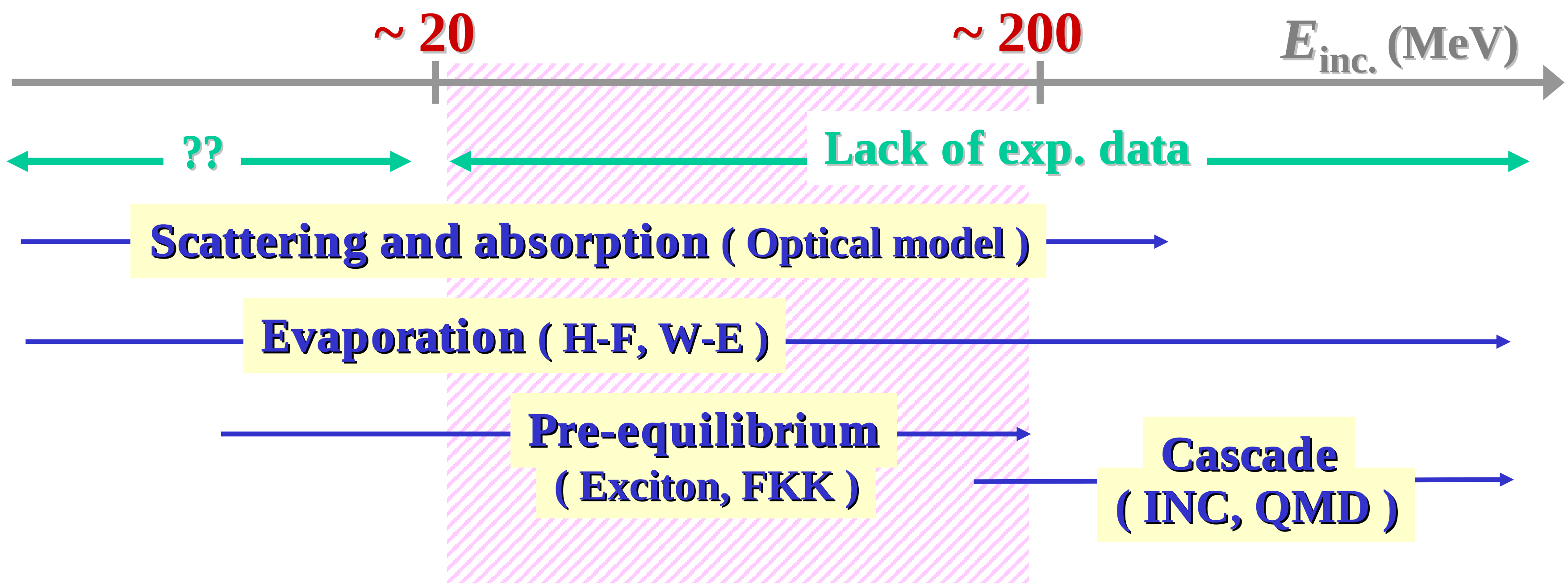
Introduction

- Accelerator-based application facilities
- Estimation of the cosmic ray effects
- Cancer therapy

Evaluated nuclear reaction data

- Neutron & proton inc.
- ~ GeV range
- Various nuclei

Status



JENDL-3.3,
ENDF/B-VI,
JEFF-3.0

JENDL-HE,
LA150

JAM,
LAHET,
JQMD,
etc.

Purpose of this study

^{90,91,92,94,96}Zr, ^{93}Nb, ^{182,183,184,186}W

Zr : Nuclear fuel element for ADS

Nb : Superconducting material such as NbTi, Nb_3Sn

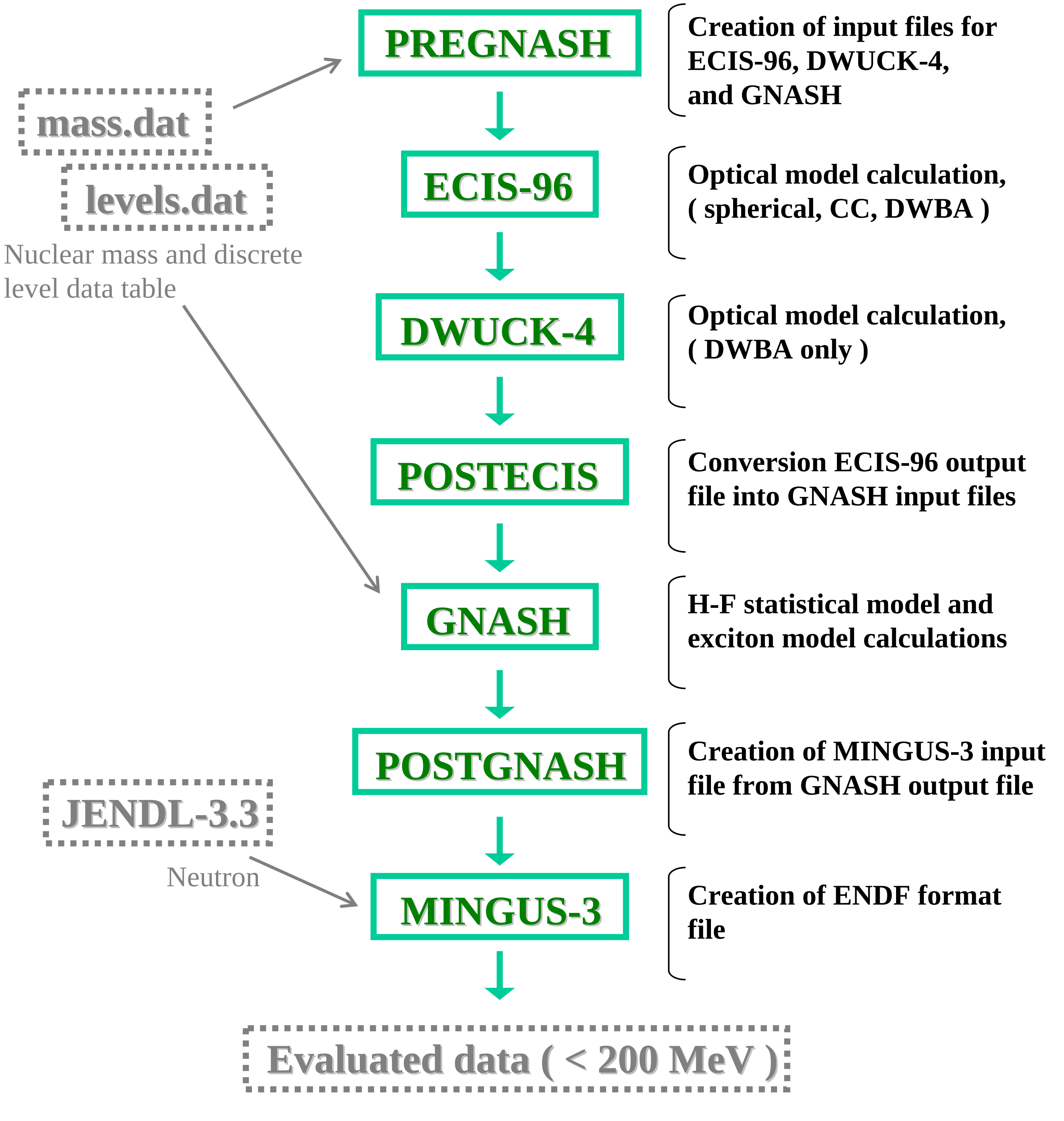
W : Spallation neutron source, beam window

