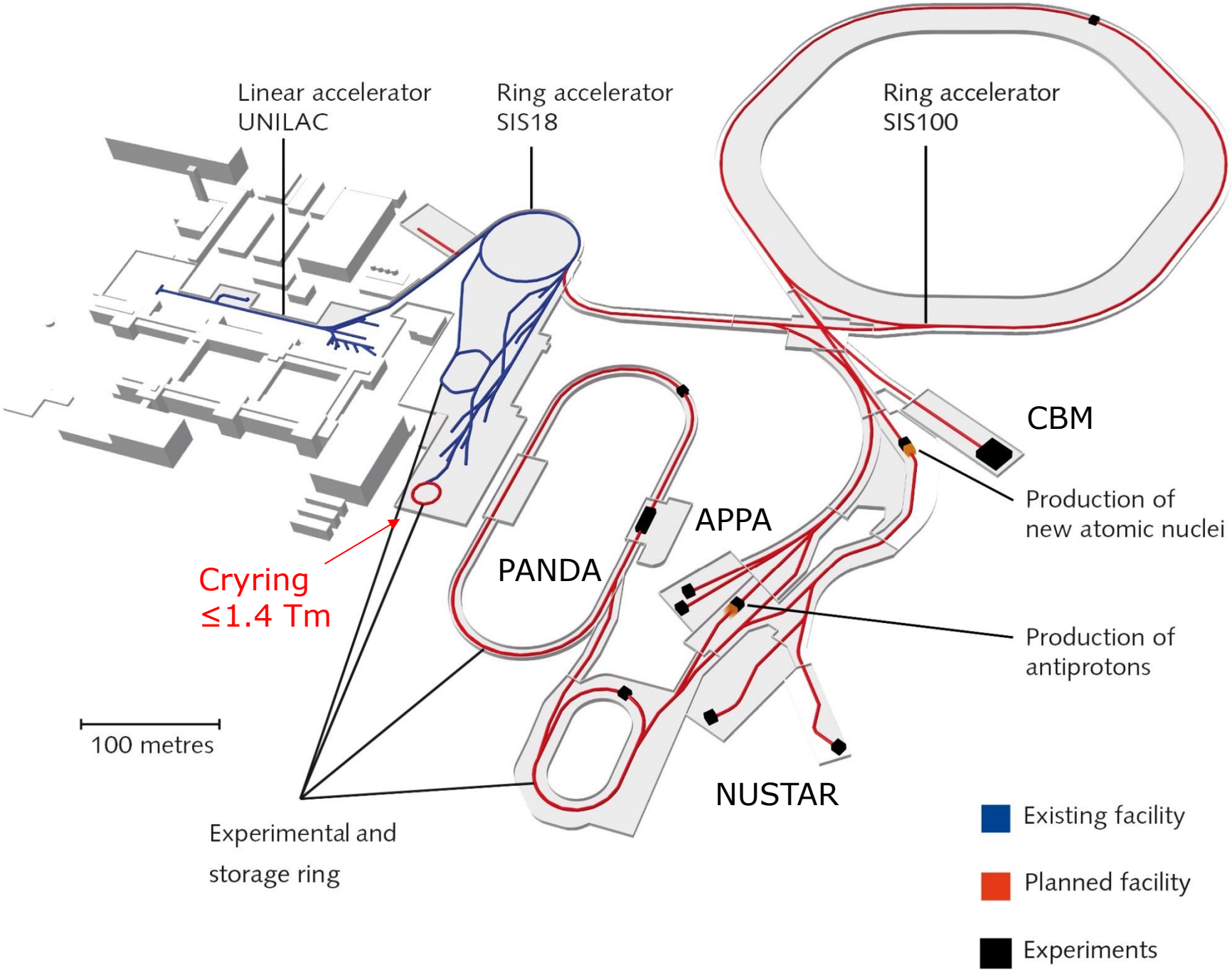
Symmetry Energy at GSI/FAIR

W. Trautmann, GSI Helmholtzzentrum, Darmstadt, Germany

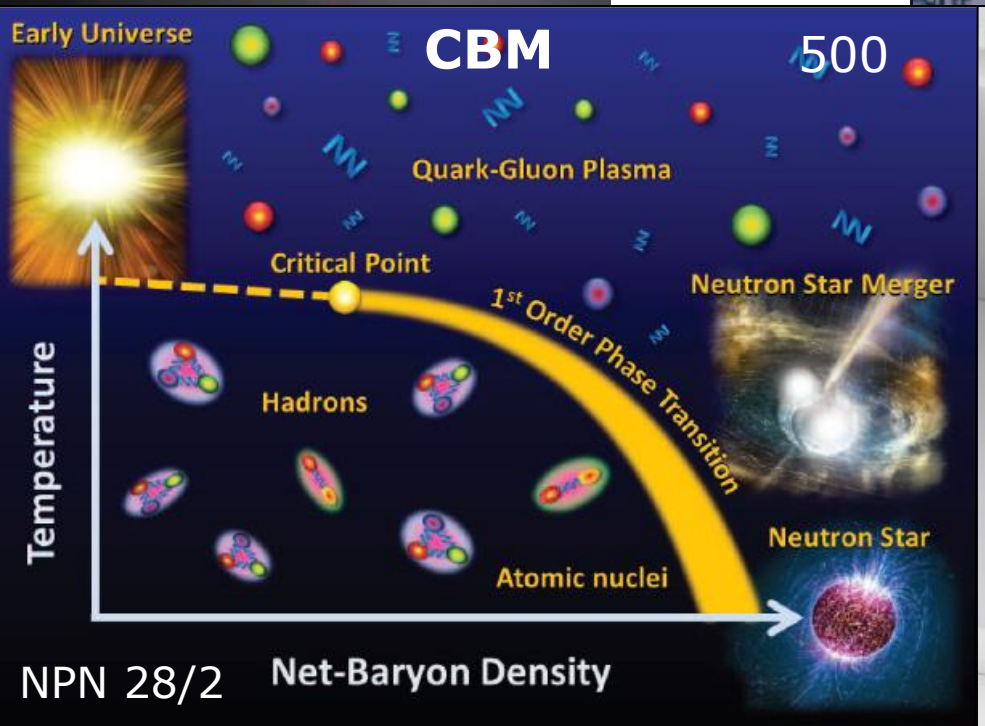

Linear accelerator
UNILAC
Ring accelerator
SIS18
Ring accelerator
SIS100
CBM
Production of
new atomic nuclei
APPA
PANDA
Cryring
≤1.4 Tm
Production of
antiprotons
100 metres
NUSTAR
Experimental and
storage ring
Existing facility
Planned facility
Experiments

