News from the MAGNEX-EDEN facility at the LNS

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Catania (Italy)

Orsay, 15 November 2011

Working group in Catania

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2. *Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud, Italy*
3. *Istituto Nazionale di Fisica Nucleare – Sezione Catania, Italy*

Collaborations on specific subjects

1. *IN2P3 –IPN, Orsay, France*
2. *IFUSP, Sao Paolo, Brazil*
3. *IFUFF- Niteroi, Brazil*
4. *TRIUMF, Vancouver, Canada*
5. *University of Joannina, Greece*
6. *University of Osaka*

Memorandum of Understanding

between

Institut National de Physique Nucleaire et de Physique des Particules – Institut de Physique Nucléaire d'Orsay (IN2P3 – IPNO)
(France)

and

Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud (INFN-LNS)

(Italy)

here referred to collectively as "Parties" and separately as "Party"

PREAMBLE

The collaboration in Nuclear Physics between French and Italian institutions has been very active for decades. With the LEA COLLIGA, this collaboration has been strengthened.
In this context the program for which this MoU is being established constitutes a perfect example of the emergence of new collaboration within the LEA.

A general agreement exists between French and Italian scientific institutions, CNRS/IN2P3, CEA-DSM, GANIL and INFN. This agreement was signed on December 1th 2007 by the President of INFN and the Directors of IN2P3, GANIL and of the Division of Matter Science, CEA (France), for the establishment of a virtual laboratory called "French-Italian European Associated Laboratory for Nuclear Structure, Nuclear reactions and dynamics and nuclear astrophysics Problems".

1. SCOPE OF APPLICATION

The purpose of this MoU is to establish the temporary transfer of the EDEN array at the LNS laboratory and its use in conjunction with MAGNEX for the experiments of the physics campaign during the years 2011-2013. The document describes the rights and duties of the parties engaged in the campaign including the human and budget resources.

EDEN is a neutron multi-detector array built for the study of neutron decay of highly excited states in nuclei. It consists of 40 individual detectors which are made of NE213 liquid organic scintillator. These detectors have a very good n-γ discrimination and a time resolution

ANNEX 2 – Names of the scientists presently participating in the Collaboration

INFN - LNS	IN2P3 - IPNO
Francesco Cappuzzello	Faical Azaiez (2%)
Angelo Cunsolo	Nicolas de Séréville (4%)
Manuela Cavallaro	Jean-Antoine Scarpaci (4%)
Diana Carbone	Marlène Assié (4%)
Salvatore Tudisco	Didier Beaumel (2%)
Antonino Foti	Serge Franchoo (2%)
Pierpaolo Figuera	Jacques Guillot (2%)
Luciano Calabretta	Fairouz Hammache (2%)
Silvio Cherubini	Fadi Ibrahim (2%)
Stefano Romano	Elias Khan (1%)
Francesca Rizzo	Francois Leblanc (1%)
Clementina Agodi	Iolanda Matea (1%)
	Iulian Stefan (2%)
	David Verney (1%)

Percentage represents the implication of each researcher, e.g. 2% represents one week.

The Collaboration is open to new researchers that want to join the initial members.

A MOU has been signed within the LEA-COLLIGA framework

Collaboration activities

Experimental activity

- Two neutron transfer reactions
- Research of GPV
- Research of the towing mode in alpha transfer

Theoretical activity

- Break-up calculations with different approaches (supplementary help of A.Bonaccorso and D. Lacroix)
- QRPA calculation of the two neutron response function

Summary

- The MAGNEX spectrometer
- Recent results and EDEN installation
- Future plans

MAGNEX

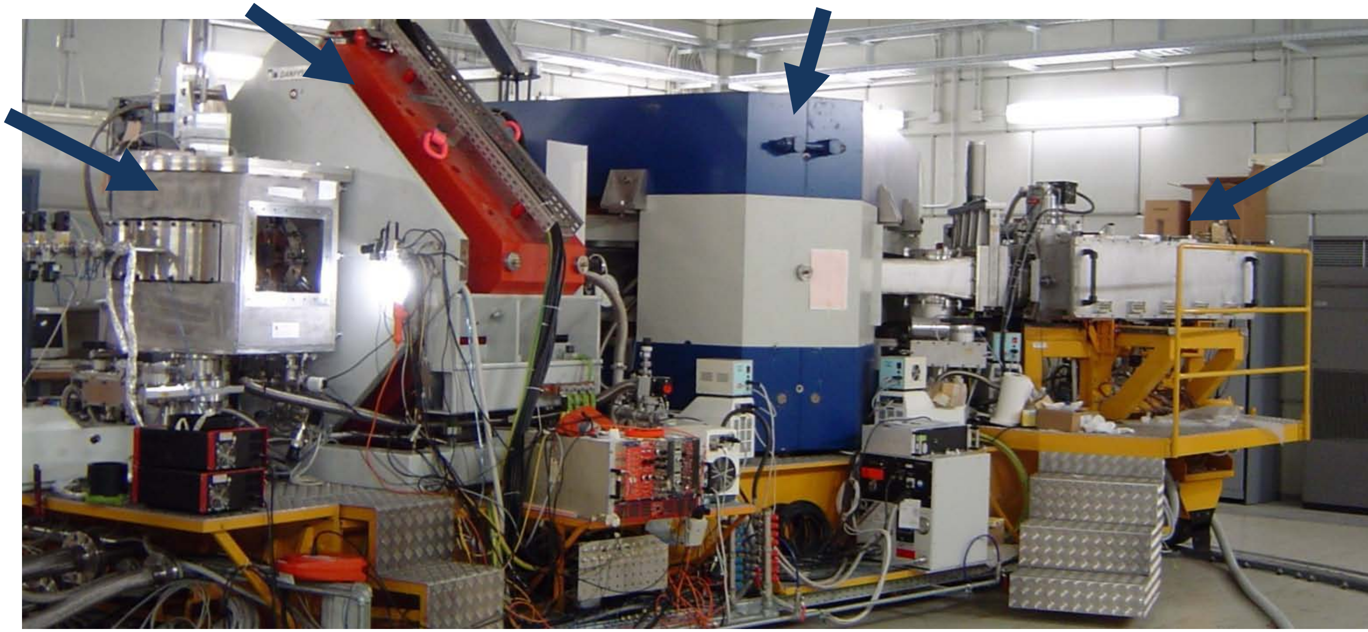
Optical characteristics	Measured values
Maximum magnetic rigidity	1.8 T m
Solid angle	50 msr
Momentum acceptance	-14.3%, +10.3%
Momentum dispersion for k= - 0.104 (cm/%)	3.68

Measured resolution

Energy $\Delta E/E \sim 1/1000$

Angle $\Delta\theta \sim 0.3$

Mass $\Delta m/m \sim 1/160$

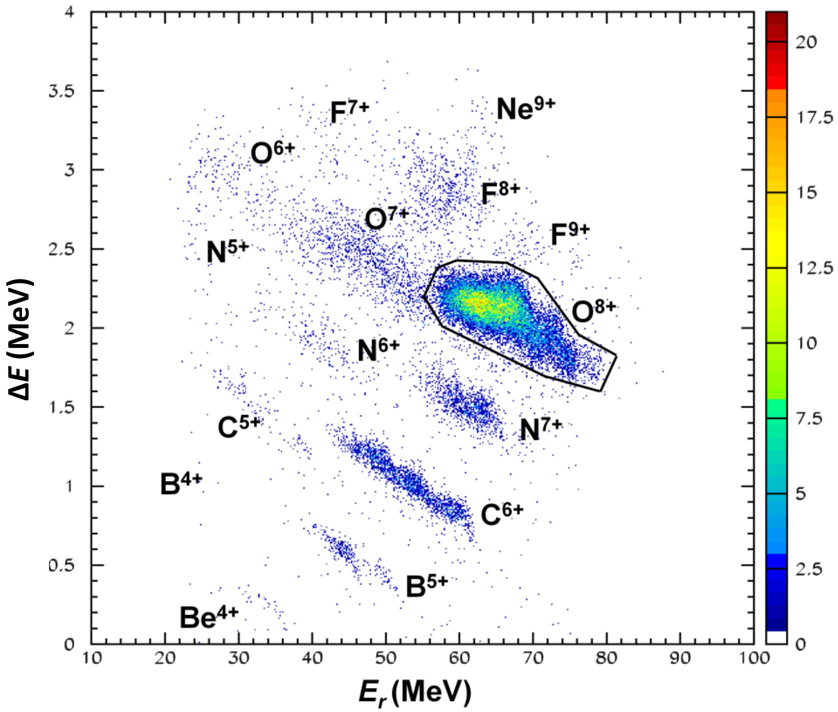


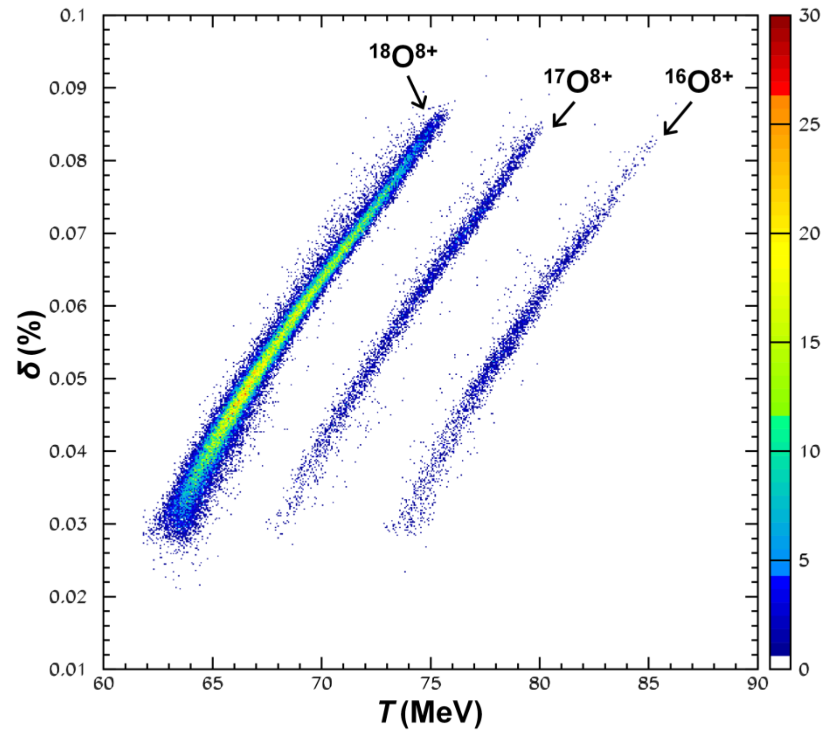
Particle Identification

$^{13}C(^{18}O,^{16}O)^{15}C$ at 84 MeV

$7° < \theta_{lab} < 19°$

$$B\rho = \frac{p}{q} \rightarrow \frac{\sqrt{m}}{q} = \frac{p_0(\delta+1)}{q\sqrt{2T}}$$





