MAGNEX@LNS

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LNS Users Committee
6 December 2013

Working group in Catania

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Collaborations on specific subjects

1. *IN2P3 –IPN, Orsay, France*
2. *IFUSP, Sao Paolo, Brazil*
3. *IFUFF- Niteroi, Brazil*
4. *TRIUMF, Vancouver, Canada*
5. *INFN- Sez. Padova, Pisa, Napoli*
6. *University of Joannina, Greece*
7. *University of Huelva, Spain*
8. *University of Osaka*
9. *University of Casablanca, Morocco*
10. *University of Notre-Dame, USA*

MAGNEX: a multipurpose device

Nuclear rainbow
Brasil, Italy

Pairing correlations
Italy, France, Brasil

α-Clustering
Brasil, Italy, USA

Nuclear break-up
Greece, Italy, Spain

Giant monopole by FRIBS beams
Italy

Pick-up reactions
Italy, France, Japan

Single and double charge exchange
Italy, Japan

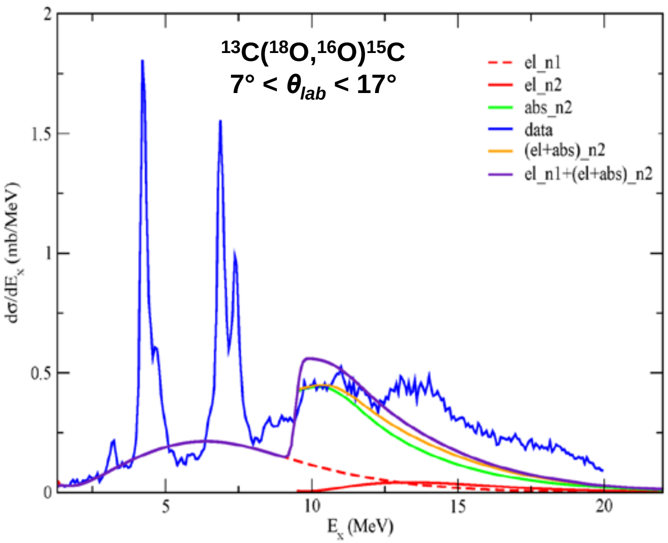
Ab initio
Canada, Italy, Brasil, Morocco

Quick and partial overview today

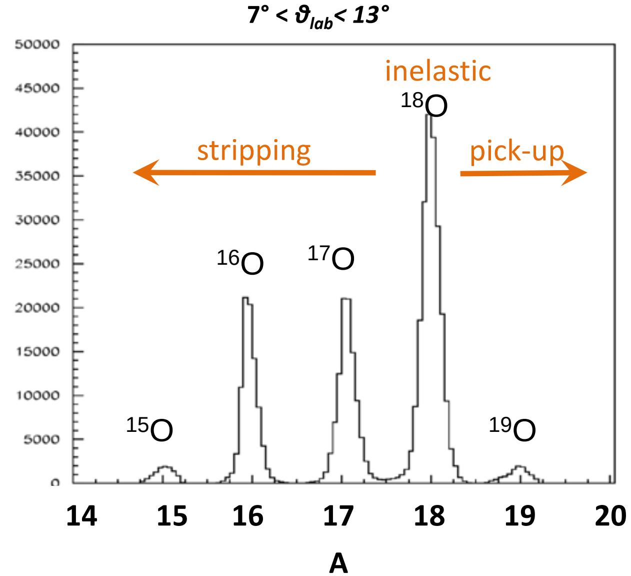
Pairing correlations
Italy, France, Brasil

Some mature activity

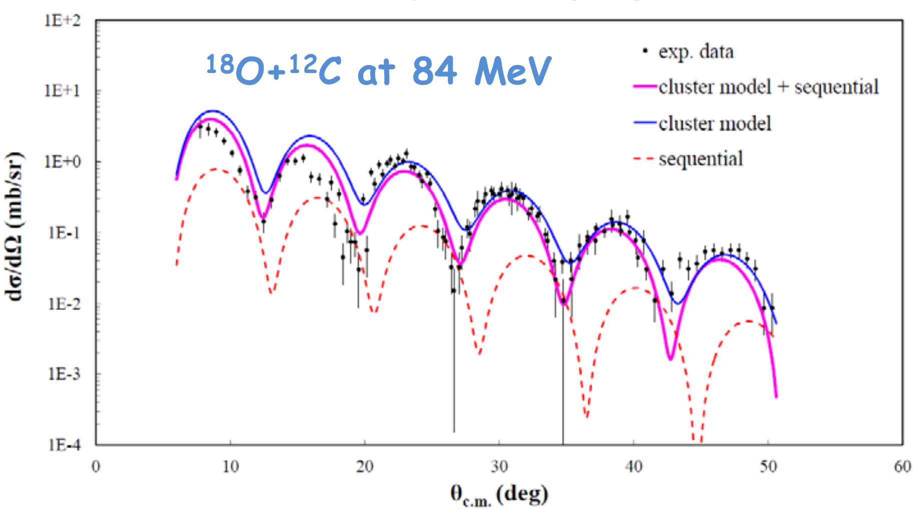
F.Cappuzzello, et al., Phys. Lett.B 711 (2012) 347-352



$^{18}O+^{13}C$ at 84 MeV



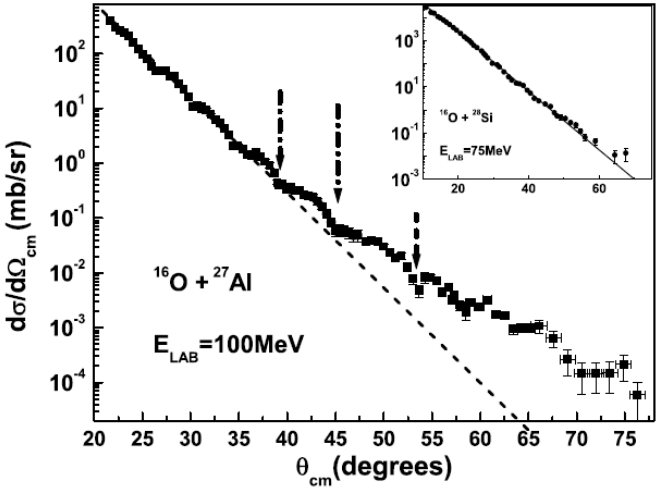
M.Cavallaro, et al., Phys.Rev.C 88 (2013) 054601



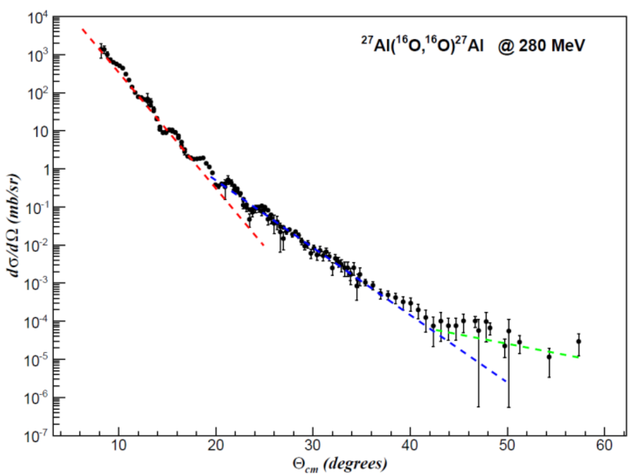
- ✓ Several experiments performed (100%)
- ✓ Analyses almost completed (80%)
- ✓ Publication step (30%)
- ✓ Major physics output: **discovery of the GPV**, determination of **pair spectroscopic factor**

