JRA1 - WP3: Astronuclear Lab

Mailing list: chetec-infra-wp3@listserv.dfn.de

M. La Cognata (INFN)

R. Spartà (INFN), T. Szücs (ATOMKI), J. J. Valiente Dobon (INFN), R. Golser (UNIVIE)

- **JRA1 –WP3** tackles four key challenges faced by the ChETEC-INFRA astronuclear laboratories that limit progress:

  - **solid targets** (**task 3.1**, PI R. Spartà/INFN, participants: IFIN-HH, ATOMKI, UKE, UoC, CNRS, UNIPD, about 43 person-months)

  - **gas targets** (**task 3.2**, PI T. Szücs/ATOMKI, participants: HZDR, CNRS, TUD, UMIL, UNIPD, about 17 person-months)

  - **neutron detection** (**task 3.3**, PI J. J. Valiente Dobon/INFN, participants: NCBJ, PTB, ISMA*, UNIPD, about 32 person-months)

  - **accelerator mass spectrometry**: production of nuclear charge separated beams (**task 3.4**, PI Robin Golser/UNIVIE, participants: HZDR, about 12 person-months)

*External collaboration – no person-months

GUF IS INVOLVED IN ALL THE ACTIVITIES CONCERNING THE WEBSITE

Task 3.1

- ultra-pure material targets for low reaction yields to be studied
- noble gases targets implanted into a host material
- Characterization of targets using sources and in-beam approaches (thickness, contaminants, long-term stability…)

Also (proposal to be implemented):

- thin self-supporting rotating target systems (1000 rpm)

R. Spartà, T. Szücs, M. Heine, M. Moukaddam, S. Courtin, L. Trache, M. La Cognata, A. Caciolli, D. Mengoni, A. Tumino, G. Lanzalone, A. Zilges, A. Blazhev, S. Prill, S. Wilden, F. Heim, …

Solid
Targets for
Astrophysics
Research

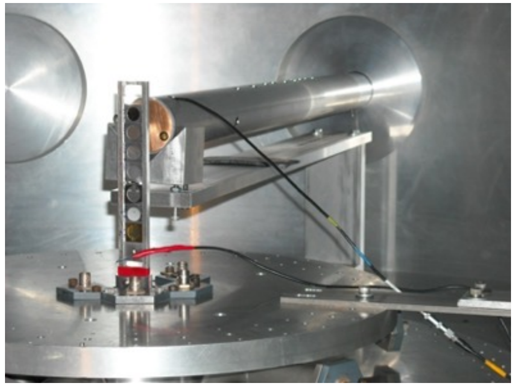
Task 3.1

participants:
UoC *(GER)* **CNRS** *(FRA)* **ATOMKI** *(HUN)*
INFN, UKE *(ITA)* **IFIN-HH** *(ROM)*

5 European target labs know-how to

- develop
- test (to follow their stability under beam bombardment)
- make protocols

of special solid targets required for the experimental study of nuclear reactions of astrophysical interest



ultra-pure material targets *for low reaction yields* to be studied to avoid parasitic reactions on impurities

Both linking to NA3 task 8.1

noble gases targets
He and Ne (cannot create solid compounds)
→ implanted into a host material
<u>key reactions</u> for s-process nucleosynthesis in evolved stars

PI: Roberta Spartà (INFN)

+ a new idea: rotating targets

Solid
Targets for
Astrophysics
Research

Task 3.1

Deliverables for 3.1

- Report on the experimental techniques used for solid target production (month 18)
- Report on testing by radioactive sources and beam bombardment (month 36)
- Publication of production protocols, characterization procedures, and results (month 48)

\+ **a service for the community**:
standardized testing of the produced targets (including contaminant checks and stability tests)

Join the mailing list
mail to rsparta@lns.infn.it

Task 3.2

- Windowless targets
- Thin-window gas-cell targets
- Diagnostics
  - effective gas thickness
  - Composition
  - Long term stability

  Nuclear Resonance, off-beam XRF and in-beam PIXE, RBS setups. Cyclotron/tandetron accelerator for target analysis.

  T. Szücs, M. Heine, M. Moukaddam, S. Courtin, D. Bemmerer, U. Bilow, K. Zuber, A. Guglielmetti, A. Caciolli, D. Mengoni, R. Depalo, …

JRA 1- WP3, Task 3.2: Gas Targets for Nuclear astrophysics (**PI: Tamás Szücs**, tszucs@atomki,hu)

Participants:	2 Deliverables:	Idea beside the two deliverable:
ATOMKI, HZDR, UMIL, UNIPD	D3.2 Report on the development of a gas-jet target with in-beam target thickness diagnostic, on the project web site and in a scientific journal (resp: HZDR, month 18)	Active target
	D3.8 Report on the development of a gas cell target to be used for angular distribution measurements, on the project web site and in a scientific journal (resp: ATOMKI, month 48)	

JRA 1- WP3, Task 3.2: Gas Targets for Nuclear astrophysics

Gas targets pro and cons:

Pro	- Ultrahigh purity is relative easy to achieve - No beam induced deterioration - Noble gases
Pro or Con	- Usually thinner targets
Con	- Beam heating effect - Absolute target thickness determination - Number of beam particles - Complicated pumping systems

3 main type of gas targets:
- Thin windowed - Windowless extended - Gas jet

JRA 1- WP3, Task 3.2: Gas Targets for Nuclear astrophysics

3 main type of gas targets:

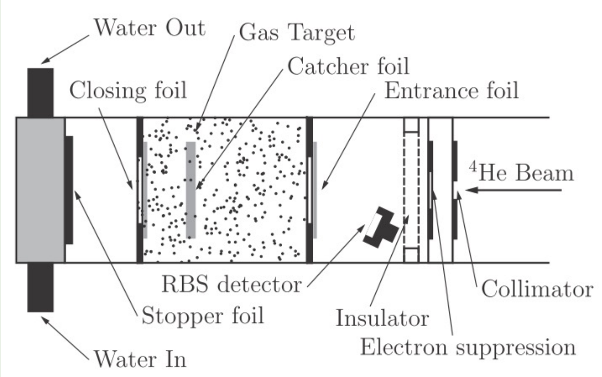
	Thin windowed	Windowless extended	Gas-jet
	Gas confined between thin foils	- Gas-flow restricted with collimators - Differential pumping - Constant supply of the lost gas (fresh or recirculated)	- Supersonic gas flow in a restricted volume - Differential pumping of the volume close to the jet
Pro	1. Beam current as charge integration 2. Target thickness from initial pressure and temperature 3. Can be geometrically thin -> point like source 4. Transportabel	1. No window -> no energy loss 2. Gas purity maintained	1. No window -> no energy loss 2. Gas purity maintained 3. Geometrically thin -> point like source
Con	1. Foil thickness determines the minimum energy 2. Beam energy straggling in the foil 3. Parasitic reactions on foil impurities 4. Outgassing of the surfaces into the cell may alter the composition	1. Differential pumping 2. Geometry shall be considered 3. Purification (for recirculation) 4. Feedback loops, precise measurements 5. ? Beam current from calorimetry	1. Differential pumping with high pressure part (compressor). 2. Overlap between particle beam and jet, to be determined 3. Purification (for recirculation) 4. Feedback loops