Mass resolution Δm/m ~ 1/160

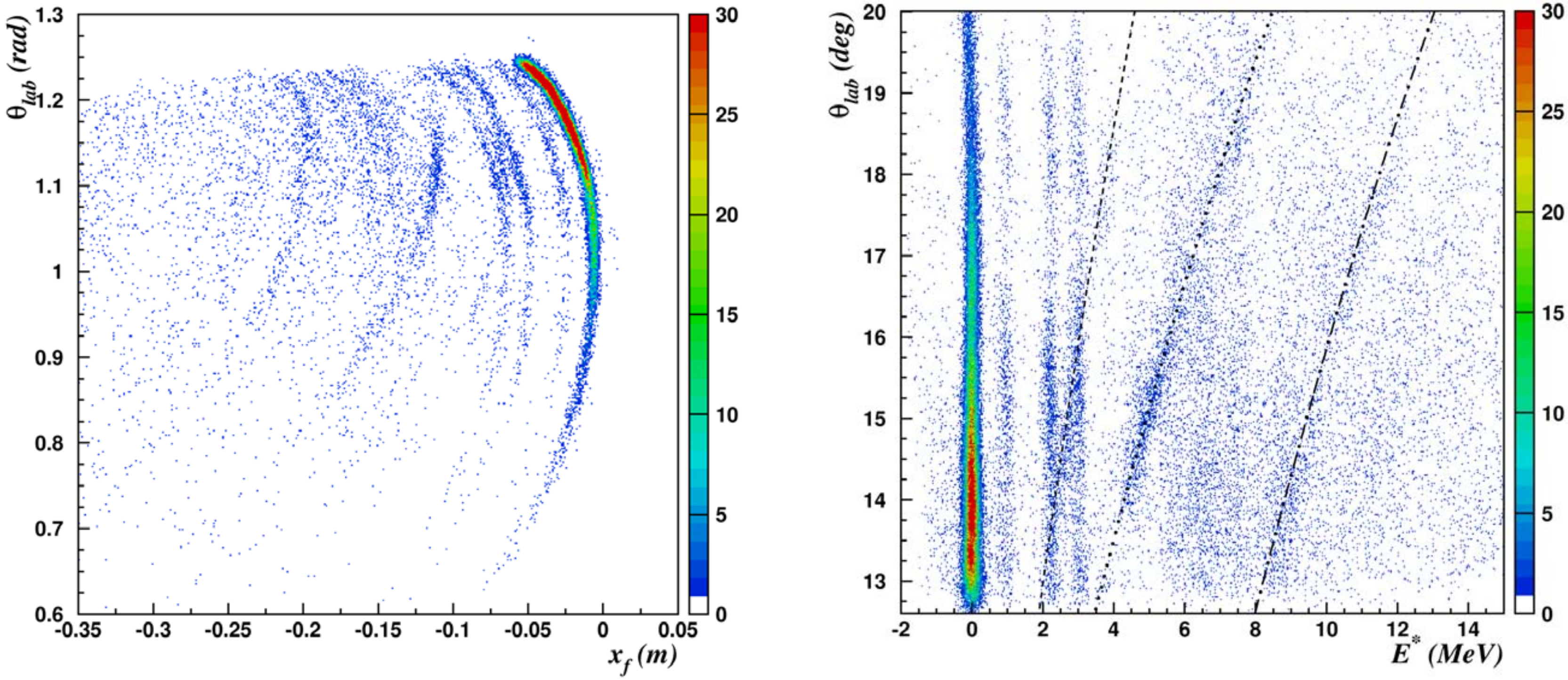
$$T = E_r + E_l + E_d$$

F. Cappuzzello et al., NIMA621 (2010) 419

Momentum reconstruction

$^{27}Al(^{16}O,^{16}O)^{27}Al$ at 100 MeV

$13^\circ<\theta_{lab}<20^\circ$



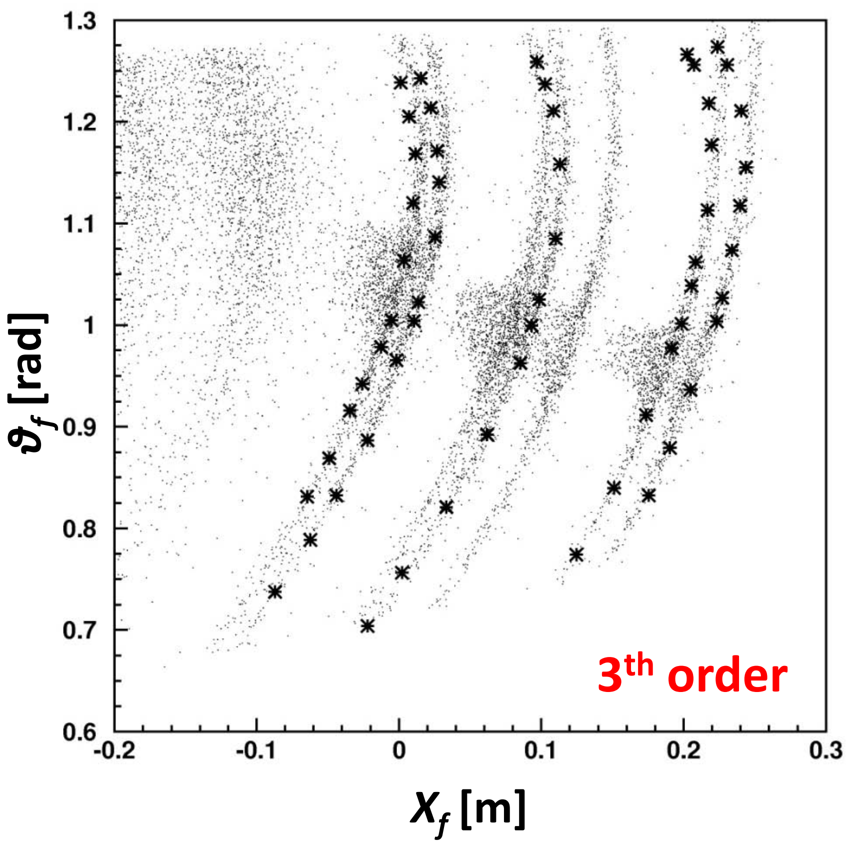
$$E^* = Q - K\left(1+\frac{M_{ejectile}}{M_{residual}}\right) + E_{beam}\left(1-\frac{M_{beam}}{M_{residual}}\right) + 2\frac{\sqrt{M_{beam}M_{ejectile}}}{M_{residual}}\sqrt{E_{beam}K}\cos\theta_{lab}$$

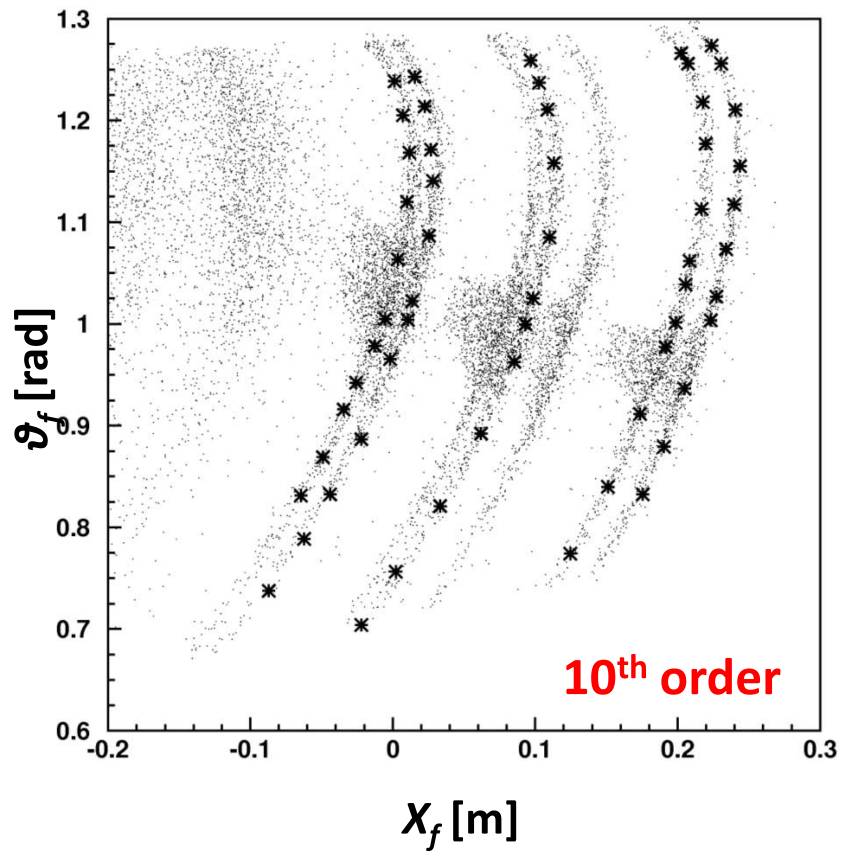
M. Cavallaro et al., NIMA 648 (2011) 46-51

