Consuntivi Scientifici 2021 Gruppo IV

Guido Montagna

Consiglio di Sezione
15 giugno 2022

Linee Scientifiche CSN4

Linea 1 Teoria dei Campi e Stringhe

Linea 2 Fenomenologia delle Particelle Elementari

Linea 3 Fisica Nucleare e Adronica

Linea 4 Metodi Matematici

Linea 5 Fisica Astroparticellare

Linea 6 Fisica Statistica e Teoria dei Campi Applicata

Iniziative Specifiche 2020

Nuova configurazione 2021/2023

BELL [4]	**R.L.** P. Perinotti	**R.N.** A. Bassi (TS)
GEOSYM_QFT [4]	**R.L.** A. Marzuoli	**R.N.** A. Marzuoli (PV)
NINPHA [3]	**R.L.** M. Radici	**R.N.** M. Boglione (TO)
QFT@COLLIDERS [2]	**R.L.** C.M. Carloni Calame	**R.N.** G. Vacca (BO)
TAsP [5]	**R.L.** M. Roncadelli	**R.N.** F. Donato (TO)

Linea 2

QFT@COLLIDERS

QFT@Colliders

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

Partecipanti 2021:
E. Budassi (dottorando)
C.M. Carloni Calame (70%)
M. Chiesa (85%)
Clara L. Del Pio (dottoranda)
A. Gurgone (dottorando, dall'autunno 2021)
G. Montagna (90%)
M. Moretti (FE)
O. Nicrosini (50%)
F. Piccinini (85%)
M. Syed Hasan (post-doc)

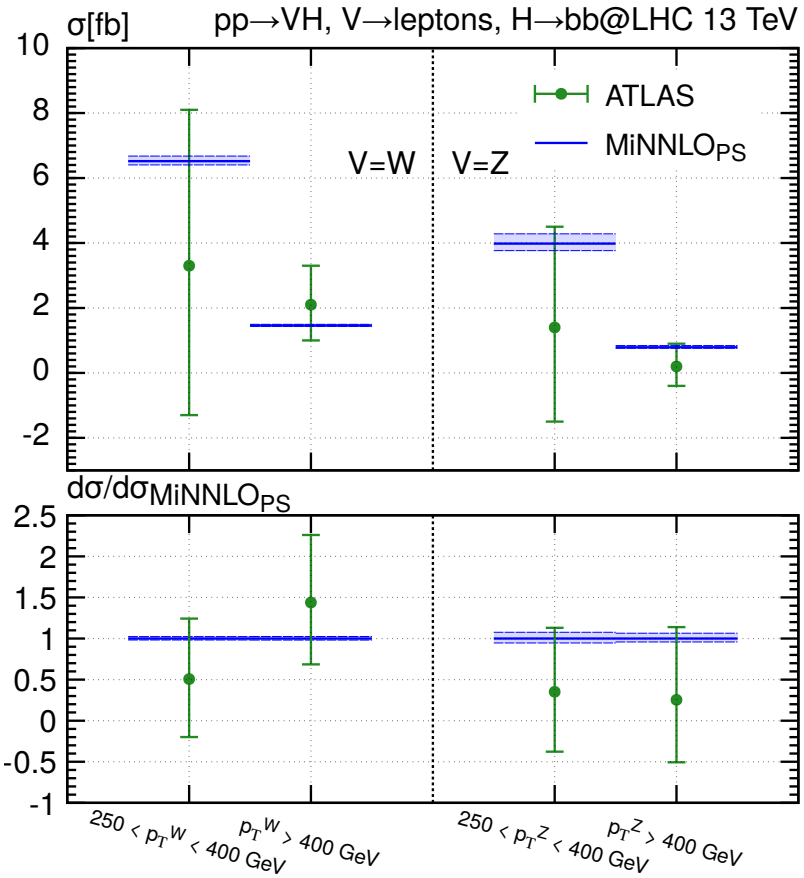
Collaborazioni:
G. Abbiendi (BO)
A. Denig (Mainz)
U. Marconi (BO)
P. Nason (MIB)
M. Passera (PD)
A. Polosa (Sapienza)
A. Signer (PSI)
R. Tenchini (PI)
G. Venanzoni (PI)
A. Vicini (Milano) *e molte altre...*

Nodi: BO, CS, FI, MIB, PV

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

- **Higgsstrahlung at NNLO with $H \to b\bar{b}$ with MINNLO$_{\text{PS}}$**

Zanoli, Chiesa, Re, Wiesemann, Zanderighi, `arXiv:2112.04168`



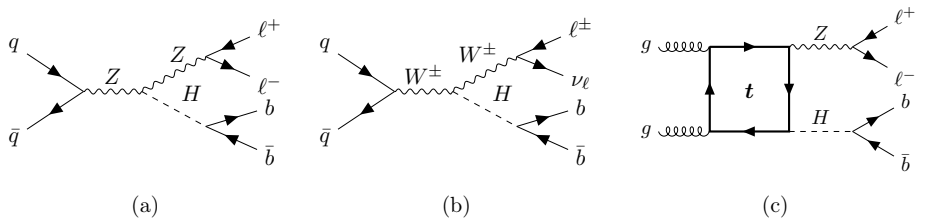


Figure 1: Sample Feynman diagrams for VH production in the $H \to b\bar{b}$ decay channel with (a,c) $V = Z$ and $Z \to \ell^+\ell^-$ and (b) $V = W^\pm$ and $W^\pm \to \ell^\pm\nu_\ell$. Panels (a) and (b) are tree-level diagrams in the quark-annihilation ($q\bar{q}$) channel at LO, while panel (c) shows a loop-induced diagram in the gluon-fusion (gg) channel entering at NNLO QCD.

