Consiglio di Sezione INFN Pavia

5-6 Giugno 2019

Consuntivi Scientifici Gruppo IV

Fulvio Piccinini, INFN Pavia

Iniziative Specifiche a PV

BELL	(4)	R.L. G.M. D'Ariano	R.N. P. Zanghì	(GE)
DYNSYSMATH	(4)	R.L. F. Borgonovi	R.N. F. Borgonovi	(PV)
GEOSYM_QFT	(4)	R.L. A. Marzuoli	R.N. F. Lizzi	(NA)
MANYBODY	(3)	R.L. C. Giusti	R.N. F. Pederiva	(TIFPA)
NINPHA	(3)	R.L. M. Radici	R.N. M.E. Boglione	(PV)
QFT@COLLIDERS	(2)	R.L. O. Nicrosini	R.N. F. Piccinini	(PV)
TASP	(5)	R.L. M. Roncadelli	R.N. E. Lisi	(BA)

presentate in ordine di linea

Dalla CSN4 di Aprile

- Premio Fubini per la tesi di Luca Mantovani (NINPHA)
- Menzione speciale Premio Fubini per la tesi di Marco Erba (BELL)

- Presentazione delle candidature alla presidenza CSN4

QFT@COLLIDERS

Responsabile nazionale: F. Piccinini
Responsabile locale: O. Nicrosini

Partecipanti 2018(2019)

C.M. Carloni Calame,
G. Montagna, M. Moretti (FE),
O. Nicrosini, F. Piccinini, J. Zou*
(* post-doc premiale INFN/assegnista UNIPV)

Collaboratori

G. Abbiendi, INFN Bologna
M. Chiesa (Wurzburg)
U. Marconi, INFN Bologna
C. Matteuzzi, INFN MiB
P. Nason (INFN Mib)
M. Passera (INFN Padova)
A. Polosa (Roma La Sapienza)
R. Tenchini (INFN Pisa)
L. Trentadue (UNI Parma)
G. Venanzoni (INFN Pisa)
A. Vicini (UNI Milano)

Altre sedi: Bologna (G.P. Vacca), Cosenza (A. Papa), Firenze (S. Catani), Milano B. (P. Nason)

Keywords: Monte Carlo generators, NLO/NNLO QCD calculations, electroweak corrections, perturbative resummations, QCD in the high-energy limit

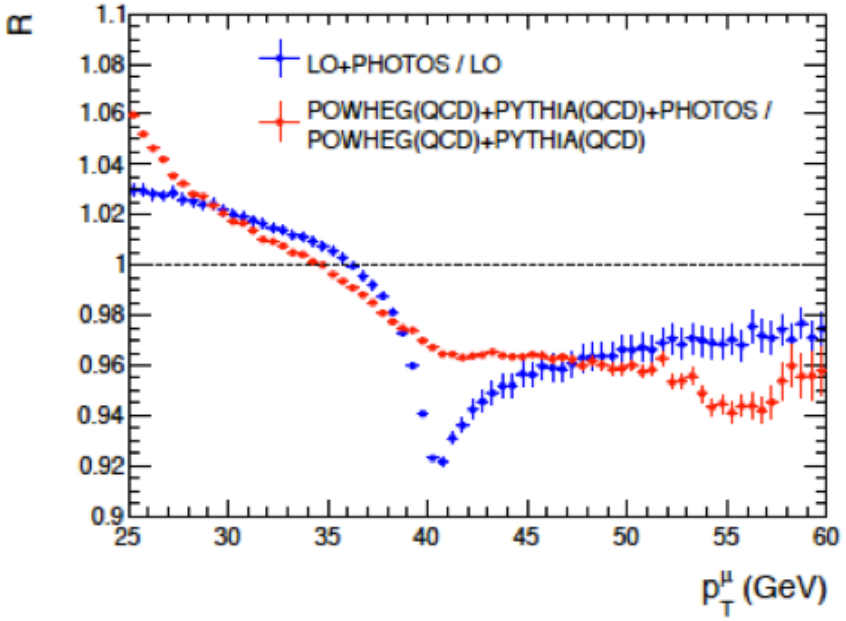
Consiglio di Sezione INFN

Pavia, 6 giugno 2019

Drell-Yan Physics at the LHC

Drell-Yan processes and W mass

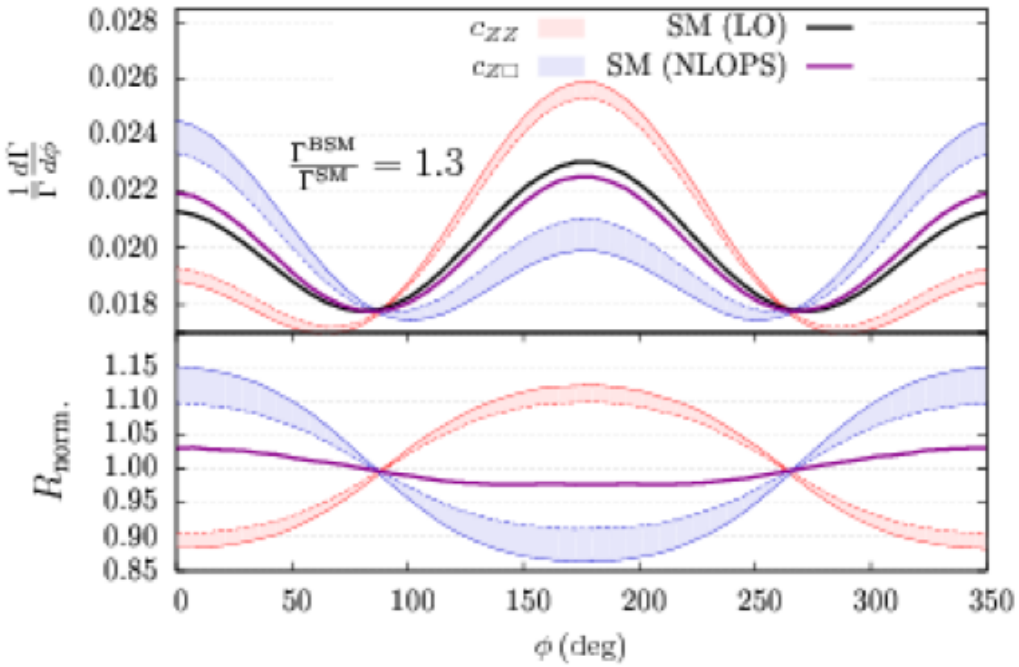
- Collaboration with ATLAS/CMS for new release of POWHEG with QCD+EW corrections
- Assessment of EW, mixed QCD/EW and higher order uncertainties in W mass and EW mixing angle measurement
- Contribution to DY WG report on precision predictions



- "**EW and mixed QCD-EW effects in the W boson mass determination**"
M. Chiesa, C.M. Carloni Calame, H. Martinez, G. Montagna, O. Nicrosini, F. Piccinini and A. Vicini
PoS LHCP2018 (2018) 297
SISSA (2018-07-18)
DOI: 10.22323/1.321.0297
Conference: C18-06-04.1

Higgs Physics at the LHC

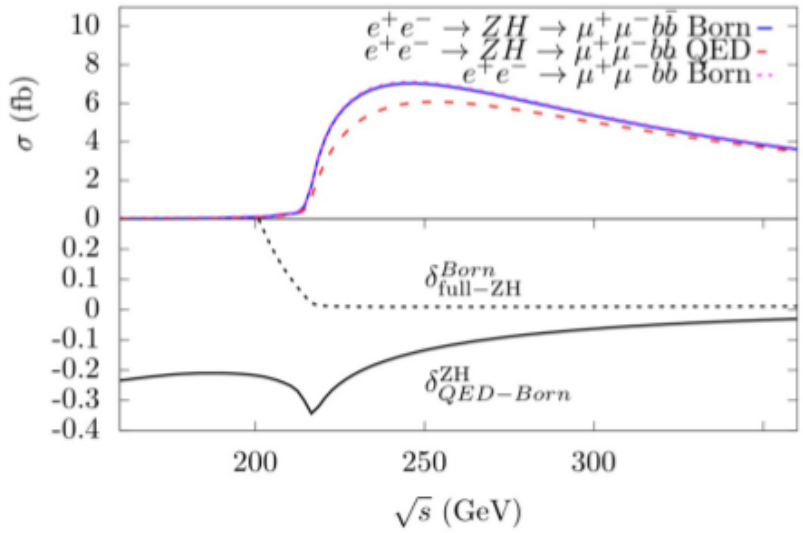
- MC for H → 4l matching exact NLO EW to QED PS (HTO4L); important for precision measurements of Higgs properties and as NP window (EFT approach)

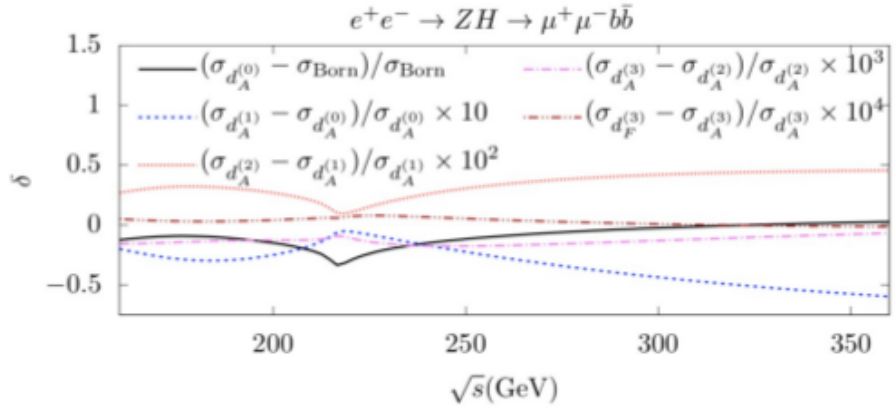


- "Higgs decay into four charged leptons in the presence of dimension-6 operators"
S. Boselli, C.M. Carloni Calame, G. Montagna, O. Nicrosini, F. Piccinini, A Shivaji
arXiv:1703.06667, JHEP 1801 (2018) 096

- "Higgs Physics at the HL-LHC and HE-LHC"
Physics of the HL-LHC Working Group
CERN-LPCC-2018-04, e-Print: arXiv:1902.00134[hep-ph]

Higgs Physics at future e^+e^- colliders





"ISR corrections to associated HZ production at future Higgs factories"
M. Greco, G. Montagna, O. Nicrosini, F. Piccinini and G. Volpi
arXiv:1711.00826
Phys.Lett. B777 (2018) 294-297

Physics at FCC-ee

Luminosity and *Z* physics

- Update of luminosity studies by using BABYAGA for small angle Bhabha scattering
- New results for precision simulation of two photon production as an alternative to Bhabha scattering for normalization

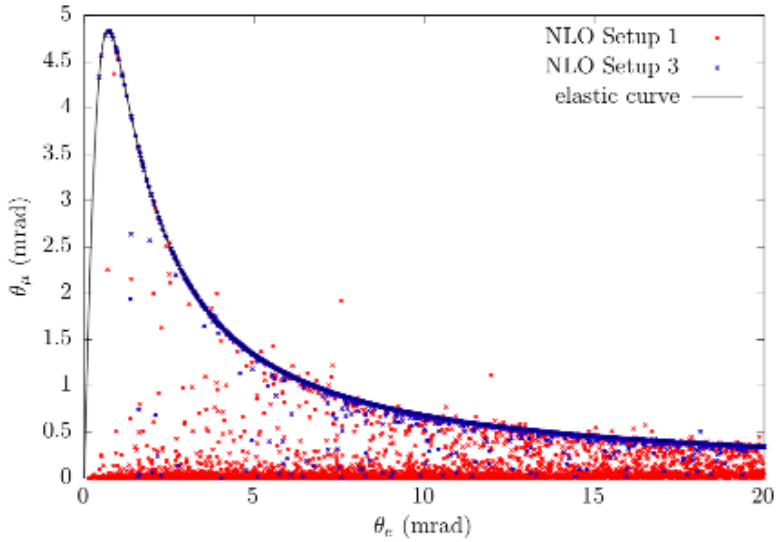
Standard Model Theory for the FCC-ee: The Tera-Z
A. Blondel *et al.* (... C.M. Carloni Calame, G. Montagna, O. Nicrosini, F. Piccinini...)
Conference: C18-01-12
BU-HEPP-18-04, CERN-TH-2018-145, IFJ-PAN-IV-2018-09, KW 18-003, MITP/18-052, MPP-2018-143, SI-HEP-2018-21
e-Print: arXiv:1809.01830 [hep-ph]

