Development of an accurate DWIA model of coherent π^0-photoproduction to study neutron skins in medium heavy nuclei

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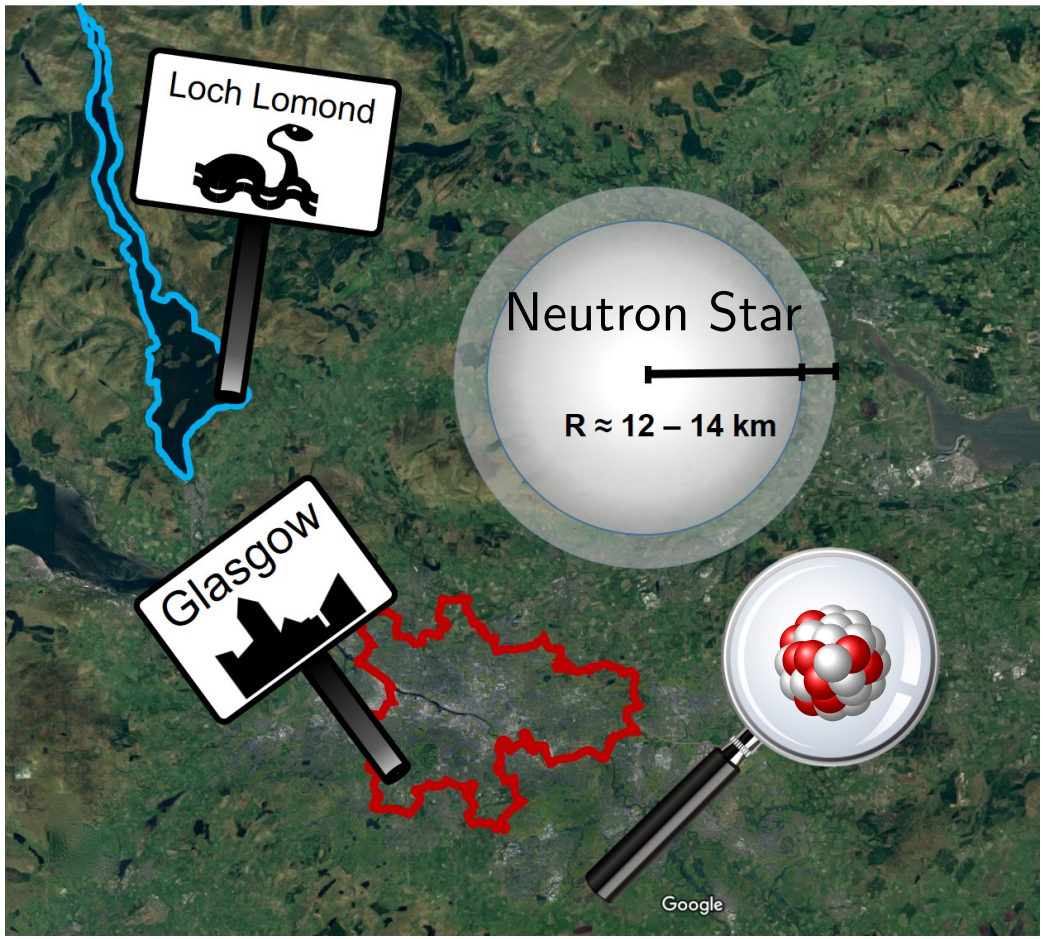
Neutron stars and nuclei

After zooming in $\times 10^{18}$ (!)



- neutron-rich nuclei
- neutron stars

} described by the same eq. of state (EOS)