- ⇝ Full predictions for ZH and $W^\pm H$ with $H \to b\bar{b}$ including spin correlations and off-shell effects
- ⇝ Accuracy at NNLO+PS in production and decay achieved for the first time
- ⇝ Good agreement with recent Higgsstrahlung cross section measurements

- Constant participation to the subgroup "Drell-Yan physics and EW precision measurements" of the LHC EWWG, with particular contribution in the $\sin\theta_W$ measurement

- **Physics at muon collider**

Chiesa, Mele, Piccinini

"Multi Higgs production via photon fusion at future multi-TeV muon colliders", arXiv:2109.10109

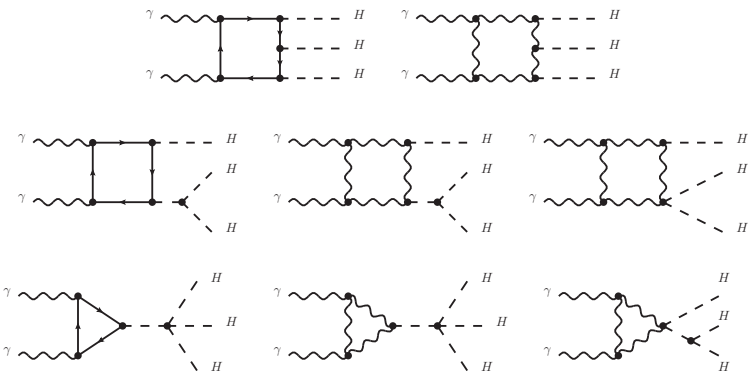
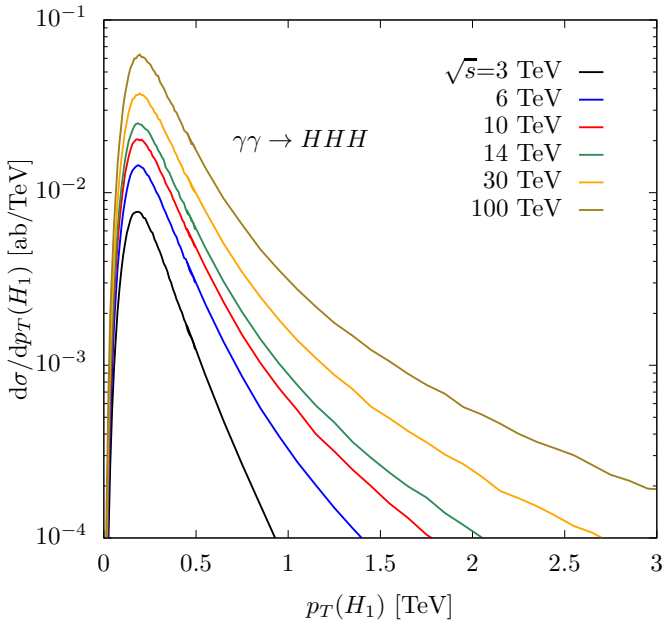
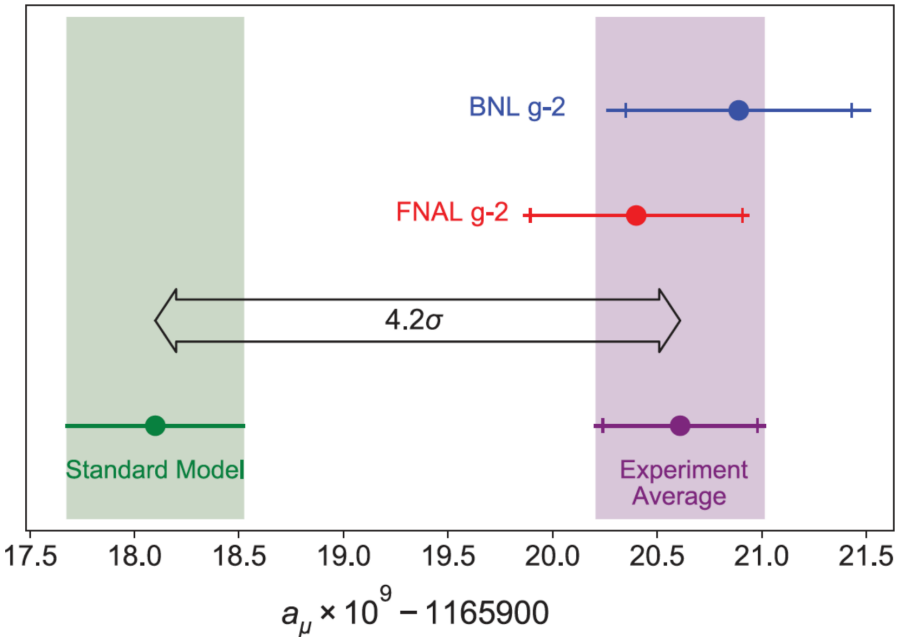


