Instytut Fizyki Jądrowej im. Henryka Niewodniczańskiego Polskiej Akademii Nauk

KNOW Krajowy Naukowy Ośrodek Wiodący 2012-2017

KATEGORIA NAUKOWA A+ 2014 - 2022

HR EXCELLENCE IN RESEARCH od 2017

KISD KRAKOWSKA INTERDYSCYPLINARNA SZKOŁA DOKTORSKA od 2019

Research topics in the field of nuclear physics at IFJ PAN

presented by Bogdan Fornal

nuclear structure

1) Properties of highly excited and fast rotating nuclei (A. Maj, M. Kmiecik et al.).
2) Nuclear structure studies using multinucleon transfer, neutron-induced fission and neutron-capture processes (B. Fornal et al.).
3) High-spin phenomena in nuclei investigated with discrete gamma-ray spectroscopy and radioactive beams (P. Bednarczyk et al.).
4) Properties of Giant, Pygmy and M4 Resonances studied with proton beam at CCB IFJ PAN (M. Kmiecik et al.).
5) Construction of the Photon Array for studies with Radioactive Ion and Stable beams (PARIS) (A. Maj et al.).

reactions, nuclear matter, fund. symmetries

6) Few-nucleon system dynamics investigated with proton-deuteron collisions (A. Kozela et al.,)
7) Properties of nuclear matter (equation of state, nuclear interactions) with heavy-ion beams at intermediate energies (J. Łukasik, P. Pawłowski, I. Ciepał et al.).
8) Fundamental symmetry tests with neutrons (BRAND and nEDM experiments) (A. Kozela, K. Pysz et al.).

ultrarelativistic and LHC energies

9) The NA61/SHINE experiment at the SPS accelerator at CERN - study of electromagnetic effects in collisions of atomic nuclei at SPS energies (A. Rybicki et al.).
10) The ALICE experiment at the Large Hadron Collider (LHC@CERN) (M. Kowalski et al.)

theory

11) Theoretical investigations of the dynamics of nuclear many-body systems (A. Szczurek et al.)
12) Shell-Model in the Continuum (Gamow SM and SMEC) (J. Okołowicz).

applications

13) Neutron and gamma spectroscopy for nuclear fusion research: IFMIF-DONES and ITER (W. Królas et al.)
14) Range and Relative Biological Effectiveness uncertainties in proton therapy (A. Ruciński et al.).
15) Dosimetry of primary beam and scattered radiation in proton therapy (J. Swakoń et al.).

PARTICIPANTS

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Dr Jan Dankowski (13)
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Dr. Jan Gajewski (14)
Dr hab. Jerzy Grębosz (1,3,4,5)
Dr. Leszek Grzanka (14,15)
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Dr. Wiktor Parol (6,7,4)
Dr. hab. Piotr Pawłowski (4,7)
Anna Pędracka (15)
Dr. hab. Krzysztof Pysz (8,7)
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Dr. Antoni Ruciński (14)
Dr. hab. Andrzej Rybicki (9)
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Dr. Iwona Sputowska (10)
Dr. Jan Swakoń (14,15)
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Prof. Urszula Woźnicka (13)
Eng. Mirosław Zięblíński (4,5,3)

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Prof. Jan Styczeń (3)

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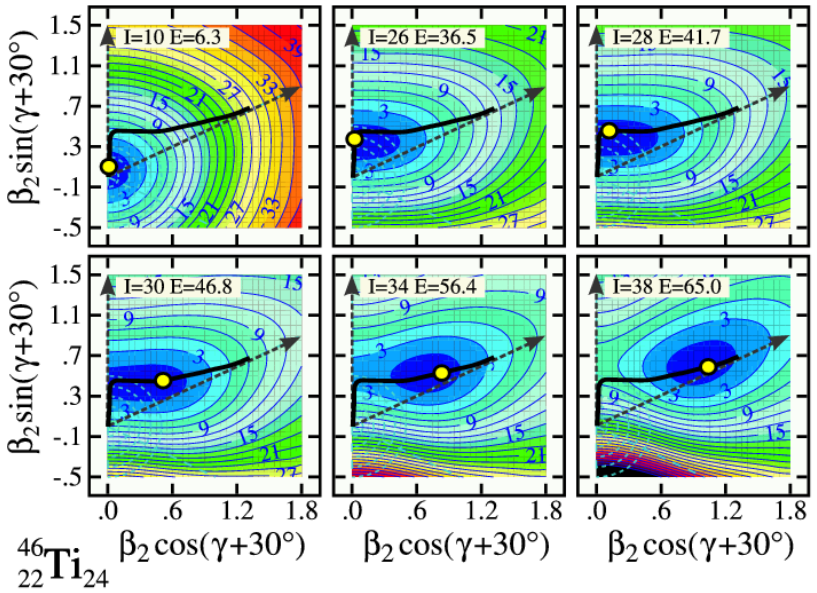
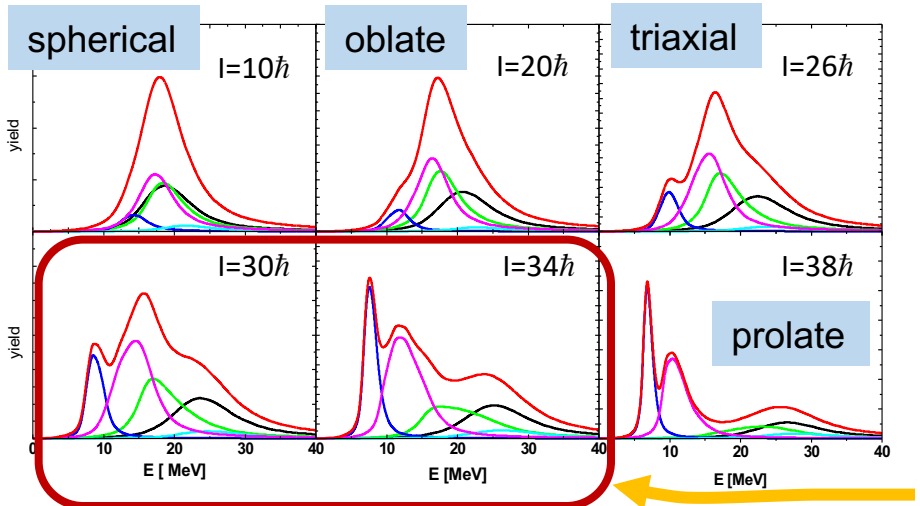
Dr. Magdalena Górska (GSI) (3)
Prof. Marek Lewitowicz (GANIL) (1,2,4,5)
Prof. Witold Nazarewicz (FRIB) (12)
Prof. Marek Płoszajczak (GANIL) (12)
Dr. Kamila Sieja (IPHC Strasbourg)

