Overview of nuclear physics theory in Belgium

Jean-Marc Sparenberg
Brussels Free University (ULB)

with special thanks to Joseph Cugnon, Kris Heyde, Frans Arickx, Stéphane Goriely, Christiane Leclercq, Pierre Descouvemont, Pierre Capel, Paul-Henri Heenen, and all Belgian nuclear theorists!

NuPECC meeting, FRS-FNRS, June 12, 2009

Belgian nuclear theorists (permanent)

Gent: 4

Brussels (ULB): 6

Brussels (VUB): /

Louvain-la-Neuve: /

Mons: 1

Antwerp: 2

Mol: exp

Hasselt: /

Leuven: exp

Liège: 7

Namur: exp

Total: 20, decreasing!

Common features (I won't speak about)

- publications: several per year
- docs and postdocs: several for each
- international collaborations: several for each
- collaborations with experimentalists: most of the time
- grants: « regional », national (IAP program), european

Large variety of subjects

PNT – Mons University

Research unit

- Theoretical Nuclear Physics (PNT, sciences faculty)

Permanent staff

- SEMAY Claude (FNRS Research Associate)

Research themes

- hadron (meson) spectroscopy with constituent quark model
- gluons: glueballs, gluon plasma

CoMP – Antwerp University

Research unit

- Computational Modeling and Programming (CoMP, sciences faculty, mathematics and computer science department)

Permanent staff

- ARICKX Frans (UA Full Professor)
- BROECKHOVE Jan (UA Full Professor)

Research themes (mostly) outside nuclear physics

- grid/distributed computing
- computational modeling of complex systems (electronics, molecular physics...)

Universiteit Antwerpen

CoMP – Antwerp University

Computational quantum scattering

- J-matrix method in oscillator formulation
- hybrid implicit/explicit time evolution algorithms for
  large-scale molecular and nuclear scattering

Nuclear physics applications

- microscopic 3 (or more) cluster models for light nuclear systems
  (hyperspherical/bi-oscillator bases, Faddeev-like expansion)
  (self-scheduling parallel computing algorithm when necessary)
- nuclear spectroscopy: resonances in ^{4}H, ^{5}H, ^{4}He, ^{4}Li, ^{7}Be
- nuclear reactions: ^{6}Li (p,^{3}He) ^{4}He

CMM – Gent University

Research unit

- Center for Molecular Modeling
  (CMM, sciences and applied sciences faculties)

Permanent staff involved in nuclear physics (out of 3)

- VAN NECK Dimitri (UG Full Professor)

Research themes outside nuclear physics

- microscopic molecular physics

Research themes in (or with possible applications in) nuclear physics

- nuclear self-energy parametrizations from dispersive optical model
  Application: Ca isotopes
- Green's function calculations with Faddeev-RPA self-energy
- variational determination of 2-body density matrix from semidefinite program techniques

NS – Gent University

Research unit

- Nuclear Structure and correlations in the nuclear many-body system
  (NS, sciences faculty, subatomic and radiation physics department)

Permanent staff

- HEYDE Kristiaan (UG Full Professor, recently retired)

Research themes

- geometrical Bohr-Mottelson model (new analytic solutions, algebraic Cartan-Weyl perspective)

- shape coexistence and phase transitions (+ connection with deformation using group theory)
  examples: intruder configurations in the Pb region

- changing mean-field in exotic nuclei (study of realistic/schematic forces, pairing, multipole excitations... in shell-model perspective)
  examples: Z, $N = 29$, 51 regions

TMEP – Gent University

Research unit

- Theoretical Medium Energy Physics
  (TMEP, sciences faculty, subatomic and radiation physics department)

Permanent staff

- RYCKEBUSCH Jan (UG Full Professor)

- JACHOWICZ Natalie (UG Full Professor, recently appointed)

Research highlights

- Development of reaction models involving finite nuclei

- Study of the crossover between hadronic and partonic degrees of freedom

- Structure of the nucleon (strangeness content, sea quarks)