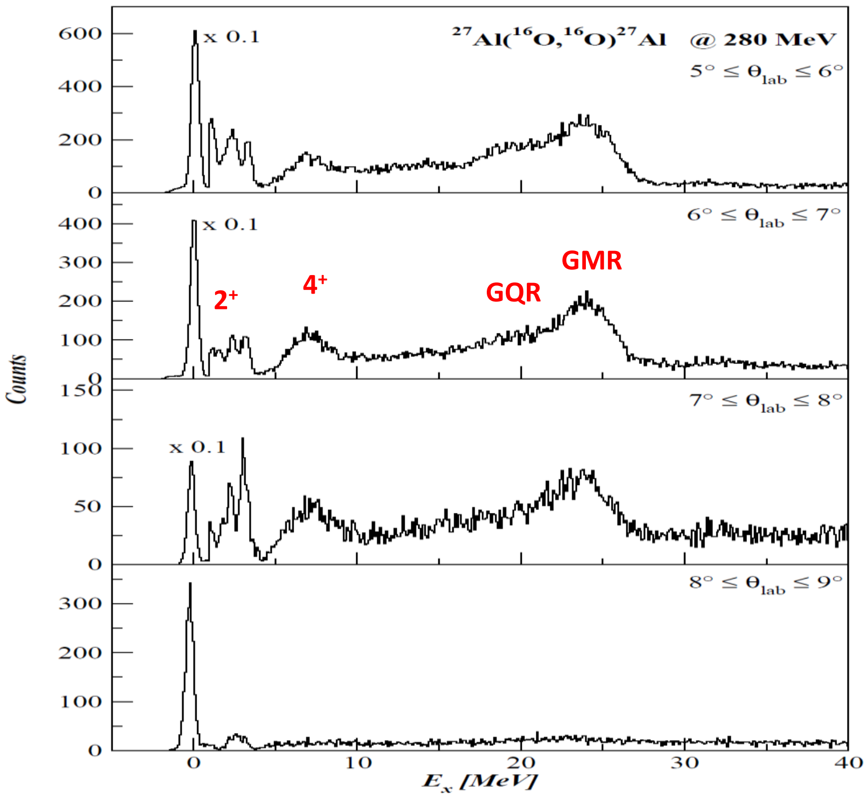
Nuclear rainbow
Brasil, Italy

Some mature activity



M.Cavallaro et al NIMA (2011) 648 (2011) 46-51
D.Pereira et al. PLB 710 (2012) 426
J.R.B.Oliveira et al. JPG 40 (2013) 105101





- ✓ Several experiments performed (70%)
- ✓ Analyses almost completed (70%)
- ✓ Publication step (40%)
- ✓ Major physics output: **discovery of the nuclear rainbow in heavy nuclei**
- ✓ Major technological achievement: **high resolution measurement with CS**

α-Clustering
Brasil, Italy, USA

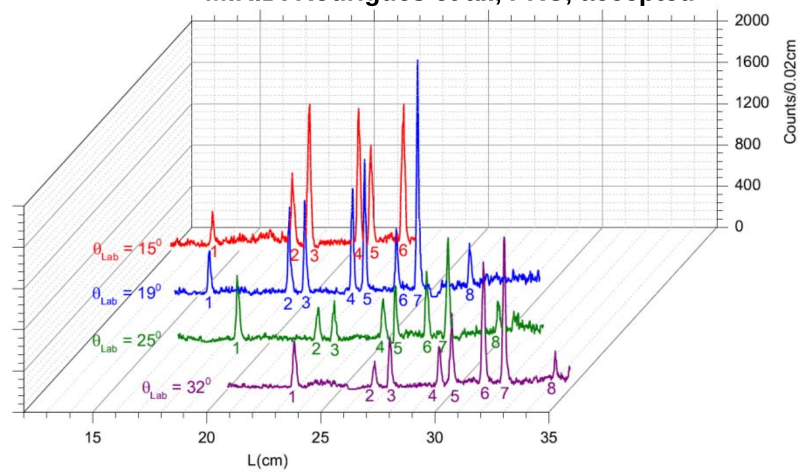
Some novel activity

Qualifying aspect: 15 keV energy resolution thanks to the Split-Pole to be compared to values of at least 100 keV in literature

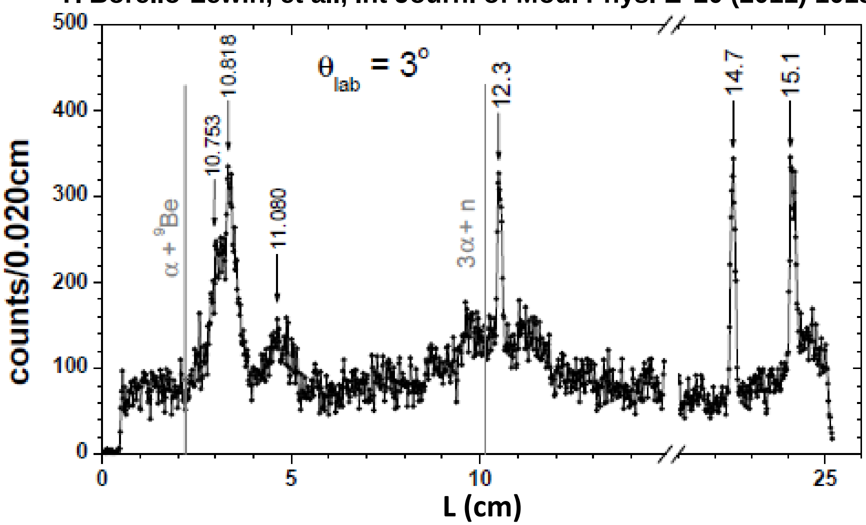
Started at LAFN Pelletron

- $^{12}C(^{6}Li,d)^{16}O$ done
- $^{13}C(^{6}Li,d)^{17}O$ done
- $^{9}Be(^{6}Li,d)^{13}C$ done
- $^{11}B(^{6}Li,d)^{15}N$, new run in september 2013

M.R.D. Rodrigues et al., PRC, accepted



T. Borello-Lewin, et al., Int Journ. of Mod. Phys. E 20 (2011) 1018



- ✓ Major discovery: **experimental widths are much smaller than reported in lieterature!**
- ✓ **α-clustering needs to be revised**

At INFN-LNS Catania

α-Clustering
Brasil, Italy, USA

Qualifying aspect:

- Wide incident energy range (up to 80 MeV)
- Large acceptance (50 msr)
- Good energy resolution (1/1000)
- Coincidence detection of reaction products

(^{6}Li,d) reactions as probes

Approved experiments at LNS:
^{90}Zr(^{6}Li,d)^{94}Mo and ^{12}C(^{6}Li,d)^{16}O at 40 MeV
February 2014

(α,α') reactions as probes

The ^{94}Mo(α,α´) experiment approved by LNS PAC and foreseen in 2014-2015

Ab initio

Canada, Italy, Brasil, Morocco

A new research program on fundamental nuclear forces

- C. Agodi, M. Bondì, F. Cappuzzello, D. Carbone, M. Cavallaro, A. Cunsolo, M. De Napoli, A. Foti, D. Nicolosi, S. Tropea
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- L. Chamon, P.R.S. Gomes, R. Linares, J. Lubian, J.R.B. Oliveira
- *Instituto de Fisica Nuclear, Universidade de Sao Paulo, Brasil*
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- M. L. Bouhssa, A. Khouaja, J. Inchaouh, A. Morsad, H. Chakir, S. Ouaskit
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Ab initio
Canada, Italy, Brasil, Morocco

