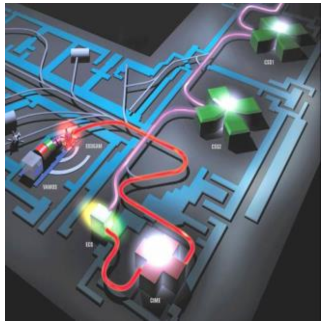

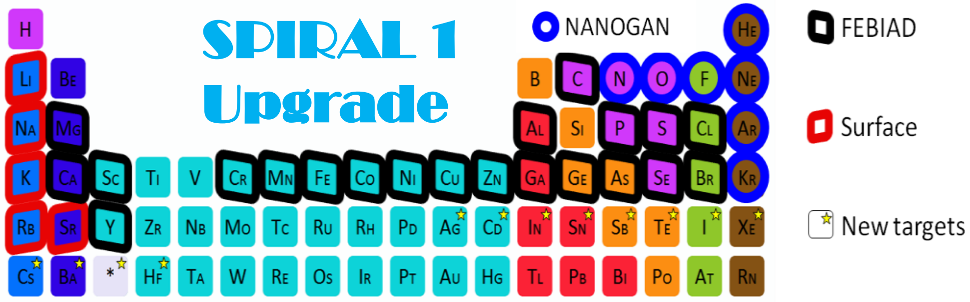

LoIs update, perspectives for low energy and reaccelerated beams

Pierre Delahaye

GANIL spiral2
laboratoire commun CEA/DSM CNRS/IN2P3

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- Perspectives for low energy beams (DESIR, 2027 -…)
  - General considerations for DESIR
    - Light nuclei
    - N=Z nuclei
    - What can we do before DESIR?
  - MORA and the ^{23}Mg / ^{39}Ca cases
- Perspectives for reaccelerated beams, using CIME (2023 -…)
  - Short term perspectives
    - ^{8}Li for study of primordial nucleosynthesis using ACTAR
    - ^{79}Se and ^{85}Kr for s-process study using MUGAST
    - ^{48}Cr for various physics cases in nuclear structure
  - Longer term prospects using MUGAST@LISE
- Summary table for developments

Perspectives with low energy beams

Some perspectives at LIRAT, but limited due to beam purity issues ⇒ ^{6}He searching for
* dark decay (H. Savajols DESIR session)
* evidence for tensor currents (bSTILED)

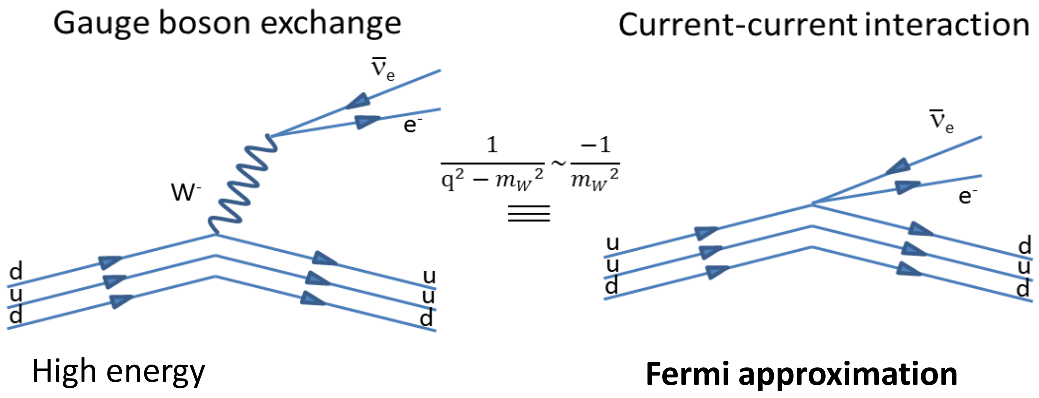
At longer term, low energy physics @ DESIR

- Upgraded SPIRAL 1 facility
- S3 – Low Energy Branch **when available**

⇒ **DESIR**

Unique perspectives for SPIRAL 1 beams at DESIR

Nuclear β-decay as a laboratory for weak interaction



$$\mathcal{H} = \frac{G_F V_{ud}}{\sqrt{2}} \sum_{i=V,A,S,T,P} (\overline{\Psi}_p O_i \Psi_n)[\overline{\Psi}_e O^i (C_i + C_i' \gamma_5) \Psi_\nu] + h.c.$$

Accessible via Ft-values
~$2\cdot10^{-4}$ thanks to 0+ 0+ transitions

Hardy and Towner, arXiv:1807.01146v1

T. D. Lee and C. N. Yang, Phys. Rev. 104, 254 (1956).
Explicit parity violation Ci'≠0
Sum of Lorentz invariants

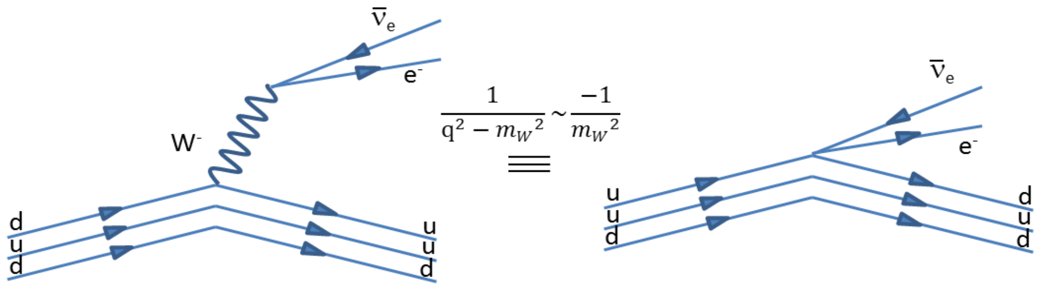
$|V_{ud}| = 0.97370(10)_{NP}(10)_{RC}$ Seng et al., PRL 121 (2018)

$|V_{ud}| = 0.97389(10)_{NP}(14)_{RC}$ Czarnecki, Marciano,Sirlin, Phys Rev D 100 (2019)

Belfatto et al., EPJC (2020)
CKM: is deviation from unitarity a sign of new physics at the TeV scale?

