Project SPIRAL2-CZ and nuclear astrophysics

collaboration with GANIL/SPIRAL2

Jaromír Mrázek

Nuclear Physics Institute of the CAS, Rez, Czech Republic

April 26, 2019

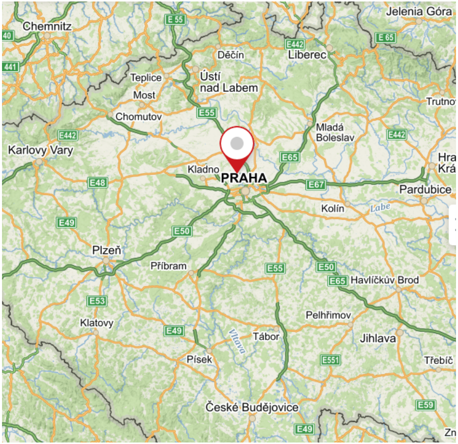
EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education

MINISTRY OF EDUCATION,
YOUTH AND SPORTS

1. NPI CAS
   - location and the experimental base
2. Project SPIRAL2-CZ
   - Advertising posters on activation
3. Nuclear astrophysics in Řež
   - Asymptotic Normalization Coefficients
   - Trojan Horse Method
   - ^{26}Al efforts

Nuclear Physics Institute of the CAS

- Located near Prague in Řež
- Accelerators:
  - Cyclotron U120M
    p+/ H-: 5.4–38 MeV,
    D+/ D-: 11–20.5 MeV,
    ^{3}He+2: 16.2–55 MeV,
    ^{4}He+2: 22–40 MeV
  - Cyclotron TR24 (new)
    protons 8 MeV to 24 MeV, CUSP ion source, up to 300μA
  - Tandetron 4130 MC (3MV)
    H - Au 0.4-20 MeV up to tens of mA
    RBS, RBS-channeling, ERDA, ERDA-TOF, PIXE, PIGE, ion microprobe 1μm



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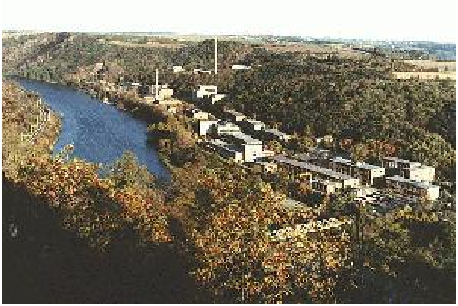

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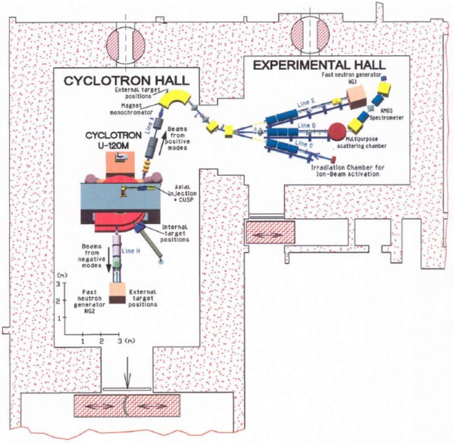

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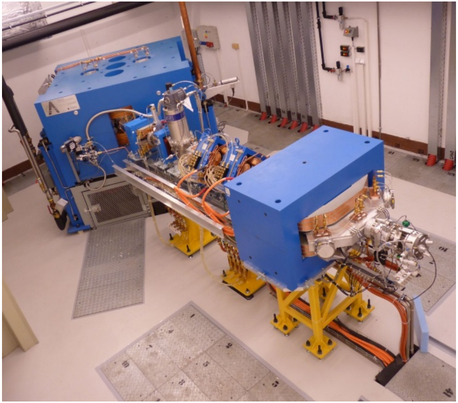

