High density with elliptic flows

W. Trautmann, GSI Helmholtzzentrum, Darmstadt, Germany

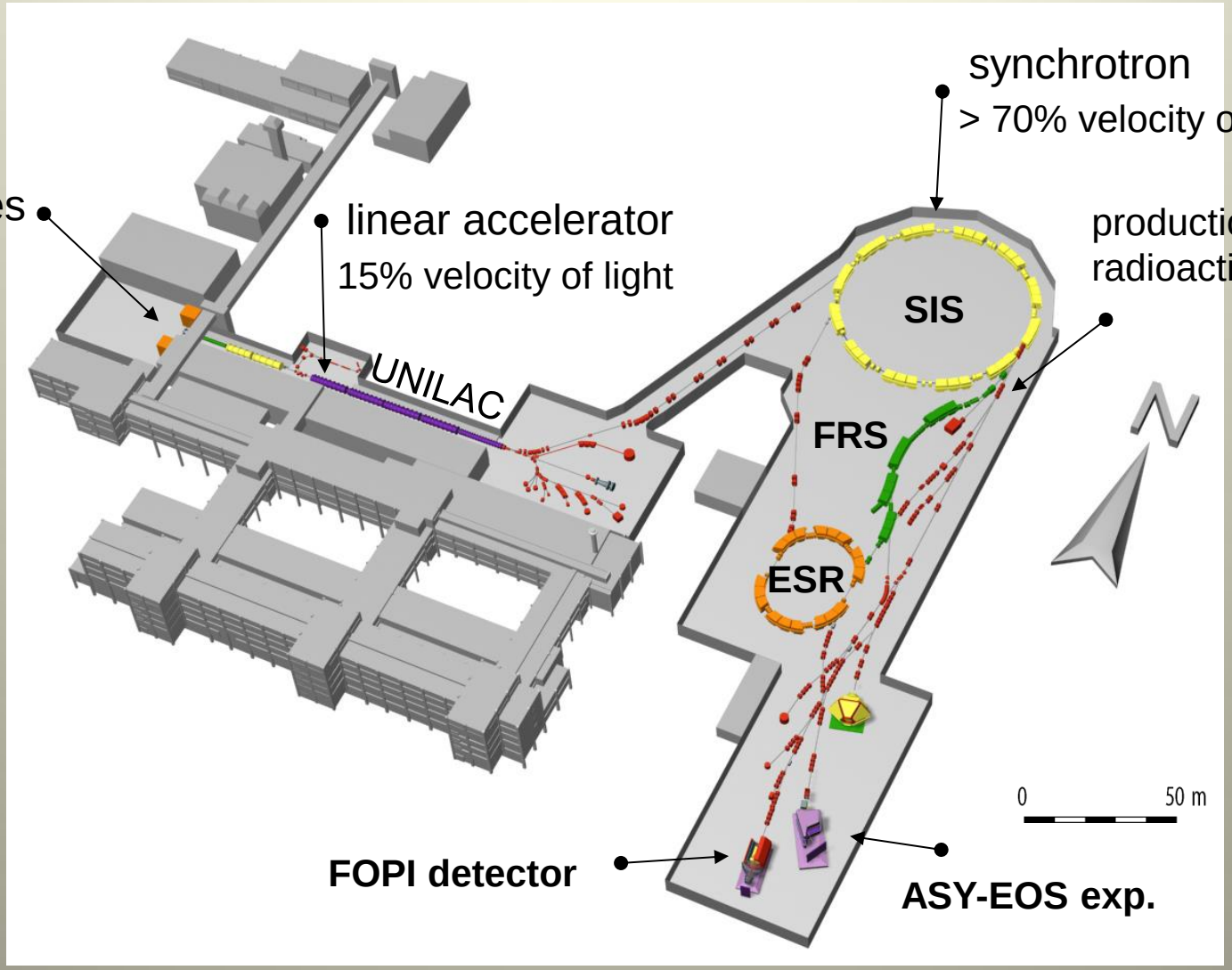
FAIR construction site

from the visitors' platform on December 18, 2018

GSI upgrade

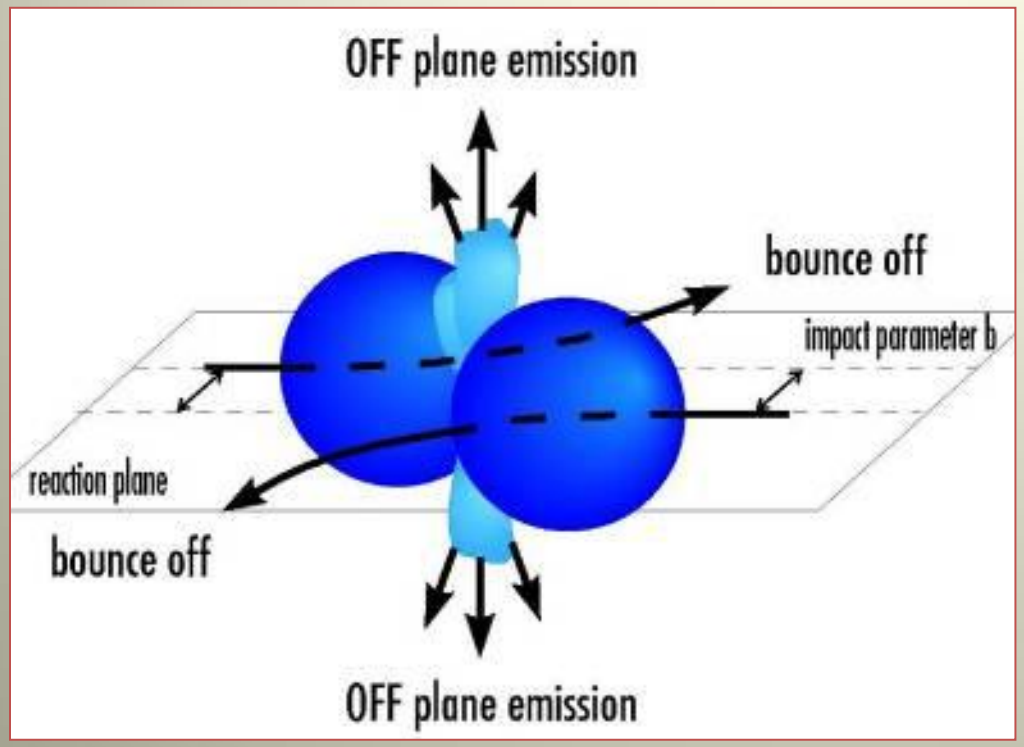
September 2018

experiments FOPI-LAND and ASY-EOS



pressure gauge for neutron-star matter

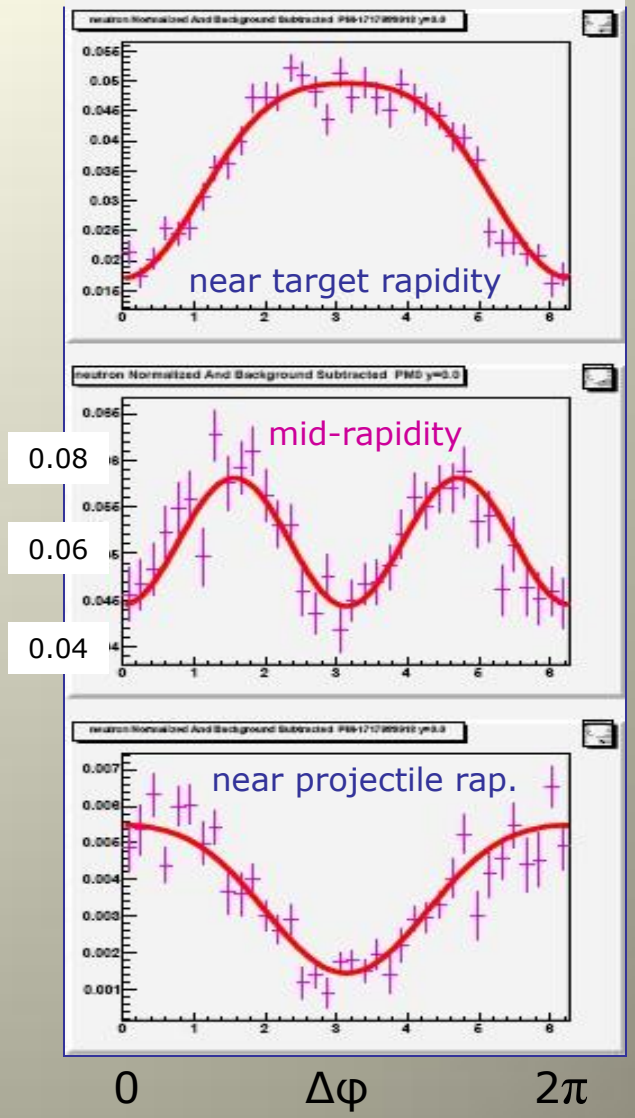
Buchwald/Frankfurt



tested with existing **FOPI-LAND** data
^{197}Au + ^{197}Au @ 400 A MeV
Russotto et al. PLB 697 (2011)

