Multi-channel analysis of the ^{18}O + ^{48}Ti reaction at 275 MeV within the NUMEN project

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for the NUMEN collaboration

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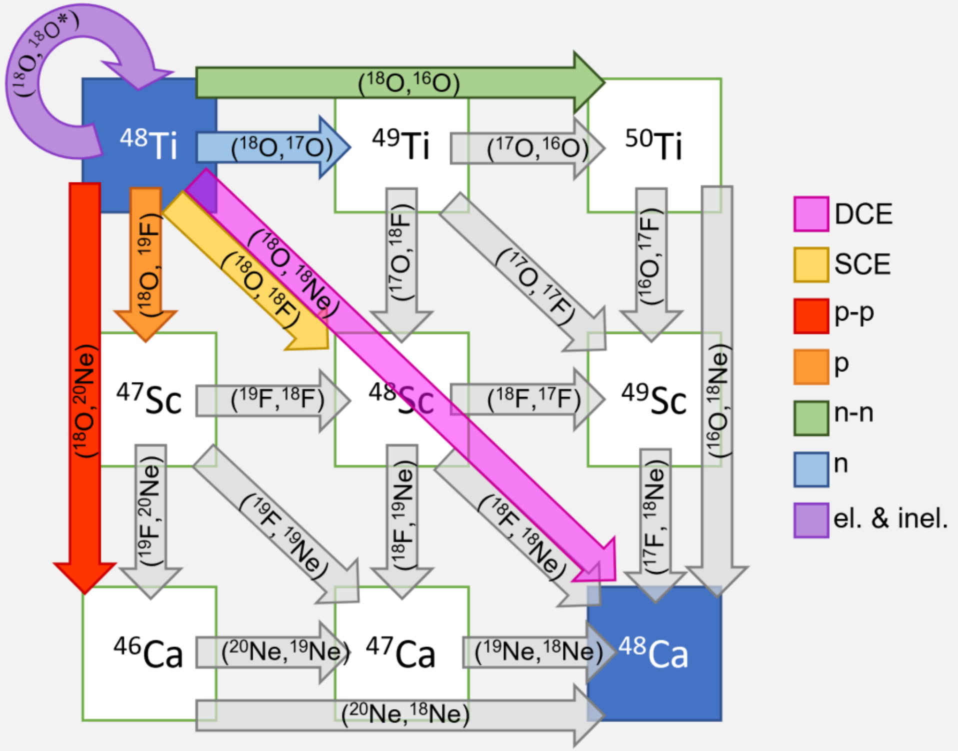
7th International Conference on Collective Motion in Nuclei under Extreme Conditions (COMEX7)

11 – 16 June 2023, Catania (Italy)

NUMEN and the multi-channel approach

NUclear
Matrix
Elements for
Neutrinoless
double beta decay

F. Cappuzzello et al., Eur. Phys. J. A 54 (2018) 72



J. Bellone talk

There are **competing processes** leading to the **same final states** as **double charge exchange (DCE)**

Multi-channel approach:
- Study the **complete net** of reaction channels that contribute to the DCE cross-section
- Probing **different features** of the **nuclear many-body wave function** by analyzing different nuclear reaction channels

F. Cappuzzello et al., Prog. Part. Nucl. Phys. 128 (2023) 10399

Application of the multi-channel approach

I. Ciraldo talk

^{40}Ca – ^{40}Ar

F. Cappuzzello et al. EPJA 51, 145 (2015)
J.L. Ferreira et al., PRC 103, 054604 (2021)
M. Cavallaro et al., Front. Astron. Space Sci. 8, 659815 (2021)
S. Calabrese et al., PRC 104, 064609 (2021)

^{116}Cd – ^{116}Sn

D. Carbone et al., PRC 102, 044606 (2020)
S. Calabrese et al., NIMA 980, 164500 (2020)
D. Carbone et al., Universe 07, 58 (2021)
S. Burrello et al. PRC 105, 024616 (2022)
J. Ferreira et al., PRC 105, 014630 (2022)

^{76}Ge – ^{76}Se

A. Spatafora et al., PRC 100, 034620 (2019)
L. La Fauci et al., PRC 104, 054610 (2021)
I. Ciraldo et al., PRC 105 (2022) 044607

This talk

^{130}Te – ^{130}Xe

M. Cavallaro et al., Res. Phys. 13, 102191 (2019)
V. Soukeras et al., Res. Phys. 28, 104691 (2021)
D. Carbone et al., Universe 07, 58 (2021)

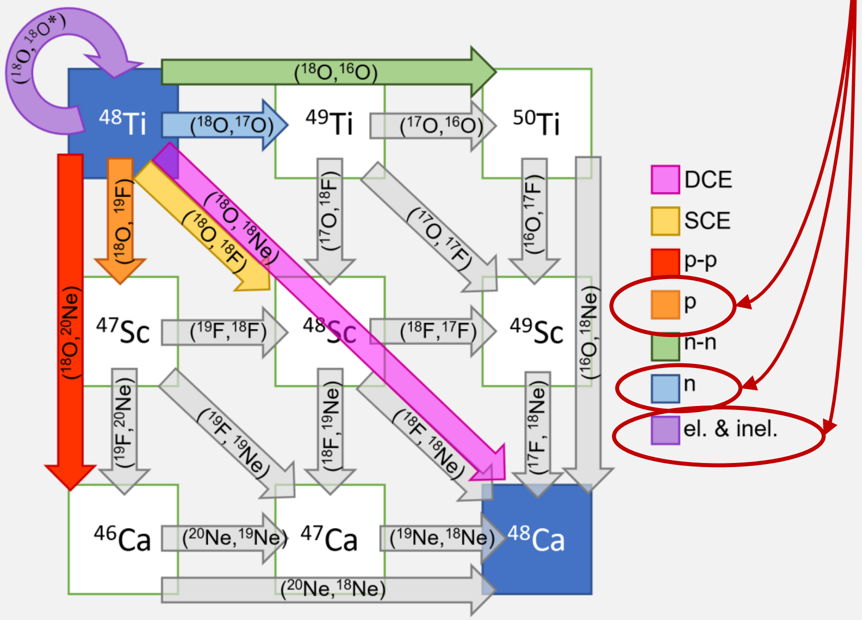
^{48}Ca – ^{48}Ti

O. Sgouros et al., PRC 104, 034617 (2021)

^{12}C – ^{12}Be

F. Cappuzzello et al., EPJA 57, 34 (2021)
A. Spatafora et al., PRC 107, 024605 (2023)

Elastic&inelastic and one-nucleon transfer in the multi-channel approach



This talk

Why study elastic and inelastic scattering?

Why study one-nucleon transfer?

