NINPHA: Understanding the (3D) structure of hadrons

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Summary

- Some history and some facts about NINPHA
- Main research topics and interests
- Sinergies and complementarity
- Recent achievements and future prospects

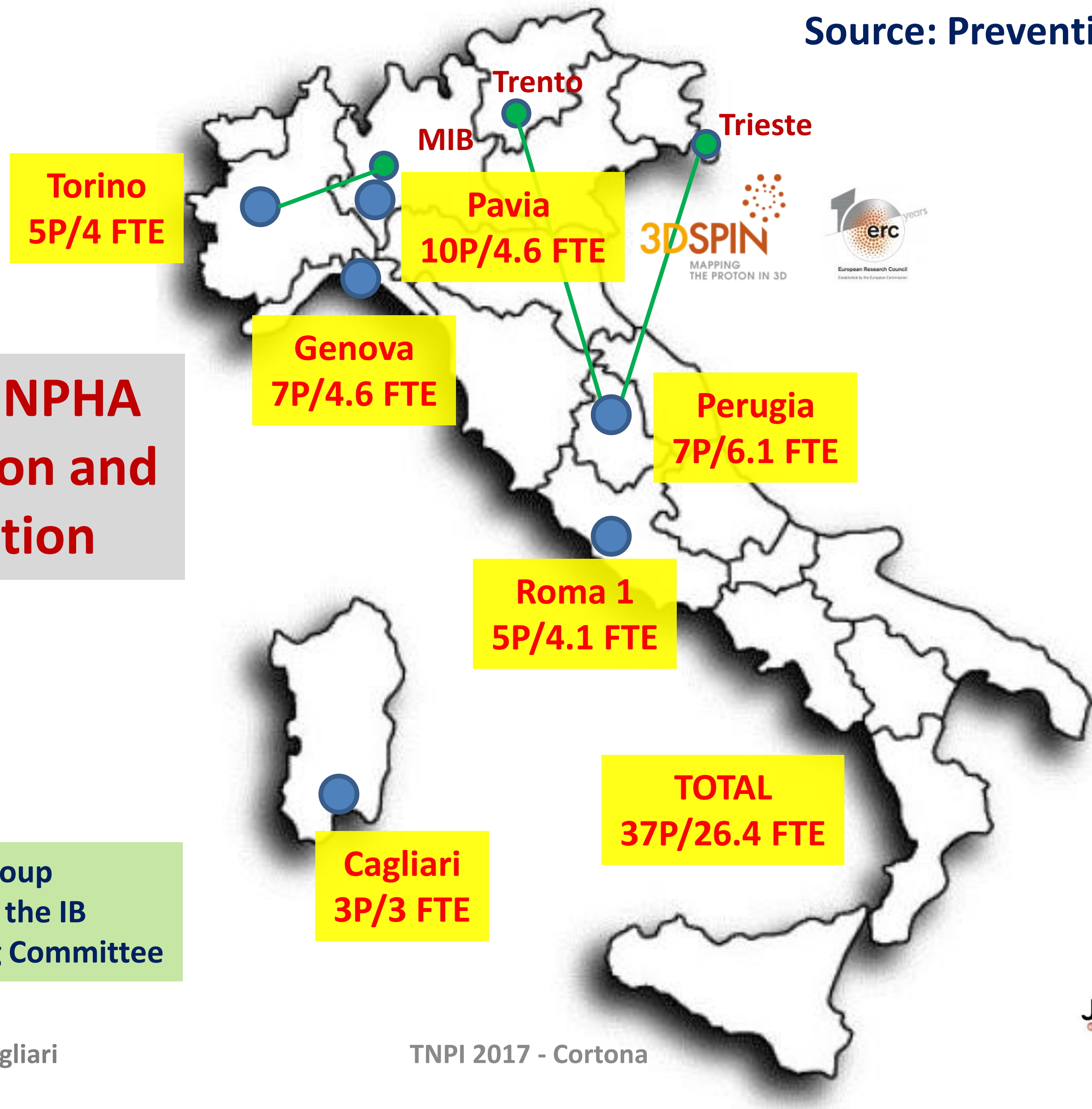
National INitiative on the Physics of HAdrons

https://web.infn.it/CSN4/IS/Linea3/NINPHA/index.html

Many thanks, in particular, to: M. Boglione, E. Pace, G.Salmè, E. Santopinto, S. Scopetta, M. Radici

Present NINPHA configuration and organization

Source: Preventivi INFN 2018



EIC User Group
Many of us in the IB
M.Radici – Steering Committee

Historical recollections...

