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THE STATE UNIVERSITY
OF NEW JERSEY

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laboratoire commun CEA/DSM CNRS/IN2P3

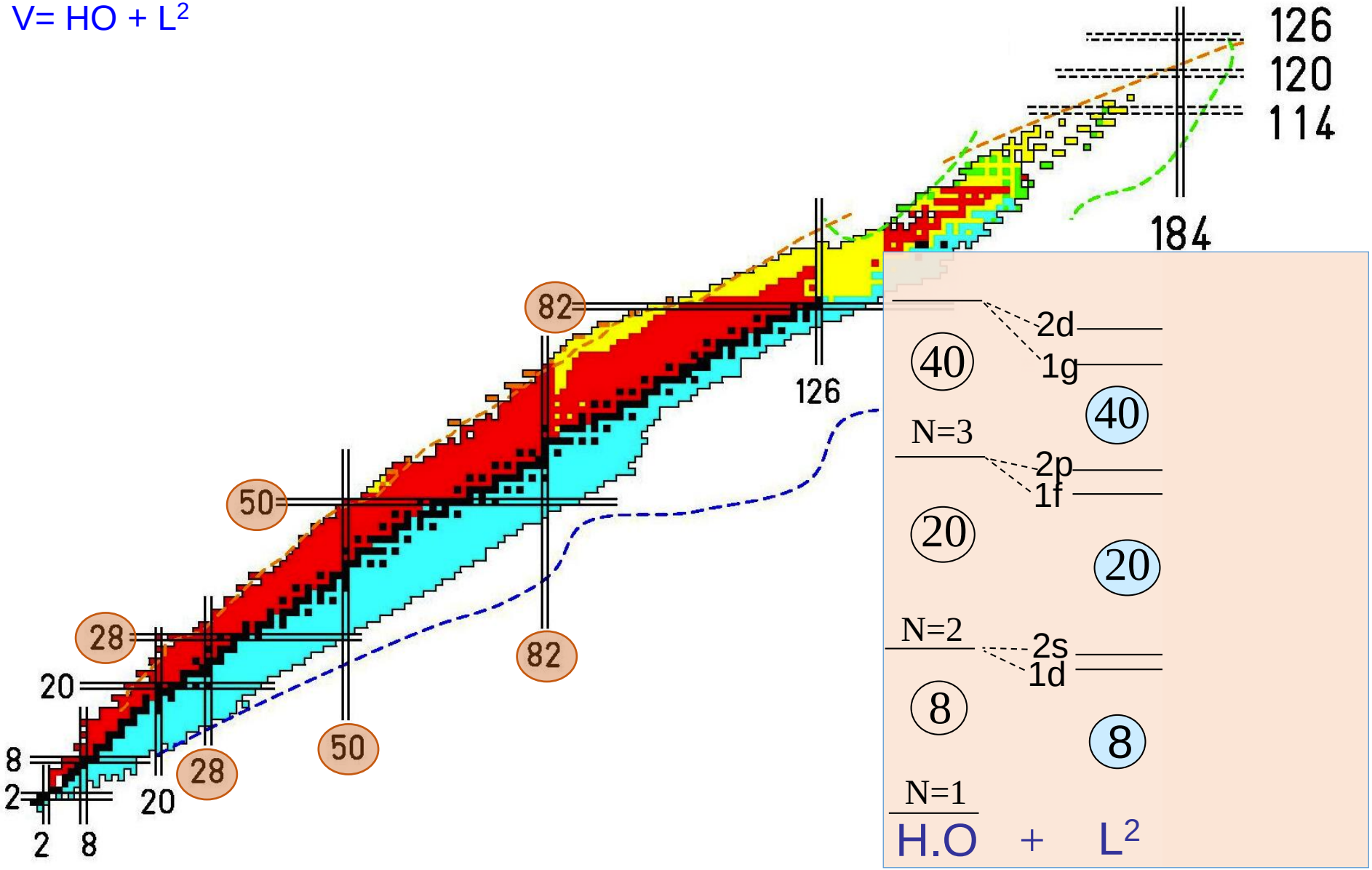
Constraining the spin orbit force using the ^{34}Si "bubble" nucleus

Alexandre Lepailleur

Brief introduction

First version of Shell Model did not reproduce all the magic numbers (28, 50, 82…)

$V = HO + L^2$



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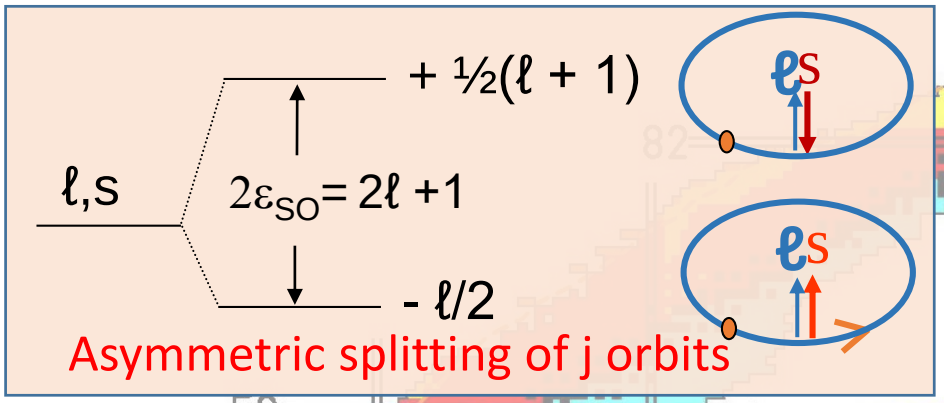
Spin Orbit (SO) term



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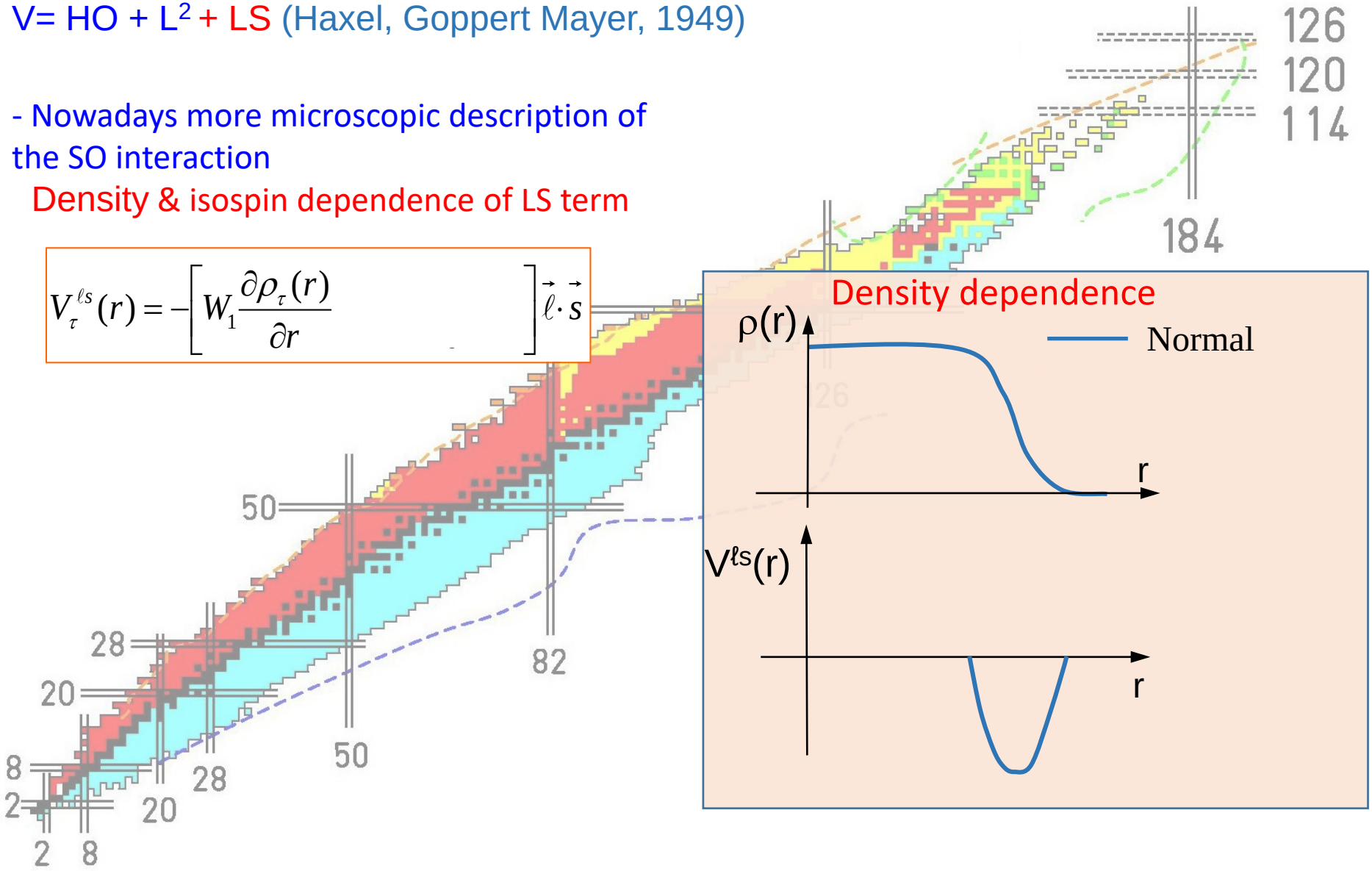
$$V_\tau^{\ell s}(r) = -\left[W_1 \frac{\partial \rho_\tau(r)}{\partial r} \right] \vec{\ell} \cdot \vec{s}$$



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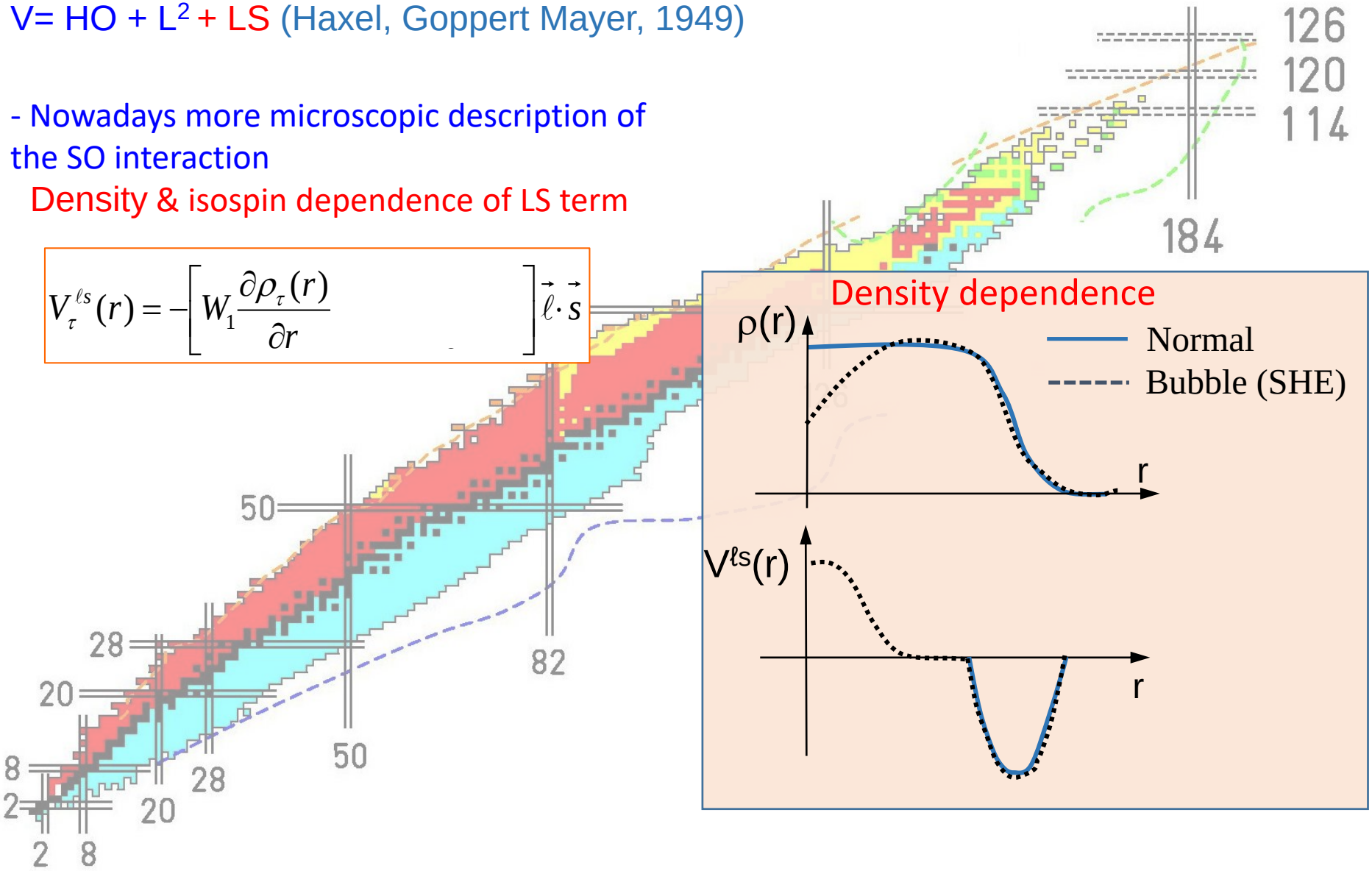

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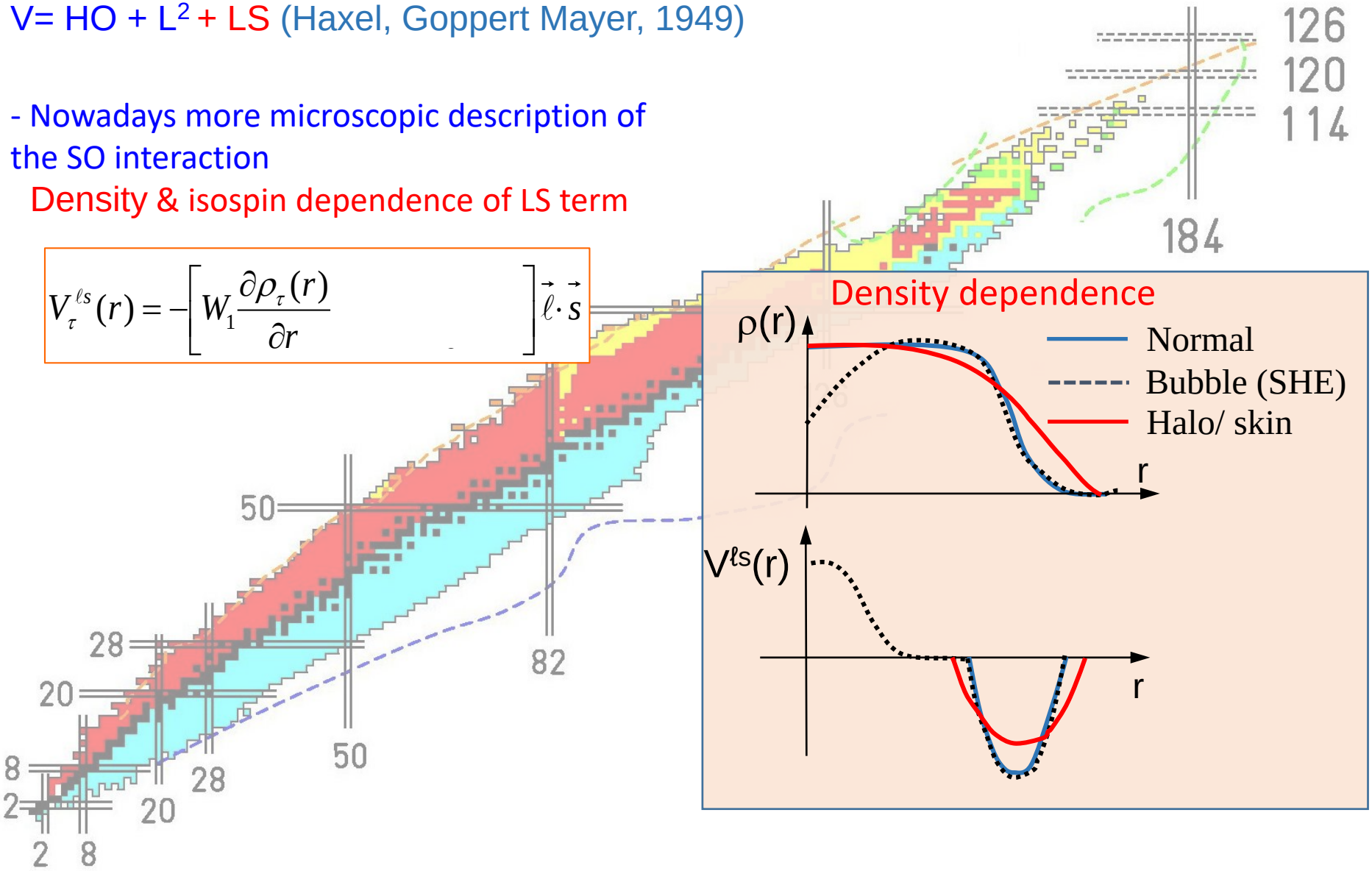