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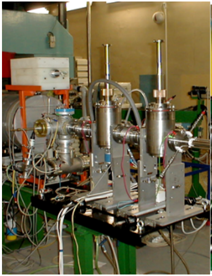
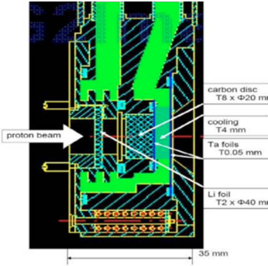
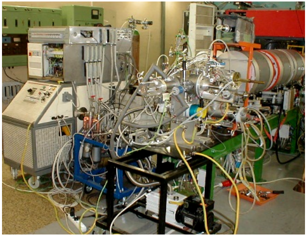
- Fast Neutron Generators (FNG)

  see talk of M.Ansorge

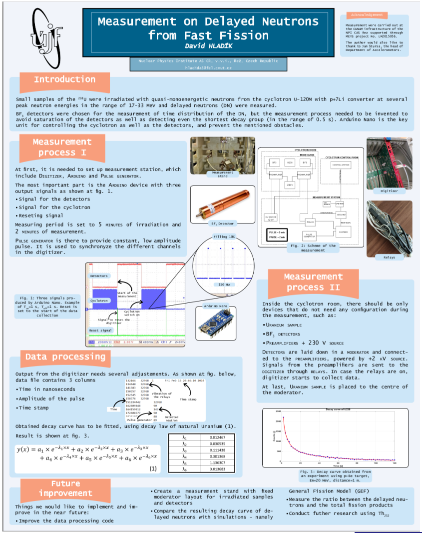




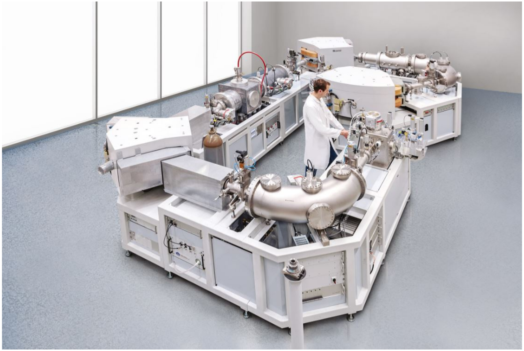


activation by neutrons

see poster of D.Hladik for delayed neutron's measurement



- Project RAMSES
  AMS 300kV
  spectrometer to 2020+
  Determination of long-lived radio-nuclides
  ^{14}C, ^{10}Be, ^{26}Al, cosmogenic nuclides
  actinides and fission products at levels or in amounts up to 10^{-6} lower compared to decay counting methods



Center of Accelerators
and Nuclear Analytical Methods
(CANAM)

Project SPIRAL2-CZ

SPIRAL2-CZ as the project of Czech support to GANIL/SPIRAL2

Timeline of the project

- 2011 - LEA NuAG[1] - first official support of collaboration NPI CAS and GANIL
- 2015- SPIRAL2 in *Roadmap of Large Infrastructures for Research, Experimental Development and Innovation of the Czech Republic for the years 2016-2022*
- 2015 - LIA NuAG - prolongation
- 2016 - MEYS[2] financing the international abroad infrastructure SPIRAL2-CZ $\sim$ 8-12 people on the project
- 2017 - MEYS and EU Operational Program - research, development and education financing the investments to the infrastructure SPIRAL2-CZ OP
- 2019 - green light for the next LIA NuAG
- June 2019 - next call of the EU OP program for investments
- 2020 - expecting the continuation of the MEYS support for running costs

[1] Laboratoire Europèen Associè - Nuclear Astrophysics and Grids
[2] Ministry of Education, Youth and Sports

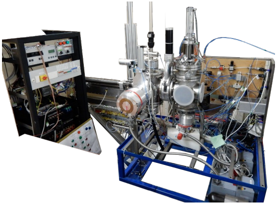
content of the project

Two main activities within the project:

- Nuclear astrophysics
- Activation by charged particles and neutrons

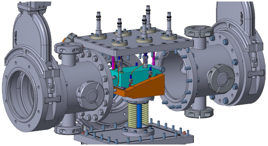
Three investments within the project:

Irradiation Chamber (IC) for activation on NFS



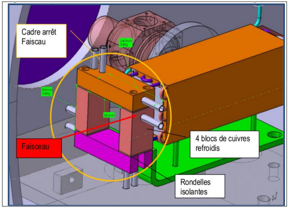
see the poster of Eva Šimečková

Target for radioisotopes with medical potential



yesterday's talk of Gilles and Ondrej

Target for production of radioactive beams



Astrophysics interest

content of the project

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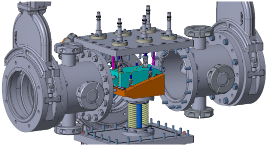