Spin physics
Diffraction
Quarkonium decays

The many facets of nuclear and hadron physics

Y2008

TO21
TO, CA

PI31

GE

PG31

PV31

RM31

TN31

RN M. Anselmino

Spin physics
TMD approach
3D N structure

Y2009

TO31
TO, CA

AD31

RN M. Radici

Spin & Hadron physics
3D nucleon structure
TMD approach, IFFs
DVCS, GPDs, Form Fact.s,
Quark models
Diquarks, Pentaquarks
Three-body systems
Hadron Spectroscopy
Multiparton interactions

Y2013

NINPHA

RN M. Radici, M. Boglione (2017)

Main research topics and motivations

- Understanding confinement and the hadron structure from QCD is one of the most challenging problems in physics.
- We do not know how the nucleon spin is formed in terms of the spin and angular momentum of partons and we are unable to precisely compare the spectrum of baryon and meson resonances with all the colorless bound states predicted by QCD.
- The goal of NINPHA is to achieve an exhaustive 3-dimensional description of the distribution of quarks and gluons inside free and bound nucleons, and in general inside hadrons and their resonances.

Source: NINPHA proposal and Preventivi INFN 2018

Main research topics and motivations

- Following an initial explorative phase, in the next years NINPHA will work towards a full implementation of the multi-dimensional picture of the nucleon both in momentum and coordinate space. This will be achieved by systematically exploring the properties of Transverse Momentum Distributions (TMDs), Generalized Parton Distributions (GPDs) and the related form factors. Formal issues, such as factorization, universality and scale evolution, will be thoroughly investigated [CA,GE, PG,PV, RM1,TO].

- Effective models of QCD will be built, either adding continuum components to quark models, or exploiting novel solutions of both homogeneous and inhomogeneous Bethe-Salpeter equations, directly in Minkowski space [GE, PG, PV, RM1].

- Dedicated phenomenological analyses will be performed, where reliable flavour decomposition will require the extraction of neutron data from effective nuclear targets, implying a detailed knowledge of nuclear effects both in the initial and final states [CA, PG, PV, RM1, TO].

Source: NINPHA proposal and Preventivi INFN 2018

Research topics: a more exhaustive list - 1

3D Nucleon structure [essentially all nodes, mostly CA, PV, TO]

- Generalized PM & TMD approaches to spin and azimuthal asymmetries in Drell-Yan processes, Semi-Inclusive DIS and e^+e^- annihilations (two energy scales, factorization proved)
- SSAs in single inclusive hadron production in pp collisions (one single scale, no factorization proof)
- TMD PDFs and FFs, transversity, Sivers function, Collins FF, Boer-Mulders distribution, ...
- Unpolarized cross sections and hadron multiplicities in the TMD approach
- TMD Factorization, universality and process dependence and TMD evolution with scales, soft terms and matching problems
- Phenomenological fits and extraction of TMD PDFs and FFs, flavour separation, $k_\perp$ dependence
- Interference FFs and transversity distribution
- Unpolarized and linearly polarized Gluon TMDs, Gluon Sivers function
- DVCS and GPDs
- Wigner function, GPDs, Generalized TMDs, parton Orbital Angular Momentum and proton spin
- Hadron tomography
- Quasi-PDFs on the lattice and PDFs
- Models: bag, diquarks, NJL, holographic QCD, chiral models, spectator models, ...
- Multiparton interactions & double parton distributions (dPDFs) [see next talk by Matteo Rinaldi]
- Three-body systems, ^{3}He SSAs at JLab, role of ISIs and FSIs, neutron TMDs, GSF

Research topics: a more exhaustive list - 2

Hadron spectroscopy and quark models [mostly GE]

- Baryon & Quarkonium spectroscopy, Pentaquarks
- Baryon-meson molecules and pentaquarks
- Unquenched Quark Model [see later talk by H. Garcia Tecocoatzi]
- Strangeness suppression
- Hypercentral constituent quark model
- Quark-diquark models
- Light-front dynamics

Research topics: a more exhaustive list - 3

Light-front dynamics and few-body systems [mostly PG & RM1]

- LF approach, parton correlations for double PDFs in pp and pA collisions at LHC
- Nuclear tomography through GPDs in DVCS off light nuclei
- G-Parity violating J/ψ decays
- Bethe-Salpeter equation in Minkowski space
- Bound states and LF momentum distributions for two-scalar, two-fermion, bound states
- Polarized ^3He as effective polarized neutron target
- Generalized Eikonal Approximation and Final State Interactions
- Sivers and Collins azimuthal asymmetries in SIDIS
- Spectator SIDIS in $^3\vec{H}e(\vec{e}, e'\,^2H)X$ and $g_1{}^p$ for bound protons
- LF spin-dependent nucleon Spectral Function in DIS (EMC effect) and in SIDIS processes

