Relativistic covariance corrections to transport models and symmetry energy constraints

Dan Cozma

IFIN-HH, Bucharest, Romania

NUSYM18
13 September 2018
Busan, South Korea

Motivation

Previous studies: pionic observables D.C, PRC 95, 014601 (2017)
TuQMD elliptic flow D.C. EPJA 54, 40 (2018)

Conclusions of these studies:

- pions: large dependence on the pion optical potential

- elliptic flow: need to perform experimental measurements at different energies for n/p and n/H(or ch) elliptic flow ratios

Eventually:

- describe kaon production to constrain the symmetry energy above 2 ρ_0

Known facts:

- probed density and relativistic effects increase with projectile energy

However:

TuQMD – relativistic kinematics

- non-relativisitc dynamics

Expected magnitude of correction : ~γ = 1.1 @ 400 MeV/u

Gogny inspired potential (MDI2)

momentum dependent potential **MDI2**

$$\frac{E}{N}(\rho,\beta,x,y)=\frac{1}{2}A_1u+\frac{1}{2}A_2(x,y)u\beta^2+\frac{Bu^{\sigma}}{\sigma+1}(1-x\beta^2)+\frac{Du^2}{3}(1-y\beta^2)$$

$$+\frac{1}{u\rho_0^2}\sum_{\tau,\tau'}C_{\tau\tau'}\int\int d^3p\,d^3p'\frac{f_{\tau}(p,p')f_{\tau'}(p,p')}{1+(\vec{p}-\vec{p}\,')^2/\Lambda^2}$$

$$A_2(x,y)=A_2^0+\frac{2xB}{\sigma+1}\bar{u}^{\sigma-1}+\frac{2yD}{3}\bar{u} \qquad u=\frac{\rho}{\rho_0}$$

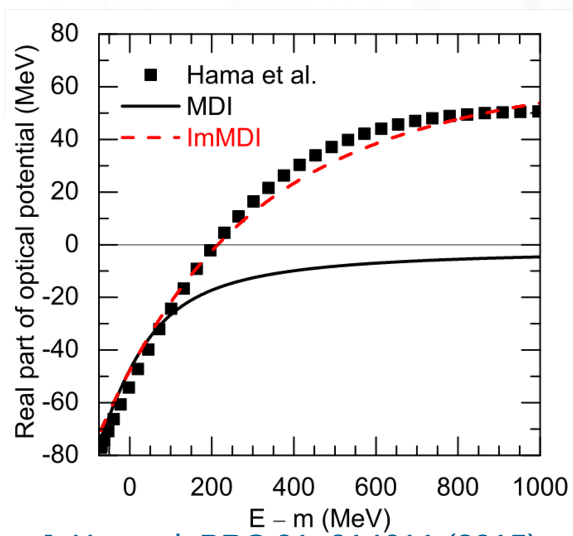
Fit:
U_{∞},K,J_0,m* -isoscalar
S(ũ),L,K_{sym},δm_{isv} -isovector

A_l^0, x, y

$C_l - C_u$

$\delta^*_{n\text{-}p}$

momentum dependent part: similar with that of J. Xu et al. PRC 91, 014611 (2015)
(see also C. Hartnack, J. Aichelin PRC 49, 2801 (1994))
used previously to test model dependence: flow ratio PRC 88, 44912 (2013)
pion multiplicity ratio PLB 753, 166 (2016)
independent part: extra term (vary L vs. K_{sym} and also J_0 vs. K independently)

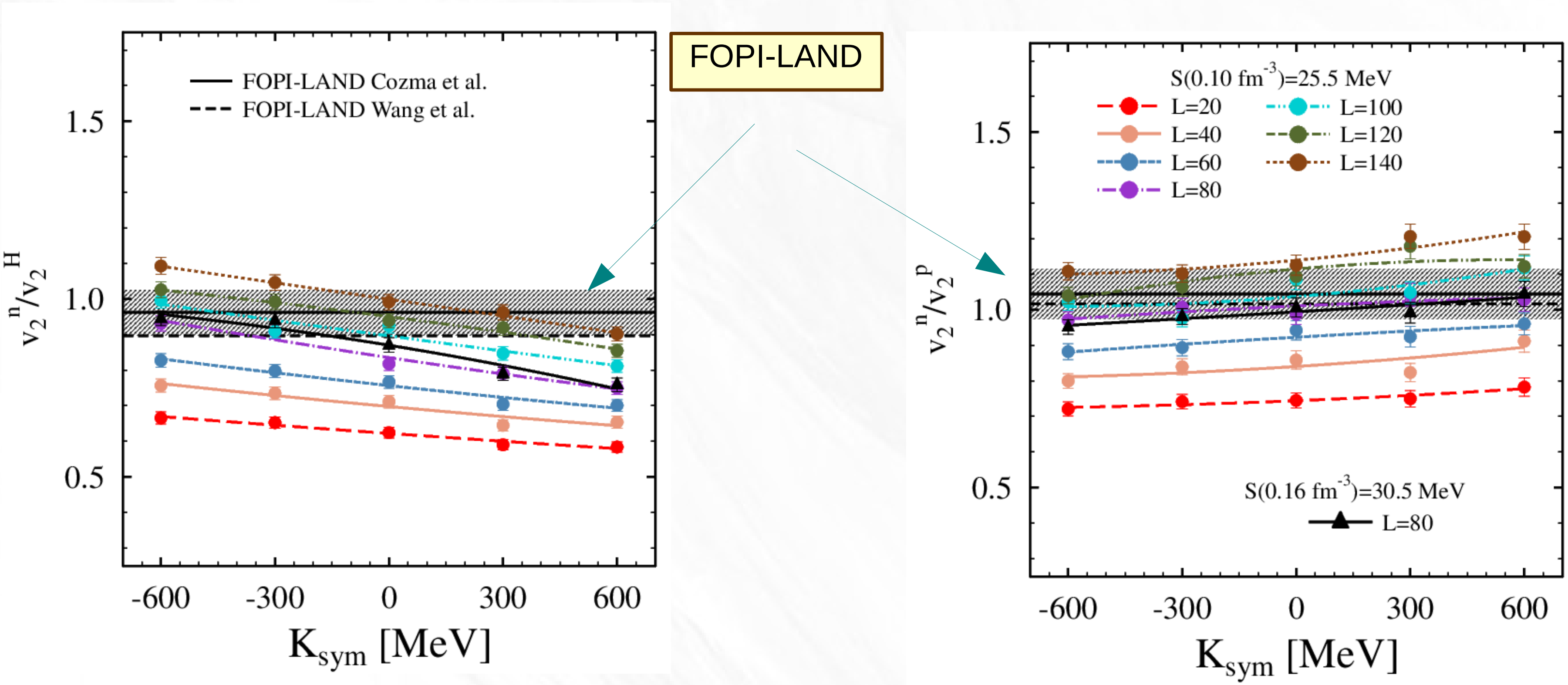


from J. Xu et al. PRC 91, 014611 (2015)

Input		Parameters	
ρ_0 [fm^{-3}]	0.16	Λ [MeV]	708.001
E_B [MeV]	-16.0	C_l [MeV]	-13.183
m_s^*/m	0.70	C_u [MeV]	-140.405
δ^*_{n-p} ($\rho_0, \beta=0.5$)	0.165	B [MeV]	137.305
K_0 [MeV]	245.0	σ	1.2516
J_0 [MeV]	-350.0	$\tilde{A}_l$ [MeV]	-130.495
$\tilde{\rho}$ [fm^{-3}]	0.10	$\tilde{A}_u$ [MeV]	-8.828
S($\tilde{\rho}$) [MeV]	25.4	D [MeV]	7.357

