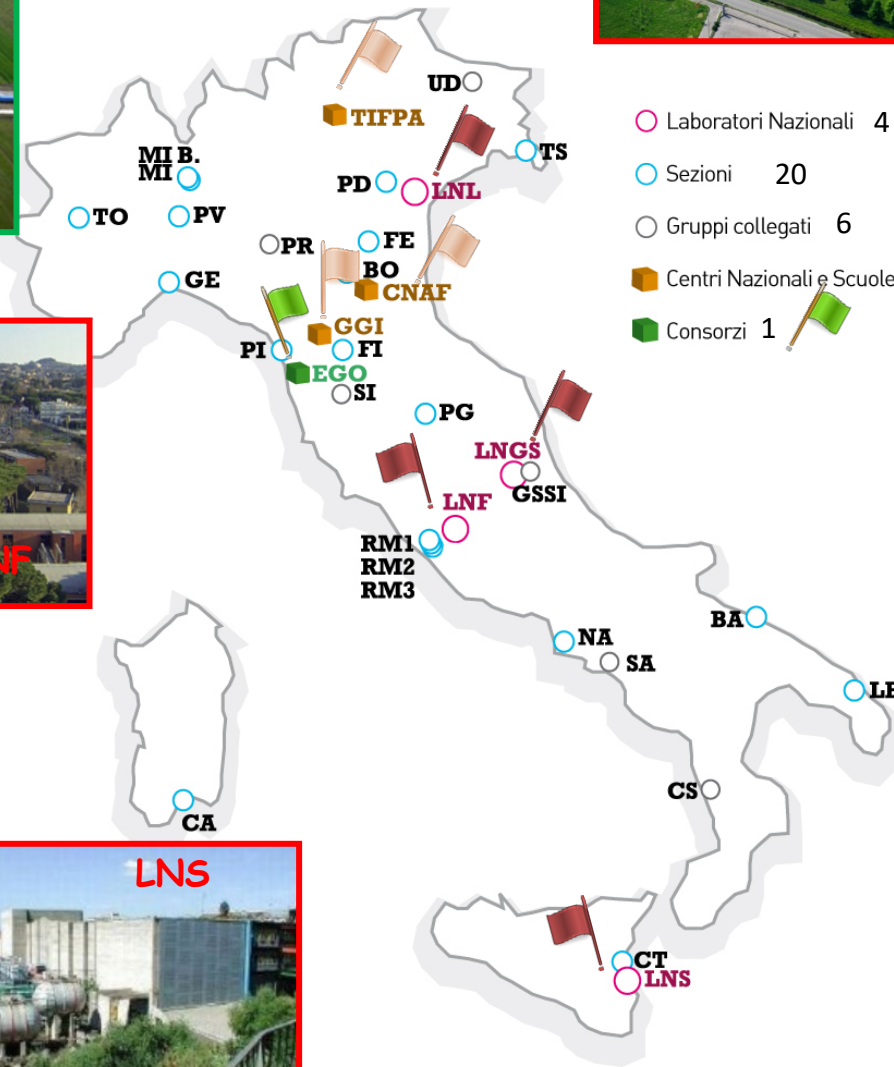


# INFN activities in the field of hadron physics

2° EIC Yellow Report Workshop  
Pavia University  
20-22 May 2020



- Laboratori Nazionali 4
- Sezioni 20
- Gruppi collegati 6
- Centri Nazionali e Scuole 3
- Consorzi 1

~ 2000 employees  
~ 4000 associated

# Research Lines and Scientific Commissions



**CSN1**  
**Particle**  
physics



**CSN2**  
**Astroparticle**  
physics



**CSN3**  
**Nuclear**  
physics



**CSN4**  
**Theoretical**  
physics



**CSN5**  
**Technological**  
research

Fundamental interactions of matter in experiments using particle accelerators (CERN-LHC, Fermilab, KEKB...)

Research in the field of neutrino and astroparticle physics (Fermilab, LNGS, Kamioande, EGO, KM3-net...)

Research into the structure and dynamics of nuclear matter including nuclear astrophysics (LNF, LNGS, LNL, LNS, CERN, GANIL, JLAB, JPARK...)

Coordinates theoretical physics research that develops hypotheses, models and physics theories to explain the results of experiments and open up new scenarios for physics (GGI...)

Coordinates technological research and promotion of the use of fundamental physics instruments, methods and technologies in other sectors.

**COMPASS**  
(LHCB, CMS, ATLAS..)

**JLAB, ALICE**  
(MAMBO, JEDI...)

**NINPHA**

**Possible R&D projects for EIC**

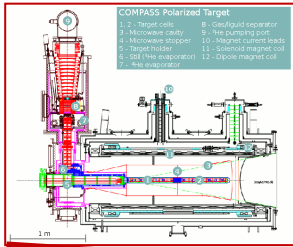
# COMPASS - fix target experiment at CERN SPS

- On the unique M2 beam line: high energy polarized muons / secondary hadron beams
- Active since 2002

The 60 m long two-stage spectrometer

NIMA 577 (2007) 455–518,  
NIMA 779 (2015) 69–115

Polarized target  
1.2 m long

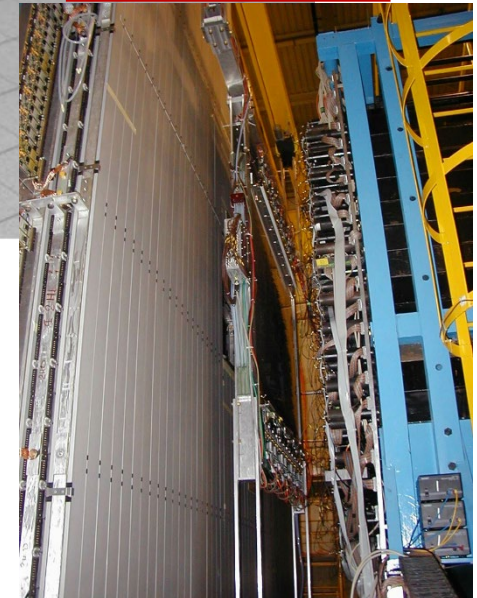
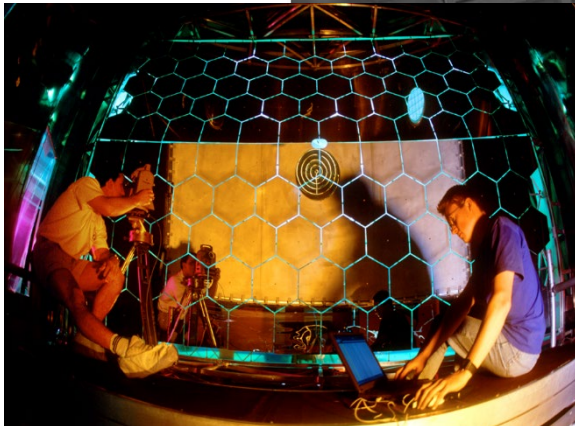


RICH/muon wall

34 Tracking MWPCs

Spectrometer magnets

Gaseous trackers, scintillating fibers,  
scintillator hodoscopes, E-Cals, H-Cals..

