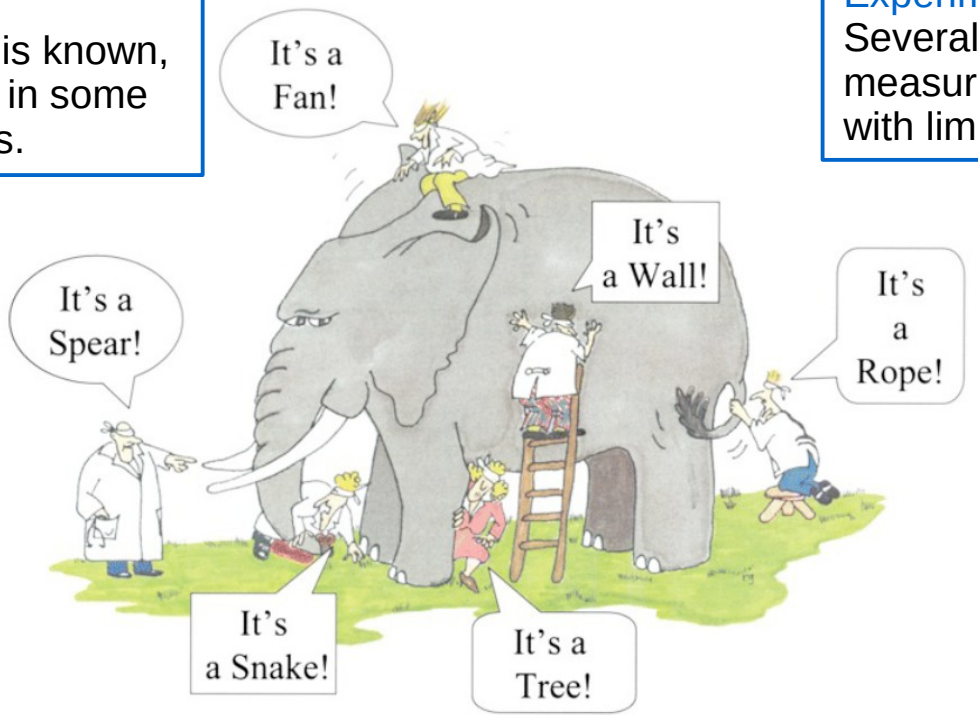
PHENOMENOLOGY
Mission: devise simple flexible and efficient models to link THEORY with EXPERIMENTS

EXPERIMENTS
- Drell-Yan scattering
- Di-hadron production from e+e- scattering
- DIS and SIDIS processes
- Inclusive single particle production from hadronic scattering

NINPHA – Torino: PHENOMENOLOGY

Theory → Blind Men
The Lagrangian of QCD is known, but it can only be solved in some particular approximations.

Experiments → Blind Men
Several different experiments measuring the same observable, with limited coverage

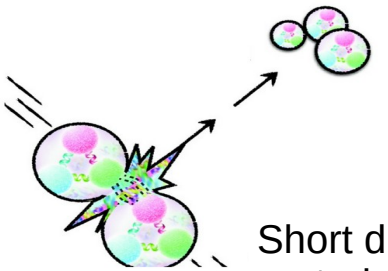


Phenomenology → "where everything comes together nicely"
Combine different sources of information to get the whole picture

From the theory point of view … QCD

QCD → Confinement

QCD → Asymsymptotic Freedom



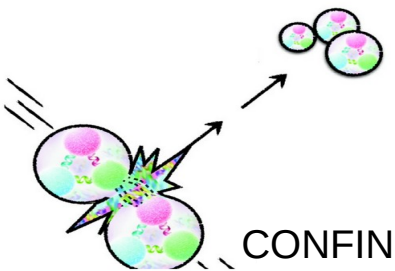
Long distance physics, non-perturbative structure functions.

Short distance effects, perturbative QCD

QCD → Non perturbative regime (non computable but universal terms)

QCD → Perturbative regime (computable but process dependent terms)

Strong interactions: **hadron structure** is a playground to understand QCD



HADRONIZATION

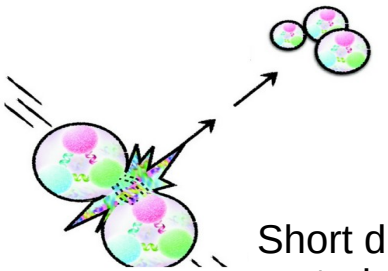
CONFINEMENT

From the theory point of view … QCD

QCD

Non perturbative regime (non computable but universal terms)

Perturbative regime (computable but process dependent terms)



Long distance physics, non-perturbative structure functions.