- Energy range -

Neutron : 20 ~ 200 MeV

Proton : 10 ~ 200 MeV

GNASH code system



Optical model analysis

Local OMPs : around Zr, and W

Phenomenological, spherical OMP

Continuous-energy dependent OMP

- $V_r(E)$, $W_v(E)$, $W_d(E)$ ⟶ **Empirical search**
- $V_{so}(E)$, $W_{so}(E)$ ⟶ **Koning & Delaroche**

Elastic, total and total-reaction c.s. ⟶ **Evaluated c.s.**

Transmission coeff. $T_l(\varepsilon)$ ⟶ **For H-F calculations**

H-F statistical calculation

OMPs for transmission coeff. " $T_l(\varepsilon)$ "

- n, p : Our OMP
- d, ^{3}He : Daehnick *et al.*
- t : Becchetti & Greenlees
- α : Avrigeanu *et al.*

Level density parameter " a " (Fermi-gass region in G-C)

- Taken from RIPL (The same parameter used for JENDL-3.3),
- Ignatyuk *et al.* (If there were no data in the RIPL)

Exciton model calculation

Nucleon emissions

- State density parameter " g " : $A/13$
- " $|M|^2$ " for transition rate : slight adjustment
- Average effective well depth " V_{eff} " : adjusted for p_{inc} eval.
  (Nuclear surface effect)

Composite-particles emissions

- Pickup : original Kalbach semi-empirical model
- α-knockout : modified Kalbach semi-empirical model

Note, A factor was multiplied to get reasonable agreement with exp. data

Calculation for α-knockout

Kalbach original expression

$$\frac{d\sigma_{\mathrm{knoc.}}(a,b)}{d\epsilon} = \mathcal{F}_{\mathrm{knoc.}} \times \frac{\sigma_a}{p_a E_a^3}(2s_b+1)p_b\epsilon\sigma_b(\epsilon)\frac{\omega_{\mathrm{knoc.}}(U)}{A^2}F$$

$$\omega_{\mathrm{knoc.}}(U) = g_i g_\alpha \left(U - \frac{1}{2g_i} - \frac{1}{2g_\alpha}\right)$$

$$\frac{d\sigma_{\mathrm{knoc.}}(a,b)}{d\epsilon} = \mathcal{F}'_{\mathrm{knoc.}} \times \frac{\sigma_a}{p_a}(2s_b+1)p_b\epsilon\sigma_b(\epsilon)\frac{\omega_{\mathrm{knoc.}}(U)}{\omega_{\mathrm{knoc.}}(U_{\mathrm{max}})}\frac{F}{A^2}$$

$$\omega_{\mathrm{knoc.}}(U) = g_i g_\alpha \left(U - \frac{1}{2g_i} - \frac{1}{2g_\alpha}\right)\exp\left(\frac{U}{\eta}\right)$$

Adjustable (η)

DWBA calculation

(In-elastic direct reaction calc.)

Excitations of low-lying levels

OMP : Our OMP

Level info. (E_{ex}, l, π, β) : RIPL

Excitation of GR (LEOR; $l^{\pi} = 3^{-}$)

$$\left(\frac{d\sigma}{d\varepsilon}\right)_{GR} = \beta^2 \sigma^{dw} \times f\left(\hbar\omega, \Gamma\right)$$

β (deformation parameter)	:	sum rule
$\hbar\omega$ (average E_{ex})	:	Adjustable
$f(\hbar\omega,\Gamma)$	:	Lorentzian func.
Γ (resonance width)	:	~ 5 MeV

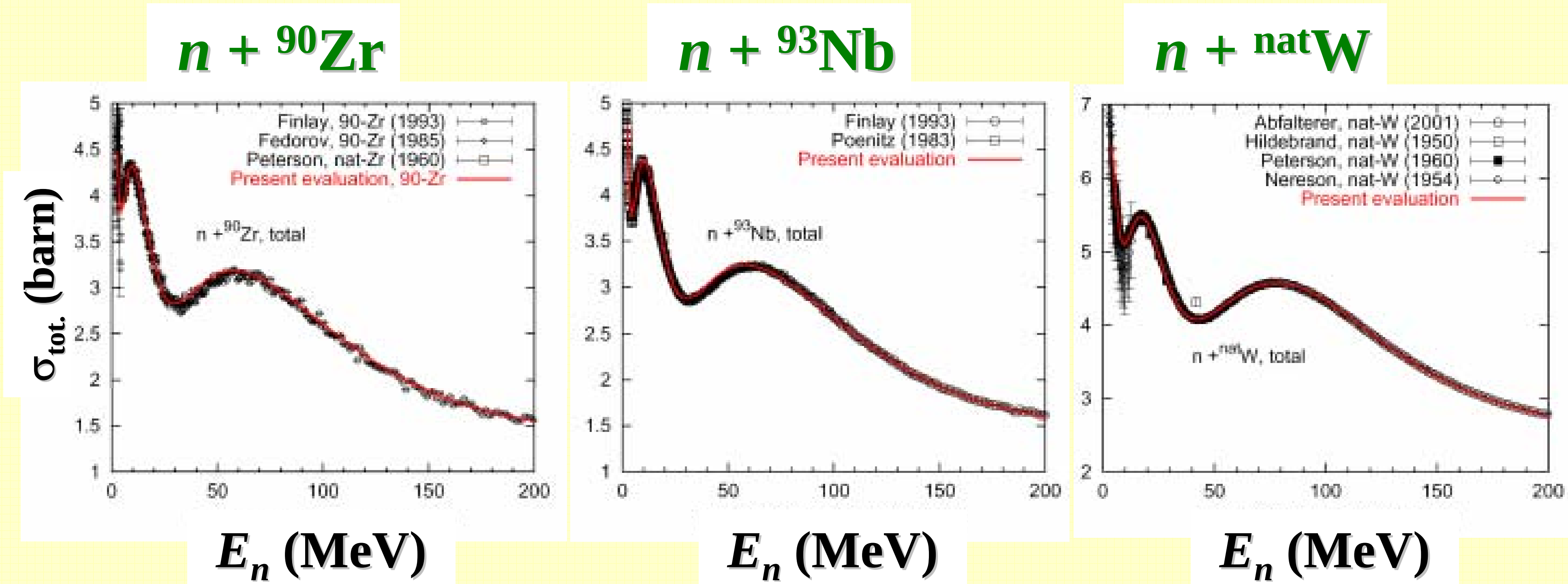
This evaluation vs LA150

(Summary for main differences)

	Our eval.	LA150
Target	Zr, Nb, W	No data for Zr
OMP (*n*,*p*)	Local (continuous *E* dependent)	Global (slight adjustment)
$V_{eff.}$	Adjusted for p_{inc} eval.	No adjustment
Composite-particle pre-equilibrium emiss.	Modified semi-empirical model	Original semi-empirical model
LEOR	Nb, W	Only for W

