

Exp
setup

The Active Target for SPES

SPES- β

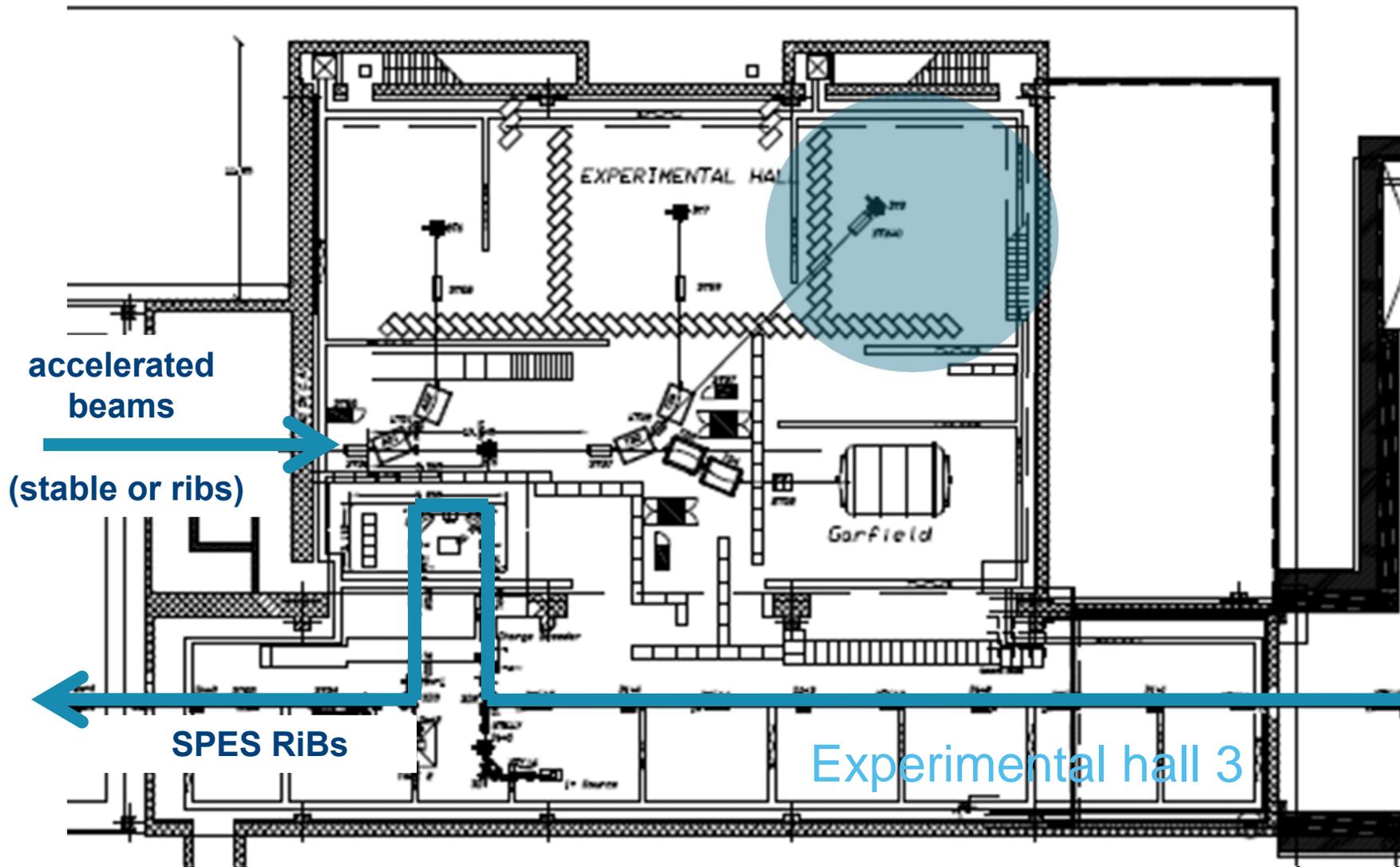
Low energy experiments

The tape station for beam diagnostics

*T. Marchi, 21 Nov 2017
LNL User Group Meeting*



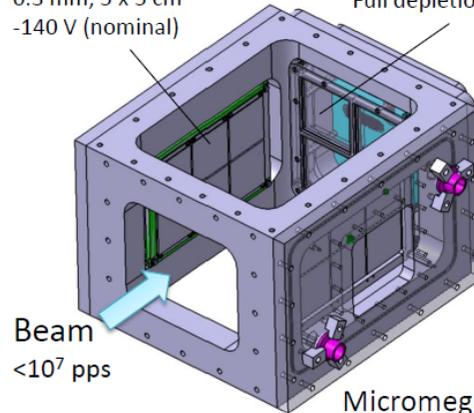
ATS – Active Target for SPES



ACTAR TPC Demonstrator chamber

Maya-Si

Pad type
0.3 mm, 5 x 5 cm²
-140 V (nominal)