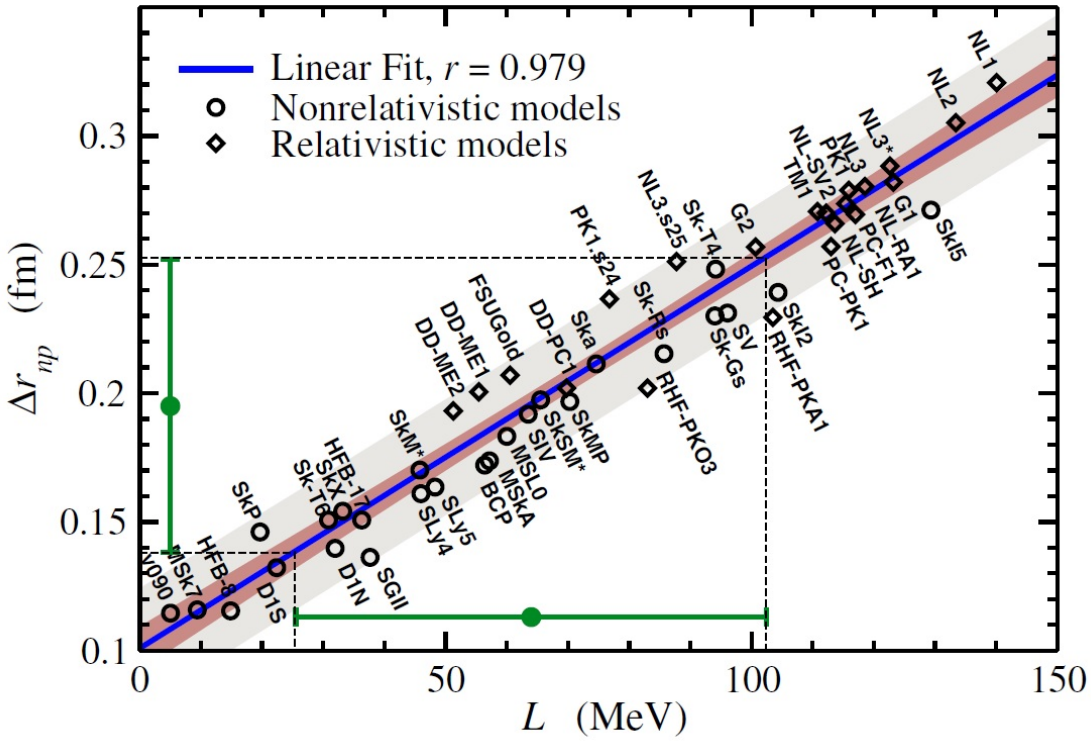
The symmetry energy and the neutron skin

In EOS, symmetry energy: $S(\rho) = J + L\left(\frac{\rho-\rho_0}{3\rho_0}\right) + \frac{1}{2}K_{\text{sym}}\left(\frac{\rho-\rho_0}{3\rho_0}\right)^2 + \ldots$

Where go the extra neutrons in n-rich systems (^{208}Pb: N=126, Z=82)?

- Surface tension favors spherical drop of *uniform* equilibrium density
- Symmetry energy favors to move them to the surface

$\Rightarrow$ formation of a neutron skin Δr_{np}, larger as A increases



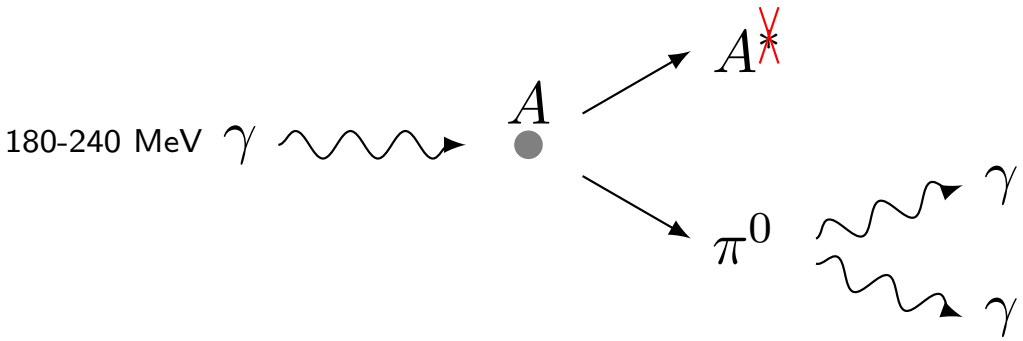
PRL 106, (2011) 252501

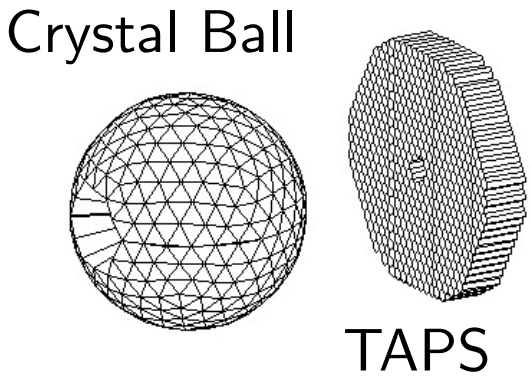
L strongly correlated to Δr_{np}
$\rightarrow$ need to measure accurately

How can we measure it?

