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for the **NUCL-EX collaboration**

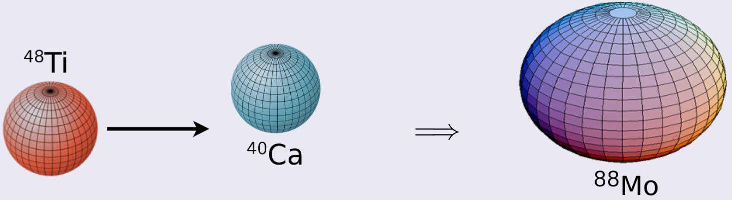
Decay features of medium mass nuclei at high excitation and spins

Comex5, Kraków

September 16$^{\mathrm{th}}$, 2015

Introduction

The reaction



Reaction parameters

E_b [MeV]	E_{cm} [MeV]	ε^* [MeV/u]	l_{gr} [$\hbar$]	$l_{B_f=0}$ [$\hbar$]
300	135	1.4	91	79
450	203	2.2	124	79
600	271	3.0	149	79

Introduction

Why ^{88}Mo?

- large fission barrier up to **high spins**
- mass region not well explored in literature
- **GDR study** performed here in Krakow
  - Michal Ciemała talk
  - M. Ciemała *et al.*, Phys. Rev. C **91**,054313 (2015)

Introduction

Why ^{88}Mo?

- large fission barrier up to **high spins**
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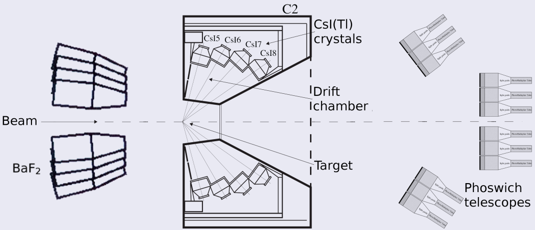
- **GDR study** performed here in Krakow
  - Michal Ciemała talk
  - M. Ciemała *et al.*, Phys. Rev. C **91**,054313 (2015)
- This talk will be focused on:
  - light charged particles emission in fusion-evaporation channel
  - check of **statistical model** parameters
  - fusion-evaporation and fusion-fission **cross sections**
  - S. Valdré *et al.*, submitted to Phys. Rev. C. arXiv:1509.03184

Experimental apparatus

Experimental apparatus



The experiment

- performed at *Laboratori Nazionali di Legnaro* (LNL)
- beam from ALPI linac
- Main detectors: GARFIELD and Hector

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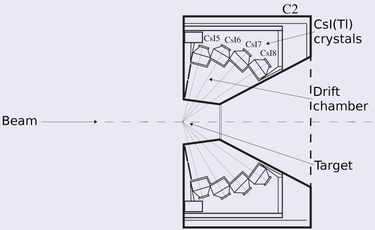

GARFIELD

- ΔE(gas)-E(CsI(Tl)) telescope array
- cylindrical symmetry; divided into 24 azimuthal sectors
- detects LCPs and IMFs at $29^\circ < \theta < 85^\circ$

Experimental apparatus

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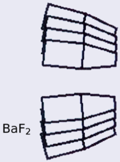
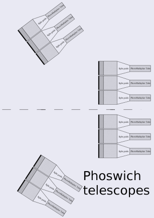


Hector

- 8 BaF_2 scintillators from Hector setup
- detect high energy γ-rays ($E_\gamma \gtrsim 4\,\mathrm{MeV}$)
- not considered in the present work

Experimental apparatus

Experimental apparatus

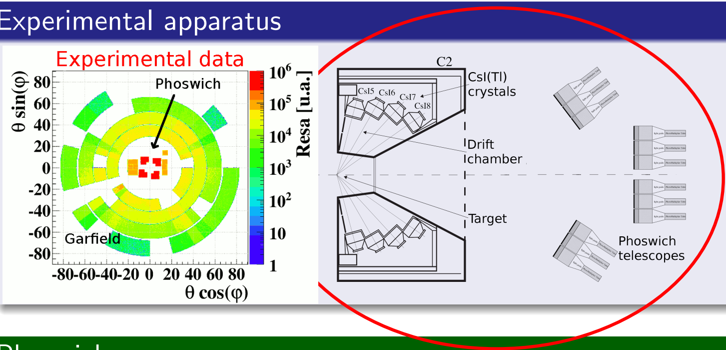


Phoswiches

- 48 scintillator telescopes from FIASCO experiment
- identify evaporation residues and fission fragments
- at forward angles ($5^\circ < \theta < 15^\circ$)