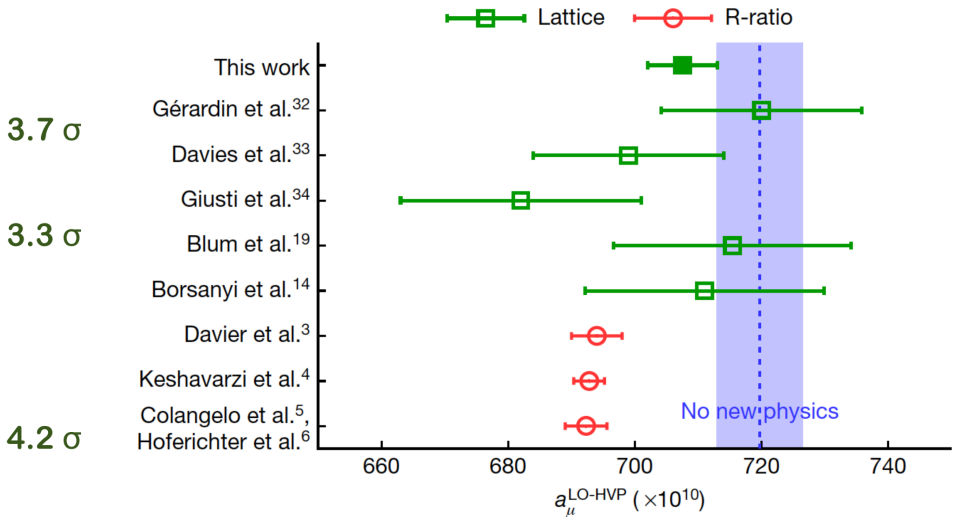
FIG. 3. Representative Feynman diagrams contributing to the process $\gamma\gamma \to HHH$, involving top-quark and W-boson loops.



- ⇝ loop suppressed single-, double- and triple-Higgs production via $\mu^+\mu^- \to \mu^+\mu^-\gamma^\star\gamma^\star \to \mu^+\mu^-[H, HH, HHH]$ in the SM, compared to $V^\star V^\star \to H, HH, HHH$ background
- ⇝ calculation performed in the "equivalent photon approximation"
- ⇝ unique enviroment to study multi-Higgs production in $\gamma\gamma$ collisions

Anomalous magnetic moment of the muon





BMW lattice collaboration, Nature 2021

- A 4.2σ discrepancy between a_μ^{exp} and $a_\mu^{\text{th, SM}}$ persists after the 2021 FNAL number. The theory uncertainty is dominated by the error on the hadronic contribution a_μ^{HLO}.
- A tension exists also between $a_\mu^{\text{th, SM}}$ and the "most aggressive" lattice evaluation by the BMW collaboration.

T. Aoyama, *et al.*
"The anomalous magnetic moment of the muon in the Standard Model",
Phys. Rept. **887** (2020), 1-166

Anomalous magnetic moment of the muon - The **MUonE** experiment

- The **MUonE** experiment will start to perform a ***test run*** in a few days

  MUonE coll., Letter of Intent, CERN-SPSC-2019-026 / SPSC-I-252 (2019)

- The experiment aims at a high-precision measurement of the hadronic contribution to the running of $\alpha_{\text{QED}}(t)$ in the space-like region, by means of 160 GeV muons scattering off electrons in a fixed target
- The measurement can be used for a new and independent determination of a_μ^{HLO}

  and data point can be in principle compared to lattice data

- In order to be competitive, a challenging $\mathcal{O}(10^{-5})$ theoretical and experimental accuracy must be achieved
- A high-precision Monte Carlo generator, including EWK NLO, QED NNLO and QED higher-order corrections, is mandatory for data analysis.

  The generator `Mesmer` is under heavy development in Pavia and it is already used by the collaboration for feasibility studies and current simulations

⋆ In 2021 we considered virtual and real leptonic corrections at NNLO. Real corrections are a potentially a large background to the signal.

Budassi, Carloni Calame, Chiesa, Del Pio, Hasan, Montagna, Nicrosini, Piccinini
"NNLO virtual and real leptonic corrections to muon-electron scattering"
JHEP 11 (2021) 098

Organization/coordination activity and papers

- ⋆ Several talks at international workshops and conferences

⇝ Carloni Calame, co-organizer of the topical workshop "The Evaluation of the Leading Hadronic Contribution to the Muon g-2: Toward the MUonE Experiment", MITP, Mainz, postponed to November 2022 due to the pandemic

⇝ Piccinini, co-convener of the subgroup "Drell-Yan physics and EW precision measurements" of the LHC EWWG

⇝ Piccinini, co-convener of the ECFA Working Group 2 (Physics Analysis Methods)

1. NNLO virtual and real leptonic corrections to muon-electron scattering
   Budassi, Carloni Calame, Chiesa, Del Pio, Hasan, Montagna, Nicrosini, Piccinini, JHEP 11 (2021) 098
2. Towards NNLO corrections to muon-electron scattering
   Hasan, contribution to Radcor and LoopFest 2021 proceedings
3. Vector boson scattering processes: Status and prospects
   . . . , Chiesa, . . . , Rev. Phys. 8 (2022) 100071, `arXiv:2106.01393`
4. Multi Higgs production via photon fusion at future multi-TeV muon colliders
   Chiesa, Mele, Piccinini, `arXiv:2109.10109`
5. Next-to-next-to-leading order event generation for VH production with $H \to b\bar{b}$ decay
   Zanoli, Chiesa, Re, Wiesemann, Zanderighi, `arXiv:2112.04168`

Linea 3

NINPHA

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

4 iniziative specifiche
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NINPHA

National INitiative in Physics of HAdrons

Coordinatore nazionale: M. Boglione (Torino)
5 sedi: Torino, Pavia, Genova, Perugia, Cagliari
2021 performance: ~**25** FTE, ~**48** pubblicazioni, **97** talks, **23** tesi (undergr. & PhD)

Pavia

Coordinatore locale: M. Radici

INFN

- M. Radici (Primo ric.)
- Y. Makris (borsa Fellini)

Univ.