ASY-EOS experiment in 2011
Russotto et al., PRC 94 (2016)

FOPI-LAND data
neutrons, b ≈ 5-7 fm
fit with Fourier expansion



L vs flow ratio or difference

Yongjia Wang et al., Phys. Rev. C 93 (2016)

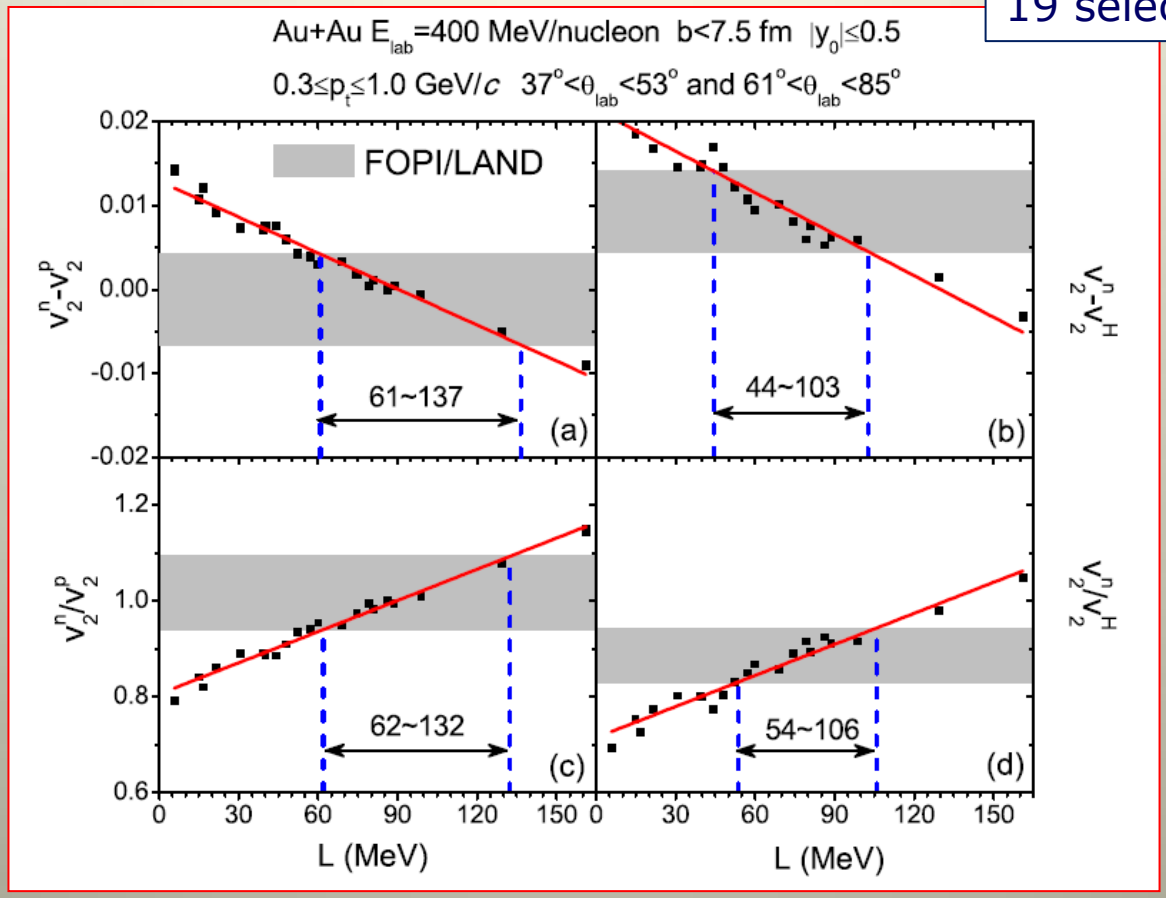
UrQMD with
19 selected Skyrmes

neutrons
vs protons
left panels

differences →

ratios →

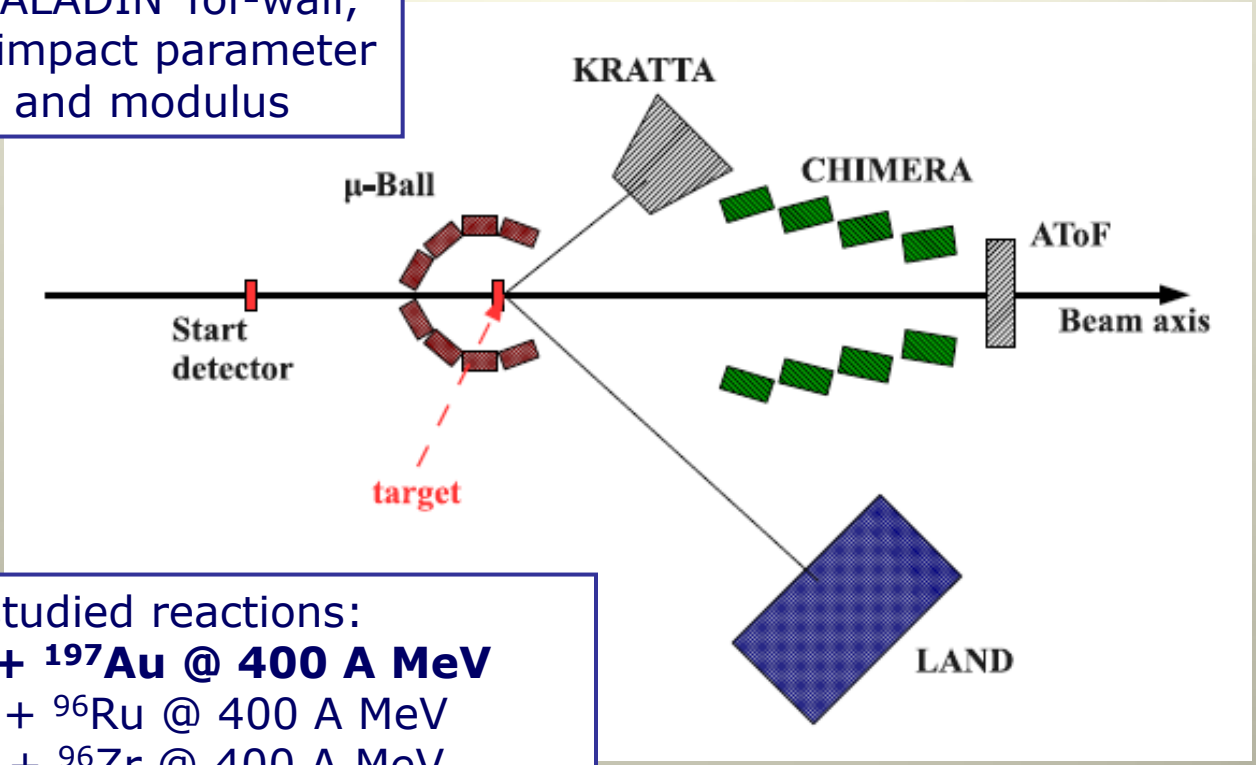
neutrons
vs all Z=1
right panels



$$S(\rho) = S_0 + \frac{L}{3}\frac{\rho-\rho_0}{\rho} + \frac{K_{sym}}{18}\left(\frac{\rho-\rho_0}{\rho}\right)^2 + \cdots$$