Experimental apparatus

Experimental apparatus



Phoswiches

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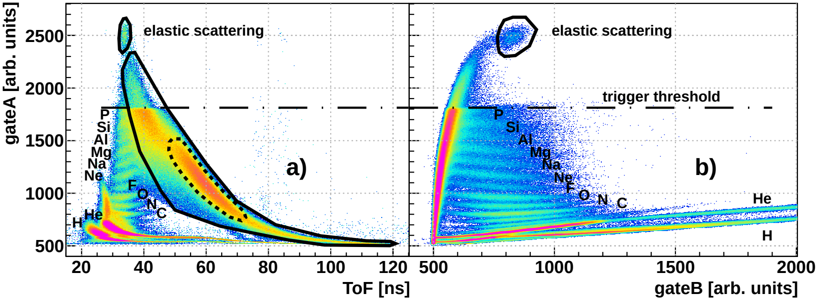
Evaporation residue selection



Condition for the selection of fusion-evaporation events

1 particle in dotted areal gate in any phoswich

no other particles in continuous areal gates

Statistical model of Compound Nucleus decay

The GEMINI++ statistical model code

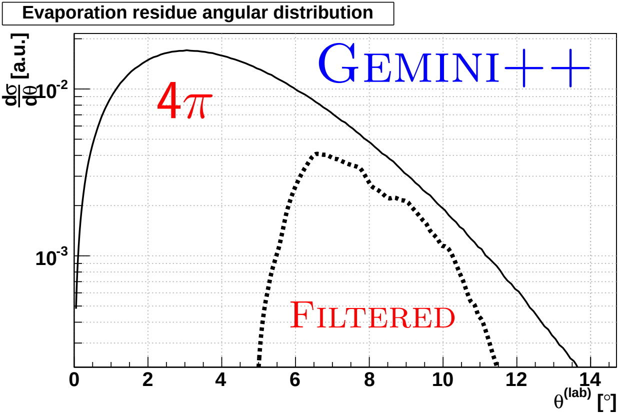
- is a widely used statistical model code
- adopts a default set of parameters obtained by fitting data from several previous experiments
  - parameters are tuned for heavy nuclei ($A \gtrsim 150$)
  - there aren't many experimental data to fix parameters for medium-light nuclei
- We compared experimental data with GEMINI++ varying many parameters:
  - level density
  - Coulomb barrier distribution
  - yrast energy parametrization
  - etc...

R. J. Charity, Phys. Rev. C **82**, 014610 (2010)

From 4π to experimental geometry and vice-versa

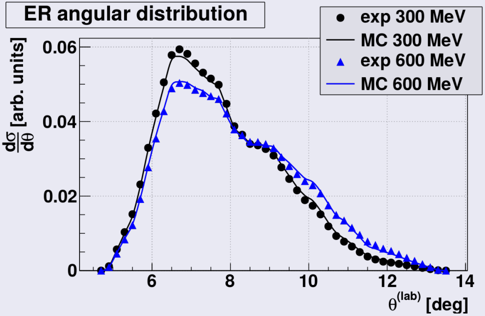
Geometry and efficiency filter

- directly compare experimental spectra with filtered simulations
- correct experimental yields for the apparatus efficiency



Comparison between experimental data and GEMINI++

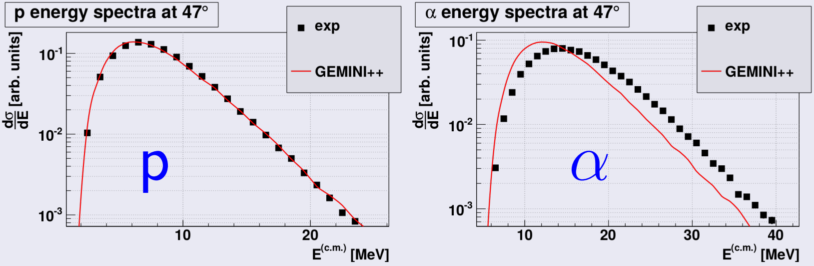
300 and 600 MeV ER angular distributions



- Spectra are scaled to the same integral to compare the shape
- Very good agreement

