Isotopic Flows in Au+Au at 400 A MeV

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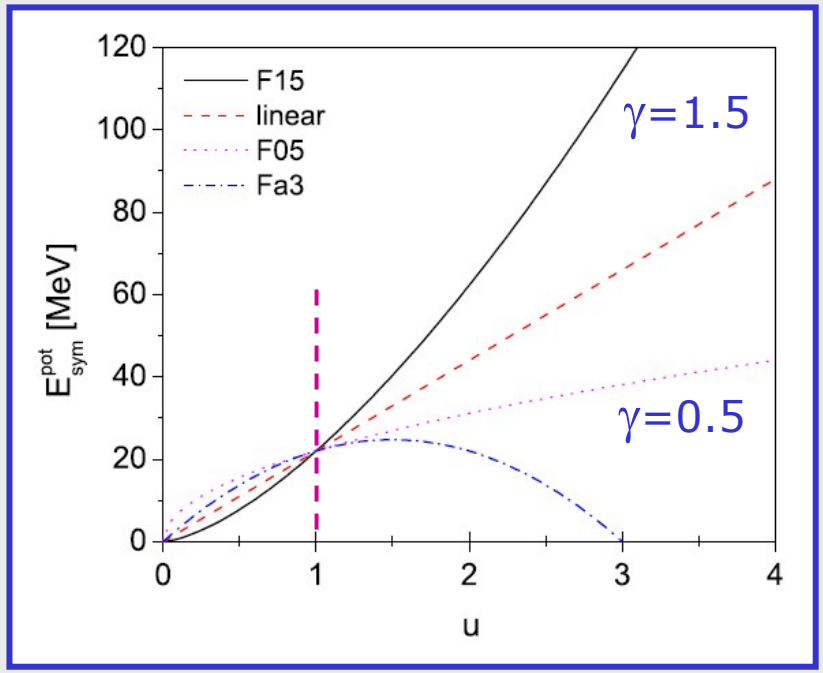
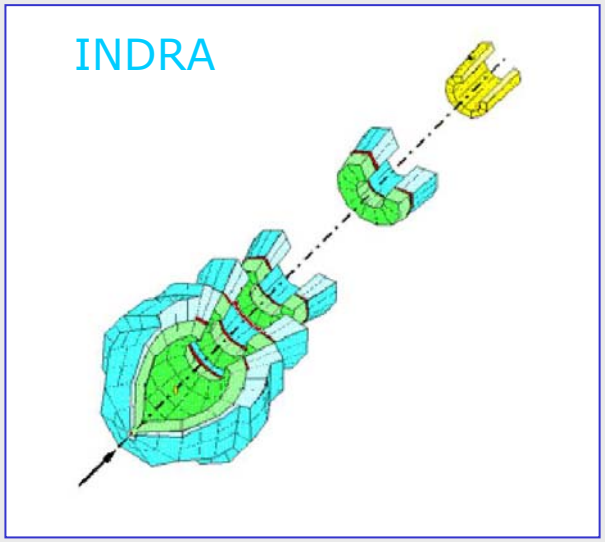
I. Collective flow and the symmetry energy at supra-saturation density