- A. Bacchetta (P.O.), B. Pasquini (P.A.)
- A. Signori assegnista (borsa Marie-Curie internazionale)
- S. Rodini (assegnista poi postdoc a Regensburg)
- C. Bissolotti (co-fellow JLab EIC^2 center - Pavia, postdoc ad ANL dal 1-10-2021)
- M. Cerutti, S. Venturini, L. Rossi (studenti Dottorato)

Main goal

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

New tools :

- TMDs → 3D maps in mom. space
- GPDs → 3D maps in position space
- GTMDs (Wigner distrib.) → maximum info
- QCD Energy-momentum tensor $T^{\mu\nu}$ → N mass

phenomenology

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

properties

evolution eqs., universality, etc..
renormalisation, scheme dependence,
operator mixing, etc..

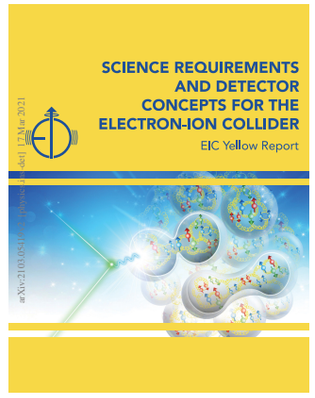
modeling

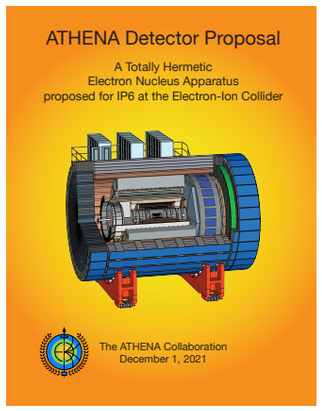
support to experiments

NINPHA-PV at the forefront in many fields : examples

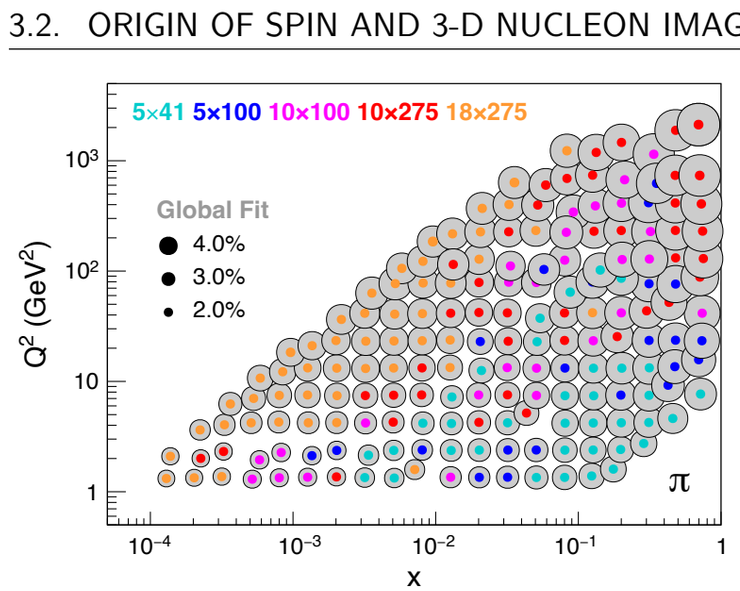
phenomenology

EIC Yellow Report:
902 pp., **415** authors, **121** institutions
M. Radici co-editor
B. Pasquini co-convener of Exclusive WG
arXiv:2103.05419, Nucl.Phys.A in press





EIC Detector proposal by the **ATHENA** Collab.
435 authors, **112** institutions
M. Radici co-convener of SIDIS WG
JINST in press

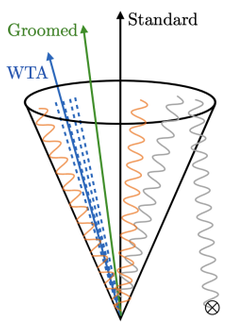


projected uncertainties for unpolarized SIDIS dσ at EIC kin. (colors) using Pavia unpolarized TMD $f_1(x,k_T;Q)$ (grey)

Also:

- impact of using e^+ beams in extracting N generalized polarizabilities in VCS, within studies of science program with e^+ beams at JLab

B. Pasquini and M. Vanderhaeghen, 2106.05683
also Accardi et al., E.P.J. A57 (21) 8



- new EIC-focussed definitions/algorithms for jets: grooming, jet substructure,..