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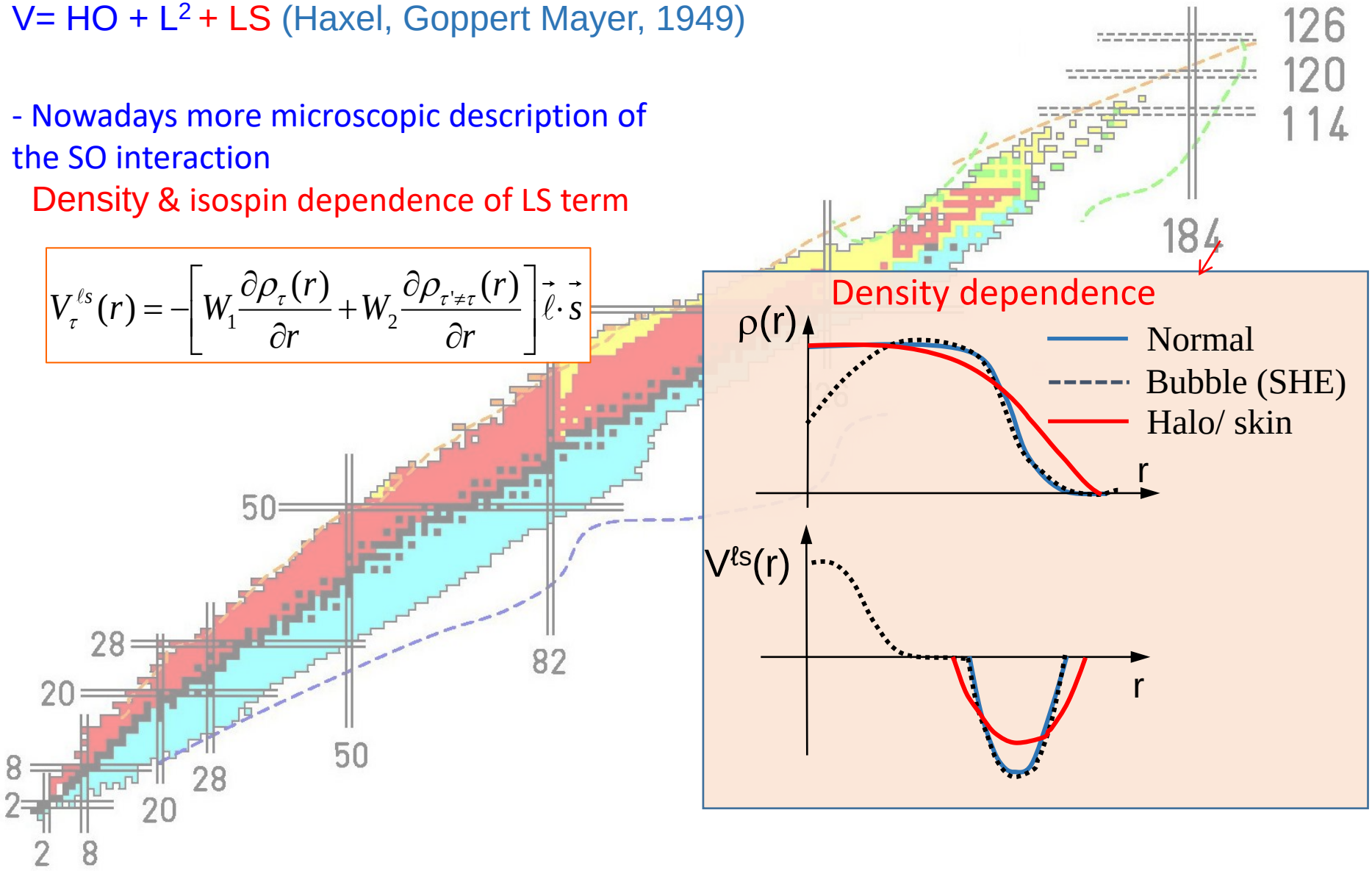

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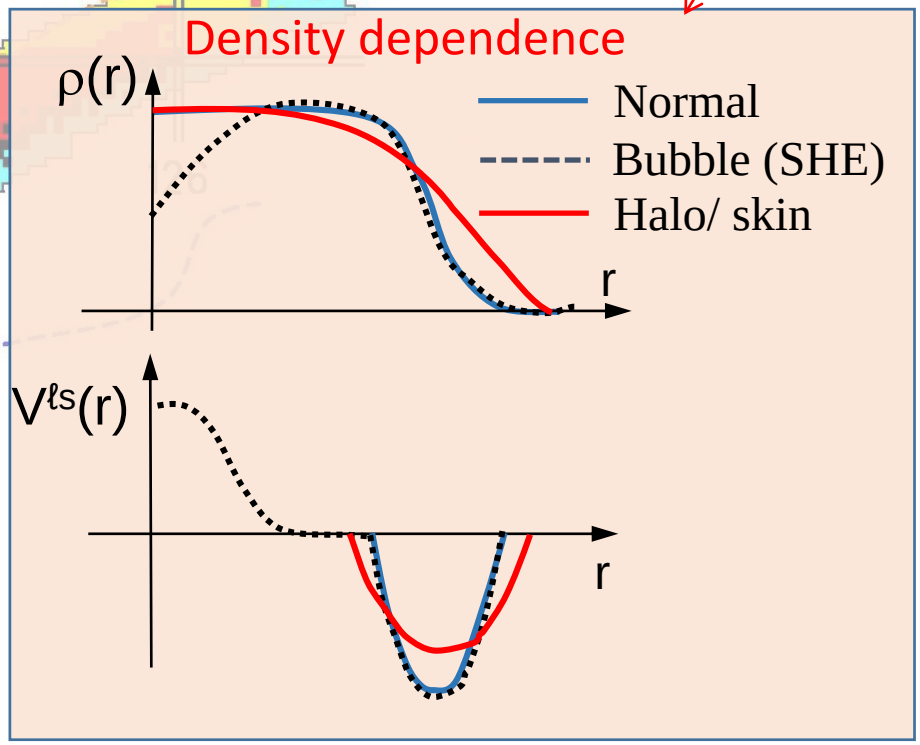
Isospin dependence

$$W_1 \approx 2W_2(MF)$$

$$W_1 \approx W_2(RMF)$$

No isospin dependence in RMF

Density dependence



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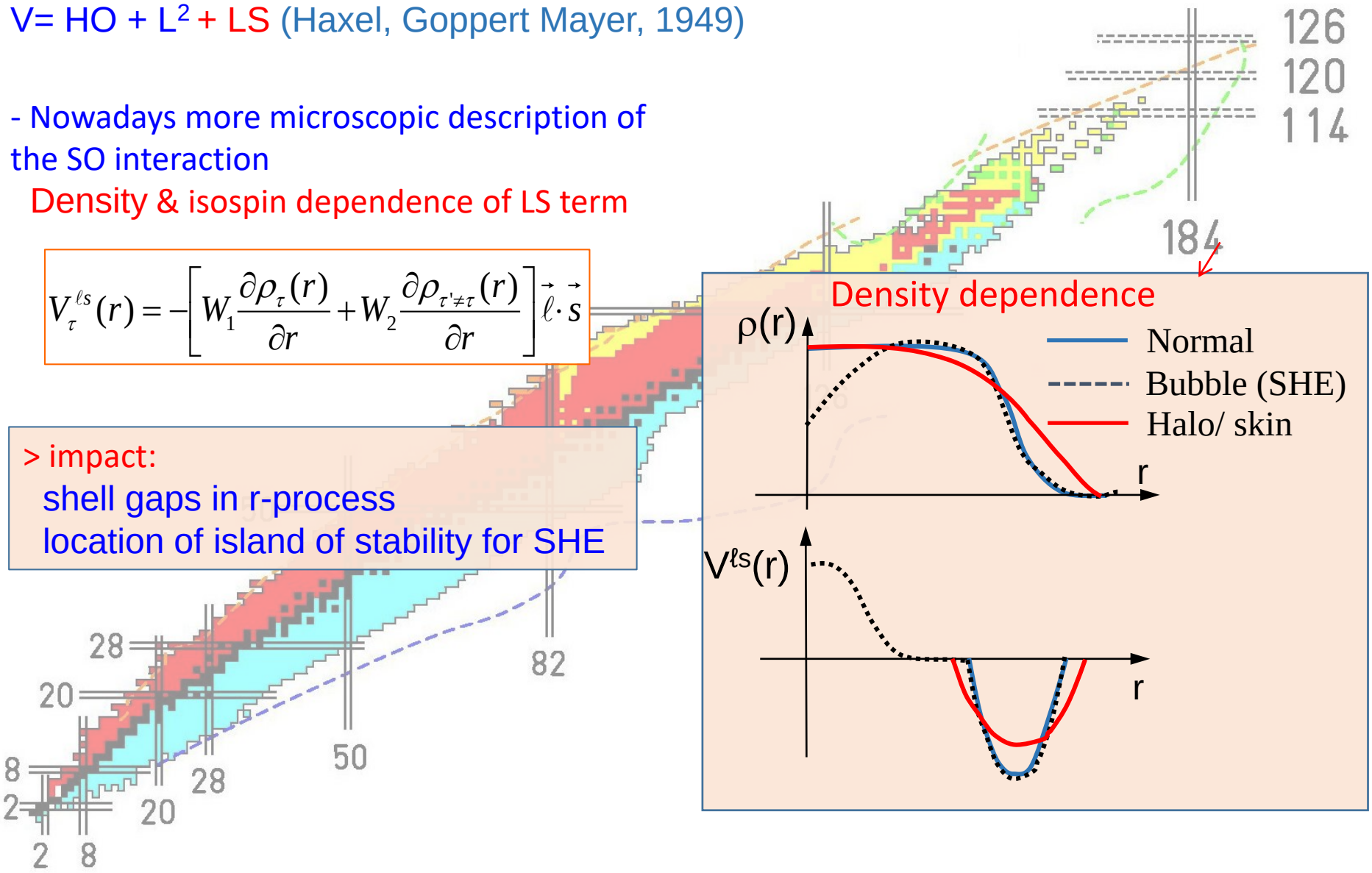
> impact:
shell gaps in r-process
location of island of stability for SHE



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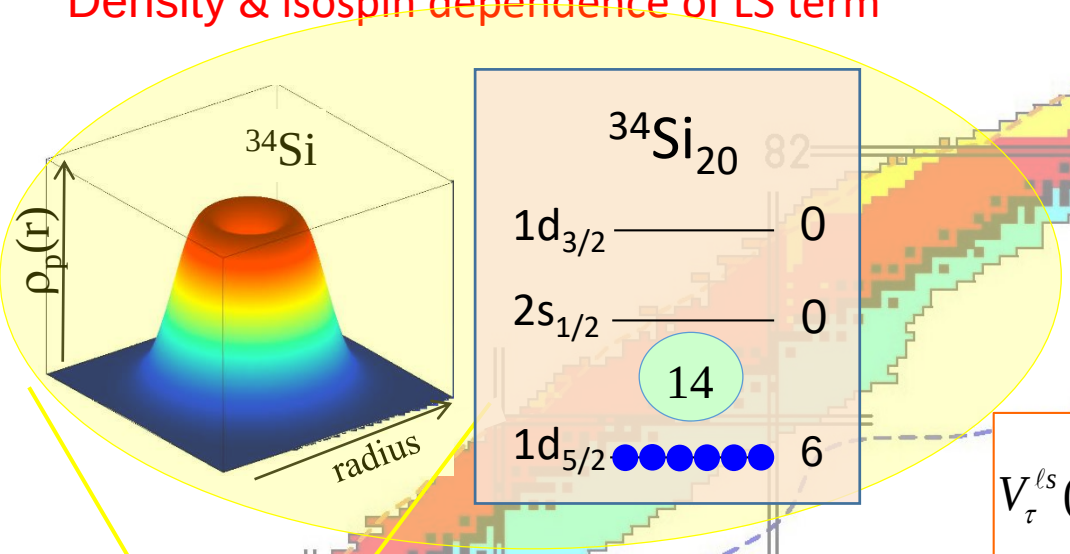

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^{34}Si: ideal case

-> Proton central density depletion (L=0)

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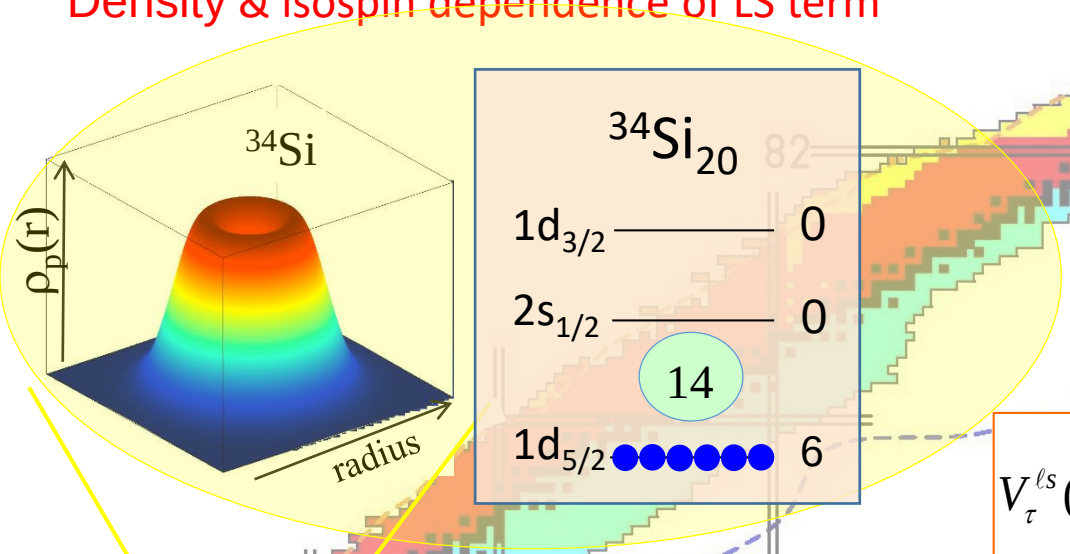

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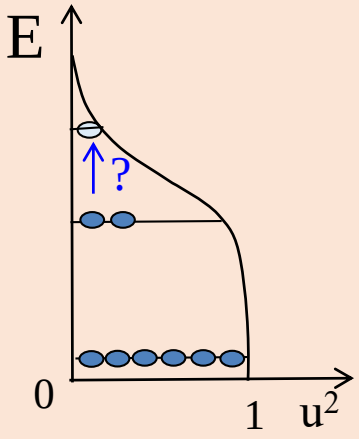
Proton density depletion in ^{34}Si as compared to ^{36}S?



$^{36}S_{20}$

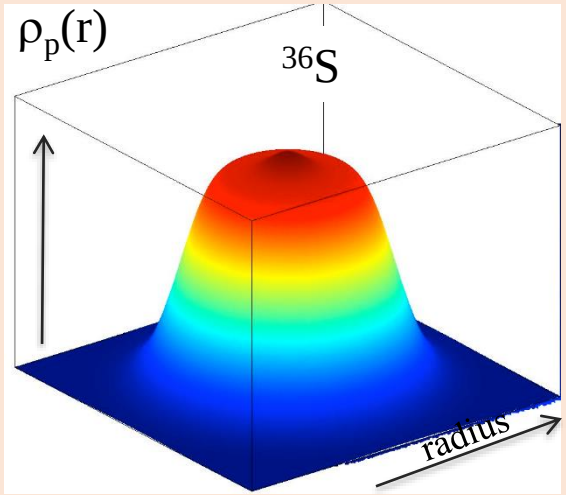
$1d_{3/2}$ —— 0

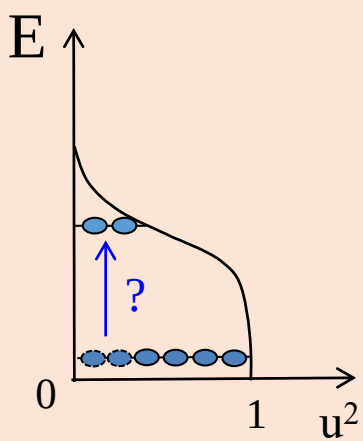
$2s_{1/2}$ —— 2

14

$1d_{5/2}$ —— 6

Proton orbits occup.





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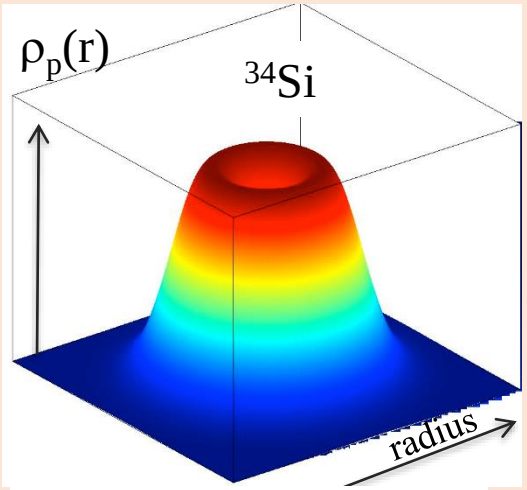


J.P. Ebran DDME2 interaction

- Amplitude of the central depletion depends on the change in $2s_{1/2}$ occupancy
- Pairing and quadrupole correlations can reduce the amplitude of this depletion
- The two nuclei have similar neutron occupancies (N=20)

Constraining the spin orbit force using the ^{34}Si "bubble" nucleus

- Probing the proton density in
  - ^{36}S
  - ^{34}Si

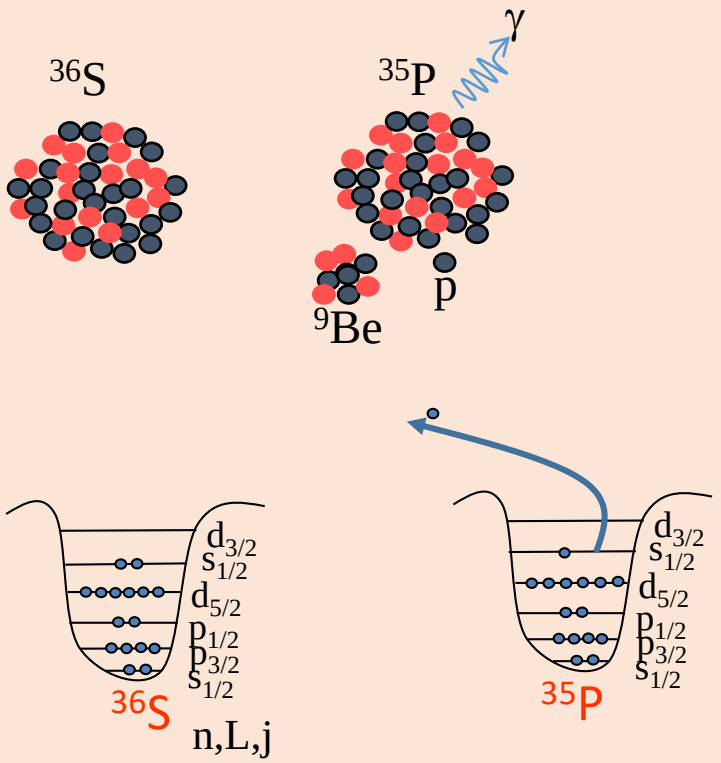
- (d,p) transfer reactions on ^{34}Si and ^{36}S
  - Follow the evolution of the SO splitting

