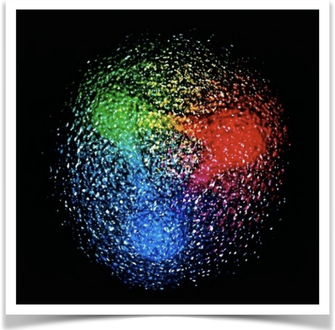
INFN Giornate di studio sulla Fisica Teorica

Santo Stefano Belbo - 20-21 Novembre 2021

The NINPHA project

National Initiative for the Physics of Hadrons



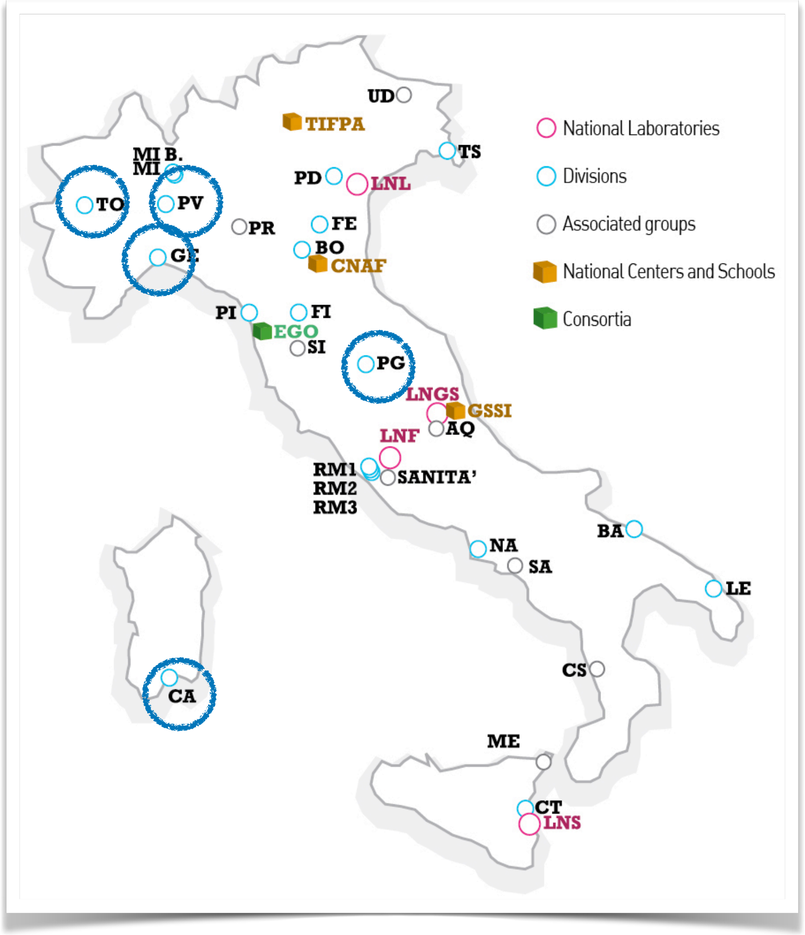
Elena Boglione - INFN Sezione di Torino

The NINPHA teams

NINPHA is structured in 5 nodes

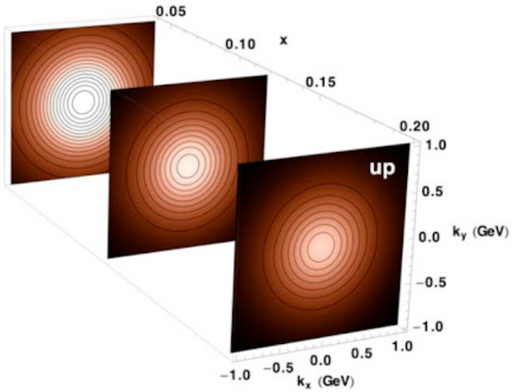
National Coordinator: *Elena Boglione*

- Cagliari
- Genova
- Pavia
- Perugia
- Torino
  - Enzo Barone (Piemonte Orientale)
  - Elena Boglione (UniTo)
  - Osvaldo Gonzalez (UniTo)
  - Andrea Simonelli (UniTo)
  - Philip Ratcliffe (Insubria)



NINPHA main objectives

A quick outline …



- The goal of the NINPHA project is the study of the **inner structure of hadronic matter**.
- The focus is on how hadron phenomenology emerges from the interactions generated by the symmetries of QCD, and from the breaking of these symmetries.
- Building accurate maps of the **internal dynamics of partons** and of their mutual interactions will shed light on the origin of hadronic masses and spins, and their composition in terms of elementary constituents.
- Shaping these maps in momentum and coordinate space requires advanced non-perturbative techniques, as well as highly accurate perturbative computations and extensive global phenomenological analyses.
- NINPHA activities are also dedicated to the study of the **excited hadron spectrum and decays**, especially to exotic hadrons.