Sensitivity to K_{sym} (and S_0)

3 dimensional parameter space: heavy-ion observables → 1 dim constraint
+nuclear structure → <u>determine values</u>



$S(0.10\,\mathrm{fm}^{-3}) = 25.5\,\mathrm{MeV}$ B.A. Brown, PRL111, 232502 (2013)

n/p and n/H (n/ch) elliptic flow ratios probe on average different densities

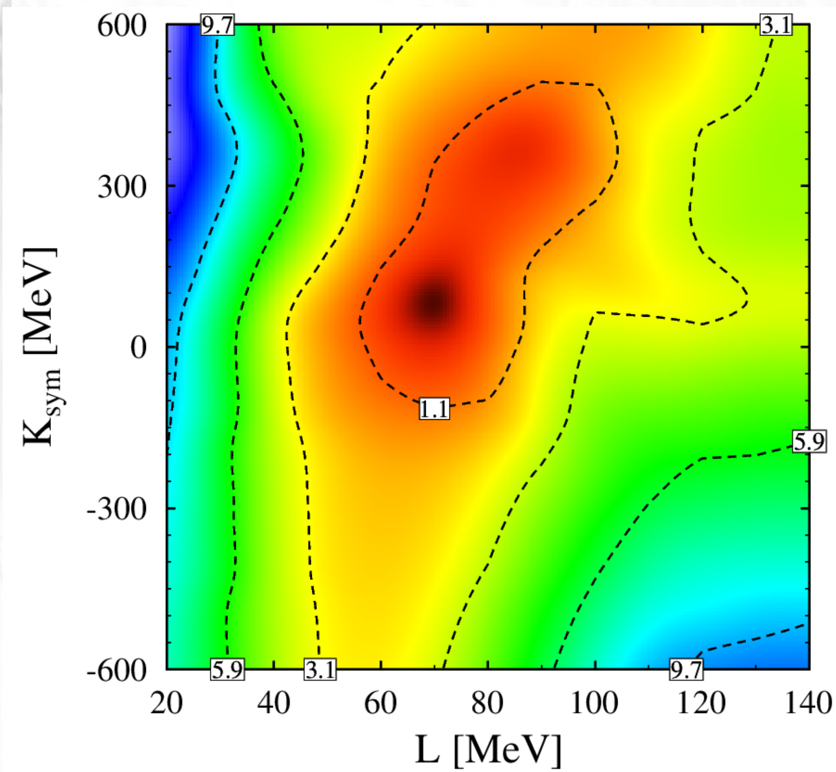
1.4-1.5 ρ_0 1.0-1.1 ρ_0

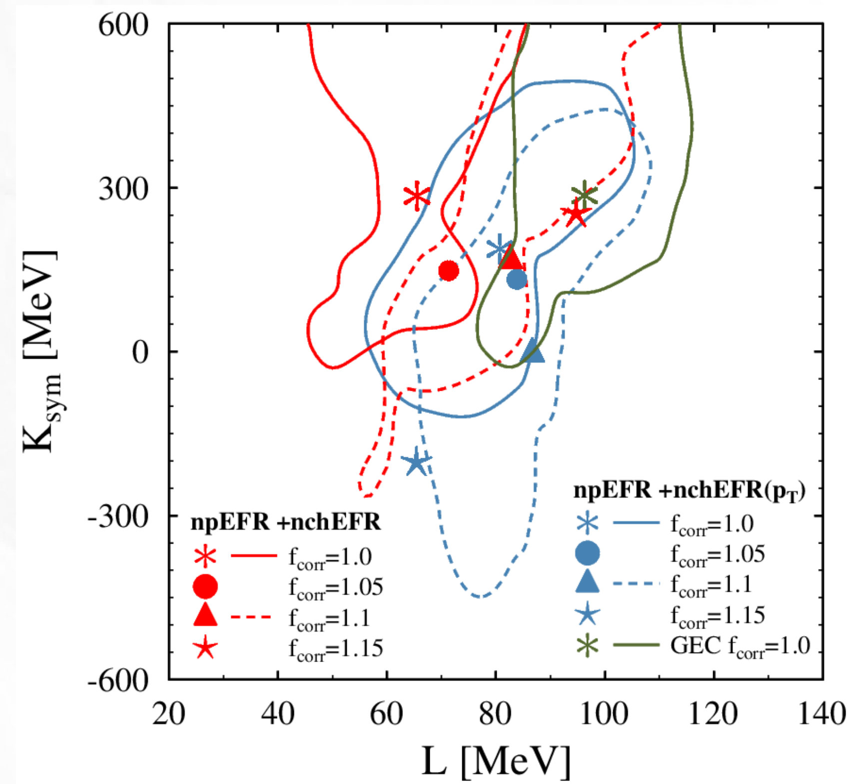
P. Russotto et al, PRC 94, 034608 (2016)

Constraints for L and K_{sym}

MDI2

n/p [FOPILAND] + n/ch (p_T)[ASYEOS] elliptic flow ratios





neutron-proton v_2^n/v_2^p +neutron-charged part. v_2^n/v_2^{ch}

$$L = 85 \pm 22(\mathrm{exp}) \pm 20(\mathrm{th}) \pm 12(\mathrm{sys})\ \mathrm{MeV}$$
$$K_{sym} = 96 \pm 315(\mathrm{exp}) \pm 170(\mathrm{th}) \pm 166(\mathrm{sys})\ \mathrm{MeV}$$

D.C. EPJA 54, 40 (2018)

Equations of Motions

RQMD Hamiltonian:

$$H \approx \sum_{i=1}^{i=N} u_i \left(p_i^2 - m_i^2 - 2 m_i V_i \right)$$

$$u_i = \frac{1}{2 p_i^0}, \; p_i^0 = \sqrt{\vec{p}_i^2 + m_i^2 + 2 m_i V_i}$$

particular time fixation compatible with particle production

T. Maruyama et al., Prog. Theor. Phys. 96, 263 (1996)

Equations of Motion:

$$\frac{d\vec{r}_i}{d\tau} \approx \frac{-\partial H}{\partial \vec{p}_i} = \frac{\vec{p}_i}{p_i^0} + \sum_{j=1}^{N} \frac{m_j}{p_j^0} \frac{\partial V_j}{\partial \vec{p}_i}$$

$$\frac{d\vec{p}_i}{d\tau} \approx \frac{\partial H}{\partial \vec{r}_i} = -\sum_{j=1}^{N} \frac{m_j}{p_j^0} \frac{\partial V_j}{\partial \vec{r}_i}$$

approximation:

$$p_i^0 = \sqrt{\left(\vec{p}_i^2 + m_i^2 \right)}$$

covariant expressions for distance and momentum difference

$$\vec{r}_{ij}^{\,2} \rightarrow -q_{Tij}^2 = -q_{ij}^2 + \frac{(q_{ij} \cdot P_{ij})^2}{P_{ij}^2}$$

$$\vec{p}_{ij}^{\,2} \rightarrow -p_{Tij}^2 = -p_{ij}^2 + \frac{(p_{ij} \cdot P_{ij})^2}{P_{ij}^2}$$