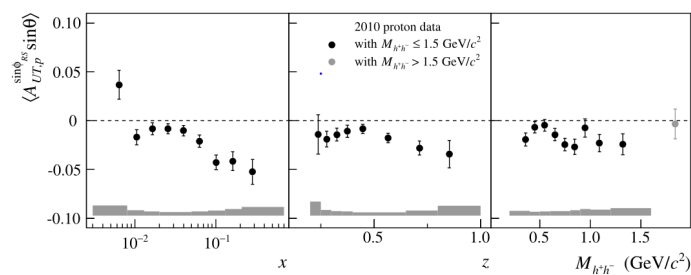
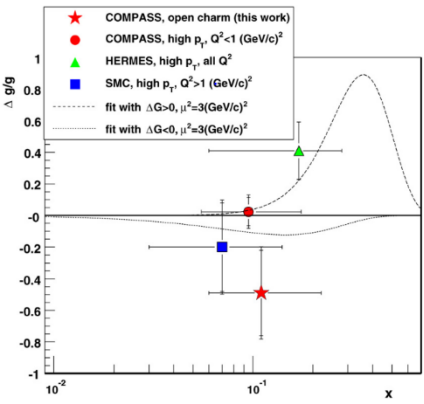
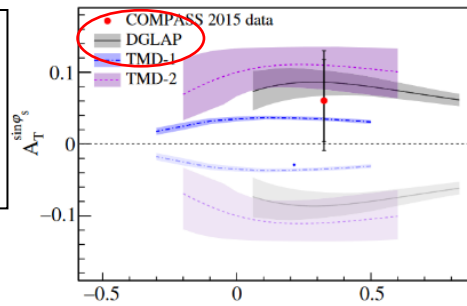


# COMPASS physics - few examples

## nucleon quark-gluon structure

- the gluon polarisation by *SIDIS*
- Transversity and TMDs by *SIDIS*
- Polarized Drell-Yan
- 3-D nucleon structure
  - Deeply Virtual Compton scattering (DVCS)
  - Hard Exclusive Meson Production (HEMP)

First Measurement of  
Sivers asymmetry  
in the Drell-Yan  
Process  
PRL119,112002 (2017)



High-statistics measurement of  
transverse spin effects in dihadron  
production from muon-proton SIDIS  
Physics Letters B 736 (2014) 124-131

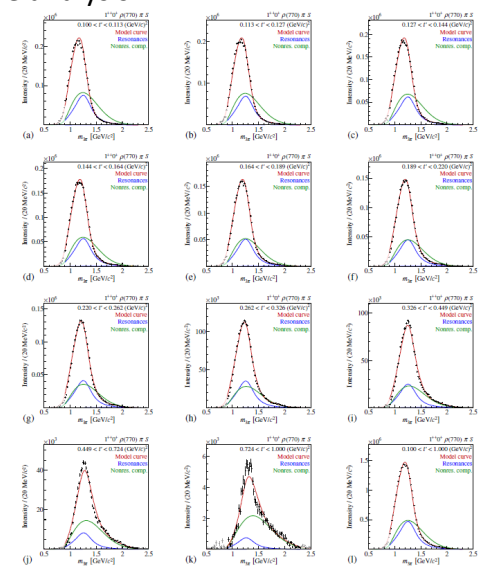
Gluon polarization in the nucleon  
from open charm muoproduction  
Physics Letters B 676 (2009) 31-38

# High statistic hadron spectroscopy

Light isovector resonances in  $\pi^- p \rightarrow \pi^- \pi^+ p$  at 190 GeV/c

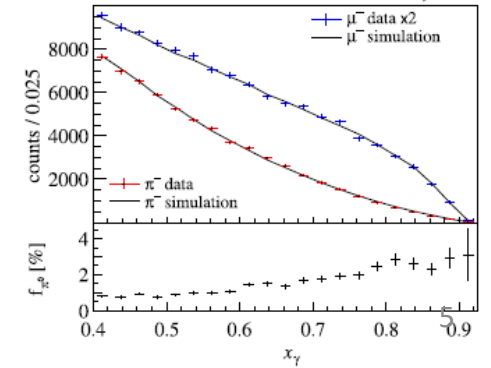
88 partial wave analysis

PHYSICAL REVIEW D 98, 092003 (2018)



# pion polarizability by Primakoff scattering with large statistics

PRL 114, 062002 (2015)



# COMPASS future

**Approved** (data taking in 2021):

- **d-quark transversity** by the measurement of SIDIS off transversely polarised deuterons

**Proposal** under evaluation (for data taking within 2024):

- **Proton radius** measurement using muon-proton elastic scattering
- **Drell-Yan** and charmonium production using conventional hadron beams
- Measurement of **antiproton production cross sections** for Dark Matter Search

**LOI**

measurements requiring **RF-separated hadron beams** of high intensity and purity  
(unique high-energy kaon and antiproton beams)

- **Spectroscopy of kaons**
- **Drell-Yan** with high-intensity kaon and antiproton beams
- **Kaon polarizability**
- Direct measurement of the **lifetime of the neutral pion**
- **Vector-meson production** off nuclei by pion and kaon beams

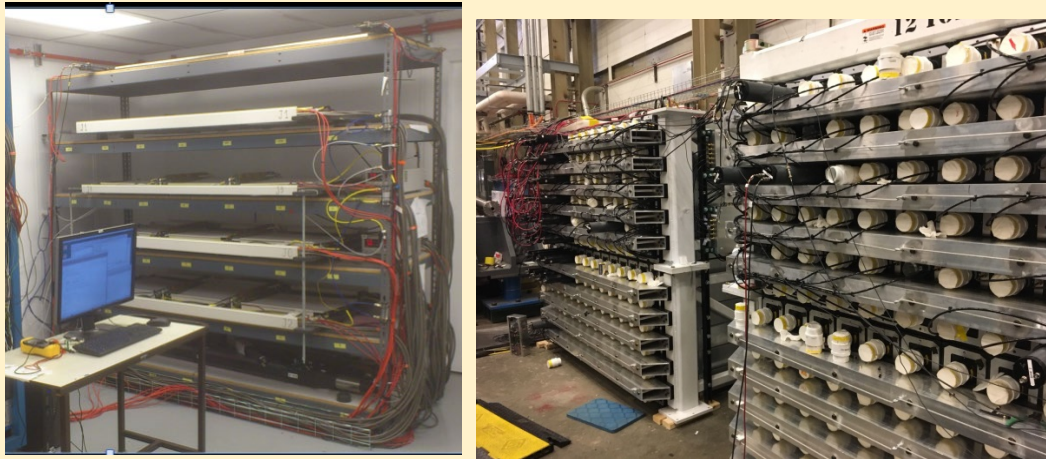
COMPASS++ / AMBER  
collaboration

## Possible synergies with EIC

- Development of a trigger-less DAQ
- R&D on RICH detector for  $p < 10 \text{ GeV}/c$