ASY-EOS experiment S394 in May 2011

CHIMERA, ALADIN Tof-wall, μ-ball, for impact parameter orientation and modulus



studied reactions:

^{197}Au + ^{197}Au @ 400 A MeV

^{96}Ru + ^{96}Ru @ 400 A MeV

^{96}Zr + ^{96}Zr @ 400 A MeV

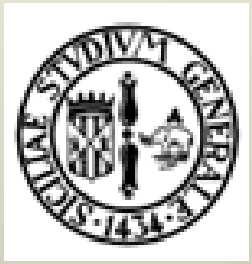
Constraining the Symmetry Energy at Supra-Saturation Densities with Measurements of Neutron and Proton Elliptic Flows

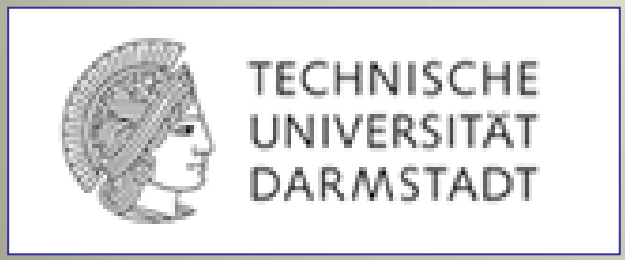
Co-Spokespersons: R.C. Lemmon and P. Russotto

very international

spokespersons: P. Russotto (Catania)
R.C. Lemmon (Daresbury)

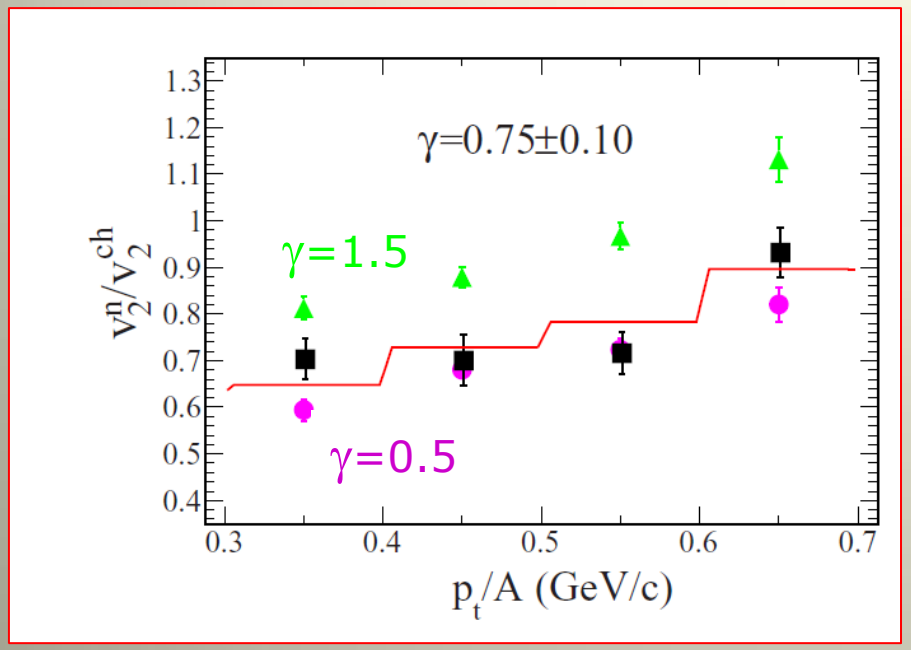
P. Russotto, PRC 94, 034608 (2016)
93 authors from 14 countries



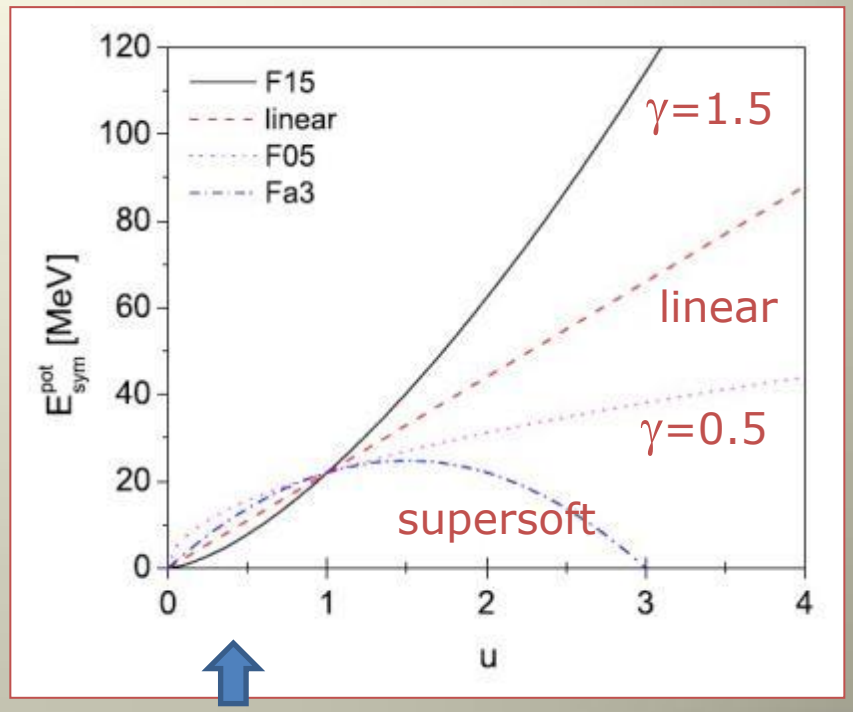


ASY-EOS: flow ratio vs transverse momentum

data
Au + Au 400 MeV/nucleon



parametrization
in transport theory: UrQMD, Q.F. Li et al.



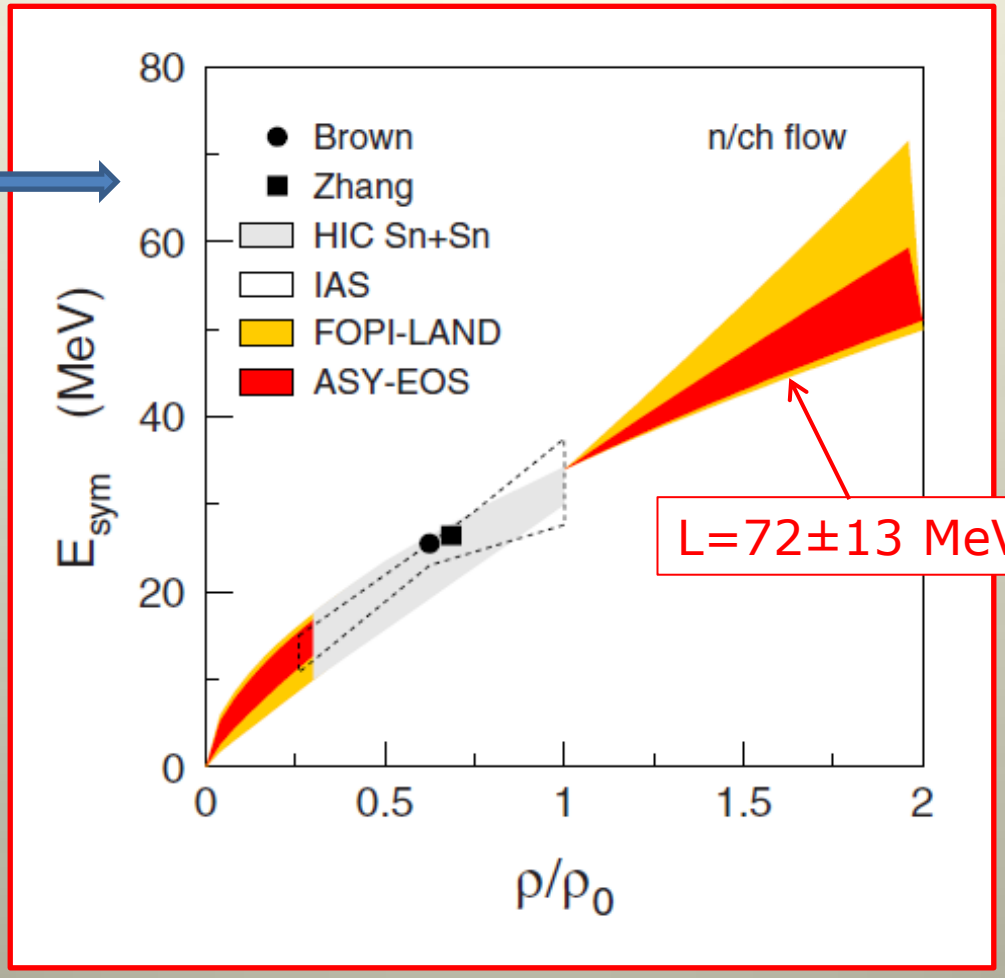
E_{sym} = 22 MeV·$(\rho/\rho_0)^{\gamma}$+12 MeV·$(\rho/\rho_0)^{2/3}$