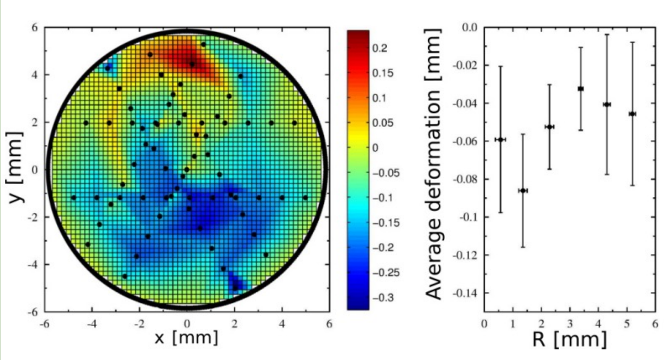
JRA 1- WP3, Task 3.2: Gas Targets for Nuclear astrophysics

Experience of the participants

Thin windowed

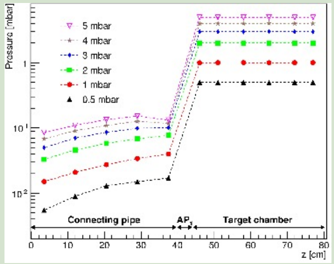
C. Bordeanu et al, NIMA 693 (2012) 220
Z. Halász et al, PRC 94 (2016) 045801

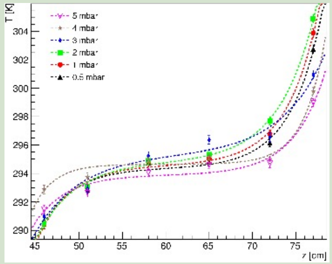


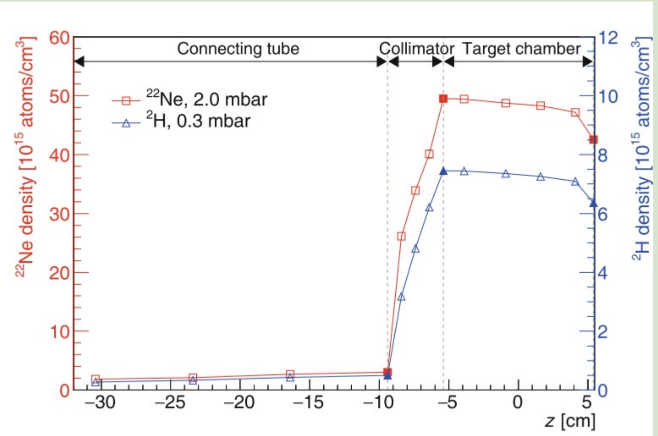


Windowless extended

F. Cavanna et al, EPJ A 50 (2014) 179
F. Ferraro et al, EPJ A 54 (2018) 44
V. Mossa et al, EPJ A 56 (2020) 144

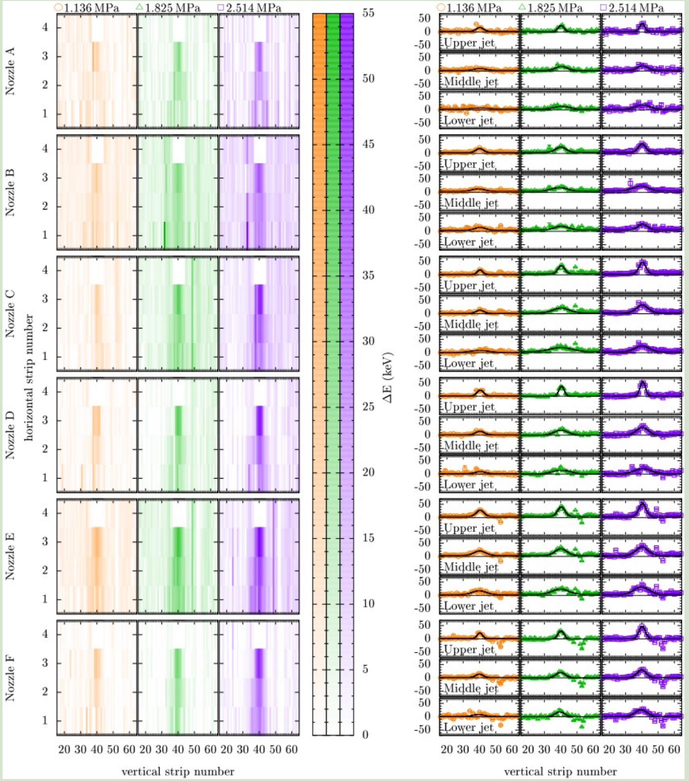






Gas-jet

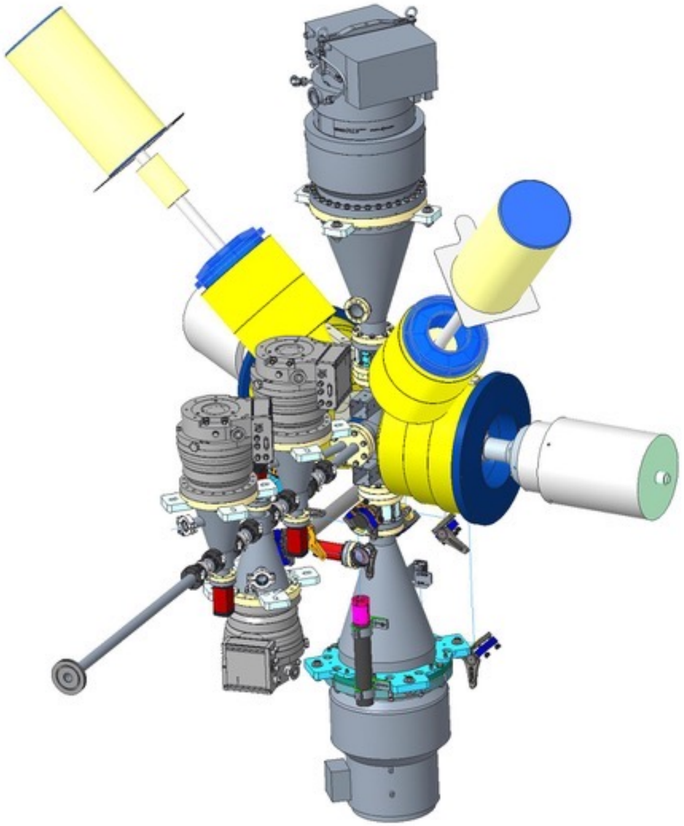
K. Schmidt et al, NIMA 911 (2018) 1

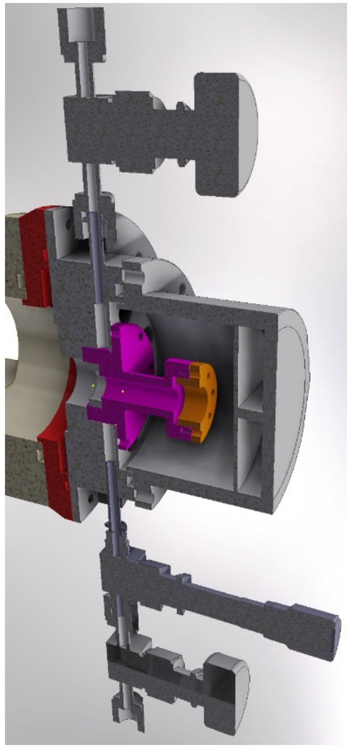


JRA 1- WP3, Task 3.2: Gas Targets for Nuclear astrophysics

Progress of the deliverables

	Thin windowed	Gas-jet + windowless extended
	Thin gas volume for activation and/or gamma angular distribution particle scattering with windowed gas target	gas jet with optical gas thickness measurement directly after the jet, a static-type windowless gas target