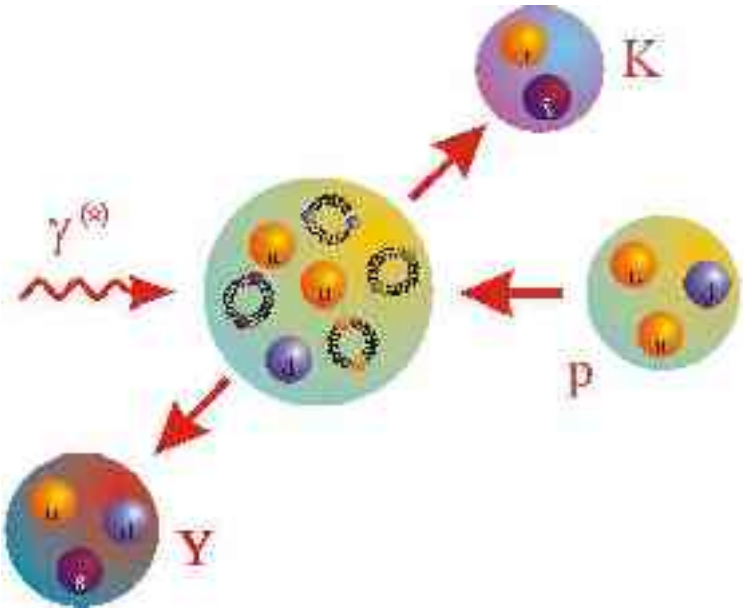
TMEP – Gent University

1. Nucleon and pion propagation through nuclei

- global relativistic « hadronic » calculations of cross sections like
  A(p, pp), A(p, pn), A(γ, Nπ), A(e, e'π), A(e, e'p), A(e, e'pp), A(e, e'pn)

2. Strangeness production on the nucleon

- study of p(γ, K)Y and p(e, e'K)Y processes:
  « missing resonances »?
  analysis of hypernuclei?



- effective-lagrangian approach at tree level
  with hybrid Regge+resonance approach

3. Neutrino interactions with nuclei

- calculation of nucleon and pion production
  motivation: analysis of long-baseline experiments

- included: final-state interactions, Δ properties in nuclear medium,
  nucleon strangeness content...

PNTPM / PQ – Brussels University (ULB)

Research unit

- Theoretical Nuclear Physics and Mathematical Physics (PNTPM, sciences faculty, physics department)
- Quantum Physics (PQ, applied sciences faculty)

Permanent staff

- DESCOUVEMONT Pierre (FNRS Senior Research Associate)
- HEENEN Paul-Henri (ULB Full Professor)
- BAYE Daniel (ULB Full Professor)
- SPARENBERG Jean-Marc (ULB Junior Professor)