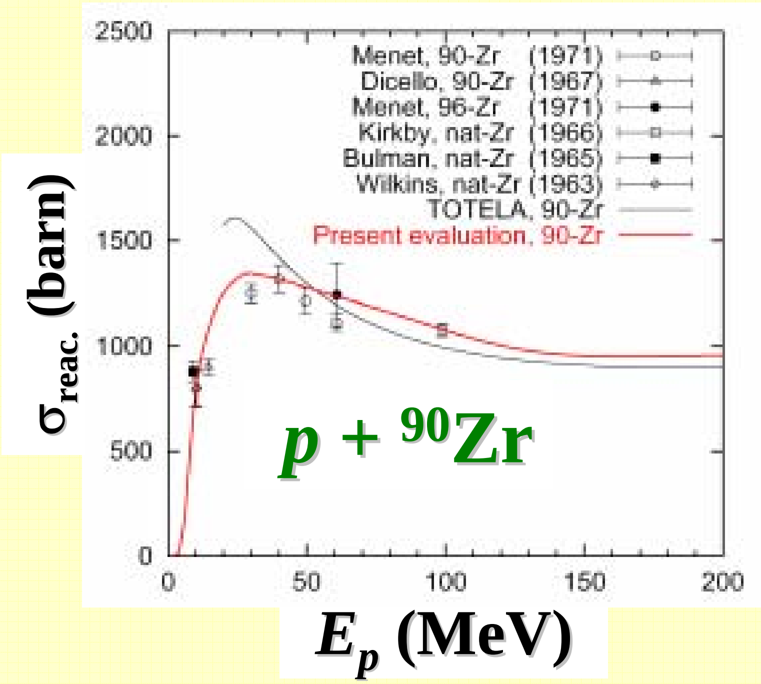
Results of $\sigma_{tot.}(E_n)$

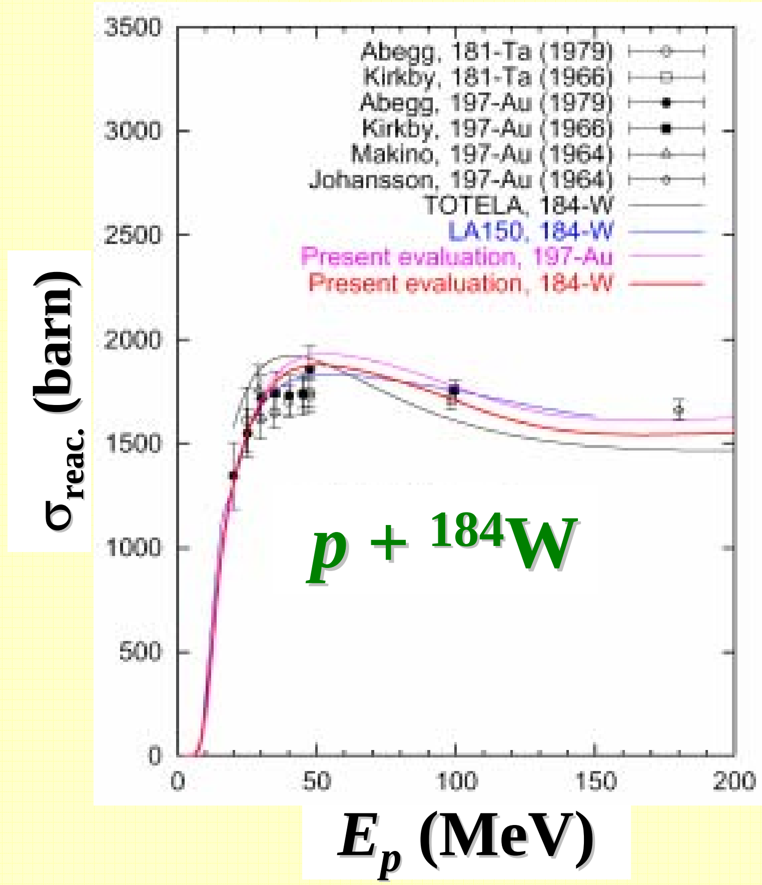
(Total cross sections)



Results of $\sigma_{reac.}(E_p)$

(Total-reaction cross sections)

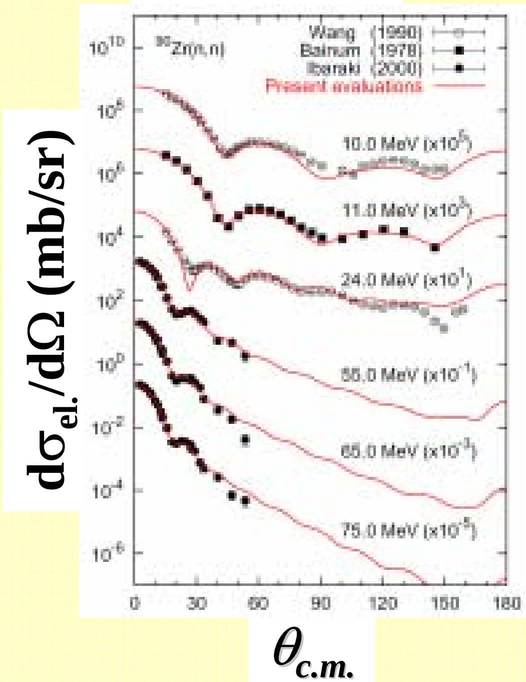




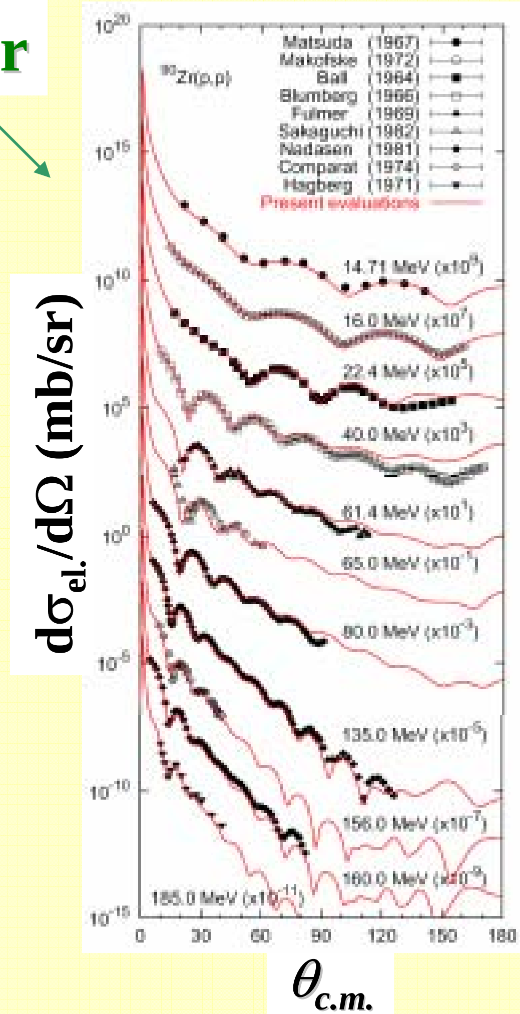
Results of $(d\sigma_{el.}/d\Omega)$

(Elastic differential cross sections)