Y. Makris et al. 2101.02708

- prospects about impact on gluon TMDs of quarkonium production at the LHC

Chapon, …, Makris, … et al., Prog.Part.Nucl.Phys. 122 (2022) 103906

NINPHA-PV at the forefront in many fields : examples

properties and exploratory studies

- Properties of the energy-momentum tensor $T^{\mu\nu}$ (renormalisation, scheme dependence, operator mixing, etc..):

  QED at one loop: gravitational form factors of the electron — A.Metz, B.Pasquini, S. Rodini, 2104.04207

  QCD: N mass decomposition and mechanical equilibrium — C.Lorcé, A.Metz, B.Pasquini, S.Rodini, 2109.11785

- studies on resummation scale dependences in PDF extractions — S.Bertone, G.Bozzi, F.Hautmann, arXiv:2202.03380

modeling

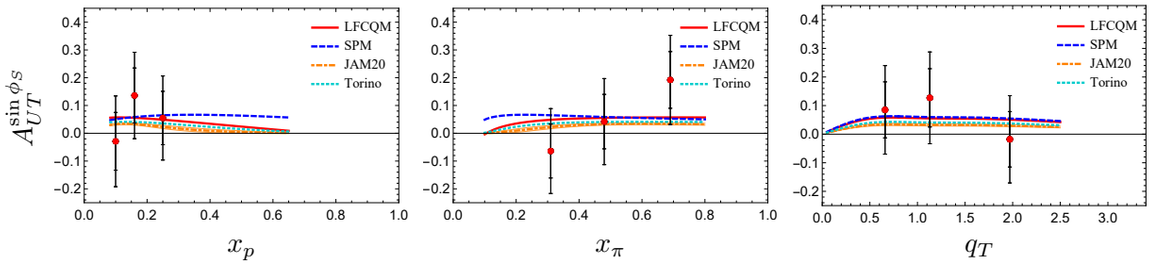


Figure 5. $A_{UT}^{\sin\phi}$ as a function of x_p (left), x_π (middle) and q_T (right) vs COMPASS data [46].

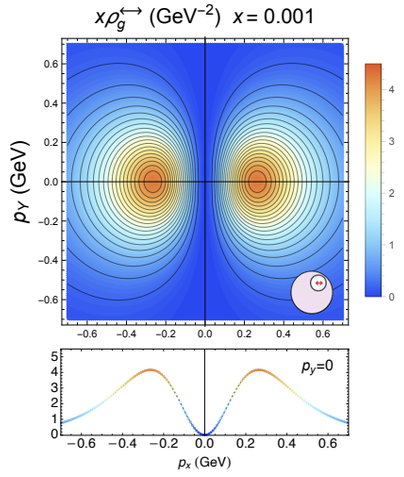
- Test models of Pion and Nucleon TMD using $\pi N^{\uparrow} \to \ell^+\ell^- + X$ Drell-Yan data from COMPASS

  S.Bastami et al., JHEP 02 (21) 166

- First tomography of T-odd gluon TMDs in spectator model with mass spectral density

  A.Bacchetta, F.G.Celiberto, M. Radici, 2111.01686

probability density of gluons linearly polarized in ⊥ plane in unpolarized proton



Also...

- **prominent role in EIC Users Group structure:**
  - M.Radici: Vice-Chair of the Steering Committee (till 01-08-2023), member of the Council Board and of the Charter Committee; co-editor of the EICUG Yellow Report; convener of the SIDIS WG in ATHENA Collaboration
  - B.Pasquini: convener of the EICUG Yellow Report Exclusive WG
  - A.Bacchetta: convener of the EICUG Theory WG; member of the JLab PAC

- **various memberships** in IAC, Editorial Boards of refereed journals, Committees in selection procedures

- F.G. Celiberto awarded JLab EIC center fellowship
- S. Rodini awarded “Sergio Fubini 2021” prize for his Ph.D. thesis

- **outreach:**
  - M.Radici: local coordinator of INFN CC3M-Asimov; member of Scientific Committee Premio Asimov 2021; co-organizer of Premio Asimov 2021 - Lombardia
  - F.G.Celiberto: member of the Scientific&Organizing Committee “Notte Europea dei Ricercatori 2021” and “Physics MasterClass 2021”
  - various seminars and lectures by all members

Other funds - Strong2020 A. Bacchetta spokesperson of WP22 “TMD-next”
B. Pasquini local coordinator of WP22 “TMD-next”