Nuclear β-decay as a laboratory for weak interaction

Gauge boson exchange — Current-current interaction



High energy — **Fermi approximation**

$$\mathcal{H} = \frac{G_F V_{ud}}{\sqrt{2}} \sum_{i=V,A,S,T,P} (\overline{\Psi}_p O_i \Psi_n)[\overline{\Psi}_e O^i (C_i + C_i' \gamma_5)\Psi_\nu] + h.c.$$

T. D. Lee and C. N. Yang, Phys. Rev. 104, 254 (1956).

Explicit parity violation Ci’≠0

Sum of Lorentz invariants

Accessible via **correlation measurements**

Standard Model

At quark level: $C_V = -C_A = 1, C_S = C_T = 0$

And $C_i = -C_i'$ for maximal parity violation

Real for T reversal/CP conserving interactions

Perspectives with low energy beams

Some perspectives at LIRAT, but limited due to beam purity issues ➡ ^{6}He searching for
* dark decay (H. Savajols DESIR session)
* evidence for tensor currents (bSTILED)

At longer term, low energy physics @ DESIR

- Upgraded SPIRAL 1 facility
- S3 – Low Energy Branch **when available**

➡ **DESIR**

Unique perspectives for SPIRAL 1 beams at DESIR

Perspectives with low energy beams

Some perspectives at LIRAT, but limited due to beam purity issues

At longer term, low energy physics @ DESIR

- Upgraded SPIRAL 1 facility
- S3 – Low Energy Branch **when available**

→ **DESIR**

Unique perspectives for SPIRAL 1 beams at DESIR

The best* workhorse for DESIR at startup may well be …

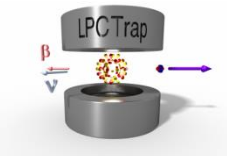
_ _ _ _ _ 1

* FT-value measurements

Extension of 0+ -> 0+ superallowed to mirror transitions for the determination of V_{ud}

* Correlation measurements

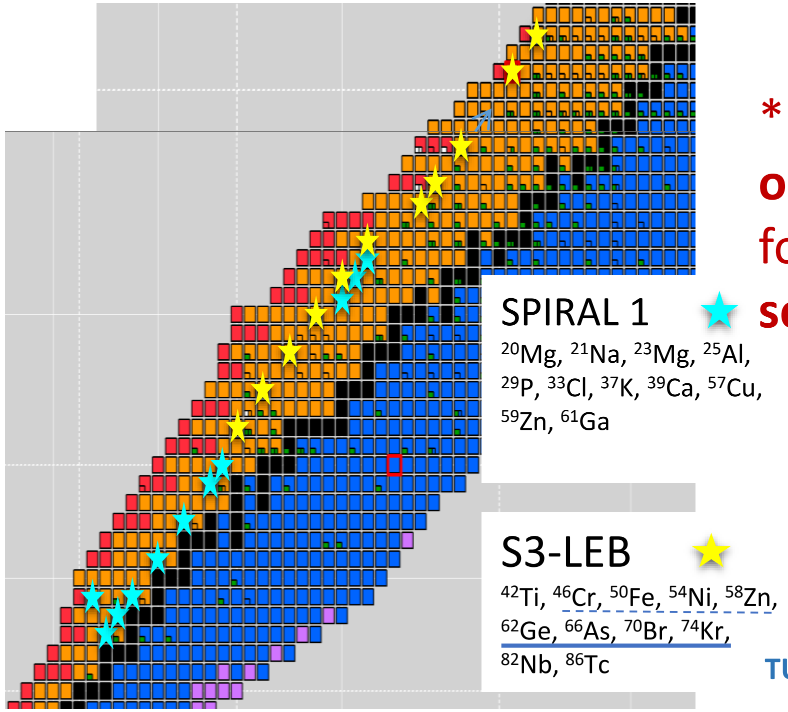
$a_{\beta\nu}$ (ρ) in the mirror decay of ^{21}Na, ^{23}Mg, ^{33}Cl, ^{37}K, ^{39}Ca, ^{41}Sc



Test of CP violation in beta-decay
^{23}Mg^{+} , ^{39}Ca^{+} beams from SPIRAL 1
The MORA project

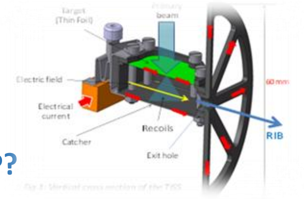
THE MORA PROJECT
MATTER'S ORIGIN FROM RADIOACTIVITY

anr
RÉGION NORMANDIE



*** Availability, operationability,** for producing **scientific highlights**

TULIP?



+ Mass measurements, 2p radioactivity with ^{22}Al, ^{31}Ar, ^{26}P,^{35}Ca etc.

What can be done before DESIR?

