

Consiglio di Sezione INFN Pavia

7-8 Maggio 2018

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



QFT@COLLIDERS

Responsabile nazionale: F. Piccinini

Responsabile locale: O. Nicrosini

Partecipanti 2017(2018)

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

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

Collaboratori

G. Abbiendi, INFN Bologna
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)

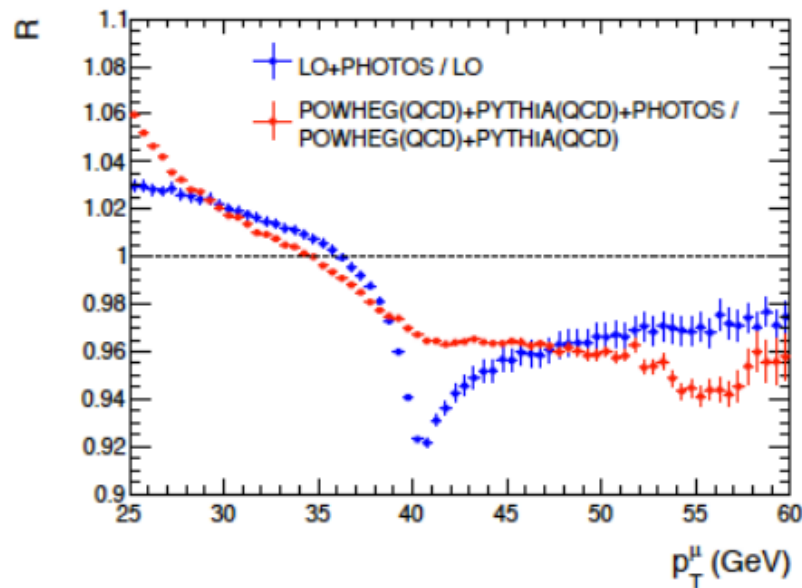
Consiglio di Sezione INFN

Pavia, 8 maggio 2018

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 measurement
- Contribution to DY WG report on precision predictions



- “Precision Measurement of the W-Boson Mass: Theoretical Contributions and Uncertainties”

C.M. Carloni Calame, M. Chiesa, H. Martinez, G. Montagna, O. Nicrosini, F. Piccinini and A. Vicini

[arXiv:1612.02841](https://arxiv.org/abs/1612.02841)

Phys.Rev. D96 (2017) no.9, 093005

- “Precision studies of observables in $pp \rightarrow W \rightarrow l\nu$ and $pp \rightarrow \gamma, Z \rightarrow l+l-$ processes at the LHC”

S. Alioli *et al.*, arXiv:1606.02330

Published in Eur.Phys.J. C77 (2017) no.5, 280

- “Physics at a 100 TeV pp collider: Standard Model processes”

M.L. Mangano *et al.*

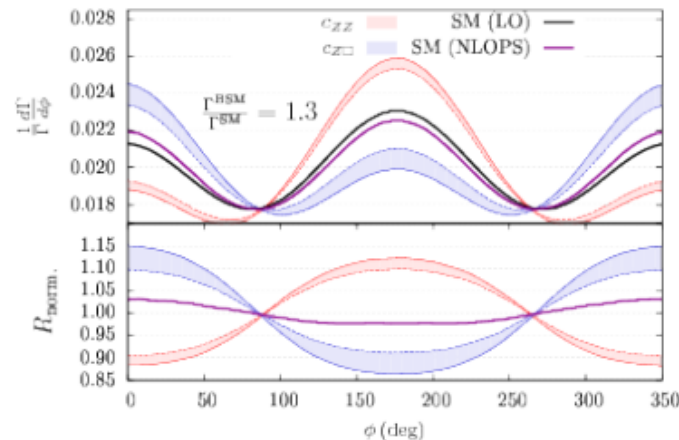
CERN-TH-2016-112, FERMILAB-FN-1021-T

arXiv:1607.01831

CERN Yellow Report (2017) no.3, 1-254

Higgs Physics at the LHC

- MC for $H \rightarrow 4l$ 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 & contribution to

JHEP 1801 (2018) 096

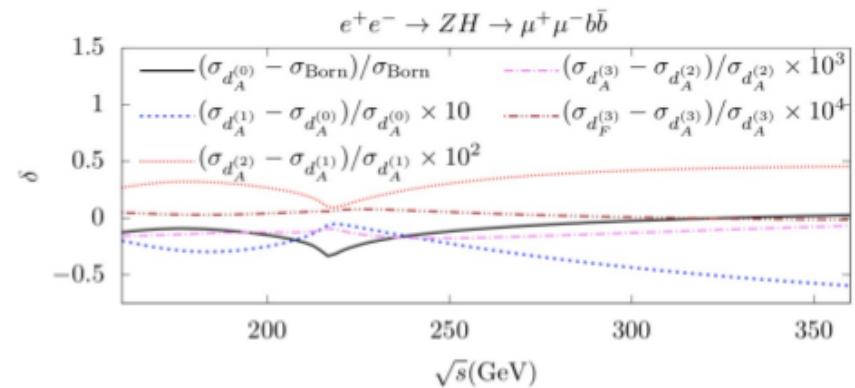
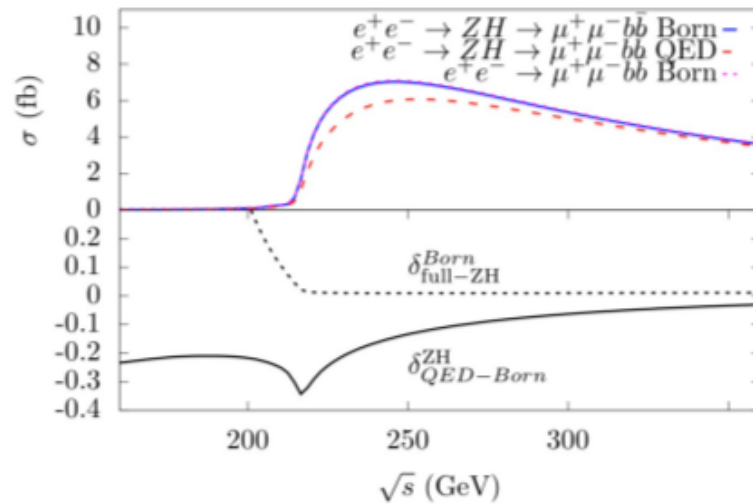
- LHCHiggsXS Working Group, YR 4

“Handbook of LHC Higgs Cross Sections: 4. Deciphering the Nature of the Higgs Sector”

FERMILAB-FN-1025-T, CERN-2017-002-M

[arXiv:1610.07922](https://arxiv.org/abs/1610.07922)

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 the intensity frontier

BabaYaga@NLO: reference MC used by all experimental collaborations for

- monitoring of luminosity and prediction of QED processes
- simulation of ISR emission

“A new G -parity violating amplitude in the J/ψ decay?”

R. Baldini Ferroli *et al.* (BESIII Collaboration),
[arXiv:1608.07191](https://arxiv.org/abs/1608.07191)

Published in Phys.Rev. D95 (2017) no.3, 034038

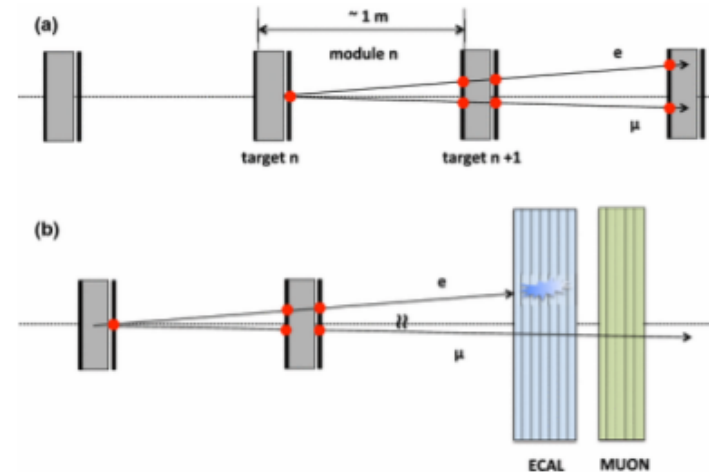
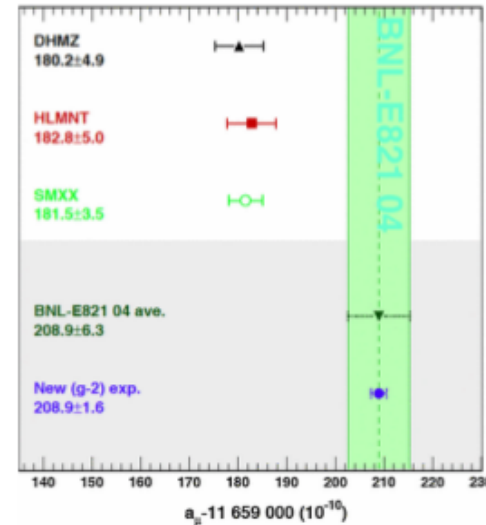
Muon $g-2$

“Measuring the leading hadronic contribution to the muon $g-2$ via μe scattering”

G. Abbiendi *et al.*, [arXiv:1609.08987](https://arxiv.org/abs/1609.08987)
Eur.Phys.J. C77 (2017) no.3, 139

Experimental proposal – test beam performed at CERN H8 (September 2017)

