What Experimentalists Want (a personal view)

William Lynch, NSCL MSU

- “Overall” objectives for symmetry energy investigations
- Sensitivity of observables to EoS or symmetry energy
- New vs. more established observables
- Discussion of various observables
  - HIC observables
    - Benchmarks for transport codes
    - Isospin diffusion
    - n-p, t-^{3}He, etc: spectra and flows
    - Pion and kaon production
    - Fragmentation and low density EoS
  - Structure observables
    - neutron skins (also elastic scattering)
    - masses and Isobaric Analog States
    - Polarizabilities, Pygmy and Giant resonances
    - charge exchange
  - Astrophysical observables

"Overall" objectives for symmetry energy investigations

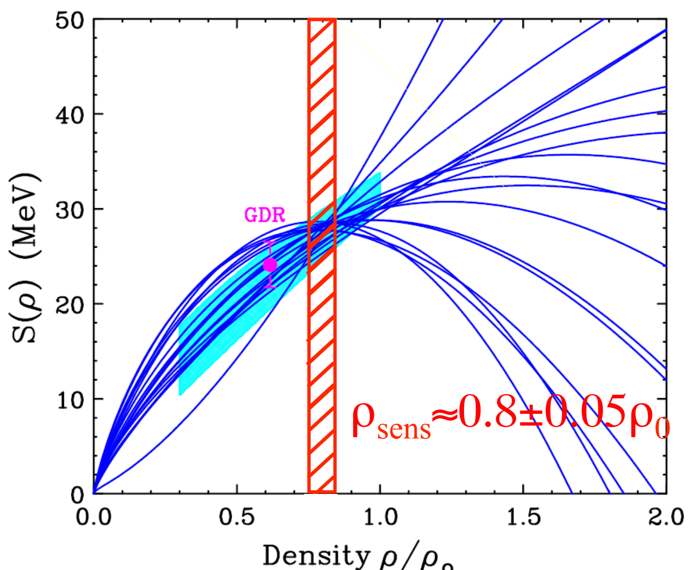
- We want the EoS to be constrained as a function of all relevant thermodynamic and internal variables.
  - example: $\varepsilon \equiv E/A(\rho,\delta,T)$. For computation purposes in mean field theory, we need the potential energy $U(\rho,\delta,T,\vec{r},\vec{k})$ where $\delta = (\rho_n - \rho_p)/\rho$
    - for hadronic matter, which requires $0.3 \le \rho/\rho_0 \le 3,\ 0 \le T \le \varepsilon_F$?
    - for Neutron Stars $0 \le \delta \le 1$
    - for excited and non-equilibrium system $0 \le k \le 3k_F,\ 0 \le T \le \varepsilon_F$?
- We would like approximate expressions that embody this information to facilitate computations, e.g.
  - "Skyrme" expressions in powers of density, etc.
  - Expansions in powers of ρ, δ, etc.
- We would like to know the uncertainties in these expressions e.g.
  - Ranges of values for the energy or pressure at a given density
  - Ranges of values for the parameters of the EoS expression.
- What else?

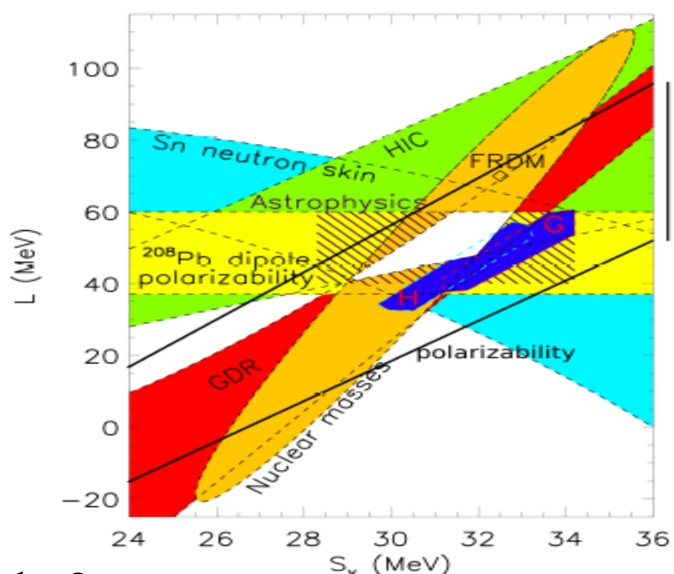
Sensitivity of observables to EoS or symmetry energy