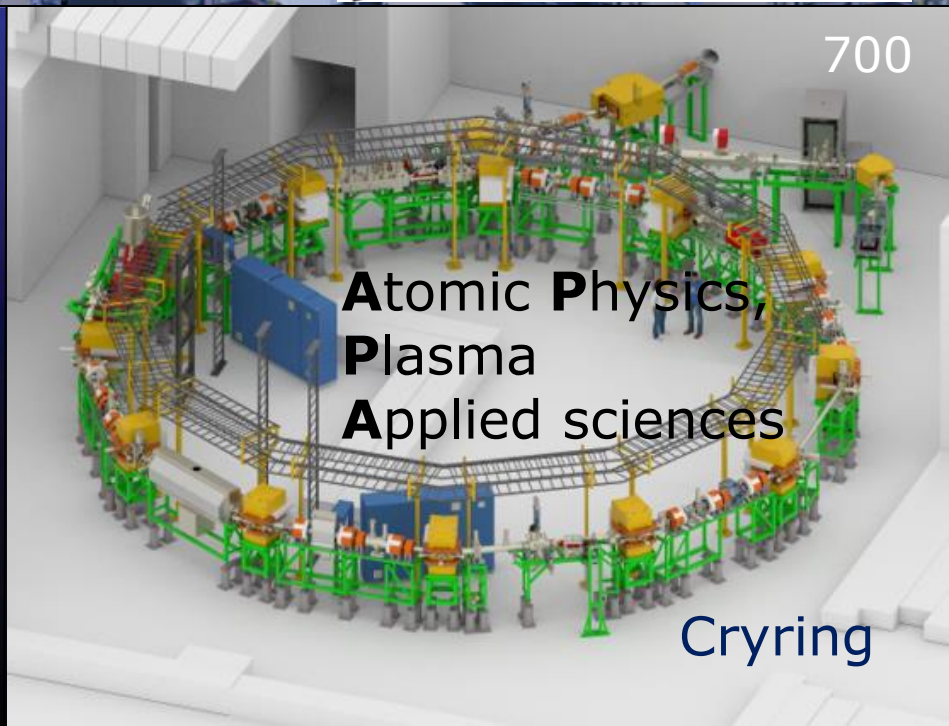

VLT/MUSE
NGC 4993
eso 1733c

800

NUSTAR


400
collaborators
NPN 27/3
panda

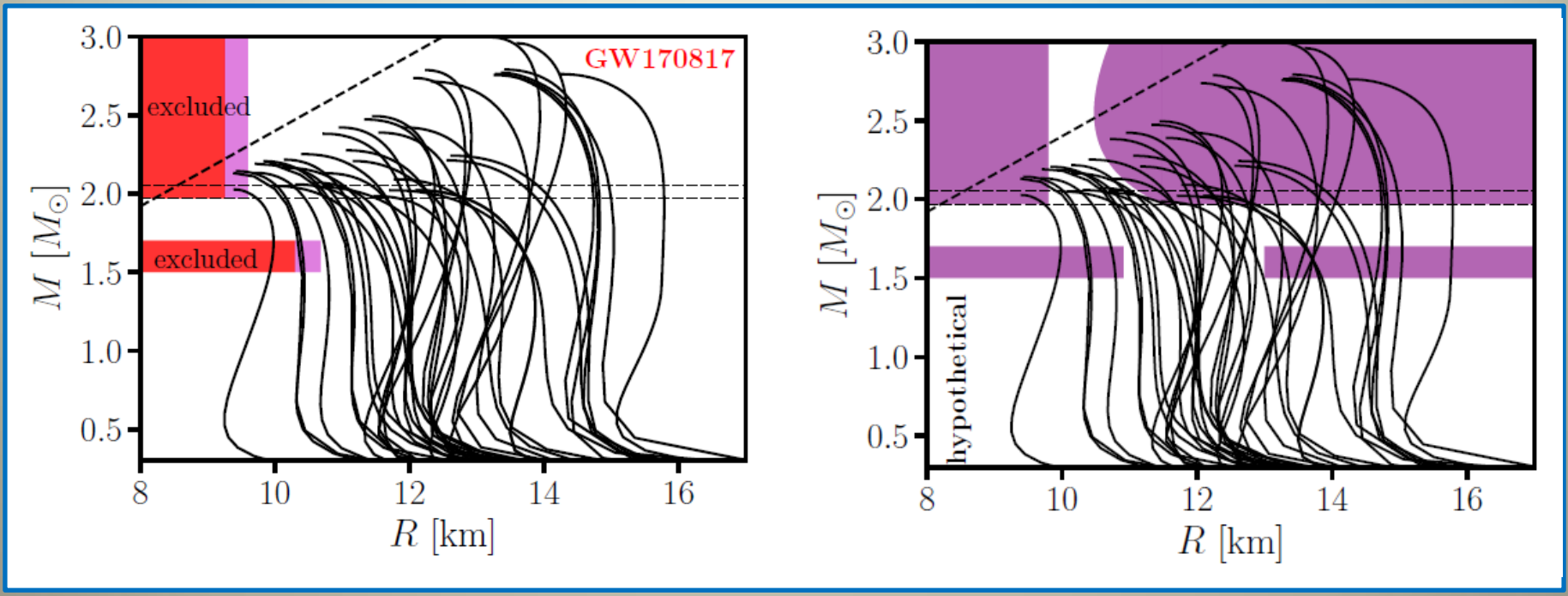

Early Universe
CBM
500
Quark-Gluon Plasma
Critical Point
1st Order Phase Transition
Neutron Star Merger
Hadrons
Neutron Star
Atomic nuclei
Temperature
Net-Baryon Density
NPN 28/2


700
Atomic Physics,
Plasma
Applied sciences
Cryring

radius constraint from GW170817

A. Bauswein et al., ApJL 850 (2017)

radius constraint from chirp mass and collapse not prompt



R (1.6) > 10.68 km

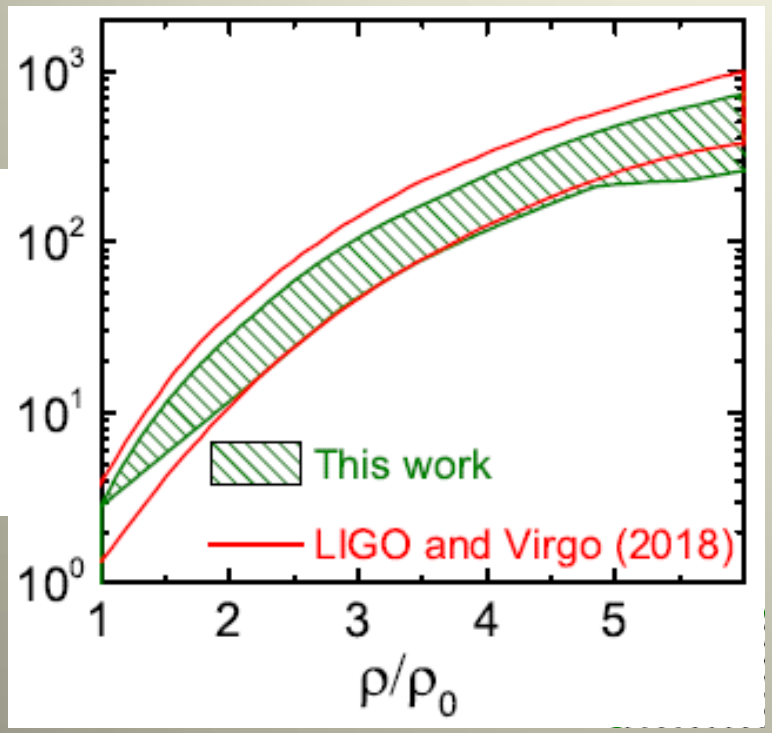
L > 37 MeV

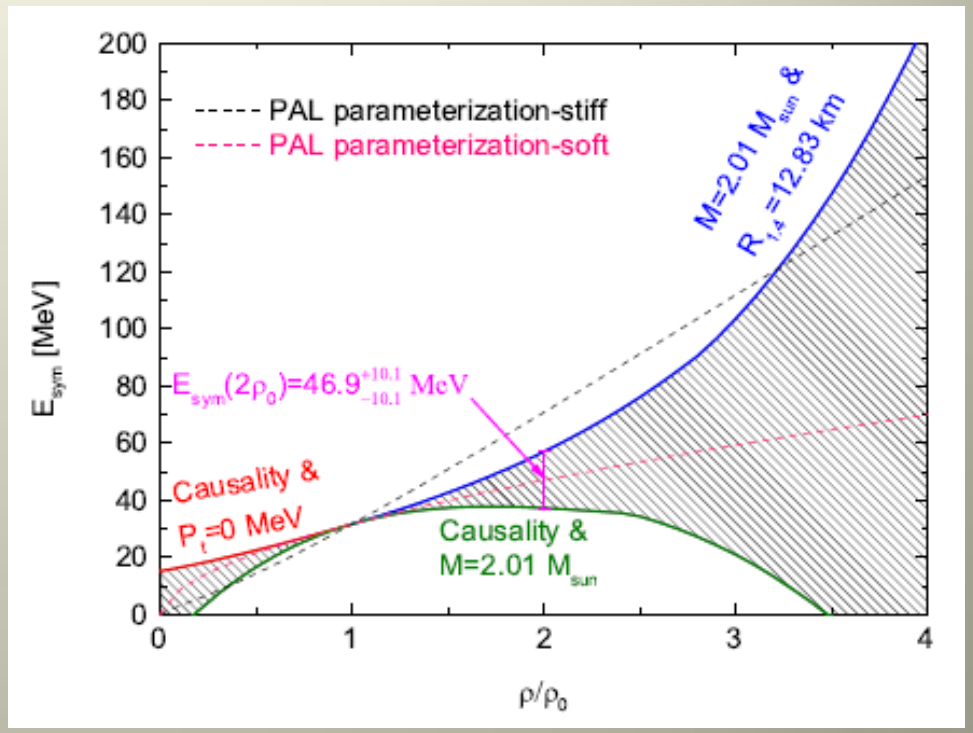
expectation for future observations

41 MeV < L < 77 MeV

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)