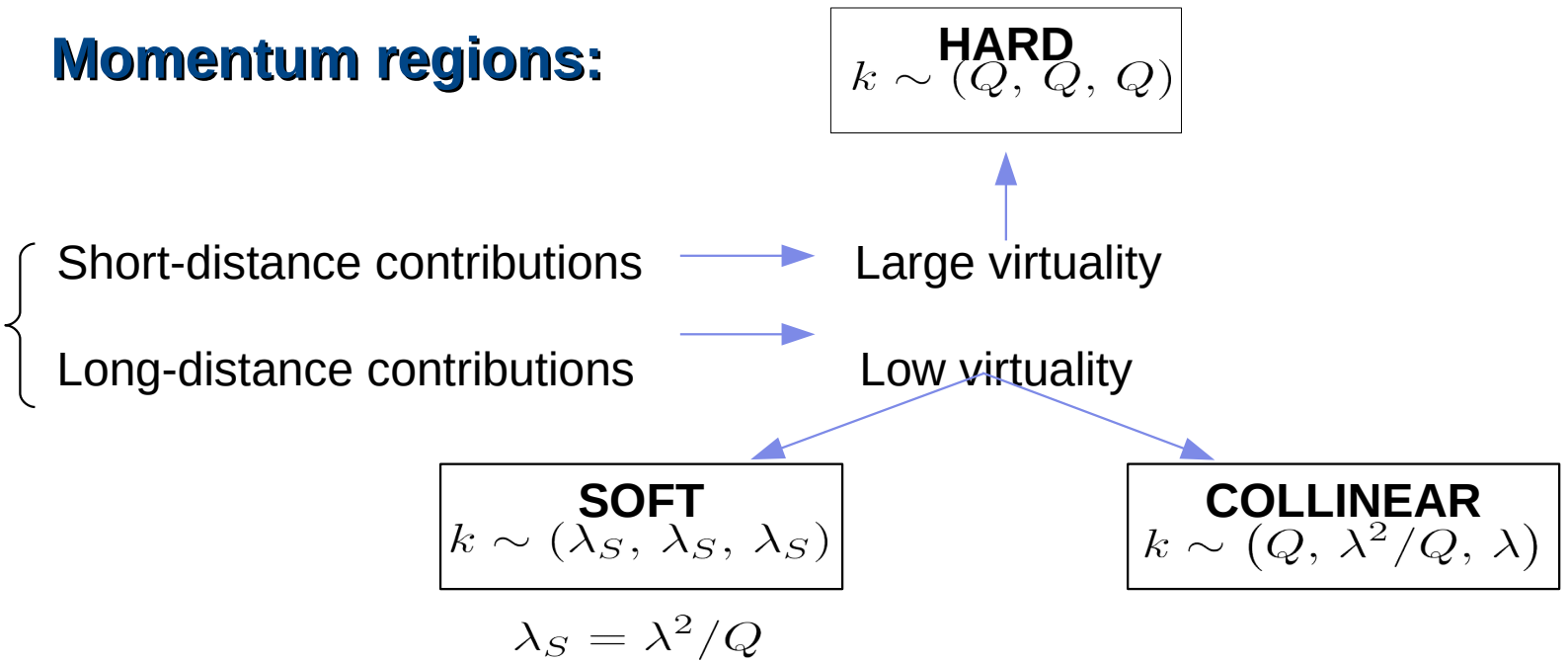
Short distance effects, perturbative QCD

- The interplay between **perturbative** and **non-perturbative** regimes is currently one of the most challenging aspects in phenomenology.
- **Factorization** allows to separate the perturbative content of an observable from its non-perturbative content. At large *Q* and small *m*, the non-perturbative contributions are separated out from anything that can be computed by using perturbative techniques, and identified with universal quantities (structure functions).
- **Factorization** restores the predictive power of QCD