NINPHA Experimental connections

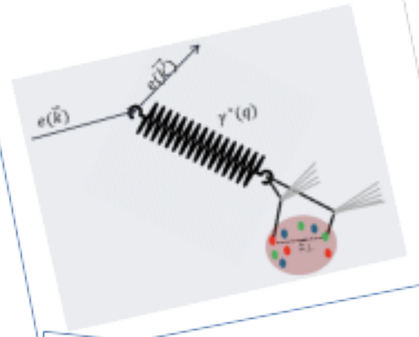
NINPHA activities are connected to the following experiments:

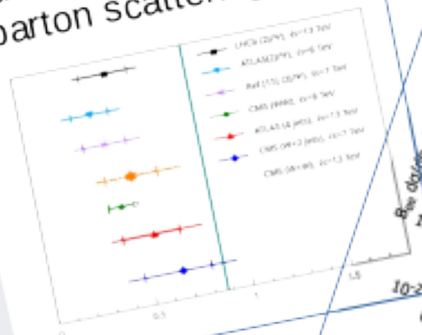
- Alice,CMS, Atlas, LHCb - LHC - CERN - Geneva (Switzerland)
- COMPASS - CERN - Geneva (Switzerland)
- HERMES - DESY - Hamburg (Germany)
- MAMBO – Mainz-Bonn (Germany)
- NUMEN - INFN-LNS
- CLAS, Hall A, Hall B, Hall C - Jefferson Laboratories (JLab) - (VA) USA
- STAR, Phenix - Brookhaven National Laboratories (BNL) - (NY) USA
- CDF, DØ- Tevatron - Fermi National Accelerator Laboratory - (IL) USA
- BaBar - SLAC National Accelerator Laboratory - (CA) USA
- BELLE - KEK - Tokio – Japan
- BESIII - Beijing – China
- NICA-SPD - JINR - Dubna - Russia
- In the last two years NINPHA has been deeply involved in the planning and design work of a brand new, dedicated facility, the **Electron Ion Collider** (EIC). All members have co-authored the EIC Yellow Report, which was published earlier this year.