A new puzzle in nuclear physics

S. Bacca et al., PRL 110 (2013) 042503

^{4}He 0$^+$ resonance at 20.29 MeV

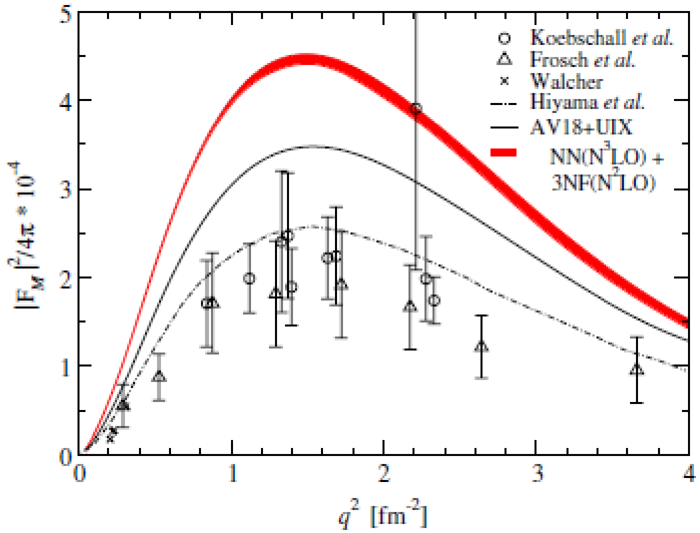


FIG. 1 (color online). Theoretical transition form factor $|F_{\mathcal{M}}(q^2)|^2$ with $G_E^n = 0$ calculated with various force models: AV18 + UIX (full line), N^{3}LO + N^{2}LO (red band), result from Ref. [17] (dot-dashed line). Data from Frosch *et al.* [10], Walcher [4], and Köbschall *et al.* [11].

Very different form factors !

^{4}He 0$^+$ ground state

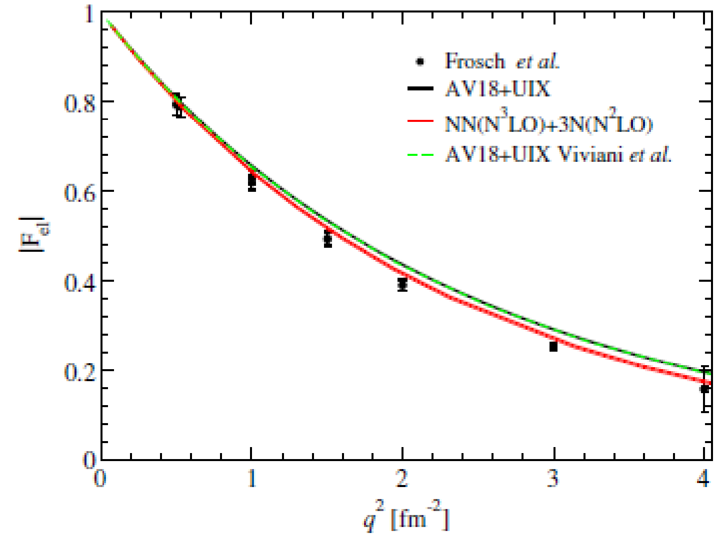


FIG. 2 (color online). Elastic form factor $|F_{\rm el}(q^2)|$ of ^{4}He calculated with various force models: AV18 + UIX (full line), N^{3}LO + N^{2}LO (red band), result from Ref. [21] with AV18 +UIX (dot-dashed line). Data from Frosch *et al.* [36].

Very similar form factors

Best Hamiltonians largely deviate from ^{4}He(e,e')^{4}He* data !!

Ab initio
Canada, Italy, Brasil, Morocco

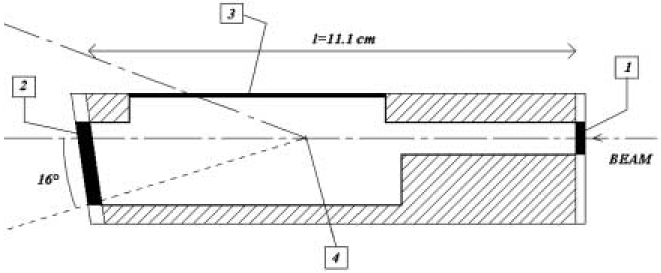
What we propose to do

Studying the $^4He(^4He,^4He)^4He^*$ reaction at 55 MeV

Main tools

- Superconducting Cyclotron beam

- Gaseous target



and implanted ^4He + Ta target

- MAGNEX spectrometer at forward angles (θ_{CM} = 0° – 30°)

Ab initio
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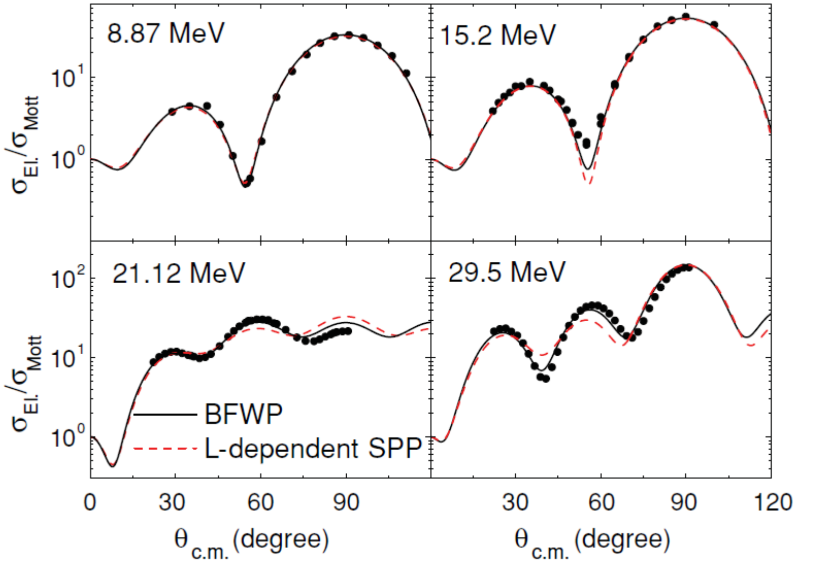
Extracting the form factors

- Measuring the elastic and inelastic cross sections
- Determining the distorted waves by Coupled Channel analysis
- Using the Sao Paulo double folding optical potential
- Extracting the form factors
- Expected accuracy 10 - 20%