- Preparing DESIR!
  - N=Z nuclei with TULIP
  - ? Mass measurements and identification with PILGRIM at LIRAT
    - MR TOF MS: **a must-have** for beam identification at RIB facilities
      - Unique tool for long-lived beams (^{56}Ni, ^{48}Cr etc) yield measurement
      - Unique tool for identifying contaminants
      - Powerful/cost effective tool for purifying beams for beta decay experiments
    - Feasibility to be assessed: Human resources, Planification for DESIR, need for RFQ cooler
      - **Do we just wait that DESIR is built?**
    - LoI Pauline Ascher et al, mass measurements for probing
      - N=28 island of inversion (isotopic chains up to ^{49}Ar, ^{48}Cl, ^{43}P)
      - Vpn and possibility for 2n decay in $^{24-28}$F and $^{22-24}$O
  - ^{23}Mg and ^{39}Ca beam development for MORA

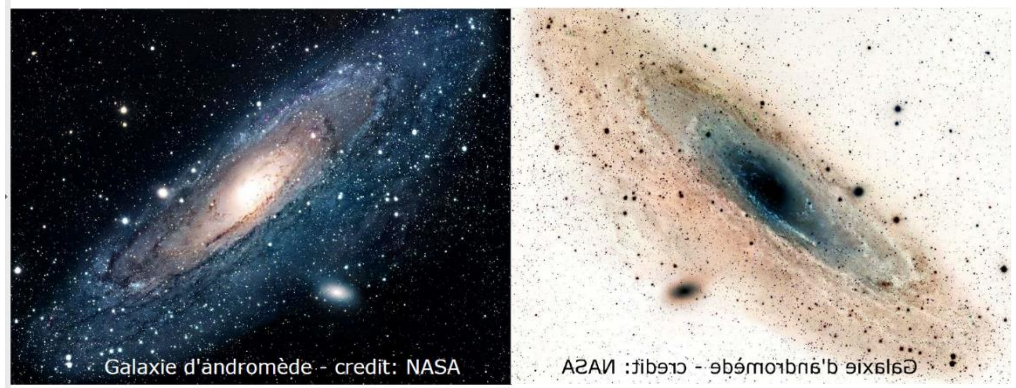
Search for new physics via the *D* correlation measurement

$$D\frac{\langle\vec{J}\rangle}{J}\cdot\left(\frac{\vec{p_e}}{E_e}\times\frac{\vec{p_\nu}}{E_\nu}\right)$$

T reversal odd

A non-zero *D* can arise from CP violation

- CP violation observed in the K, B and D - meson decays is not enough to account for the large matter – antimatter asymmetry
- T-odd correlations in beta decay (*D* and *R*) and n-EDM searches are sensitives to larger CP violations by 5 to 10 orders of magnitude



See P. Herczeg, Prog. Part. Nucl. Phys. 46 (2001) 413.

Below 10^{-4}, Final State Interactions mimic a non zero correlation

Best measurement so far: D_n= (–0.94 ±1.89±0.97)·10^{-4} *emiT collaboration, PRL 107, 102301 (2011),*

$D_{^{19}Ne}$=(1 ±6)·10^{-4} *Calaprice, Hyp. Int. 22(1985)83*

MORA: *D* correlation measurement to the 10^{-5} level with some beam, laser and trapping R&D

- **Search for leptoquarks beyond the TeV scale**
- First approach to probe of **Final State interaction effects**

MORA: Best candidates for *D* measurement

$$D \equiv \sin(\varphi_{AV}) \cdot \underbrace{\frac{2\rho}{1+\rho^2} \cdot \left(\frac{J}{J+1}\right)^{1/2}}_{F(X)}$$

Sensitivity to CP violating phase between V and A currents

Search for New Physics

- **Direct constraints** on CP-violating Wilson coefficients in the nucleon-level EFT
- via **the L-R symmetric model**
- via **the LQ model**

Neutron and mirror nuclei (N=Z-1): strong mixed (GT+ Fermi) transitions between analog states

	n	^{19}Ne	^{23}Mg	^{35}Ar	^{39}Ca
Sensitivity *F(X)*	0,43	-0,52	-0,65	0,41	0,71
D_1 (x10^{-4})	0,108	2,326	1,904	0,386	-0,489
D_2 (x10^{-4})	0,023	0,169	0,099	0,010	-0,024

D_n= (−0.94 ±1.89±0.97)·10^{-4} D_{19Ne}=(1 ±6)·10^{-4}

Best measurement so far, *statistics limited*

$$D_{FSI}(p_e) = \left(D_1 \cdot \frac{p_e}{p_{emax}} + D_2 \cdot \frac{p_{emax}}{p_e}\right) \times 10^{-4}$$

Callan and Treiman, Phys. Rev. 162(1967)1494.
Chen, Phys. Rev. 185(1969)2003.

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MORA: Alkali earth elements for in trap laser ion polarization

1st candidate; 10^5 pps from JYFL
>10^8 pps from SPIRAL 1

2^{nd} candidate, R&D for ISOL production required

	n	**^{19}Ne**	**^{23}Mg**	**^{35}Ar**	**^{39}Ca**
Sensitivity *F(X)*	0,43	-0,52	-0,65	0,41	0,71
D_1 (x10^{-4})	0,108	2,326	1,904	0,386	-0,489
D_2 (x10^{-4})	0,023	0,169	0,099	0,010	-0,024

10^7 pps requested

$D_n = (-0.94 \pm 1.89 \pm 0.97) \cdot 10^{-4}$ $D_{19Ne} = (1 \pm 6) \cdot 10^{-4}$

Best measurement so far, *statistics limited*

$$D_{FSI}(p_e) = \left(D_1 \cdot \frac{p_e}{p_{emax}} + D_2 \cdot \frac{p_{emax}}{p_e}\right) \times 10^{-4}$$

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Chen, Phys. Rev. 185(1969)2003.

