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Title: Light-ion production from O, Si, Fe and Bi induced by 175 MeV quasi-monoenergetic neutrons

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Light-ion production from O, Si, Fe and Bi induced by 175 MeV quasi-monoenergetic neutrons

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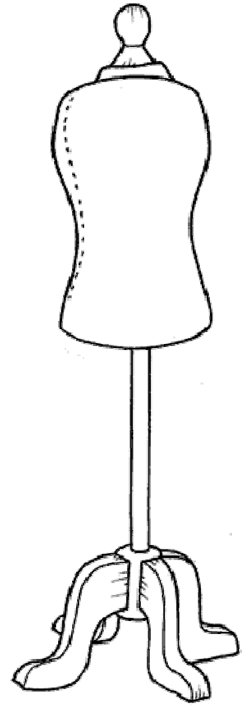
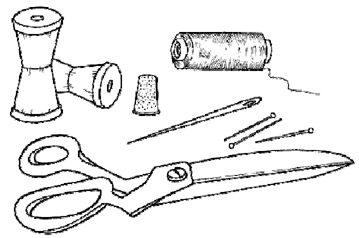
International Conference on
Nuclear Data for Science and Technology
ND2013

A good model can advance fashion by ten years.

(Yves Saint-Laurent, 1936-2008)





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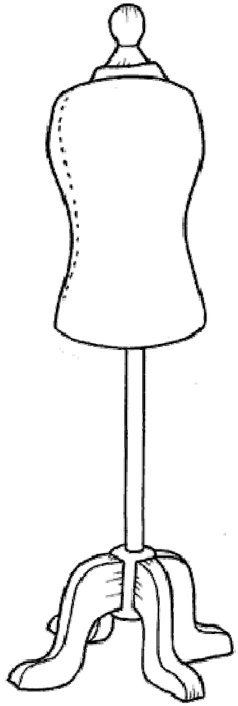
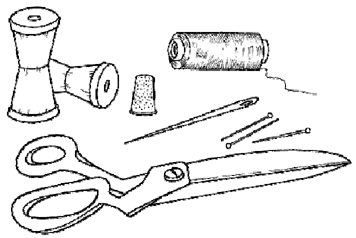


to have a good model, we need good experimental data



Outline

- The Medley spectrometer
- Double differential cross sections at 175 MeV QMN

  composite charged particles production

  from O, Si, Fe, Bi (C and U measured, not presented here)

  in comparison with model calculations:

  - MCNP6
  - Quantum Molecular Dynamics (QMD) with PHITS
  - Modified QMD with PHITS
  - INCL4.5-Abla07
  - TALYS-1.2
  - Modified TALYS-1.2
- Angle integrated cross sections for Fe and Bi
- Conclusions

Neutrons @
The Svedberg Laboratory

Uppsala University, Sweden

Cyclotron: 180 MeV protons

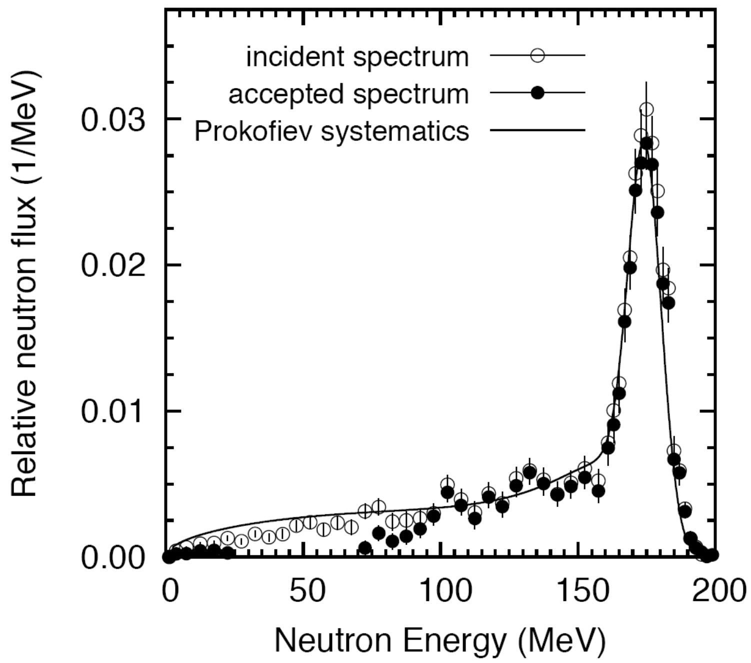
Pulsed neutron beam line:

^{7}Li(p,n) reaction

Quasi-monoenergetic neutrons

with energies up to 175 MeV

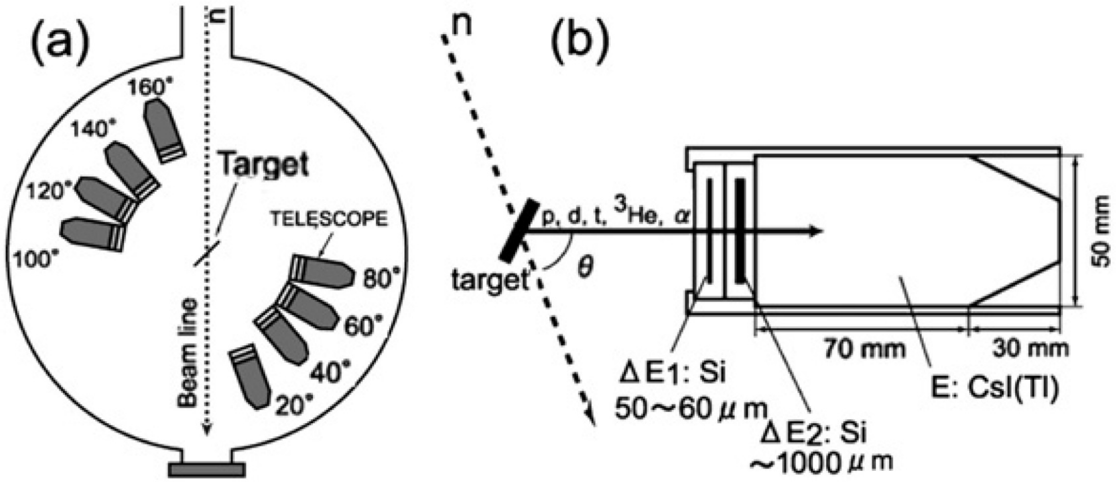
175 MeV QMN spectrum



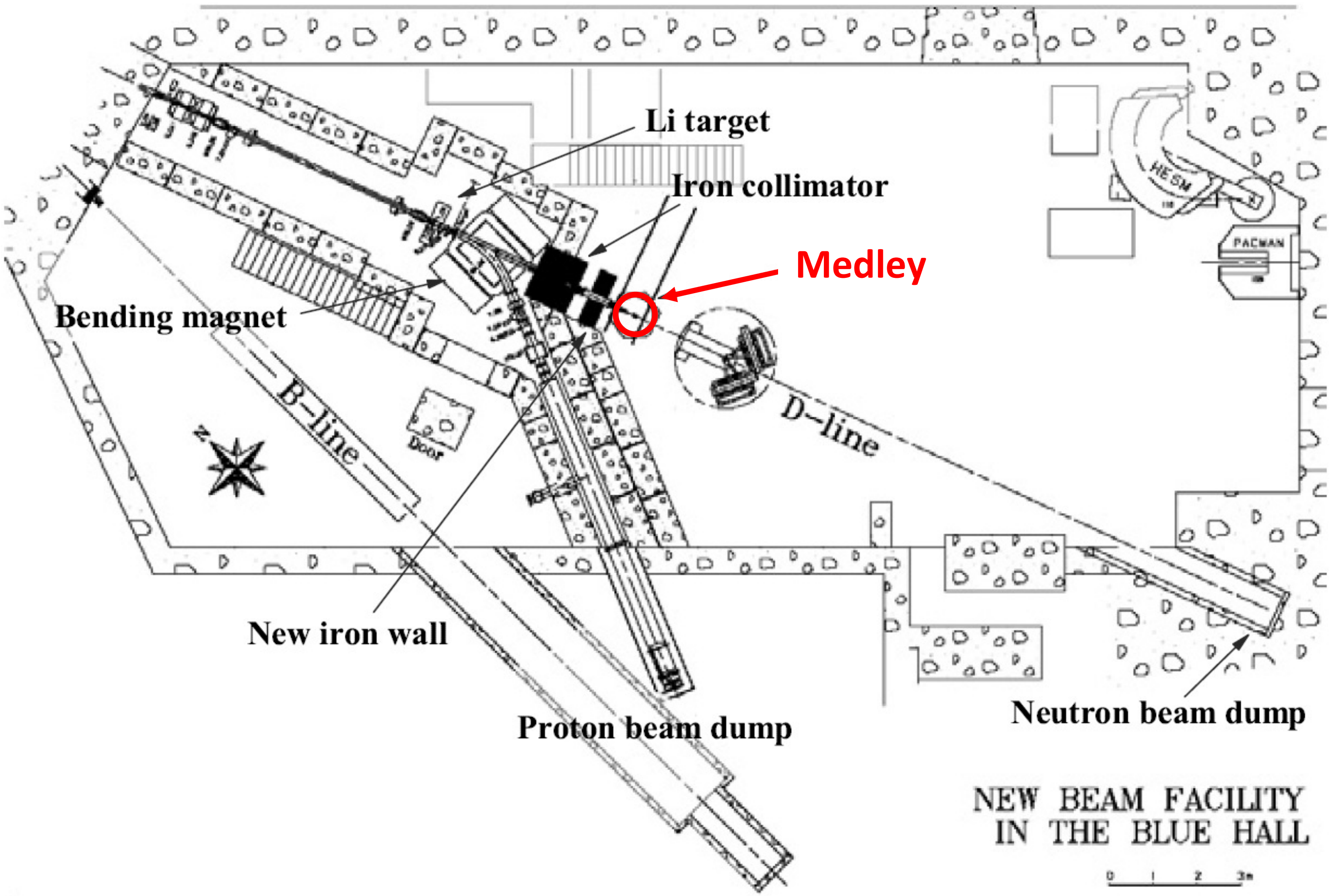
Medley Spectrometer

@ The Svedberg Laboratory

- Eight three-elements ΔE-ΔE-E telescopes
- Detects: protons, deuterons, tritons, 3He, α particles
- Low particle identification threshold (2 MeV for protons)
- Wide dynamic range (up to 170 MeV)



Medley Spectrometer
@ The Svedberg Laboratory



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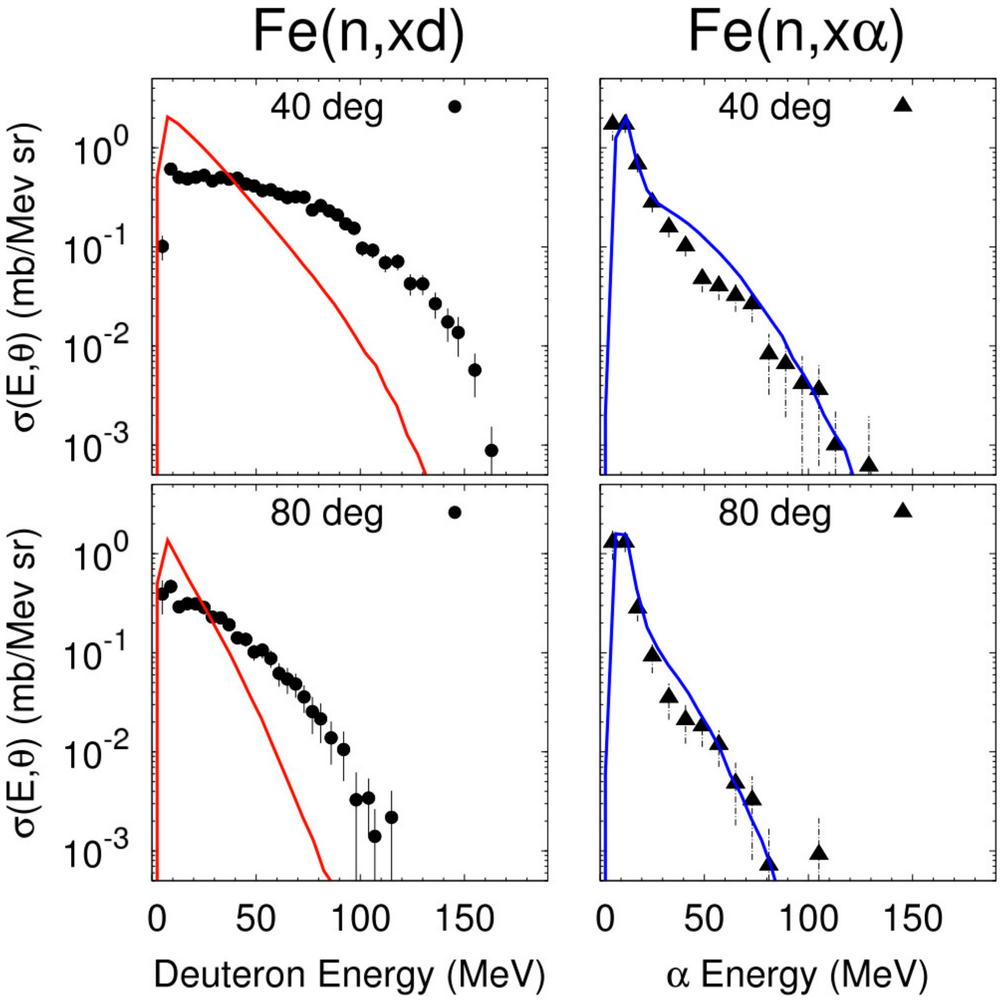
MCNP6