A closer look to the nucleon structure

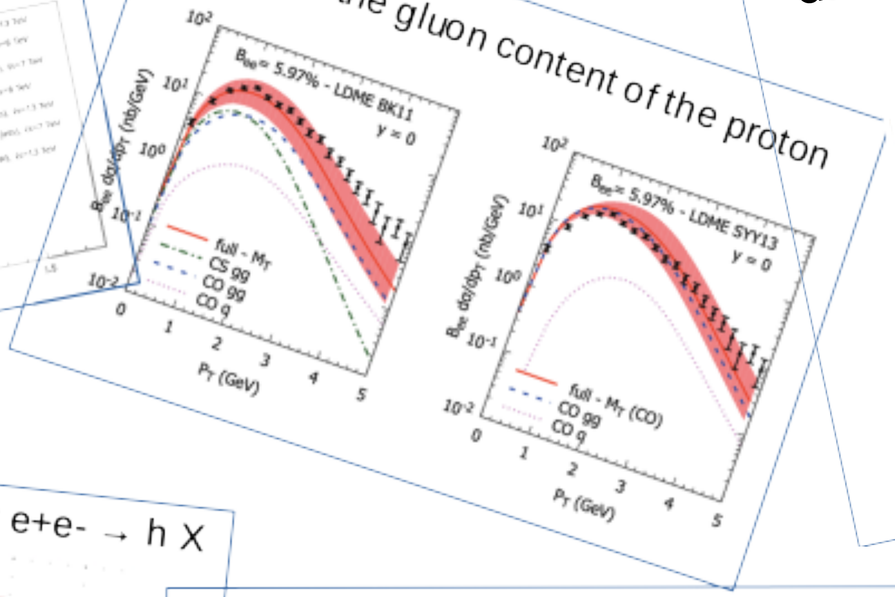
A few examples …

Perugia: transverse size of the proton via double parton scattering

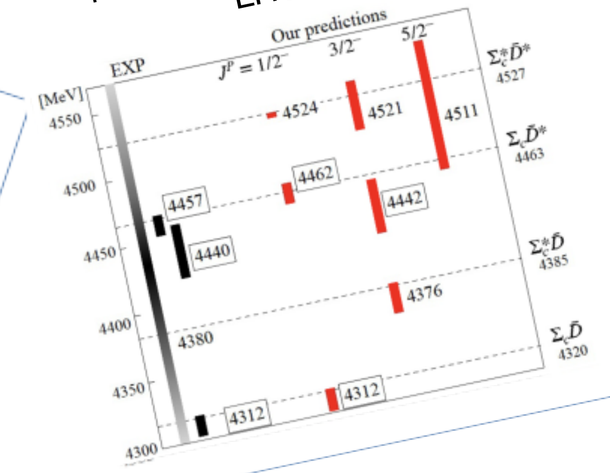




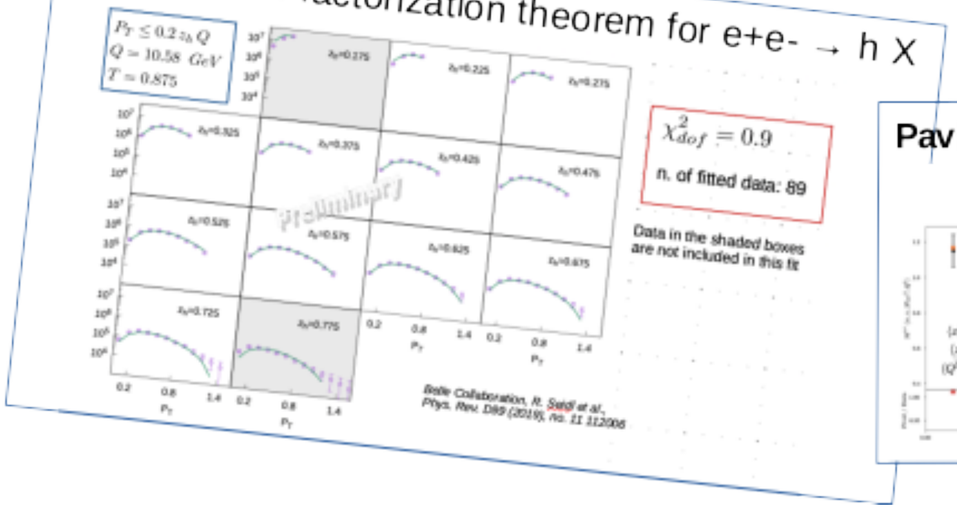
Cagliari: the gluon content of the proton



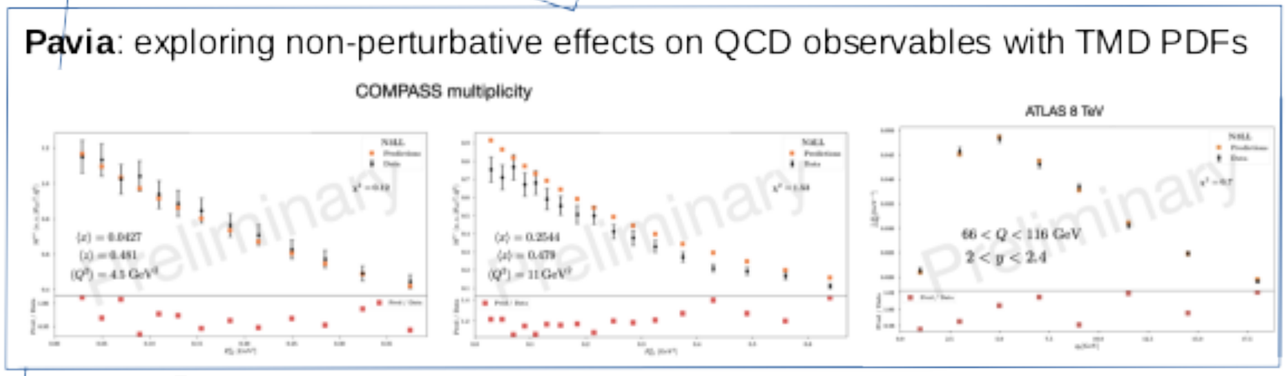
Genova: predictions of the new LHCb pentaquark states before the LHCb data