The coherent π^0 photoproduction

In Mainz, at MaMi (A2): coherent π^0-photoproduction (on ^{116,120,124}Sn)





Advantages:

- Same amplitude for n and p
  - $\rightarrow$ Sensitivity to nucleon dist.
- Photon is neutral
  - $\rightarrow$ Whole volume is probed

Drawbacks:

- Final state interactions
  - $\rightarrow$ Model dependence
- Delta resonance region
  - $\rightarrow$ Model dependence

PRL 112, 242502 (2014): skin of 0.15 $\pm$ 0.05 fm on ^{208}Pb

- ◇ Influence of the choice of density?
- ◇ Errors due to model dependencies?

Plane wave impulse approximation (PWIA)

- Plane wave: no final state interactions of the pion with nucleus.
- Impulse approximation: only one nucleon interacts with the photon.

Cross section (Drechsel, Tiator, Kamalov and Yang in NPA 660, 423):

$$\frac{d\sigma^{\gamma\to\pi}_{\mathrm{PWIA}}}{d\Omega_{\mathrm{CM}}} \propto |f_2(\vec{k}_\pi, \vec{k}_\gamma)\rho_A(q)|^2$$

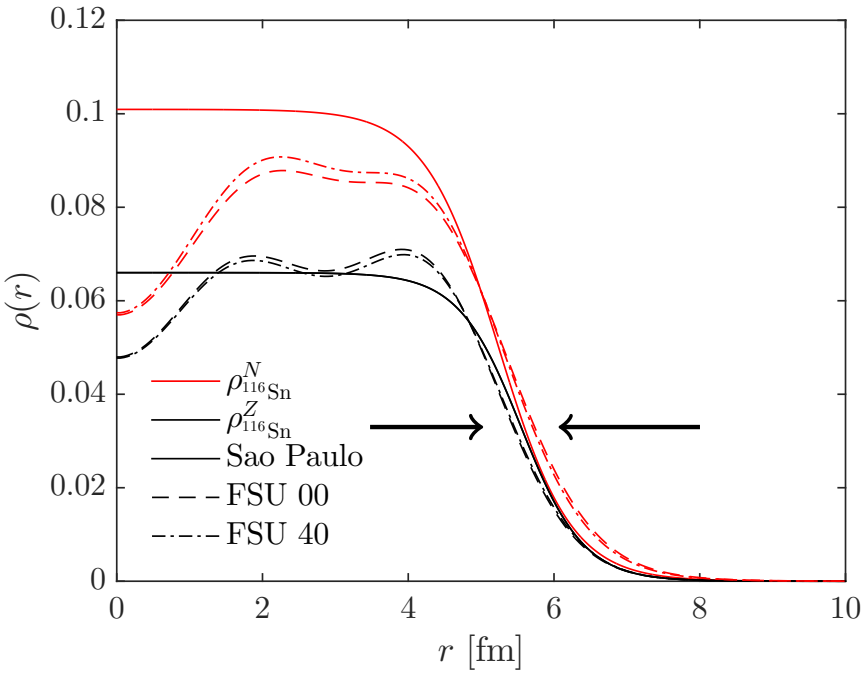
photo-production elementary amplitude (on one nucleon)

Nucleon density

CGLN amplitudes taken from MAID (https://maid.kph.uni-mainz.de/maid2007/helic.html)