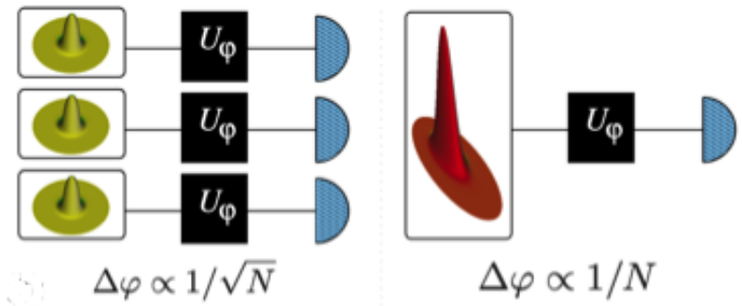
Linea 4

BELL

Lorenzo Maccone

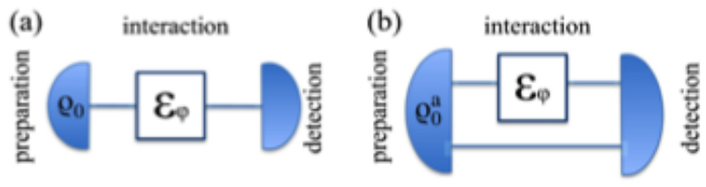
Gruppo IV
BELL

A unified framework for squeezing metrology



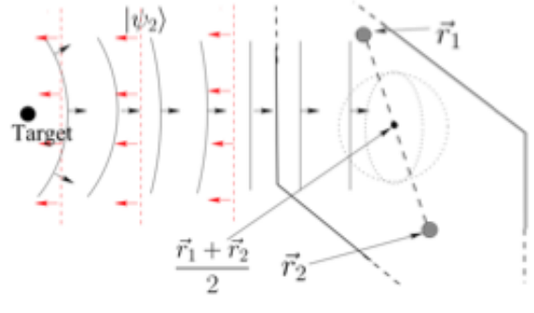
The theory of **quantum metrology** focused only on the gains obtained through entanglement, here we devised a general **theory** also **for squeezing**.

Entanglement-assisted Gaussian state phase estimation



We show that **entanglement-assisted scheme outperforms** coherent state interferometry for all levels of loss **in Gaussian state phase estimation**.

Quantum metrology: quantum radar



We introduce a protocol to **estimate** the **range** and **direction** of an uncooperative target **with quantum-metrological improved precision**.

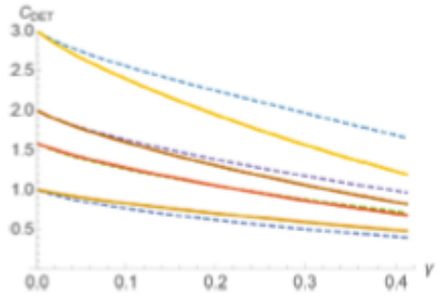
QUit
quantum information theory group

Chiara Macchiavello

Gruppo IV

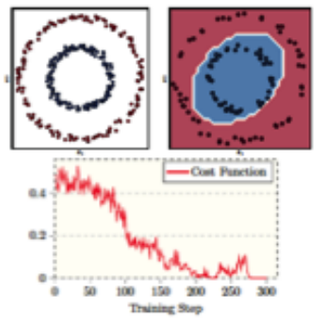
BELL

Detection of quantum channel capacities



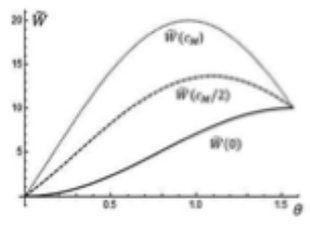
A recent method to **certify** the classical **capacity of quantum communication channels** is applied for general damping channels in finite dimension. We propose an **experimental** method to detect lower **bounds to the quantum capacity** of two-qubit channels, based on polarisation degrees of freedom of two photons.

Quantum computation and machine learning



We show how the **design** for the implementation of a previously introduced **quantum artificial neuron**, which fully exploits superposition states to encode binary valued input data, can be further generalized to accept **continuous**-instead of discrete-**valued input** vectors, without increasing the number of qubits.

Quantum thermodynamics



We study the **energy exchange between two bosonic systems** that interact via bilinear transformations in the mode operators, where the first mode is considered as the thermodynamic system, while the second is regarded as the bath.

QUit quantum information theory group

Paolo Perinotti

Gruppo IV

BELL

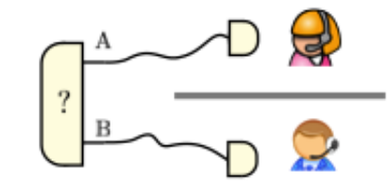
Shannon theory beyond quantum: Information content of a source

Published in Phys. Rev. A 105, 052222

The information content of a source is defined in terms of the minimum number of bits needed to store the output of the source in a perfectly recoverable way, and it is quantified through Shannon's entropy. Here we extend the definition of **information content** to **operational probabilistic theories**, and prove its subadditivity, as well as the relation between purity and information content of a state. A lower bound on the information content is derived in terms of the maximum **accessible information**.

Unambiguous discrimination of Fermionic states through local operations and classical communication

Published in Physical Review A 103, 012416 (2021)



Ψ or Φ ?

The paper studies **unambiguous discrimination of Fermionic states** through local operations and classical communication (LOCC). In the task of unambiguous discrimination, no error is tolerated but an inconclusive result is allowed. Contrarily to the quantum case, **it is not always possible** to distinguish two Fermionic states through LOCC unambiguously with the same success probability as if global measurements were allowed. Furthermore, we prove that **we can overcome such a limit through an ancillary system** made of two Fermionic modes, independently of the dimension of the system, prepared in a maximally entangled state: in this case, LOCC protocols achieve the optimal success probability.