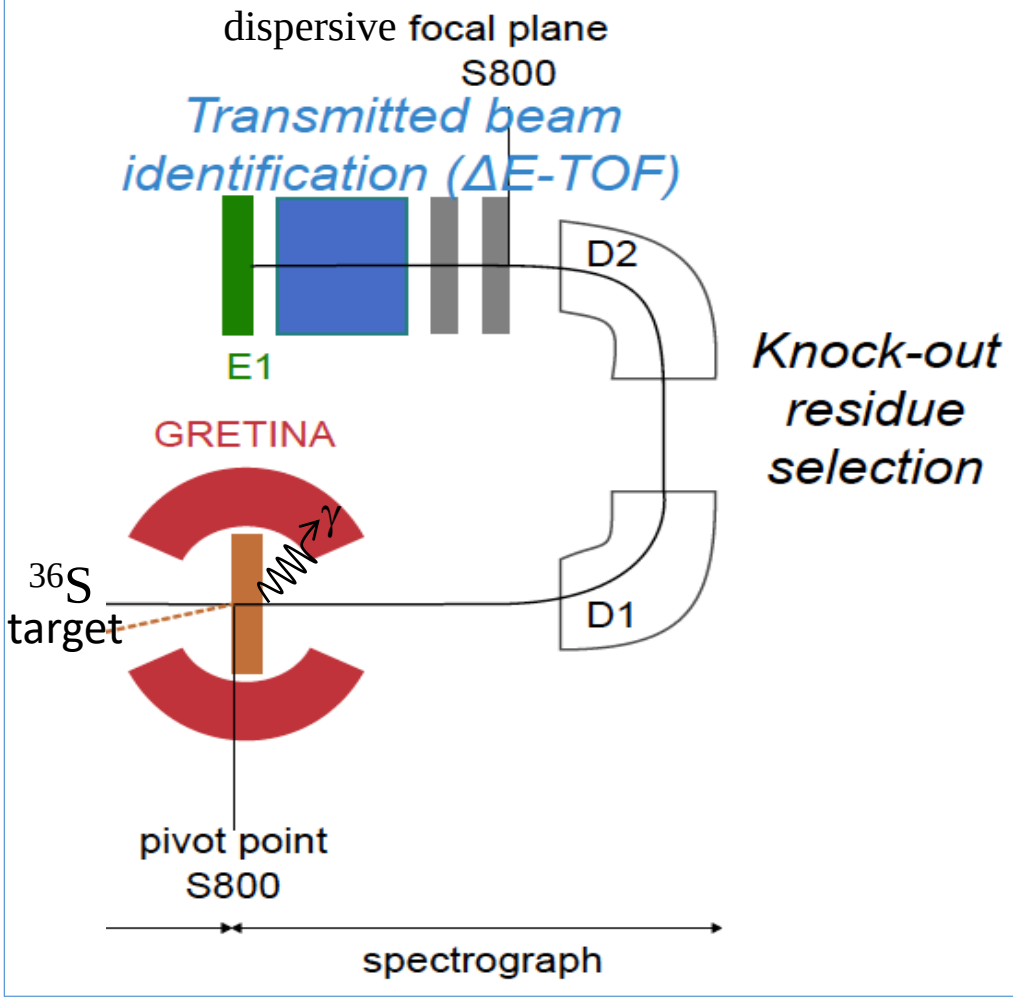
Probing proton density in ^{36}S

Knock-out reactions at $\beta \approx 0.4$

$$\sigma(n,L) = C^2S\,(j,n,L) \quad \sigma_{sp}(j,S_p)\,R_S$$

normalized occupancy — *reaction theory*





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it is derived from a model and may differ when various experimental techniques (and models) are used
Relative occupancy values are more relevant

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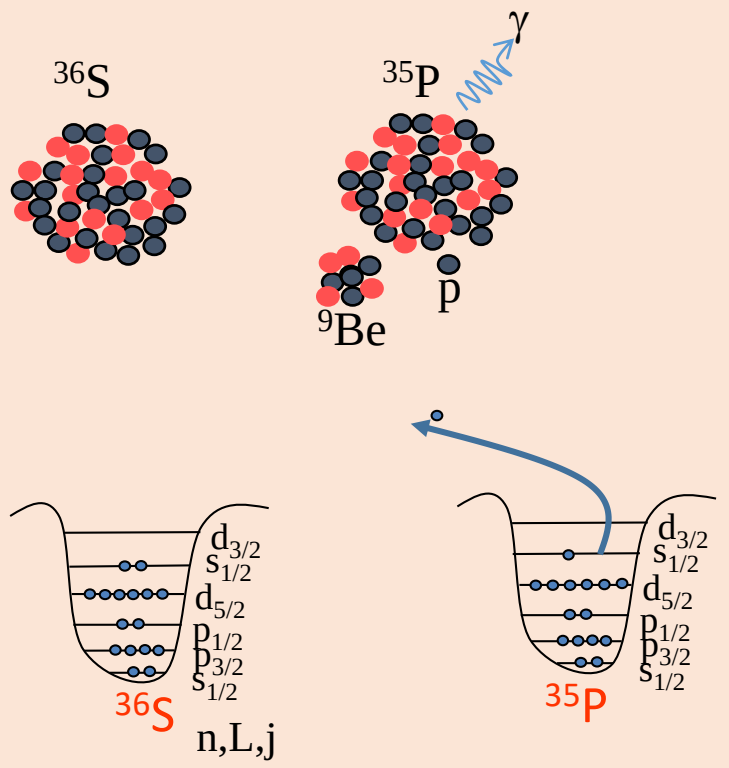

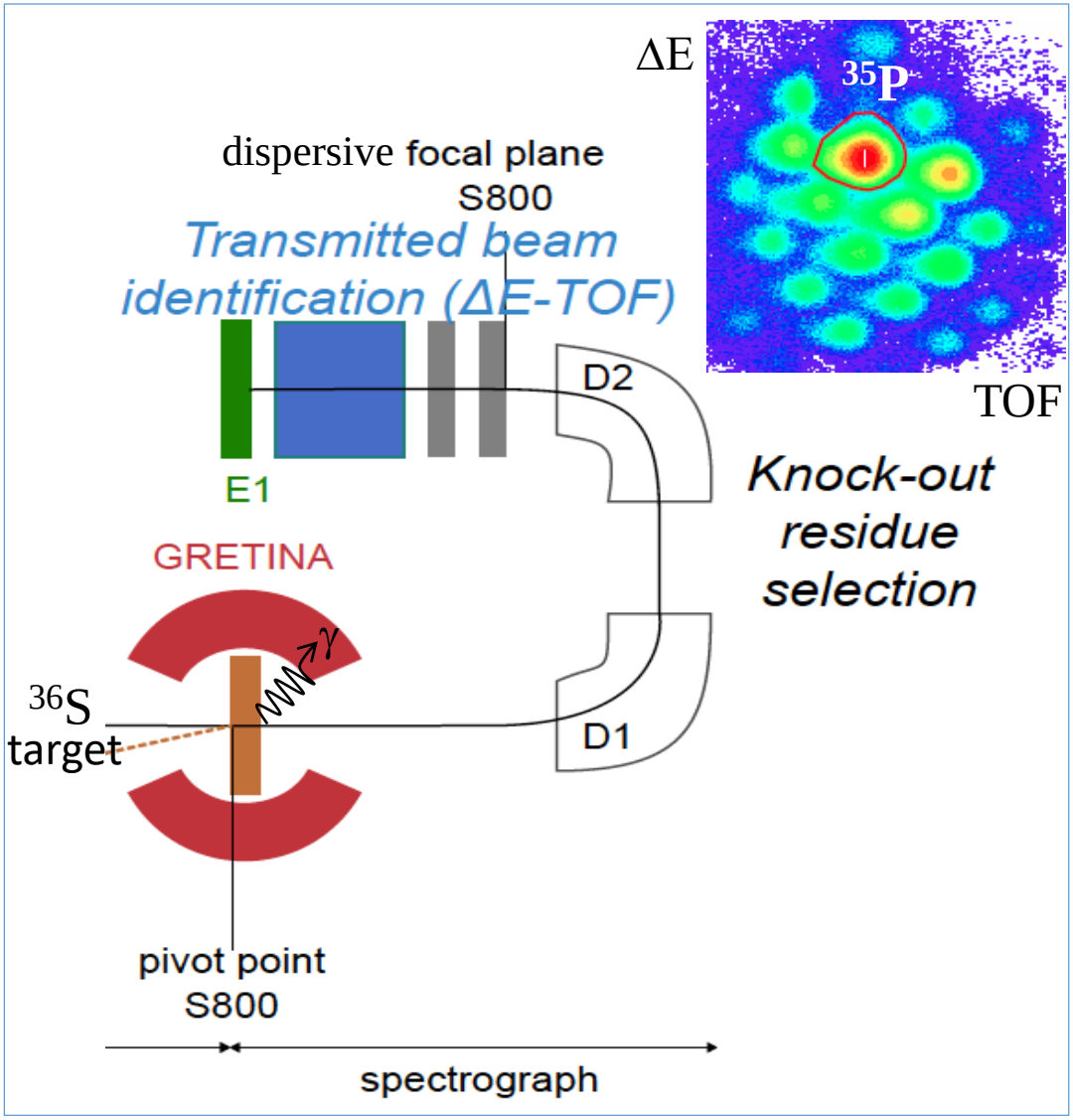

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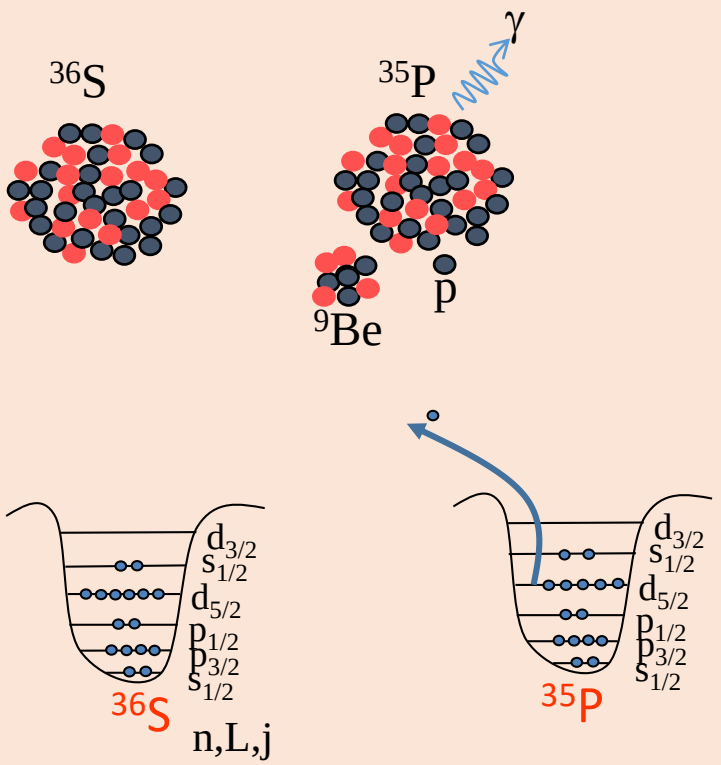

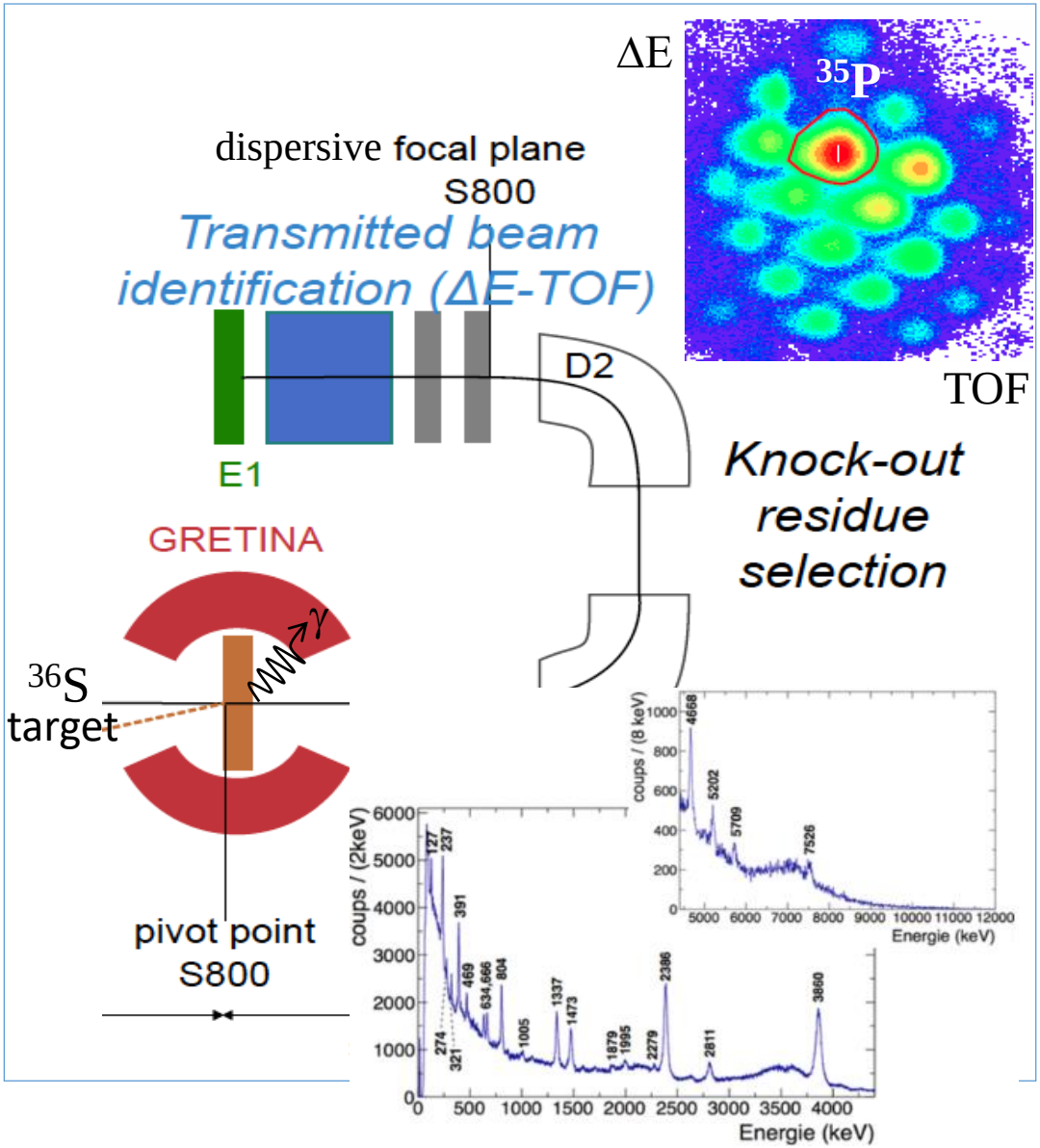

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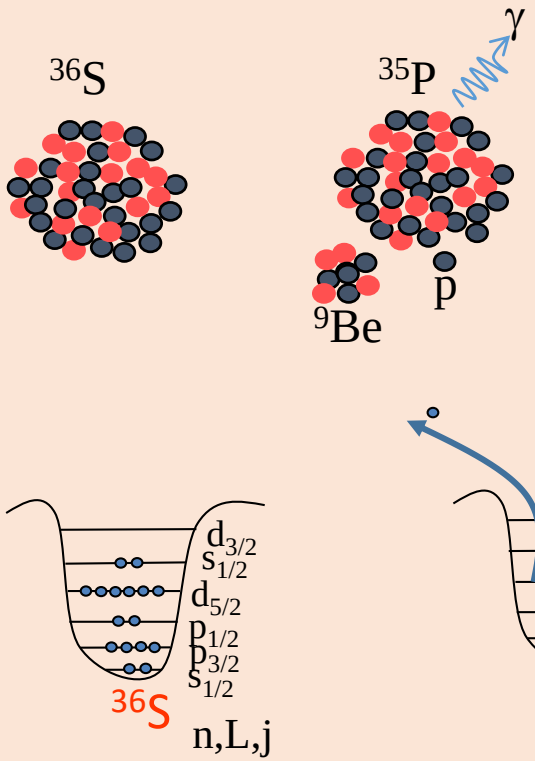