F. Cappuzzello et al., NIMA 638 (2011) 74-82

Accuracy of the ray-reconstruction

With condition:
$-0.01\ \text{m} < Y_f < 0.01\ \text{m}$



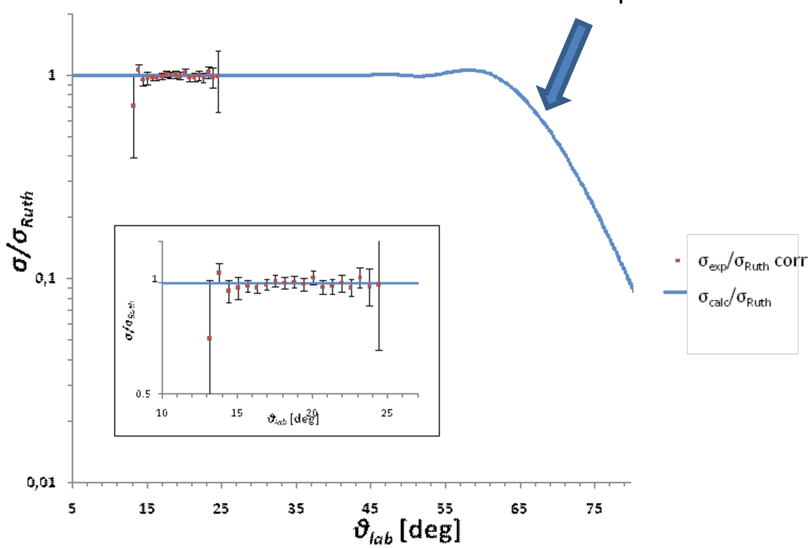


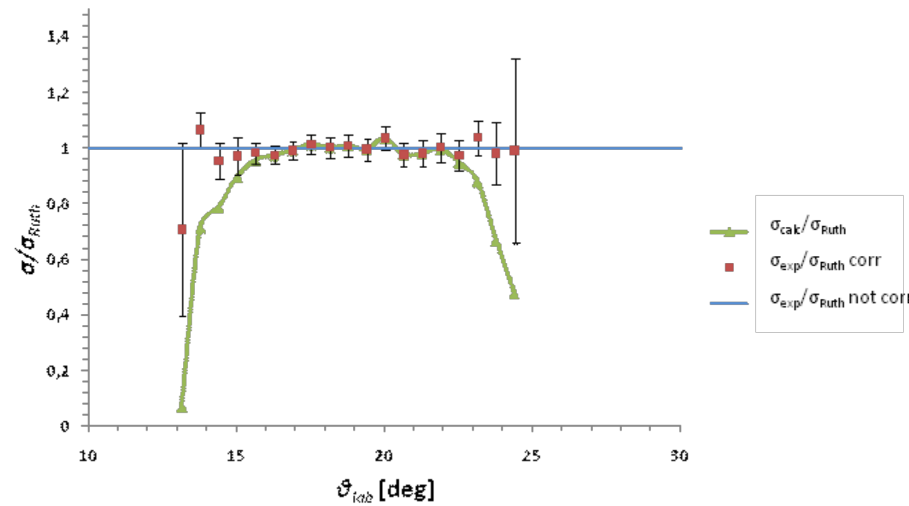
Transport efficiency

✓The transport efficiency accurately determined by trajectory reconstruction

^{16}O + ^{197}Au elastic scattering at 100 MeV

DWBA with San Paolo potential





$<\sigma_{exp}/\sigma_{ruth}> = 0.996 \pm 0.015$

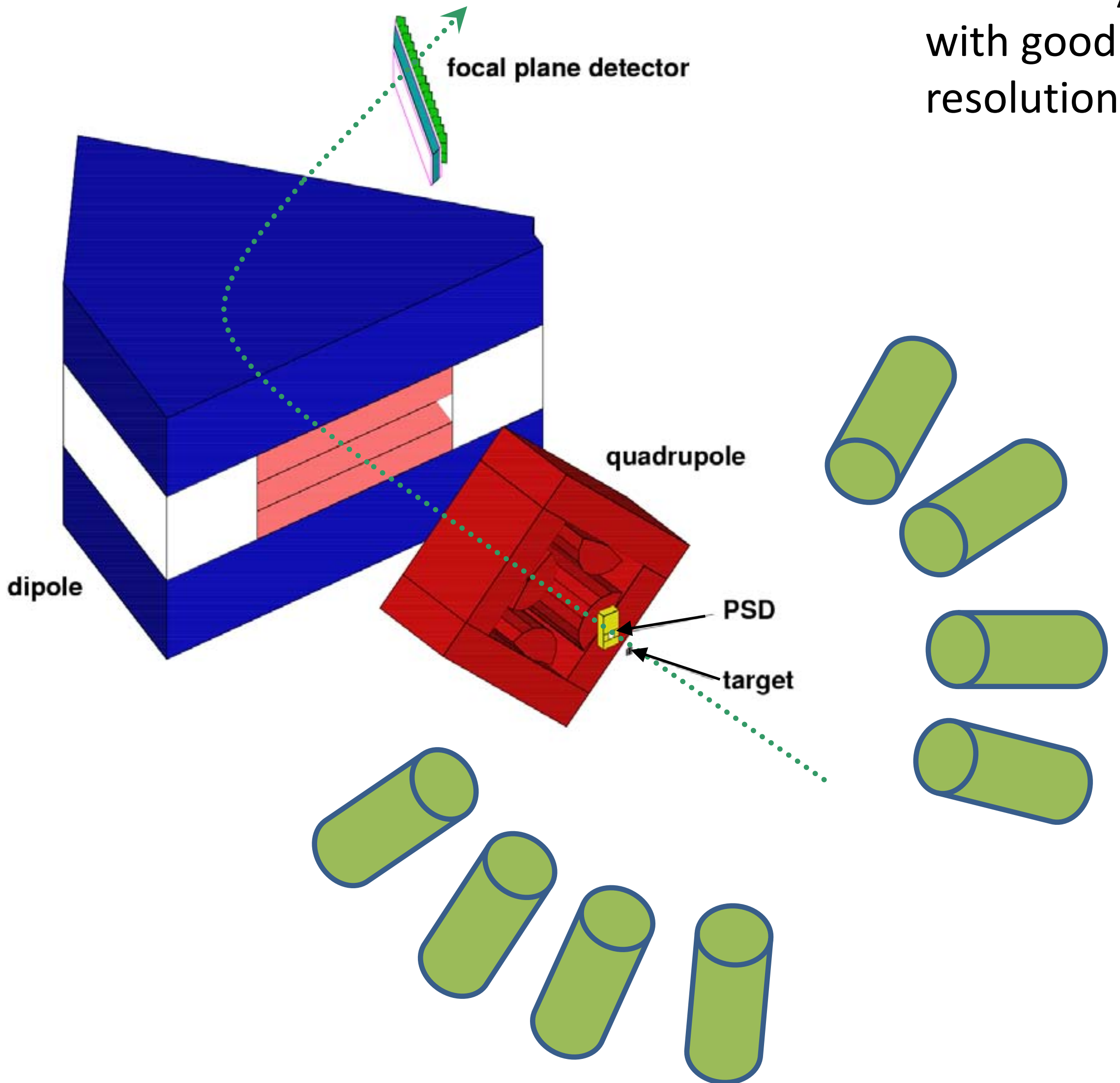
$\Delta\ \sigma_{exp}/\ \sigma_{exp} = \pm\ 0.05$

M.Cavallaro et al. NIM A 637 (2011) 77

MAGNEX + EDEN

MAGNEX to measure high resolution energy spectra for well identified reaction products

EDEN to study the decaying neutrons emitted by the observed resonances with good efficiency and energy resolution



Unique facility to study the resonant states of neutron rich nuclei (low separation energy)

The EDEN neutron multidetector

H. Laurent et al., NIM A326 (1993) 417-525

❖ 40 liquid scintillator detectors (NE213)

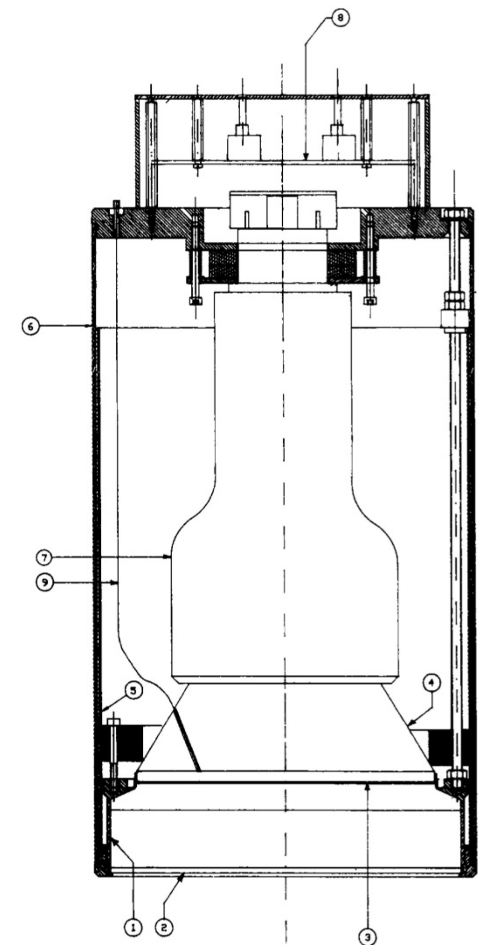
❖ Possibility of n - γ discrimination by pulse shape analysis

❖ Time resolution of 0.9 ns for TOF measurements

❖ Typical energy resolution at a 1.7 m distance from the target: 60 keV for 850 keV neutrons and 500 keV for 6 MeV neutrons

❖ Intrinsic efficiency ~ 50% for 1 MeV and 30% for 6 MeV neutrons

❖ Mechanical assembly easily configurable for different experimental requirements