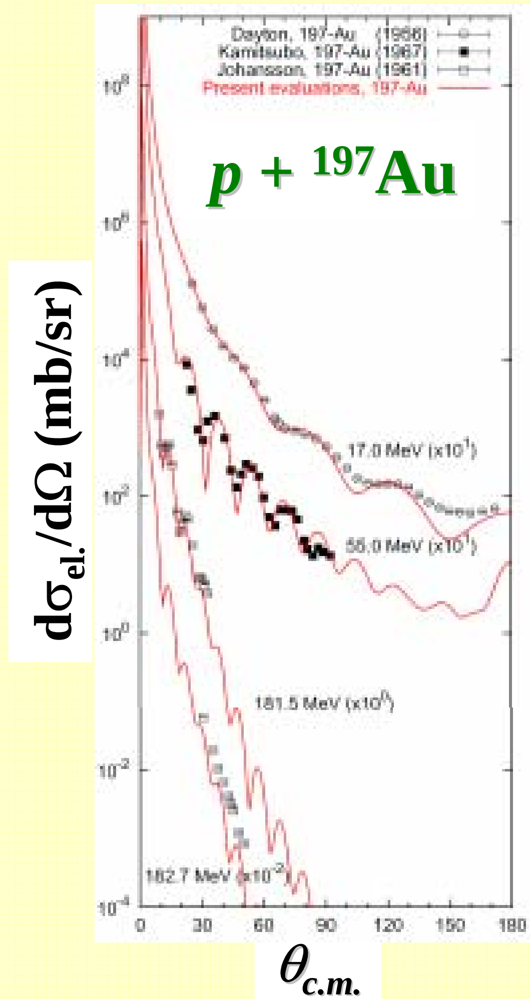
n **+ ^{90}Zr**



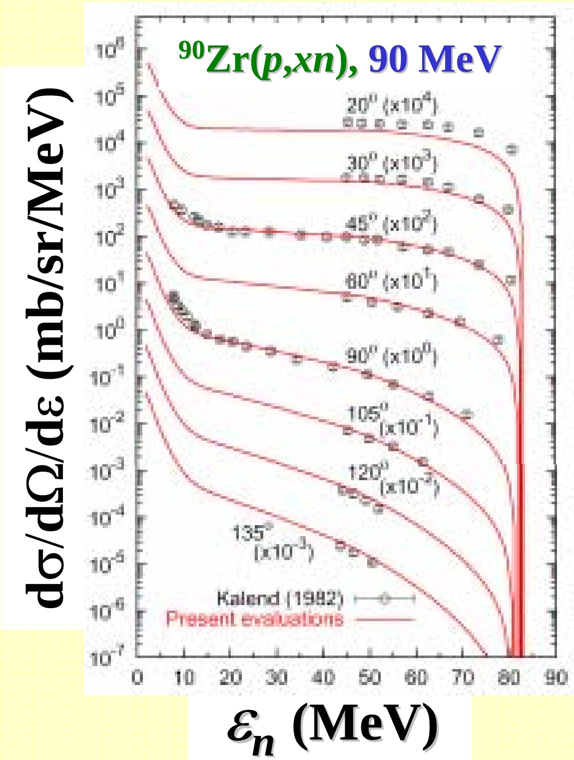
p **+ ^{90}Zr**

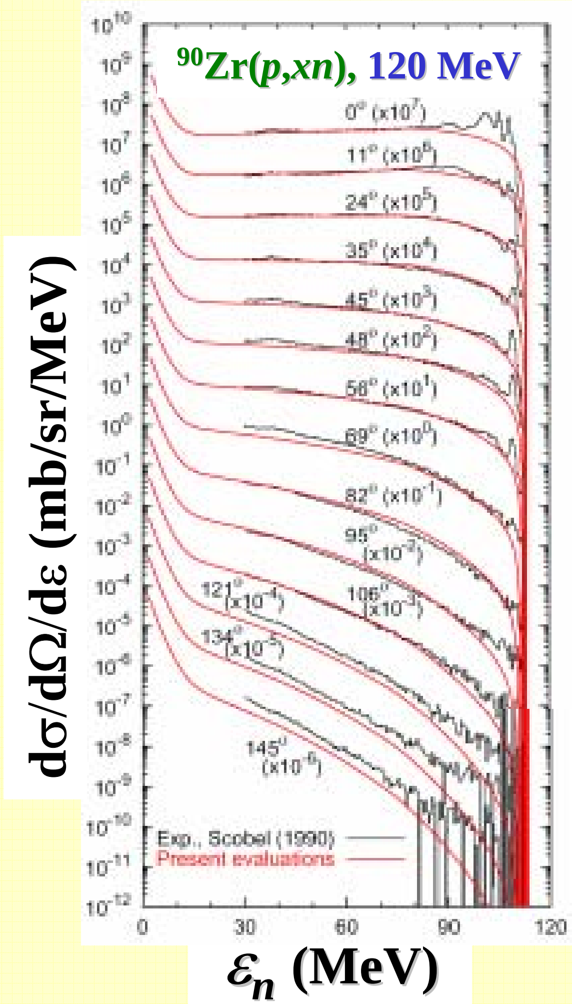


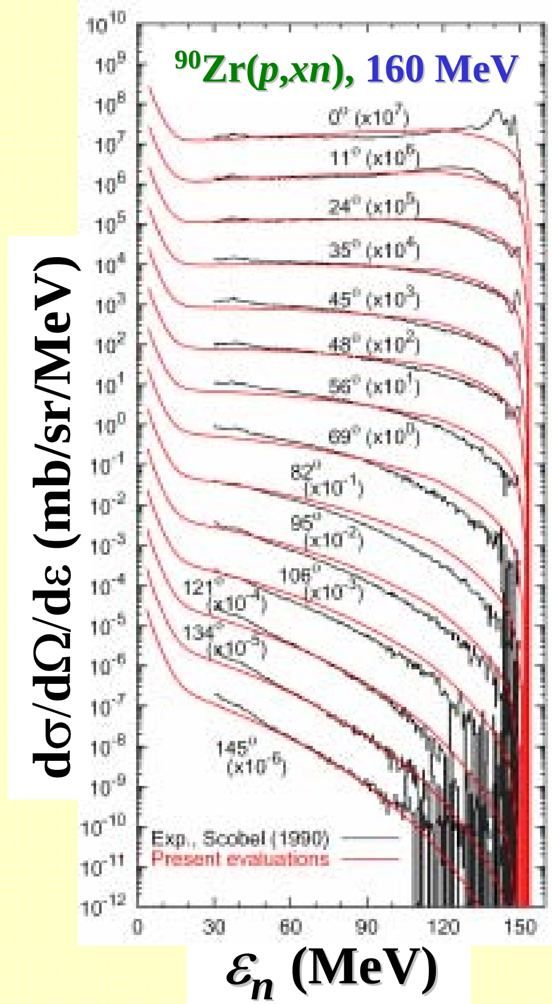