Task 3.3

- Develop and test new neutron detector materials, such as composite scintillators, new plastics, etc. especially with low afterglow
- neutron-gamma discrimination capabilities
- new methodologies and algorithms for neutron/gamma discrimination
- Develop a read-out system based on SiPM or Photomultipliers that will allow to obtain a spatial resolution and to be used in environments with intense gamma flash

J.J. Valiente Dobon, L. Swiderski, R. Nolte, E. Pirovano, M. Dietz, A. Caciolli, D. Mengoni, R. Depalo, A. Gottardo, …

University of Padova - UNIPD

Members: **A. Caciolli,** R. Depalo, D. Mengoni, D. Piatti
Involvement in ChETEC-INFRA: JRA1-WP3 (6 months) and NA2-WP7 (6 months)
Connection between WP3 and WP7: networking with industrial partners - Industry Days

Main goal: work on polysiloxane detectors applications in nuclear astrophysics:

Detectors already available and tested in Padua and LNL by project other than ChETEC-INFRA
They offers many interesting characteristics.
They can be used for fast or thermal neutrons. Good gamma ray discrimination

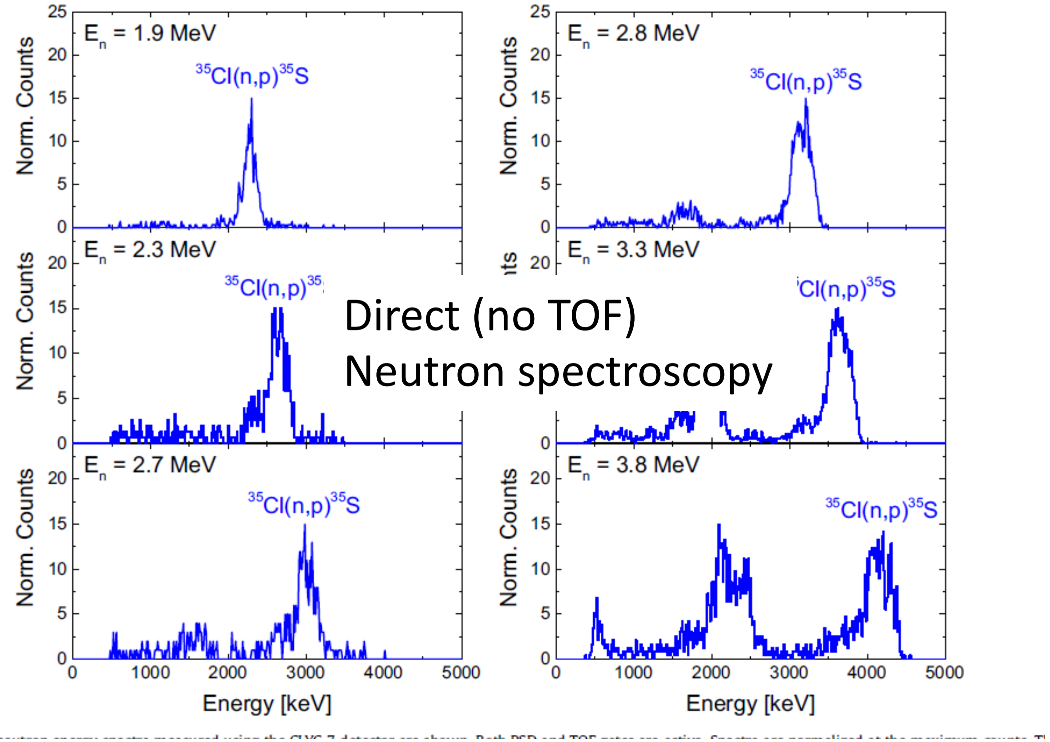
Possible use in nuclear astrophysics experiments
Possible test case: study of the d+d -> n + ^{3}He and d+d -> p + ^{3}H at LNL and other facilities involved in the ChETEC-INFRA network

References:

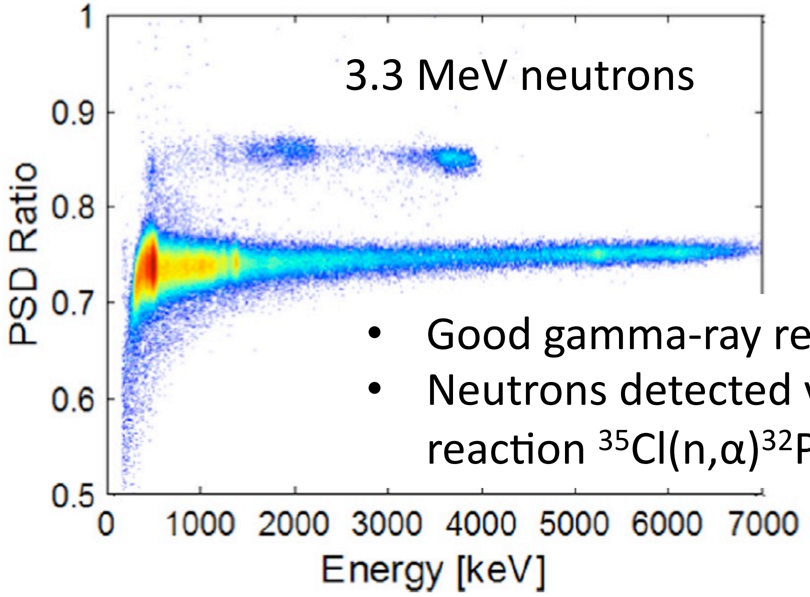
T. Marchi et al., Sci. Rep., 9 (1) (2019), p. 9154
S. Carturan et al., Nucl. Instrum. Methods A, 925 (2019), p. 109
A. Quaranta et al., Mater. Chem. Phys., 137 (2013), p. 951

CLYC (TLYC) scintillators for combined neutron/gamma-ray spectroscopy

A. Giaz et al. Nuclear Instruments and Methods in Physics Research A825 (2016) 51–61



Direct (no TOF)
Neutron spectroscopy



- Good gamma-ray resolution (<4% at 1MeV)
- Neutrons detected via the ^{35}Cl(n,p)^{35}S reaction ^{35}Cl(n,α)^{32}P

Excellent n/gamma-ray discrimination

What we want to do

- Tests with ^{252}Cf, AmBe source: TOF and direct spectrum at the same time
- Test also a TLYC ?
- Proton/α PSA to improve the neutron P/T ratio
- Towards a 4π array for beta-delayed neutron spectroscopy ?