II. First results from the FOPI (Phase I)-LAND experiment

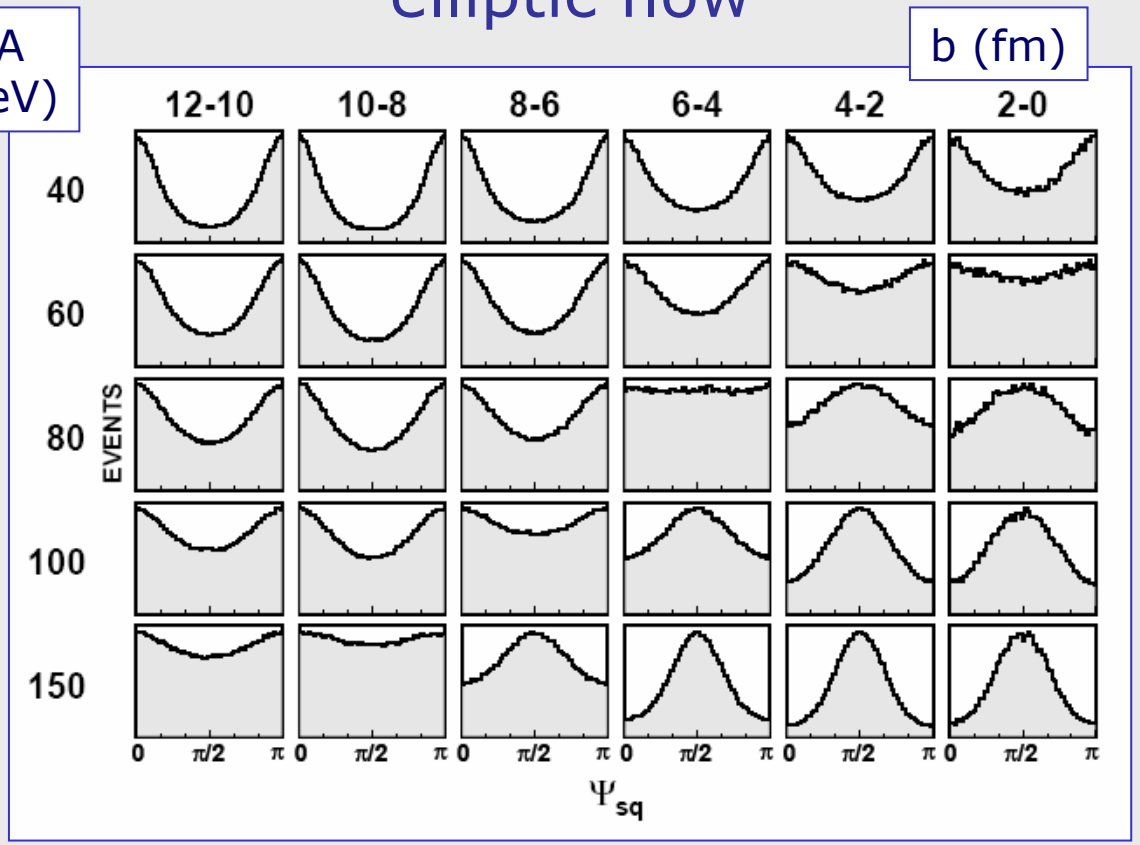
UrQMD, Q.F. Li et al.