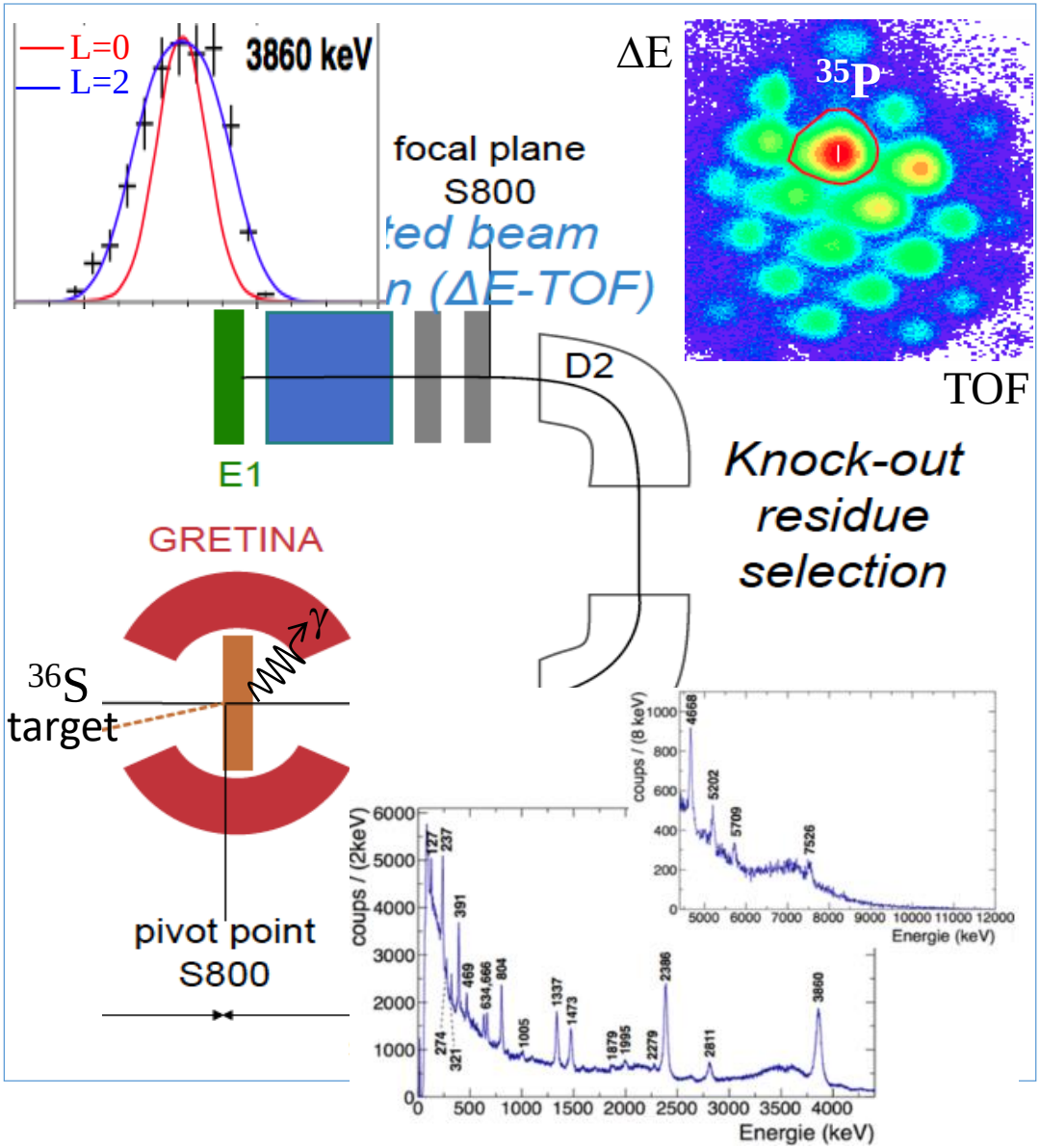

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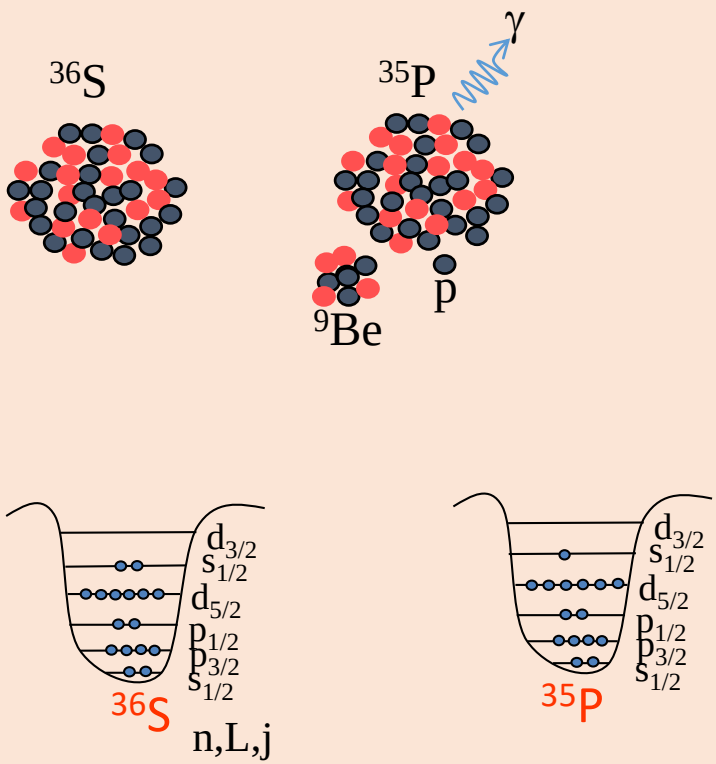
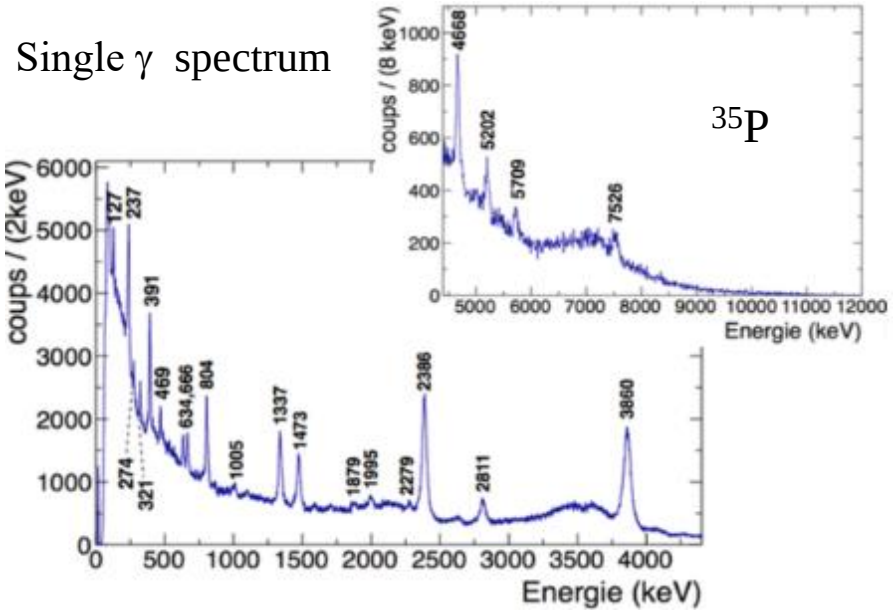
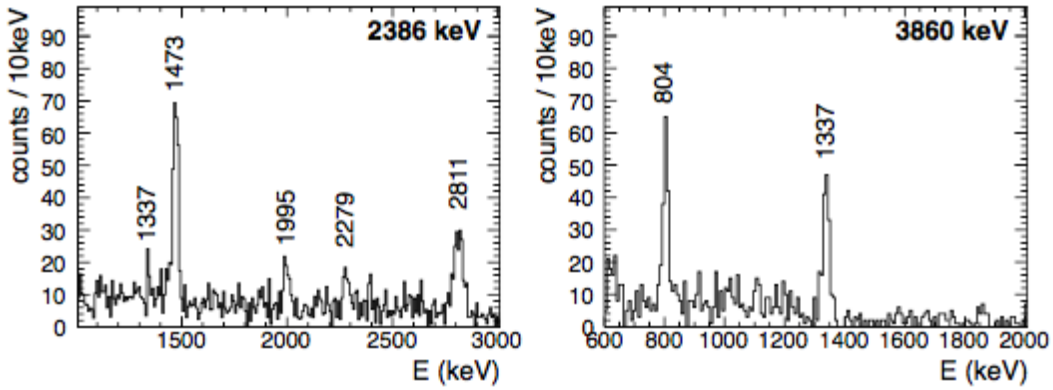


Single γ spectrum



γ γ coincidences



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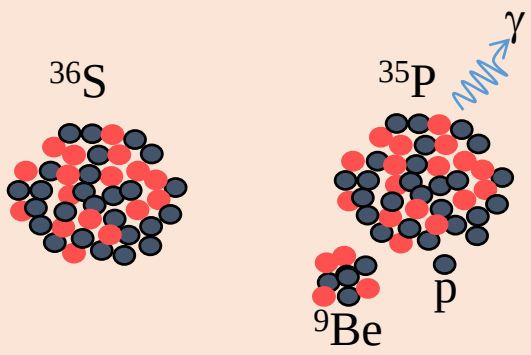

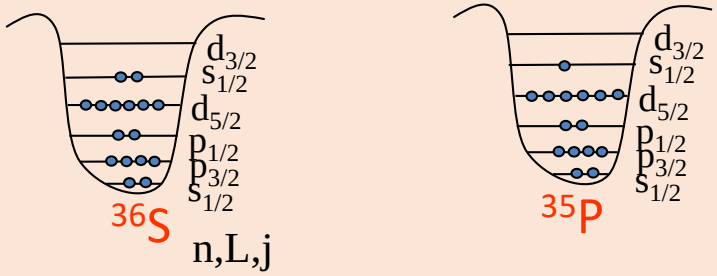

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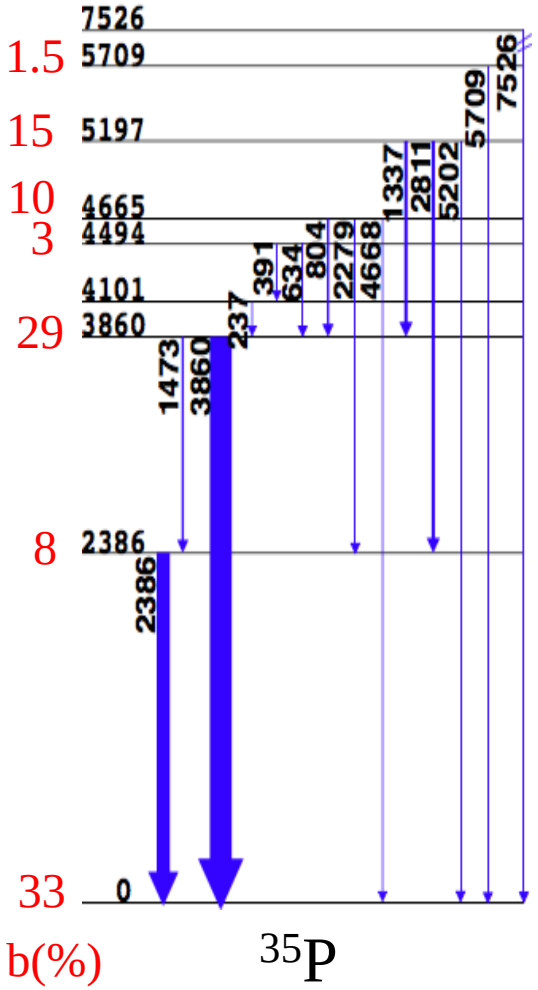

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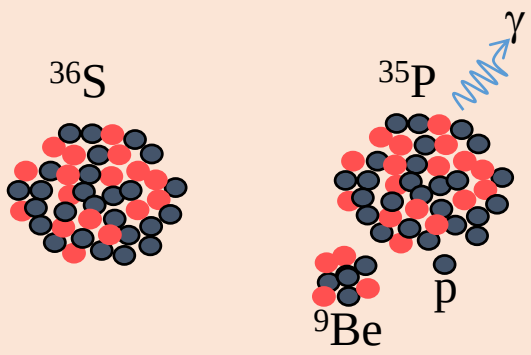

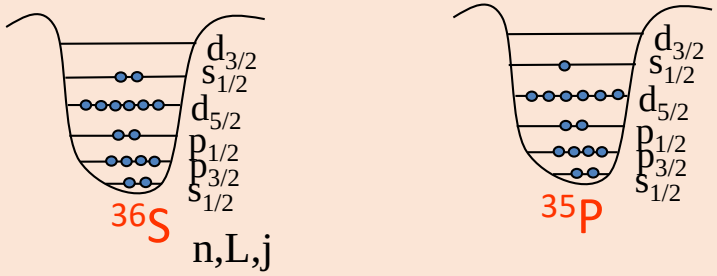

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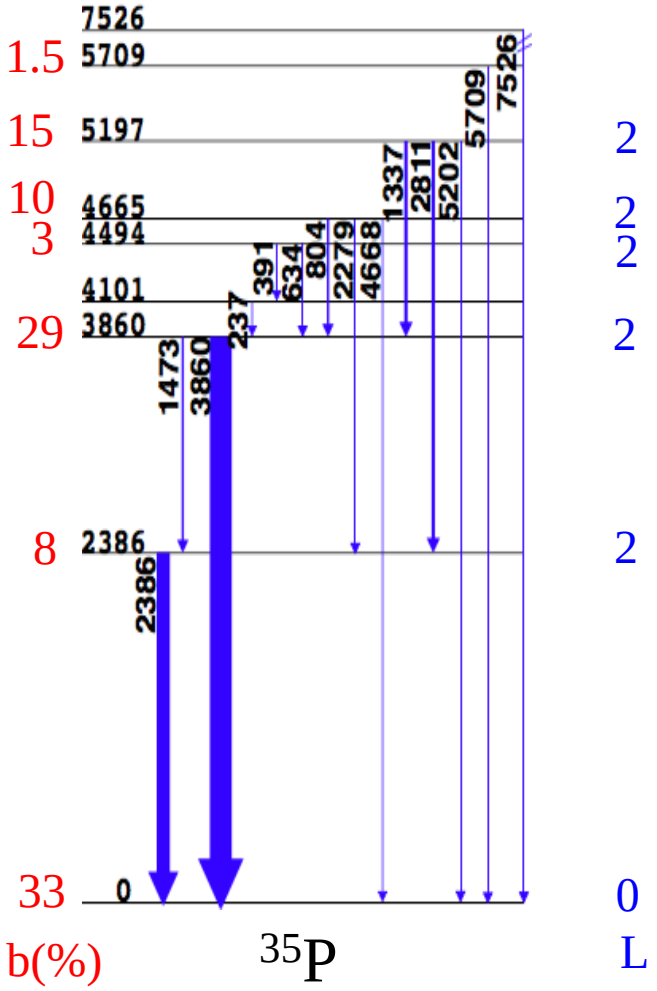

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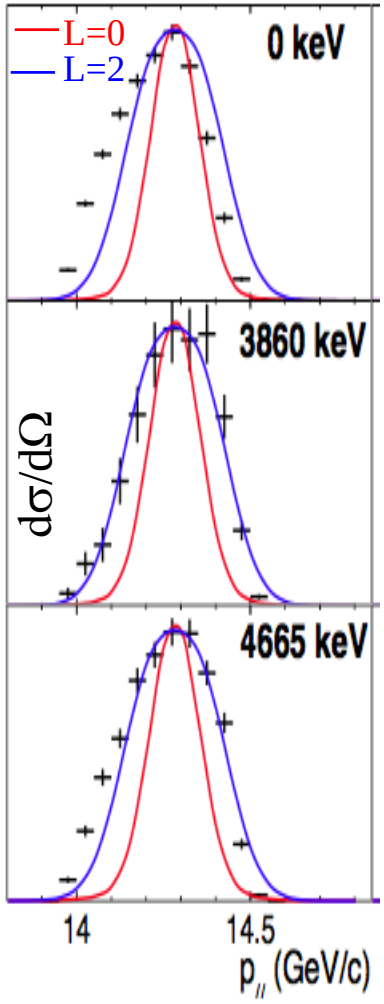

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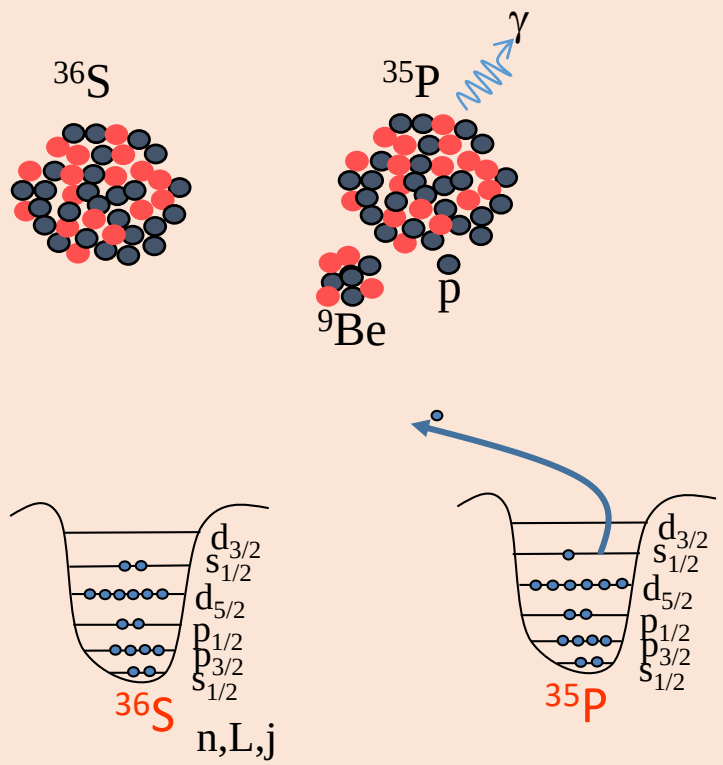

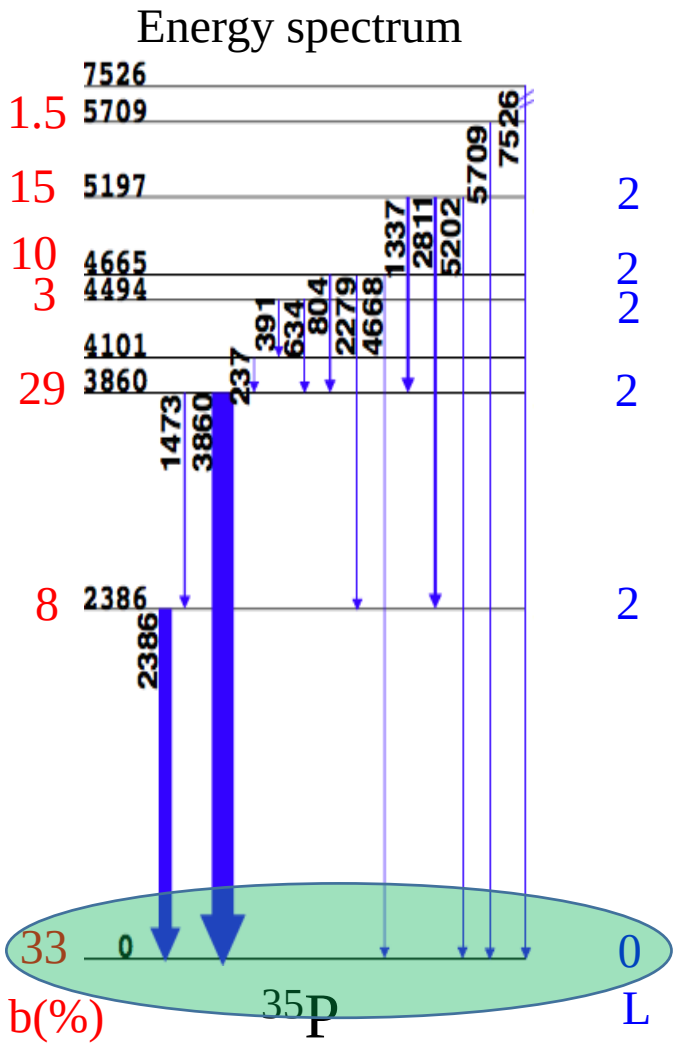

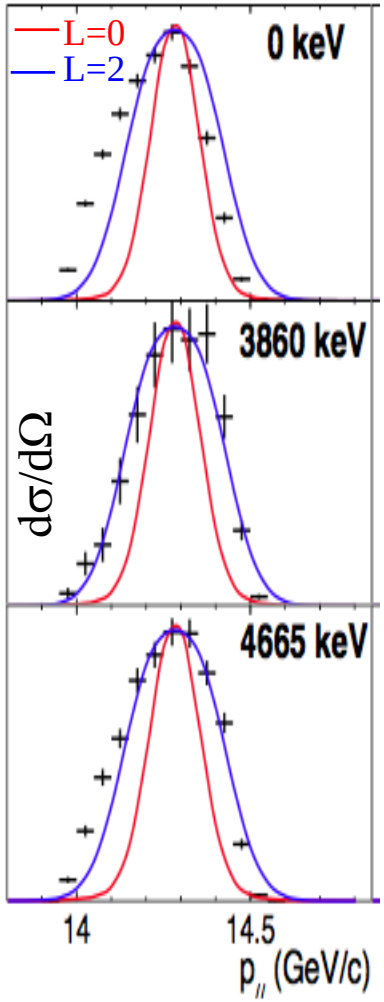

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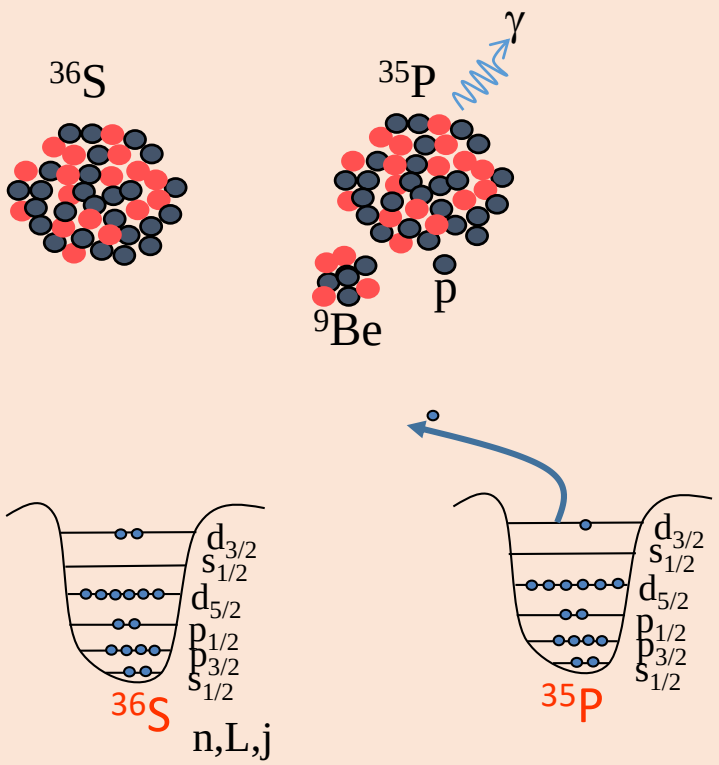

