Open Problems in Quantum Mechanics

Coordinator: **Catalina Curceanu, LNF-INFN, associated to Centro Fermi**

Participants: **Piscicchia Kristian, assegnista CF Feb. 2016 – Feb. 2018**

Place of Work: LNF- INFN, LNGS- INFN

Collaborations:

Univ. Trieste
Wigner Institute, Hungary
INFN e Univ. Trieste, Italia
Poli. e INFN Milano, Italia
SMI-Vienna, Austria
IFIN-HH, Bucharest, Romania
Univ. Zagreb, Croazia
TUM Monaco, Germania
RIKEN e Univ. Tokyo, Giappone
Jagellonian Univ., Cracovia, Polonia
Univ. Bologna, Italia
Univ. Rennes, Francia
Univ. Vienna, Austria
Univ. Southampton, UK
Princeton, USA

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Project main goal and results so far achieved

Collapse models:

1) solve the measurement problem in Quantum Mechanics

2) they consist in NON-LINEAR & STOCHASTIC modifications of the Schrödinger dynamics.

Continuous Spontaneous Localization (CSL) phenomenological model:

$$d|\psi_t\rangle = \left[-\frac{i}{\hbar}Hdt + \sqrt{\lambda}\int d^3x(N(\mathbf{x}) - \langle N(\mathbf{x})\rangle_t)dW_t(\mathbf{x}) - \frac{\lambda}{2}\int d^3x(N(\mathbf{x}) - \langle N(\mathbf{x})\rangle_t)^2 dt\right]|\psi_t\rangle$$

System's Hamiltonian

NEW COLLAPSE TERMS → New Physics

$\lambda =$ collapse strength

$r_C = 1/\sqrt{\alpha} =$ correlation length

two parameters

proposed values: S. Adler $\lambda = 10^{-6} - 10^{-10}\ s^{-1}$, G. C. Ghirardi $\lambda = 10^{-16} - 10^{-17}\ s^{-1}$

3) Diosi-Penrose gravity induced collapse model: predicts the scale r_c at which the breakdown of the superposition occurs $r_c \sim 10^{-7}$ m.

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Collapse of the state vector to the position basis → charged particles energy radiation not present in standard QM: *Spontaneous Radiation* (SR)
comparing the measured and predicted SR rate we can put constrains on the collapse rate λ and on the scale r_c at which the breakdown of the superposition occurs
→ chart the landscape of (gravity induced) collapse models

Calculation and measurement of the spontaneous emission rate:

1) the sponatneous emission rate was calculated for CSL model (left) and Diosi-Penrose model (right) (electrons and nuclear protons):

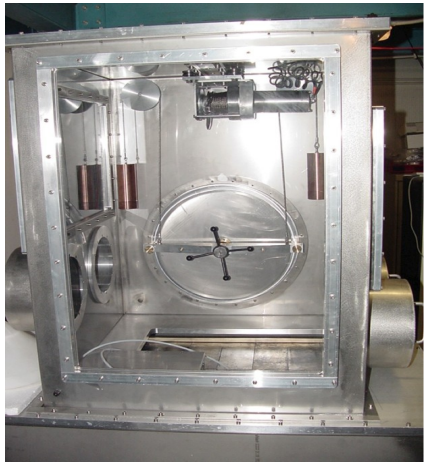
CSL

$$\frac{d\Gamma}{dE} = \{(N_p^2 + N_e) \cdot (m\,n\,T)\} \frac{\lambda \hbar e^2}{4\pi^2 \epsilon_0 c^3 m_N^2 r_c^2 E}$$

Diosi - Penrose

$$\frac{d\Gamma'}{dE} = \{(N_p^2 + N_e) \cdot (m\,n\,T)\} \frac{e^2 G}{4\pi^{5/2} \epsilon_0 c^3 R^3 E}$$

2) First data taking campaign in 2015.
Coaxial p-type Ge crystals (375 cm^3 active volume), Pb+Cu shielding, air tight steel housing flushed with boil-off nitrogen.



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3) MC simulations to optimize the geometry of the setup and lead target. Better then 80% background description for the 2015 data.