INFN-LNL: Jose Javier Valiente Dobon and collaborators

INFN Istituto Nazionale di Fisica Nucleare

T3.3 proposed activity

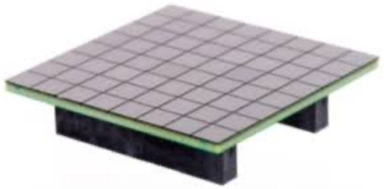
Position sensitive fast neutron detector

Scintillator material(s):

- stilbene crystals
- plastics
- organic glass (OGS)
- composite scintillators

+

Photodetector(s)



Large area SiPM (MPPC)

Position sensitive PMT (MAPMT)

Required detector characteristics/performance:

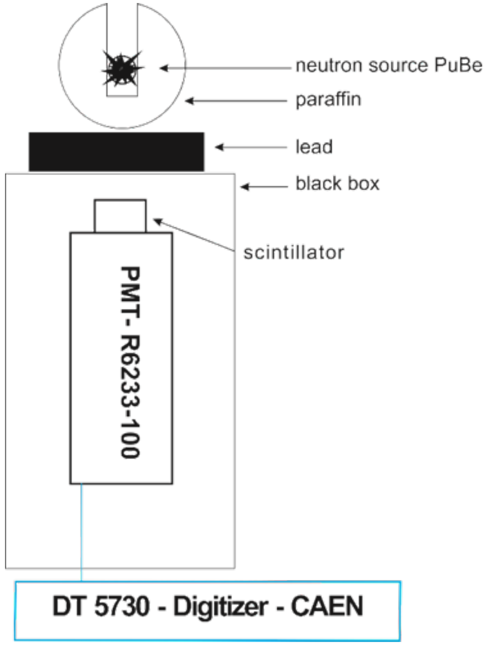
- positional resolution of (?)
- n/γ discrimination down to (?)
- ToF with resolution of (?)
- new methods for fast-n/γ discrimination (?)
- capability to operate in intense gamma flux (?)
- radiation damage studies (?)
- slow neutron detection (?)

Contact persons: L. Swiderski
L.Swiderski@ncbj.gov.pl

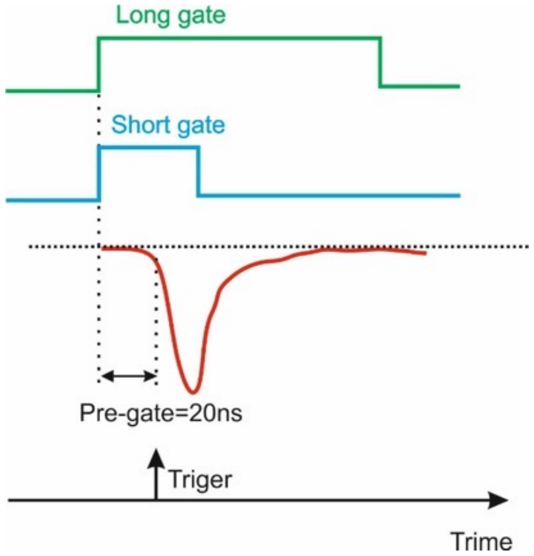
T3.3 proposed activity

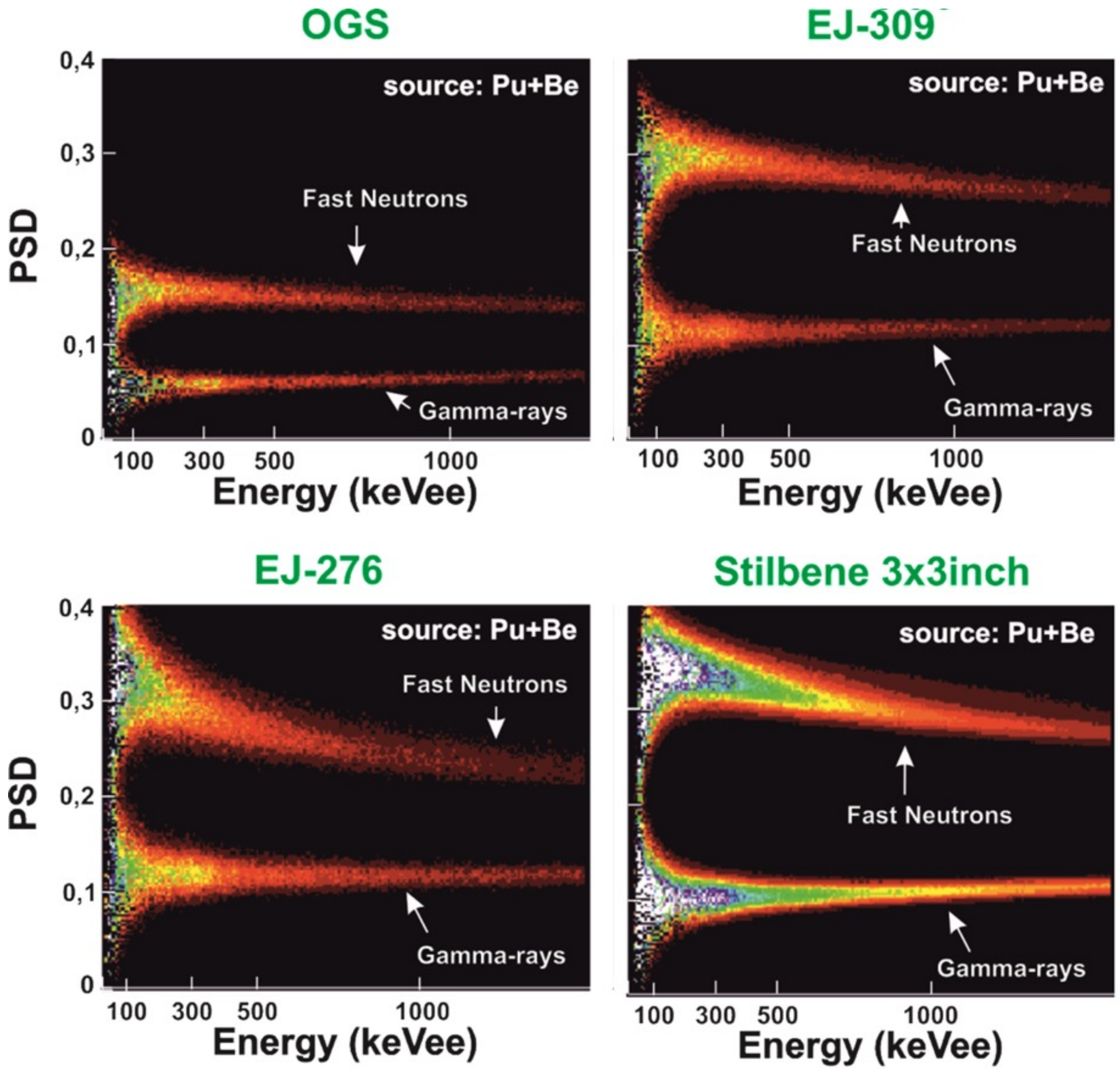
Organic Glass Scintillator – developed at Sandia NL (USA):

