ŚLCJ
Środowiskowe
Laboratorium
Ciężkich Jonów

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INFN
Istituto Nazionale di Fisica Nucleare

Wzbudzenia kulombowskie w INFN Laboratori Nazionali di Legnaro

PRZESZŁOŚĆ, TERAŹNIEJSZOŚĆ i PRZYSZŁOŚĆ

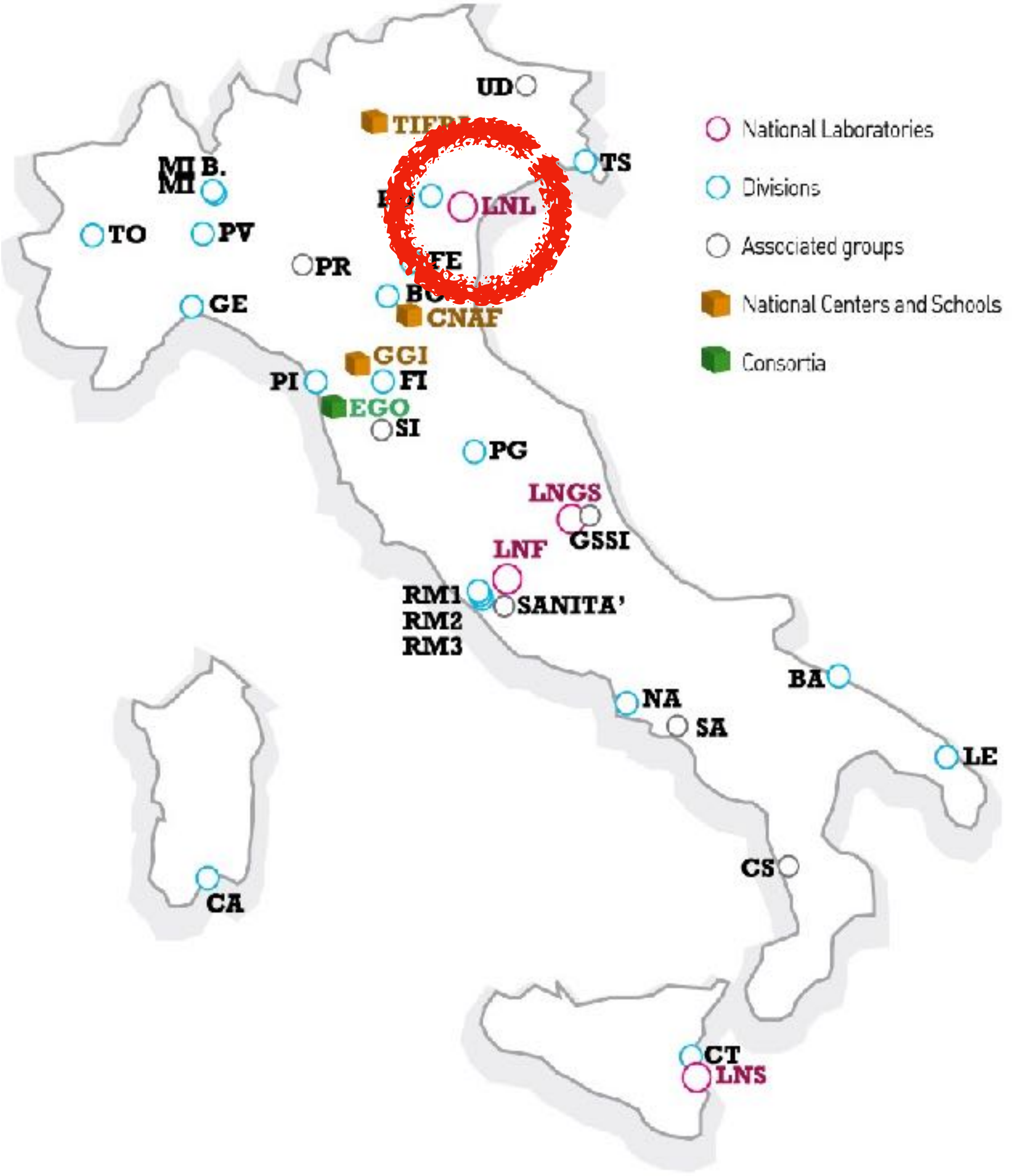
SEMINARIUM FIZYKI JĄDRA ATOMOWEGO

19.12.2019

Istitito Nazionale di Fisica Nucleare – Italy

- **INFN-LNL**
- Coulex @LNL
- ^{42}Ca - results
- SPIDER
- First Experiment: ^{66}Zn
- Next Experiments: ^{94}Zr, ^{116}Sn, ^{130}Xe, ^{58}Ni
- Future Perspectives

- **4** National Laboratories
- **20** Divisions
- **6** Associated Groups
- **3** National Centers and Schools
- **1** Consortia (EGO, European Gravitational Observatory)
- **5** Lines of Research:
  - CSN1: Particle Physics
  - CSN2: Astroparticle Physics
  - **CSN3: Nuclear Physics**
  - CSN4: Theoretical Physics
  - CSN5: Technological Physics



INFN LNL Accelerators

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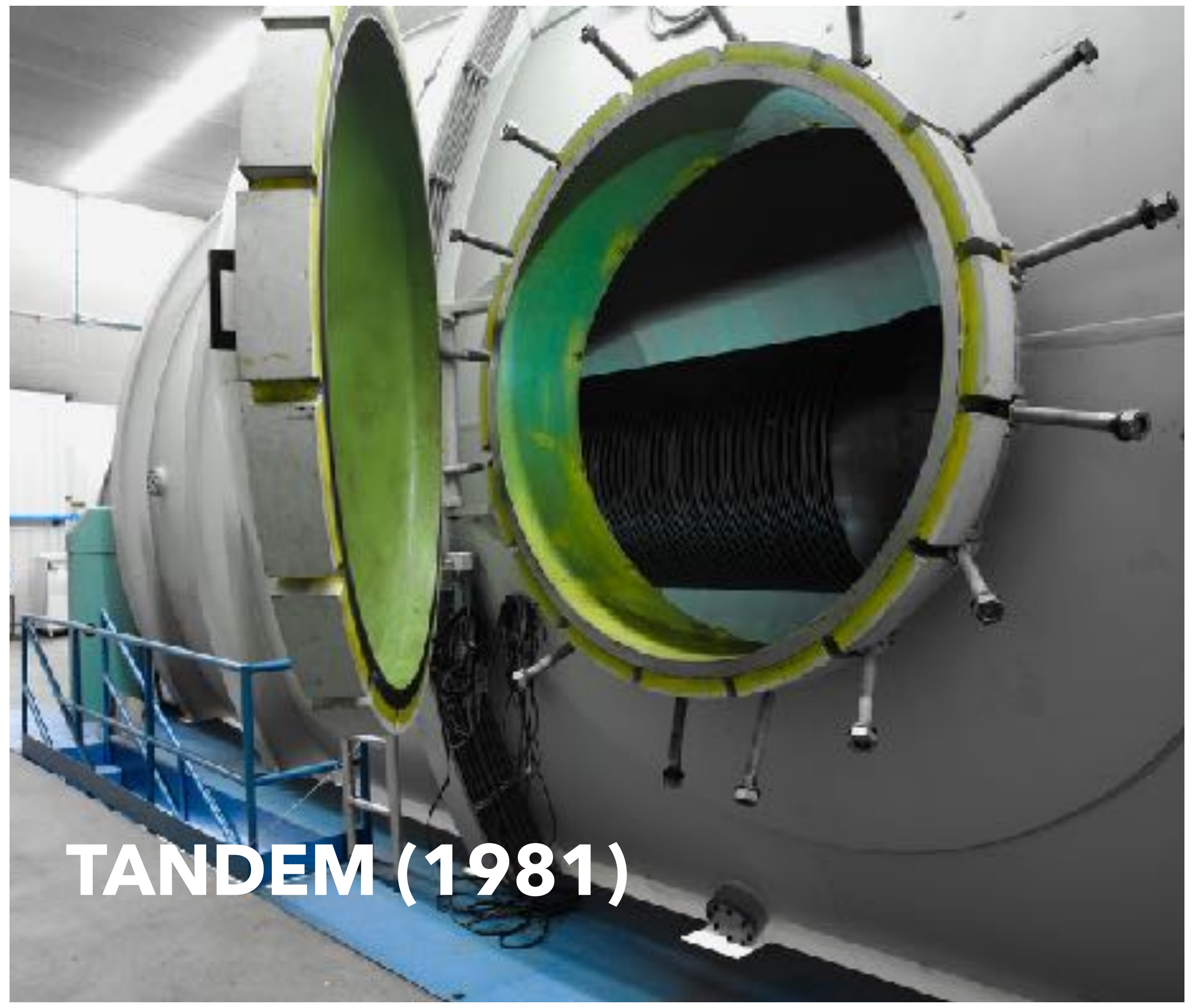

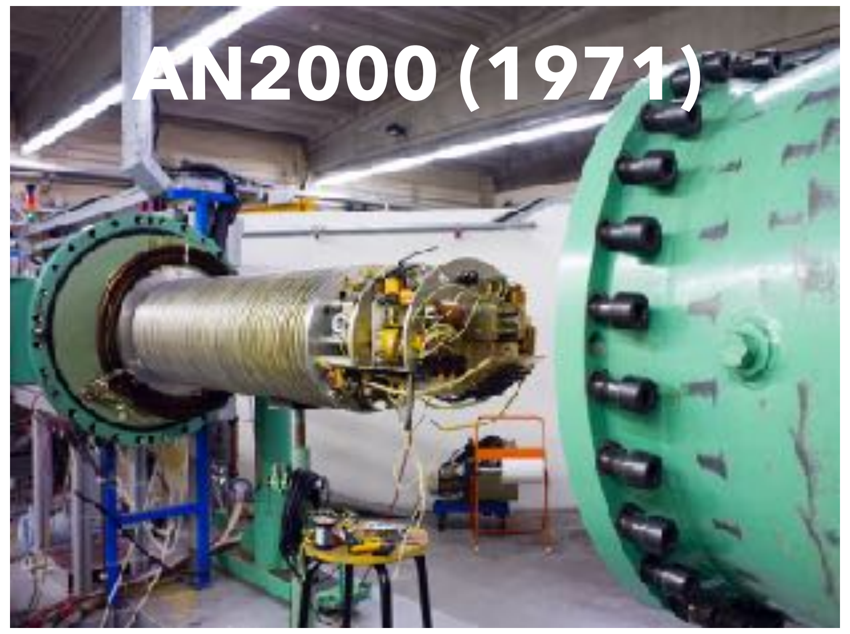

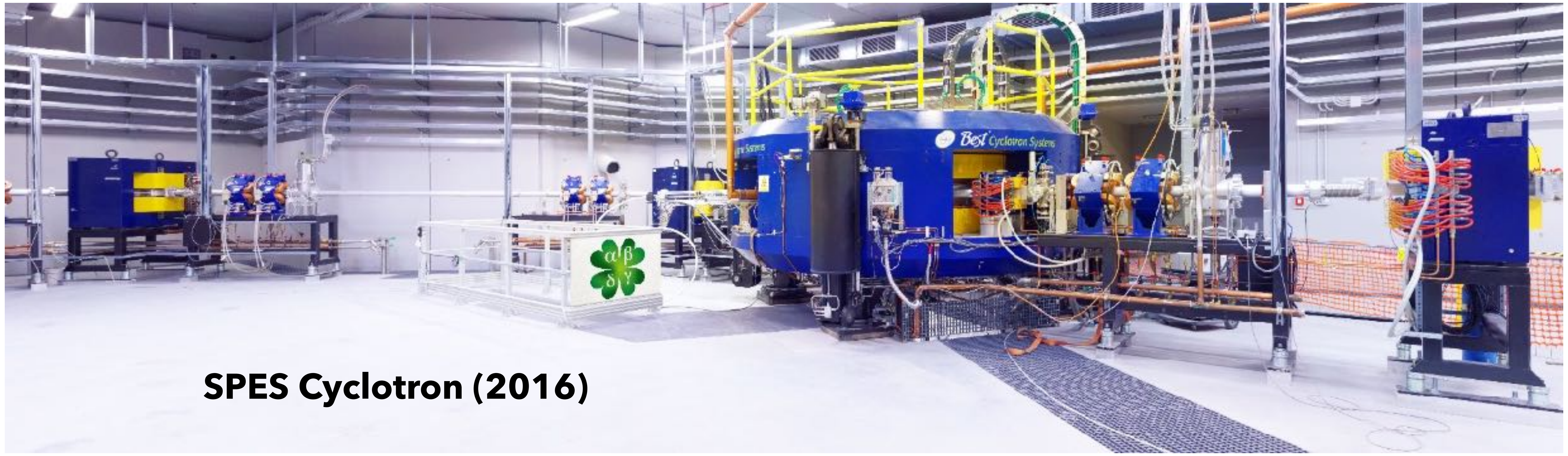

Stable beams at INFN LNL

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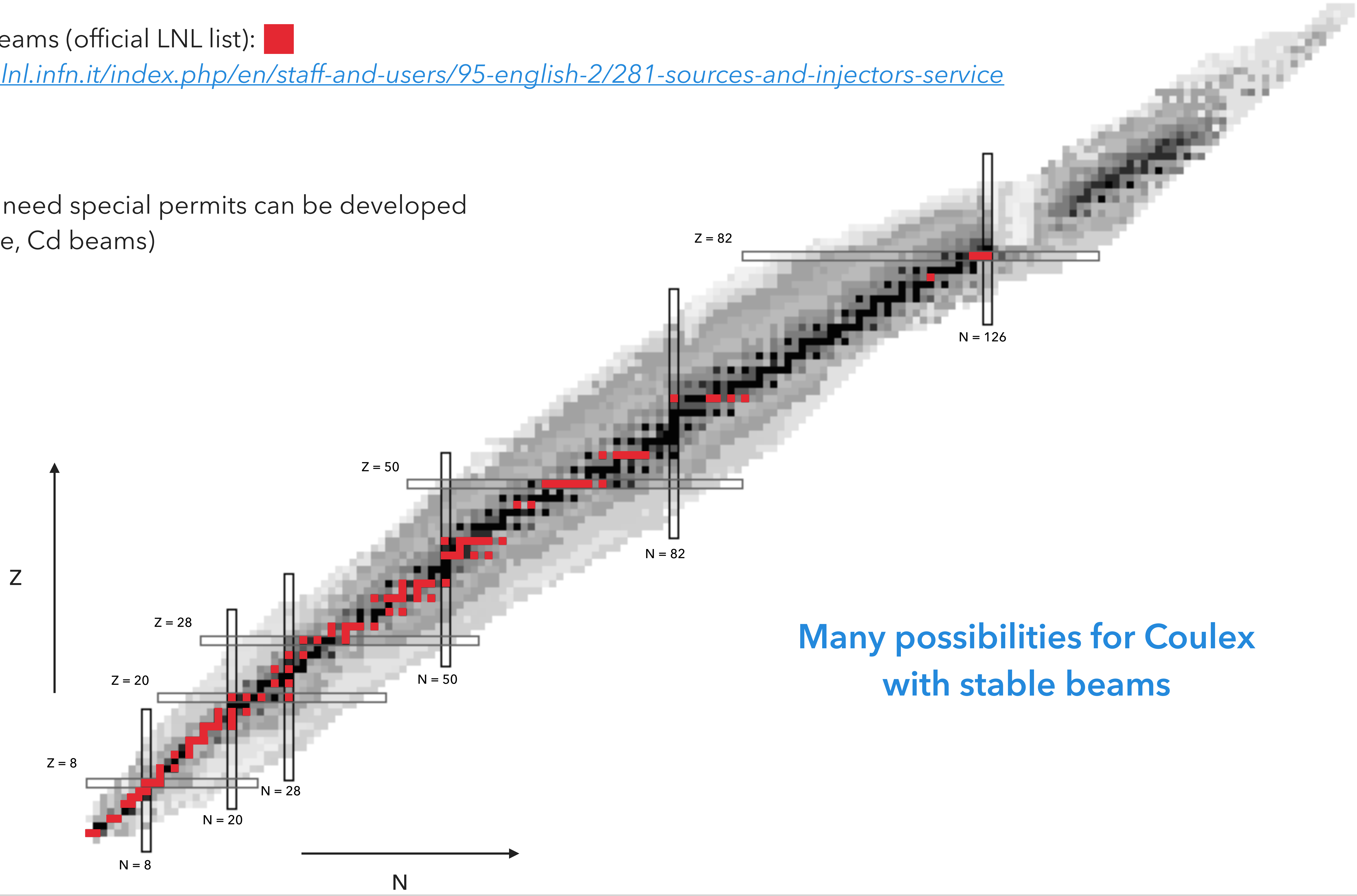
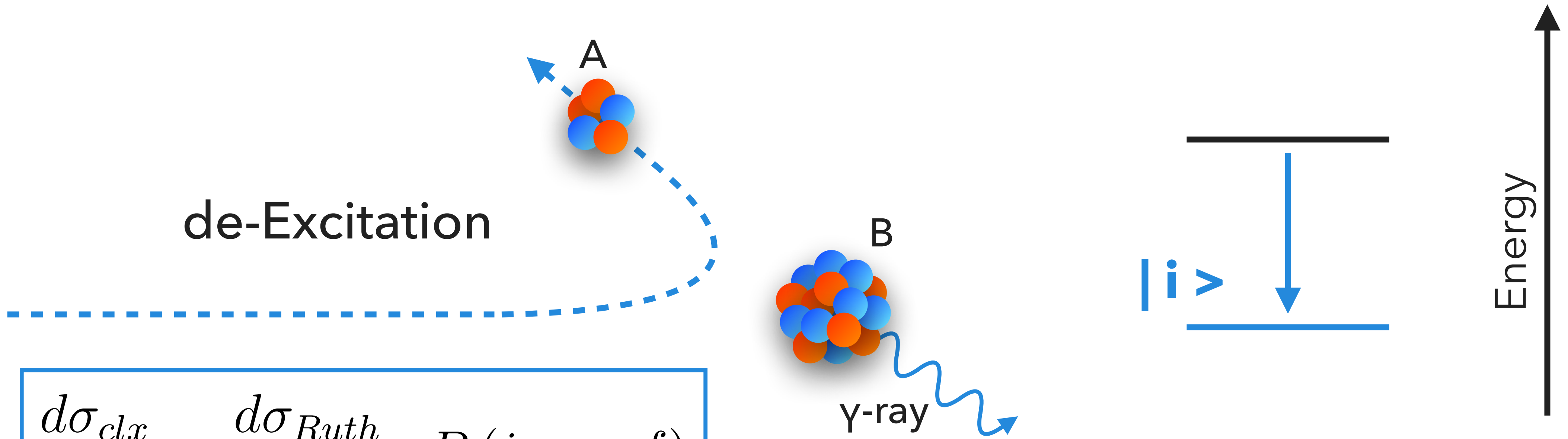
- Available beams (official LNL list): ■
  http://www.lnl.infn.it/index.php/en/staff-and-users/95-english-2/281-sources-and-injectors-service
- Beams that need special permits can be developed (for example, Cd beams)



Many possibilities for Coulex with stable beams

Coulomb excitation

- Beam energy < **Safe energy** (~ 5 MeV/A)



$$\frac{d\sigma_{clx}}{d\Omega} = \frac{d\sigma_{Ruth}}{d\Omega} \cdot P\left(i \longrightarrow f\right)$$

- Example: first 2$^+$ state in an even-even target nucleus

~|<2$^+$||E2||0$^+$>|^2 ~<2$^+$||E2||2$^+$>

$$P\left(0_1^+ \longrightarrow 2_1^+\right) = F\left(\theta, E_P\right) B(E2) \left[1 + 1.32 \frac{A_P}{Z_T} \frac{\Delta E}{\left(1+\frac{A_P}{A_T}\right)} Q_s\left(2^+\right) K\left(\theta, E_P\right)\right]$$

Access to: transition probabilities, spectroscopic quadrupole moments

Typical COULEX setup:

- **Gamma detector**:
  - To measure γ-ray yields
- **Particle detector**:
  - To select Coulomb excitation events
  - To distinguish between projectile and target
  - To select the scattering angle
  - To perform the Doppler correction
  - To monitor the experiment

PAST

COULEX of ^{42}Ca – 2010

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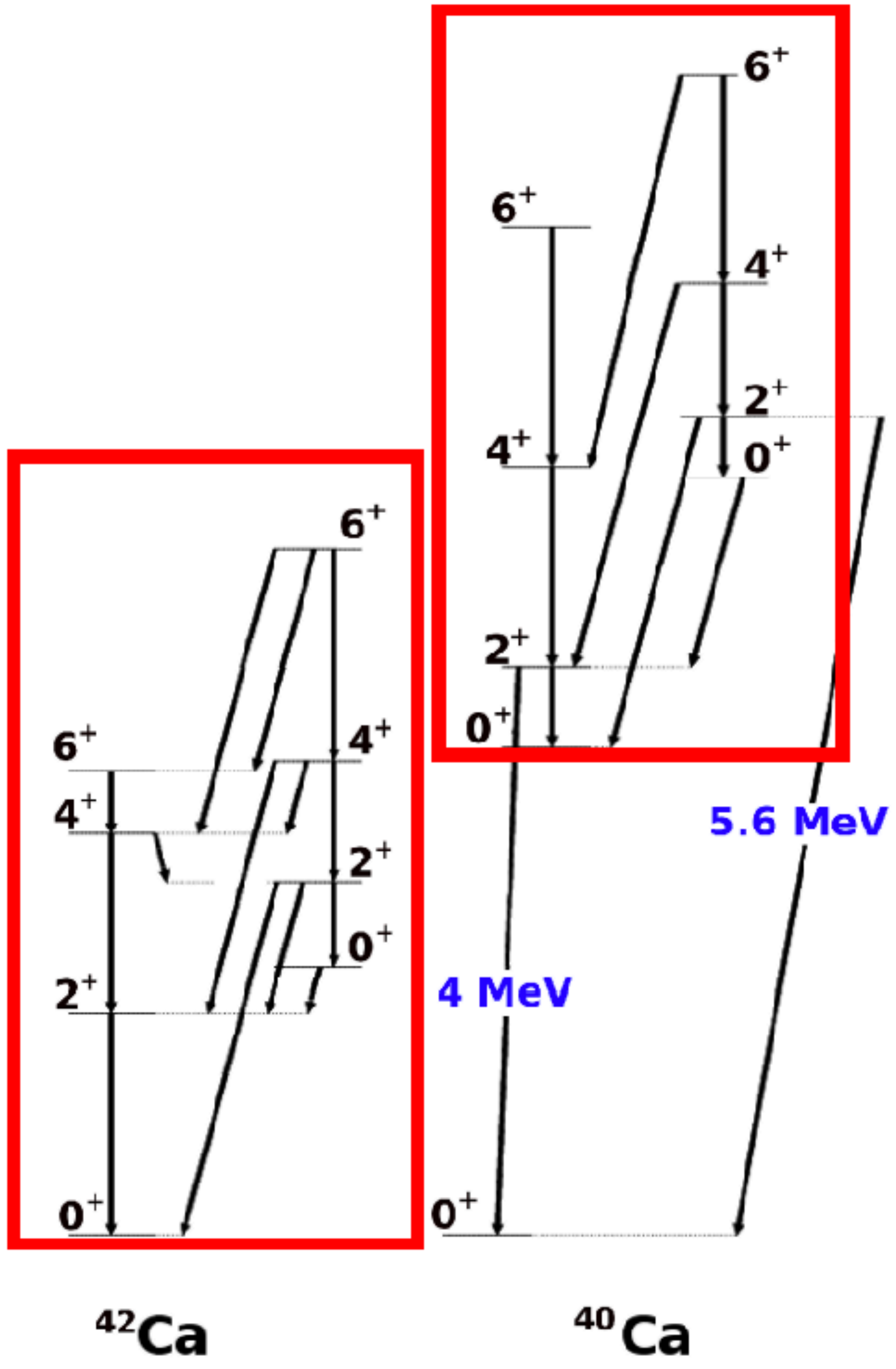
Superdeformed band in ^{40}Ca:

- B(E2) $[4_2^+ \rightarrow 2_2^+] = 170$ W.u. (DSAM)
- deformation in the side band β_2=0.6
  E.Ideguchi et al., PRL 87 (2001) 222501
  C.J.Chiara et al., PRC 67 (2003) 041303(R)

Superdeformation in other isotopes:

- ^{36}Ar: C.E.Svensson et al., PRL 85 (2000) 2693
- ^{38}Ar: D.Rudolph et al., PRC 65 (2002) 034305
- ^{40}Ar: E.Ideguchi et al., PLB 686 (2010) 18
- ^{44}Ti: D.C.O'Leary et al., PRC 61 (2000) 064314



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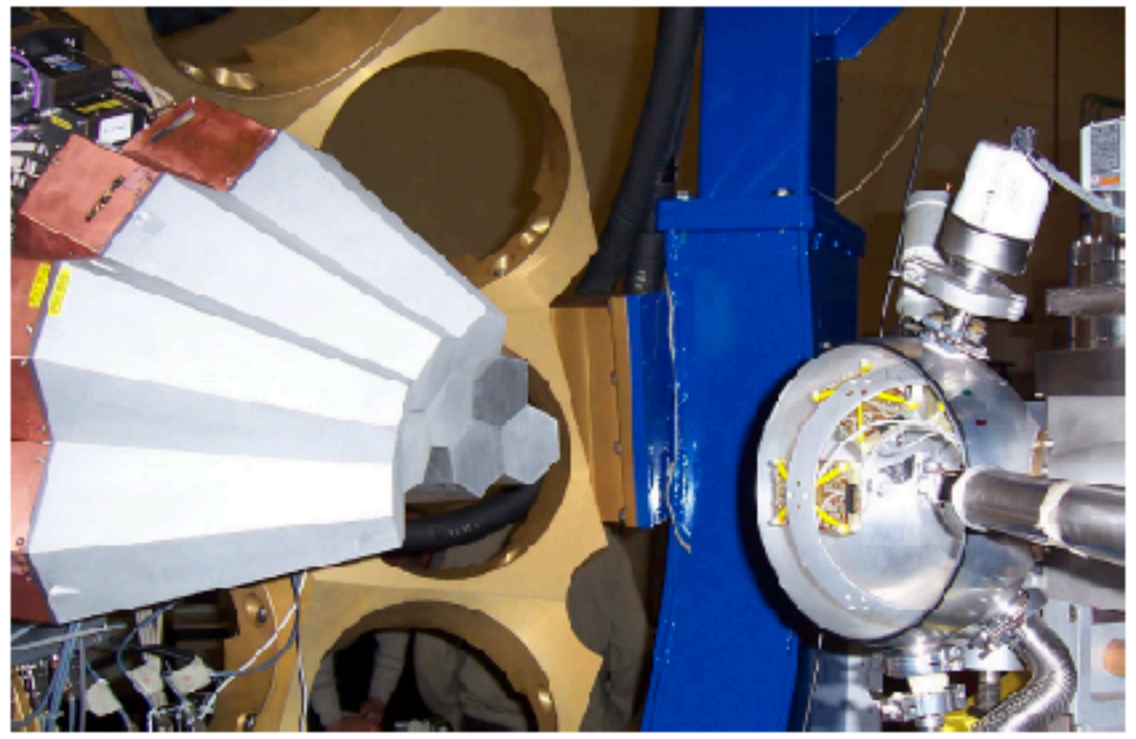
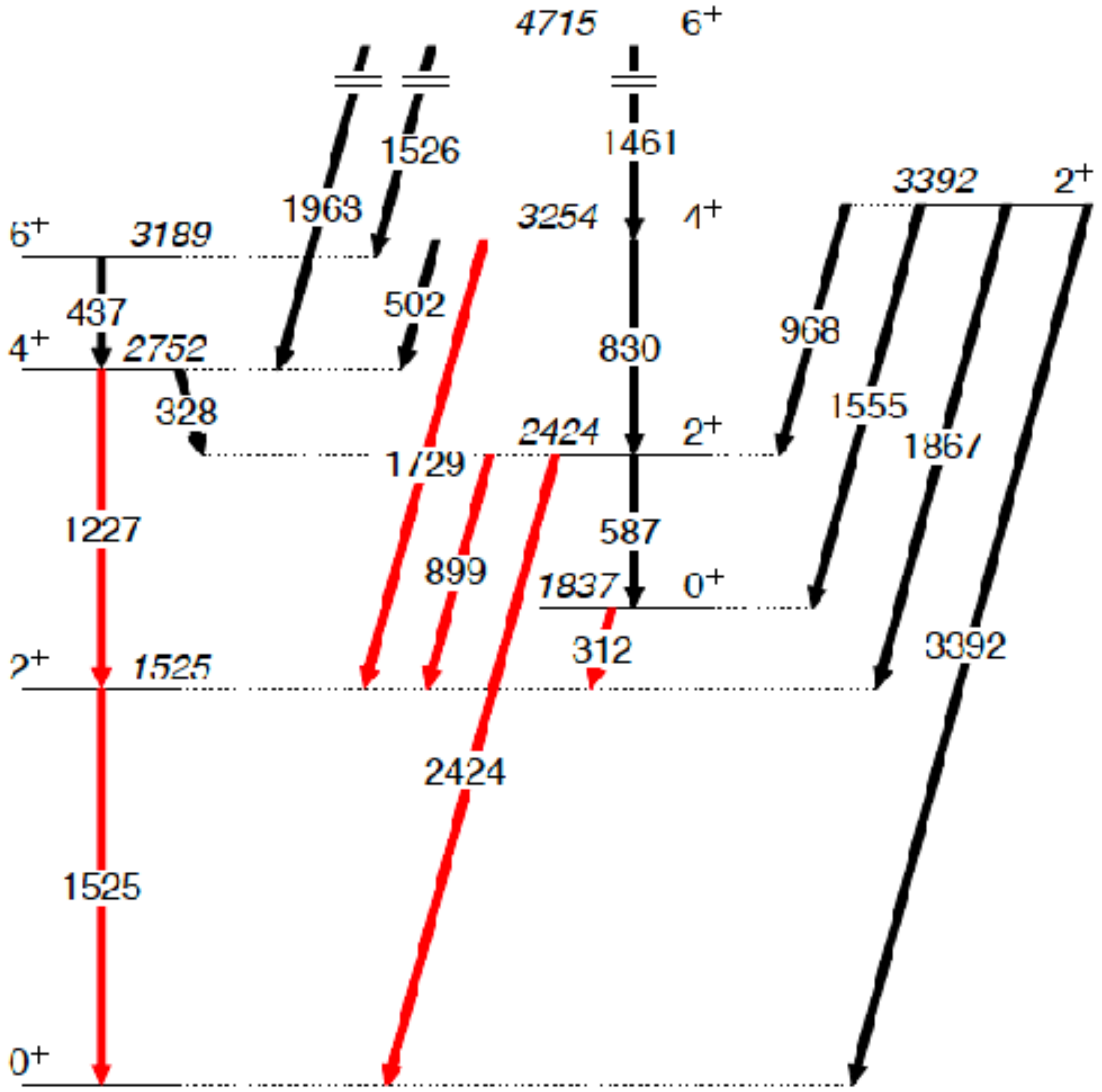
- Beamtime:
  Feb.2010, INFN LNL
- Beam:
  ^{42}Ca, E=170 MeV
- Targets:
  ^{208}Pb, 1 mg/cm^2
  ^{197}Au, 1 mg/cm^2
- AGATA: 3 triple clusters, 143.8 mm from the target
- DANTE: 3 MCP detectors, θ range from 100^o-144^o