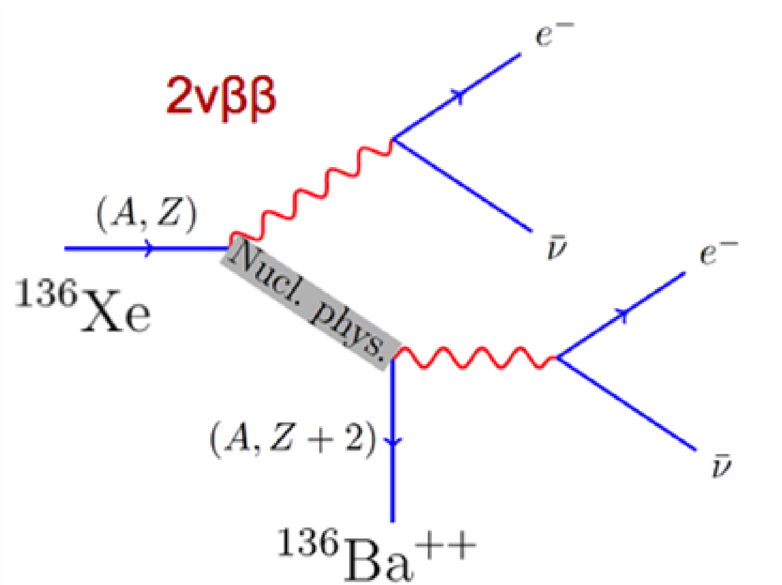
$^4He + {}^4He$ elastic scattering



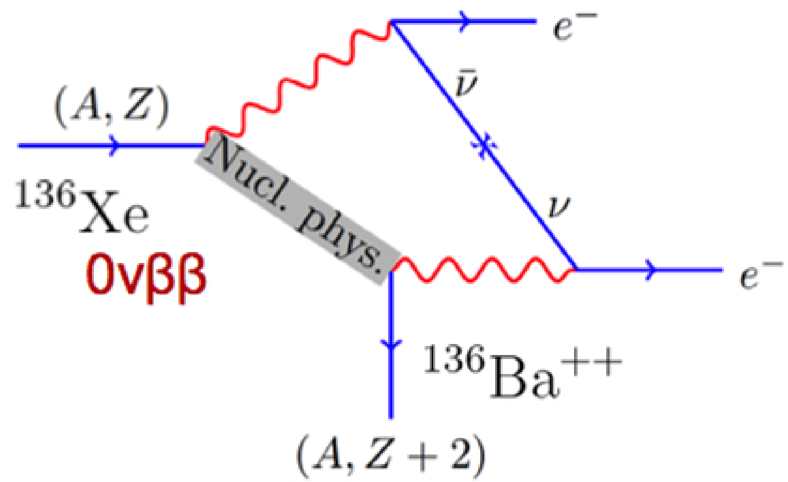
*L.C.Chamon et al PRC **83**, 034617 (2011)*

Single and double charge exchange
Italy, Japan

Double β-decay



(simple 0νββ mechanism)



A lot of new physics inside

$$T_{1/2}^{0\nu}(0^+ \to 0^+) = G_{01}\boxed{\left|M^{\beta\beta 0\nu}\right|^2}\left|\frac{\langle m_\nu \rangle}{m_e}\right|^{-2}$$

$$\langle m_\nu \rangle = \sum_i \left|U_{ei}\right|^2 m_i e^{i\alpha_i}$$

but one should know **Nuclear Matrix Element** (NME)

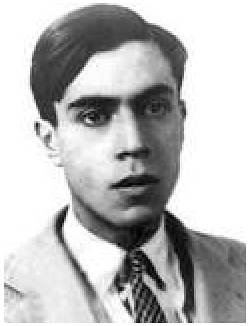
$$\left|M_\varepsilon^{\beta\beta 0\nu}\right|^2 = \left\langle 0_f \middle\| \hat{O}_\varepsilon^{\beta\beta 0\nu} \middle\| 0_i \right\rangle$$

β β-decay

1) <u>2ν double β-decay</u>

1) **Does not distinguish between Dirac and Majorana**
2) **Experimentally observed in several nuclei since 1987**

ν **and anti-ν can be distinguished**



ν **and anti-ν are the same**

2) <u>0ν double β-decay</u>

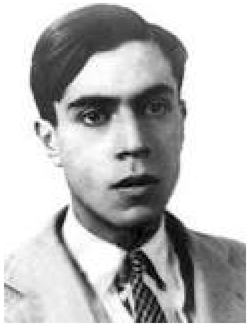
Neutrino has mass

Neutrino is Majorana particle

Violates the leptonic number conservation

Experimentally not observed

Beyond the standard model



New physics for the next decades

but

requires

Nuclear Matrix Element (NME)!

$$\left| M_{\varepsilon}^{\beta\beta 0\nu} \right|^2 = \left\langle 0_f \left\| \hat{O}_{\varepsilon}^{\beta\beta 0\nu} \right\| 0_i \right\rangle$$

- ✓ Calculations: QRPA, Large scale shell model, IBM …..
- ✓ Measurements: Network cross sections including Double Charge Exchange, Single charge exchange, transfer reactions and so on.

