# Consuntivi Scientifici 2023

**C.M. Carloni Calame**

**Consiglio di Sezione, Pavia**
**5 giugno 2024**


Istituto Nazionale di Fisica Nucleare

# Iniziative Specifiche (fotografia 2023)

| *Iniziativa Specifica* | *Responsabile Locale* | *Responsabile Nazionale* |
|---|---|---|
| **BELL [4]** | Paolo Perinotti | Angelo Bassi (TS) |
| **GEOSYM_QFT [4]** | Claudio Dappiaggi | Francesco Bonechi (FI) |
| **NINPHA [3]** | Marco Radici | M. Boglione (TO) / F. Murgia (CA) |
| **QFT@COLLIDERS [2]** | Carlo Carloni Calame | Gian Paolo Vacca (BO) |
| **CC3M/ASIMOV** | Marco Radici | Francesco Vissani (LNGS) |

Linee scientifiche di CSN4:

**[1]** Teoria dei Campi e Stringhe, **[2]** Fenomenologia delle particelle elementari,

**[3]** Fisica Nucleare e Adronica, **[4]** Fondamenti e Metodi Matematici, **[5]** Fisica astroparticellare,

**[6]** Fisica Statistica e Teoria di Campo Applicata

# BELL

Linea 4

**Fondamenti & Metodi Matematici**

# Anagrafica BELL 2023

| Cognome | Nome | Esperimenti |
|---|---|---|
| Bisio | Alessandro | 100% - (PV:CSN4) **BELL** (*Ricercatore*) |
| D'Ariano | Giacomo | 100% - (PV:CSN4) **BELL** (*Ricercatore*) |
| Lugli | Matteo | 100% - (PV:CSN4) **BELL** (*Ricercatore*) |
| Macchiavello | Chiara | 80% - (PV:CSN4) **BELL** (*Ricercatore*) |
| Maccone | Lorenzo | 100% - (PV:CSN4) **BELL** (*Ricercatore*) |
| Mangini | Stefano | 100% - (PV:CSN4) **BELL** (*Ricercatore*) |
| Morgillo | Angela Rosy | 100% - (PV:CSN4) **BELL** (*Ricercatore*) |
| Nicrosini | Oreste | 40% - (PV:CSN4) **BELL** (*Ricercatore*) |
| Perinotti | Paolo | 100% - (PV:CSN4) **BELL** (*Ricercatore*) |
| Rolino | Davide | 100% - (PV:CSN4) **BELL** (*Ricercatore*) |
| Tosini | Alessandro | 100% - (PV:CSN4) **BELL** (*Ricercatore*) |
| Vaglini | Leonardo | 100% - (PV:CSN4) **BELL** (*Ricercatore*) |

Showing 1 to 12 of 12 entries

**11.2 FTE totali**

QUit
quantum information theory group

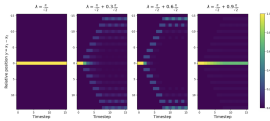
Paolo Perinotti

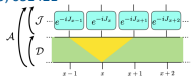
Gruppo IV
BELL

## A massless interacting Fermionic Cellular Automaton exhibiting bound states

E. Centofanti, P. Perinotti, and A. Bisio, Phys. Rev. A 109, 052421

QCA model for massless fermions in 1+1 dimension coupled with local, number preserving interaction.



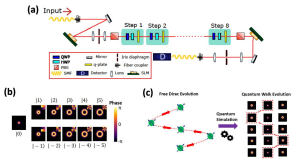


The time discreteness of the evolution allows, for specific values of the total momentum and of the coupling constant, the formation of bound states.

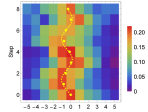
## Photonic cellular automaton simulation of relativistic quantum fields: observation of Zitterbewegung

A. Suprano, D. Zia, E. Polino, D. Poderini, G. Carvacho, F. Sciarrino, M. Lugli, A. Bisio, P. Perinotti, accepted in PRR (12 April 2024)

In collaboration with an experimental group at "Sapienza" University of Rome, we developed a photonic simulation of the Dirac equation in 1+1 dimension using a Dirac QCA. The particle's position is encoded in the orbital angular momentum of the photon.



Our setup enabled the observation of Zitterbewegung motion.



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## Which entropy for general physical theories?

P. Perinotti, A. Tosini, L. Vaglini, arXiv:2302.01651, under review for Quantum

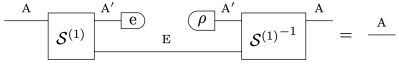
Information content of a source for an arbitrary information theory, is defined as the asymptotic achievable compression rate. The functions that quantify it in classical and quantum theory are Shannon's and von Neumann's entropy, respectively. In a general information theory there are three different functions that extend the notion of entropy, and this opens the question as to whether any of them can universally play the role of the quantifier for the information content. Here we answer the question in the negative, by evaluating the information content as well as the various entropic functions in a toy theory called Bilocal Classical Theory.