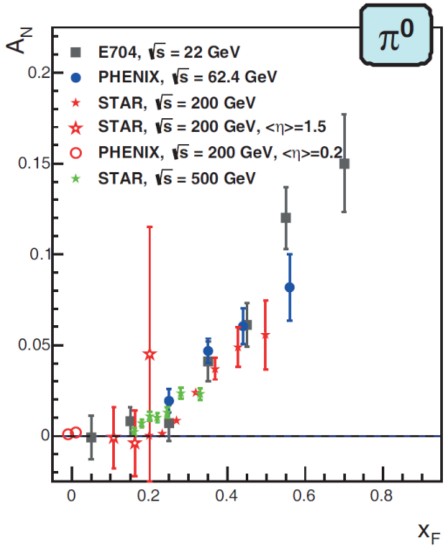
A (very partial) selection of recent achievements

See also next two talks on

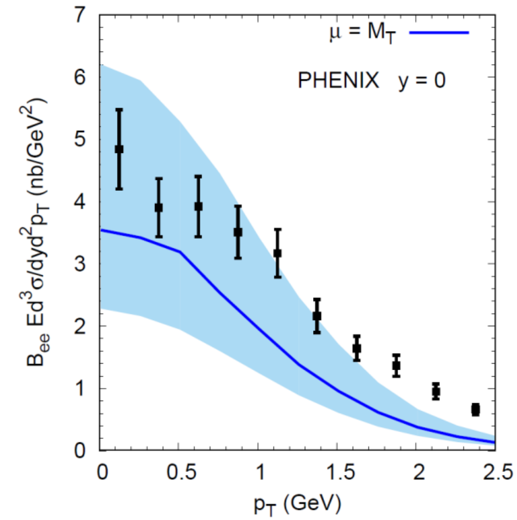
Double Parton Interactions [Matteo Rinaldi]

Unquenched Quark Model [Hugo Garcia T.]

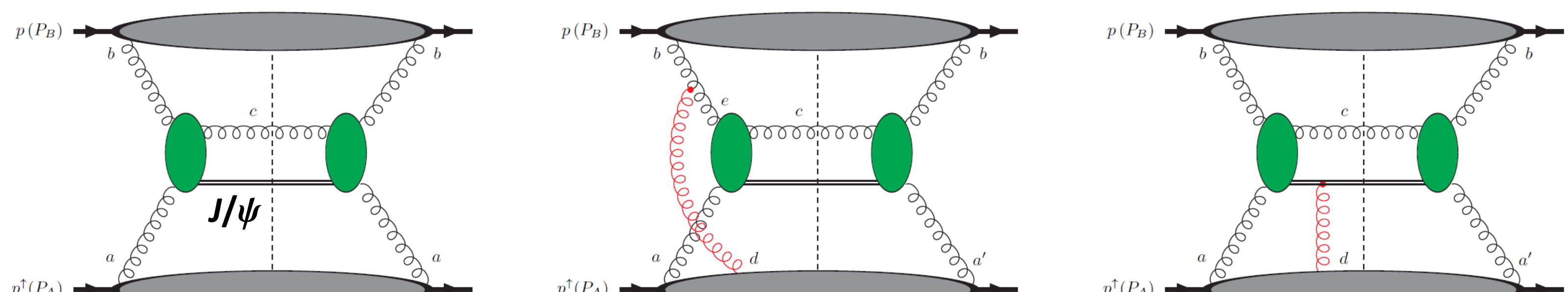
Probing the Gluon Sivers Function in $p^{\uparrow}p \to J/\psi + X$ and $p^{\uparrow}p \to D + X$ in a Color Gauge Invariant Generalized Parton Model [CA, PV]



$$A_N = \frac{d\sigma^{p^{\uparrow}p} - d\sigma^{p^{\downarrow}p}}{d\sigma^{p^{\uparrow}p} + d\sigma^{p^{\downarrow}p}} = \frac{d\Delta\sigma}{2d\sigma^{\mathrm{unp}}}$$