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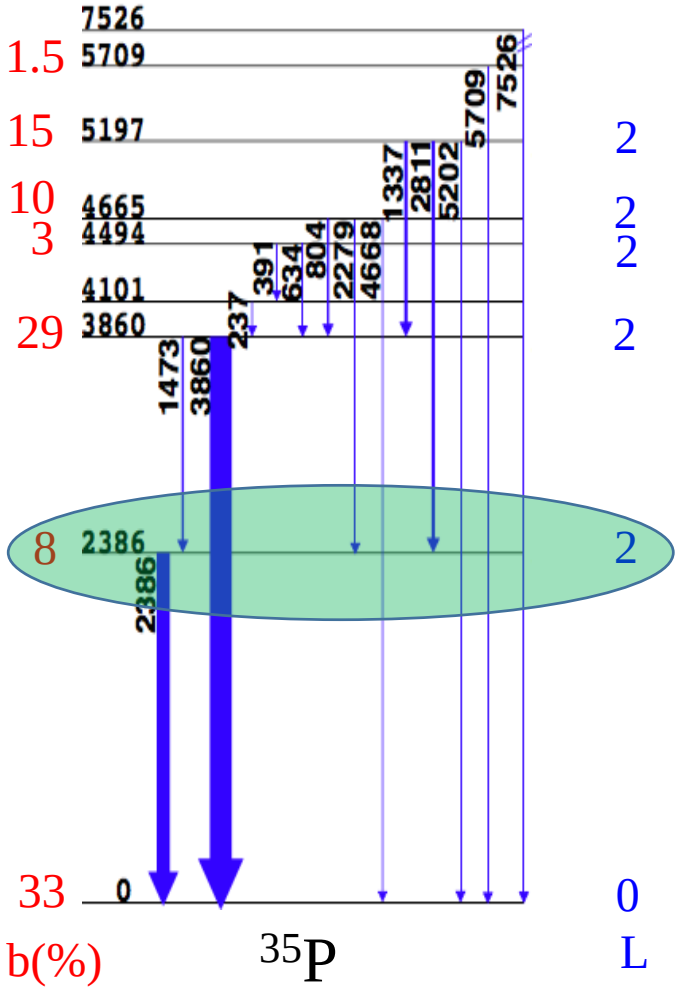

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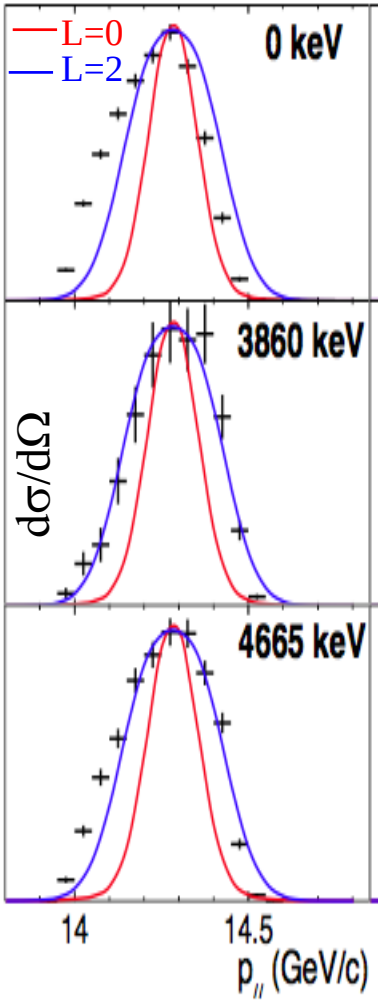

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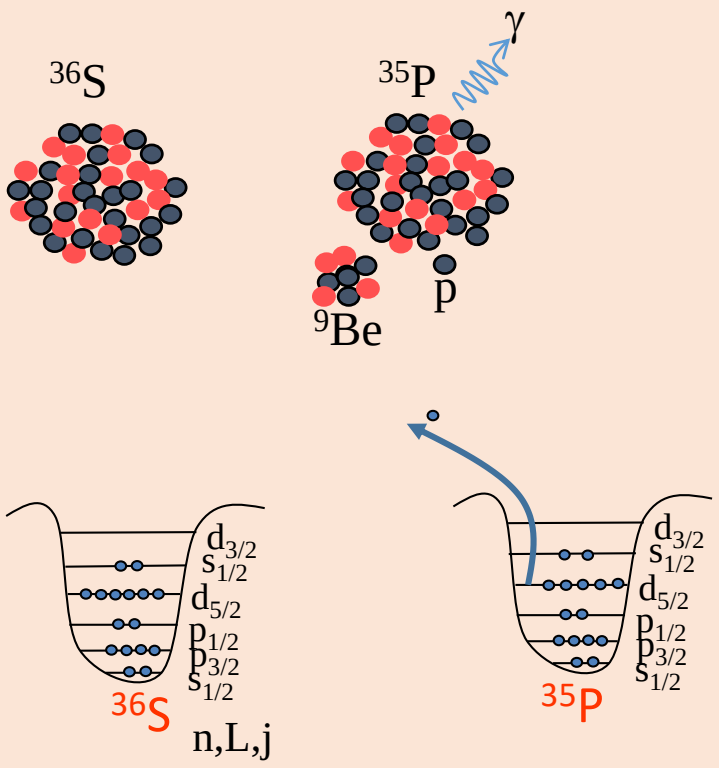

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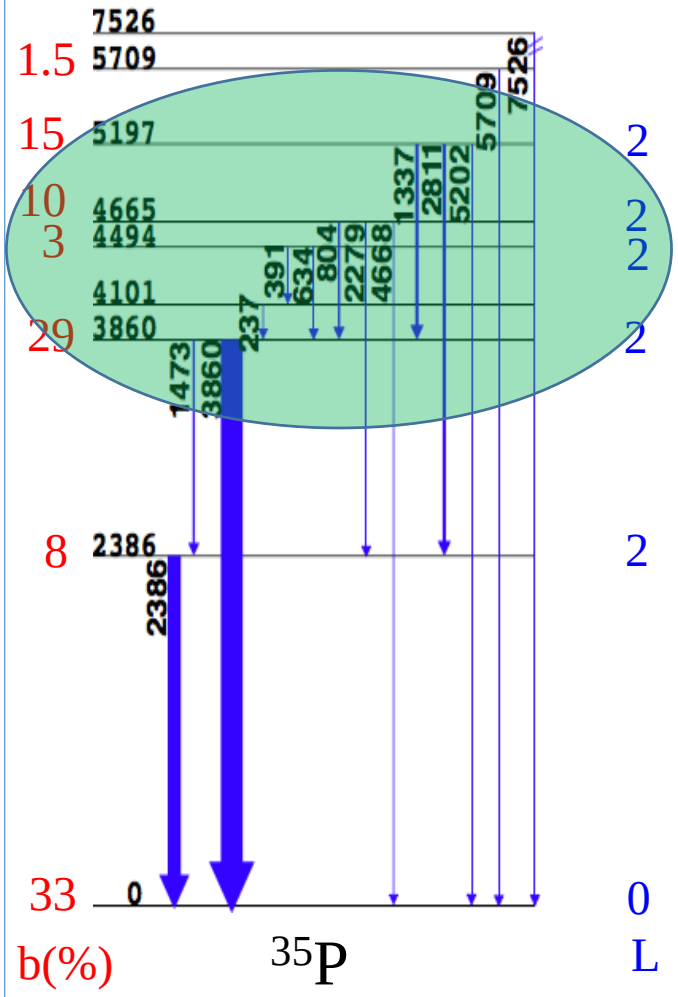

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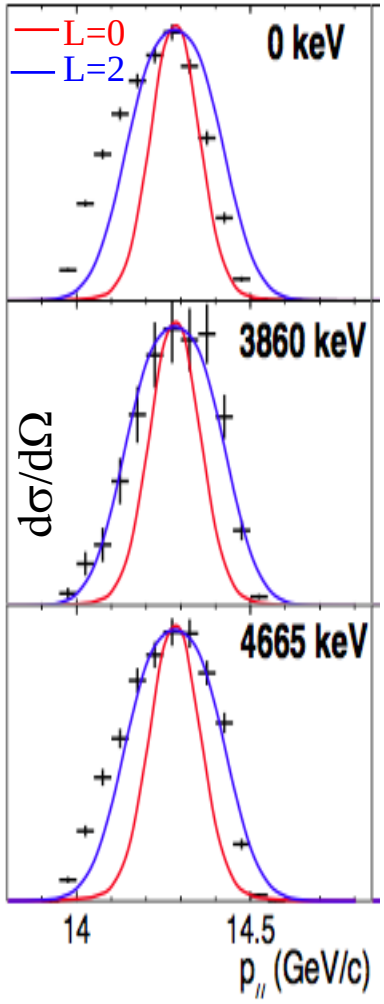

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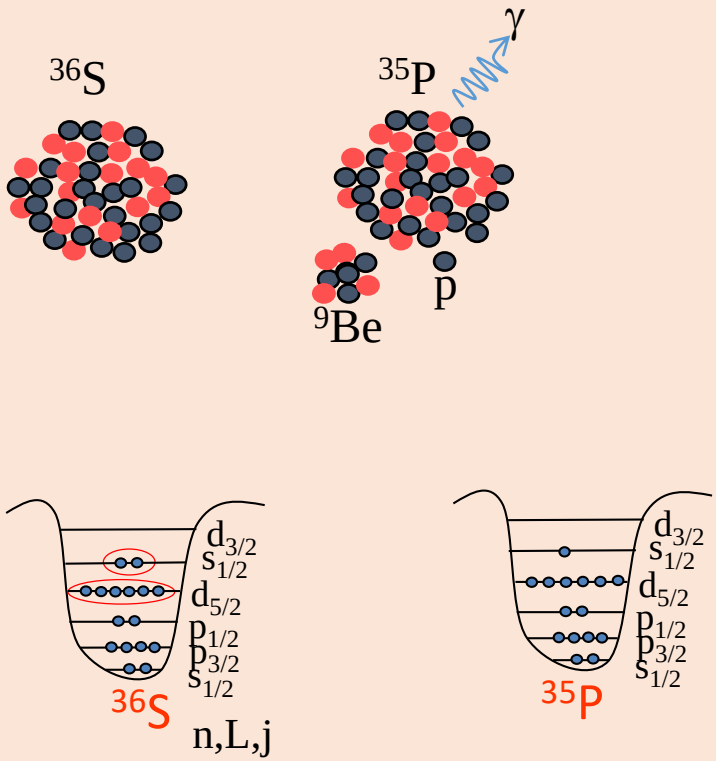
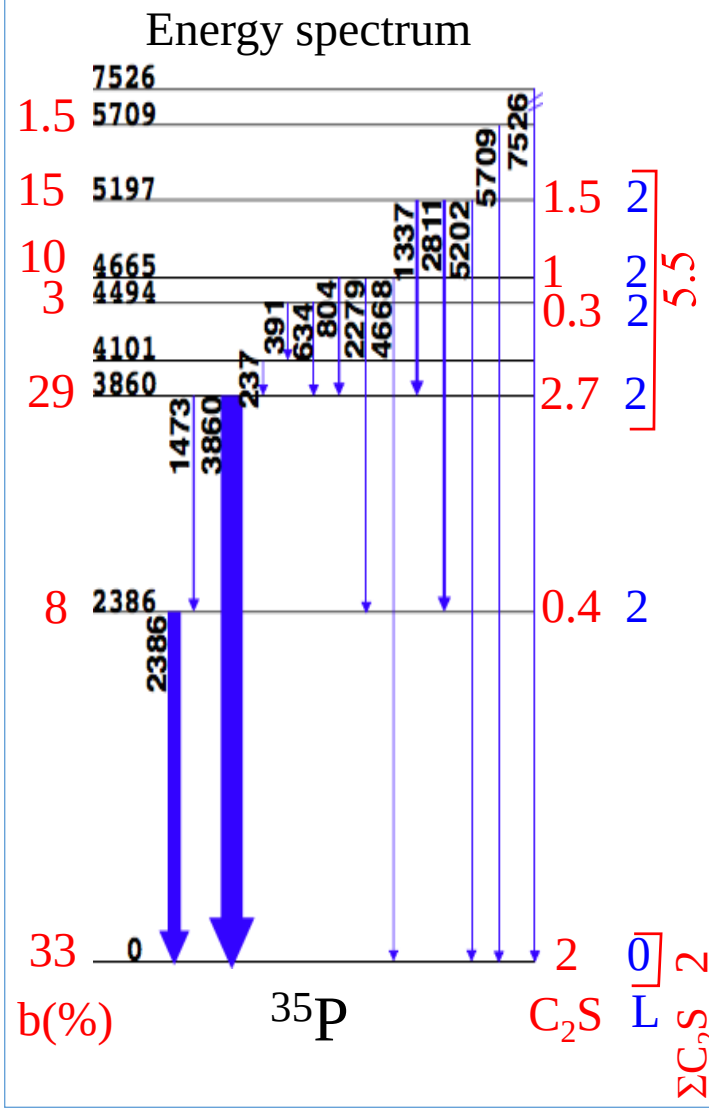
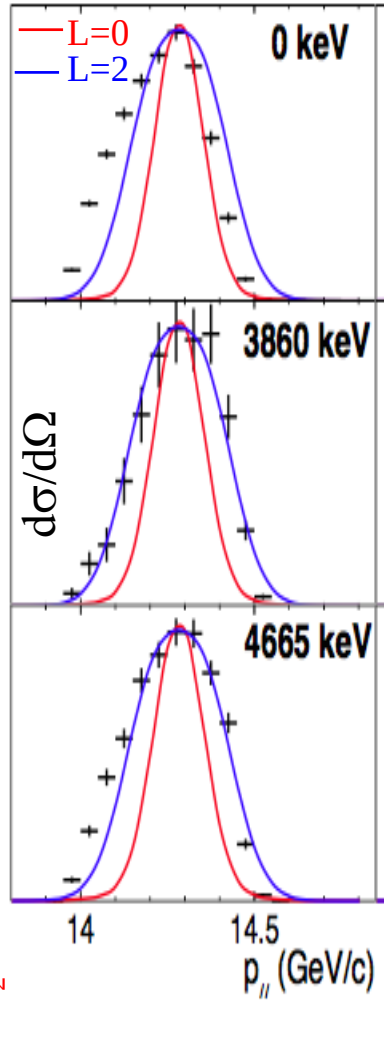
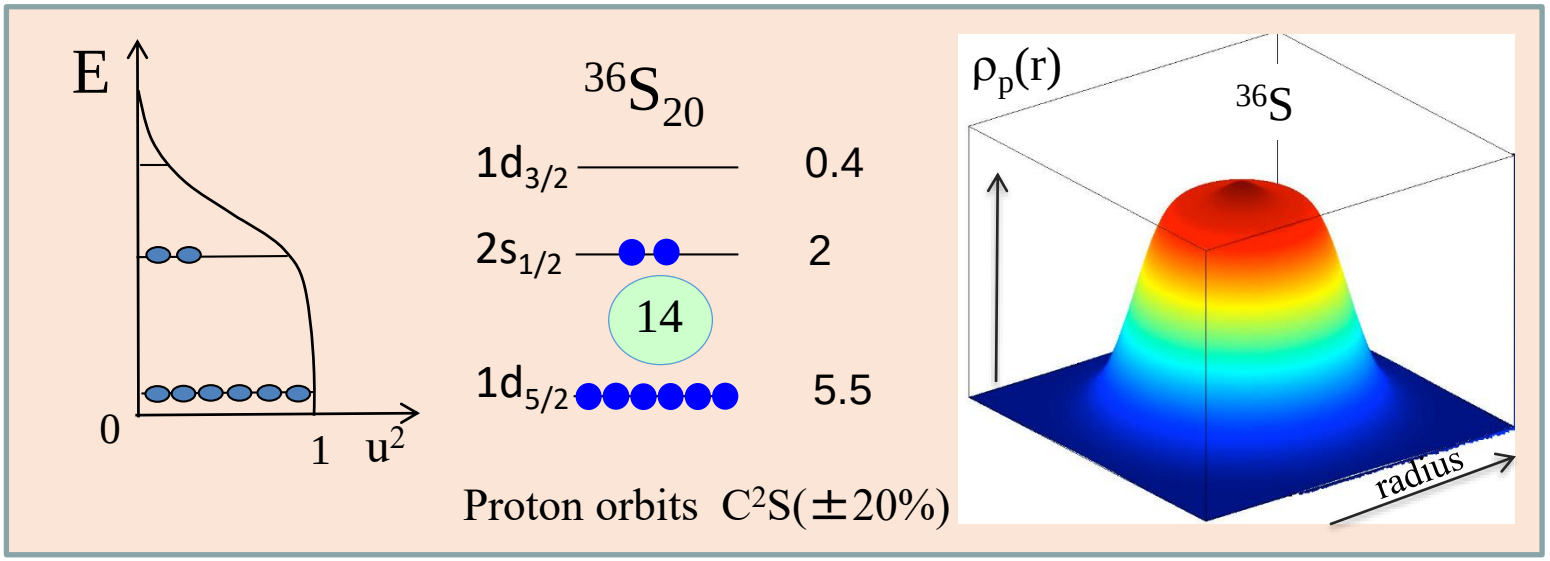






Quasi full filling of $s_{1/2}$ and $d_{5/2}$ orbits (within errors)
Only few scattering to the upper $d_{3/2}$ orbital.