Properties of highly excited and fast rotating nuclei

LSD model predictions – energy



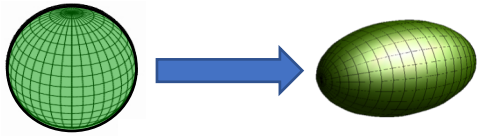
GDR strength functions



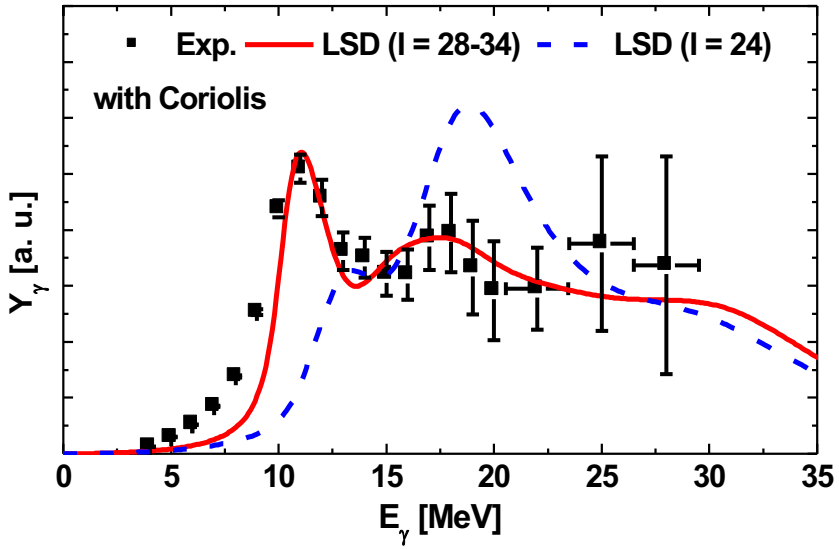
elongated triaxial

Jacobi shapes

Jacobi shape transition in ^{46}Ti



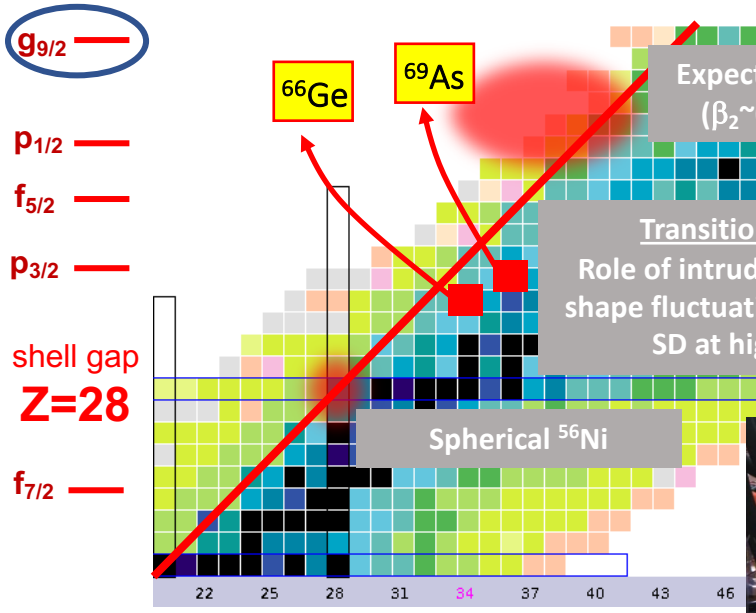
EUROBALL + HECTOR exp. @ Strasbourg

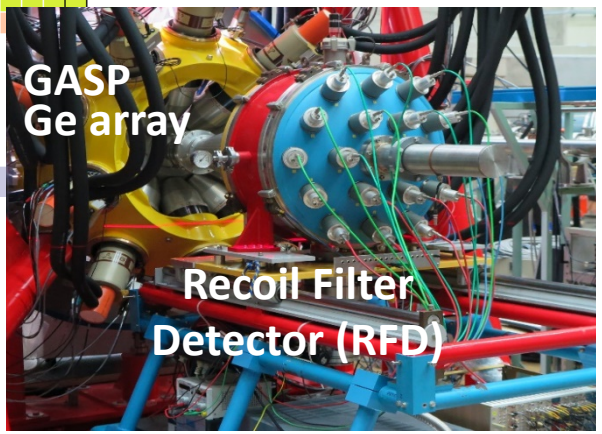


Jacobi shape transition and Coriolis effect in ^{46}Ti

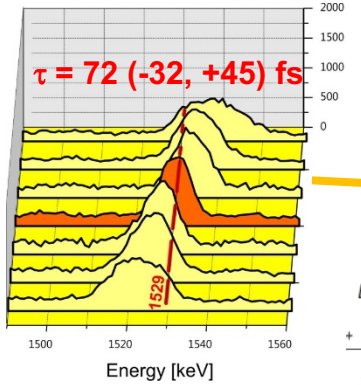
High-spin phenomena in nuclei investigated with discrete gamma-ray spectroscopy and radioactive beams

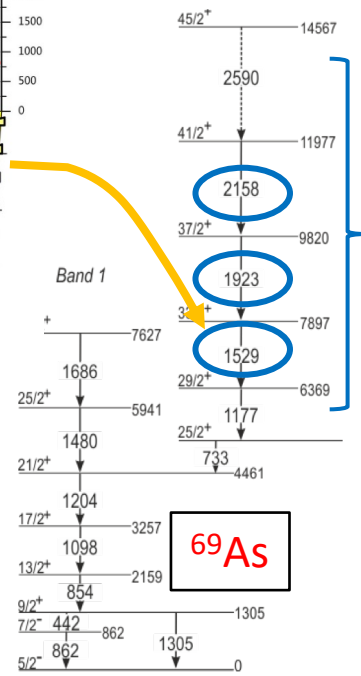
Shape transition in A~70, N~Z nuclei

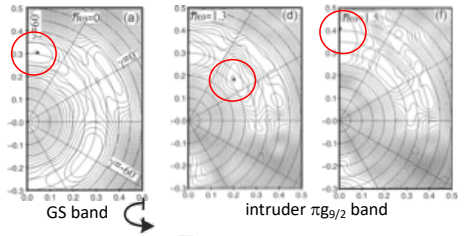


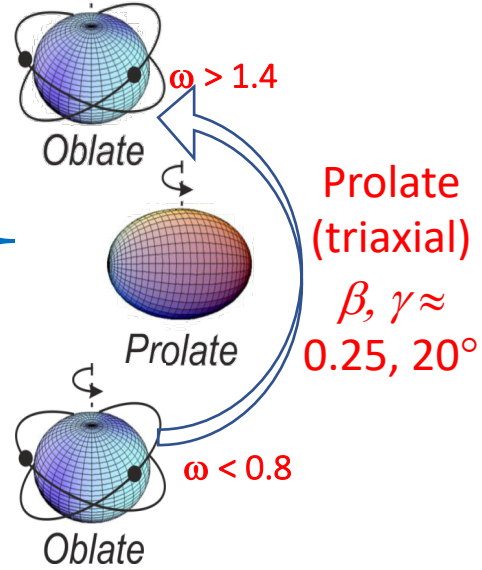


Fusion-evaporation:
95 MeV ^{32}S + 0.8 mg/cm^2 ^{40}Ca
^{69}As (3p), ^{66}Ge (α2p) at INFN LNL Legnaro (Padova)









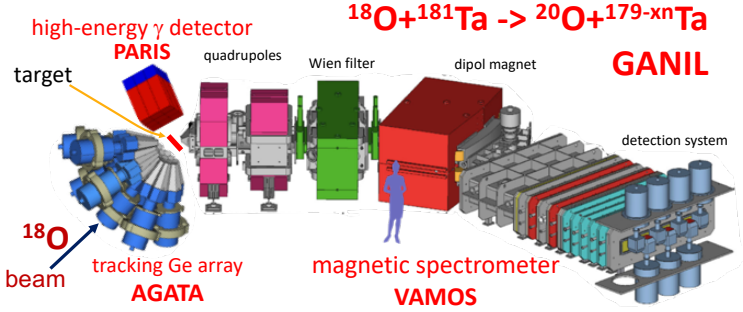
Measurement of very short lifetimes (fs) by DSAM thanks to application of the RFD for precise Doppler shift correction

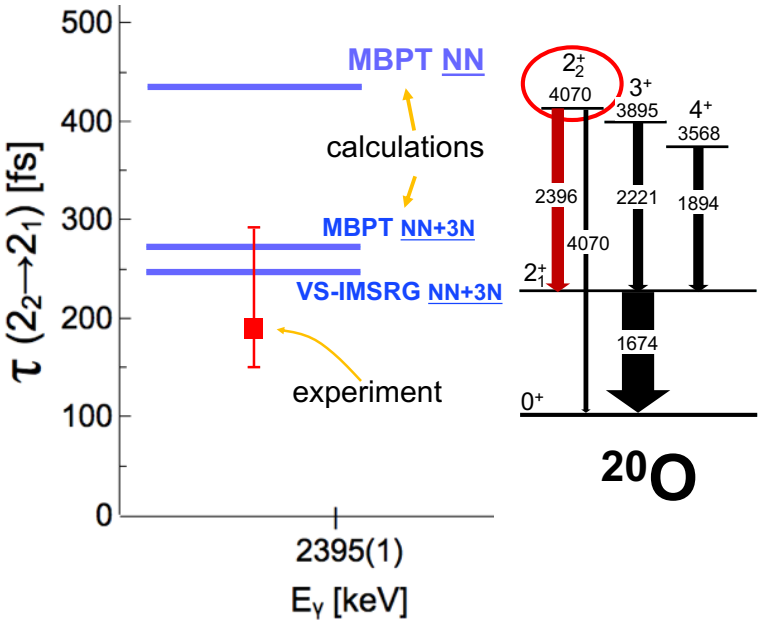
Important observation:
Very short lifetimes may indicate large beta deformation (SD), or rather moderate elongation but significant triaxiality.

M. Matejska-Minda. P. Bednarczyk, B. Fornal et. al, PRC **100**, 054330 (2019)

Nuclear structure studies using multinucleon transfer, neutron-induced fission and neutron-capture processes

Electromagnetic observables as a probe of three-nucleon forces

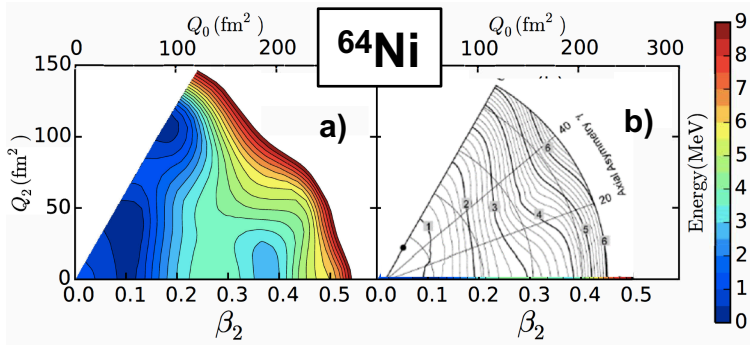




Collaboration with **Univ. and INFN Milano + AGATA + PARIS + VAMOS**

M. Ciemała *et al.*, Phys. Rev. C 101, 021303(R) (2020).

Shape coexistence driven by the monopole tensor interaction



potential energy surfaces with

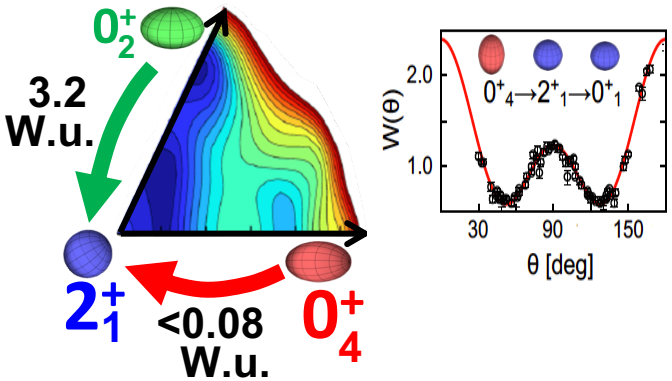
(a) MCSM with tensor force (b) Macro-Microscopic Model