- New observables to constrain the symmetry energy are very welcome
- We would like to know what aspect of the EoS or symmetry energy each observable constrains.
  - the energy?
  - the derivative with respect to density (pressure)?
  - the derivative with respect momentum (effective mass)?
  - or what combination of parameters (S_0, L, etc.)
- We would like to know what other poorly constrained aspects of matter influence this observable:
  - effective masses, in-medium cross sections, etc.
- We would like to know the range of densities that each observable probes.
- What else?

What range of densities does each observable probe?

- The absence of such information creates confusion. This is especially common when we claim to constrain a parameter in a Skyrme or power law expression, e.g.
  - Why does your value for K_∞ from Kaon production disagree with my value for K_∞ from the GMR?
  - Does your value for γ (as in $S(\rho) \approx S_0 \cdot \rho^\gamma$) obtained from pion production equal my value obtained from the GDR?
- The sensitive density range can be assessed by varying the EoS or symmetry energy using different function forms. Done by Pawel for flow measurements probing high densities. Assuming linear dep. $\rho_{sens.} = \rho_0\left(1-3/M\right)$; M is slope





$\rho_{mass} \approx 0.78\rho_0$

$\rho_{GDR} \approx 0.64\rho_0$

$\rho_{pol} \approx 0.54\rho_0$

$\rho_{HIC} < 0.45\rho_0$

$\rho_{skin} < 0$

sensitive to L

why is it curved?

what else?

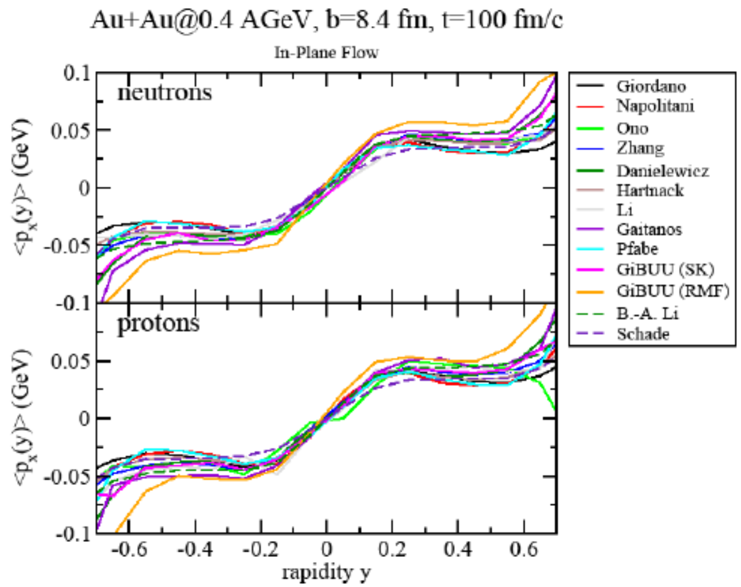
New vs. “established” observables

- Experimentalist are typically interested in new observables that display sensitivity to the EoS or the symmetry energy. We want the calculation to be correct and reproducible, but often do not insist that the sensitivity of the new observable to other transport quantities such a cross sections, etc. be fully explored.
- The standard is different for more established observables. For these experimentalist want to know how the uncertainties in other transport quantities influence predictions for the experimental observables. This is important because the measurements must be designed and performed to constrain all important transport parameters.
- We would like there to be benchmark predictions for more established observables using “standard” transport parameters.
- What else?

What experimentalists want for HIC observables
Benchmarks for transport codes

- Benchmark calculations were performed in late Process started at ECT workshop, May 11-15, 2009.
  - Some areas of agreement and disagreement between codes for similar input were identified.
  - Process not completed; differences in predictions remain.
- Such benchmarks are essential for quantitative scientific conclusions.
- Additional requests:
  - Accurate descriptions of what is in the code and how it may have been changed from prior versions.
- What else?

transverse flow



•The predictions for some other quantities, such as the collision rates differed more. (See the talk by Herman Wolter during the first week of ICNT.)