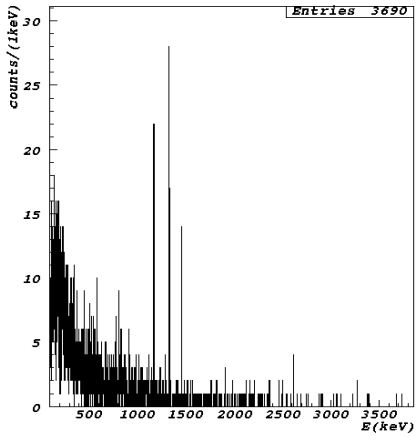
3) The 2015 data were analysed, based on a dedicated Bayesian model, extraction of the best upper limit ever on λ and first lower limit on r_c (paper under preparation):

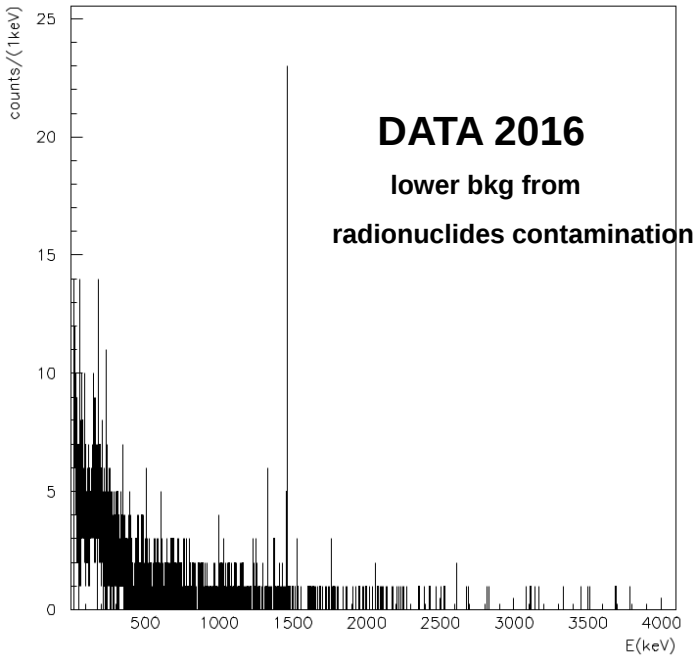
$$\lambda < 5 \cdot 10^{-13}\ s^{-1} \quad ; \quad r_c > 3 \cdot 10^{-12}\ m, \quad \text{with probability 95\%}$$

factor 20 gain respect (our) best published limit in the word (J. Adv. Phys. 4, 263-266 (2015))

5) Second data taking performed at LNGS (INFN) in August/September 2016, data analysis presently ongoing.