final: γ = 0.72 ± 0.19 (incl. syst. error)

P. Russotto et al., PRC 94, 034608 (2016)

neutron vs charged-particle flow ratios

compiled by Horowitz et al., JPhysG (2014)

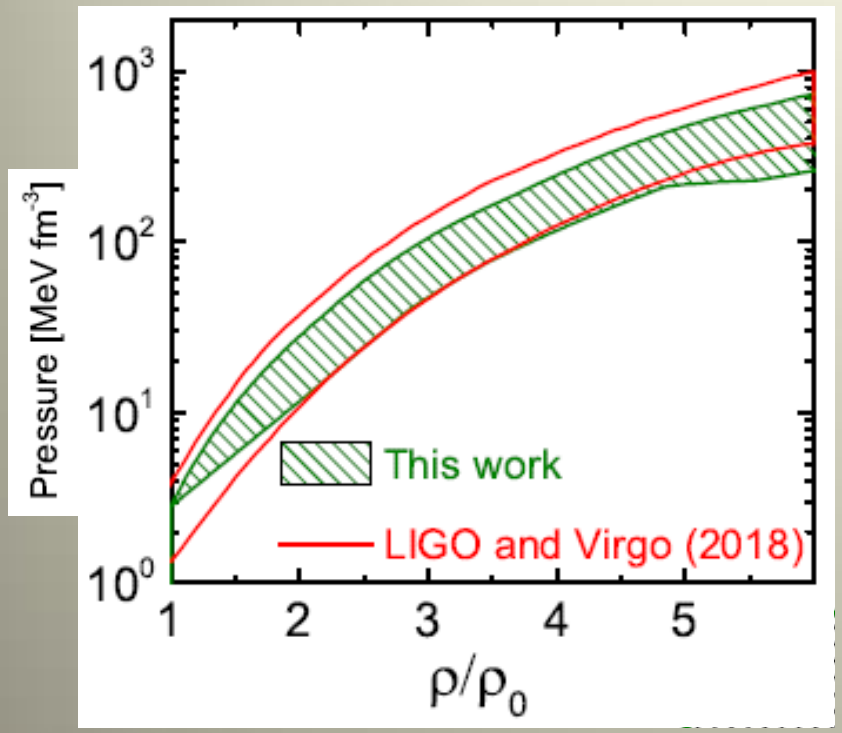


FOPI-LAND: Russotto et al. PLB 697 (2011)

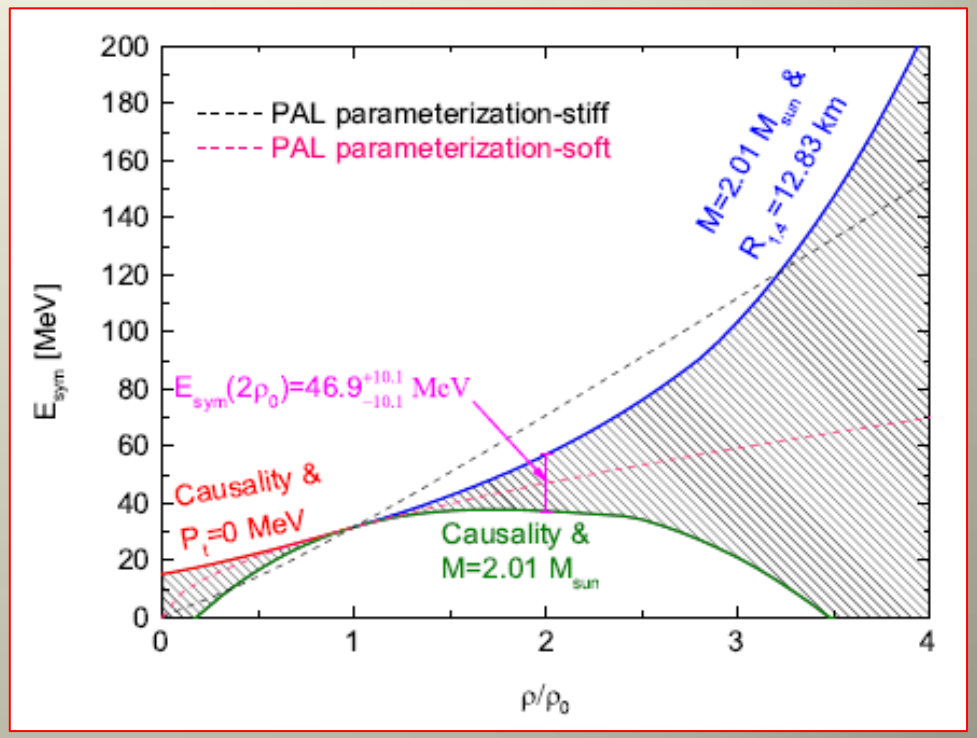
ASY-EOS: P. Russotto et al., PRC 94, 034608 (2016)

symmetry energy from neutron star observations

Nai-Bo Zhang and Bao-An Li, to appear in EPJA topical issue
pressure from neutron star observations, arxiv:1807.07698
(radius, maximum mass, tidal polarizability and causality condition)