Research themes outside nuclear physics

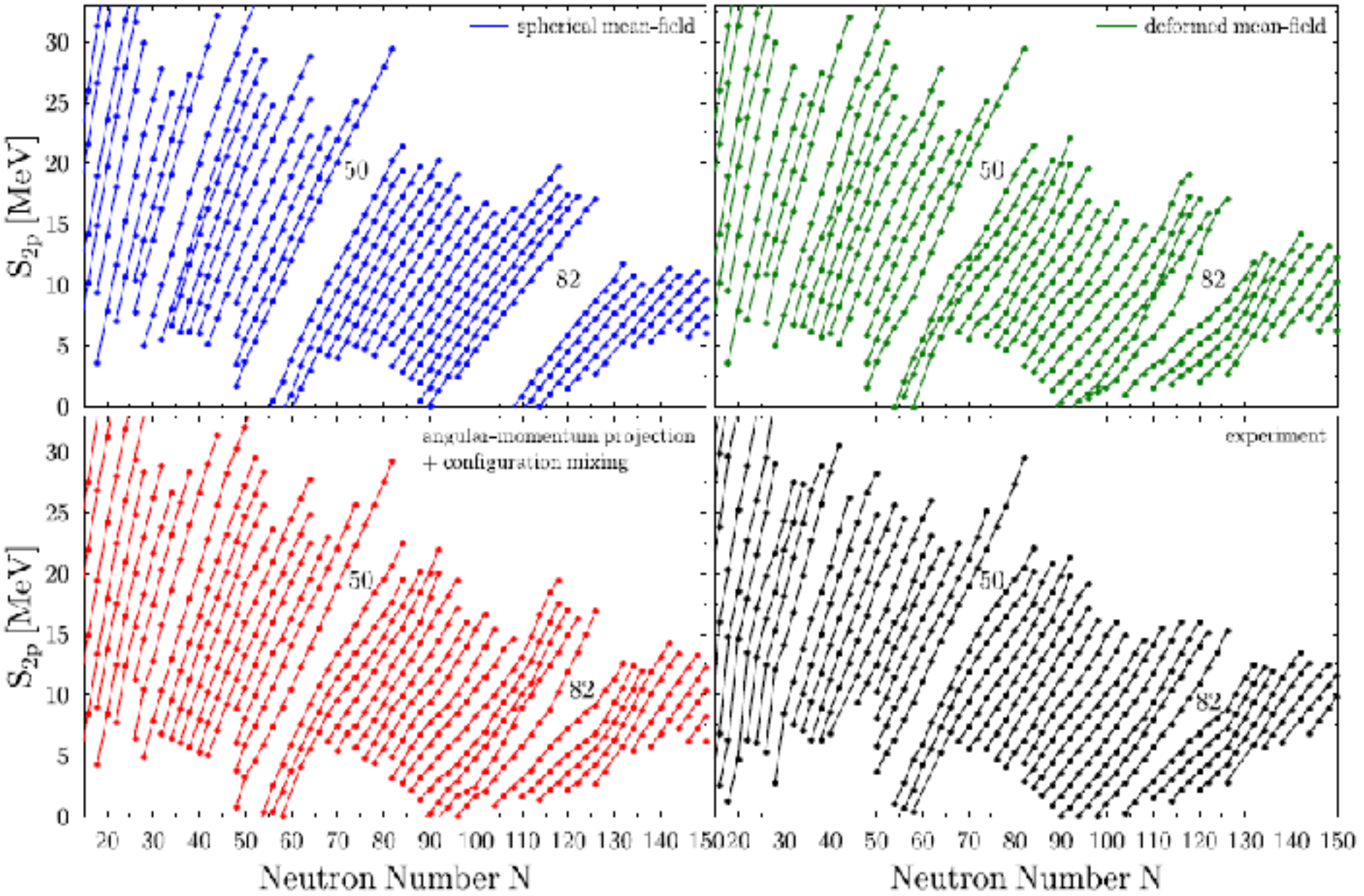
- mathematical physics
- atomic physics

PNTPM / PQ – Brussels University (ULB)

1. Nuclear spectroscopy (recently: exotic nuclei)

- cluster models (microscopic, non-microscopic): light nuclei
  - ❑ microscopic: all nucleons are taken into account → predictive power
  - ❑ non-microscopic: based on nucleus-nucleus interactions → simple
  - ❑ can be applied to spectroscopy **and** reactions
  - ❑ examples: ^{6}He = α+n+n, ^{12}C = α+α+α, ^{19}C = ^{18}C+n…
- mean-field calculations: heavy nuclei
  - ❑ restoration of rotational symmetry
  - ❑ superheavy nuclei
  - ❑ examples: - spectra and transition probabilities in nuclei in the vicinity of neutron deficient Pb isotopes
    - **global calculations (625 nuclei) of correlation energies**

PNTPM / PQ – Brussels University (ULB)



2-proton separation energy [Bender, Bertsch, Heenen, PRC 2008]

PNTPM / PQ – Brussels University (ULB)