DATA 2015





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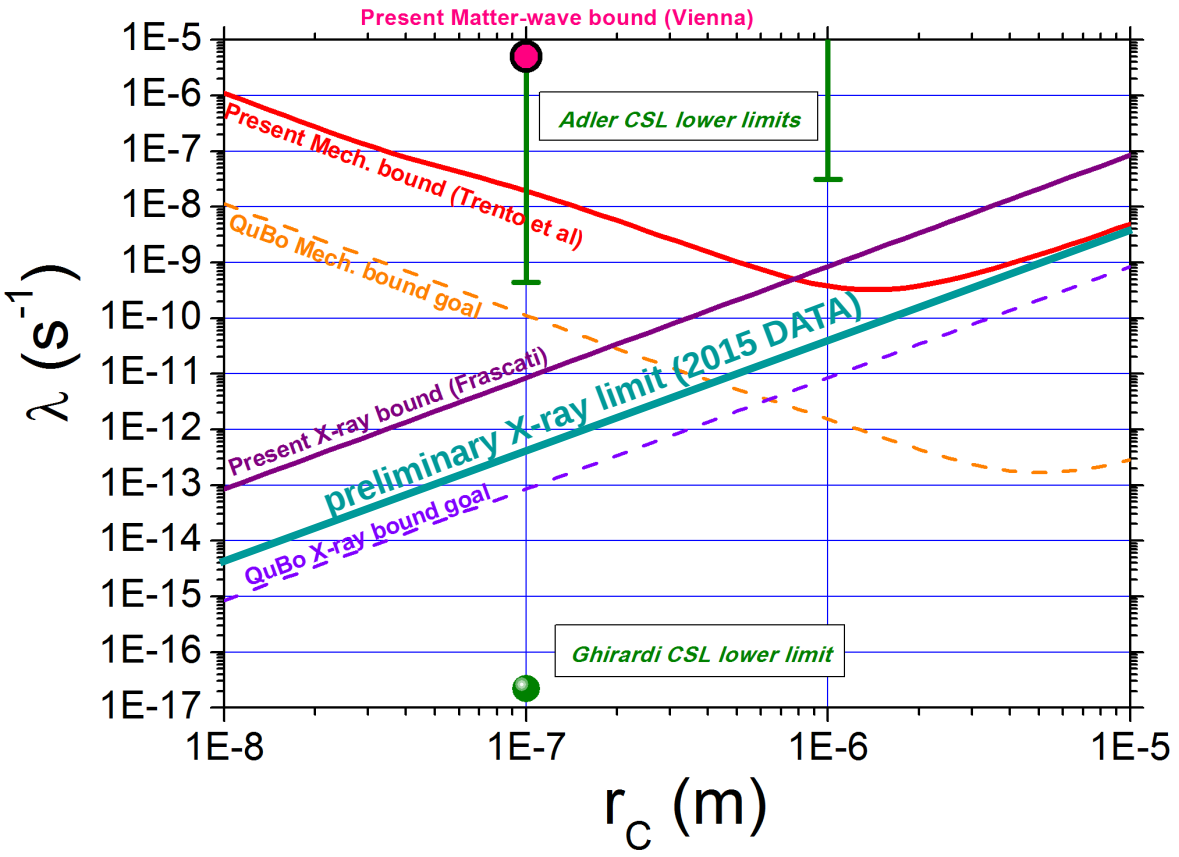

The project was presented by Catalina at:

- **30 conferences in schools and universities (Women in Physics Lecture 2016 of the Australian Institute of Physics)**
- **TEDxRoma:http://tedxroma.com/en/portfolio-items/catalina-curceanu/**
- **Festival della Scienza di Genova 2016 (2 talks)**

PUBLICATIONS OPQM:

- **5 PUBLICATIONS IN PEER-REVIEWED JOURNALS**
  2 in 2016

- **9 PUBLICATIONS IN CONFERENCE PROCEEDINGS**
  2 in 2016

18 PUBLICATIONS in 2016 with C. F. affiliation

CONFERENCES OPQM:

- **PARTICIPATION TO 40 INTERNATIONAL CONFERENCES ON OPEN PROBLEMS IN Q. M.**
  12 in 2016 (2 invited colloquia)