Prospects with ^{39}Ca

^{39}Ca: a counter part of ^{23}Mg for looking for New Physics and verifying the Final State Interactions

Place and type of measurement	Trapped ions /cycle	Decays/s	Beam time (days)	Detected coinc. (P)	σ_P stat (%)	Detected coinc. (D)	σ_D stat*
JYFL: P - 23Mg	2,00E+04	1,23E+03	8	1,7E+05	**1,9E+00**	1,5E+06	1,0E-03
JYFL: D - 23Mg	2,00E+04	1,23E+03	32	6,7E+05	9,4E-01	6,1E+06	**5,2E-04**
DESIR: D - 23Mg	5,00E+06	3,07E+05	24	1,3E+08	6,9E-02	1,2E+09	**3,8E-05**
DESIR: D - 39Ca**	5,00E+06	4,03E+06	24	1,7E+09	1,5E-03	1,5E+10	**1,0E-05**

* All measurements so far have been statistics dominated

Assuming **10^7 pps produced from SPIRAL 1 or S3 – LEB

4 years for developping ^{39}Ca at GANIL/SPIRAL2, in parallel of

- First *D* measurement(s) and careful study of systematic effects at JYFL
- Theoretical studies at IJCLab - Adam Falkowski, Antonio Rodriguez-Sanchez
  - Full classification of models of New Physics probed by a D~10^{-5} measurement
  - Verification of Final State Interactions calculations with modern EFTs
- Construction of DESIR and associated instruments (HRS, Lasers cabins, …)

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JYFL: P - 23Mg	2,00E+04	1,23E+03	8	1,7E+05	**1,9E+00**	1,5E+06	1,0E-03
JYF							4
DES							5
DES							5

The ultimate sensitivity of MORA to New Physics technically depends on:

- **Statistics**
- **Control of systematic effects**

Taking example of successful measurements carried out with neutron decay, and EDM

A regular access to online run with possible long data accumulation periods* is highly desired

*** 3 to 4 weeks typically**

ted

Assuming **10^7 pps produced from SPIRAL 1 or S3 – LEB

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LoI6_20 @ GANIL: «Li-Alpha» -Measurement of $^{8}Li(\alpha,n)^{11}B$ cross section with ACTAR