p **+ ^{197}Au**



Nucleon prod. DDX for Zr

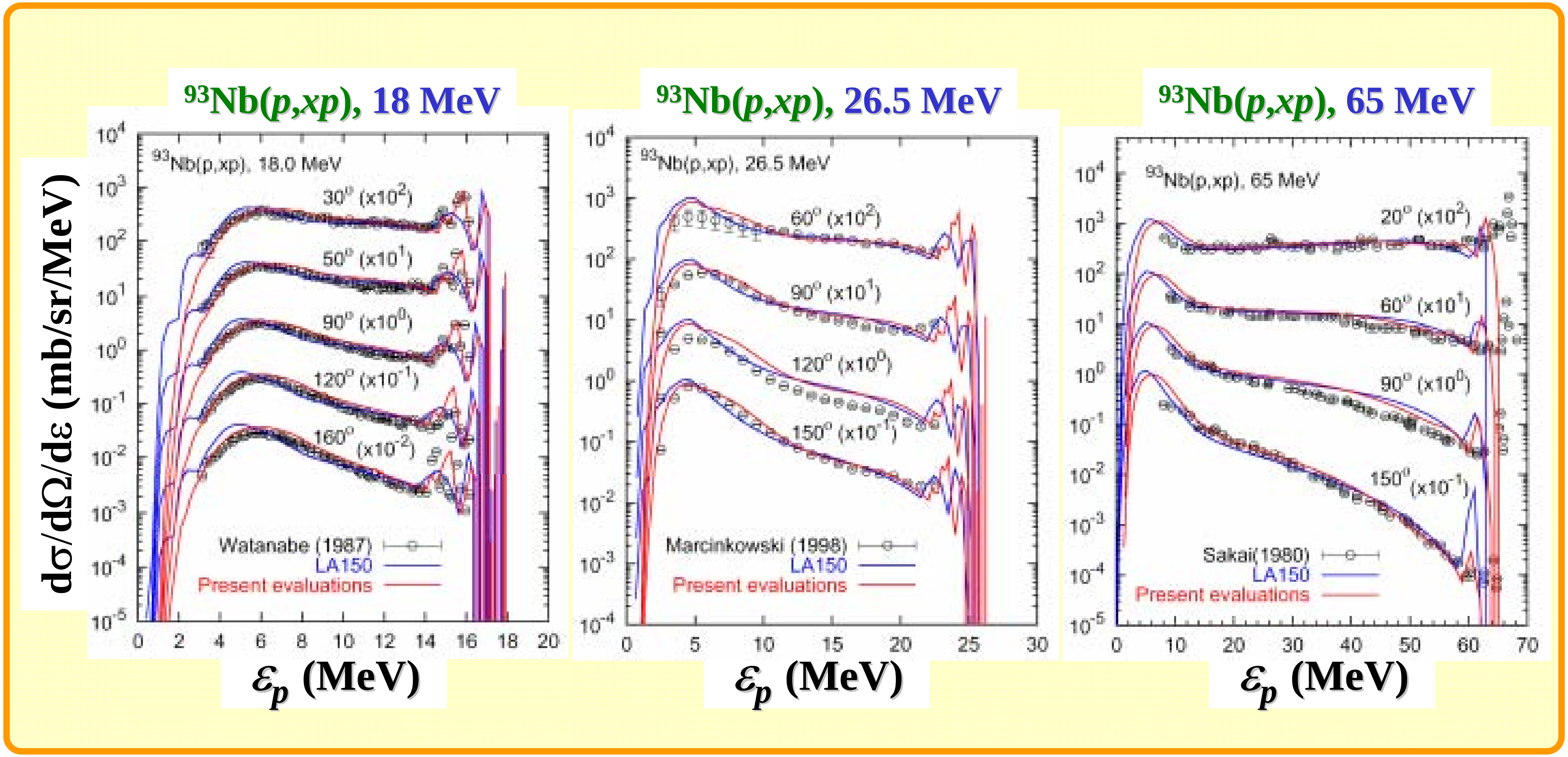






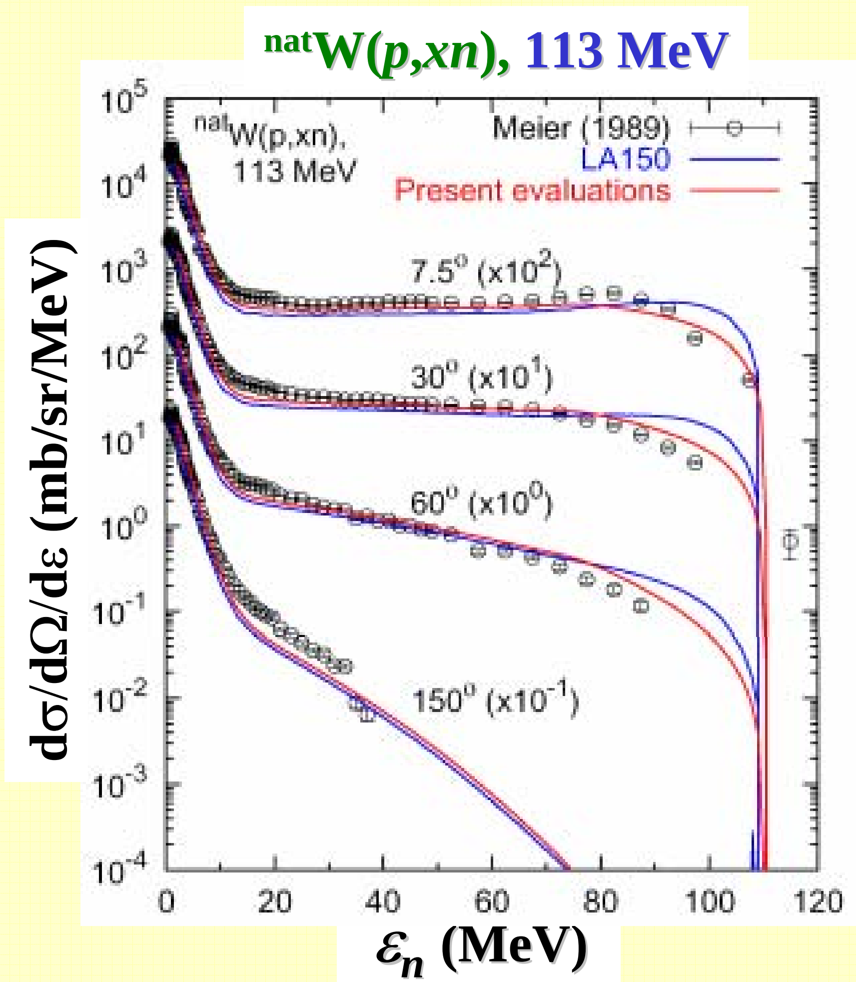
Nucleon prod. DDX for Nb

(Our evaluations & LA150 eval.)