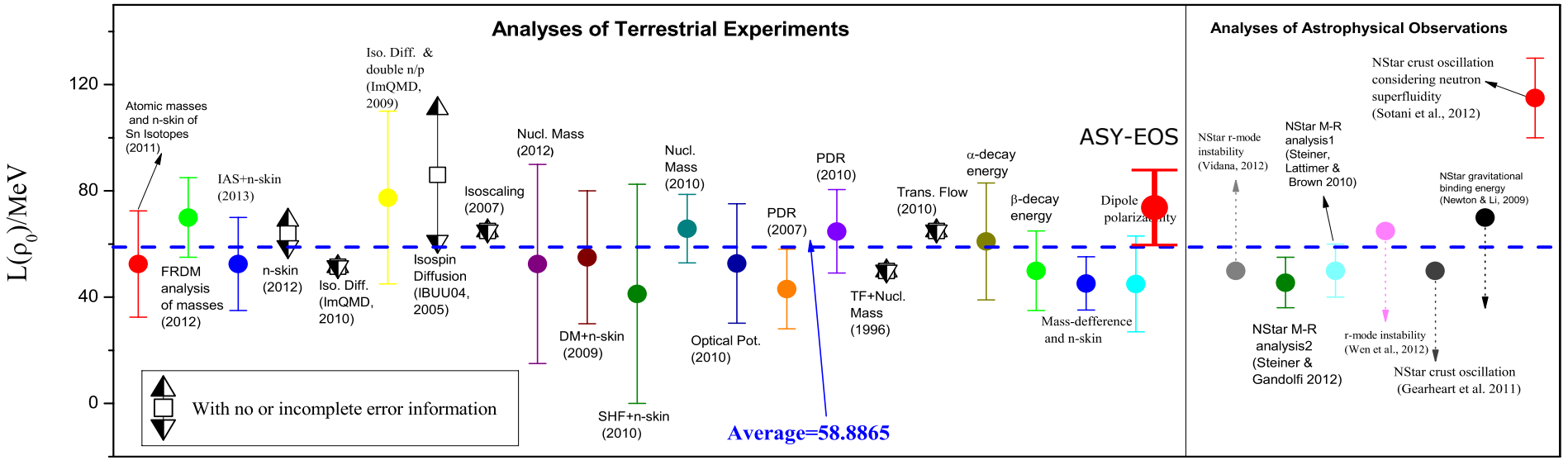
Abbott et al. (LIGO & VIRGO)
pressure from tidal deformability
in GW170817, arxiv (2018)

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

the world average: L = 58.8865 MeV

Li and Han, PLB 727 (2013)

$(L=3p_0/\rho_0)$



PDR in Sn

elliptic flow in Au+Au

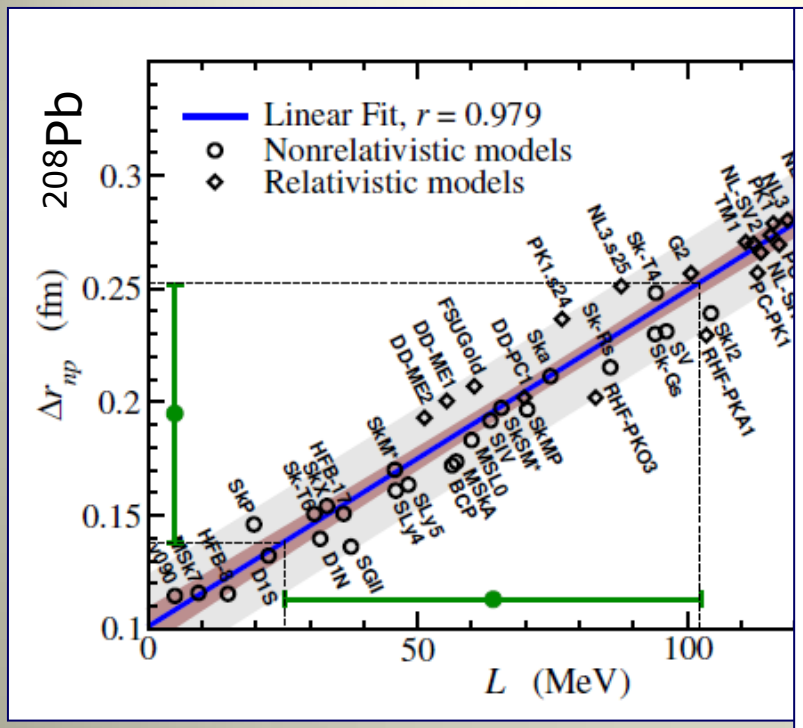
observation of neutron stars

neutron skins
masses
collective excitations
isospin diffusion

Klimkiewicz et al. (R3B) PRC 76 (2007)

Russotto et al. (ASY-EOS) PRC 94 (2016)

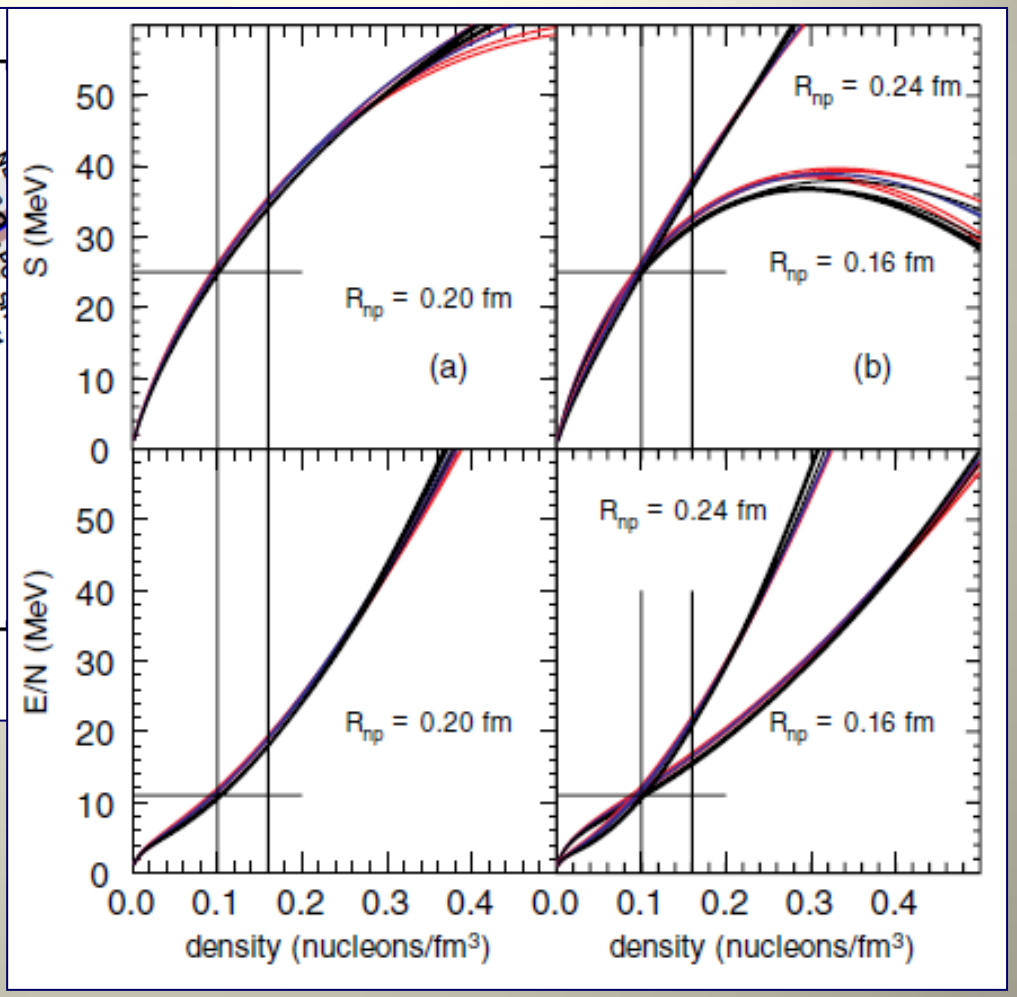
crust oscillations
r-mode instabilities
mass-radius analysis