- high light output (~20 000 ph/MeV)
- emission spectrum peaked at ~430nm
- fast scintillation Decay (~3 ns)
- very good PSD discrimination (FOM = 1.4 @ 100 keVee)



PSD = $(Q_{long} - Q_{short})/Q_{long}$





Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

E. Pirovano, R. Nolte, M. Dietz

White Neutron Beams for Detector Studies

(Quasi-)monoenergetic and 'white' neutron sources:

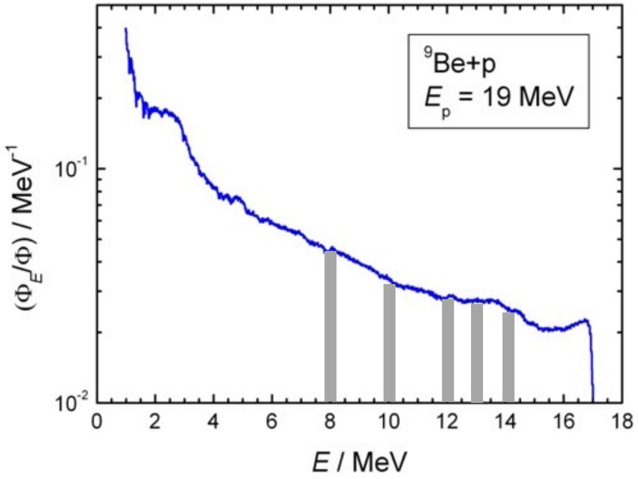
D(d,n), ^{15}N(p,n), ...

^{9}Be + p(19 MeV), ^{9}Be + d(13 MeV)

Energy selection via TOF

Flight paths: 11 m - 30 m

Ref: D1, RPT1



Detector development:

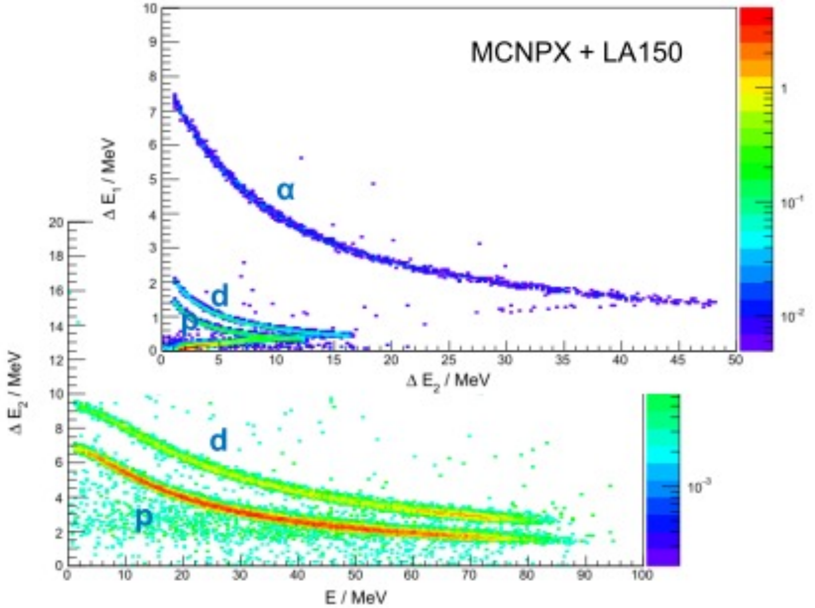
- Light yield (Quenching)
- Efficiency (ref.: D1, RPT1)
- …

High-energy DDX for ^{12}C(n, lcp x) at n_TOF

Experiment:

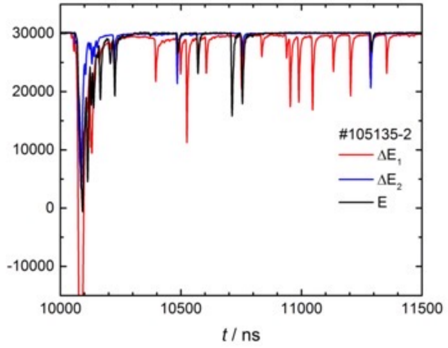
- n_TOF EAR1
- 3×10^{18} protons on spallation target (about 30 days)
- sample: 225 mg/cm² C
- development of ΔE^2-E telescopes for H and He ions
- neutron energy range of interest: 100-200 MeV

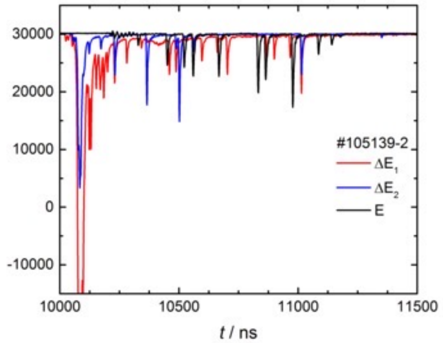
Goal: provide data to support improvement of INC models

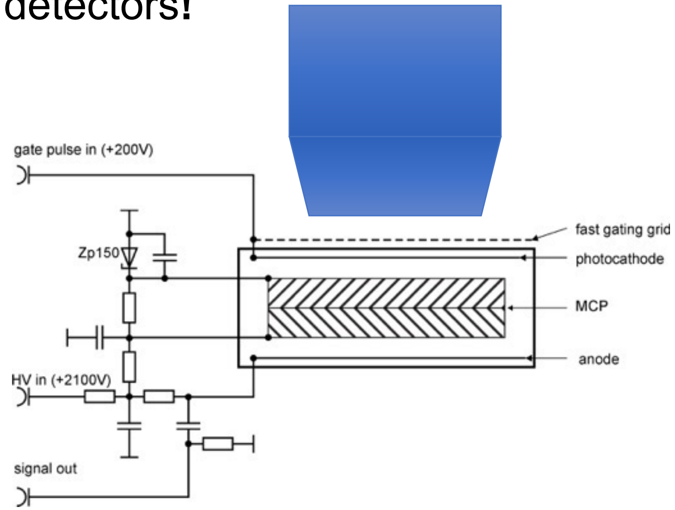


Gated PLANACON MCP PMT

… the γ-flash is a problem for *E* detectors!