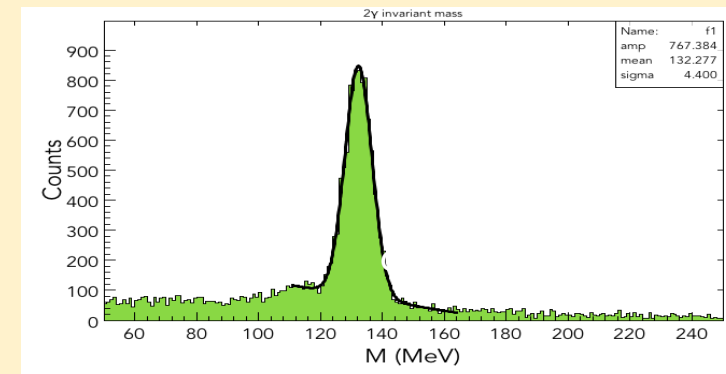
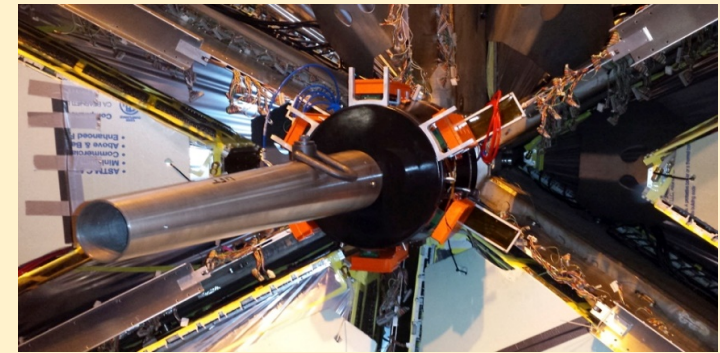
# INFN @ JLAB

GEM tracker & HCAL-J under cosmic test before installation in Hall-A

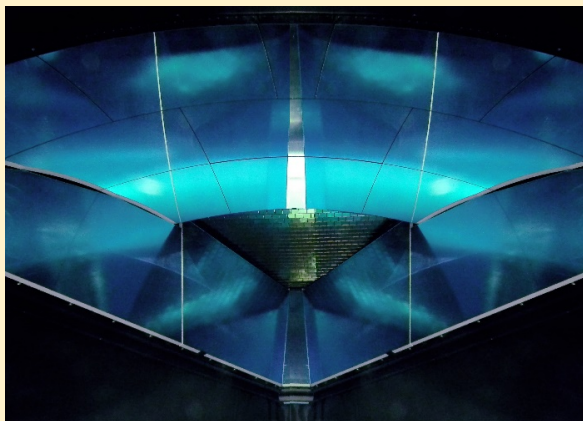


Radiat.Eff.Def.Solids 171 (2016) 9-10, 775-781

Forward Tagger in Hall-B (CLAS12):  
e,  $\gamma$ , trigger

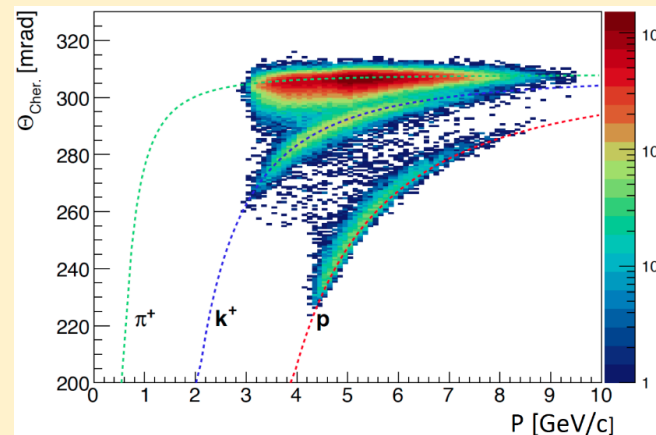


Ring Cherenkov Detector in Hall-B (CLAS12): Hadron ID



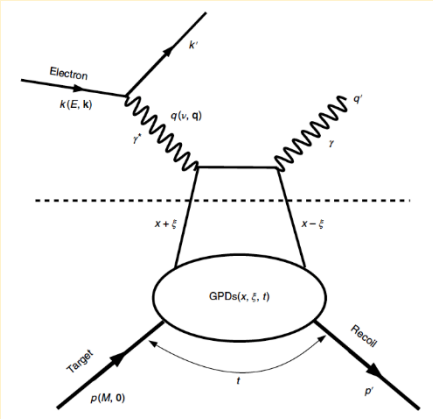
Nucl.Instrum.Meth.A 964 (2020) 163791

Nucl.Instrum.Meth.A 959 (2020) 163475



# JLAB physics: examples of INFN interests

**Hall-A deep-virtual Compton scattering measurement on deuteron ( $ed \rightarrow ed\gamma$ ) determines elusive quark flavor contributions to the hadron spin structure**