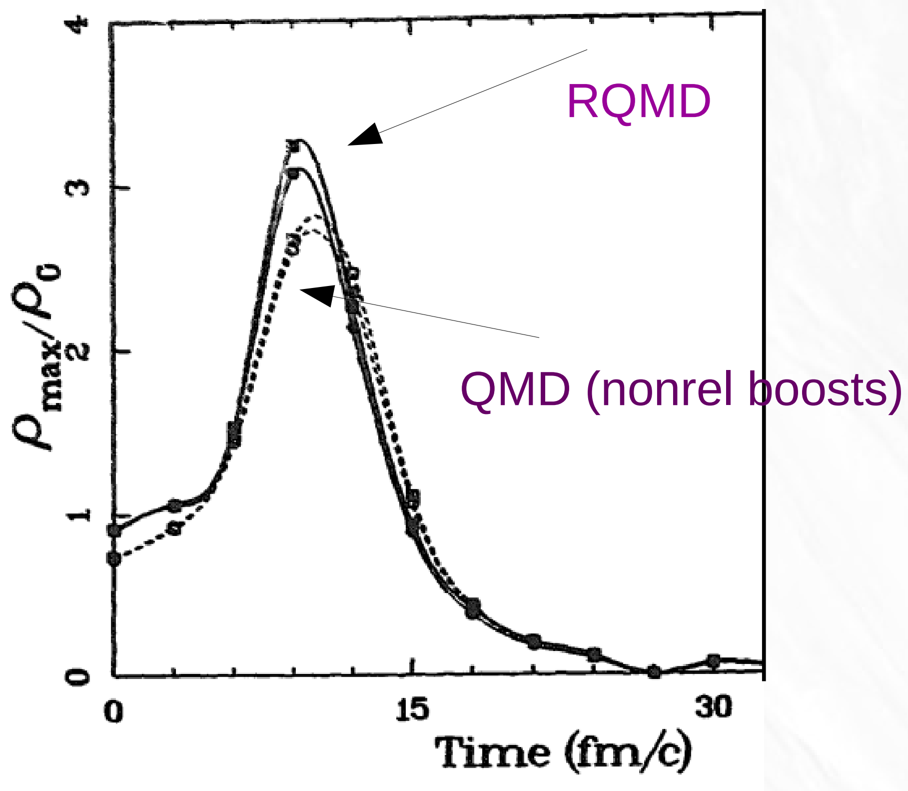
Non-relativistic limit: V_i identified with the non-relativistic potential

Pauli blocking: surface correction terms evaluated in the rest frame of particle *i*, rather than in computational frame

Additionally: algorithm to select initial configurations (nuclei) with improved stability