Event generator:
Cascade-Exciton Model
(CEM03.03)



Calculations by Stepan Mashnik

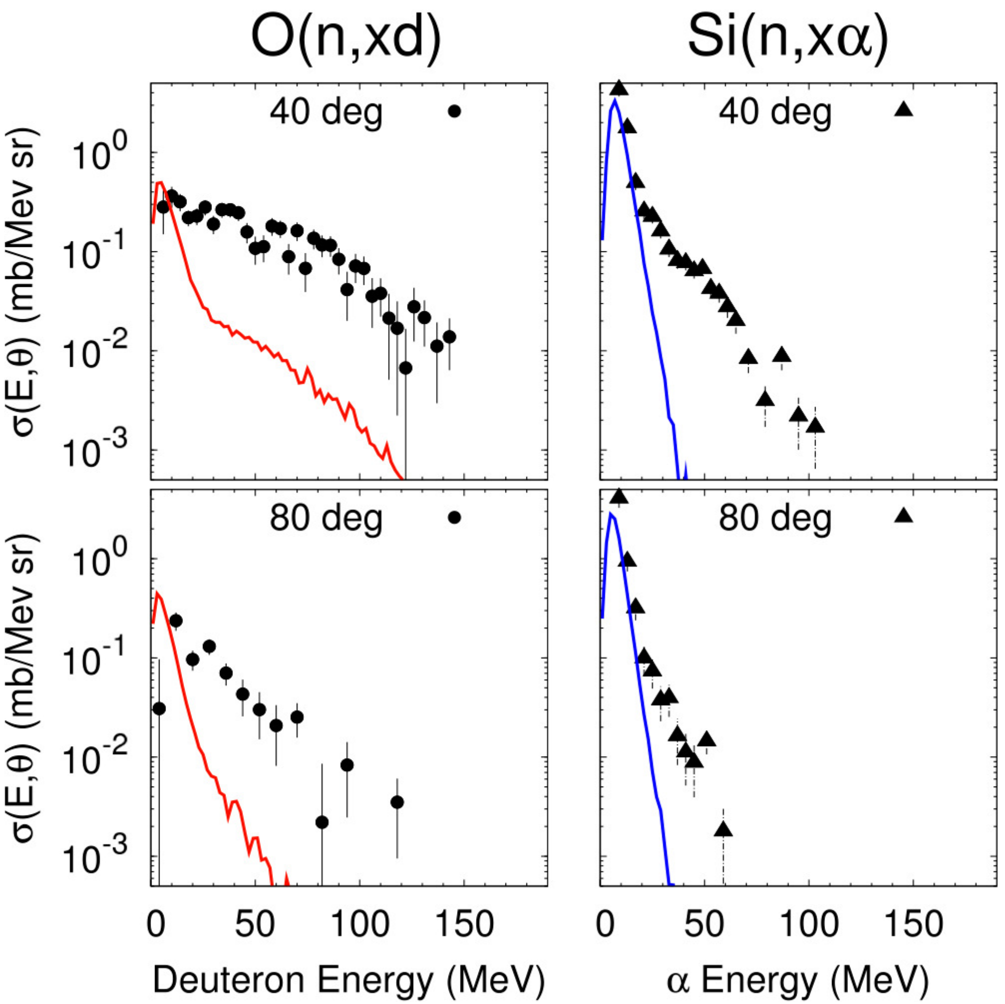
Leslie M. Kerby “Preequilibrium Emission of Light Fragments in Spallation Reactions”
Central Park West, **now** (unfortunately!)

Quantum Molecular Dynamics

PHITS calculations

- pre-equilibrium: QMD

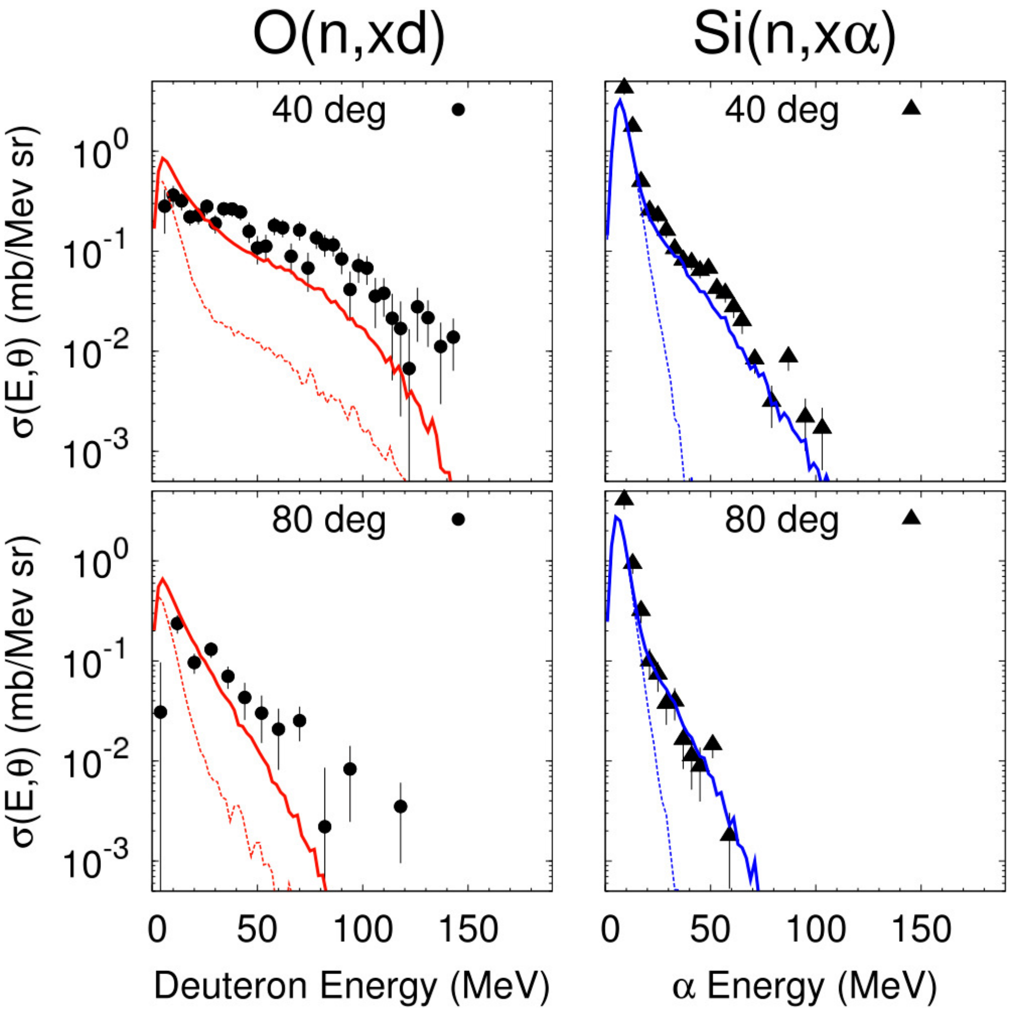
- statistical decay: generalized evaporation model (GEM)