Isospin diffusion

Main effect

- Isospin diffusion equation:

$$\vec{j}_n - \vec{j}_p = -\rho D_\delta \vec{\nabla}\delta - D_\rho \delta \vec{\nabla}\rho$$

important for other observables

- Naive expectations:
  - D_δ increases with $S(\rho)$
  - D_δ decreases with σ_{np}
- We tested this by performing extensive BUU and QMD calculations with $S(\rho)$ for the form:
  - $S(\rho) = 12.5\cdot(\rho/\rho_0)^{2/3} + S_{int}\cdot(\rho/\rho_0)^{\gamma_i}$
- Observed sensitivities:
  - Diffusion sensitive to $S(0.4\rho_0)$
  - Diffusion decreases with σ_{np}
  - Diffusion decreases when mean fields are momentum dependent

  Can constrain

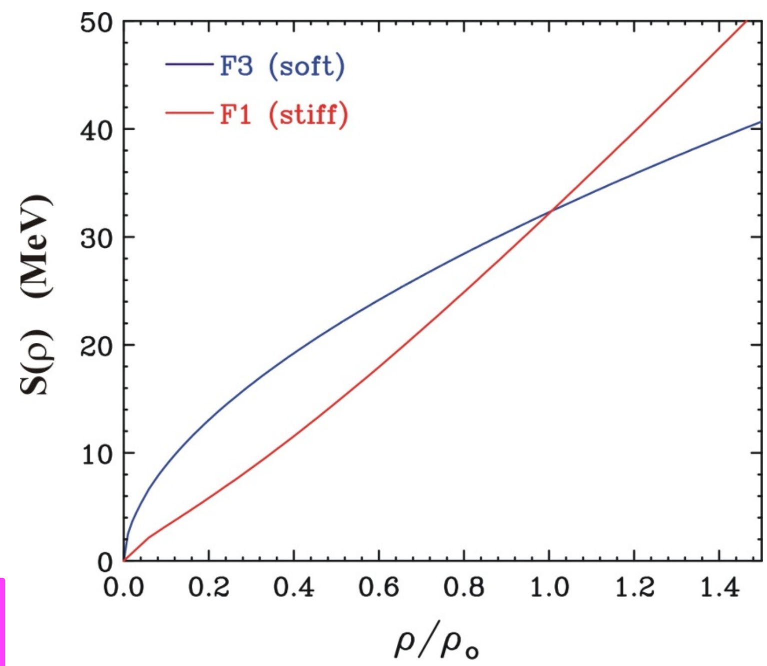
  - Diffusion decreases with cluster production.

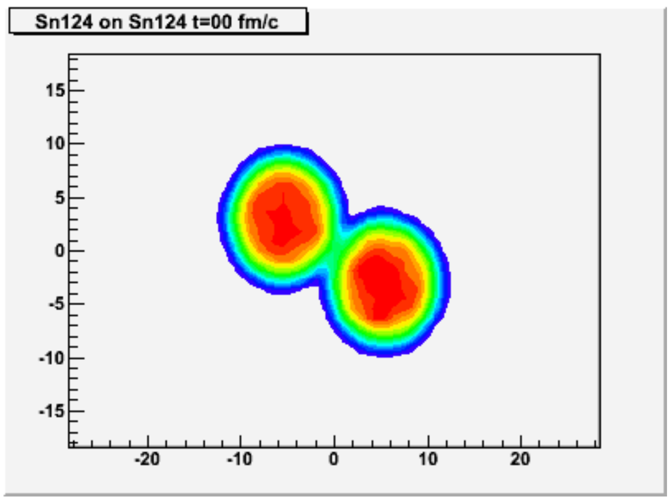
  Cannot constrain

Want emission of realistic alpha particles in the models.

Also results from the AMD model.

What else?