- **ORGANIZATION OF 5 INTERNATIONAL CONFERENES ON OPEN PROBLEMS IN Q. M.**

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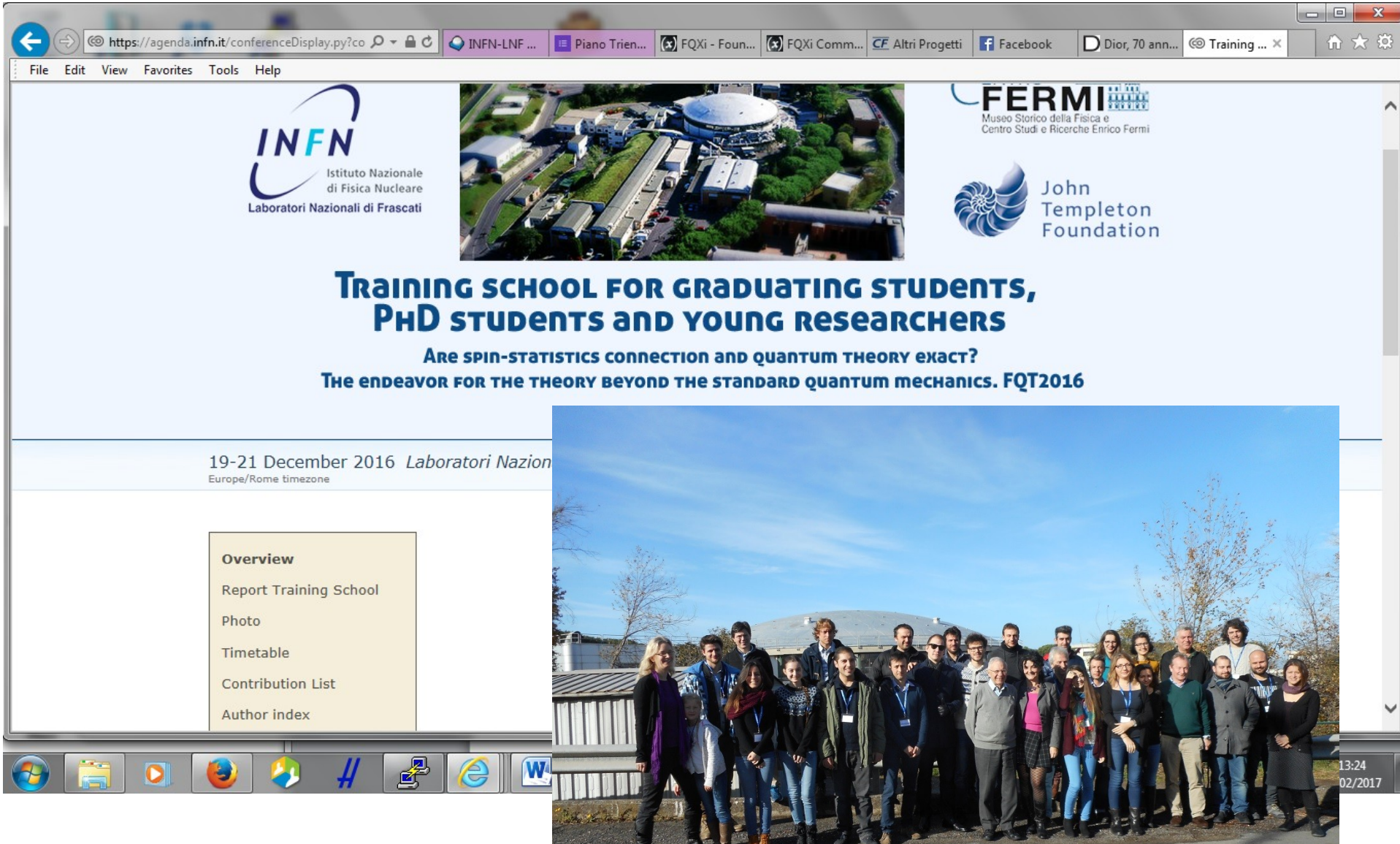

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Plan of activities for 2017 (1)

- **to publish the results of the analysis of LNGS 2015 Ge test-run in a high impact peer-reviewed journal (analyses concluded, paper in preparation)**

- **to analyse the data acquired in LNGS 2016 Ge data taking**

- **to perform a new data taking at LNGS with two ultrapure Ge detectors with target, in order to enhance the statistics with spontaneous emission Pb source**

- **activity within VIP2 at LNGS**

- **publish at least one paper within VIP2**

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Plan of activities for 2017 (2)

- presentation at Conferences and Workshops

- organization of a Workshop/Training School FQT Open Problems in Quantum Mechanics at LNF

- participation to the next call of the John Templeton Foundations, deadline for proposal submission 31 August 2017

- preparation for: Quantum Flagship EU

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Plan of activities: 2018-2019

- to perform a new data taking at LNGS with SDDs and ultrapure Ge detectors (refined setup)
- to perform a refined analysis of the background subtracted Ge data to improve the experimental limit on λ and r_c
- refined study of the gravity induced collapse models: towards dedicated experiments
- VIP2 activities
- publication of at least 5 articles in peer-reviewed journals
- presentations at Conferences and Workshops
- organization of Workshop/Training School and dissemination activities
- 2019: a dedicated International Conf. on Open Problems in QM
- participate to calls: Quantum Flagship EU, Templeton, FQXi

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Expected funding in the 3-year period:

- **Request of funding by Centro Fermi**

Grant: Assegno Ricerca (3 years): about 66 keuro kEuro
Funds for organizing 3 workshops: 3 x 5 = 15 kEuro
Travel expenses (missioni): 3 years x 5 kEuro/year = 15 keuro
Consumables/year for the experimental setup: 10 kEuro (30 keuro in 3 years)
Inventory: 5 keuro/year (15 kEuro)

- **Co-funding in 3 years period (estimate)**

INFN: 90 kEuro (VIP)
FQXI: 40 kEuro
Austrian Scence Foundation: 20 kEuro
Others (IFIN-HH, Templeton, Trieste): 15 kEuro

- **Potential external funding**

Templeton Foundation: 50 kEuro
EU Funding (COST Actions, MCurie, FET): 50 kEuro
Bandi Regionali e Ministeriali: 100 kEuro
Other nationals and internationals possible fundings: 50 kEuro
QuantumFlagship projects

SPARE SLIDES

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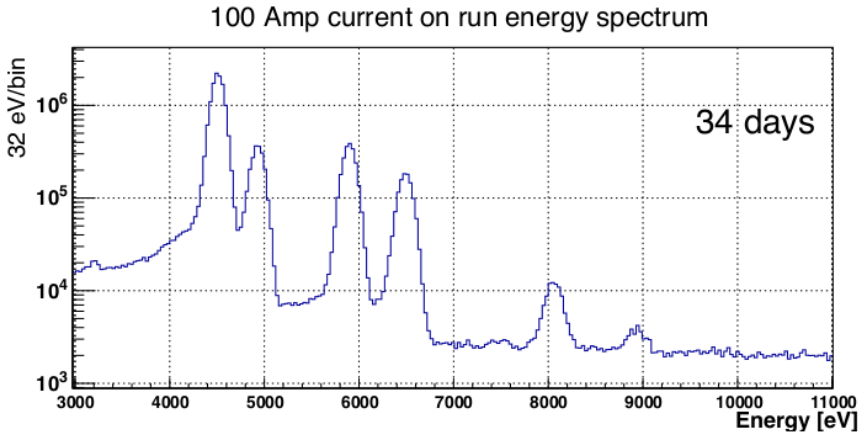
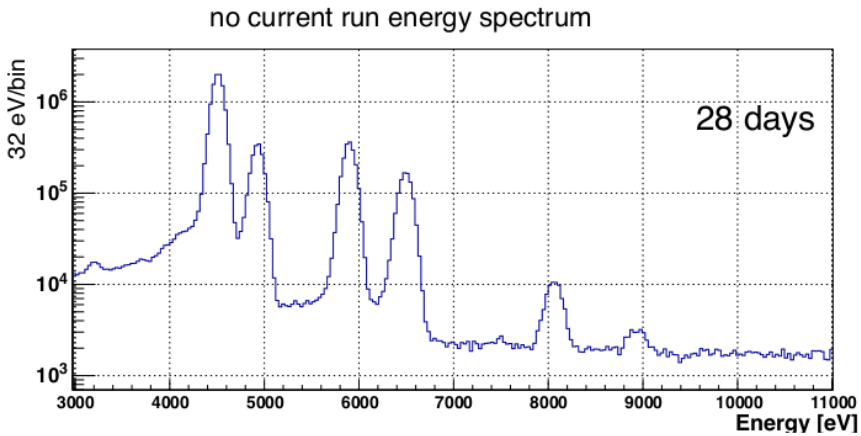
- **VIP2 data taking started:**

  data is acquired

  with current
  & without current

  applied to the copper strip,
  with 6 SDDs functioning





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VIP2 activities 2016

- full Monte Carlo simulation of the VIP2 setup at LNGS, in particular: acceptance, background rejection efficiency, SDD background recreation,

- energy calibration of the SDDs with tube,

- data taking started: data is acquired with current applied to the copper strip, with 6 SDDs functioning.

- measurement of the deposited energy threshold and the detection efficiency of the gamma background at the LNGS with VIP scintillators,

- implementation of the new slow control setup.