Torino: new factorization theorem for e+e- → h X



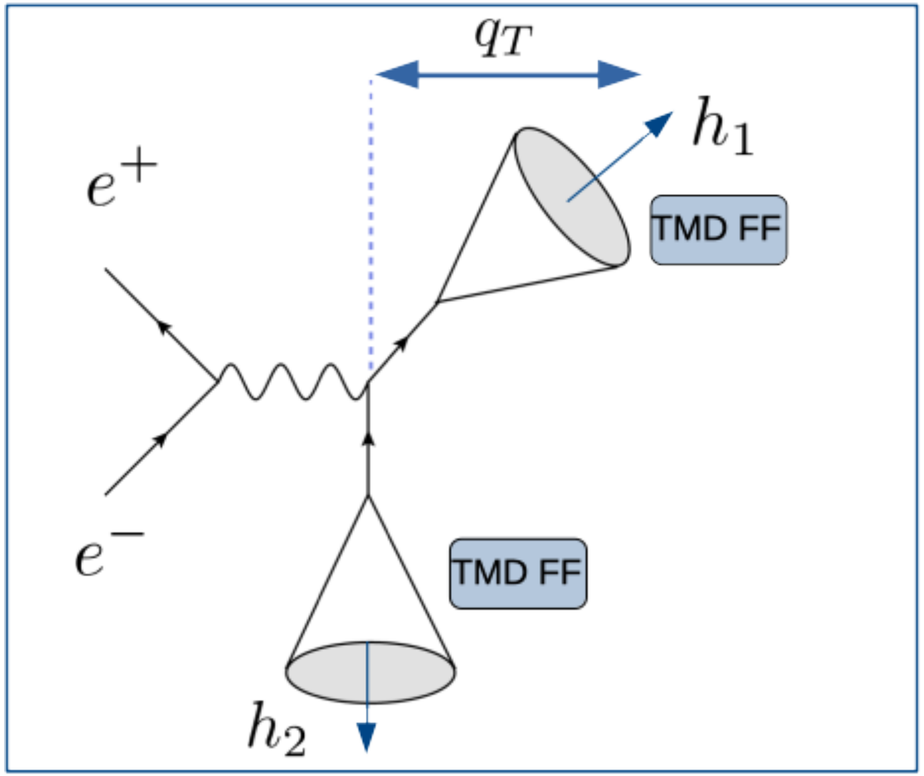
Pavia: exploring non-perturbative effects on QCD observables with TMD PDFs



Disentangling hard from soft …and soft from collinear

e^+e^- annihilations
Into two hadrons

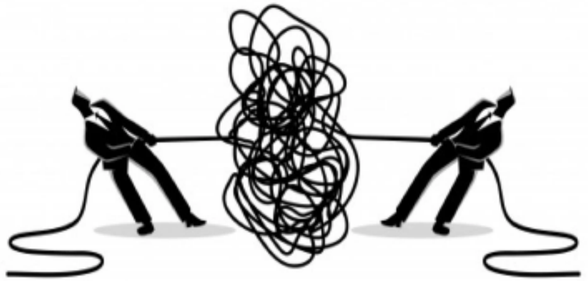
$$e^+ e^- \to h_1 h_2 X$$



$$\frac{d\sigma}{dq_T} = \mathcal{H}_{2\text{-h}} \int \frac{d^2\vec{b}_T}{(2\pi)^2} e^{i\vec{q}_T\cdot\vec{b}_T} D_1(b_T)\, D_2(b_T)$$