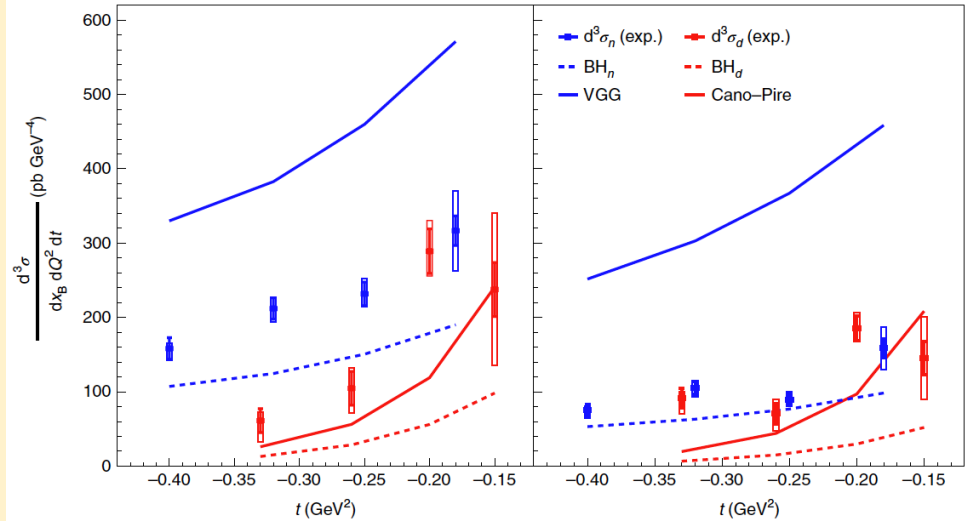


nature  
physics

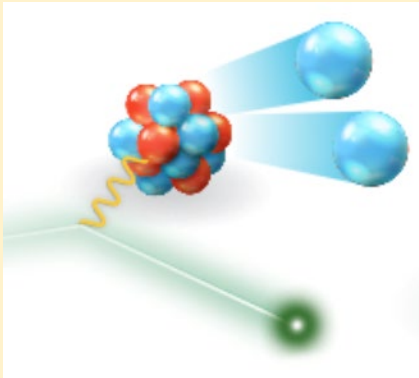
Nature 16 (2020) 191, 198

ARTICLES

<https://doi.org/10.1038/s41567-019-0774-3>

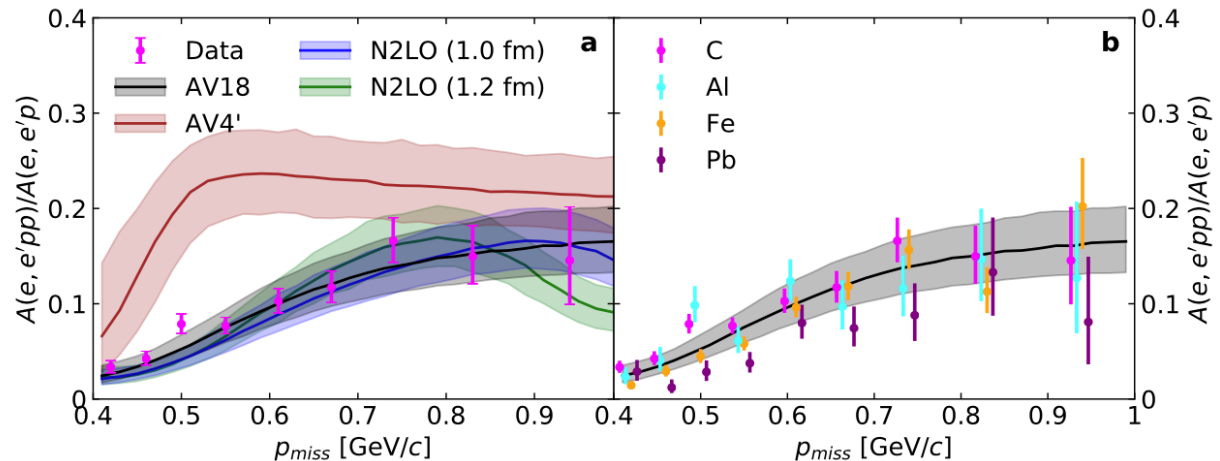


**CLAS scattering measurements on short-range correlated nucleon pairs probe nuclear interaction at unprecedented short distances**



nature  
International journal of science

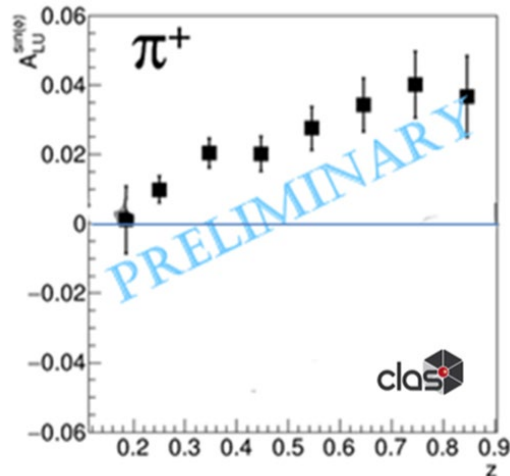
578 (2020) n.7796, 540-544



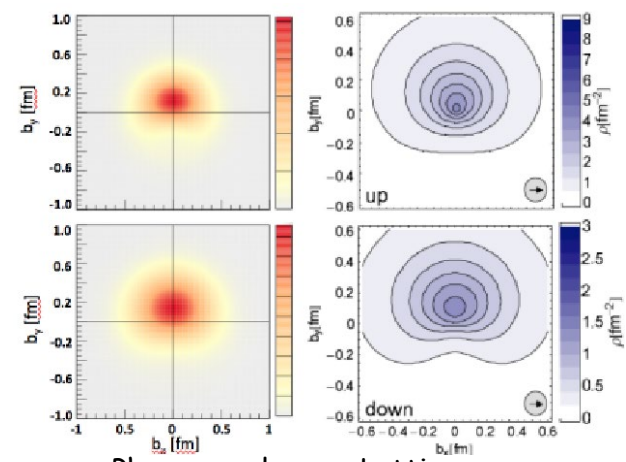


**Strong-commitment in EIC Precursor Physics ...**

Hadron 3D Structure in the valence  
 Strong-Force correlate. and dynamics  
 Exotic Hadronic States  
 Beyond Standard Model Search



M. Mirazita PoS SPIN2018 (2019) 041

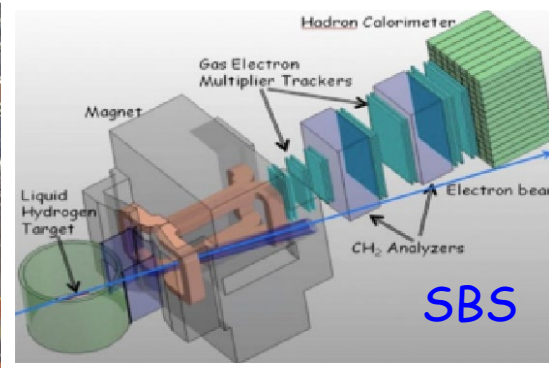
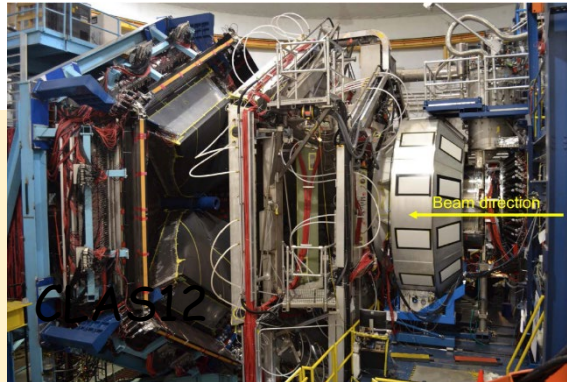


Phenomenology vs Lattice  
 V. Kubarovsky arXiv:1902.02643  
 M. Gockeler++ PRL 98 (2007) 222001

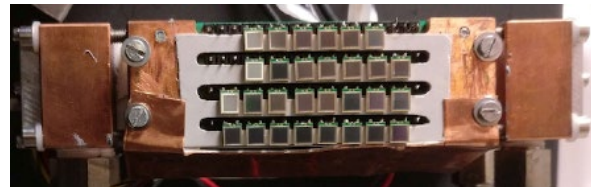
CLAS12: large acceptance spectrometer    SBS: high luminosity spectrometer

**... & New Technology Developments**

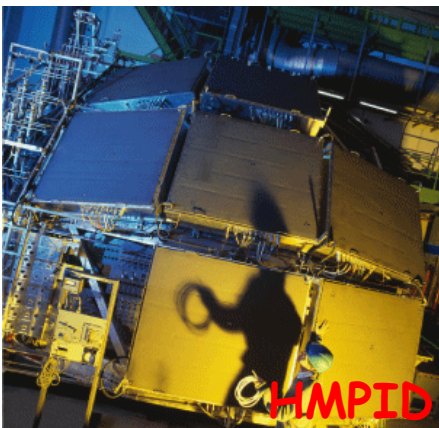
Luminosity frontier ( $10^{39} \text{ cm}^{-2}\text{s}^{-1}$ )  
 Bulk superconducting magnets  
 Large-area ring-Imaging detectors  
 Cost-effective Single Photon Detectors  
 Trigger-less streaming readout