State of the art NME calculations

From A. Giuliani and A. Poves Adv. in High En. Phys. 2012 (2012) 857016

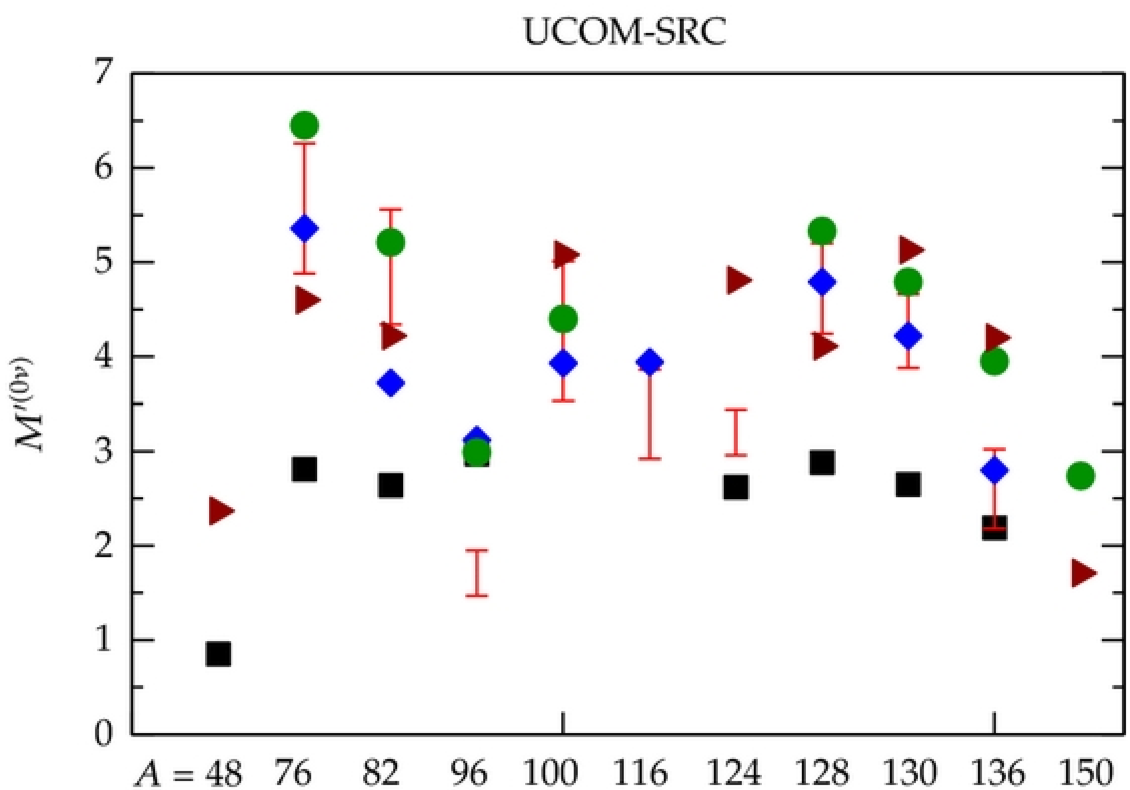


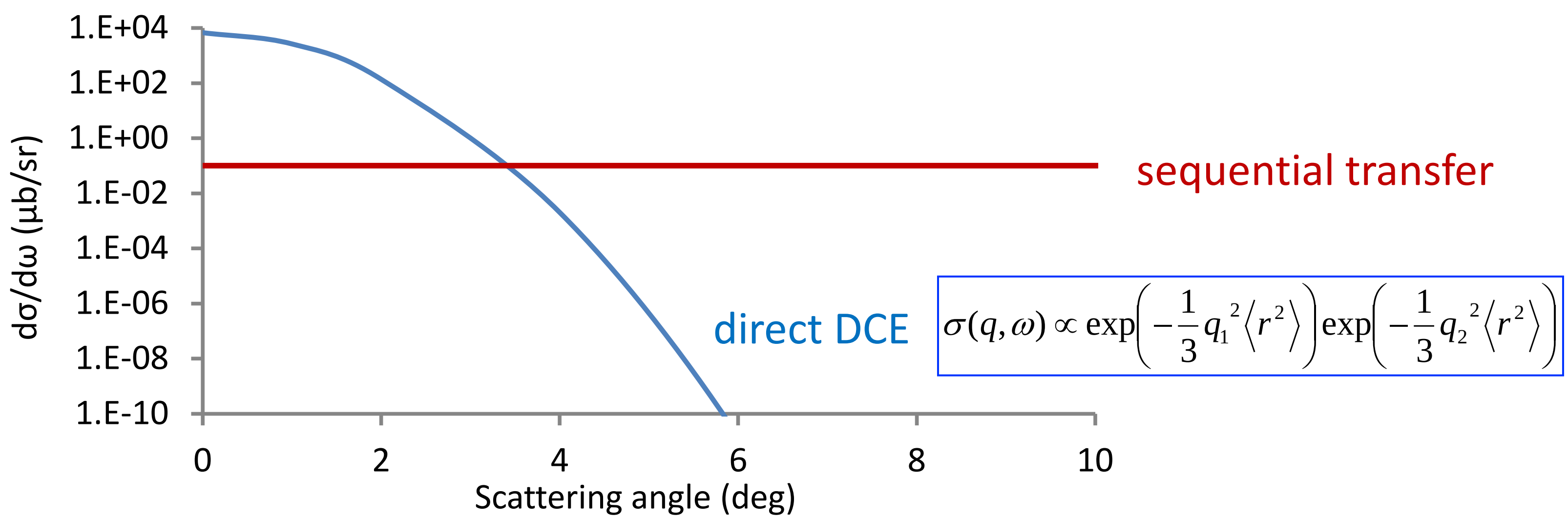
Figure 2: The neutrinoless double-beta decay; "state-of-the-art" NMEs: QRPA [30] (red bars) and [21, 22] (diamonds), ISM [31] (squares), IBM [25] (circles), and GCM [26] (triangles).

(^{18}O,^{18}Ne) DCE reactions in Catania

^{40}Ca(^{18}O,^{18}Ne)^{40}Ar @ 270 MeV

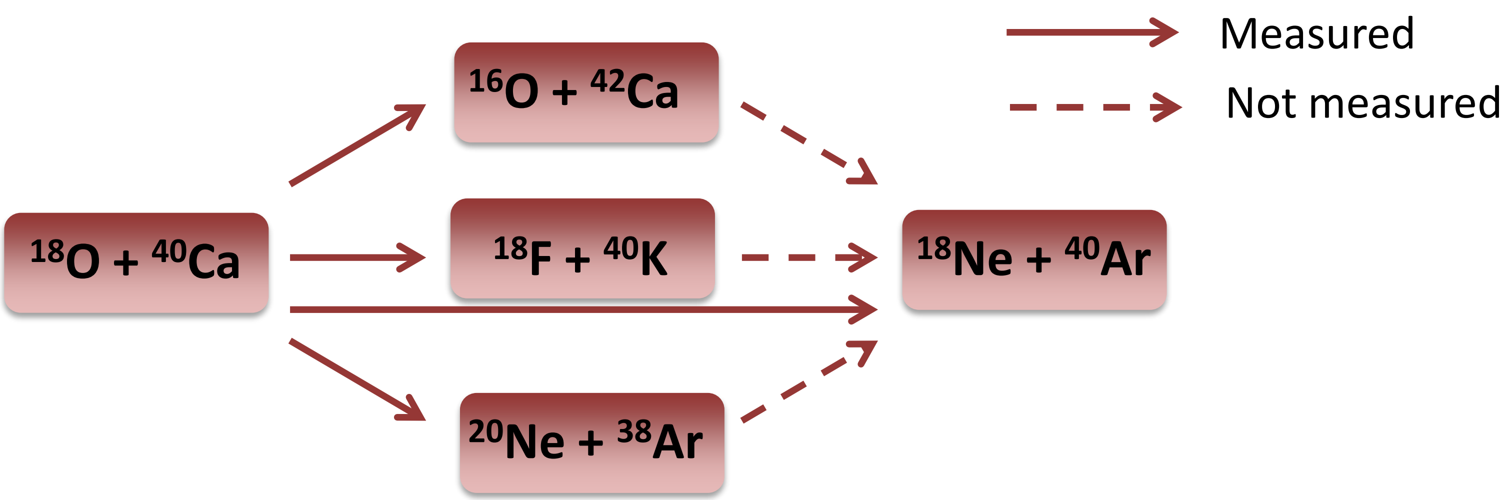
$0° < \vartheta_{lab} < 10°$ Q = -5.9 MeV

- ^{18}O and ^{18}Ne belong to the same multiplet in S and T
- Very low polarizability of core ^{16}O
- Sequential transfer processes very mismatched
- Target $T = 0$ $\longrightarrow$ only $T = 2$ states of the residual



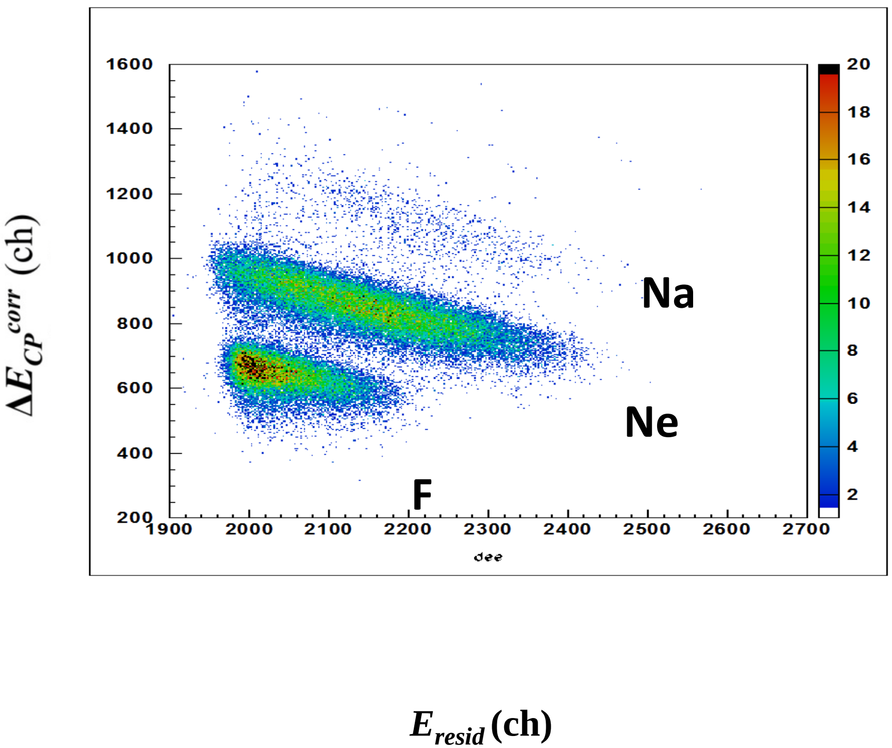
Experimental Set-up

- $^{18}O^{7+}$ beam from Cyclotron at **270 MeV (10 pnA)**
- ^{40}**Ca** solid target of 300 μg/cm^2
- Ejectiles detected by the MAGNEX spectrometer
- Angular setting $\theta_{opt} = 4° \longrightarrow \boxed{-2° < \theta_{lab} < 10°}$