Roca Maza et al., PRL 106 (2011)

$\Delta r_{np} = 0.1 + 0.00147 * L$

Brown, PRL 111 (2013)

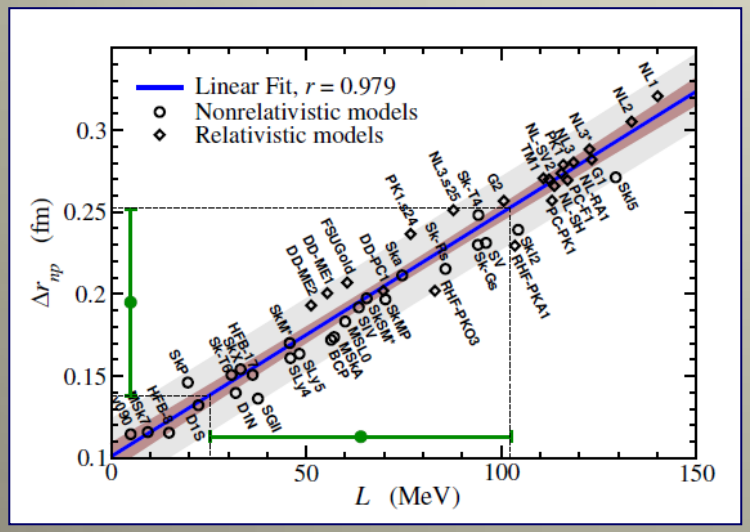


13 Skyrme sets fitted to ground-state properties of doubly magic nuclei
E_{sym} determined at 0.1 fm^{-3}
neutron skin determines slope at 0.1 fm^{-3}

$\Delta L = 10 \text{ MeV} * \Delta(\Delta r_{np}) / 0.015 \text{ fm}$

neutron skin from PDR and dipole polarizability

	Δr_{np} in ^{208}Pb
GSI → Klimkiewicz et al., PRC 76 (2007)	0.18 ± 0.035 fm
→ Rossi et al., PRL 111 (2013)	0.15 ± 0.03 fm
Tamii et al., EPJA 50 (2014)	0.165 ± 0.026 fm
PREX at Jlab (run in 2019)	± 0.05 fm
MESA at Mainz (proposal)	± 0.03 fm
→ Aumann et al. at FAIR-0 (2019)	± 0.02 fm ←



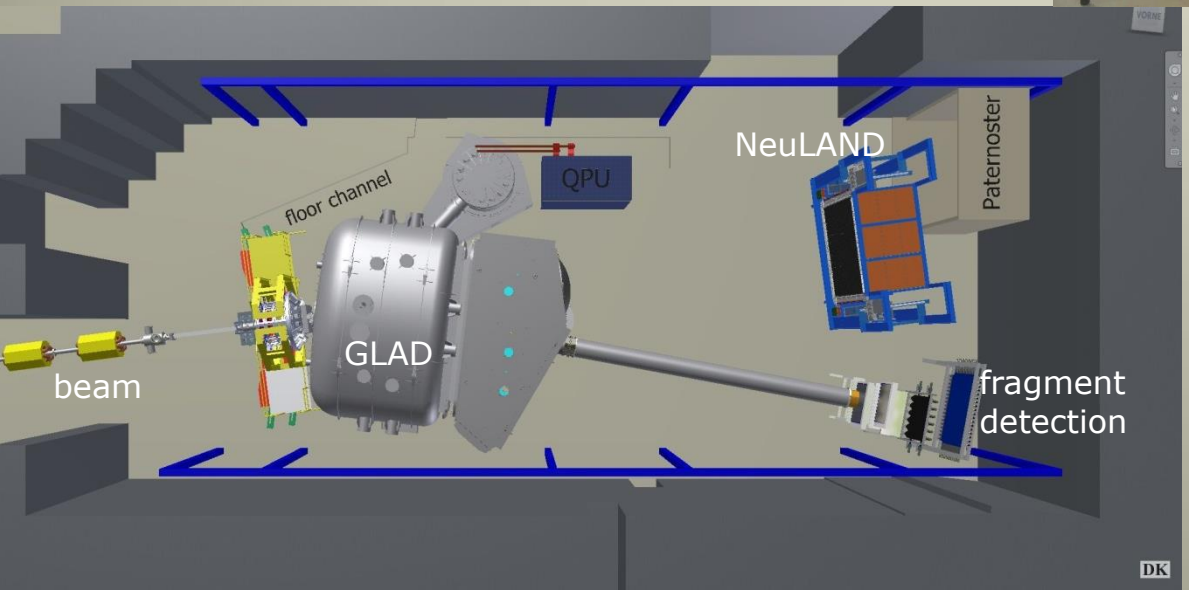
$\Delta L = 10\ \text{MeV} * \Delta(\Delta r_{np})/ 0.015\ \text{fm}$

accurate cross sections and EDF theory

experiment scheduled for 2019

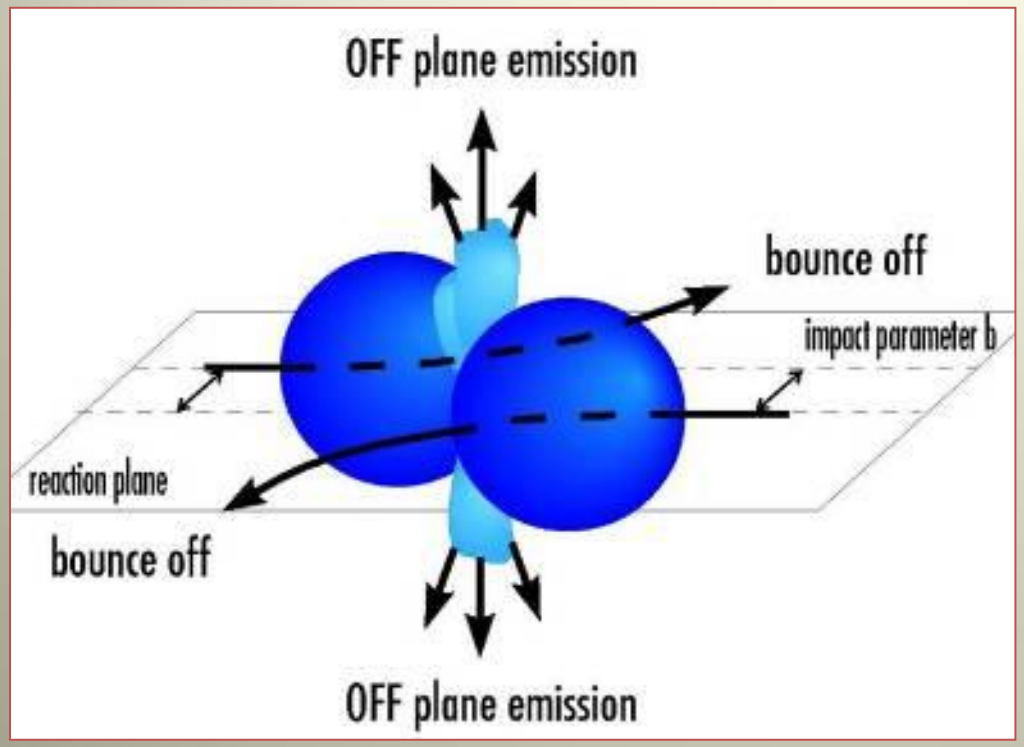
measurement of:
total reaction cross sections
charge-changing "
neutron-removal (~ 0.5 b) ← most sensitive
collective excitations
for ^{124,128,132,134}Sn
at 400, 650, 900 MeV/nucleon
with 2% accuracy