Collaboration with Belle2 and BESIII



Workshops and Working Groups

F. Piccinini:

FCC-ee: WG1 (Z pole) and WG2 (Di-bosons) co-convener with R. Tenchini

Co-organizer FCC-ee Workshop “Physics behind Precision” – CERN, 2-3 February 2016

“Physics behind precision”

P. Azzi et al (F. Piccinini)

arXiv:1703.01626

C.M. Carloni Calame:

MITP Topical Workshop “The Evaluation of the Leading Hadronic Contribution to the Muon Anomalous Magnetic Moment”, Mainz, 19-23 February 2018. I



Several Talks at international Workshops/Conferences

MANYBODY

Carlotta Giusti

MANYBODY

Carlotta Giusti

nuclear effects in electron and neutrino-nucleus scattering
collaborations for the analysis of data $^{40}\text{Ar}(e,e'p)$ data Jlab
electron scattering experiments MAMI

derivation of a microscopic optical potential
collaboration with M. Vorabbi (TRIUMF), P. Finelli (Bologna)

PUBLICATIONS

M. Vorabbi, P. Finelli, C. Giusti, PRC 96 044601 (2017)

Optical Potential derived from NN chiral potentials at
 $N^4 LO$

C. Giusti, Bulg. J. Phys. 44 16 (2017)

Phenomenological and Theoretical Optical Potentials

TALKS

C. Giusti

Phenomenological and Theoretical Optical Potentials

Meeting on Advanced Aspects on Nuclear Structure and Reactions at
Different Energy Scales

Arbanasi, Bulgaria, April 25-28 2017

C. Giusti

From (e,e'p) to Neutrino Scattering:

Int. Workshop on (e,e'p) Processes, Bled, Slovenia July 2-6 2017

OPTICAL POTENTIAL

The OP provides a suitable framework to describe elastic nucleon-nucleus scattering

Its use can be extended to calculate the cross section of a wide variety of nuclear reactions

In our models for QE electron and neutrino-nucleus scattering the OP describes FSI between the emitted nucleon and the residual nucleus

Phenomenological OPs are quite successful in comparison with data but the use of different available OPs can produce theoretical uncertainties and ambiguities in the interpretation of the results



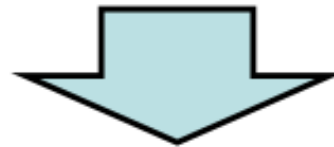
MICROSCOPIC OPTICAL POTENTIAL

MICROSCOPIC OPTICAL POTENTIAL

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

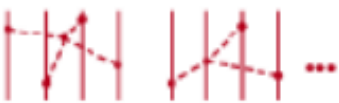
n, p densities calculated within the relativistic mean field description

NN interaction chiral potentials...



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

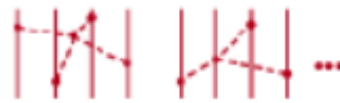
CHIRAL POTENTIAL AT N⁴LO

	Two-nucleon force	Three-nucleon force	Four-nucleon force
LO (Q^0)			
NLO (Q^2)			
N ² LO (Q^3)			
N ³ LO (Q^4)			
N ⁴ LO (Q^5)			

E. Epelbaum et al. . PRL 115 122391 (2015), EPJA 51 53 (2015) **EKM**

D.R. Entem et al. PRC 91 014002 (2015), PRC 96 024004 (2017) **EMN**

CHIRAL POTENTIAL AT N⁴LO

	Two-nucleon force			
LO (Q^0)				
NLO (Q^2)				
N ² LO (Q^3)			—	
N ³ LO (Q^4)				...
N ⁴ LO (Q^5)				...

Graphs analyzed in terms of $(Q/\Lambda_\chi)^n$
 Nuclear forces dominated by NN int.
 many-body 3N 4N.. forces created on
 an equal footing and emerge in
 increasing order going to higher order
 ansion parameters.

E. Epelbaum et al. . PRL 115 122391 (2015), EPJA 51 53 (2015) **EKM**

D.R. Entem et al. PRC 91 014002 (2015), PRC 96 024004 (2017) **EMN**

CHIRAL POTENTIAL AT N⁴LO

NN

	Two-nucleon force
LO (Q^0)	
NLO (Q^2)	
N ² LO (Q^3)	
N ³ LO (Q^4)	
N ⁴ LO (Q^5)	

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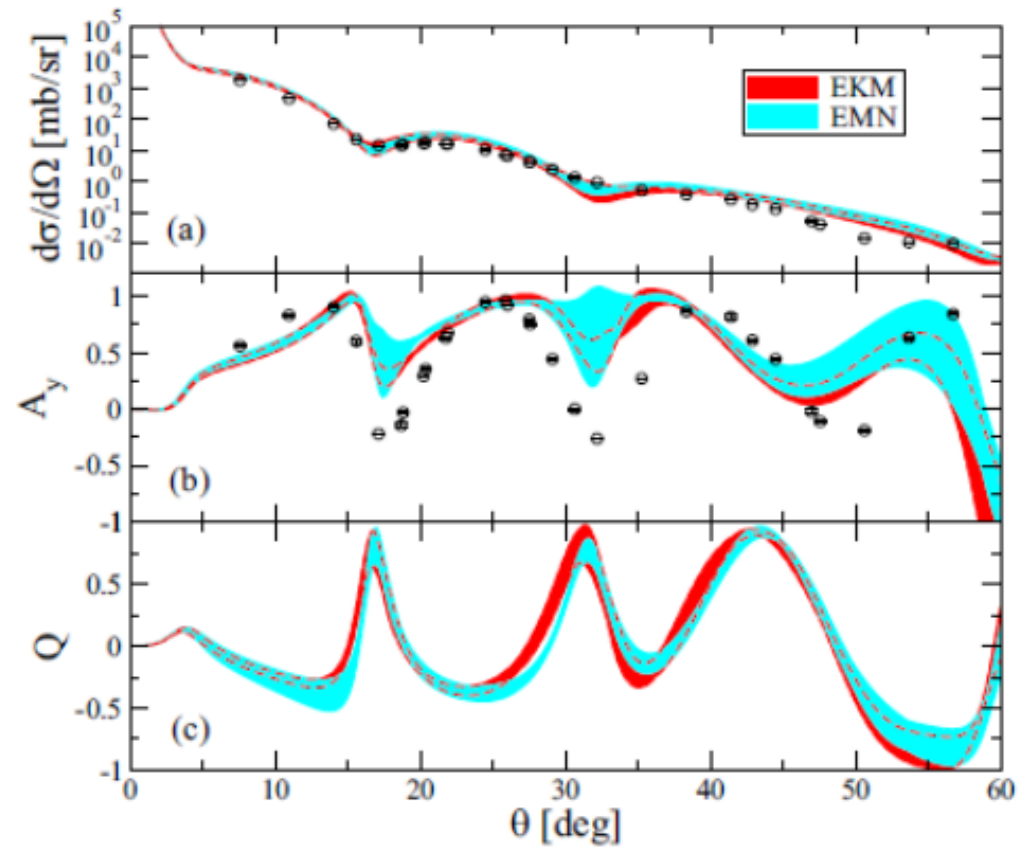
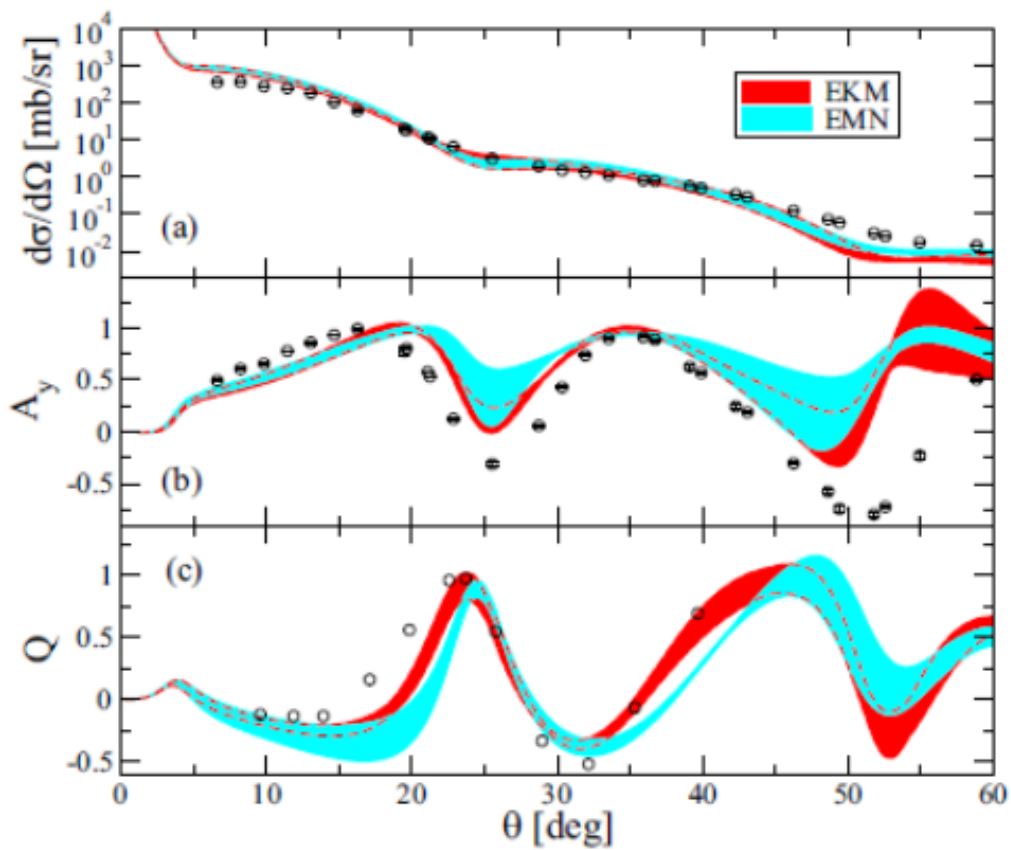