I. why collective flows



elliptic flow



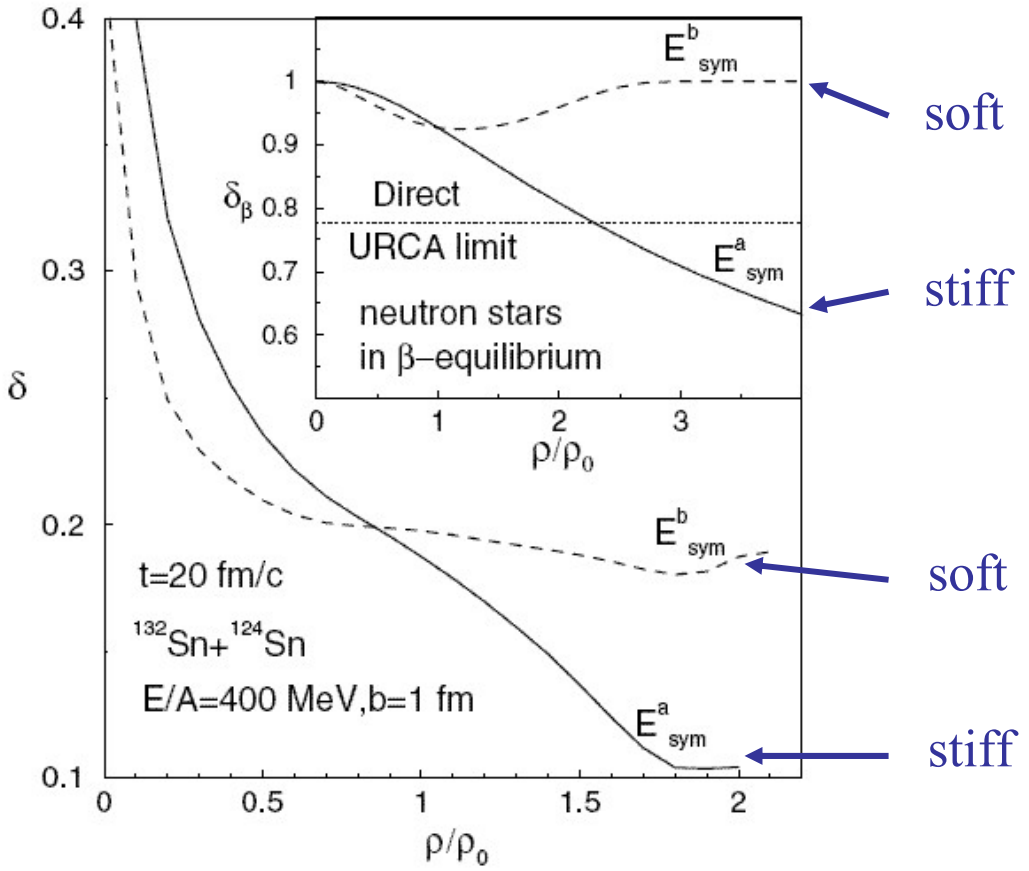
Ψ (azimuthal event) distributions
in the plane of directed flow

J. Łukasik et al.,
PLB 608 (2005)

motivation 1: probes of high-density stage ?

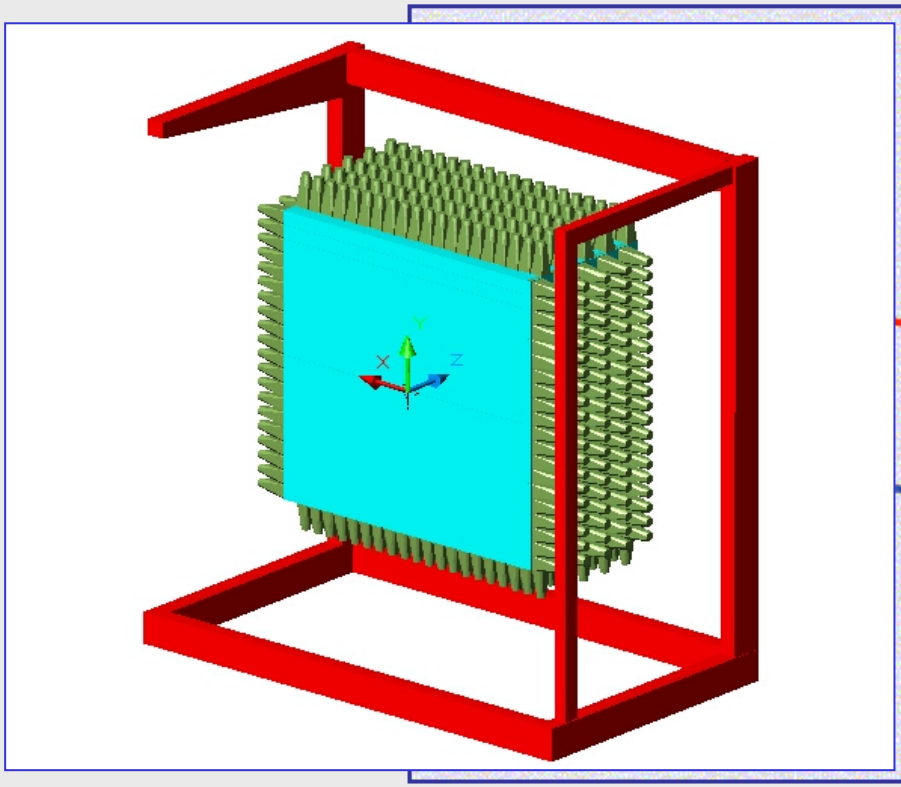
probe the early reaction phase with suitable observables like differential neutron-proton flow

$\delta=(\rho_n-\rho_p)/\rho$ =0.22



Bao-An Li, PRL 88, 192701 (2002)

motivation 2: can LAND be used to measure differential neutron-proton flows ?