Consequences of Relativistic Dynamics

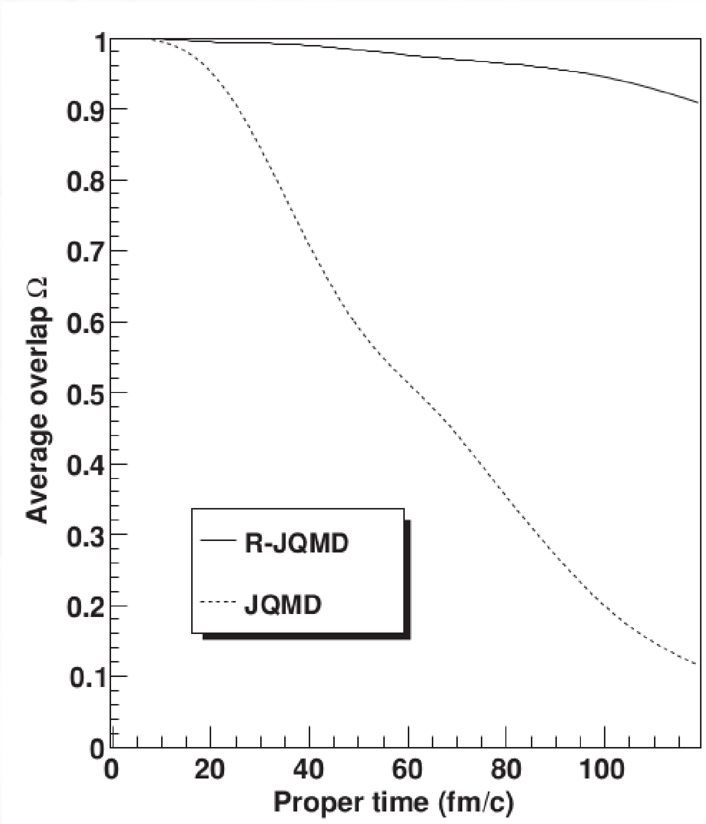
maximum density reached



$^{12}C+^{12}C$ 800 MeV/u b=0.0 fm

T. Maruyama et al., NPA 534, 720 (1991)

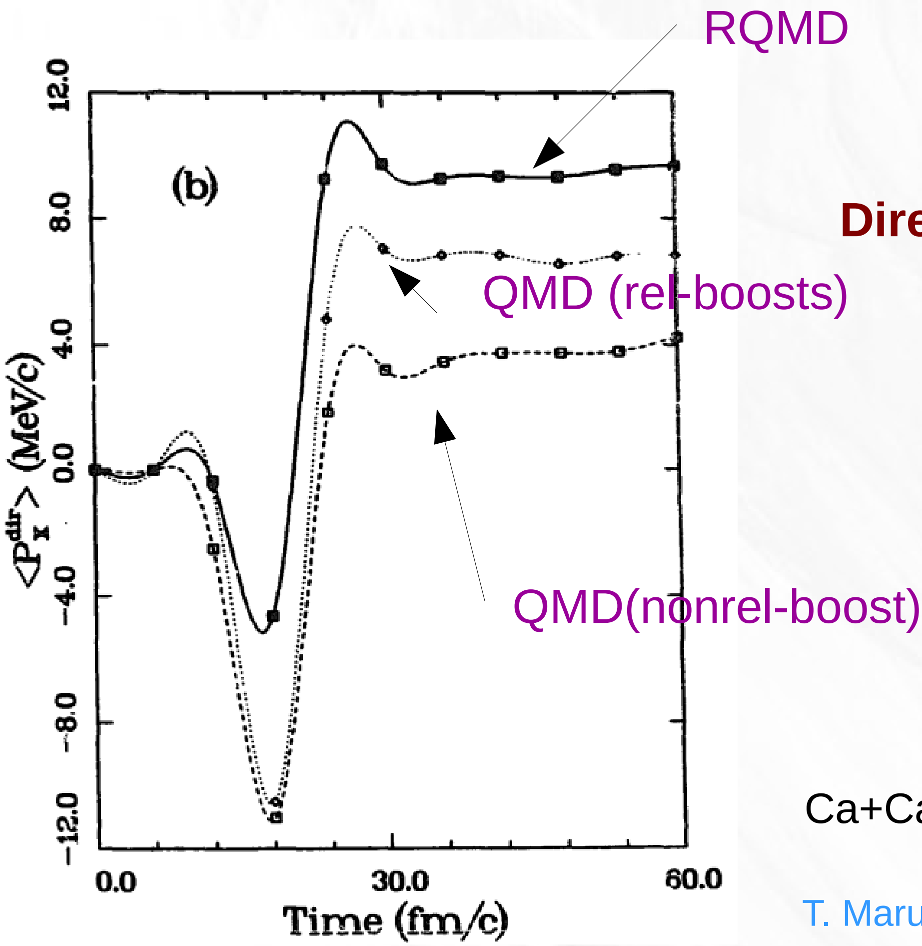
stability of nucleus's wavefunction



^{40}Ca, γ=1.24

D. Mancusi et al., PRC 79, 014614 (2009)

Consequences of Relativistic Dynamics



Directed transverse momentum

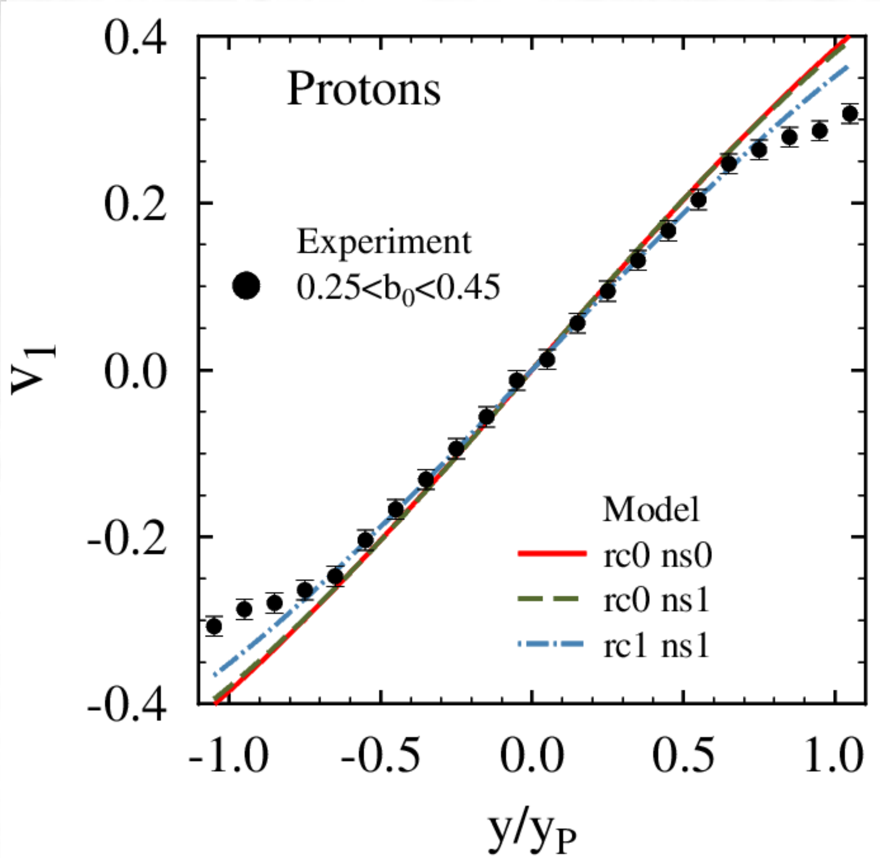
$$\langle p_x^{dir} \rangle = \frac{1}{N} \sum_{i=1}^{N} sign(y^{(i)})\, p_x^{(i)}$$