QUIT quantum information theory group

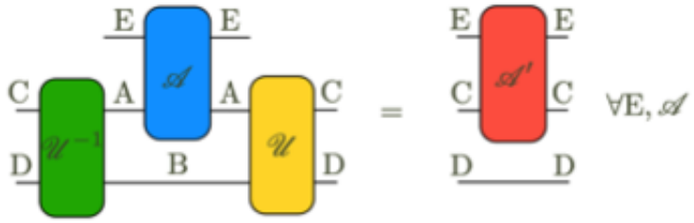
Paolo Perinotti

Gruppo IV
BELL

Causal influence in operational probabilistic theories

Published in Quantum 5, 515 (2021)

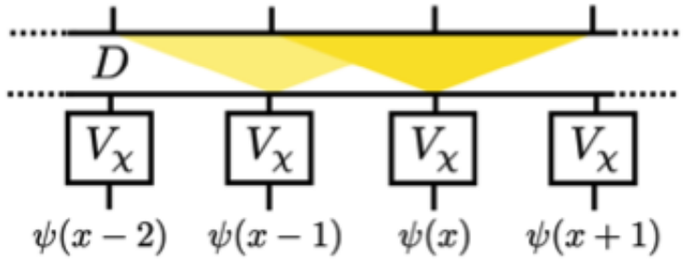
$$A \not\to D$$



We introduce the notion of **causal influence** and its **relation with** the usual property of **signalling**. We show that the two coincide in quanutm theory and in all theories with "no interaction without disturbance", while they differ in other theories, among which the theory of classical systems.

Scattering and perturbation theory for discrete-time dynamics

Published in Phys. Rev. Lett. 126, 250503 (2021)



We develop two **perturbative techniques** for the power series expansion of the scattering operator for quantum systems whose **time evolution is discrete**, the first one analogous to the iterative solution of the Lippmann-Schwinger equation, the second one to the Dyson series of perturbative Quantum Field Theory. This framework can be applied to a wide class of quantum simulators, like **quantum walks** and **quantum cellular automata**.

Oreste Nicrosini
Gruppo IV
BELL

Collapse dynamics and Hilbert-space stochastic processes

Published in Sci.Rep. 11 22179 (2021)

Spontaneous collapse models of state vector reduction represent a possible solution to the quantum measurement problem. In the present paper we focus our attention on the Ghirardi-Rimini-Weber (GRW) theory and the corresponding continuous localisation models in the form of a Brownian-driven motion in Hilbert space. We consider experimental setups in which a **single photon hits a beam splitter and is subsequently detected** by photon detector(s), generating a superposition of photon-detector quantum states. Through a numerical approach we study the dependence of collapse times on the physical features of the superposition generated, including also the effect of a finite reaction time of the measuring apparatus. We find that **collapse dynamics is sensitive to the number of detectors and the physical properties of the photon-detector quantum states superposition**.

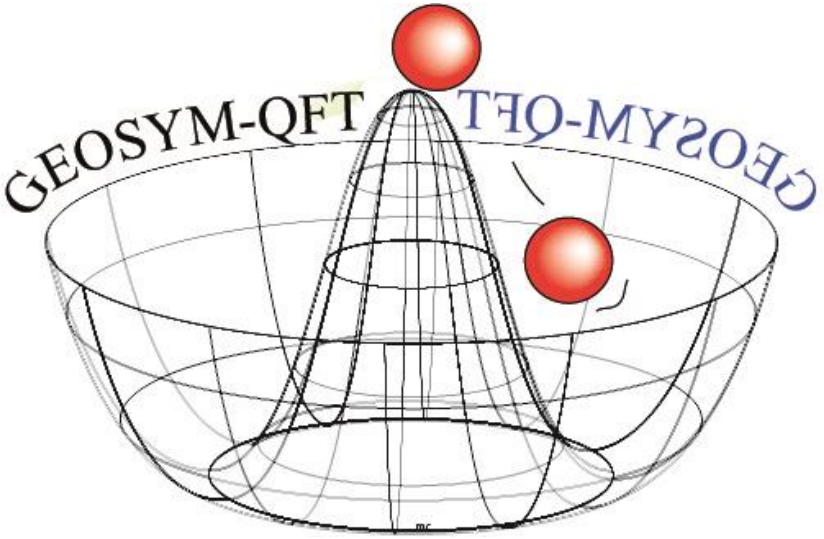
Linea 4

GEOSYM_QFT

Geometry and Symmetry in Quantum Field Theory
Consuntivo 2021

Staff:

Mauro Carfora
Claudio Dappiaggi
Giancarlo Jug
Annalisa Marzuoli



Dottorandi:

Lissa de Sousa Campos (3°)
(postdoc since 2022)
Francesca Familiari (2°)
Paolo Rinaldi (3°)
Federico Sclavi (2°)
Alberto Bonicelli (1°)

- Algebraic, topological and geometrical methods in Quantum Field Theory and Relativistic Cosmology
- Applications to condensed matter systems and optics

- **Algebraic Quantum Field Theory**

We have focused our attention on several problems. On the one hand we have shown how to implement generalized boundary conditions for quantum fields living on Lifshitz spacetimes. On the other hand, we have continued our efforts aimed at investigating how to apply microlocal techniques to the analysis of stochastic PDEs. Moreover, we have investigated the large time behaviour of Unruh-de Witt detectors in presence of thermal states for the underlying quantum field on a generic black hole spacetime as well as applications of the algebraic quantum field theory framework to the study of hyperbolic, stochastic partial differential equations, extending our results obtained for elliptic and parabolic SPDEs.

Algebraic Quantum Field Theory

PREPRINT 2021-22

- C. Dappiaggi, P. Rinaldi and F. Sclavi,
  ``On a Microlocal Version of Young's Product Theorem``
  [arXiv:2104.12423 [math-ph]].