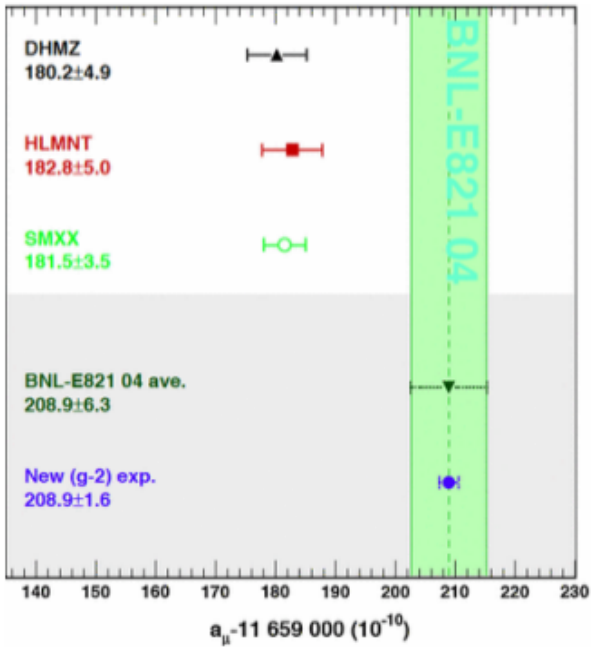
Theory report on the 11th FCC-ee workshop
A. Blondel *et al.* (... C.M. Carloni Calame, M. Chiesa, G. Montagna, O. Nicrosini, F. Piccinini...)
e-Print: arXiv:1905.05078 [hep-ph]

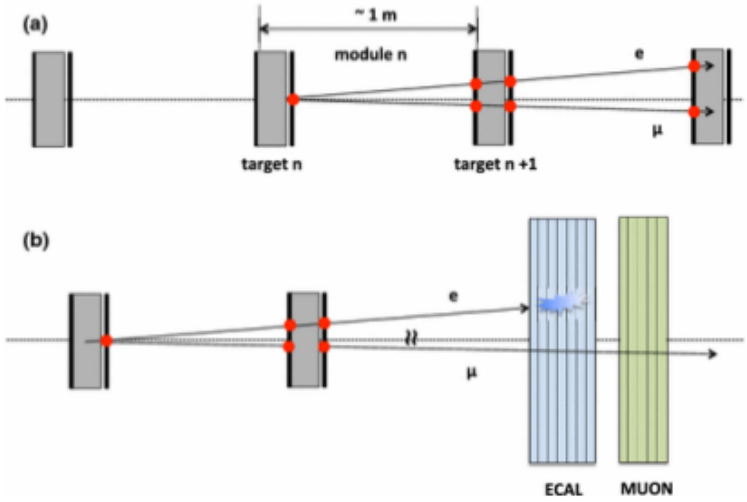
Muon anomalous magnetic moment

Muon g-2
"Measuring the leading hadronic contribution to the muon g-2 via μe scattering"
G. Abbiendi *et al.*, arXiv:1609.08987
Eur.Phys.J. C77 (2017) no.3, 139

Muon-electron scattering at NLO
M. Alacevich, C.M. Carloni Calame, M. Chiesa, G. Montagna, O. Nicrosini, F. Piccinini
JHEP 1902 (2019) 155 (arXiv:1811.06743 [hep-ph])







- Several talks and lectures at international workshop/schools
- F. Piccinini: co-convener of WG1 and WG2 of FCC-ee physics study group
- F. Piccinini: co-editor of Chapter 11 (W and Z boson physics) of CEPC CDR
- F. Piccinini: member of the program committee of LHCP, 4-9 June 2018
- C.M. Carloni Calame: member of the organizing committee of the MITP Topical Workshop ”The evaluation of the Leading Hadronic Contribution to the Muon Anomalous Magnetic Moment”, Mainz, 19-23 February 2018

MANYBODY

Carlotta Giusti

PUBLICATIONS

P. Finelli, M. Vorabbi, C. Giusti, Journal of Physics, IOP Conf. Series 981 012002 (2018)
Chiral Nucleon-Nucleus Potentials at N^3LO

H.Dai et al. Physical Review C 98 014617 (2018)
First Measurement of the Ti(e,e')X Cross Section at Jefferson Lab

M. Vorabbi, P. Finelli, C. Giusti, Physical Review C 98 054608 (2019)
Proton-Nucleus Elastic Scattering: Compaison between Phenomenological and Microscopic Optical potentials

H. Dai et al. Physical Review C 99 064602 (2019)
First Measurement of the Ar(e,e')X Cross Section at Jefferson Lab

C.Giusti, M. Vorabbi, P. Finelli, Proceedings of the 15° Int. Conf. on Nuclear Reaction Mehanisms, Varenna, CERN- Proceedings-2019-001 pp. 203-210 (2019)
Theoretical Optical Potential Derived from Chiral Potentials

C.Giusti, Proceedings of the Int. Workshop on (e,e'p) Processes EEP17, Bled Workshop in Pysics Vol.18 No.3 71-86 (2018) DMFA Zaloniznistva, Ljubljana (2018)
From (e,e'p) to Neutrino Scattering

TALKS (C. GIUSTI)

Microscopic Optical Potential from NN Chiral Potentials
INT Program Nuclear Ab-Initio Theories and Neutrino Physics, Seattle February 26-March 30 2018.

From (e,e'p) to Neutrino Scattering
Workshop on Neutrino Detection and Interactions: Challenges and Opportunities for Ab-initio Nuclear Theory, Seattle March 5-9 2018.

Microscopic Optical Potential Derived from NN Chiral Potentials,
15th Varenna Conference on Nuclear Reaction Mechanisms, Varenna, 11-15 June 2018

Electron and Proton Scattering on Stable and Exotic Nuclei,
Workshop on Probing Exotic Structure of Short-Lived Nuclei by Electron Scattering, ECT* Trento, July 16-20 2018

Theoretical Models for Electron end Neutrino Scattering off Nuclei,
SFB1044 Workshop: Electromagnetic Observables for Low-Energy Nuclear Physics, Mainz, October 1-3 2018.

Modeling Lepton-Nucleus Scattering
Workshop on Women in Nuclear and Hadron Theoretical Physics: the Last Frontier WTPLF 2018, Genova, 10-11 Dcemeber 2018.

Lepton-nucleus scattering

Microscopic optical potential

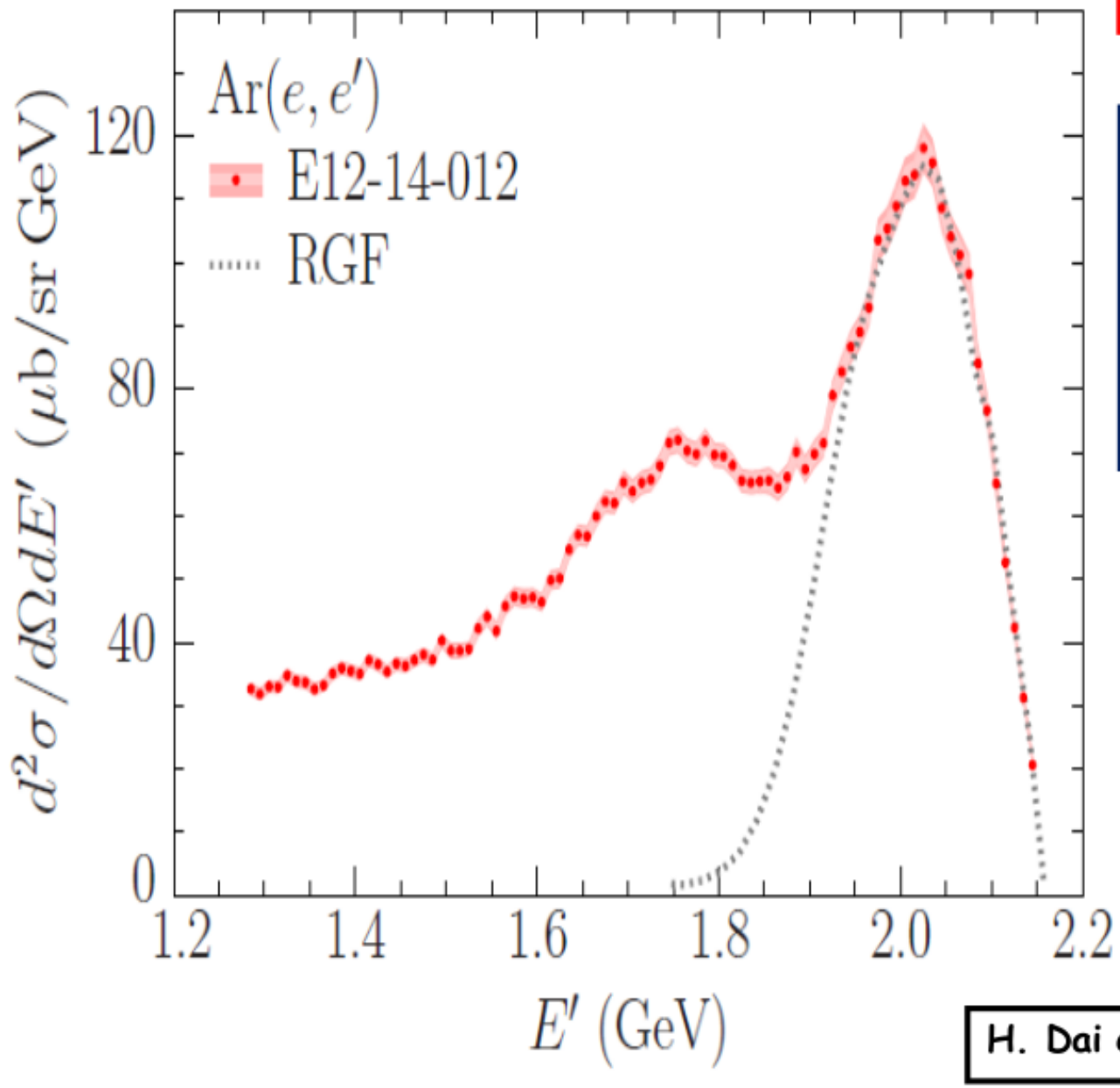
Lepton-nucleus scattering

Collaboration for proposals and analysis of new electron scattering experiments with the aim to study

- properties of exotic nuclei SCRIT (RIKEN) ELISe (FAIR)
- nuclear effects in electron and neutrino-nucleus scattering JLab MAMI

^{40}Ar(e,e')

E12-14-012 JLab exp aimed to determine e spectral function of Ar.



RGF relativistic Green's function model to describe final-state interactions in quasielastic inclusive electron scattering

H. Dai et al. PRC 99 064602 (2019)

MICROSCOPIC OPTICAL POTENTIAL

for elastic proton-nucleus scattering derived from nuclear chiral potentials

collaboration with
Matteo Vorabbi (TRIUMF)
Paolo Finelli (Bologna)

MICROSCOPIC OPTICAL POTENTIAL

- multiple scattering th. ⟹ **single scattering**
- **impulse approximation** : neglect medium effect
- **optimum factorization** of **n,p densities** and **NN t-matrix**

n,p densities calculated within the relativistic mean field description

NN interaction **chiral potentials**...