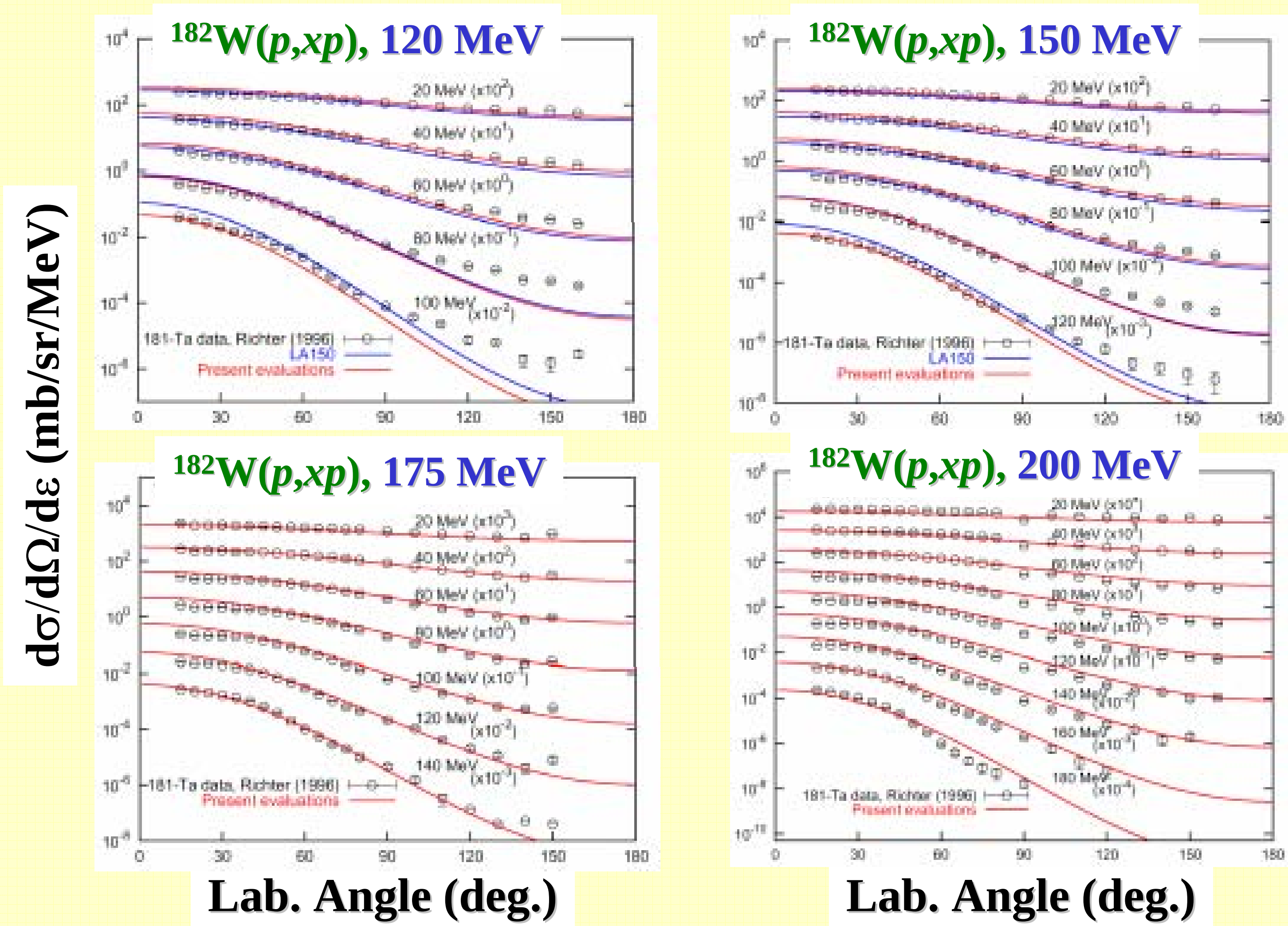
Nucleon prod. DDX for W

(Our evaluations & LA150 eval.)

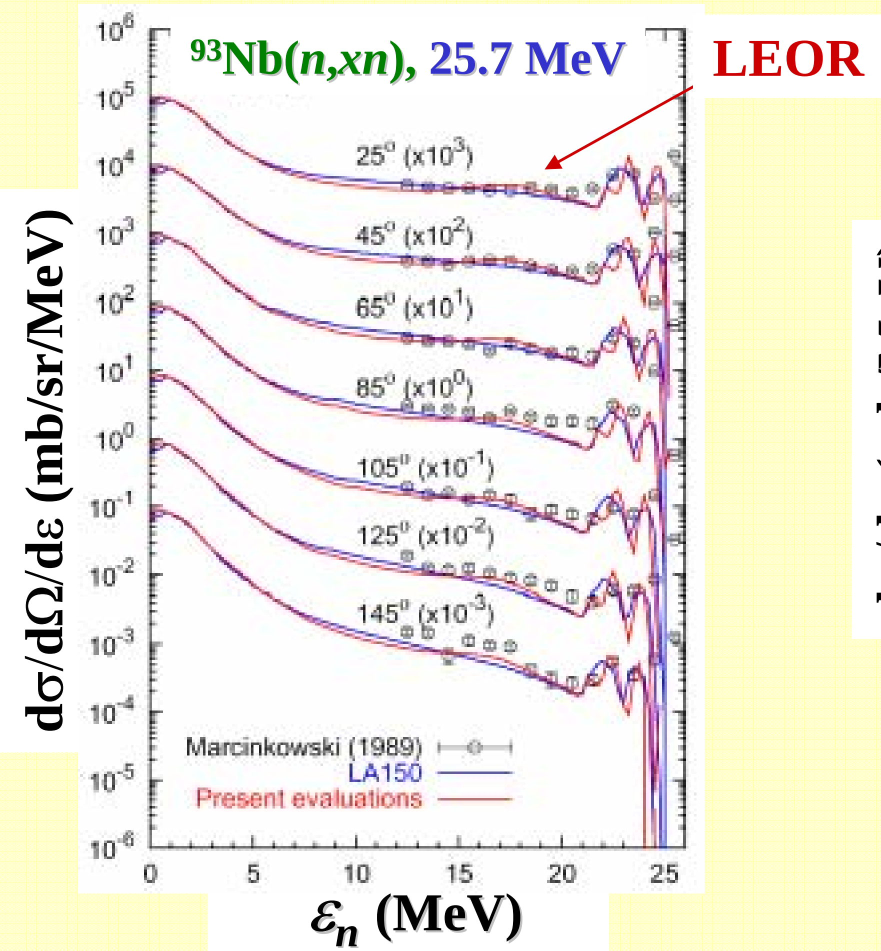


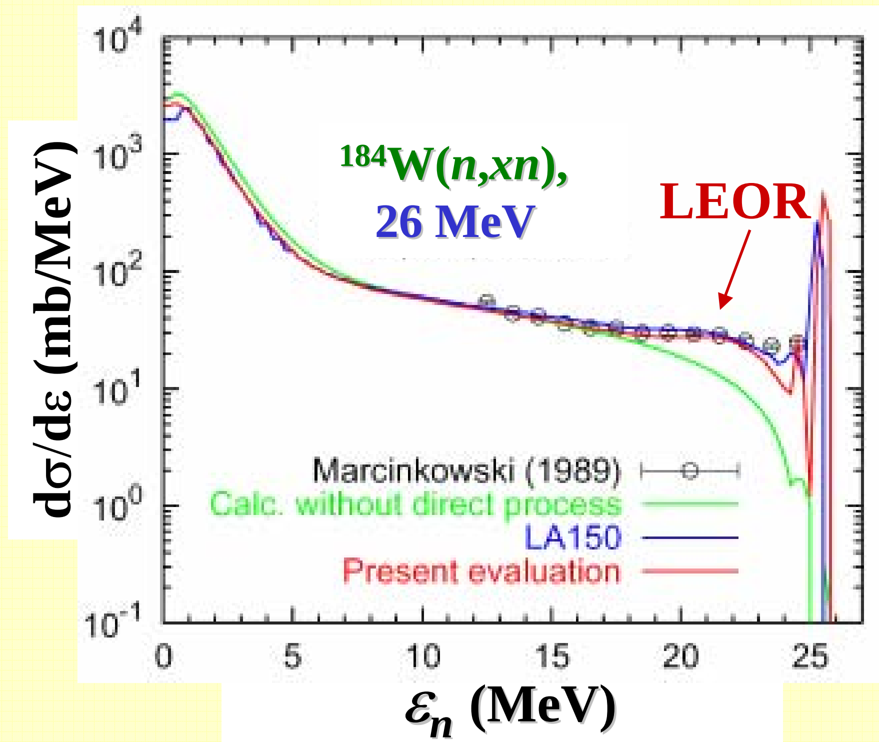
Nucleon prod. DDX for W

(Our evaluations & LA150 eval.)