Densities used for the calculations

Densities of ^{116}Sn



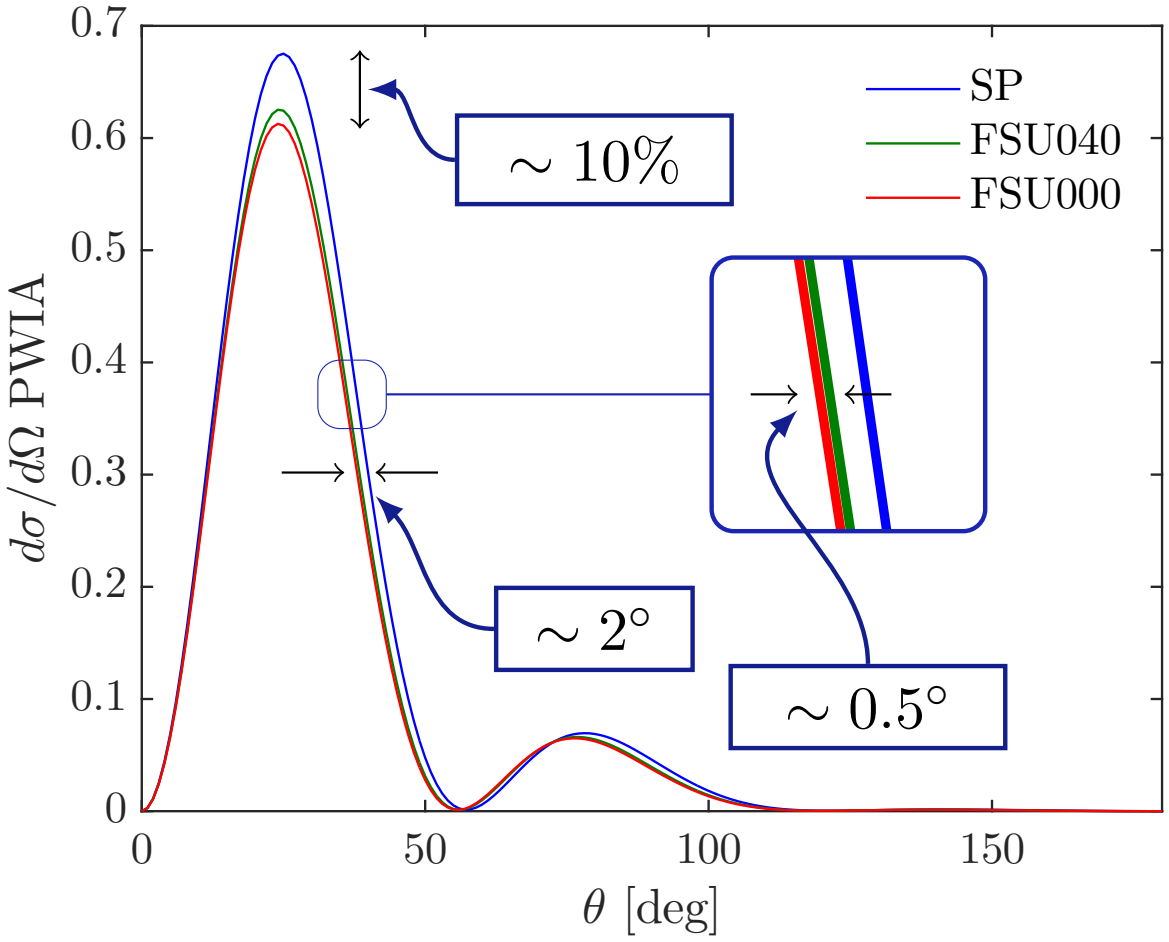
$\neq$ skins

- Sao Paulo (Phenomenological)
  - $\rightarrow$ Fermi-Dirac
    $\Delta r_{np} =$ -0.12 fm
- FSU model (courtesy of J. Piekarewicz)
  - $\rightarrow$ Microscopic MF model
    $\Delta r_{np}^{\mathrm{FSU00}} =$ 0.17 fm
    $\Delta r_{np}^{\mathrm{FSU40}} =$ 0.10 fm

Can we differentiate them on a photo-production cross section?