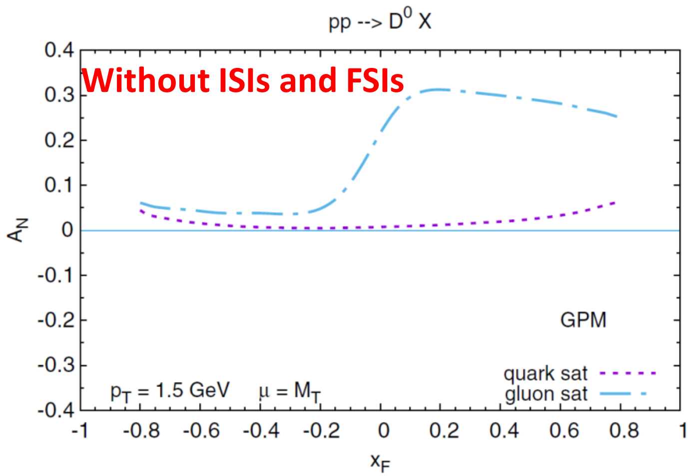


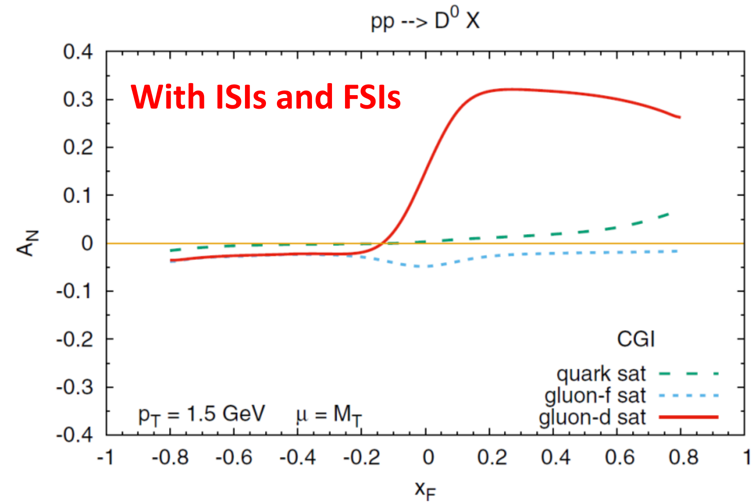
U. D'Alesio, FM, C. Pisano
PRD 96, 036011 (2017)



(a) (b) (c)

$p^{\uparrow}p \rightarrow D + X$ in a Color Gauge Invariant Generalized Parton Model

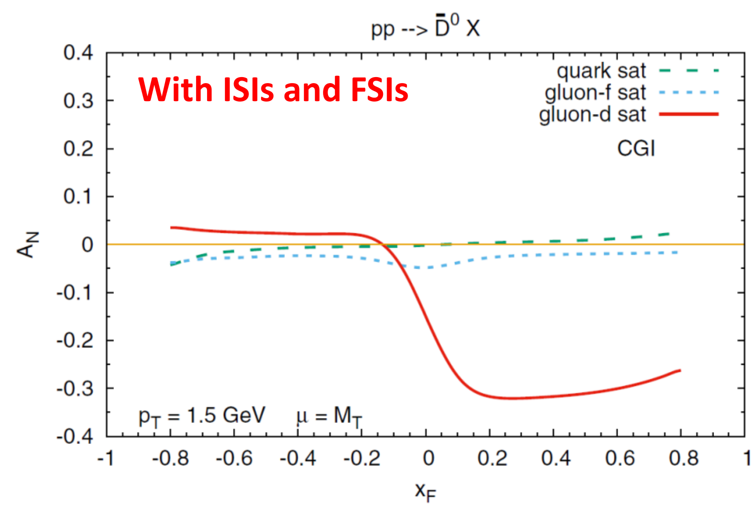




In this (approximated) scenario $d\sigma(D^0) = d\sigma(\bar{D}^0)$, so that

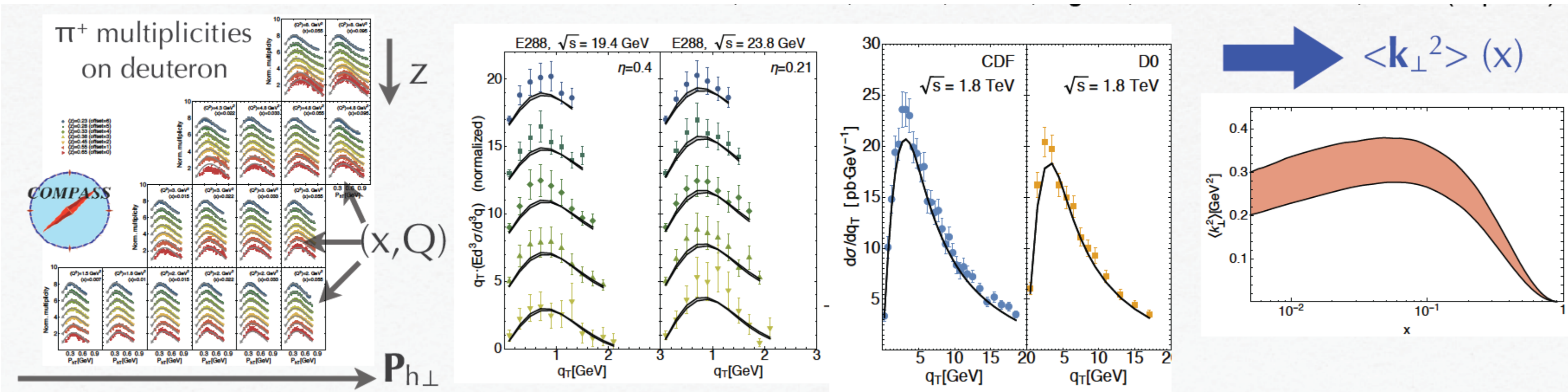
$$A_N(D^0) = A_N(\bar{D}^0) = A_N(D^0 + \bar{D}^0) \quad [\mathrm{GPM}]$$

$$A_N(D^0) = -A_N(\bar{D}^0), \;\; A_N(D^0 + \bar{D}^0) \simeq 0 \quad [\mathrm{CGI-GPM}]$$