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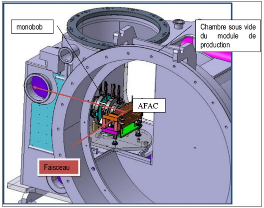
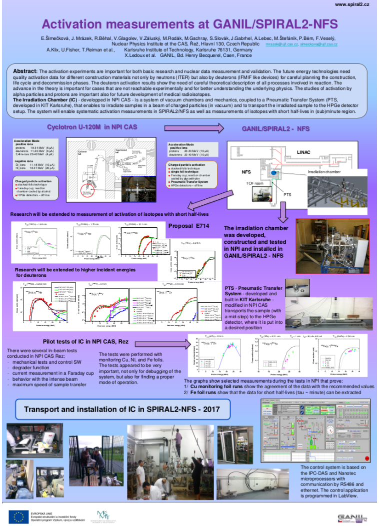


Astrophysics interest

activation by charged particles

Irradiation Chamber (IC)
Pneumatic transport System (PTS)

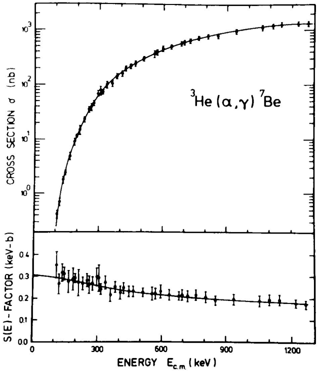
see poster of Eva Šimečková



Nuclear astrophysics

Nuclear astrophysics (in Řež and in collaborations)

The problem of the mesurement of charged particle reaction cross sections at low energies
– is the Coulomb barrier



The problem of the mesurement of charged particle reaction cross sections at low energies
– is the Coulomb barrier

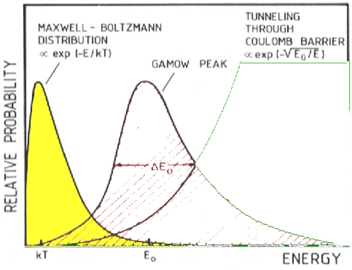
reaction	Coulomb barrier [MeV]
p+p	0.55
α+^{12}C	3.43
^{16}O+^{16}O	14.7

	T [10^6K]	kT [keV]
Sun - core	15	1
AGB star -(H)	90	8
AGB star (He)	300	38
Classical Nova	100 - 400	10 – 50

The problem of the mesurement of charged particle reaction cross sections at low energies

– **is the Coulomb barrier**

- high energy tail of Maxwell distribution



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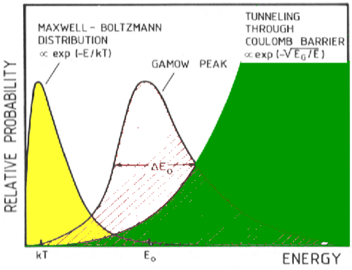

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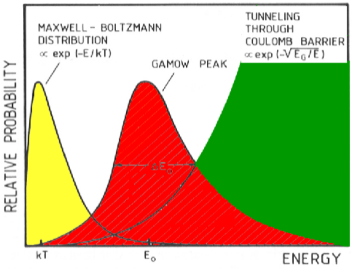
- Gamow peak



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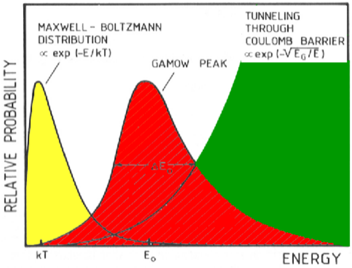

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- huge beam intensities
  - extremely long measurements (together)
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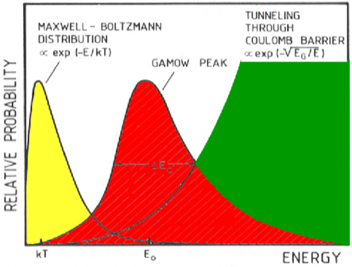

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How to face the low x.s. in measurements ?

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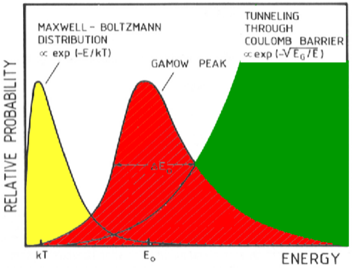
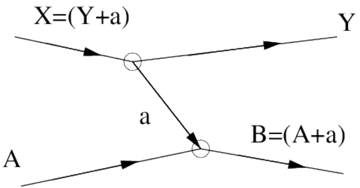
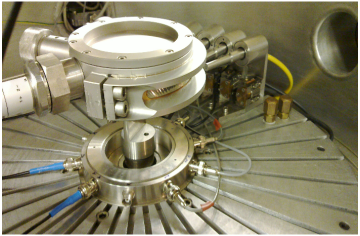
- **indirect methods**
  - Asymptotic Normalization Coefficients
  - Trojan Horse Method



Asymptotic Normalization Coefficients

Trick: Deducing the **direct radiative capture** cross section from direct transfer reaction
Benefit: Overcoming the Coulomb barrier
Conditions: The reaction must be direct process and be peripheral.