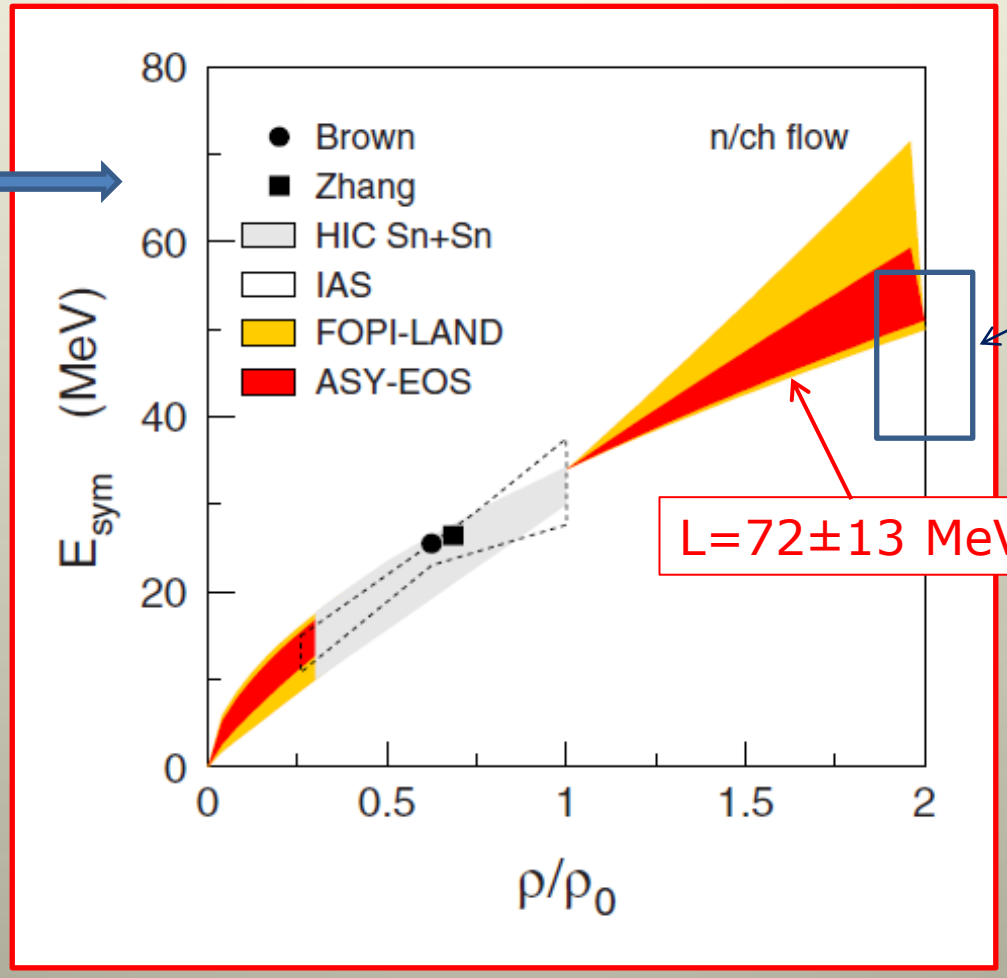
Abbott et al. (LIGO & VIRGO)
pressure from tidal deformability
in GW170817, PRL 121 (2018)



$E_{sym}(2\rho_0)=47\pm10$ MeV

neutron vs charged-particle flow ratios

compiled by Horowitz et al., JPhysG (2014)



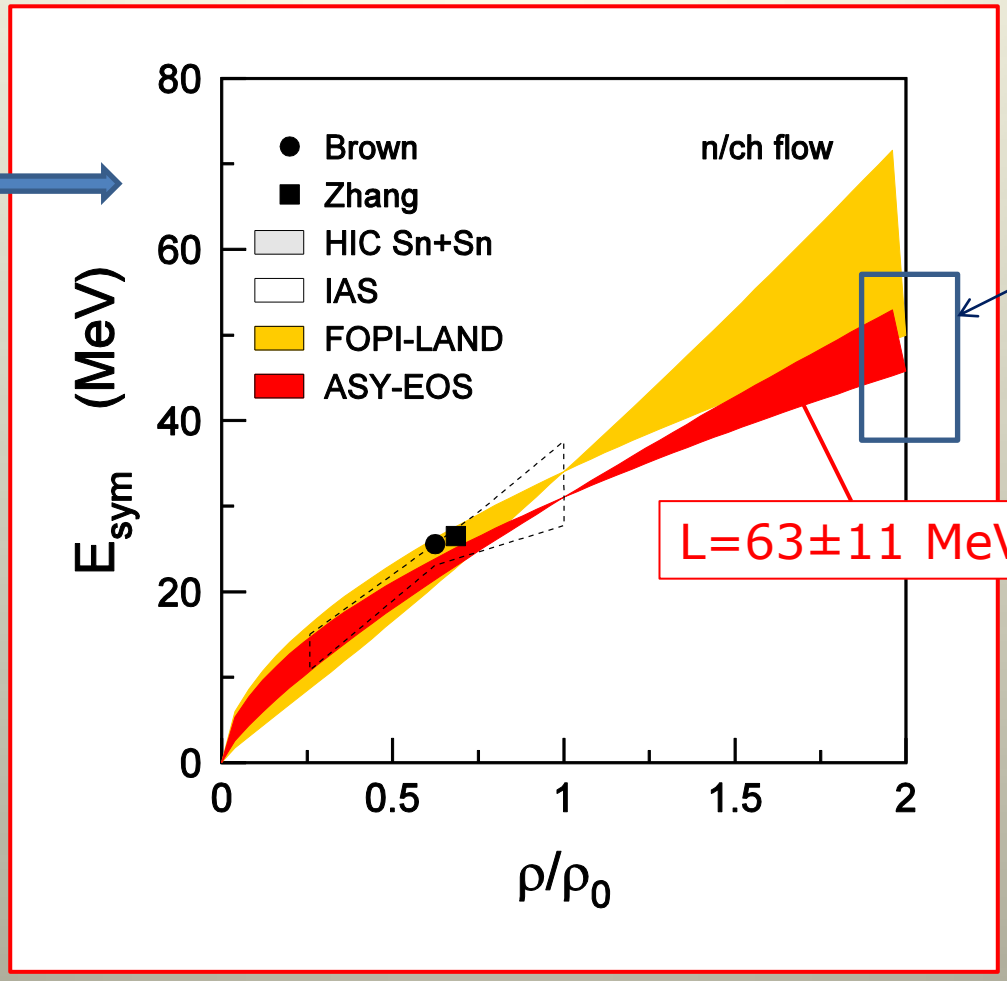
neutron stars
Zhang & Li
E_{sym} $(2\rho_0)$ =
47 ± 10 MeV

FOPI-LAND: Russotto et al. PLB 697 (2011)

ASY-EOS: P. Russotto et al., PRC 94, 034608 (2016)

with $E_{sym}(\rho_0)$ = 31 MeV

compiled by Horowitz et al., JPhysG (2014)



neutron stars
Zhang & Li
E_{sym} $(2\rho_0)$ =
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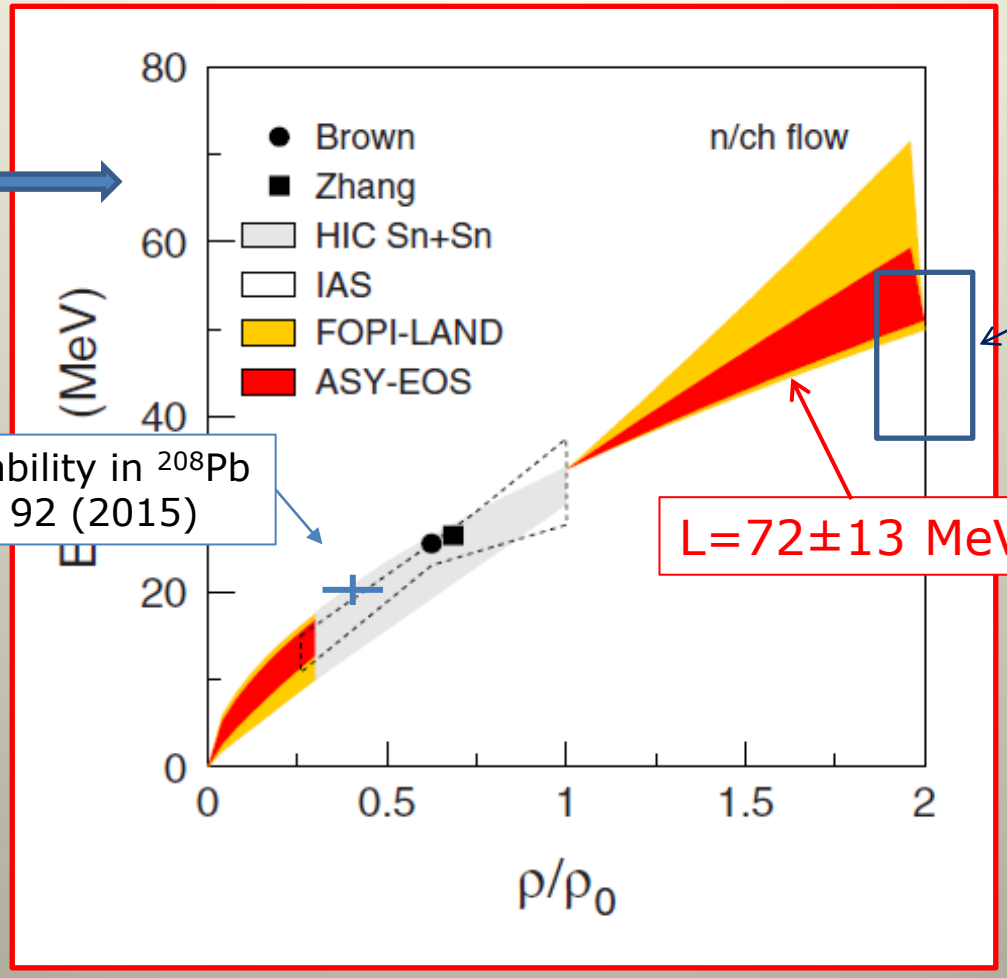
FOPI-LAND: Russotto et al. PLB 697 (2011)