Leuven DSSD

Micron BB7-1500
1.5 mm, 6.4 x 6.4 cm²
32 x 32 strips
Full depletion at +300 V

Micromegas

6 x 12 cm²
2,000 pads of 2 x 2 mm²



Demonstrator runs with Bacchus Spectrometer at IPN Orsay, June/July 2015

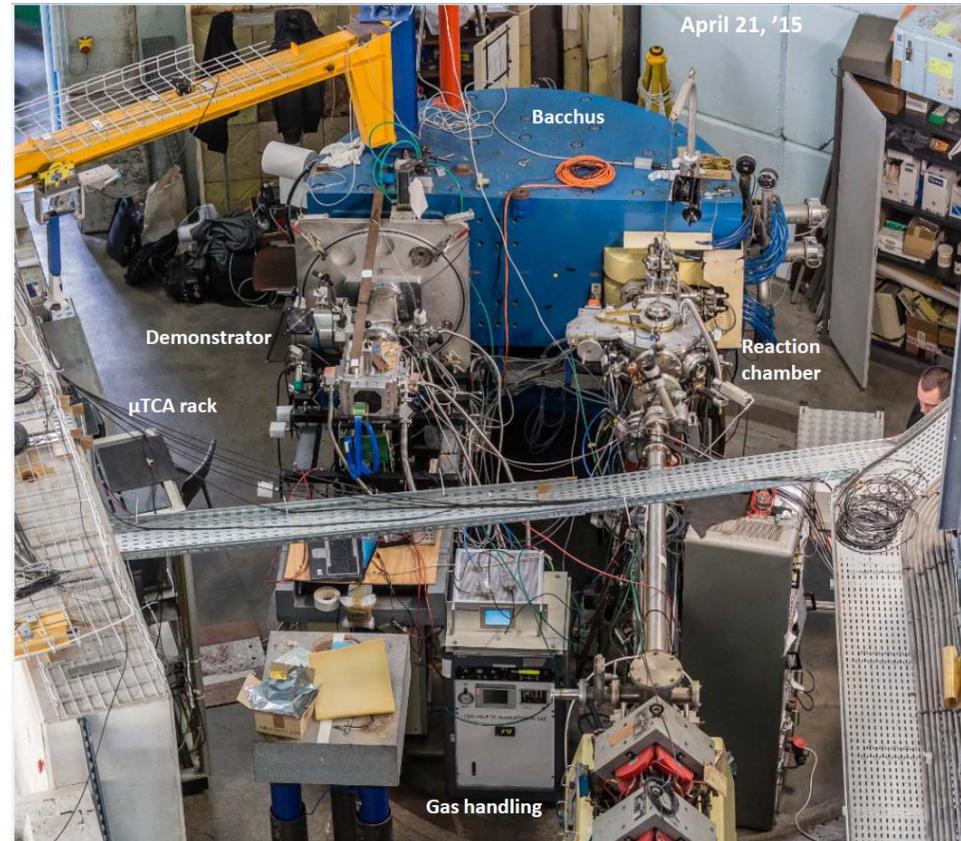
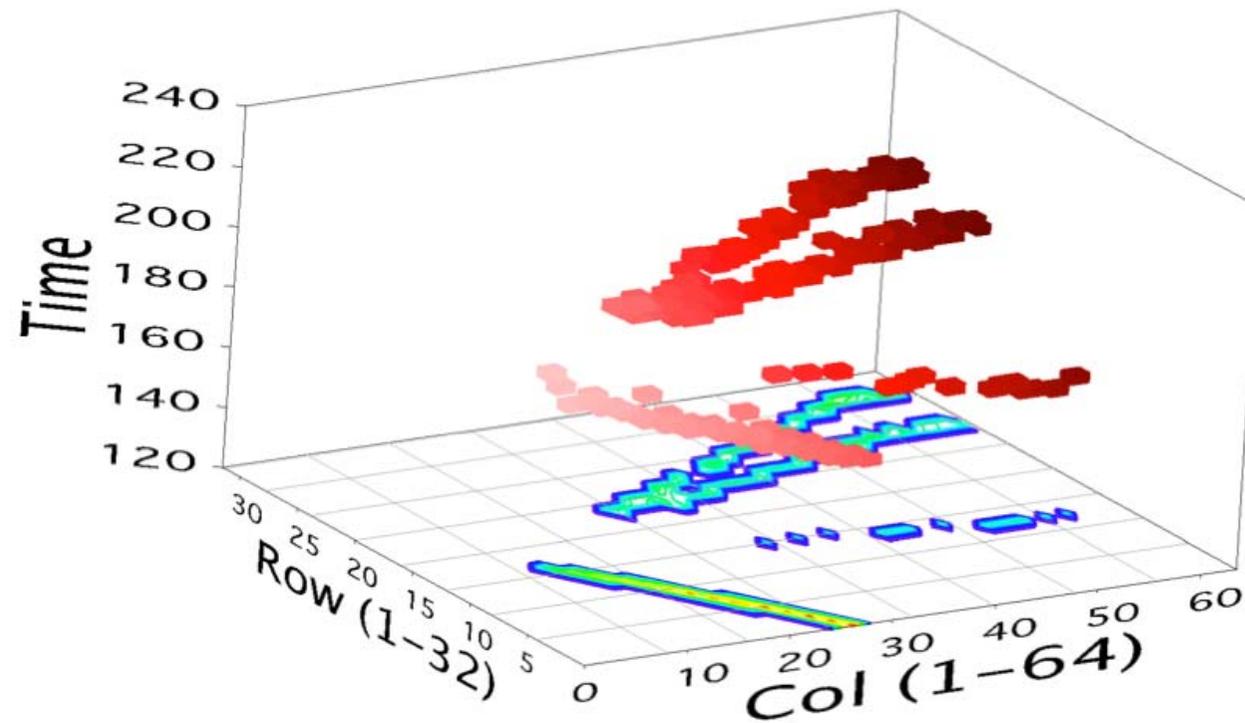


Figure and photos from D. Suzuki

ACTAR TPC @ IPNO

^{12}C on $\text{He}:\text{C}_4\text{H}_{10}$

- 4-particle event



$f_{7/2}$ vs $p_{3/2}$ neutron orbitals, in Sn like in Ca?



Z	134Te 41.8 M	135Te 19.0 S	136Te 17.63 S	137Te 2.49 S	138Te 1.4 S	139Te >150 NS	140Te >300 NS	141Te >150 NS	142Te
	β^- : 100.00%	β^- : 100.00%	β^- : 100.00% β -n: 1.31%	β^- : 100.00% β -n: 2.99%	β^- : 100.00% β -n: 6.30%	β -n β^-	β -n β^-	β -n β^-	
51	133Sb 2.34 M	134Sb 0.78 S	135Sb 1.679 S	136Sb 0.923 S	137Sb 492 MS	138Sb 350 MS	139Sb 93 MS	140Sb >407 NS	
	β^- : 100.00%	β^- : 100.00%	β^- : 100.00% β -n: 22.00%	β^- : 100.00% β -n: 16.30%	β^- : 100.00% β -n: 49.00%	β^- : 100.00% β -n: 72.00%	β^- : 100.00% β -n: 90.00%	β -2n β -n	
50	132Sn 39.7 S	133Sn 1.46 S	134Sn 1.050 S	135Sn 530 MS	136Sn 0.25 S	137Sn 190 MS	138Sn >408 NS		
	β^- : 100.00%	β^- : 100.00% β -n: 0.03%	β^- : 100.00% β -n: 17.00%	β^- : 100.00% β -n: 21.00%	β^- : 100.00% β -n: 30.00%	β^- : 100.00% β -n: 58.00%	β -n β^-		
49	131In 0.28 S	132In 0.207 S	133In 165 MS	134In 140 MS	135In 92 MS				
	β^- : 100.00% β -n: 2.00%	β^- : 100.00% β -n: 6.30%	β^- : 100.00% β -n: 85.00%	β^- : 100.00% β -n: 65.00%	β^- : 100.00% β -n				
48	130Cd 162 MS	131Cd 68 MS	132Cd 97 MS	133Cd 57 MS					
	β^- : 100.00% β -n: 3.50%	β^- : 100.00% β -n: 3.50%	β^- : 100.00% β -n: 60.00%	β^- : 100.00% β -n					
	82	83	84	85	86	87	88		

[Adapted from O. Sorlin, M.-G. Porquet, Progr Part. Nucl Phys 61 (2008) 602]