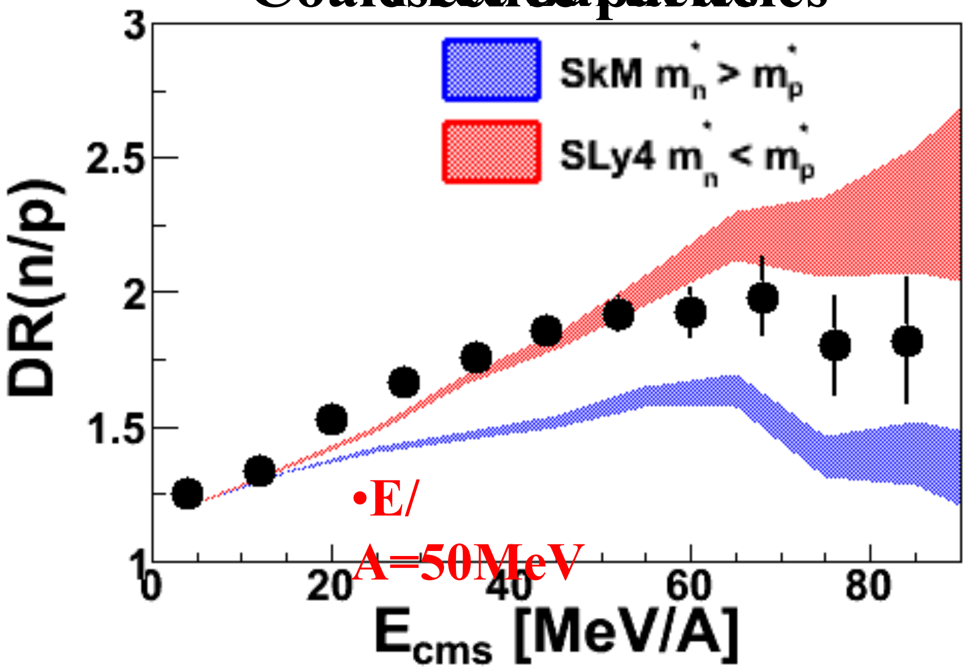




n-p, t-3He, etc: spectra and flows

•Coalescence particles

•Free particles



Unsatisfactory solution because alpha emission and fragment emission influences dynamics. This is less important at high energies. Want predictions to include emission of alpha particle with correct binding energies.

What else?

•ImQMD:

- Cluster production for alphas is not realistic
- Ignore the cluster production mechanism and look all the light particles (neutrons and protons) at a given velocity

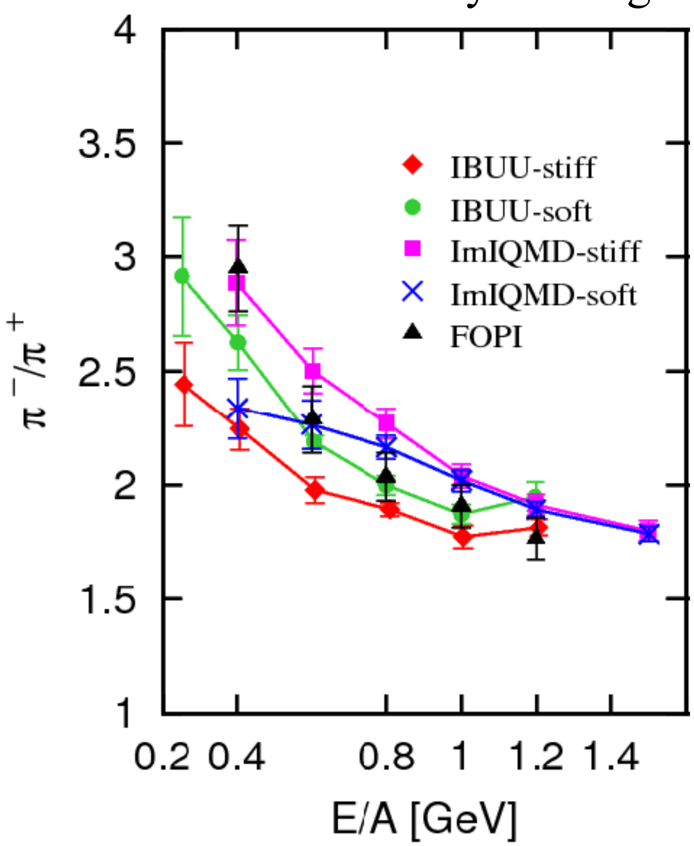
•Coalescence invariance:

- Coalescence protons (neutrons): Include protons (neutrons) from within clusters with the free proton (neutron) spectra
- Possibly a better match between simulation and experimental data

Pion and Kaon production

- The dependence of the total yield ratio $Y(\pi^-)/ Y(\pi^+)$ is opposite for some BUU and QMD calculations.
- BUU trend in BUU has been attributed to the influence of the symmetry potential on the incoming neutrons and protons.
- We would like a qualitative explanation for the QMD trend.
- Similar trends by Ferini et al., have been attributed to difference in production thresholds caused by the mean field potentials. Is this real?
- We would also like to have mean field potentials to be included in the calculations for entrance and exit channel particles and for intermediate resonances.
- Would also like to know the influence of in-medium cross sections.
- Would like predictions for the pionic energy spectra and flows from the various transport theories.
- More predictions of kaon production.
- What else?

