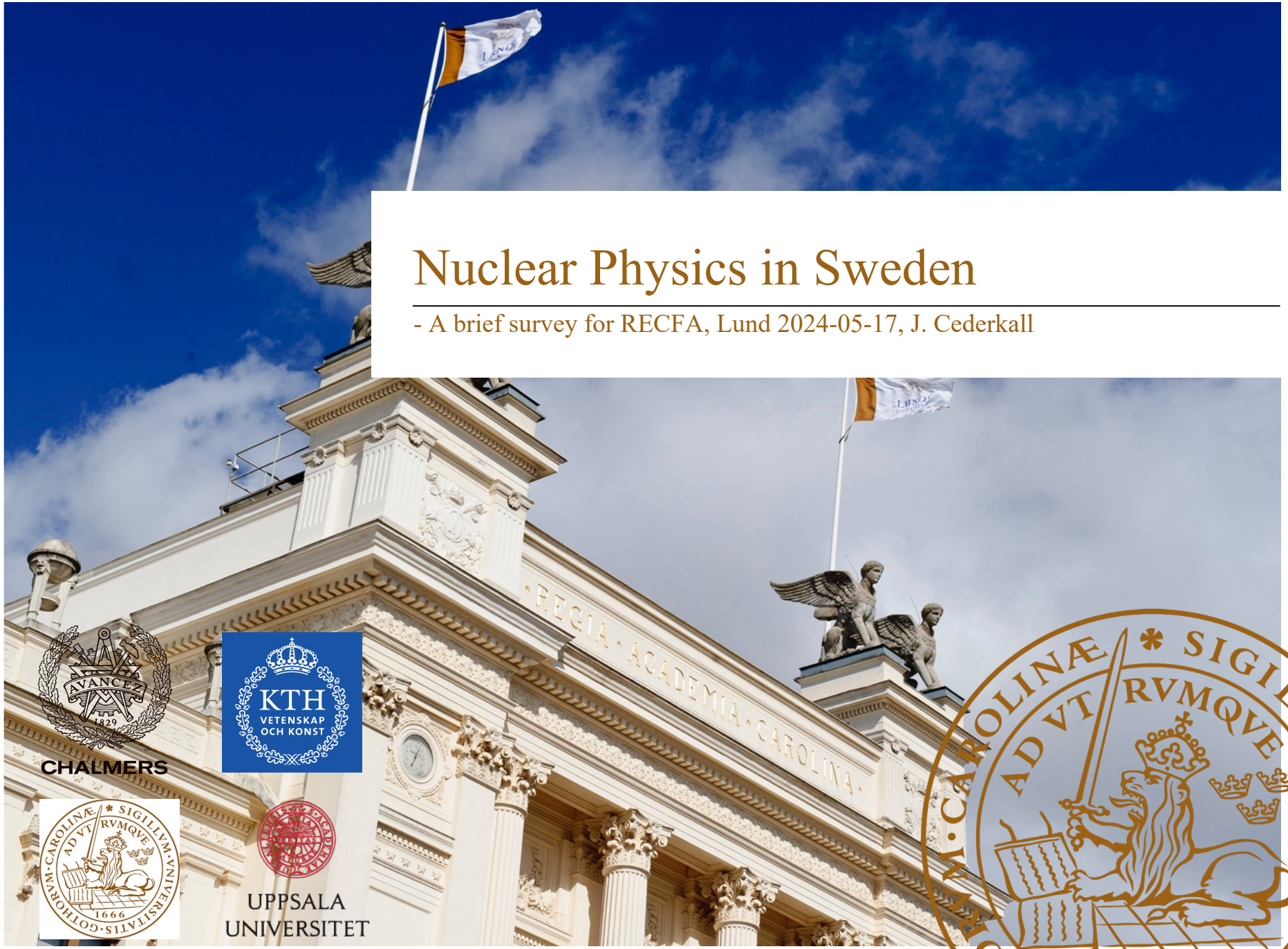
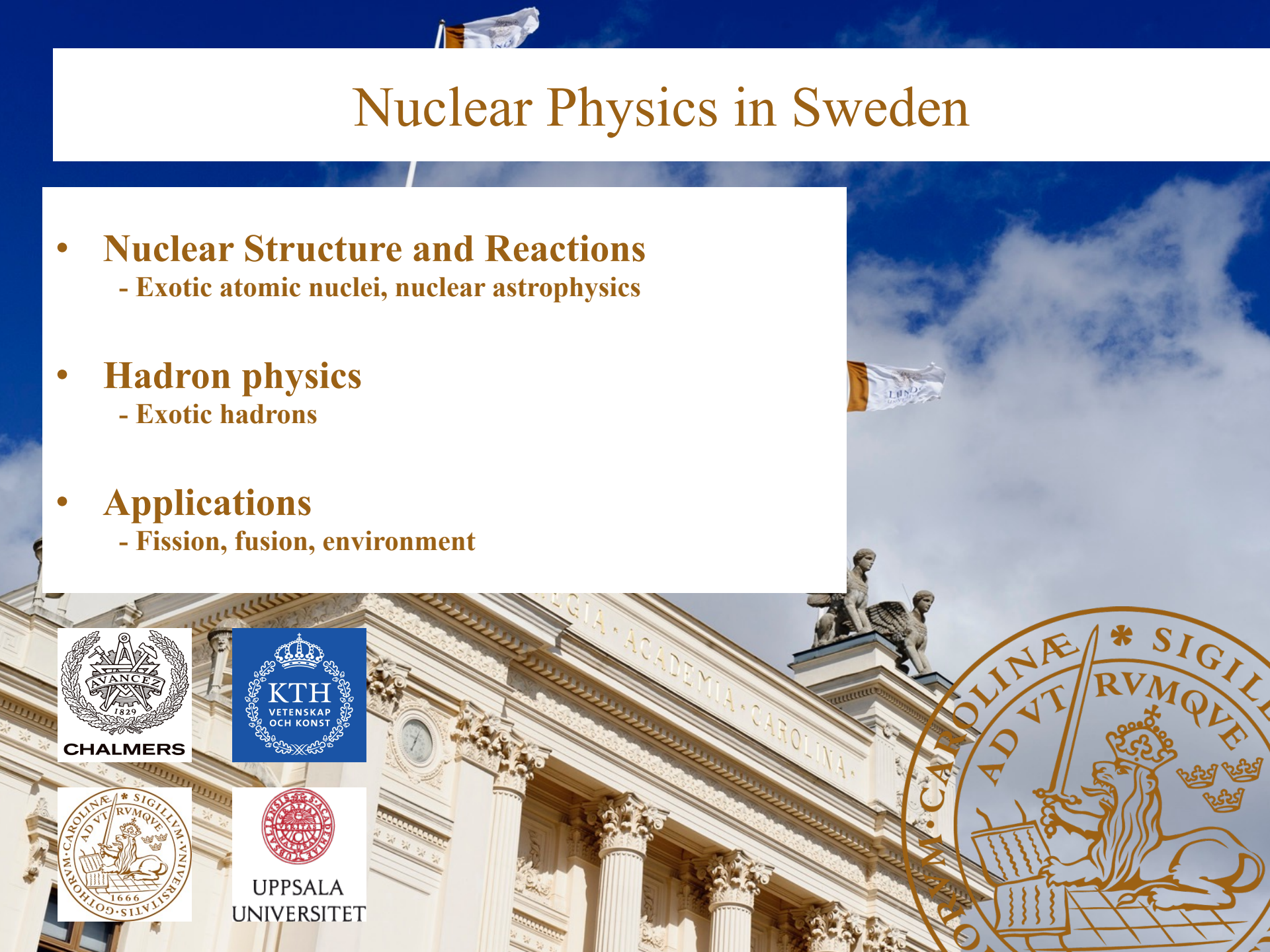