goal: ΔL = 15 MeV



analysis:
direct comparison
of the non-collective part
of the cross sections
to predicted cross sections
based on EDF theory and
eikonal reaction theory

pressure gauge for neutron-star matter

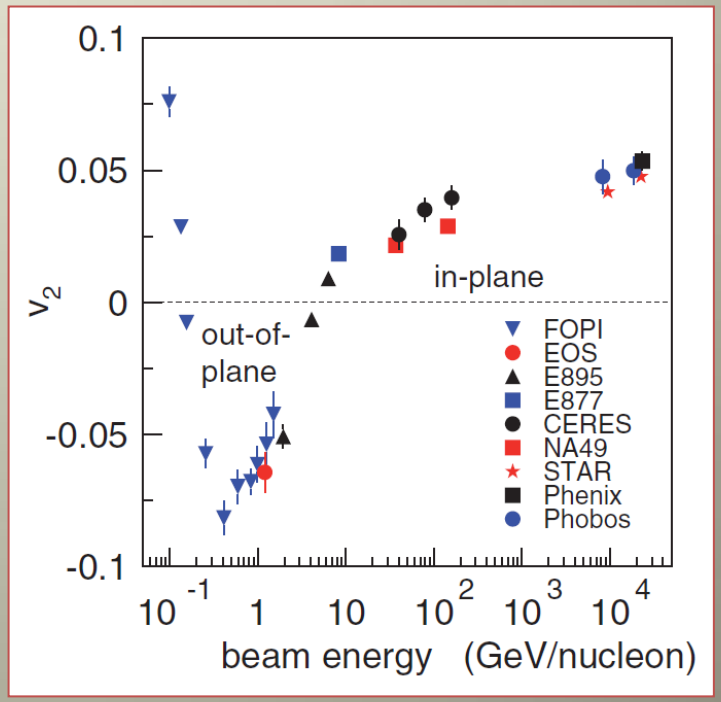


tested with existing **FOPI-LAND** data
^{197}Au + ^{197}Au @ 400 A MeV
Russotto et al. PLB 697 (2011)

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

neutron-over-charged particle
elliptic-flow ratio
in neutron-rich systems

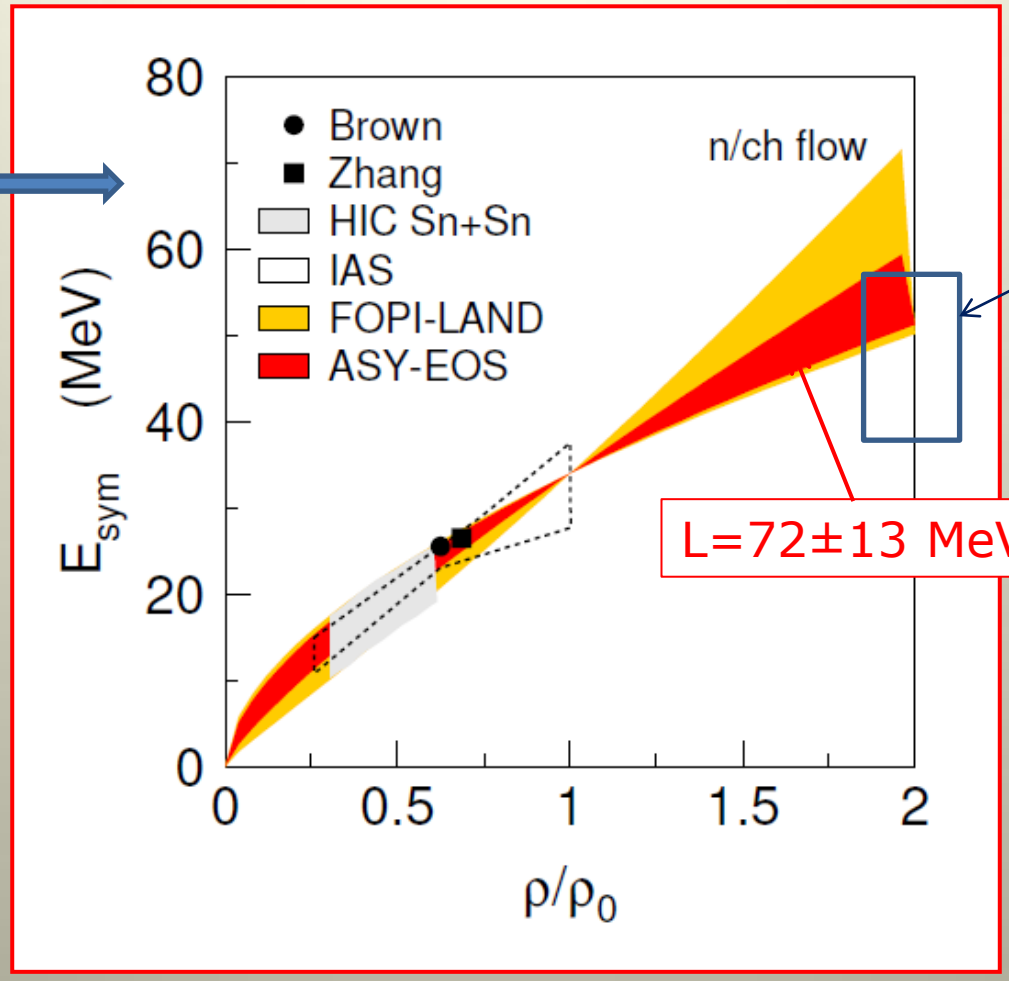
analysis with transport
UrQMD (Li & Bleicher)
Tübingen QMD (Cozma)



Le Fèvre et al., PRC 98 (2018)

neutron vs charged-particle flow ratios

compiled by Horowitz et al., JPhysG (2014)



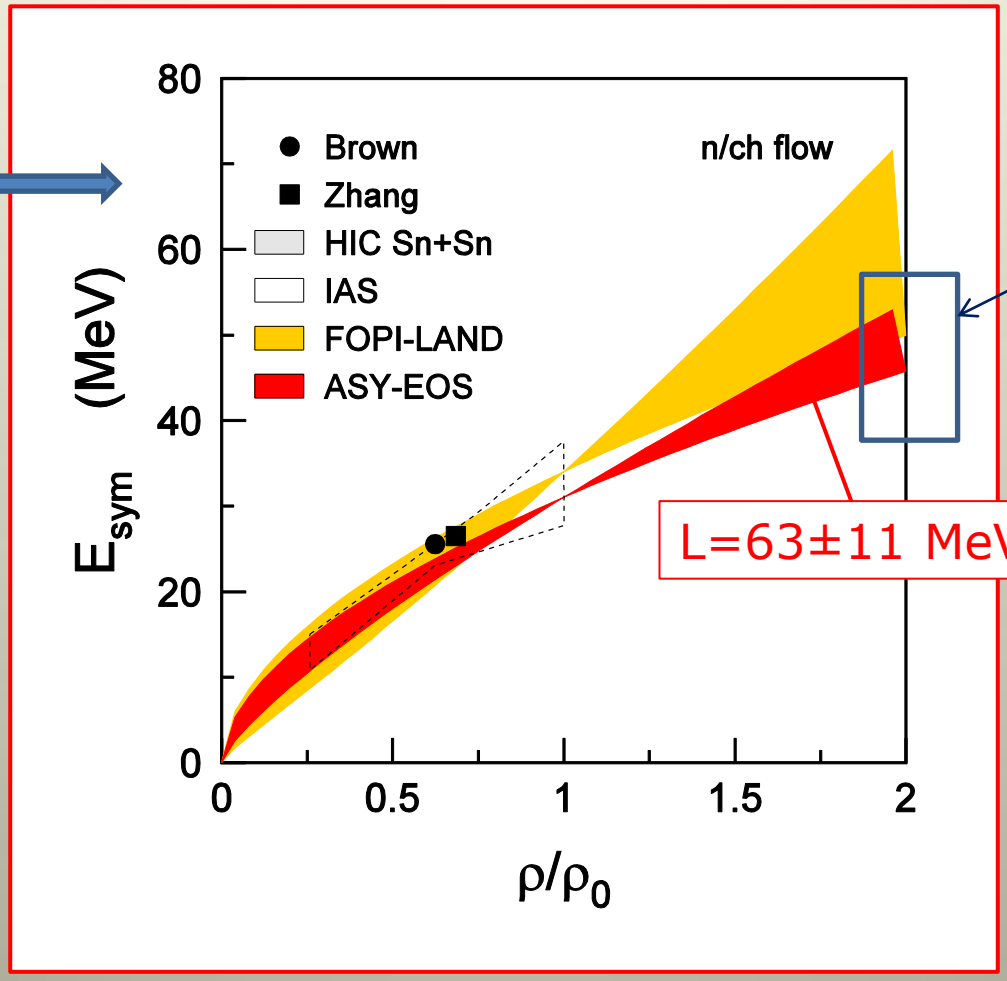
neutron stars
Zhang & Li
E_{sym} $(2\rho_0)$ =
47 ± 10 MeV