MICROSCOPIC OPTICAL POTENTIAL

study the domain of applicability of microscopic two-body chiral potentials to the construction of an OP

check the convergence and assess the theoretical errors associated with the truncation of the chiral expansion in the construction of an OP

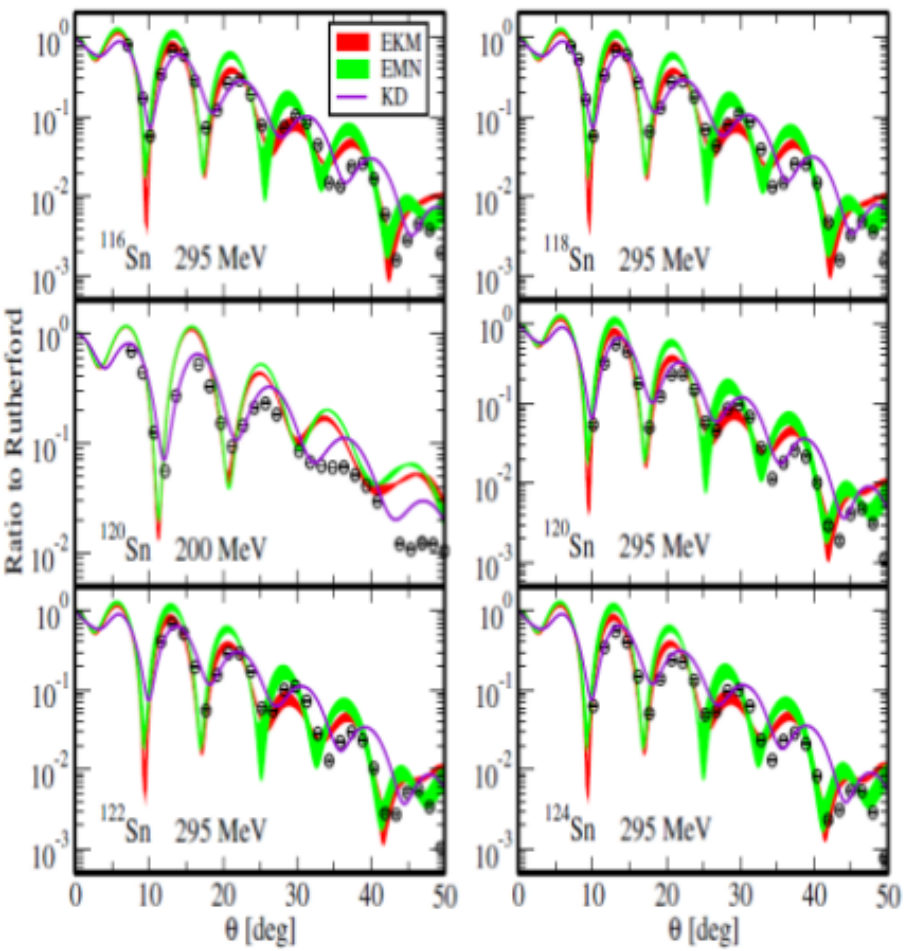
Comparison with phenomenological OP

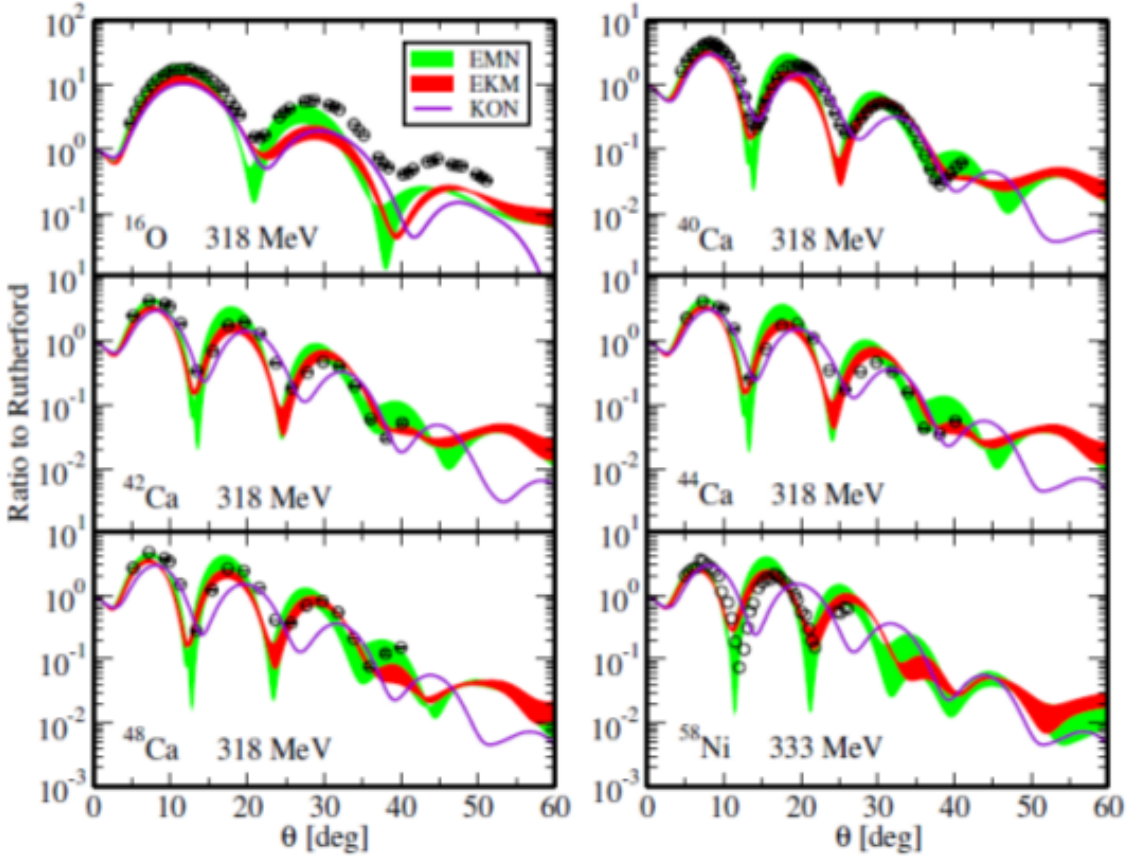
- investigate and compare predictive power of our microscopic OP and of phenomenological OP in comparison with exp. data in a wider range of nuclei, including isotopic chains

PHENOMENOLOGICAL OP
parameters fitted to data, data very well described in particular situations.
Investigate capability to describe data in different situations

MICROSCOPIC OP
obtained from a model and approximations
may be less able to describe specific data
should have a greater predictive power for situations for which data not yet available

Comparison with phenomenological OP (KD)





M. Vorabbi, P. Finelli, C. Giusti PRC 98 054609 (2019)

WORK IN PROGRESS...

- folding integral
- 3N forces, medium effects
- antiproton scattering

NINPHA National INitiative in Physics of HAdrons

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

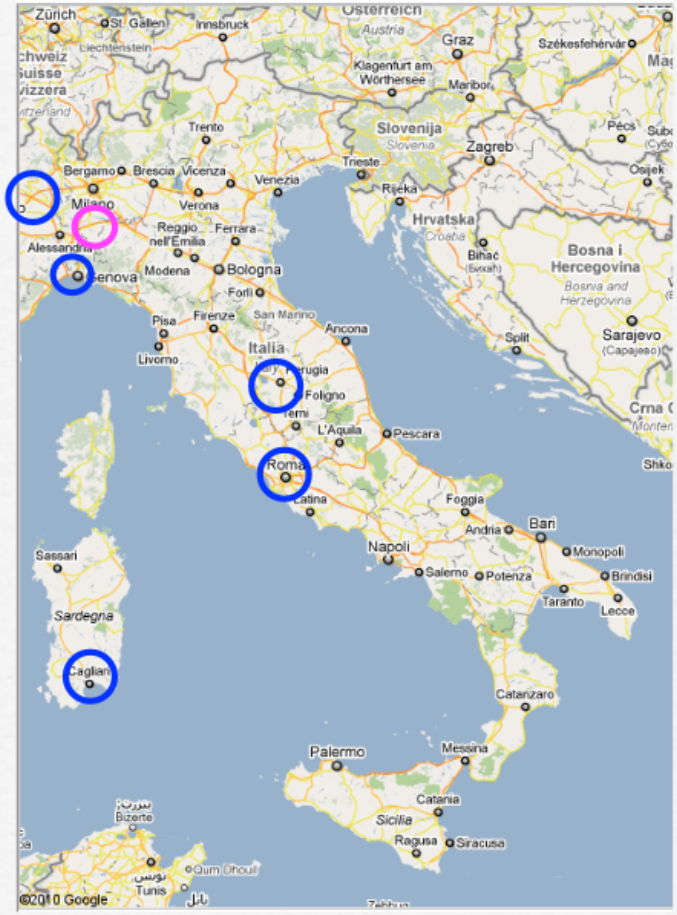
Responsabile naz.: M. Boglione (TO)
Sedi: PV, TO, CA, PG, RM1, GE

PV : gruppo di Fisica Adronica
iniziativa associata ERC-funded
responsabile: M. Radici

3DSPIN
MAPPING THE PROTON IN 3D

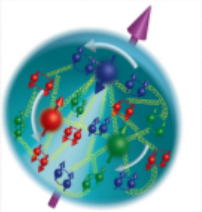
INFN 1 I ric. M. Radici (Resp. loc.)
1 Art.20 M. Echevarria (da sett.'18, borsa Marie Curie, sigla GLUECORE)
1 post-doc P. Taels (fino ad ott.'18)
1 post-doc Y. Makris (borsa Fellini, da ott.'19?)

Univ. 2 P.A. A. Bacchetta, B. Pasquini
1 RTDA G. Bozzi (da lug.'16)
2 assegn. V. Bertone, F. Celiberto (da ott.'18)
5 Ph.D. C. Bissolotti, F. Piacenza, S. Rodini, S. Sconfietti, F. Delcarro (fino sett.'18)

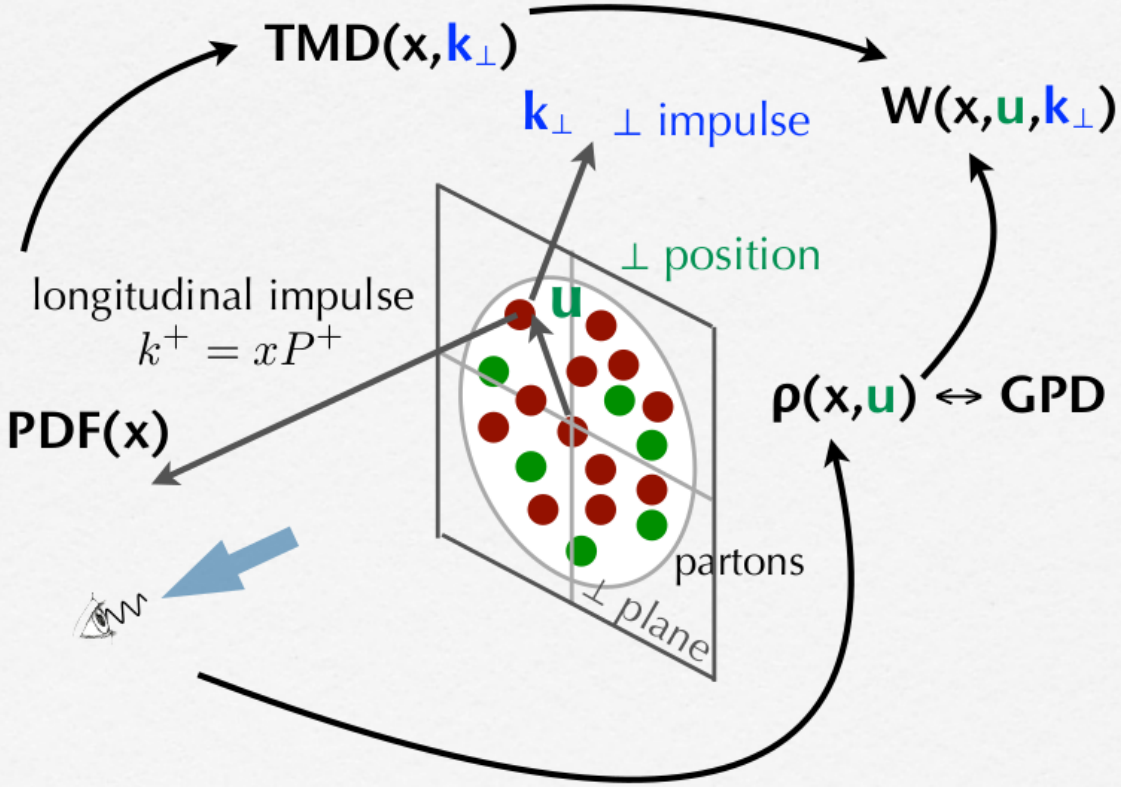


Main goal :

solving QCD confinement requires
understanding non-linear QCD dynamics
of partons inside hadrons



3Dim mapping of parton dynamics inside the proton
new tools : PDF → TMD, GPD → Wigner Distr. W (↔ GTMD)
study factorization th.'s, their evolution eqs., universality,...



first extraction of TMD
from global fit of data on
SIDIS + hadronic collisions

transition to era
of precision physics

Some recent achievements

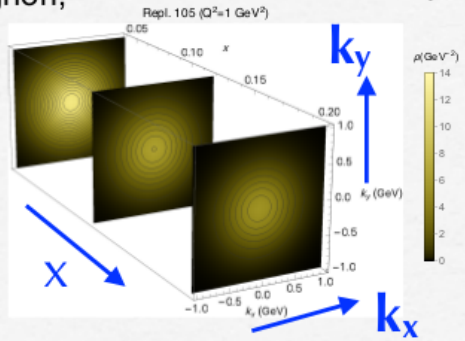
from first TMD global fit (+8000 points)

LO+NLL

Bacchetta, Delcarro, Pisano, Radici, Signori, JHEP **06** (2017) 081, arXiv:1703.10157