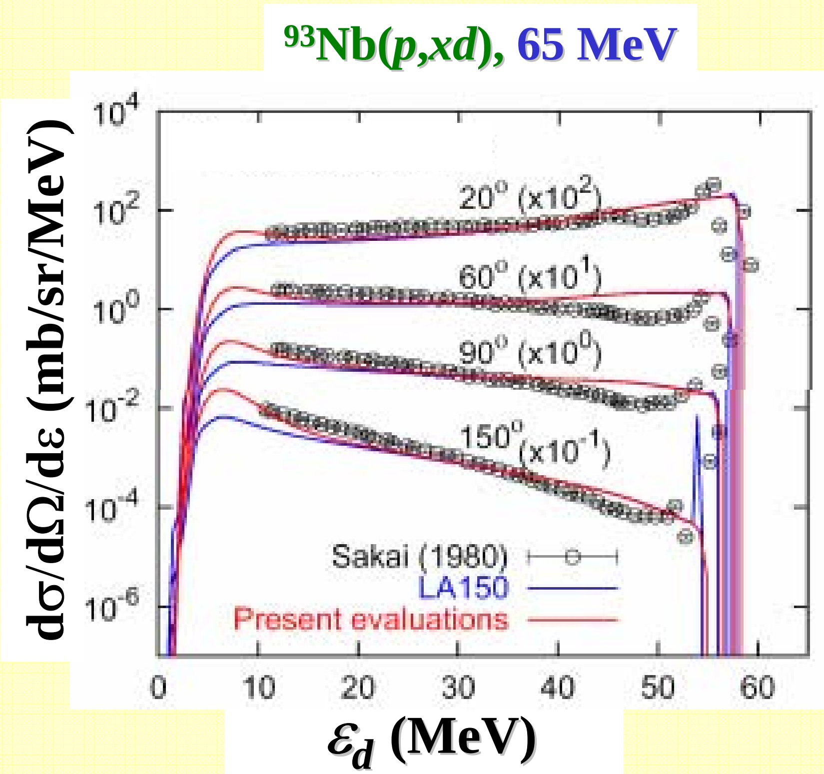
LEOR contributions
(Our evaluations & LA150 eval.)

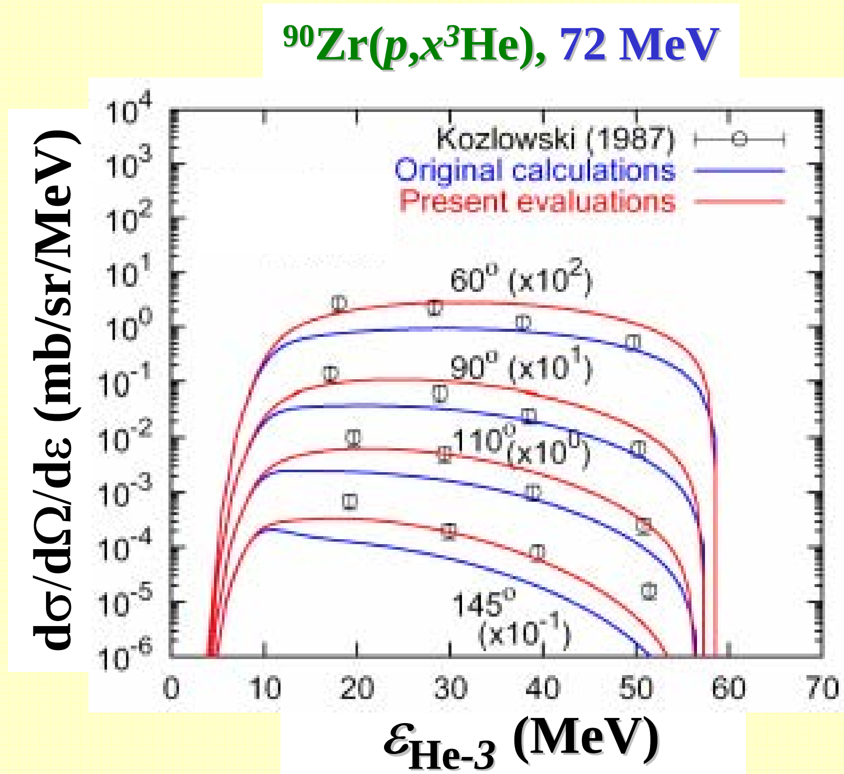




Composite-particle prod.

(Our evaluations & LA150 eval.)