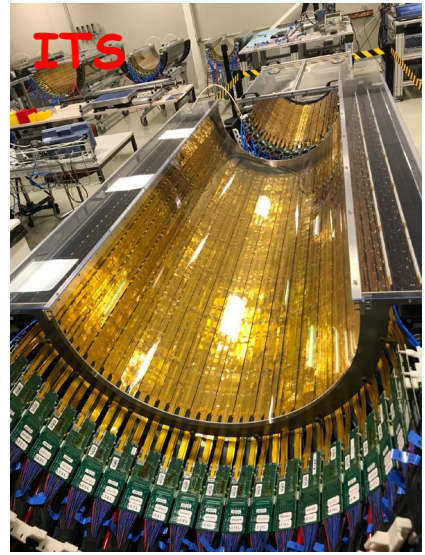
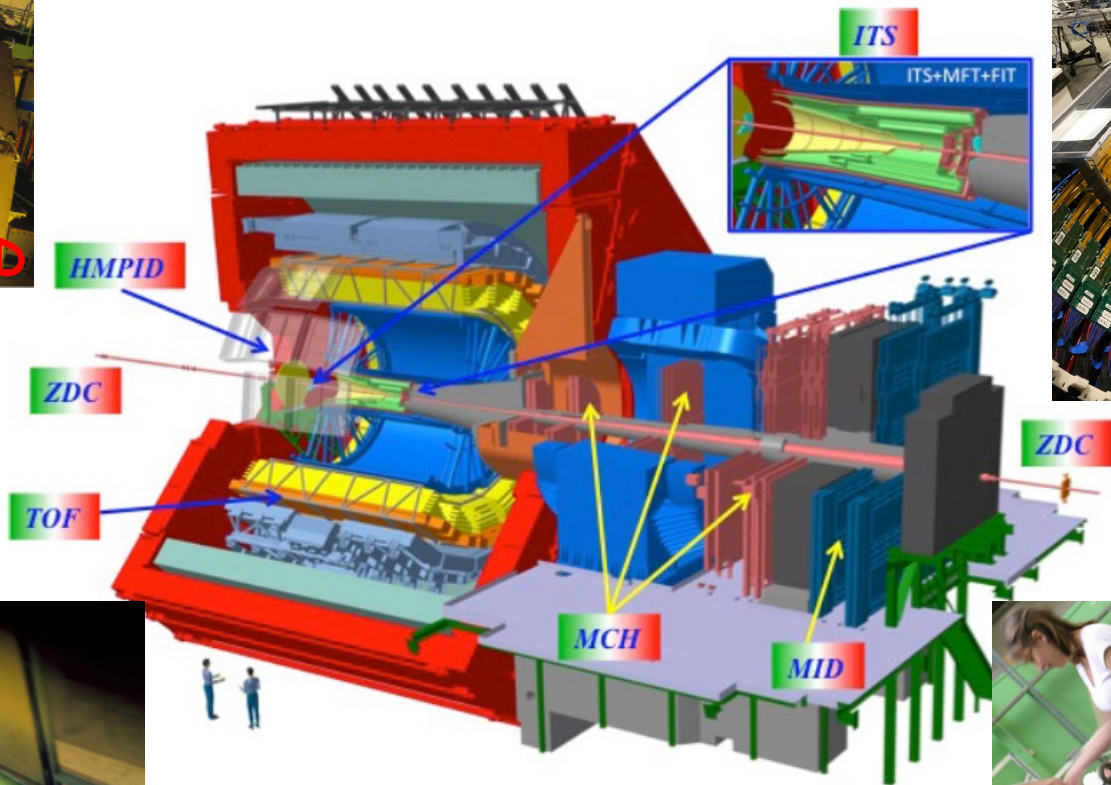
RICH: silicon photomultipliers