Nuclear Physics in Sweden

- A brief survey for RECFA, Lund 2024-05-17, J. Cederkall

Nuclear Physics in Sweden

- **Nuclear Structure and Reactions**
  - **Exotic atomic nuclei, nuclear astrophysics**
- **Hadron physics**
  - **Exotic hadrons**
- **Applications**
  - **Fission, fusion, environment**



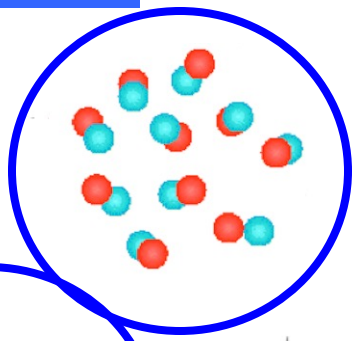
Nuclear Physics - current questions

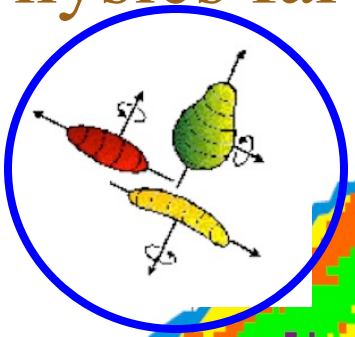
- **How are nuclei built from their constituents?**
  - the nuclear interaction in the medium
- **Where are the limits of nuclear existence?**
  - location of the driplines, existence of superheavy elements
- **Do nuclear shells change far from stability?**
  - shell evolution and changes of the nuclear many-body potential
- **How can we relate and connect collective phenomena to the motion of individual nucleons?**
  - interplay between single particle and collective motion, emergent phenomena
- **How were and are the elements formed?**
  - reaction rates, masses, astrophysical sites and observations