EXPERIMENTS:

IFIN-HH (Bucharest, Romania): 2*n* and *p* sub-barier transfer

ILL (Grenoble, France): *n* capture on a radioactive ^{63}**Ni** target

ANL (Argonne, USA): Coulomb excitation of a ^{64}**Ni** beam



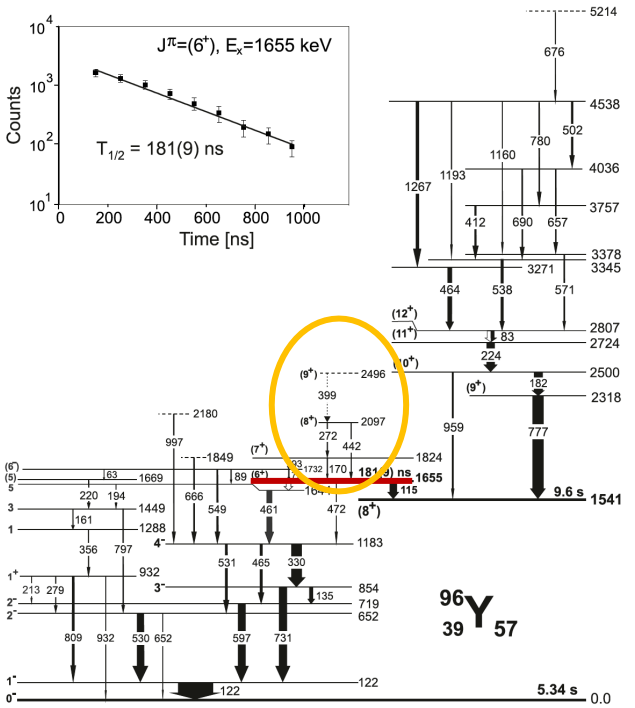
Collaboration with **Univ.+INFN Milano + IFIN-HH + ILL + ANL**

N. Marginean *et al.*, Phys. Rev. Lett. 125, 102502 (2020).

Onset of shape coexistence before N = 60

EXPERIMENT:

ILL (Grenoble, France): *neutron-induced fission* of ^{236}U



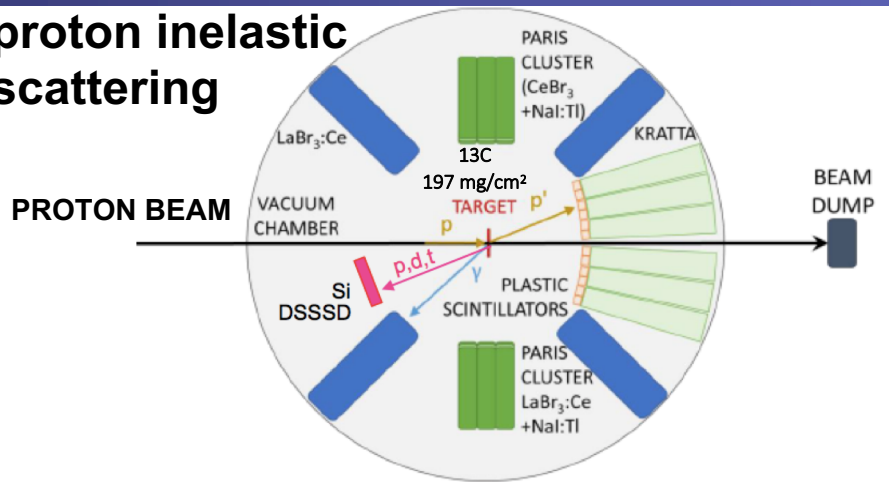
First observation of a deformed structure in the N = 57 isotone

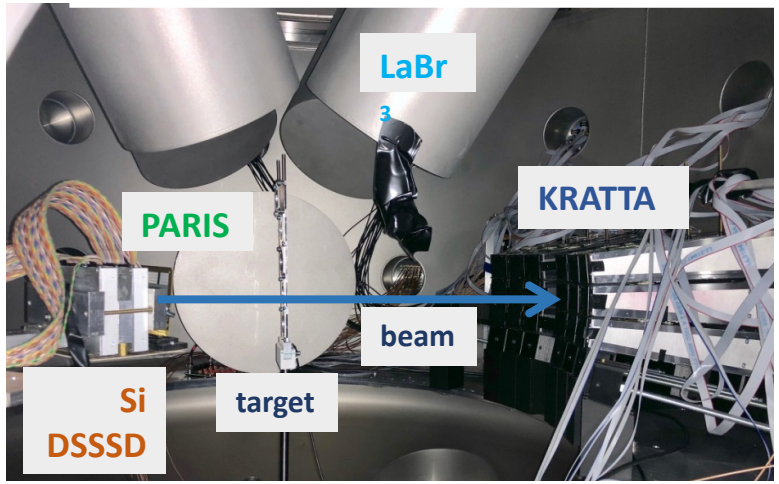
Collaboration with **Univ.+INFN Milano + ILL**

Ł. Iskra *et al.*, Phys. Rev. C (accepted)

Properties of Giant, Pygmy and M4 Resonances studied with proton beam at CCB IFJ PAN

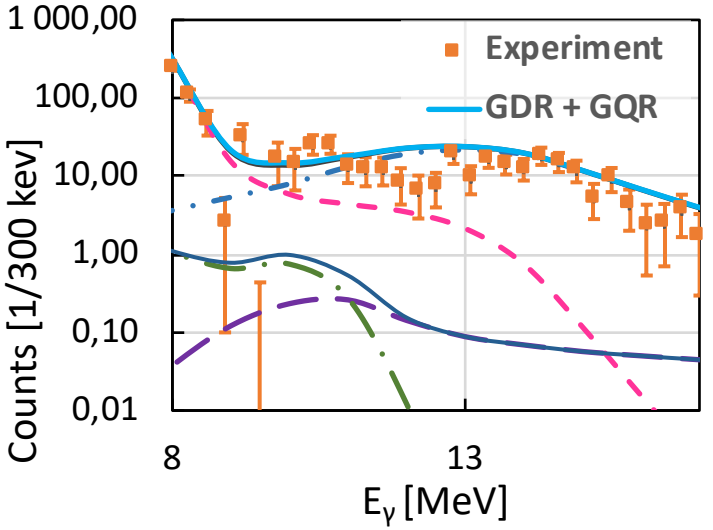
proton inelastic scattering

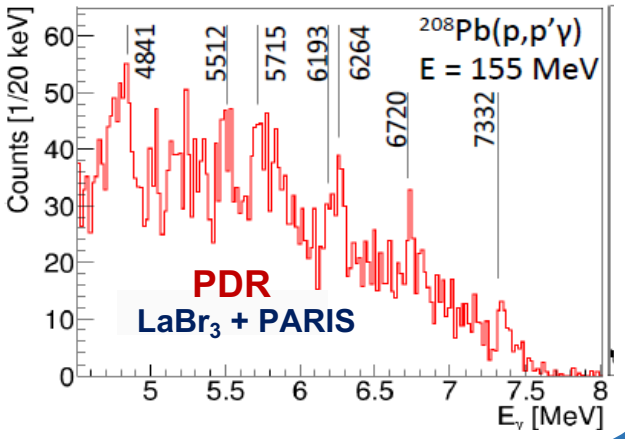




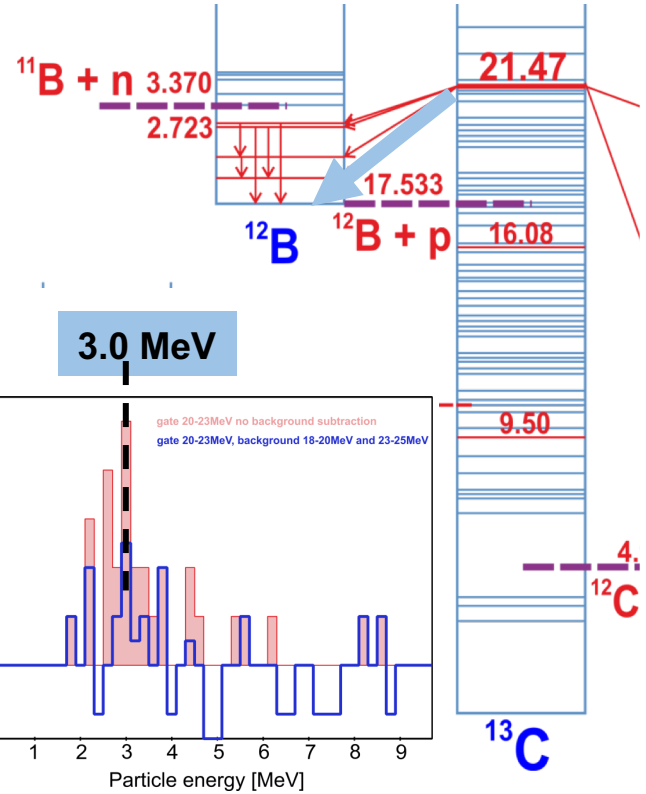
<u>Collaboration:</u> **Univ. and INFN Milano, KVI Groningen, GANIL, UW, ŚLCJ, IFIN-HH and NIPNE Bucharest, IPHC Strasburg, ATOMKI Debrecen, RCNP Osaka, IJCLab Orsay**