Ca+Ca @ 1050 MeV/u, b=3.9 fm

T. Maruyama et al., NPA 534, 720 (1991)

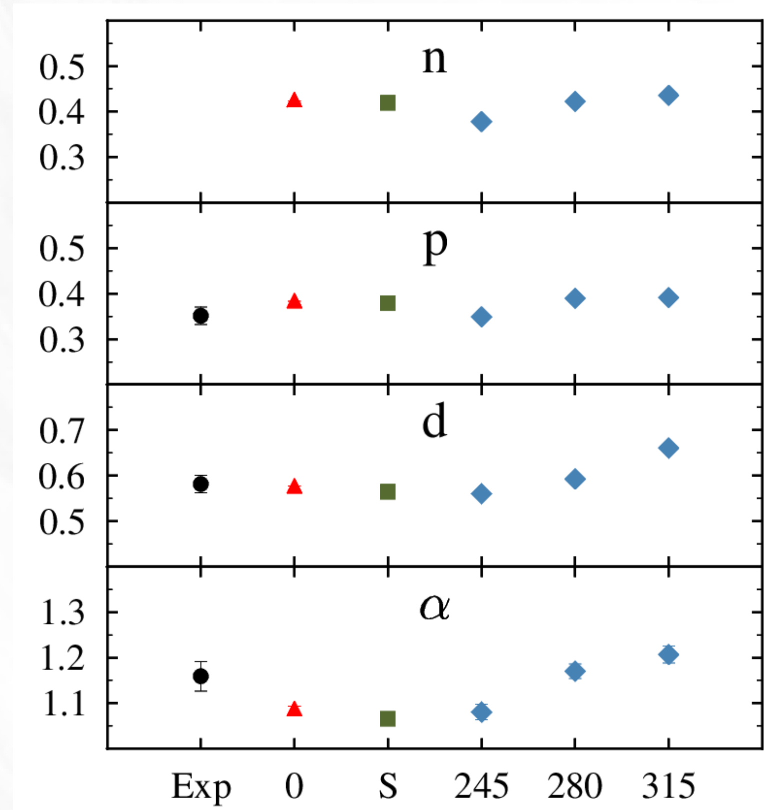
Directed Flow

Au+Au @ 400 MeV/u
$0.25<b_0<0.45$; $u_{t0}>0.4$



$$v_1 = v_{11}\, y_0 + v_{13}\, y_0^3 + \ldots$$

v_{11}

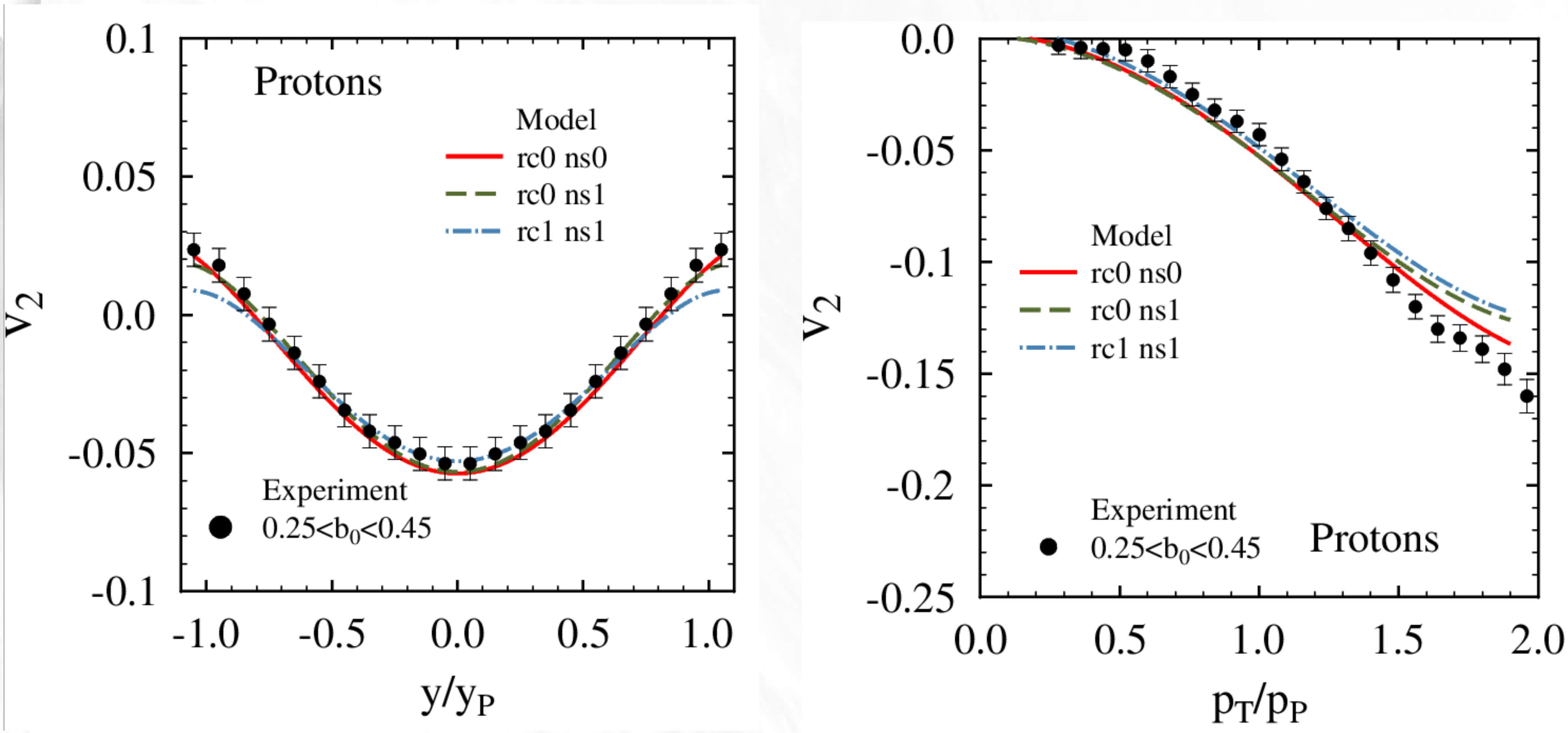


Model: asyEoS L=70 MeV
K_{sym}= 0 MeV

Experimental data: W. Reisdorf et al. (FOPI), NPA 876, 1 (2012)

Elliptic Flow

Au+Au @ 400 MeV/u
0.25<b_0<0.45; u_{t0}>0.4



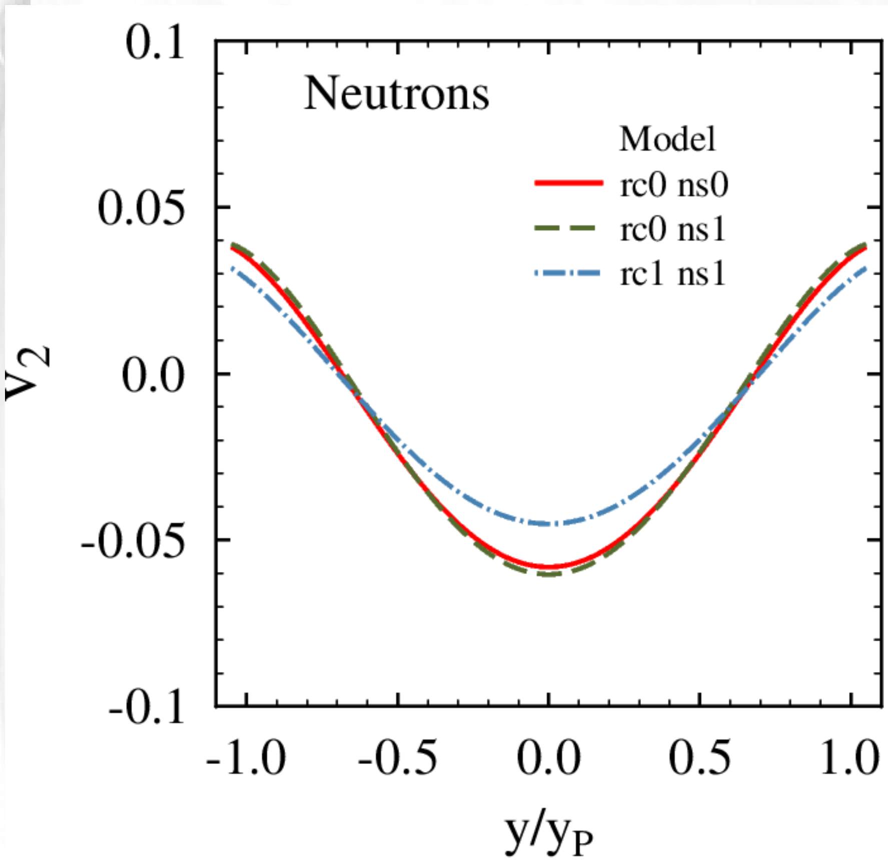
Experimental data: W. Reisdorf et al. (FOPI), NPA 876, 1 (2012)