Calculations by Y. Watanabe

Quantum Molecular Dynamics

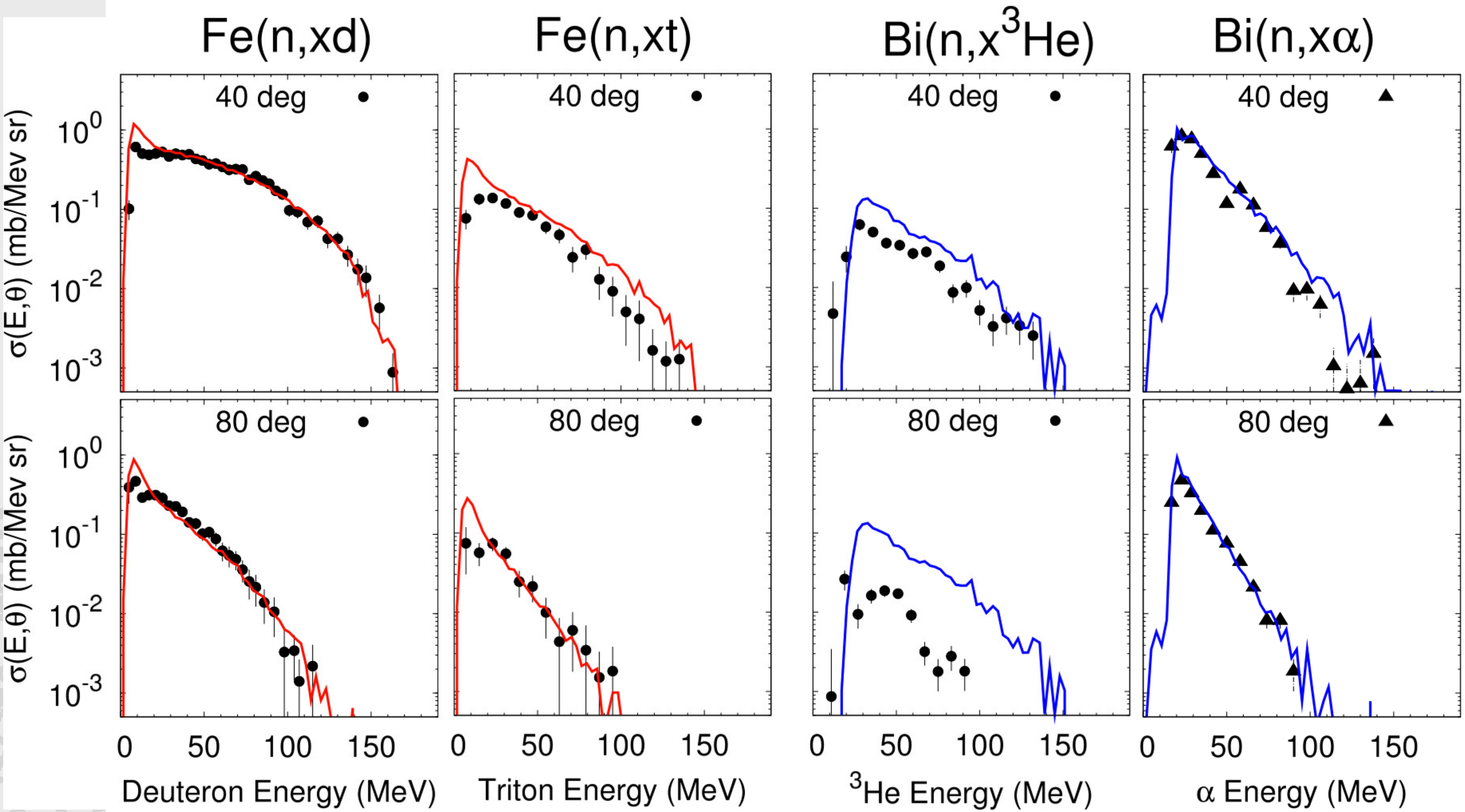
Modified with a Surface Coalescence Model