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OPQM:

C. Curceanu, K. Piscicchia et al., Found Phys (2016) 46: 263-268

International Journal of Quantum Information, Vol. 14, No. 1 (2016) 1640017

C. Curceanu , K. Piscicchia et al., J. Advan. Phys. 4, (2015), 1-4

K. Piscicchia, C. Curceanu et al., Acta Phys.Polon. B46, (2015), 147-152

C. Curceanu, K. Piscicchia, et al., Phys. Scr. 90, (2014) 028003

A. Pichler et al., J.Phys.Conf.Ser. 718 (2016) no.5, 052030
VIP Collaboration, J.Phys.Conf.Ser. 718 (2016) no.4, 042055
H. Shi et al., Phys.Procedia 61 (2015) 552-559
A. Pichler et al., PoS EPS-HEP2015 (2015) 570
C. Curceanu, K. Piscicchia et al., Journal of Physics: Conference Series 631 (2015) 012068
J. Marton et al., Journal of Physics: Conference Series 631 (2015) 012070
A. Pichler, Hyperfine Interact. 233 (2015) 1-3, 121-126
C. Curceanu et al. J.Phys.Conf.Ser. 626 (2015) 1, 012027
J. Marton et al., J.Phys.Conf.Ser. 447 (2013) 012070

Open Problems in Quantum Mechanics

Full pub. List (1):

- C. Curceanu , K. Piscicchia et al., X-Rays Help to Unfuzzy the Concept of Measurement, J. Advan. Phys. 4, (2015), 1-4.
- K. Piscicchia, C. Curceanu et al., Beyond Quantum Mechanics? Hunting the `Impossible' Atoms Pauli Exclusion Principle Violation and Spontaneous Collapse of the Wave Function at Test, Acta Phys.Polon. B46, (2015), 147-152
- H. Shi et. al, Testing the Pauli Exclusion Principle for electrons at LNGS, Phys.Procedia 61 (2015) 552-559
- C. Curceanu, K. Piscicchia et al., X rays on quantum mechanics: Pauli Exclusion Principle and collapse models at test, Journal of Physics: Conference Series 631 (2015) 012068
- J. Marton et al., High sensitivity tests of the Pauli Exclusion Principle with VIP2, Journal of Physics: Conference Series 631 (2015) 012070
- C. Curceanu, K. Piscicchia et al., Spontaneously emitted X rays: an experimental signature of the dynamical reduction models, Found Phys (2016) 46: 263-268
- J. Zmeskal et al., Measurement of the strong interaction induced shift and width of the 1s state of kaonic deuterium at J-PARC, Acta Phys.Polon. B46 (2015) 1, 101-112
- C. Curceanu, K. Piscicchia et al., Unprecedented studies of the low-energy negatively charged kaons interactions in nuclear matter by AMADEUS, Acta Phys. Polon. B46 (2015) 1, 203-215
- A. Pichler, C. Curceanu, K. Piscicchia et al., VIP 2: Experimental tests of the Pauli Exclusion Principle for electrons, Hyperfine Interact. 233 (2015) 1-3, 121-126
- I. Tucakovic et al., Low-energy kaon-nucleon/nuclei interaction studies at DAΦNE by AMADEUS, EPJ Web Conf. 95 (2015) 04072
- C. Curceanu et al., Experimental search for the “impossible atoms” Pauli Exclusion Principle violation and spontaneous collapse of the wave function at test, J.Phys.Conf.Ser. 626 (2015) 1, 012027
- T. Yamaga et al., Spectroscopic Study of Hyperon Resonances below \(\bar{K}N\) Threshold via the \(\left(K^{ - },n \right)\) Reaction on Deuteron , JPS Conf.Proc. 8 (2015) 021016
- K. Piscicchia, C. Curceanu, et al., Investigation of the low energy kaons hadronic interactions in light nuclei by AMADEUS, Hyperfine Interact. 234 (2015) 9-15
- J-PARC E15 Collaboration, Search for the K-pp bound state via the in-flight 3He(K-,n) reaction, EPJ Web Conf. 81 (2014) 02016
- K. Piscicchia, et al., Investigation of the low energy kaons hadronic interactions in light nuclei by AMADEUS, EPJ Web Conf. 81 (2014) 01016
- J-PARC E15 Collaboration, Search for the K-pp bound state via the in-flight 3He(K-,n) reaction at 1 GeV/c, J.Phys.Conf.Ser. 569 (2014) 012080
- SIDDHARTA and SIDDHARTA2 and AMADEUS Collaborations, Progress and perspectives in the low-energy kaon-nucleon/nuclei interaction studies at the DAΦNE collider, J.Phys.Conf.Ser. 556 (2014) 012004
-J-PARC E15 Collaboration, Search for the deeply bound K-pp state from the semi-inclusive forward-neutron spectrum in the in-flight K- reaction on helium-3, PTEP 2015 061D01