rc – relativistic covariance
ns - nucleus stability

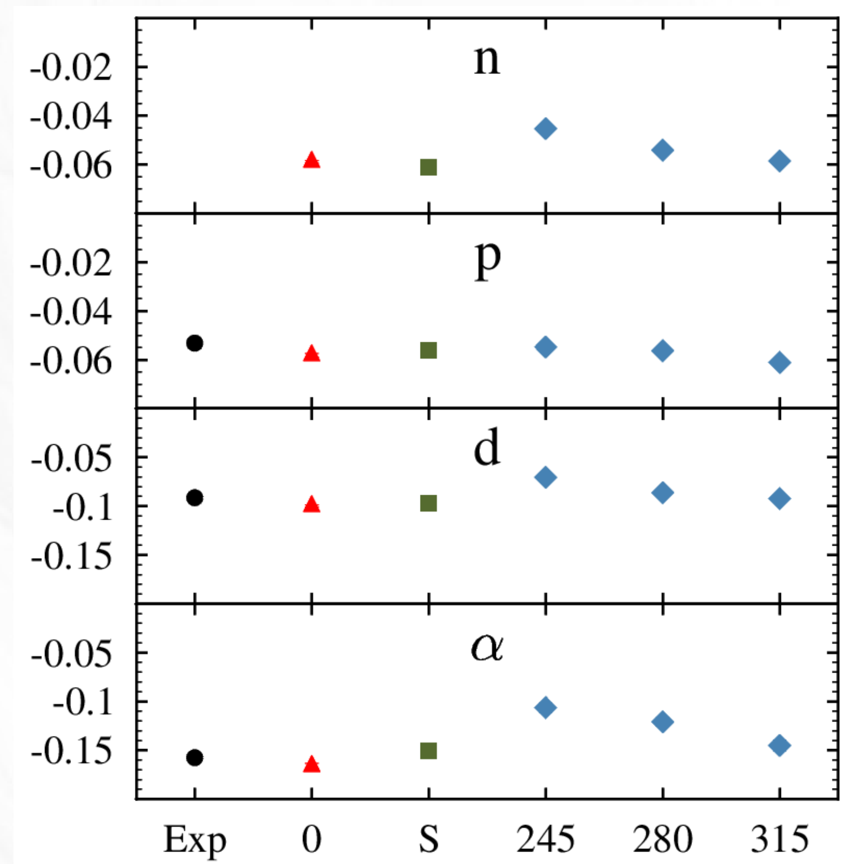
Elliptic Flow

Au+Au @ 400 MeV/u
$0.25<b_0<0.45$; $u_{t0}>0.4$

$$v_2 = v_{20} + v_{22} y_0^2 + \ldots$$



v_{20}



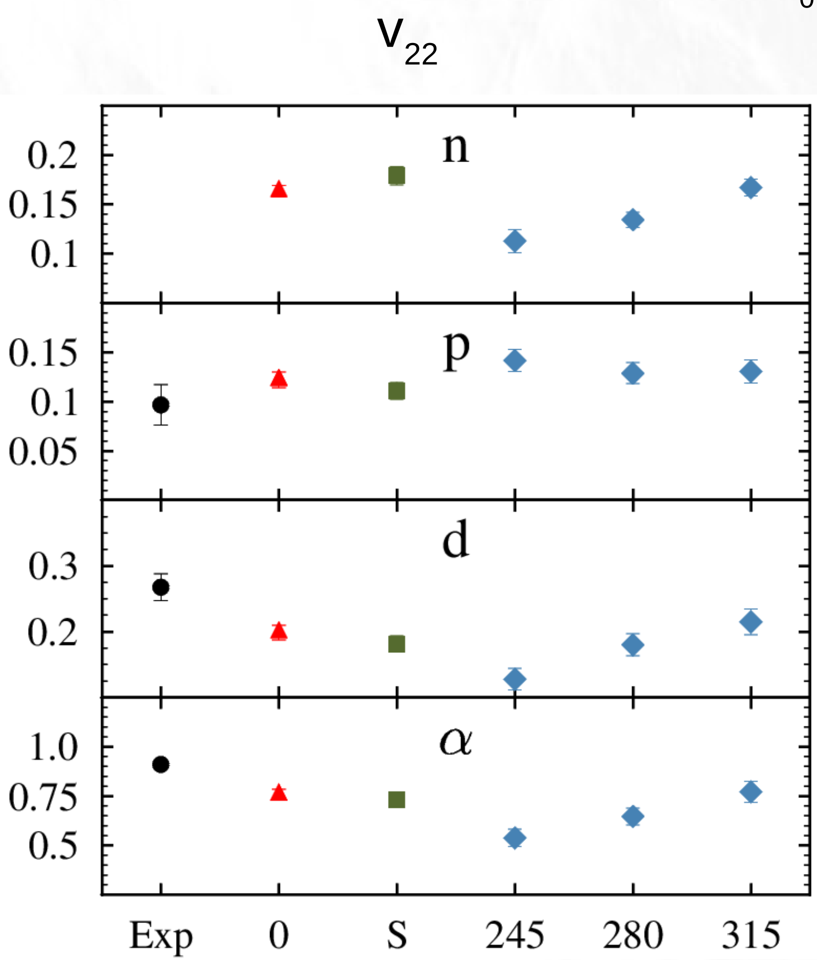
Experimental data: W. Reisdorf et al. (FOPI), NPA 876, 1 (2012)

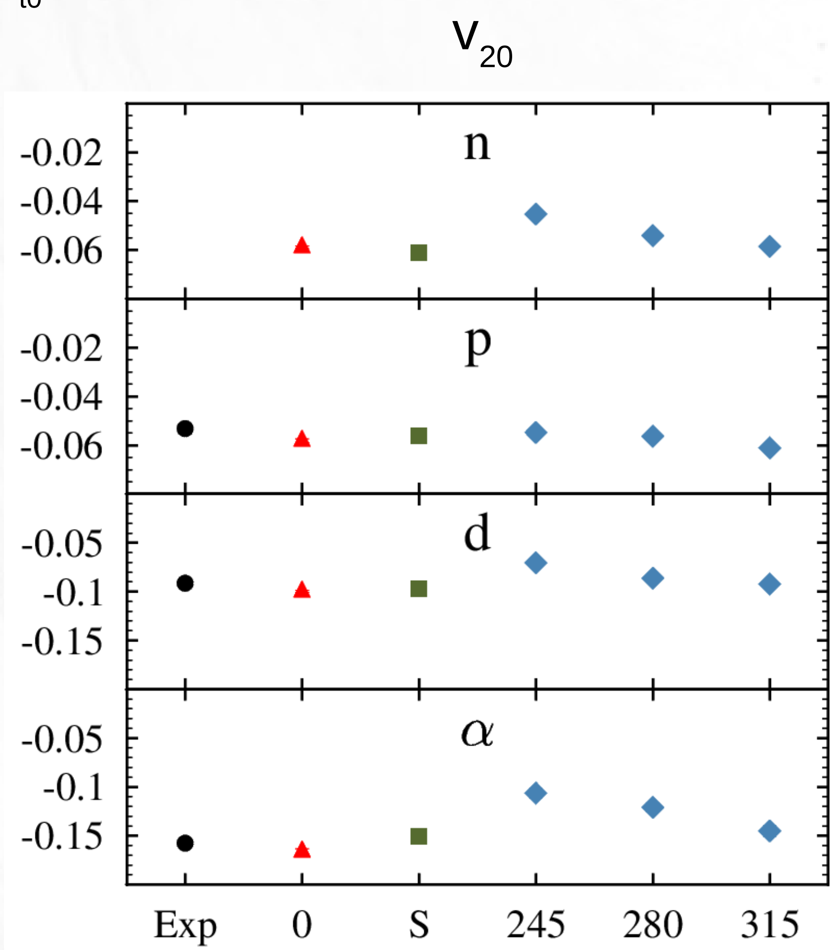
rc – relativistic covariance
ns - nucleus stability