Proton density depletion in ^{36}S



- Probing the proton density in
  - ^{36}S
  - ^{34}Si

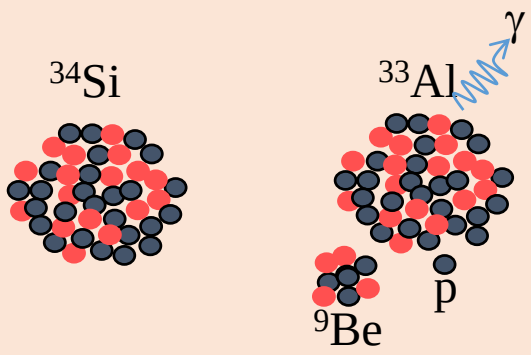
- (d,p) transfer reactions on ^{34}Si and ^{36}S
  - Follow the evolution of the SO splitting

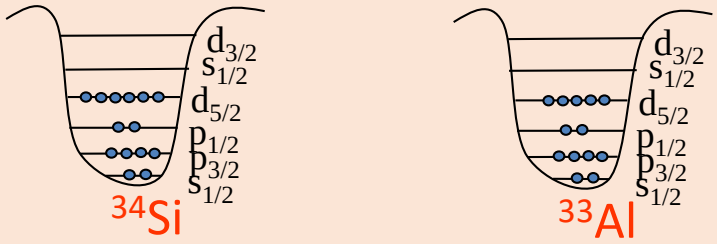
Probing proton densities in ^{34}Si

Knock-out reactions at β≈0.4

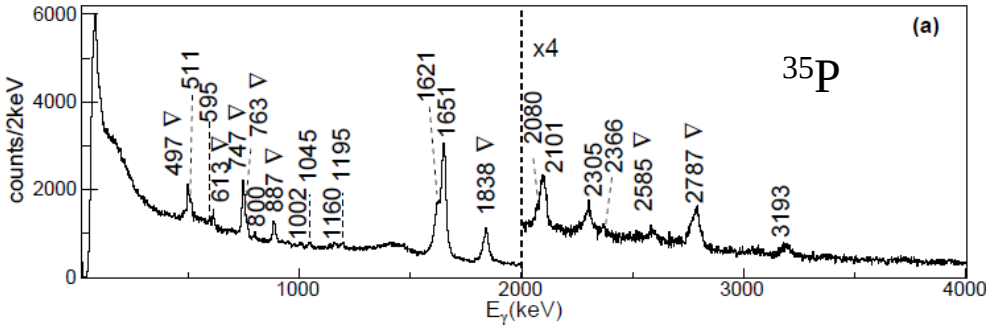
$$\sigma(n,L) = C^2S(j,n,L) \quad \sigma_{sp}(j,S_p)\, R_S$$

normalized occupancy — *reaction theory*

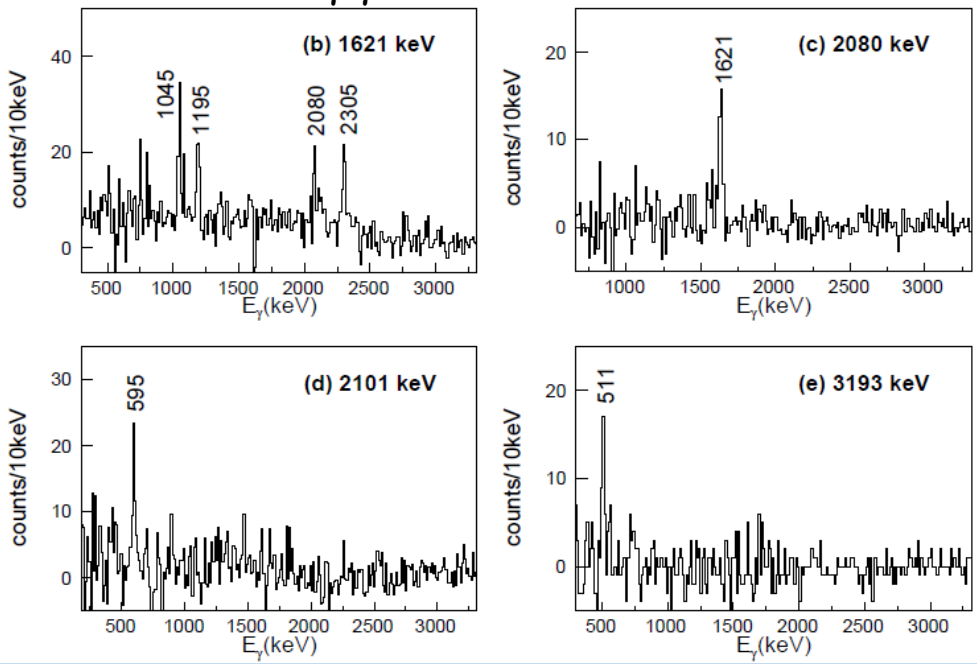




Single γ spectrum



γ γ coincidences



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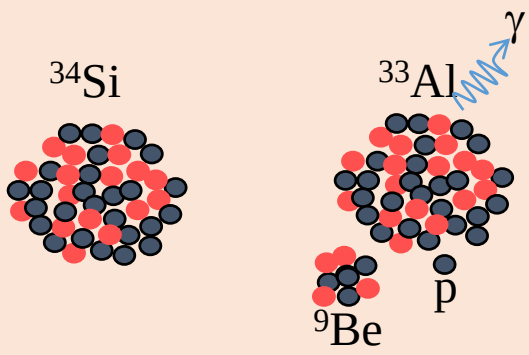
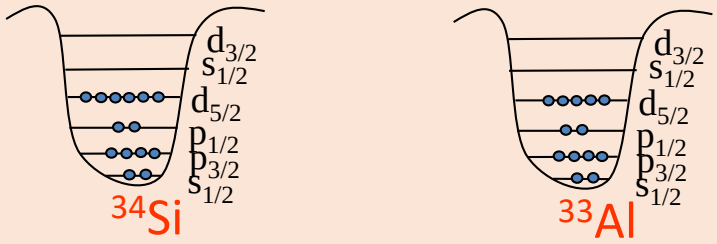
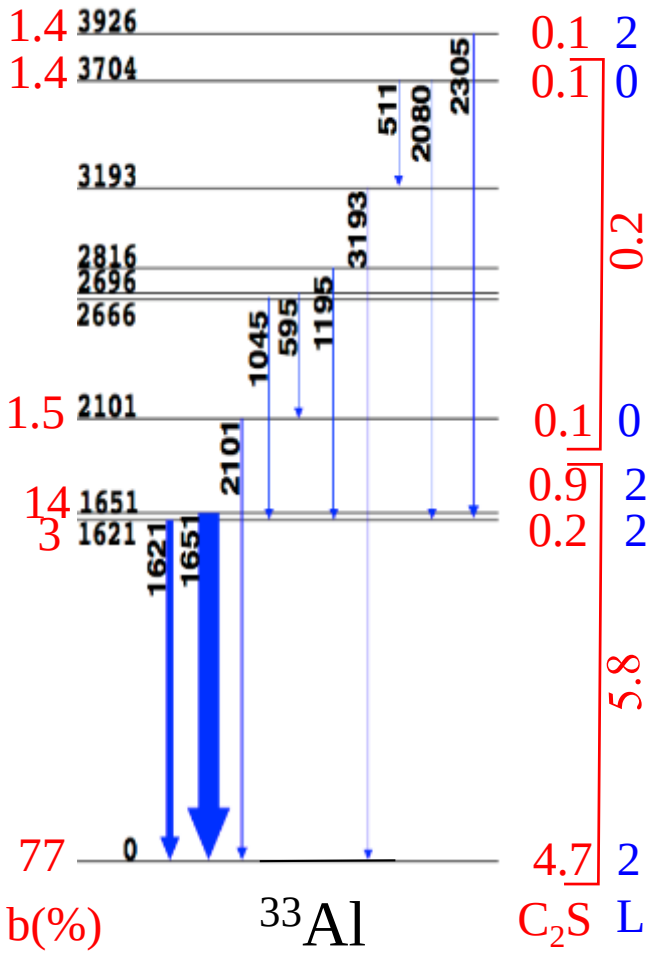
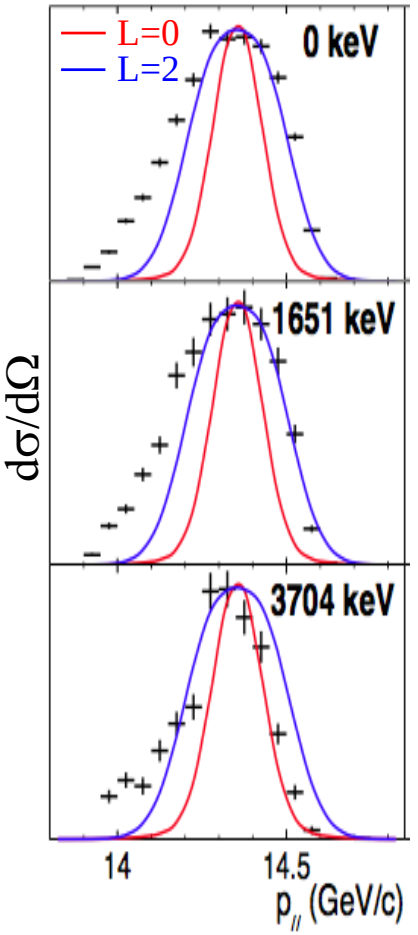




Energy spectrum



Momentum distrib.



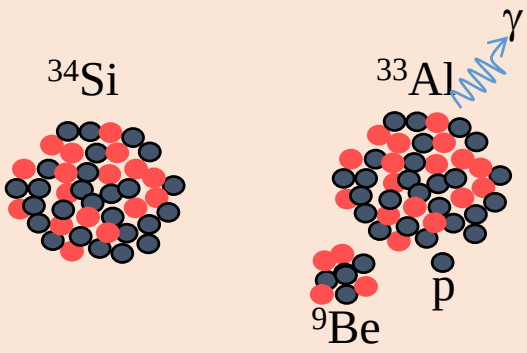
Very weak $2s_{1/2}$ occupancy -> large central density depletion

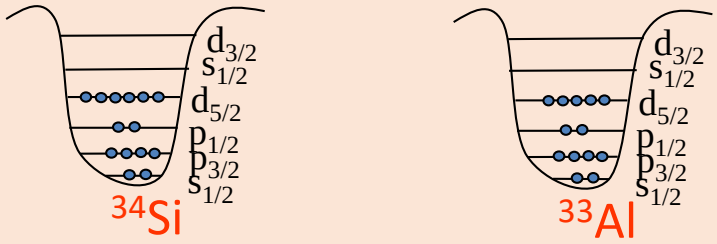
Probing proton densities in ^{34}Si

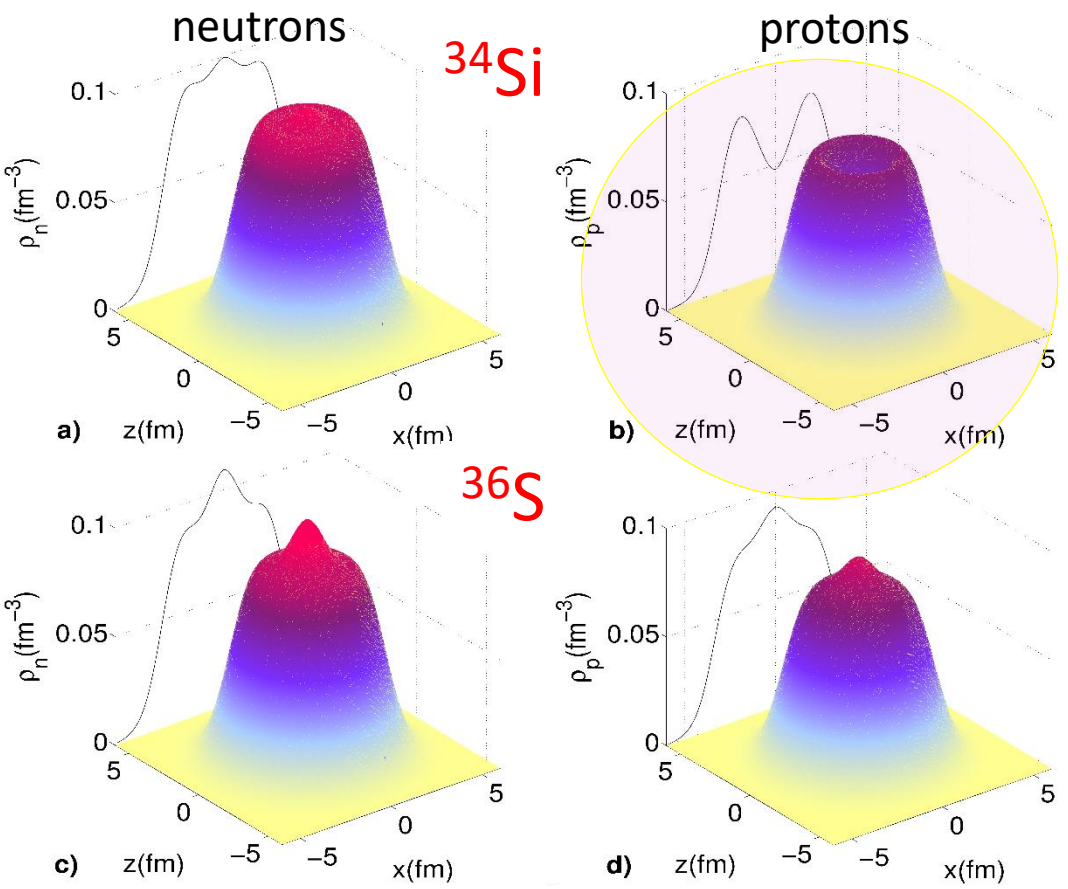
Knock-out reactions at $\beta \approx 0.4$

$$\sigma_{-1p}(n,L) = C^2S(j,n,L) \quad \sigma_{sp}(j,S_p)\, R_S$$

normalized occupancy — *reaction theory*







In ^{34}Si, the proton $2s_{1/2}$ is occupied by less than 10% -> central depeletion

Neutron density distributions of ^{34}Si and ^{36}S look similar

A. Mutschler, accepted for publication in Nature Phys.

Constraining the spin orbit force using the ^{34}Si "bubble" nucleus

- Probing the proton density in
  - ^{36}S
  - ^{34}Si

- (d,p) transfer reactions on ^{34}Si and ^{36}S
  - Follow the evolution of the SO splitting

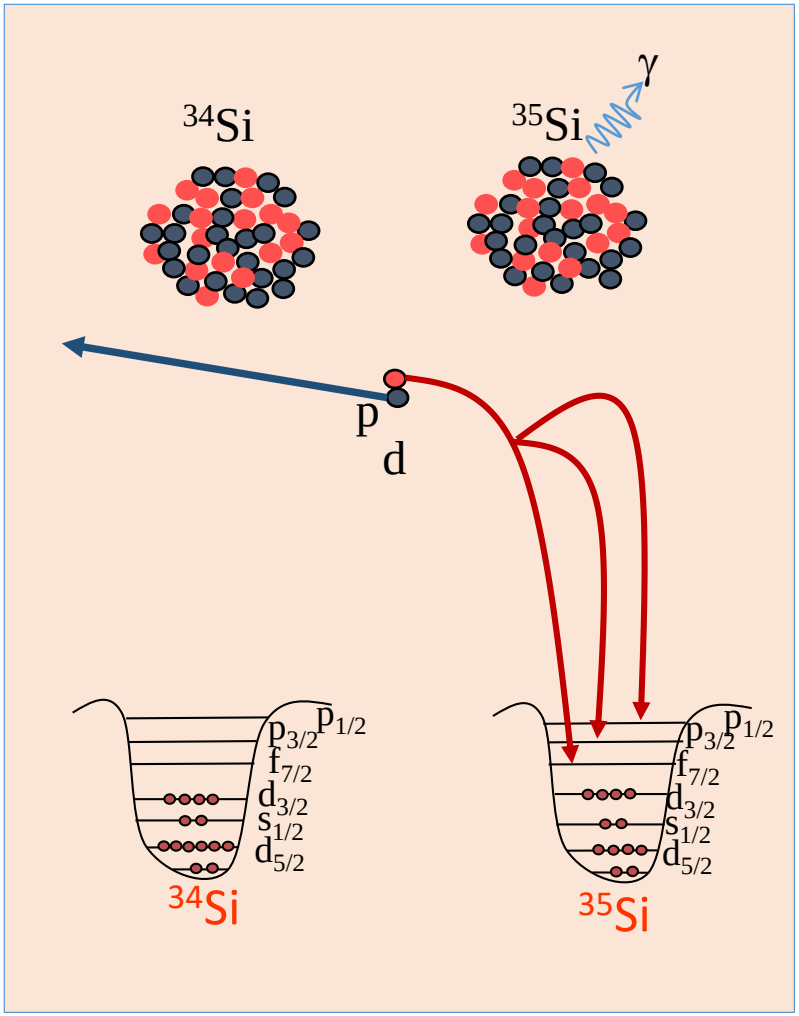
^{34}Si(d,p) reaction in inverse kinematics

Transfer reaction (d,p) at $\beta \approx 0.15$

$$\frac{d\sigma(n,L,\theta)}{d\Omega} = (2j+1)\, C^2S^+ \; \frac{d\sigma_{AWBA}(n,L,\theta)}{d\Omega}$$

vacancy — *reaction theory*

Proton energy -> (binding) energy of orbit
Proton angle -> orbital momentum L
Cross section -> vacancy of the orbit
Appropriate momentum matching required



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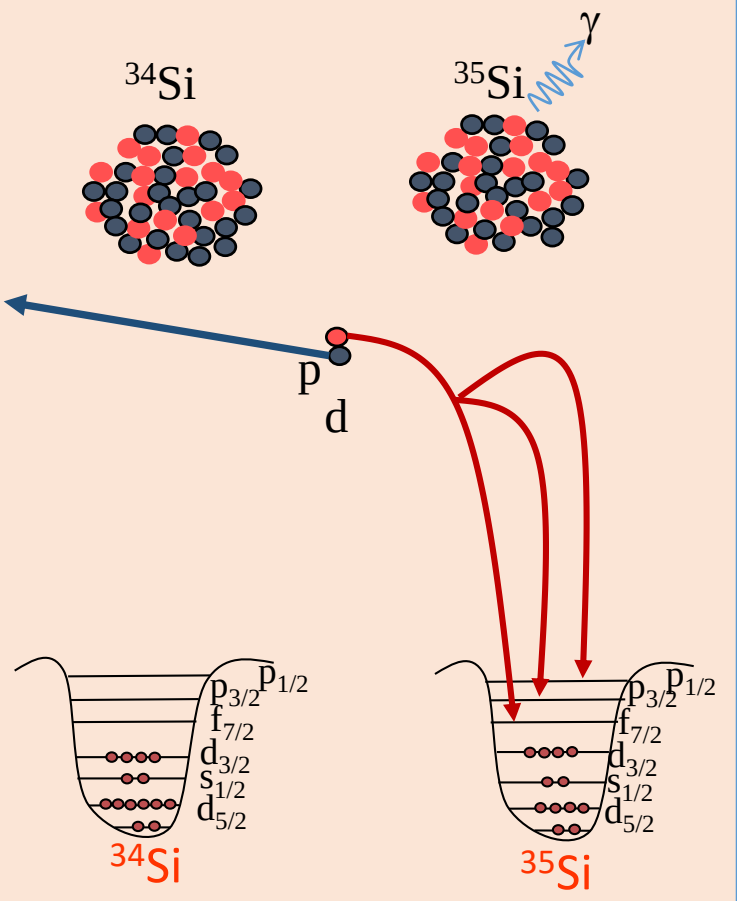