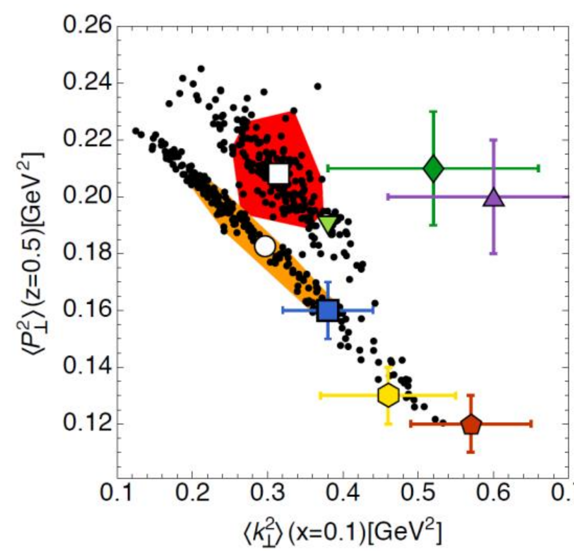
U. D'Alesio, FM, C. Pisano, PRD 96, 036011 (2017)

Extraction of TMDs from first global fit (+8000 data points) [PV]

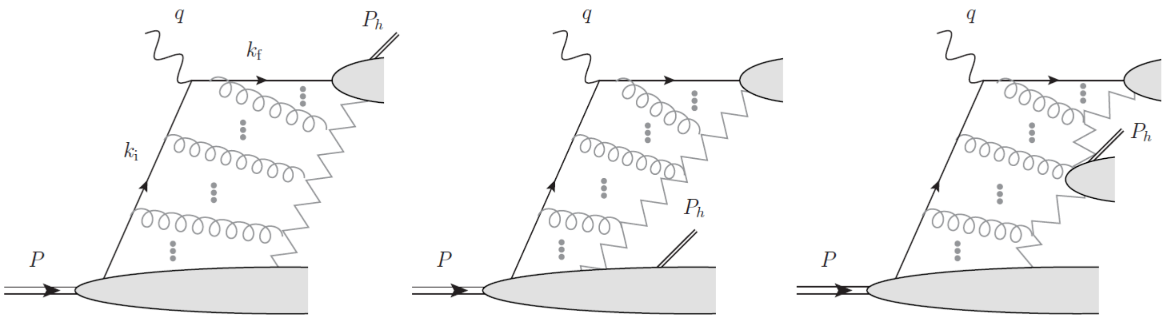


First global fit of available data at low $k_\perp$ from SIDIS, Drell-Yan and Z boson production; extraction of unpolarized TMD PDFs and FFs in a TMD factorization framework, including TMD evolution effects up to NLL

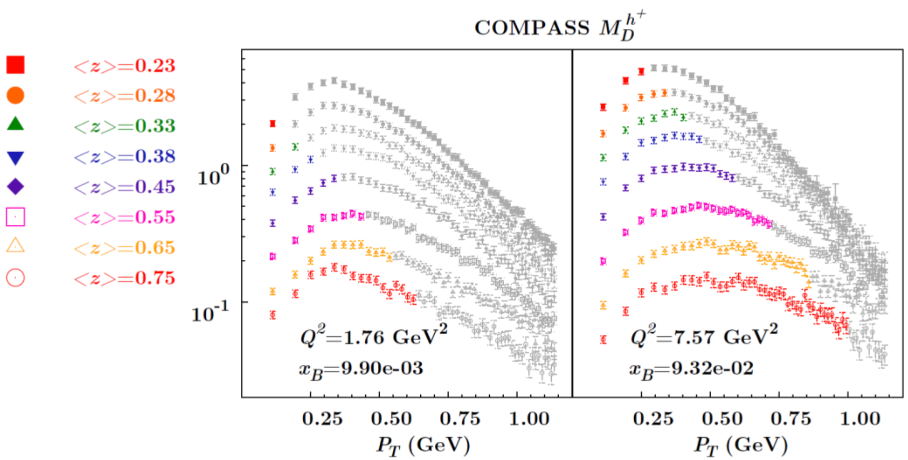
Bacchetta, Delcarro, Pisano, Radici, Signori, JHEP 1706 (2017) 081