2. Nuclear reactions:

- nuclear astrophysics (elastic, inelastic, transfer, capture at low energies)
  - ❑ microscopic and non-microscopic cluster models: ^{14}O+p, α+^{6}He, ^{18}F(p,α)^{15}O, ^{7}Be(p,γ)^{8}B...
  - ❑ R-matrix fits of experimental data: ^{12}C(α,γ)^{16}O...
- breakup
  - ❑ dynamical eikonal approximation, CDCC recently started
  - ❑ examples: ^{11}Be+^{208}Pb, ^{6}He+^{208}Pb, **^{8}B+^{208}Pb**...
- 3-body continuum states
  - ❑ hyperspherical formalism (non-microscopic): ^{12}Be+n+n
  - ❑ extension to microscopic theories: α+n+n
- inverse scattering problem
  - ❑ supersymmetric quantum mechanics: nucleon+nucleon

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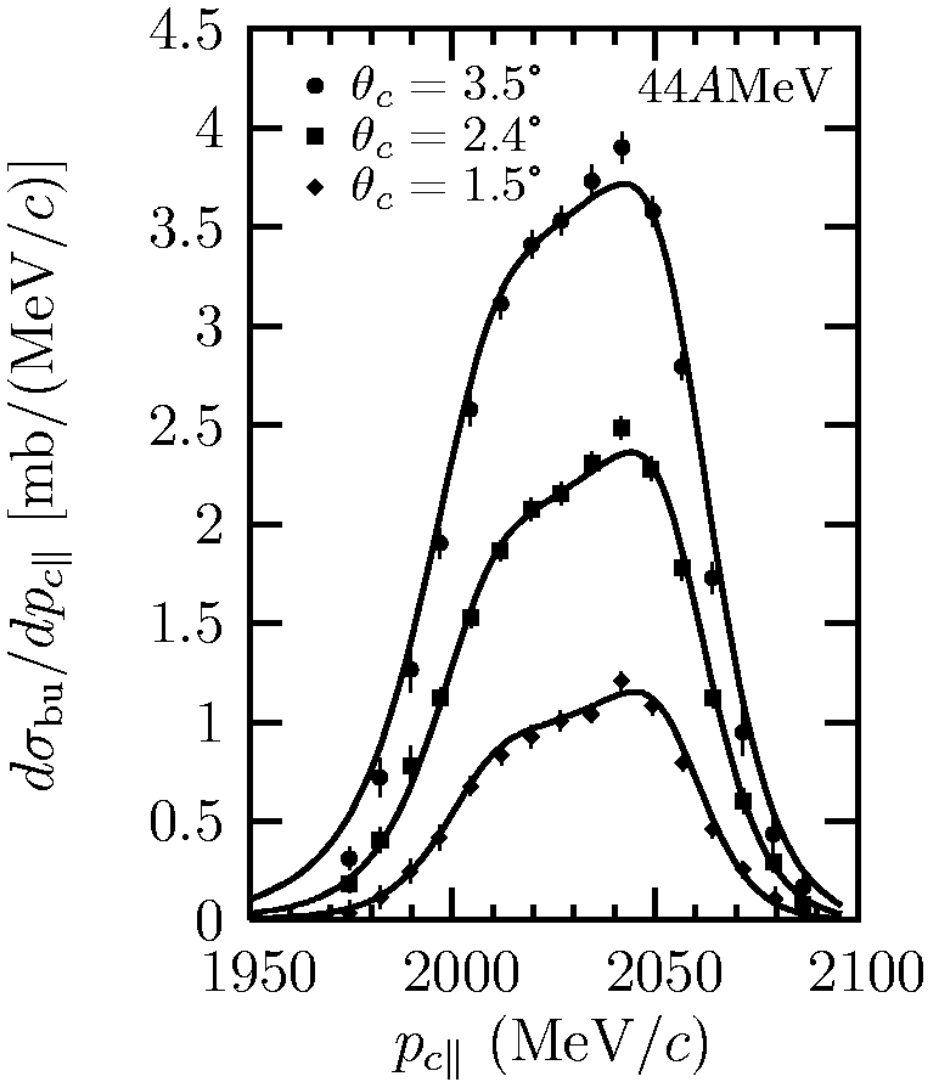