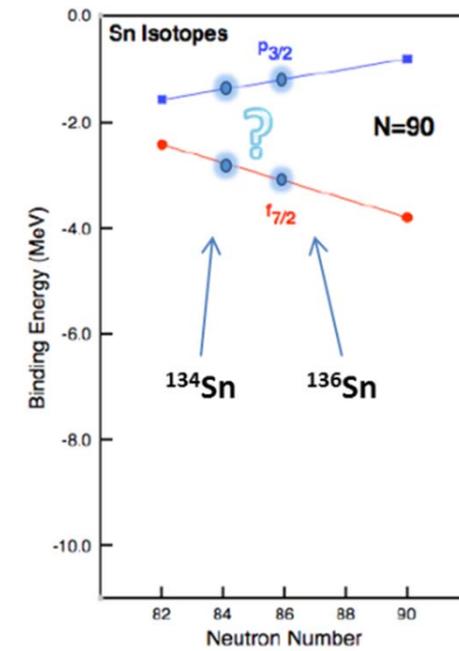
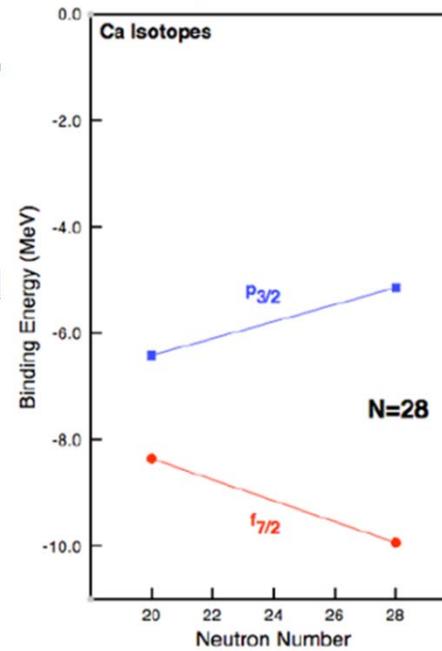


Fig.1 Analogy between $f_{7/2}$ and $p_{3/2}$ evolution of binding energies in the known Ca isotopes to what could be expected for the Sn isotopes approaching N=90. Figure adapted from¹³.

Possible setup and beams

Expected beam intensities @ 10 AMeV		
	SPES 1 st day (5 μ A p beam)	SPES full power (200 μ A p beam)
¹³² Sn	$7.8 \cdot 10^5$	$3.1 \cdot 10^7$
¹³³ Sn	$7.0 \cdot 10^4$	$2.8 \cdot 10^6$
¹³⁴ Sn	$1.2 \cdot 10^4$	$4.9 \cdot 10^5$
¹³⁵ Sn	$1.6 \cdot 10^2$	$6.2 \cdot 10^3$
¹³⁶ Sn	-	$0.9 \cdot 10^2$

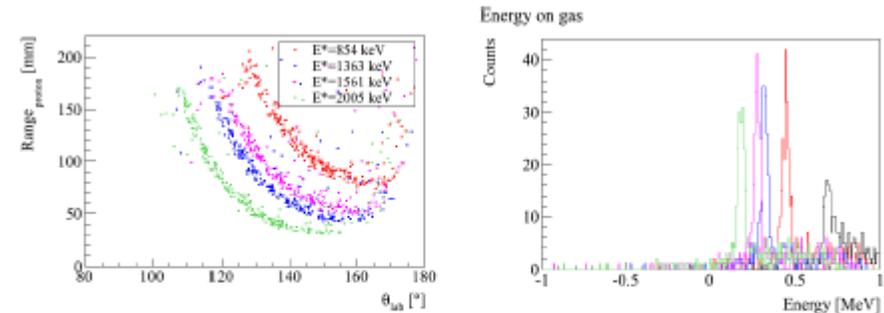


Fig. 5: Reconstructed kinematics plot for the different excited states populated in ¹³²Sn for protons stopped in the gas at a pressure of 400 mbar. Note that the majority of protons populating the ground state escape the gas and the resolution is thus slightly degraded.

Stopped in gas: ~ 110 keV FWHM res

ACTAR + Si wall

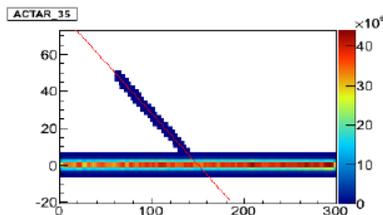


Fig. 4: Sample digitized trace for a ¹³²Sn(d,p) reaction with 2x2mm² sized pads. The red line corresponds to the fitted trajectory used for determining the range of the proton.

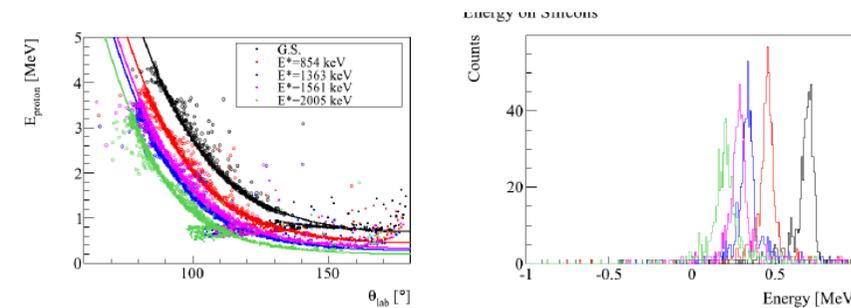
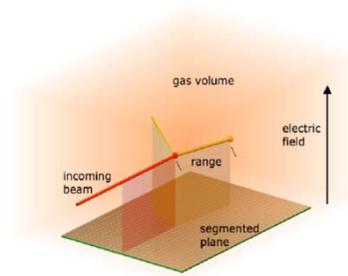


Fig. 6: Reconstructed kinematics plot for the different excited states populated in ¹³³Sn for protons stopped in the Si detectors (open circles) and stopped in the gas (closed circles).