Optical potential

Coupling effects

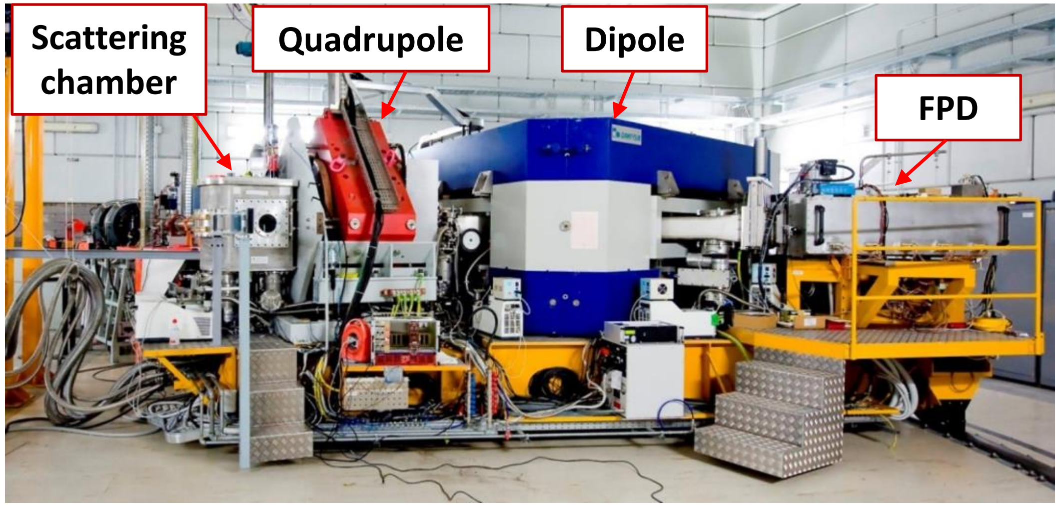
Initial State Interaction (ISI)

To evaluate the **contribution** of **multi-step nucleon transfer** to DCE cross-section

To access **single-particle configurations** in nuclear states

The MAGNEX facility @ INFN-LNS

The MAGNEX magnetic spectrometer

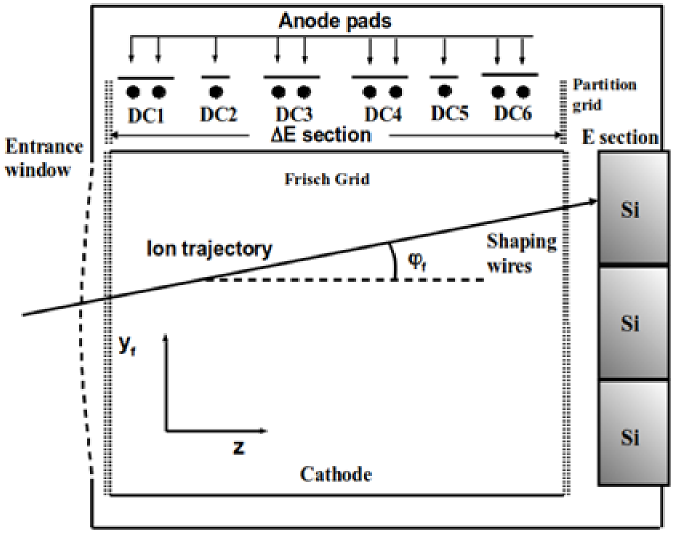


F. Cappuzzello et al., Eur. Phys. J. A 52 (2016) 167

Experimental set-up

- **Beam**: $^{18}O^{8+}$ at 275 MeV
- **Target**: TiO_2 evaporated onto Al
- **Optical axis**:
  - Elastic & inelastic: 9°, 15°, and 21°
  - 1-p & 1-n: 9°

Focal Plane Detector



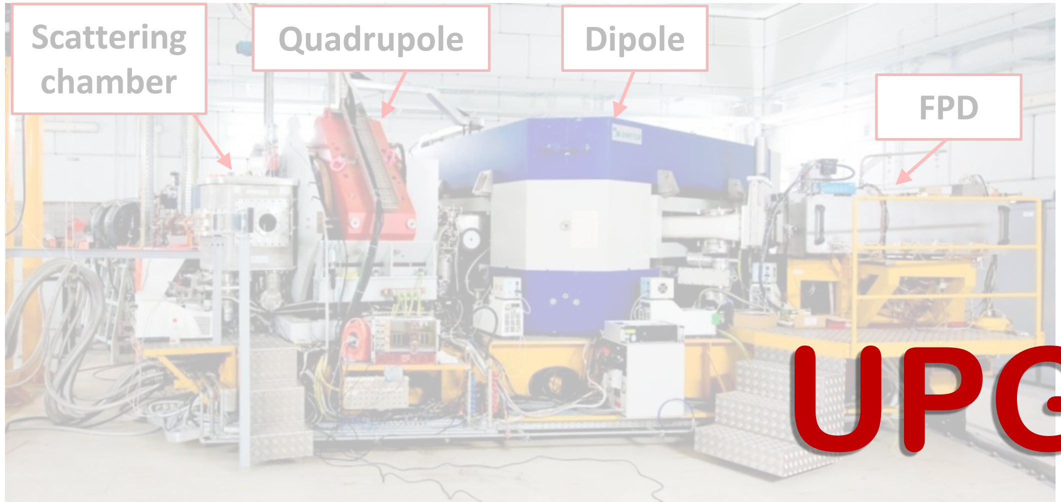
D. Torresi et al., NIM A 989 (2021) 164918

Hybrid detection system based on:

- **Proportional drift chamber:**
  - Measure of x, y, θ, φ
  - Measure of ΔE
- **Wall of 60 silicon detectors:**
  - Measure of E_{resid}

The MAGNEX facility @ INFN-LNS

The MAGNEX magnetic spectrometer



F. Cappuzzello et al., Eur. Phys. J. A 52 (2016) 167

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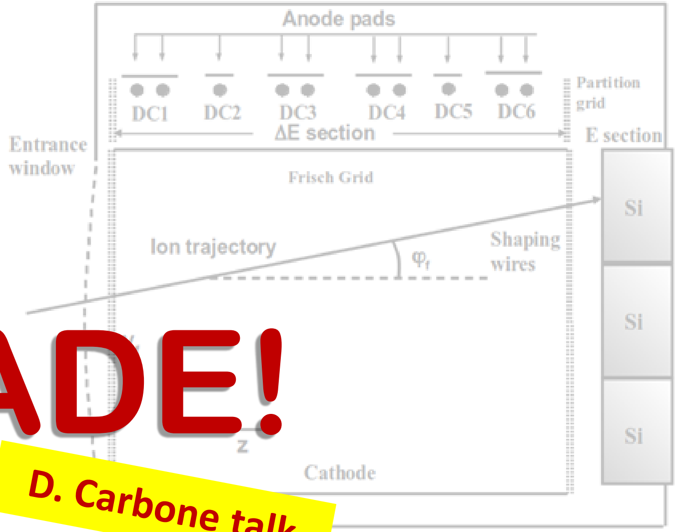

D. Torresi et al., NIM A 989 (2021) 164918

UPGRADE!

D. Carbone talk

Hybrid detection system based on:

- **Proportional drift chamber:**
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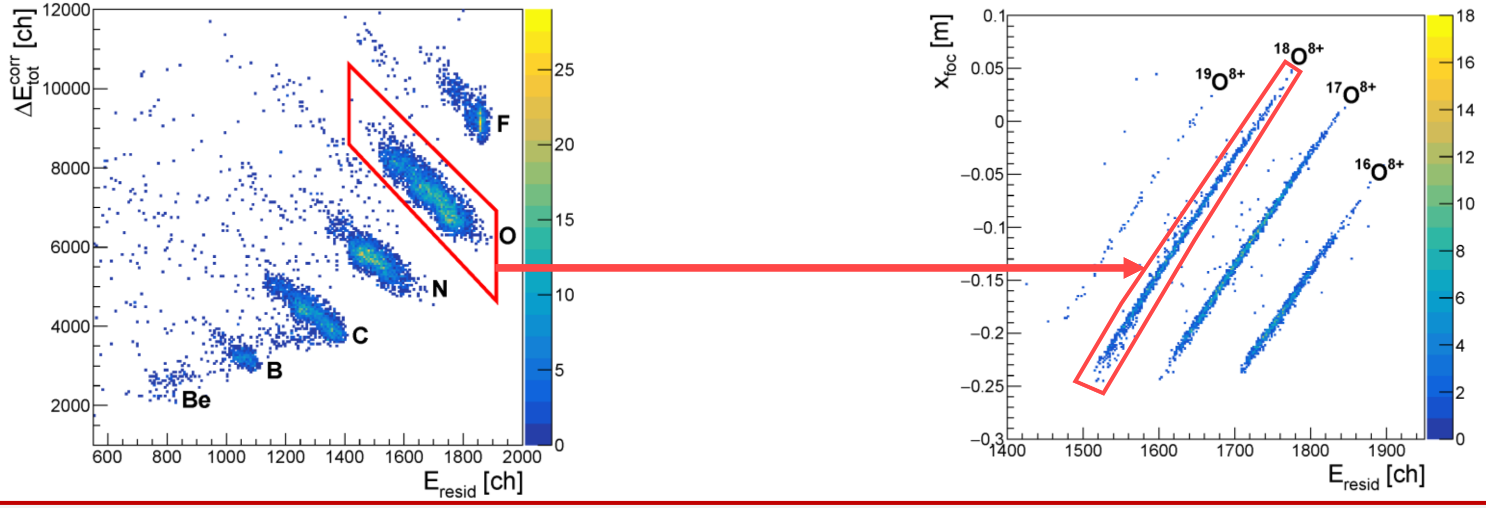
Particle Identification