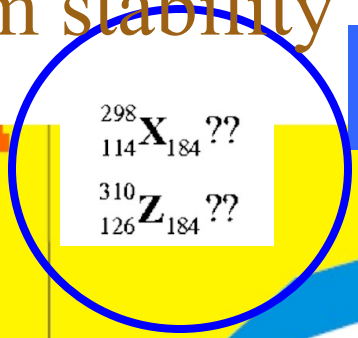
clear Physics far from stability

Neutron-proton pairing

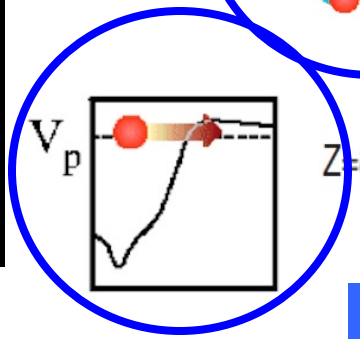
Number of protons







Superheavy elements



Nuclear shapes

Z=82

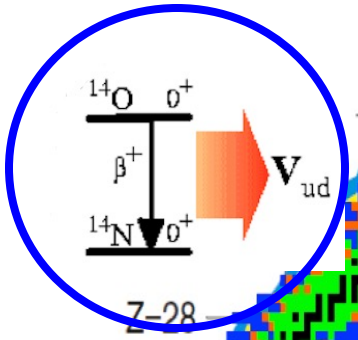
Neutron skins

N=258

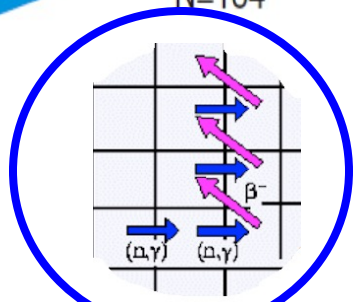
Proton emitters

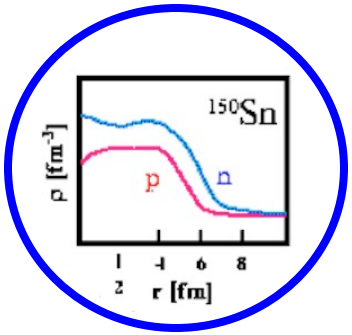
r-process

N=184



Z=28



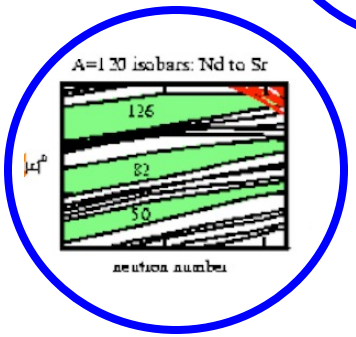


N=126

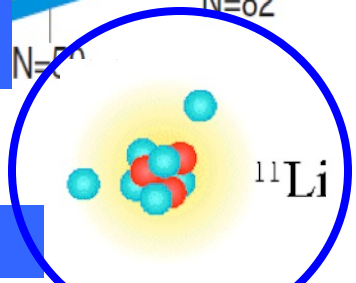
N=82

Superallowed beta decay

N=28



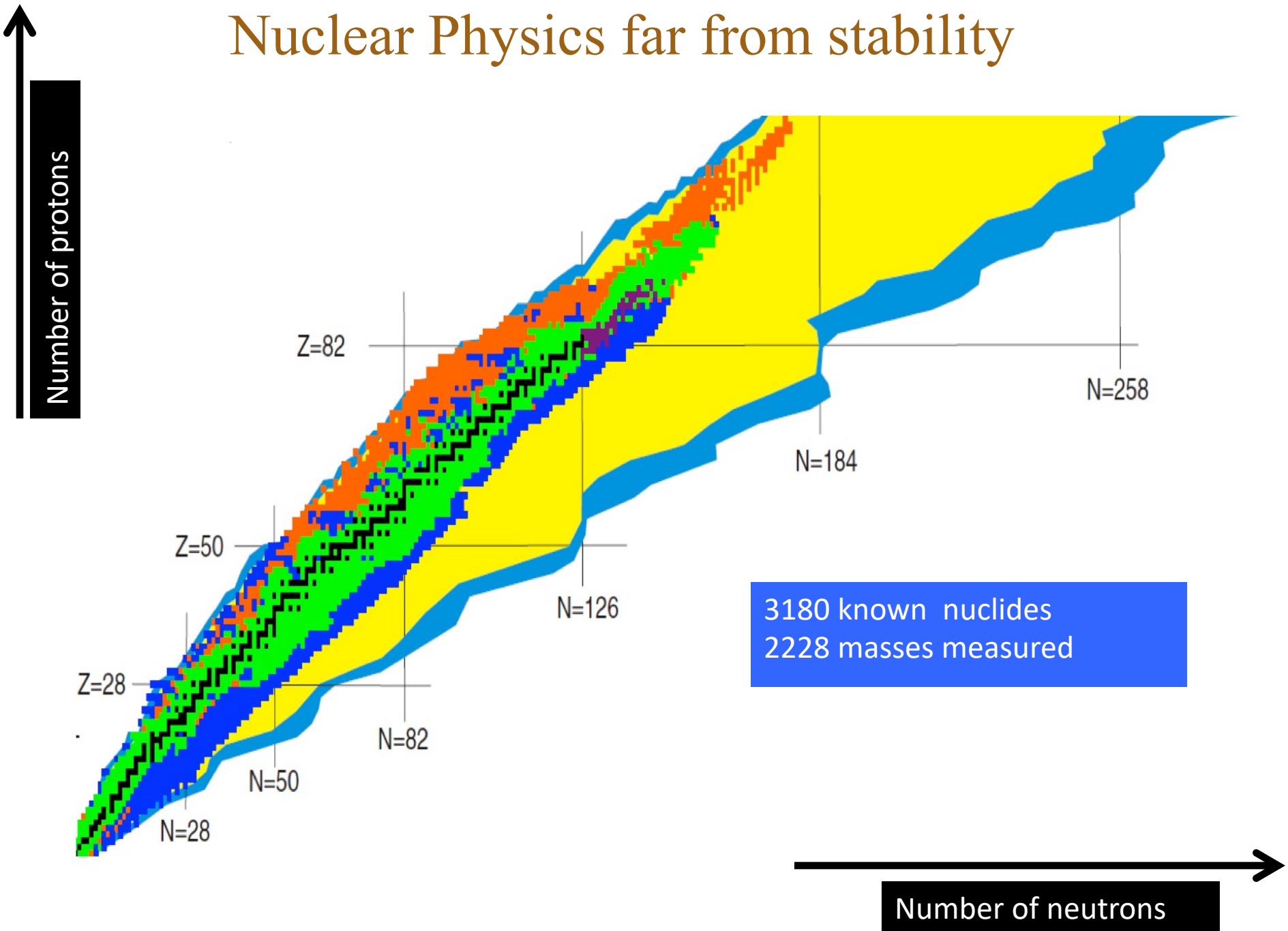
Shell evolution



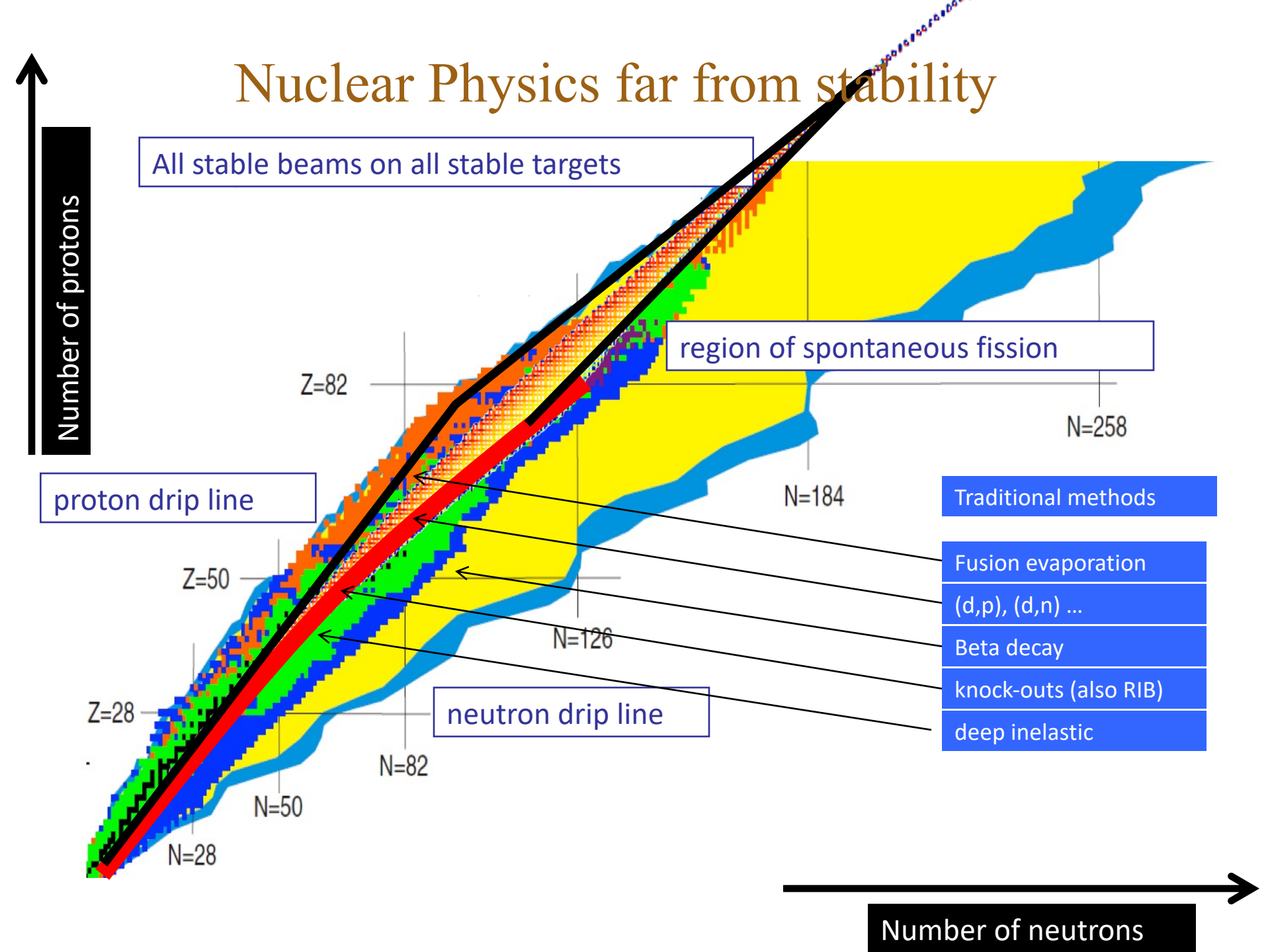
Nuclear halos

Number of neutrons

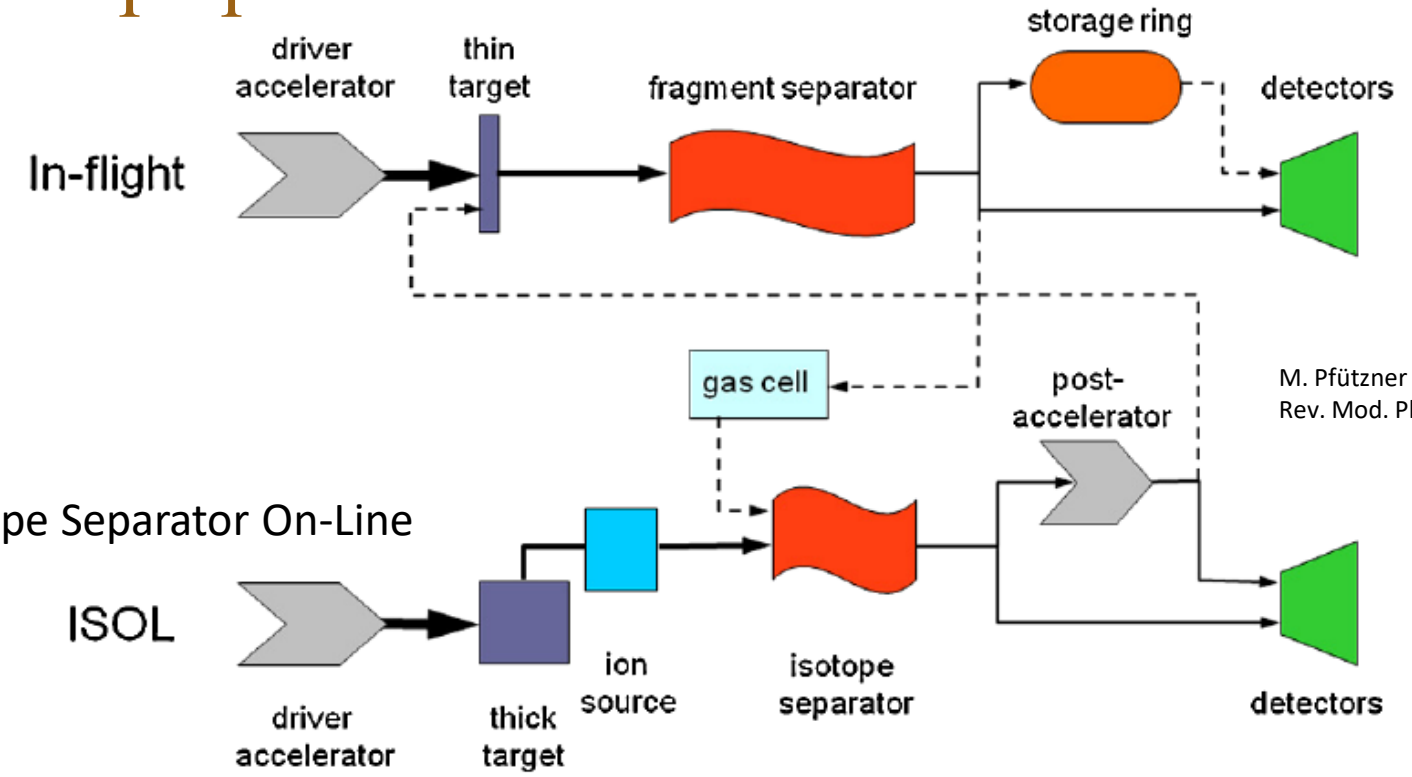
Nuclear Physics far from stability



Nuclear Physics far from stability



Isotope production



M. Pfützner et al.,
Rev. Mod. Phys. 84, 567 (2012)

Nuclear reaction types:
Fragmentation
Fission
Spallation
Fusion
Coulomb dissociation

	ISOL	In-flight