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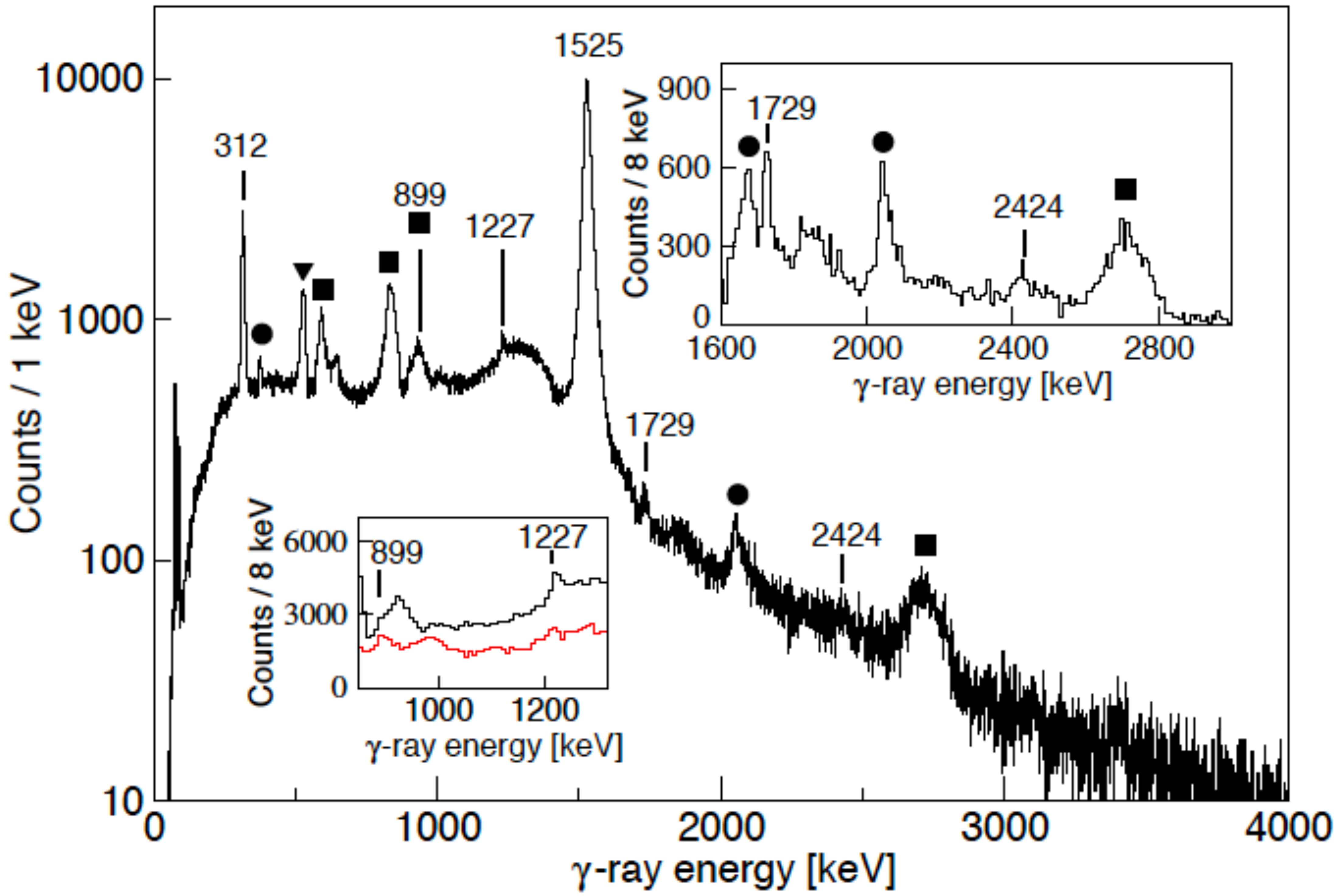

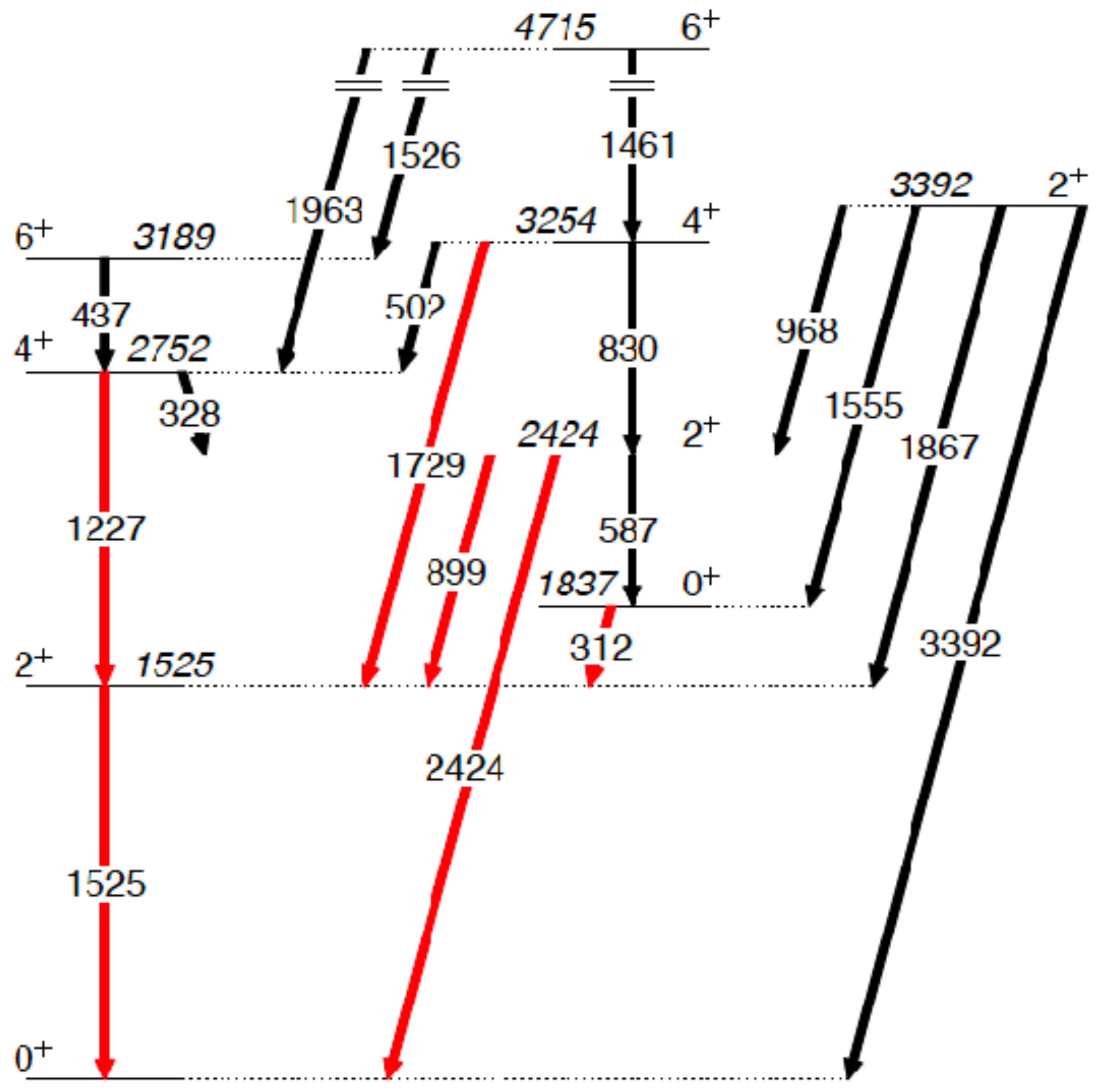

KHK et al., PRL 117, 062501 (2016)
KHK et al., PRC 97, 024326 (2018)

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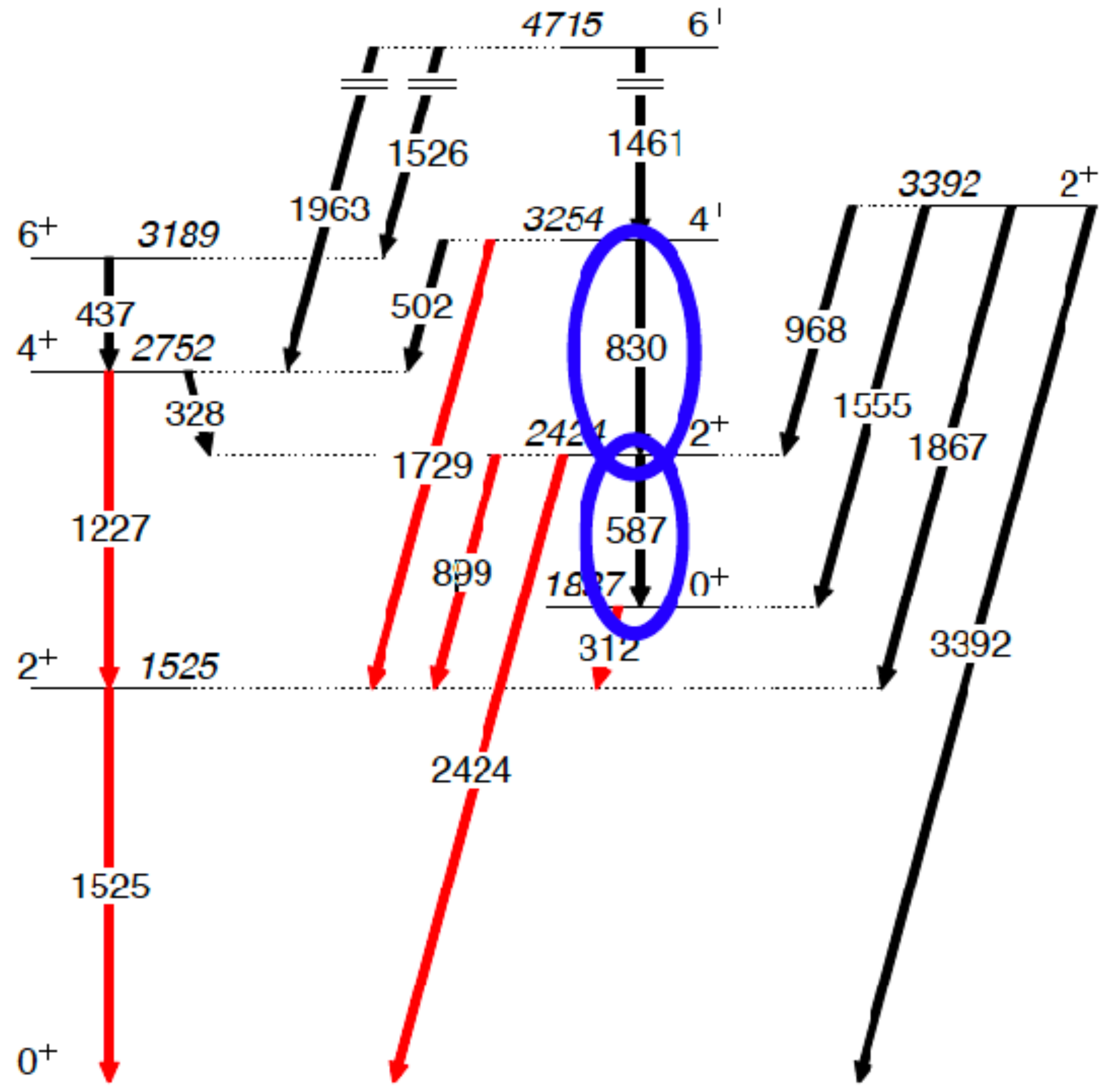
$I_i^+ \to I_f^+$	$\langle I_i \Vert E2 \Vert I_f \rangle$ [e fm^2] Present	SM	BMF	$B(E2\downarrow; I_i^+ \to I_f^+)$ [W.u.] Present	Previous
$2_1^+ \to 0_1^+$	$20.5^{+0.6}_{-0.6}$			$9.7^{+0.6}_{-0.6}$	$9.3 + 1$ [36]
					11 ± 2 [28]
					9 ± 3 [27]
					8.5 ± 1.9 [45]
$4_1^+ \to 2_1^+$	$24.3^{+1.2}_{-1.2}$			$7.6^{+0.7}_{-0.7}$	50 ± 15 [28]
					11 ± 3 [27]
					10^{+10}_{-8} [45]
$6_1^+ \to 4_1^+$	$9.3^{+0.2}_{-0.2}$			$0.77^{+0.03}_{-0.03}$	0.7 ± 0.3 [27]
$0_2^+ \to 2_1^+$	$22.2^{+1.1}_{-1.1}$			57^{+6}_{-6}	64 ± 4 [27]
					100 ± 6 [28]
					55 ± 1 [42]
					64 ± 4 [45]
$2_2^+ \to 0_1^+$	$-6.4^{+0.3}_{-0.3}$			$1.0^{+0.1}_{-0.1}$	2.2 ± 0.6 [28]
					1.5 ± 0.5 [27]
					1.2 ± 0.3 [45]
$2_2^+ \to 2_1^+$	$-23.7^{+2.3}_{-2.7}$			$12.9^{+2.5}_{-2.5}$	17 ± 11 [28]
					19^{+22}_{-14} [27]
					14^{+35}_{-9} [45]
$4_2^+ \to 2_1^+$	42^{+3}_{-4}			23^{+3}_{-4}	$30 + 11$ [28]
					16 ± 5 [27]
					12^{+7} [45]
$2_2^+ \to 0_2^+$	26^{+5}_{-3}			15^{+6}_{-4}	< 61 [27]
					< 46 [45]
$4_2^+ \to 2_2^+$	46^{+3}_{-6}			27^{+4}_{-6}	60 ± 30 [27]
					60 ± 20 [28]
					40^{+40}_{-30} [45]

	$\langle I_i \Vert E2 \Vert I_f \rangle$ [e fm^2]	Q_{sp} [e fm^2]	
$2_1^+ \to 2_1^+$	-16^{+9}_{-3}	-12^{+7}_{-2}	-19 ± 8 [36]
$2_2^+ \to 2_2^+$	-55^{+15}_{-15}	-42^{+12}_{-12}	

GOSIA



KHK et al., PRL 117, 062501 (2016)
KHK et al., PRC 97, 024326 (2018)

COULEX of ^{42}Ca – triaxial superdeformation

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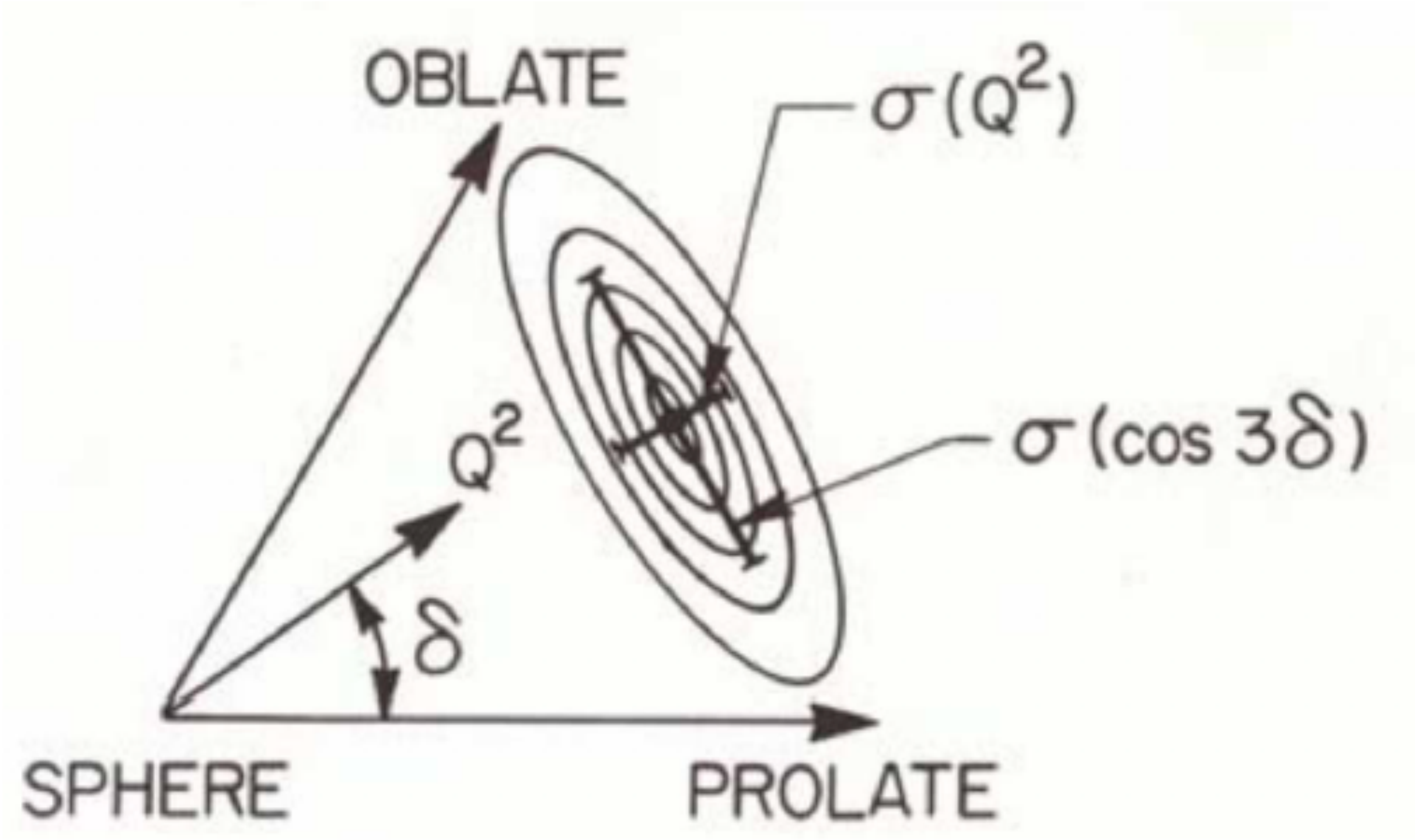

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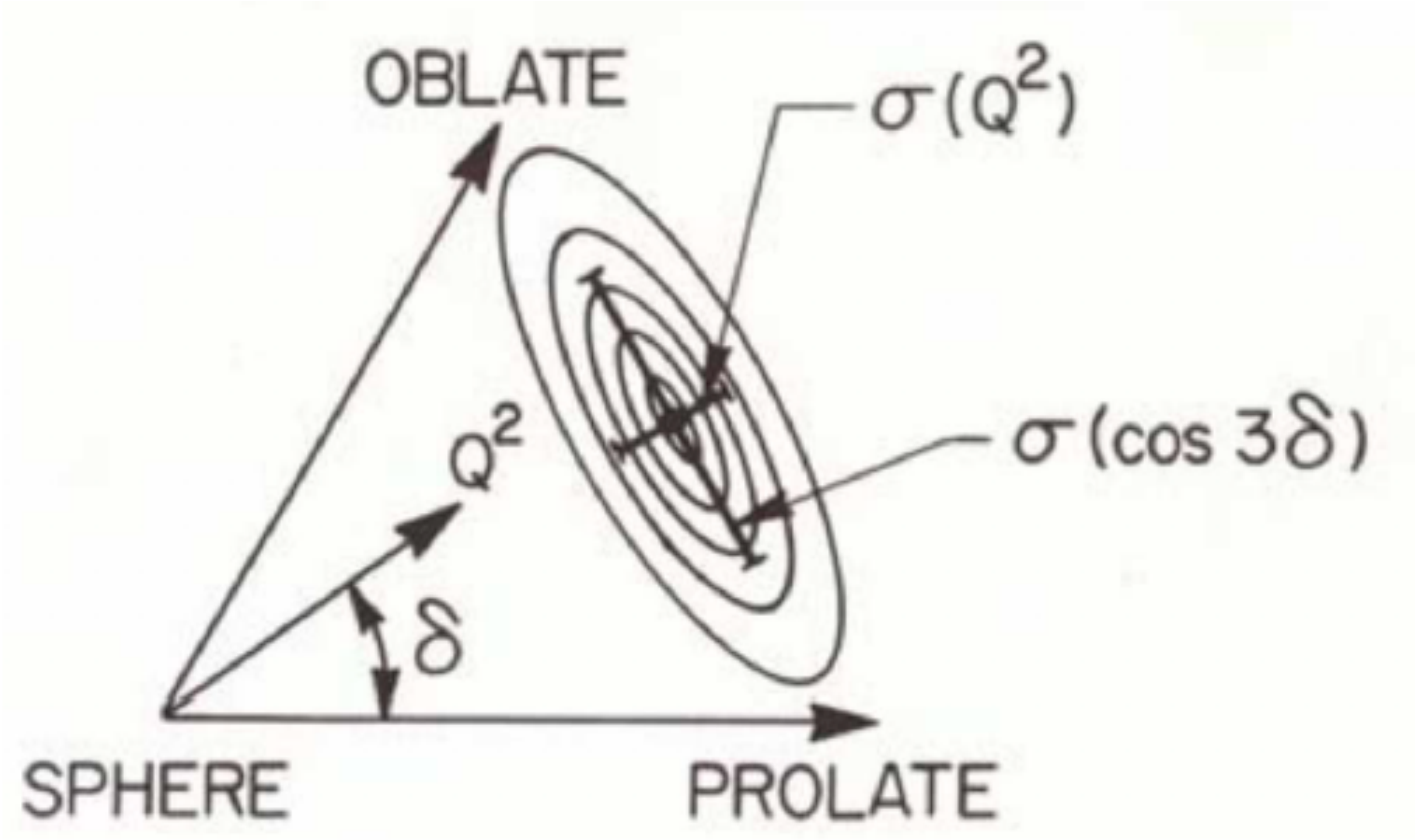

State	$\langle Q^2\rangle_{exp}$	$\langle Q^2\rangle_{SM}$	$\sigma(Q^2)_{SM}$	$\langle Q^2\rangle_{BMF}$	$\sigma(Q^2)_{BMF}$
0_1^+	500 (20)	240	470	100	250
2_1^+	900 (100)	250	490	100	310
0_2^+	1300 (230)	1200	500	1900	520
2_2^+	1400 (250)	1130	500	1900	300
State	$\langle\cos(3\delta)\rangle_{exp}$	$\langle\cos(3\delta)\rangle_{SM}$		$\langle\cos(3\delta)\rangle_{BMF}$	
0_1^+	0.06 (10)	0.34		0.34	
0_2^+	0.79 (13)	0.67		0.49	

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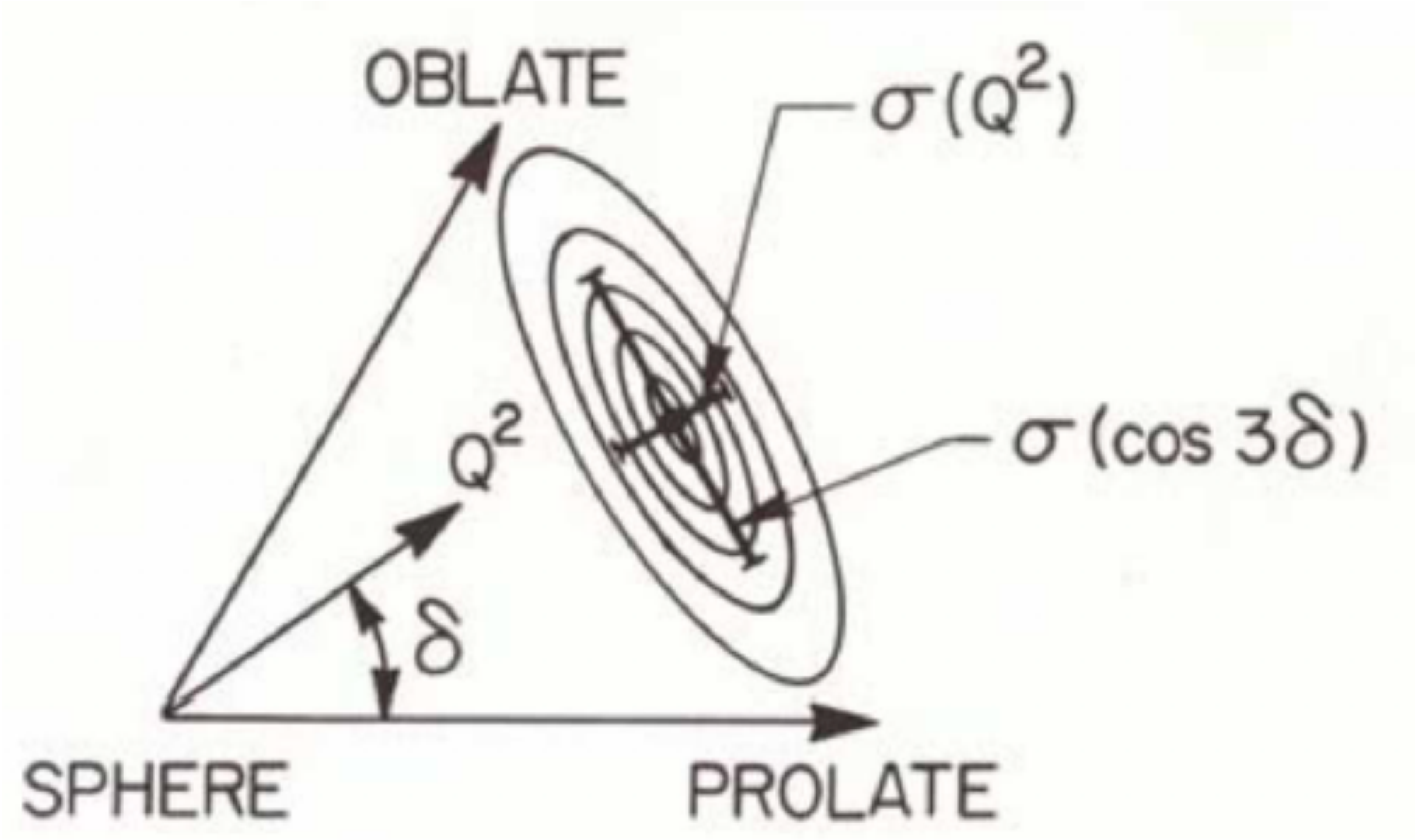