Encoding Decoding

## Measurement incompatibility is strictly stronger than disturbance

M. Erba, P. Perinotti, D. Rolino, and A. Tosini, Phys. Rev. A 109, 022239 (2024)

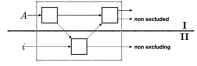
Heisenberg's gamma-ray microscope argument for the uncertainty principle hinges upon the existence of measurements that irreversibly alter the state of the system. Measurement incompatibility in quantum theory, namely, the existence of measurements that cannot be performed jointly is now understood to be different from irreversibility of measurement disturbance. We provide a compelling argument showing that measurement incompatibility is indeed a sufficient condition for irreversibility of measurement disturbance; on the other hand, we exhibit a toy theory that is a counterexample for the converse implication. This theory is classical, hence it does not have complementarity nor preparation uncertainty relations, and it satisfies irreversibility of measurement disturbance.




## Unifying different notions of quantum incompatibility into a strict hierarchy of resource theories of communication

F. Buscemi, K. Kobayashi, S. Minagawa, P. Perinotti, A. Tosini, Quantum 7, 1035 (2023)

We introduce the notion of q-compatibility, which unifies different notions of POVMs, channels, and instruments incompatibility into one hierarchy of resource theories of communication between separated parties. The resource theories that we obtain are complete, in the sense that they contain complete families of free operations and monotones providing necessary and sufficient conditions for the existence of a transformation.



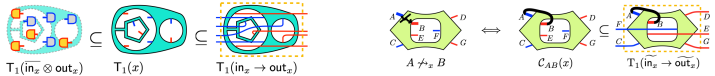
Paolo Perinotti

Gruppo IV
BELL

## No-signalling constrains quantum computation with indefinite causal structure

L. Apadula, A. Bisio, P. Perinotti, Quantum 8, 1241 (2024)

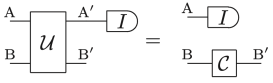
**Quantum processes with indefinite causal structure can be described within the framework of higher-order quantum theory which, starting from considering maps from quantum transformations to quantum transformations, recursively constructs a hierarchy of quantum maps of increasingly higher order. In this work, we characterize the computational structure of higher order quantum maps, providing a mathematical characterization of the admissible composition for arbitrary higher order quantum maps. We prove that these rules, which have a computational and information-theoretic nature, are determined by the more physical notion of the signalling relations between the quantum systems.**




## Causal influence versus signalling for interacting quantum channels

K. Barsse, P. Perinotti, A. Tosini, L. Vaglini, arXiv:2309.07771, under review for Phys. Rev. Letters

**A causal relation between quantum agents, say Alice and Bob, is necessarily mediated by an interaction. Modelling the last one as a reversible quantum channel, an intervention of Alice can have causal influence on Bob's system, modifying correlations between Alice and Bob's systems. Causal influence between quantum systems necessarily allows for signalling. Here we prove a mismatch between causal influence and signalling via direct computation of the two quantities for the C-not gate. Finally we show a continuity theorem for causal effects of unitary channels: a channel has small causal influence iff it allows for a small amount of signalling.**



Chiara Macchiavello

Gruppo IV
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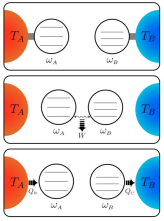
## Quantum thermodynamics

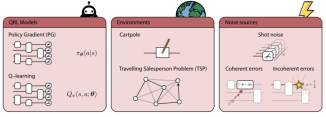
Published in Entropy 25, 1528 (2023)

We studied the work fluctuations in ergotropic heat engines and provided an exhaustive analysis for the case of two qutrits whose energy levels are equally spaced at two different frequencies by deriving the complete work statistic.




## Quantum neural networks

Published in Quantum 7, 1023 (2023); EPJ Quantum Technology 10, 8 (2023)

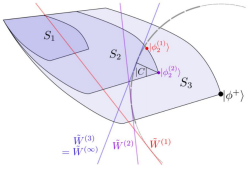



We analytically and empirically investigated how the presence of noise during training and evaluation of variational quantum reinforcement learning algorithms affect the performance of the agents and robustness of the learned policies.
Moreover, we employed matrix product states to characterize recently studied QNN architectures with random parameters up to fifty qubits.

## Entanglement detection

Published in Phys. Rev. A 107, 022431 (2023)

We developed an iterative algorithm that finds Schmidt number witnesses tailored to the measurements available in specific experimental setups. We applied the algorithm to find a witness that requires the measurement of a number of density matrix elements that scales linearly with the local dimension of the system.



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Lorenzo Maccone

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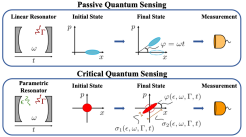
## Optimality and Noise-Resilience of Critical Quantum Sensing

U. Alushi, W Gorecki, S. Felicetti, R. Di Candia, arXiv:2402.15559




We compare critical quantum sensing to passive quantum strategies to perform frequency estimation, in the case of single-mode quadratic Hamiltonians. While in the unitary case both strategies achieve precision scaling quadratic with the number of photons, in the presence of dissipation this is true only for critical strategies. We also establish that working at the exceptional point or beyond threshold provides sub-optimal performance. When considering both time and system size as resources, for both strategies the precision scales linearly with the product of the total time and the number of photons. However, we show that critical protocols outperform optimal passive strategies if preparation and measurement times are not negligible.