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

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

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

compiled by Horowitz et al., JPhysG (2014)



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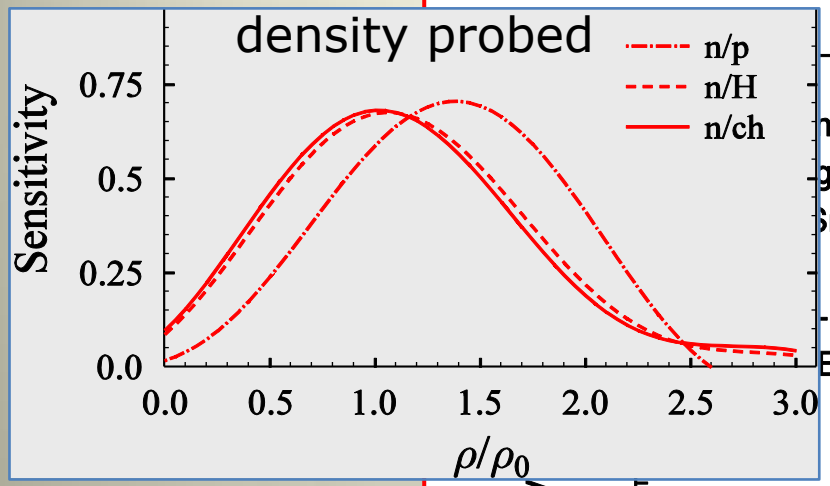

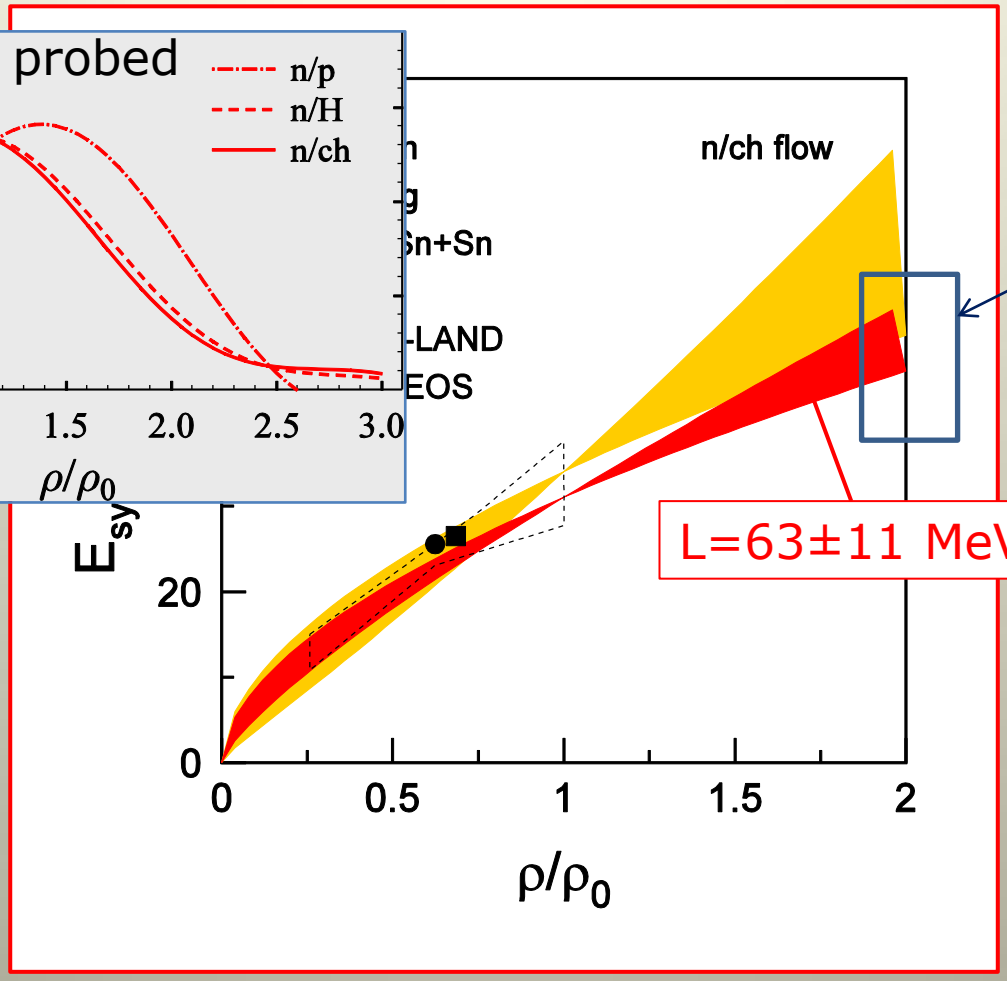

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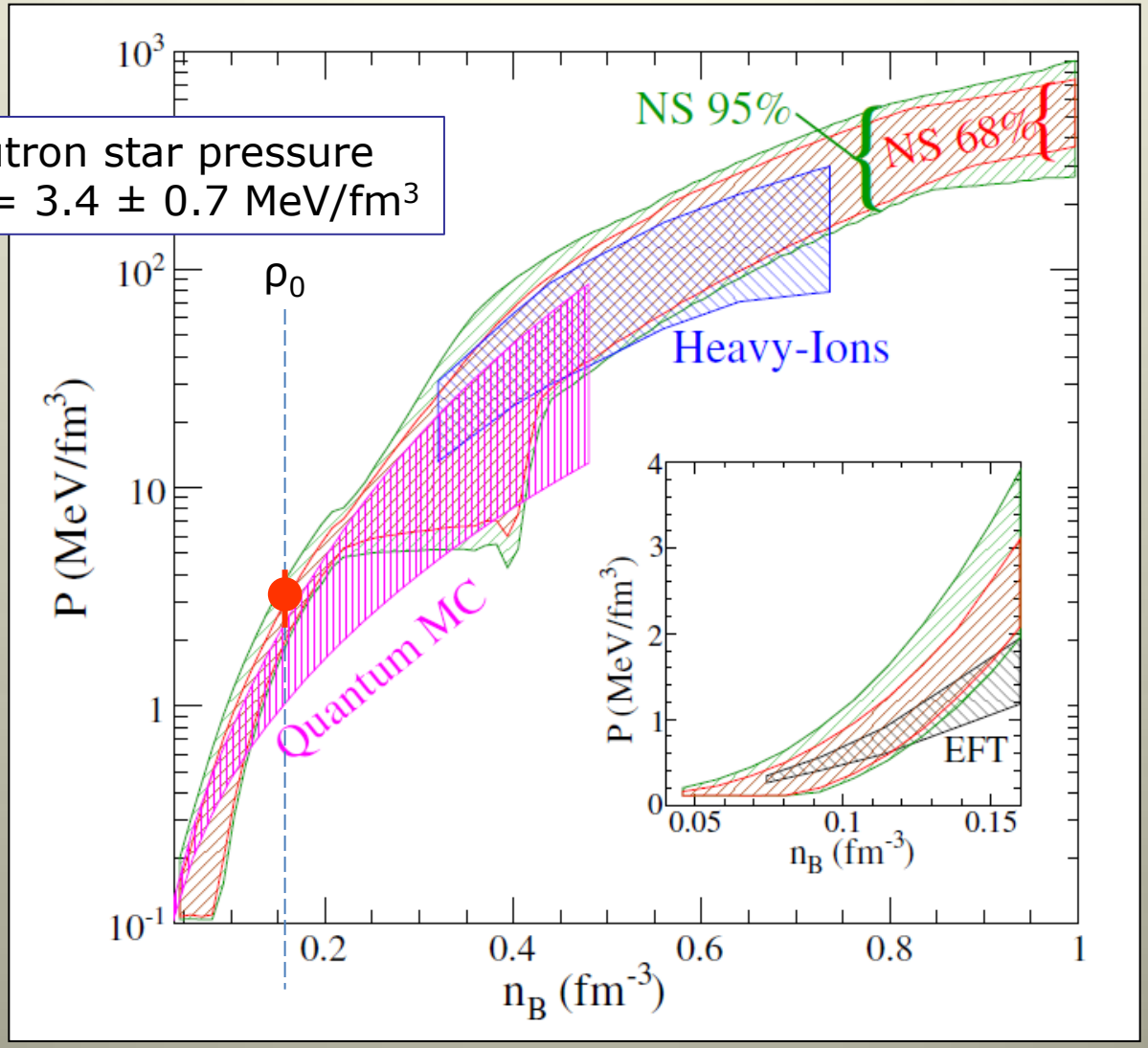
P. Russotto et al., PRC 94, 034608 (2016)