# ALICE at LHC



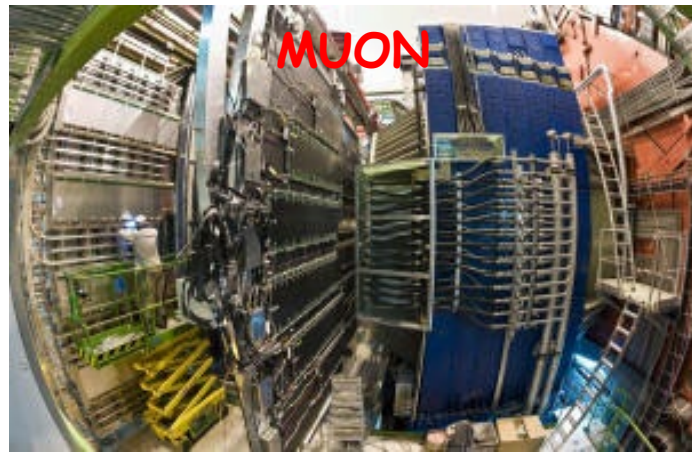
HMPID



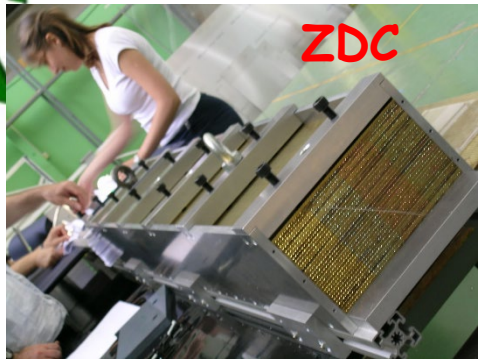
ITS



TOF

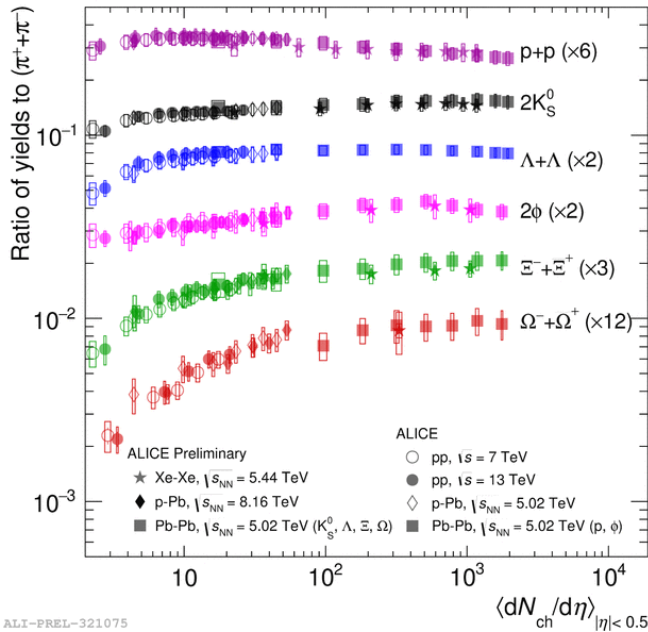


MUON

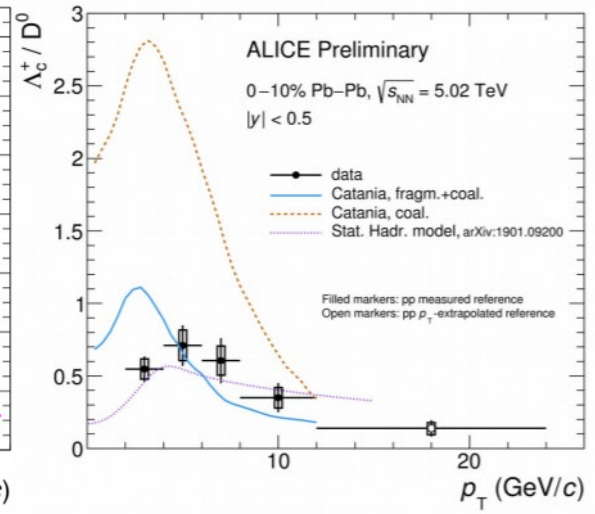
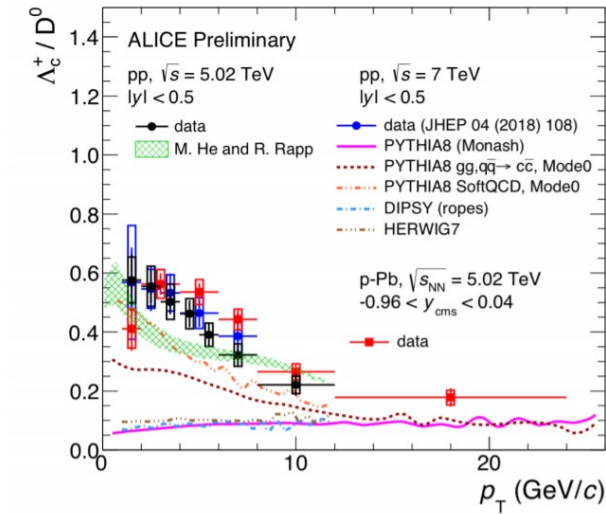


ZDC

# ALICE physics: examples of INFN interests

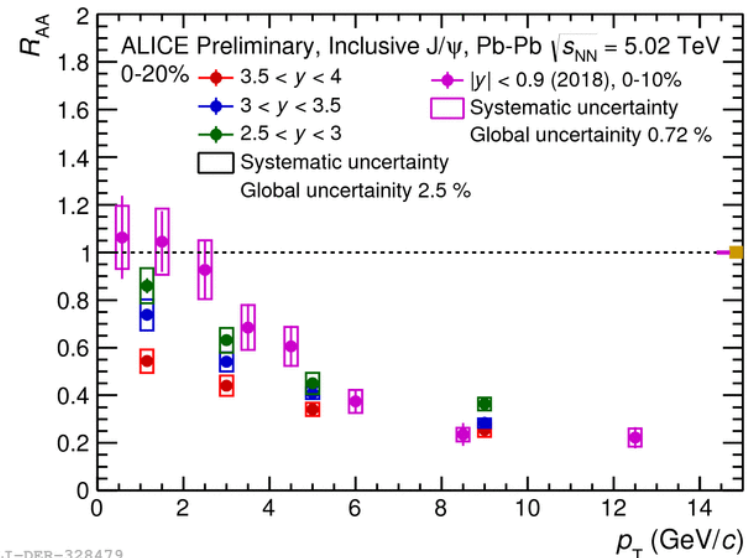


Particle (and nuclei)  
production vs multiplicity in  
different system sizes



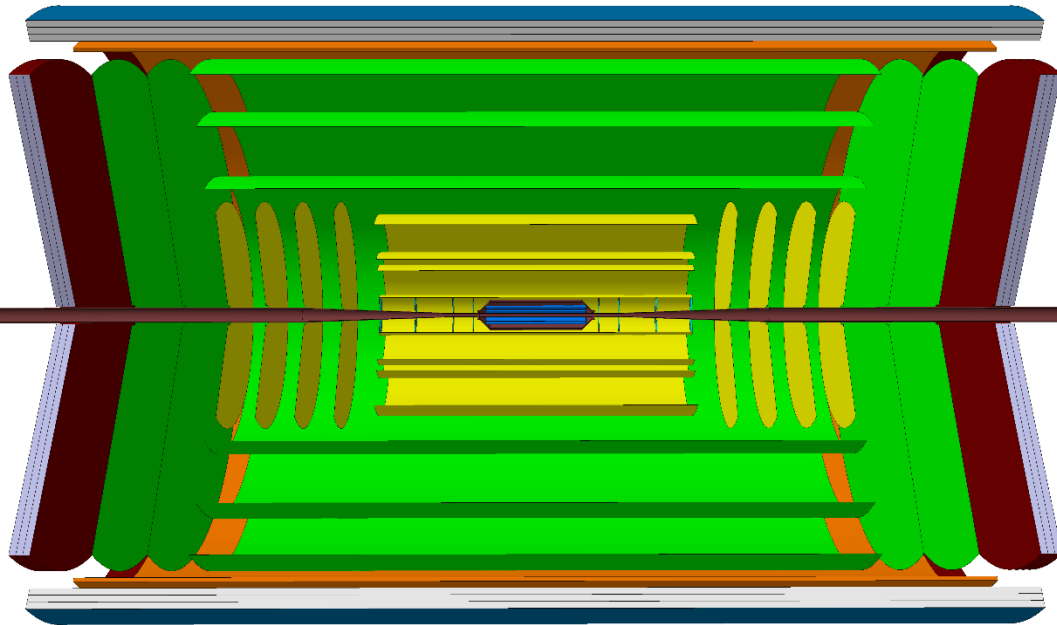
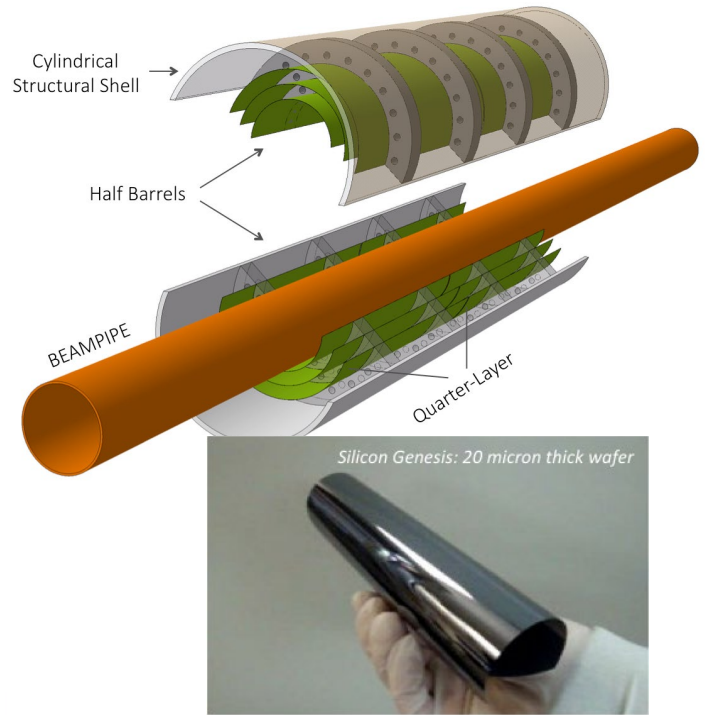
## Charm hadrons production