^{8}B breakup on ^{208}Pb

- ^{8}B = ^{7}Be+p one-proton halo nucleus
- astrophysical interest: breakup = inverse reaction of ^{7}Be(p,γ)^{8}B
- data: MSU [Davids, PRL'01]
- model: dynamical eikonal approx. [Baye, Capel, Goldstein, PRC'06]

IAA – Brussels Free University (ULB)

Research unit

- Astronomy and Astrophysics Institute
  (IAA, sciences faculty, physics department)

Permanent staff (out of 6)

- GORIELY Stéphane (FNRS Research Associate)
- CHAMEL Nicolas (FNRS Research Associate)

Research themes outside nuclear physics

- stellar evolution and chemical composition
- binary stars
- Modified Newtonian Dynamics

IAA – Brussels Free University (ULB)

Nuclear physics for astrophysics applications

- challenge: universal global microscopic description of nuclei
- nuclear structure with HFB mean field method, « universal » effective interaction, constrained on nuclear/neutron matter:
  accurate tables of nuclear masses, radii, deformations, charge densities...
- nuclear reactions with (semi-)microscopic models:
  fission paths, level densities, γ-ray strength function, optical potentials...
- ~8000 nuclei, $8 \leq Z \leq 110$, from p- to n-drip lines
- compilation of reaction rates (update of NACRE):
  p- and α-capture on stable (up to Si) and unstable ($A<40$) nuclei
- application to stellar evolution and nucleosynthesis:
  S-, P-, R-processes in AGB stars, supernovae, neutron stars...
- nuclear band theory for inner regions of neutron star crusts

IFPA – Liège University

Research unit

- Fundamental Interactions in Physics and Astrophysics (IFPA, sciences faculty, astrophysics, geophysics and oceanography department)

Permanent staff

- CUGNON Joseph (ULg Full Professor)
- STANCU Floarea (ULg Full Professor)
- SARTOR Renato (ULg Researcher)
- CUDELL Jean-René (ULg Researcher)
- JAMINON Martine (ULg Researcher)
- BAWIN Michel (FNRS Senior Research Associate)
- STASSART Pierre (FNRS Research Associate)

Research themes outside nuclear physics

- QCD
- standard model
- astroparticles

IFPA – Liège University

1. Nuclear models

- nuclear matter (Brueckner-Bethe-Goldstone theory):
  convergence with 3-body graphs
- spallation reactions (INCL4(Liège)-KHSvp(GSI) model):
  IntraNuclear Cascade + evaporation/fusion model
  motivation: physics of spallation sources and ADS machines
- antiproton annihilation on nuclei