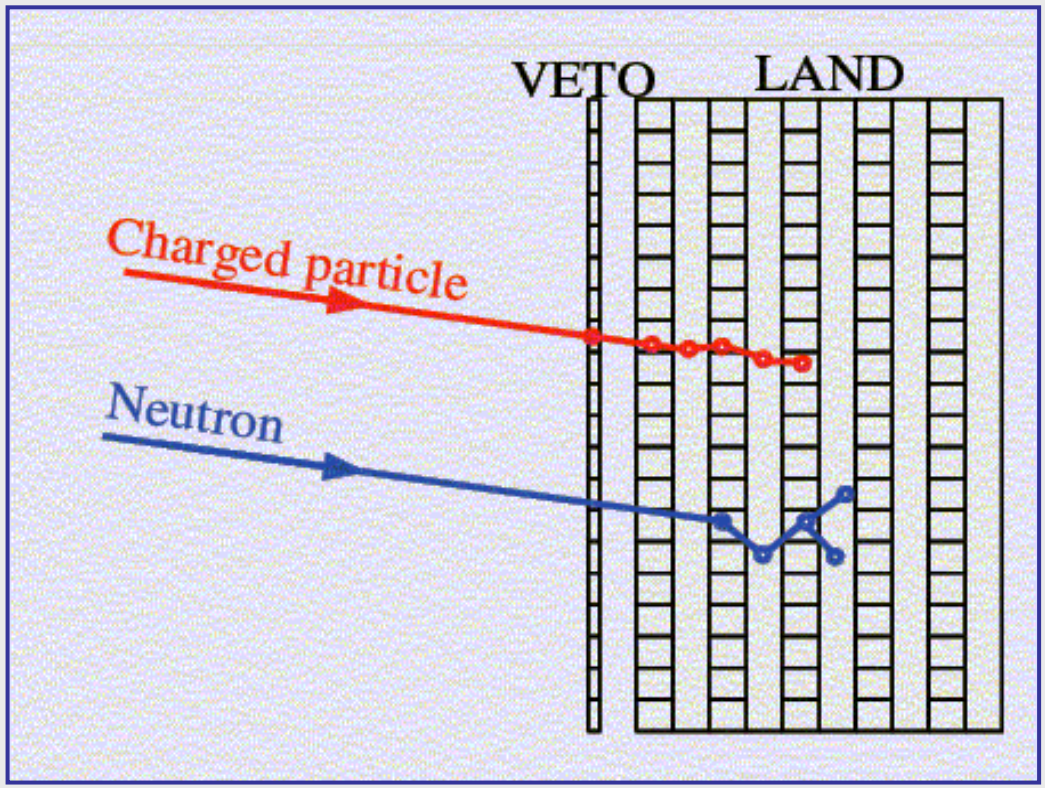


cluster recognition

analysis of ALADIN experiment S254 by J. Brzychczyk, P. Pawlowski

neutron and proton detection with the same device and method

motivation 2: can LAND be used to measure differential neutron-proton flows ?