Calculations by Y. Watanabe

INCL4.5-Abla07

- Intranuclear cascade model
- Abla de-excitation model

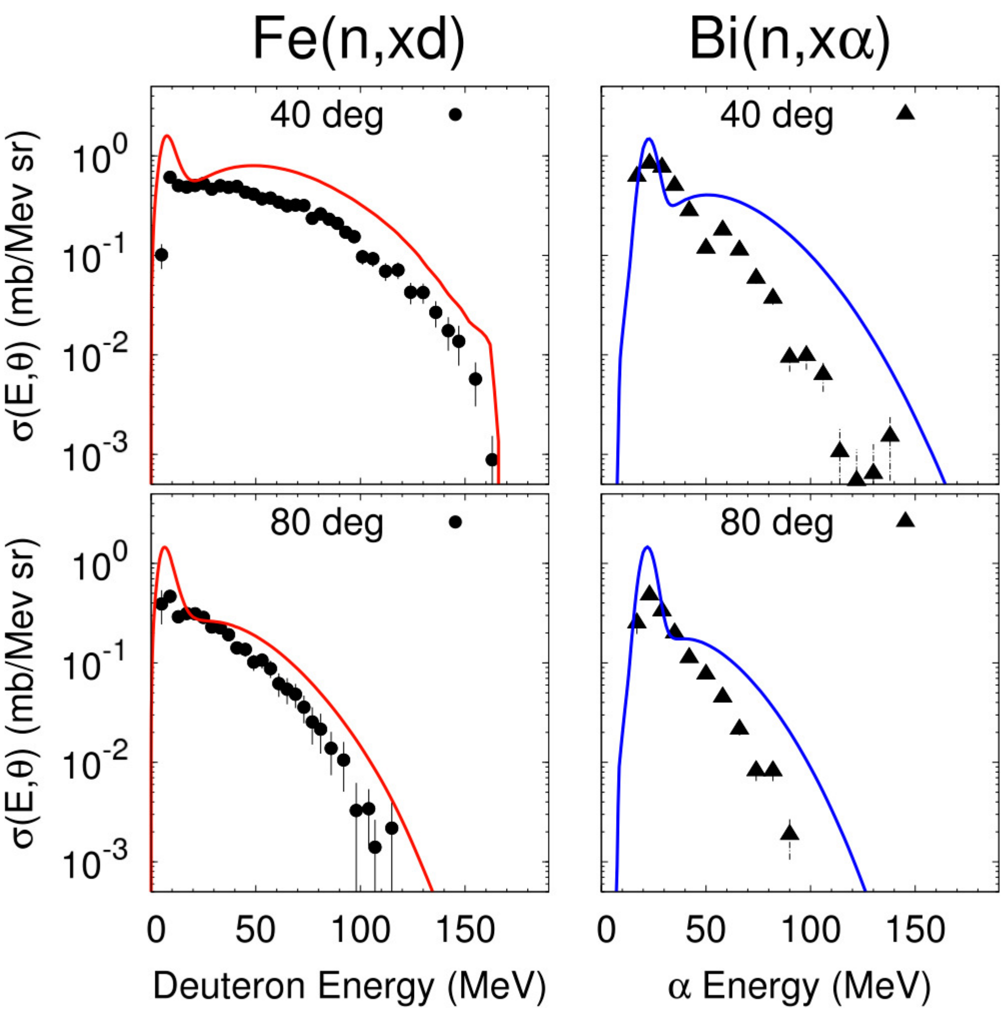


Calculations by Jean-Cristophe David

TALYS-1.2

Pre-equilibrium:

- two component exciton model (EM)
- composite particles direct-like mechanisms (Kalbach systematics)
- nucleon transfer (pick-up)
- knock-out for α particles



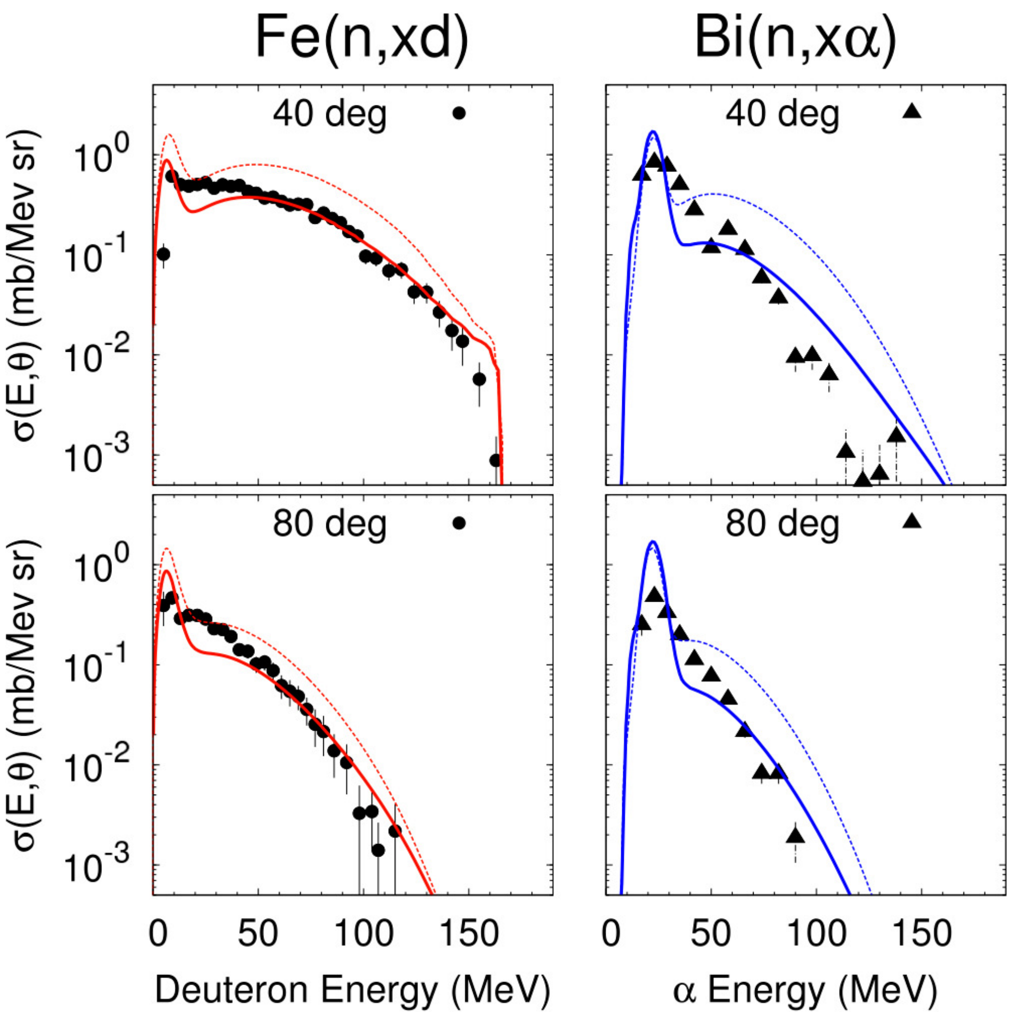
Riccardo Bevilacqua

Modified TALYS-1.2

Scaling down
the nucleon transfer
mechanism

Calculations folded
with QMN spectrum:

energy dependence
in the scaling factor



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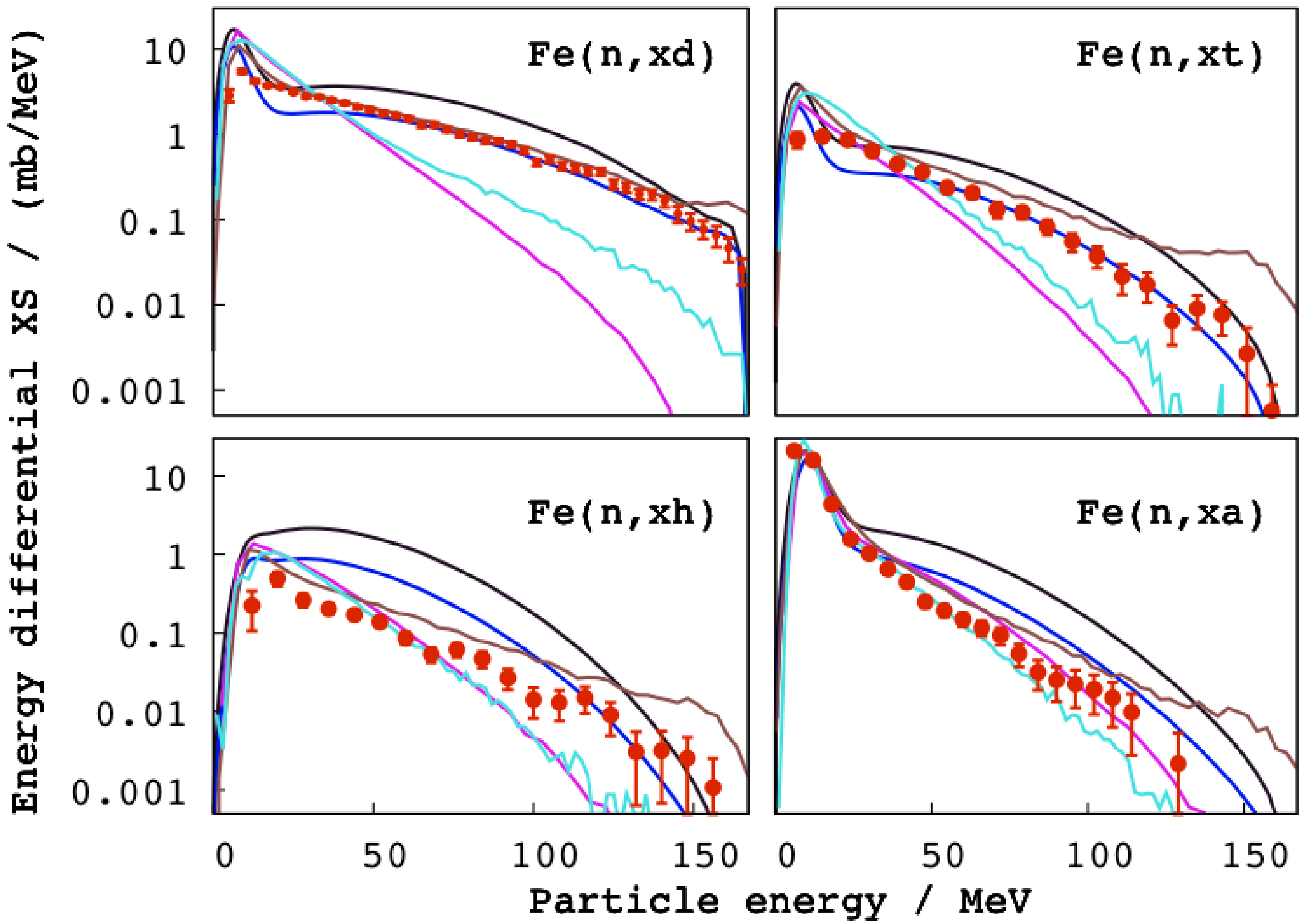
Light-ion production from Fe

Energy differential cross sections

"All together now"



TALYS-1.2

modified TALYS-1.2

MCNP6

INCL4.5-Abla07

MQMD (PHITS)