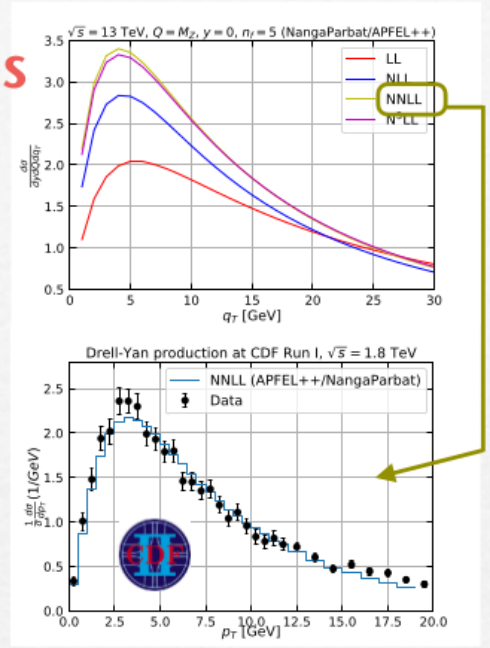
tomography in mom. space

$\langle \mathbf{k}_\perp^2 \rangle (x)$



precision studies (up to NNLO+N³LL)

Bacchetta, Bertone, Bissolotti, Bozzi, Piacenza, Radici, in preparation



Impact of TMD flavor dependence on extracted W mass

Bacchetta, Bozzi, Radici, Ritzmann, Signori, P.L. **B788** (2019) 542, arXiv:1807.02101

$pp \to W \to lept+\nu$

QCD radiation + intrinsic quark k_T → p_T^W distribution → p_T^{lept} distribution

usually assumed flavor independent

template-fit technique:
effect on Δm_W only from flavor-dep. parameters of TMD that reproduce data for $Z(q_T)$

"TMD error" ~ "PDF error" !

	valence		sea		
Set	u_v	d_v	u_s	d_s	s
1	0.34	0.26	0.46	0.59	0.32
2	0.34	0.46	0.56	0.32	0.51
3	0.55	0.34	0.33	0.55	0.30
4	0.53	0.49	0.37	0.22	0.52
5	0.42	0.38	0.29	0.57	0.27
6	0.40	0.52	0.46	0.54	0.21
7	0.22	0.21	0.40	0.46	0.49
8	0.53	0.31	0.59	0.54	0.33
9	0.46	0.46	0.58	0.40	0.28

ATLAS		LHCb	
Δm_{W^+}	Δm_{W^-}	Δm_{W^+}	Δm_{W^-}
-1	+3	-5	-3
-6	0	-15	+5
+9	+4	+1	-7
0	-4	-15	-4
+4	-3	-4	-7
0	+4	-5	+2
-1	0	+15	-6
+2	+7	0	+3
+4	0	-7	+4

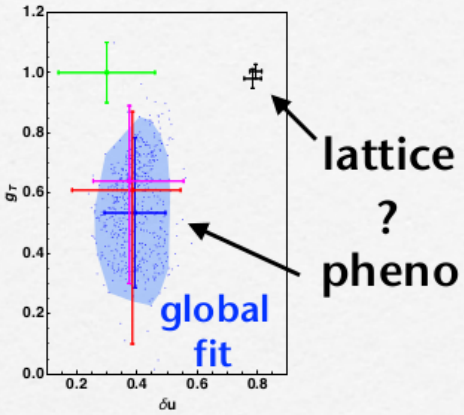
extraction of chiral-odd transversity PDF from first global fit

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

first global fit of $(\pi^+\pi^-)$ production in SIDIS $e\,p^\uparrow \to e'\,(\pi^+\pi^-)\,X$ (Hermes, Compass)

annihilation $e^+e^- \to (\pi^+\pi^-)\,(\pi^+\pi^-)\,X$ (Belle)

collisions $p\,p^\uparrow \to (\pi^+\pi^-)\,X$ (STAR @BNL)



tensor charge $\delta q(Q^2)=\int dx\, h_1^{q-\bar{q}}(x,\bar{Q}^2)$

important for searches of BSM physics

statistical tension between phenomenology and lattice

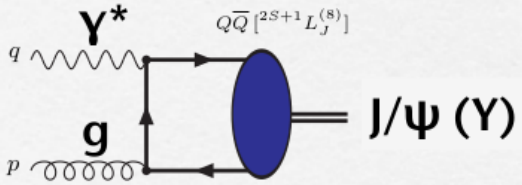
(plot of $g_T = \delta u - \delta d$ vs. δu at $Q^2=4$ GeV^2)

studies towards gluon TMD

Bacchetta, Boer, Pisano, Taels, arXiv:1809.02056

gluon-TMD from gluon fusion contribution to

$e\,p \to Q\,Q \to J/\psi\,(\Upsilon) + X$ at EIC



the unpol. chiral-odd twist-3 TMD $e(x,k_T)$

Pasquini, Rodini,
P.L. **B788** (2019) 414, arXiv:1806.10932

related to π-N σ term and N scalar form factor

model study of quark-gluon correlation (and including usually neglected divergent term)

proton polarizabilities from Compton Scattering data

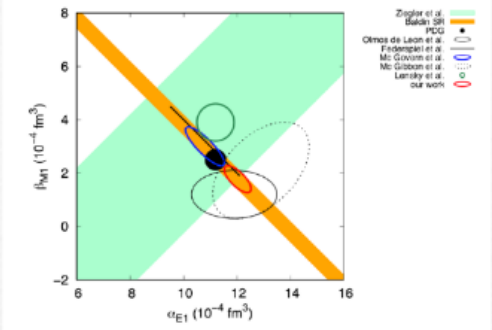
ANNUAL REVIEWS

Pasquini, Vanderhaeghen,
Ann.Rev.Nucl.Part.Sci. **68** (2018) 75

Annual Review of Nuclear and Particle Science

Dispersion Theory in Electromagnetic Interactions

Barbara Pasquini[1,2] and Marc Vanderhaeghen[3]



review of dispersion relation techniques applied to RCS and VCS
application to constrain corrections to μ-hydrogen spectroscopy

first attempt to extract dipole dynamical polarizabilities from RCS below π threshold (using dispersion th. and bootstrap technique)

Pasquini, Pedroni, Sconfietti, arXiv:1903.07962
invited paper on special issue of J.Phys.G

extraction of electric generalized polarizabilities from VCS
(consistent with p(e,e'π) world data)

Blomberg, .., Pasquini, .. *et al.*, arXiv:1901.08951

"Premio Fubini 2018":

L. Mantovani, Ph.D. Thesis
"Applications of Light-Front Quantization in QED and QCD"
supervisor: B. Pasquini

spatial distribution of angular momentum of partons

from Energy-Momentum Tensor $T^{\mu\nu}$ to $J^{\mu\alpha\beta} = L^{\mu\alpha\beta} + S^{\mu\alpha\beta}$

Lorcè, Mantovani, Pasquini, P.L. **B776** (2018) 38

parametrization in form factors and different (charge-conserving) densities

Also:

- 27 invited talks (3 plenary); co-organizers of FF18 (Stresa) and TMD@JLab (PV)
- conveners at EuNPC18 (BO), SPIN18 (FE), INT Progr. 18-3 (Seattle)
- members of IAC at QNP18 (Tsukuba), LC18 (JLab), EICUG18 (Washington), MENU19 (Pittsburgh), INPC19 (Glasgow)
- co-authors of docs. #99 and #111 (arXiv:1901.08002) to CERN Eur.Part.Phys.Strat.Update
- A. Bacchetta member of PAC at Jefferson Lab
- B. Pasquini member of IAC of CFNS (Stony Brook)
  member of EICUG Conf.&Talk Committee
- M. Radici re-elected member of EICUG Steering Committee
  member of the EICUG Council Board

Collaborations:

- JLab Hall A & B Coll.'s; Univ. Connecticut & Temple; NMSU; Penn State
- Univ. Mainz; VU Amsterdam; Univ. Groeningen; Ecole Polytech. (Paris)

Other funds - ERC consolidator 3DSPIN MAPPING THE PROTON IN 3D P.I. A. Bacchetta

- Strong2020 A. Bacchetta coordinator of WP22 "TMD-next"

BELL

Giacomo Mauro D'Ariano
Paolo Perinotti

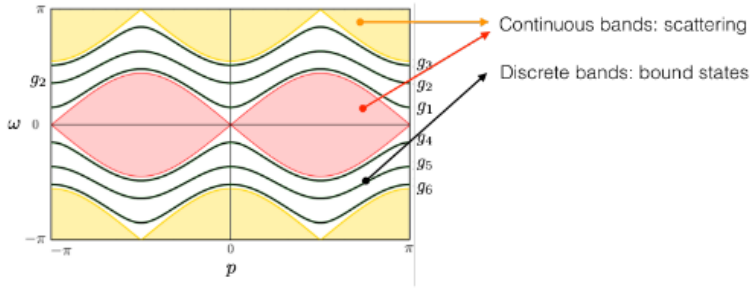
Cellular automata

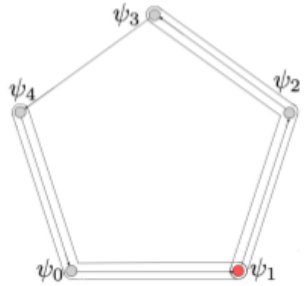
- Goal: recover mechanical concepts in a purely informational approach
- Former results:
  - Free relativistic quantum field theories (Weyl, Dirac, Maxwell)
  - Poincaré group for discrete massless CA

Cellular automata

- Recent results
  - Study of simple non-linear models to approach interactions

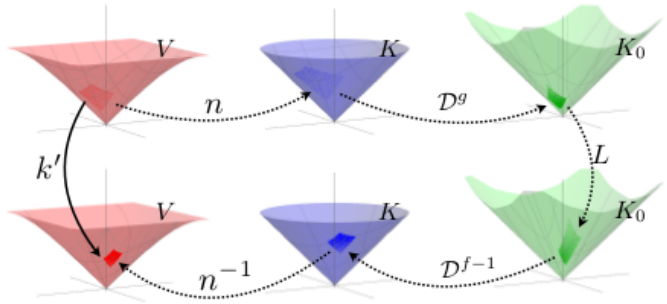
    (A. Bisio, G.M. D'Ariano, P. Perinotti, A. Tosini, Thirring quantum cellular automaton. Phys. Rev. A 97, 032132 2018; A. Bisio, G. M. D'Ariano, N. Mosco, P. Perinotti, and A. Tosini, Solutions of a Two-Particle Interacting Quantum Walk, Entropy 20(6), 435 2018; P. Perinotti and L. Poggiali, Scalar fermionic cellular automata on finite Cayley graphs, Phys. Rev. A 98, 052337 2018)





  - Symmetries of 1+1 - d free massive CA: mass becomes a degree of freedom de Sitter group

    (L. Apadula, A. Bisio, G.M. D'Ariano, and P. Perinotti, Symmetries of the Dirac quantum walk and emergence of the de Sitter group, arXiv:1806.03940)



Operational probabilistic theories

- Definitions and general results for the theory of CA in OPTS
  (P. Perinotti, in preparation)

- Simplicial theories without local discriminability: a non-local classical theory
  (G. M. D'Ariano, M. Erba, and P. Perinotti, in preparation)

- No-information without disturbance in general OPTs
  (G. M. D'Ariano, P. Perinotti, and A. Tosini, in preparation)

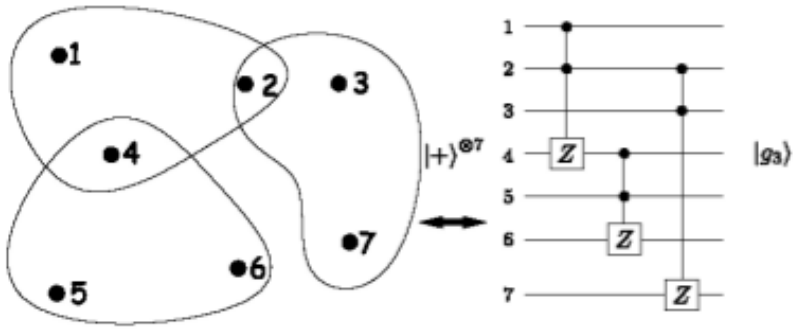
- Higher-order quantum theory and indefinite causal structures
  (A. Bisio and P. Perinotti, Theoretical framework for Higher-Order Quantum Theory, Proc. R. Soc. A 475: 20180706 2019)

Chiara Macchiavello

Quantum hypergraph states

We studied multipartite entanglement and entanglement detection in quantum hypergraph states

Ghio, Malpetti, Rossi, Bruss & Macchiavello, JPA 51 (2018



Multipartite entanglement

We investigated quantum steering properties of multipartite entangled systems based on entropic uncertainty relations.