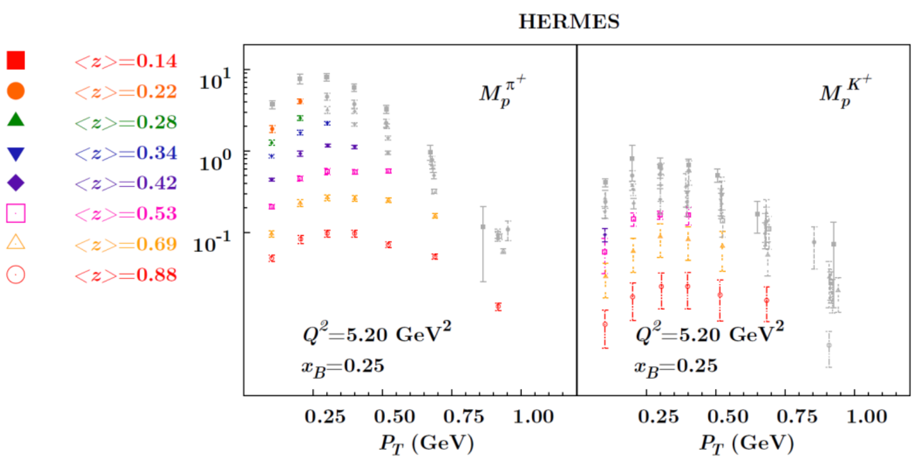


Identifying the current fragmentation region in semi-inclusive DIS [TO]



current region **target region** **central (soft) region**

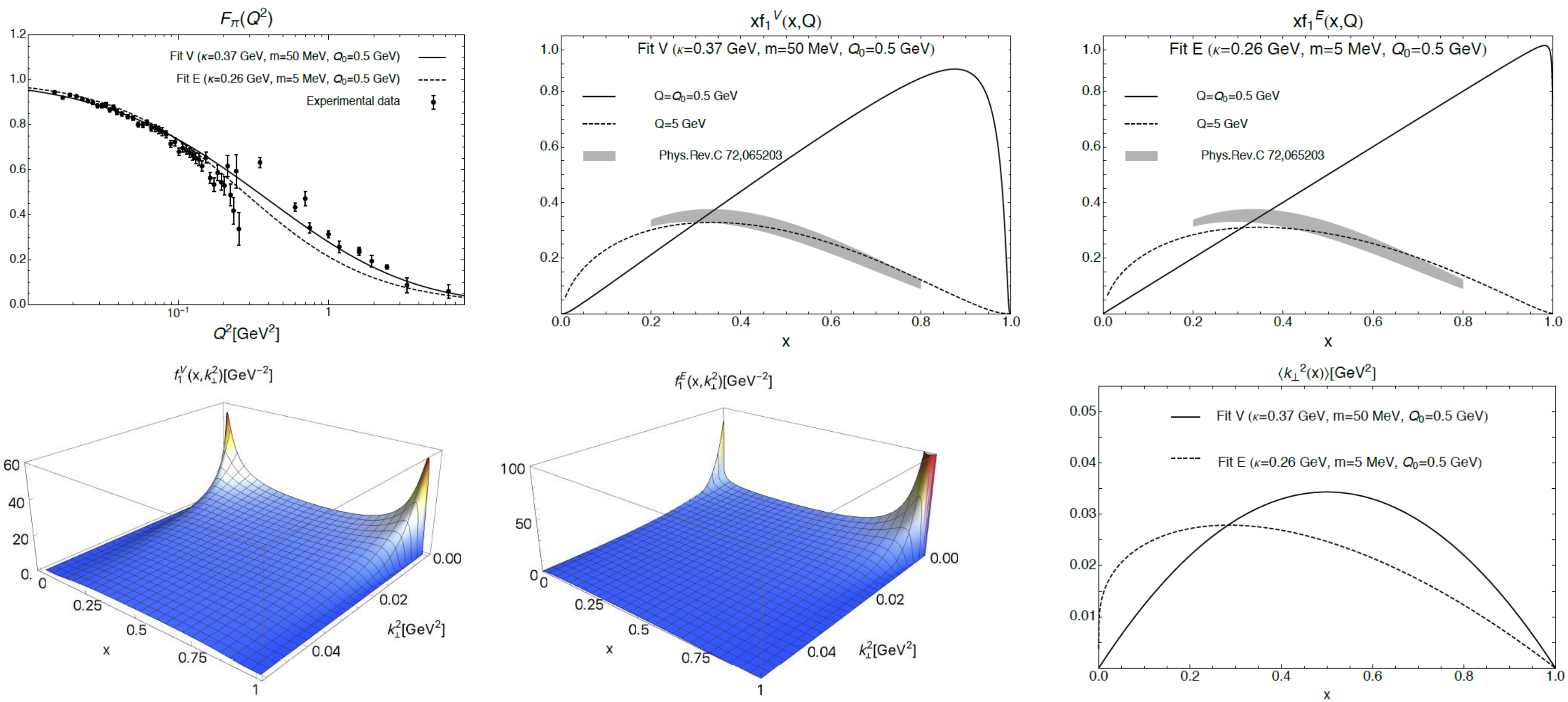




Boglione, Collins, Gamberg, G.-Hernandez, Rogers, Sato, PLB 766, 245 (2017)