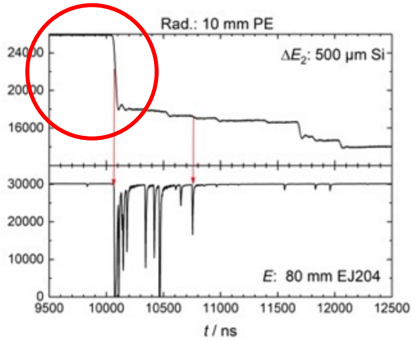
Gated Preamplifiers for Si Diodes

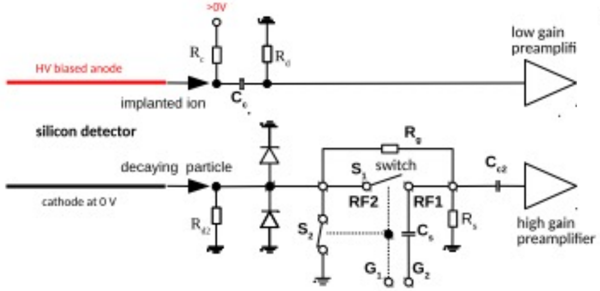
Adaption of gated pre-amps (HZDR development) for Si diodes (ΔE detectors):

- γ-flash immunity
- improved dynamic range

Canberra 2006 preamp:

γ-flash limits dynamic range





Ref.: Sebastian Urlass (CERN/HZDR), PhD Thesis

Task 3.4

- develop techniques to access the nuclear charge of the isotope to be provided for accelerator mass spectrometry, e.g. by ion-gas or ion-laser-interaction
- Develop high performance community-accepted methods to measure non-routine AMS isotopes of astrophysical relevance

R. Golser, P. Steier, M. Martschini, D. Bemmerer, A. Wallner, J. Lachner, …

Ion Laser Inertaction Mass Spectrometry

R. Golser, M. Martschini, P. Steier and Colleagues

UNIVIE, Austria

A. Wallner, J. Lachner and Colleagues

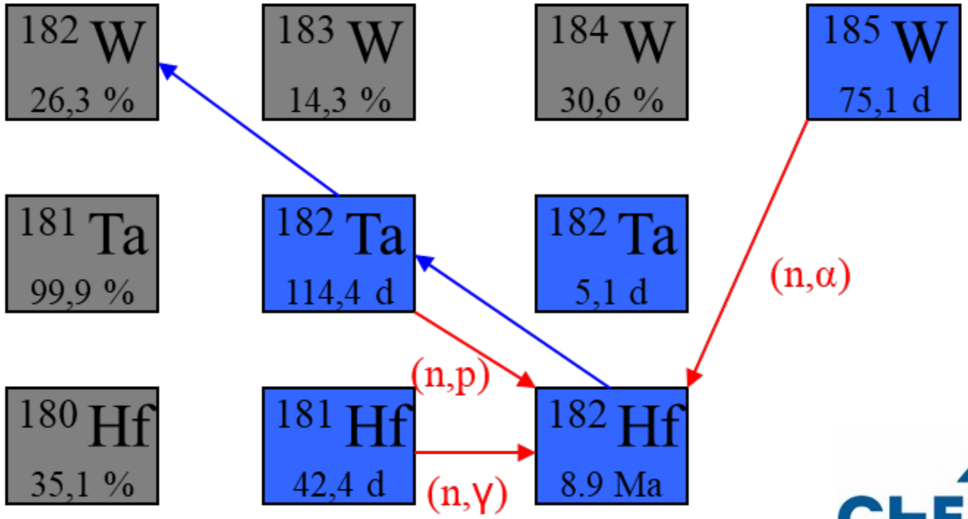
HZDR, Germany

“For accelerator mass spectrometry, the genesis and reactions of hafnium-182 will be used as an example to develop and benchmark a greatly enhanced capability of nuclear charge sensitivity, which on top of the exquisite sensitivity of mass spectrometry without molecules will allow nuclear astrophysicists to venture into new territory.”

Scientific Question: Is There Life ^{182}Hf From a Nearby Supernova at Earth ?

- Half-life: 8.9 Myr [1]
- Signal expected from supernova

$^{182}\mathrm{Hf}/^{180}\mathrm{Hf} \leq 10^{-13}$



Challenge

stable ^{182}W orders of magnitude more abundant than ^{182}Hf

VERA
Vienna Environmental Research Accelerator
Faculty of Physics - Isotope Physics

[1] Vockenhuber *et al.* Phys. Rev. Lett. **93**, 172501 (2004)

ChETEC INFRA

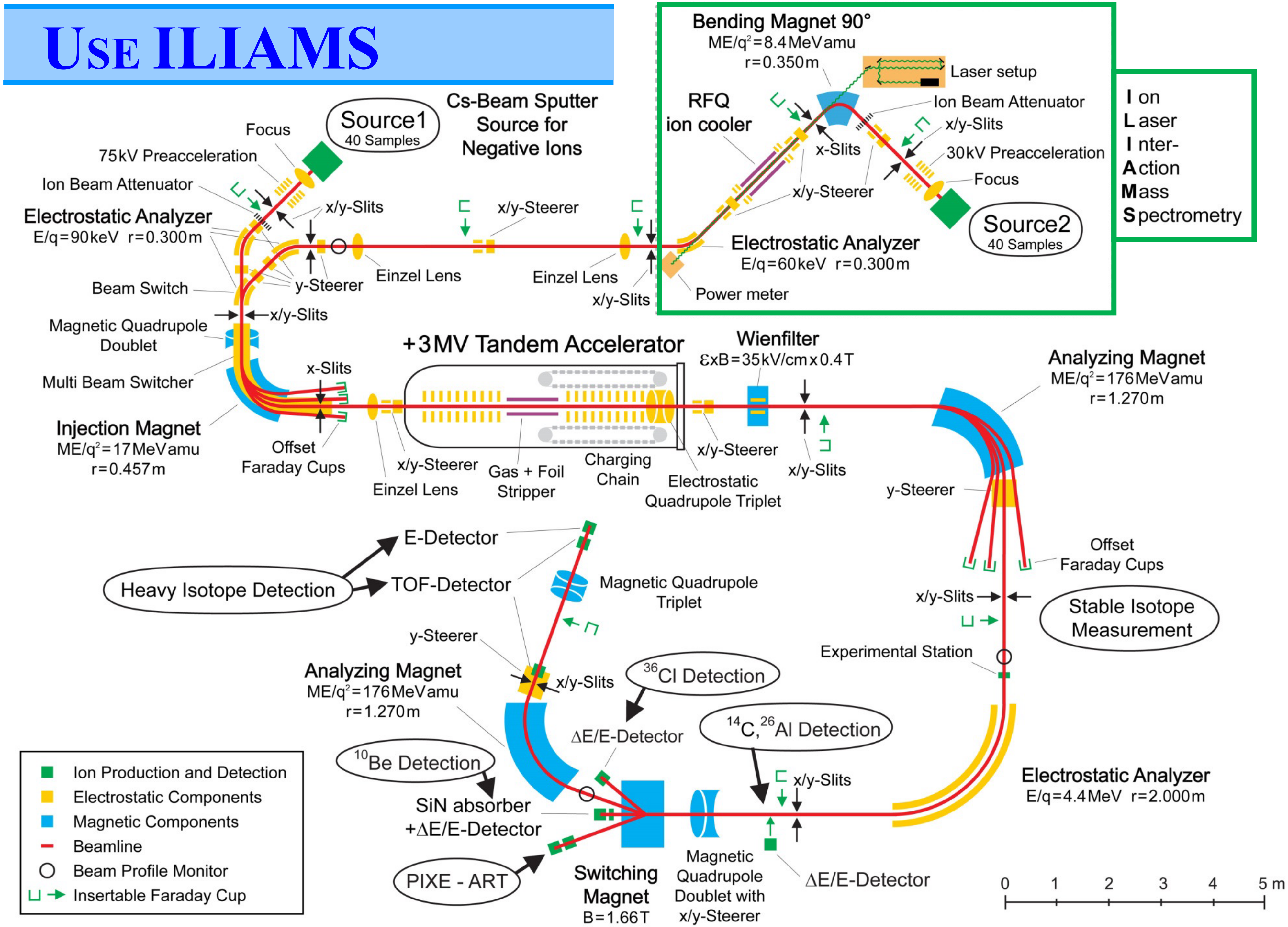
Use $^{182}HfF_5^-$ as $^{182}WF_5^-$ is Greatly Reduced