Riccardi, Macchiavello & Maccone, Phys. Rev. A 97, 052307 (2018)

Detection of properties of quantum channels

We extended a recently proposed method to detect capacities of quantum channels [Macchiavello & Sacchi, PRL 116 (2016)] to the case of mixed inputs

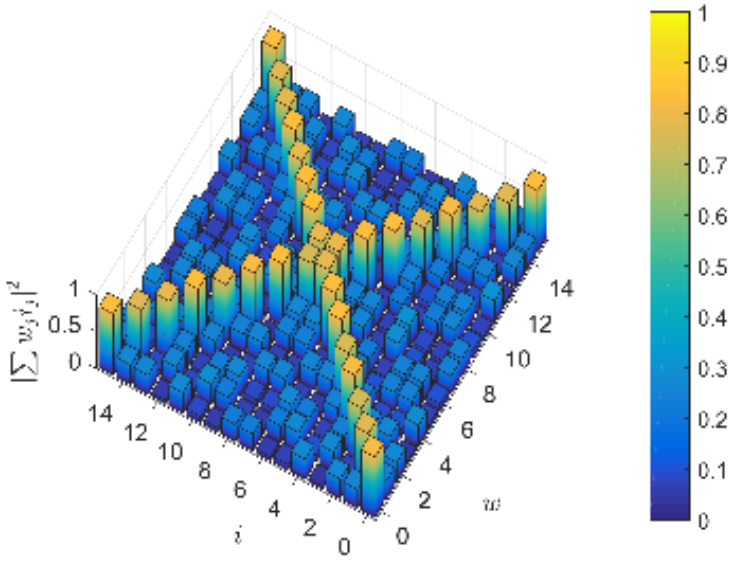
Macchiavello & Sacchi, Phys. Rev. A 97, 012303 (2018)

Quantum artificial neuron model

We introduced a quantum information-based algorithm implementing the quantum computer version of a perceptron, which shows exponential advantage in encoding resources over alternative realizations.

Tacchino, Macchiavello, Gerace & Bajoni,

Npj Q. Info. 5, 26 (2019)



Lorenzo Maccone

Lorenzo Maccone

- **Quantum metrology**: estimation of parameters in the framework of quantum technologies.

– Squeezing metrology: preprint arXiv:1901.07482
– Digital quantum metrology: M. Hassani, C. Macchiavello, L. Maccone, Digital quantum metrology, Phys. Rev. Lett. 119, 200502 (2017).
– Cryptographic quantum metrology: Z. Huang, C. Macchiavello,L. Maccone, Cryptographic quantum metrology, Phys. Rev. A 99, 022314 (2019).
– Noise dependent quantum metrology: Z. Huang, C. Macchiavello, L. Maccone, Noise-dependent optimal strategies for quantum metrology, Phys. Rev. A 97, 032333 (2018).

- **Quantum foundations**:

– Quantum time measurements: preprint arXiv:1810.12869.
– Contextuality and time loops: preprint arXiv:1903.01349.
– Quantum events: preprint: arXiv:1807.01307.
– Uncertainty Relations: we have continued the research on sum uncertainty relations, financed by the Blue Sky research project. P. Giorda, L. Maccone, A. Riccardi, State-independent uncertainty relations from eigenvalue minimization, Phys. Rev. A in press.

- **Quantum technologies**: we have won a European project for the development of quantum medical tomography, to employ the mathematical transformations that are used in quantum state reconstruction for the reconstructions of medical images in CT scans. The hope is to demonstrate a decrease in the radiation dose that is necessary to obtain images of diagnostic quality. A first collaboration with the group of Prof. Russo in Naples has obtained a publication.

THE THIRRING QUANTUM CELLULAR AUTOMATON [Phys. Rev. A 97, 032132 (2018)]
The four-fermion interaction, describing the coupling between four fermionic fields at the same spacetime point, has been extensively studied in several Hamiltonian models,
which differ each other in the symmetry of the interacting term. The Hubbard and the Thirring model are two notable examples of integrable systems with a four fermion interaction.
Other relevant models are the Nambu-Jona-Lasinio and Gross-Neveu. While the above systems have been studied both in the continuous space and on the lattice, they all share the
continuous time of the unitary evolution.
In Ref. [Phys. Rev. A 97, 032132 (2018)] we have presented a discrete time model of the four-fermion interaction and shown its analytical solution in the two-particles sector.
Analogously to any Hamiltonian integrable system, also in the discrete time case the solution is based on the Bethe Ansatz technique. However, the discreteness of the evolution prevents
the application of the usual Ansatz, and a new Ansatz has been introduced successfully. The analysis highlights non-trivial consequences of the discrete time in the physical phenomenology
predicted by the model. The Thirring automaton exhibits scattering solutions with nontrivial momentum transfer, jumping between different regions of the Brillouin zone, in stark contrast with
the momentum-exchange of the one dimensional Hamiltonian systems. A further difference compared to the Hamiltonian model is that there exist bound states for every value of
the total momentum, and even for vanishing coupling constant.

SYMMETRIES OF ONE DIMENSIONAL INTERACTING QUANTUM WALKS AND FEYNMAN DIAGRAMS [Entropy 20(6), 435 (2018)]
In Ref. [Entropy 20(6), 435 (2018)] we have studied the symmetries of the Thirring automaton of Ref. [Phys. Rev. A 97, 032132 (2018].
Notice that the Thirring quantum cellular automaton in the two-particles sector can be regarded as a one dimensional interacting quantum walk. Indeed the evolution operator is given by the sequence of two steps, the first one corresponding to a unitary interaction activated by two-particle excitation at the same site, and the second one to two independent one-dimensional Dirac quantum walks. The evolution operator displays both discrete and global symmetries, which have been exploited to simplify the analytical solution of the model.

INTERACTING FERMIONIC QUANTUM CELLULAR AUTOMATA [Physical Review A 98 (5), 052337 (2018)]
A map on finitely many fermionic modes represents a unitary evolution if and only if it preserves canonical anti-commutation relations. In Ref. [Physical Review A 98 (5), 052337 (2018)] we use this condition for the classification of fermionic
cellular automata (FCA) on Cayley graphs of finite groups in two simple but paradigmatic case studies. The physical properties of the solutions are discussed.
Finally, features of the solutions that can be extended to the case of cellular automata on infinite graphs are analyzed.

HIGHER ORDER QUANTUM THEORY [arXiv:1806.09554]
Higher order quantum theory is an extension of quantum theory where one introduces transformations whose input and output are transformations, thus generalising the notion of channels and quantum operations.
Quantum channels, which are normally considered as the logical gates in a quantum circuit, can play the role of inputs, thus introducing
"second-order" gates that transform channels into channels. The generalisation then goes recursively, with the construction of a full hierarchy of maps of increasingly higher order.
The analysis of special cases already showed that higher order functions exhibit features that cannot be tracked down to the usual circuits, such as indefinite causal structures, providing provable advantages over circuital maps.
In Ref. [arXiv:1806.09554] we provide a general framework where the analysis of higher order computation can be carried out in full generality. Higher order quantum computation is introduced axiomatically with a formulation based on the language of types of transformations. Every map comes then with a type, which summarises basic information such as its domain and its range. We introduce admissibility requirements as the loosest constraints for the higher order maps to respect the probabilistic structure of quantum theory, as in the axiomatisation of completely positive maps done by Kraus and Stinespring.
This definition of admissibility is fully operational, avoiding explicit reference to the mathematical properties of maps in the hierarchy. In

particular, complete positivity is not postulated as in previous approaches, but derived.
We give a complete characterisation of the admissible higher order maps and we use this result to prove equivalence relations between different types of higher order maps.
Since the axioms for higher order computation do not refer to the specific mathematical structure of quantum theory, they can be exported in the context of any operational probabilistic theory, thus opening a new promising line of research.

PROBABILISTIC STORAGE AND RETRIEVAL OF UNITARY TRANSFORMATIONS
[arXiv:1809.04552, arXiv:1809.02008]
A quantum memory is a valuable resource for Quantum Technology, and a great experimental effort is spent to its realisation.
Clearly, one can one can store unknown quantum states on a quantum memory but can we exploit it to store an unknown quantum transformation? In this way we could transmit the transformation to a distant party by just transmitting a state, without the need of transferring the device. The scenario of storing and retrieval of a quantum transformation is a follows. Imagine that a user can dispose of N uses of a black box implementing an unknown unitary transformation U. Today the user is allowed to use the black box at his convenience, running an arbitrary quantum circuit that makes N calls to it. Tomorrow, however, the black box will no longer be available, and the user will be asked to reproduce U on a new input state unknown to him of her.
Such a framework differs from the similar one of quantum cloning in the causal order of the available resources. While in the cloning the cloned device is available after the input states are at the disposal, In storage and retrieval this order is reversed and the device is available only before the input states. In Ref. [arXiv:1809.04552] we studied the storage an retrieval of a unitary transformation in the case in which the retrieved channel is required to perfectly reproduce the unknown unitary and with the same probability of success ("covariance" property) for all considered channels. Clearly, such a procedure cannot be deterministic, and we proved that optimal probability of success is N/(N 1 + d^2) where d is the dimension of Hilbert space. This result is closely related to probabilistic perfect alignment of reference frames, since we proved that given N uses of an unknown SU(2) rotation U, the inverse transformation can be perfectly retrieved with the same optimal probability of success of retrieving U. Moreover our result proves that the optimal probability of probabilistic port based teleportation coincides with the optimal success probability of probabilistic storage and retrieval. This is a surprising result because, while any probabilistic port based teleportation protocol can be turned into a probabilistic storage and retrieval one, the converse does not hold. Therefore, the optimal probabilistic port based teleportation can be thought as structurally simple realisation of the optimal probabilistic storage and retrieval.
The solution of the optimal probabilistic storage and retrieval had an unexpected application in the field of pure mathematics. Indeed, the solution of the optimization problem is equivalent to a new hook-content identity which we proved in Ref. [arXiv:1809.02008].

DATADRIVEN INFERENCE AND QUANTUM OBSERVATIONAL COMPLETENESS
[arXiv:1812.08470]
The goal of conventional quantum measurement tomography is the reconstruction of an unknown measurement from the statistics collected in a sequence of experimental trials via a known and trusted state-preparator.
In Ref. [arXiv:1812.08470] we introduce an alternative procedure for the inference of an unknown quantum measurement that only requires the analysis of the bare outcome distributions: the state-preparator could, for example, emit a different unknown state at each repetition of the experiment.
The range of a quantum measurement is the set of output probability distributions that can be produced by varying the input state. We have introduced data-driven inference as a protocol that, given a set of experimental
data as a collection of output distributions, infers the quantum measurement which is, i) consistent with the data, in the sense that its range contains all the distributions observed, and, ii) maximally noncommittal, in the sense
that its range is of minimum volume in the space of output distributions. We have shown that the inference is possible in principle up to gauge symmetries, that is, symmetries of the set of states of the system at hand, and that this accuracy
limit is achieved for (hyper)-spherical state spaces (for example, the

classical or the quantum bit).
Then, we considered the task of reconstructing an unknown measurement via data-driven inference. To this aim, we introduced observationally complete sets of states, (defined in analogy to the property of informational complete set
of states in quantum tomography) as those enabling a correct inference universally, that is, for any unknown measurement on a given support. Deriving a closed-form characterisation of observational completeness allowed us to show that, while observational completeness is a strictly stronger condition than informational completeness, in the case of (hyper)-spherical state space observationally completeness with minimum number of states is equivalent to symmetric informational completeness, thus providing a data-driven operational interpretation to symmetric informationally complete sets. We concluded by conjecturing that such an equivalence holds for quantum systems of arbitrary dimension.

QUANTUM PARAMETER ESTIMATION: ESTIMATION OF PARAMETERS IN THE FRAMEWORK OF QUANTUM TECHNOLOGIES
This line of research is usually referred to as ‘‘quantum metrology’’. In this research line we have
various results.
- Squeezing metrology: we derived a theory to describe how quantum squeezing can be used in parameter estimation. Our theory is valid for arbitrary systems, whereas previous results were valid only for very specific systems (e.g. the electromagnetic field in quantum optics). The results of this research has been published with the preprint arXiv:1901.07482, currently submitted.
- Digital quantum metrology: a parameter estimation theory that is valid in the presence of digital sensors. This has been published in [M. Hassani, C. Macchiavello, L. Maccone, Digital quantum metrology, Phys. Rev. Lett. 119, 200502 (2017)].
- Cryptographic quantum metrology: where we show how to protect the estimation procedure with quantum cryptography, to achieve an unconditionally secure estimation. The results of this research have been published in [Z. Huang, C. Macchiavello, L. Maccone, Cryptographic quantum metrology, Phys. Rev. A 99, 022314 (2019)].
- Noise dependent quantum metrology: we have shown some examples where the optimal strategy for measuring a parameter in quantum metrology may depend on the noise level, showing that a crossover may occur: the optimal strategy for some noise level may be suboptimal for other noise levels. The results were published in [Z. Huang, C. Macchiavello, L. Maccone, Noise-dependent optimal strategies for quantum metrology, Phys. Rev. A 97, 032333 (2018)].