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$$\bar{\beta} = \sqrt{\langle\beta^2\rangle} = \sqrt{\frac{\langle Q^2\rangle}{q_0^2}}$$

$$\bar{\gamma} = \frac{1}{3}\, arc\langle cos(3\gamma)\rangle$$

J. Srebrny and D. Cline,
Int. J. Mod. Phys. E20, 422 (2011)

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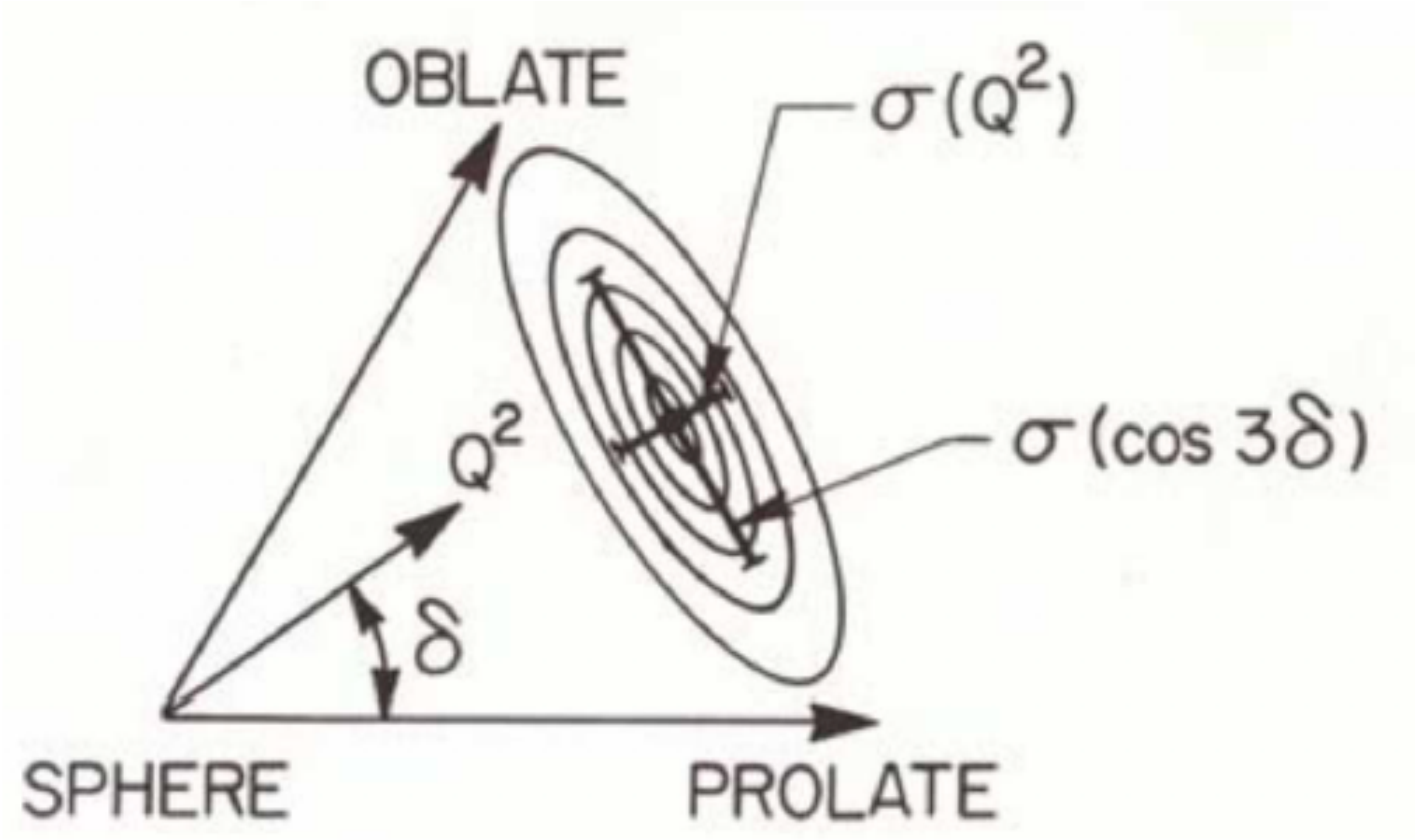

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0_2^+ $\bar{\beta}$=0.43(4) and $\bar{\gamma}$=13($^{5}_{6}$)°

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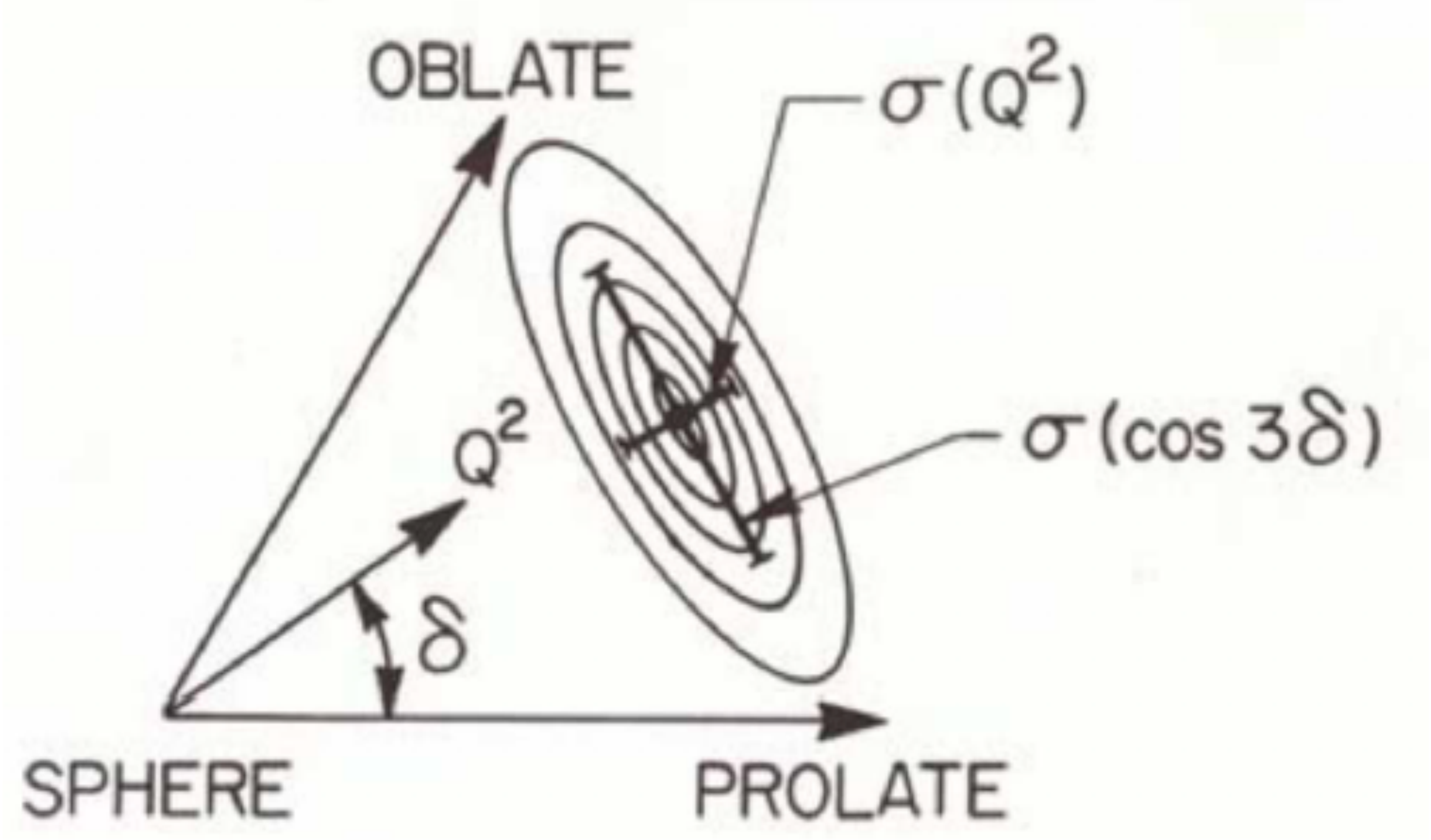

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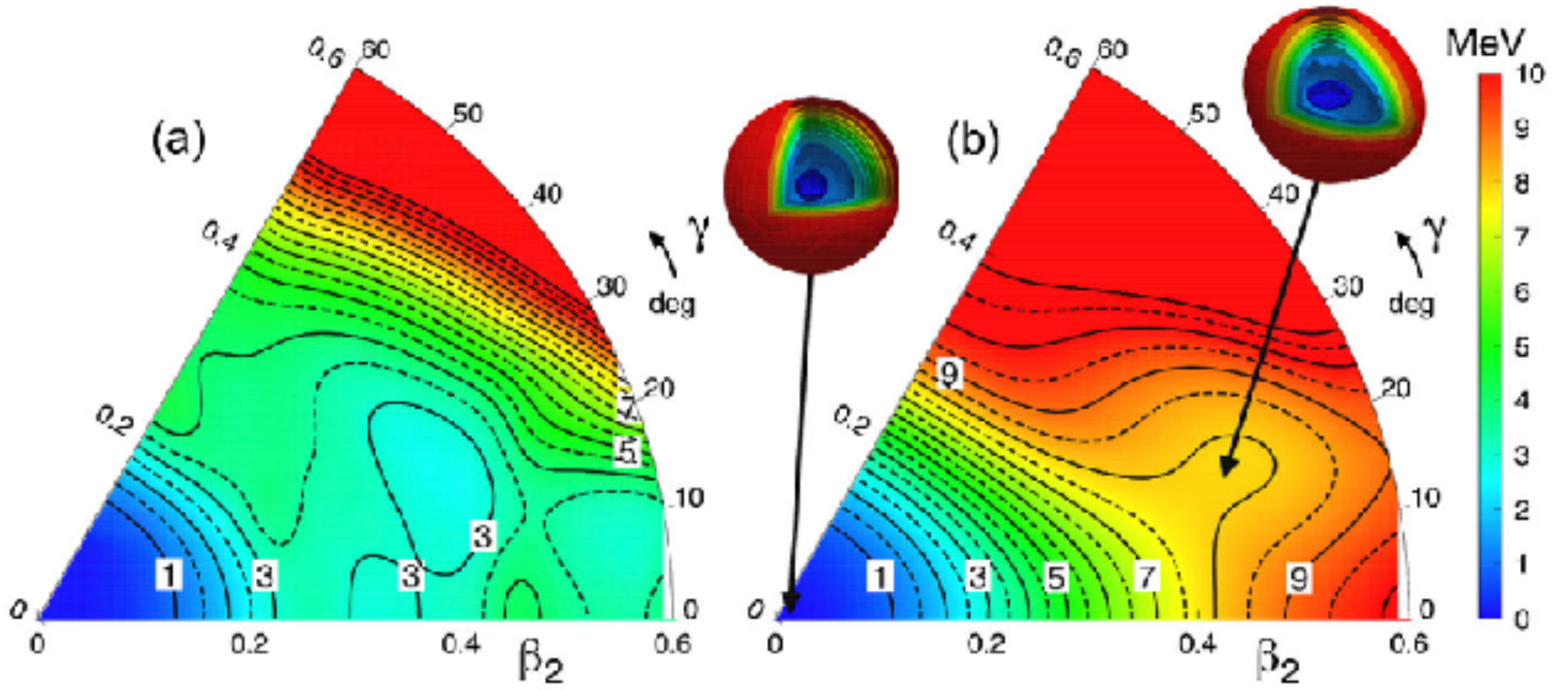

PRESENT

GALILEO 1st Phase

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- 25 HPGe Compton-suppressed detectors (GASP type)
- FWHM (@1332.5 keV) < 2.4 keV
- Efficiency (@1332.5 keV) = 2.1%
- Complete digital DAQ (takes advantage of the developments made for AGATA):
  - Trigger-less mode
  - Typical operational rate ~ 20 kHz/det
  - Common clock synchronization
  - Local data processing
- **GALILEO 2nd phase**: 30 GASP detectors + 10 triple cluster

GALILEO – ancillary detectors

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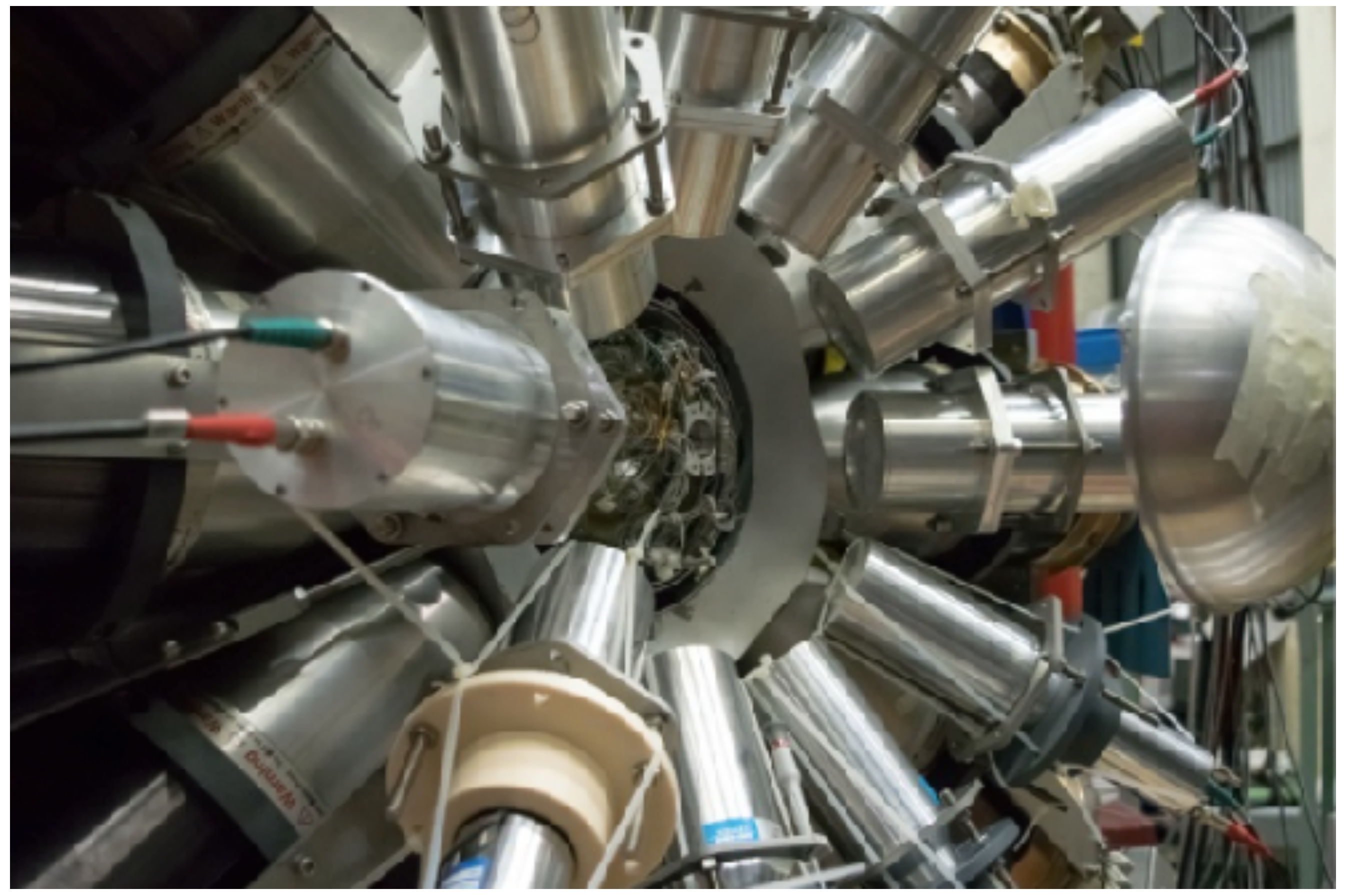
- Light charged particle detectors: EUCLIDES, Trace
- Neutron detector: Neutron Wall
- Recoil detector: Recoil Filter Detector
- Fast timing & High energy γ-ray detector: LaBr array
- Plunger (lifetime measurements) + EUCLIDES
- **Coulomb excitation detector: SPIDER**

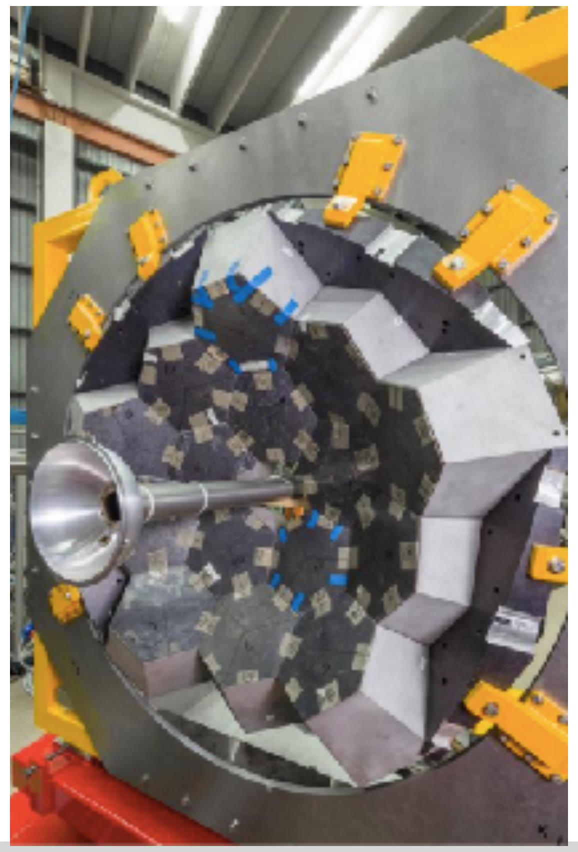
LaBr array



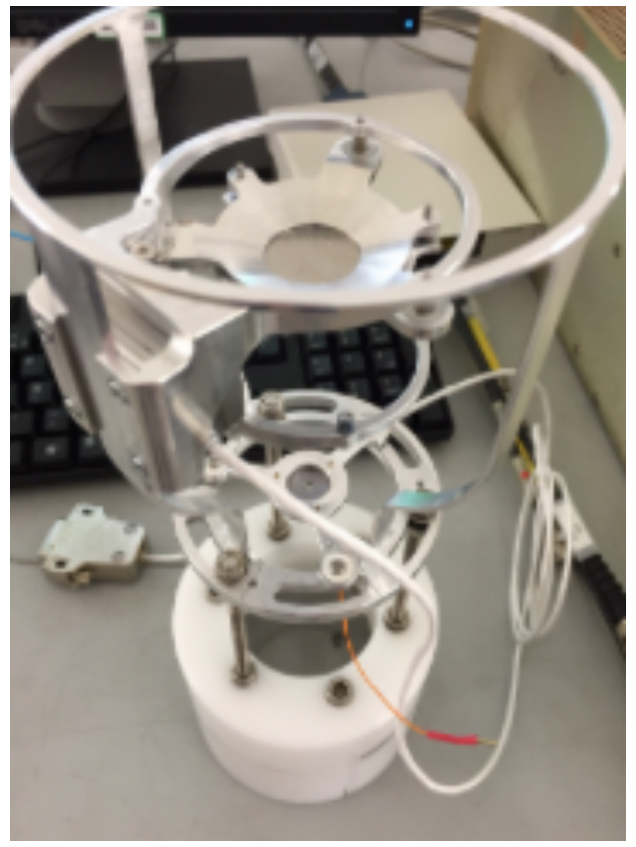
EUCLIDES

Trace

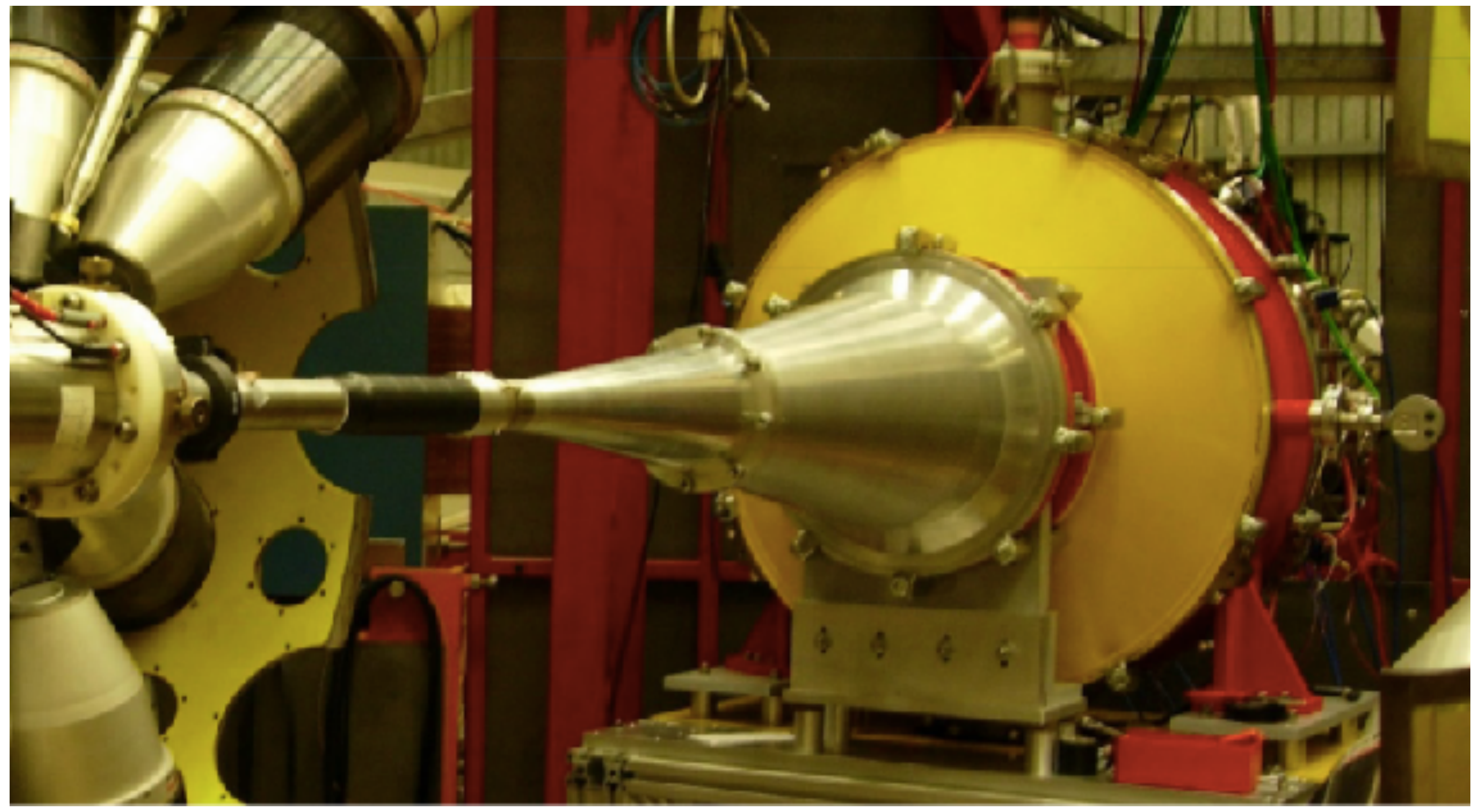
Neutron Wall



Plunger



Recoil Filter Detector



SPIDER – Silicon PIe DEtectoR

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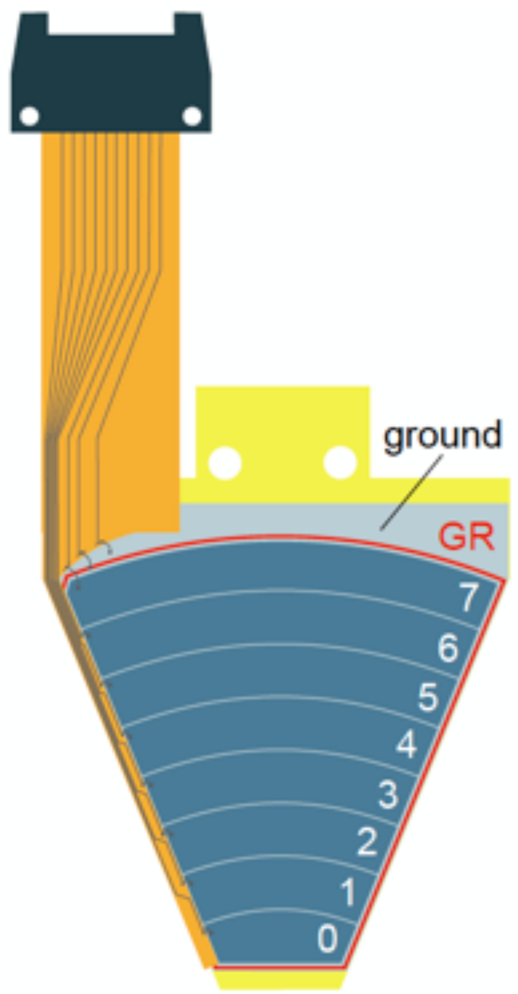
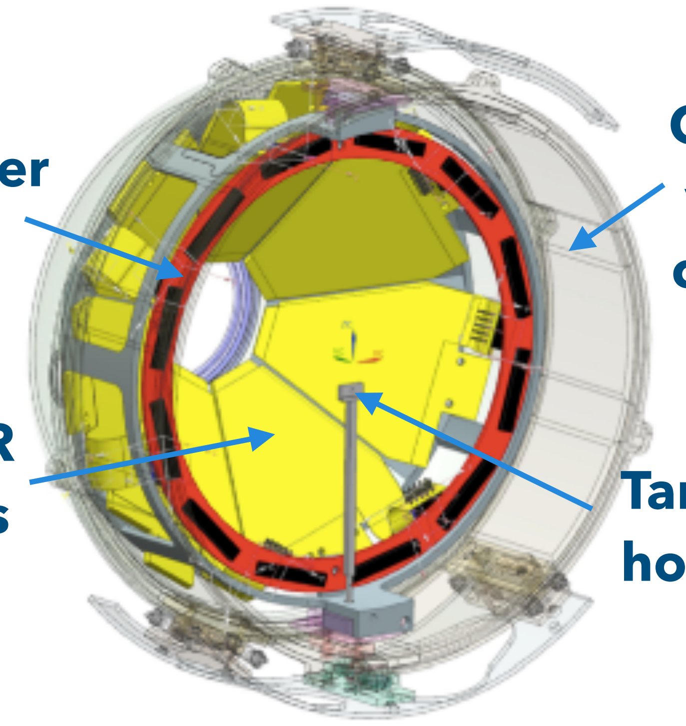
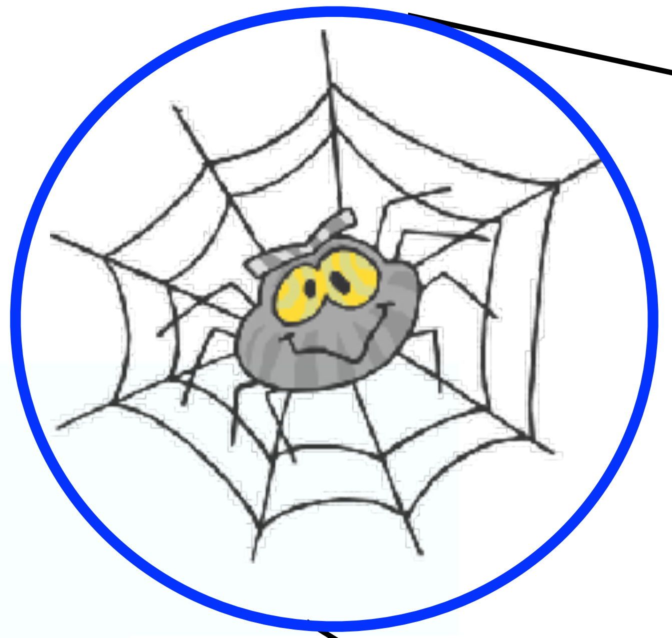
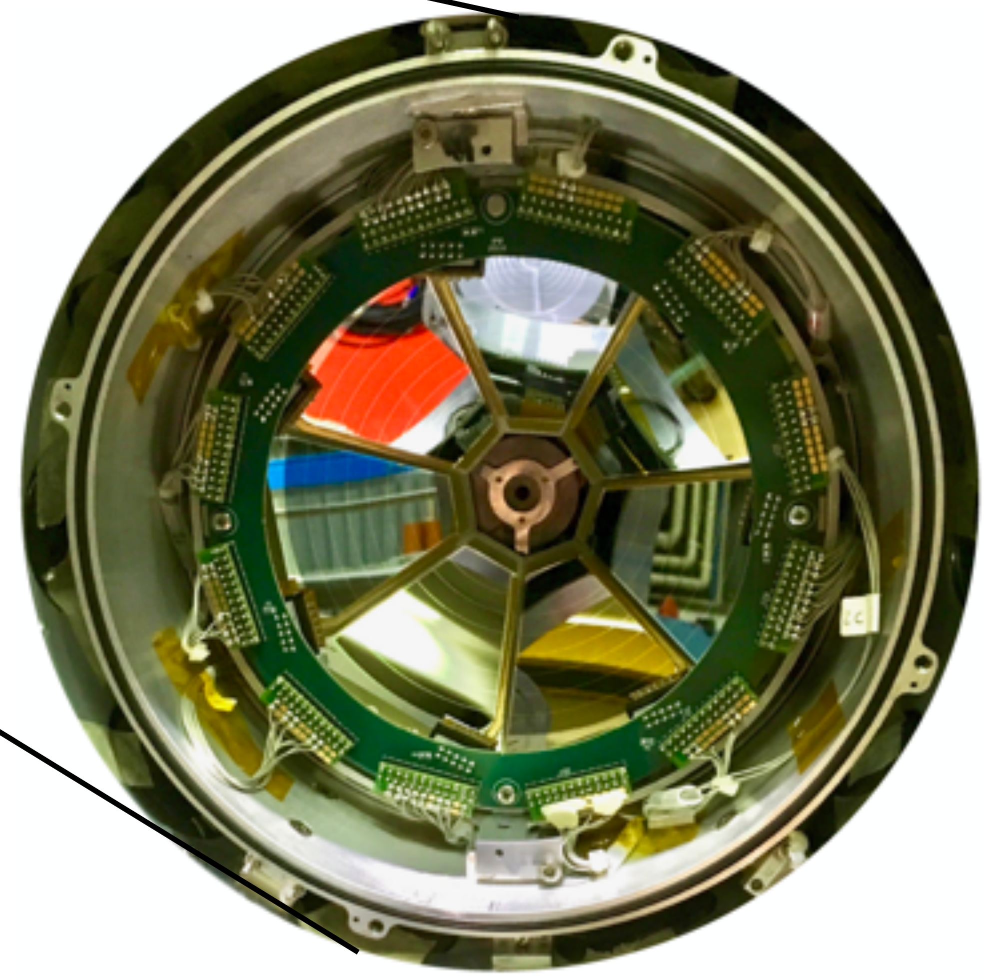