γ decay of Giant and Pygmy Resonances in ^{208}Pb





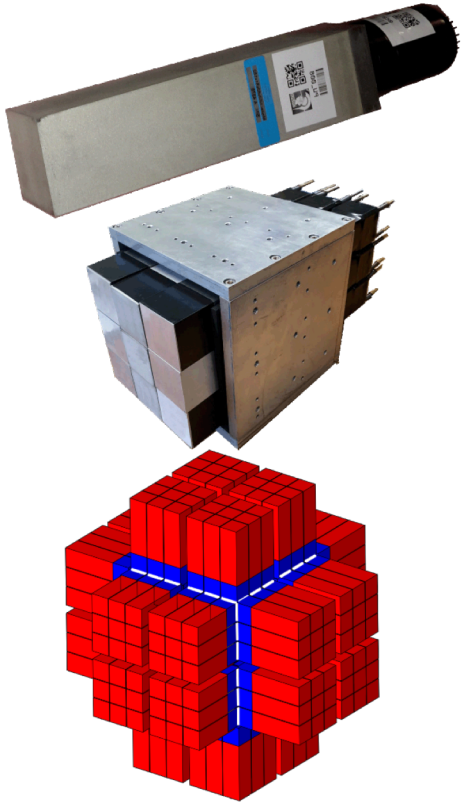
decay of M4 Resonance in ^{13}C

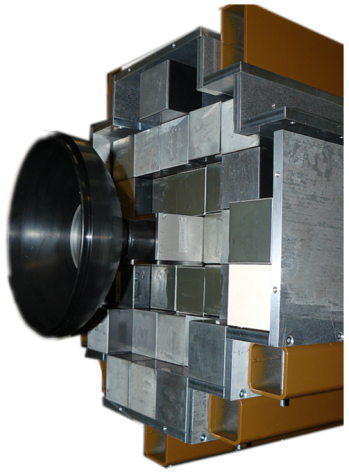


Construction of the Photon Array for studies with Radioactive Ion and Stable beams (PARIS)

PARIS is an international research project, lead by IFJ PAN, with the aim of developing and building a novel 4π gamma-ray calorimeter benefiting from recent advances in scintillator technology.

It is composed of two shells: the most advanced scintillator technology ($LaBr_3$ or $CeBr_3$) for the inner volume — offering simultaneously high efficiency and relatively good energy resolution in a large energy range (up to 40 MeV); and more conventional scintillation techniques (NaI) for the outer shell.





List of Parties

FRANCE
IN2P3/CNRS
GANIL

POLAND
Consortium COPIN

INDIA
BARC Mumbai
TIFR Mumbai
VECC Kolkata

UNITED KINGDOM
University of York
University of Surrey

ITALY
INFN

TURKEY
Nigde Univ.
Sebahattin Zaim U.
Instanbul Technical U.
Akdeniz Univ.

ROMANIA
IFIN-HH Bucharest

RUSSIA
JINR Dubna

Germany
GSI

The array will be used in experiments with both intense stable and radioactive ion beams, to study the structure of atomic nuclei and new nuclear excitation modes as a function of angular momentum, isospin, and temperature.

Few-nucleon system dynamics investigated with proton-deuteron collisions

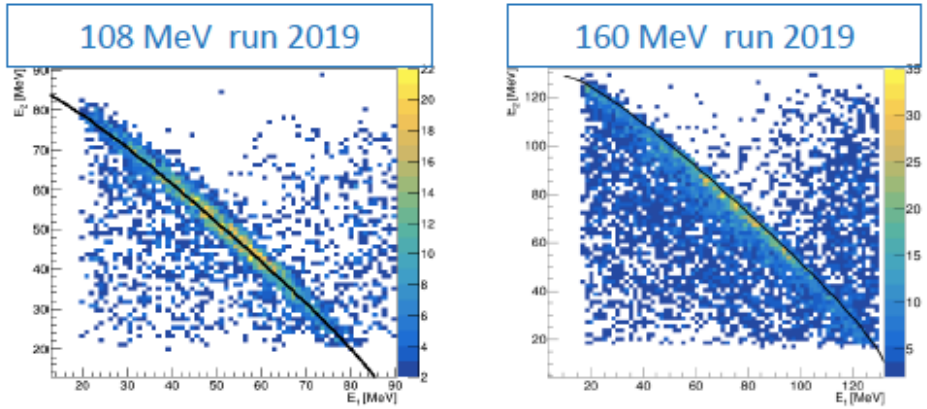
Big **I**nstrument for **N**uclear reaction **A**nalysis (**BINA**)

presently installed at CCB IFJ PAN Krakow

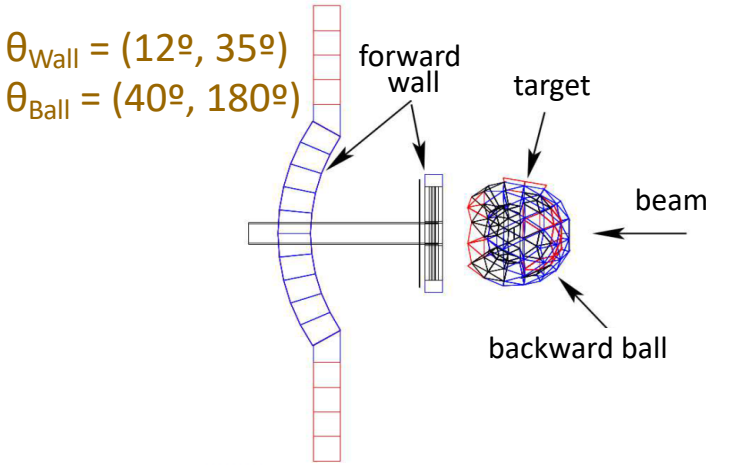
3N system studied at CCB: **p+d**

aim: tests of the chiral effective field theory (three-nucleon forces, electromagnetic and relativistic effects)

measured: elastic scattering and breakup reaction differential cross section at 108 and 160 MeV proton beam energy

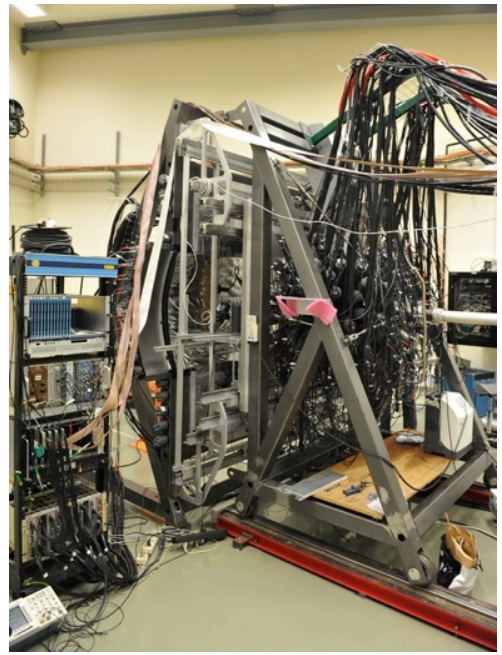


^{2}H(p,pp)n breakup reaction



Wall:
- MWPC (3 planes)
- ΔE (24 x 2 mm)
- E (20 x 120 mm)

Ball:
- Phoswich (149 x 90/30 mm)



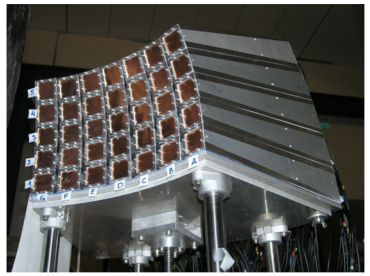
Collaborations: University of Silesia, Jagiellonian University, Warsaw University, KVI Groningen

Properties of nuclear matter (equation of state, nuclear interactions) with heavy-ion beams at intermediate energies

KRATTA

(**KRA**ków **T**riple **T**elescope **A**rray)

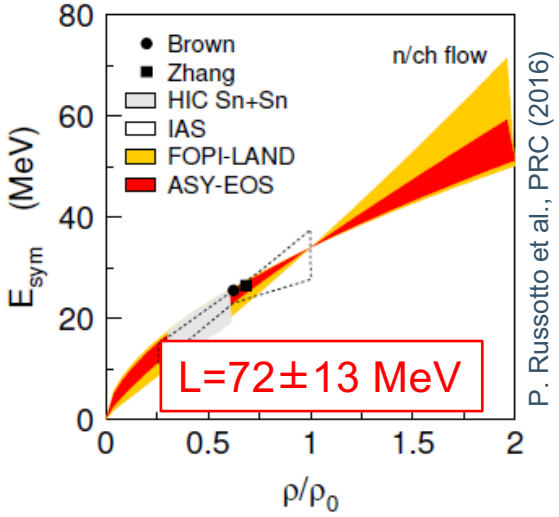
- a versatile triple telescope array for charged reaction products



J. Łukasik et al., NIM A 709 (2013) 120

MNiSW/NCN: DPN/N108/GSI/2009

ASY-EOS @ GSI 2011
KRATTA @ CCB 2016-2020



P. Russotto et al., PRC (2016)

ASY-EOS: Symmetry Energy at high densities extracted from neutron / charged particle elliptic flow ratio