See T. Roger's presentation on ACTAR

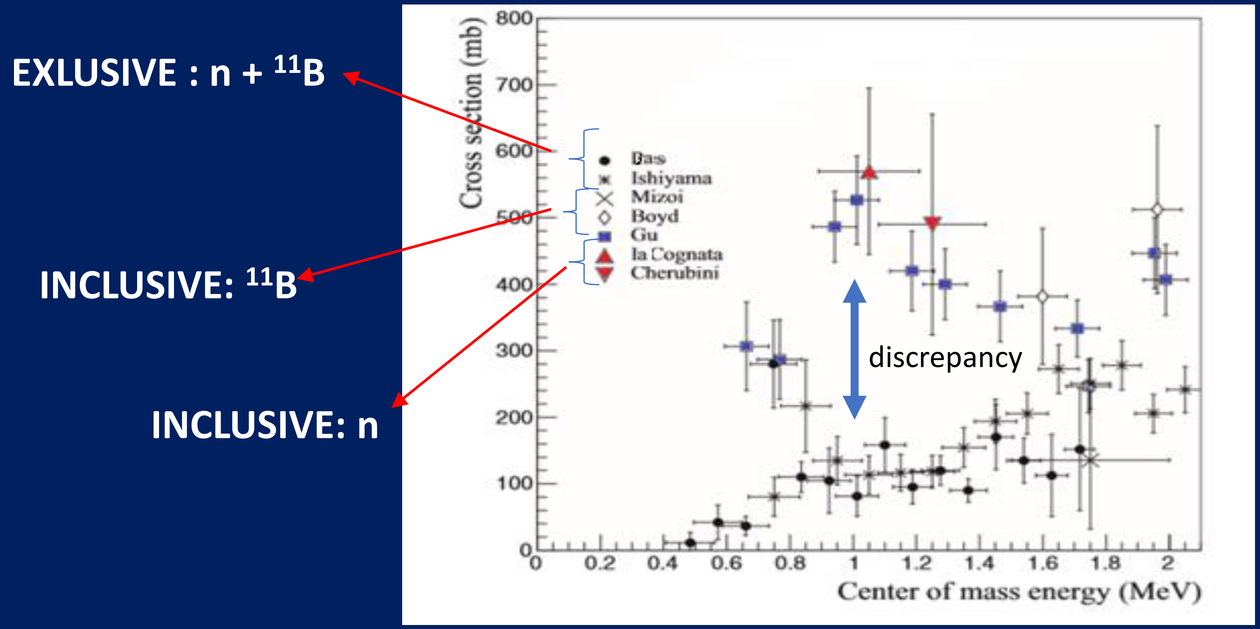
^{8}Li beam development @ SPIRAL1

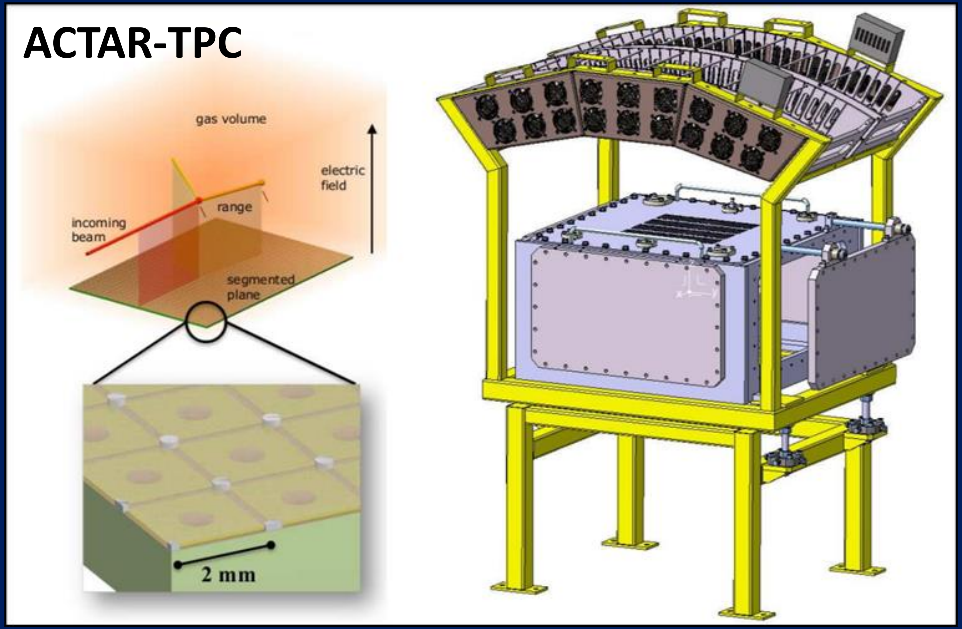
New Proposal for December 2022 GANIL PAC - Spokesperson: M.G. Pellegriti, I. Lombardo, T. Roger

ASTROPHYSICS: nucleosynthesis in the early evolutionary stage of our universe, starting of r-process nucleosynthesis in supernovae, collapsars and neutron star mergers

STRUCTURE: α-structure of ^{12}B

inclusive ^{11}B detection with a factor 5 smaller pitch





Huge discrepancy between inclusive and exclusive measurements !!

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STRUCTURE: α-structure ... th a factor 5 smaller pitch

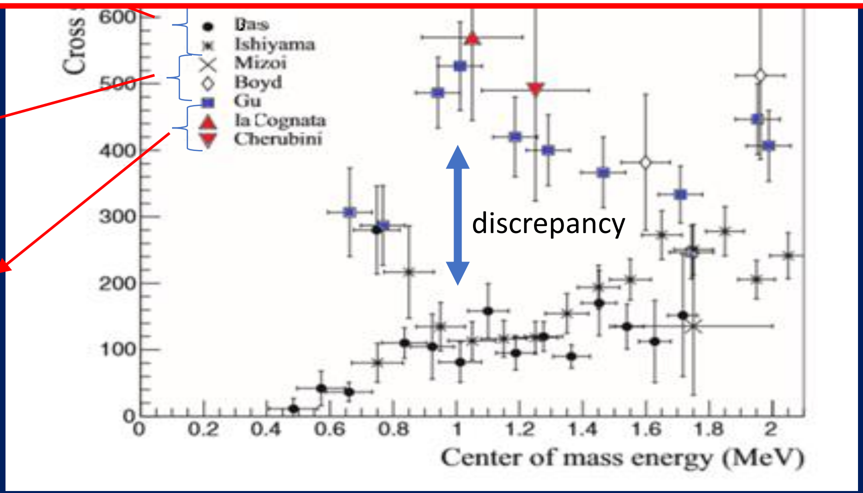
Tests are completed:

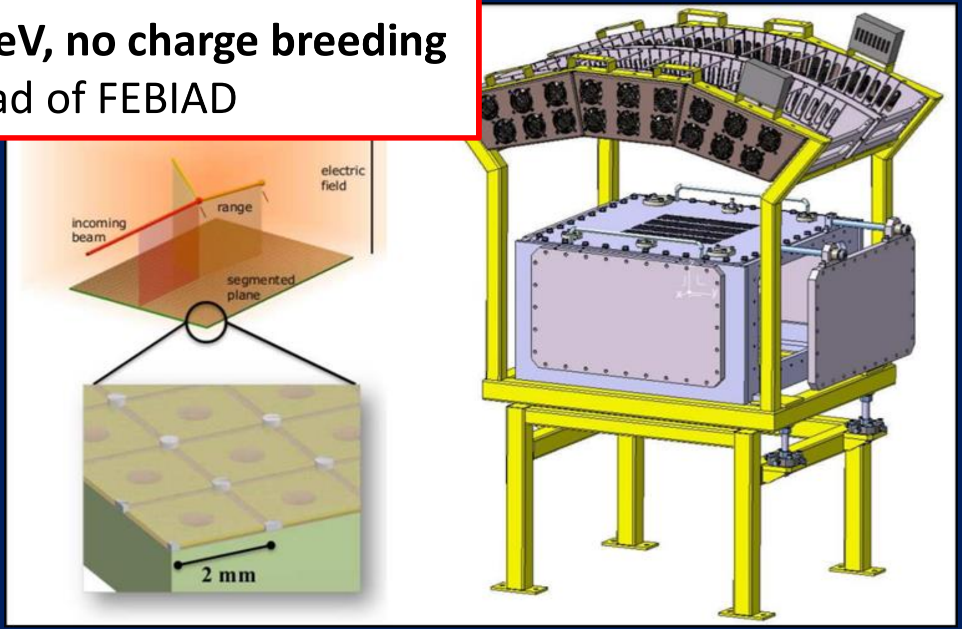
- Beam produced with FEBIAD source, 10^6 pps feasible with ^{13}C
- 2% for reacceleration **through CIME at 1.2 AMeV, no charge breeding**
- Interesting prospects for ^{9}Li if Mononake instead of FEBIAD

EXLUSIVE : n + ^{11}B

INCLUSIVE: ^{11}B

INCLUSIVE: n





Huge discrepancy between inclusive and exclusive measurements !!