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Full pub. List(2):

- A. Scordo et al., Study of the Λ(1405) Resonance Through its Neutral and Charged Decay Channels by AMADEUS at DAFNE, Few Body Syst. 55 (2014) 741-744
- J-PARC E15 Collaboration, A Search for Deeply-bound Kaonic Nuclear States by In-flight 3He(K-,n) Reaction at J-PARC, Acta Phys.Polon. B45 (2014) 767
- H. Shi, et al., The yield of kaonic hydrogen X-rays in the SIDDHARTA experiment, EPJ Web Conf. 66 (2014) 09016
- J-PARC E15 Collaboration, A search for the K-pp bound state in the 3He(K- in-flight,n) reaction at J-PARC, EPJ Web Conf. 66 (2014) 09008
- C Curceanu, et al., Unveiling the strangeness secrets: low-energy kaon-nucleon/nuclei interactions studies at DAΦNE, EPJ Web Conf. 66 (2014) 09004
- S. Ajimura, et al., A search for deeply-bound kaonic nuclear state at the J-PARC E15 experiment, Nucl.Phys. A914 (2013) 315-320
- C. Curceanu, et al., Unlocking the secrets of the kaon-nucleon/nuclei interactions at low-energies: The SIDDHARTA(-2) and the AMADEUS experiments at the DAΦFNE collider, Nucl.Phys. A914 (2013) 251-259
- S. Ajimura, et al., A Search for Deeply Bound Kaonic Nuclear States at J-PARC, Few Body Syst. 54 (2013) 1195-1199
- K. Piscicchia, et al., Low energy kaon-nuclei interaction studies through the Σ0π0 channel with the KLOE detector, PoS Bormio2013 (2013) 034
- A. Scordo, C. Curceanu, K. Piscicchia, et al., Study of Σ+π− Invariant Mass spectrum with the KLOE detector; preliminary results and possible hints for Σ+ n internal conversion, PoS Bormio2013 (2013) 011
- C. Curceanu, K. Piscicchia, et al., Phys. Scr. 90, (2014) 028003
- K. Piscicchia, S. Wycech, C. Curceanu, Nuclear Physics A, 954, (2016) 75-93
- K. Piscicchia, S. Wycech, C. Curceanu, Nuclear Physics A, 954, (2016) 75-93
- Bazzi et al., Nuclear Physics A, 954, (2016), 7-16
- O. Vazquez Doce et al., K− absorption on two nucleons and ppK− bound state search in the Σ0 p final state, Phys. Lett. B, 758 (2016) 134
- The X-ray machine for the examination of quantum mechanics, International Journal of Quantum Information, Vol. 14, No. 1 (2016) 1640017
- J. Marton et al., AIP Conf.Proc. 1735 (2016) 080014
- T. Yamaga et al., AIP Conf.Proc. 1735 (2016) 040007
- J. Marton et al., EPJ Web Conf. 113 (2016) 03009
- A. Pichler et al., J.Phys.Conf.Ser. 718 (2016) no.5, 052030
- VIP Collaboration, J.Phys.Conf.Ser. 718 (2016) no.4, 042055
- A. Scordo et al., AIP Conf.Proc. 1735 (2016) 080015
- R. Del Grande et al., PoS BORMIO2016 (2016) 010
- A. Scordo et al., EPJ Web Conf. 130 (2016) 02011
- H. Tatsuno et al., EPJ Web Conf. 130 (2016) 01018
- M. Iliescu et al., J.Phys.Conf.Ser. 770 (2016) no. 1, 012034
- S. Wycech, K. Piscicchia, EPJ Web Conf. 130 (2016) 02011
- J-Parc E15 Collaboration, PTEP 2016 (2016) no.5, 051D01