ASY-EOS: P. Russotto et al., PRC 94, 034608 (2016)

consistency at subsaturation density

compiled by Horowitz et al., JPhysG (2014)



neutron stars
Zhang & Li
E_{sym} ($2\rho_0$) = 47 ± 10 MeV

electric dipole polarizability in ^{208}Pb
Zhang and Chen, PRC 92 (2015)

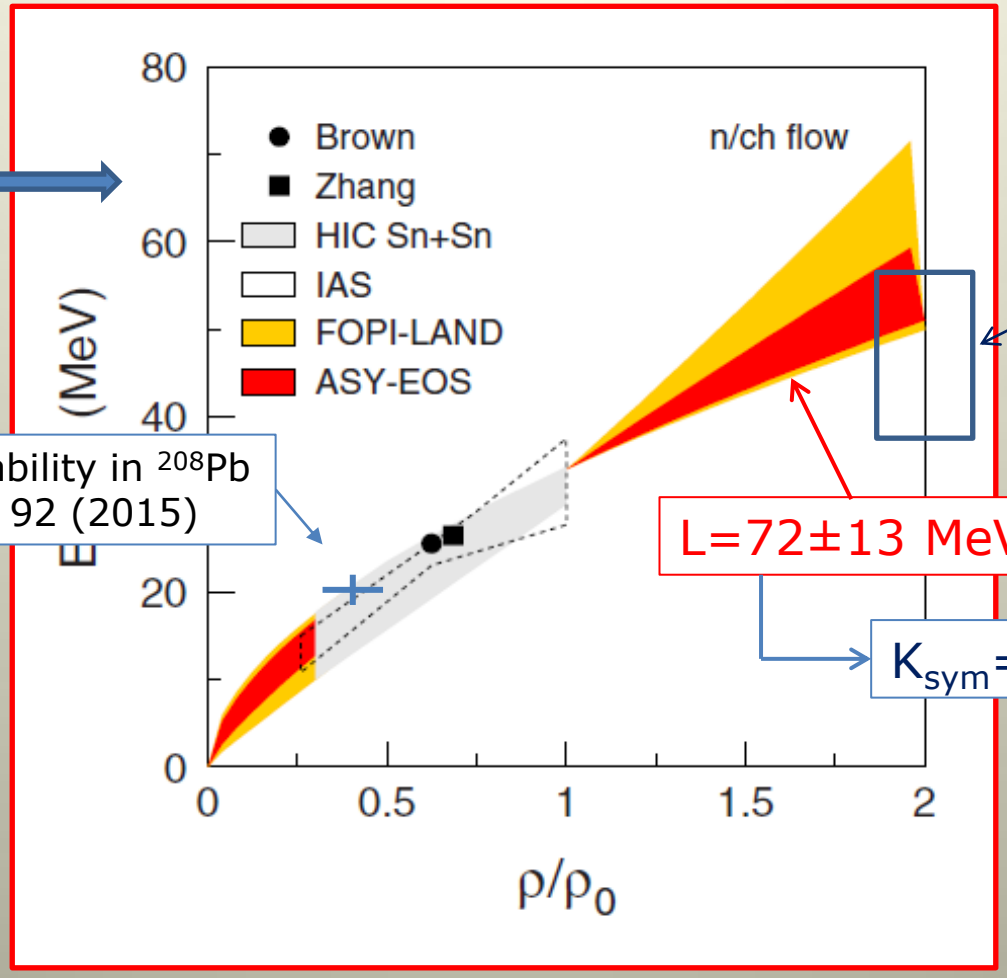
L=72±13 MeV

FOPI-LAND: Russotto et al. PLB 697 (2011)

ASY-EOS: P. Russotto et al., PRC 94, 034608 (2016)

consistency at subsaturation density

compiled by Horowitz et al., JPhysG (2014)



neutron stars
Zhang & Li
E_{sym} ($2\rho_0$) =
47 ± 10 MeV

electric dipole polarizability in ^{208}Pb
Zhang and Chen, PRC 92 (2015)

L=72±13 MeV

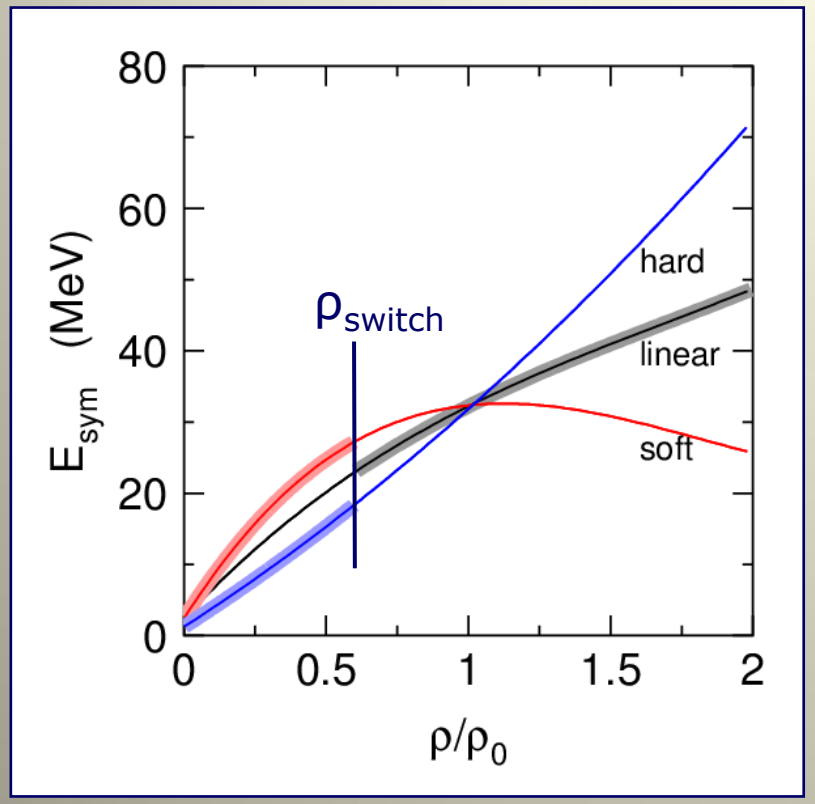
K_{sym}=-70 to -40 MeV

FOPI-LAND: Russotto et al. PLB 697 (2011)

ASY-EOS: P. Russotto et al., PRC 94, 034608 (2016)