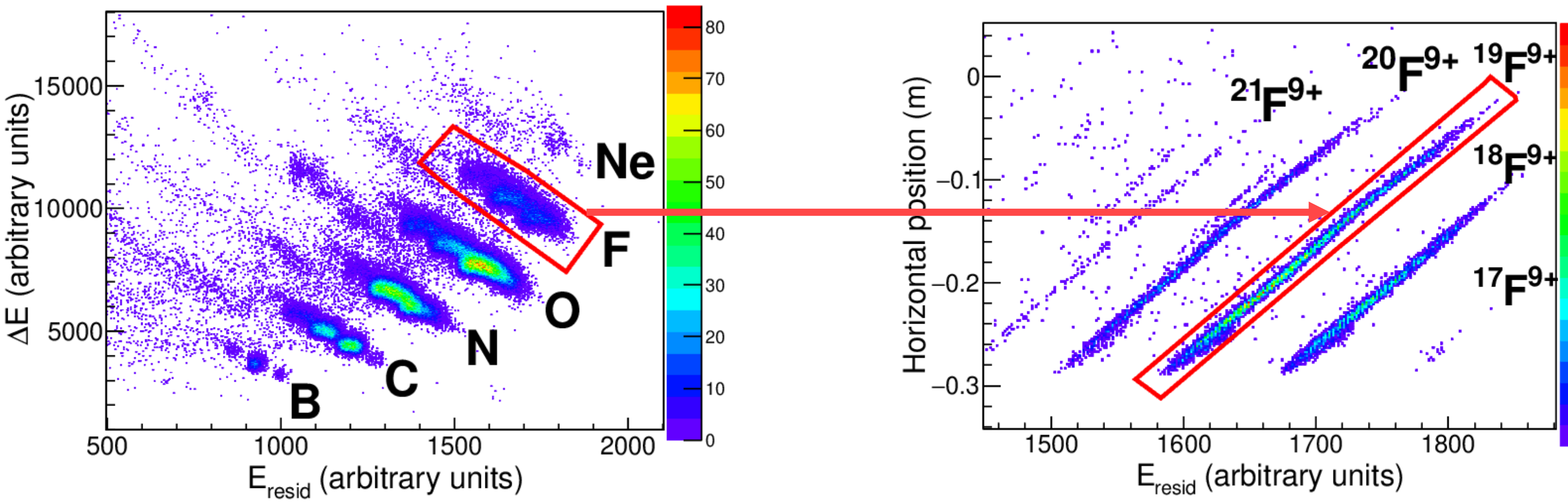
F. Cappuzzello et al., Nucl. Instrum. Meth. A 621 (2010) 419

Elastic and inelastic scattering



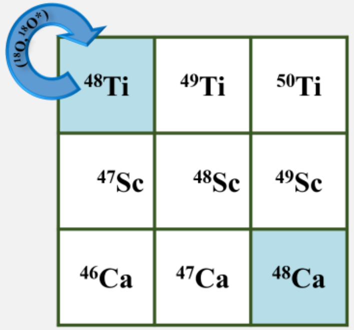
G. A. Brischetto et al., Il Nuovo Cimento C 45 (2022) 96

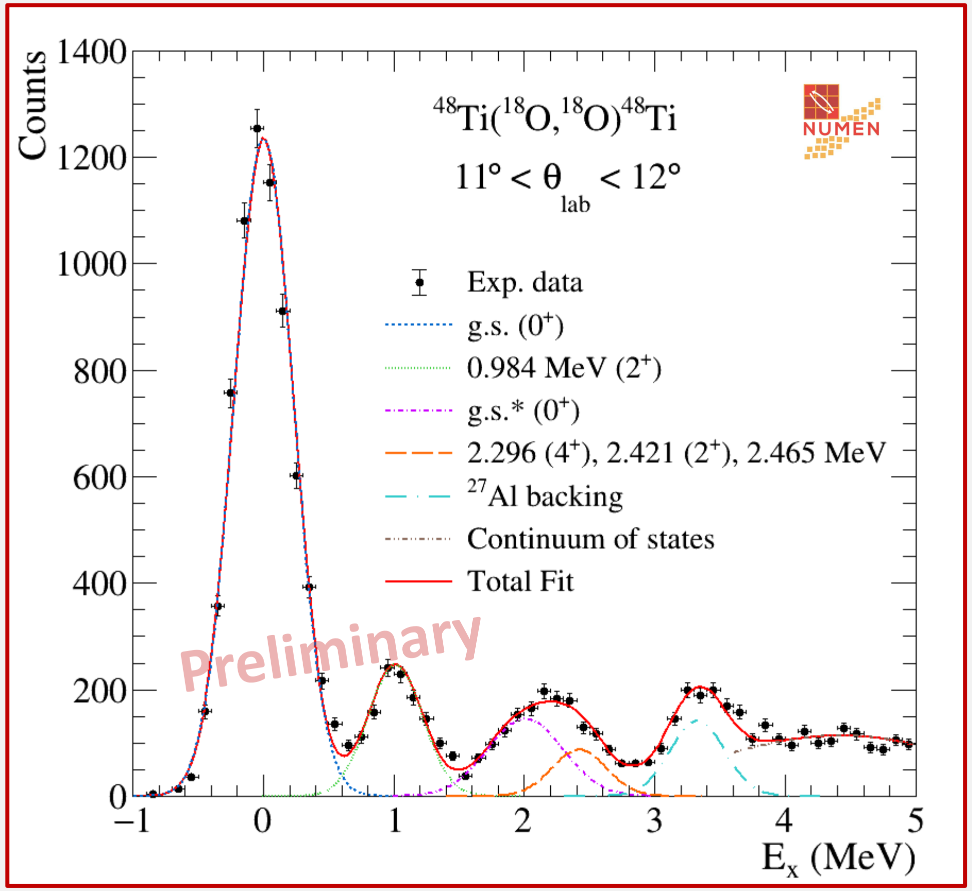
One-proton transfer channel $^{48}Ti(^{18}O,^{19}F)^{47}Sc$