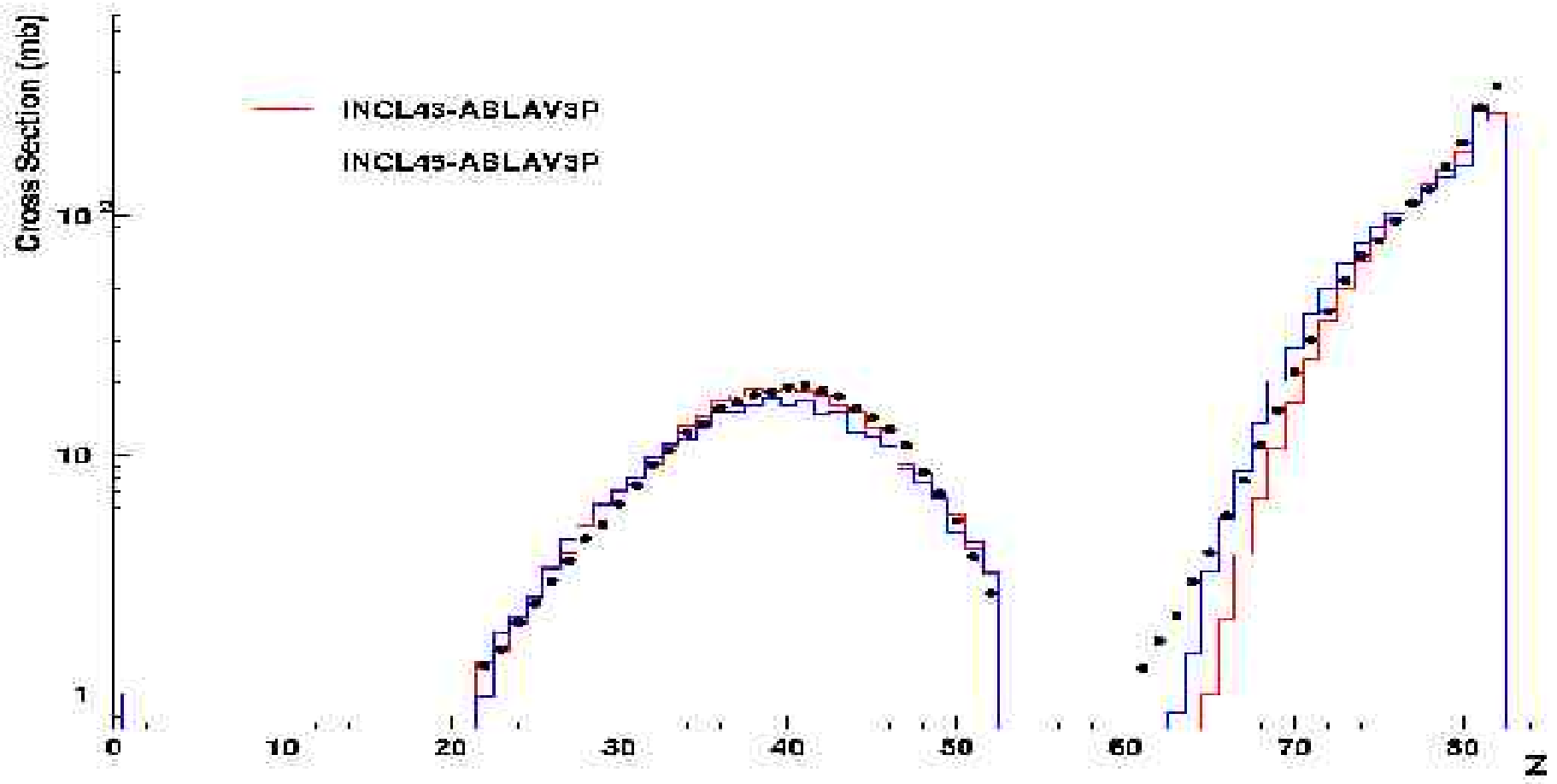
2. Hadron structure

- constituent quark model for exotic baryons:
  stability, effects of heavy quarks, symmetry...