ASY-EOS: symmetry pressure p_0 = 3.8 ± 0.7 MeV/fm^3



Steiner, Lattimer, and Brown, ApJ 765, L5 (2013)

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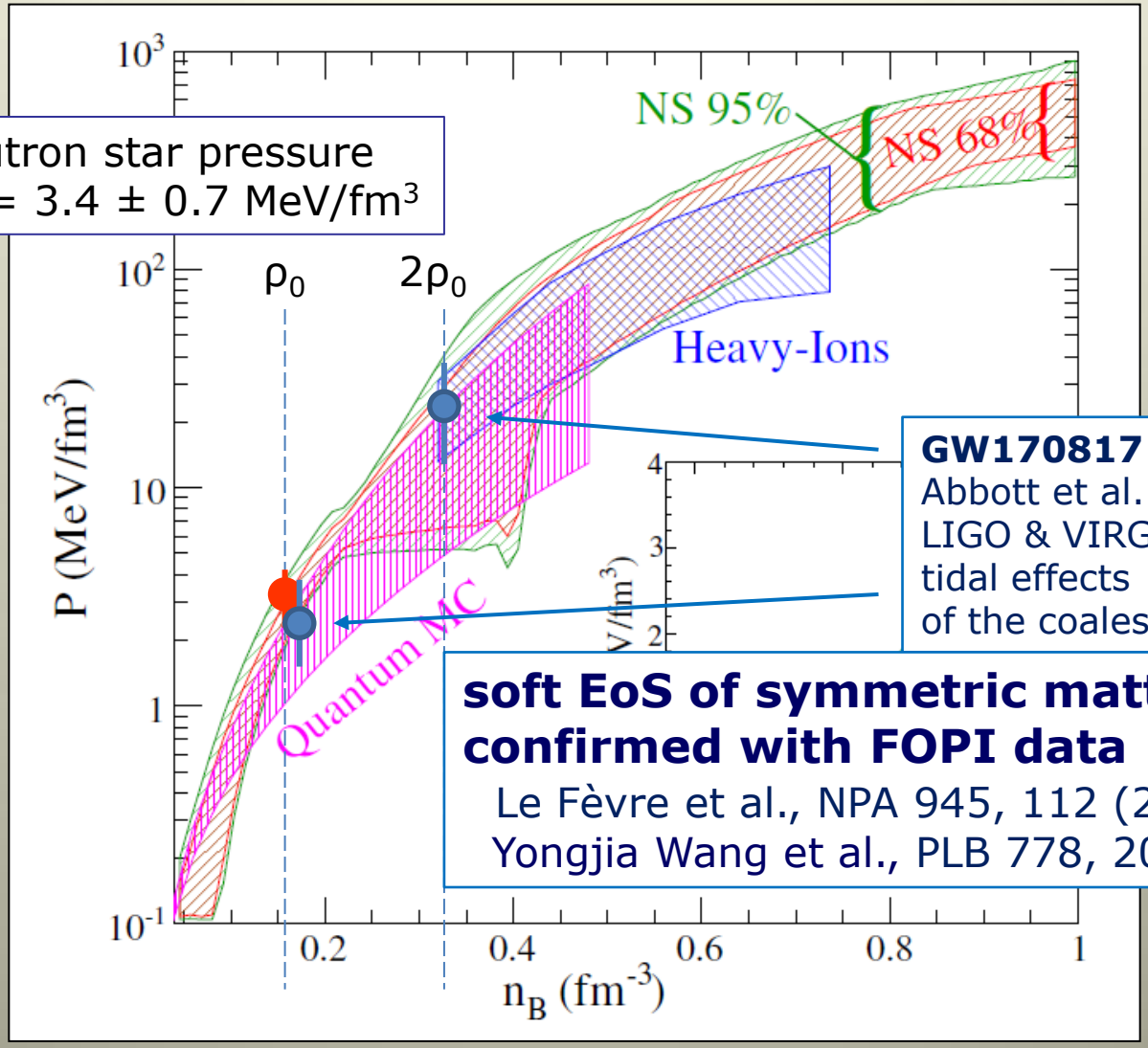
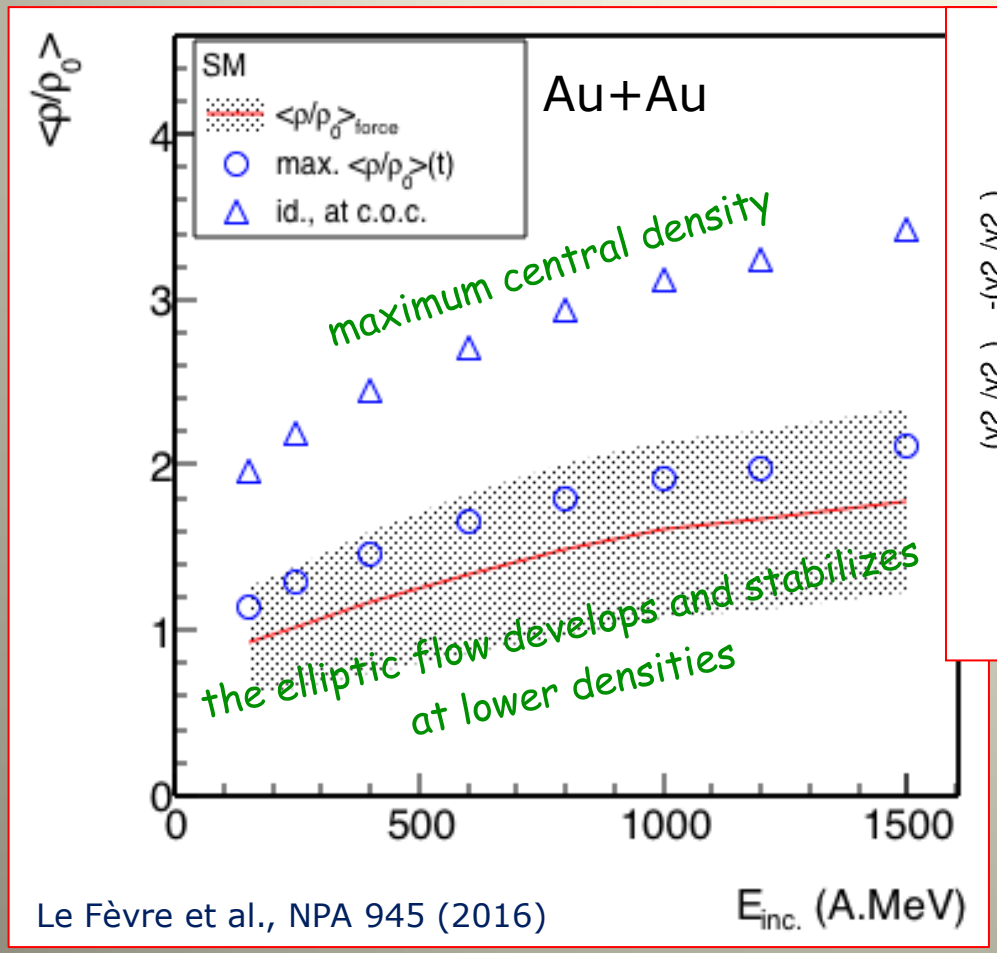