O. Sgouros et al., Phys. Rev. C 104 (2021) 034617

Elastic & inelastic scattering excitation energy spectrum





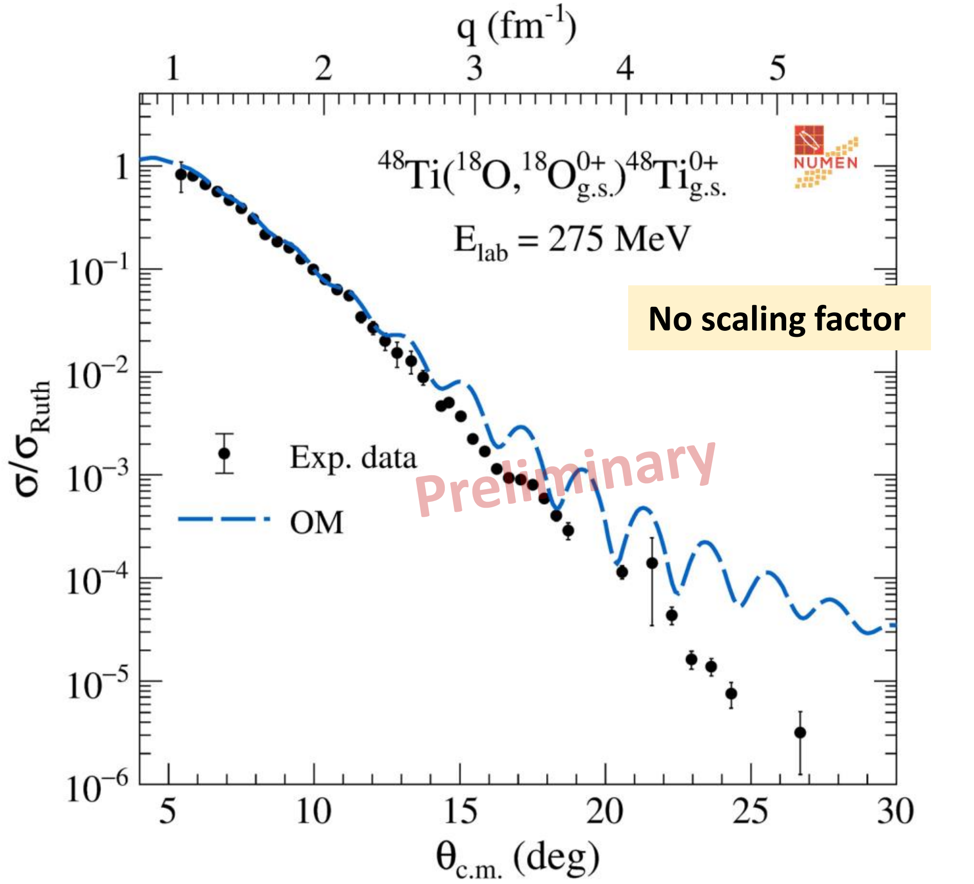
^{18}O		^{48}Ti	
E_x (MeV)	J^π	E_x (MeV)	J^π
0	0^+	0	0^+
1.982	2^+	0.984	2^+
3.555	4^+	2.296	4^+
3.634	0^+	2.241	2^+
3.920	2^+	2.465	
		2.997	0^+
		3.062	2^+
		3.224	3^+

Missing mass formula

$$E_x = Q_0 - K\left(1+\frac{M_e}{M_r}\right) + E_{beam}\left(1-\frac{M_b}{M_r}\right) + 2\frac{\sqrt{M_b M_e}}{M_e}\sqrt{E_{beam}K}\ \cos\theta_{lab}$$

Energy resolution ≈ 500 keV (FWHM)
Angular resolution ≈ 0.5°

Elastic scattering cross-section angular distribution



G. A. Brischetto et al., (to be submitted)

Optical Potential:

- Double-folding **São Paulo Potential** V_{SPP}

$$U_{opt} = (N_V + iN_W)\,V_{SPP}$$

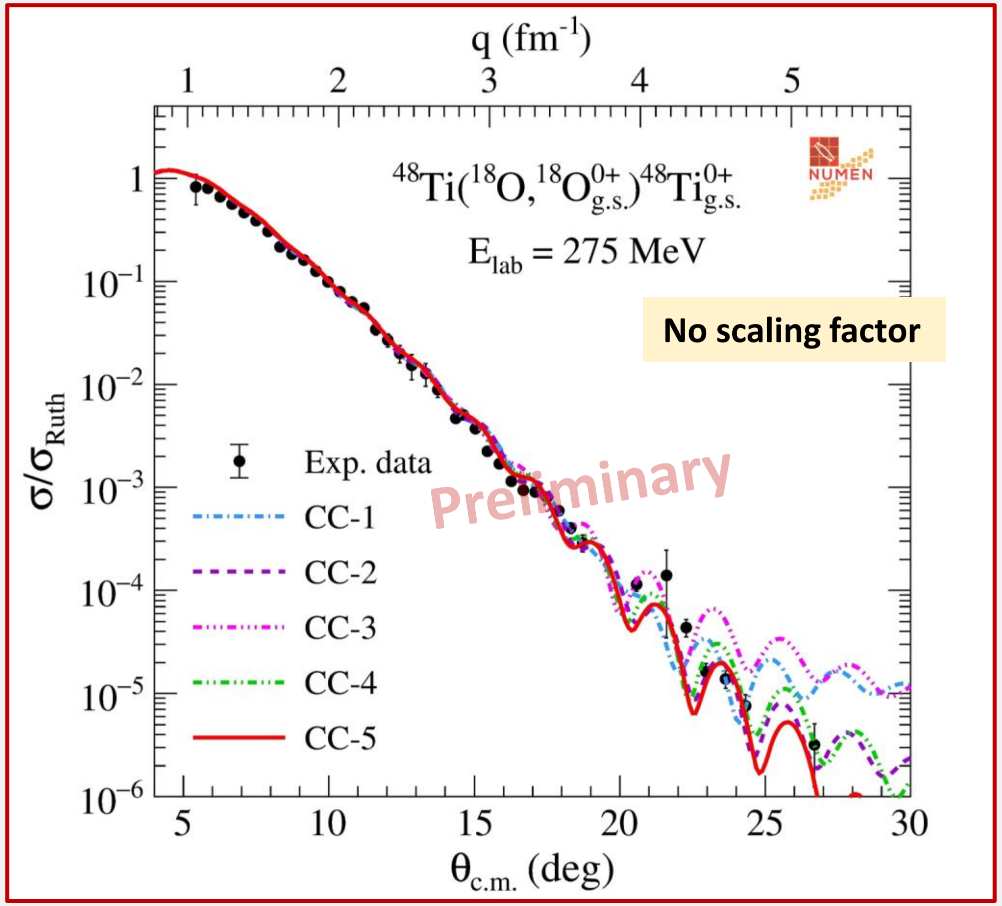
where

$$V_{SPP} = e^{-\frac{4v^2}{c^2}} \int\int \mathrm{d}\vec{r}_1 \mathrm{d}\vec{r}_2\, \rho_1(\vec{r}_1)\, \rho_2(\vec{r}_2)\, V_{NN}(r_{12}, E_N)$$