Production rate	Slow	Fast
Beam intensity	High	Low
Beam energy	Low	High
Beam quality/purity	Good	Poor
Beam chemistry	Selective ionization	Independent

Isotope production

In-flight

Isotope Separator

ISOL

Nuclear reaction types:
Fragmentation
Fission
Spallation
Fusion
Coulomb dissociation

	ISOL	**In-flight**
Production rate	Slow	Fast
Beam intensity	High	Low
Beam energy	Low	High
Beam quality/purity	Good	Poor
Beam chemistry	Selective ionization	Independent

Isotope production

In-flight

Relativistic (tracked) beams

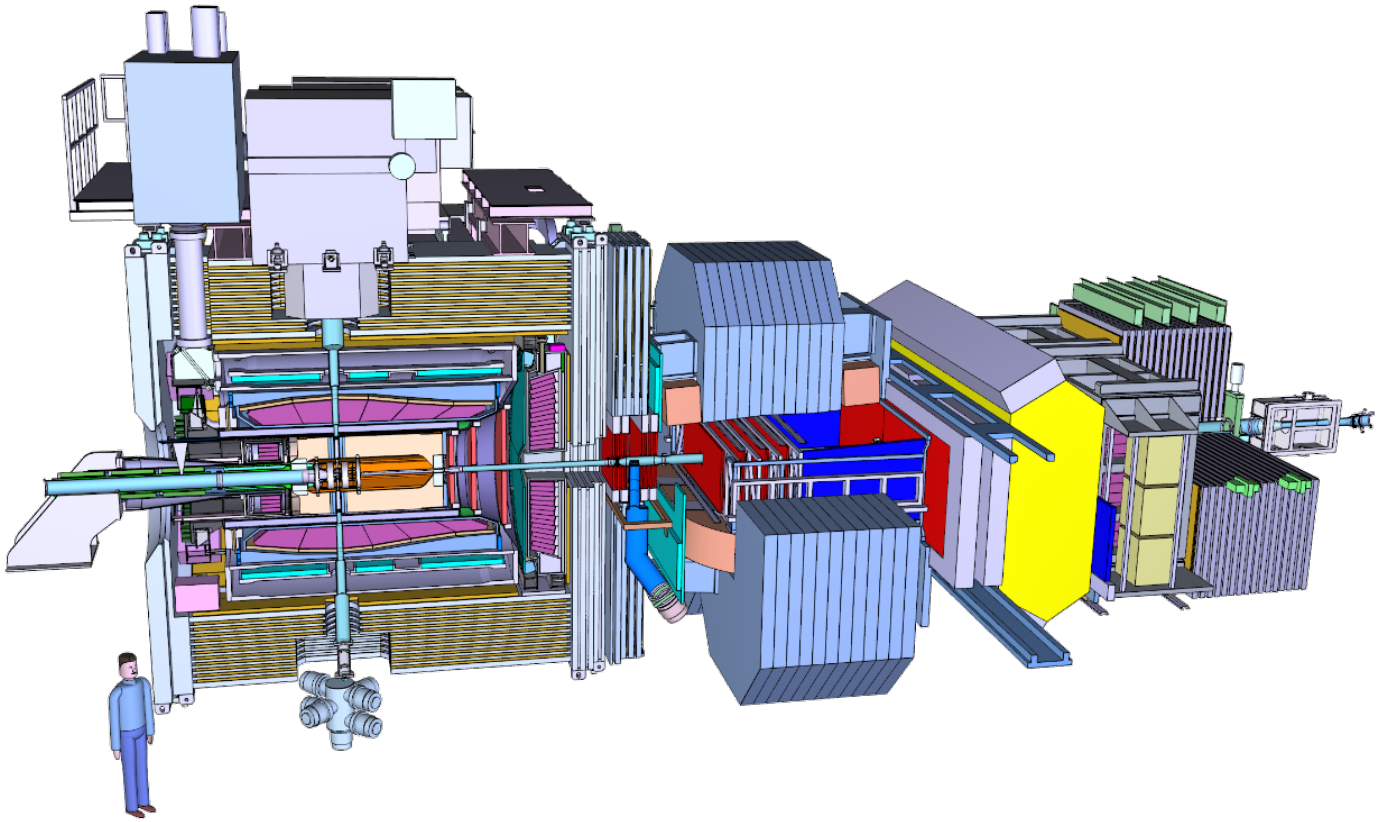
Stopped beams

Isotope Separator

ISOL

Well-defined beams (i.e. emittance, energy spread)

Exotic hadron production



Nuclear Physics Groups (incl. Swedish geography primer…)

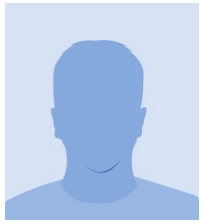
Swedish universities with groups in experimental nuclear physics:
Three universities: **Lund, Uppsala, Stockholm**
Two technical universities: **KTH**, Stockholm & **Chalmers**, Gothenburg