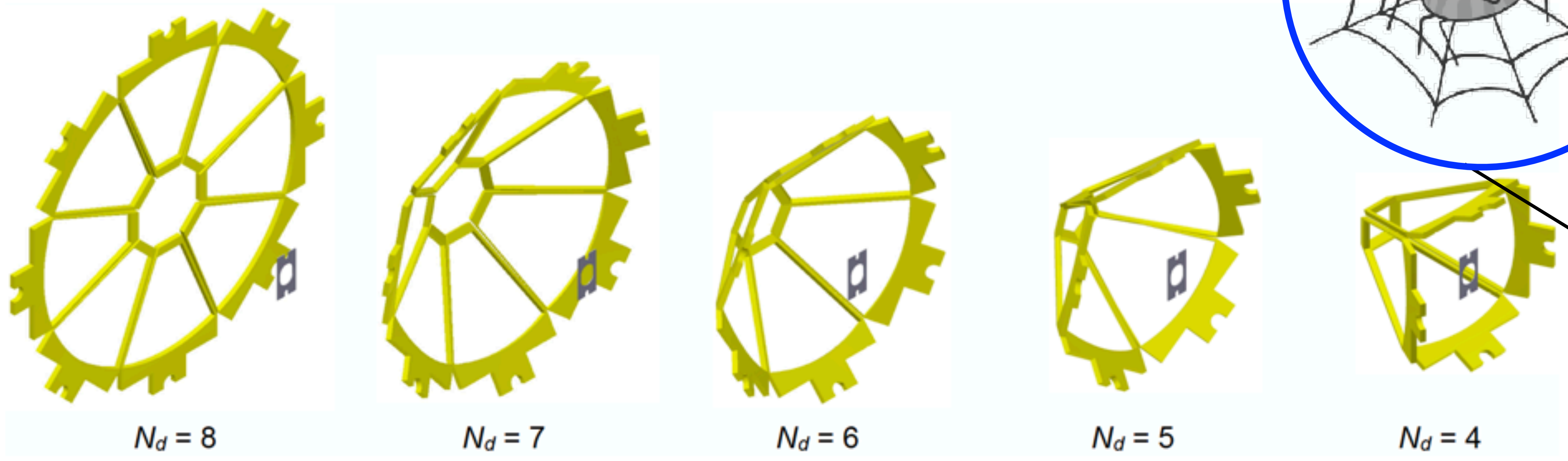
- Collaboration between **INFN Firenze**, INFN LNL, INFN Padova
- Independent **sectors**, 8 **strips** + guard ring
- Detector **thickness** ~ 300 μm, dead layers ~ 50 nm in the junction (front) side and ~ 350 nm in the ohmic (rear) side
- **Cone-like configuration** (7 sectors) at **backward angles**: 8.5 cm from the target

$\Delta\Theta = 37.4°$, $\Omega/4\pi = 17.3\%$









M. Rocchini, K. Hadyńska-Klęk, A. Nannini et al., to be submitted

Commissioning experiment – Coulomb Excitation of ^{66}Zn (2016)

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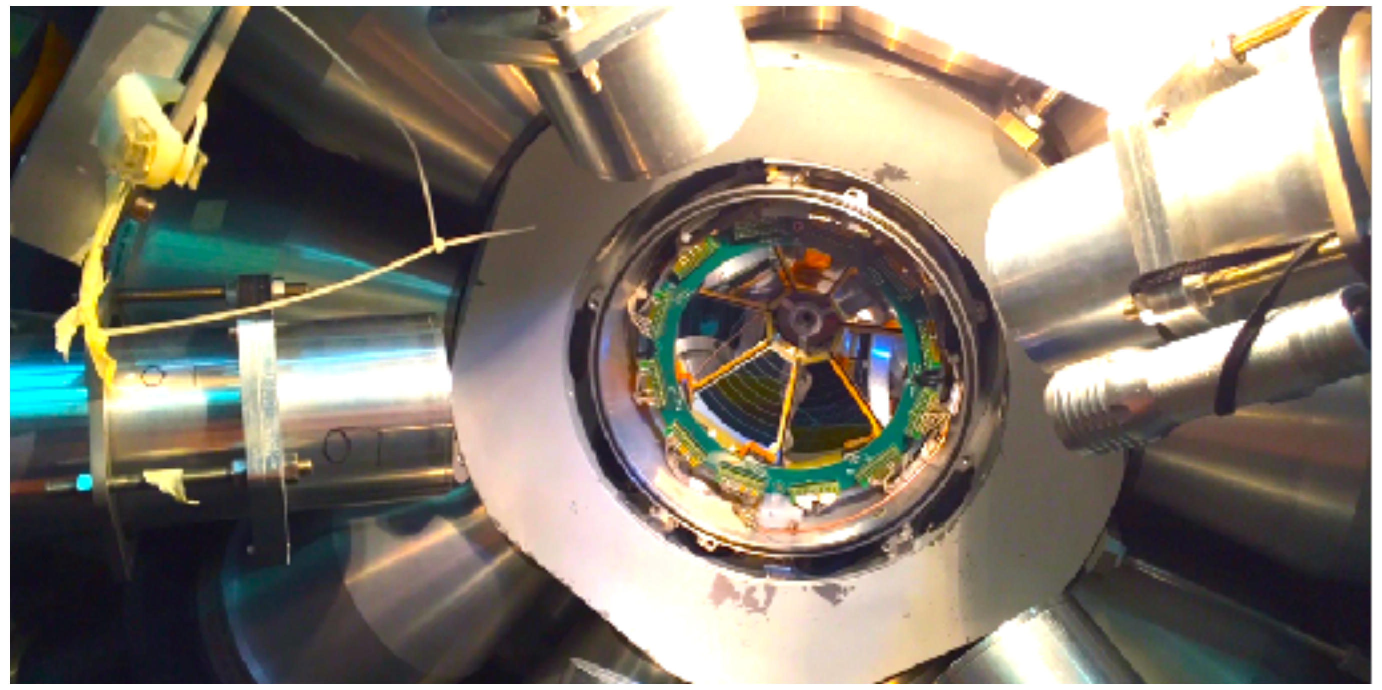

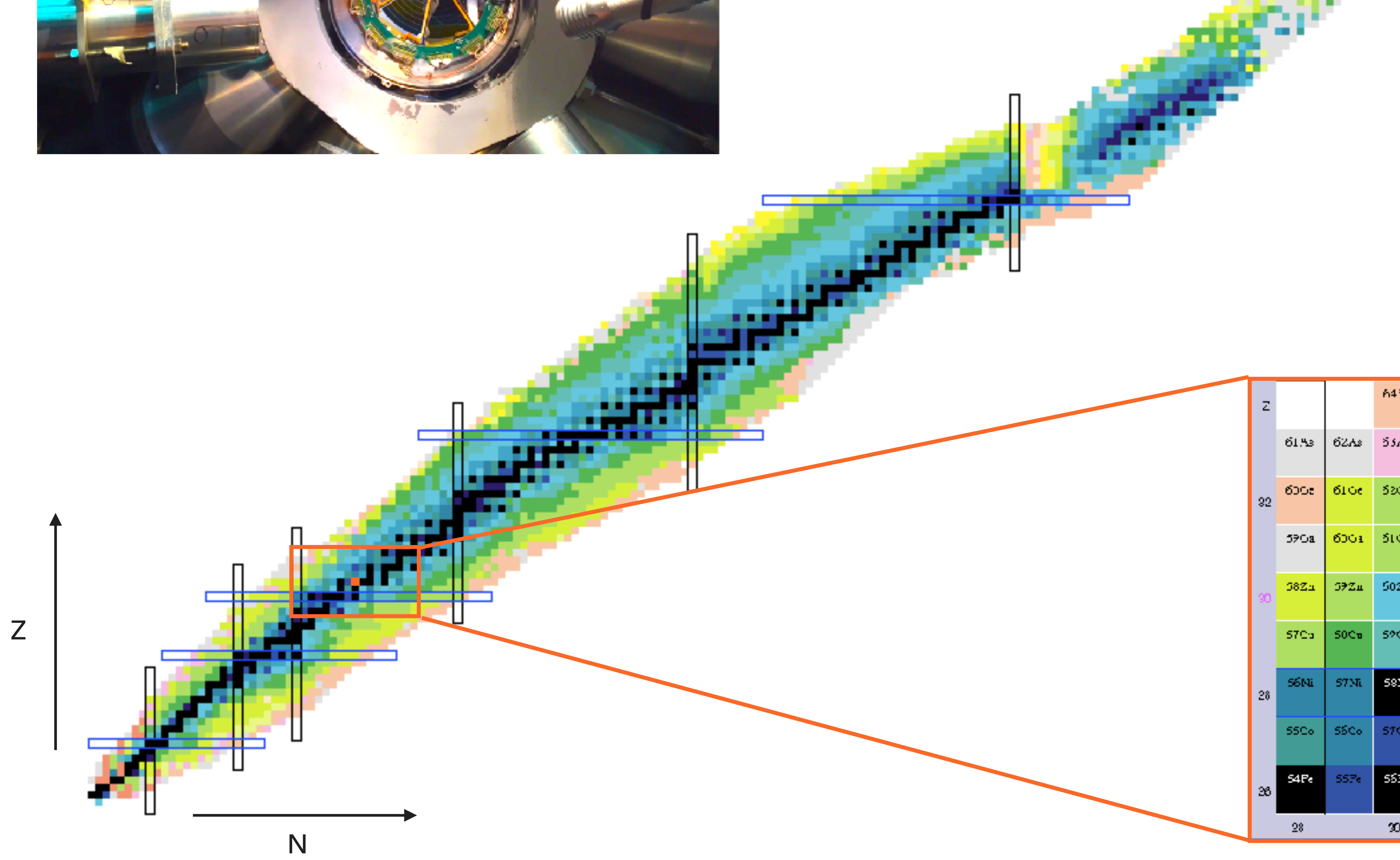

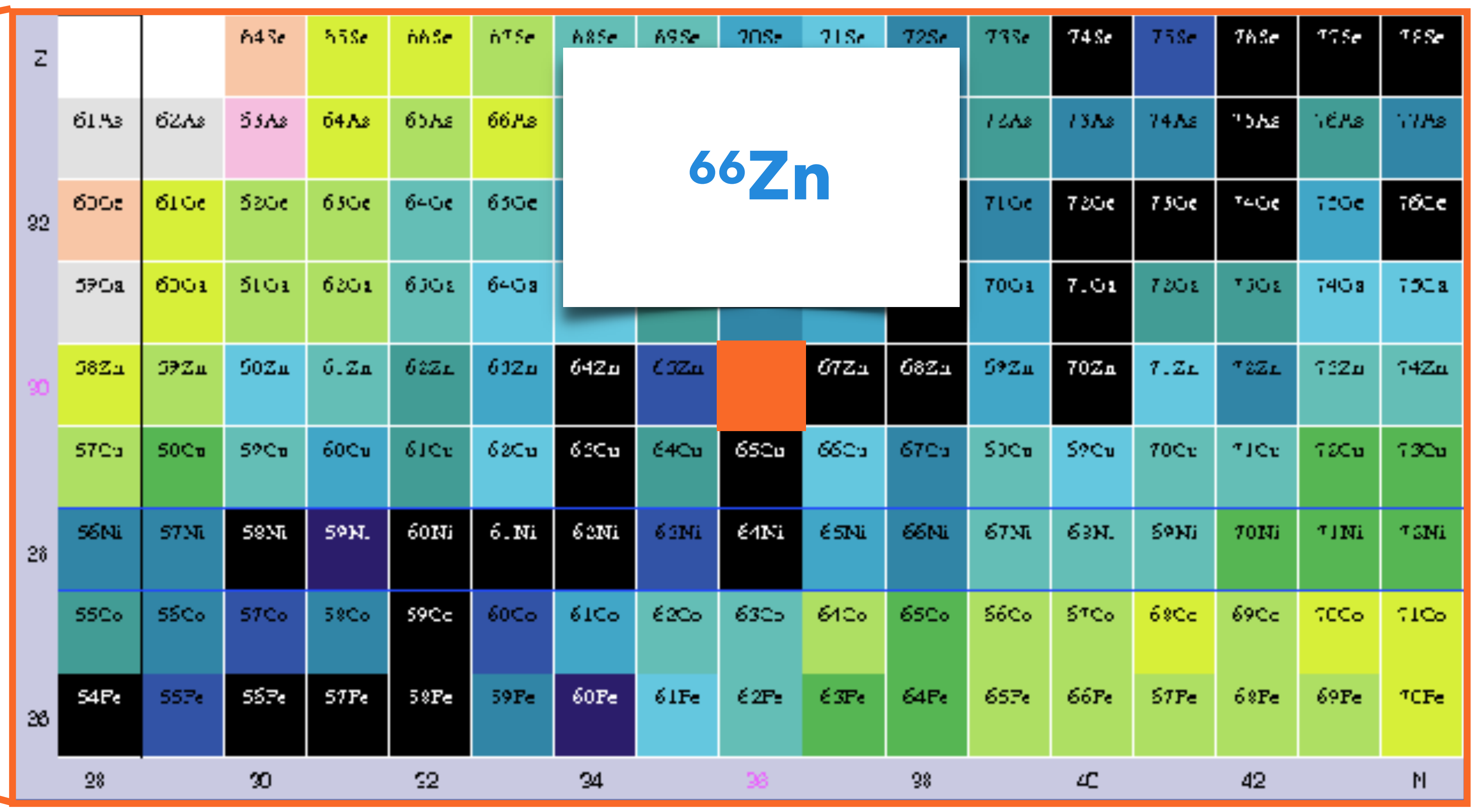

- Beam: ^{66}Zn (240 MeV, 1 – 1.5 pnA)
- TANDEM-XPU
- Target: 1 mg/cm^2 of ^{208}Pb
- 4 days of measurement
- GALILEO + SPIDER
- **Benchmark reaction**

Commissioning experiment – Coulomb Excitation of ^{66}Zn

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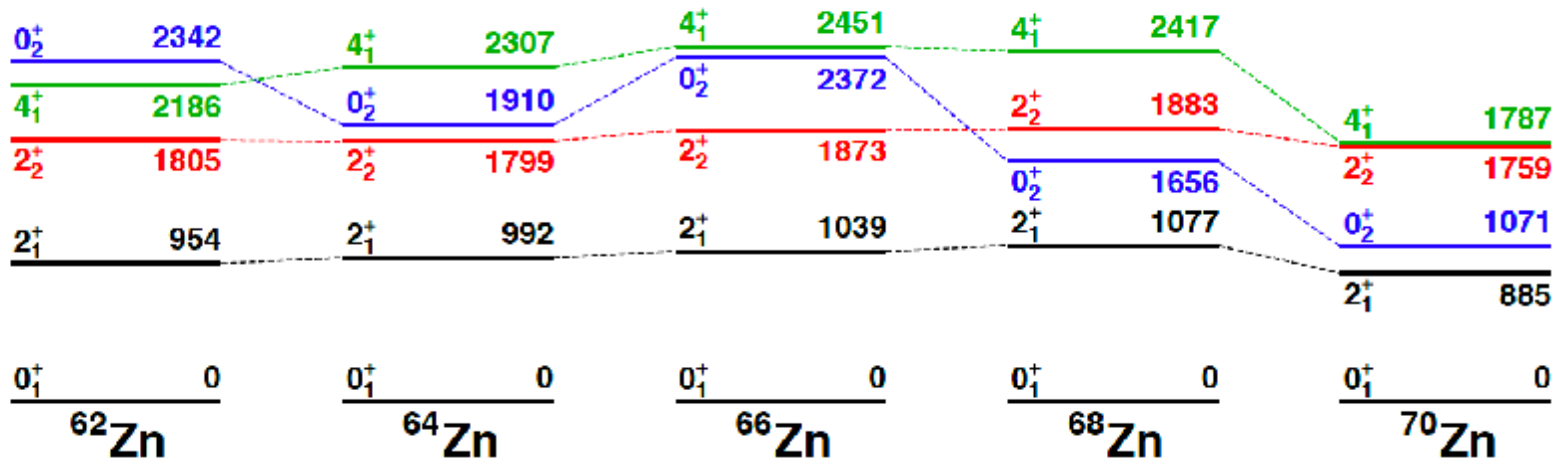
- SPIDER
- **First Experiment: ^{66}Zn**
- Next Experiments: ^{94}Zr, ^{116}Sn, ^{130}Xe, ^{58}Ni
- Future Perspectives

- **B(E2; $2_1^+ \longrightarrow 0_1^+$)** and **$Q_s(2_1^+)$** known with high precision $\Longrightarrow$ **Commissioning**
- Low-lying structure of stable and nearly stable Zn isotopes:
  - Several interpretations (**vibrational** nuclei, **quasi-rotational** bands, **γ-soft** nuclei)
  - No firm conclusions, many **discrepant results** regarding key observables, the case of ^{66}Zn

	NDS	M. Koizumi *et*	K. Moschner *et*
B(E2; $4_1^+ \longrightarrow 2_1^+$)	18(3)	17.5(7)	8.4(15)
B(E2; $2_2^+ \longrightarrow 2_1^+$)	330(130	41(14)	

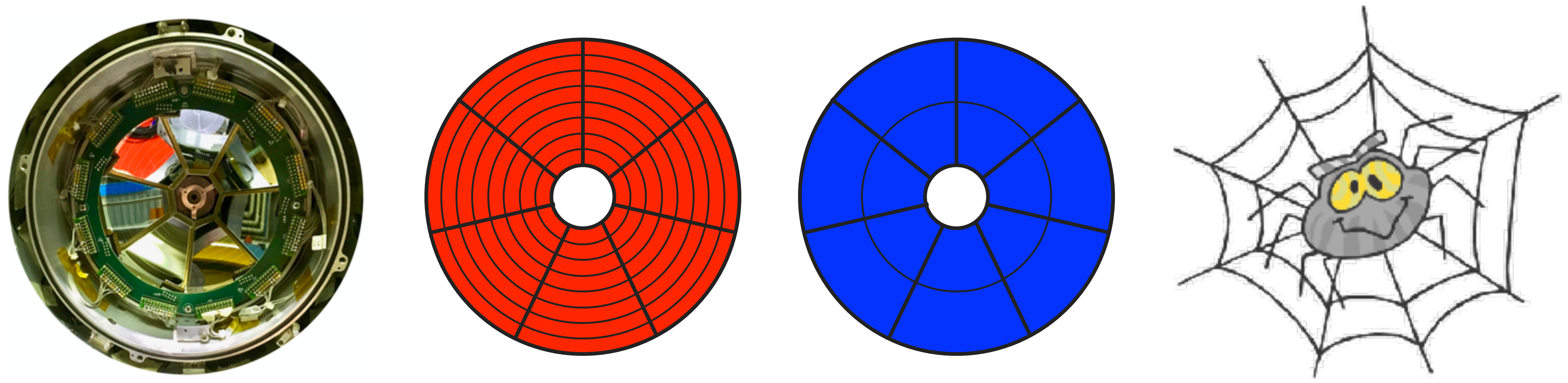
M. Koizumi et al., Eur. Phys. J. A 18, 87 (2003) 87
K. Moschner et al., Phys. Rev. C 82, (2010) 014301

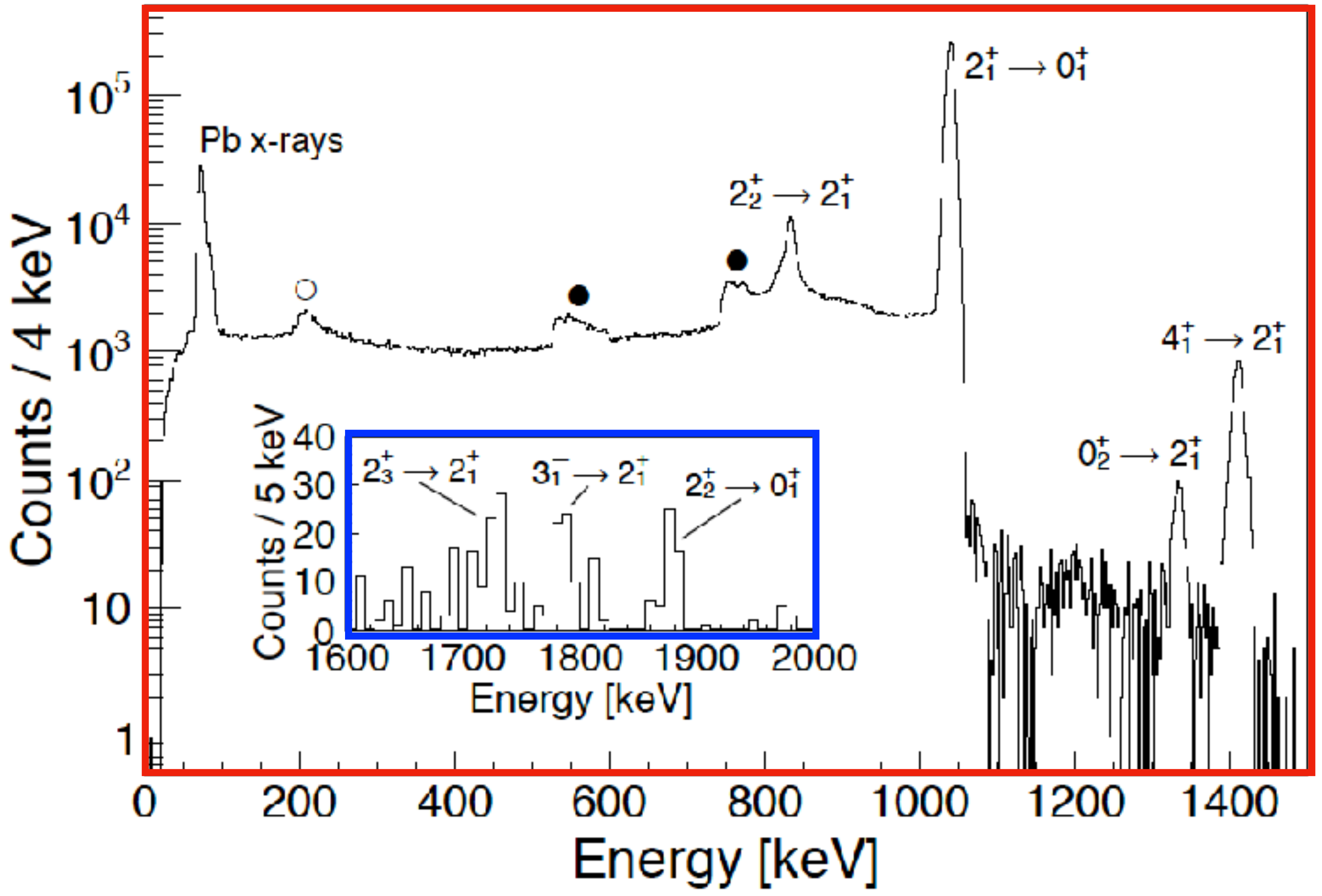
- **Shape coexistence** and **triaxiality** already observed in Ge and Se isotopes
- **0_2^+ state** in Zn isotopes:
  - B(E2) known only for the $0_2^+ \longrightarrow 2_1^+$ transition for A = 64, 68, 70
  - Energy vs mass $\Longrightarrow$ **Unusual trend**

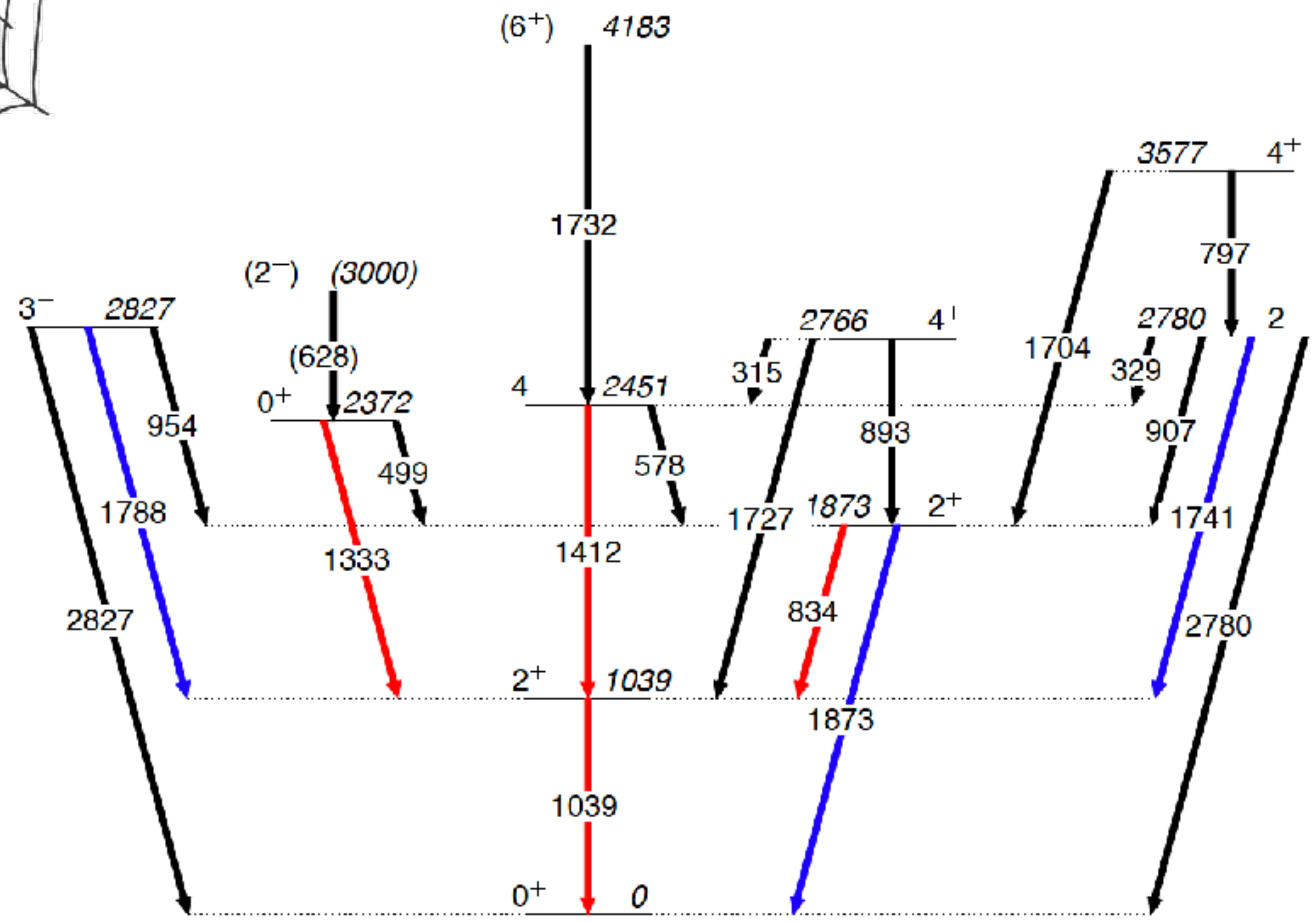


Coulomb Excitation of ^{66}Zn – results

- INFN-LNL
- Coulex @LNL
- ^{42}Ca - results
- SPIDER
- **First Experiment: ^{66}Zn**
- Next Experiments: ^{94}Zr, ^{116}Sn, ^{130}Xe, ^{58}Ni
- Future Perspectives