- C. Dappiaggi, N. Drago, P. Rinaldi and L. Zambotti,
  ``A Microlocal Approach to Renormalization in Stochastic PDEs,''
  to appear on Communications in Contemporary Mathematics 2021

- C. Dappiaggi, B. A. Juàrez-Aubry and A. Marta,
  ``Ground State for the Klein-Gordon field in anti-de Sitter spacetime with dynamical Wentzell boundary conditions,''
  [arXiv:2203.04811 [hep-th]].

- A. Bonicelli, C. Dappiaggi and P. Rinaldi,
  ``An Algebraic and Microlocal Approach to the Stochastic Non-linear Schr odinger Equation,''
  [arXiv:2111.06320 [math-ph]].

- C. Dappiaggi, F. Finster and M. Oppio,
  ``Linear Bosonic Quantum Field Theories Arising from Causal Variational Principles,''
  Lett. Math. Phys. **112** (2022), 38
  [arXiv:2112.10656 [math-ph]].

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

✓ 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.

Cf. M Carfora, F Familiari "A distance functional between lightcones and precision cosmography" , arXiv:210112698

✓ Applications of the Ricci-Perelman flow in General Relativity

Cf. M Carfora, A Marzuoli "Einstein Constraints and Ricci Flow" (Springer Briefs in Mathematical Physics, to appear)

- **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, in preparation)

- **Theory and phenomenology of amorphous solids**

Research work has been carried out along two directions: 1) The theoretical analysis of experimental data of the magnetization of glasses to extract the intrinsic magnetization due to the vitreous heterogeneous structure itself. 2) The development of a topological theory for the melting of glasses, based on the established heterogeneous structure.

G Jug, S Recchia "A new phenomenon: glass paramagnetism-Further experimental and theoretical details" arXiv: 2111.12644

G Jug, S Recchia "Revealing the intrinsic magnetism of non-magnetic glasses" arXiv: 2111.00614

Linea 5

TAsP

TaSP – Pavia – ATTIVITÀ 2021

Marco Roncadelli

INFN – Pavia

COMPOSIZIONE DEL GRUPPO

Marco Roncadelli, INFN (PV), primo ricercatore, FTE = 1.

Andrea De Luca, IASF-INAF (MI), ricercatore, docente a contratto Università di PV, FTE = 0.5.

Andrea Tiengo, IUSS-INAF (PV), responsabile locale, ricercatore, docente a contratto Università di PV, FTE = 0.5.

Attività di M. Roncadelli

E' continuata l'analisi delle implicazioni delle axion-like particle (ALPs) per l'astrofisica delle alte energie. In collaborazione con il gruppo di fisica fondamentale del Cherenkov Telescope Array (CTA) di cui faccio parte, ho studiato la possibilita' di effettuare osservazioni indirette delle ALP mediante il CTA.
Ho studiato in collaborazione con G. Galanti il comportamento centrale di molti modelli galattici a simmetria sferica. Abbiamo scoperto che i modelli di Jaffe e di Hernquist – usualmente impiegati per descrivere le galassie ellittiche – non possono essere usati per distanze galattocentriche inferiori a circa 0.2 raggi efficaci. Inoltre abbiamo dimostrato che il famoso modello di Navarro-Frenk-White (NFW) – tipicamente usato per descrivere gli aloni oscuri delle galassie e degli ammassi – perde validità nella regione centrale, in quanto nel centro il campo gravitazionale è non nullo.

Attività di A. De Luca e A. Tiengo

La loro attività principale riguarda il progetto EXTraS (Exploring the X-ray Transient and variable Sky), finanziato dalla comunità europea nell'ambito di FP7-SPACE ed avente come *principal investigator* A. De Luca. Il suo fine è estrarre sistematicamente e caratterizzare temporalmente le proprietà di circa 650,000 sorgenti di raggi X osservati dal satellite XMM-Newton dell'ESA. L'analisi dei risultati è ancora in corso. L'attenzione è focalizzata su diversi casi scientifici, dalla ricerca di rari eventi astrofisici allo studio sistematico delle proprietà di differenti classi di sorgenti.
Due fra i risultati più importanti che hanno ottenuto sono i seguenti.

- Sviluppo di nuovi algoritmi finalizzati ad effettuare tutti gli step dell'analisi dati di EXTraS, includenti la preparazione dei dati di XMM/EPIC, la modellizzazione delle sorgenti e del fondo, la generazione di serie temporali e spettri di potenza, la ricerca e la caratterizzazione di differenti tipi di sorgenti variabili. Sono stati anche descritti i risultati e vengono date informazioni sulle loro fondamentali proprietà statistiche e consigli sul sul loro uso. Infatti il database dei risultati di EXTraS ed i suoi prodotti accessori costituiscono una ricca risorsa per ogni tipo di analisi in quasi tutti i campi dell'astrofisica.

- Una nuova osservazione del “supergiant fast X-ray transient (SFXT) IGR J08408-4503” è stata effettuata nel giugno del 2020. La sorgente è composta da un oggetto compatto (probabilmente una stella di neutroni) che orbita intorno una stella di tipo O8.5Ib-II(f)p. La curva di luce in raggi X mostra un livello molto basso di emissione, punteggiata da singoli deboli bagliori (flare). In questo stato di emissione molto basso ($(4.8 \pm 1.4)\, 10^{31}\, \mathrm{erg\, s^{-1}}$) l’emissione X dal vento della stella di tipo O8.5Ib-II(f)p può essere studiata in dettaglio per la prima volta, insieme ad un livello molto basso di accrescimento sull’oggetto compatto.