Nuclear Structure Physics with Advanced Detector Systems

KTH VETENSKAP OCH KONST

UPPSALA UNIVERSITET

Ayse Atac Nyber
Professor, KTH

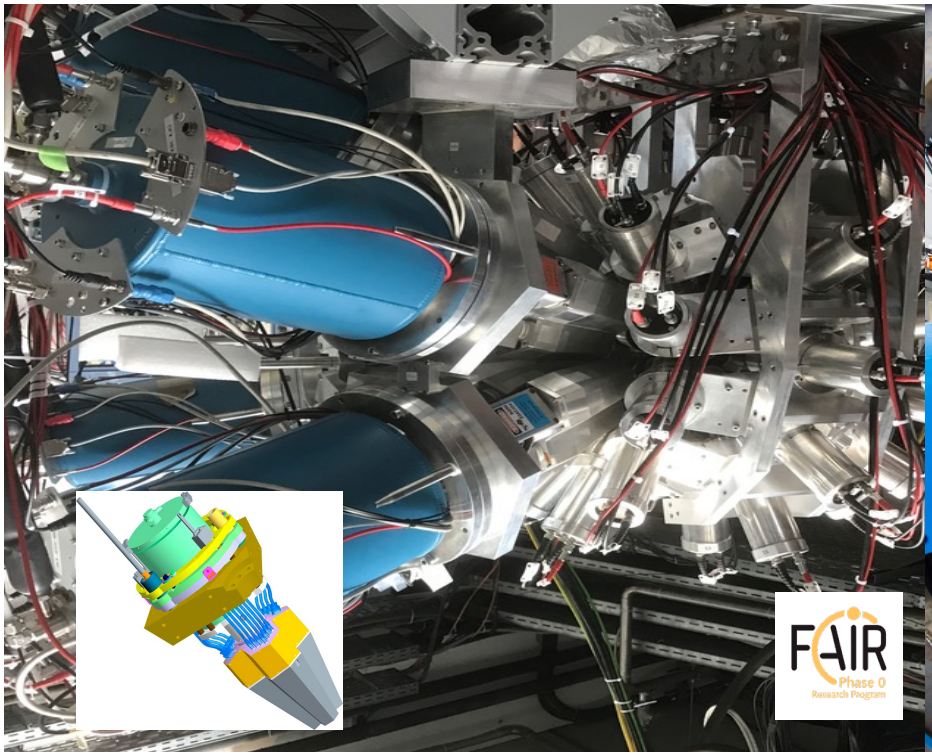


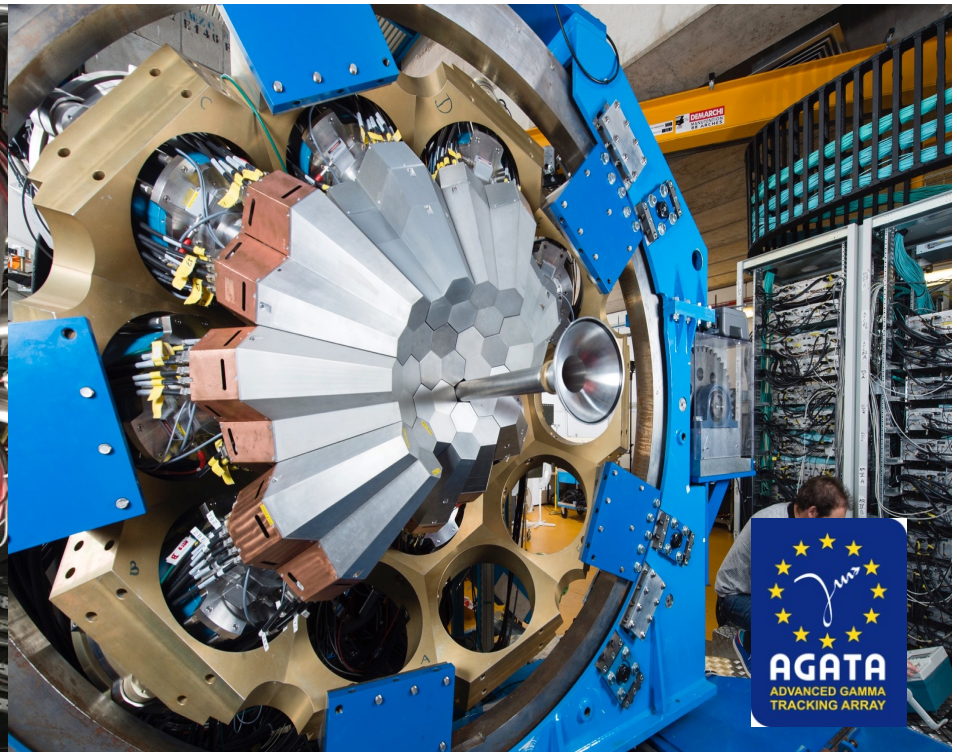
Torbjörn Bäck
Assoc. Professor, KTH

Bo Cederwall
Professor, KTH

Chong Qi
Assoc Professor, KTH

Johan Nyberg
Professor, UU





Nuclear Structure Physics with Advanced Detector Systems

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Professor, KTH

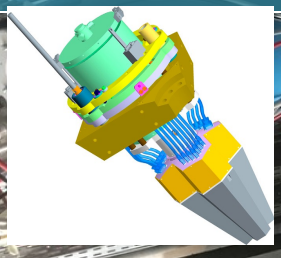
Torbjörn Bäck
Assoc. Professor, KTH

Bo Cederwall
Professor, KTH

Johan Nyberg
Professor, UU

Chong Qi
Assoc Professor,
KTH

- Experiments at GSI, GANIL, INFN-LNL, JYFL…
- Gamma spectroscopy far from stability using multidetector systems.
- Detector and analysis development with the AGATA collaboration (gamma-ray tracking)
- Development work for the FAIR HISPEC/DESPEC experiment with the DEGAS detector (segmented Germanium)
- Applied: Earth-quake warning from radon detection. Nuclear safeguard instrumentation.
- Theory support for nuclear structure experiments
- KTH is also active in the Swedish PANDA collaboration



Light exotic nuclei, nuclear astrophysics, nuclear theory

CHALMERS

Andreas Ekström,
Assoc. Professor

Christian Forssén
Professor

Andreas Heinz,
Assoc. Professor

Thomas Nilsson
Professor, Head of
Physics Department

Light exotic nuclei, nuclear astrophysics, nuclear theory

CHALMERS

Andreas Ekström,
Assoc. Professor

Christian Forssén
Professor

Andreas Heinz,
Assoc. Prof.