L. C. Chamon et al., Phys. Rev. C 66 (2002) 014610

	N_R	N_I
OM/DWBA	1.0	0.78
CC	1.0	0.60

Elastic scattering cross-section angular distribution



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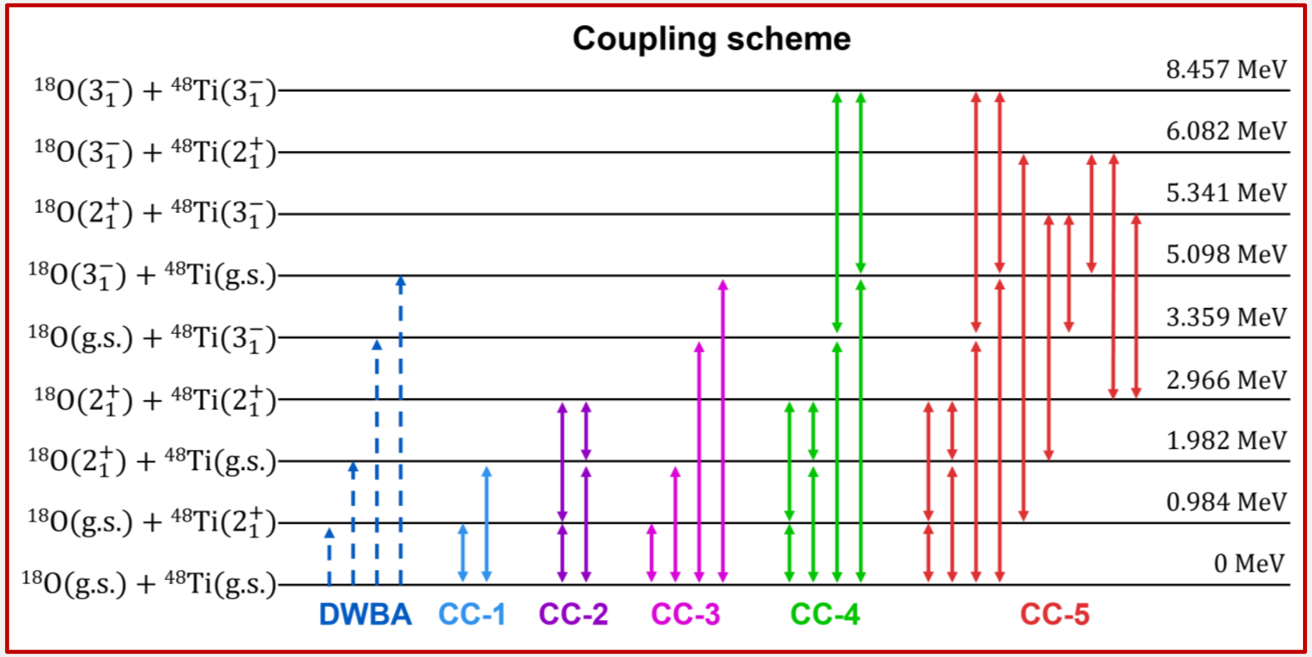
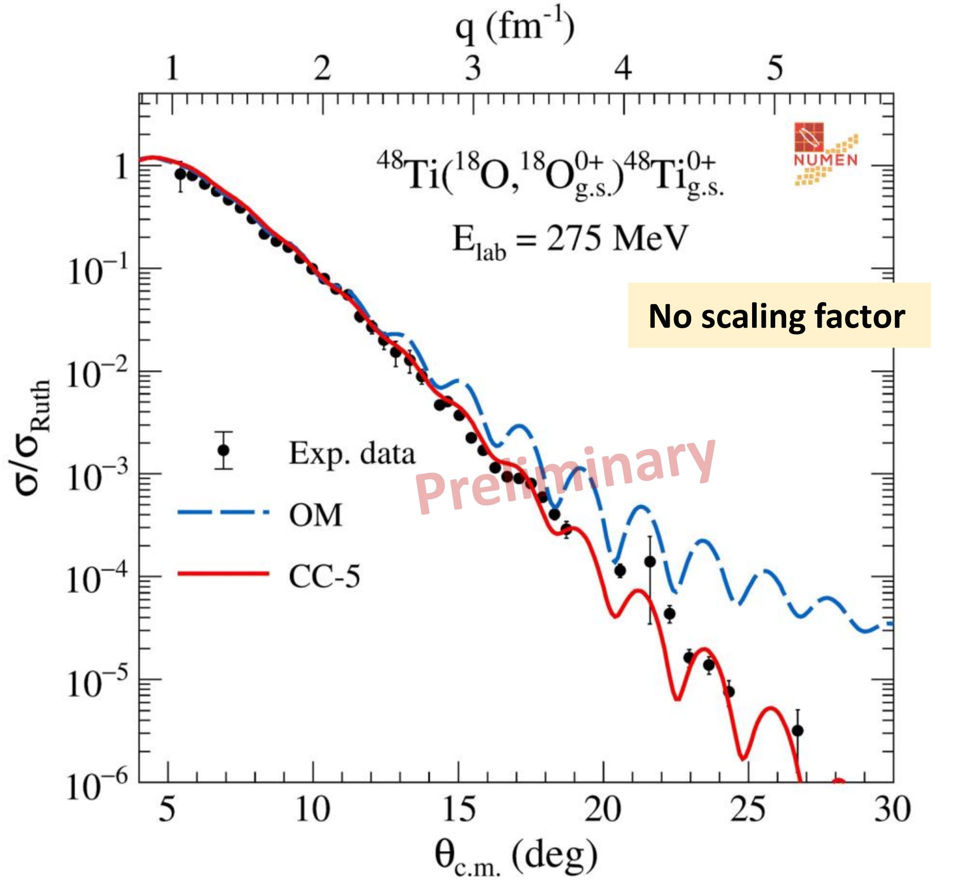


Rotational model for the **2⁺** and **3⁻** collective excited states of both **projectile** and **target**

G. A. Brischetto et al., (to be submitted)

Elastic scattering cross-section angular distribution



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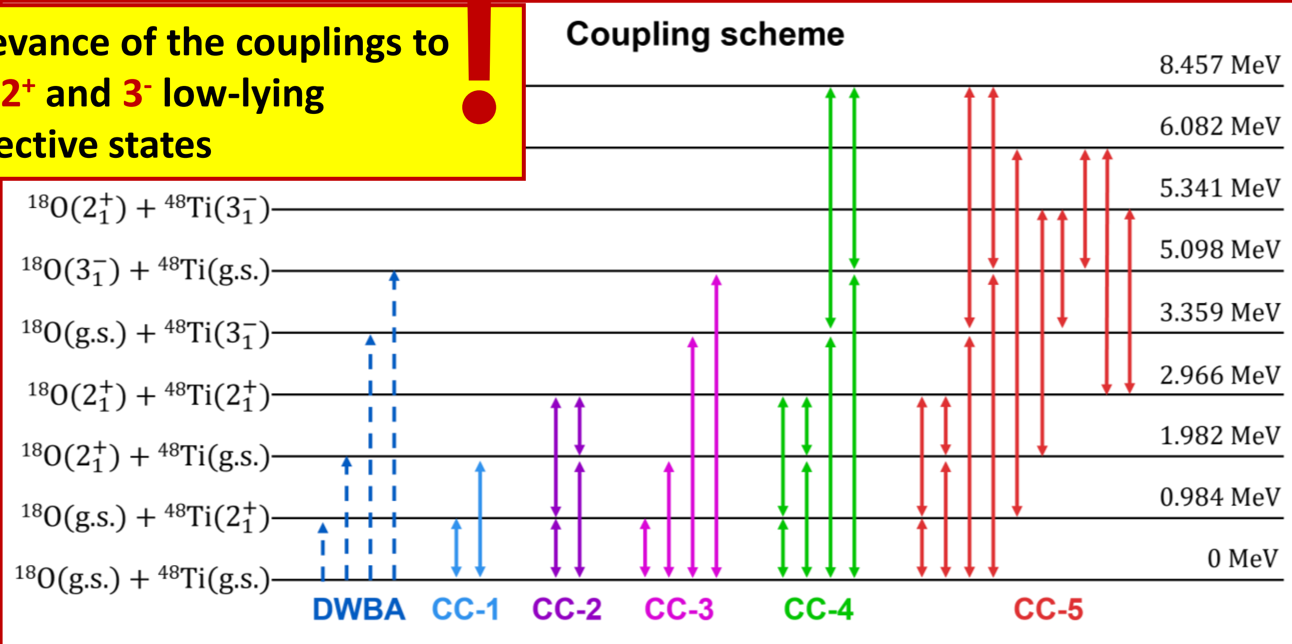
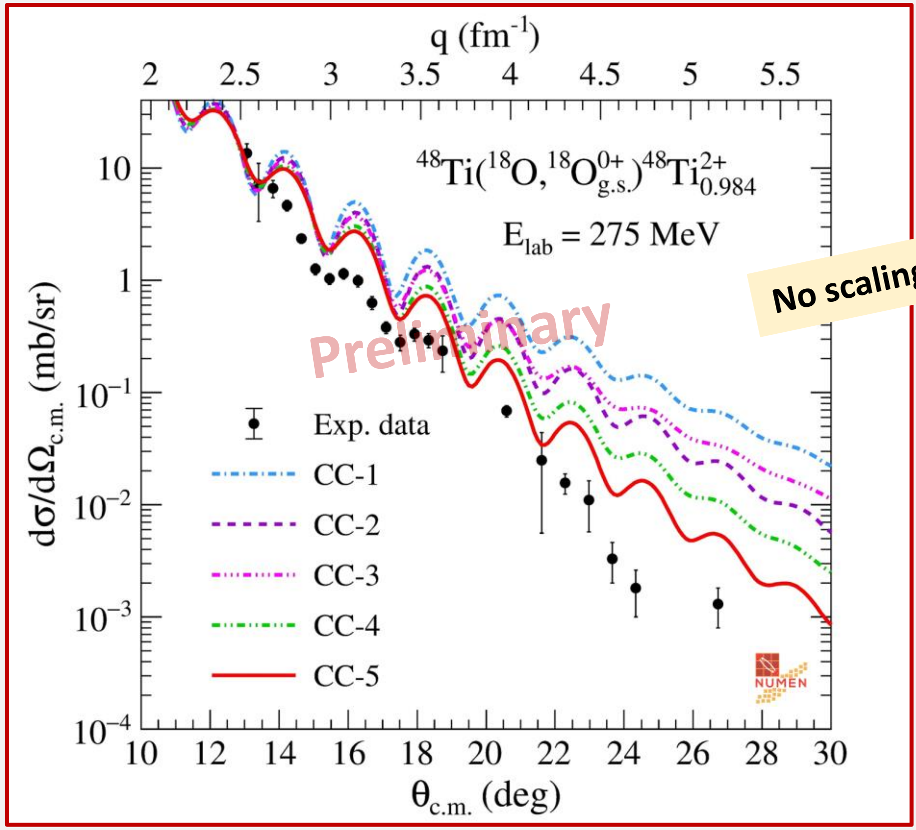
Relevance of the couplings to the 2$^+$ and 3$^-$ low-lying collective states