Photo-production cross section in PWIA

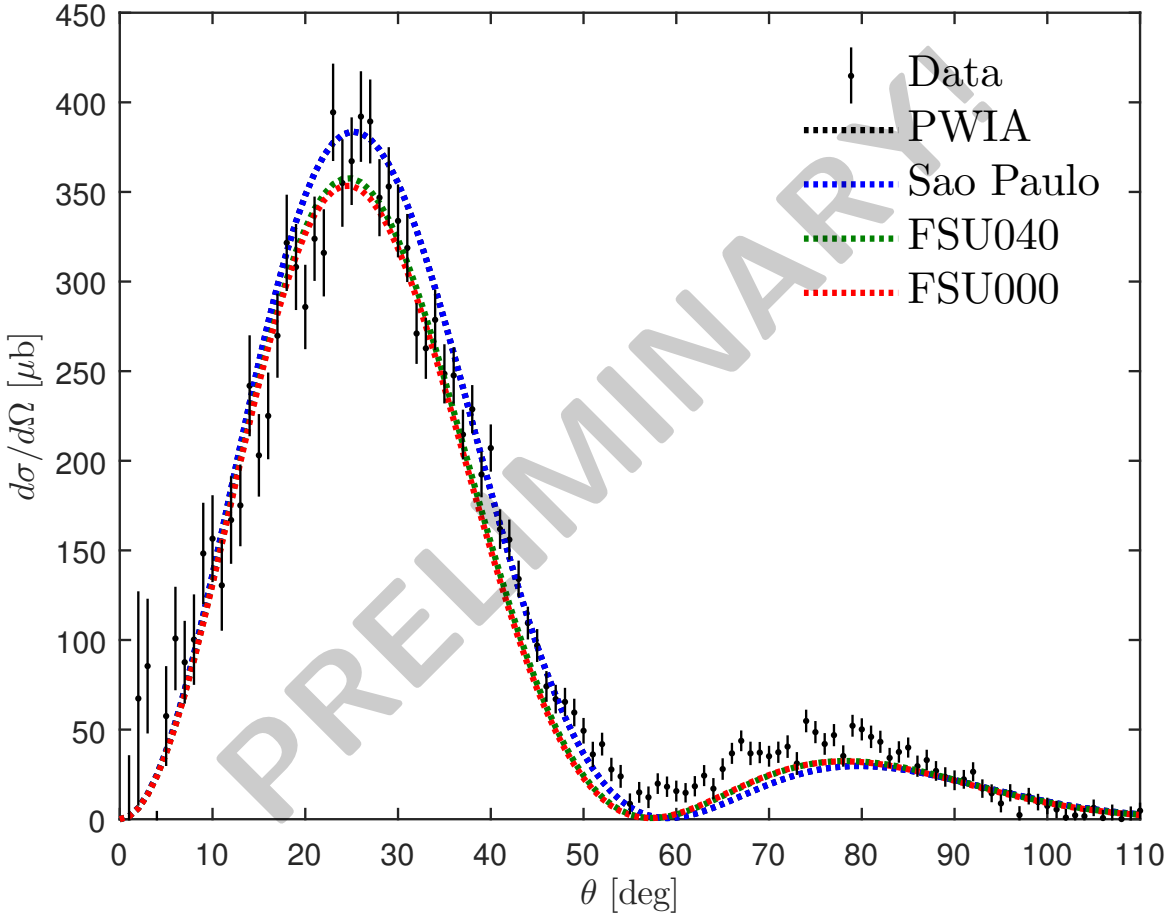
For these densities, photo-production in PWIA (^{116}Sn, 180-190 MeV):



Δr_{np}= -0.12 fm
$\Delta r_{np}^{\mathrm{FSU40}}$= 0.10 fm
$\Delta r_{np}^{\mathrm{FSU00}}$= 0.17 fm

How does that compare with experimental data?