¹³²Sn(d,p)¹³³Sn @ 5 AMeV
400 mbar D₂

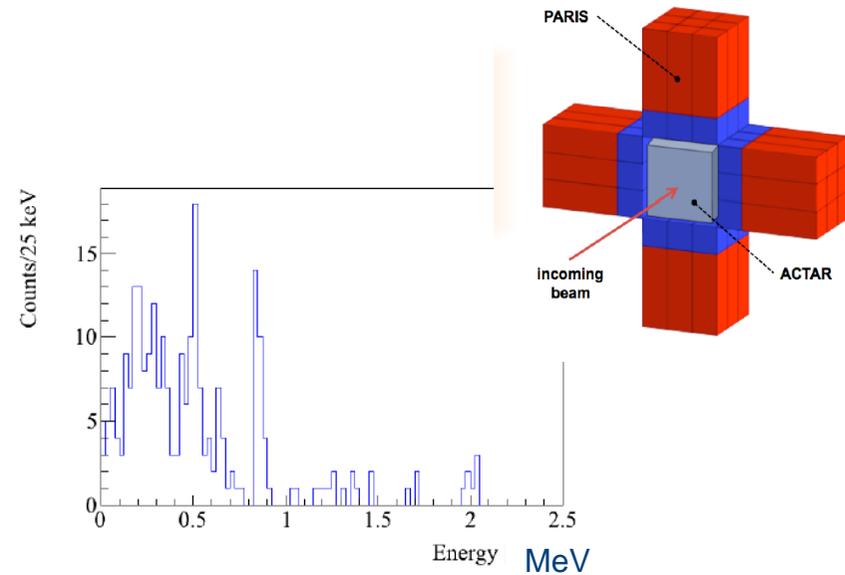
Gas-Si ($\Delta E-E$): ~ 90 keV FWHM res

[D..Perez-Loureiro and G.F.Grinyer, ACTARsim Report (2013)]

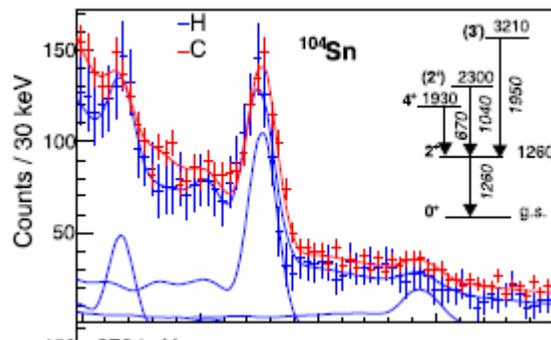
Improving resolution with gamma-ray detectors

- γ -rays in PARIS-like detectors from population of 854, 1363, 2005 keV states in ^{133}Sn
- Statistics corresponding to 2 days of beam time at 10^3 pps (total cross section 10 mb, photopeak eff 17%)

Issue: might reduce global efficiency



Further steps... (p,p')



[A. Corsi et al, PLB 743 (2015) 451]

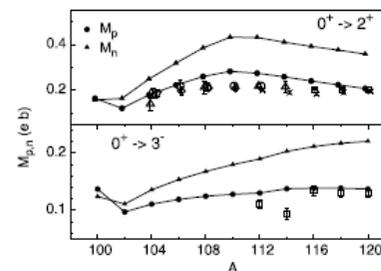
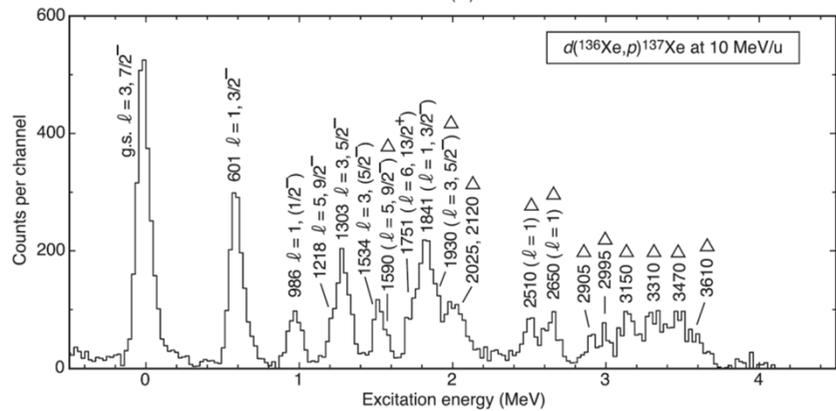


Fig. 4. M_p (\bullet) and M_n (\blacktriangle) from QRPA calculations with the Gogny D1M interaction compared to experimental M_p (∇ : RIKEN [14], \circ : NSCL [9,13], \times : GSI Doppler Shift Attenuation Method [34], Δ : GSI Coulomb excitation [6,10-12], \diamond : ISOLDE [7,8], \square : NNDC [28]). Top: 2_1^- . Bottom: 3_1^- . Experimental M_n values are taken from the literature [22].

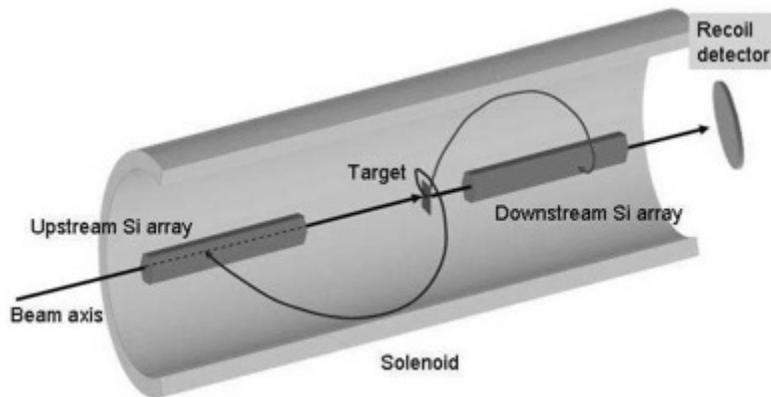
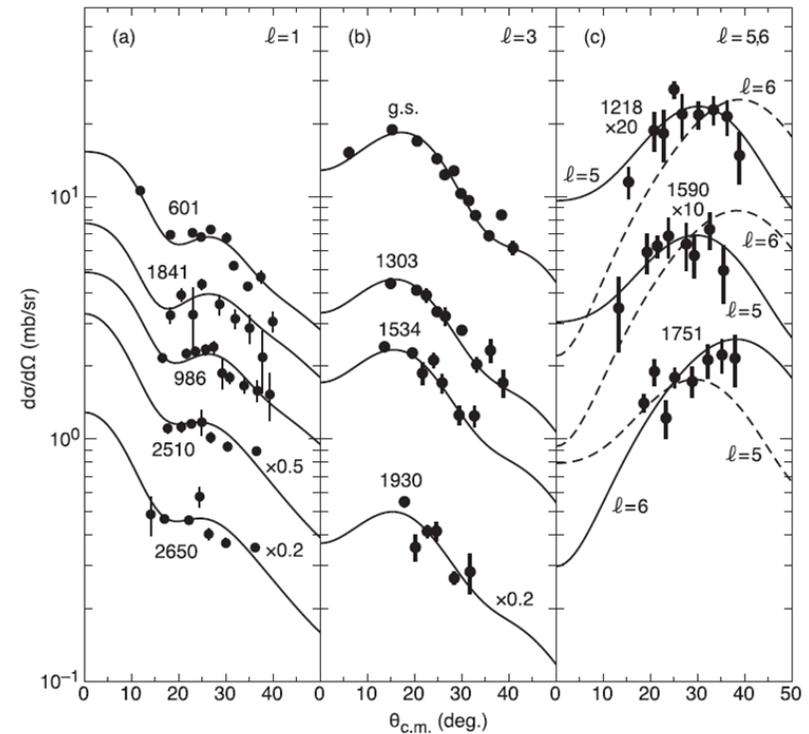
Getting ready for RIBs: MT implementation



Benchmark: $^{136}\text{Xe}(d,p)^{137}\text{Xe}$ - inv kinem



B.P. Kay et al, PRC 84 0243325 (2011)
HELIOS @ ANL



Beyond MagicTin: physics opportunities with an active target at SPES

3. Physics of interest : ACTAR @LNL with SPES → elastic scattering

At low energy (<20MeV) elastic scattering can be used, due to very high cross section, to determine the optical model parameters, needed to analyze the inelastic and transfer reaction data.