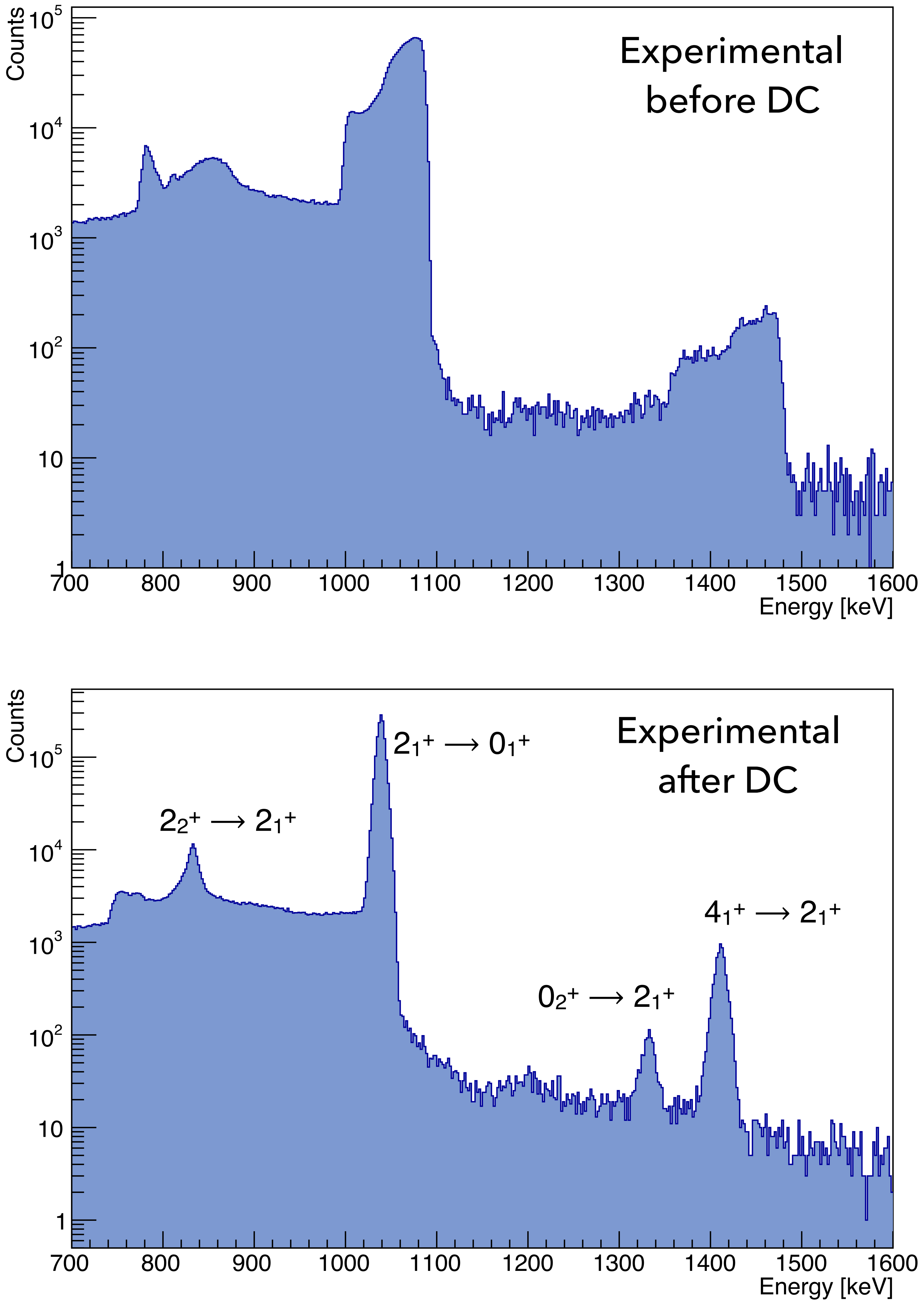


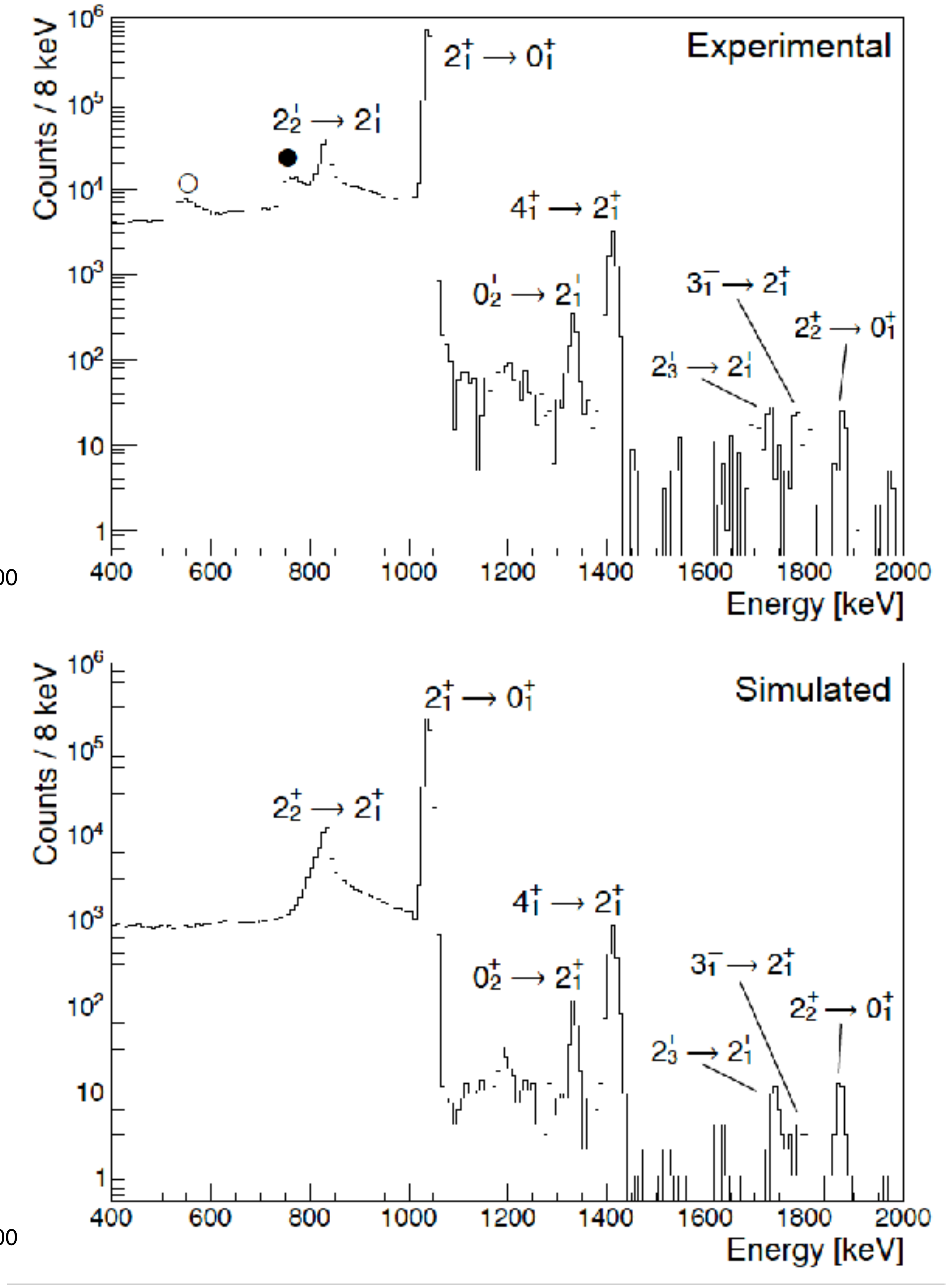


38 Experimental Yields

Coulomb Excitation of ^{66}Zn - results: gamma-ray spectra

- INFN-LNL
- Coulex @LNL
- ^{42}Ca - results
- SPIDER
- **First Experiment: ^{66}Zn**
- Next Experiments: ^{94}Zr, ^{116}Sn, ^{130}Xe, ^{58}Ni
- Future Perspectives





FWHM of 2_1^+ –> 0_1^+

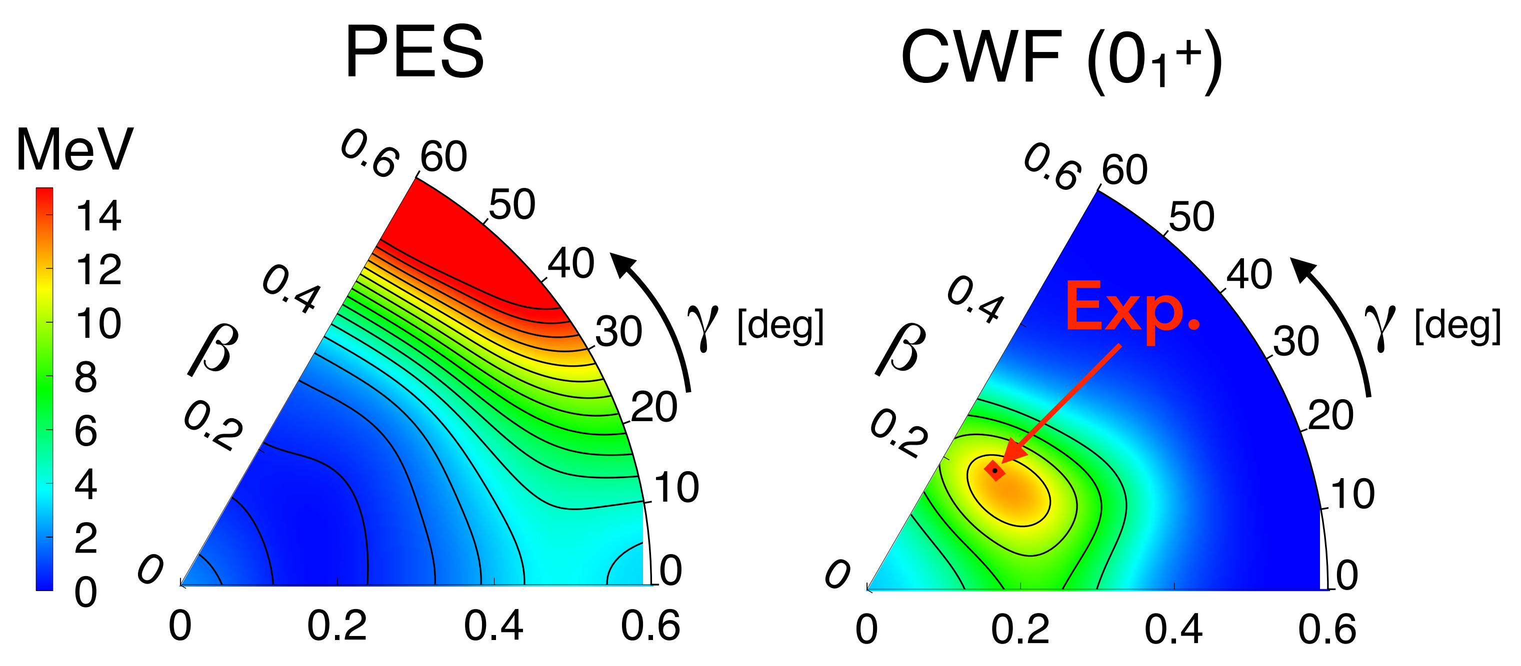
- simulated = 11.8 keV (GEANT4)
- Measured = 11.3 keV

✳ 0_2^+ –> 2_1^+: only the upper limit was available in the literature

Coulomb Excitation of ^{66}Zn – physics

- INFN-LNL
- Coulex @LNL
- ^{42}Ca - results
- SPIDER
- **First Experiment: ^{66}Zn**
- Next Experiments: ^{94}Zr, ^{116}Sn, ^{130}Xe, ^{58}Ni
- Future Perspectives

- **Data already available in the literature confirmed**, sufficient precision **to distinguish between discrepant values** achieved
- First measurement of **B(E2) values from 0_2^+**: B(E2; $0_2^+ \longrightarrow 2_1^+$), B(E2; $0_2^+ \longrightarrow 2_2^+$)
- First measurement of **B(E3; $3_1^- \longrightarrow 0_1^+$)** in ^{66}Zn using Coulomb excitation
- **Quadrupole sum rule**
  - **0_1^+**: $\langle\beta\rangle = 0.225(8)$, $\langle\gamma\rangle = 43°(3°)$
  - **0_2^+**: $\langle\beta\rangle = 0.055(5)$
- Comparison with **BMF calculations** (*T. Rodriguez*)



coexistence of an traixial-oblate-deformed 0_1 and a spherical 0_2 state

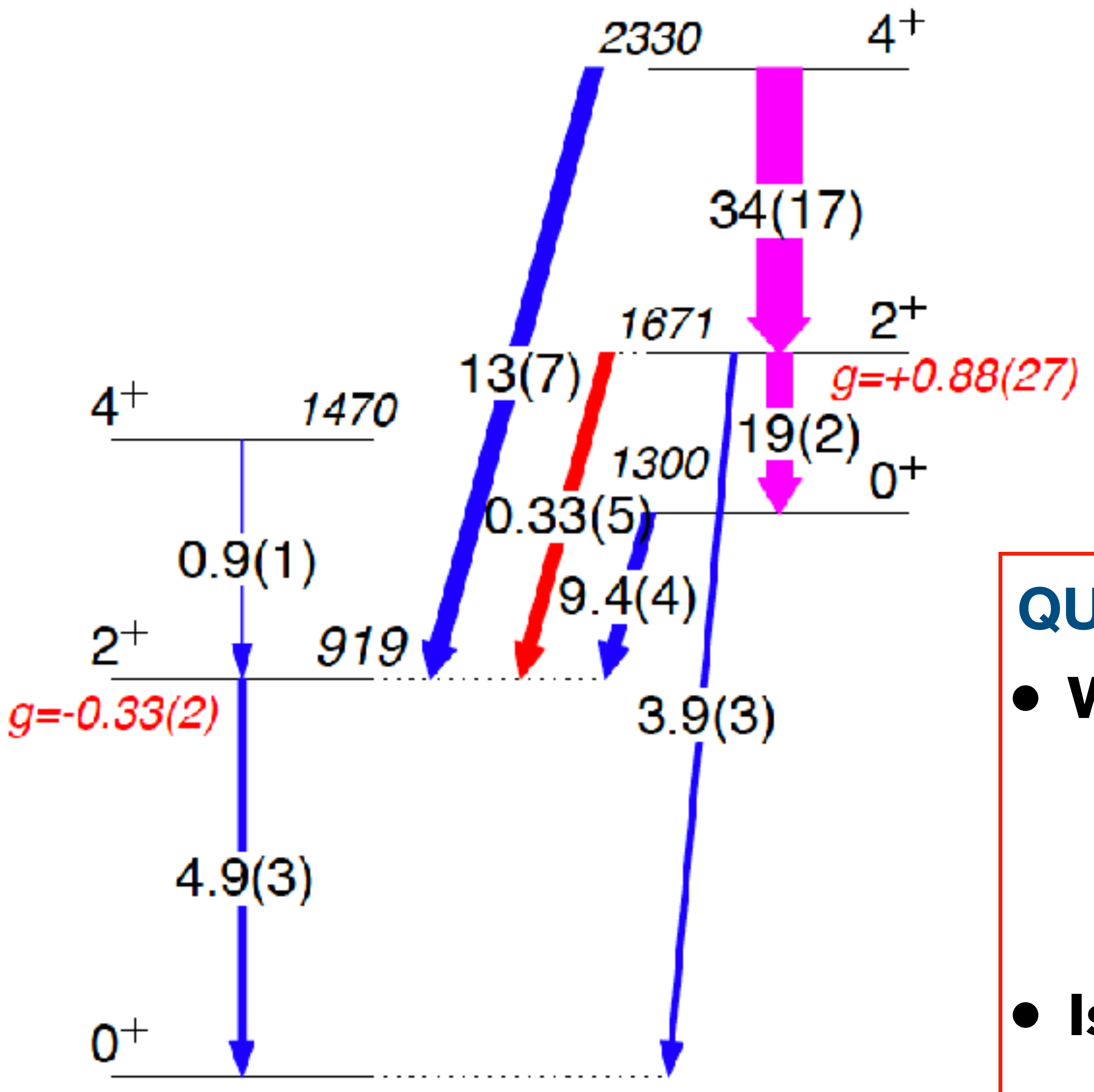
- **Shell Model calculations** in various model spaces and using different interactions - under progress (*F.Nowacki and A.Gargano*)

PRC - in preparation

Coulomb Excitation of ^{94}Zr (2018)

Proposal: D. Doherty (Uni of Surrey), M. Zielińska (CEA Saclay), M. Rocchini (INFN Firenze)
Data analysis: N. Marchini (INFN Firenze)

- INFN-LNL
- Coulex @LNL
- ^{42}Ca - results
- SPIDER
- First Experiment: ^{66}Zn
- **Next Experiments:** **^{94}Zr**, ^{116}Sn, ^{130}Xe, ^{58}Ni
- Future Perspectives



A. Chakraborty et al, PRL 110, 022504 (2013)
E. Elhami et al, PRC 78 R011301 (2008)
Erratum: E. Elhami et al, PRC 83 029903 (2013)

- g factors indicate very different configurations of 2_1 (neutron dominance) and 2_2 (proton dominance)
- strong M1 $2_2 \rightarrow 2_1$ transition (δ=0.02(2), B(M1)=0.33(5)μ_{2N})suggests mixed-symmetry character of the 2_2 state
- observation of a strong $2_2 \rightarrow 0_2$ transition (19 W.u.) – deformed band built on 0_2
- shell model calculations suggest an oblate shape

QUESTIONS:

- **What is the shape of ^{94}Zr in $2_{1,2}$ states?**
  - measurement of quadrupole moments of $2_{1,2}$ states – verification of the spherical-deformed (oblate?) scenario
  - is mixing between the coexisting structures small, like in ^{96}Zr and ^{98}Sr?
- **Is 2_2 a mixed-symmetry state?**
  - are quadrupole moments of $2_{1,2}$ states similar?
  - γ-ray angular distributions yielded two possible values of δ: 0.02(2) and 2.2(5) – which one is correct?
- **How important are octupole correlations in ^{94}Zr?**
  - 3^- excitation cross section is related to B(E3; 3− → 0+)

Coulomb Excitation of ^{94}Zr (2018)

- INFN-LNL
- Coulex @LNL
- ^{42}Ca - results
- SPIDER
- First Experiment: ^{66}Zn
- **Next Experiments: ^{94}Zr**, ^{116}Sn, ^{130}Xe, ^{58}Ni
- Future Perspectives

- ^{94}Zr beam at 374 MeV
- ^{208}Pb target

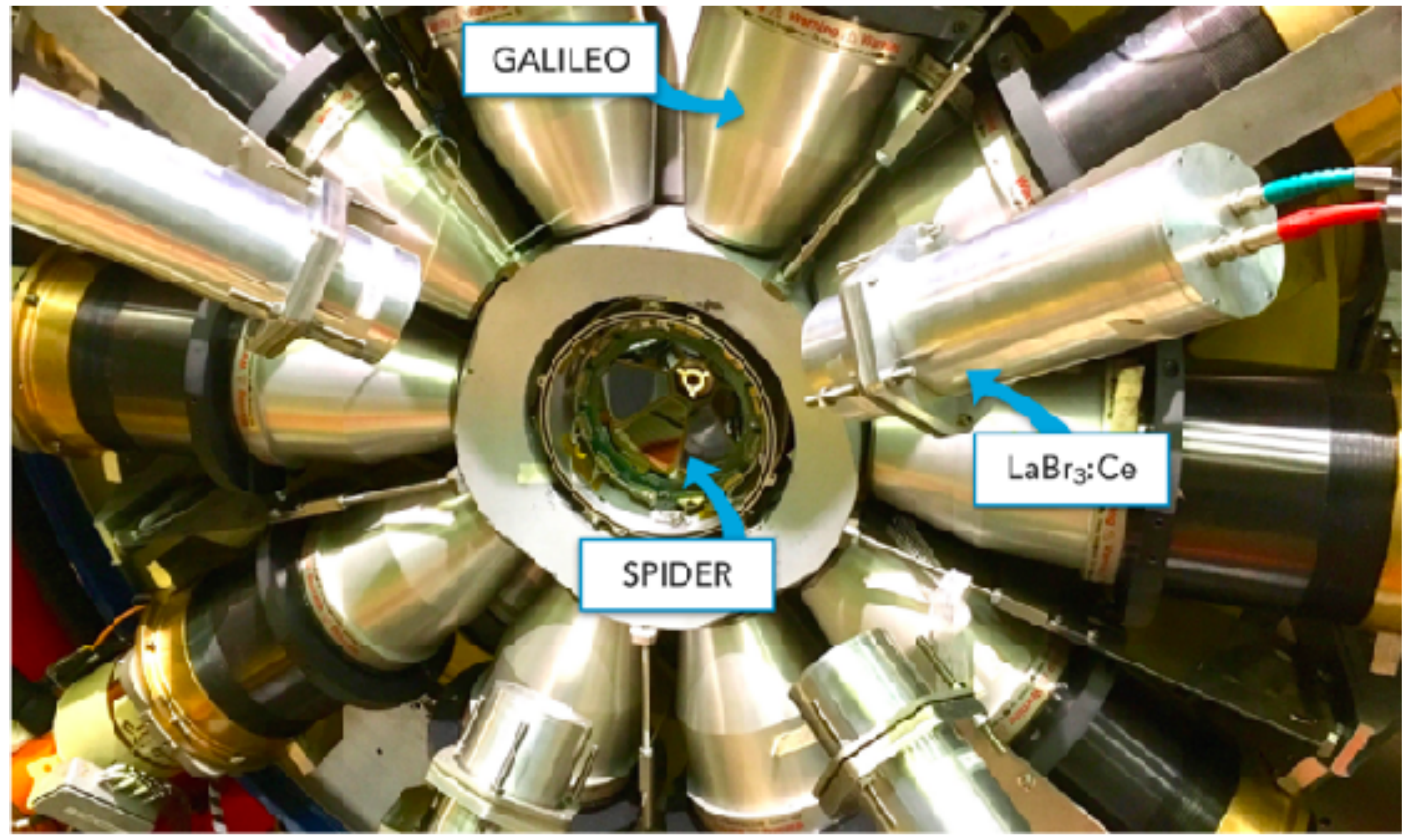
- **Gamma ray detectors**

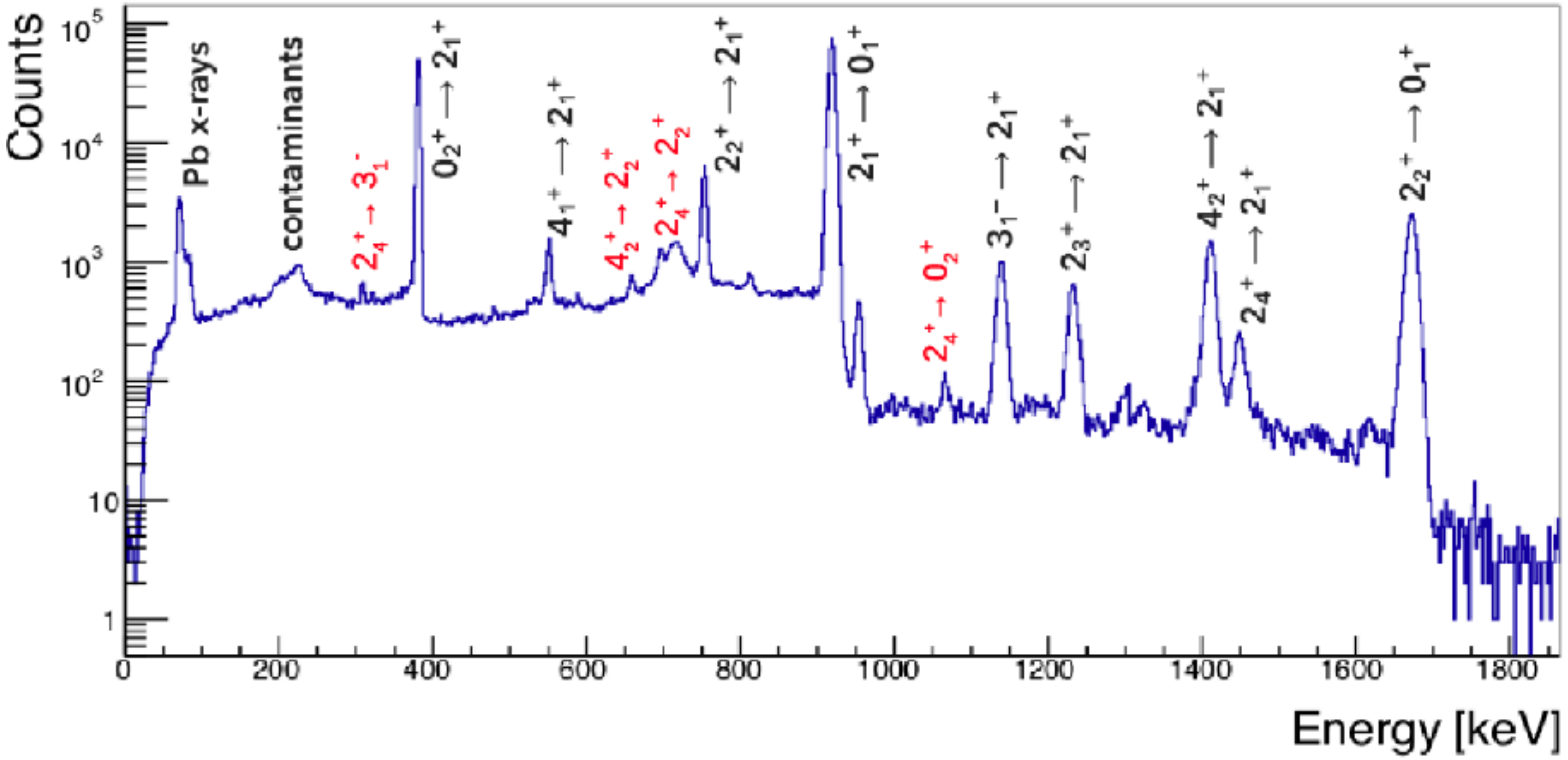
GALILEO
25 HPGe Compton-suppressed detectors
Total FWHM (@1332.5 keV) ~ 0.2%
Total Efficiency (@1332.5 keV) ~ 2%

LaBr3:Ce
6 3″ X 3″ Lanthanum Bromide Scintillators
Total FWHM (@1332.5 keV) ~ 2%
Total Efficiency (@1332.5 keV) ~ 4%

- **Particle detector**

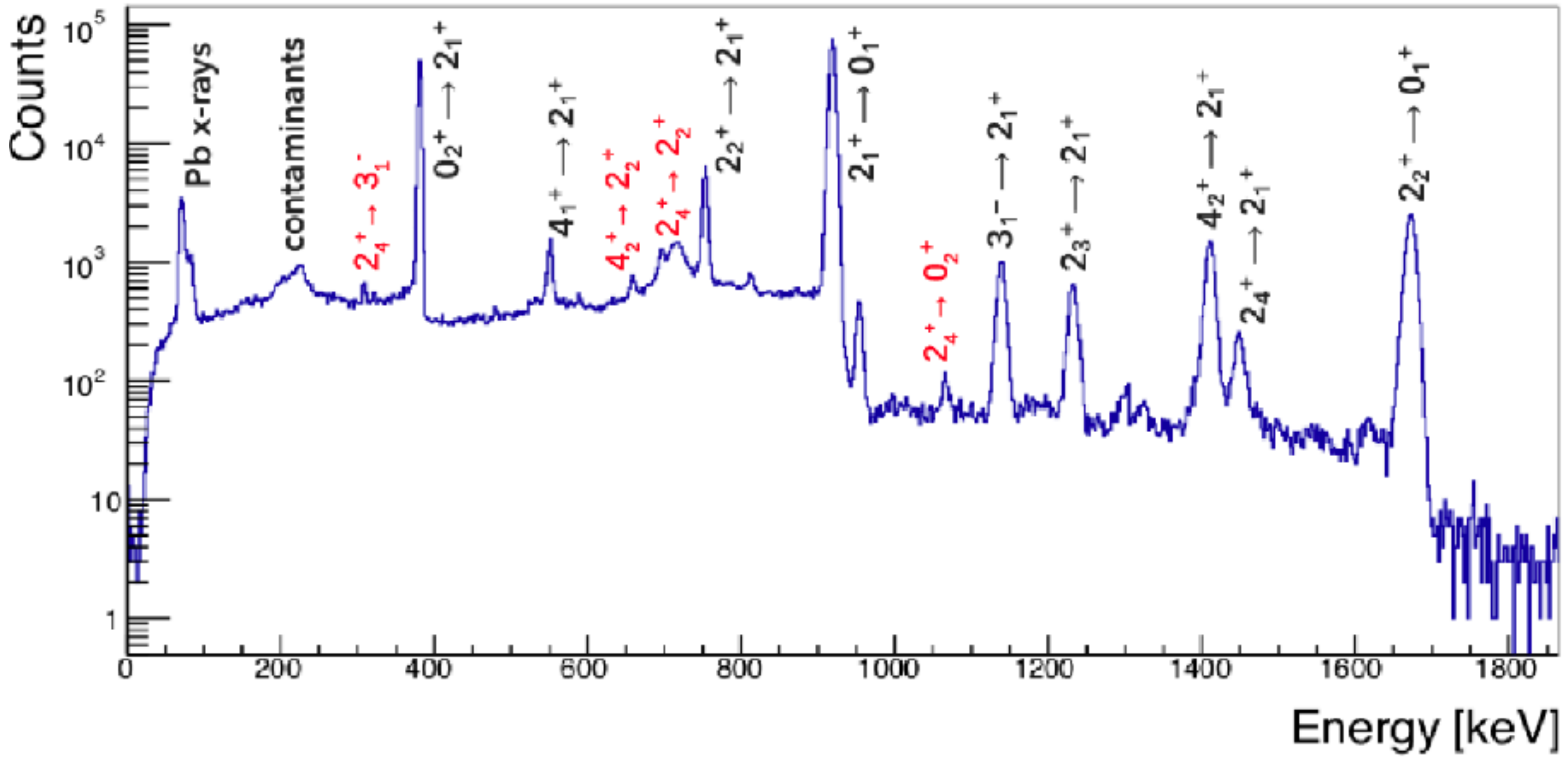
SPIDER

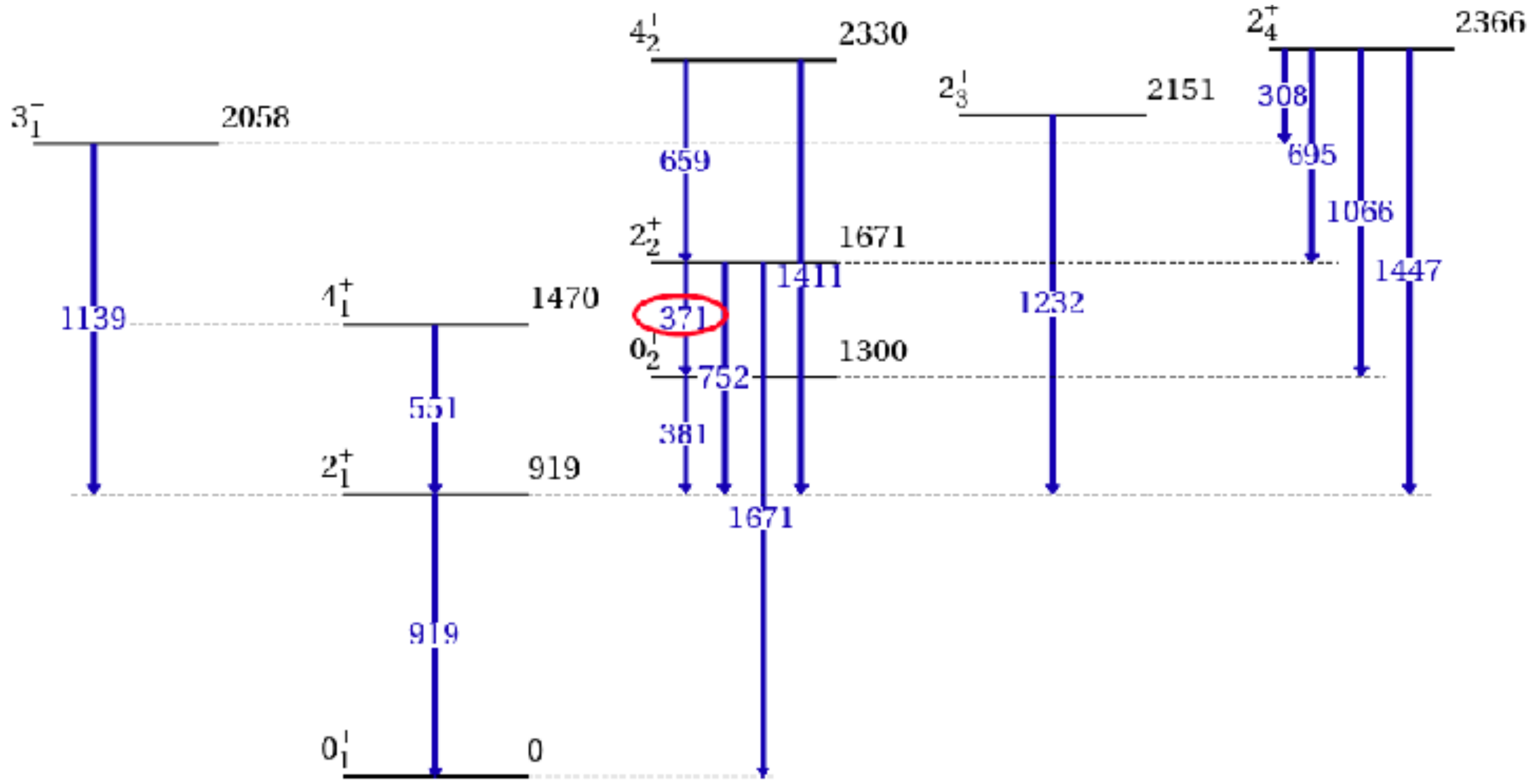




Coulomb Excitation of ^{94}Zr (2018)