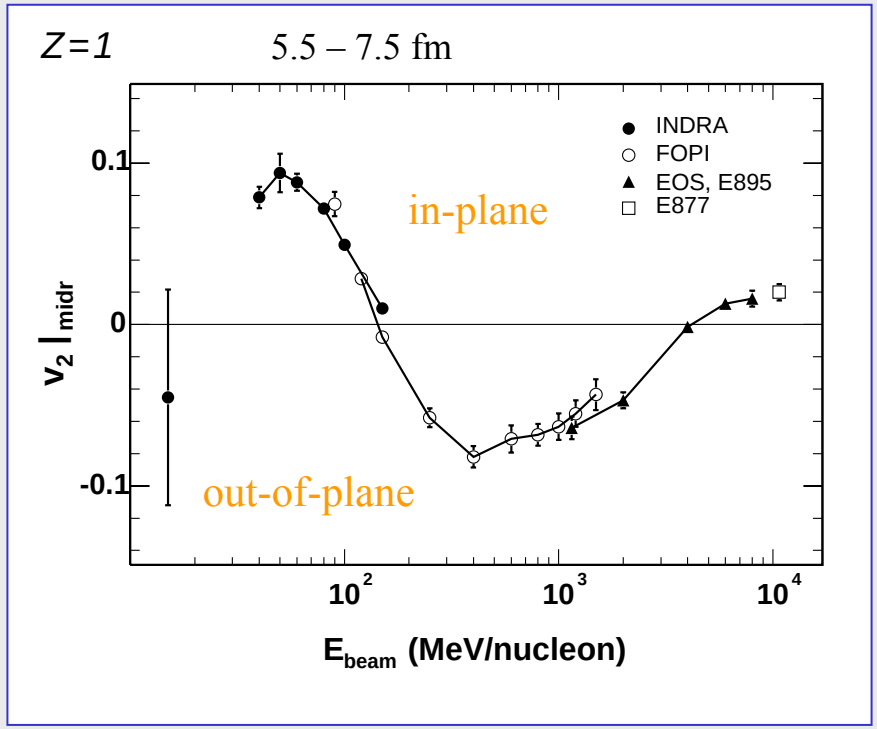
cluster recognition

analysis of ALADIN experiment S254 by J. Brzychczyk, P. Pawlowski

neutron and proton detection with the same device and method

motivation 3:
high quality of excitation functions of flow

elliptic flow v_2



^{197}Au + ^{197}Au,
data from
INDRA, FOPI,
AGS experiments

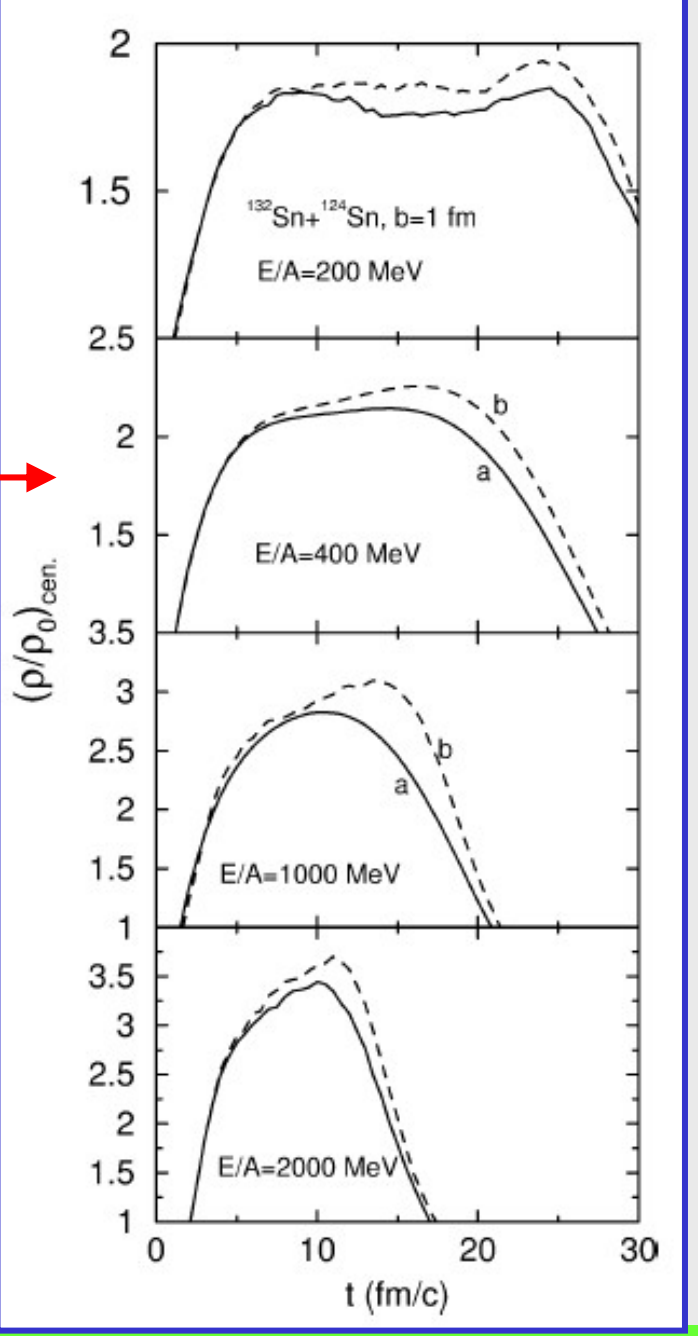
from
A. Andronic et al.,
EPJA 30 (2006)