ORNL expts @ 10 MeV/u

Progress in Particle and Nuclear Physics 63 (2009) 396447

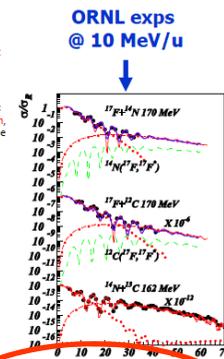
Elastic scattering and reactions of light exotic beams

N. Keeley, N. Alamanos, K.W. Kemper, K. Rusek

Survey to the light (<20) radioactive nuclei:

By careful choice of target/beam combination, different aspects of the coupling effects may be emphasized

Inverse kinematics $^{16}\text{O}(p,p)^{16}\text{O}$



$^{134}\text{Sn}(p,p)^{134}\text{Sn}$ SPES yield $5.0 \cdot 10^5$
 $^{135}\text{Sn}(p,p)^{135}\text{Sn}$ SPES yield $6.0 \cdot 10^5$

3. Physics of interest : inelastic scattering, transfer reactions

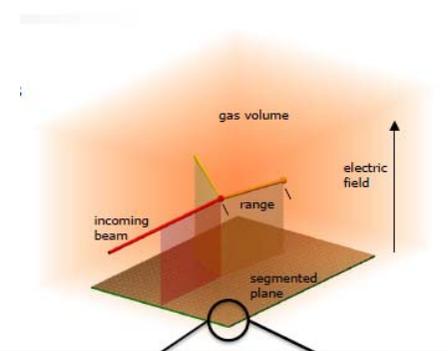
How does the differential cross section vary with beam energy?

@SPES

$^{133}\text{Sn}(d,p)^{134}\text{Sn}$ - yield $2.8 \cdot 10^6$
 $^{134}\text{Sn}(d,p)^{135}\text{Sn}$ - yield $5.0 \cdot 10^5$
 $^{135}\text{Sn}(d,p)^{136}\text{Sn}$ - yield $6.0 \cdot 10^5$

With transfer we can probe:

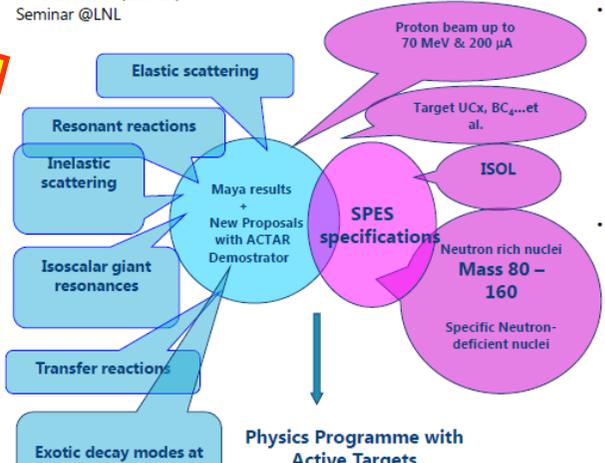
- occupancy of single-particle (shell model) orbitals in the original nucleus A, ground state or distribution of sp. strength in all final states of A-1 or A+1 nuclei
- identify the angular momentum of the transferred nucleon
- hence, identify the s.p. level energies in A-1 or A+1 nuclei produced from even-even nuclei
- identify the s.p. purity of coupled states in A-1 or A+1 nuclei produced from odd nuclei
- and the scattered particle is detected, with most yield being at small centre-of-mass angles



2. MAYA & ACTAR

S. Sami (Leuven)
Seminar @LNL

RIB → Inverse kinematics reactions → ACTIVE TARGET: very low intensity beams can be used



- Proton inelastic scattering can yield important information on the structure of nuclei, in particular on transition densities. Protons interact with both protons and neutrons in the nucleus, whereas Coulomb excitation on a heavy partner or lifetime measurements probe only the proton density distributions. The combination of these two types of measurements can disentangle proton and neutron contribution to excited states
- Transfer reactions: The advantage of active targets for these kinds of studies lies in the possibility of using high pressures and thus having a very large effective target thickness that allows precise measurements to be performed with beam intensities as low as 10^3 pps. There is therefore a niche for active target experiments with the most exotic nuclei where incident intensities are too low, or when the recoil nucleus has such a low energy that it cannot exit from a solid target without drastically degrading the energy resolution.

Intensities	Energy
$10^7 - 10^8$ pps ^{130}Sn , ^{90}Kr ,	9-13 MeV/u
$10^5 - 10^4$ pps ^{134}Sn , ^{94}Kr , ^{95}Kr , ^{96}Kr	

3. Physics of interest : ACTAR @LNL with SPES → inelastic scattering

Collectivity at $N=50$: ^{56}Fe and ^{58}Ni

@SPES Ge, Se, Kr, Rb (p,p')

Rb → first days beams @SPES...

Possible coupling with γ -array? → PARIS?