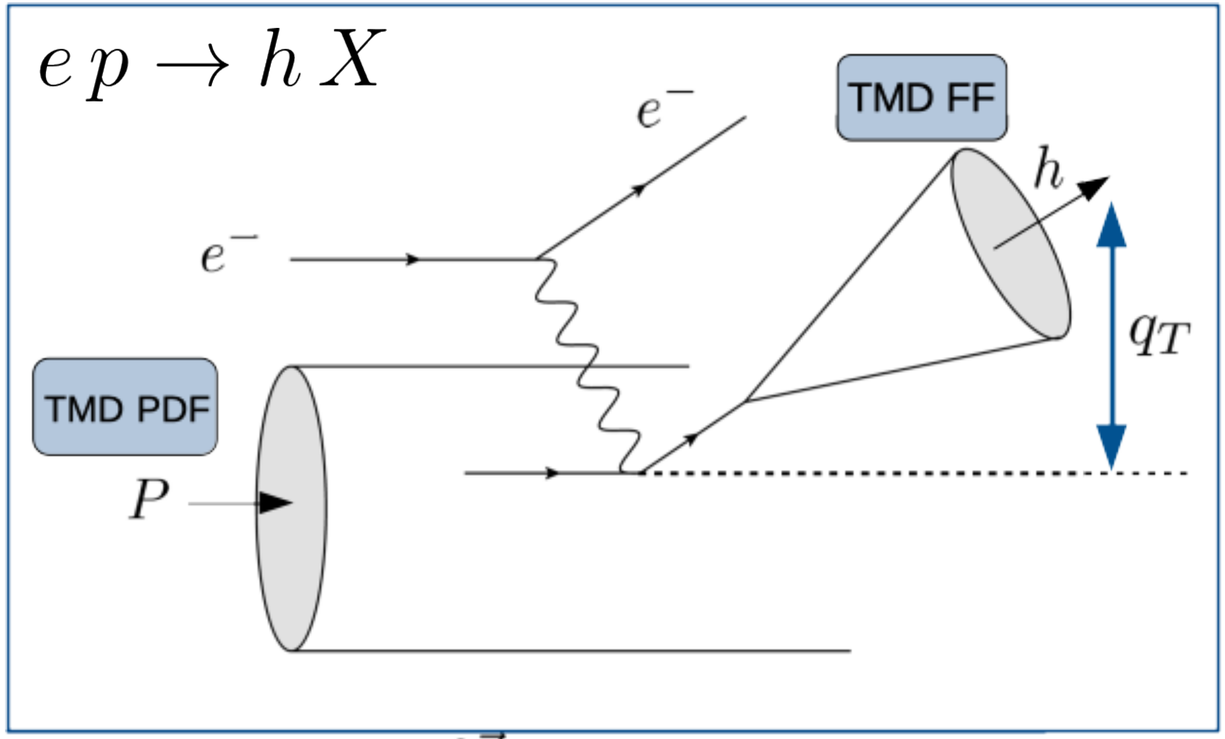
3D-picture of the **hadronization** of partons into hadrons

In e^+e^- cross sections, distribution and fragmentation TMDs are convoluted.
How can they be disentangled?



Disentangling hard from soft …and soft from collinear

SIDIS

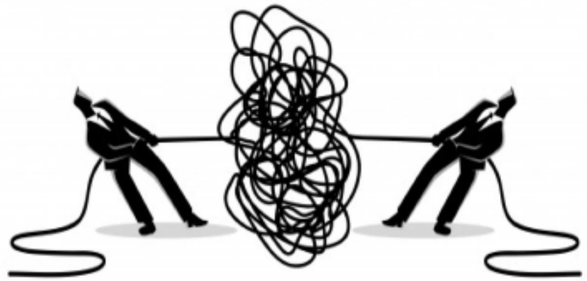


$$\frac{d\sigma}{dq_T} = \mathcal{H}_{\rm sidis} \int \frac{d^2\vec{b}_T}{(2\pi)^2} e^{i\vec{q}_T\cdot\vec{b}_T}\, F(b_T)\, D(b_T)$$

3D-picture of partons inside the target hadron

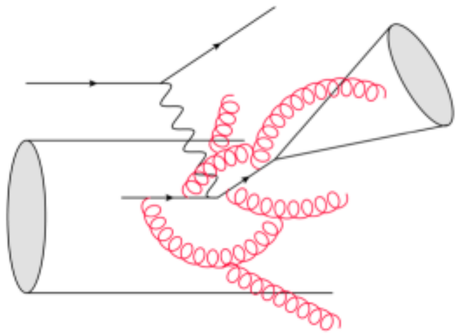
3D-picture of partons hadronizing into the detected hadron

In the SIDIS cross sections, distribution and fragmentation TMDs are convoluted.
How can they be disentangled?