Comparison with experiment at $T_\gamma = 180\text{-}190$ MeV



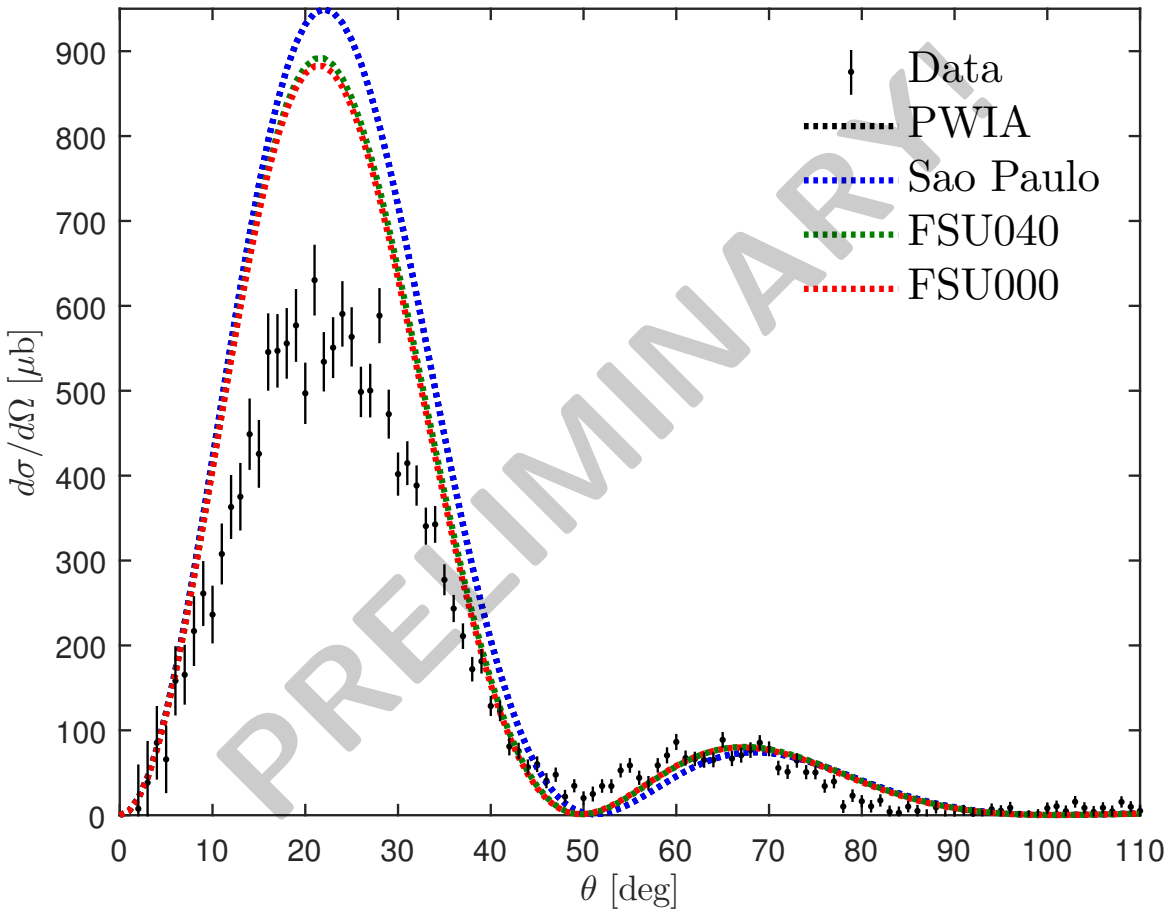
Data courtesy of M. Ferretti (PRELIMINARY)

θ precision $\sim 1^\circ$

Fair agreement

Second peak not reproduced @ PWIA

Comparison with experiment at $T_\gamma = 200\text{-}210$ MeV



Data courtesy of M. Ferretti (PRELIMINARY)