Comparison between experimental data and GEMINI++

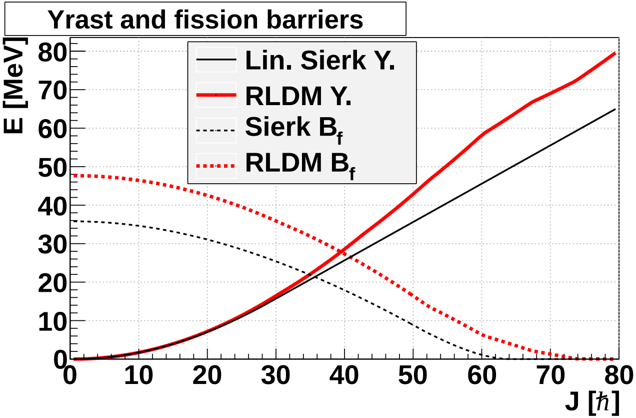
300 MeV energy spectra in coincidence with ER



- Spectra are scaled to the same integral to compare the shape
- Very good agreement for protons
- Simulated α spectra have a correct slope, but lower energy

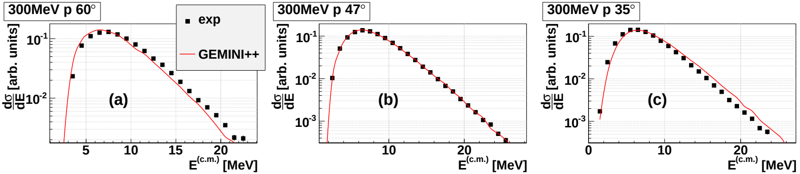
Improvement of the agreement for α-particles

Only adopting **RLDM yrast and fission barrier** (instead of linearized Sierk) the agreement improves