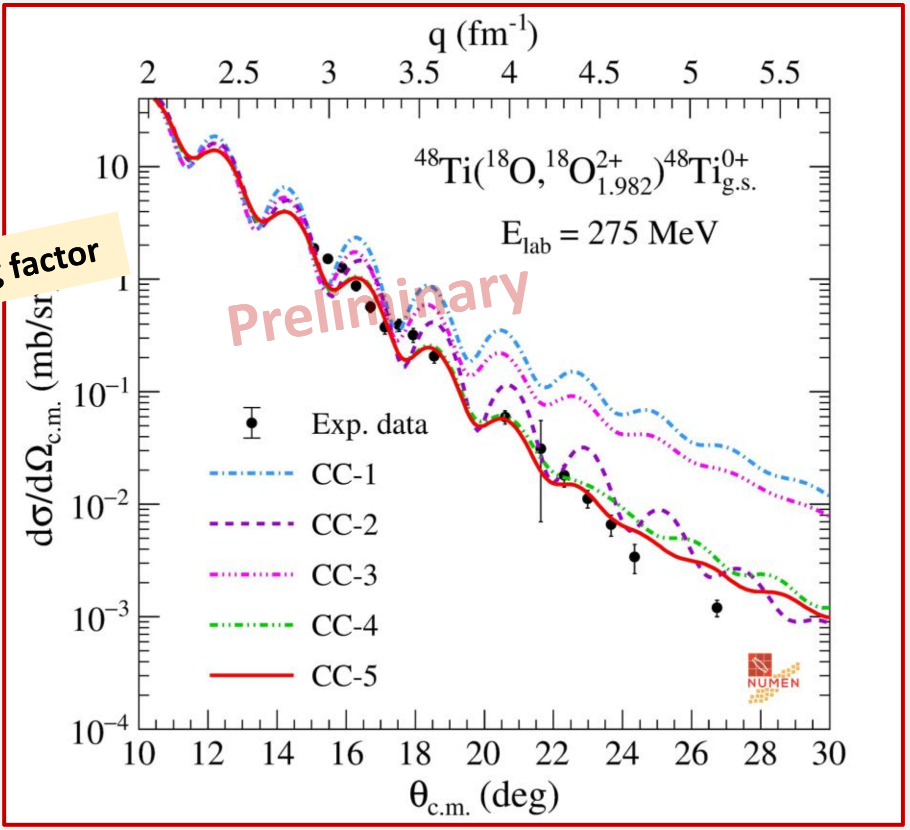
Rotational model for the **2$^+$** and **3$^-$** collective excited states of both **projectile** and **target**