θ precision $\sim 1^\circ$

Less good agreement

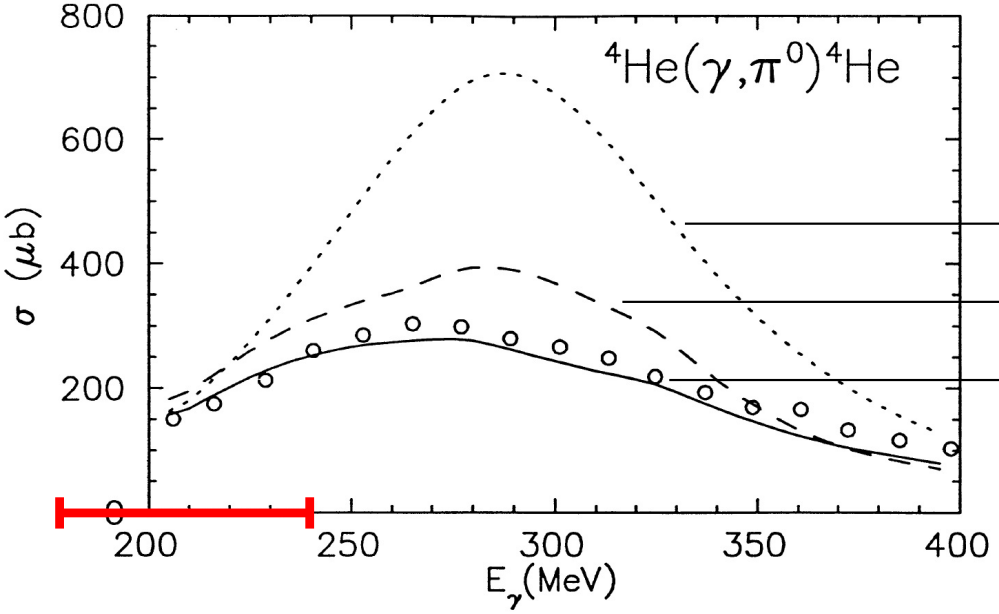
Second peak not reproduced @ PWIA

Distorted wave impulse approximation (DWIA)

Cross section of photoproduction in DWIA

$\rightarrow$ Final state interactions taken into account

$\frac{d\sigma^{\gamma\rightarrow\pi}_{\mathrm{DWIA}}}{d\Omega_{\mathrm{CM}}}$ loses its proportionality to $|\rho_A|^2$