Elliptic Flow

Au+Au @ 400 MeV/u
$0.25<b_0<0.45$; $u_{t0}>0.4$

$v_2 = v_{20} + v_{22}\, y_0^2 + \ldots$

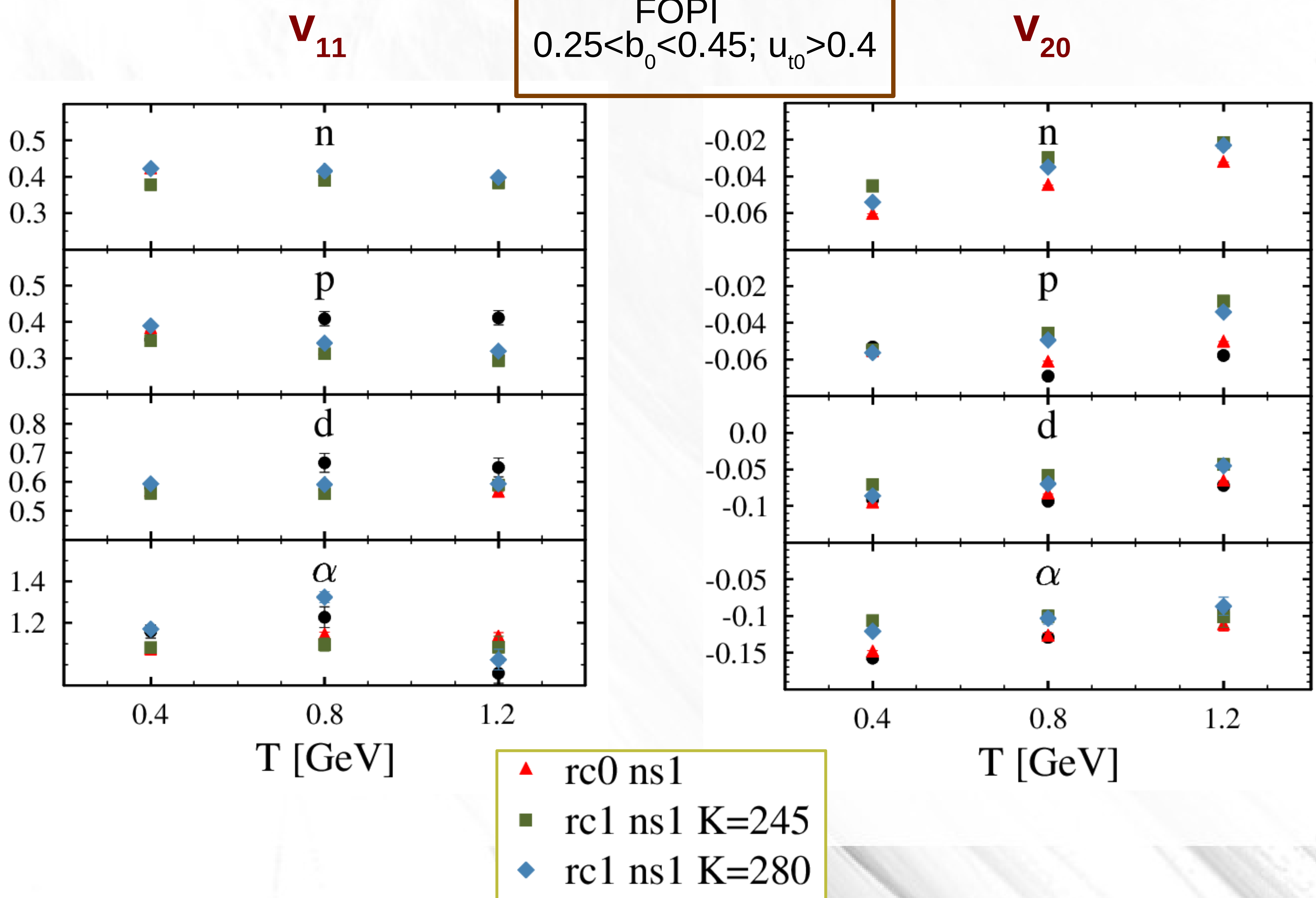




Experimental data: W. Reisdorf et al. (FOPI), NPA 876, 1 (2012)