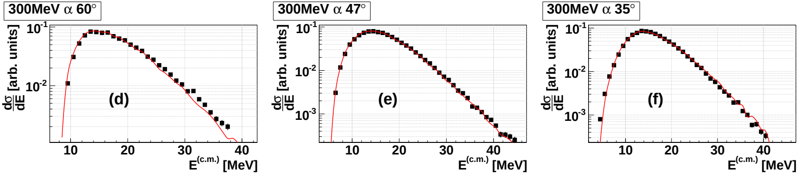


Comparison between experimental data and GEMINI++

proton energy spectra at 300 MeV

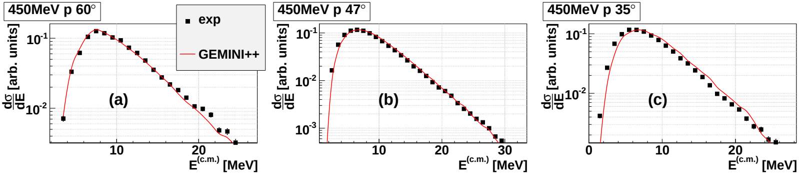


α-particle energy spectra at 300 MeV

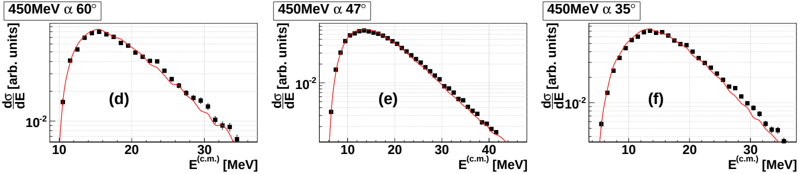


Comparison between experimental data and GEMINI++

proton energy spectra at 450 MeV

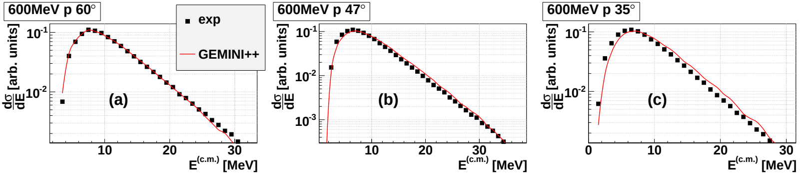


α-particle energy spectra at 450 MeV

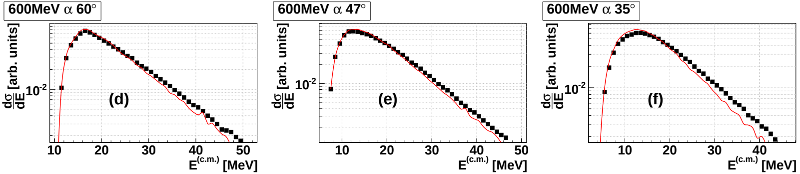


Comparison between experimental data and GEMINI++

proton energy spectra at 600 MeV

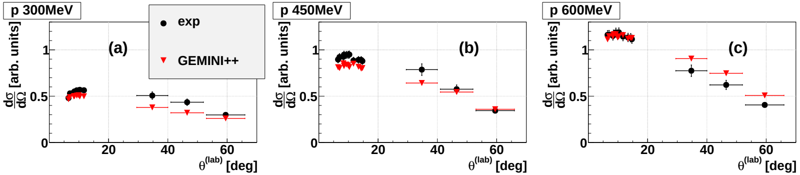


α-particle energy spectra at 600 MeV

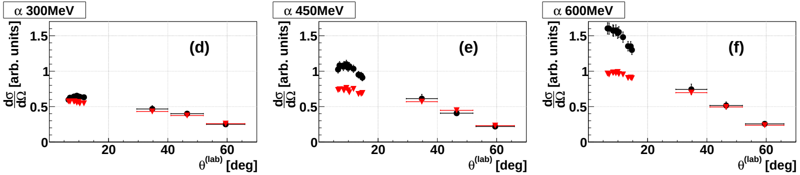


Comparison between experimental data and GEMINI++

proton angular distributions



α-particle angular distributions



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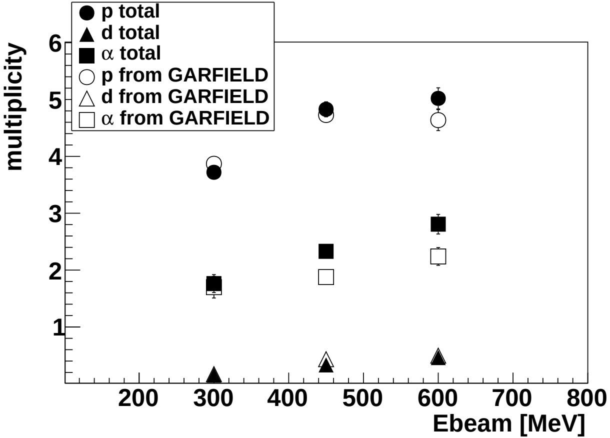


Cross section estimations

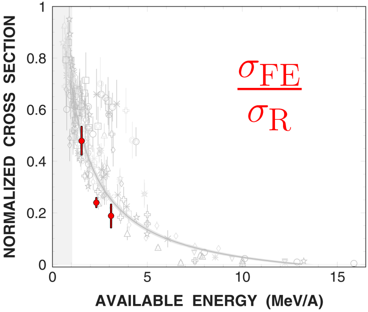
Rutherford cross-section normalization

It's possible to measure cross sections via a normalization obtained from a plastic scintillator at 2° that measures elastic scattering

$$\sigma_{\mathrm{FE}}(300\,\mathrm{MeV}) = 0.89(11)\,\mathrm{b}$$

$$\sigma_{\mathrm{FE}}(450\,\mathrm{MeV}) = 0.55(5)\,\mathrm{b}$$

$$\sigma_{\mathrm{FE}}(600\,\mathrm{MeV}) = 0.46(12)\,\mathrm{b}$$



P. Eudes *et al.*, Europhys. Lett. **104**, 22001 (2013)

Cross section estimations

Rutherford cross-section normalization

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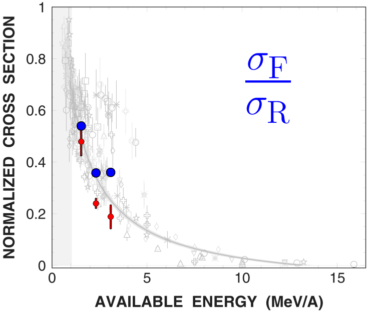
$$\sigma_{\mathrm{F}}(300\,\mathrm{MeV}) = 1.01(11)\,\mathrm{b}$$

$$\sigma_{\mathrm{F}}(450\,\mathrm{MeV}) = 0.81(6)\,\mathrm{b}$$

$$\sigma_{\mathrm{F}}(600\,\mathrm{MeV}) = 0.88(16)\,\mathrm{b}$$



Conclusions

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- We found an α-particle yield excess, in particular at forward angles and increasing with energy.
- It's difficult to improve the agreement by tuning the model parameters; indication of the onset of minor pre-equilibrium emission or contamination from other processes.
- We gave an estimation of fusion-evaporation and total fusion cross section. Expecially at higher energies, there is room for DIC and quasi-fission decays.

The 5th international conference on
"COLLECTIVE MOTION IN NUCLEI UNDER EXTREME CONDITIONS"

COMEX5

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Thanks for your attention!