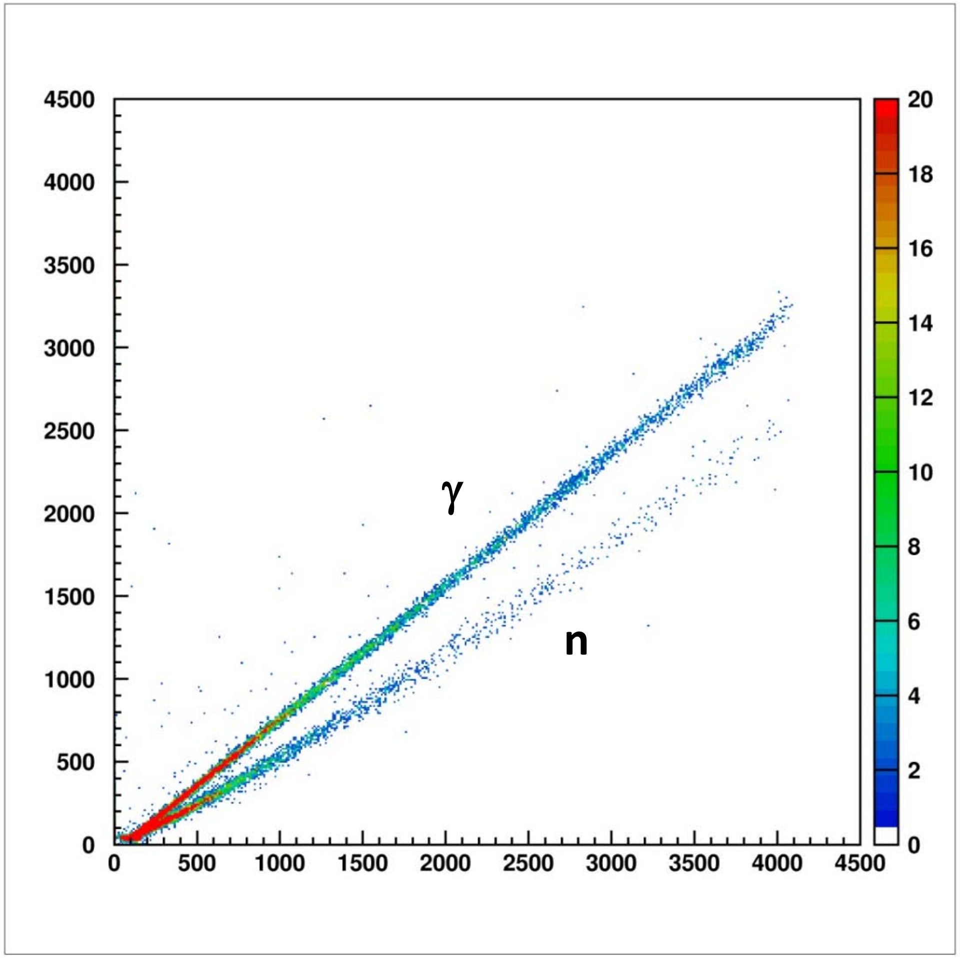


❖ Obsolete and unreliable CAMAC electronics

June 2011

MAGNEX + EDEN

commissioning



Fast vs. Slow

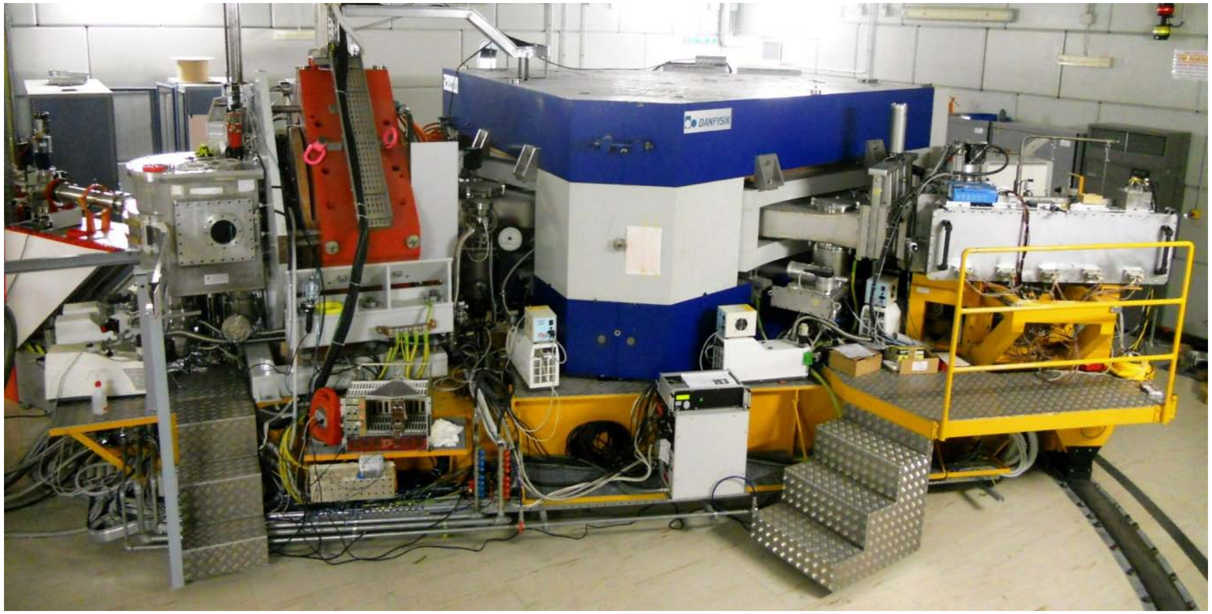
Good n-γ discrimination

2n transfer reactions (18O,16O) at 84 MeV

The experiment: $^{12}C, ^{13}C(^{18}O, ^{16}O)^{14}C, ^{15}C$

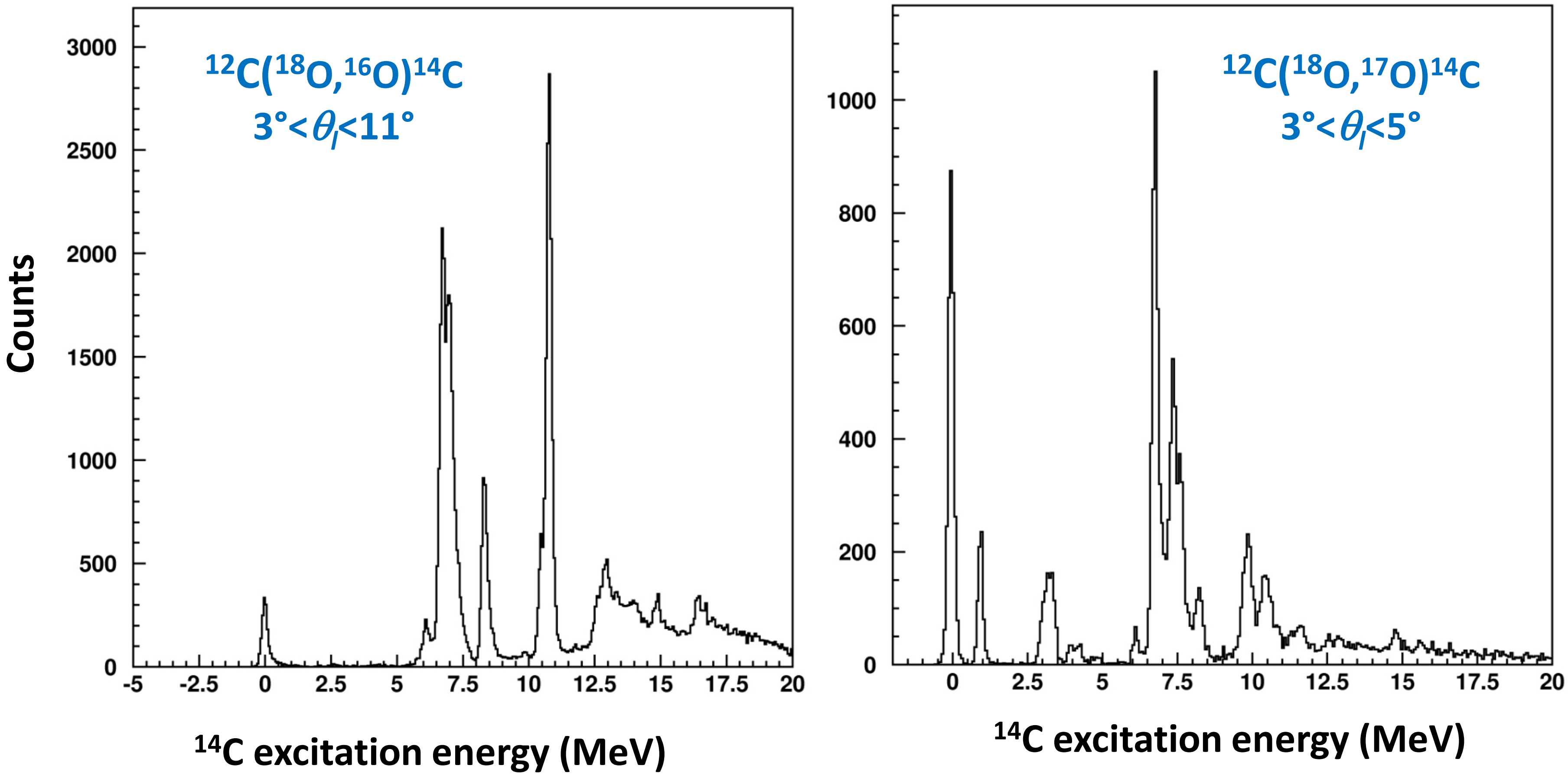
LNS - INFN (Catania)

- $^{18}O^{7+}$ beam from Tandem accelerator at 84 MeV
- Targets: ^{9}Be, ^{11}B, ^{12}C, ^{13}C, ^{16}O, ^{28}Si, ^{58}Ni, ^{64}Ni, ^{120}Sn, ^{208}Pb
- Ejectiles detected by the MAGNEX spectrometer
- Angular setting $\theta_{opt} = 6°, 12°, 18°, 24°$ ⟶ $4° < \theta_{lab} < 30°$



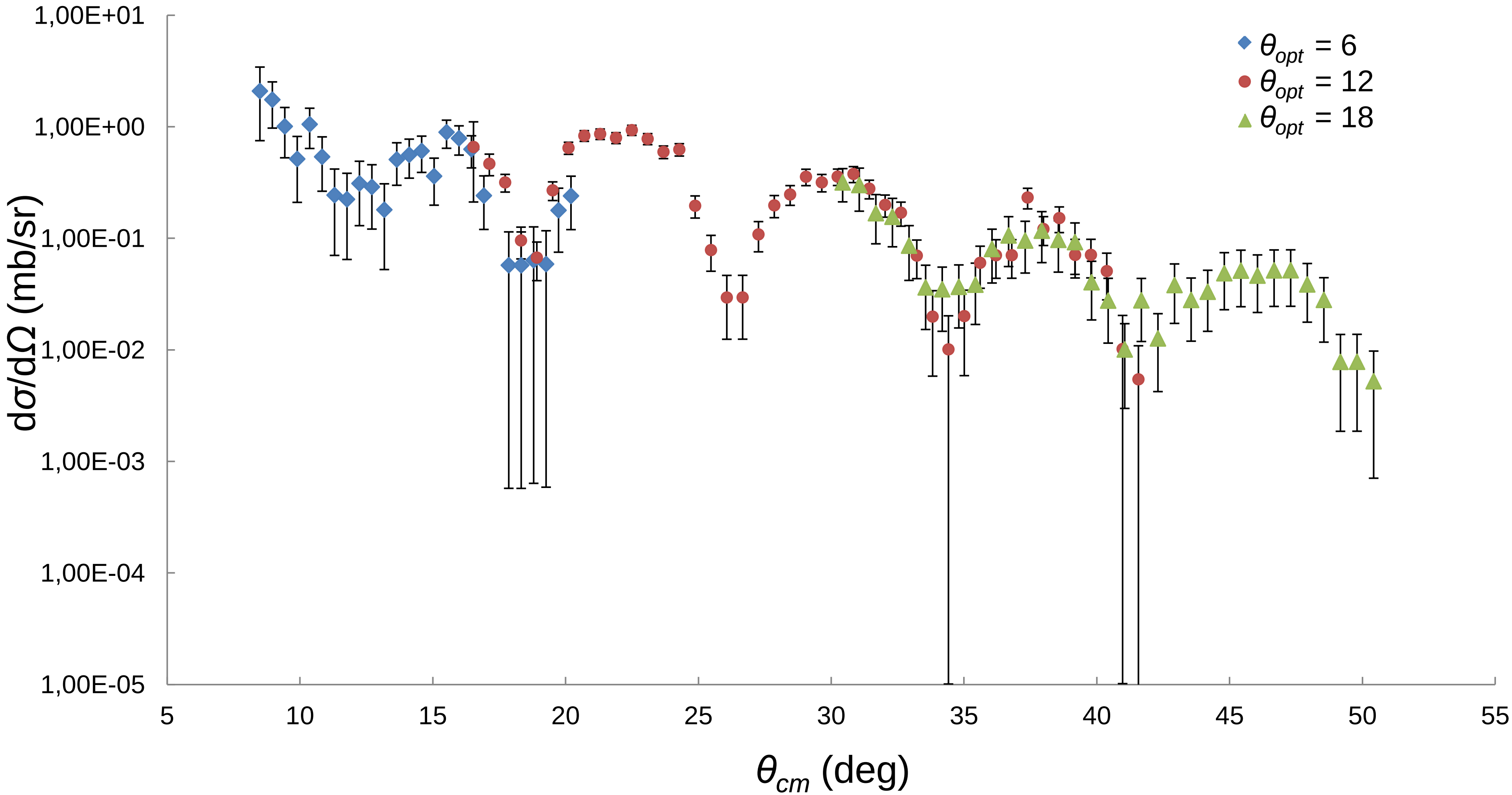
Examples of energy spectra

Two-neutron transfer | One-neutron transfer

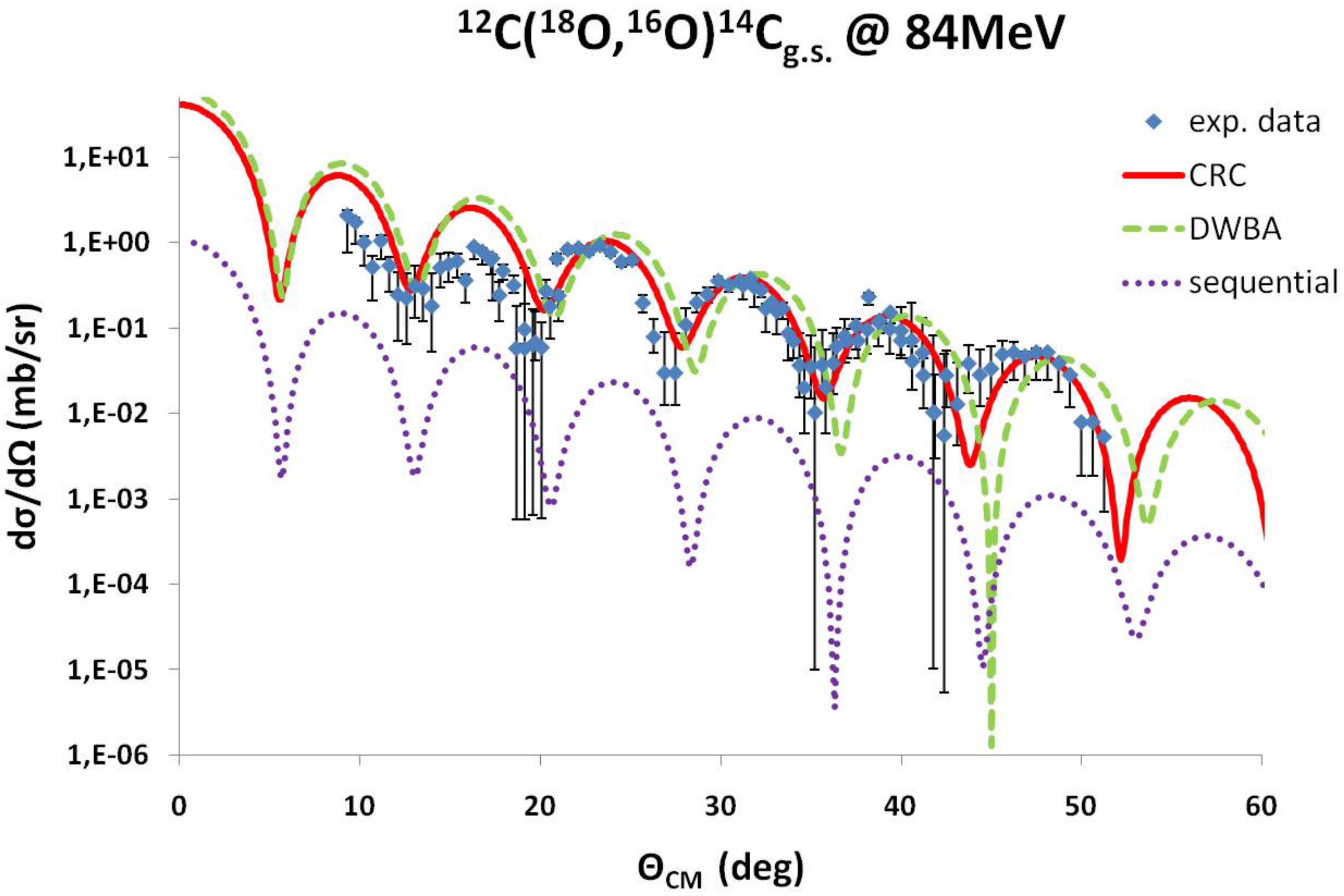


Angular distributions

$^{12}C_{g.s.}(0^+) \rightarrow {}^{14}C_{g.s.}(0^+)$ ***L* = 0**



DWBA & CRC calculations



Calculations by J.Lubian Rios
UFF - Niteroi

M.A.Candido Ribeiro,et. al. *Phys. Rev. Lett.* **78** (1997)3270
L.C..Chamon, D.Pereira, et. al. *Phys. Rev. Lett.* **79** (1997)5218
L.C.Chamon, et. al. *Phys. Rev. C* **66** (2002) 014610