- $^{182}W^-$ isobaric background, suppression 6000 for **Hf F_5^-**
- previous VERA detection limit: **$^{182}Hf/^{180}Hf \approx 10^{-11}$** [2]

Ion species	Typical $^{180}Hf^{4+}$ current (nA)[a]	^{182}W suppression[b]	$^{182}Hf/^{180}Hf$ detection limit
Hf^-	0.004	~0.02	$\sim 10^{-4}$
HfH^-	0.06	0.1	3×10^{-5}
HfH_2^-	0.33	3	8×10^{-7}
HfH_3^-	0.35	4	5×10^{-7}
HfH_4^-	0.07	4	5×10^{-7}
HfH_5^-	0.31	100	2×10^{-8}
Hf^-	0.02	0.0002	3×10^{-4}
HfF_2^-	0.3	5	1×10^{-8}
HfF_3^-	35	250	2×10^{-10}
HfF_5^-	80	6000	1×10^{-11}

[2] Vockenhuber, Bichler, Golser, Kutschera, Priller, Steier, Winkler, Nucl. Instr. Meth. B 223-224 (2004) 823-828; Forster *et al.*, Nucl. Instr. Meth. B 269 (2011) 3180-3182.

USE ILIAMS



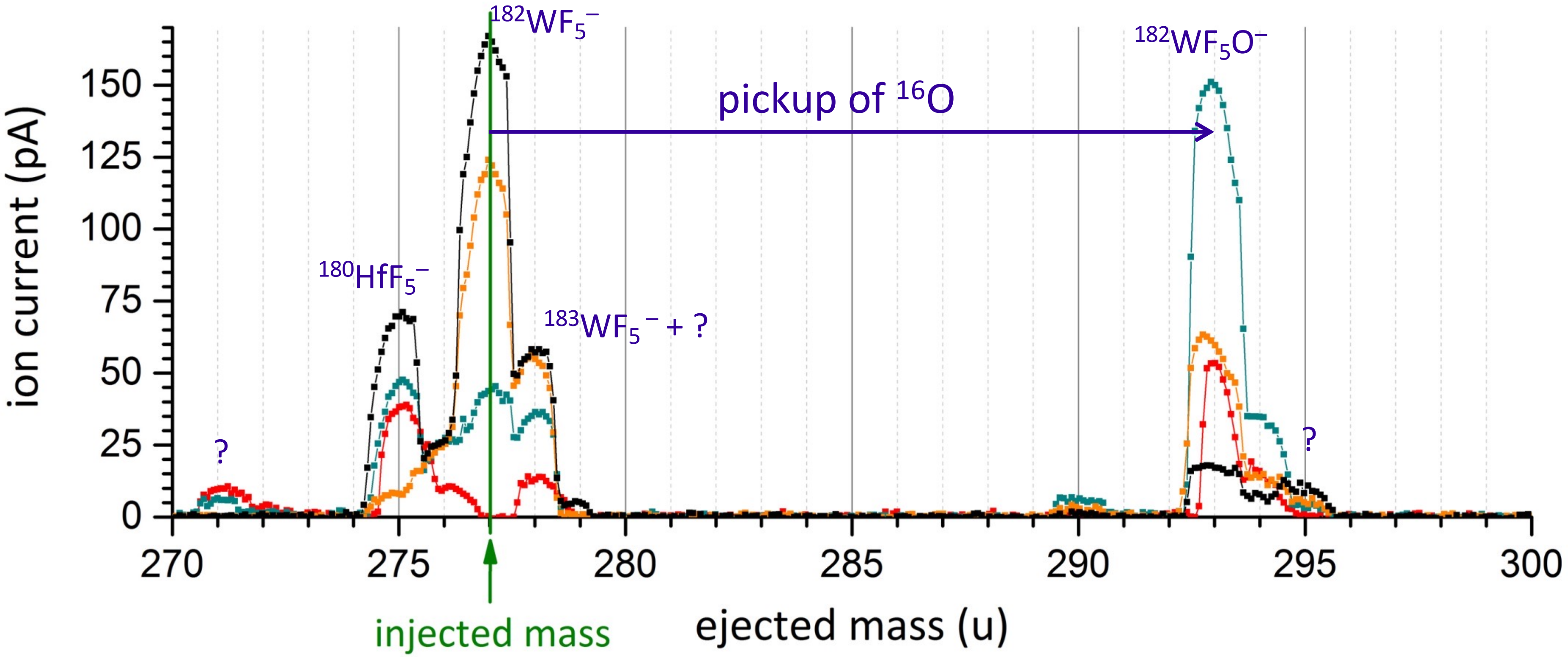
Bending Magnet 90°
ME/q²=8.4MeVamu
r=0.350m
Laser setup
RFQ
ion cooler
Ion Beam Attenuator
x-Slits
x/y-Slits
30kV Preacceleration
Focus
x/y-Steerer
Source2
40 Samples
Electrostatic Analyzer
E/q=60keV r=0.300m
Power meter
I on
L aser
I nter-
A ction
M ass
S pectrometry
Source1
40 Samples
Cs-Beam Sputter
Source for
Negative Ions
Focus
75kV Preacceleration
Ion Beam Attenuator
x/y-Slits
x/y-Steerer
Electrostatic Analyzer
E/q=90keV r=0.300m
Beam Switch
y-Steerer
Einzel Lens
Einzel Lens
x/y-Slits
x/y-Slits
Magnetic Quadrupole
Doublet
Multi Beam Switcher
x-Slits
Injection Magnet
ME/q²=17MeVamu
r=0.457m
Offset
Faraday Cups
+3MV Tandem Accelerator
Einzel Lens
x/y-Steerer
Gas + Foil
Stripper
Charging
Chain
Electrostatic
Quadrupole Triplet
Wienfilter
ε×B=35kV/cm×0.4T
x/y-Steerer
x/y-Slits
Analyzing Magnet
ME/q²=176MeVamu
r=1.270m
y-Steerer
Offset
Faraday Cups
x/y-Slits
Stable Isotope
Measurement
Experimental Station
E-Detector
TOF-Detector
Heavy Isotope Detection
Magnetic Quadrupole
Triplet
y-Steerer
x/y-Slits
Analyzing Magnet
ME/q²=176MeVamu
r=1.270m
36Cl Detection
ΔE/E-Detector
14C, 26Al Detection
10Be Detection
SiN absorber
+ΔE/E-Detector
PIXE - ART
Switching
Magnet
B=1.66T
Magnetic
Quadrupole
Doublet with
x/y-Steerer
x/y-Slits
ΔE/E-Detector
Electrostatic Analyzer
E/q=4.4MeV r=2.000m
Ion Production and Detection
Electrostatic Components
Magnetic Components
Beamline
Beam Profile Monitor
Insertable Faraday Cup
0 1 2 3 4 5 m

START DEVELOPING !