- INFN-LNL
- Coulex @LNL
- ^{42}Ca - results
- SPIDER
- First Experiment: ^{66}Zn
- **Next Experiments:** **^{94}Zr**, ^{116}Sn, ^{130}Xe, ^{58}Ni
- Future Perspectives





GOSIA ANALYSIS:

76 experimental yields
20 known spectroscopic data (lifetime, mixing and branching ratios)

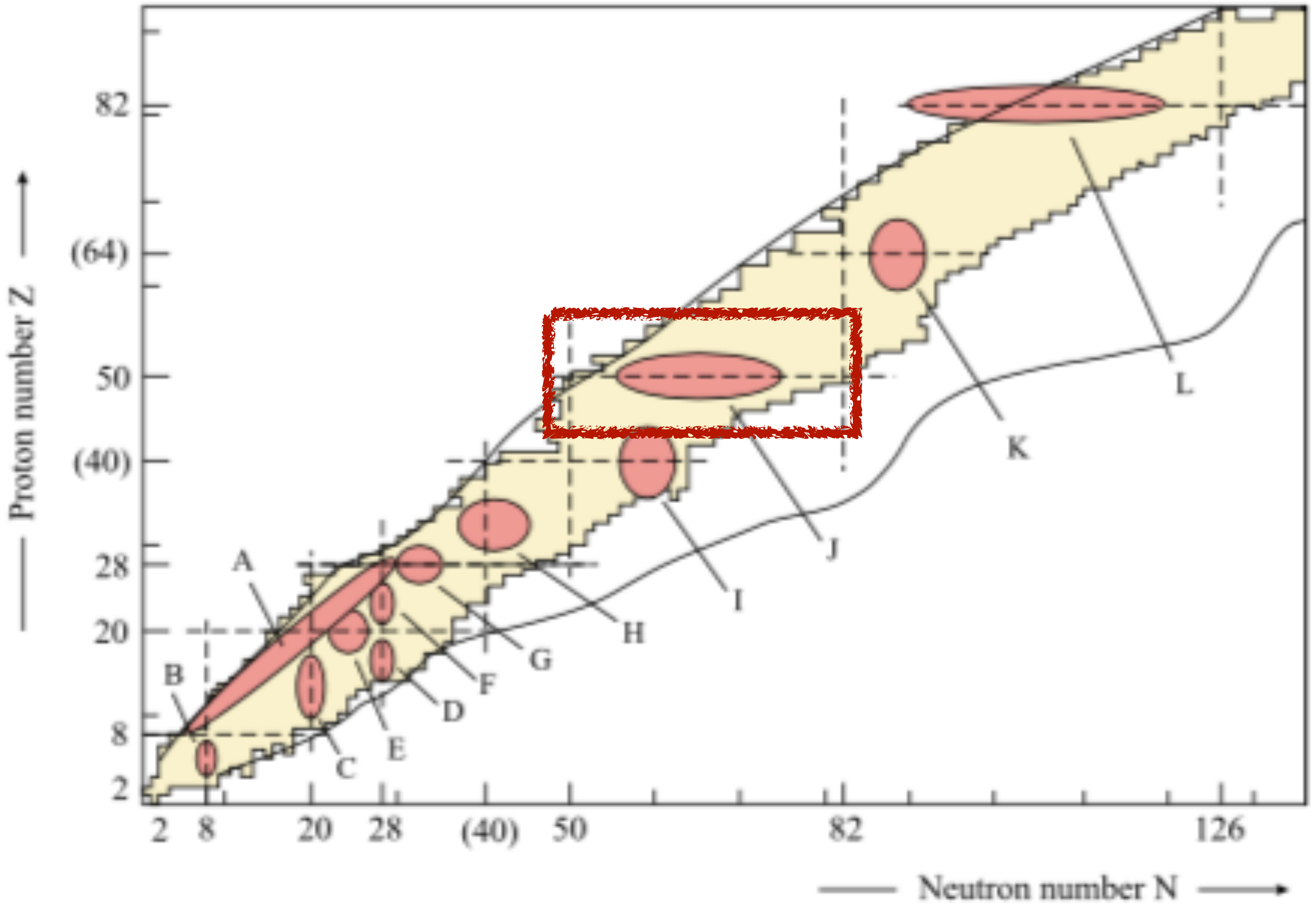
- B(ΩL)
- $Qs(2_1)$, $Qs(2_2)$
- Deformation parameters (β,γ)
- δ for the transition $2_2 \to 2_1$

Classified

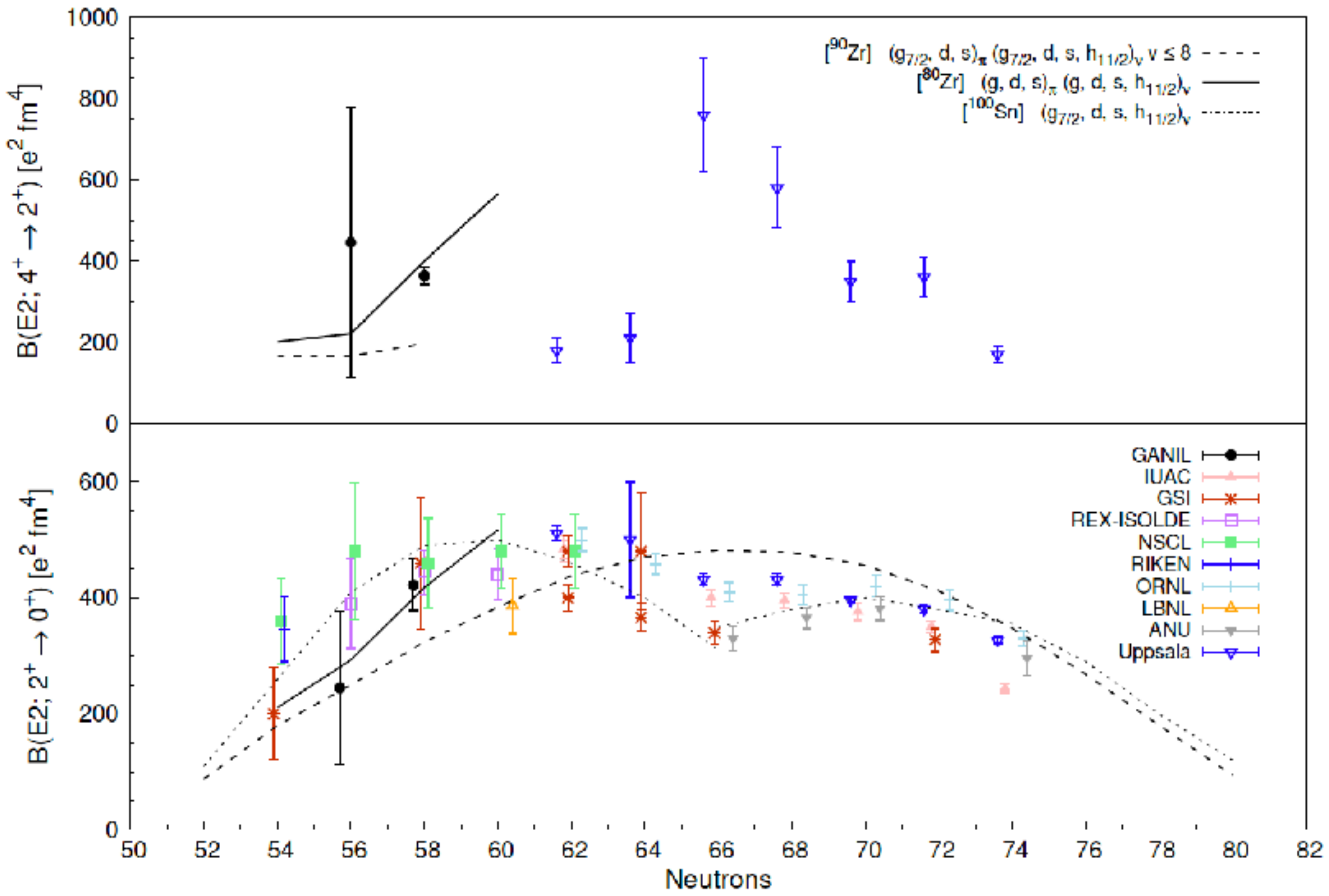
Coulomb Excitation of ^{116}Sn (2018)

Proposal: M. Siciliano (INFN LNL), M. Saxena (ŚLCJ UW), A. Ilana Sison (INFN LNL)
Data analysis: M. Siciliano

- INFN-LNL
- Coulex @LNL
- ^{42}Ca - results
- SPIDER
- First Experiment: ^{66}Zn
- **Next Experiments:** ^{94}Zr, **^{116}Sn,** ^{130}Xe, ^{58}Ni
- Future Perspectives



K. Heyde and J. Woods, Rev. Mod. Phys. 83 (2011) 1467

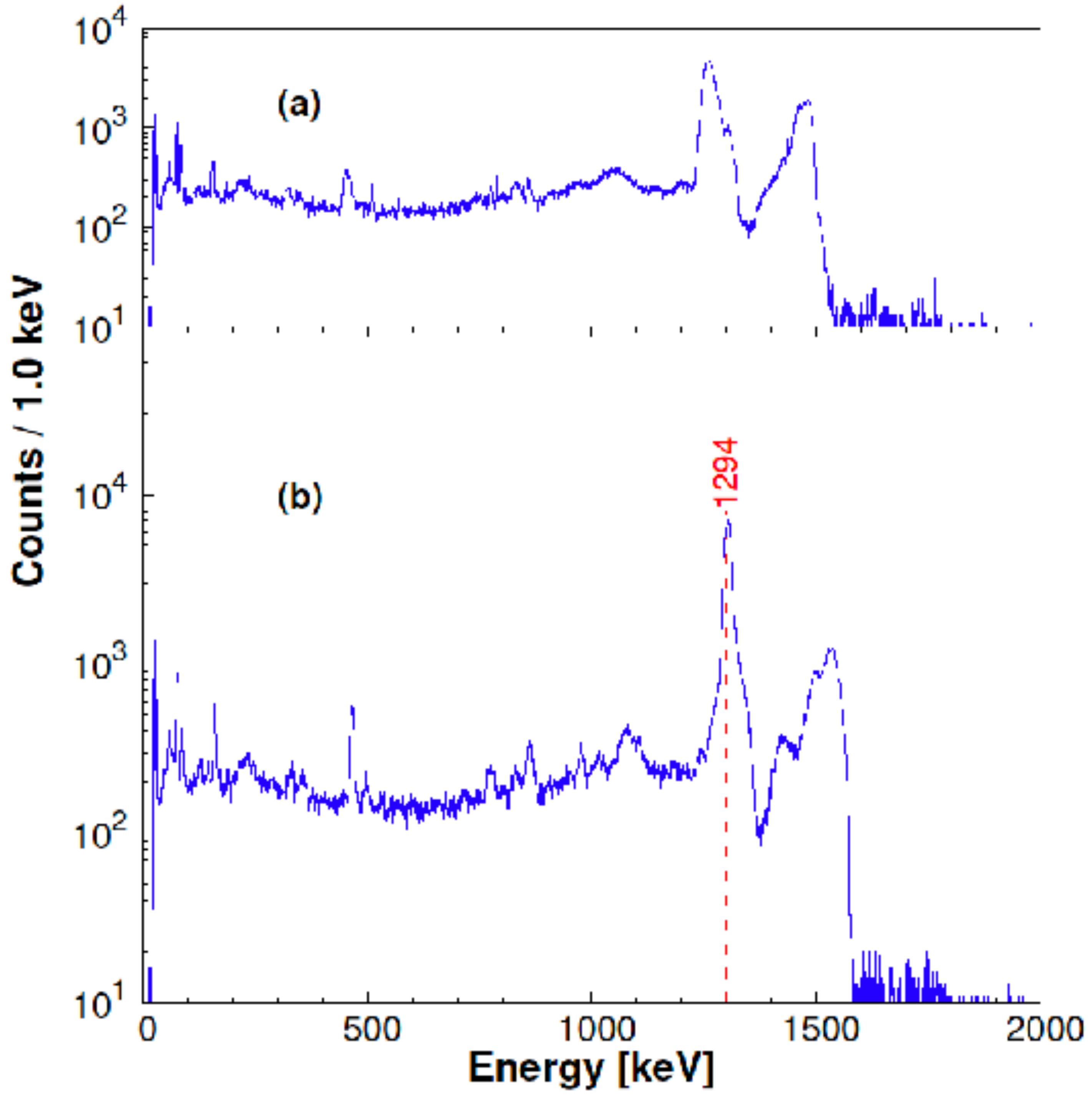


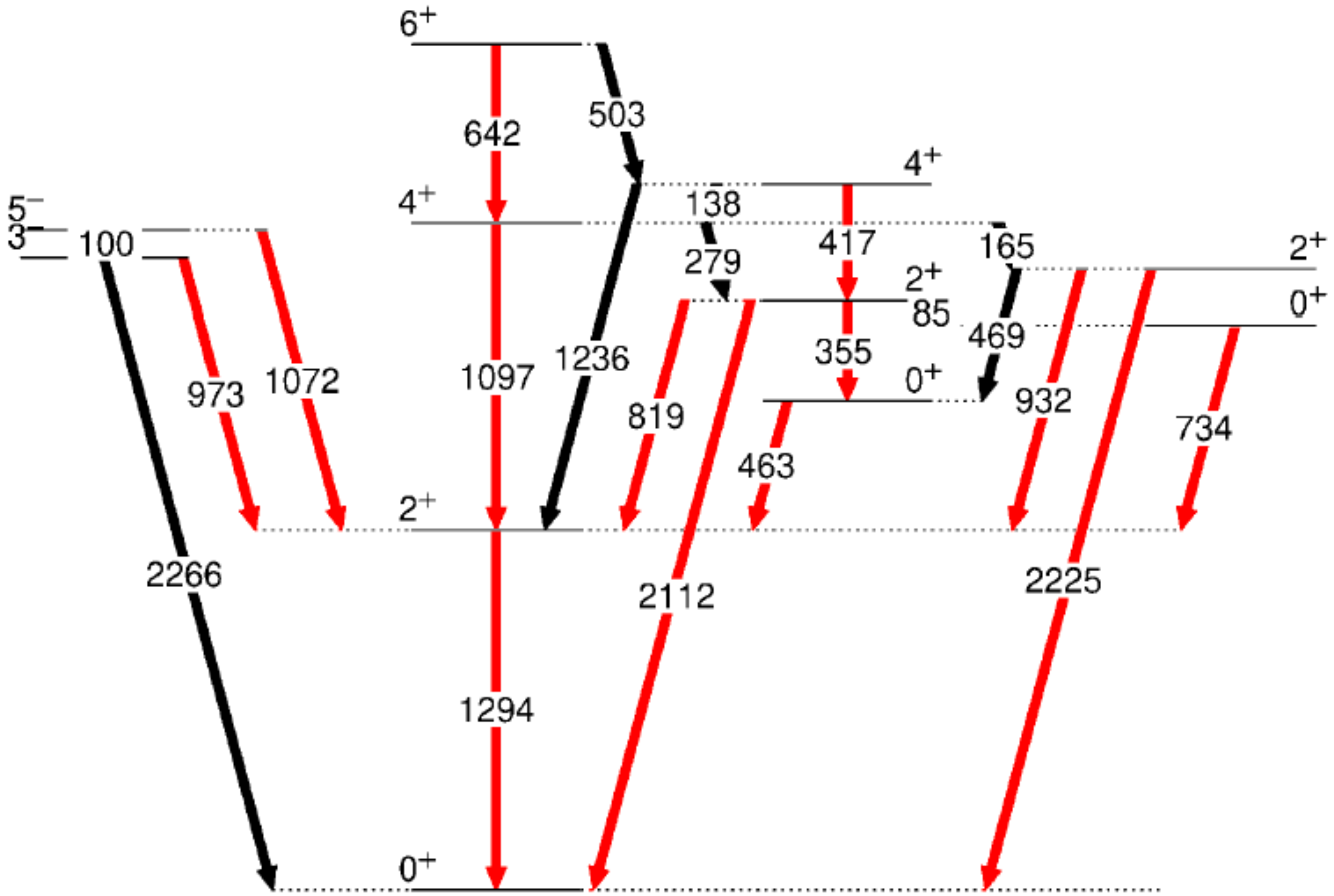
- The semi-magic Sn isotopes represent a good case to study shape coexistence
- Within Sn isotopes ^{116}Sn intriguing position Z=50, N=66
- Discrepant values for the 2_1^+ quadrupole moments in the literature
- Presence of isomer limits the investigation of the electromagnetic properties of low-lying states –> Coulomb Excitation

Coulomb Excitation of ^{116}Sn (2018)

- INFN-LNL
- Coulex @LNL
- ^{42}Ca - results
- SPIDER
- First Experiment: ^{66}Zn
- **Next Experiments:** ^{94}Zr, **^{116}Sn,** ^{130}Xe, ^{58}Ni
- Future Perspectives

- Beam: ^{58}Ni @ 180 MeV 4 pnA, continuous
- Target: ^{116}Sn 1 mg/cm^2 ^{12}C backing
- Setup:
  - GALILEO (25 HPGe)
  - 6 $LaBr_3$
  - SPIDER





Credits: M. Siciliano (CEA Saclay)

Coulomb Excitation of ^{130}Xe (2019)

- INFN-LNL
- Coulex @LNL
- ^{42}Ca - results
- SPIDER
- First Experiment: ^{66}Zn
- **Next Experiments:** ^{94}Zr, ^{116}Sn, **^{130}Xe**, ^{58}Ni
- Future Perspectives

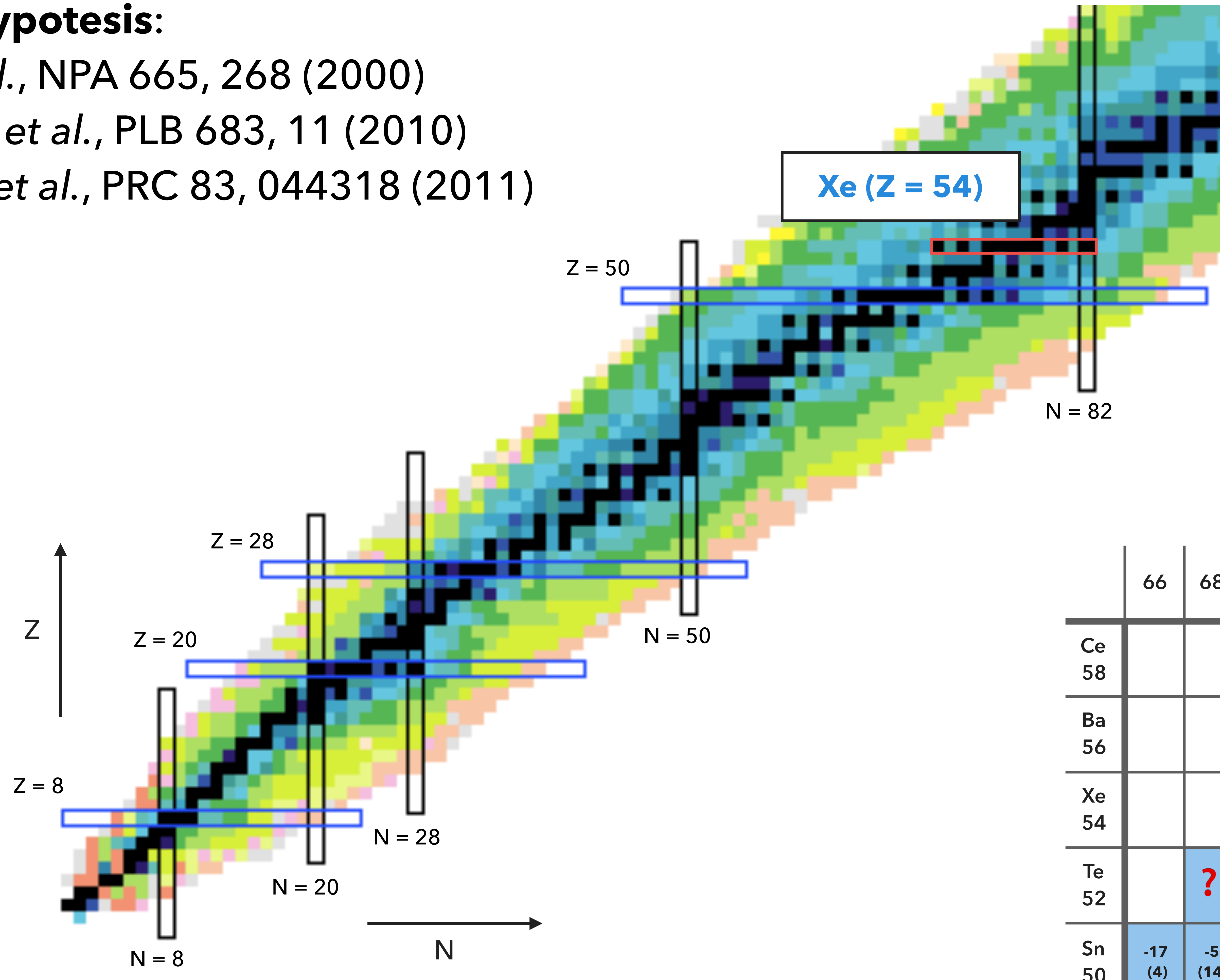
Collectivity in Xenon Isotopes

IBM - **O(6)-like hypotesis**:

👍 A. Gade *et al.*, NPA 665, 268 (2000)

❓ G. Rainovski *et al.*, PLB 683, 11 (2010)

👎 L. Coquard *et al.*, PRC 83, 044318 (2011)



No definitive conclusion

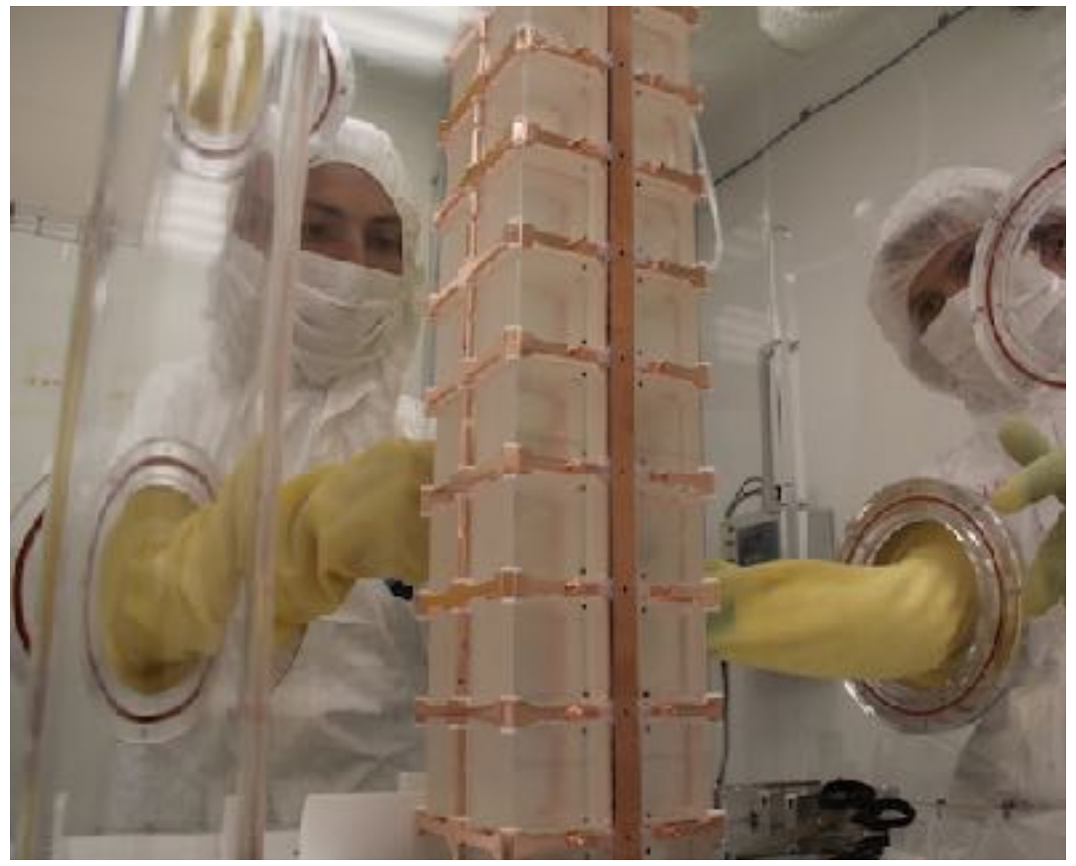
	66	68	70	72	74	76	78	80	82	84
Ce 58							?	?	?	-16 (5)
Ba 56					-86 (8)	?	-32 (8)	-19 (6)	-14 (7)	
Xe 54			?	?	?	?	?	?	?	
Te 52		?	-50 (5)	-45 (5)	-20 (9)	-6 (5)	-15 (10)			
Sn 50	-17 (4)	-5 (14)	-5 (10)	?	0 (2)					

$Q_s(2_1^+)$ [fm]

Coulomb Excitation of ^{130}Xe (2019)

- INFN-LNL
- Coulex @LNL
- ^{42}Ca - results
- SPIDER
- First Experiment: ^{66}Zn
- **Next Experiments:** ^{94}Zr, ^{116}Sn, **^{130}Xe**, ^{58}Ni
- Future Perspectives