SPES expectation

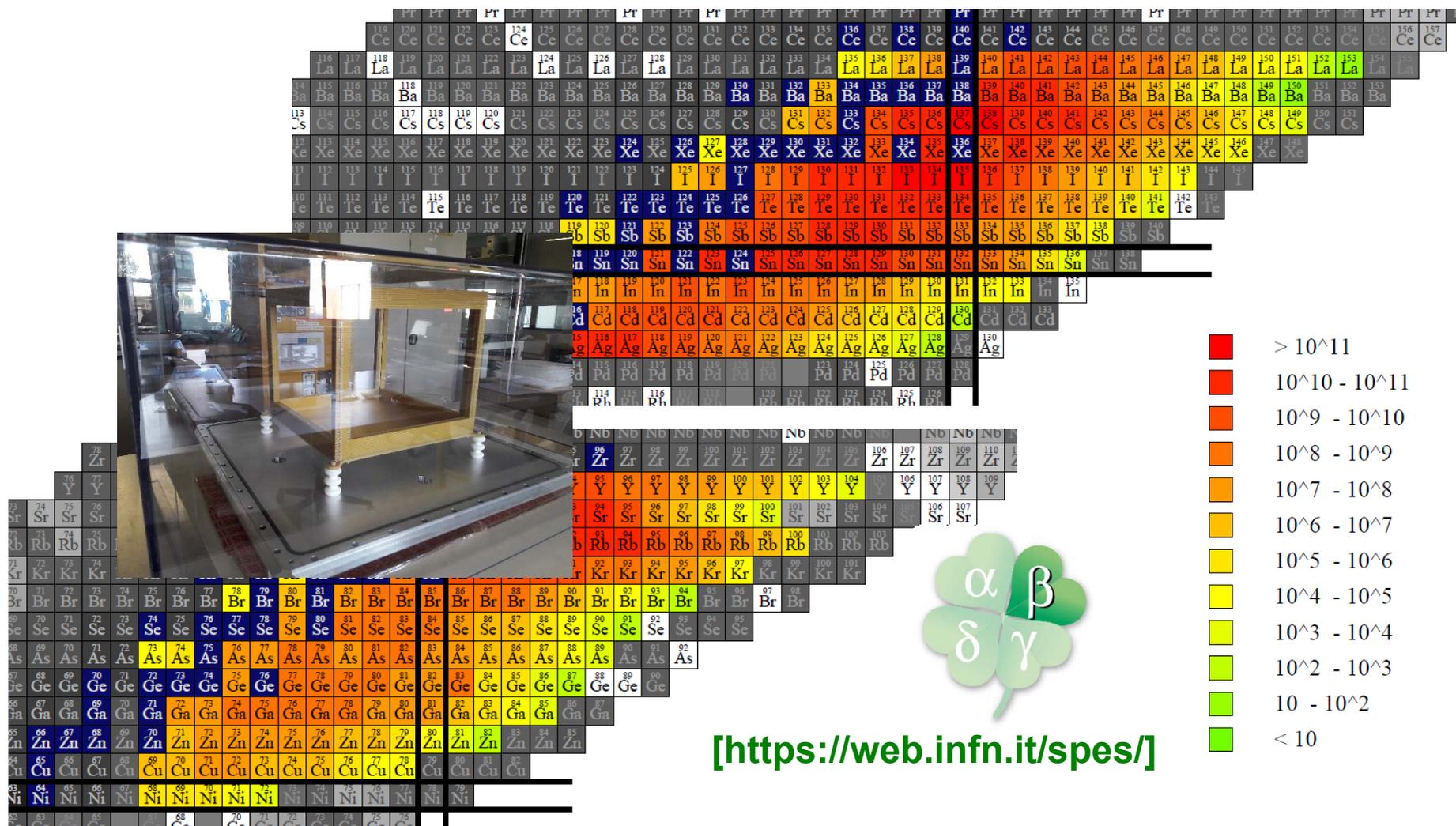
Isotope	RIB $^{1+}$ (260 keV)	Re-accelerated
^{94}Kr	$2.5 \cdot 10^7$	$4.9 \cdot 10^5$
^{95}Kr	$1.1 \cdot 10^7$	$2.3 \cdot 10^5$
^{96}Kr	$1.5 \cdot 10^6$	$2.9 \cdot 10^4$
^{97}Kr	$4.8 \cdot 10^4$	$9.7 \cdot 10^2$

Evidence for a Smooth Change of Deformation in the Neutron-Rich Kr Isotopes

Isotope	Year	I_K [pps]	E_K [MeV]	t_{exp} [s]	$R_{\text{Kr/Rb}}$
^{94}Kr	2009	8×10^6	267.9	60 480	75(6)/25(3)
^{95}Kr	2010	4×10^6	267.9	43 560	74(7)/26(4)
^{96}Kr	2009	4×10^5	273.6	32 760	43(4)/57(6)
^{97}Kr	2010	7×10^3	273.6	59 400	46(7)/54(8)
^{98}Kr	2011	$< 5 \times 10^2$	273.6		

Coulex @ISOLDE

Beyond MagicTin: physics opportunities with an active target at SPES



[<https://web.infn.it/spes/>]

Two letters of intent for SPES endorsed by the SAC:

- B. Fernandez Dominguez et al, Direct Reactions with exotic nuclei in the r-process using an active target
- R. Raabe, T. Marchi et al, Shell Structure in the vicinity of ¹³²Sn with an active target

Ongoing activities and plans

Actar demonstration installation at LNL

- Detector setup in the lab
- Runs with low energy beams at CN
- Energy loss measurement in different gases



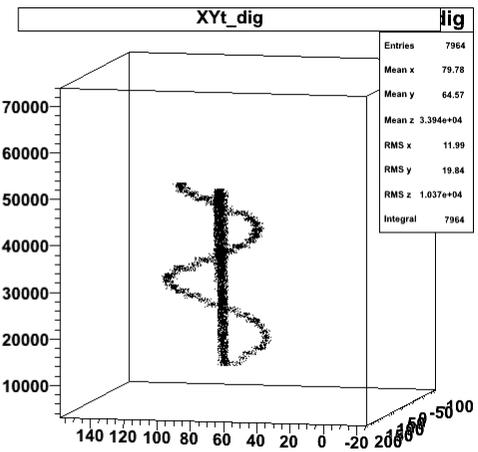
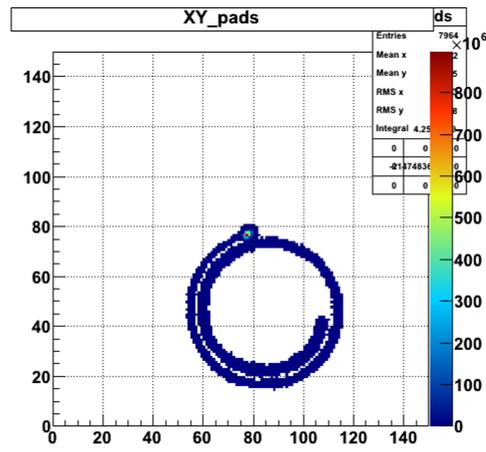
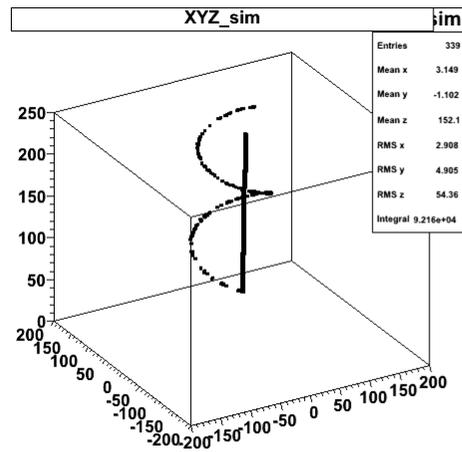
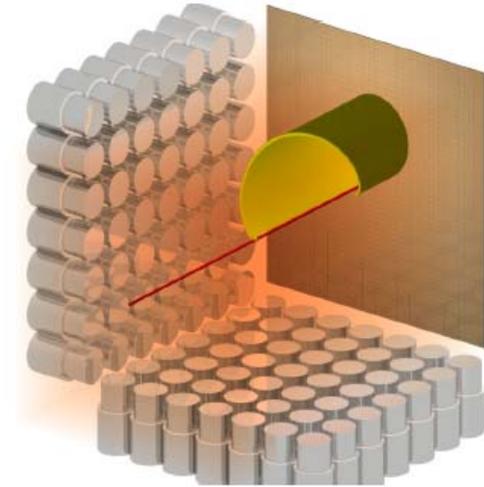
Further detector R&D with heavy ions at 10 AMeV (proposal submitted to LNS PAC)