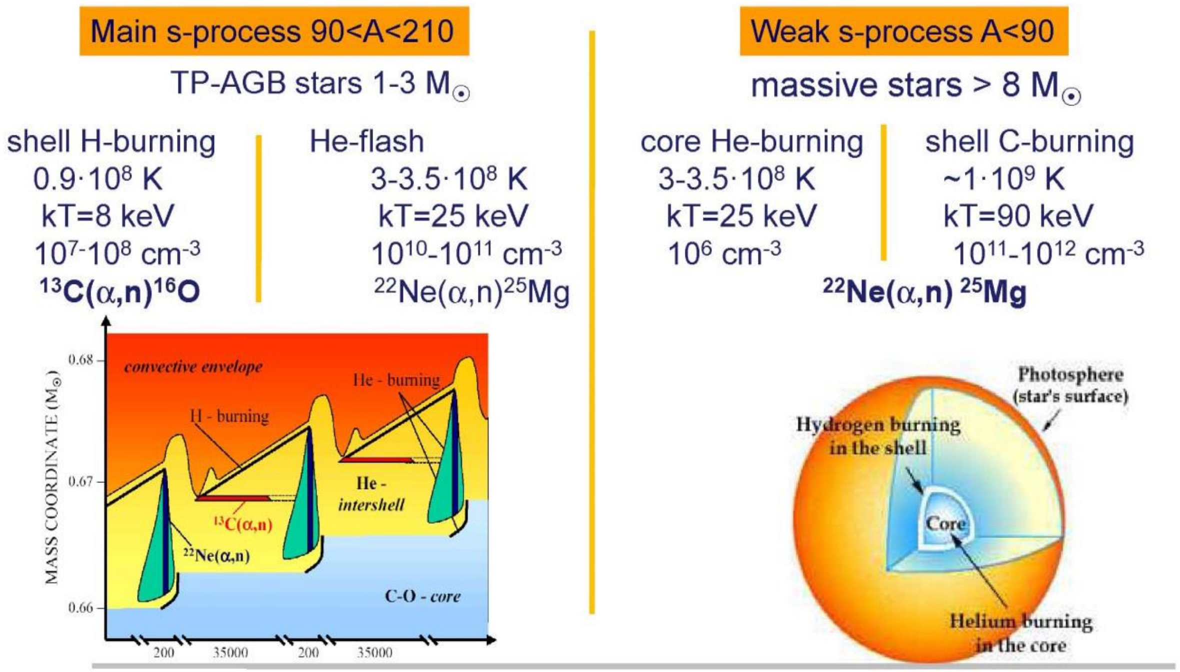
^{79}Se and ^{85}Kr for nuclear astrophysics using MUGAST

See O. Sorlin's presentation on LISE

Neutron capture at the 85Kr s-process branching: F. Recchia and G. De Angelis (LoI/proposal 2018, resubmitted)
The 79Se(n,γ) capture cross section via the 79Se(d,p)80Se reaction, G. De Angelis et al. (LoI 2019)

(p,d) surrogate reactions to (n, γ)

(n, γ) cross section for constraining s process path, associated neutron densities and temperature



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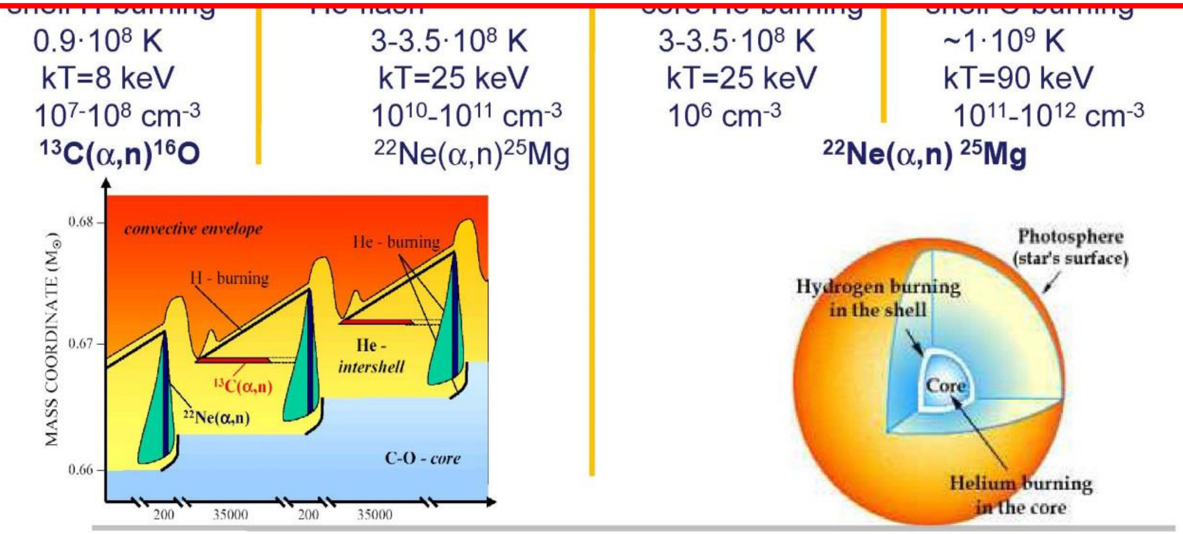
(p,d) surrogate reactions to (n, γ)

(n, γ)

Very long lived beams:

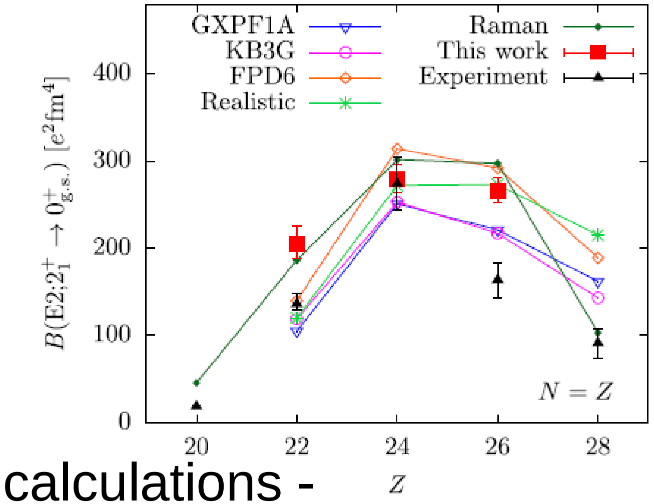
- ^{85}Kr (10.7y) **commercially available** for ORANO as a gas, 2 bottles (120MBq) purchased
- ^{79}Se(327ky) **not yet available** while ^{75}Se is. Latest test with ^{84}Kr@SPIRAL1: **^{71}Se produced**.

Production at SPIRAL 1 with or without the CSS?



^{48}Cr physics cases

- LoI E. Clément, W. Korten 2019: probing **rotational character** of the most collective N=Z nucleus in fp shell via **safe Coulomb excitation**
  1. An independent measurement of the B(E2,4+→2+)
  2. The study of the non-yrast states collectivity
  3. A first measurement of the static quadrupole moment $Q_s(2^+)$



- ^{48}Cr using MUGAST (see presentation by O. Sorlin)
  - **Spectroscopic factors via (d,p) transfert** to compare with LSSM calculations - ANTOINE K3B interaction. A Gadea et al.
  - **Probing the effect of deformation for T=1 np pairing** in **^{48}Cr(^{3}He,pγ)^{50}Mn** reaction (cryogenic target). M. Assié et al.

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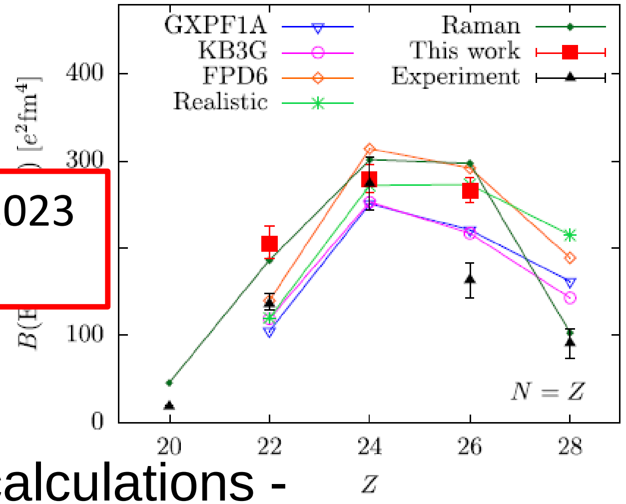
Focus on ^{48}Cr, for which measurements would have to start in 2023
Production with the FEBIAD source at SPIRAL 1



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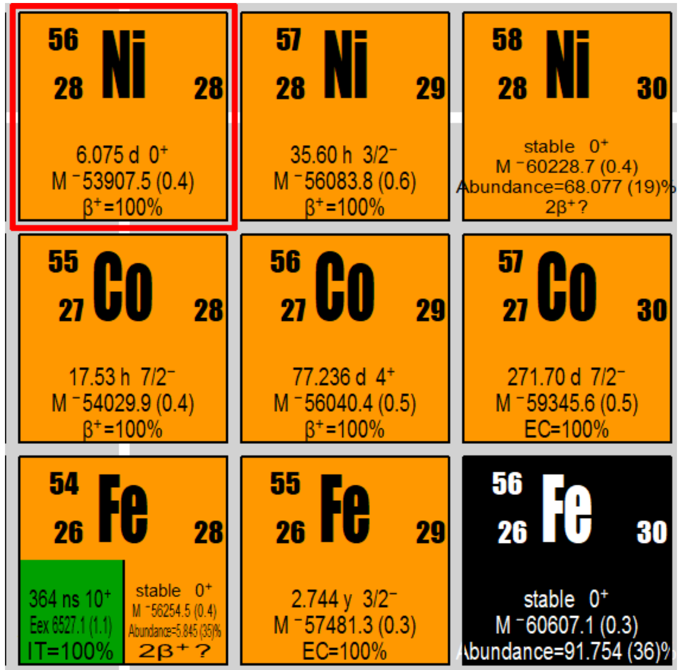
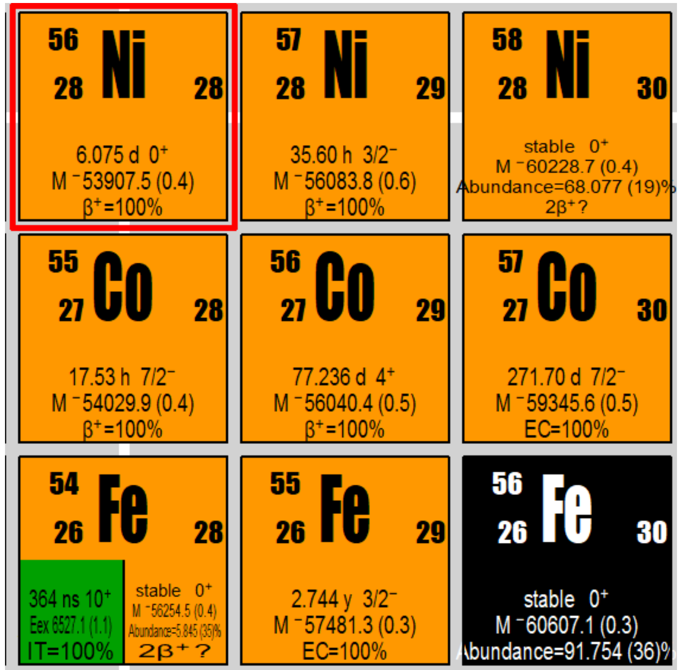
Other Physics cases using MUGAST