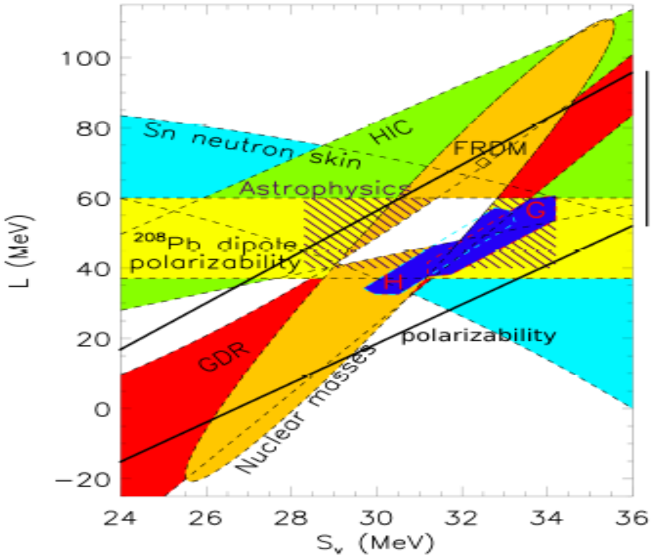
Courtesy J. Hong



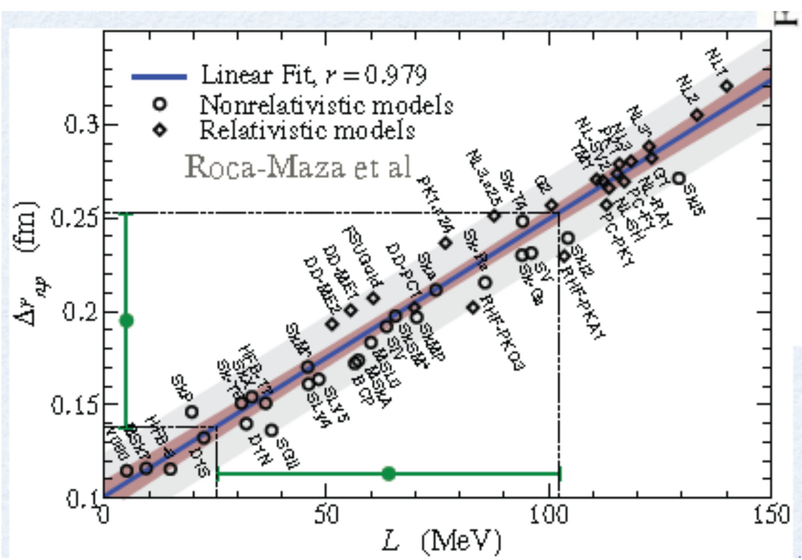
Low density EoS

- Involves comparisons of fragmentation data to calculations of low density inhomogenous matter.
- Production mechanism:
  - Excitation (and possibly compression) via a nuclear collision.
  - Expansion and disassembly into gas of fragments and nucleons.
  - Continued interactions until mean free path for further interactions exceeds system size. This is the condition of thermal freezeout
  - Secondary decay of excited nuclear fragments.
- Experimentalist would like to know how does the time dependence of this process cause the observations to differ from equilibrium predictions.
  - Models for expansion and disassembly exist.
  - Secondary decay calculations exist.
  - It would be useful to improve models of the freezeout and determine how it differs from equilibrium at the freezeout density and temperature.
  - How uncertain is the extrapolation from zero temperature to finite temperature for uniform matter (or vice-versa)?
  - Asymmetry dependence of heat capacities (level densities)
  - What else?

neutron skins (also elastic scattering)