Thomas Nilsson
Professor, Head of
Physics Department

- Longstanding involvement in experiments at ISOLDE@CERN and R3B@FAIR
- Light exotic nuclei, neutron halos and skins
- Relativistic beams for knock-out
- Decay studies and low-energy reactions for the r-process
- Development work for the R3B experiment calorimeter
- Data acquisition expertise

- Theory linking nuclear many-body systems to nuclear forces including prediction error estimates

FAIR

ISOLDE

Nuclear Structure, Reactions and Astrophysics

LUND UNIVERSITY

Gillis Carlsson
Assoc. Professor

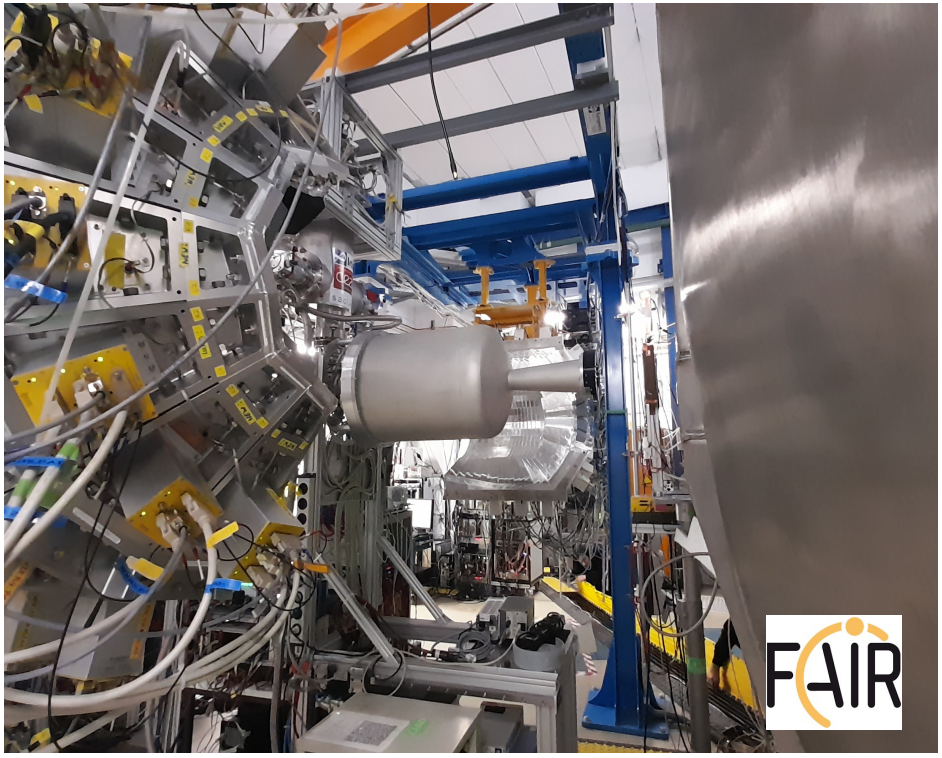
Joakim Cederkall,
Professor

Pavel Golubev
Assoc. Professor

Andrea Idini
Assoc. Professor

Dirk Rudolph
Professor

Luis Sarmiento Pico,
Assoc. Professor



Nuclear Structure, Reactions and Astrophysics

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Assoc. Professor

Joakim Cederkall,
Professor

Pavel Golubev
Assoc. Professor

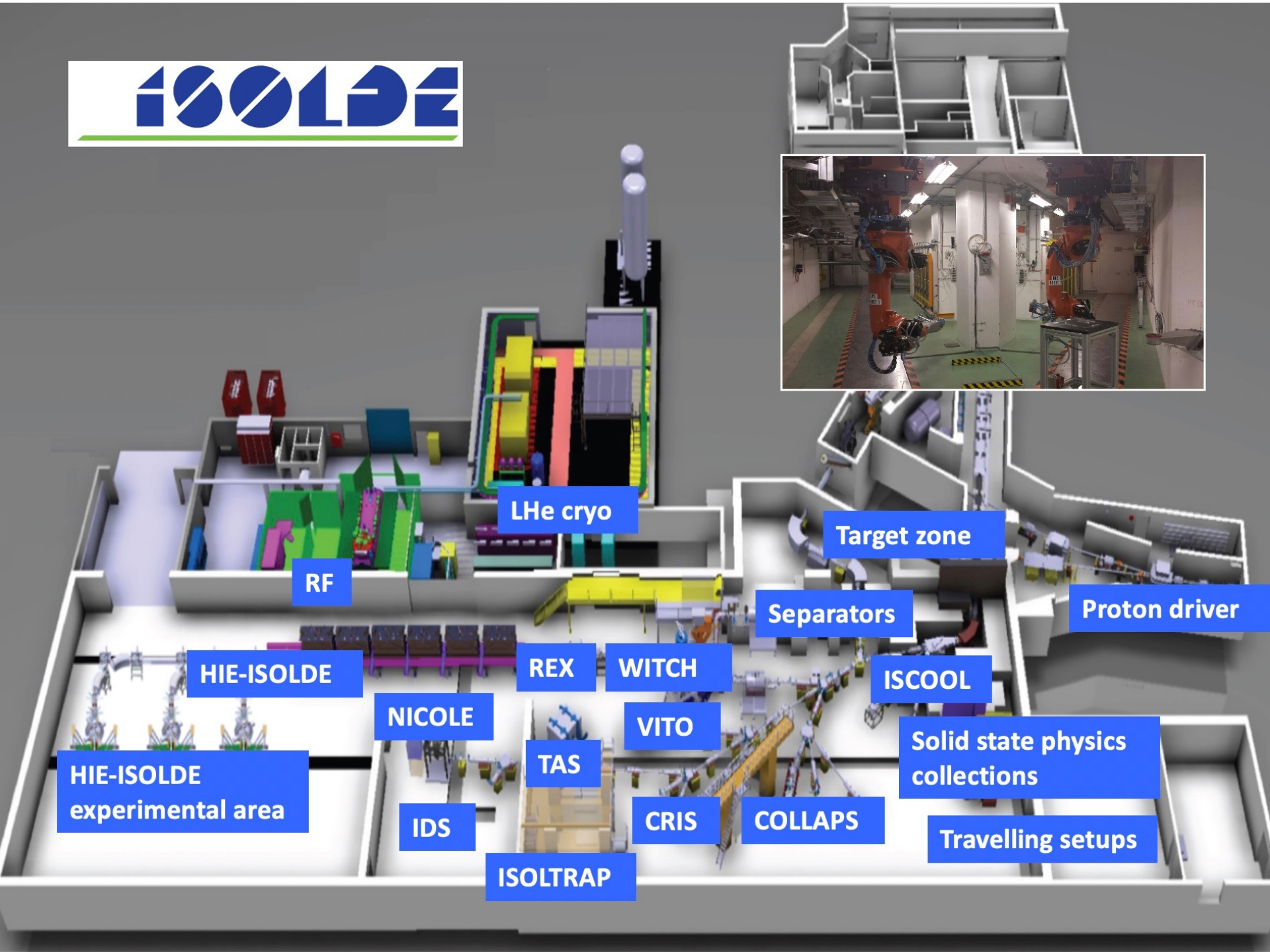
Andrea Idini
Assoc. Professor

Dirk Rudolph
Professor

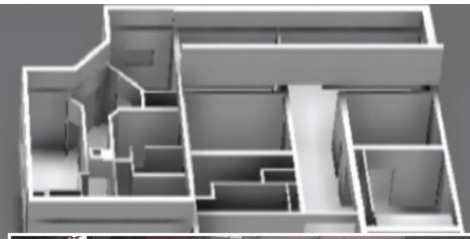
Luis Sarmiento Pico,
Assoc. Professor

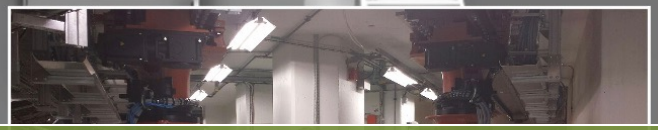
- Longstanding involvement in experiments at ISOLDE@CERN and R3B@FAIR
- Experiments also at GSI, GANIL, INFN-LNL (AGATA), JYFL, ANL and LBNL (SHE)
- Spectroscopy, reactions and nuclear astrophysics with radioactive beams
- Spectroscopy in the region of superheavy nuclei
- Leading the development work for the FAIR R3B experiment calorimeter
- Central role in the development of the FAIR HISPEC/DESPEC calorimeter