^{130}Te ββ-Decay @CUORE

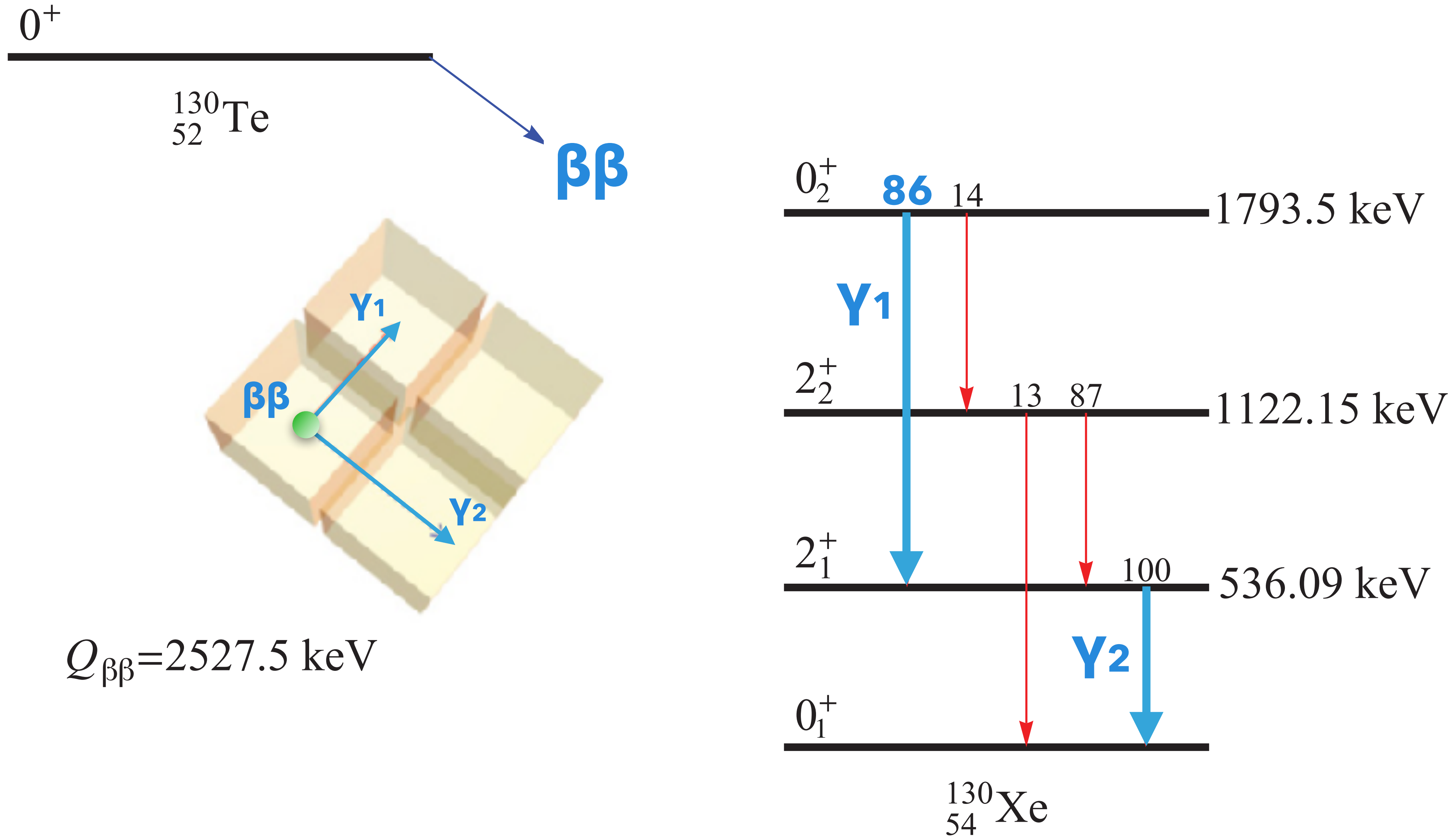


- Decay to **ground state**: standard detection method
- Decay to **excited state** (coincidence analysis):
  - 👍 background-free environment
  - 👎 lower Q-value ⟹ larger $T_{1/2}$

1

2νββ: ββ continuous distribution

0νββ: ββ monocromatic peak



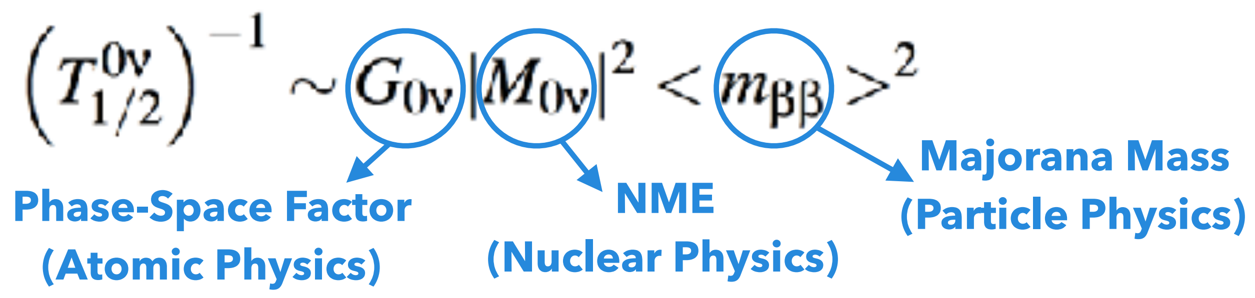
ββ-decay to states with J ≠ 0 suppressed

Coulomb Excitation of ^{130}Xe (2019)

- INFN-LNL
- Coulex @LNL
- ^{42}Ca - results
- SPIDER
- First Experiment: ^{66}Zn
- **Next Experiments:** ^{94}Zr, ^{116}Sn, **^{130}Xe**, ^{58}Ni
- Future Perspectives

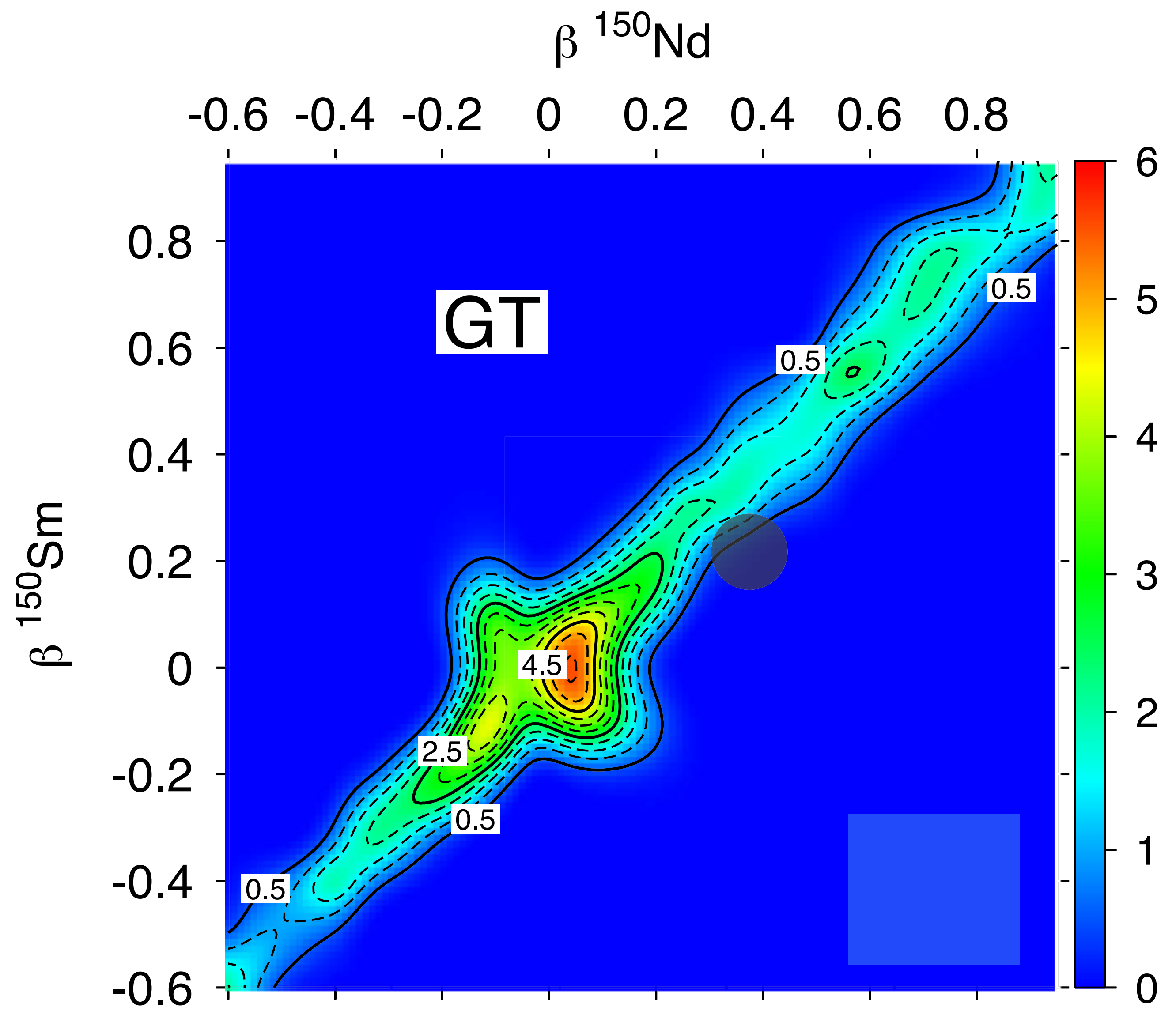
- 0νββ-decay rate and Nuclear Matrix Element (**NME**):

$$\left(T_{1/2}^{0\nu}\right)^{-1} \sim G_{0\nu} |M_{0\nu}|^2 < m_{\beta\beta} >^2$$



  - Calculation of ββ-decay rates ⟹ **Design of experiments**
  - If 0νββ-decay will be observed ⟹ Neutrino Majorana mass, and then, combining with neutrino oscillation data ⟹ **Neutrino masses**

- Importance of **deformation** of the states involved in ββ-decay:
  - Shell Model
    E. Caurier, F. Nowacki and A. Poves, EPJ A 36, 195 (2008)
  - Beyond-Mean-Field
    T.R. Rodriguez and G. Martinez-Pinedo, PRL 105, 252503 (2010)



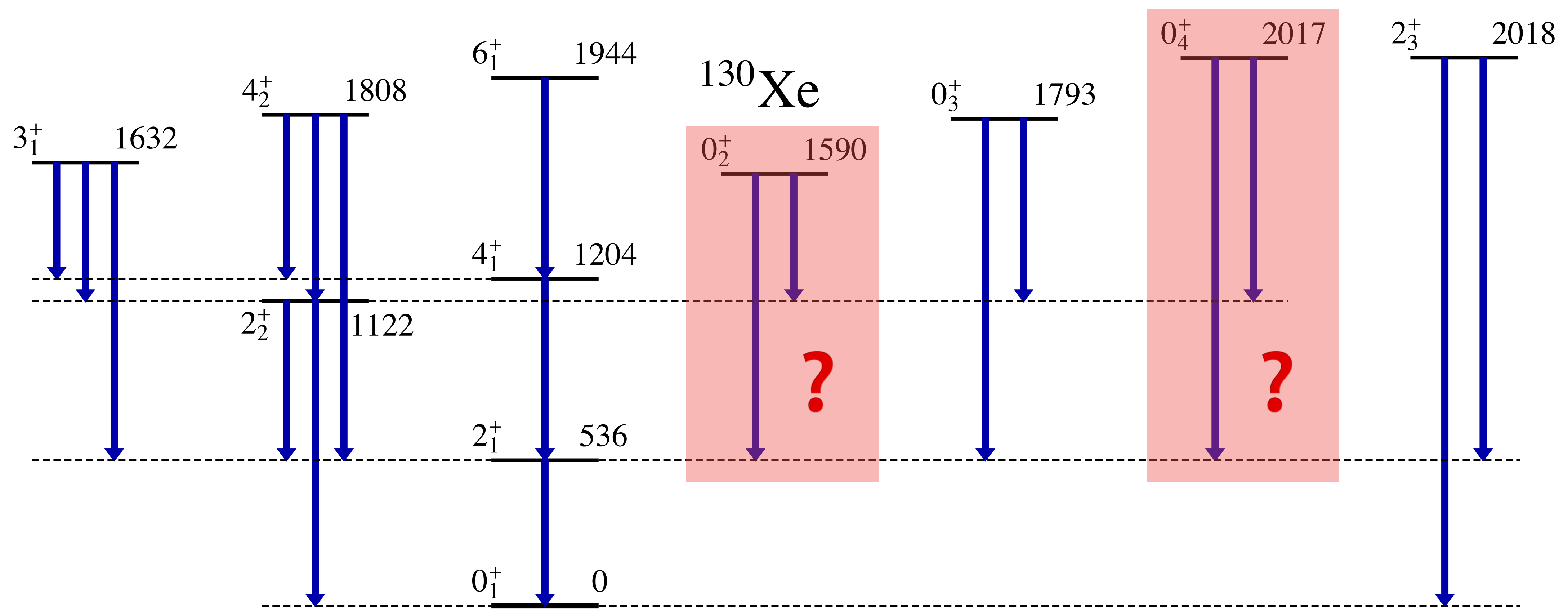
Coulex – shapes of ground and excited 0^+ states

Coulomb Excitation of ^{130}Xe (2019)

Proposal: A. Nannini & M. Rocchini (INFN Firenze), P. Napiorkowski (ŚLCJ UW),
Data analysis: M. Rocchini

- INFN-LNL
- Coulex @LNL
- ^{42}Ca - results
- SPIDER
- First Experiment: ^{66}Zn
- **Next Experiments:** ^{94}Zr, ^{116}Sn, **^{130}Xe**, ^{58}Ni
- Future Perspectives

- ββ-decay to states with $J \neq 0$ suppressed ⟹ **Identification of excited 0+ states really crucial for coincidence analysis**
- **0+ @1793keV** clearly identified (the one already considered by CUORE)
- L. Coquard *et al.*, PRC 82, 024317 (2010) ⟹ **0+ @1590keV** and **2+ @2018keV**
- E.E. Peters *et al.*, PRC 94, 024313 (2016) ⟹ Close doublet with **0+ @2017keV** and **2+ @2018keV** but **0+ @1590keV refuted**
- Need to clarify the position of excited 0+ states



- **Multi-Step Coulex of ^{130}Xe** to obtain:
  - Q_s moments
  - First determination of quadrupole invariants
  - B(ΩL) with precisions of ~ 5–10%
- **Questions we want to answer**:
  - Is ^{130}Xe an O(6)-like nucleus?
  - Which are the low-lying 0+ states in ^{130}Xe?
  - Which is their shape?

Coulomb Excitation of ^{130}Xe (2019)

- INFN-LNL
- Coulex @LNL
- ^{42}Ca - results
- SPIDER
- First Experiment: ^{66}Zn
- **Next Experiments:** ^{94}Zr, ^{116}Sn, **^{130}Xe**, ^{58}Ni
- Future Perspectives

- Beam: ^{130}Xe with 545 MeV and 1 pnA (PIAVE + ALPI)
- Target: ^{208}Pb 1 mg/cm^2, self-supporting
- Experimental setup:
  - GALILEO (ε = 2.4% @ 1.3 MeV)
  - SPIDER
  - $LaBr_3$:Ce detectors

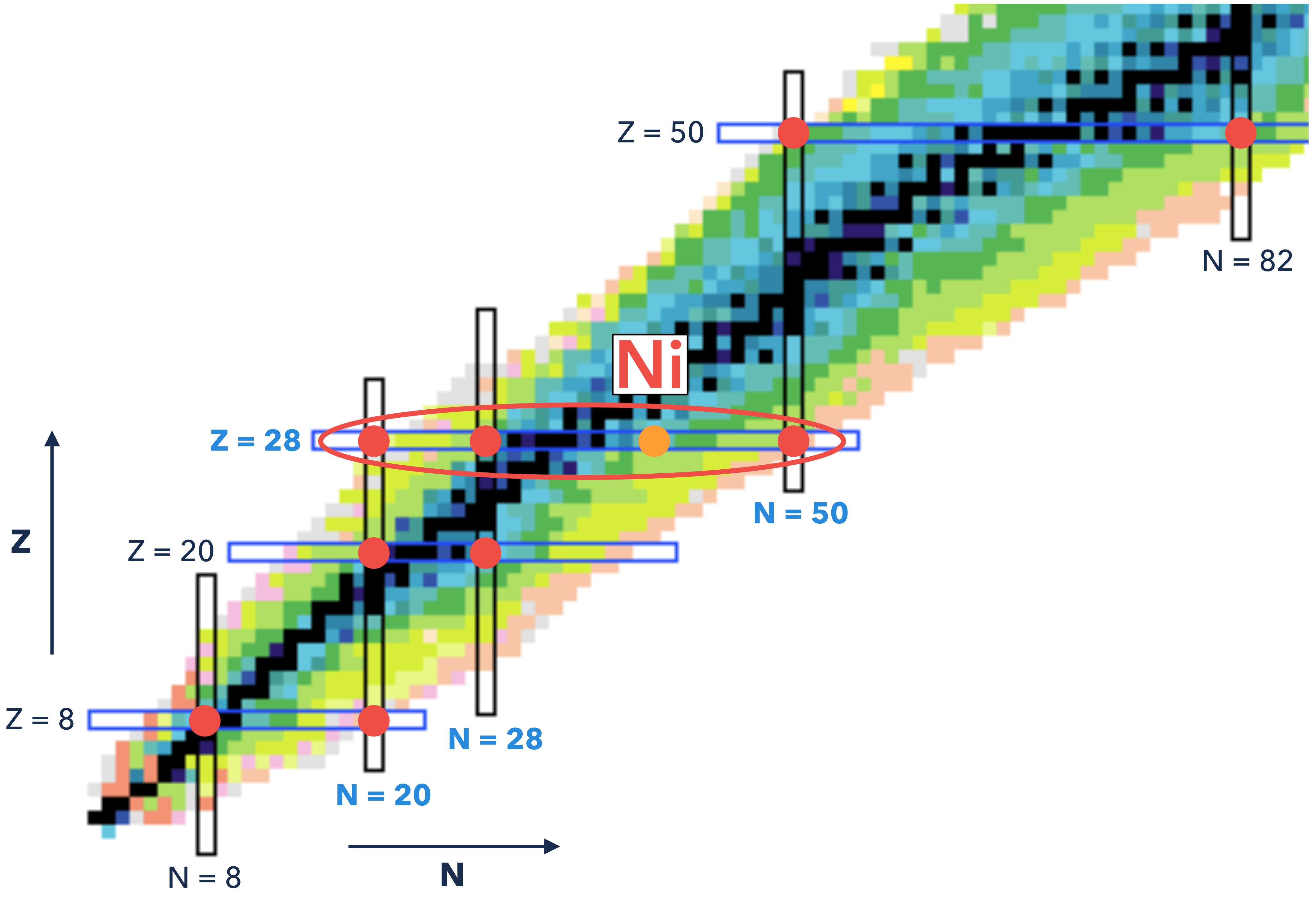
Classified

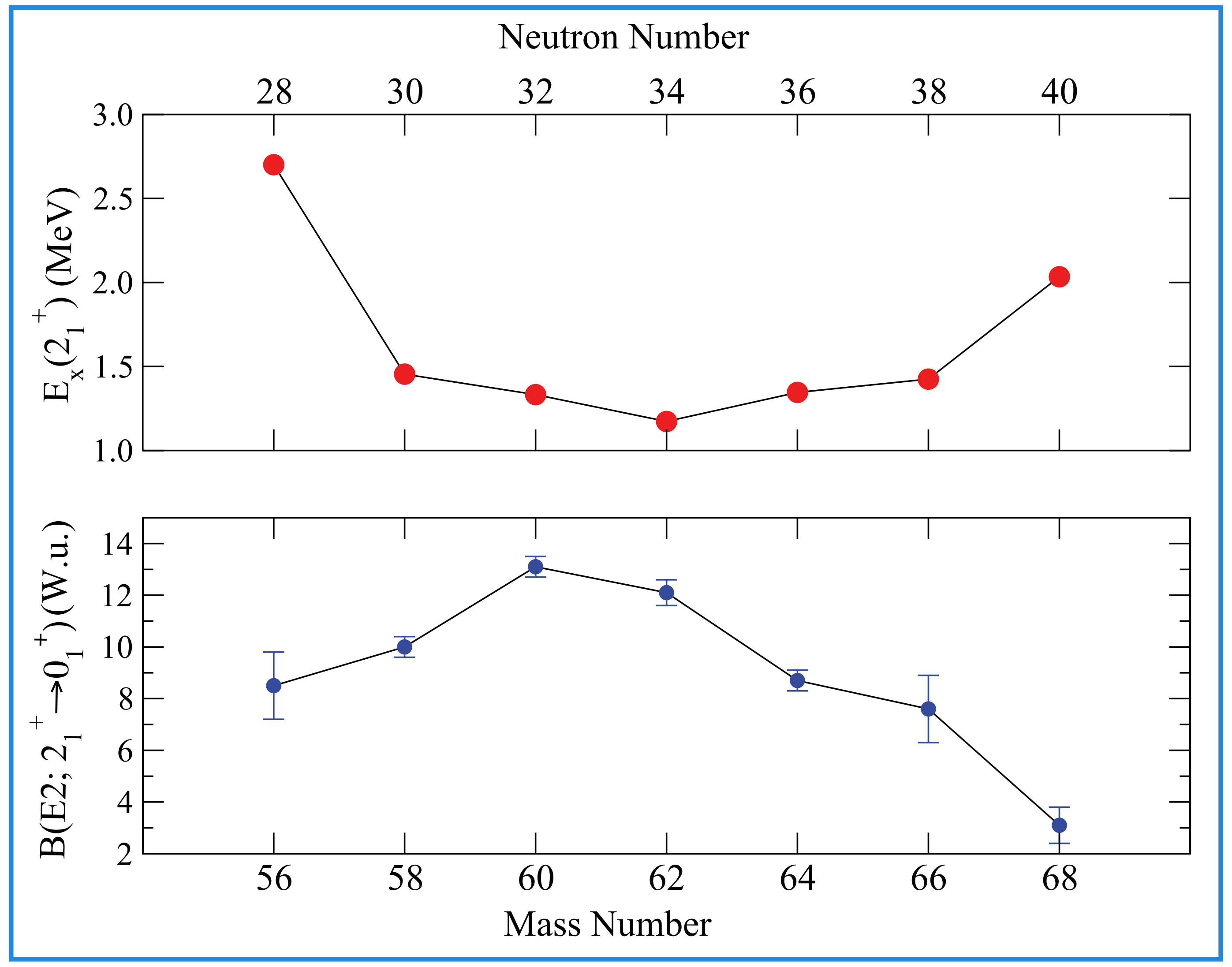
Credits: M. Rocchini (Uni of Guelph)

FUTURE

Coulomb Excitation of ^{58}Ni (2020)

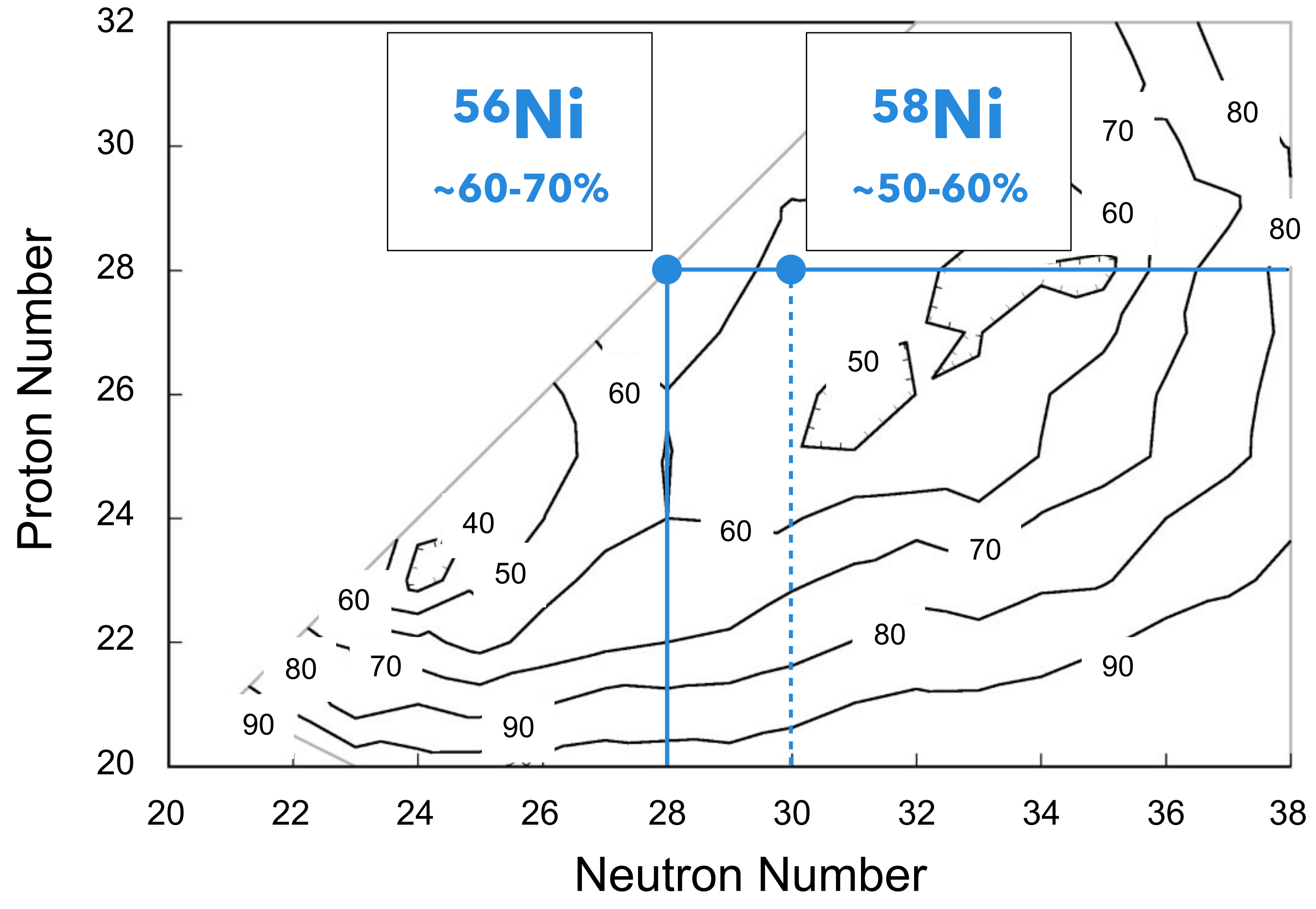
- INFN-LNL
- Coulex @LNL
- ^{42}Ca - results
- SPIDER
- First Experiment: ^{66}Zn
- **Next Experiments:** ^{94}Zr, ^{116}Sn, ^{130}Xe, **^{58}Ni**
- Future Perspectives





Closed core g.s. wave function probability

M. Honma *et al.*, PRC 69 (2004) 034335

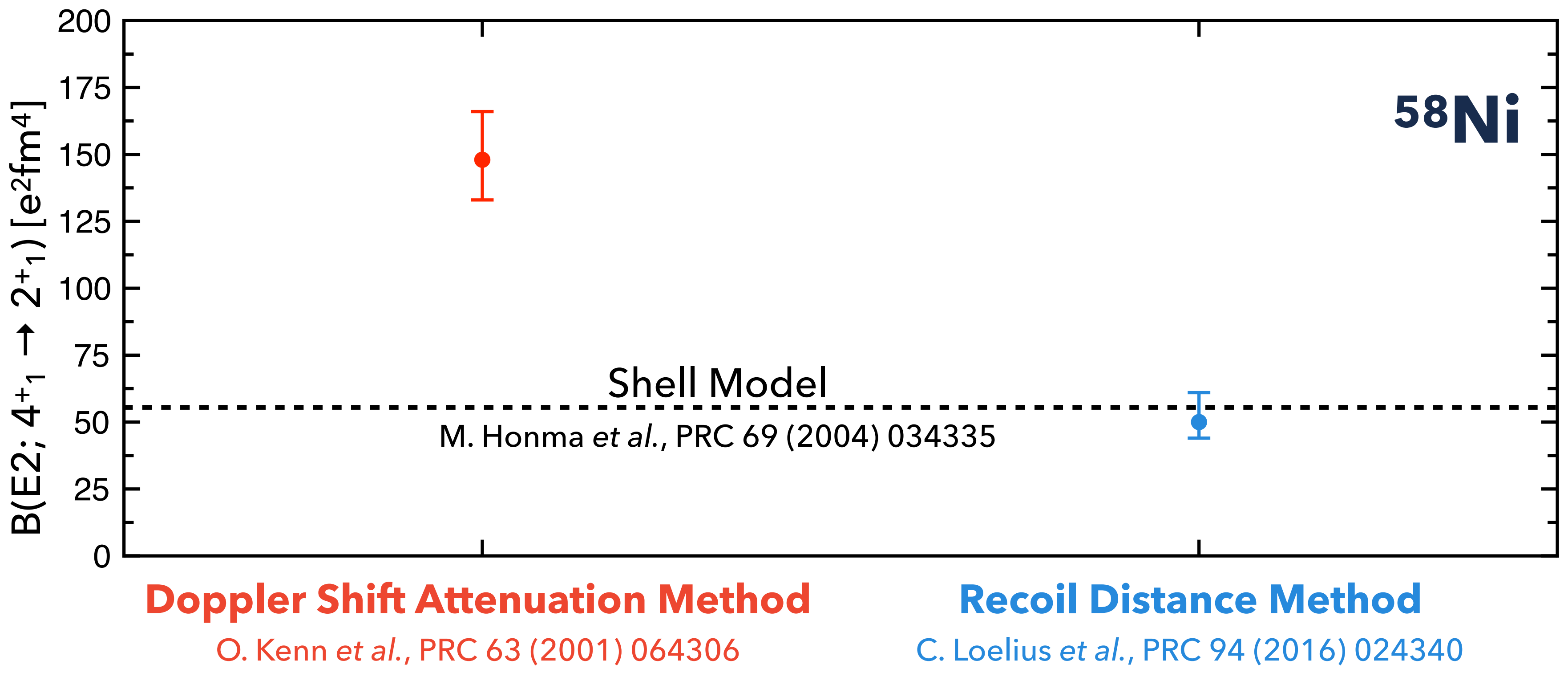


- further and more precise experimental data in order to better quantify the role of core-excitations in ^{56}Ni and the arising collectivity in nuclei close to it.
- ^{58}Ni has been suggested as the perfect candidate - only two valence neutrons outside the ^{56}Ni core