QUANTUM FOUNDATIONS:
- Quantum time measurements:
we studied the problem of describing time measurements in quantum mechanics. The textbook quantum mechanics is not able to describe these types of measurements because time in conventional quantum mechanics is described as a classical parameter. We have evolved our former ‘‘quantum time’’ research to obtain a description of arbitrary time measurements, for example the time of arrival of a quantum particle at some position. The results of this research have been published in the preprint arXiv:1810.12869.
- Contextuality and time loops: we have shown how the knowledge of quantum hidden variables would allow a person to communicate to his own causal past. This can be seen as a further indication that quantum hidden variables should remain hidden as a matter of principle. The results of this research are in the preprint arXiv:1903.01349.
- Quantum events: we have analyzed one of the fundamental reasons why it is difficult to quantize general relativity. The main reason is the difficulty in giving a good definition of a quantum event. The results of this research are in the preprint: arXiv:1807.01307.
- Uncertainty Relations: we have continued the research on sum uncertainty relations, financed by the Blue Sky research project. We have derived a general way to derive lower bounds for sum of variances, based on a minimization of a Hamiltonian problem. The results of this research are in [P. Giorda, L. Maccone, A. Riccardi, State-independent uncertainty relations from eigenvalue minimization, Phys. Rev. A in press].

QUANTUM TECHNOLOGIES

We have won a European project for thedevelopment of quantum medical tomography, to employ the mathematical transformations that are used in quantum state reconstruction for the reconstructions of medical images in CT scans. The hope is to demonstrate a decrease in the radiation dose that is necessary to obtain images of diagnostic quality. A first collaboration with the group of Prof. Russo in Naples has obtained a publication that will be submitted in these days.

Entanglement in hypergraph states

We studied the entanglement properties of a class of multiqubit states, called hypergraph states, focusing mainly on multipartite entanglement. Moreover, we derived efficient methods to for entanglement detection for these states [M. Ghio, D. Malpetti, M. Rossi, D. Bruss and C. Macchiavello, J. Phys. A 51, 045302 (2018)].

Quantum communication channels

We extended a recent method to detect lower bounds to the quantum capacity of quantum communication channels by considering realistic scenarios with general input probe states and arbitrary detection procedures at the output. Realistic certification relies on a new bound for the coherent information of a quantum channel that can be applied with arbitrary bipartite mixed input states and generalized output measurements [C. Macchiavello and M.F. Sacchi, Phys. Rev. A 97, 012303 (2018)].

Titolo Autori Sigla Rivista Autori BELL Autori Totali

1 Causality re-established <http://www.infn.it/pubblicazioni/autori/index.php/gestionepubblicazione/mostra/WOS:000433362900003> D'Ariano, Giacomo Mauro BELL PHILOS T R SOC A , 2123-376 1 1

2 Experimental ancilla-assisted phase estimation in a noisy channel <http://www.infn.it/pubblicazioni/autori/index.php/gestionepubblicazione/mostra/WOS:000426900500003> Sbroscia, Marco et al. BELL PHYS REV A , 3-97 2 8

3 Mixed-state certification of quantum capacities for noisy communication channels <http://www.infn.it/pubblicazioni/autori/index.php/gestionepubblicazione/mostra/WOS:000419309300002> Macchiavello, Chiara et al. BELL PHYS REV A , 1-97 1 2

4 Multipartite entanglement detection for hypergraph states <http://www.infn.it/pubblicazioni/autori/index.php/gestionepubblicazione/mostra/WOS:000418550400002> Ghio, M. et al. BELL J PHYS A-MATH THEOR , 4-51 1 5

5 Multipartite steering inequalities based on entropic uncertainty relations <http://www.infn.it/pubblicazioni/autori/index.php/gestionepubblicazione/mostra/WOS:000432019800005> Riccardi, Alberto et al. BELL PHYS REV A , 5-97 1 3

6 Noise-dependent optimal strategies for quantum metrology <http://www.infn.it/pubblicazioni/autori/index.php/gestionepubblicazione/mostra/WOS:000428010600003> Huang, Zixin et al. BELL PHYS REV A , 3-97 2 3

7 Solutions of a Two-Particle Interacting Quantum Walk <http://www.infn.it/pubblicazioni/autori/index.php/gestionepubblicazione/mostra/WOS:000436275400044> Bisio, Alessandro et al. BELL ENTROPY-SWITZ , 6-20 2 5

8 State-independent uncertainty relations <http://www.infn.it/pubblicazioni/autori/index.php/gestionepubblicazione/mostra/WOS:000447916200002> de Guise, Hubert et al. BELL PHYS REV A , 4-98 1 4

9 The solution of the sixth Hilbert problem: the ultimate Galilean revolution <http://www.infn.it/pubblicazioni/autori/index.php/gestionepubblicazione/mostra/WOS:000427878700003> D'Ariano, Giacomo Mauro BELL PHILOS T R SOC A , 2118-376 1 1

10 Thirring quantum cellular automaton <http://www.infn.it/pubblicazioni/autori/index.php/gestionepubblicazione/mostra/WOS:000428647300004> Bisio, Alessandro et al. BELL PHYS REV A , 3-97 3 4

DYNSYSMATH

DYNamical systems and non equilibrium states of complex SYStems : MATHematical methods and physical concepts

Fausto Borgonovi, Chahan Kropf, Francesco Mattiotti

INFN Pavia

DYNSYSMATH

DYNamical systems and non equilibrium states of complex SYStems : MATHematical methods and physical concepts

National Coordinator : Fausto Borgonovi (Pavia)

Catania

- **Staff members**
  - Andrea Rapisarda, Alessandro Pluchino, Giuseppe Falci, Elisabetta Paladino, Bernardo Spagnolo
- **Postdoc fellows, PhD students**
  - Michele Cascio, Nicola Cinardi

Firenze

- **Staff members**
  - Lapo Casetti, Duccio Fanelli, Stefano Lepri, Roberto Livi, Paolo Politi, Stefano Ruffo
- **Postdoc fellows, PhD students**
  - Giulia Cencetti, Stefano Gherardini, Pierfrancesco Di Cintio, Stefano Iubini
- **High school teachers**
  - Alessandro Mossa

NETWORK

Milano

- **Staff members**
  - Roberto Artuso, Giorgio Mantica

Pavia

- **Staff members**
  - Fausto Borgonovi, Giulio Giusteri, Giuseppe Luca Celardo, Italo Guarneri
- **Postdoc fellows, PhD students**
  - Francesco Mattiotti, Chahan Kropf

Roma I

- **Staff members**
  - Andrea Giansanti, Irene Giardina, Alessandro Campa, Andrea Gabrielli, Francesco Sylos Labini
- **Postdoc fellows, PhD students**
  - Maddalena Dilucca, Giulio Cimini, Sergio Forcelloni

DYNSYSMATH

DYNamical systems and non equilibrium states of complex SYStems : MATHematical methods and physical concepts

- Better understanding of fundamental properties of **classical and quantum dynamical** systems, with a particular prominence on **unconventional transport** and **dynamical features**
  - fractal spectra
  - weak chaos
  - infinite ergodic theory
  - almost resonant quantum systems
- Sudy of features that characterize the behavior of **many particle systems**, with a methodology that takes into account the former **dynamical perspective**
  - normal and anomalous heat conduction in long chains
  - equilibrium and non equilibrium aspects of systems with long range interactions - with an emphasis on self-gravitating systems -
  - coherent transport in light harvesting systems
  - statistical analysis of social and economic systems.

Research Activity 2018

1) Quantum transport in small chains with application to photosynthetic systems

We studied the optimal conditions for quantum coherence enhanced transport in a one-dimensional chain of finite length N. We investigated the effects of dephasing and of electron interactions on the transport and found both to have a similar detrimental effect on the transport efficiency. We derived bounds on both below which quantum coherence play a key role for transport enhancement.
We also studied the effect of adding a constant electric field on the transport efficiency in the one-dimensional chain of finite length N with dephasing, and a coupling to a sink. We found that the interplay between the magnitude of the electric field, the dephasing strength and the properties of the initial state gives rise to different optimal conditions for efficient quantum transport.

2) Macroscopic coherence in light-harvesting nanotubes

We studied the presence of quantum coherence at room temperature in some realistic models of molecular light-harvesting nanotubes. We found that these models show a superradiant state very close to the lowest-energy edge of the single-excitation spectrum. We found that the superradiant state is generated by a supertransfer coupling between the subunits forming the cylinder. We also connected the supertransfer coupling to the low density of states at low energy, resulting in a high coherence length at equilibrium at room temperature.

3) Common properties to superconducting and superradiant systems

We compared the spectra for a superconductivity model and a superradiance model. We find that the superradiance model exhibits an imaginary gap mathematically equivalent to the superconducting gap. We also reinterpret the superradiance transition as a transition to a gapped regime and we show how the imaginary gap makes the system robust to static disorder.

Research Activity 2018

4) Thermalization in quantum systems

We demonstrate analytically and numerically that in isolated quantum systems of many interacting particles, the number of many-body states participating in the evolution after a quench increases exponentially in time, provided the eigenstates are delocalized in the energy shell. The rate of the exponential growth is defined by the width of the local density of states and is associated with the Kolmogorov-Sinai entropy for systems with a well-defined classical limit. In a finite system, the exponential growth eventually saturates due to the finite volume of the energy shell. Numerical data obtained for a two-body random interaction model of bosons and for a dynamical model of interacting spin-1/2 particles show excellent agreement with the analytical predictions.

Publications (2018-2019)

- Spiros Kechrimparis, Tanmay Singal, **Chahan M. Kropf,** and Joonwoo Bae, *Preserving Measurements for Optimal State Discrimination over Quantum Channels,* arXiv:1811.07721 (2018)
- **Chahan M. Kropf**, Angelo Valli, Paolo Franceschini, **G. Luca Celardo**, Massimo Capone, Claudio Gianetti, and **Fausto Borgonovi**, *Towards high-temperature coherence-enhanced transport in few-atomic layers heterostructures,* arXiv:1812.08105 (2018)
- Marco Gullì, Alessia Valzelli, **Francesco Mattiotti**, Mattia Angeli, **Fausto Borgonovi** and **G. Luca Celardo**, *Macroscopic coherence as an emergent property in molecular nanotubes*, New J. Phys. 21, 013019 (2019)
- Nahum C. Chavez, **Francesco Mattiotti**, J. A. Mendez-Bermudez, **Fausto Borgonovi**, and **G. Luca Celardo**, *Real and imaginary energy gaps: a comparison between single excitation superradiance and superconductivity,* arXiv:1805.03153 (2018) (accepted for publication in EPJB, 2019)
- **Fausto Borgonovi** and Felix M. Izrailev, *Emergence of correlations in the process of thermalization of interacting bosons* , Phys. Rev. E 99 012115 (2019)
- **Fausto Borgonovi**, Felix M. Izrailev and Lea F. Santos, *Exponentially fast dynamics of chaotic many-body systems,* Phys. Rev. E 99, 010101(R) (2019);

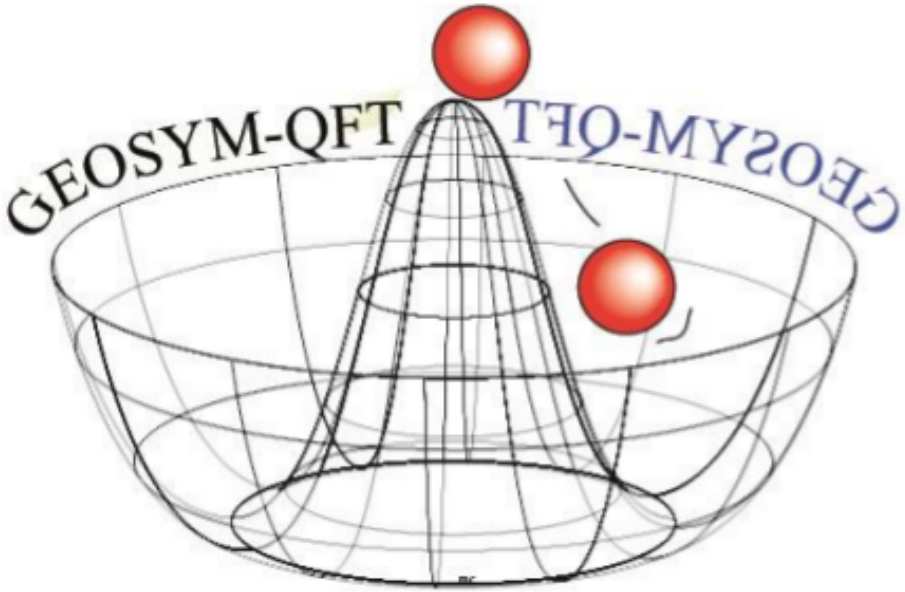
Current and future projects (2019)

- Quantum correlations and coherences in many-body atomic states of strongly correlated high-temperature superconducting materials and their relation to the electron spectroscopy spectrum.
- Application of quantum machine learning to the quantum entanglement measurement problem.
- Identification of materials in measured emission spectra using convolutional neuronal networks
- The quantum state discrimination problem for unknown states in the presence of noise. How to preserve optimal measurements for qsd. proof of principle on a quantum computer.
- Superradiance in perovskite nanocrystal superlattices
- Cooperative robustness of superradiance and delocalization to static disorder in natural light-harvesting nanotubes
- Quantum transport in disordered Anderson chains with real or imaginary all-to-all interaction
- Quantum light diode inspired by light-harvesting complexes

Geometry and Symmetry in Quantum Field Theory
Consuntivo 2018

Staff:
Mauro Carfora
Claudio Dappiaggi
Giancarlo Jug
Annalisa Marzuoli

Dottorandi:
[Francesco Bussola]
Barbara Giunti (3°)
Lissa de Sousa Campos (1°)
Paolo Rinaldi (1°)



Temi di ricerca & preprint

- Algebraic Quantum Field Theory

This long-standing activity includes several new results, namely:

i) The study of the ground state and correlation functions of a real massive scalar field on AdS_n and its universal covering, with the determination of all the admissible boundary conditions, see C. Dappiaggi, H. Ferreira and A. Marta, arXiv: 180503135 [hep-th];

ii) The analysis of the local behavior of the 2-point correlation function of a quantum state for a scalar field on a neighborhood of a Killing horizon going beyond the 2+1 case, see F. Bussola and C. Dappiaggi, arXiv:1806.00427 [gr-qc];

iii) A comprehensive theory of linearized fields based on causal variational principles, see C. Dappiaggi and F. Finster, arXiv: 1811.10587 [math-ph].