- Many-body theory for structure and reactions, neutrino-nucleus cross sections


ISOLDE
LHe cryo
RF
Target zone
Separators
Proton driver
HIE-ISOLDE
REX
WITCH
ISCOOL
NICOLE
VITO
Solid state physics collections
HIE-ISOLDE experimental area
TAS
IDS
CRIS
COLLAPS
Travelling setups
ISOLTRAP

ISOLDE covers questions over a variety of fields: nuclear physics, nuclear astrophysics, laser physics, solid-state physics and medical physics. More than 1000 different isotopes of 74 elements can be produced with energies from 30 keV to ~10 MeV/u





- Sweden is member of ISOLDE since its inception in 1967
- Facility has undergone several reincarnations. Started at the SC and moved to the PS-booster in 1992. Latest the introduction of post-accelerated beams with HIE-ISOLDE
- Swedish physicists contribute continuously to the development of the facility
- Swedish physicists have held positions as group leader, physics co-ordinator, technical co-ordinator, staff physicist (LD) and research fellows

Physics program:

- Structure and reactions of exotic isotopes, shell-evololution, nuclear shapes
- Nuclear astrophysics
- Atomic physics

Future:

- Beam switching
- Target beam dump upgrade for higher power
- HIE-ISOLDE beyond 10 MeV/u
- SC reaction product separator and/or storage ring
- Expansion of experimental hall

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Physics program:

- Structure and reactions of exotic isotopes, shell-evololution, nuclear shapes
- Nuclear astrophysics
- Atomic physics

Several high-profile publications in Nature, Nature Communications, PRL etc

Future:

- Beam switching
- Target beam dump upgrade for higher power
- HIE-ISOLDE beyond 10 MeV/u
- SC reaction product separator and/or storage ring
- Expansion of experimental hall

Hadron Physics

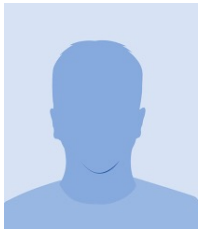
Lars Eklund,
Professor

Stefan Leupold,
Professor

Tord Johansson
Professor (senior)

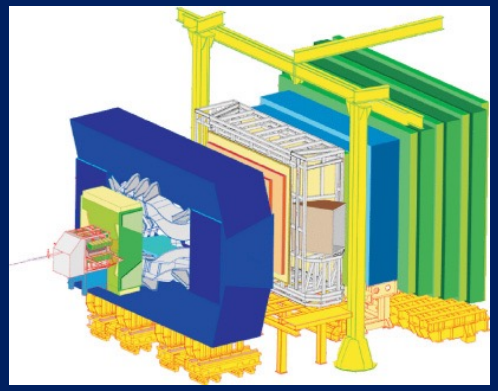
Karin Schönning,
Professor

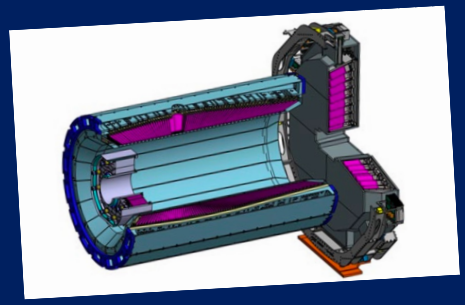
Per-Erik Tegner,
Professor, SU



Magnus Wolke,
Assoc. Professor

- Hadrons, glueballs and related theory
- Long history in the field with WASA experiment at UU/Celsius and later at COSY.
- Major effort with detector development and in-kind contribution to PANDA@FAIR (EMC)
- Program at BESIII and BELLEII waiting for FAIR
- Recent development entering LHCb





- Sweden is founding member and shareholder of FAIR in partnership with Finland
- Swedish physicists work within three of the four scientific pillars and their governing structures

    - **NUSTAR**
    - **PANDA**
    - **APPA**

Sweden contibutes ca 100 MSEK to FAIR construction including in-kind contributions.

NUSTAR:

- **R3B** (Reactions with Relativistic Radioactive Beams) with deliveries to the R3B calorimeter from LU and Chalmers. The calorimeter working group is lead from LU.

- **HISPEC/DESPEC** with deliveries of high-resolution Ge detectors (KTH) and detectors for reaction channel id (LU)

PANDA: major contribution to the PANDA EMC (UU)

APPA: The storage ring cryring has been moved to GSI/FAIR and installed as part of the Swedish in-kind contribution.

R3B

Relativistic Beams for quasi-elastic scattering with a versatile complete kinematics setup

- In-medium interactions as function of isospin
- Shell structure, unbound states, resonances
- Nuclear matter radii, halo and skin structures,
- The nuclear equation-of-state
- Nucleon-nucleon correlations
- Reaction rates with astrophysical applications.

HISPEC

Nuclear spectroscopy of fast and slowed-down radioactive ion beams produced in relativistic fission or nuclear fragmentation reactions using gamma-ray tracking (AGATA) as well as other high-resolution systems.

- Nuclear structure far from stability
- γ-spectroscopy at low and intermediate energy,
- n-decay, α, β and p-spectroscopy

PANDA

QCD studies from p-pbar annihilation

- Search for gluonic degrees of freedom like hybrids and glueballs
- Spectroscopy of charmonium states
- Spectroscopy of double hypernuclei
- In-medium modifications of charmed mesons
- Antihyperon-hyperon physics.

SPARC

Atomic physics with highly charged ions.

- Photon or electron spectroscopy produced in collisions between free target electrons and stored ions.
- Precision spectroscopy and lifetime studies utilizing energy-sharp resonant features in the electron-ion cross section.