## Hidden Charm/Beauty production



# ALICE Future and possible synergies with EIC R&D

**Upgraded Vertex Detector LS3 (2024)**  
Innermost 3 Layers with new ultra-light Inner Barrel (CDS, ALICE-PUBLIC-2018-013)



**An upgraded ALICE experiment beyond LS4 (> 2030)**

based on a "all-silicon" detector, fast timing detectors .. arXiv: 1902.01211

# INFN & EIC, a sequences of synergic actions from both management and community

- Interest of INFN experimentalist in the hadron physics sector for EIC
  - Collaboration within the projects supported by "Generic R&D for EIC" (first ones in 2011!)
  - Growing and growing number of subscription to EIC-UG
- INFN participation in EIC scientific program is discussed in the periodical bilateral meeting between INFN and DOE: October 2016                      October 2017    December 2018
- 11 May 2017 - a BNL delegation visits INFN headquarters: EIC is the main element of the agenda
  - Representatives of the EIC interested community invited
- 19-22/7/2017 - EICUG meeting in Trieste
  - E. Nappi: "INFN consider EIC an important opportunity for the hadronic physics community and encourage partnerships and collaborations with the other Institutions involved in the project"
- May 2018 - INFN management visits Jlab, INFN contribution to the EIC project discussed in this context
- May 2018 - a collaboration of INFN experimentalists interested in EIC is formed
- 10 June 2018 - project EIC\_NET approved within CSN3 activity formally started on 1/1/2019
- 3 August 2019 - London, "in camera meeting" : INFN ready to collaborate
- August-September 2019 - EICUG starts activity towards a future TDR: EIC\_NET groups answer to the survey, offering concrete contributions for the YR in preparation

# EIC\_NET in short

- **PARTICIPANTS:** 46 experimentalists from 11 INFN units
  - *Mainly physicists active in ALICE, COMPASS, JLAB experiments*
- **SCIENTIFIC REFERENCE with INFN CSN3** (Scientific Committee for Nuclear Physics)
- **GOALS:** internal and external networking, preparatory R&D
- **INFN support :** both for networking and R&D
- **ACTIVITIES:**
  - **PHYSICS**  
Event generators for the eN and eA scattering, physics case for hadron spectroscopy at EIC, extraction of *diffractive structure functions*
  - **MONTE CARLO STUDIES**  
Simulation studies for physics and detectors , Particle identification by a TOF
  - **DETECTOR R&D**  
Ecal, Streaming R-O, R&D for Cherenkov PID and gaseous single photon detectors for PID
  - **EIC related international meetings**  
EICUG2017 (Trieste 2017) , The spectroscopy program at EIC and future accelerators (Trento 2018), EIC software meeting (Trieste 2019), EIC Streaming Readout consortium (Camogli 2019)

# More support to EIC\_NET physicists

## EIC\_NET ACTIVITIES ALSO RELATED TO COLLABORATION IN CONSORTIA "Generic R&D for EIC"

- eRD1 "Calorimeter Consortium" (Genova, Roma 2)
- eRD6 "Tracking & PID detector R&D towards an EIC detector" (Trieste)
- eRD14 "ID Consortium for an integrated program for Particle Identification (PID) at a future Electron-Ion Collider" (Ferrara, Roma 1)
- eRD20 "Developing Simulation and Analysis Tools for the EIC" (Trieste)
- eRD23 "Streaming Readout for EIC Detectors" (Genova, Roma 2)

### STRONG-2020 financed by the EU community, 2 WPs:

- JRA4 "3D structure of the nucleon in momentum space"  
(Cagliari, Pavia, Torino, Trieste) [Theorists & Experimentalists]
- JRA14 "Micropattern Gaseous Detectors for Hadron Physics" (Trieste)
- JRA6-Challenges "Photon detectors for particle identification using RICH".

From  
EU

### AIDA++

- Proposal being assembled for a new EC call (following AIDA, AIDA2020):  
EoI 24 " Photon detectors for hadron particle identification at high momenta with compact RICHes " (Bari, Trieste)

APPROVED

Proposal  
submitted

### PROGETTI GRANDE RILEVANZA (Projects of Large Relevance) 2018 (Ministry of Foreign Affairs )

#### "A triggerless DAQ for the Electron Ion Collider (EIC)"

INFN Participants: Genova, Roma1, Roma2 ; Other Participants : MIT

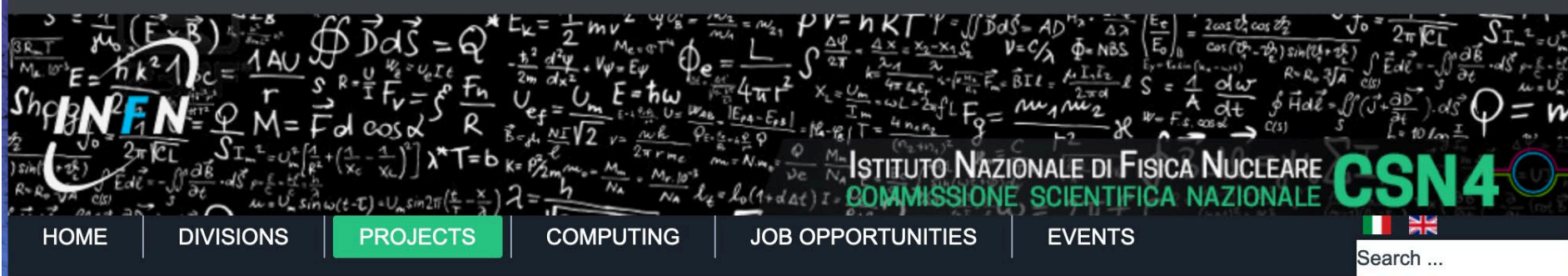
From  
ITALY

### MPGD\_NEXT High Performance Micromegas

IDEA (2020-2022) development of photocathode with nano diamond powder for gas detectors

APPROVED

CSN5 Project



**CSN4 = INFN theoretical activities**

- Fields and String Theory
- Phenomenology of Elementary Particles
- Nuclear and Hadronic Physics**
- Mathematical Methods
- Astroparticle Physics
- Statistical Physics and Applied Field Theory

5 projects  
 ....  
 ....  
**NINPHA**



## National Initiative in Physics of Hadrons

National Coordinator: M. Boggione (Torino)

5 units: Pavia, Torino, Genova, Perugia, Cagliari

29.2 FTE, 5 post-docs, 8 PhD students (end of 2019)

2019 performance: 135 publications, 77 talks, 20 thesis (undergr. & PhD)





# NINPHA Main goal

Understand QCD confinement by mapping in detail the non-linear dynamics of **partons** inside hadrons

- New tools :**
- TMDs → 3D maps in mom. space
  - GPDs → 3D maps in position space
  - GTMDs (Wigner distrib.) → maximum info
  - Double Distributions ...