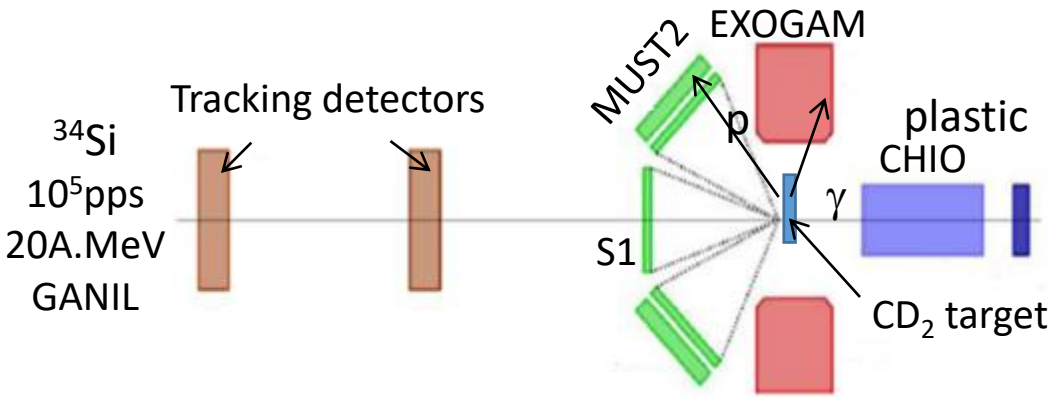

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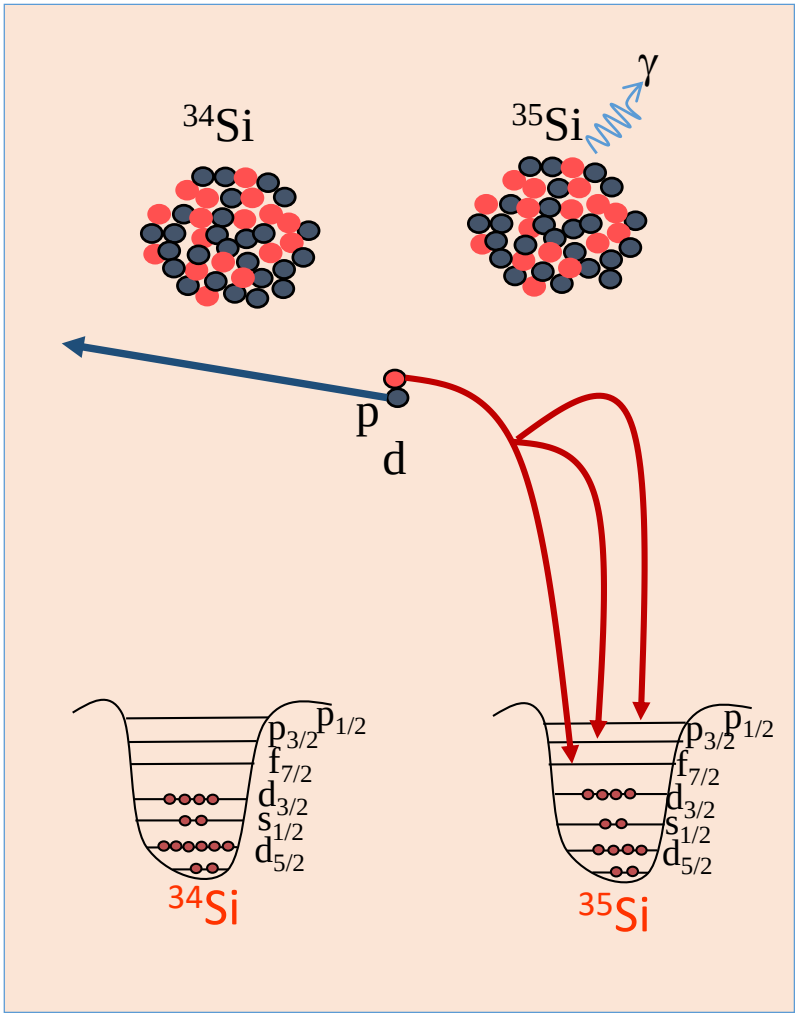

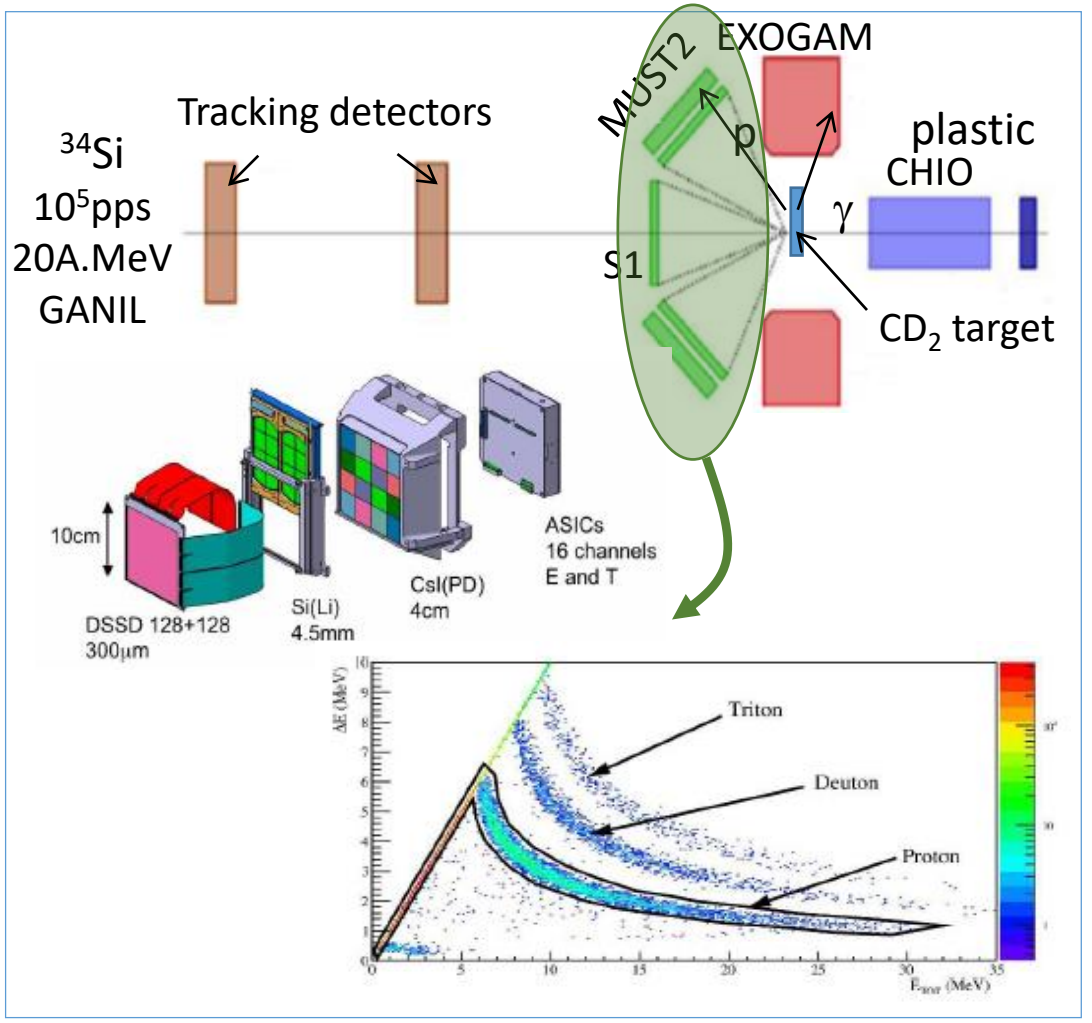

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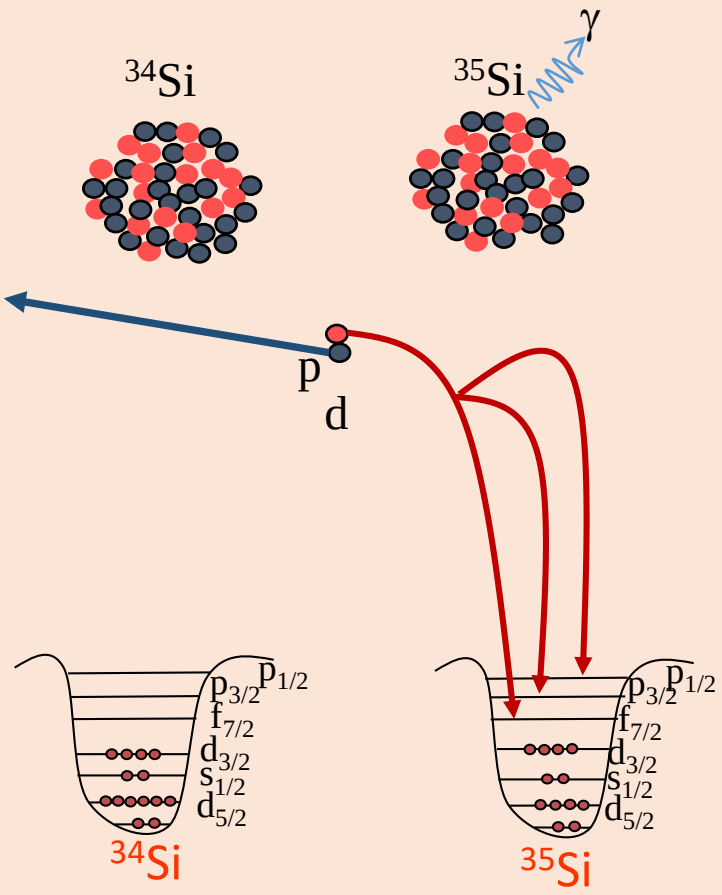

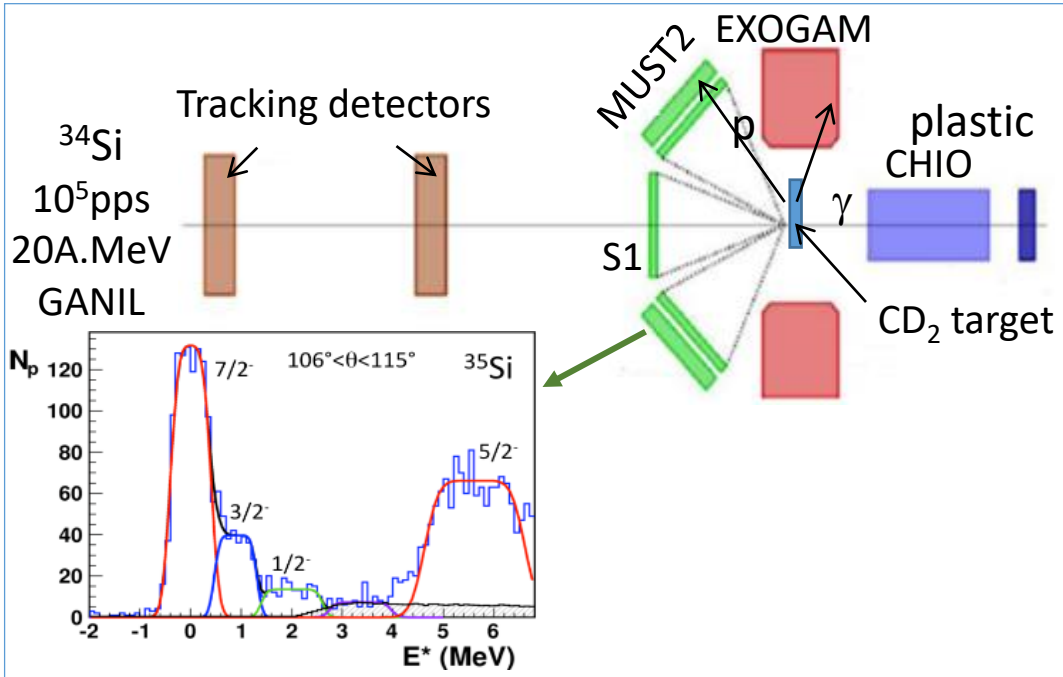

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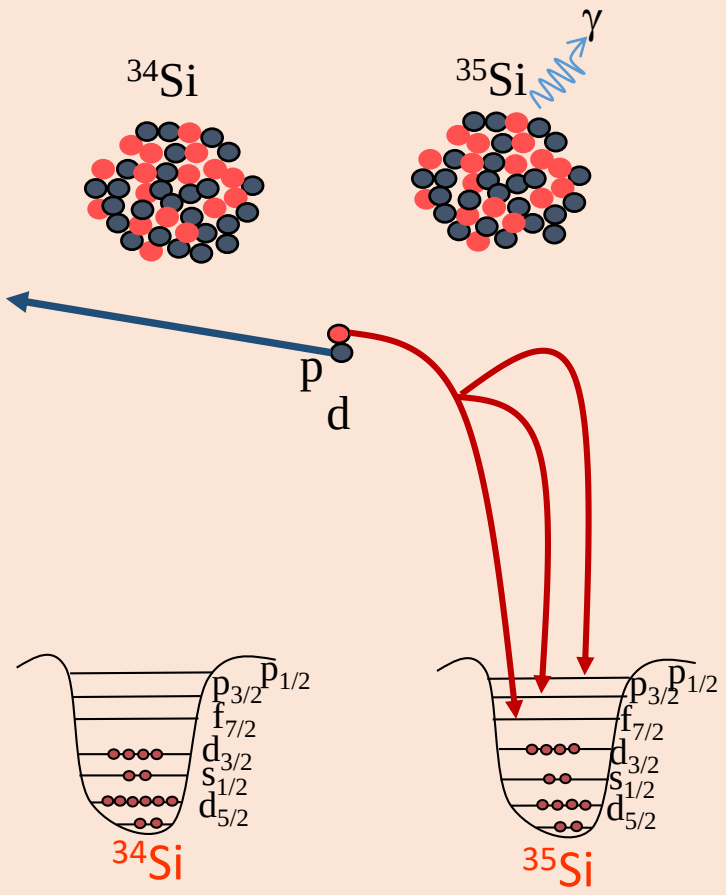