3. Fundamental interactions: QCD phenomenology

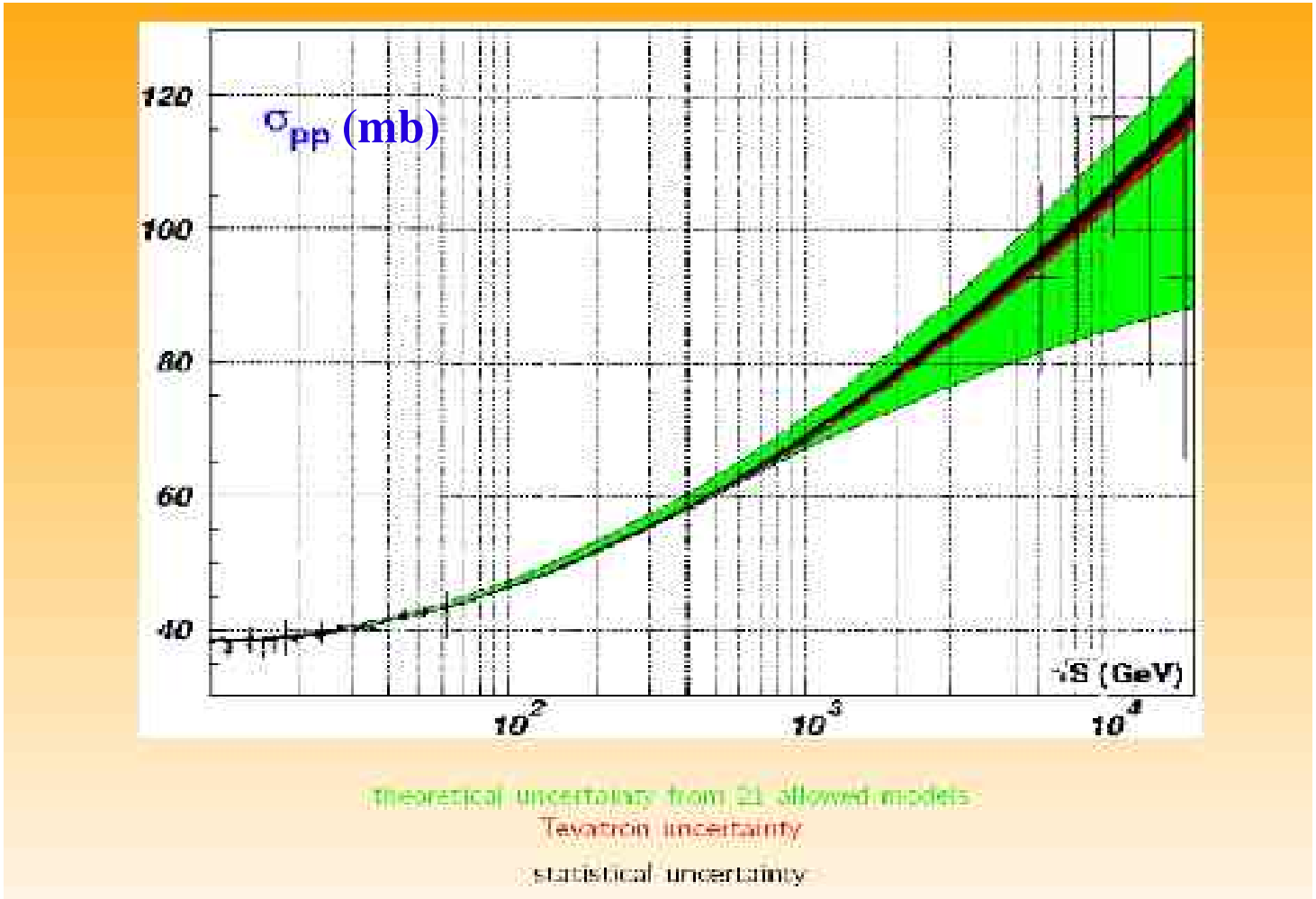
- diffractive collisions at high energy: pomeron, odderon...
- parton distributions: effects of saturation, of unitarity,
  models for generalized parton distributions

IFPA – Liège University



Residue mass spectra in p(1GeV)+^{208}Pb spallation reactions

[Cugnon, Mancusi, Kelic, 2009]



Analytic Regge fit of the pp cross section
[Cudell and the Compete collaboration, 2009]

Conclusions

- Belgian nuclear theorists = endangered species:
  only 20 left, rapidly disappearing!
- Very active (publications, (post)-docs, collaborations with experiments)
- Very individualistic → rich variety of subjects
  from quarks and gluons to nuclear matter
  from very light to very heavy nuclei
  from spectroscopy to reactions
  from very low to very high energies
- Very individualistic → lack of mutual knowledge,
  despite some working networks (IAP programs...)