E. Epelbaum et al. . PRL 115 122391 (2015), EPJA 51 53 (2015) **EKM**

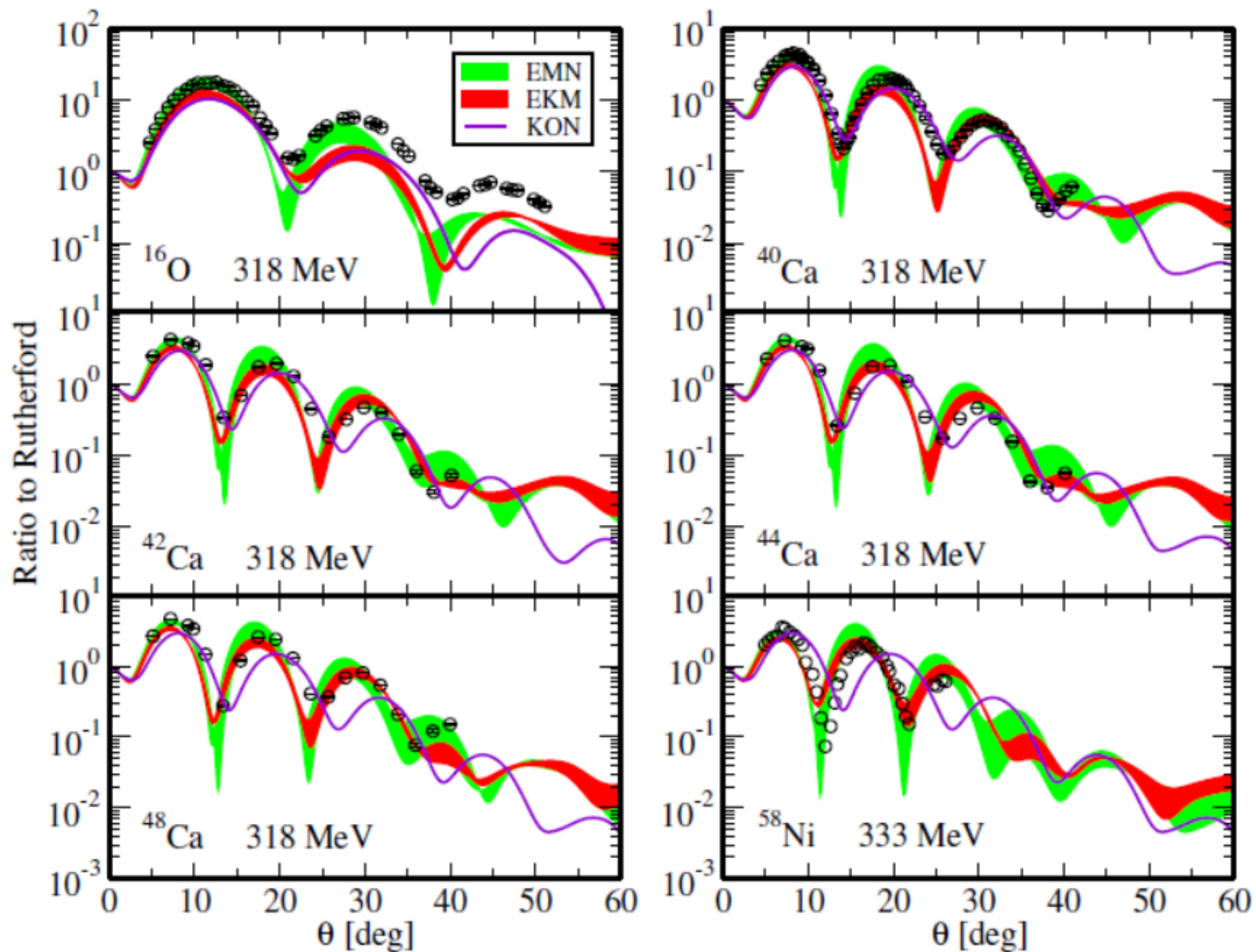
D.R. Entem et al. PRC 91 014002 (2015), PRC 96 024004 (2017) **EMN**

^{16}O

200 MeV

 ^{40}Ca 

Comparison with phenomenological OP





NINPHA National Initiative in Physics of Hadrons

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

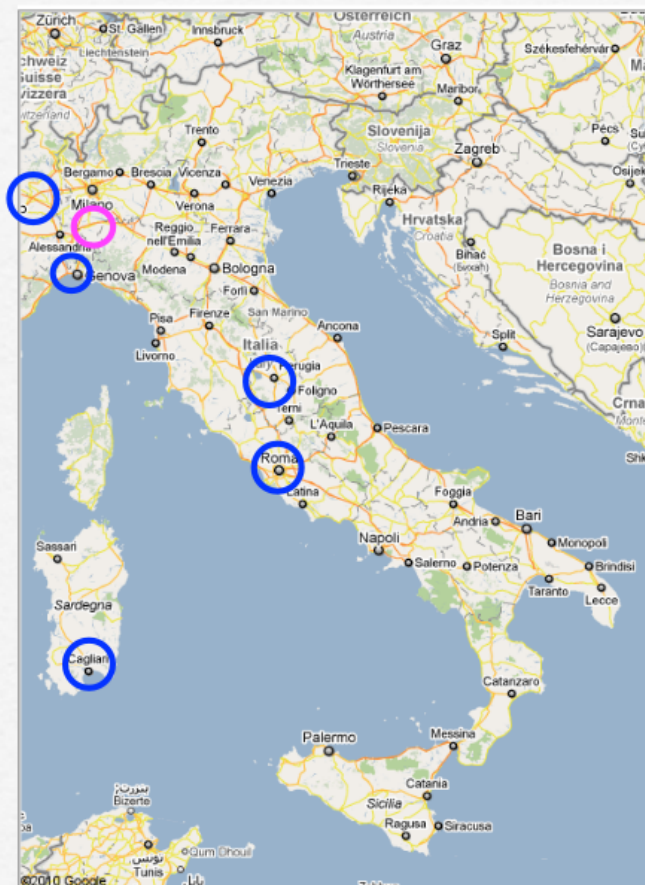
Responsabile naz.: E. Boglione (TO)

Sedi: PV, TO, CA, PG, RM1, GE

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

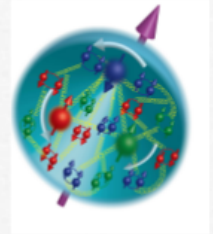


INFN	1 Ric.	M. Radici (Resp. loc.)
	2 post-doc	M. Echevarria (da sett.'17) P. Taels (da ott.'17)
Univ.	3 P.A.	A. Bacchetta, A. Bianconi (30%), B. Pasquini
	1 RTDA	G. Bozzi (da lug.'16)
	1 assegn.	C. Bissolotti (da nov.'17)
	4 Ph.D.	F. Delcarro, F. Piacenza, S. Rodini, S. Sconfietti
	(-1 post-doc	C. Pisano fino a dic.'17)
	(+1 post-doc	V. Bertone da ott.'18)

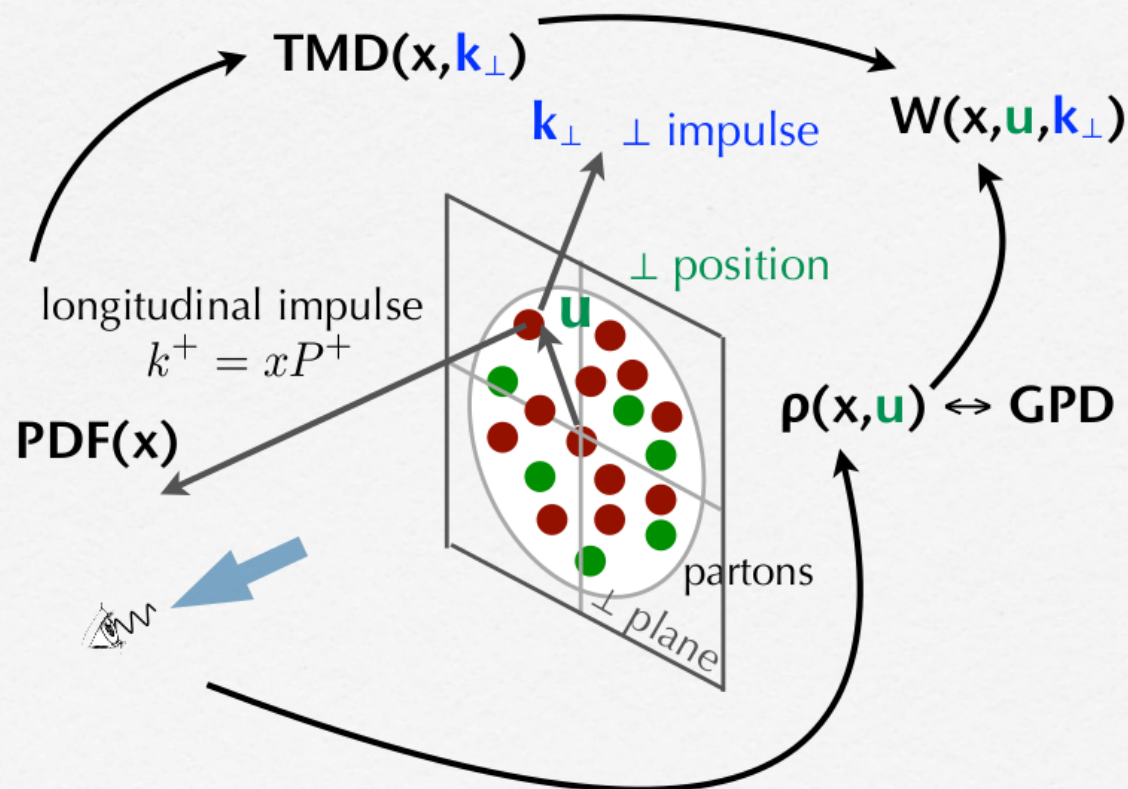


Main goal :