- Geometric Analysis and Ricci Flow

i) The second order approximation to the perturbative renormalization group flow for the non-linear sigma model (RG-2) is invariant under diffeomorphisms but not under scaling of the metric. It has been proven that a suitably-defined coupling constant of geometric nature can turn the flow into an equivalent, scale-invariant one. Moreover, a modified Perelman entropy is introduced and the local existence of the associated variational system is verified, see
C. Guenter and M. Carfora, arXiv: 1805.09773.

ii) The perturbative approach to non-linear sigma models quoted above can be addressed from a new perspective by resorting to the framework of Algebraic QFT and to the requirement of general local invariance. This approach provides a mathematically rigorous proof that, at first order, the RG flow of non-linear sigma model is the Ricci flow, see
M. Carfora, C. Dappiaggi, N. Drago and P. Rinaldi, arXiv: 1809.07652 [math-ph].

- Topological QFT and discrete gravity models

Within this traditional line of research, the focus has been on algebraic formalizations of low-dimensional topological invariants suitable to be processed by quantum computers, together with an improved analysis of their computational complexity.

- Topological Methods in Data Science

Discretized methods in standard geometric topology provide quite effective tools in addressing also topological data analysis. Simplicial homological methods are commonly used in the characterization of the global features of concrete data sets and complex systems modeled by graphs. An improved setting for the decompositions of sequences of persistent homology groups has been developed, and preliminary simulations carried on (B. Giunti, PhD Thesis, in preparation).

- Theory and phenomenology of amorphous solids

This line of research, developed over the last few years, aims to establish a well-grounded theory describing the semi-phenomenological aspects of the physics of glasses. In particular, significant achievements have been reached on the theoretical side and on the planning of an experimental setting in the search for a new form of intrinsic paramagnetism in amorphous systems. Applications might include the construction of low-noise resonators for detectors of gravitational waves as well as of tunneling barriers in Josephson junctures of interest for building up long-coherent qubits assembly.

CONSUNTIVO TAsP – PAVIA – 2018

4 giugno 2019

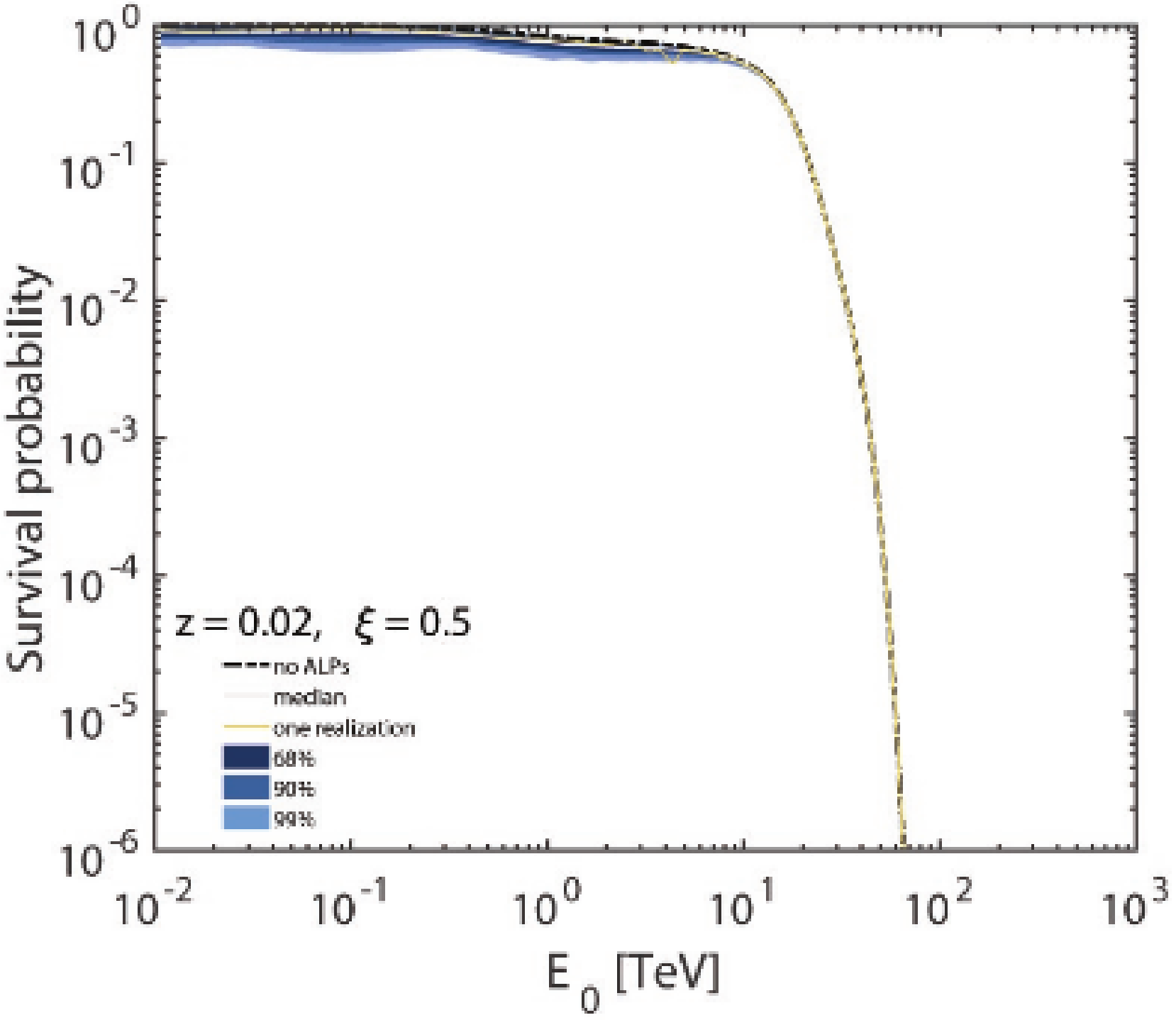
COMPOSIZIONE:

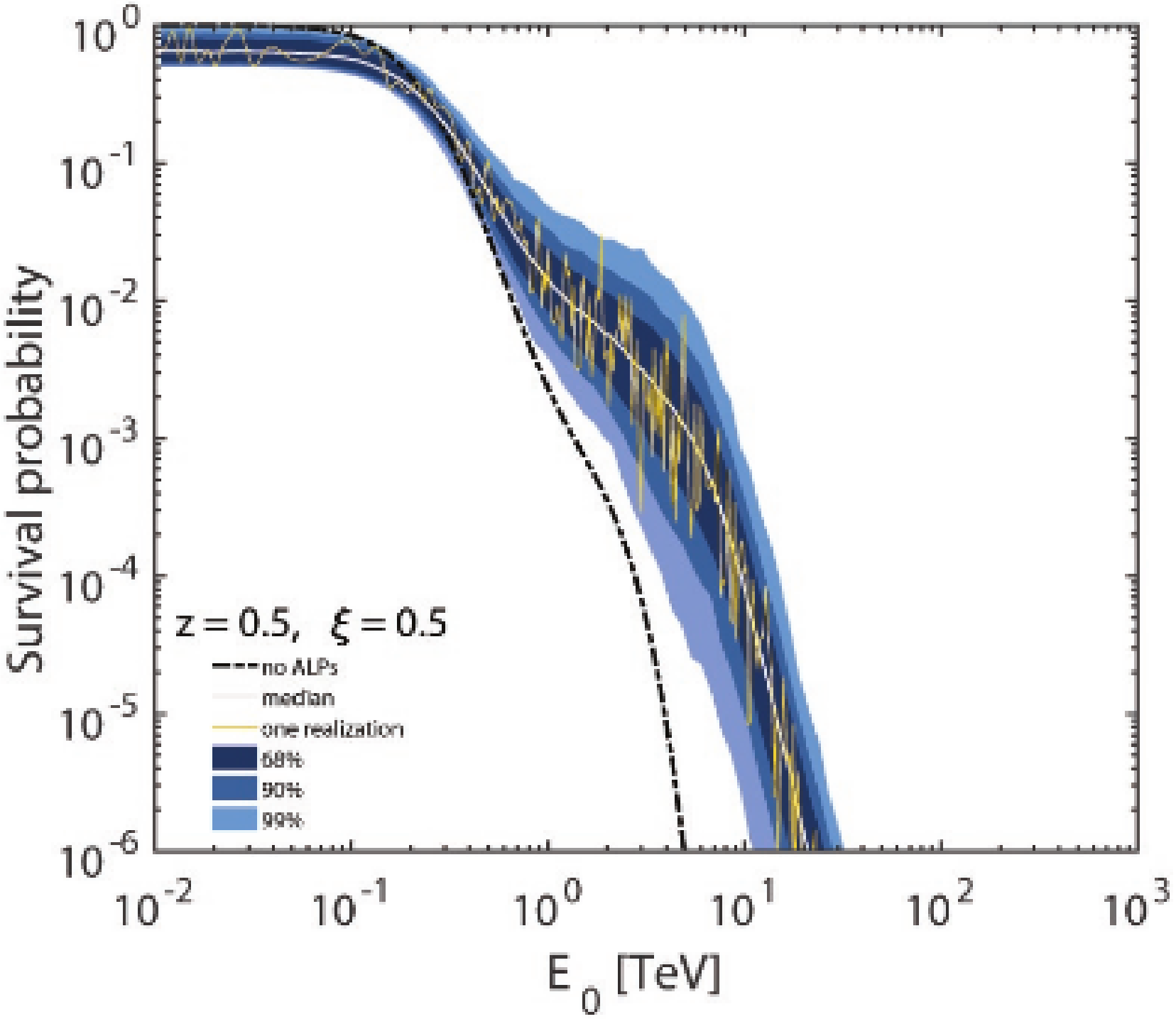
M. Roncadelli, coordinatore locale, Primo Ricercatore INFN, 80 %, P. Caraveo, Dirigente di Ricerca INAF (IASF, Milano), Professore a contratto UNIPV, 25 %, A. De Luca, Ricercatore INAF (IASF, Milano), Professore a contratto UNIPV, 25 %, A. Giuliani, Ricercatore INAF (IASF, Milano), Professore a contratto UNIPV, 25 %, A. Tiengo, Ricercatore IUSS (Pavia), Professore a contratto UNIPV, 25 %.