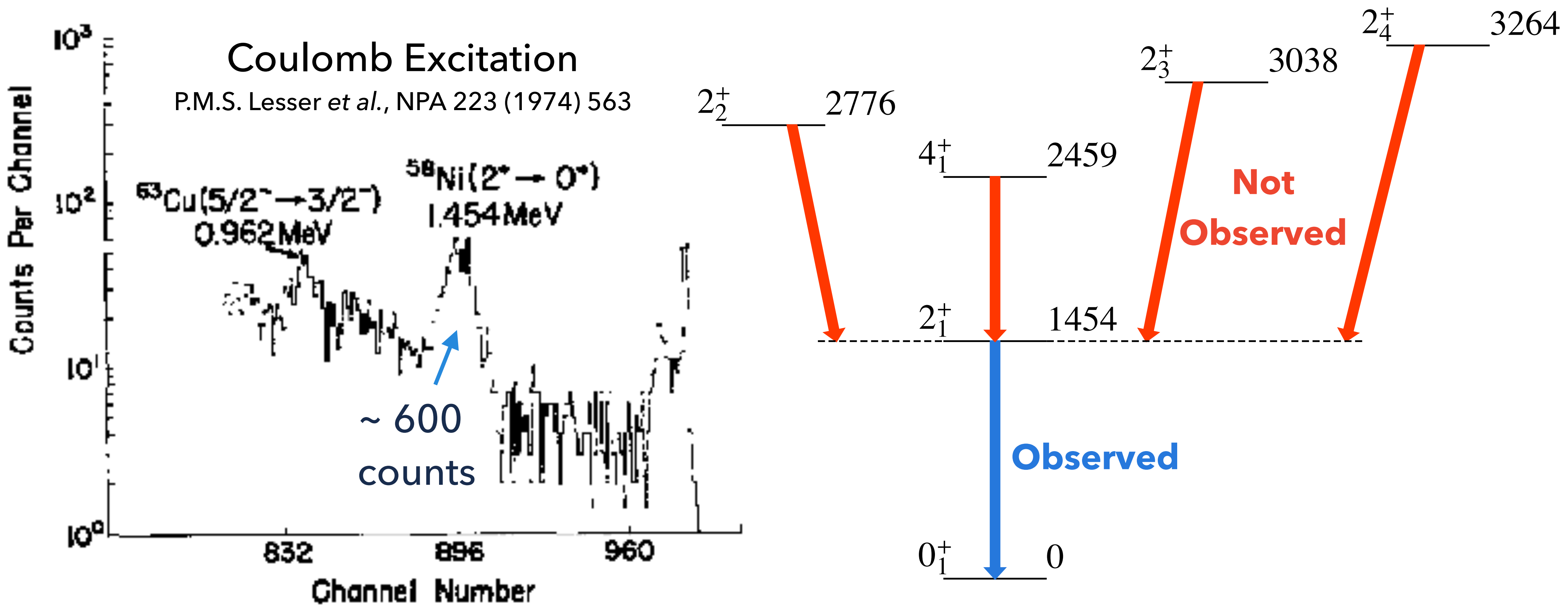
Coulomb Excitation of ^{58}Ni (2020)

- INFN-LNL
- Coulex @LNL
- ^{42}Ca - results
- SPIDER
- First Experiment: ^{66}Zn
- **Next Experiments:** ^{94}Zr, ^{116}Sn, ^{130}Xe, **^{58}Ni**
- Future Perspectives

- DSAM measurement 3 times larger than SM prediction ⟹ Underestimation of core excitations (also confirmed by the positive value of $g(2^+_1)$)
- New RDM measurement resolves the discrepancy and suggest much less collectivity
- No evident reasons to prefer one of the two measurements ⟹ <u>Third measurement will help to understand the relevance of core excitations and collectivity</u>



- Only 1 measurement: neither possible to observe higher-lying states nor to perform a differential cross-section measurement ⟹ $Q_s(2^+_1)^{exp} = -10\ (\pm 6\ ^{stat} \pm 7.5\ ^{sys})\ efm^2$

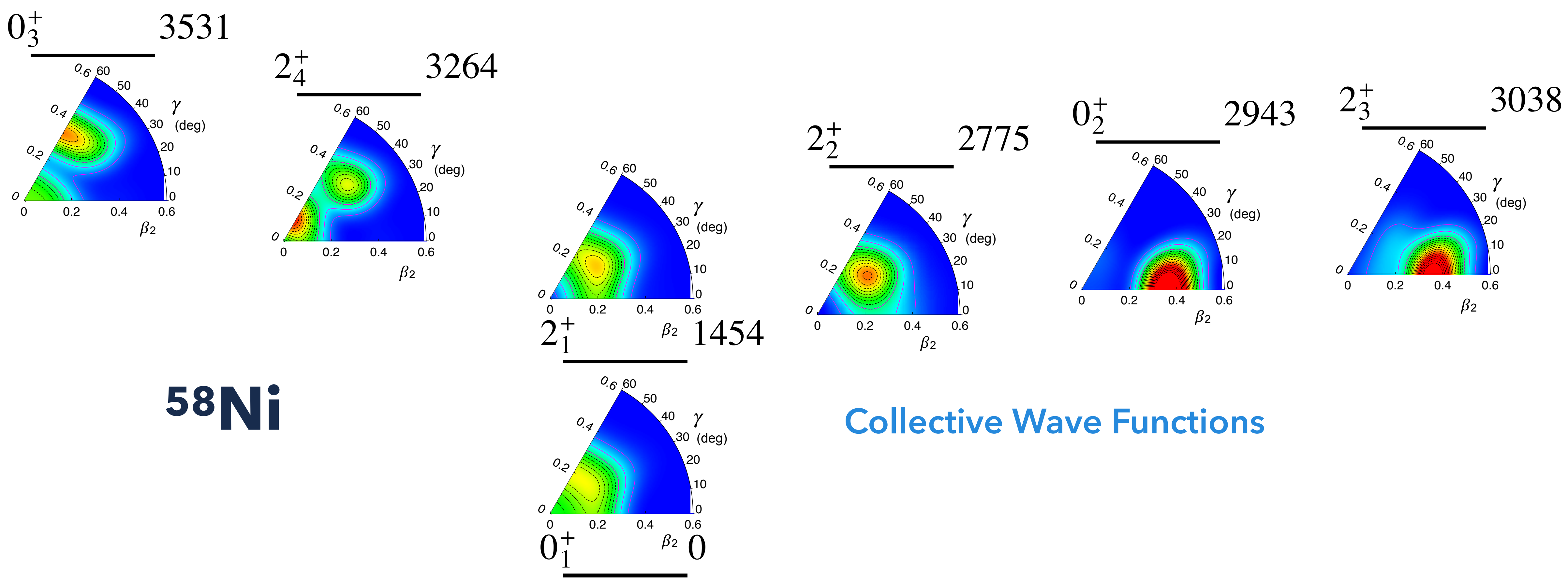


Coulomb Excitation of ^{58}Ni (2020)

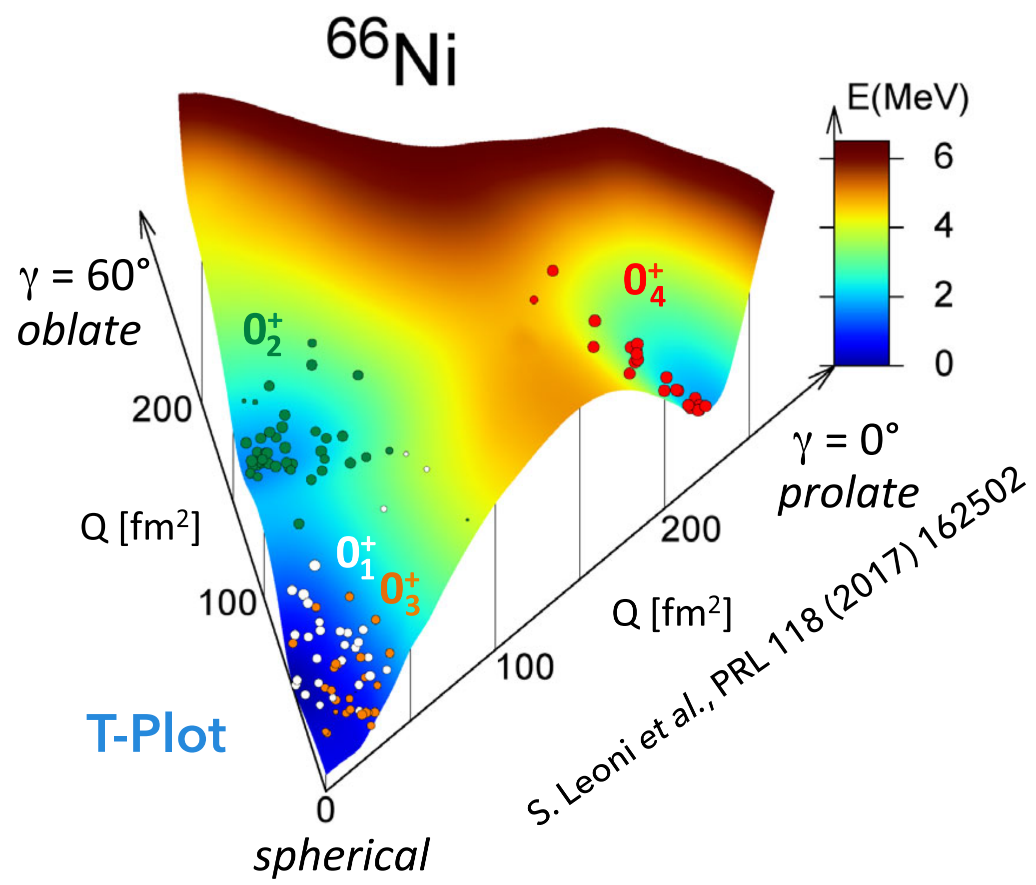
Proposal: M. Rocchini (INFN Firenze), KHK (ŚLCJ UW), A. Nannini (INFN Firenze)

- INFN-LNL
- Coulex @LNL
- ^{42}Ca - results
- SPIDER
- First Experiment: ^{66}Zn
- **Next Experiments:** ^{94}Zr, ^{116}Sn, ^{130}Xe, **^{58}Ni**
- Future Perspectives

- Beyond-Mean-Field calculations in ^{58}Ni by T. Rodríguez



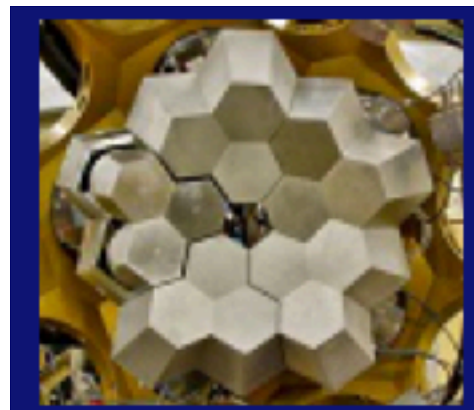
- Conventional and Monte Carlo Shell Model can be applied:
  - Variety of spherical and deformed states in ^{66}Ni predicted by MCSM, consistent with a recent lifetime measurement



- **How important are core-excitations in ^{58}Ni? Which is the nature of its low-lying states?**
- Quantities to be measured:
  - $B(E2; 4^+_1 \rightarrow 2^+_1)$
  - $Q_s(2^+_1)$
  - $Q_s(2^+_2)$ (and $Q_s(2^+_3)$, $Q_s(2^+_4)$)
  - Relative signs for matrix elements connecting 2^+ states to 0^+ states, to deduce deformation of $0^+_{g.s.}$, 0^+_2 and 0^+_3
  - Experiment by-product: $B(E2; 2^+_1 \rightarrow 0^+_1)$

AGATA is coming back to town

- INFN-LNL
- Coulex @LNL
- ^{42}Ca - results
- SPIDER
- First Experiment: ^{66}Zn
- Next Experiments: ^{94}Zr, ^{116}Sn, ^{130}Xe, ^{58}Ni
- **Future Perspectives**



Workshop AGATA@LNL for stable beams

25-26 March 2019
INFN-LNL
Europe/Rome timezone

AGATA Efficiency

Nominal and compact positon position (-10 cm) at 1,3 MeV considering a reaction chamber of Al 4 mm.

Start of the camapign with 20TC. By the end of the campaign with 30TC.

Configuration	Nominal position	Compact position
20TC	8.8%	13.9%
30TC	13.6%	19.0%

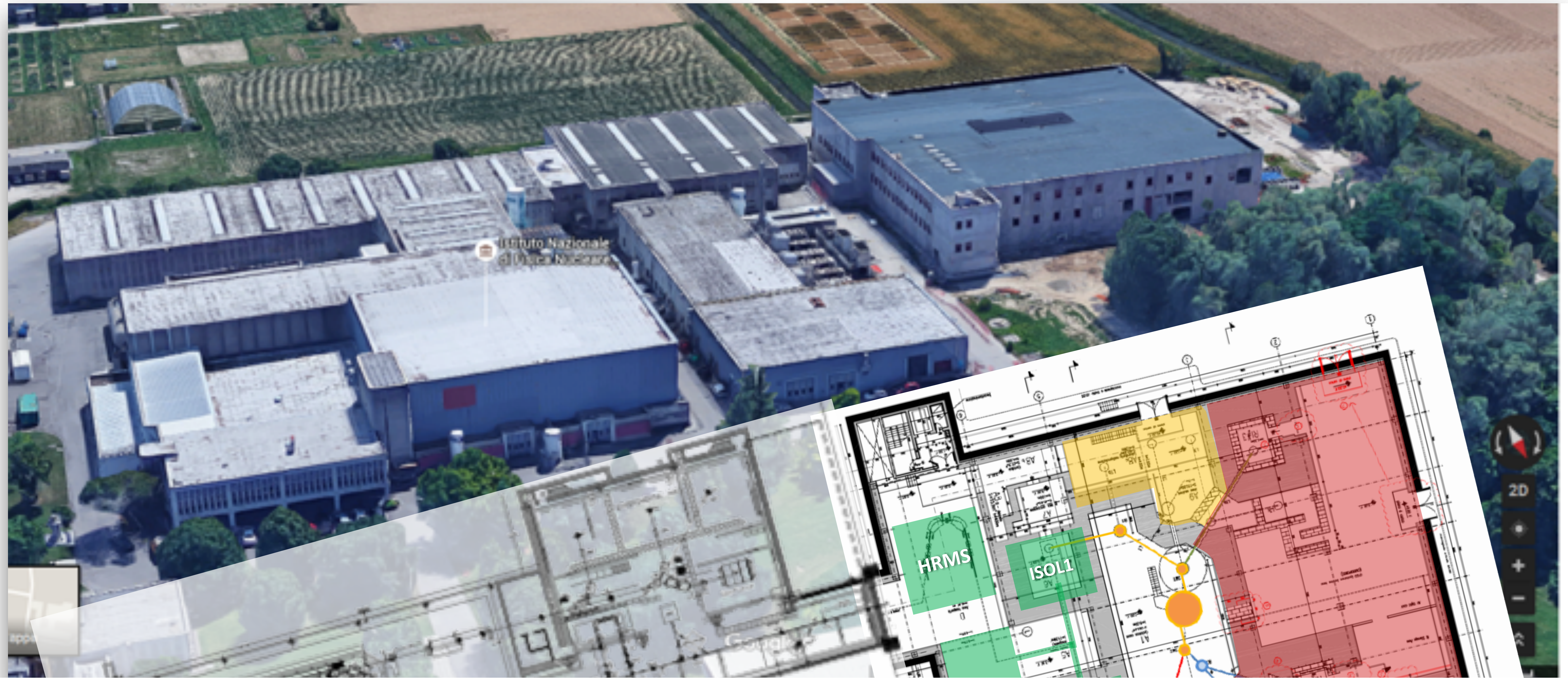
Complementary detectors

- PRISMA vacuum mode, angular coverage 80 msr, from Theta=20º to 100º.
- EUCLIDES silicon det. (with beam absorbers) Eff_p = 60% Eff_alpha = 25%
- EUCLIDES plunger configuration (with beam absorbers) Eff_p = 25% Eff_alpha = 15%
- TRACE highly-segmented silicon det. (up to four modules) E-DE with PSA for light charged particles at least up to Oxygen - 22 degrees angular coverage each.
- Plunger (grazing and zero degrees configuration): range 7 micrometers to 1.2 cm
- LaBr (3''x3'') 10 detectors Eff (1.3 MeV) = 2.3%
- LaBr (3.5''x8'') 10 detectors Eff (1.3 MeV) = 3%
- NEDA Eff_1n = 27% Eff_2n = 2.8%
- SPIDER Coulex detector backward angles, angular coverage 124-165 degrees
- PARIS 8 clusters – Efficiency curve attached.
- Mini-orange Si-Li: resolution ~3-4KeV @1MeV, efficiency about 16% in the range of 800-2500 keV. Efficiency at lower energy (200-800 keV)10% (estimated).
- Recoil Filter Detector: 18 HI detectors, efficiency 20-50 % depending on the reaction, TOF determination of evaporation residua (required pulsed beam as a time reference), variable distance from the target (1m-1,50m), theta angular coverage 2-7 deg. (at 1,3m from the target).

Many ideas, many projects
AGATA will be back at LNL in 2021

Radioactive beams at INFN LNL – Selective Production of Exotic Species

- INFN-LNL
- Coulex @LNL
- ^{42}Ca - results
- SPIDER
- First Experiment: ^{66}Zn
- Next Experiments: ^{94}Zr, ^{116}Sn, ^{130}Xe, ^{58}Ni
- **Future Perspectives**



- Next generation ISOL-type accelerator facility aimed to develop RIB
- BEST cyclotron: 2 exits – 2 proton beams feeding 2 targets at the same time, max 70 MeV
- Proton beam of 40 MeV, 0.2mA on multi-foil Uranium Carbide (UCx) target designed to sustain 10kW beam power to reach 10^3 f/s
- Once ionized and mass-selected RIB is boosted and re-accelerated using ALPI
- New and existing upgraded experimental experimental stations

Courtesy: M. Rocchini

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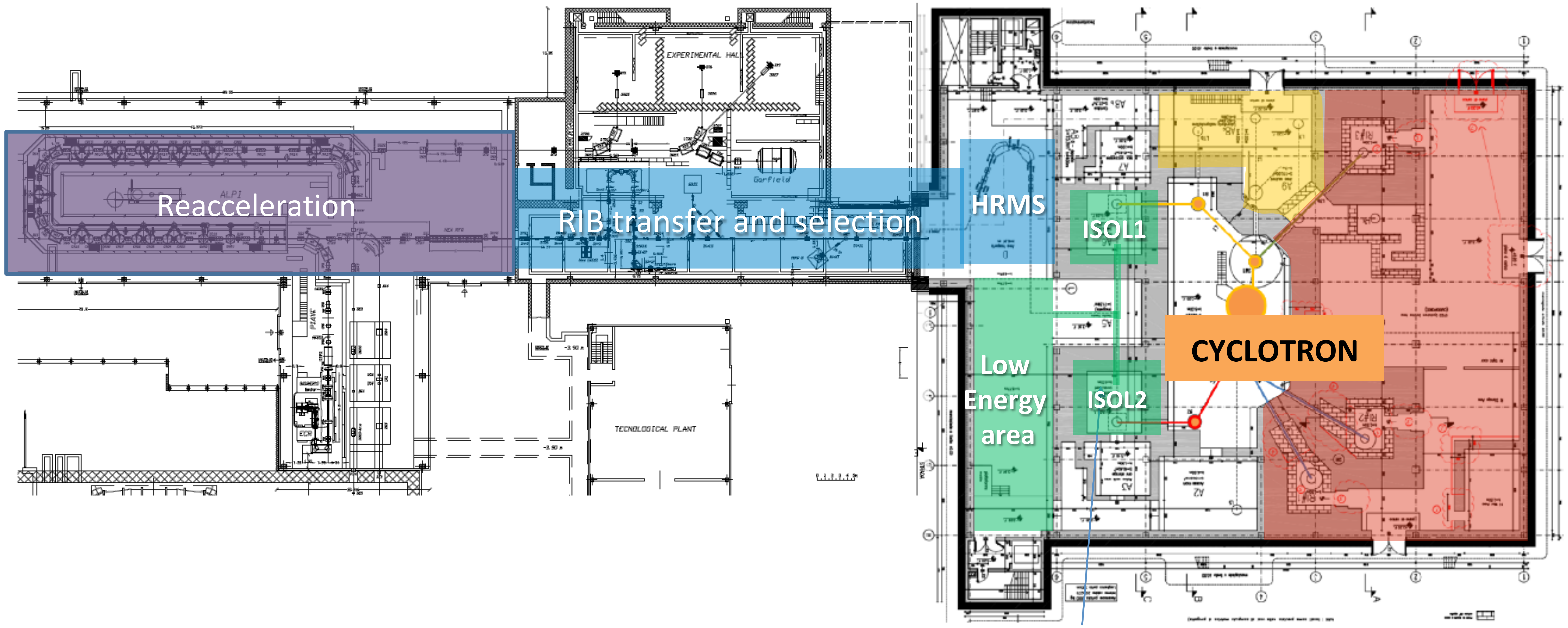

RIB reacceleration:

- new RFQ
- ALPI

1/20.000 Mass separator (Beam Cooler + HRMS)
Electrostatic beam transport
Charge Breeder (n+)
1/1000 mass separator

ISOL bunkers
1/200 mass separator
low energy experimental area

Radioisotopes production area

Courtesy: A. Nannini

SPES at INFN LNL

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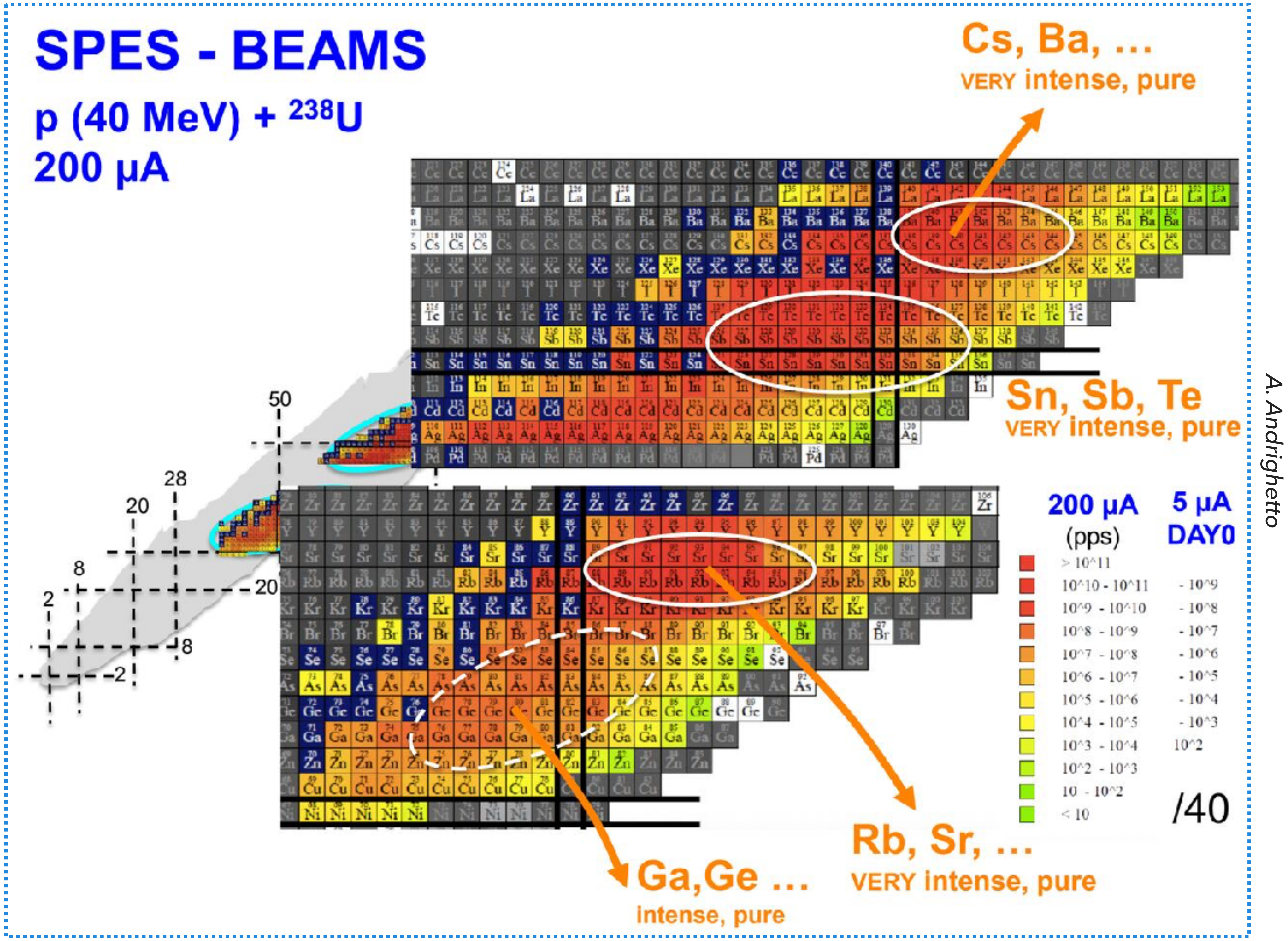

SPES at INFN LNL

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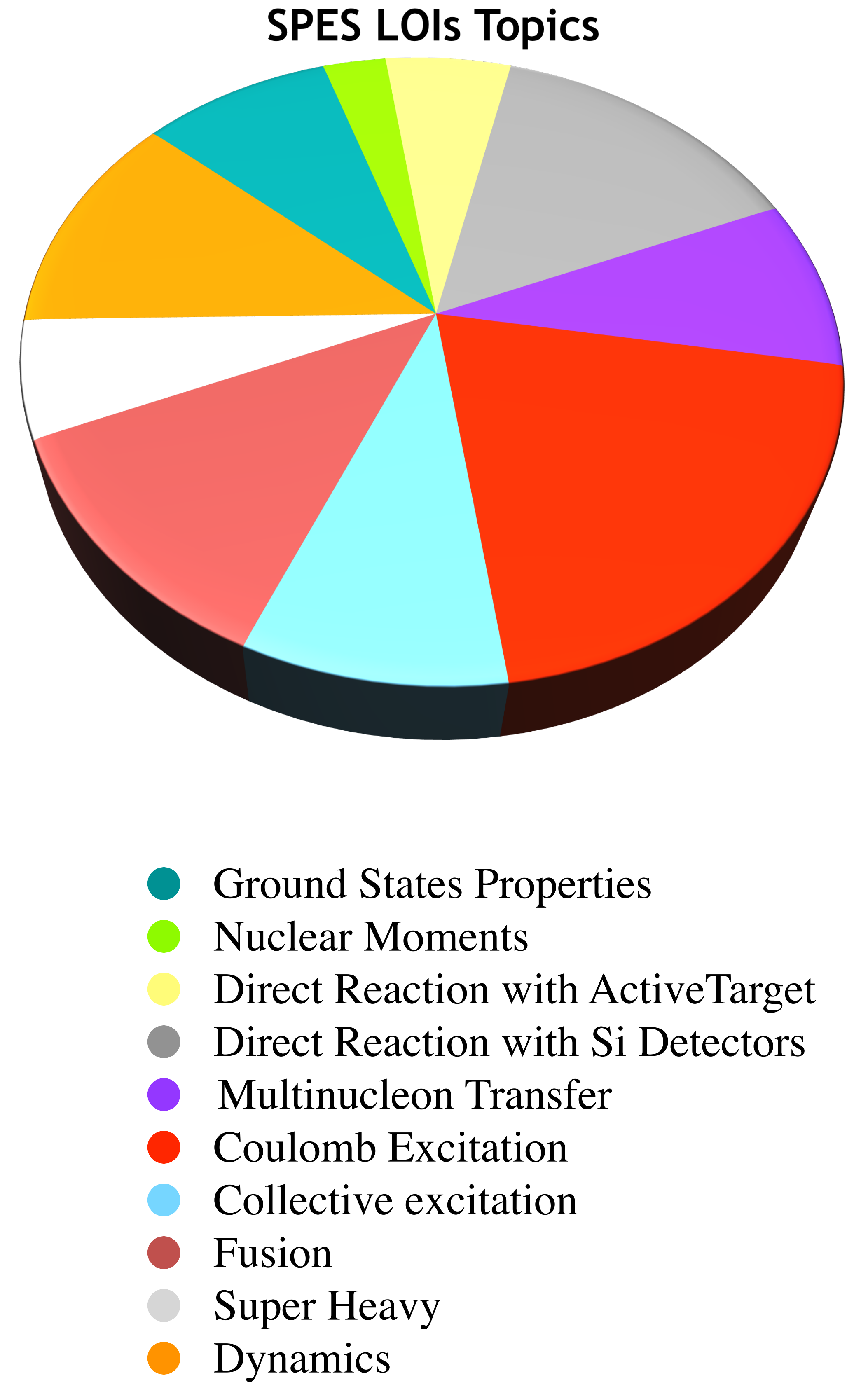
SPES International Workshop: 47 Letter of Intents



Courtesy: A. Nannini

- Exploring shape coexistence, triaxiality and configuration mixing in ^{90,92}Kr (KHK, M. Zielińska)
- Coulomb-excitation measurements in nuclei around ^{132}Sn – ^{135}Sb, ^{126,128}Cd (INFN Firenze, INFN Napoli, CEA Saclay)
- Search for Exotic-Octupole deformation effects in n-rich Ce-Xe-Ba Nuclei (University of Oslo, INFN LNL)
- Proton-neutron balance of quadrupole-collective states of even-even n-rich Isotopes (TU Darmstadt)
- Shape coexistence in Kr isotopes towards N = 60 (INFN LNL)
- Spectroscopy studies around ^{78}Ni and beyond N=50 via transfer and Coulomb excitation reactions (INFN LNL)

The future is bright… and busy

Special thanks to SPIDER collaboration:

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