Applied Nuclear Physics

UPPSALA UNIVERSITET

Peter Andersson, Assoc. Professor

Göran Ericsson, Assoc. Professor

Jacob Ericsson, Assoc. Professor

Sofie Grape, Assoc. Professor

Cecilia Gustavsson, Assoc. Professor

Ane Håkansson, Professor

Stefan Pomp, Professor

Daniel Primetzhofer, Professor

Henrik Sjöstrand, Assoc. Professor

Andreas Solders, Assoc. Professor

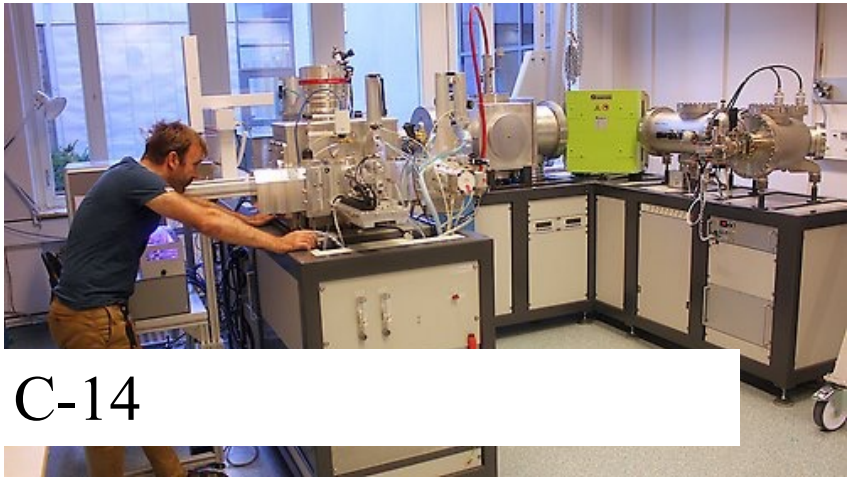
Matthias Weiszflog, Assoc. Professor

- Fission fuel diagnostics and nuclear safeguards
- Ion beam physics at local tandem laboratory
- Fusion diagnostics e.g. neutron spectrometry for fusion plasmas (JET, ITER)
- Nuclear reaction studies and related nuclear data
- APPA at FAIR

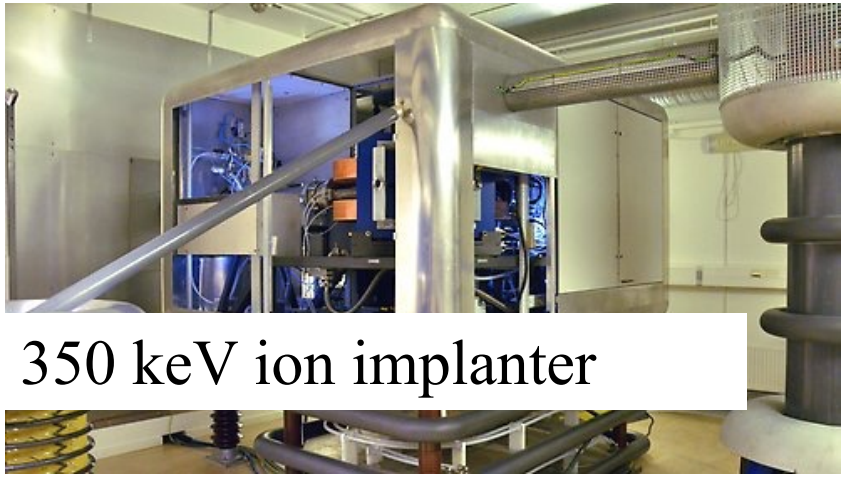
Applied Nuclear Physics – local laboratories for ion-beam analysis

UPPSALA UNIVERSITET

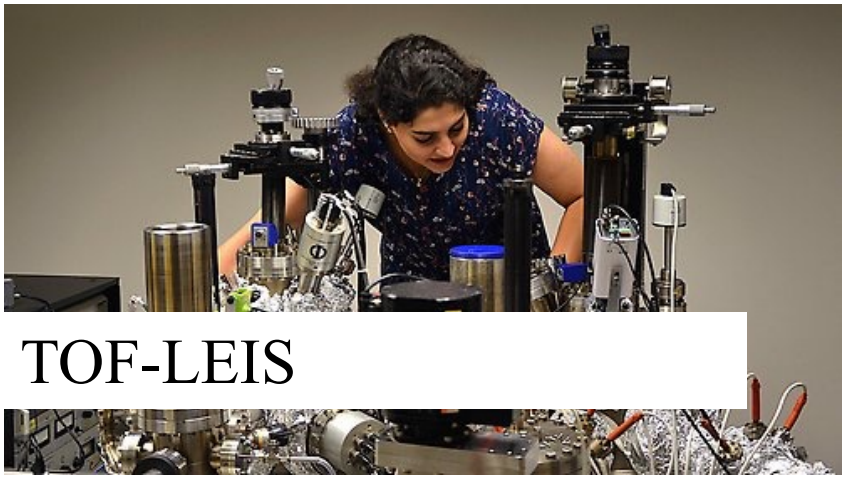
5 MeV Pelletron



C-14



350 keV ion implanter

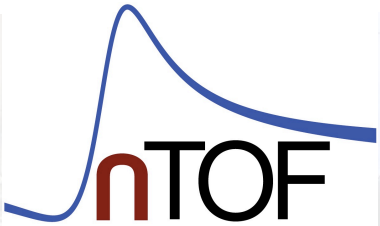


TOF-LEIS

Applied Nuclear Physics – international accelerator laboratories

UPPSALA UNIVERSITET

Neutrons for Science: cross sections for n-induced reactions, light-ion production

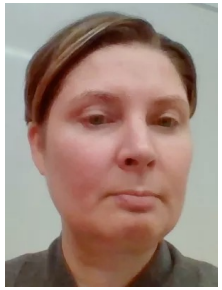


CERN nTOF: fission studies

Applied Nuclear Physics

LUND UNIVERSITY

Kristina Stenström,
Professor



Charlotta Nilsson,
Assoc. Professor

Predicting and tracking man-made radionuclides in the environment, including from power plants in Sweden and abroad as well as from experimental facilities (ESS) and from oceanic or atmospheric transport.

- Decay measurements
- Accelerator mass spectrometry
- Focus on ^{14}C and ^{3}H.

KTH VETENSKAP OCH KONST

Sevostian Bechta,
Professor

Jan Dufek
Assoc. Professor

Pär Olsson
Professor

Janne Wallenius
Professor

- Nuclear engineering
- Reactor physics
- Lead-cooled SMR
- Material development

External funding

Swedish Research Council

Individual project grants typically 300 - 400 kEuro of 4 years
Infrastructure grants e.g. etc for in-kind to FAIR > 1 Meuro
Membership in collaborations, i.e ISOLDE and AGATA

Knut och Alice Wallenbergs Stiftelse

Larger grants for project > 1 Meuro
Examples, REX-ISOLDE, RILIS and experimental project with ISS at ISOLDE (Gbg). SHE element searches (Lund)

CARL TRYGGERS STIFTELSE FÖR VETENSKAPLIG FORSKNING

Crafoordska stiftelsen GRUNDAD AV HOLGER CRAFOORD 1980

Smaller grants (10 – 100 kEuro) for instrumentation, travel, conferences etc.

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Smaller grants (10 – 100 kEuro) for instrumentation, travel, conferences etc.

Funded by the Horizon 2020 Framework Programme of the European Union

Messsage

Funding: the time scales and the efforts to design and build facilities and detectors are often long also in nuclear physics (~10+ years). Proper exploitation of investments made in instrumentation and manpower requires a long-term commitment that can be difficult with shorter funding cycles. Funding of technical manpower and postdoctoral researchers is central for long-term success.

ISOLDE: The facility evolves continuously and support for this work has been a key factor for the success of the facility. In the shorter term that work currently involves upgrades of the target station beam dumps to take higher intensity and energy. After HIE-ISOLDE several new developments are discussed, i.e. introduction of a storage ring and/or a SC separator for reaction products. The experimental program will soon also need more surface area, i.e hall extension including a long-term wish for more target stations.

FAIR: Swedish contributions largely follow the given timeline. It is central that FAIR is completed, and that first physics is not delayed further.