KATANA

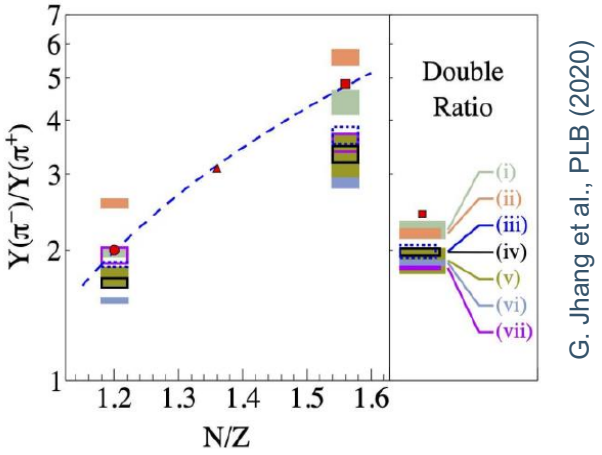
(**K**raków **A**rray for **T**riggering with **A**mplitude discrimi**NA**tion)

- a charge-sensitive trigger/veto array for the SπRIT TPC

P. Lasko et al., NIM A 856, 92 (2017)

NCN: 2013/09/B/ST2/04064, 2013/10/M/ST2/00624

SPiRIT @ RIKEN 2016



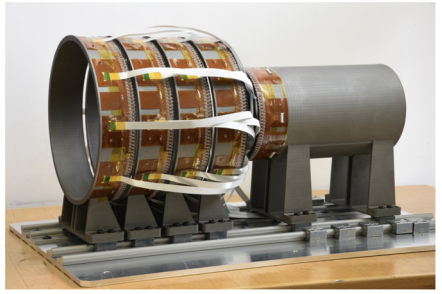
G. Jhang et al., PLB (2020)

SPiRIT: Constraints on Symmetry Energy from charged pion yield ratios as a function of N/Z

KRAB

(**KRA**ków **B**arrel)

for multiplicity and precise measurement of azimuthal distributions of charged particles

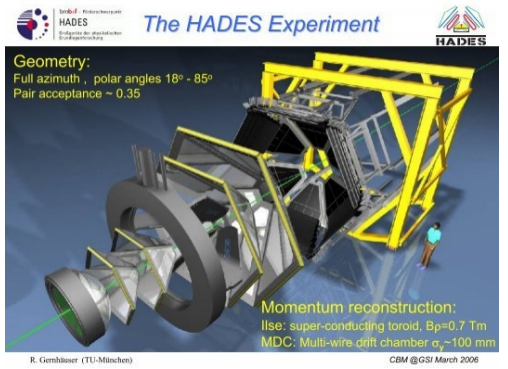


J. Łukasik arXiv:1810.01844 [nucl-ex]

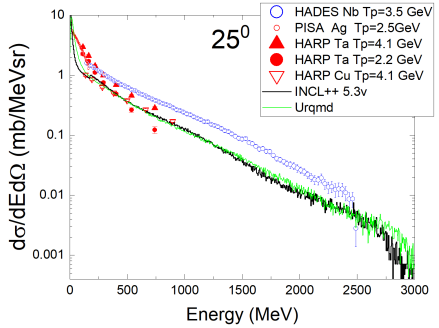
NCN: 2017/25/B/ST2/02550

ASY-EOS II @ FAIR 202?

Interactions in nuclear matter - experiment HADES



Proton production in *p*+Nb at 3.5 GeV



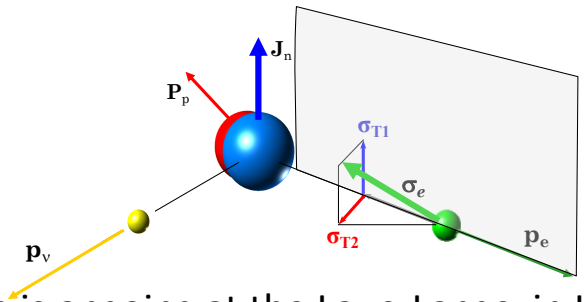
Fundamental symmetry tests with neutrons

BRAND

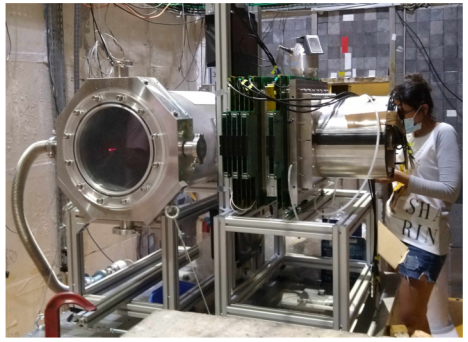
- a measurement of the momentum and transverse polarization of the electron and the proton momentum in the neutron decay.

Accessing 11 directional correlation coefficients, including 5 for the first time, with an accuracy of 10^{-4}.

The first run is ongoing at ILL, Grenoble



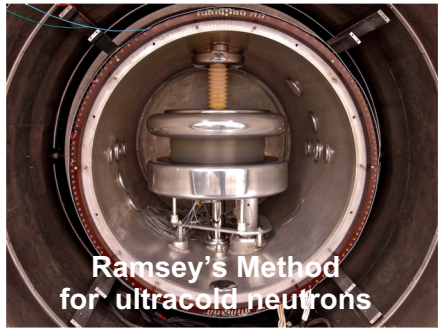
The first run is ongoing at the Laue-Langevin Institute (ILL) in Grenoble, France

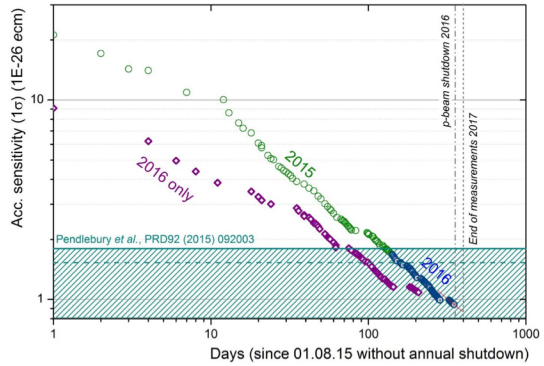


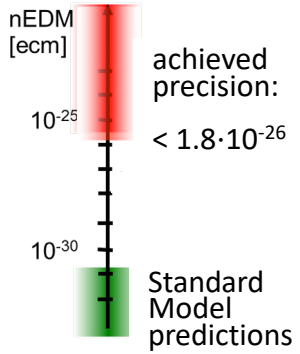
Collaboration with Jagiellonian University

nEDM

- currently the most accurate measurement of the electric dipole moment of a neutron in a single experiment at PSI, Villigen (Switzerland)



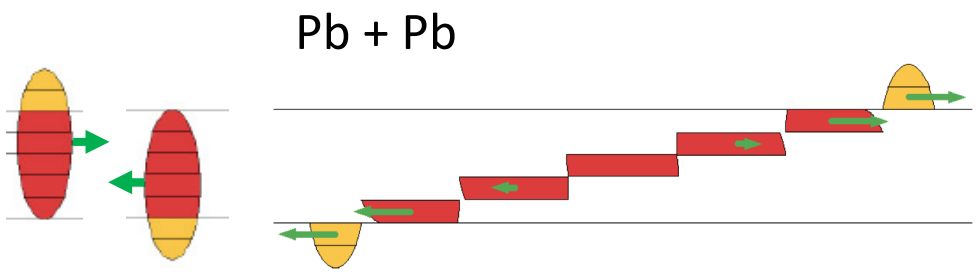


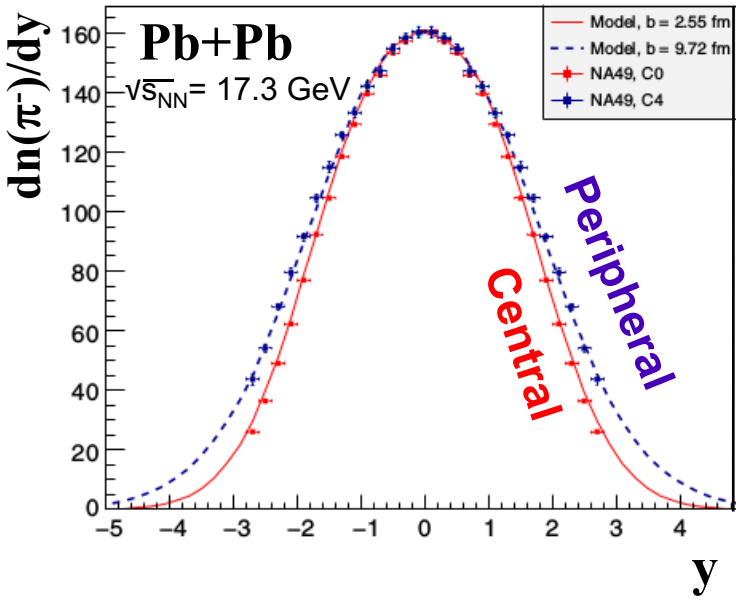


C. Abel et al., Phys. Rev. Lett. 124, 081803 (2020).

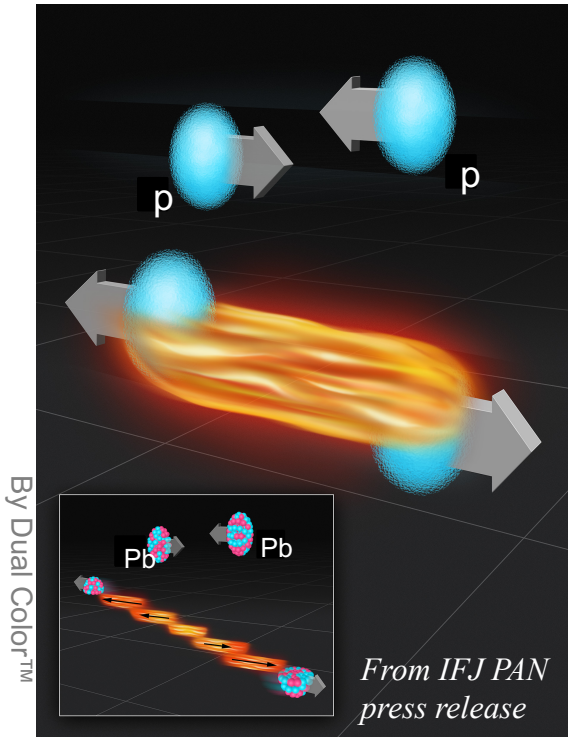
The NA61/SHINE experiment at the SPS accelerator at CERN - study of electromagnetic effects in collisions of atomic nuclei at SPS energies