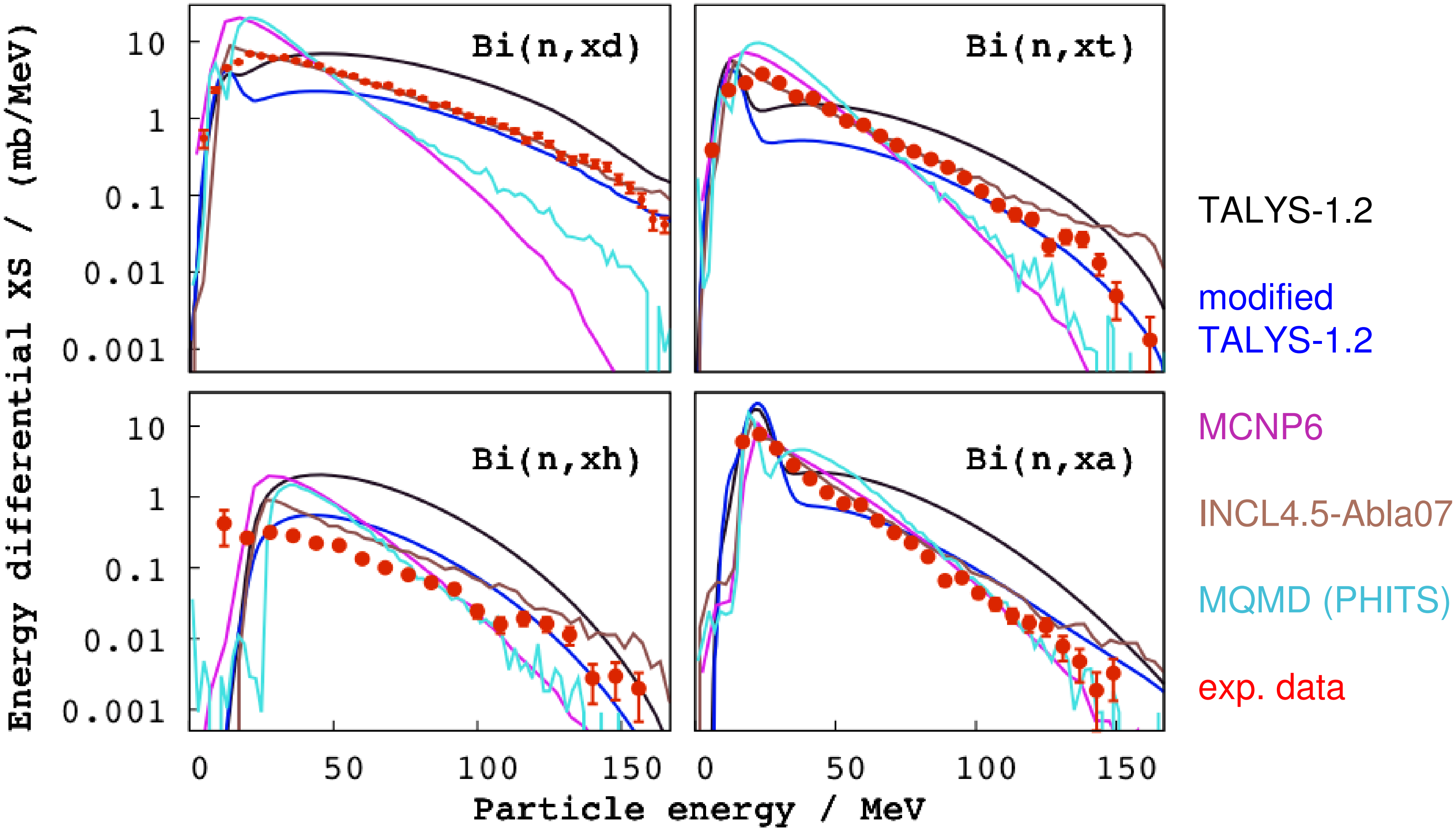
exp. data

angular integration by Kaj Jansson

Light-ion production from Bi

Energy differential cross sections

“All together now”



angular integration by Kaj Jansson

Conclusions

- We have measured light ion production at 175 MeV QMN for O, Si, Fe, Bi (also C and U, not shown in this talk).
- Double differential cross sections for O, Si, Fe, Bi and
- Energy differential cross sections for Fe and Bi.
- Compared with model calculations.
- Pre-equilibrium emission of composite light-ions is the most critical issue at these energies.
- More work is required to fully reproduce all experimental results.

participating institutions:

this work is part of the ANDES project (WP4)

Thank you for your attention!

Riccardo.BEVILACQUA@ec.europa.eu

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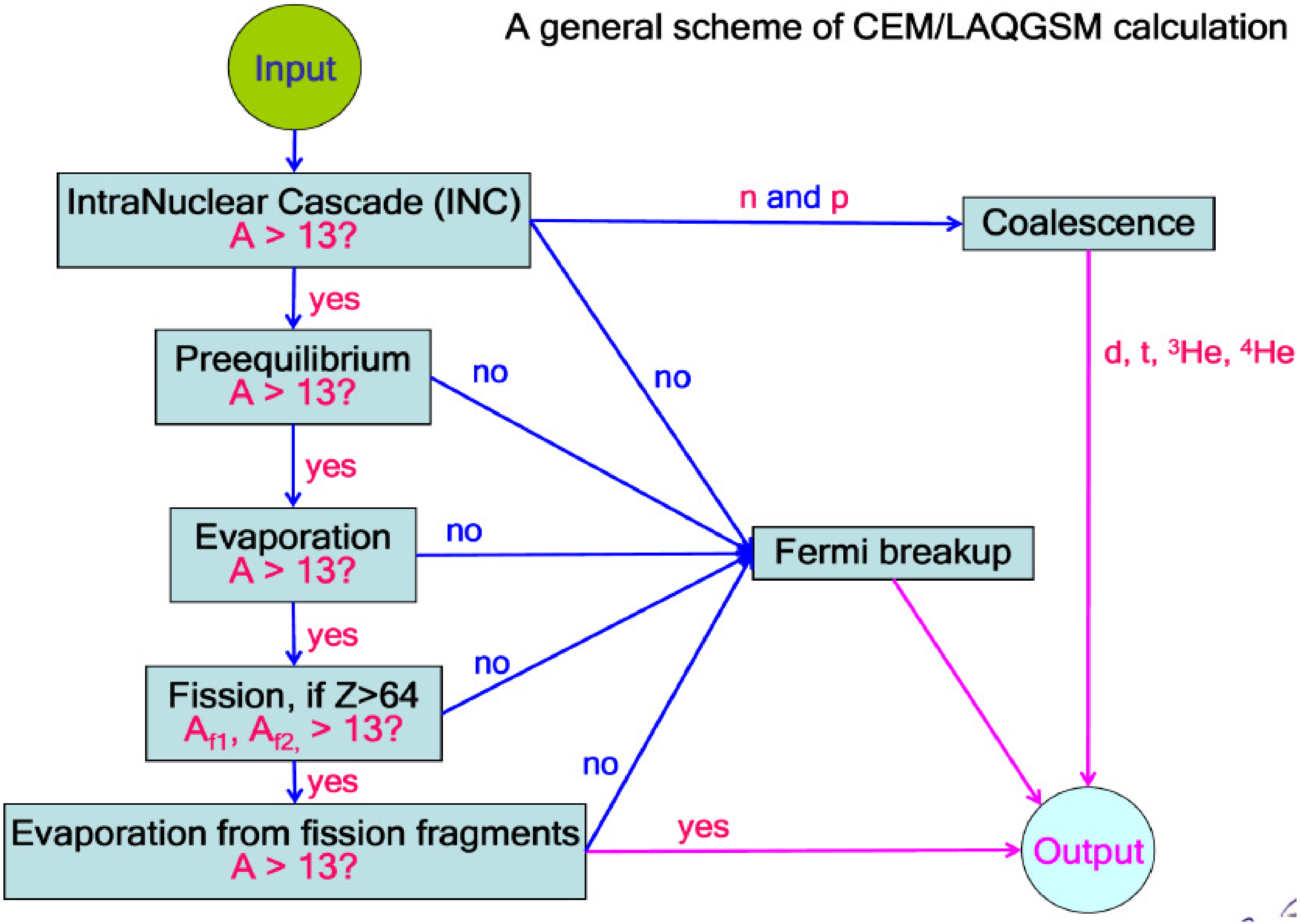
European Nuclear Education Network
ENEN PhD Prize 2011