## Mutual Information Bounded by Fisher Information

W. Gorecki, X. Lu, C. Macchiavello, L. Maccone arXiv:2403.10248

We derive a general upper bound to mutual information in terms of the Fisher information. The bound may be further used to derive a lower bound for Bayesian quadratic cost. These two provide alternatives to the Efroimovich and to the van Trees inequality that are useful also for classes of prior distributions where the latter ones give trivial bounds. We illustrate the usefulness of our bounds with a case study in quantum phase estimation. Here, they allow us to adapt to mutual information the known and highly nontrivial bounds for Fisher information in the presence of noise. This nicely complements quantum metrology, since Fisher information is useful to gauge local estimation strategies, whereas mutual information is useful for global strategies.

## How many bits does your quantum estimation return?

X. Lu, W. Gorecki, C. Macchiavello, L. Maccone arXiv:2403.17345

We give two upper bounds to the mutual information in arbitrary quantum estimation strategies. The first is based on some simple Fourier properties of the estimation apparatus. The second is derived using the first but, interestingly, depends only on the Fisher information of the parameter, so it is valid even beyond quantum estimation. We illustrate the usefulness of these bounds by characterizing the quantum phase estimation algorithm in the presence of noise. In addition, for the noiseless case, we extend the analysis beyond applying the bound and we discuss the optimal entangled and adaptive strategies, clarifying inaccuracies appearing on this topic in the literature

## Universal time scalings of sensitivity in Markovian quantum metrology

A. Das, W. Gorecki, R. Demkowicz-Dobrzanski, arXiv:2404.03954

Assuming a Markovian time evolution of a quantum sensing system, we provide a general characterization of the optimal sensitivity scalings with time, under the most general quantum control protocols. We allow the estimated parameter to influence both the Hamiltonian as well as the dissipative part of the quantum master equation. We focus on the asymptotic-time as well as the short-time sensitivity scalings, and investigate the relevant time scales on which the transition between the two regimes appears. This allows us to characterize, via simple algebraic conditions (in terms of the Hamiltonian, the jump operators as well as their parameter derivatives), the four classes of metrological models that represent: quadratic-linear, quadratic-quadratic, linear-linear and linear-quadratic time scalings. We also provide universal numerical methods to obtain quantitative bounds on sensitivity that are the tightest that exist in the literature.

## Quantum optical classifier with superexponential speedup

S. Roncallo, A. R. Morgillo, C. Macchiavello, L. Maccone, S. Lloyd arXiv:2404.15266

We present a quantum optical pattern recognition method for binary classification tasks. Without direct image reconstruction, it classifies an object in terms of the rate of two-photon coincidences at the output of a Hong-Ou-Mandel interferometer, where both the input and the classifier parameters are encoded into single-photon states. Our method exhibits the same behaviour of a classical neuron of unit depth. Once trained, it shows a constant O(1) complexity in the number of computational operations and photons required by a single classification. This is a superexponential advantage over a classical neuron (that is at least linear in the image resolution). We provide simulations and analytical comparisons with analogous neural network architectures.

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Gruppo IV
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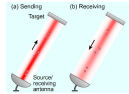
## Gaussian beam quantum radar protocol

L. Maccone, Y. Zheng, C. Ren, arXiv:2309.11834




We present an entangled quantum radar protocol. It consists in scanning the sky with a thin Gaussian beam and measuring the travel time of the radiation reflected from the target, as in conventional radars. Here the Gaussian beam is composed of N photons entangled in the frequency degrees of freedom. We show that this provides a √N quantum enhancement over the unentangled case, as is usual in quantum metrology.

## Quantum JPEG

S. Roncallo, L. Maccone, C. Macchiavello, AVS Quantum Sci. 5, 043803 (2023)

The joint photographic expert group algorithm compresses a digital image by filtering its high spatial-frequency components. Similarly, we introduce a quantum algorithm that uses the quantum Fourier transform to discard the high spatial-frequency qubits of an image, downsampling it to a lower resolution. This allows one to capture, compress, and send images even with limited quantum resources for storage and communication. We show under which conditions this protocol is advantageous with respect to its classical counterpart.

## A protocol for global multiphase estimation

G. Chesi, R. Rubboli, A. Riccardi, L. Maccone, C. Macchiavello, Phys. Rev. A 108, 012613 (2023)

We devise a global multiphase protocol based on Holevo's estimation theory and apply it to the case of digital estimation, i.e., we estimate the phases in terms of the mutual information between them and the corresponding estimators. Then we retrieve the ultimate digital bound on precision when a generic number of phases is simultaneously estimated. We show that in the multiphase strategy there is only a constant quantum advantage with respect to a sequence of independent single-phase estimations.