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



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



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

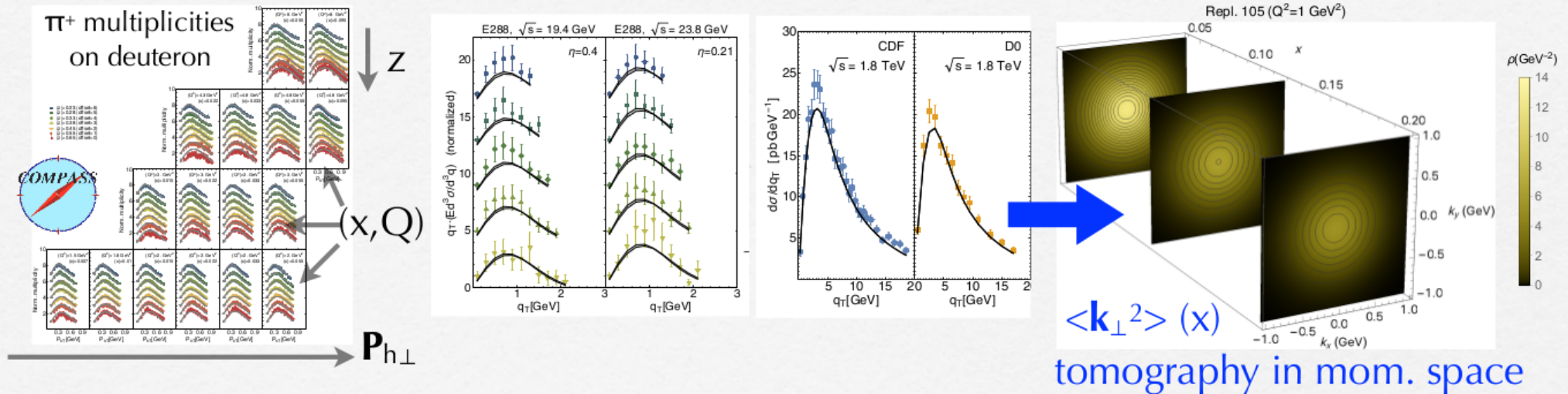
transition to era
of precision physics

Some recent achievements

extraction of unpol. TMD from first global fit (+8000 points)

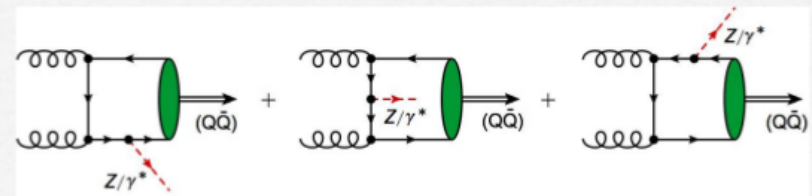
first global fit of available data at low $k_{\perp}$ from SIDIS, Drell-Yan and Z boson production, to extract the unpolarized TMD in a TMD factorization framework, including TMD evolution effects up to NLL

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



studies towards gluon TMD

gluon TMD from gluon fusion contribution to
 $pp \rightarrow Q (Z/\gamma^*) X \rightarrow (Y / J/\psi) \ell^+ \ell^- X$ at LHC
 $ep \rightarrow QQ X$ at EIC



Lansberg, Pisano, Schlegel, N.P. **B920** (17) 192

extraction of chiral-odd transversity PDF from first global fit

first global fit of $(\pi^+\pi^-)$ production in SIDIS

**annihilation
collisions**

$$e p^{\uparrow} \rightarrow e' (\pi^+ \pi^-) X$$

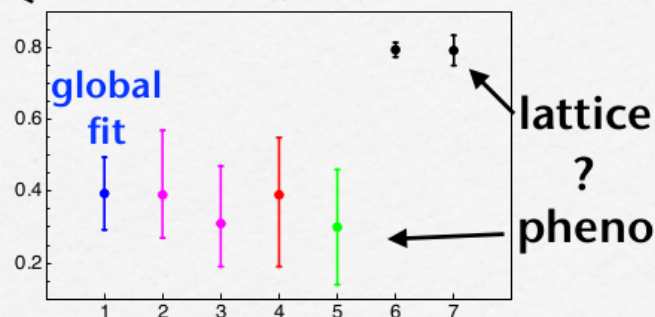
(Hermes, Compass)

$$e^+e^- \rightarrow (\pi^+\pi^-)(\pi^+\pi^-) X$$

(Belle)

$$p p^{\uparrow} \rightarrow (\pi^+ \pi^-) X$$

(STAR @BNL)

 $Q^2=4 \text{ GeV}^2$ 

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

important for searches of BSM physics

discrepancy between phenomenology and lattice

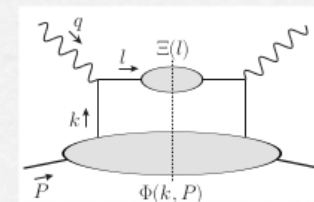
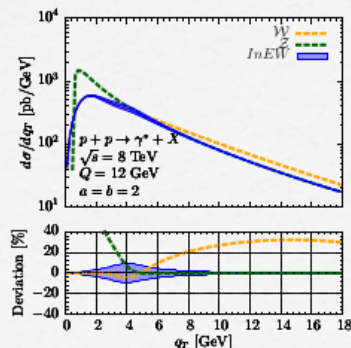
Radici, Bacchetta, P.R.L. in press, arXiv:1802.05212

new way to transversity from subleading inclusive DIS

realistic final state in inclusive DIS $\rightarrow$ jet of hadrons

$$\rightarrow W_A^{\mu\nu} \sim a^{\mu\nu} g_1(x, Q^2) + b^{\mu\nu} g_2(x, Q^2) \text{ with } g_2 \sim \dots + \frac{M_{\text{jet}} - m}{M} \frac{h_1(x, Q^2)}{x}$$

$M_{\text{jet}} \sim 10\% M \rightarrow$ not suppressed!

Accardi, Bacchetta, P.L. **B773** (17) 632

matching factoriz. th.'s at low k_T (TMD) to large k_T (collinear)

$$d\sigma_{q_T \ll Q} \sim W + \Delta W [O(q_T/Q)]$$

$$d\sigma_{qT \sim Q} \sim Z + \Delta Z [O(m/q_T)]$$

$$d\bar{\sigma} \sim \omega_1(\Delta W) \ W + \omega_2(\Delta Z) \ Z$$

inverse-error weighting

Echevarria, Kasemets, Lansberg, Pisano, Signori, P.L. **B781** (18) 161

studies of deeply-virtual Compton scatt. (DVCS) at twist-3

no direct access to individual GPDs at subleading twist-3 → no access to orbital angular momentum (need Wigner Distributions) Aslan, Burkardt, Lorcé, Metz, Pasquini, arXiv:1802.06243

proton polarizabilities from Compton scatt. data

review of dispersion relation techniques applied to real and virtual CS
application to constrain corrections to muonic hydrogen spectroscopy
first attempt to extract dipole dynamical polarizabilities
from RCS below π threshold

Pasquini, Vanderhaeghen, Ann.Rev.Nucl.Part.Sci. **68** in press

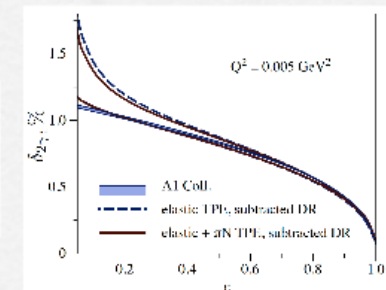
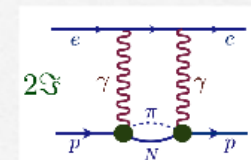
Pasquini, Pedroni, Sconfiatti, arXiv:1711.07401

2 γ -exchange mechanism in

elastic e-p scattering

First-time full dispersion treatment including elastic+inelastic channels. Compare with MAMI data

Tomalak, Pasquini, Vanderhaeghen, P.R. D95 (17) 096001

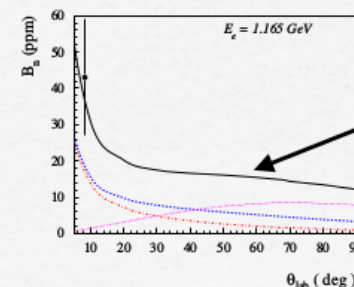


beam spin asymmetry in $\vec{e} p \rightarrow e \Delta$

cross section $\sim |T_{2Y}|^2 \rightarrow$ access ($N \rightarrow \Delta$) on shell.