Particle Identification

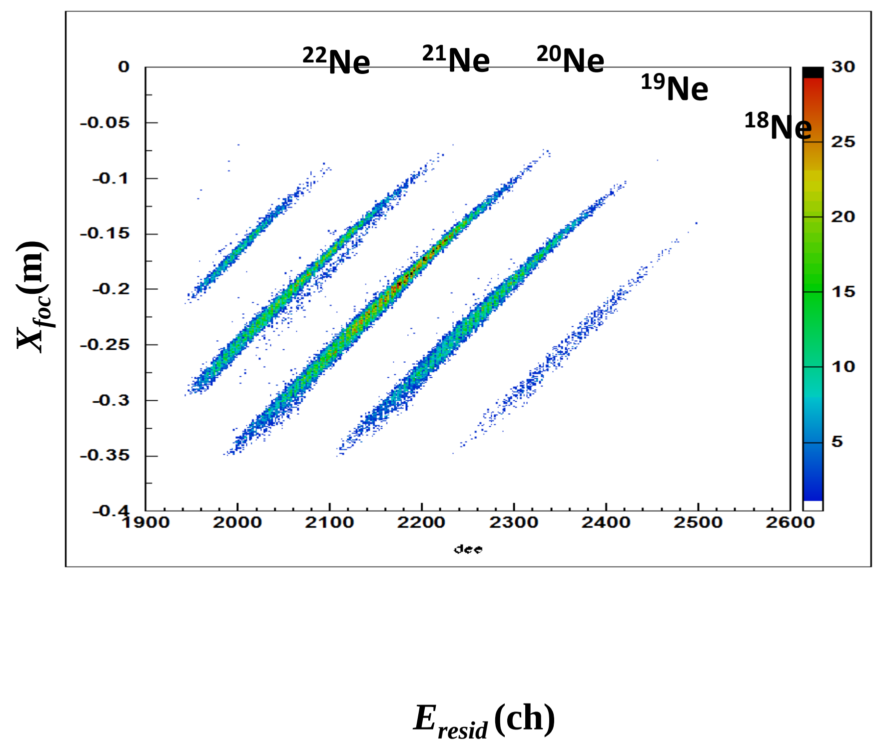
Z identification



A. Cunsolo, et al., NIMA484 (2002) 56
A. Cunsolo, et al., NIMA481 (2002) 48
F. Cappuzzello et al., NIMA621 (2010) 419
F. Cappuzzello, et al. NIMA638 (2011) 74

A identification

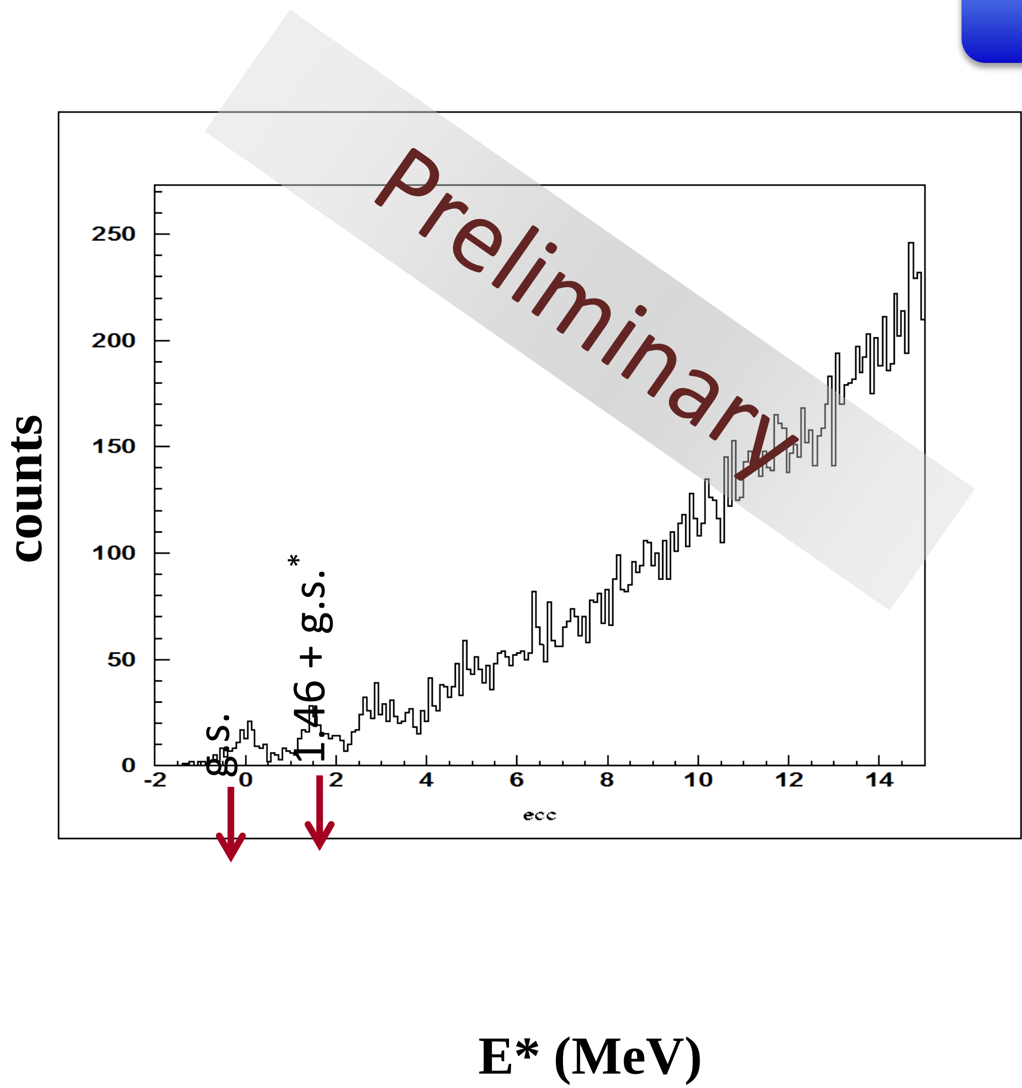
$$B\rho = \frac{p}{q} \rightarrow X_{foc}^2 \propto \frac{m}{q^2} E_{resid}$$