Energy Dependence

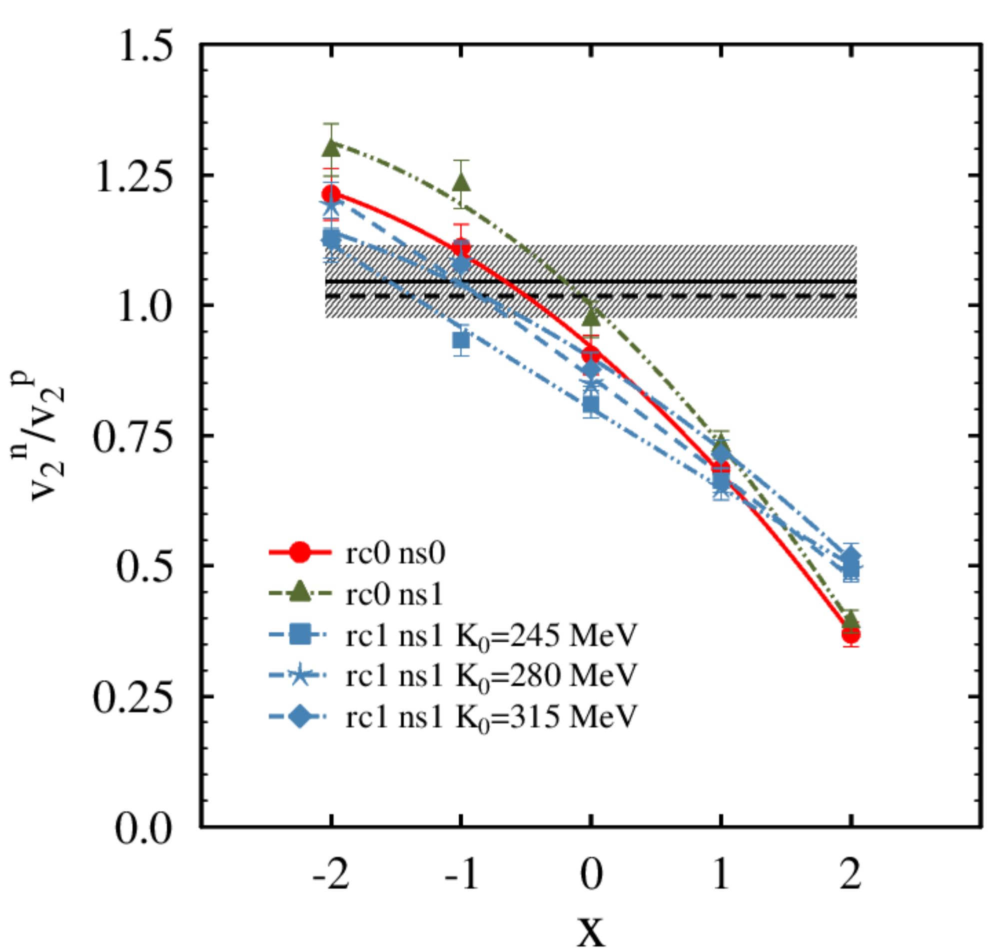
FOPI
$0.25<b_0<0.45;\ u_{t0}>0.4$

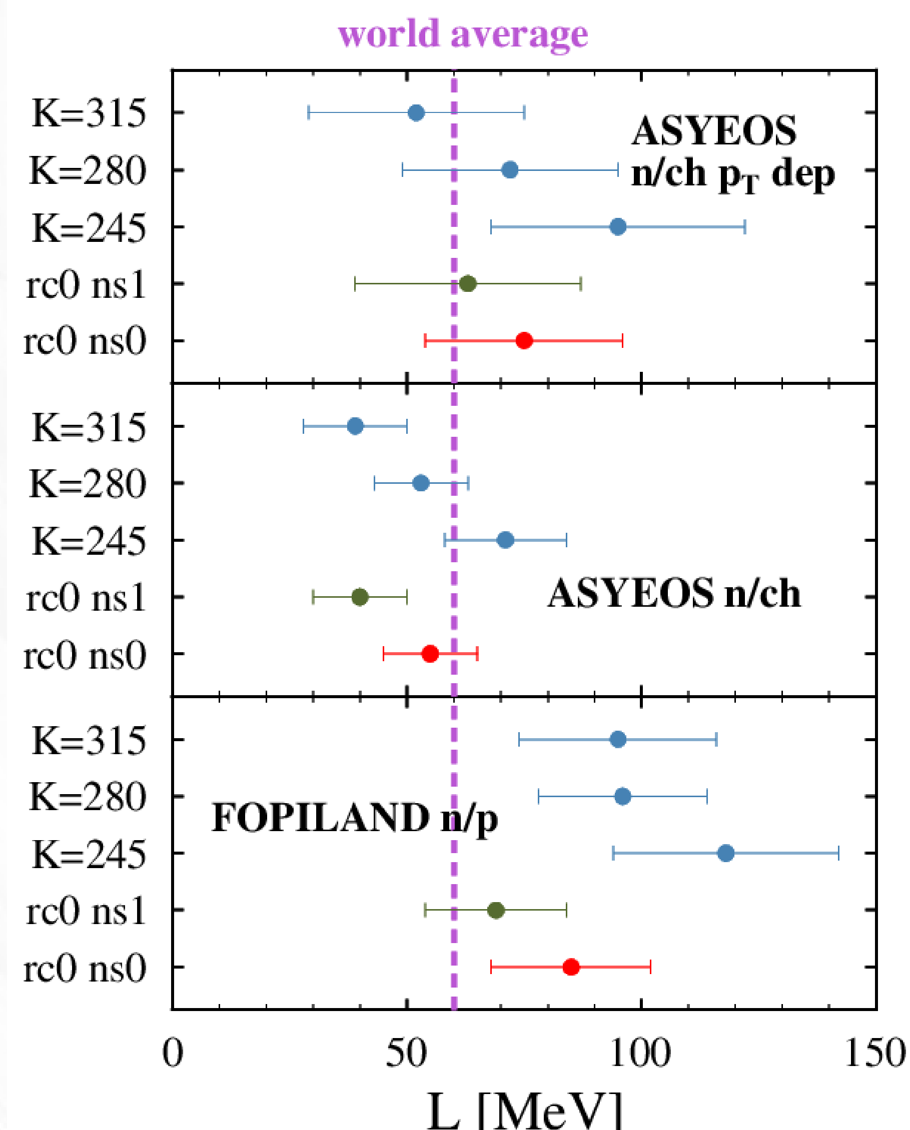


Symmetry Energy Constraint

1 free parameter (cMDI2)

FOPILAND n/p elliptic flow ratio





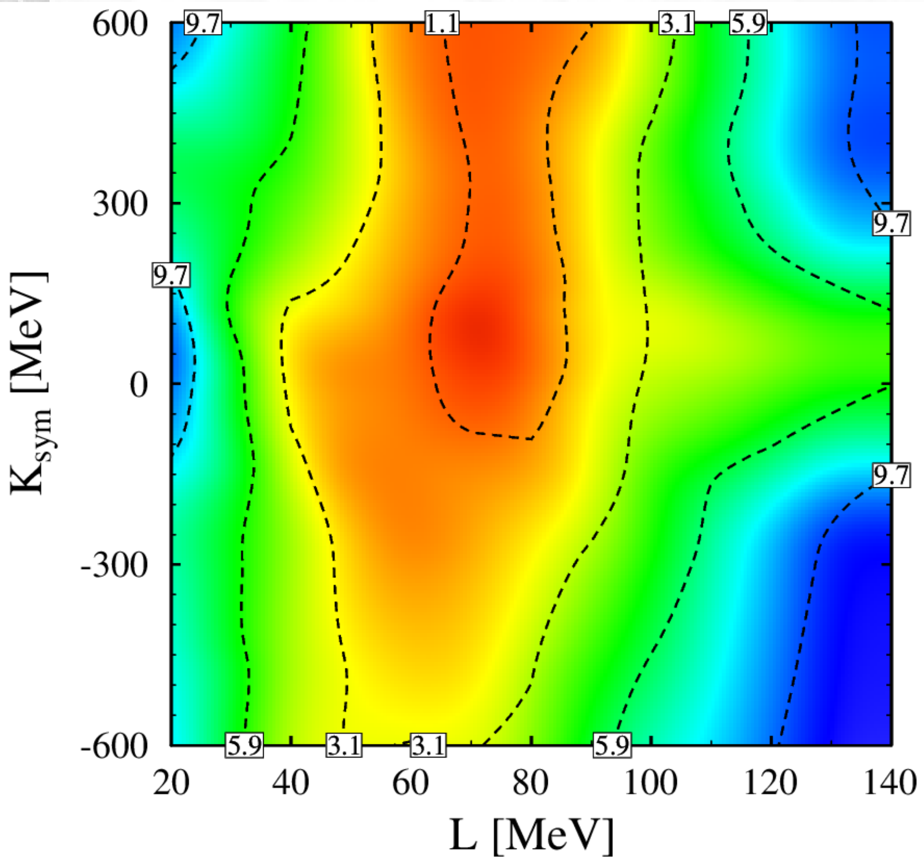
increased sensitivity to compressibility by a factor ~3 !!

D.C. EPJA 54, 40 (2018)

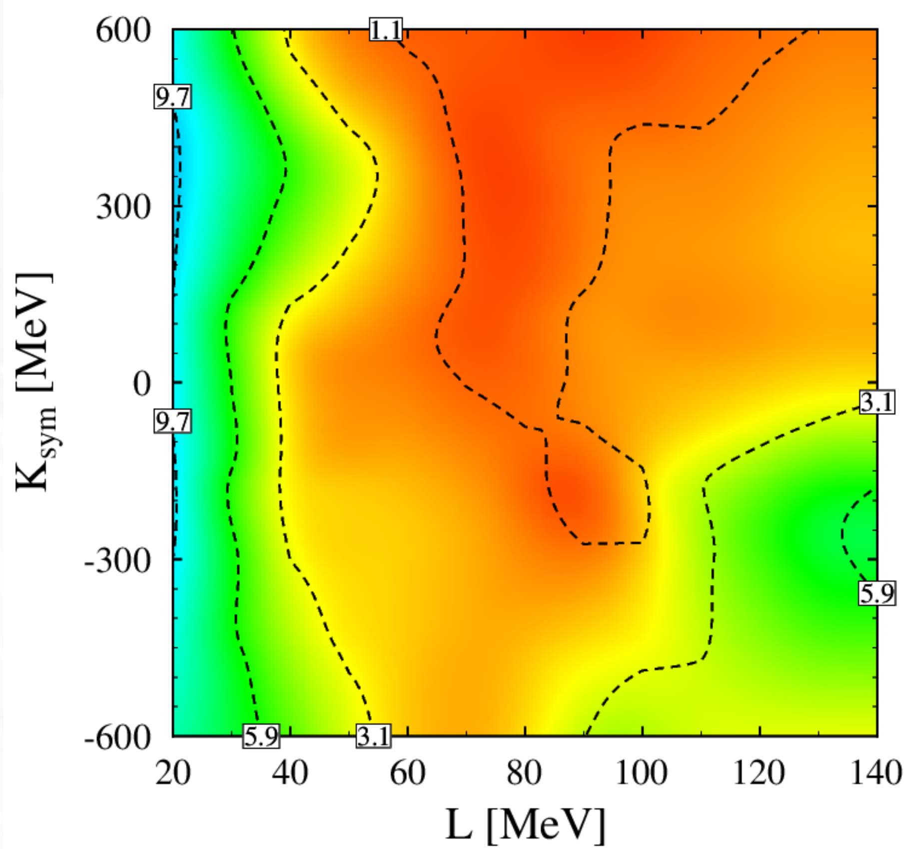
Symmetry Energy Constraint

2 free parameters (full MDI2) ⟶ **extract both L and K_{sym}**

non-relativistic dynamics (K=245 MeV)



relativistic corrections included (K=280 MeV)



Relativistic corrections → less sensitivity in the stiffer region, allowing for a stiffer SE above saturation

Conclusions

First results with a QMD transport model that accounts for relativistic dynamics effects in the meanfield propagation.

Failure to include these effects ⟶ spurious density dependence of symmetry energy

Relativistic dynamics ⟶ sizable impact on flows, increasing with impact energy (directed, elliptic flow)

⟶ need to readjust model parameters

⟶ qualitative approach: tune compressibility modulus to reproduce magnitude of flows

⟶ reasonable description at 400 MeV/u; insufficient in the region 1 GeV/u.

Symmetry Energy Constraints: compatible with the non-relativistic dynamics model

However: less sensitivity towards stiffer asy-EoS
non-negligible sensitivity to the compressibility modulus