The electromagnetic effects of repulsion and attraction of π^+ and π^- mesons measured by NA61/SHINE allowed the IFJ PAN group to determine that the system created in the nucleus-nucleus collision consists of several longitudinal streaks, while in the smaller p+p system only one streak may be formed.

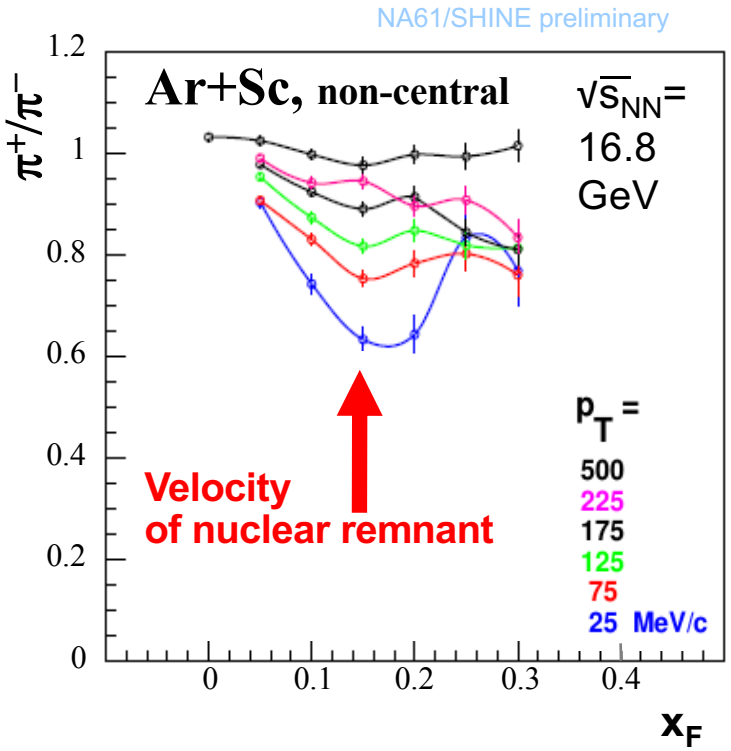




$$y = \frac{1}{2}\ln\left(\frac{E+p_L}{E-p_L}\right)$$



The electromagnetic effects of repulsion and attraction of π^+ and π^- mesons, recently observed in collision of light nuclei.



$$x_F = \frac{p_L}{p_L^{beam}}$$

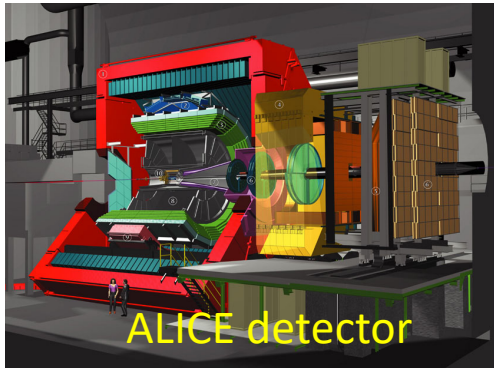
M. Kiełbowicz, A. Marcinek, Acta Phys. Polon. B50 (2019) 1127
A. Rybicki, A. Szczurek, M. Kiełbowicz *et al.*, Phys.Rev.C 99 (2019) 2, 024908
V. Ozvenchuk *et al.*, Phys.Rev.C 102 (2020) 1, 014901

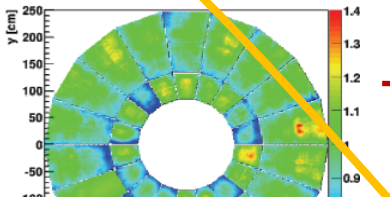
The ALICE experiment at the Large Hadron Collider (LHC@CERN)

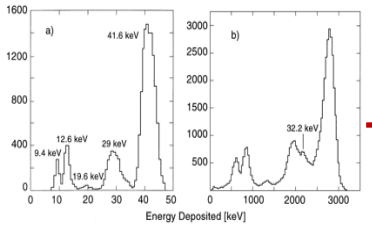
ALICE: A Large Ion Collider Experiment – dedicated heavy ion experiment at CERN LHC

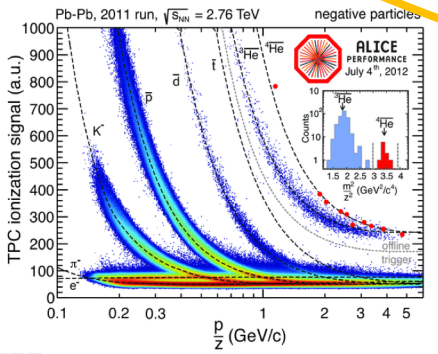
IFJ PAN activity:

- Detector upgrade
- Simulation and calibration of the TPC
- Design and simulation of the AD and FIT detectors
- Studies of ultraperipheral collisions (Krakow specialty)
- Studies of forward-backward correlations

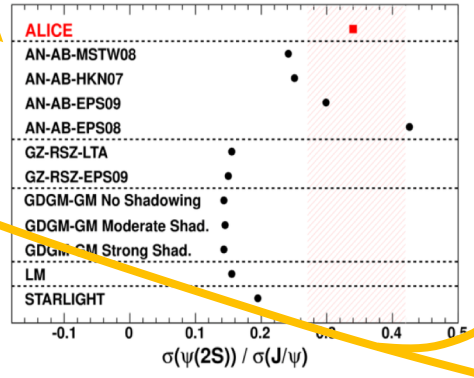




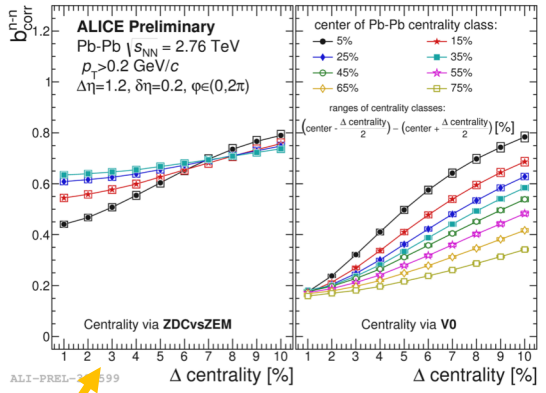


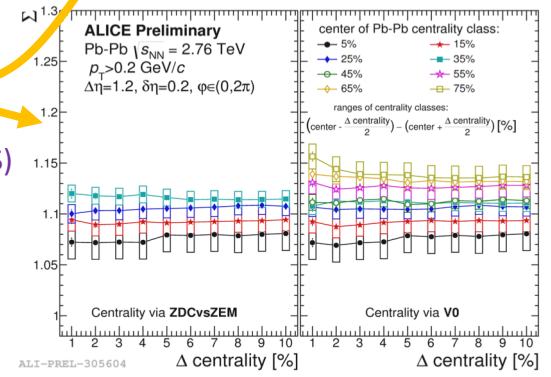


Production of Ψ(2S) in ultraperipheral collisions Pb+Pb



The nuclear environment acts differently on the production of Ψ(2S) comparing to J/Ψ (1S)

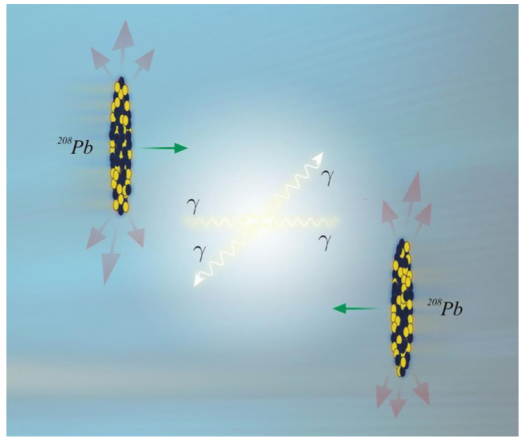


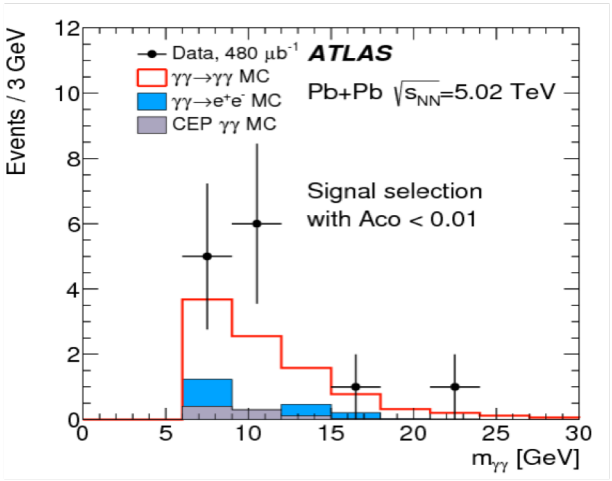


Theoretical investigations of the dynamics of nuclear many-body systems

Photon induced processes, and real and virtual photon emission in ultraperipheral, ultrarelativistic heavy-ion collisions