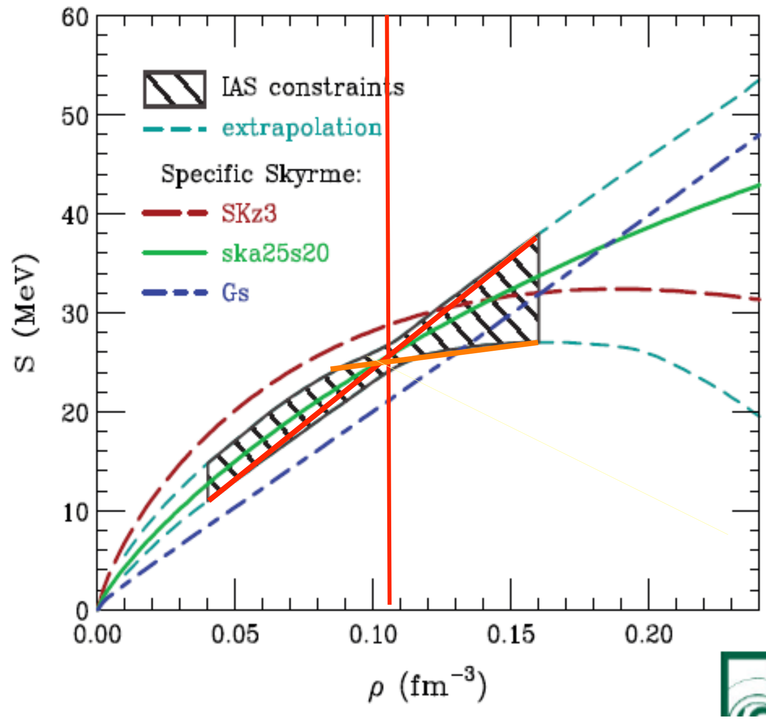
- I would like to understand the model dependence between the connection of L and Δ_{np}



- Can the precision of proton elastic scattering by improved enough to measure the variation of Δ_{np} across an isotope chain with negligible systematic error?
  - Test case could be proton scattering on the Calcium and Tin isotopes.
- Can one extract the neutron skin thickness from an accurate measurement of the reaction cross section of a very neutron rich nucleus.
- Do we lose sensitivity for weakly bound halo nuclei. How weakly bound can we use.
- What else?

Masses and Isobaric Analog States

Danielewicz

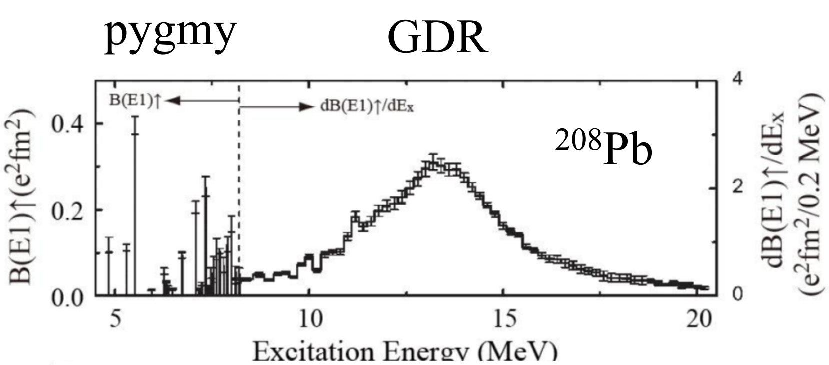


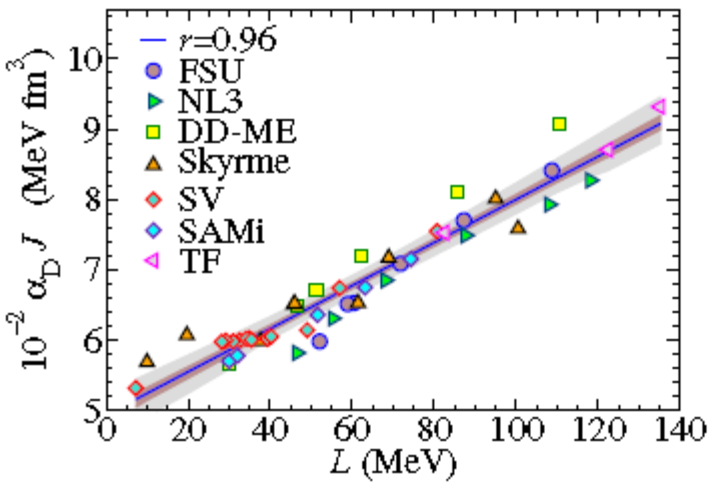
•Sensitive density is 0.67 ρ_0 and from the orange and red lines, 18 MeV < L <108 MeV. Should the constraints be obtained differently? Does Pawel get the same sensitivity and resultsfor the masses?