AdS/QCD correspondence and the transverse structure of the pion in momentum space

[PV]



Bacchetta, Cotogno, Pasquini, PLB 771, 546 (2017)

Solving Bethe-Salpeter Equation in Minkowski space [RM1]

Aims and Tools

- To achieve a fully covariant description for a two-body **bound** system also with spin dof, in Minkowski space, through the **non perturbative framework** yielded by the Bethe-Salpeter equation (BSE), the QFT analogue of the Schr̈odinger eq.
- To determine from the BS amplitude, directly in Minkowski space, the momentum distributions relevant for applications, in primis for hadronic physics but also for condensed matter
- The Nakanishi Integral Representation (NIR) of the Bethe-Salpeter amplitude together with the so-called Light-front (LF) projection are the tools for achieving our aim. In particular, the spin dof are suitably managed within NIR + LF framework, making the numerical calculations quite affordable..

Solving Bethe-Salpeter Equation in Minkowski space

Example: two fermions interacting through a scalar with a mass μ/m ($m \equiv$ fermion mass)

	$\mu/m = 0.15$			$\mu/m = 0.50$		
B/m	g^2_{dFSV}(full)	g^2_{CK}		g^2_{dFSV}(full)	g^2_{CK}	g^2_E
0.01	7.844	7.813		25.327	25.23	-
0.02	10.040	10.05		29.487	29.49	-
0.04	13.675	13.69		36.183	36.19	36.19
0.05	15.336	15.35		39.178	39.19	39.18
0.10	23.122	23.12		52.817	52.82	-
0.20	38.324	38.32		78.259	78.25	-
0.40	71.060	71.07		130.177	130.7	130.3
0.50	88.964	86.95		157.419	157.4	157.5
1.00	187.855	-		295.61	-	-
1.40	254.483	-		379.48	-	-
1.80	288.31	-		421.05	-	-

First column: binding energy. Red digits: coupling constant g^2, with NIR+LF analytical treatment of the fermionic singularities. - Black digits: results with a numerical treatment of the singularities (Carbonell & Karmanov EPJA **46**, (2010) 387). Blue digits: results in Euclidean space from Dorkin et al FBS. **42** (2008) 1.

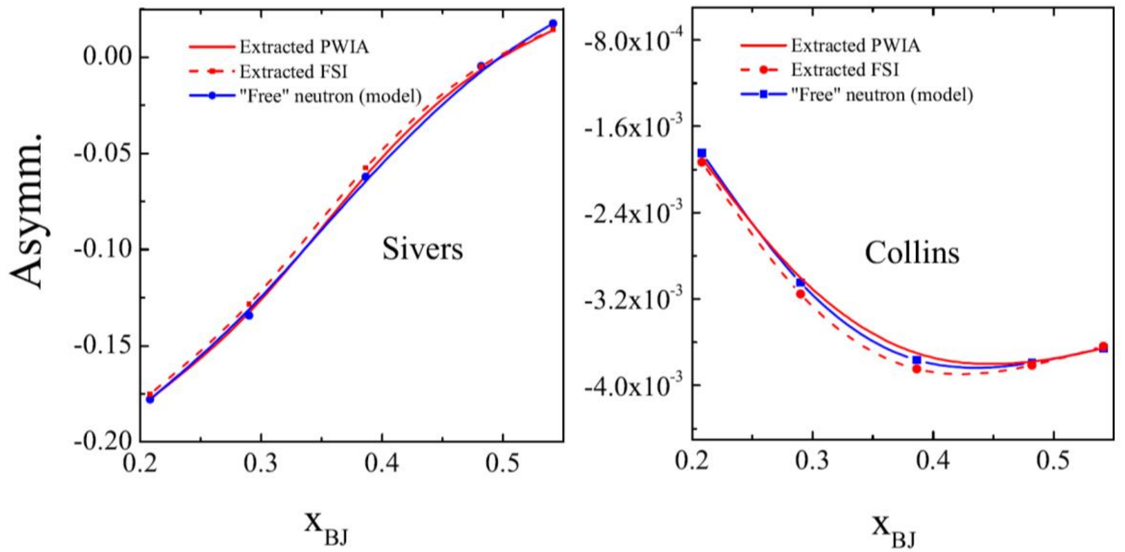
De Paula, Frederico, Salmè, Viviani, PRD 94, 071901 (2016)

Extraction of Sivers and Collins asymmetries from ^3He

Good news from GEA studies of FSI!