Preliminary spectrum of ^{40}Ar

$^{40}Ca(^{18}O,^{18}Ne)^{40}Ar$ @ 270 MeV

$0° < \theta_{lab} < 4°$

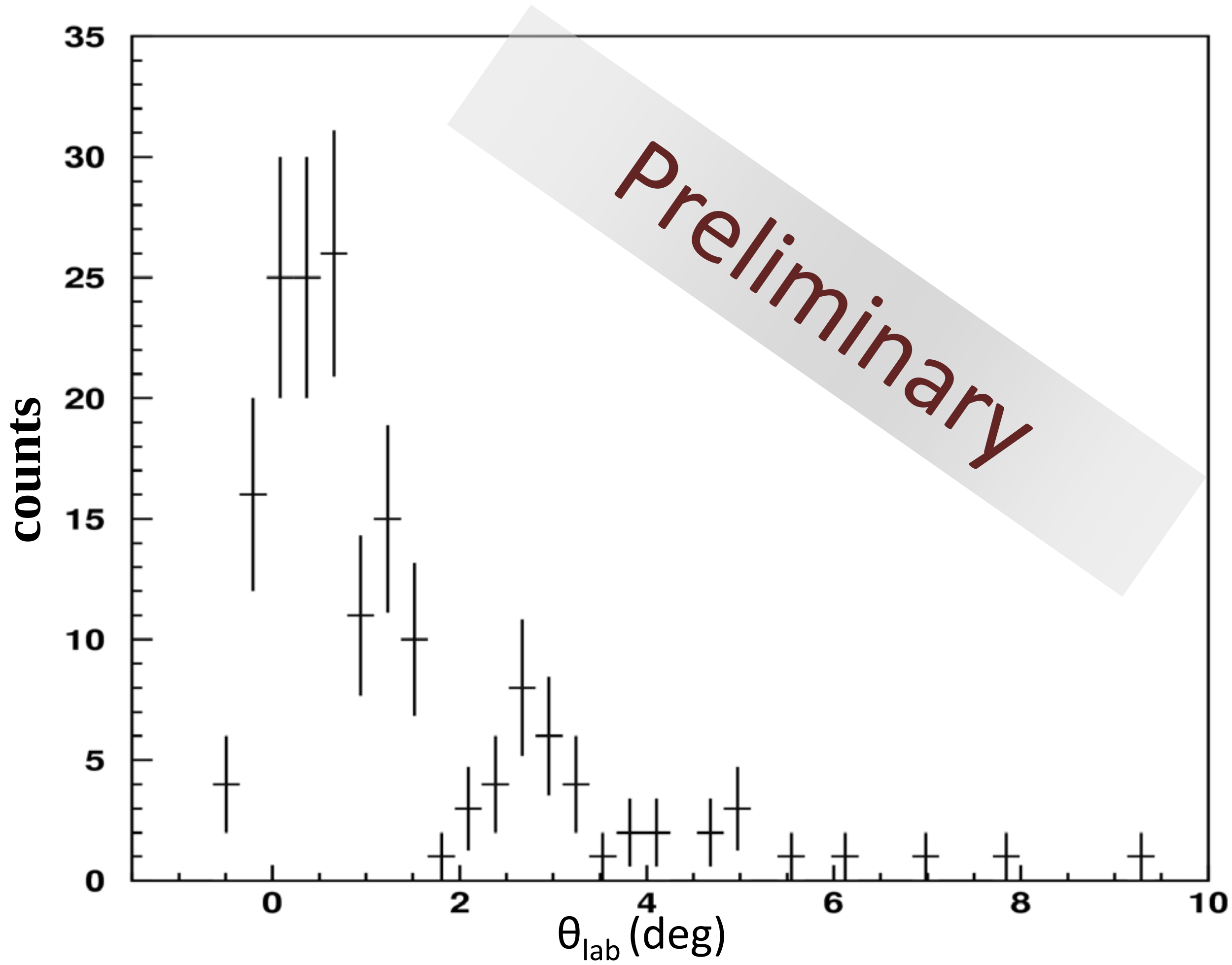


FWHM ~ 0.5 MeV

The ^{40}Ar 0^+ ground state is well separated from the first excited state 2^+ at 1.46 MeV

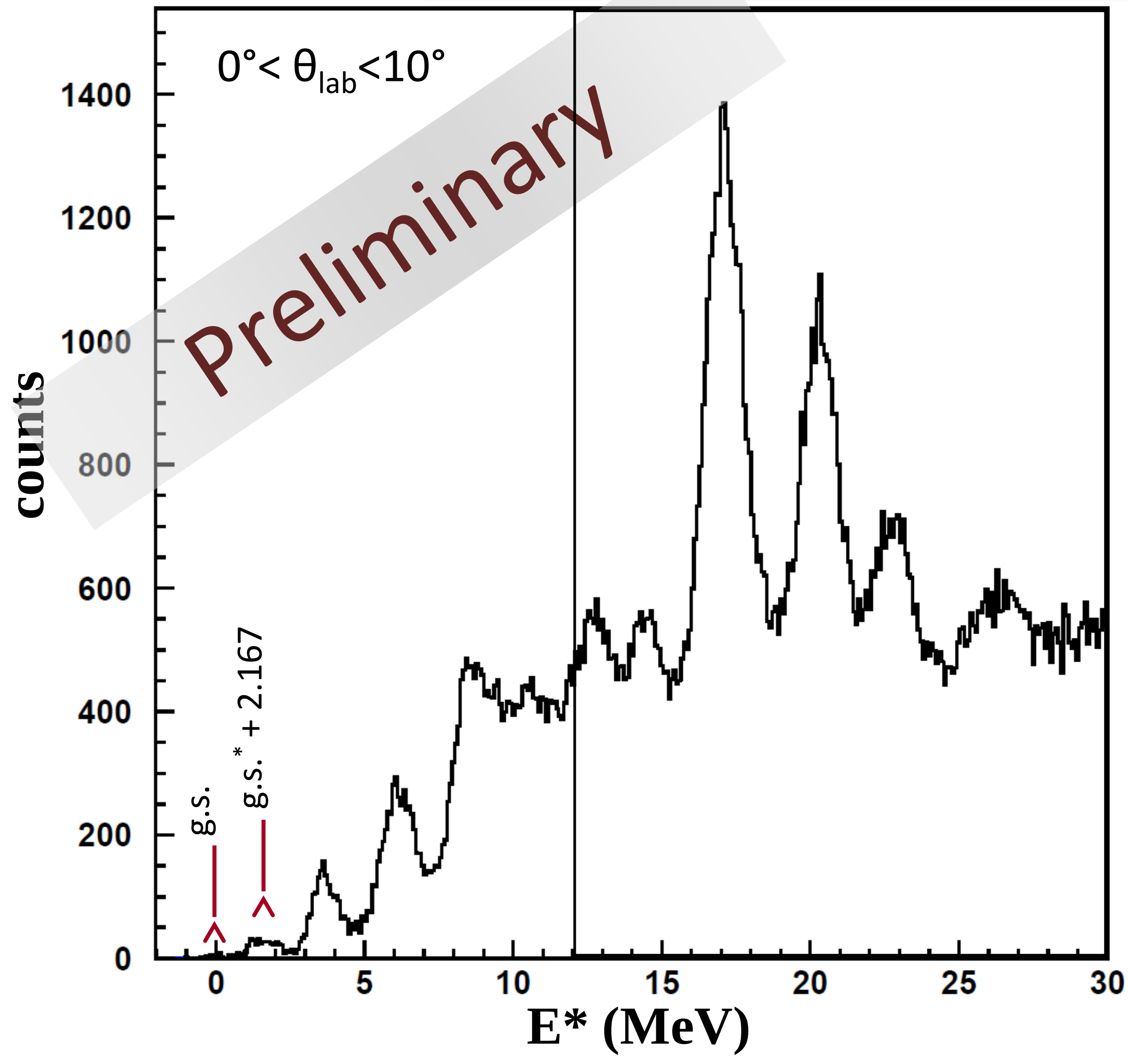
Preliminary $^{40}Ar_{g.s.}$ angular distribution