UPPSALA UNIVERSITET

Department of Physics and Astronomy
Division of Applied Nuclear Physics

A general scheme of CEM/LAQGSM calculation



Slide courtesy of Stepan Mashnik

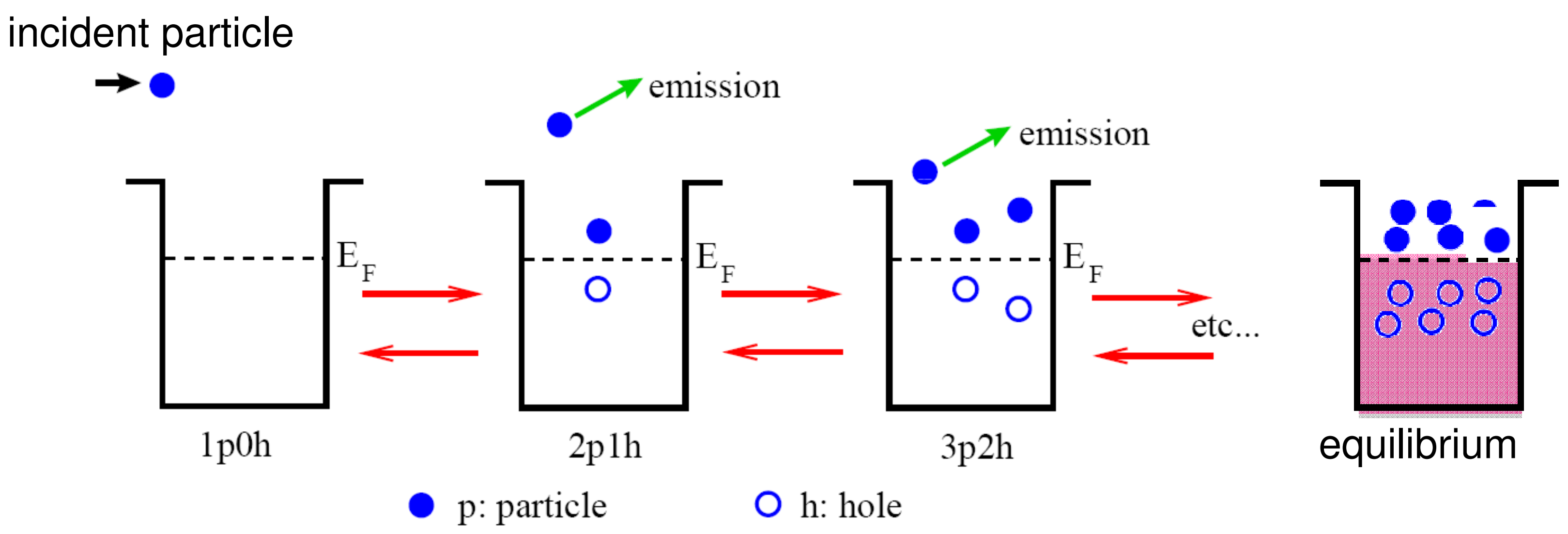
Pre-equilibrium emission: Exciton Model

Time evolution of the occupation probability of n-exciton state in the energy space

exciton = particle-hole pair

Projectile energy gradually redistributed among nucleons

Allows emission of particles



PHYSICAL REVIEW C **71**, 034606 (2005)

Preequilibrium reactions with complex particle channels

Neutron induced reactions ≤ 63 MeV

C. Kalbach
Physics Department, Duke University, Durham, North Carolina 27708-0305
(Received 10 November 2004; published 22 March 2005)

Investigations of nucleon induced reactions at incident energies of 14–90 MeV resulting in the emission of complex particles ($A = 2$–4) have provided insights which complement those previously obtained from (N, xN) reactions. The description of the preequilibrium energy spectra required modifications to an earlier phenomenological model for direct pickup reactions. This model supplements the usual exciton preequilibrium model. Work on complex particle induced reactions confirms some of these results, extends them to include stripping and exchange reactions, and provides evidence for a projectile dependence of the average effective matrix elements for the residual interactions in the exciton model. A full description of reactions with complex projectiles will require the inclusion of a realistic breakup component and the resulting reduction of the cross section available for the exciton model calculations. Reactions with complex particles in the entrance and/or exit channels have provided indirect evidence for the amount of surface peaking of the initial target-projectile interaction. A summary of additional data needed to help resolve remaining questions is presented.

DOI: 10.1103/PhysRevC.71.034606 PACS number(s): 24.60.Gv, 24.10.Pa

TALYS pre-equilibrium

Direct-like reactions not included in the Exciton Model:

nucleon transfer (NT): pick-up and stripping
knock-out (KO) of performed clusters

Kalbach phenomenological model
pre-equilibrium reactions with complex particle channels

C. Kalbach, Phys. Rev. C 37, 2350 (1998), Phys. Rev. C 71, 034606 (2005)

$$\frac{d\sigma_k^{\mathrm{PE}}}{dE_k} = \frac{d\sigma_k^{EM}}{dE_k} + \frac{d\sigma_k^{NT}}{dE_k} + \frac{d\sigma_k^{KO}}{dE_k}$$

Energy dependence scaling of Nucleon Transfer in TALYS

$$cstrip = \begin{cases} 1.0 & \text{if} \quad E \leq 90\ \text{MeV} \\ 1.9 - \frac{E}{100\,\text{MeV}} & \text{if} \quad 90\ \text{MeV} \leq E \leq 180\ \text{MeV} \\ 0.1 & \text{if} \quad 180\ \text{MeV} \leq E \end{cases}$$

Absolute double-differential cross-sections σ_x, for a reaction target **x** and a given light-ion, are obtained from net counts N_x, applying the following expression:

$$\frac{\sigma_x}{N_x} = \frac{\sigma_H}{I_H}\frac{2A_x}{A_{CH_2}}\frac{m_{CH_2}}{m_x}\frac{\Phi_{CH_2}}{\Phi_x}\frac{\Omega_{CH_2}}{\Omega_x}\frac{1}{\Delta E} \qquad (3.5)$$

where A_x and A_{CH_x} are respectively the atomic weight of the reaction target and of the CH_2 target, m_x and m_{CH_2} are the target masses, Φ_X and Φ_{CH_2} are the neutron fluences measured with one of the neutron monitors, Ω_{CH_2}/Ω_X is the ratio between the solid angle seen by the telescope at 20 degrees and the telescope used for the measurement, and ΔE is the energy bin width.