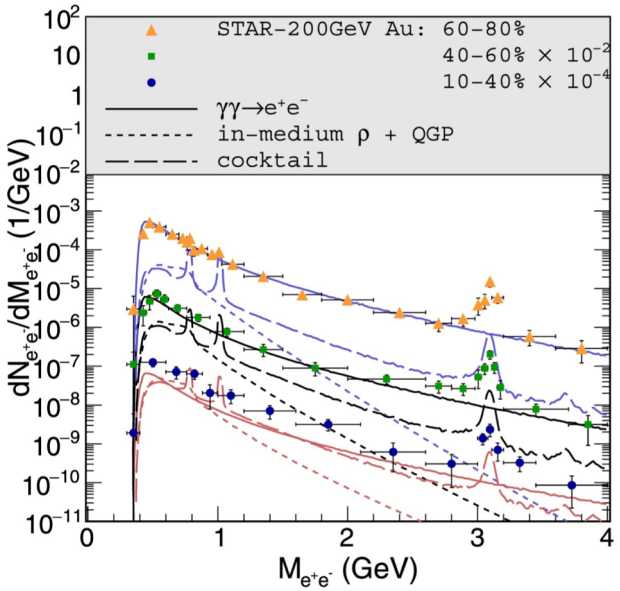
Light-by-light scattering studied with Pb+Pb collisions





Diphoton invariant mass for Pb-Pb UPC. Data (points) are compared to theory predictions (histograms).

Dilepton production in Au+ Au collisions



Dielectron invariant-mass spectra in Au+Au collisions for 3 centrality classes including experimental acceptance cuts for *γγ* fusion* (solid lines), thermal radiation (dotted lines) and the hadronic cocktail (dashed lines). Comparison to STAR data.

First verification that the photon fusion is the missing process to a correct description of the low-PT invariant-mass as well as PT (pair transverse momenta) spectra for different centrality classes.

Theoretical results on L-by-L scattering obtained at the IFJ PAN* inspired the first measurement which was performed at ATLAS@LHC**.

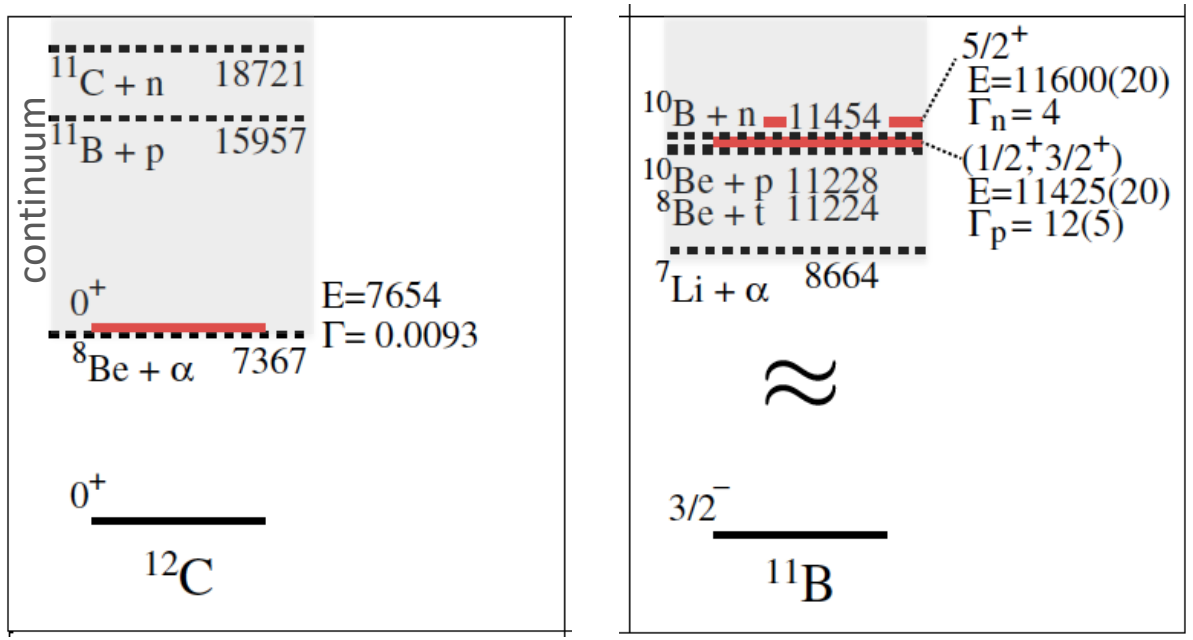
* M. Kłusek-Gawenda, P. Lebiedowicz & A. Szczurek, Phys. Rev. **C93** (2016) 044907

**ATLAS Collaboration, Nature Phys. 13 (2017) 852

*M. Kłusek-Gawenda, R. Rapp, W. Schaefer & A. Szczurek, Phys. Lett. **B790** (2019) 339

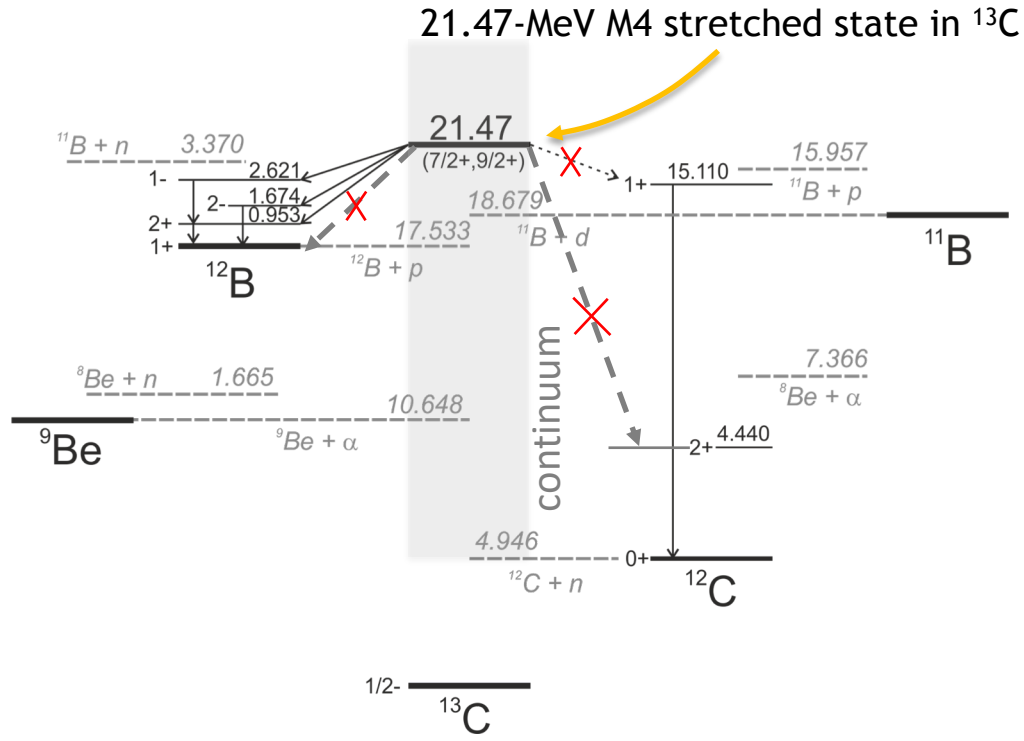
Shell-Model in the Continuum (Gamow SM and SMEC)

Near-threshold collectivization and clusterization within the shell model embedded in the continuum (SMEC) - the effect of internal configuration mixing by interactions and external configuration mixing via decay channels.



Near-threshold collectivization may have a noticeable effect on electromagnetic transitions and nuclear moments and, in particular, may modify the γ-decay selection rules for states close to the particle decay thresholds.