Compare with Qweak data

Carlson, Pasquini, Pauk, Vanderhaeghen, P.R. D96 (17) 113010



$N + \Delta + S_{11} + D_{13}$

Also:

- 25 invited talks (5 with proceedings)
- co-organization of workshops at ECT* and INT (Seattle)
- convener at EICUG 2017 (Trieste)
- members of IAC at LC 2017, NPQCD 2017, Transversity 2017
- **B. Pasquini** DOE Panel member for Nat. Lab. Nucl. Th. Research Programs
member of IAC of Center for Frontiers in Nuclear Sciences
(CFNS - Stony Brook)
- **M. Radici** elected member of EIC User Group Steering Committee
member of the EIC User Group Council Board

Collaborations:

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

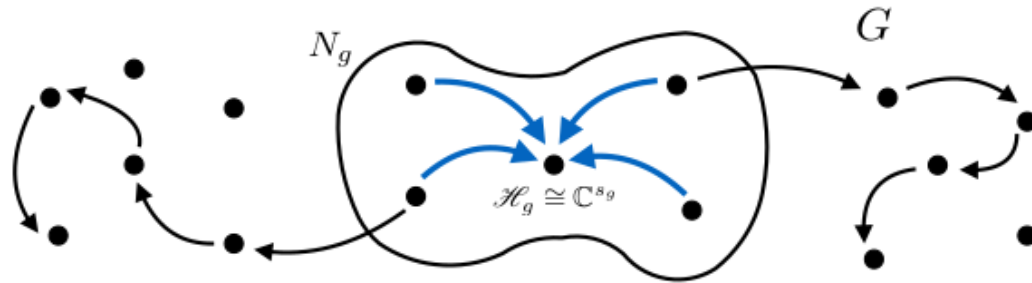
Other funds - ERC consolidator



P.I. A. Bacchetta

Gruppo QUIT

Reconstructing Dirac dynamics from scalar Quantum Walks



$$\psi_g = \begin{pmatrix} \psi_{g,1} \\ \psi_{g,2} \\ \vdots \\ \psi_{g,s_g} \end{pmatrix}$$

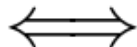
$$\psi_g(t+1) = \sum_{g' \in N_g} A_{gg'} \psi_{g'}(t)$$

Quantum Field Theory on graphs,
using Quantum Walks (QWs)
in the free case

Scalar case: choose $s_g = 1$,
namely the QW
has minimal algorithmic complexity

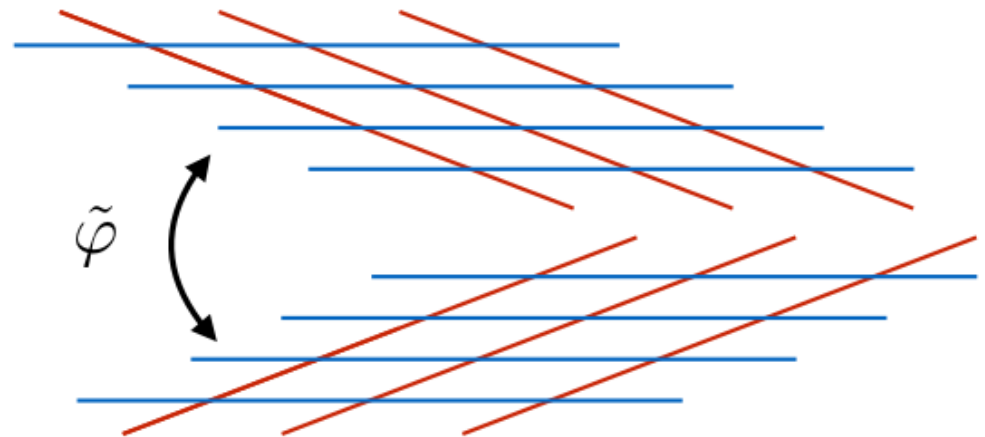
Non-trivial existence conditions
on the graphs allowing for
a unitarity evolution

Flat emergent metric



Virtually Abelian Cayley graphs

Finitely many copies of a d-dimensional
lattice intertwined by the automorphism
of the underlying Abelian group



➔ Reconstruction of the Dirac equation
and of a Minkowski space-time

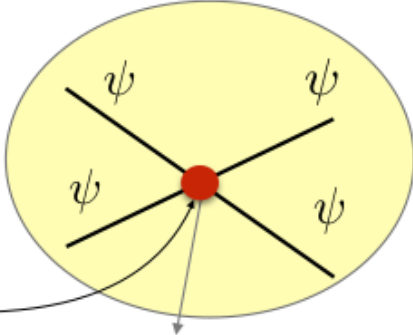
AUTOMI CELLULARI PER TEORIA DI CAMPO (D'Ariano, Perinotti, Bisio, Mosco, Erba, Poggiali)

Four fermion interaction

kinetic term

$$\mathcal{L} = \bar{\psi}(\not{\partial} - m)\psi + \sum_{\alpha} \frac{g_{\alpha}}{2} (\bar{\psi} \Gamma_{\alpha} \psi)^2$$

interaction



spacetime point

In the literature

Lagrangian/Hamiltonian models

- 1) continuous spacetime
- 2) on the lattice

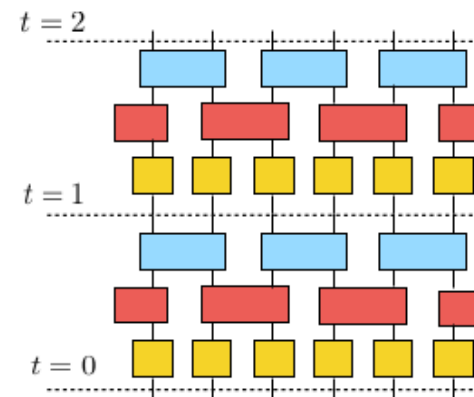
Thirring: 1958

Hubbard model: 1968

Gross-Neveu: 1974

TIME is continuous

Our work



**Quantum
cellular
automaton**

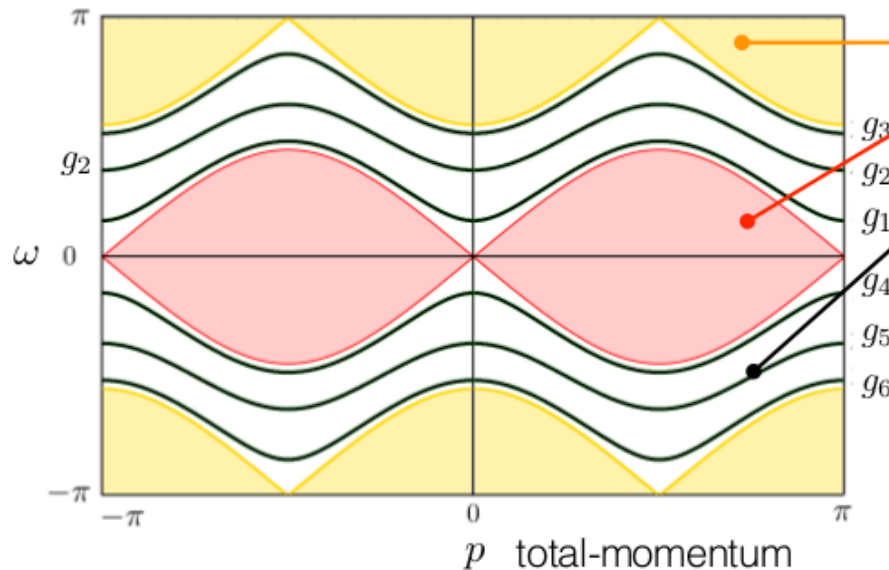
$$U^t = \underbrace{U \cdots U}_t$$

t times

discrete TIME

New kind of Bethe Ansatz: Automaton in 1+1 dimensions *integrated* in the two-particle sector

A. Bisio, G.M. D'Ariano, P. Perinotti, A. Tosini, *Thirring quantum cellular automaton*. Phys. Rev. A **97**, 032132 (2018).

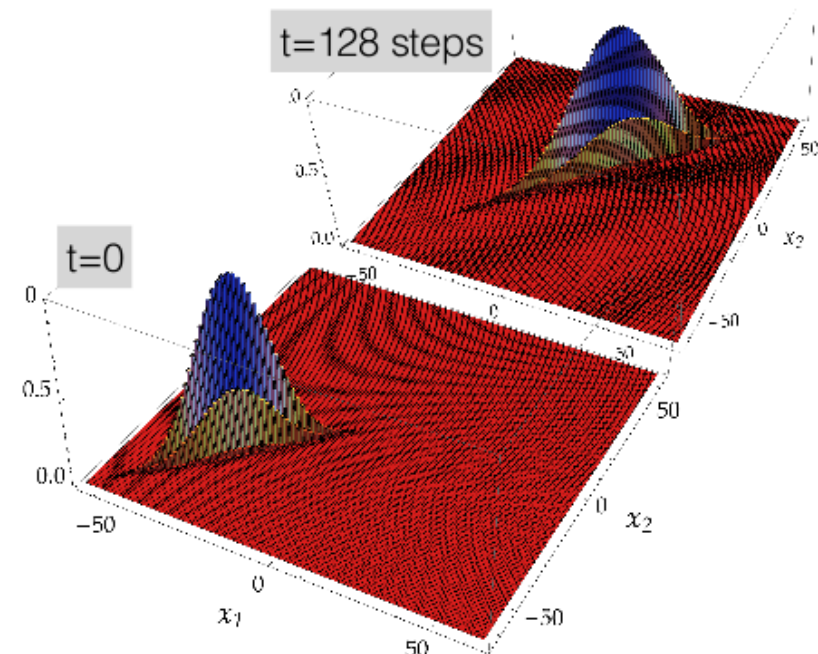


Continuous bands: scattering

Discrete bands: bound states

Example of bound state evolution

$p=0.035\pi$ mass=0.6 coupling=0.2 π



We find three phenomenological novelties:

- 1) non-trivial momentum transfer in scattering
- 2) bound state for any value of p
- 3) bound state for null coupling

QUANTUM INFORMATION (Maccone)

Uncertainty relations

The sum of variances is a measure of the “total” uncertainty: It represents the squared length of the diagonal of a box with the variances as edges

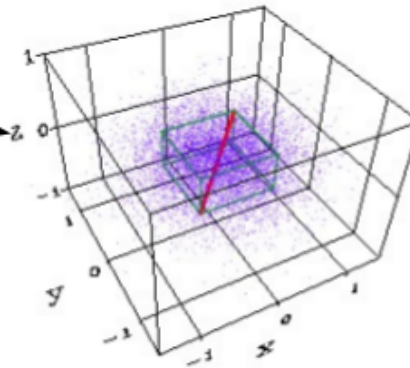
$$\text{su}(2) \quad \Delta J_x^2 + \Delta J_y^2 + \Delta J_z^2 \geq j$$

$$\text{su}(1,1) \quad \Delta K_x^2 + \Delta K_y^2 - \Delta K_z^2 \geq \kappa$$

$$\text{Weyl-Heisenberg} \quad \Delta x^2 + \Delta p^2 \geq 1$$

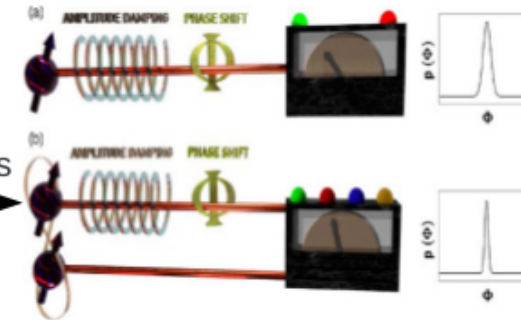
$$\text{su}(3) \quad \frac{1}{2} \sum_i \Delta e_i^2 \geq 2(\lambda_1 + \lambda_2)$$

...



Quantum metrology: ancillary systems in estimations

In the presence of noise, the use of external ancillary systems is useful in the problem of estimating a parameter. We analyzed specific examples and performed a proof-of-principle experiment.



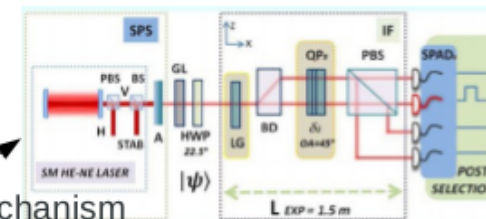
Quantum correlations: study of multipartite steering

We derived entropic inequalities that detect the presence of multipartite steering

Quantum time

We showed how one can bypass Pauli's theorem against the creation of a time operator in quantum mechanics.

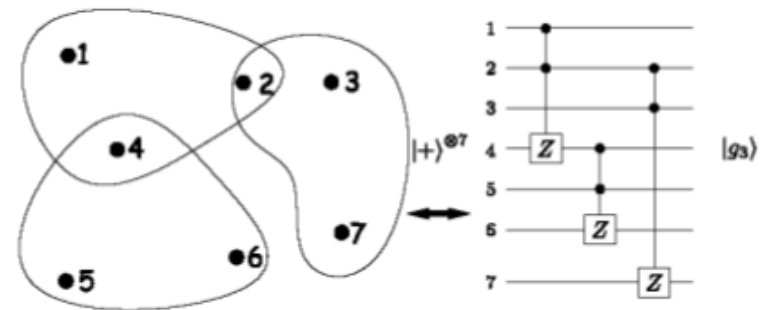
We performed a quantum optics experiment to illustrate the mechanism



Quantum hypergraph states

We studied multipartite entanglement and entanglement detection in quantum hypergraph states

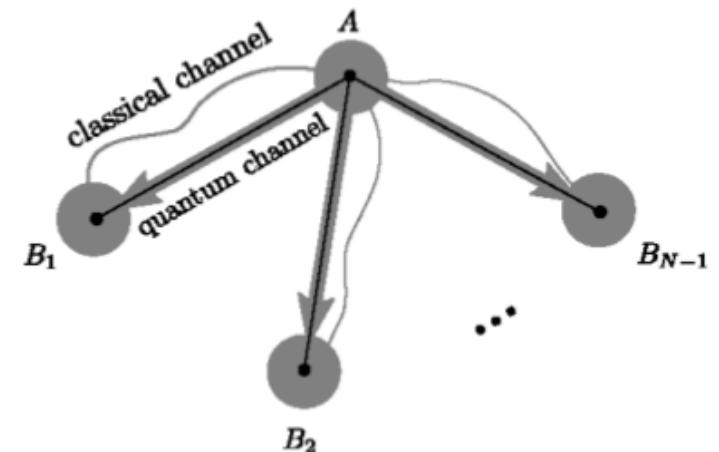
Ghio, Malpetti, Rossi, Bruss & Macchiavello, JPA 51 (2018)



Multipartite quantum cryptography

We introduced a protocol to share a secret key among many users based on multipartite entangled states and showed its advantages in quantum networks

Epping, Kampermann, Macchiavello & Bruss,
NJP 19, 045302 (2017)



Detection of properties of quantum channels

We introduced an efficient and easy to implement method to detect non-Markovianity of quantum evolutions

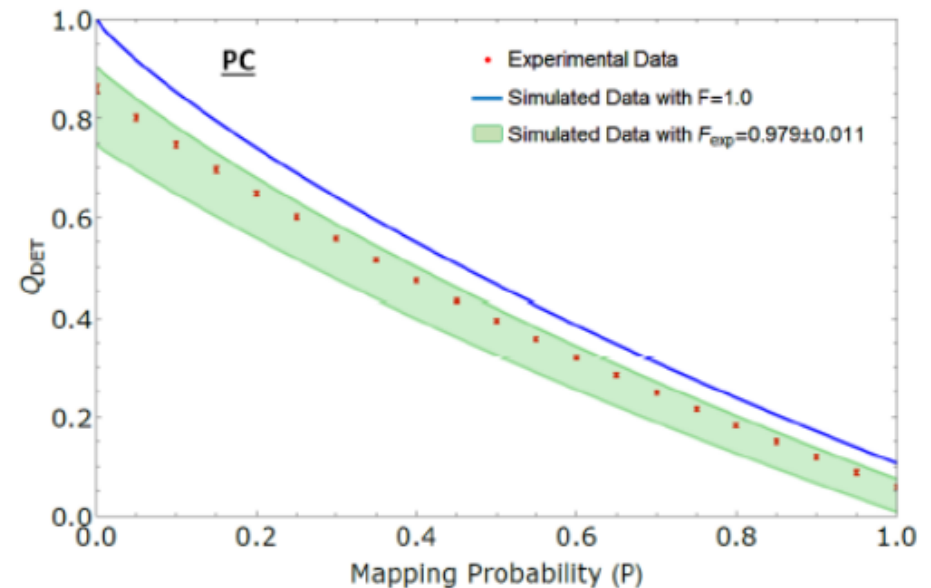
Chruscinski, Macchiavello & Maniscalco, Phys. Rev. Lett. 118, 080404 (2018)

We extended a recently proposed method to detect capacities of quantum channels [Macchiavello & Sacchi, PRL 116 (2016)] to the case of general mixed input and collaborated to an experimental implementation based on polarised photons

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

Cuevas, Proietti, Ciampini, Duranti, Mataloni, Sacchi

& Macchiavello, PRL 119, 100502 (2017)



DYNSYSMATH

DYNamical systems and non equilibrium states of complex **SY**stems :
MAThematical methods and physical concepts



Fausto Borgonovi, Chahan Kropf, Francesco Mattiotti
Dip. di Mat. e Fisica, Univ. Cattolica BS
INFN Pavia

Pavia 08.05.2018

DYNSYSMATH

DYNAmical systems and non equilibrium states of complex SYStems :
MATHeMATical methods and physical concepts



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National Coordinator : Fausto Borgonovi (Pavia)

NETWORK

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



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 **SY**stems :
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
- Study 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.

Pavia research

Cooperativity: Even if the basic constituents of a system interact following well understood laws, they can cooperate to produce new phenomena which were not foreseen nor are easily understood. These **emergent phenomena** occur at all scale and thus belong to the system as a whole and not to its components.

- robustness to noise?
- exploit such properties to build efficient quantum devices for energy transport and light harvesting?
- existence of a common mechanism to robust collective phenomena?