Typical setup of ANC experiment - with gas target

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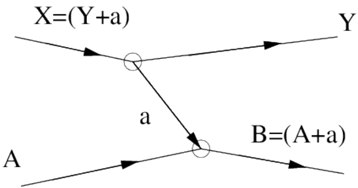

The experimental hall in NPI CAS

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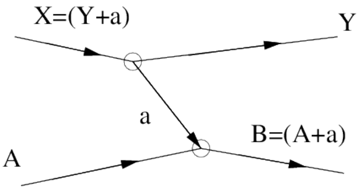
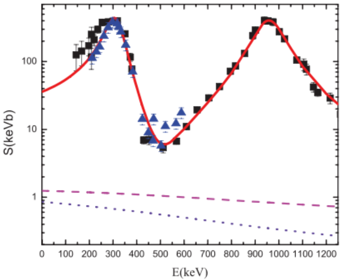


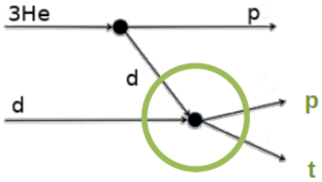


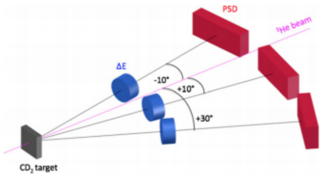
The example of the result applied to the resonances and the R-matrix fit of the resonances in ^{16}O for ^{15}N(p,γ)^{16}O

Trojan Horse Method

collaboration with INFN LNS Catania: C.Spitaleri, M.LaCognata, G.Pizzone, A.Tumino...

Trick: extraction of the two-body process from the three-body reaction.
Benefit: Overcoming the Coulomb barrier and
the electron screening
Conditions: carefull selection of the quasi-free component of the three-particle process.





Typical setup of THM experiment

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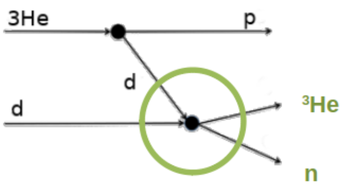

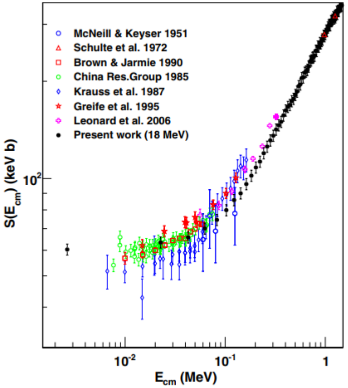

The exctracted S-factor (analog to cross section) for d+d $\rightarrow$ ^{3}He + n

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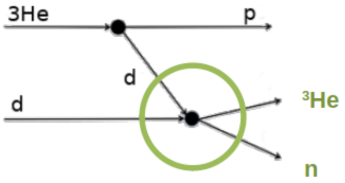
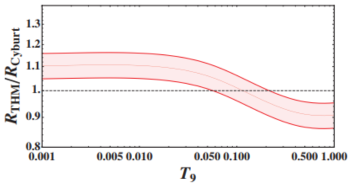
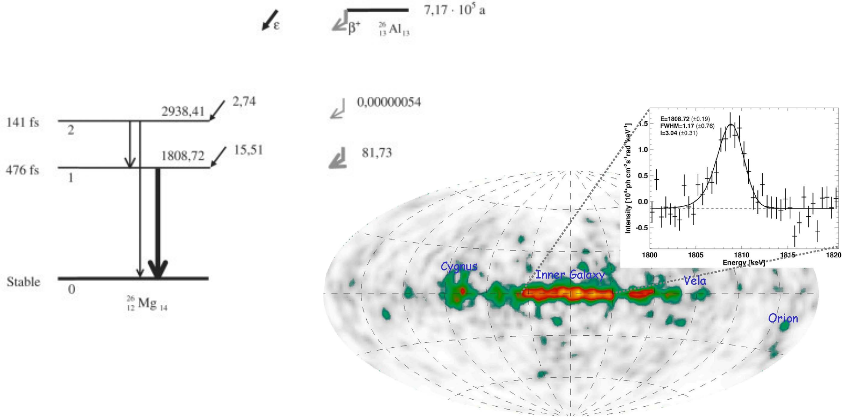