G. A. Brischetto et al., (to be submitted)

Inelastic scattering cross-section angular distributions



No scaling factor

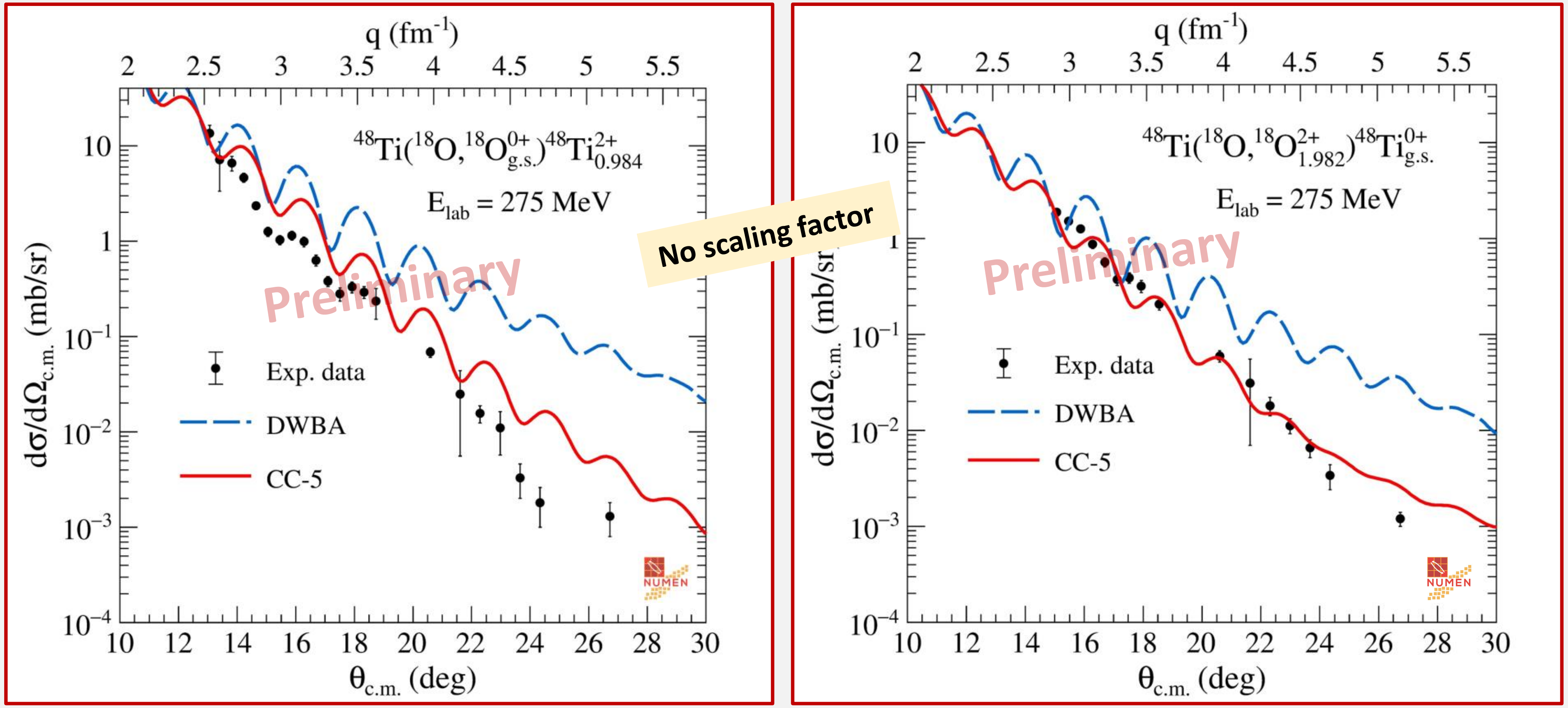


Coulomb coupling	$V_\lambda^{coul}(r) = \boldsymbol{M(E\lambda)}\, e^2 \dfrac{\sqrt{4\pi}}{2\lambda+1} \dfrac{1}{r^{\lambda+1}}$
Nuclear coupling	$V_\lambda^{nucl}(r) = -\dfrac{\boldsymbol{\delta_\lambda}}{\sqrt{4\pi}} \dfrac{dU_{opt}(r)}{dr}$

$\boldsymbol{M(E\lambda)}$ and $\boldsymbol{\delta_\lambda}$ from experimental data

G. A. Brischetto et al., (to be submitted)

Inelastic scattering cross-section angular distributions



Confirmed the relevance of the couplings to the 2^+ and 3^- low-lying collective states !

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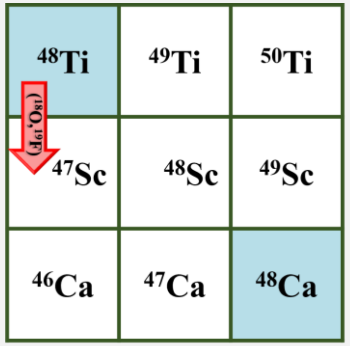
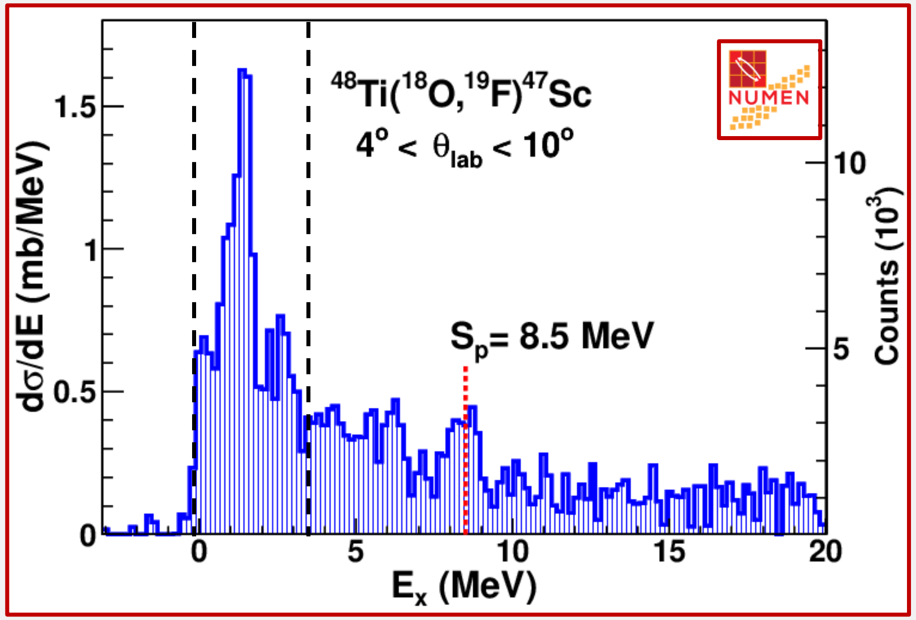
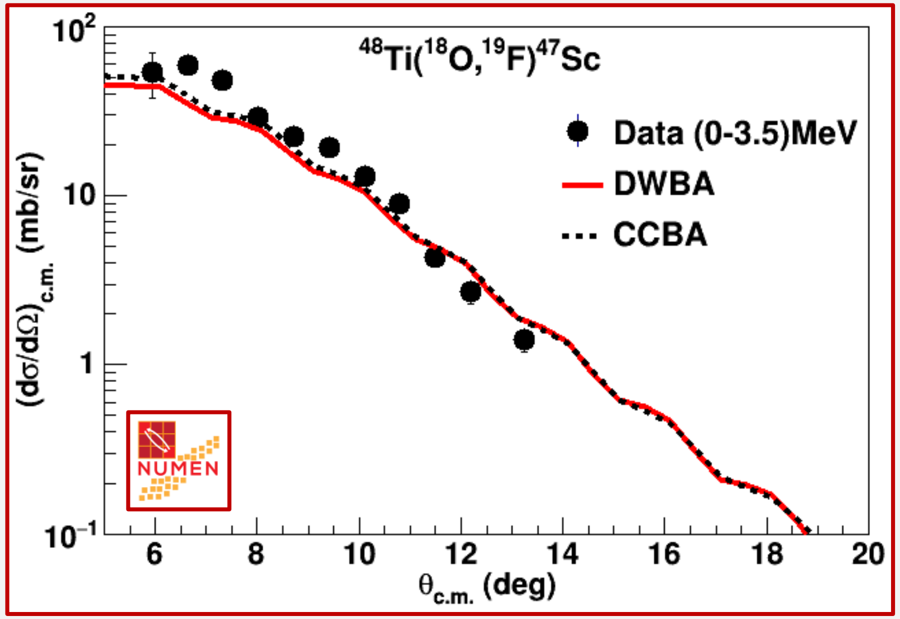
$\boldsymbol{M(E\lambda)}$ and $\boldsymbol{\delta_\lambda}$ from experimental data

G. A. Brischetto et al., (to be submitted)

One-proton transfer reaction







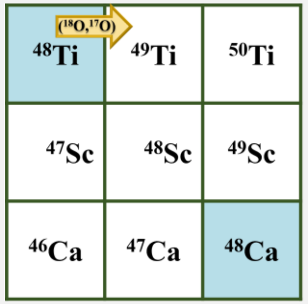
REACTION DYNAMICS → **Distorted waves:** solution of the Schrödinger equation with the **optical potential** derived from the analysis of **elastic scattering**

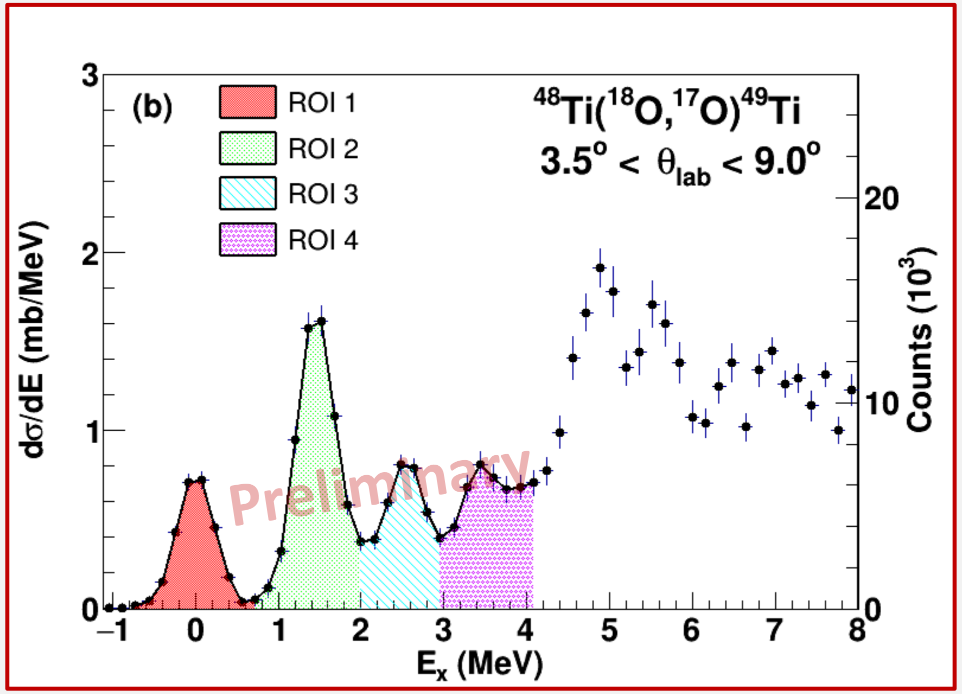
NUCLEAR STRUCTURE → **Spectroscopic amplitudes** derived from **Large-scale Shell Model** calculations