From the theory point of view … factorization

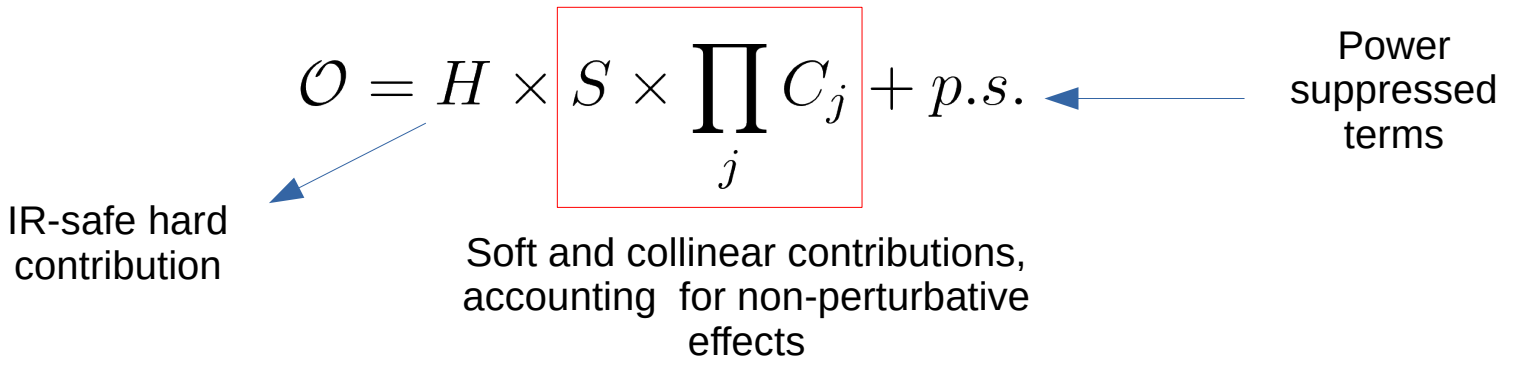
Particles are classified according to how they propagate in space,
i.e. according to their virtuality.

Momentum regions:



From the theory point of view … factorization

General structure of a generic factorization theorem:



- Each term is equipped with proper subtractions.
- The soft factor S encodes the *correlation* among the various collinear parts.
- While H can be computed in pQCD, S and C have to be determined using non perturbative methods. For instance they can be modeled and extracted from experimental data, or computed in lattice QCD

NINPHA – Torino

Main objectives

The activity of the Torino group focuses on the study of the **inner structure of hadronic matter,** in the framework of QCD

- **State of the art accuracy of collinear parton distribution functions (PDFs) of the proton**. We produce unpolarized and longitudinally polarized PDF sets accurate to (approximate) N3LO and NNLO, respectively. Extractions include uncertainty estimates of missing higher-order corrections
- **Quark-flavor dependence and intrinsic transverse momentum**. Global analyses of SIDIS and DY data are performed, to determine transverse-momentum dependent functions (TMDs) and their flavor dependence. Higher-twist contributions and mass corrections are also being explored