$v_1 \equiv \langle \cos(\phi - \phi_R) \rangle$ directed flow

$v_2 \equiv \langle \cos 2(\phi - \phi_R) \rangle$ elliptic flow

motivation 4:
high density over a long time

ρ•Δt maximum here

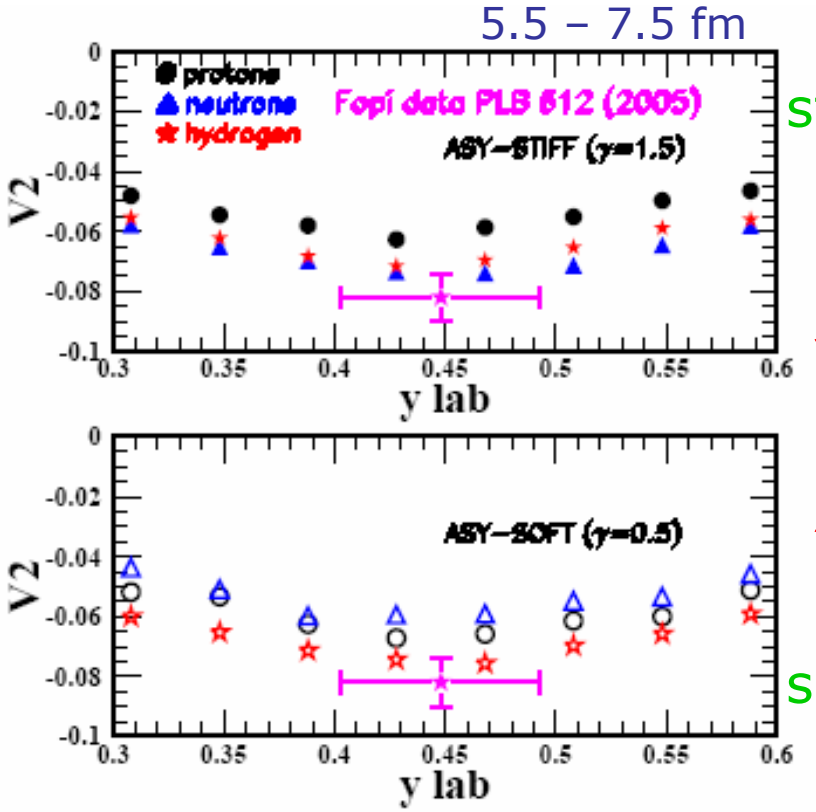


in the central region
of 132Sn + 124Sn central collisions

according to the isospin dependent
transport model of
Bao-An Li, NPA 708(2002)