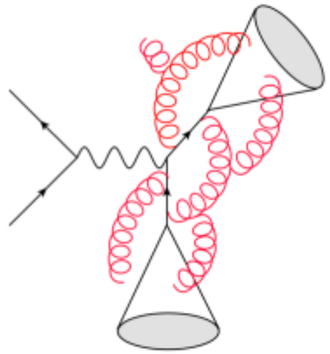
Soft contributions are the main cause of the tangle …

SIDIS



$$\frac{d\sigma}{dq_T} = \mathcal{H}_{\text{sidis}} \int \frac{d^2\vec{b}_T}{(2\pi)^2} e^{i\vec{q}_T\cdot\vec{b}_T}\, F(b_T)\, D(b_T)$$

Double hadron production



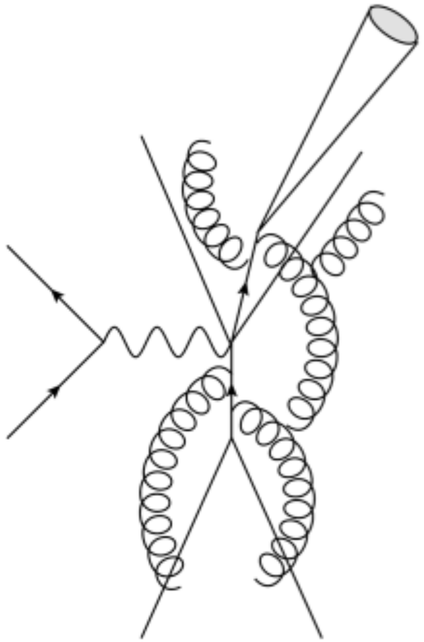
$$\frac{d\sigma}{dq_T} = \mathcal{H}_{\text{2-h}} \int \frac{d^2\vec{b}_T}{(2\pi)^2} e^{i\vec{q}_T\cdot\vec{b}_T}\, D_1(b_T)\, D_2(b_T)$$

Soft Gluon Factor:

- Non-Perturbative contribution
- Evenly shared by the TMDs

New factorisation scheme … New definition of TMD…

$$e^+e^- \to hX$$



$$\frac{d\sigma}{dP_T} = d\hat{\sigma} \otimes D^{\star}(P_T)$$

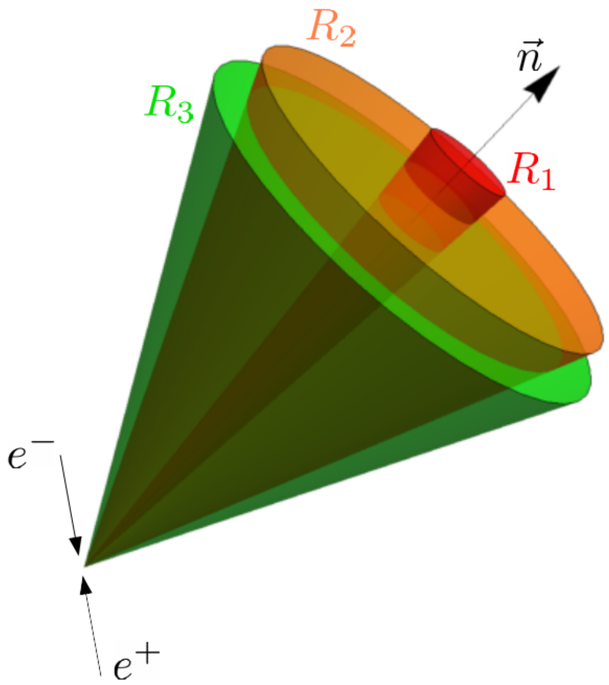
Soft Gluon Factor:

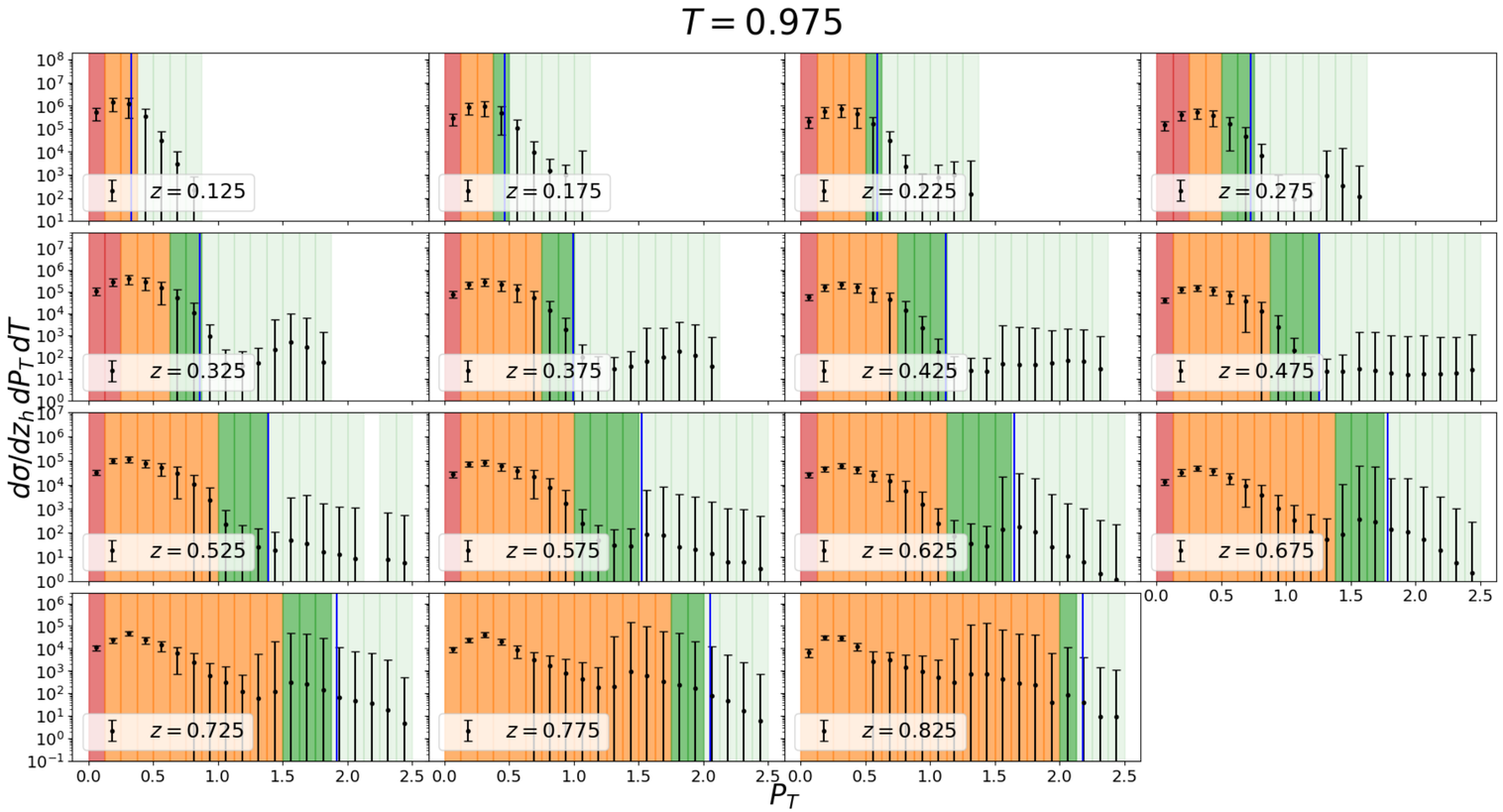
- Perturbative (computable) contribution (soft thrust function in the partonic cross section).
- The TMD FF* is **free** from any soft gluon contributions

$D(P_T)$ and $D^*(P_T)$ are different,
BUT
the relation between D and D* is known!

We can perform combined analyses and disentangle non-perturbative terms.