## Schrödinger cats and quantum complementarity

L. Maccone, Found. Phys. 54, 17 (2024)

We show that a Schrödinger cat has a well defined value of a property that is complementary to its "being dead or alive" property. Then, thanks to complementarity, it has an undefined value of the property "being dead or alive". In other words, the cat paradox is explained through quantum complementarity. We detail how to build an Arduino based simulation of Schrödinger's experiment based on these concepts for science outreach events.

## Tight Bounds from Multiple-Observable Entropic Uncertainty Relations,

A. Riccardi, G. Chesi, C. Macchiavello, L. Maccone, Ann Phys. 2400020 (2024)

The additivity properties for both bipartite and multipartite systems are investigated by using entropic uncertainty relations (EUR) defined in terms of the joint Shannon entropy of probabilities of local measurement outcomes. In particular, state-independent and state-dependent entropic inequalities are introduced. Interestingly, the violation of these inequalities is strictly connected with the presence of quantum correlations. It is shown that the additivity of EUR holds only for EUR that involve two observables, while this is not the case for inequalities that consider more than two observables or the addition of the von Neumann entropy of a subsystem. They are applied to bipartite systems and to several classes of states of a three-qubit system.

# GEOSYM_QFT

Linea 4

**Fondamenti & Metodi Matematici**

# Geometry and Symmetry in Quantum Field Theory
# Consuntivo PV 2023

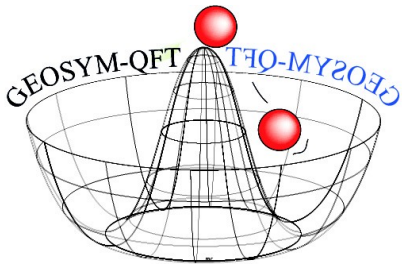
***Staff:***

**Mauro Carfora**
**Claudio Dappiaggi**
**Giancarlo Jug**
**Annalisa Marzuoli**
**Michele Schiavina**

**Francesca Familiari**
**(postdoc fino a 31/12/24)**

**Beatrice Costeri**
**(1° anno Dottorato in Fisica**

**Alberto Bonicelli**
**Luca Sinibaldi**
**(3° anno Dottorato in Fisica )**



## ➢ Algebraic and geometric methods in Quantum Field Theory

- **Algebraic Quantum Field Theory**

During 2023, we have investigated

- the existence of an interplay between the ***occurrence of IR divergences*** and the choice of suitable boundary conditions in the construction of ground and thermal states for a large class of quantum field theories living on curved spacetimes,
- the interplay between the choice of boundary conditions and the ***IR & UV behavior of the renormalization group flow*** for a large class of non-linear quantum field theories living on curved spacetimes.

1 paper published on PLB and 1 preprint (Dappiaggi & Sinibaldi)

## ➢ Algebraic and renormalization techniques in complex systems

- **Stochastic ordinary and partial differential equations**

During 2023, we have investigated

- the construction of the solutions of an arbitrary stochastic, ordinary differential equation using a path-integral formulation. This is known as ***Martin-Siggia-Rose correspondence*** which we have proven using algebraic techniques.
- the ***stochastic Thirring model*** for self-interacting Fermions in presence of an additive Gaussian white noise. Using algebraic techniques, we have constructed perturbatively the expectation value both of the solutions and of the associated correlation functions.
- The ***2D stochastic sine-Gordon equation*** proving convergence of the perturbative series encoding the information both of the solutions and of the correlation functions of the underlying model.

3 preprints (Bonicelli, Costeri, Dappiaggi)

- **Geometric analysis, mathematical cosmology and Ricci Flow**

✓ ***Cosmography and analysis of the physical past lightcone***. We have extended the analysis of the distance functional recently introduced by us for what concerns a detailed analysis of the observational past lightcone and a careful comparison with the standard Friedman-Lemaitre-Robinson-Walker model past lightcone.

1 paper and 1 preprint (M. Carfora and F. Familiari)

- **Topological Quantum Field Theories**

✓ We have studied a family of possibly ***non topological deformations of BF theory*** which is known as quadratically extended General Relativity (qeGR). We have shown in particular that it is classically equivalent to certain models of gravity with dynamical torsion.

3 preprints (Schiavina)

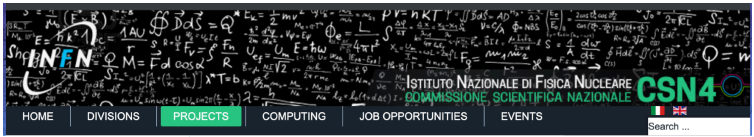
- **Topological structures in optical fields**

There have been proposed novel topological and geometrical characterizations to handle '***structured light***', namely optical fields with shaped spatial and temporal features –such as knotted and braided configurations- recently observed in experiments. (A Marzuoli and N Sanna)

# NINPHA

Linea 3

**Fisica Adronica e Nucleare**




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

## NINPHA

**N**ational **IN**itiative
in **P**hysics of **HA**drons

**Coordinatore nazionale**: F. Murgia (Cagliari)
**5 sedi**: Torino, Pavia, Genova, Perugia, Cagliari

**2023** performance: **27.4** FTE, **31** pubblicazioni, **64** talks, **21** tesi (undergr. & PhD)

## Pavia

**Coordinatore locale**: M. Radici

**INFN**

- M. Radici (Primo Ric.)