motivation 5: UrQMD predictions for elliptic flow

Q.F. Li and P. Russotto



stiff

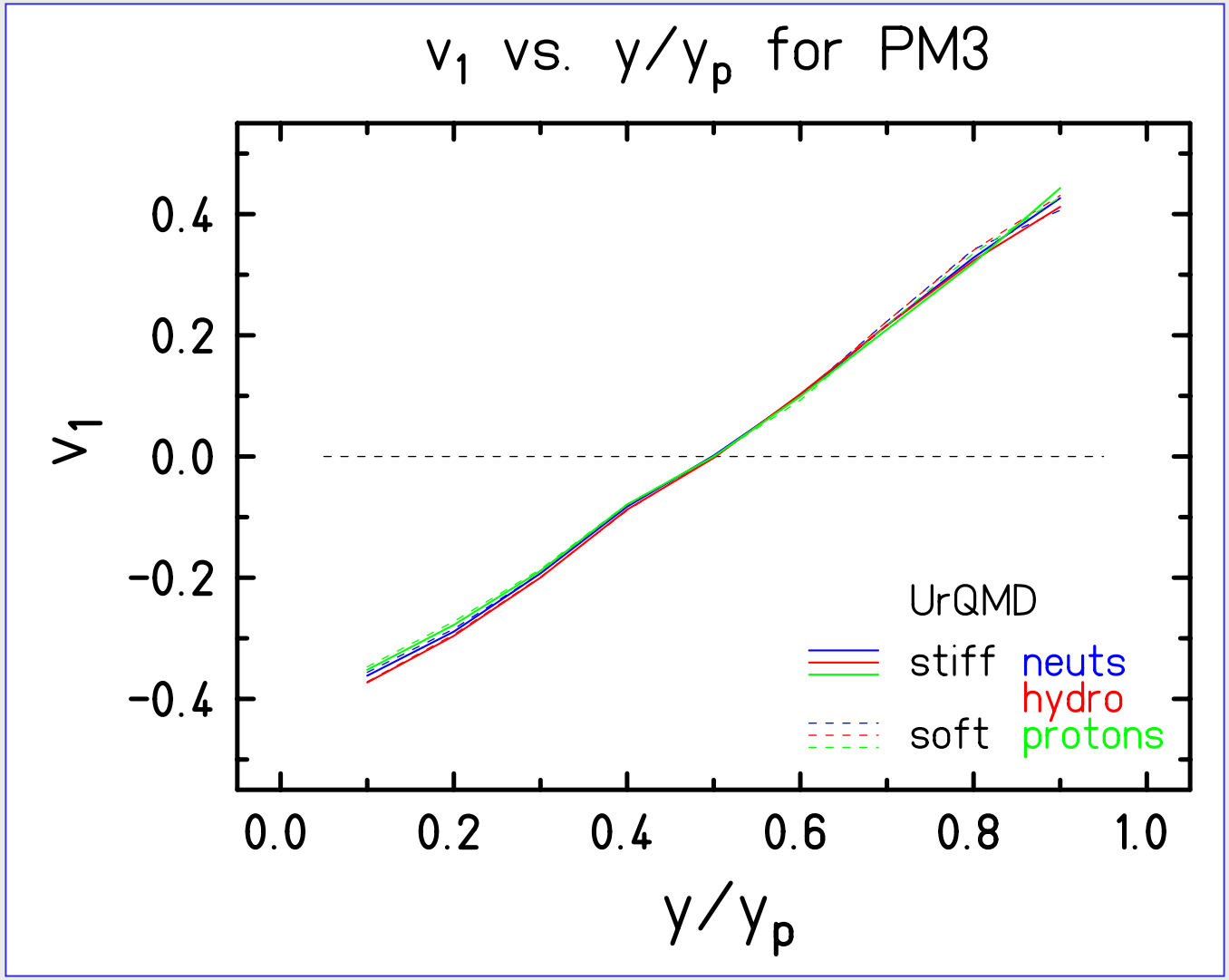
soft

UrQMD vs. FOPI data:
Au+Au @ 400 A MeV