Infrastructure - Setting up a new experimental area for SPES

- Clearing out and cleaning up
- Services
- New beamline installation
- Setup installation



Outlook



ENSAR2 Network Activity: Gas Detection Systems



W.P. Leader: T. Roger (GANIL)

Deputy Leader: F. Gramegna (LNL)

Task 1: ... gather together the GDS community ...

4 topical meetings

Task 2: GDS in strong and non-uniform magnetic fields

***Task 3: Novel detection systems for high-intensity and heavy beams
January 2018 at USC - Santiago De Compostela***

Task 4: Rare gas target handling and recycling systems

Task 5: Auxiliary detectors

Exp
setup

The GARFIELD array
The Active Target for SPES

SPES- β

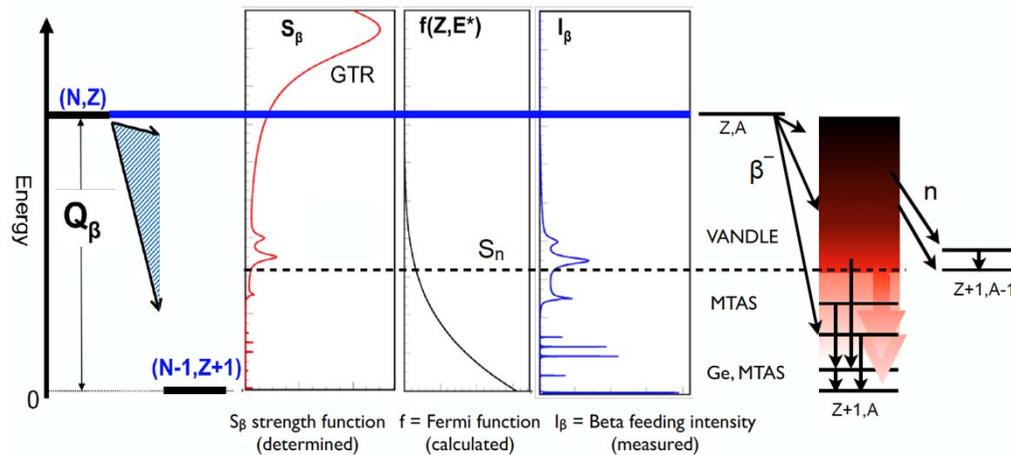
Low energy experiments
The tape station for beam diagnostics

*T. Marchi, 21 Nov 2017
LNL User Group Meeting*



1+ area (A13) mainly devoted to β -decay related studies

- Study of β decay properties ($T_{1/2}$, P_n , BR, S_β ,.....)
 - strong link to astrophysics
 - inputs for r- and s-process
- Study of nuclear structure complementing data coming from
 - selective tool
 - egs. Study of shape coexistence and exotic shapes
 - evolution of magic numbers
- Exotic decay modes: PDR via β decay
- Fundamental questions: CKM unitarity via study of super-allowed decays



Going away from stability we have access to larger part of the decay strength

Study group for 1+ installation:
 M.Cinausero, G.Benzoni,
 D.Scarpa, T. Marchi, F.
 Gramegna

1+ area (A13)

3 main installations:

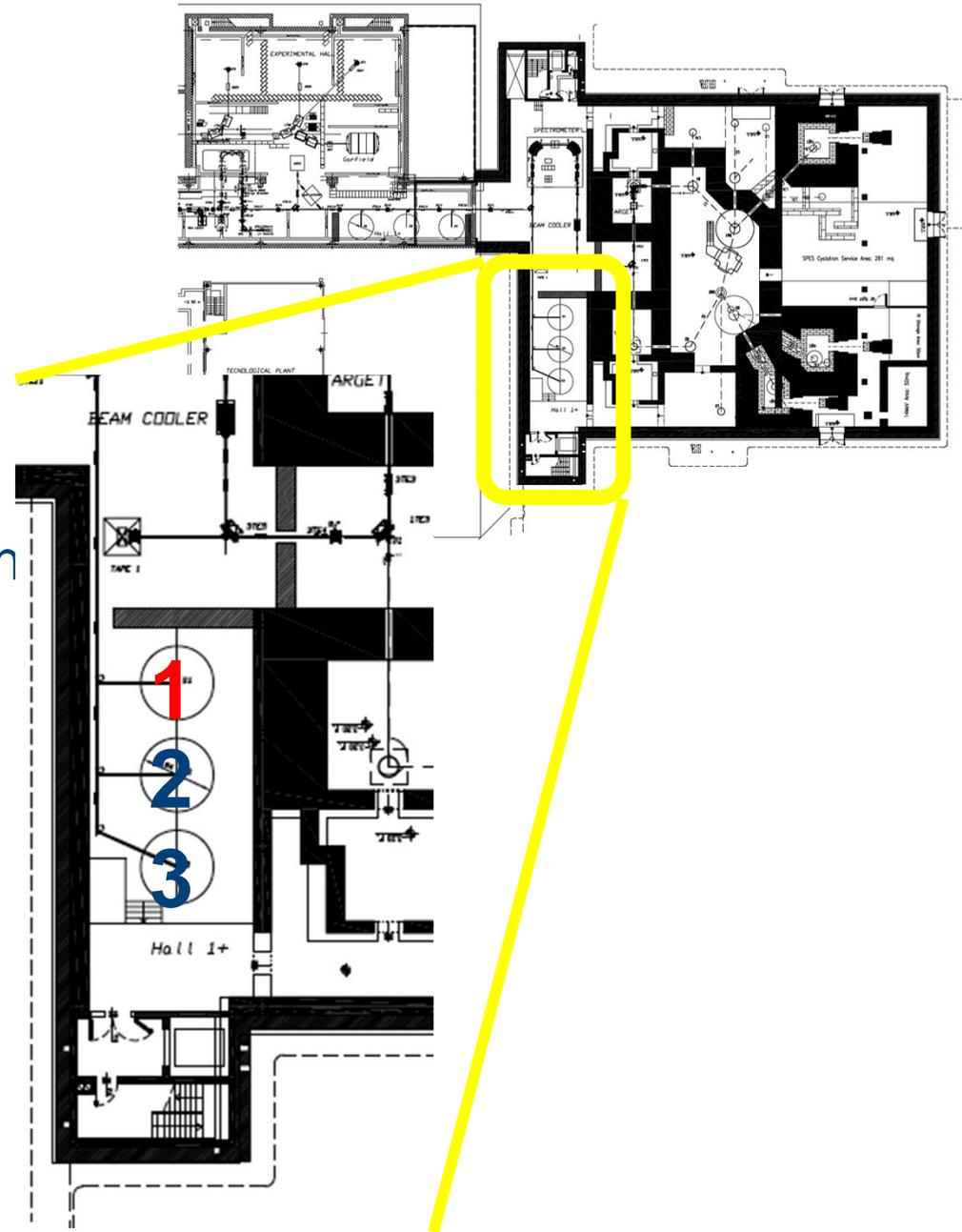
1- Beam diagnostic Tape station

2- β -decay station

+ E0 measurement

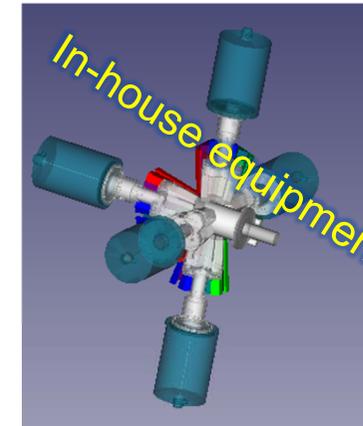
+ VANDLE/3HEN

3- MTAS (Oak Ridge)

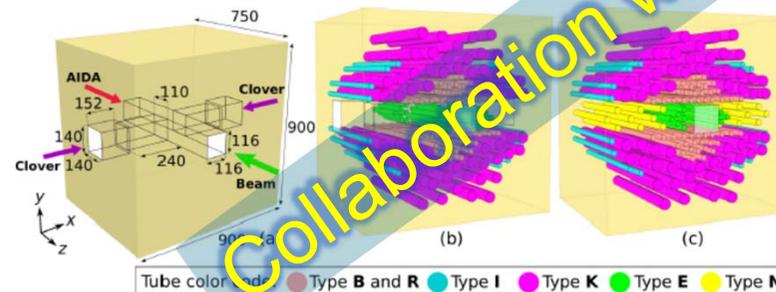
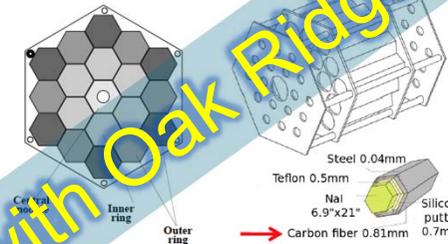


Proposed setups for β decay studies

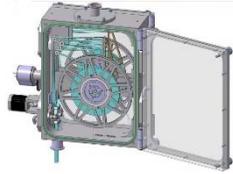
- SPES β decay station (β -DS)
 - Plastic β detectors, covering large solid angle
 - HPGe detectors (Galileo triple clusters)
 - + LaBr₃(Ce)
 - + second decay chamber for E0 measurements (collaboration with INFN-Firenze and Universita' di Camerino)
- Modular Total Absorption Spectrometer:
 - NaI covering 4π
 - Single crystal HPGe
 - β detector
- 3Hen:
 - 3He tubes
 - Single crystal HPGe
 - β detector



MTAS final design: 19 hexagonal modules, with a central module having a 2.5" hole to accommodate a beam line and auxiliary beta detectors. Each module is 21" long, 8" diameter (6.9" face-to-face) and has custom made carbon fiber housing. Weight ~120 lbs/module, ~2200 lbs total.



Collaboration with Oak Ridge



SPES β decay station (β -DS)



- Cassette design adapted from BEDO @ ALTO
- Common element to beam diagnostic installations (STS1-STS2)
- Realization: LNL + Milano INFN Mechanical workshops
- Low level controls developed together with IThemba-LABS (South Africa)
- High level developed by electronic workshop in LNL



→ Delivery and commissioning Summer/Fall 2017

- Simulations for β and γ detectors:

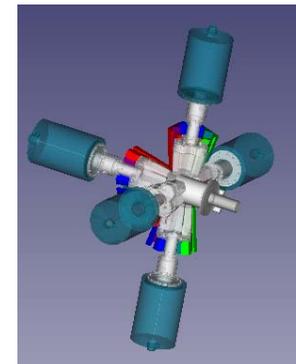
Simulated efficiency with the Co-60 in the center: 7.0% @ 1332 keV

Simulated P/T: 51.0 %

Simulated β efficiency: 70%

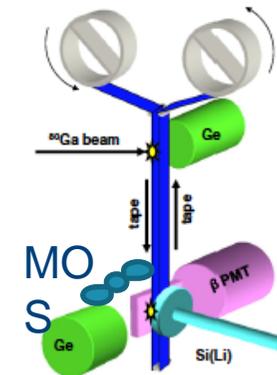
- Design of the setup (Milano)
- Design of MOS and 2nd decay chamber (Milano/Camerino/Firenze)

→ Delivery in 2019



1st decay chamber

2nd decay chamber



Joint collaboration with **LNL + INFN-Mi + ALTO Orsay** (France) + **iThemba-Labs** (South Africa) for mechanics/electronics/controls

STS – SPES TAPE STATION



Mechanics

Cassette: Design completed (IPN Orsay)
Cassette: Production completed (INFN-LNL INFN-MI)
Cassette: Assembly and test in progress (LNL/MI/IPNO)
Scattering Chamber: Design started (LNL)

Motion and Control

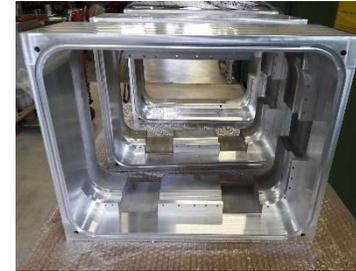
Beckhoff Hardware purchased
Beckhoff Driver for EPICS system: test bench OK (iThremba/LNL)
High level EPICS software: in progress (LNL)

Data Acquisition

ALL Hardware purchased (CAEN+WIENER+Servers+PC)
EPICS compatible acq software: in progress (INFN-NA / LNL)

Detectors

3 HPGe detectors purchased (n-type, C window. Canberra - REGe)
 β -counter design in progress



Documentation

STS Project description delivered. DOC_0000050
Detailed design documentation in preparation
Safety assessment with PILZ performed. Reply with partial corrections submitted. No major issues identified.
CE certification might be needed for the machine.