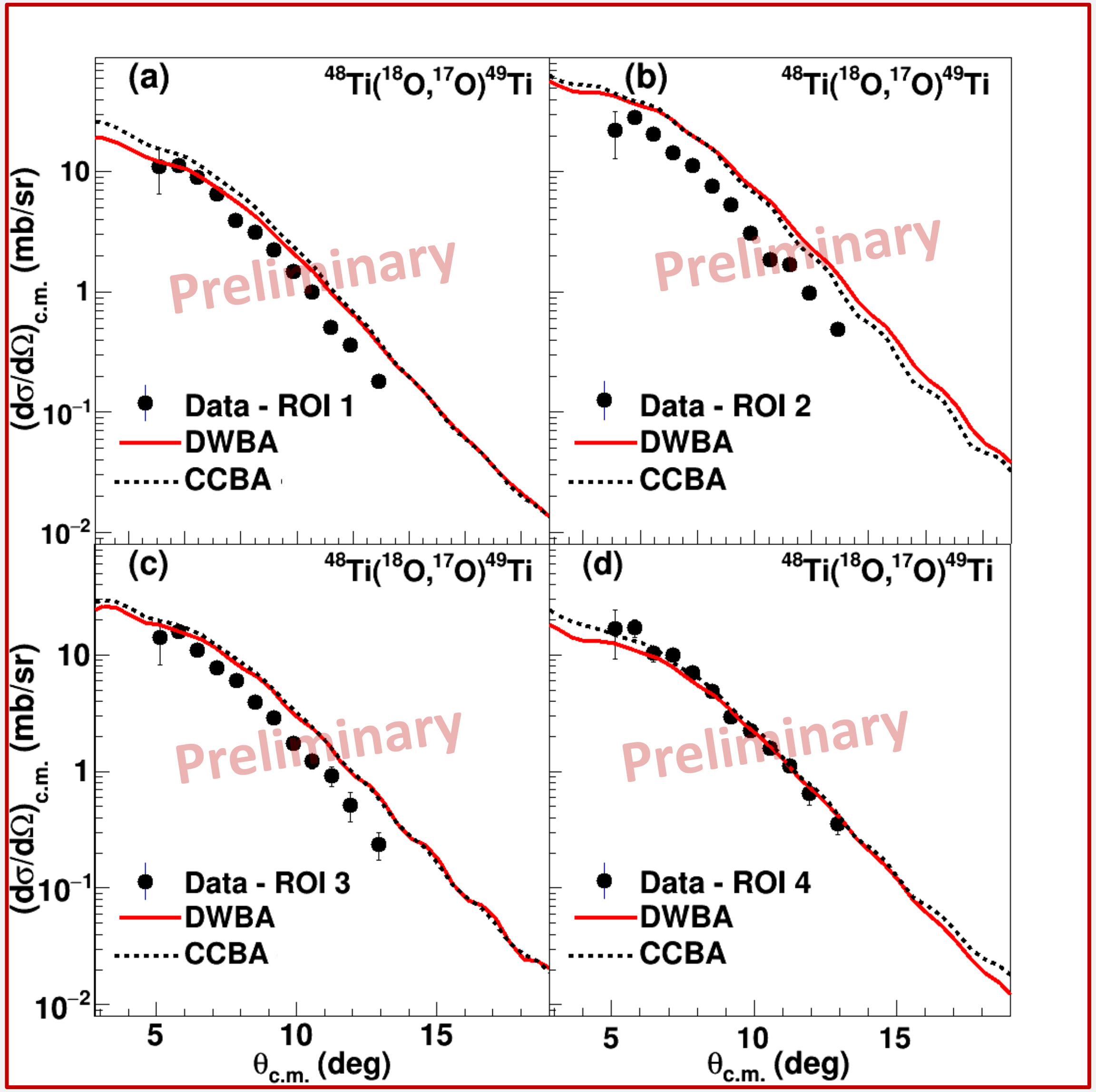
No significant role of core excitation !

O. Sgouros et al., Phys. Rev. C 104 (2021) 034617

One-neutron transfer reaction







Same prescriptions as in one-proton transfer reaction

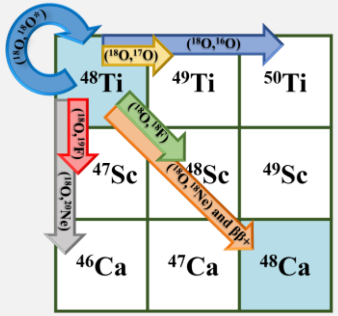
No significant role of core excitation !

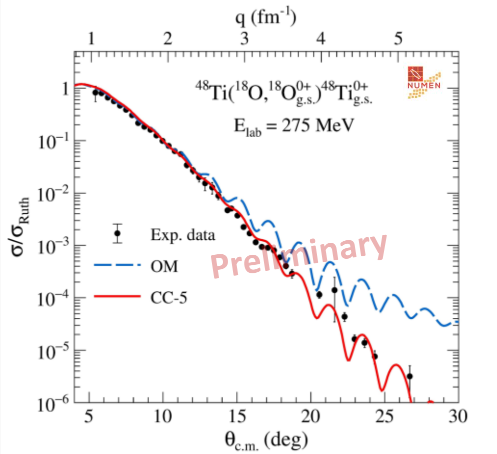
O. Sgouros et al., (to be submitted)

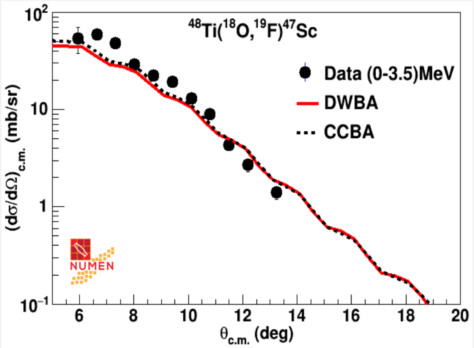
Conclusion & Perspectives

- ✓ Study of the **^{18}O + ^{48}Ti system at 275 MeV** in the context of the NUMEN project
- ✓ Determination of **angular distributions** for **elastic and inelastic** scattering and **one-proton** and **one-neutron** transfer reactions
- ✓ **Good agreement** between **experimental** and **theoretical** cross sections for elastic, inelastic and one-nucleon transfer channels **without any free parameter**
- ✓ **Couplings** to the 2^+ and 3^- low-lying collective states **relevant** for **ISI**, **not significant** for **one-nucleon transfer** reactions

- ○ Completion of the analysis of the whole **^{18}O + ^{48}Ti reaction net**
- ○ Determination of the **DCE cross section** for the ^{18}O + ^{48}Ti system







Thank you for your attention