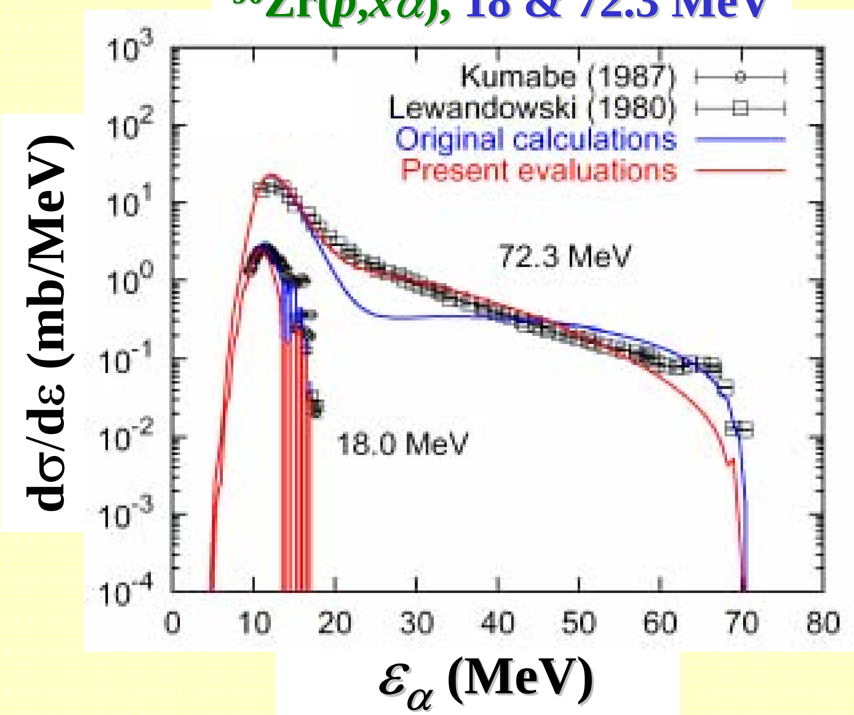




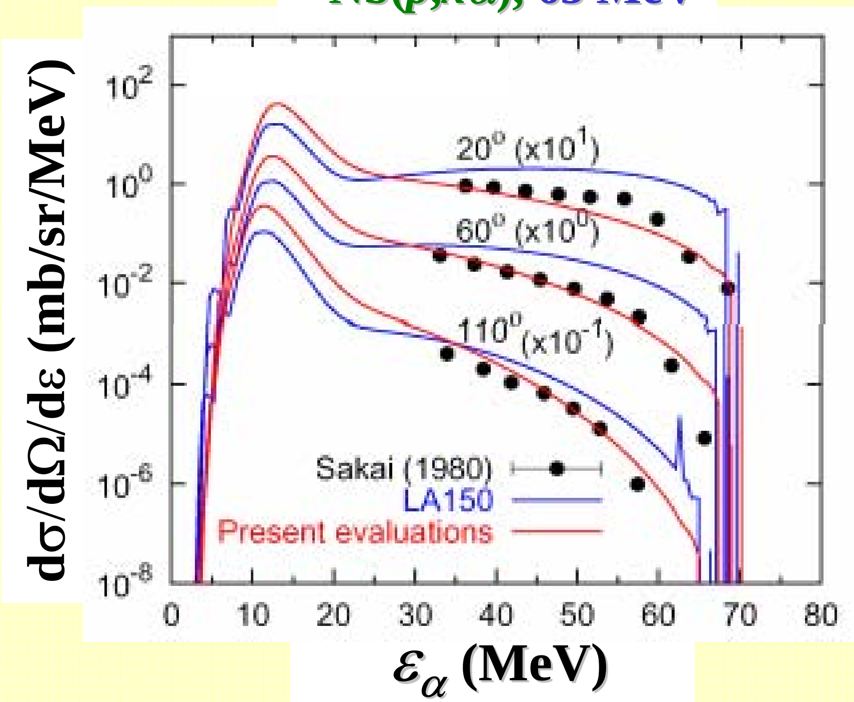
α-particle prod.

(Our evaluations & LA150 eval.)

^{90}Zr(p,$x\alpha$), 18 & 72.3 MeV

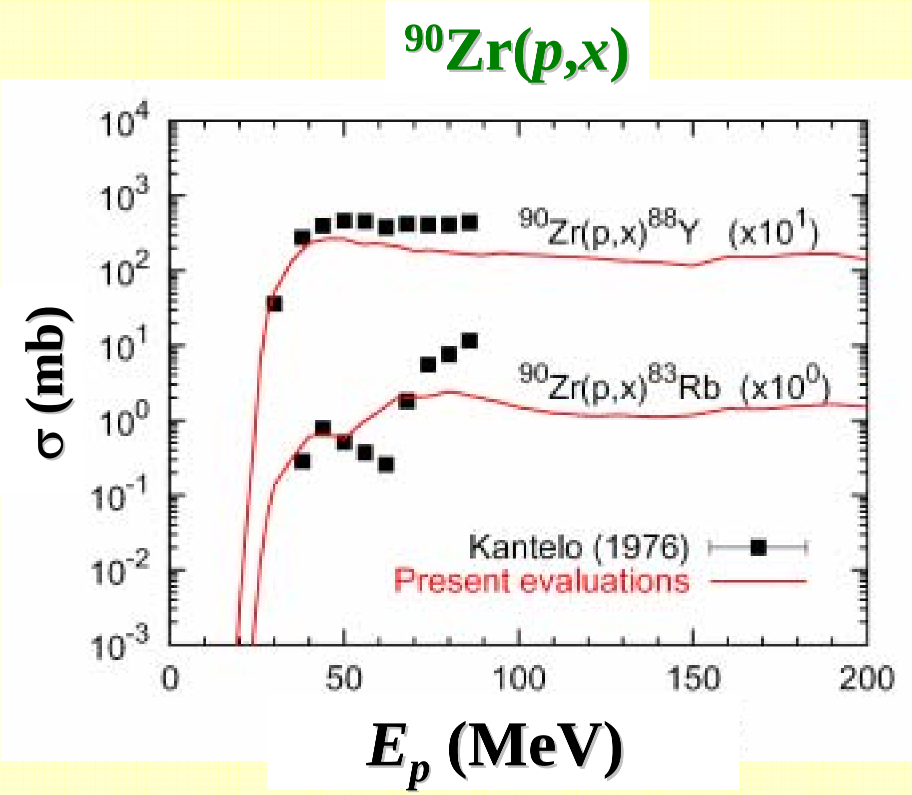


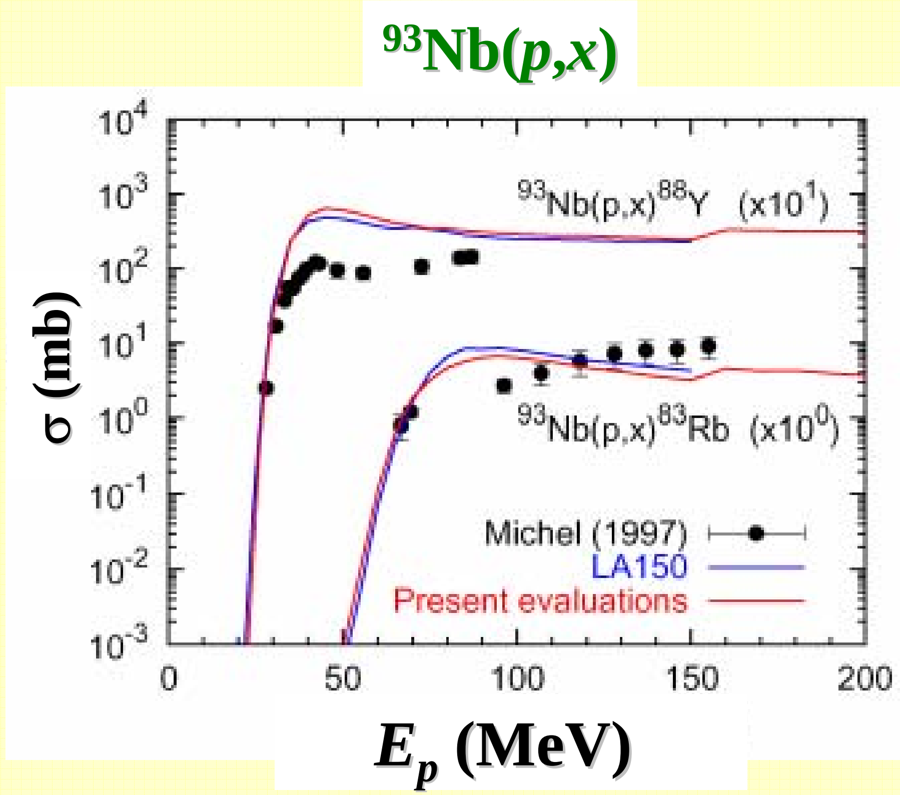
^{93}Nb(p,$x\alpha$), 65 MeV



Isotope-prod. c.s.

(Our evaluations & LA150 eval.)





Summary

- **Nuclear data were evaluated for neutron and proton on Zr, Nb, and W up to 200 MeV.**
- **Average well depth was treated as adjustable parameter.**
- **Giant resonance contribution were considered for (*n*,*xn*).**
- **Modified semi-empirical Kalbach model was used for α-particle pre-equilibrium emission.**
- **Our evaluations agreed with experimental data better than LA150 evaluations especially for (*p*,*xn*), (*p*,xα)**