## properties

factorization theorems, universality, evolution eqs., matching to pQCD at higher energies, gauge-invariant definition of orbital angular momentum, etc..

## modeling

support to experiments, meson & baryon wave funct.'s, (hybrid) spectroscopy

## phenomenology

extraction from (global) fits of exp. data

**NINPHA examples**

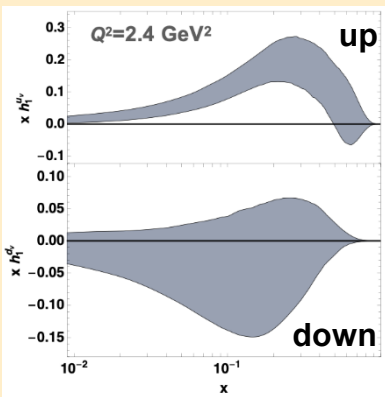
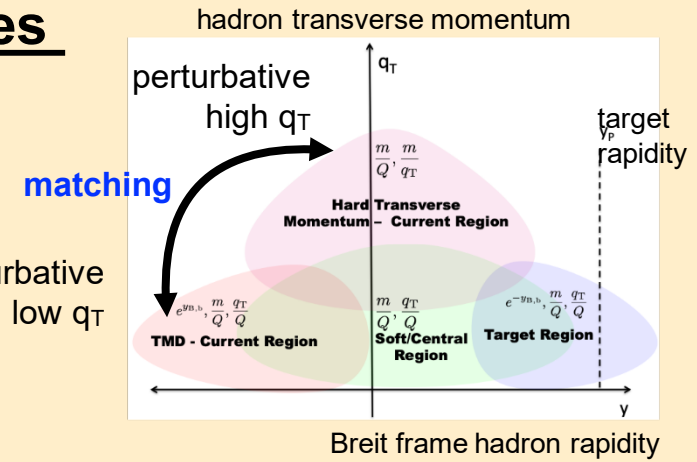
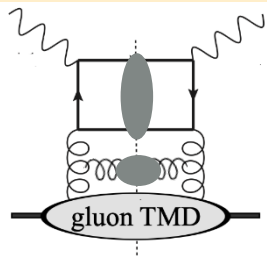
# Properties and exploratory studies

Mapping the *kinematical* regimes in *Semi-Inclusive Deep-Inelastic Scattering*

M. Boglione et al., JHEP **10** (2019) 122  
arXiv:1904.12882

*Azimuthal asymmetries in semi-inclusive  $J/\psi + jet$  production at an EIC*

U. D'Alesio et al., P.R. D**100** (2019) 094016  
arXiv:1908.00446



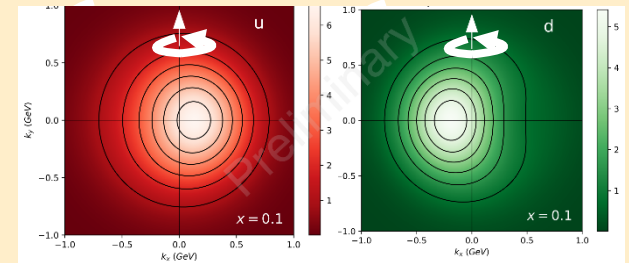
## Phenomenology

First extraction of *transversity* from a *global* analysis of  $e^-p$  and  $p-p$  data

M. Radici, A. Bacchetta, P.R.L. **120** (2018) 192001, arXiv:1802.05212

The 3dim distribution of quarks in momentum space

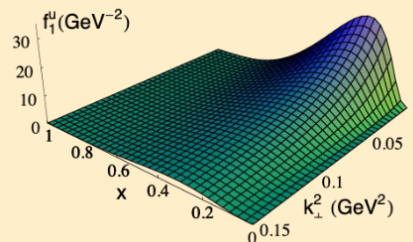
A. Bacchetta et al., arXiv:2004.14278



## Modeling and support to experiments

*Unified framework* for GPD and TMD within a *3Q light-cone picture* of the nucleon

C. Lorcé, B. Pasquini, M. Vanderhaeghen, JHEP **05** (2011) 041  
arXiv:1102.4704



*Generalized parton distributions of He-3*

S. Scopetta, P.R. C**70** (2004) 015205  
nucl-th/0404014

## NINPHA and EIC

- All NINPHA members are EICUG members and contribute to activities of various working groups of the "Yellow-Report" process
- F. Murgia (CA), M. Radici (PV), S. Scopetta (PG) are also members of the EICUG Institutional Board
- B. Pasquini (PV) is member of EICUG Conf.&Talk Committee and IAC member of CFNS (Stony Brook)
- M. Radici (PV) is member of EICUG Steering Committee and member of the Committee for EICUG Charter Review

**Strong commitment in the Yellow Report work**



**CSN3**  
Nuclear  
physics



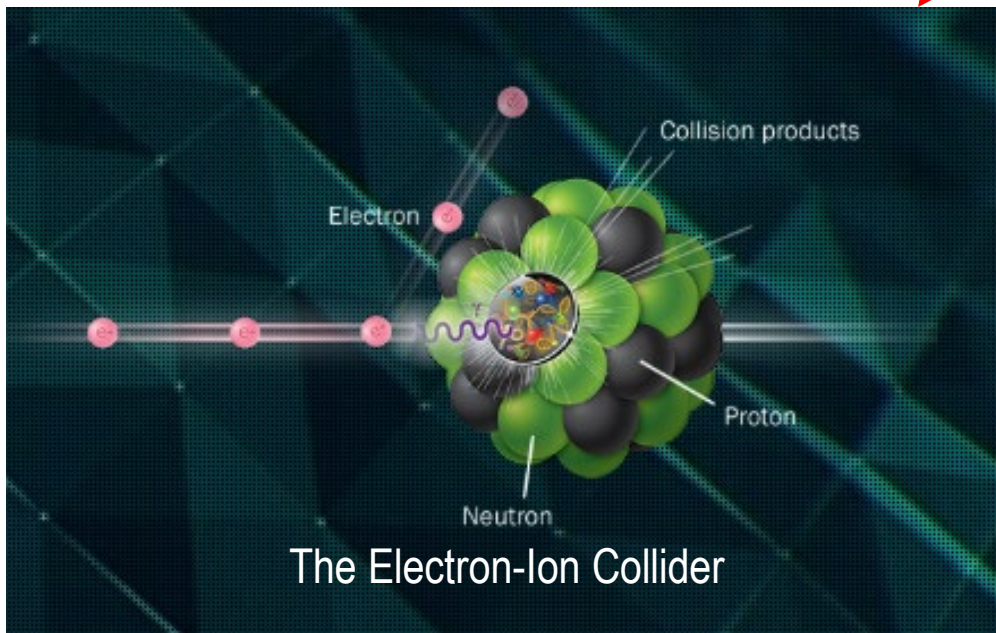
**CSN4**  
Theoretical  
physics



**CSN5**  
Technological  
research



Machine  
Advisory  
Committee



**INFN - EIC**  
Very good premises  
for a strong future  
collaboration