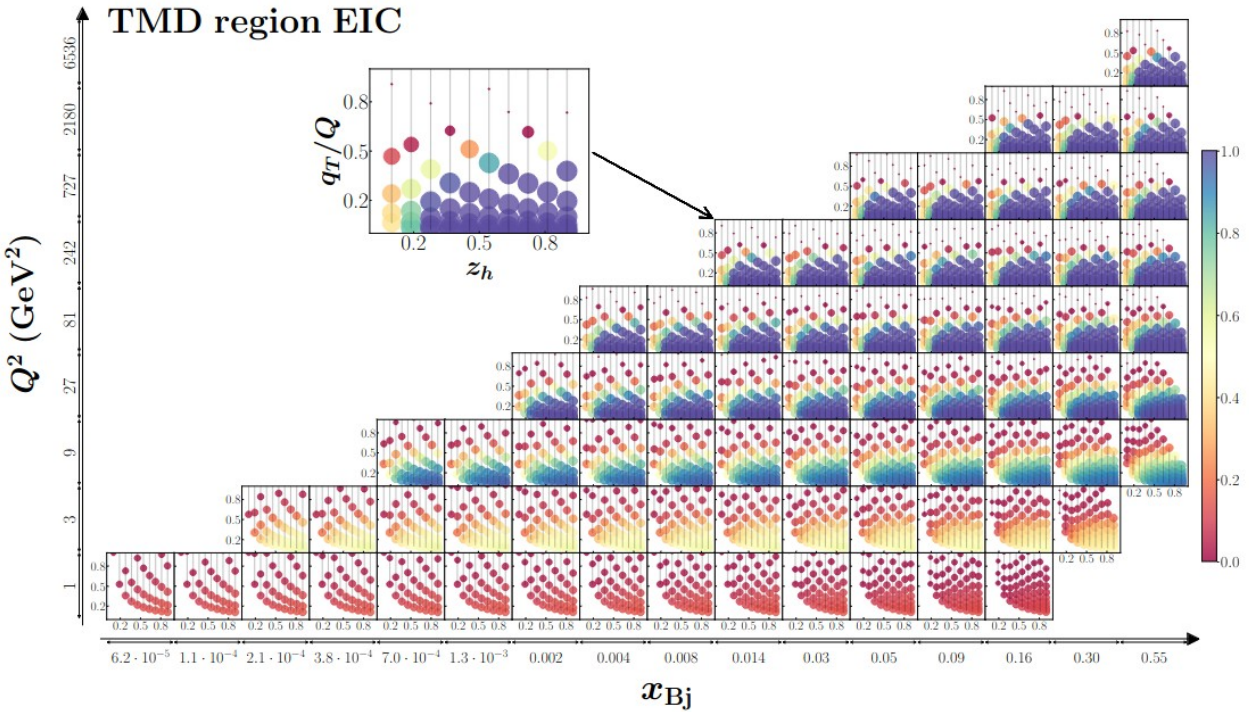
NINPHA – Torino

Main objectives

- **Consistency of factorization theorems and phenomenological applications**. Concrete recipes that exploit the relation of collinear and TMD factorization theorems are implemented into phenomenological analyses aiming at describing the entire transverse momentum spectrum of observables

- **Phenomenology of hadronization**. We study the factorization properties of single inclusive hadron production in e+e- annihilation $e+ e- \to h$ X data, which allow the direct extraction of one isolated TMD fragmentation function and the separation of its soft content from the collinear part of the TMD.