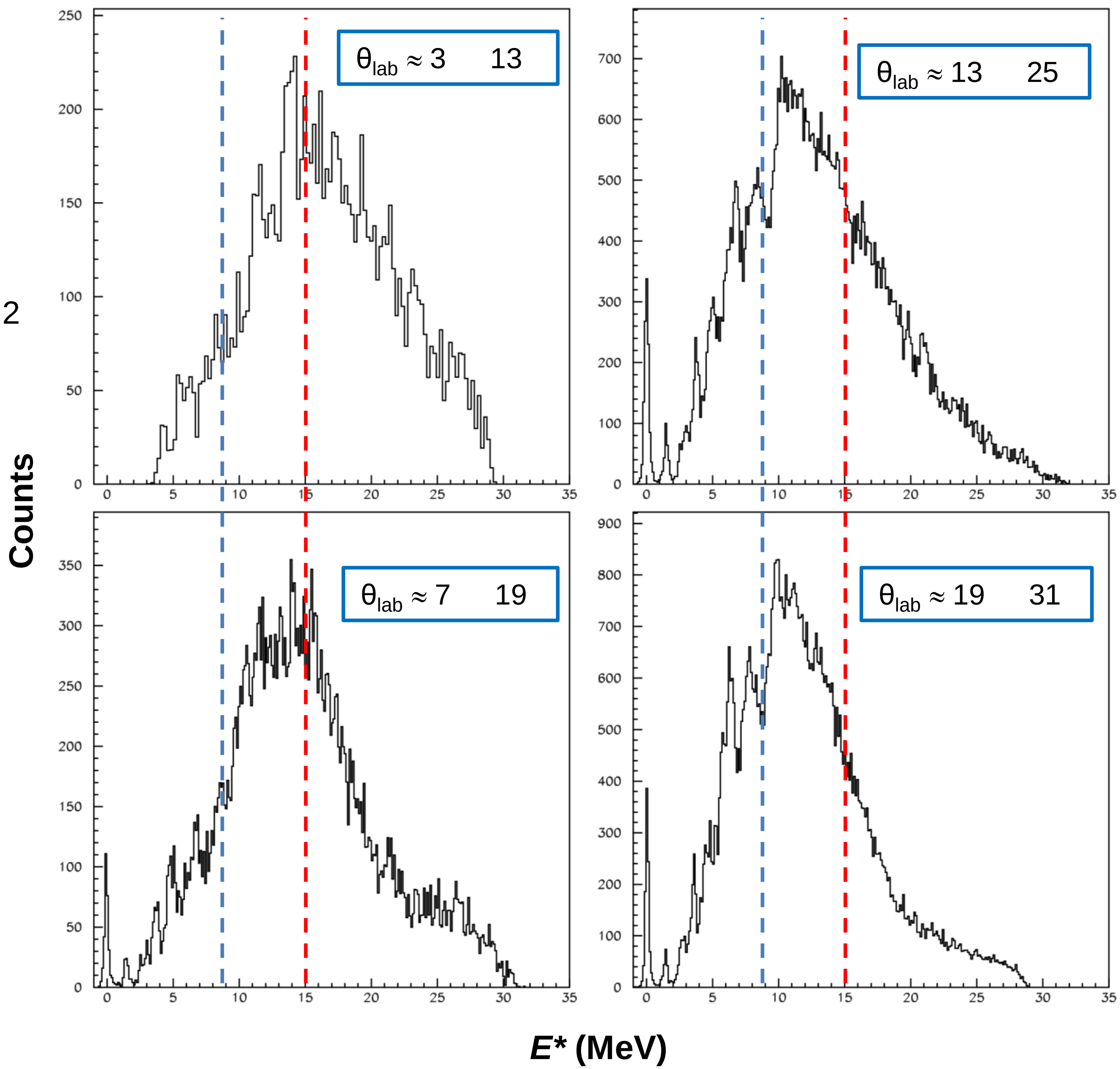
Preliminary energy spectra

$^{64}Ni(^{18}O,^{16}O)^{66}Ni$

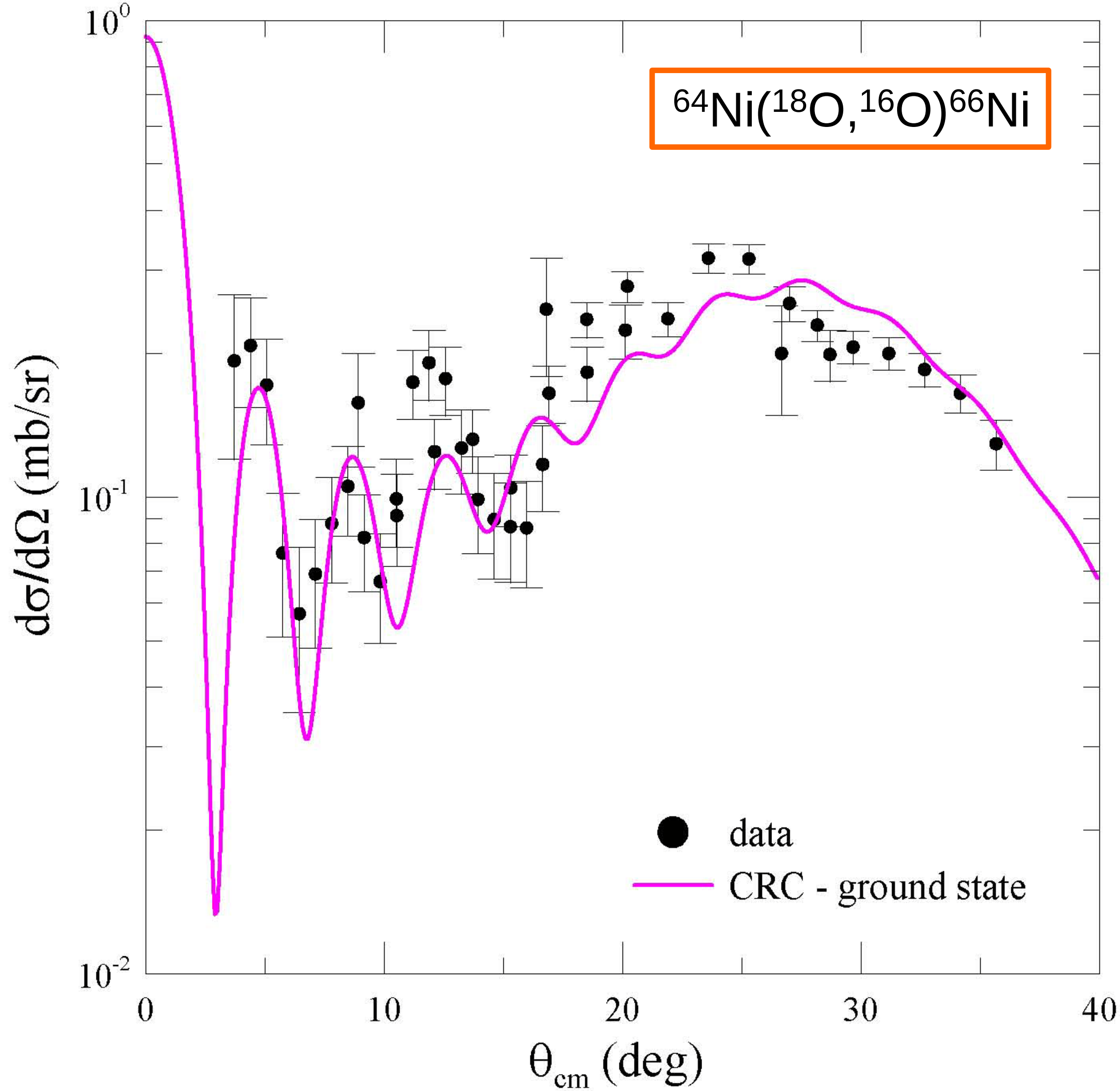
^{64}Ni target 113 μg/cm^2

- - - - S_n = 8.95 MeV

- - - - S_{2n} = 15.05 MeV



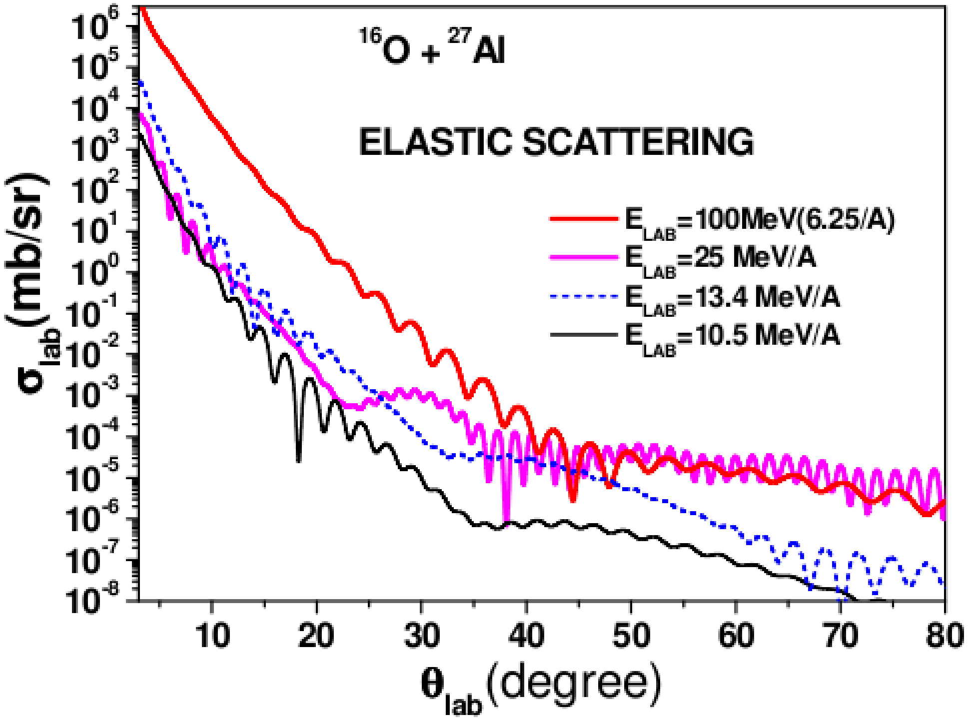
Preliminary angular distributions



Nuclear Rainbow

in the ^{16}O + ^{27}Al elastic scattering at 100 MeV

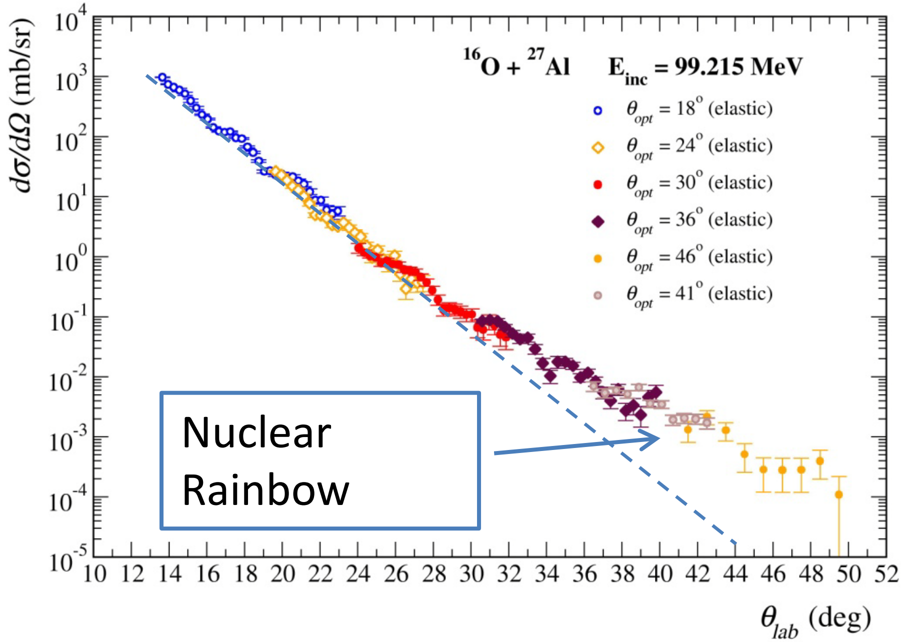
Sao Paulo potential prediction

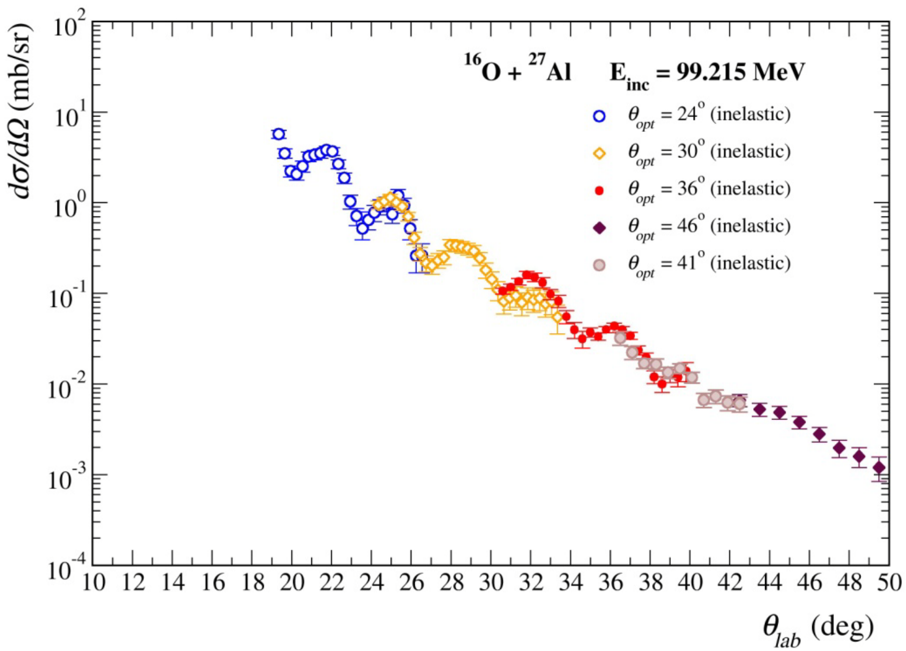


Coupled Channel formalism considering a new generation of parameter-free **Sao Paulo Potential** that takes into account surface dissipative processes (deep-inelastic/breakup)

- M.A.Candido Ribeiro,et al PRL78 (1997) 3270.
- L.C..Chamon, D.Pereira, et al, PRL 79 (1997) 5218.

D. Pereira[a], A. Cunsolo[b,c], F. Cappuzzello[b,c], M. Cavallaro[b,c], J.R.B. Oliveira[a], R. Linares[d], J. Lubian[d], A.Foti[e], D.Carbone[b,c],M. Bondì[b,c], G. Santagati [b,c], G. Taranto [b,c], L.C. Chamon [a], P.R.S. Gomes[d], E.Crema[a], C.P. Silva[a], E.S. Rossi Jr[a], and L.R. Gasques[a].
a) Instituto de física da Universidade de São Paulo, São Paulo, Brazil.
b) Dipartimento di Fisica e Astronomia, Università di Catania, Catania, Italy
c) INFN - Laboratori Nazionali del Sud, Catania, Italy