**Univ.**

- A. Bacchetta (P.O.), B. Pasquini (P.O.)
- L. Rossi, L. Polano, A. Alvaro (studenti Dottorato)
- M. Cerutti, S. Venturini (discussione tesi di Dottorato)
- F. Delcarro (assegnista dal 1 gennaio 2024)


## Main goal

Understand the mechanisms
of 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

**phenomenology**
extraction of TMDs (GPDs) from
(global) fits of exp. data

**properties**
evolution eqs., universality, etc..

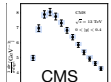
**modeling**
support to experiments

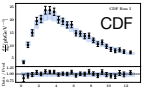
# NINPHA-PV at the forefront in many fields : examples

**phenomenology**

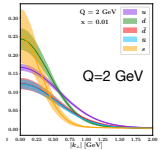
First extraction of TMD of unpolarized quark in proton including flavor sensitivity at top N$^3$LL accuracy from global fit of ~ 2K data from Drell-Yan, Z-boson production and SIDIS data

A. Bacchetta et al. (MAP Collaboration)
arXiv:2405.13833, submitted to JHEP



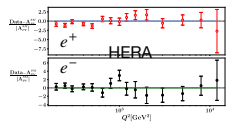


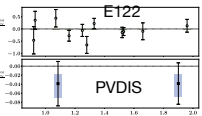



TMD($k_T$) at x=0.01 flavor tomography of the proton

Exploration of strong P-violation in inclusive DIS $\vec{e}\,p \to e'\,X$ process

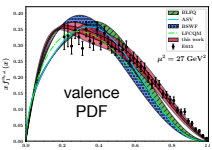
A. Bacchetta et al.
P.L. B849 (24) 138455, arXiv:2306.04704

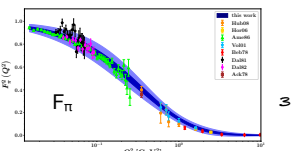



Light-front model calculation of pion PDFs and e.m. form factor $F_\pi$. Parameters fitted to $F_\pi$ data and to xFitter

B. Pasquini et al. (MAP Collaboration)
P.R. D 107 (23) 114023,
arXiv:2303.01789



# NINPHA-PV at the forefront in many fields : examples

## properties and exploratory studies

- Matching of twist-3 TMDs onto collinear PDFs for large $k_T$

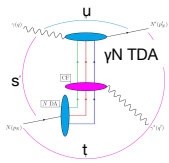
S. Rodini, A.C. Alvaro, B. Pasquini
P.L. B845 (23) 138163, arXiv:2306.15052

- formal analogies between di-hadron and hadron-in-jet fragmentation functions

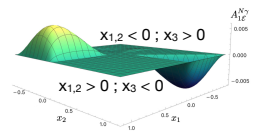
A. Bacchetta, M. Radici, L. Rossi
P.R. D 108 (23) 014005, arXiv:2303.04314

## modeling

- Light-front model of Transition Distribution Amplitudes (TDA) for Time-like Compton Scatt. in backward kinematics ($|u| \ll s, t$)



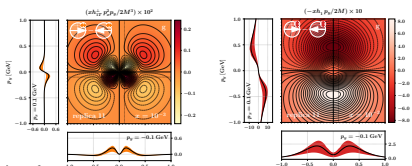

γ N -> γ* N'




one component of γN TDA($x_1$,$x_2$,$x_3$)

- First tomography of T-odd gluon TMDs in spectator model with mass spectral density, and applications to heavy-flavor production

A. Bacchetta, F.G. Celiberto, M. Radici
E.P.J. C in press, arXiv:2402.17556



For proton polarized along x, probability density of gluons linearly polarized along x and along y

# Also...

- **prominent role in EIC Users Group structure:**

- M.Radici: Chair of the Steering Committee (from 01-06-2023, formerly Vice-Chair), member of the Council Board, of the Charter Committee; convener of SIDIS WG in ePIC Collab. (till 04-2023)
- A.Bacchetta: convener of the EICUG Theory Working Group

- **and in other structures:**

- B. Pasquini: member of Scientific Board ECT*, member of IAC, CFNS (Stony Brook-US), Co-Director of ILCAC
- A. Bacchetta: member of PAC at JLab

- **various memberships** in IAC and Organiz. Committees of international conferences, Editorial Boards of refereed journals, Committees in selection procedures

- **M. Cerutti**: joint post-doc position at JLab - Hampton Univ. (Virginia - USA)

- **outreach:**

- M.Radici: local coordinator of INFN CC3M-Asimov; member of Scientific Committee Premio Asimov 2023; co-organizer of Premio Asimov 2023 - Lombardia
- various seminars and lectures by all members

**Other funds**

- Strong2020 (extended to 2024) A. Bacchetta spokesperson of WP22 “TMD-next”
  B. Pasquini local coordinator of WP22 “TMD-next”

- PRIN2022 “Proto-Taste” (from 01-09-2023) A. Bacchetta P.I.