A potential key ingredient are **long range interactions** that can arise both from **microscopic interactions** and from the **coupling with an environment**

- interplay of cooperativity and noise: from natural photosynthetic complexes to artificial quantum devices
- out-of-equilibrium dynamics in long-range interacting classical and quantum many-body systems:
- superradiance and transport in nanosystems
- thermalization and quantum chaos in many-body isolated systems
- role of entanglement

Research Activity 2017

- 1) Thermalization in isolated quantum many-body systems
-
- It is believed that thermalization in closed systems of interacting particles can occur only when the eigenstates are fully delocalized and chaotic in a preferential (unperturbed) basis of the Hamiltonian. We have demonstrated that, in contrast, in systems with random two-body interaction, even not fully delocalized eigenstates are typically thermal. Moreover we show how to define the temperature of an eigenstate as a function of both interparticle interaction and energy.
-
- 2) Quantum transport in disordered chains with application to photosynthetic systems
-
- We studied the effect of dephasing, disorder, and coupling to a sink on the transport efficiency in a one-dimensional chain of finite length N , with particular focus on the beneficial or detrimental effect of dephasing on transport.
- In our model we proved that in disordered systems, dephasing can enhance energy transfer even in the ballistic regime (and not only trivially in the localized regime). Among the other results, we show that, in the ballistic regime, the optimal dephasing decreases as $1/N$ or $1/N^{1/2}$, respectively, for weak and moderate static disorder.
- We also studied quantum enhancement of transport in the presence of disorder and dephasing in the semiclassical regime (strong dephasing). We found optimal conditions for transport. This physical behavior is reflected in the Fenna-Matthews-Olson (FMO) photosynthetic complex.

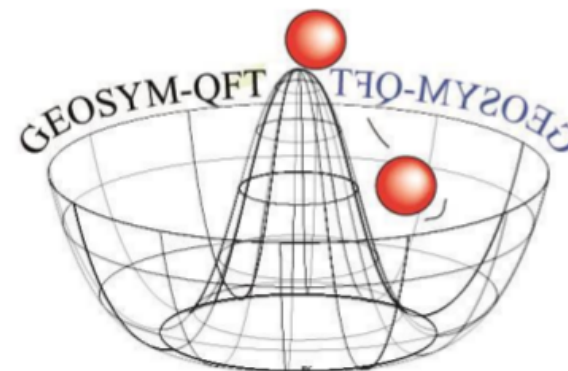
Publications (2017)

- Yang Zhang, G. Luca Celardo, **Fausto Borgonovi** and Lev Kaplan, *Transport Efficiency in Open Quantum Systems with Static and Dynamical Disorder*, AIP Conference Proceedings 1912, 020022 (2017);
- **Fausto Borgonovi** and Felix M. Izrailev, *Localized Thermal States*, AIP Conference Proceedings 1912, 020003 (2017);
- Yang Zhang, G. Luca Celardo, **Fausto Borgonovi** and Lev Kaplan, *Optimal dephasing for ballistic energy transfer in disordered linear chains*, Phys. Rev. E 96, 0521035 (2017)
- **Fausto Borgonovi**, **Francesco Mattiotti** and Felix Izrailev, *Temperature of a single chaotic eigenstate*, Phys. Rev. E 95, 042135 (2017)
- Yang Zhang, G. Luca Celardo, **Fausto Borgonovi** and Lev Kaplan, *Opening-assisted coherent transport in the semiclassical regime*, Phys. Rev. E 95, 022122 (2017)
- **Chahan M. Kropf**, Vyacheslav N. Shatokhin, Andreas Buchleitner, *Open system model for quantum dynamical maps with classical noise and corresponding master equations*, Open Systems & Information Dynamics, Vol. 24, No. 4 (2017)

Current and future projects

- Quantum light diode inspired by light-harvesting complexes
- Common properties to superconducting and superradiant systems
- Interplay of cooperativity, disorder and dephasing for transport in one-dimensional systems.
- Quantum coherent optimal transport in nano-scale solid-state heterostructures
- Entanglement of many-body atomic states.
- Application of quantum machine learning to the quantum entanglement measurement problem.
- The quantum state discrimination problem for unknown states in the presence of disorder.

GEOmetry and SYMmetry in Quantum Field Theory



Coordinatore nazionale: F. Lizzi (Napoli)

Sezioni: Firenze, Napoli, Pavia, Pisa, Salerno

Membri Sezione di Pavia

- *Staff*: A. Marzuoli (coordinatrice), M. Carfora, C. Dappiaggi, G. Jug
- *Dottorandi (Fisica)* : F.Bussola (XXXI); (Matematica): B. Giunti (XXXII)
- *Post-doc INFN*: H. Ferreira (fino a Settembre 2017)
- *Assegnista (Dip. Fisica)*: N. Drago (da gennaio 2017)

Consuntivo attività GEOSYM_QFT 2017

- **1 Tesi di Dottorato** in Matematica in co-supervisione con U. Regensburg
- **5 Tesi di Laurea** concluse nel 2017 (1 magistrale, 2 triennali e 1 IUSS)
- **8 Tesi di Laurea assegnate** per il 2018 (4 magistrali, 3 triennali, 2 IUSS)
- Attività editoriali: M. Carfora: Editor in Chief of “Geometric Flows” (De Gruyter); C. Dappiaggi: Editor of “Advances in Mathematical Physics” (Hindawi)
- **1 conferenza organizzata** presso il Mainz Institute for Theoretical Physics + **2 Workshop organizzati** presso U. di Pavia e presso U. di Genova

Lavori pubblicati nel 2017 e preprint 2018: 14 + 2 proceeding + 2 monografie (Springer)

Tematiche di ricerca della IS a Pavia

- Quantum field theory on curved backgrounds
- Mathematical aspects of gauge and of quantum field theories
- General Relativity, Geometric flows and renormalization group techniques with applications to mathematical cosmology
- Topological quantum field theory and associated discretized models;
- Applications to quantum many-body and condensed matter systems
- Comprehensive modeling of phase transitions in amorphous materials from experimental data
- Interdisciplinary topics (complex networks and Data Science) based on notions and tools from classical and quantum field theories.

TASP – PAVIA – ATTIVITÀ 2017

Marco Roncadelli

INFN – PAVIA

COMPOSIZIONE DEL GRUPPO

Marco Roncadelli, INFN (PV), primo ricercatore, responsabile locale, FTE = 0.8.

Patrizia Caraveo, IASF-INAF (MI), dirigente di ricerca, docente a contratto Università di PV, FTE = 0.5.

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

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

Attività di M. Roncadelli + I. Bombaci e G. Galanti

Finora i telescopi Cherenkov ad imaging H.E.S.S., MAGIC e VERITAS hanno scoperto più di 60 blazar nella gamma VHE.
N.B. Blazar $\equiv$ AGN (Active Galactic Nucleus) con un jet che punta occasionalmente verso di noi. VHE $\equiv$ very-high-energy: $100 \text{ GeV} \leq E \leq 100 \text{ TeV}$.

Un fascio monocromatico γ di energia E (VHE) mentre si propaga verso di noi subisce lo scattering di Breit-Wheeler

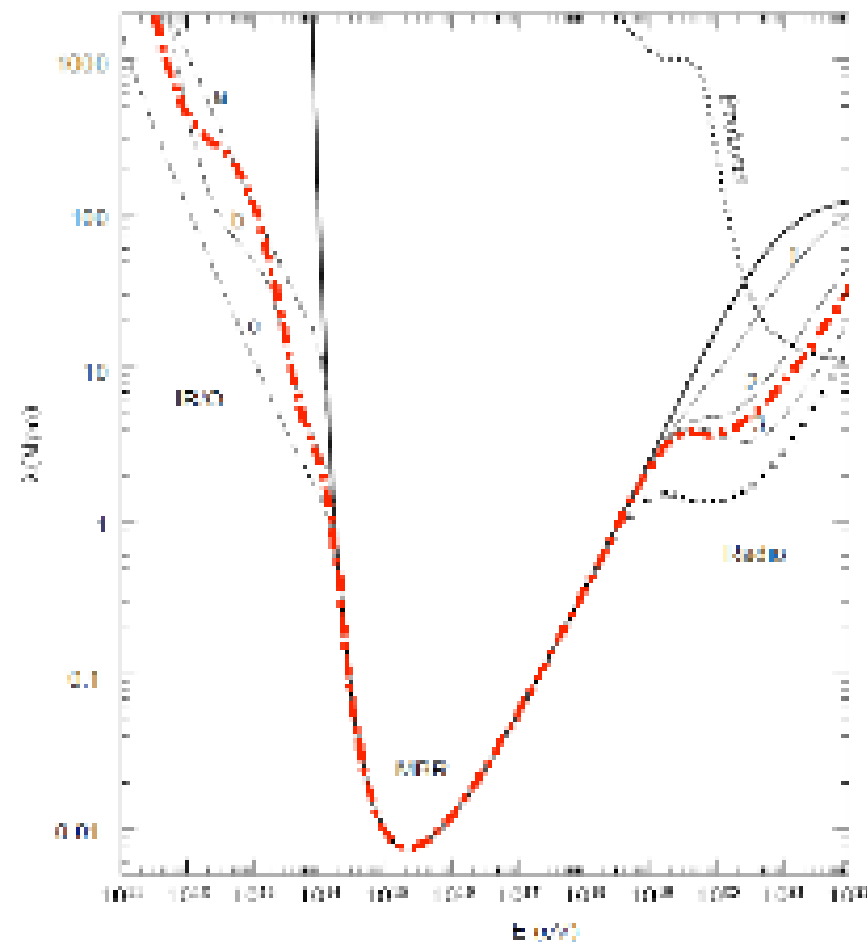
$\gamma_{\text{VHE}} + \gamma_{\text{BG}} \rightarrow e^- + e^+$, ove γ_{BG} è un fotone del fondo cosmico di energia ϵ . Poichè $\sigma(\gamma_{\text{VHE}} + \gamma_{\text{BG}} \rightarrow e^- + e^+)$ è massimizzata per

$$\epsilon \simeq \left(\frac{900 \text{ GeV}}{E} \right) \text{ eV} , \quad (1)$$

ne segue che nel range $100 \text{ GeV} \leq E \leq 100 \text{ TeV}$ si ha

$$0.009 \text{ eV} \leq \epsilon \leq 9 \text{ eV} . \quad (2)$$

Sfortunatamente in questa banda il cielo è dominato dalla *extragalactic background light* (EBL): la luce emessa da tutte le galassie durante la loro evoluzione. Pertanto si ha un severo assorbimento di fotoni VHE prima che questi siano osservati. Esplicitamente il cammino libero medio λ_{CP} dei fotoni VHE è illustrato nella figura.