d) Instituto de física da Universidade Federal Fluminense, Rio de Janeiro, Brazil
e) INFN - CT,Catania, Italy





^{16}O beam at 100 MeV

^{27}Al target

Angular range 13°< θ_{lab} < 52°

Data reduction completed

M.Cavallaro et al NIMA (2011) (in press) DOI: 10.1016/j.nima.2011.04.042

D.Pereira et al. Submitted to Nature (2011)

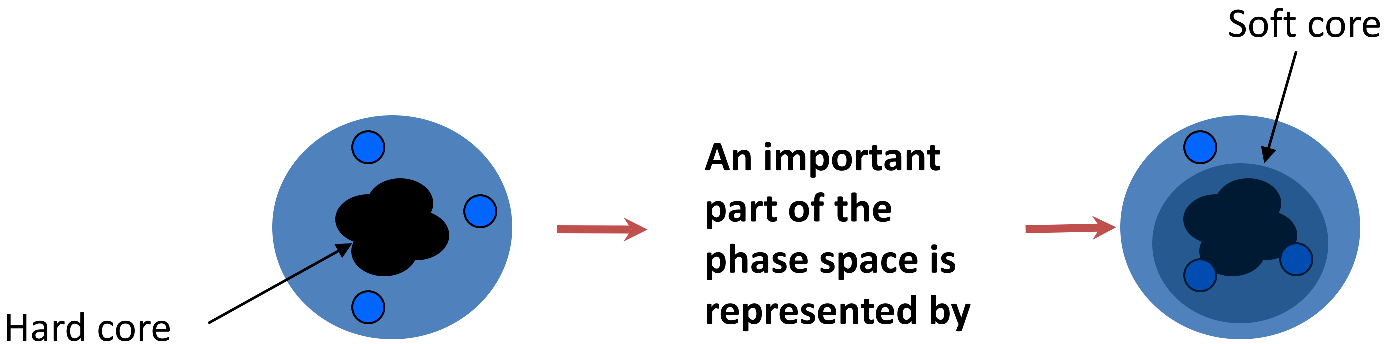
First experiment: study of the (^{7}Li,^{7}Be) reactions at 52 MeV

Excited states of nuclei with Nα + 3n via (^{7}Li,^{7}Be)

- N = 1 → ^{7}He
- N = 2 → ^{11}Be
- N = 3 → ^{15}C
- N = 4 → ^{19}O
- N = 5 → ^{23}Ne
- N = 6 → ^{27}Mg
- …

(^{11}Be, ^{15}C) →

Experimental evidence:
- **Core excitation states**
- **BSEC** (Bound States Embedded in the Continuum)



Study of the $^{19}F(^{7}Li,^{7}Be)^{19}O$

- $^{7}Li^{+++}$ beam from Tandem at 52 MeV

- AlF_3, LiF, BaF targets (80 μg/cm^2) (C, Al, WO_3 targets for background subtraction)

- ^{7}Be ejectiles detected by MAGNEX spectrometer

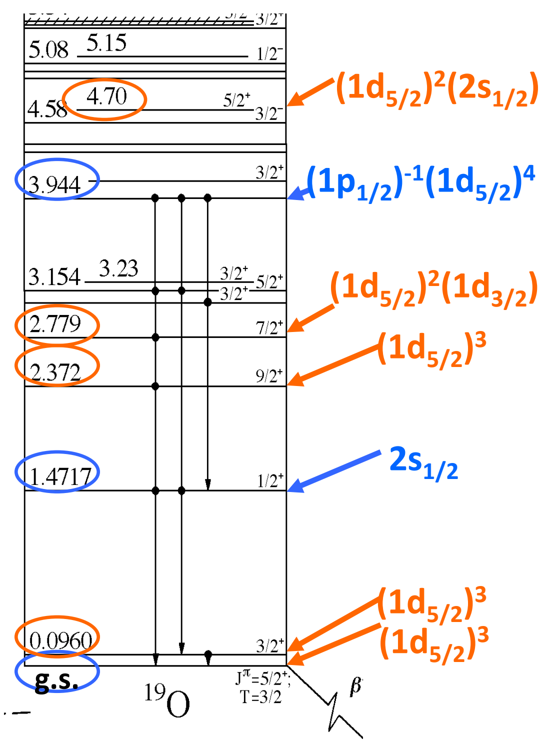
- Angular setting

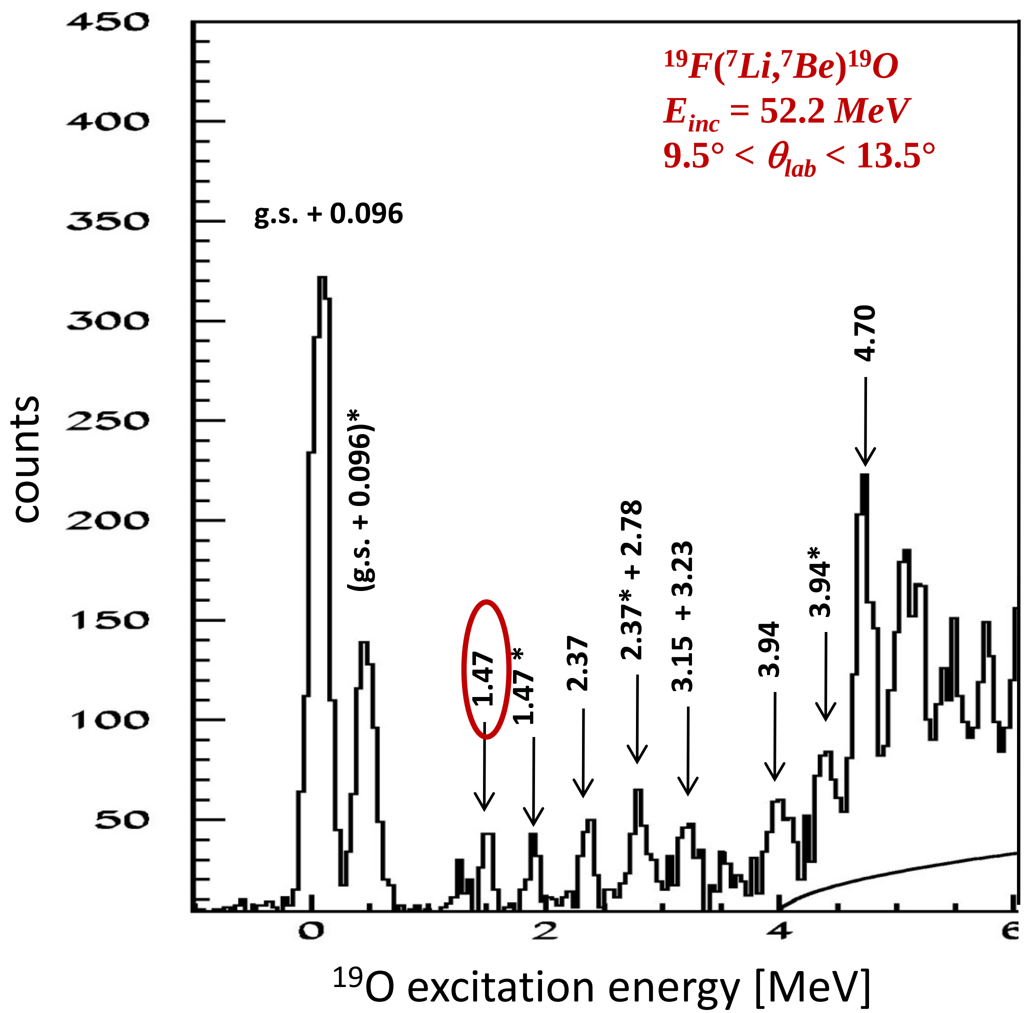
$$\bar{\theta}_{lab} = 0°$$
$$\bar{\theta}_{lab} = 6° \longrightarrow 3° < \theta_{lab} < 13°$$
$$\bar{\theta}_{lab} = 12° \longrightarrow 7° < \theta_{lab} < 18°$$