IAC: International Advisory Commitee, Center for Frontiers in Nuclear Sciences (CFNS), Stony Brook

ILCAC: International Light-Cone Advisory Commitee

PAC: Program Advisory Committee, JLAB

# QFT@COLLIDERS

Linea 2

**Fenomenologia delle particelle elementari**

# QFT@COLLIDERS

**Responsabile nazionale:** Gian Paolo Vacca (BO)
**Responsabile locale:** C.M. Carloni Calame

**Nodi:** BO, CS, FI, MIB, PV

**Partecipanti 2023:**
E. Budassi (dottorando)
C.M. Carloni Calame (70%)
M. Chiesa (85%)
Clara L. Del Pio (dottoranda)
A. Gurgone (dottorando)
G. Montagna (90%)
M. Moretti (FE)
O. Nicrosini (50%)
F. Piccinini (85%)
F.P. Ucci (laureando/dottorando)

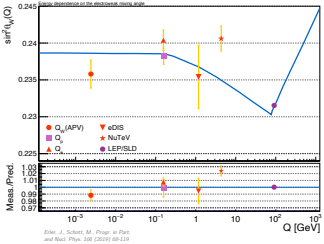
**Totale: 8.8 FTE**

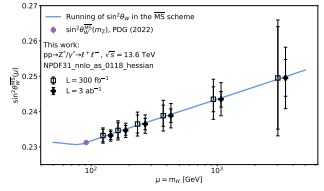
**Collaborazioni:**
G. Abbiendi (BO)
A. Denig (Mainz)
U. Marconi (BO)
P. Nason (MIB)
M. Passera (PD)
A. Signer (PSI)
G. Venanzoni (PI)
A. Vicini (Milano) *e molte altre...*

**Keywords:** Monte Carlo generators, NLO/NNLO QCD & EWK calculations, perturbative resummation, QCD in the high energy limit, phenomenology of the SM and BSM

# LHC physics

High-precision Monte Carlo event generator for Drell-Yan
`Z_ew-BMNNPV` code available at `https://powhegbox.mib.infn.it/`




- Implementation of $\overline{\text{MS}}$ scheme and $\sin^{\overline{\text{MS}}}_{\theta}$ sensitivity study at the LHC and HL-LHC

  Published in S. Amoroso, M. Chiesa, C. L. Del Pio, K. Lipka, F. Piccinini, F. Vazzoler and A. Vicini, Phys. Lett. B **844** (2023), 138103

- New code release

- Assessment of the theory uncertainties in the electroweak calculation in the context of the $\sin^{\text{eff}}_{\theta}$ measurement at the LHC

  M. Chiesa, C. L. Del Pio and F. Piccinini,arXiv:2402.14659

# Future colliders

- Contribution to the ECFA workshops on Higgs / Top / EW factories

J. de Blas, P. Koppenburg, J. List, F. Maltoni, J. A. Maestre, J. Alimena, J. Alison, P. Azzi, P. Azzurri and E. Bagnaschi, *et al.* "Focus topics for the ECFA study on Higgs / Top / EW factories," arXiv:2401.07564

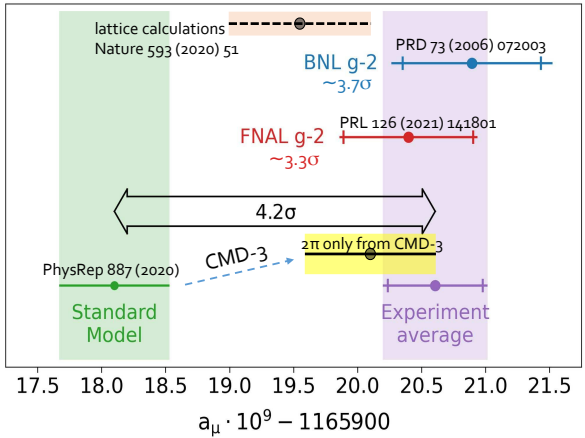
- Contribution to the studies on the physics case of a high-energy $\mu$ collider

C. Accettura, D. Adams, R. Agarwal, C. Ahdida, C. Aimè, N. Amapane, D. Amorim, P. Andreetto, F. Anulli and R. Appleby, *et al.* "Towards a muon collider," Eur. Phys. J. C **83** (2023) no.9, 864