NINPHA – Torino: Projects



TOOLS FOR UNDERSTANDING SIDIS MEASUREMENTS

MSCA4Ukraine

2023-2025

Tetiana Yushkevych

Funded by the European Union

NINPHA – Torino: Projects

STR0NG 2020

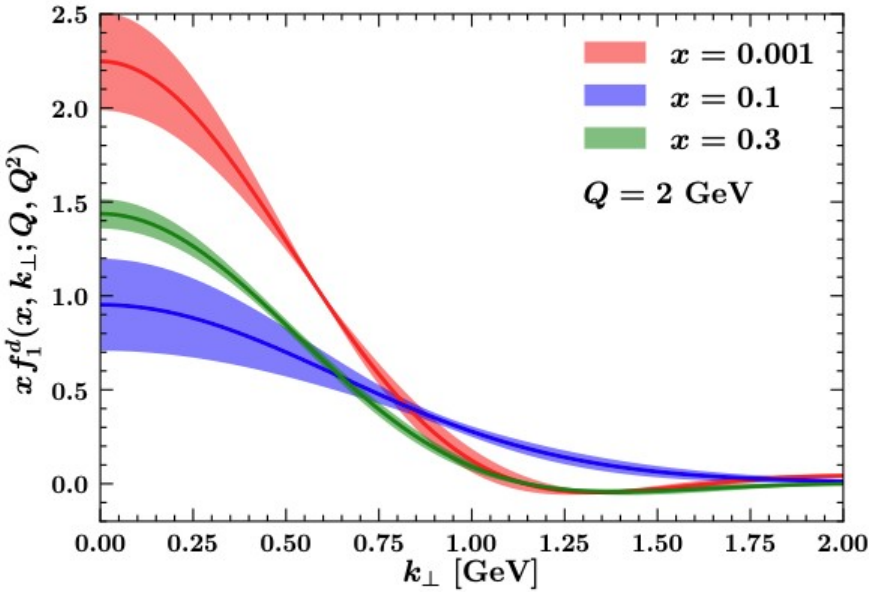
HORIZON 2020

2014-2024

M. Boglione and Osvaldo Gonzalez

Funded by the European Union

NINPHA – Torino: Projects



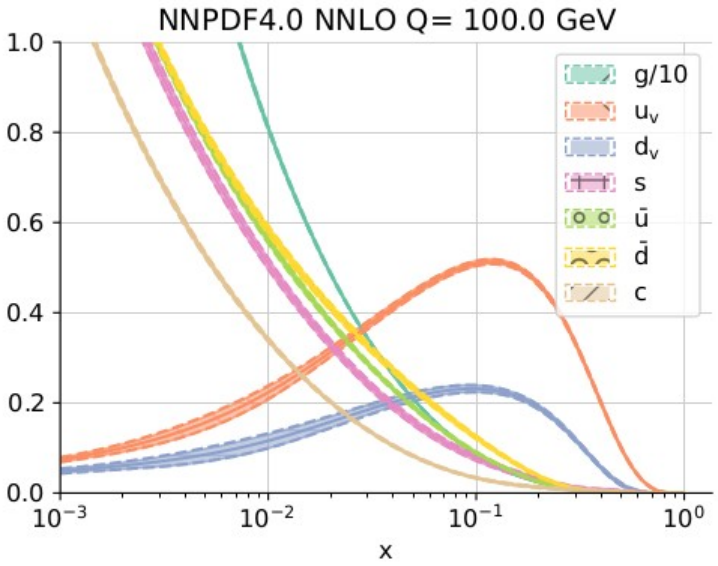
PROTO TASTE: a taste of the proton

PRIN 2023

2023 – 2025

M. Boglione

NINPHA – Torino: Projects



PDFs and FFs at NEXT-GEN COLLIDERS

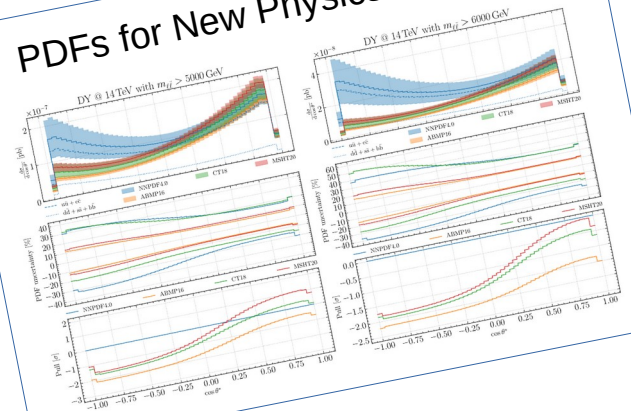
Programma Rita Levi Montalcini

2023 – 2025

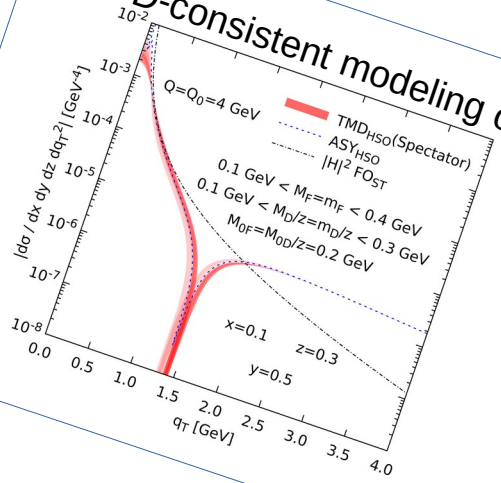
E. R. Nocera

A closer look to the 3D nucleon structure: some examples

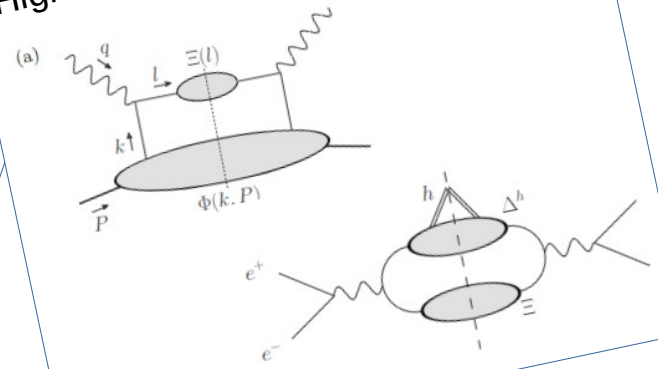
PDFs for New Physics Searches



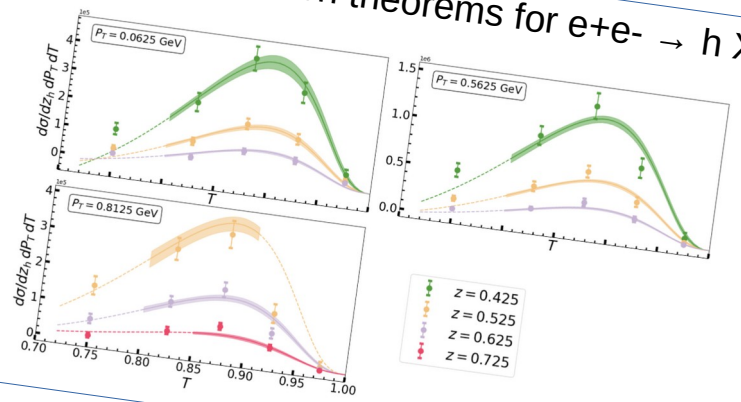
pQCD-consistent modeling of TMDs



Higher twist corrections to DIS, e+e-



New factorization theorems for e+e- → h X



New reweighting techniques for TMDs