Alex: What do you find for the sensitive density? 0.67 ρ_0 or 0.77 ρ_0?

- There is a large difference in the sensitivity to L for Moller and for Lattimer. Which is more correct?
- How much can this be improved by measuring masses further from stability?
- Is it better to measure near closed shells or mid shell and deal with the deformation?
- Can we just compare only even A or only odd A to avoid pairing effects?
- What else?

Polarizabilities, Pygmy and Giant resonances



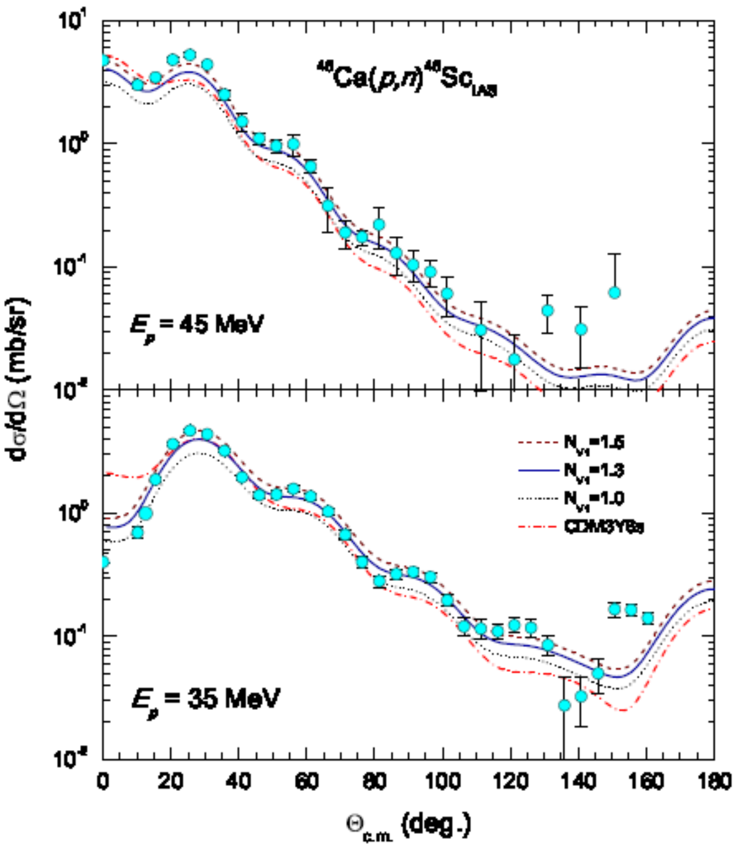


X. Roca-Maza et al., arXiv:1307.4806 (2013)

- Constraints from α_D

- Can we simply measure the GDR and neglect the Pygmy?
- Does the sensitivity to L improve for measurements on lighter nuclei.
- Are there strong interaction contributions to published α_D.
- Can one reduce the accuracy requirement for measurements of rare isotopes?
- Does it matter whether the pygmy is collective or not? How well does it have to be understood?
- What else?

Charge exchange



- Can one put quantitative constraints on the momentum dependence of the symmetry potential using charge exchange?
- How does the accuracy of such studies compare to that achievable using neutron and proton elastic scattering?

Astrophysical Observables

- Experimentalists want to understand the connections between nuclear properties and astrophysical observables. It is a "two way street". Dense matter is an interdisciplinary field.
  - Experimentalists would like to constrain such properties by measurements.
  - Experimentalists would like to understand and incorporate astrophysical constraints into their overall understanding of such properties.
  - Specific questions
    - Does the momentum dependence of the symmetry mean field potentials influence astrophysical observables. Does the momentum dependence matter or can it be modeled accurately by assuming local mean fields.
    - What specific properties of the low density inhomogeneous and homogenous EoS need to be constrained?

What else?

1.
2.
3.