# MUonE

- $|a_\mu^{\text{SM, } e^+e^- \text{ data}} - a_\mu^{\text{exp}}| \simeq 4.2\sigma$
- $|a_\mu^{\text{SM, lattice QCD}} - a_\mu^{\text{exp}}| \simeq 1.5\sigma$
- $|a_\mu^{\text{SM, new CMD3 } \pi^+\pi^- \text{ data}} - a_\mu^{\text{exp}}| < 1\sigma$

✓ MUonE can shed light over this cumbersome picture, by providing an independent determination of $a_\mu^{\text{HLO}}$ with space-like data, *i.e.* by a high precision measurement of $\Delta\alpha_{\text{had}}(q^2)$ in $\mu e \to \mu e$ scattering



# MUonE

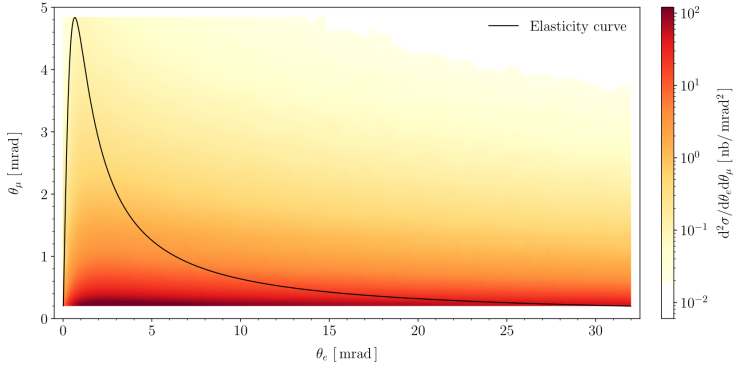
- The Pavia HEP group is among the proponents of the experiment
- By scattering $160$ GeV muons on at-rest electrons of a low-$Z$ target, $\Delta\alpha_{\text{had}}(q^2)$ can be measured and a **new** and **independent** evaluation of $a_\mu^{\text{HLO}}$ can be provided
- **A *test run* with reduced apparatus completed in August/September 2023**
- The challenge is to measure the elastic $\mu e \to \mu e$ differential cross section with an unprecedented accuracy, at the $10^{-5}$ level
- A high-precision Monte Carlo generator, including EWK NLO, QED NNLO and QED higher-order corrections, is mandatory for data analysis.
  Also relevant backgrounds need to be precisely simulated, e.g. $\boldsymbol{\mu^\pm N \to \mu^\pm N\, \ell^+\ell^-}$.

  The generator **Mesmer** is under constant development in Pavia and it is extensively used by the collaboration for feasibility studies and current simulations

  **github.com/cm-cc/mesmer**

Abbiendi, Budassi, CC, Gurgone, Piccinini, PLB 854 (2024) 138720

## Numerical results for $\mu^+ C \to \mu^+ C\, e^+ e^-$ (3)






- Further on-going work: implementation of the process $e^+e^- \to \pi^+\pi^-$ in **BabaYaga@NLO**, including $F_\pi(q^2)$ and dispersive approach in NLO box diagrams.

# QFT@COLLIDERS

- ✓ Articoli e preprint
  - ⇝ Abbiendi *et al.*, “Lepton pair production in muon-nucleus scattering”, Phys. Lett. B 854 (2024) 138720
  - ⇝ Chiesa, Del Pio, Piccinini, “On electroweak corrections to neutral current Drell-Yan with the POWHEG BOX”, arXiv:2402.14659
  - ⇝ de Blas *et al.*, “Focus topics for the ECFA study on Higgs/Top/EW factories”, arXiv:2401.07564
  - ⇝ Accettura *et al.*, “Towards a muon collider”, Eur. Phys. J. C 83 (2023) 9, 864
  - ⇝ P. Banerjee *et al.*, “High-precision muon decay predictions for ALP searches”, SciPost Phys. 15 (2023) 021
  - ⇝ Amoroso *et al.*, “Probing the weak mixing angle at high energies at the LHC and HL-LHC”, Phys. Lett. B 844 (2023) 138103
  - ⇝ “Proposal for phase 1 of the MUonE experiment”, CERN-SPSC-2024-015; SPSC-P-370
  - ⇝ diversi atti di conferenze/workshop internazionali
- ✓ Attività di coordinamento e organizzative
  - ⇝ Chiesa, co-convener della sessione “Frontiera dell’Energia” alla conferenza “Incontri di Fisica delle Alte Energie - IFAE 2023”, 12-14 aprile 2023, Catania
  - ⇝ Piccinini, co-convener dell’ECFA WG2 (Physics and Analysis Methods) dell’ECFA “Study on Physics, Experiments and Detectors at a future Higgs/EW/Top factory”
  - ⇝ Piccinini, co-convener del gruppo “Drell-Yan physics and EW precision measurements” dell’LHC EWWG
  - ⇝ Piccinini, co-organizzatore del “XXXVII Convegno Nazionale di Fisica Teorica - New Frontiers in Theoretical Physics”, 27-29 settembre 2023, Cortona
- ✓ Several talks at international conferences, workshops and collaboration meetings by all the members
- ✓ PRIN 2022 funds: Piccinini P.I. of MUS4GM2, Chiesa member of “High precision LHC phenomenology. . . ”

# Attività M. Roncadelli

Linea 5

**Fisica Astroparticellare**

ELENCO DELLE PUBBLICAZIONI

G. Galanti, L. Nava, M. Roncadelli, F. Tavecchio and G. Bonnoli, *Observability of the very-high-energy emission from GRB 221009A*, Phys. Rev. Lett. **131**, 251001 (2023).