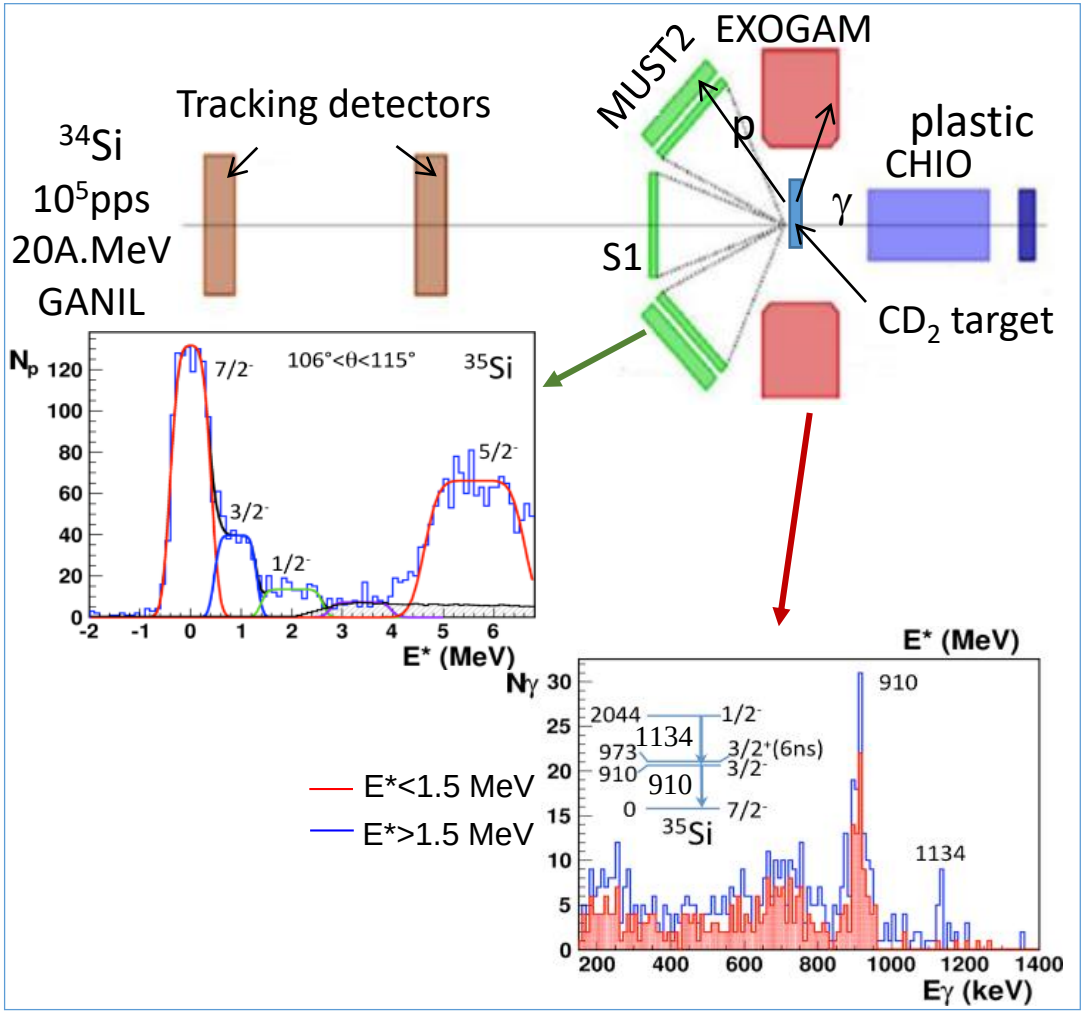

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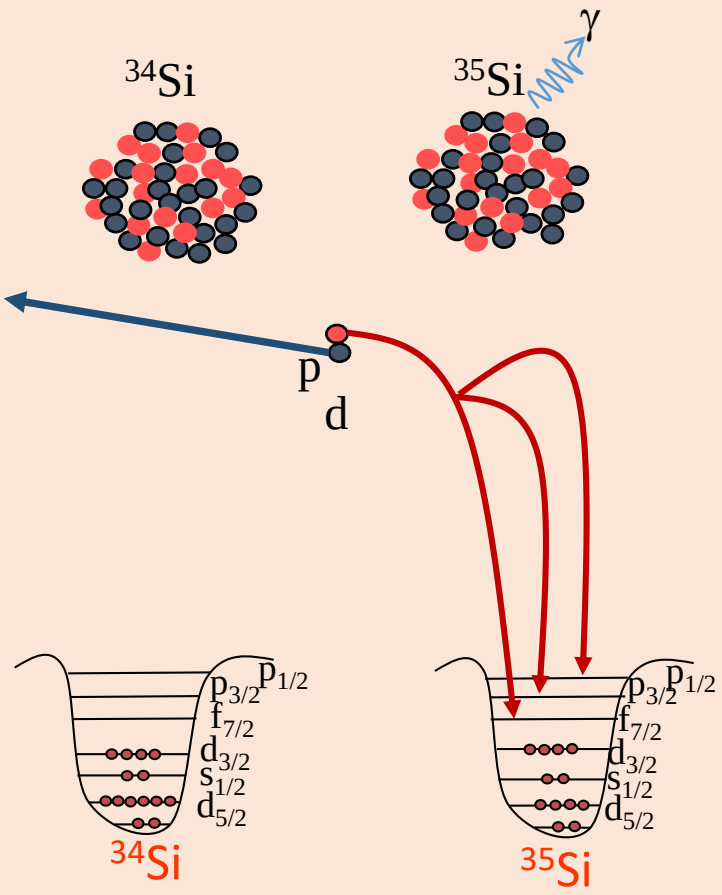
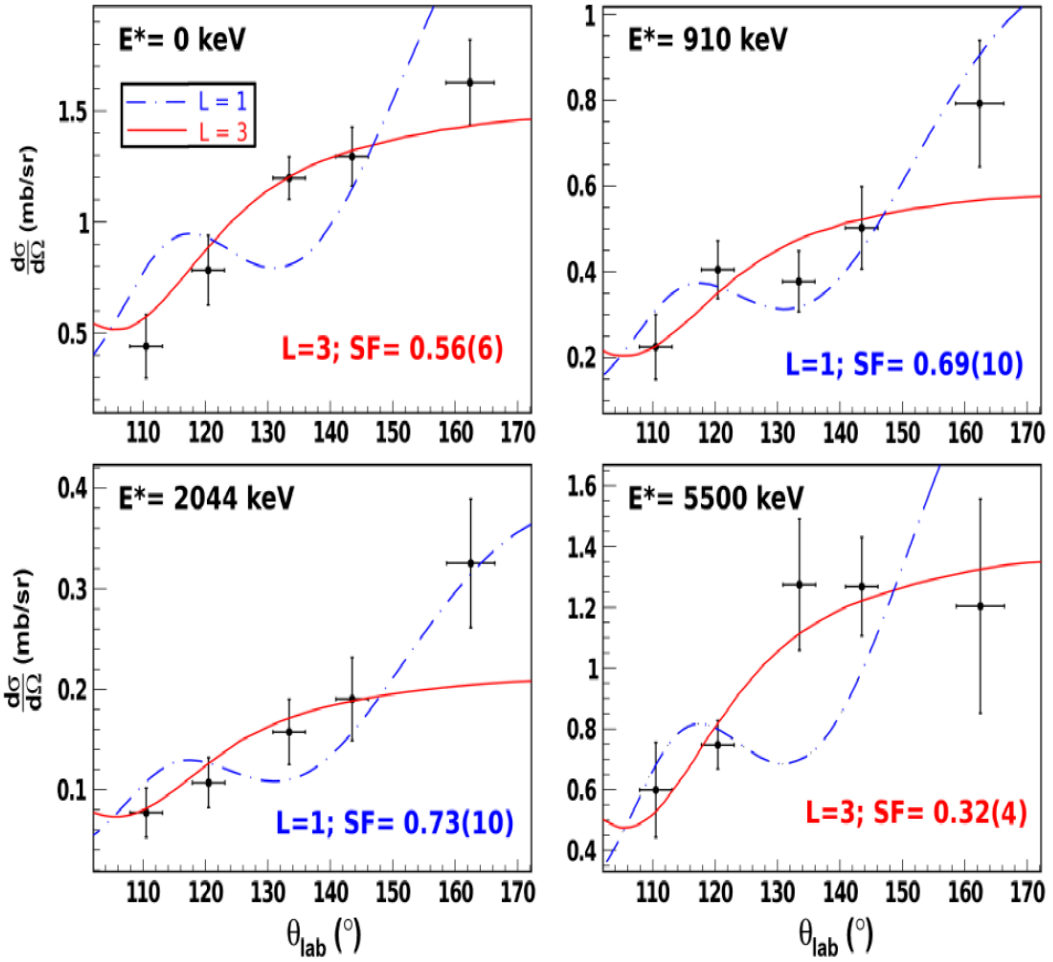
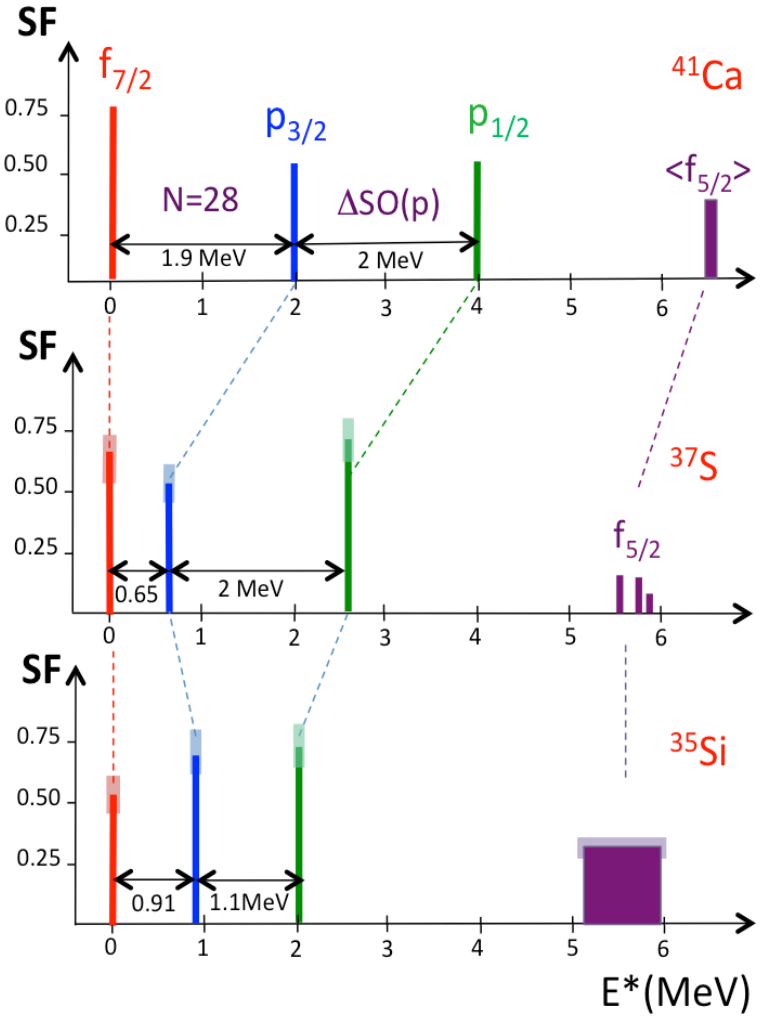
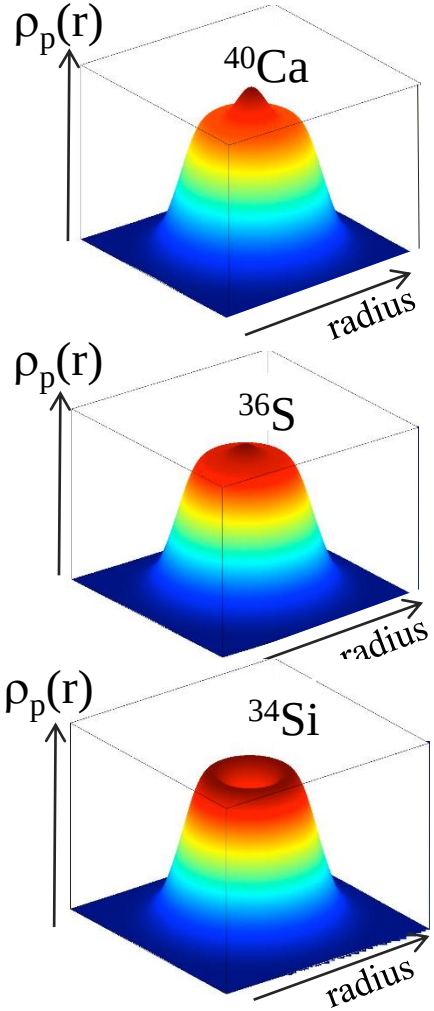




Evolution of the $p_{3/2}$-$p_{1/2}$ SO splitting using (d,p) transfer at GANIL

G. Burgunder, Phys. Rev. Lett. 112 (2014)





Z=20

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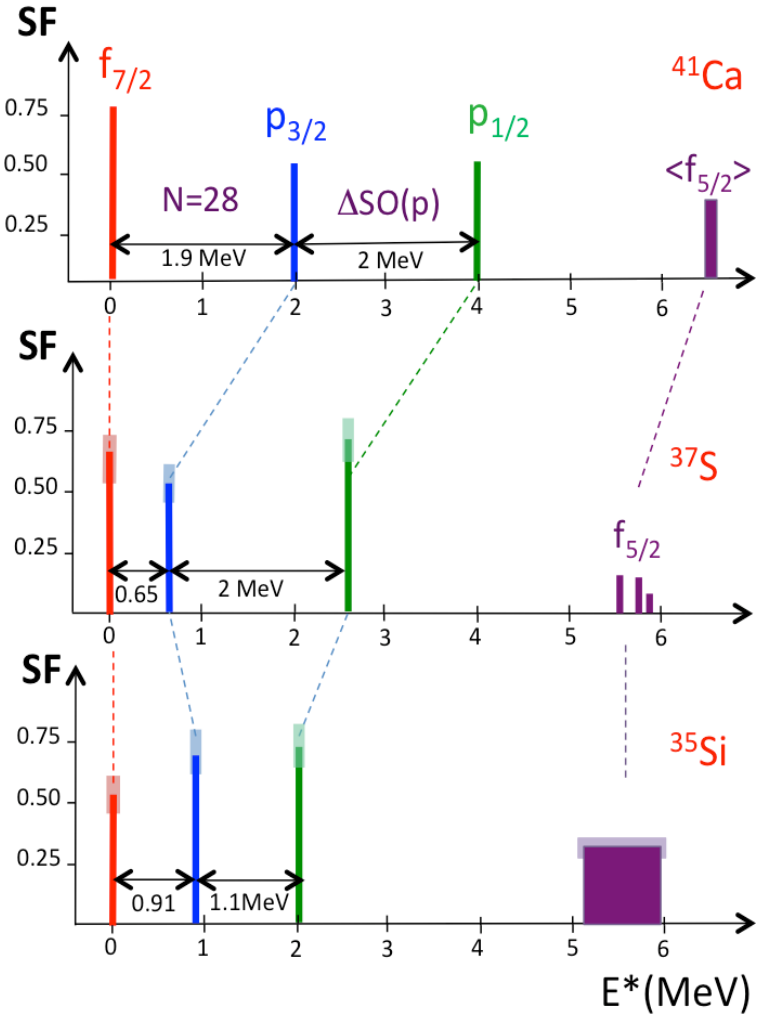

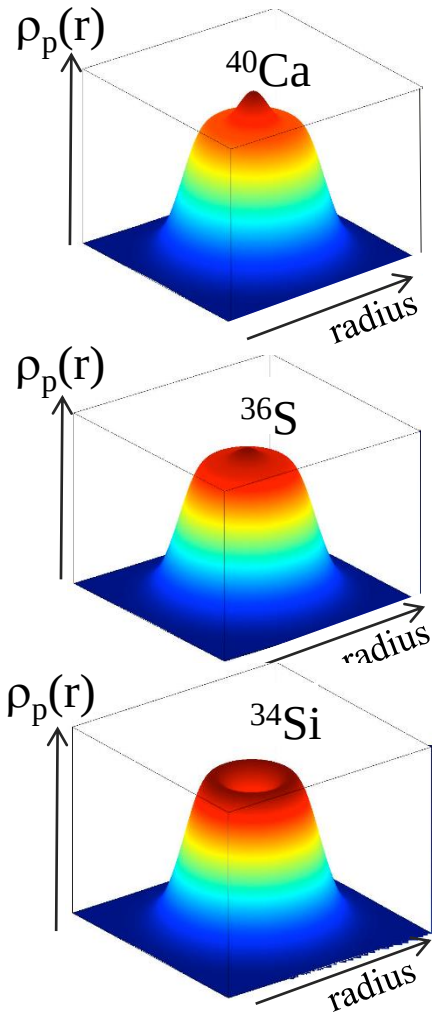

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The $p_{3/2}$-$p_{1/2}$ splitting changes by almost a factor of 2 between ^{37}S and ^{35}Si

- caused by density & isospin dependence of the SO interaction
- constrain models in the future for r process and SHE

Collaborators

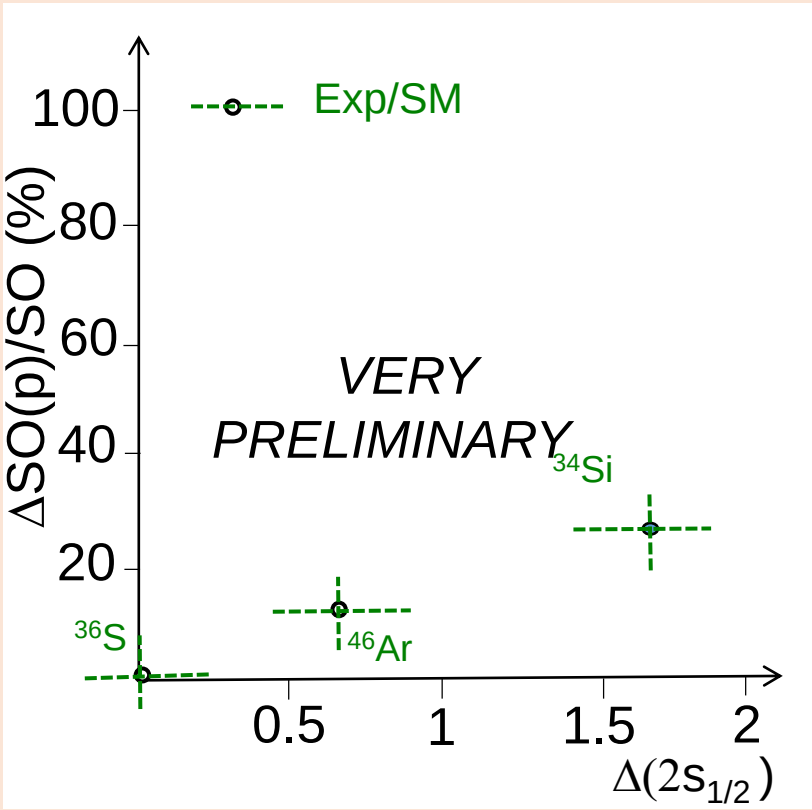
- NSCL knockout experiment
  Analysis: A. Mutschler
  Spokesperson: O. Sorlin

- GANIL (d,p) transfer experiment
  Analysis: G. Burgunder
  Spokesperson: O. Sorlin

Thanks to:
The GRETINA S800 collaboration
The LISE MUST2 collaboration

Density and Isospin dependence of the SO interaction

Evolution of the p SO splitting as a function of central depletion



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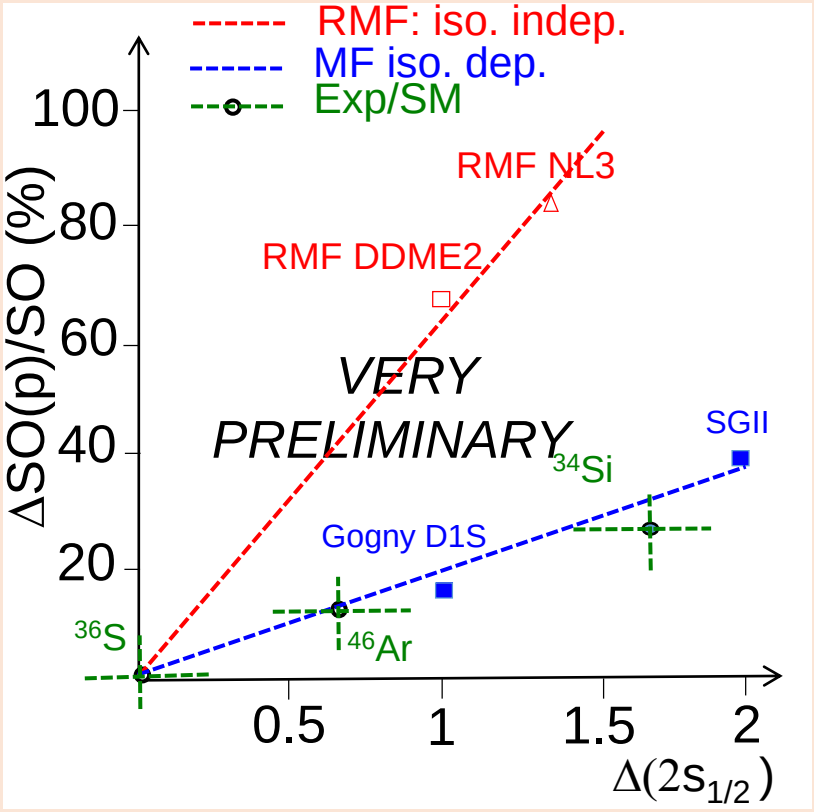

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Density & Isospin dependences well taken into account by MF calculations

RMF seems not to have the proper isospin dependence of the SO interaction

RHF model seems very promising to get correct isospin dependence

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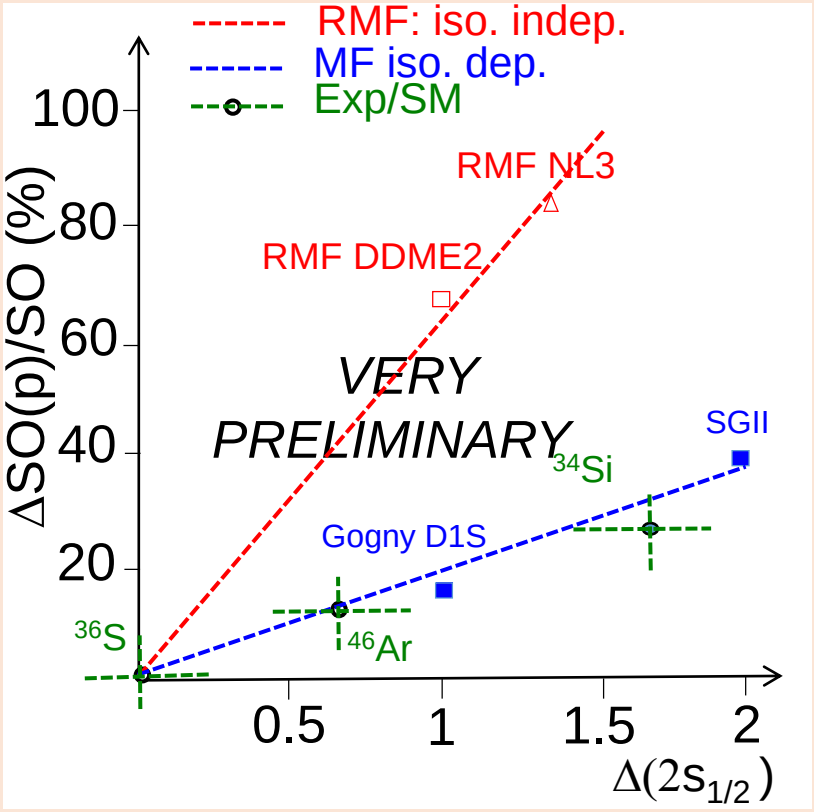

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Perspectives

Check the role of correlations in ≠ models -> compare to experiment

Evaluate the reduction of SO splitting when reaching drip line

Consequence for the r-process nucleosynthesis

Location of 'stable' Super Heavy Elements to be revisited / better constrained ?