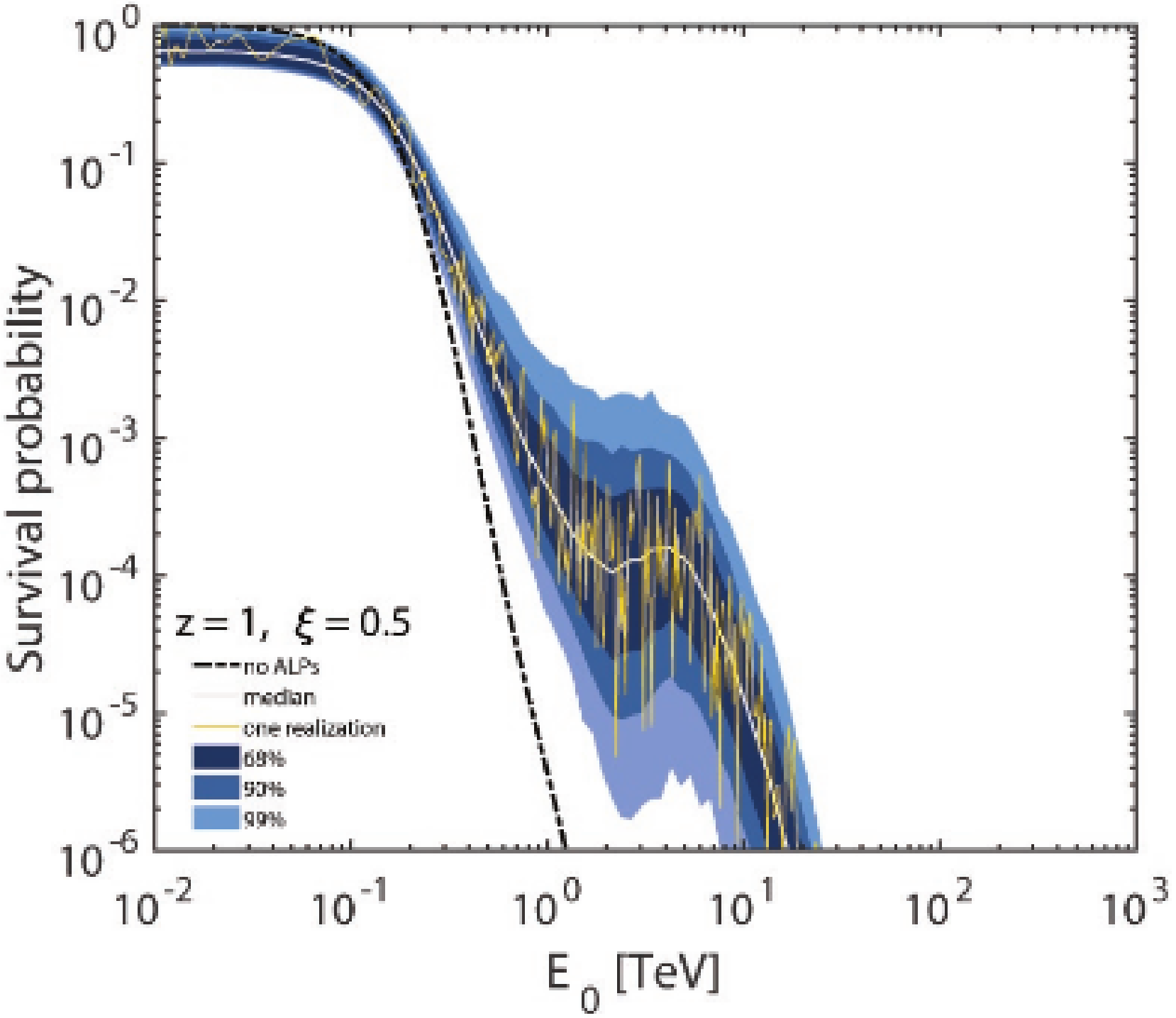
ATTIVITÀ SCIENTIFICA:
Il gruppo di Pavia di TAsP si occupa di astrofisica delle alte energie, sia da un punto di vista teorico che per quanto concerne le osservazioni e l'interpretazione dei risultati. L'attività può essere riassunta come segue.

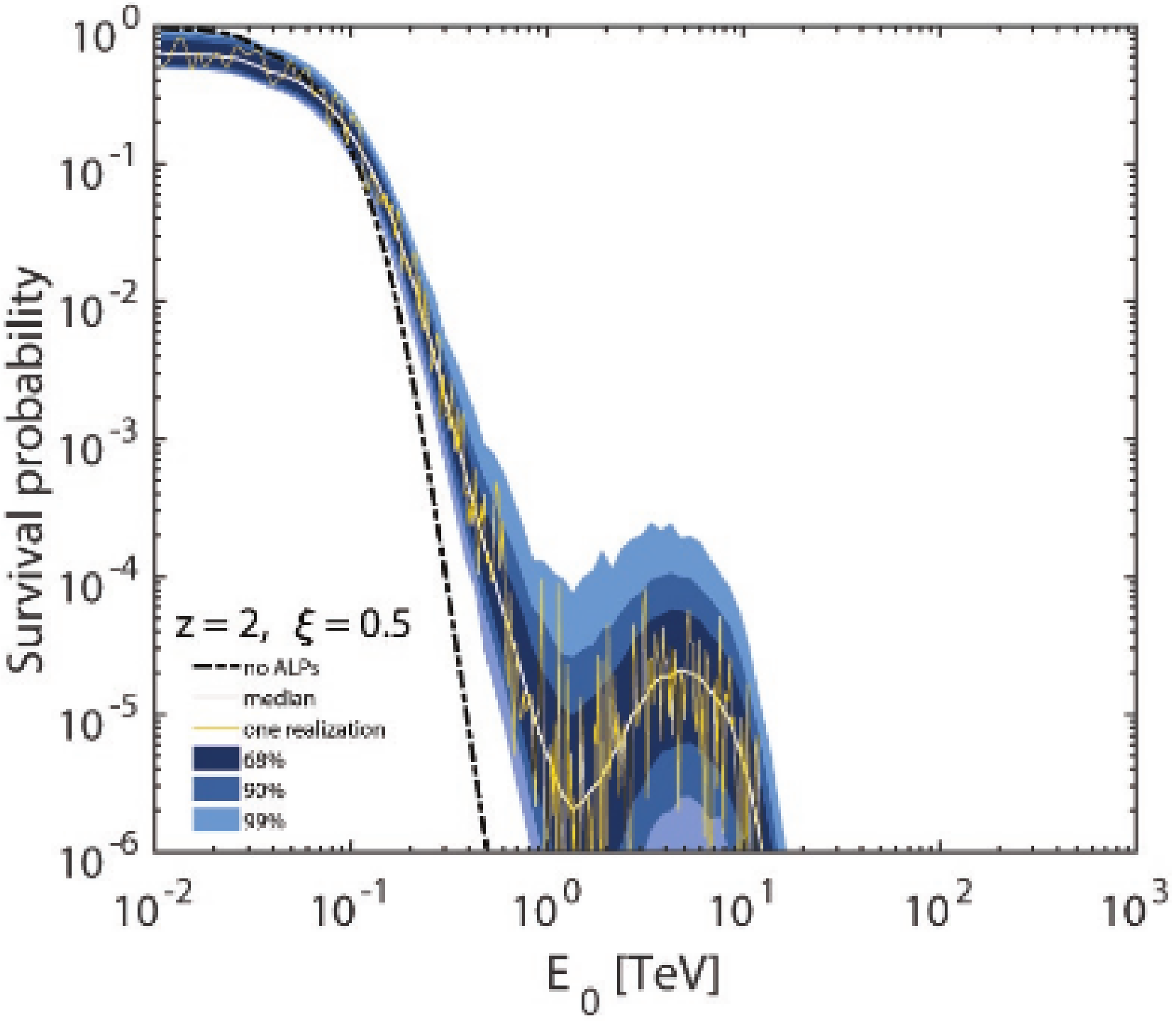
ATTIVITÀ SCIENTIFICA di M. R. – In collaborazione con G. Galanti e F. Tavecchio (INAF, Milano) è continuato lo studio delle oscillazioni fotone-ALP in relazione con le osservazioni dei blazar ad energie superiori a $E \simeq 100\,\mathrm{GeV}$. Specificamente, è stato osservato nel 2015 da Raffelt *et al.* che ad energie superiori a $E \simeq 15\,\mathrm{TeV}$ la dispersione dei fotoni sulla CMB diventa dominante. Quindi, in vista dei rivelatori gamma di nuova generazione quali CTA, HAWC, GAMMA-400, LHAASO, TAIGA-HiSCORE e HERD è necessario tener conto di questo effetto, in quanto questi esplorano energie fino a $E \simeq 300\,\mathrm{TeV}$ ed anche maggiori. Ciò però non è affatto banale. Usualmente il campo magnetico estragalattico $\mathbf{B}_{\mathrm{ext}}$ è modellizzato come un network di domini pressochè uguali – con dimensioni lineari $\mathcal{O}(1\,\mathrm{Mpc})$ – nei quali $\mathbf{B}_{\mathrm{ext}}$ ha sostanzialmente lo stesso modulo ma la sua direzione cambia in modo *discontinuo* passando da un dominio ad un'altro. Indicando con λ_{osc} lunghezza di oscillazione fotone-ALP, in assenza dell'effetto suddetto si ha $\lambda_{\mathrm{osc}} \gg \mathcal{O}(1\,\mathrm{Mpc})$, per cui la discontinuità di $\mathbf{B}_{\mathrm{ext}}$ è irrilevante: soltanto una minima parte dell'oscillazione è influenzata da $\mathbf{B}_{\mathrm{ext}}$ in un singolo dominio.

Le cose cambiano radicalmente in presenza dell'effetto considerato, in quanto per $E \gtrsim 40\,\mathrm{TeV}$ si ha $\lambda_{\mathrm{osc}} \simeq \mathcal{O}(1\,\mathrm{Mpc})$, e λ diminuisce al crescere di E. Ora una singola oscillazione – e anche più oscillazioni – sono contenute in un singolo dominio, per cui il risultato "sente" la discontinuità e quindi diventa privo di senso. È quindi compelling modificare il modello rendendo smooth il cambiamento di direzione di $\mathbf{B}_{\mathrm{ext}}$ nel passaggio da un dominio al successivo. Conseguentemente l'equazione di propagazione del fascio fotoni/ALP in un singolo dominio diventa molto più difficile da risolvere. Tuttavia, con un uso non banale delle trasformate di Laplace siamo riusciti a risolvere tale equazione in modo analitico ed esatto. Iterando il risultato per tutti i domini si ottengono tutte le traiettorie del fascio nello spazio estragalattico. Una predizione che ne emerge è un andamento oscillatorio con E, che può essere osservato da un rivelatore con buona risoluzione spettrale.
Esempi di singole realizzazioni di tale processo aleatorio – a causa della variabilità random di $\mathbf{B}_{\mathrm{ext}}$ in ogni dominio sono illustrate nelle figure seguenti.


Survival probability
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
$z = 0.02, \quad \xi = 0.5$
no ALPs
median
one realization
68%
90%
99%
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
E_0 [TeV]


Survival probability
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
$z = 0.5, \quad \xi = 0.5$
no ALPs
median
one realization
68%
90%
99%
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
E_0 [TeV]


Survival probability
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
$z = 1,\ \xi = 0.5$
no ALPs
median
one realization
69%
95%
99%
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
E_0 [TeV]


Survival probability
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
$z = 2, \ \xi = 0.5$
no ALPs
median
one realization
69%
95%
99%
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
E_0 [TeV]

ATTIVITÀ SCIENTIFICA di P. C., A. D. L., A. G., A. T. – Il progetto EXTraS (Exploring the X-ray Transient and variable Sky) finanziato dalla CE (FP7 2014-2016, P. I. De Luca) ha evidenziato circa 400.000 sorgenti variabili nella banda X fra quelle rivelate dal satellite XMM-Newton dell'ESA. I risultati sono stati resi pubblici in giugno 2017. I suddetti autori si sono concentrati su vari tipi di sorgenti interessanti e non ancora spiegate, dalla ricerca di eventi astrofisici rari allo studio sistematico delle proprietà di varie classi di sorgenti. Alcuni esempi sono i seguenti.

- È stata scoperta una sorgente molto sconcertante e variabile nell'ammasso globulare NGC 6540. La sua luminosità e durata sfidano qualsiasi spiegazionea. Sia un'esplosione nucleare sulla superficie di una stella di neutroni in un sistema binario, che un flare da una stella attiva sono due ipotesi facilmente escluse.

- Nella più brillante sorgente X in Andromeda è stata scoperto un sistema binario di bassa massa e grandissima luminosità con periodo orbitale di 4.15 ore. Tale sistema pone una sfida a tutti i modelli evolutivi e di accrescimento noti.
- È continuato lo studio precedentemente iniziato a multi-frequenza di oggetti compatti. un esempio consiste nella pulsar wind nebula associata al pulsar radio-quito e gamma-attivo PSR J2055+2539. Questa consiste in due strutture diffuse ed elongate che emettono raggi X, separate di 160° sul piano celeste. Una possibile spiegazione è che la struttura più luminosa sia formata da un jet di particelle accelerate dal pulsar, mentre l'altra sia una nebulosa che emette radiazione di sincrotrone.