MUGAST Prepac 2019

Astro	^{55}Co, ^{57}Ni(d,p) ^{33}Cl(^{3}He,d)^{34}Ar →	*G. Lotay (Surrey)* Readily produced
Pairing	^{56}Ni,^{48}Cr(^{3}He,p)	*M. Assié, IPNO*

Other Physics cases using MUGAST



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Pairing	^{56}Ni,^{48}Cr(^{3}He,p)	*M. Assié, IPNO*

Already several LoIs on ^{56}Ni in 2018 (M. Assié / F. Flavigny)
Long lived beams, not easy to identify, probably quite polluted → stripping necessary
Production with the FEBIAD source at SPIRAL 1 to be discussed for possible scheduling

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Summary table for developments

Priority 0 (accepted experiments)						
Isotope	**Intensity (min)**	**Energy**	**Timescale**	**Reference**	**Production method**	**Difficulty**
85Kr	1e6 pps	10 AMeV	<1 year	LoI Recchia 2019 -		
Priority 1 (endorsed LoI or ANR)						
Isotope	**Intensity (min)**	**Energy**	**Timescale**	**Reference**	**Production method**	**Difficulty**
8Li	10^4 -10^5pps	1.4 AMeV	2023-25	LoI Grazia 2020	Fragmentation 12C/13C	
48Cr	5 10^4 pps	4.4 AMeV	2024	LoI Clément 2019		
39Ca	> 10^7 pps	15-30 keV	2027	LoI Delahaye 2021	?	
23Mg	10^8 pps	15-30 keV	2027	LoI Delahaye 2021		
74Rb		15-30 keV		ANR TULIP	Fusion evaporation	
79Se	10^5 pps	9 AMeV	2023-25	LoI De Angelis 2019		
Priority 2: recent LoIs, recent expressed interests						
Isotope	**Intensity (min)**	**Energy**	**Timescale**	**Reference**	**Production method**	**Difficulty**
56Ni	5 10^4 pps	10-15AMeV	2023-25	LoIs Flavigny Assié 2018		
55Co	~5E4 pps	~10 AMeV	2023-25	Mugast Prepac Lotay		
57Ni	~5E4 pps	~10 AMeV	2023-25	Mugast Prepac Lotay		
33Cl	~5E4 pps	~10 AMeV	2023-25	Mugast Prepac Lotay		
67As	~5E4 pps	~10 AMeV	2023-25	Mugast Prepac Mengoni		
118,120Xe	>1e3 pps	4.4 AMeV	2023-25	LoI Clément 2018	Fusion Evaporation	
70Se	>10^4 pps	10-15AMeV	2023-25	Com. Valerian Alcindor		
69Cu	> 10^4 pps	10-15AMeV	2023-25	Com. N. De Séréville		

Open for discussion

→ Originally planned on AGATA, difficult beam

→ TULIP?

Summary table for developments

Priority 3: long term opportunities, older LoIs with case to be confirmed						
Isotope	**Intensity (min)**	**Energy**	**Timescale**	**Reference**	**Production method**	**Difficulty**
41-48Cl	1pps	15-30keV	2027?	LoI Ascher 2016		
39-43P	1pps	15-30keV	2027?	LoI Ascher 2016		
24-28F	1pps	15-30keV	2027?	LoI Ascher 2016		
46-49Ar	1pps	15-30keV	2027?	LoI Ascher 2016		
22-24O	1pps	15-30keV	2027?	LoI Ascher 2016		
25Al	1e5 pps	10-15AMeV		LoI De Séreville 2016	AlF	
30P	1e5 pps	10-15AMeV		LoI De Séreville 2016		
74Kr or 74Rb	1e3 pps	5AMeV?		LoI Singh 2016	78Kr fragmentation	None 74Kr
148Gd	1e4pps	<5AMeV?		LoI Caamaño 2016	Fusion Evaporation	
158Ho	1e4pps	<5AMeV?		LoI Caamaño 2016	Fusion Evaporation	
160Yb	1e4pps	<5AMeV?		LoI Caamaño 2016	Fusion Evaporation	
170Lu	1e4pps	<5AMeV?		LoI Caamaño 2016	Fusion Evaporation	
26mAl	1e6pps	3AMeV?		E792S		
Priority 3 (still 3): beams only discussed during the SPIRAL 1 WS in 2016						
45K	1e6 pps	2.5 AMeV		Prepac AGATA 2016		
25Na	1.8e6 pps	~2.5 AMeV		Prepac AGATA 2016		
21F	> 1e4pps?	3AMeV		Prepac AGATA 2016		
25Na	> 1e4pps?	3AMeV		Prepac AGATA 2016		
21,22, 27Mg	> 1e4pps?	3AMeV		Prepac AGATA 2016		
29Al	> 1e4pps?	3AMeV		Prepac AGATA 2016		
33P	> 1e4pps?	3AMeV		Prepac AGATA 2016		
35K	> 1e4pps?	3AMeV		Prepac AGATA 2016		
21,26Na	1e4 pps	15-30 keV	2027 DESIR	WS SPIRAL 1 2016		
22,23Mg	1e4 pps	15-30 keV	2027 DESIR	WS SPIRAL 1 2016		
29P	1e4 pps	15-30 keV	2027 DESIR	WS SPIRAL 1 2016		
37K	1e4 pps	15-30 keV	2027 DESIR	WS SPIRAL 1 2016		

… … …

Open for discussion