[PG,RM1]

Slide courtesy of E. Pace



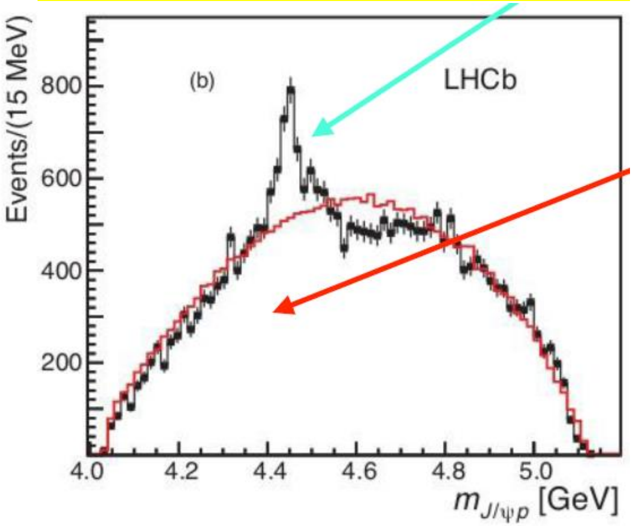
Effects of GEA-FSI (shown at $E_i = 8.8$ GeV) in the dilution factors and in the effective polarizations compensate each other to a large extent: the usual extraction is safe!

$$A_n \approx \frac{1}{p_n^{FSI} d_n^{FSI}} \left(A_3^{FSI} - 2 p_p^{FSI} d_p^{FSI} A_p^{exp} \right) \approx \frac{1}{p_n^{IA} d_n^{IA}} \left(A_3^{IA} - 2 p_p^{IA} d_p^{IA} A_p^{exp} \right)$$

Del Dotto, Kaptari, Pace, Salmè, Scopetta, arXiv: 1704.06182 [nucl-th]

Compact Pentaquarks and molecular states [GE]

Recently LHCb observed two pentaquark states
[PRL **117**, 082003 (2016)]

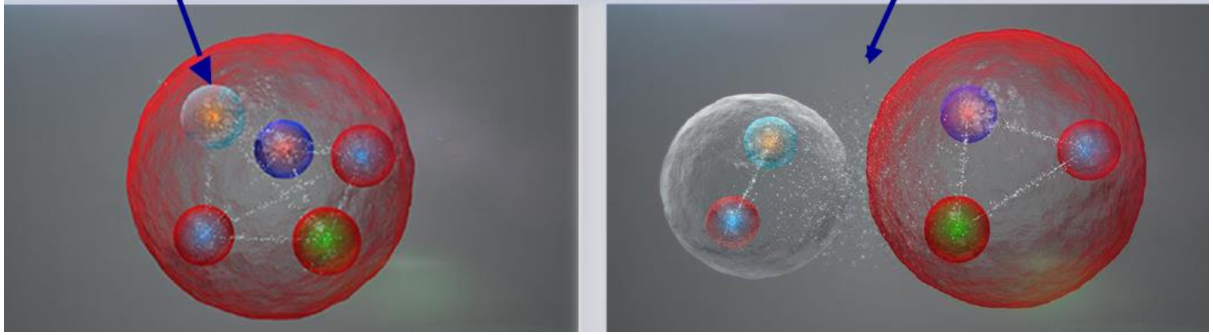


Compact Pentaquark:
E. Santopinto, A. Giachino
Phys. Rev. D96 (2017), 014014

Molecular state: for the first time a complete coupled channel model!

Predictions given also for electroproduction Jlab12 experiments

Hidden-charm pentaquarks as a meson-baryon molecule with coupled channels for $\bar{D}(*)\Lambda c$ and $\bar{D}(*)\Sigma(*)c$, Y. Yamaguchi, E. Santopinto, **Phys.Rev. D96 (2017), 014018**



Important Predictions for pentaquark in the bottom sector for LHC-b

Hidden-charm and bottom meson-baryon molecules coupled with five-quark states
Y. Yamaguchi, A. Giachino, A. Hosaka, E. Santopinto, S. Takeuchi, M. Takizawa, arXiv:1709.00819.
Moreover for the first time a complete description from an interplay of both a compact and a molecular behaviour.!

In order to arrive to a better description of the 3D view of the nucleon and its resonances several models of the nucleon and its resonances have been developed by Genoa

Unquenching model of the nucleon with higher fock components! Completed! See talk by Hugo Garcia

Relativistic quark-diquark model of baryons with a spin-isospin transition interaction, M. De Sanctis,J..Ferretti, E. Santopinto, and A. Vassallo, **Eur.Phys.J. A52 (2016) 121**

Developments on the Hypercentral Mod (useful for Jlab experiments) :Strong decays of baryons and missing resonances ,J. Ferretti, R . Bijker, G. Galatà,R. Bijker, H. Garcia, E. Santopinto,**Phys.Rev. D94 (2016)074040**

Many thanks for your attention!