Gamow Shell Model predictions for the decay of M4 resonances



J. Okołowicz , M. Płoszajczak, and W. Nazarewicz, Phys. Rev. Lett. 124, 042502 (2020)

Neutron and gamma spectroscopy for nuclear fusion research: IFMIF-DONES and ITER

International Fusion Irradiation Facility – DEMO-Oriented Neutron Source

EUROfusion WPENS, DONES Preparatory Phase project

IFMIF DONES

„a dedicated facility for material qualification that reproduces a 14 MeV neutron spectrum from D+T reaction with reasonable irradiation volume and fluence"

- ✓ Conceptual design of the Start-up and Monitoring Module (STUMM) for DONES
- ✓ Modelling of the radiation field in the irradiation cell and surrounding rooms of the DONES laboratory
- ✓ Design of the Facilities for Complementary Experiments

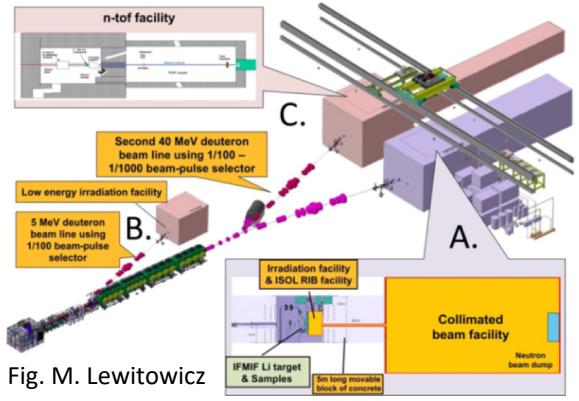
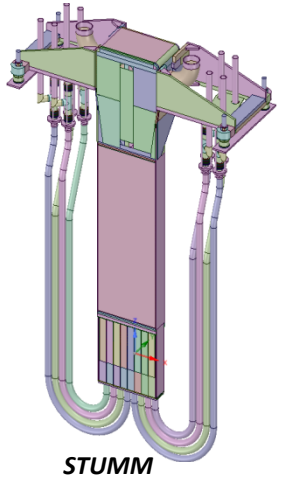


Fig. M. Lewitowicz



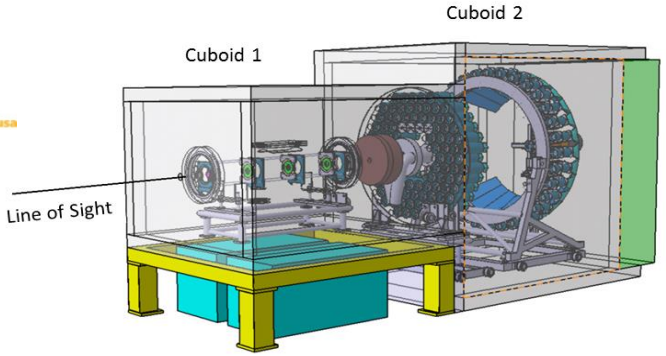
STUMM

A. Ibarra, W. Królas, et al., Nuclear Fusion 58, 105002 (2018)

High Resolution Neutron Spectrometer for ITER

Project Fusion for Energy GRT-403, IFJ PAN and Uppsala University

iter
china eu india japan korea russia usa



HRNS will consist of 4 spectrometers to determine the plasma ion ratio n_t/n_d for different ITER operating scenarios:

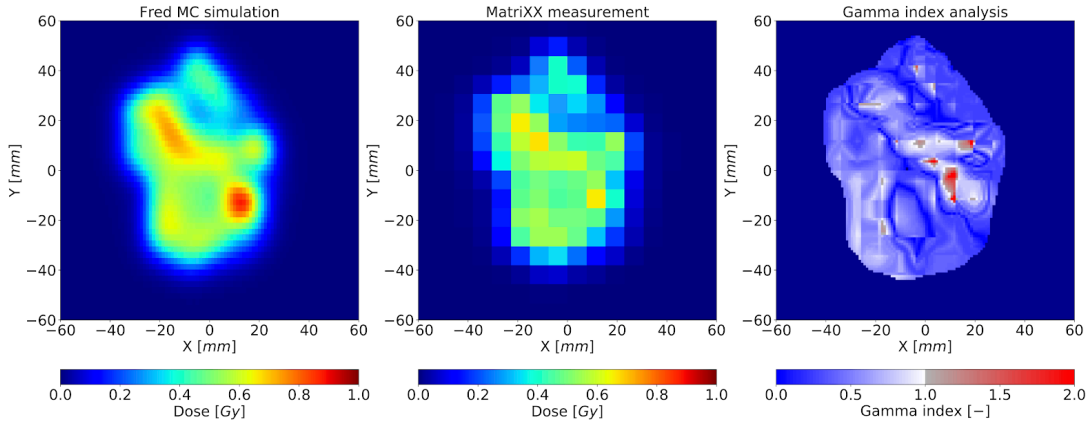
- ✓ Forward time-of-flight neutron spectrometer
- ✓ Thin foil proton recoil neutron spectrometer
- ✓ Magnetic proton recoil neutron spectrometer
- ✓ Annular proton recoil neutron spectrometer
- ✓ Neutron diamond detectors (sCVD) developed to be used as principal sensors
- ✓ Large sensitivity range: $0.01 < n_t/n_d < 10$

HRNS proposal was accepted by **ITER** (IO) as *Conceptual Design* (2019), work ongoing on the Preliminary Engineering Design

M. Scholz, et al., Nuclear Fusion 59, 065001 (2019)

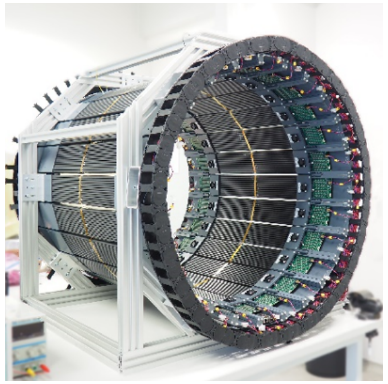
Range and Relative Biological Effectiveness uncertainties in proton therapy

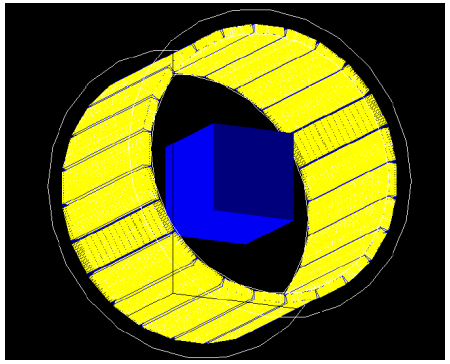
Quantification of biological range uncertainties towards an improved patient treatment in CCB Cracow proton beam therapy centre - project Foundation for Polish Science – POWROTY/2016-2/6 (2016 – 2020) (coordinator: dr. A. Rucinski)



Fast Monte Carlo proton transport code FRED implemented on graphic cards allows for fast verification of treatment plans for patients at CCB

PET technology for proton beam therapy range monitoring - project LIDER, 0157/L-8/2016, NCBiR, (2017-2020) (coordinator: dr. A. Rucinski)



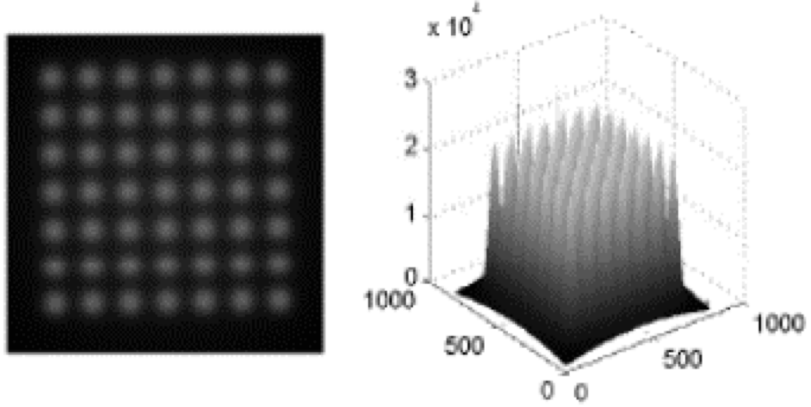


It was demonstrated that J-PET organic scintilattor scanner could be aplied for verification of proton range for patients treated using Pencil Scanning Beam technology

Dosimetry of primary beam and scattered radiation in proton therapy

Infrastructure in Proton International Research - INSPIRE -
project Horizon2020, 730983-2
(2018 – 2021) IFJ PAN
(coordinator: Prof. P.Olko)

Measured intensity of 60 MeV proton minibeams passing 1 mm mesh collimators at AIC-144



In GRID therapy separated proton minibeams (1 mm in diameter) lead to lower skin reaction. The microbeam concept, tested on AIC-144 cyclotron, could be applied e.g. in the proton therapy of eye melanoma at CCB to spare the eye lead.

EURADOS (EUropean RAdiation DOSimetry Group) -
Working Group SG9.2 *Dosimetry in Hadron Therapy*
(2014 – 2020) (coordinator: Prof. P.Olko)

Extensive measurement of scattered radiation in CCB gantry room demonstrated that the unwanted doses to patients are at least one order of magnitude lower than in classical radiotherapy with MV X-rays

L. Stolarczyk, et al., Phys. Med. Biol., 63 (2018) 085017.
M. Liszka, Med. Phys., 45 (2018) 391-401.


Widowisko z muzyką Józefa Skrzeka
oraz narracją filmową Jerzego Grębosza
Między mikroświatem atomów a ogromem Wszechświata
Na styku dwóch nieskończoności
żyjemy My, przez jedno mgnienie oka
Koncepcja i reżyseria: Adam Maj
z wykorzystaniem tekstów Krzysztofa Niewrzędy
45. ZJAZD FIZYKÓW POLSKICH
Auditorium Maximum UJ, Kraków,
15 września 2019 r., godz. 20
Projekt: Jerzy Grębosz, Foto: Łukasz Pawlikowski oraz NASA
wg scenariusza Adama Maja, Jerzego Grębosza, Marka Riley'a, Bogdana Fornala