$^{40}Ca_{g.s.}(0^+)(^{18}O,^{18}Ne)^{40}Ar_{g.s.}(0^+)$ @ 270 MeV



Preliminary spectrum of 38Ar

$^{40}Ca(^{18}O,^{20}Ne)^{38}Ar$ @ 270 MeV

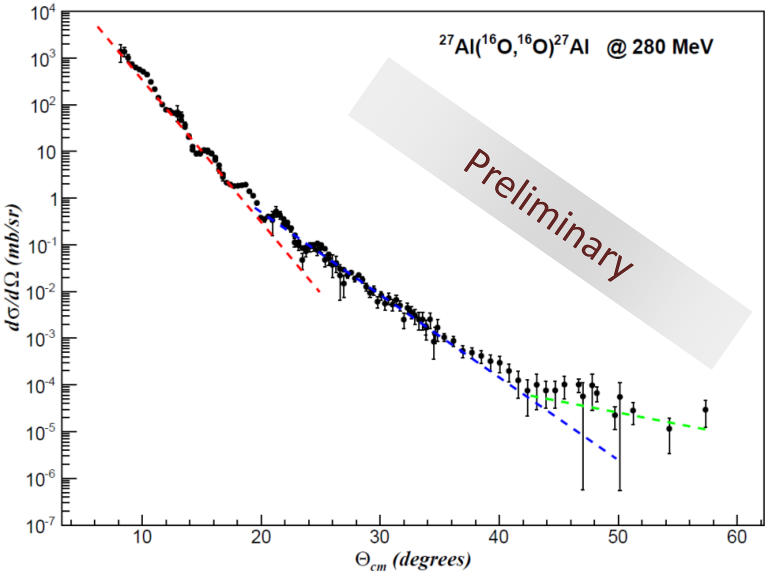


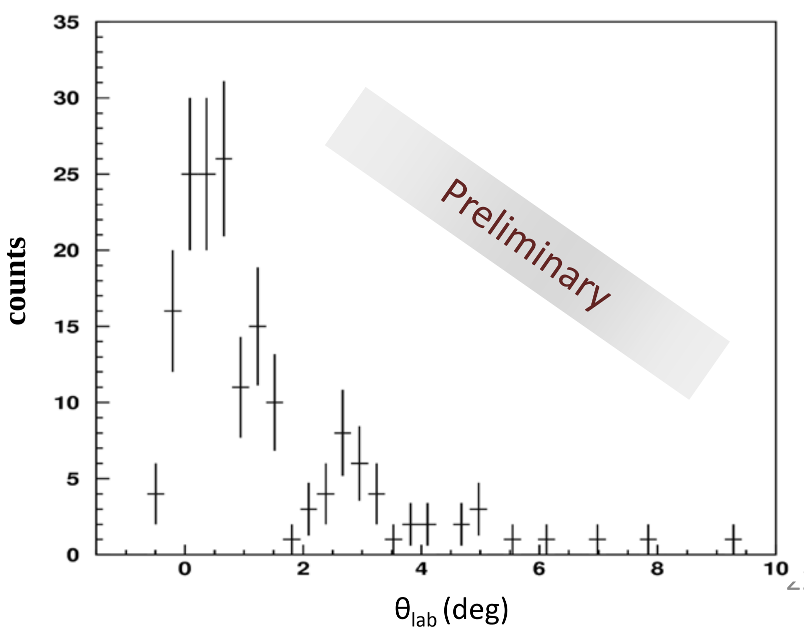
$^{16}O(^{18}O,^{20}Ne)^{14}C$

$^{12}C(^{18}O,^{20}Ne)^{10}Be$

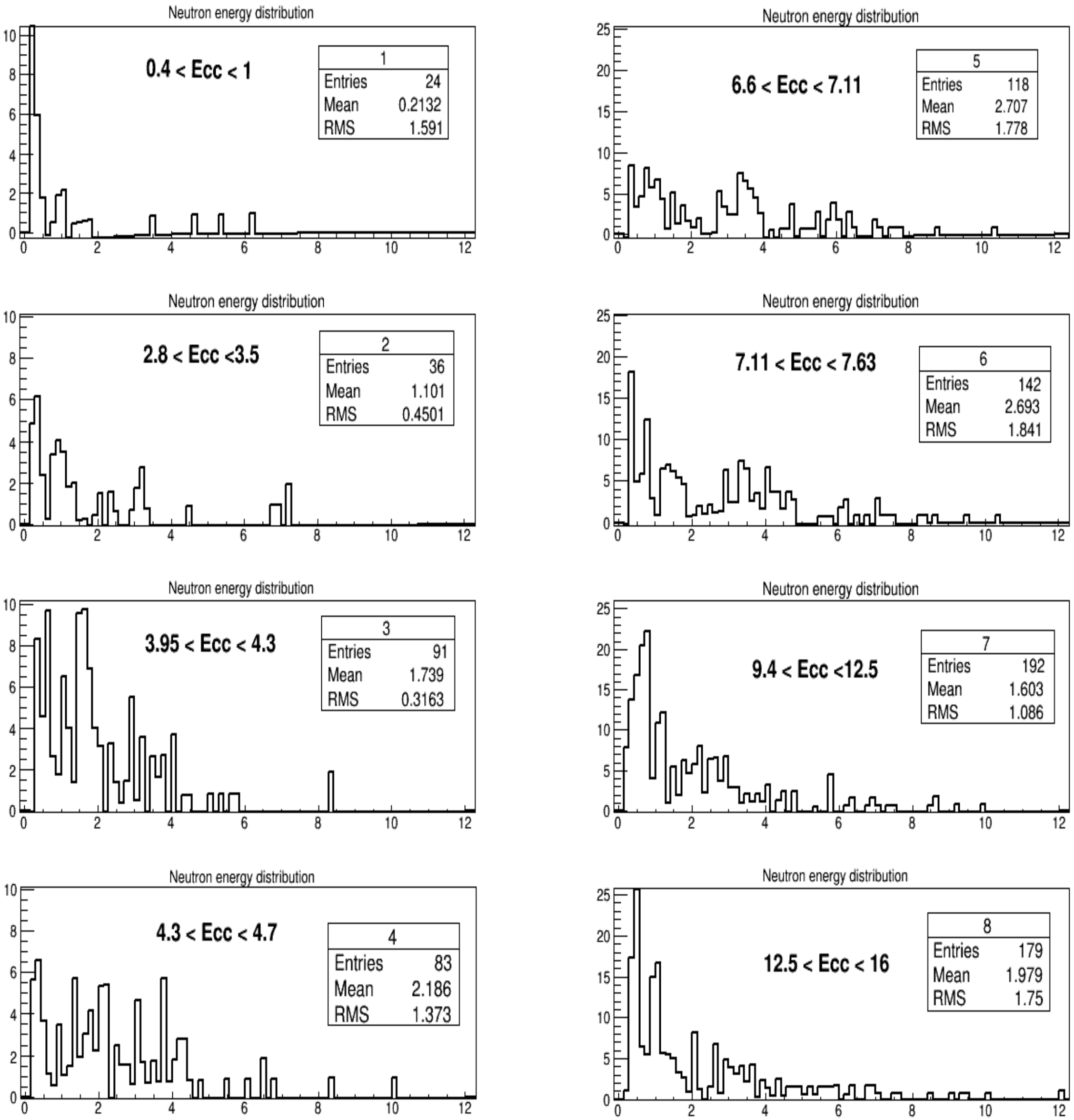
Conclusions

- MAGNEX is attracting a growing worldwide interest for challenging physics cases
- Large international collaborations are progressively setting up
- Considerable amount of beam time are routinely requested from external users
- Exciting new physics is at our reach in the present and future

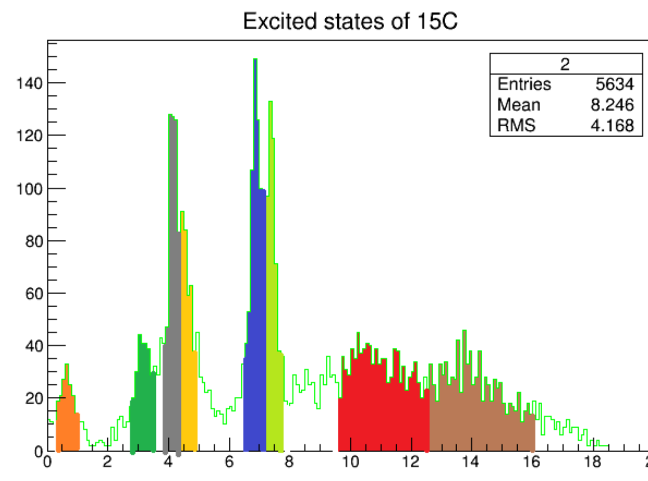




Preliminary neutron energy spectra



Neutron energy (MeV) **Neutron energy (MeV)**



Ecc = Q - Q_0 (MeV)