G. Galanti, M. Roncadelli, F. Tavecchio and E. Costa, *ALP induced polarization effects on photons from galaxy clusters*, Phys. Rev. D **107**, 103007 (2023).

G. Galanti, M. Roncadelli and F. Tavecchio, *ALP induced polarization effects on photons from blazars*, Phys. Rev. D **108**, 083017 (2023).

M. Roncadelli and G. Galanti, *New strong constraints on the central behaviour of spherical galactic models*, Astronomy **2**, 193 (2023).

M. Roncadelli, *Axion-like Particles and their role in High-Energy Gamma-Ray Astronomy*, Mem. S. A. It. **75**, 282 (2023).

- Comunicato stampa INFN-INAF

4) Sto terminando il libro Dark Matter in Astrophysics and Cosmology ISBN 978-0- 521-86447-3, che sarà pubblicato dalla Cambridge University Press. L'esistenza della materia e dell'energia oscura pone una sfida scientifica fondamentale. Quantunque esistano diversi libri divulgativi su questo argomento, non esiste alcun libro che lo tratti in modo tecnico ed interamente dedicato ad esso. Il mio libro vorrebbe essere il primo in questo senso. Suppongo che il lettore sia laureato in fisica ma che ignori qualunque nozione di astrofisica e di cosmologia. Il libro è diviso in due parti. Nella prima descrivo tutti gli strumenti concettuali e matematici necessari per comprendere l'interpretazione dei risultati — riportati nella seconda parte — delle osservazioni che quantificano la materia e l'energia oscura, dalla scala delle galassie nane all'intero universo. Stimo che il numero totale di pagine sia circa 700.

# Econofisica

# Econofisica

Physica A 622 (2023) 128886

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## Modeling and simulation of financial returns under non-Gaussian distributions

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[a] Dipartimento di Fisica, Università degli Studi di Pavia, Via A. Bassi 6, 27100, Pavia, Italy
[b] Istituto Nazionale di Fisica Nucleare, Sezione di Pavia, Via A. Bassi 6, 27100, Pavia, Italy
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Econophysics
Financial returns
Heavy-tailed distributions
Stochastic processes
Monte Carlo Simulations
Option pricing

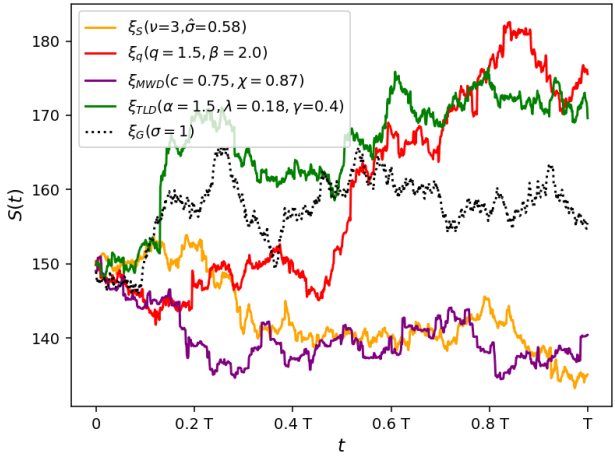
ABSTRACT

It is well known that the probability distribution of high-frequency financial returns is characterized by a leptokurtic, heavy-tailed shape. This behavior undermines the typical assumption of Gaussian log-returns behind the standard approach to risk management and option pricing. Yet, there is no consensus on what class of probability distributions should be adopted to describe financial returns and different models used in the literature have demonstrated, to varying extent, an ability to reproduce empirically observed stylized facts. In order to provide some clarity, in this paper we perform a thorough study of the most popular models of return distributions as obtained in the empirical analyses of high-frequency financial data. We compare the statistical properties and simulate the dynamics of non-Gaussian financial fluctuations by means of Monte Carlo sampling from the different models in terms of realistic tail exponents. Our findings show a noticeable consistency between the considered return distributions in the modeling of the scaling properties of large price changes. We also discuss the convergence rate to the asymptotic distributions of the non-Gaussian stochastic processes and we study, as a first example of possible applications, the impact of our results on option pricing in comparison with the standard Black and Scholes approach.



De Domenico, Livan, Montagna, Nicrosini, Physica A 622 (2023) 128886

+ Ricciardi, Montagna, Caldarelli, Cimini, “Dimensional reduction of solvency contagion dynamics on financial networks”, Physica A 630 (2023) 129287




De Domenico, Livan, Montagna, Nicrosini, Physica A 622 (2023) 128886