T_γ at MaMi: 180 - 240 MeV

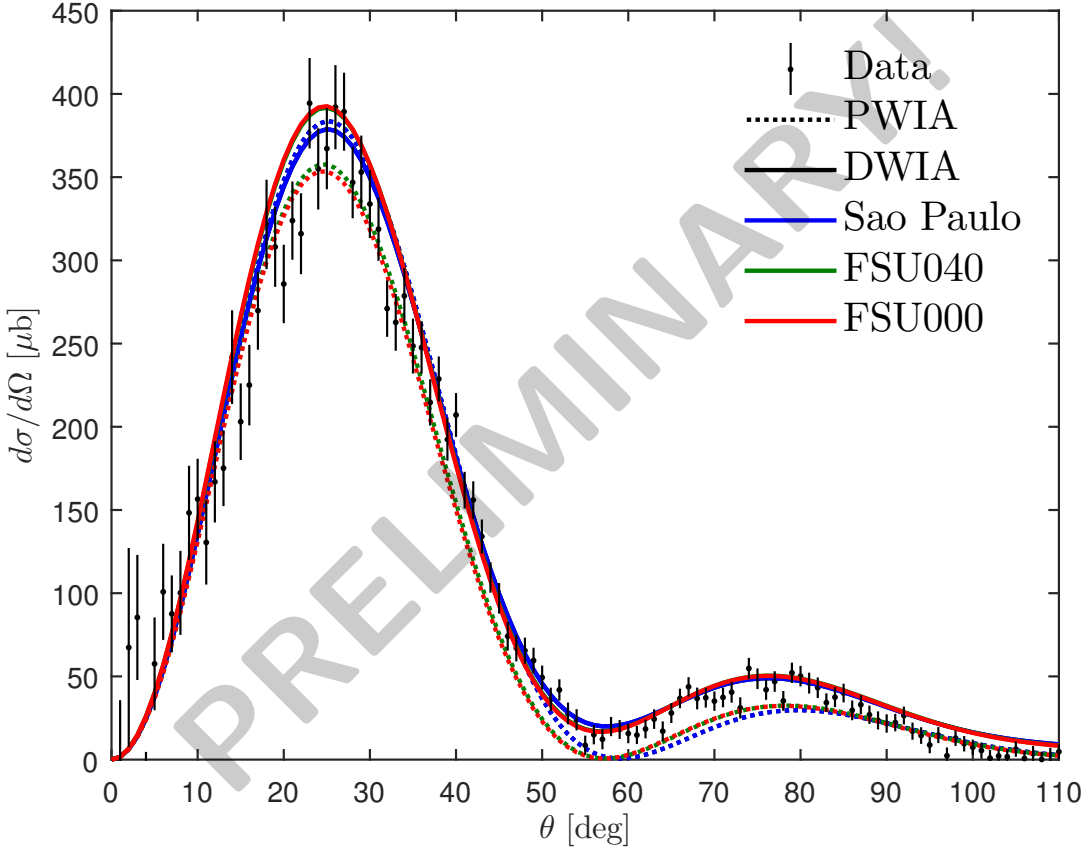
PWIA

DWIA

DWIA with DREN

NPA 660, 423

Comparison with experiment at $T_\gamma = 180\text{-}190$ MeV



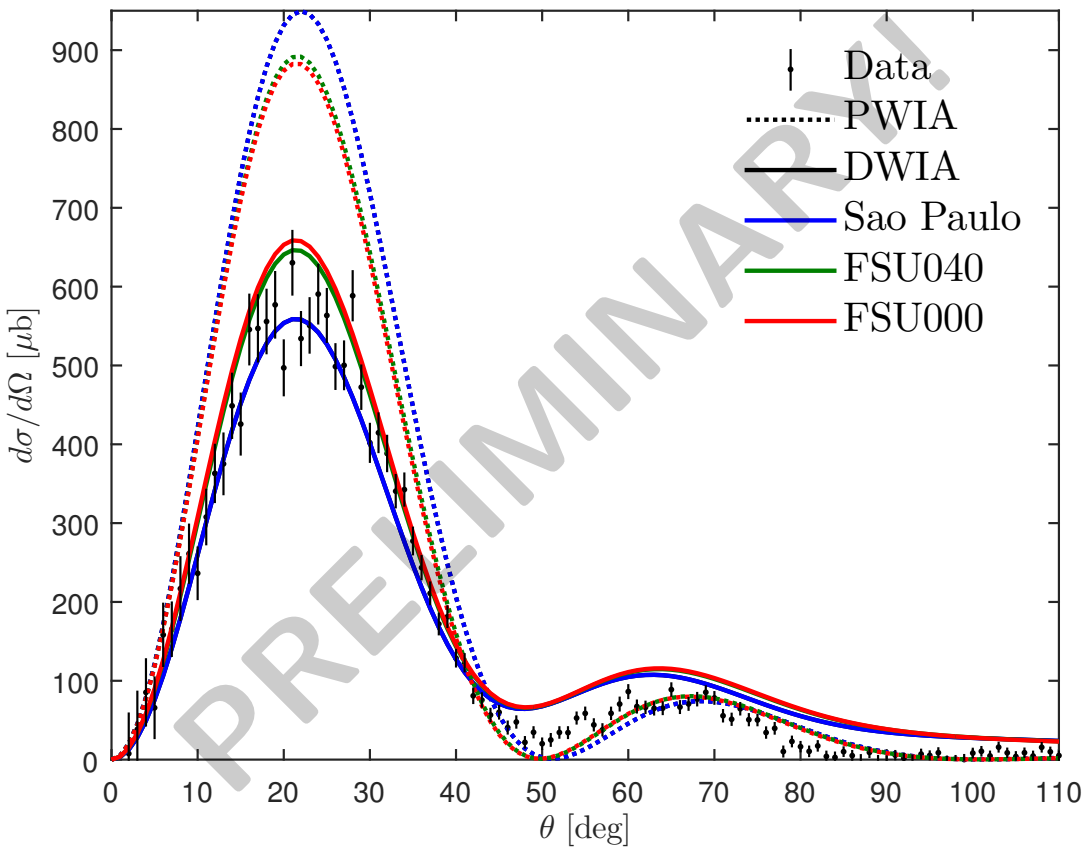
Data courtesy of M. Ferretti (PRELIMINARY)

Good agreement

2nd peak well reproduced

Distortion cancels ρ_A dependence

Comparison with experiment at $T_\gamma = 200\text{-}210$ MeV



Data courtesy of M. Ferretti (PRELIMINARY)

Less good agreement than at 180-190 MeV

DWIA reduces 1st peak $\Rightarrow$ better agreement with data

2nd peak not well reproduced even @DWIA

Curves in reversed order

$\Rightarrow$ potential needs to be adjusted

Conclusion, prospects and thanks

Study of the evolution of neutron skin in nuclei
$\Rightarrow$ information about EoS $\Rightarrow$ constrains the structure of neutron stars

Coherent π^0-photoproduction provides a way to infer n-skin thickness

- New reaction model implemented
  - PWIA has dependence when differences of skins $\sim$ 0.10 fm (small)
  - DWIA $\pi - A$ potential reduces dependence on skin
- What remains to be done
  - Can we infer information about skin from comparing different isotopes?
  - Constraints on $\pi - A$ (at energies of experiment)
  - (Bayesian) analysis of the dependence to $\pi - A$ potential (DWIA)

Many thanks to my collaborators
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Thank you for your attention