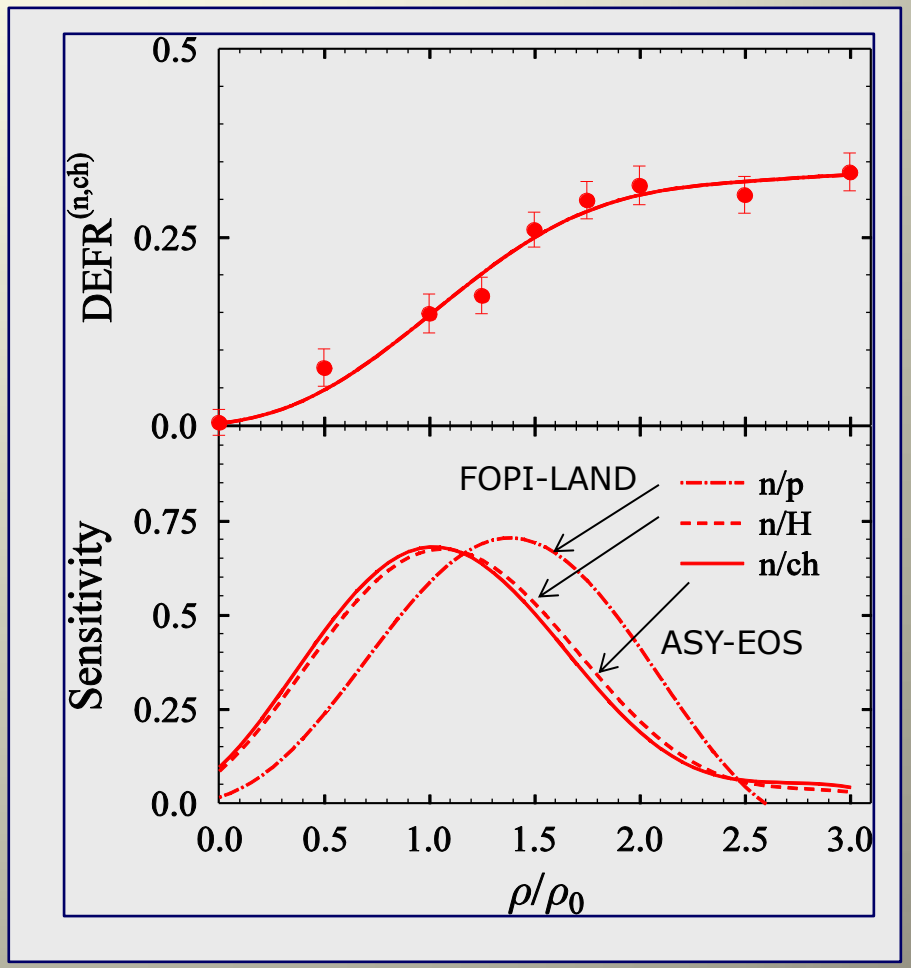
sensitivity to density

Dan Cozma using Tübingen QMD



transport with different E_{sym}
in selected density intervals

Difference of **E**lliptic-**F**low **R**atio

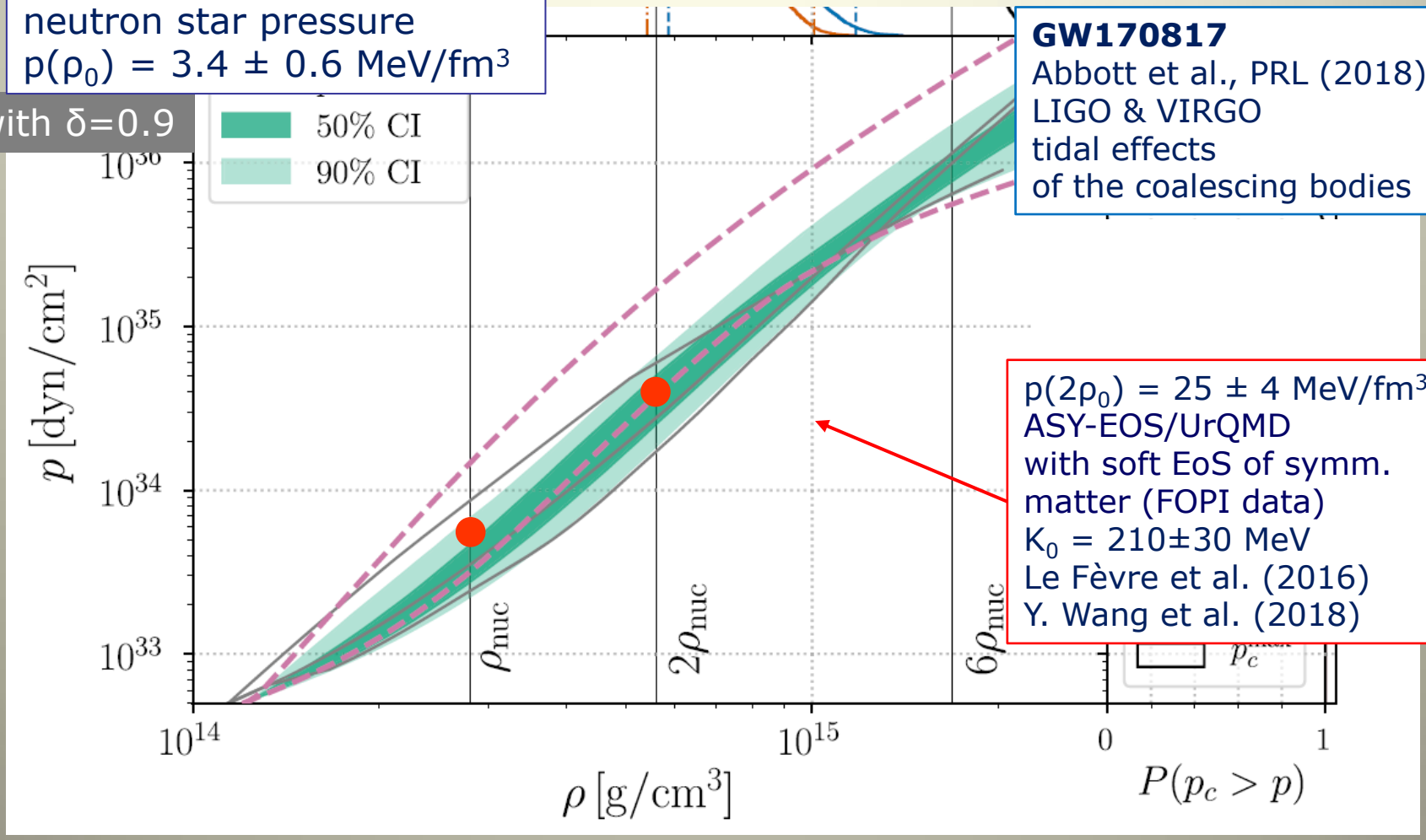


P. Russotto et al., PRC 94, 034608 (2016)

ASY-EOS: symmetry pressure $p_0 = L\rho_0/3 = 3.8 \pm 0.7$ MeV/fm^3

neutron star pressure
$p(\rho_0) = 3.4 \pm 0.6$ MeV/fm^3

with δ=0.9



GW170817
Abbott et al., PRL (2018)
LIGO & VIRGO
tidal effects
of the coalescing bodies