Ions extracted from the cooler when injecting mass 277 and neighboring masses;
Pickup of O by WF_5^- to form WF_5O^- is the most prolific reaction in this mass range

mixed sample $HfF_4 + PbF_2 + W$

gas in cooler: **He** or **$He+O_2$ (100:1)** or **$He+O_2$ (10:1)** or **$He+N_2$ (100:1)**



When?

Deliverables

D3.1	Report on the experimental techniques used for solid target production on the project web site
D3.2	Report on the development of a gas-jet target with in-beam target thickness diagnostic, on the project web site and in a scientific journal
D3.3	Provide to the community, upon request, one sample each of three possible scintillator materials for neutron detector in cooperation with industry
D3.4	Report on testing by radioactive sources and beam bombardment of the solid targets produced
D3.5	Report, on ChETEC-INFRA web site, on community-accepted methods to measure two non-routine AMS isotopes of astrophysical relevance
D3.6	Scientific publication on isobar suppression by ion-gas or ion-laser-interaction
D3.7	Publication on ChETEC-INFRA web site and in a scientific journal of target production protocols, characterization procedures, and results
D3.8	Report on the development of a gas cell target to be used for angular distribution measurements, on the project web site and in a scientific journal
D3.9	Report on the ChETEC-INFRA web site on different materials studied for neutron detection and position sensitive neutron detectors

Milestones:

- **M9** Measurement capability for Hf-182 by AMS developed and ready for external users (Task 3.4, month 36)

Key performance indicators:

- 10 scientific publications from this WP.
- 5 accelerator laboratories (both from inside and outside the consortium) where one of the target- or detector production techniques developed here is taken to routine operation.
- 5 PhD students trained in at least two of the tasks developed in JRA1.

GAANT CHART

WP3

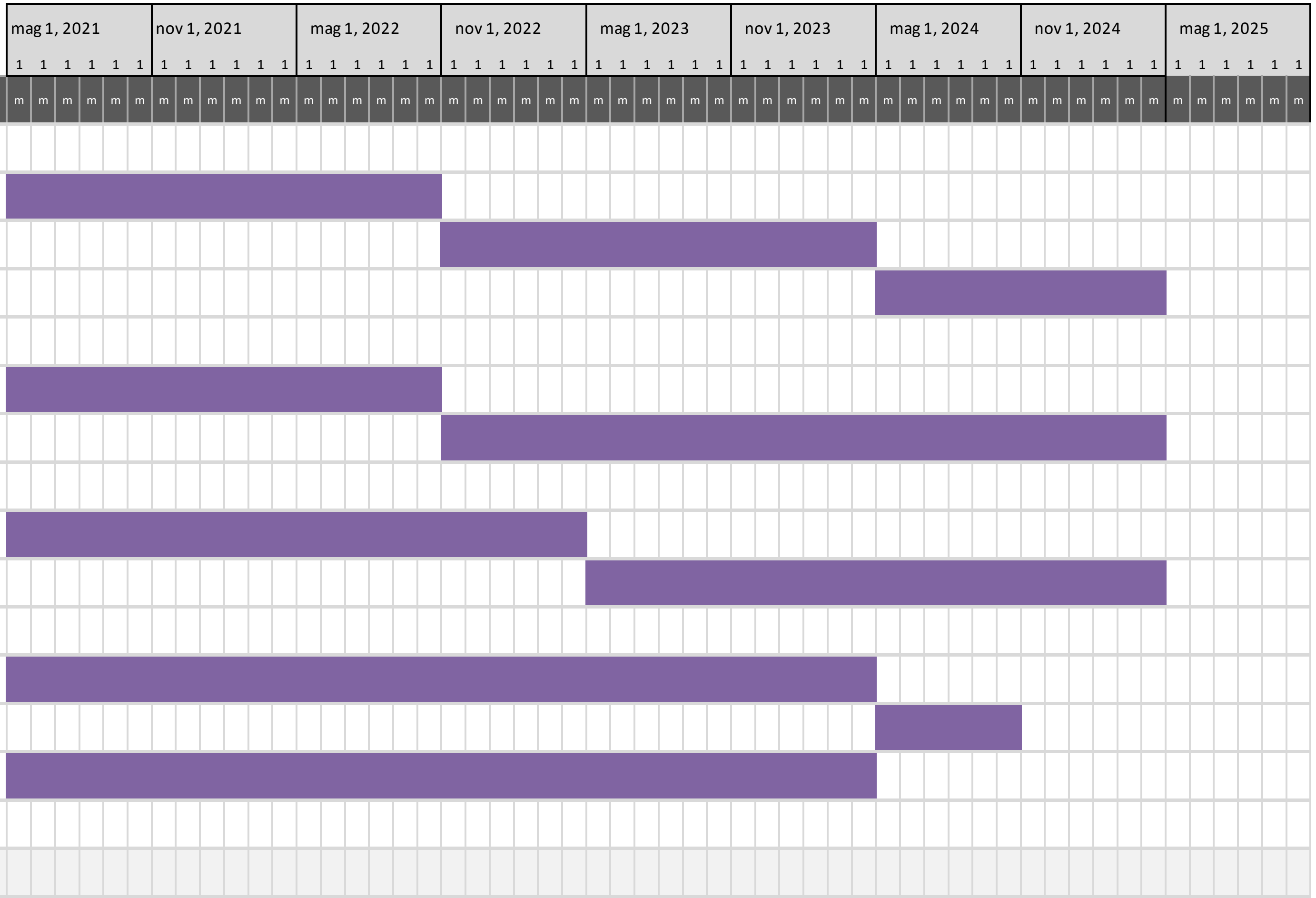
INFN
ML

SIMPLE GANTT CHART by Vertex42.com
https://www.vertex42.com/ExcelTemplates/simple-gantt-chart.html

Project Start: sab, 5/1/2021

Display Week: 1

TASK	ASSIGNED TO	PROGRESS	START	END
TASK 3.1	R. Spartà			
D 3.1		0%	5/1/21	10/31/22
D 3.4		0%	11/1/22	4/30/24
D 3.7		0%	5/1/24	4/30/25
TASK 3.2	T. Szucs			
D 3.2		0%	5/1/21	10/31/22
D 3.8		0%	11/1/22	4/30/25
TASK 3.3	J.J. Valiente Dobon			
D 3.3		0%	5/1/21	4/30/23
D 3.9		0%	5/1/23	4/30/25
TASK 3.4	R. Golser			
D 3.5		0%	5/1/21	4/30/24
D 3.6		0%	5/1/24	10/31/24
M 9		0%	5/1/21	4/30/24



Insert new rows ABOVE this one

Thank
You
Grazie
Mochchakkeram
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Chokrane
Ua Tsaug Rau Koj
Spasibo
Matur Nuwun
Asante
Obrigado
Matondo
Asante
Kiitos
Grazie
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Grazie
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Dank Je
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Raibh Maith Agat
Mochchakkeram
Ua Tsaug Rau Koj
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