Steiner, Lattimer, and Brown, ApJ 765, L5 (2013)

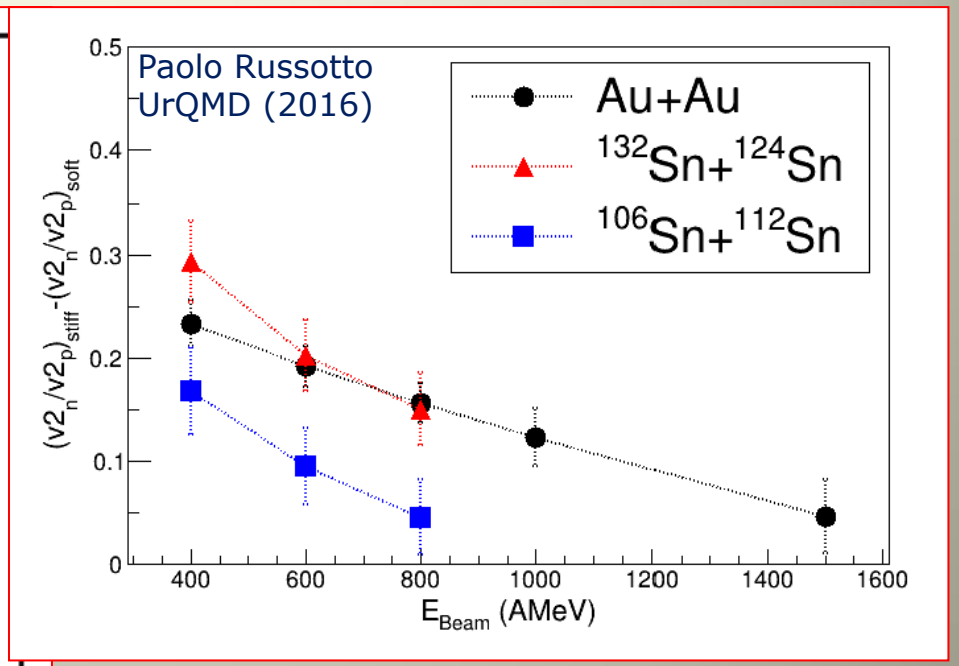
opportunities with NeuLAND at FAIR

proposal submitted 2017

density probed and sensitivity

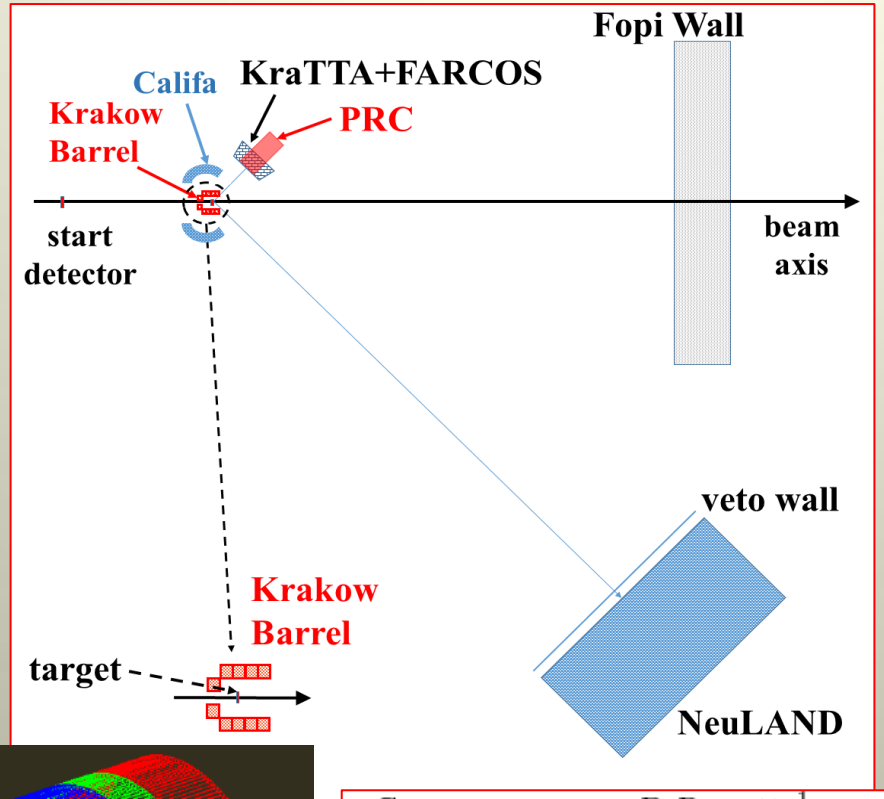


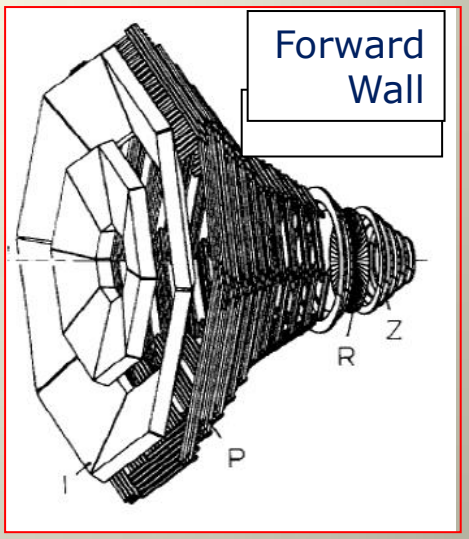
Le Fèvre et al., NPA 945 (2016)

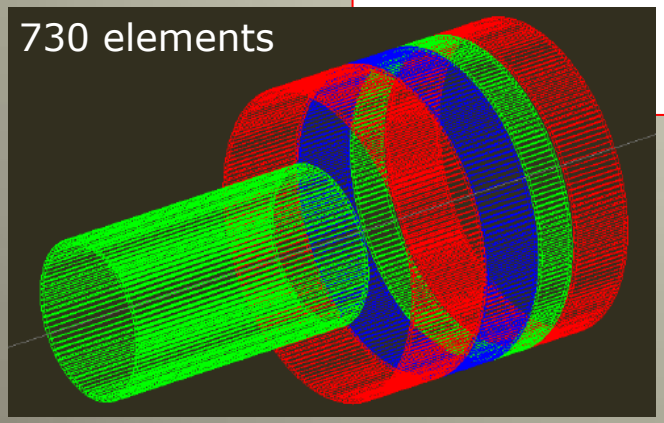


goal: $E_{sym}(2\rho_0)$
with Au+Au@1000

setup for ASY-EOS II with NeuLAND at FAIR







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(23 institutions)

summary and remarks

- **neutron skin thickness studied with different methods**
  R3B experiment in 2019 at FAIR-0
- **differential elliptic flow unique regarding high density**
- $\langle\rho\rangle \simeq$ **2** ρ_0 **within reach** with **FAIR** beams and **instrumentation**
  proposal to FAIR-0 (2017)
- **overlap of terrestrial and neutron star (merger) at 1-2** ρ_0
- **wide range of experimental and theoretical activities from very low to high densities at GSI/FAIR**