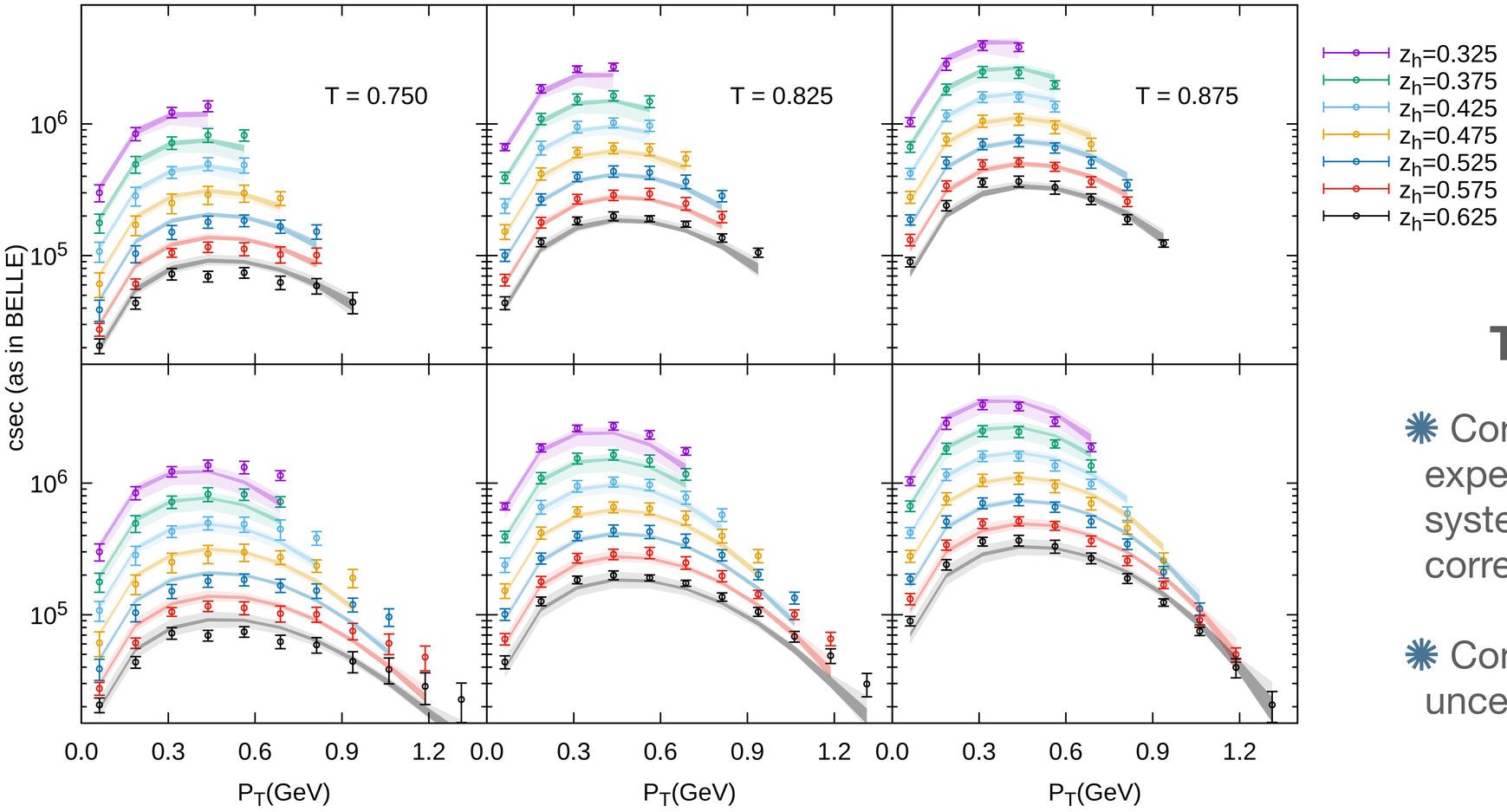
Kinematic Regions





Each kinematic region (red, orange, green) requires a different factorisation theorem

Phenomenological studies



Technical challenges:

- Consistent treatment of experimental error (Statistical, systematic uncorrelated and correlated errors)
- Consistent estimates of theoretical uncertainties

A new way to look at parton densities

The Soft Factor acquires a central role

The focus of phenomenological analyses moves from the TMDs considered as a whole, to the Soft Factor contribution (which encloses the full process dependent part of the TMD).

Can the TMD tangle finally be disentangled ?