^{19}O Excitation energy spectra

$a^{\dagger}_{n}a_{p}$ excitation on $^{19}F_{gs}$

$$\left|{}^{19}F_{gs\,\frac{1}{2}^{+}}\right\rangle = \left|{}^{18}O_{0^{+}} \otimes (s_{1/2})^{\pi} + {}^{18}O_{2^{+}} \otimes (d_{5/2})^{\pi}\right\rangle$$

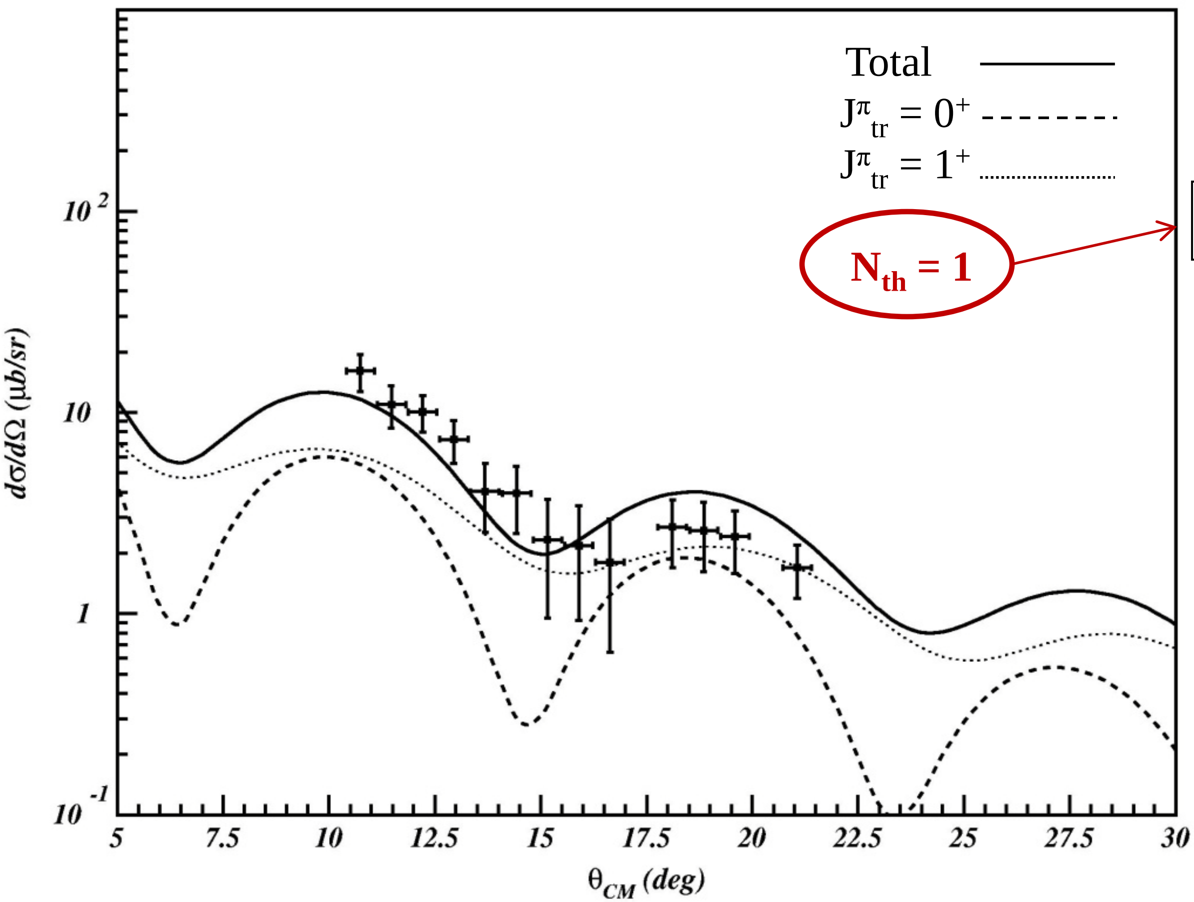




Results for the Gamow-Teller transition

Single experimental angular setting (θ_{lab} = 12°)

$^{7}Li + {}^{19}F \rightarrow {}^{7}Be + {}^{19}O(1.47\ MeV\ 1/2^{+})\ \ E_{lab}=52\ MeV$



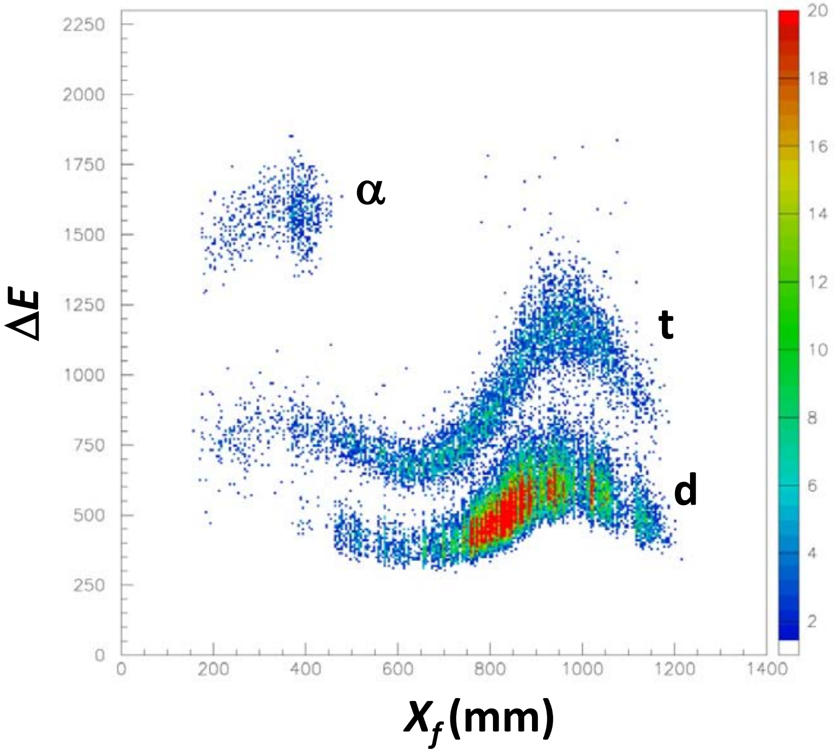
No scaling factor

Realistic description of the nuclear interaction (D3Y Hoffman – Lenske)

M.Cavallaro, Ph.D thesis, University of Catania, 2008

$^{120}Sn(p,t)^{118}Sn$ at 35 MeV (Spokesperson J.A.Scarpaci)

- A first run at forward angles has been done on June 2011



- The data reduction has been started

Conclusions

- MAGNEX is a powerful tool for nuclear spectroscopy and study of binary reactions
- The coupling with the EDEN array of neutron detectors does enhance the capabilities of the spectrometer
- Exciting new physics is going to be explored and new answer to old puzzles to be given
- Fundamental role of international collaborations to fully take profit of the new facility
- The LNS –IPN-Orsay collaboration is a key instrument along this line

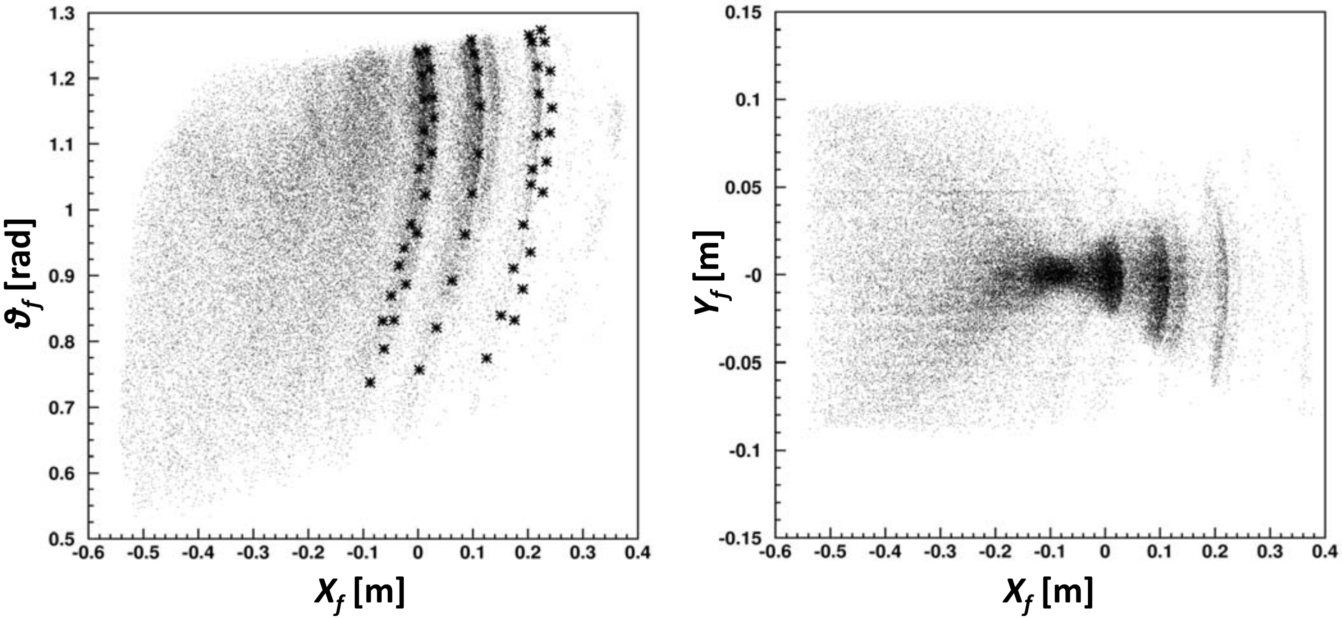
Total Reaction and break-up cross section measurements in collaboration with University of Ioannina (Greece)

- Measurement of the reaction and break-up cross section in the p(^{6}Li,^{6}Li)p reaction at near the Coulomb barrier with MAGNEX. Experiment approved.