Quantitativamente la probabilità di sopravvivenza dei fotoni emessi da una sorgente a distanza d è

$$P_{\gamma \rightarrow \gamma}^{\text{CP}}(E, d) = \exp \left(- \frac{d}{\lambda_{\text{CP}}} \right) . \quad (3)$$

Nel 2007 è stato mostrato da A. De Angelis, O. Mansutti e M. R. che in presenza di oscillazioni fotoni-ALP nello spazio extragalattico la situazione cambia radicalmente. Sostanzialmente – a causa di tali oscillazioni – il fotone VHE acquista una "split personality": quando si propaga come un vero fotone subisce l'assorbimento da parte dell'EBL, ma quando si propaga come ALP viaggia indisturbato. Pertanto, in tale situazione il cammino libero medio efficace è λ_{ALP} , cosicchè l'Eq. (3) diventa

$$P_{\gamma \rightarrow \gamma}^{\text{ALP}}(E, d) = \exp \left(- \frac{d}{\lambda_{\text{ALP}}} \right) . \quad (4)$$

Ma da quanto detto segue $\lambda_{\text{ALP}} > \lambda_{\text{CP}}$, per cui dal confronto fra le Eqs. (3) e (4) segue

$$P_{\gamma \rightarrow \gamma}^{\text{ALP}}(E, d) \gg P_{\gamma \rightarrow \gamma}^{\text{CP}}(E, d) . \quad (5)$$

Ciò implica un DRASTICO aumento della trasparenza cosmica nella banda VHE.

Sotto quali condizioni tale situazione può avvenire?

- L'accoppiamento fotone-ALP è dato da $g_{a\gamma\gamma} \mathbf{E} \cdot \mathbf{B}$ ed il limite di CAST è $g_{a\gamma\gamma} < 0.66 \cdot 10^{-10} \text{ GeV}^{-1}$, per cui una scelta plausibile è $g_{a\gamma\gamma} = (0.5 - 1) \cdot 10^{-11} \text{ GeV}^{-1}$.

- ▶ Il modello standard del campo magnetico extragalattico è basato sui galactic outflows da galassie nane primordiali ($z < 6$) e da quasar, che danno origine ad una configurazione a domini. In entrambi i casi emerge la predizione $B = \mathcal{O}(1 \text{ nG})$ e $L_{\text{dom}} = \mathcal{O}(1 \text{ Mpc})$.
- ▶ Al fine di essere nel regime di *strong mixing* nella banda VHE in cui $P_{\gamma \rightarrow \gamma}^{\text{ALP}}(E, d)$ è massima e non dipende da m_a e da E è necessario avere $m_a < 5 \cdot 10^{-10} \text{ eV}$.

Tuttavia, la mancata rivelazione di ALPs dalla supernova 1987A è stata comunemente interpretata come un forte limite alla suddetta possibilità dell'aumento della trasparenza cosmica:

$$g_{a\gamma\gamma} < 5.3 \cdot 10^{-12} \text{ GeV}^{-1} \text{ per } m_a < 4.4 \cdot 10^{-10} \text{ eV}.$$

Sembra paradossale come nel 1996 Raffelt abbia pubblicato un grosso volume sui processi elementari che avvengono in in mezzo non banale quale una protoneutron star e simultaneamente abbia pubblicato un articolo superficiale e sbagliato sull'emissione di ALP da una protoneutron star con Brockway e Carlson. Un lavoro simile è stato pubblicato nello stesso anno da Grifols, Massó and Toldrà. Un'analisi sostanzialmente identica ma più dettagliate è stata pubblicata nel 2015 da A. Payez *et al.* che fornisce il limite precedente $g_{a\gamma\gamma} < 5.3 \cdot 10^{-12} \text{ GeV}^{-1}$ per $m_a < 4.4 \cdot 10^{-10} \text{ eV}$. Le ipotesi corrette sono le seguenti.

- ▶ I protoni sono sostanzialmente non degeneri ma gli elettroni sono completamente degeneri.
- ▶ Pertanto gli elettroni non contribuiscono al processo Primakoff per la produzione delle ALP (Pauli blocking).
- ▶ Gli elettroni non possono effettuare il Debye screening dei protoni (Pauli blocking).

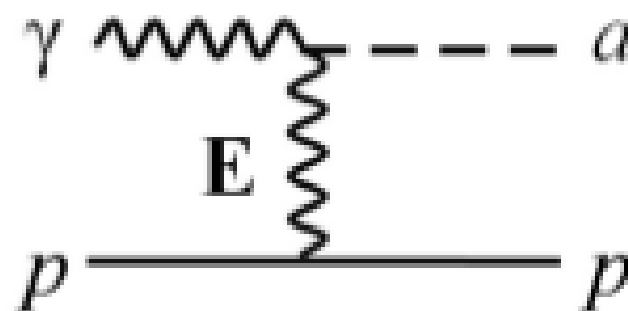


Figura: Diagramma di Feynman per il processo Primakoff.

Quindi l'analisi fatta è come se avesse luogo nel VUOTO in assenza di elettroni!

Ma un protoneutron star è di fatto un NUCLEO ATOMICO MACROSCOPICO!

Schematicamente, gli errori fatti sono i seguenti.

- I protoni sono Debye screened da protoni!

- ▶ La frequenza di plasma degli elettroni è ignorata. Tenendone conto la massa del fotone diventa $m_\gamma \simeq 15.61 \text{ MeV}$, quasi metà della temperatura $T \simeq 37.2 \text{ MeV}$. Quindi m_γ NON può essere ignorata, contrariamente a quanto è stato fatto.
- ▶ Le interazioni forti sono IGNORE! Una delle loro conseguenze è la seguente. Sperimentalmente si osserva che nello scattering di fotoni con energia $<$ della massa del pione – questo è anche il nostro caso perchè $\langle E_\gamma \rangle \simeq 100.44 \text{ MeV}$ – su nuclei pesanti i fotoni vengono assorbiti eccitando modi nucleari collettivi. Pertanto è logico aspettarsi che ciò avvenga anche in una protoneutron star. Ciò riduce DRASTICAMENTE il flusso di fotoni disponibile per la produzione di ALP attraverso il processo Primakoff.

- Infine, come mostrato da Raffelt nel suo libro, il calcolo del processo Primakoff va fatto assumendo una metrica che tiene conto delle proprietà del mezzo e NON con quella di Minkowski, come è stato fatto nei lavori considerati.

CONCLUSIONE

Il limite $g_{a\gamma\gamma} < 5.3 \cdot 10^{-12} \text{ GeV}^{-1}$ per $m_a < 4.4 \cdot 10^{-10} \text{ eV}$ è **COMPLETAMENTE SBAGLIATO**. Ciò allarga notevolmente lo spazio dei parametri sia per avere un drastico aumento della trasparenza cosmica nella banda VHE che per scoprire le ALP corrispondenti negli esperimenti ALPS II (DESY) e STAX.

I. Bombaci, G. Galanti e M.R., arxiv:1712.06205v2

Attività di P. Caraveo, A. De Luca, A. Giuliani 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 e avente come primo coordinatore A. De Luca. Il suo fine è estrarre sistematicamente e caratterizzare temporalmente tutti gli eventi serendipiti osservati dal satellite XMM-Newton e renderli accessibili a tutta la comunità scientifica. Formalmente EXTraS è terminato il 31/12/2016 ed i risultati sono disponibili dall'estate scorsa.

Il database è enorme e contiene informazioni astrofisiche riguardanti pressochè tutti i tipi di sorgenti attive nella banda X. Due fra i risultati più importanti che hanno ottenuto sono i seguenti.

- Rivelazione di una pulsazione di circa 1 s nella sorgente estrema superluminosa ULX-1 nella galassia NGC 5907. Ciò dimostra che questo sistema – che si suppone contenga un massive black hole – è alimentato da una stella di neutroni e la sua luminosità è 500 volte superiore alla luminosità di Eddington, che è il limite superiore standard per luminosità di accrescimento. Questo fatto – combinato con l'osservata derivata del periodo di rotazione estremamente grade – rappresenta una sfida ad ogni modello di accrescimento ed indica una topologia complessa del campo magnetico di una stella di neutroni, con una forte componente multipolare, maggiore di 10^{14} G, accoppiata ad una componente standard di dipolo magnetico, avente intensità di circa 10^{12} G.

- Rivelazione di abbassamenti periodici del periodo dell'ordine di 4 ore nell'emissione X della sorgente 3XMM J004232.1+411314, associata con l'emissione X dura che domina la luminosità X della galassia di Andromeda. Questo fatto dimostra che il sistema è una peculiare binaria a raggi X di bassa massa, avente una luminosità molto elevata ed uno spettro di emissione inusuale, il che pone una sfida ad i modelli standard.