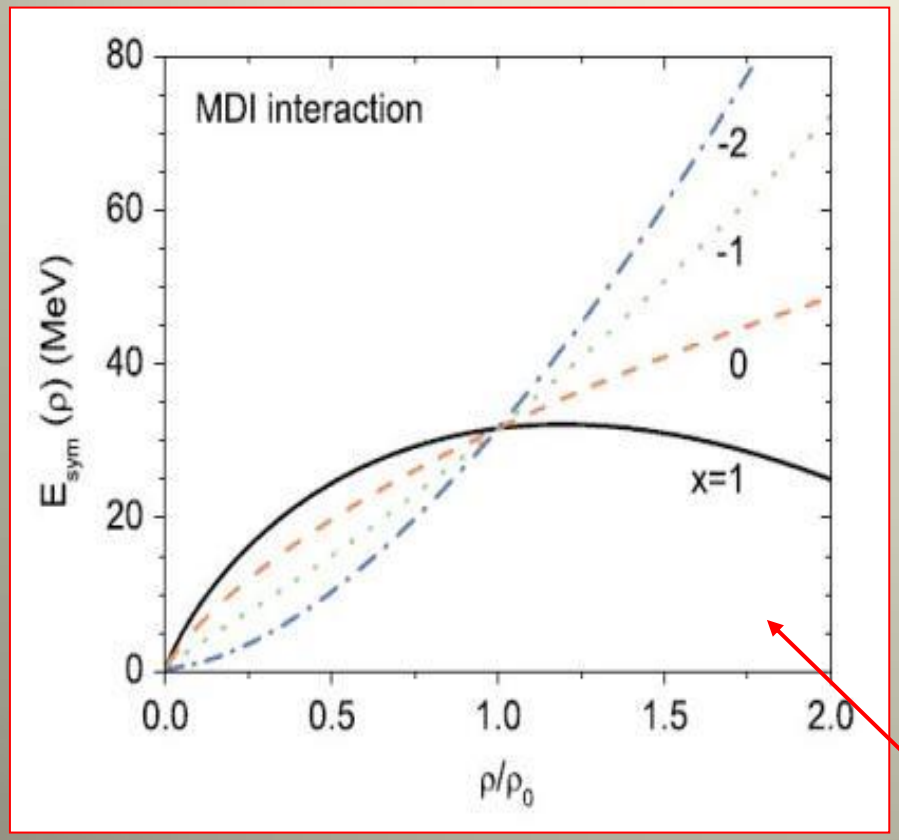
$p(2\rho_0) = 25 \pm 4$ MeV/fm^3
ASY-EOS/UrQMD
with soft EoS of symm. matter (FOPI data)
$K_0 = 210 \pm 30$ MeV
Le Fèvre et al. (2016)
Y. Wang et al. (2018)

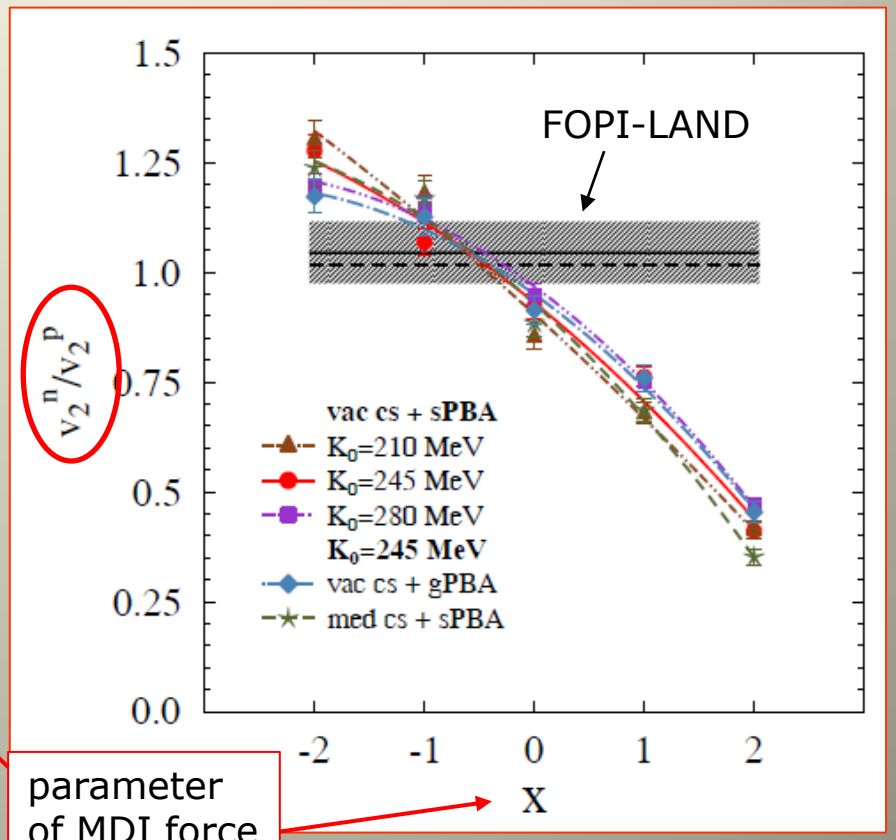
terrestrial meet astrophysical results in ρ_0 to $2\rho_0$ interval

perspectives for the curvature K_{sym}

M.D. Cozma, EPJA 54:40 (2018)
MDI force as starting point
FOPI-LAND, ASY-EOS, FOPI data

independence of model assumptions
npEFR important but has large error
→ new data with isotopic resolution!



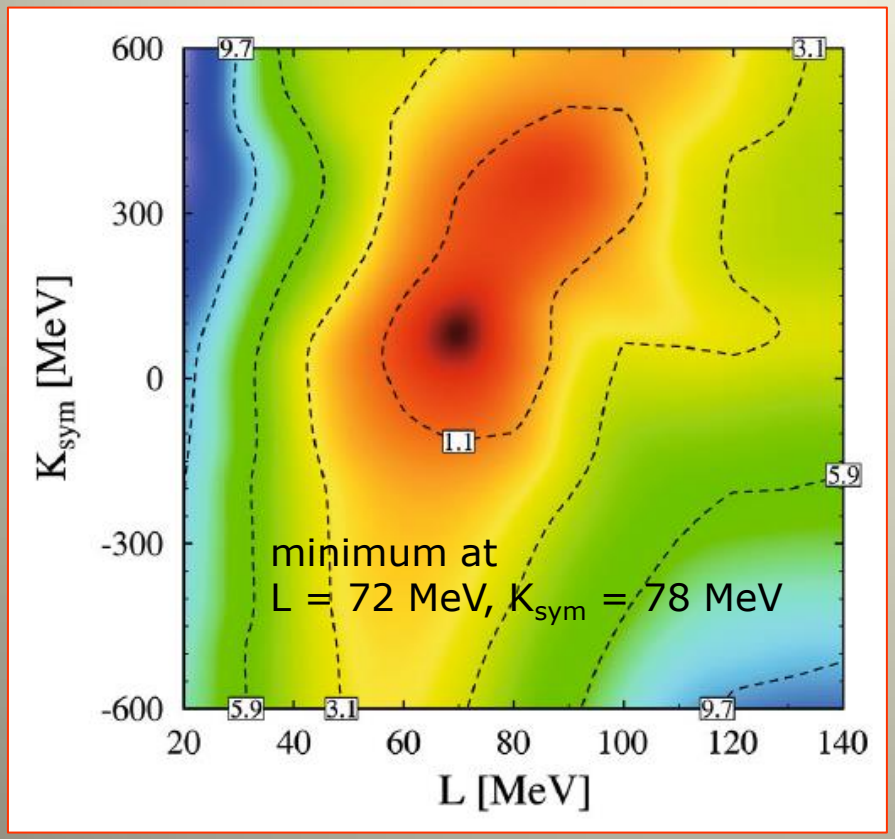


parameter
of MDI force

perspectives for the curvature K_{sym}

continued with **MDI2**:
L and K_{sym} uncorrelated
and E_{sym}=25.5 MeV at ρ=0.1 fm^{-3}

M.D. Cozma, EPJA 54:40 (2018)



with additional corrections:
e.g., energy conservation
proton to cluster yield ratios

L = 85 ± 32 MeV
K_{sym} = 96 ± 395 MeV

315 (exp)+170(th)+166(sys)

errors contain all individual uncertainties

large contribution
to the errors from **npEFR**

summary and remarks

special thanks to
Dan Cozma, Bucharest
Arnaud Le Fèvre, Darmstadt
Yvonne Leifels, Darmstadt
Jerzy Łukasik, Krakó
Paolo Russotto, Catania
Hermann Wolter, München

- differential elliptic flow presently unique regarding high density
- satisfactory overlap with neutron star (merger) results at 1-2 ρ_0
- model-independent analysis performed by Dan Cozma
- more precise data for neutron-proton elliptic-flow ratio required
- $\langle\rho\rangle \simeq 2\ \rho_0$ within reach with SIS18 beams and instrumentation prepared for FAIR (proposal to FAIR-0 (2017))