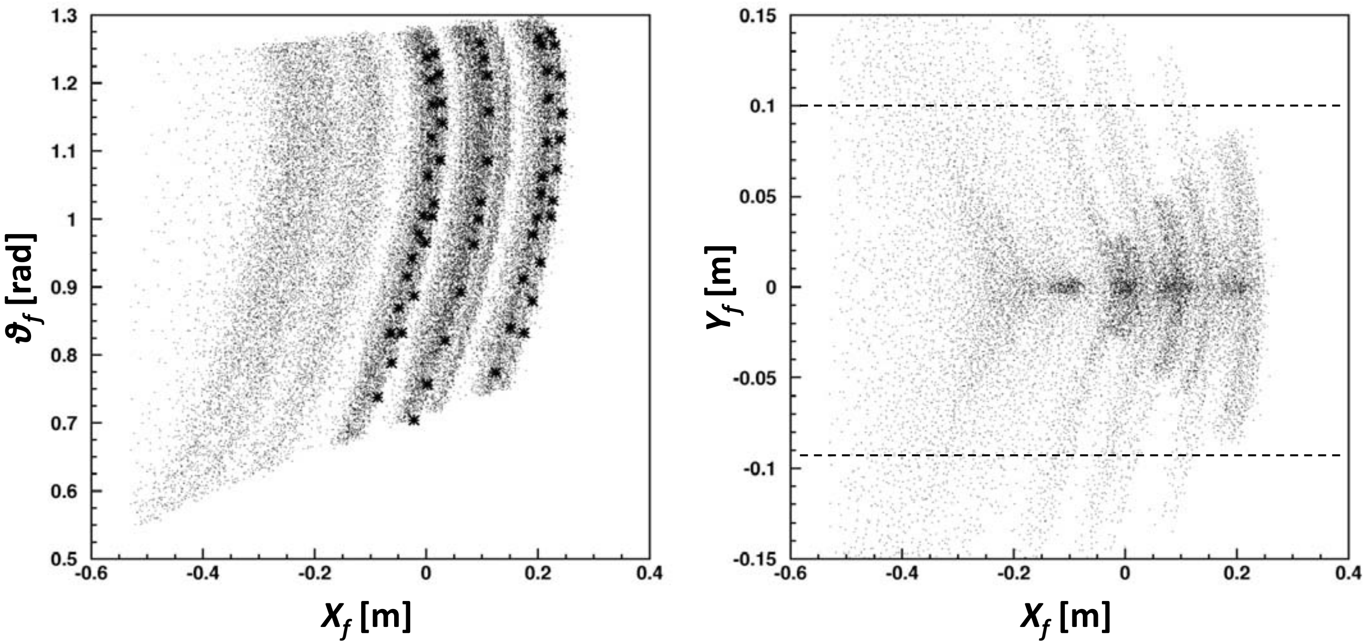
Test of the ray-reconstruction

Direct transport matrix

$^{13}C(^{18}O,^{16}O)^{15}C$ at 84 MeV



Experimental data



Simulation

EDEN Electronics Upgrading

n - γ pulse shape discrimination

Past electronics

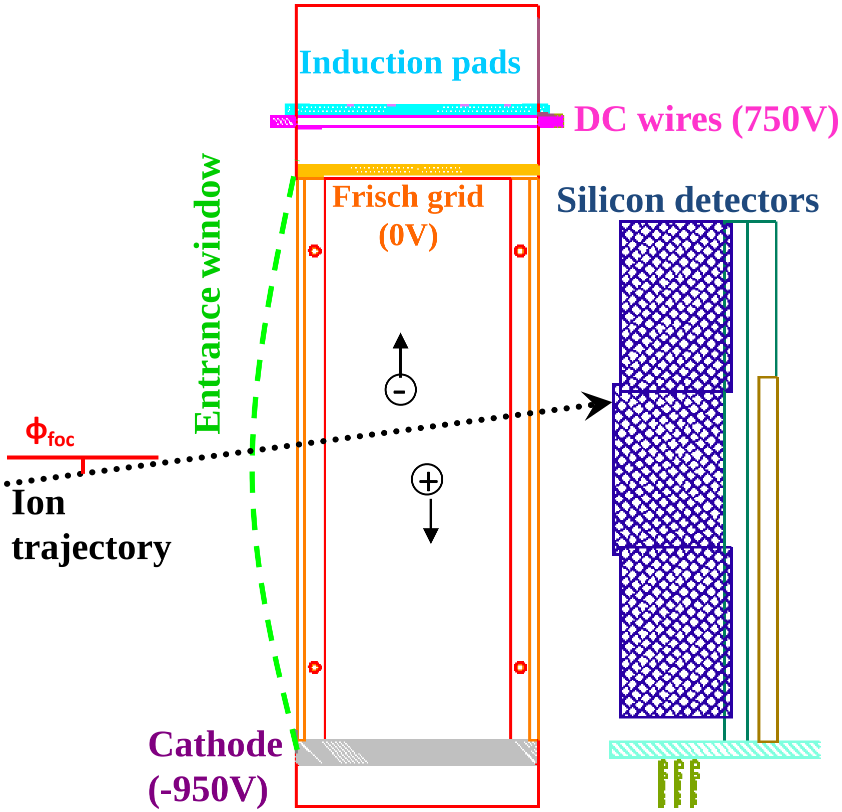
- QDC (model QDC 1612F) CAMAC standard
- CFD (model GANELEC FCC8) NIM
- Gate and Delay Generators (model RDV 8/16) NIM

New electronics

- **BaF-PRO** module NIM (developed at the INFN-MI, C. Boiano)
  - **fast-slow discrimination** by a differentiator+ gaussian shaper (fast) and an integrator + gaussian shaper (slow)
  - **timing** by CFD (optimized for rise-time from 1.5 to 8 ns)

- Peak sensing ADC (model Caen V785) VME

MAGNEX Focal Plane Detector (FPD)

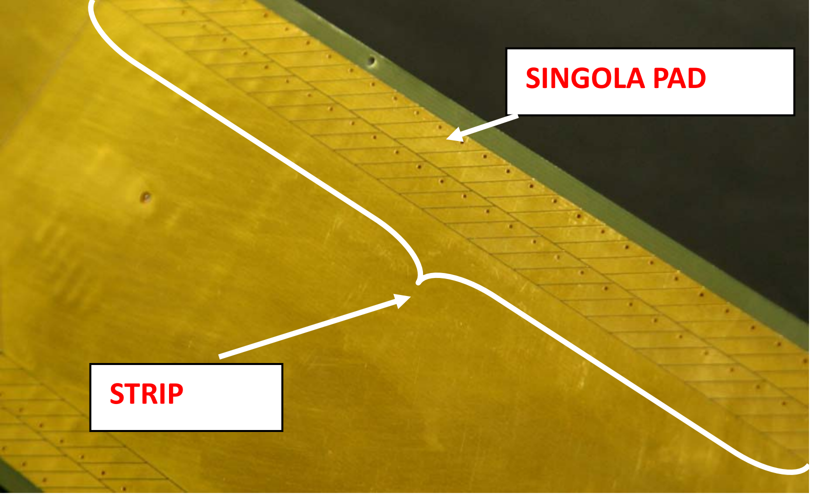


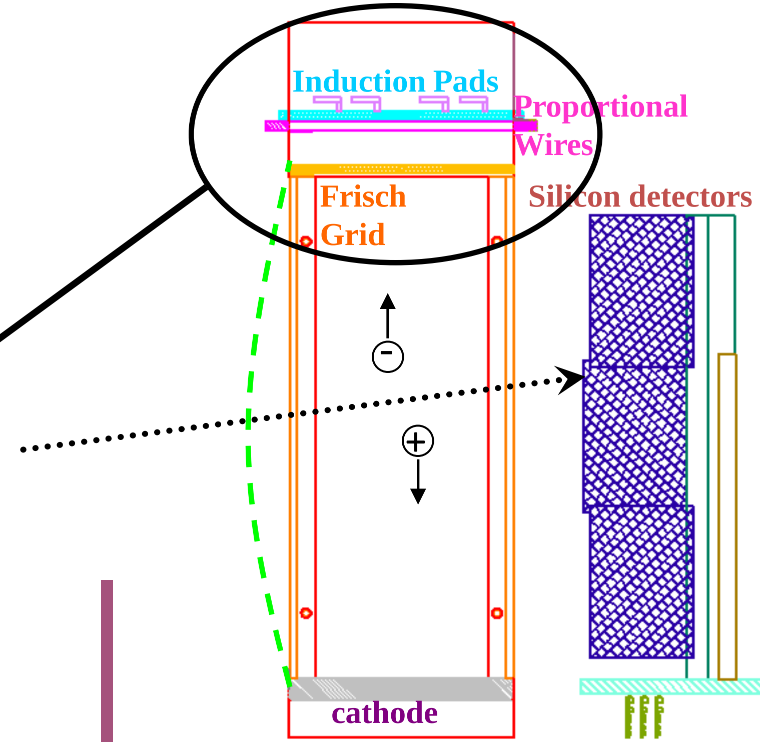
Section view

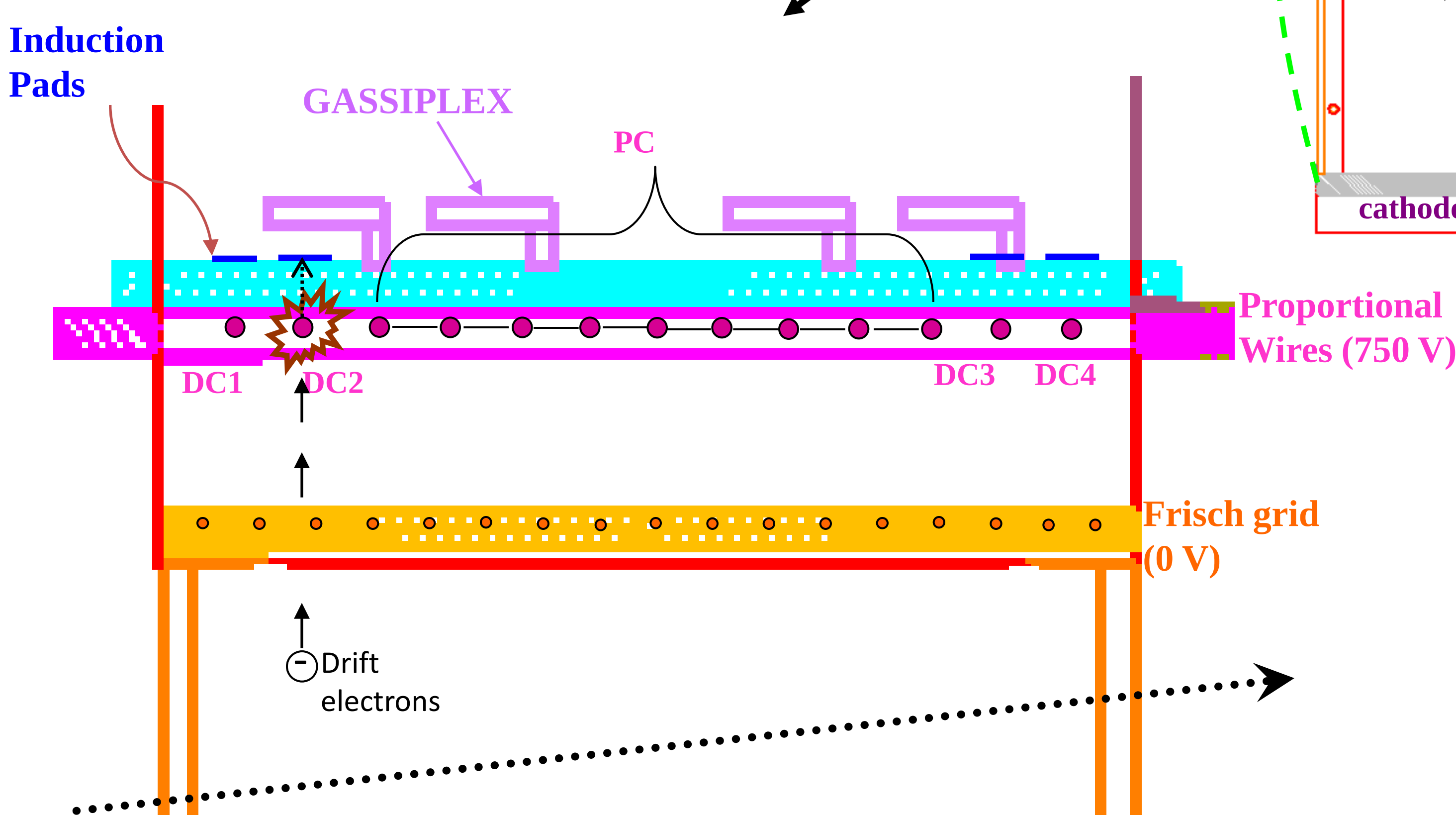
54 Silicon Detectors → E_{res} 5 Proportional Wires → ΔE	Ion identification
4 Induction Strip → X_1, X_2, X_3, X_4 → X_{foc}, θ_{foc} 4 Drift Chamber (DC) → Y_1, Y_2, Y_3, Y_4 → Y_{foc}, ϕ_{foc}	Ray-reconstruction

•C.Boiano et al., IEEE 55 (2008) 3563

•M.Cavallaro, PhD thesis, University of Catania, 2008


SINGOLA PAD
STRIP


Induction Pads
Proportional
Wires
Frisch
Grid
Silicon detectors
cathode


Induction
Pads
GASSIPLEX
PC
DC1
DC2
DC3
DC4
Proportional
Wires (750 V)
Frisch grid
(0 V)
Drift
electrons