New reaction rate margins relative to the current accepted values from NACRE

COMPTEL and INTEGRAL/SPI observations of ^{26}Al



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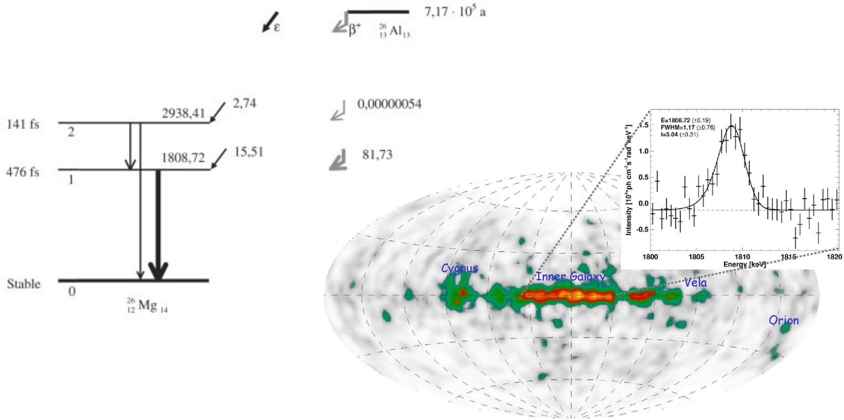

3 solar masses of ^{26}Al in our galaxy $T_{1/2} \sim 700$ ky

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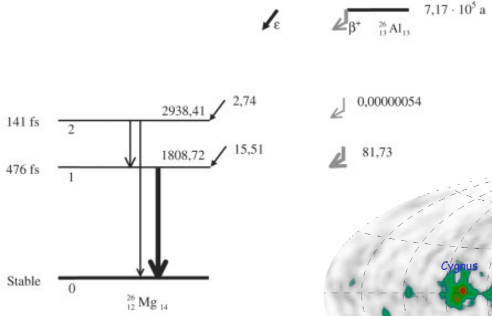
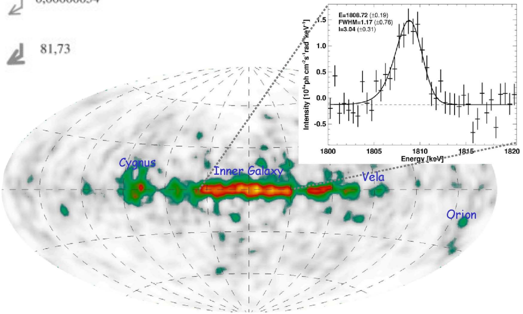
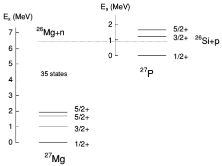




3 solar masses of ^{26}Al in our galaxy $T_{1/2} \sim 700$ ky
Conclusions: origin is mostly massive stars (ccSN, Wolf-Rayet stars?)

We analyze reaction ^{26}Mg(d,p)^{27}Mg to deduce **ANC** for mirror ^{26}Si(p,γ) ^{27}P
Bypass of Mg-Al cycle through ^{25}Al(p,γ)
(contradicting experimental conclusions)



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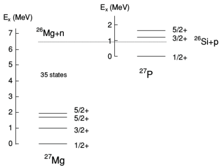
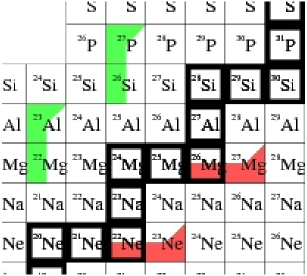
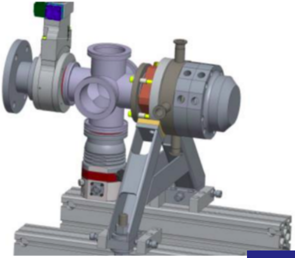




Project of THM with INFN LNS and GANIL with ^{26}Al beam (p,α)
preparation of 70μg of ^{26}Al from ^{26}Mg using new Hi-Power target developed for neutron generators (see the talk of Martin Ansorge).



Thank you for the attention,
thanks to the organizers