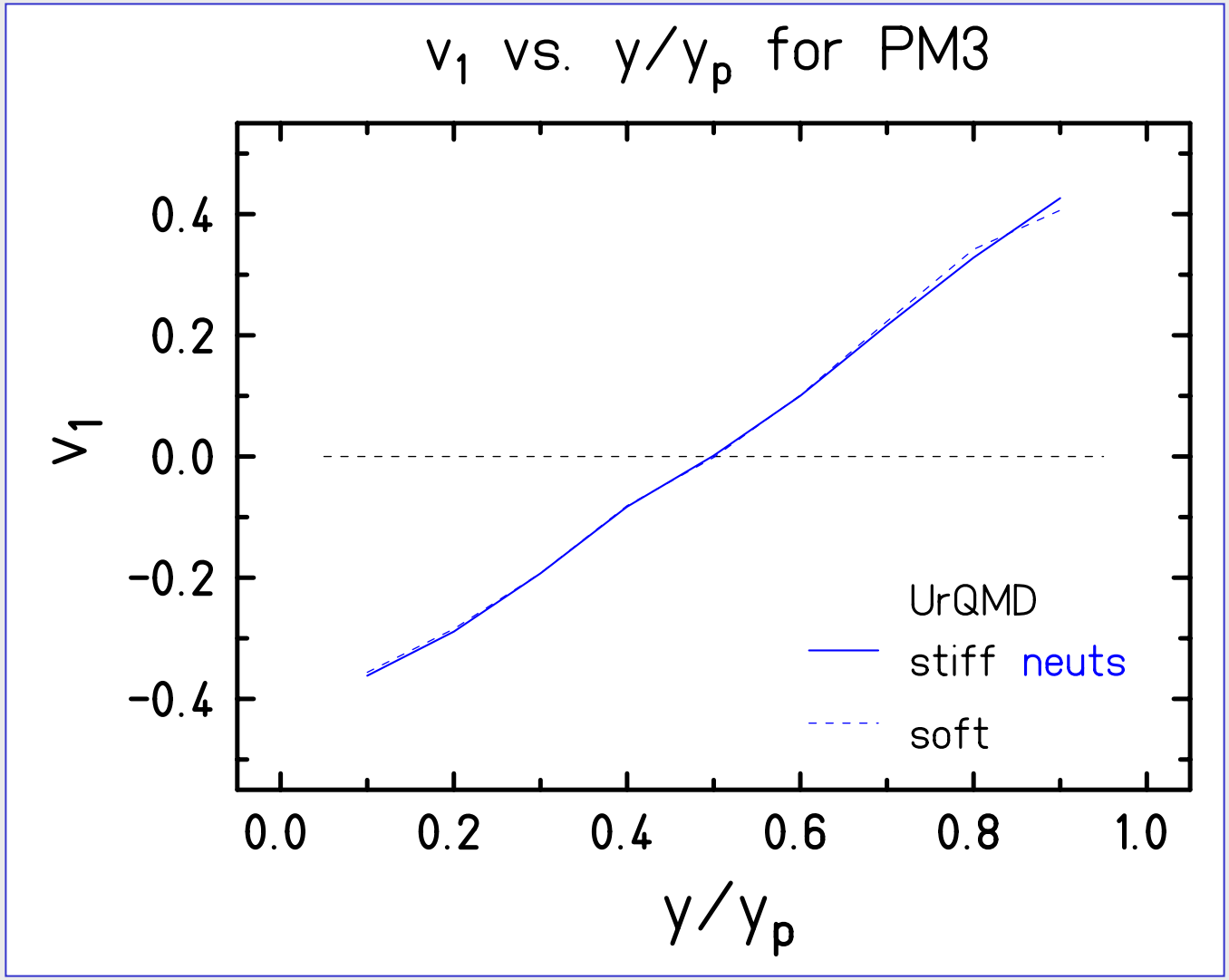
inversion of neutron and hydrogen flows

survives acceptance cuts of FOPI/LAND experiment

UrQMD: negligible sensitivity to directed flow

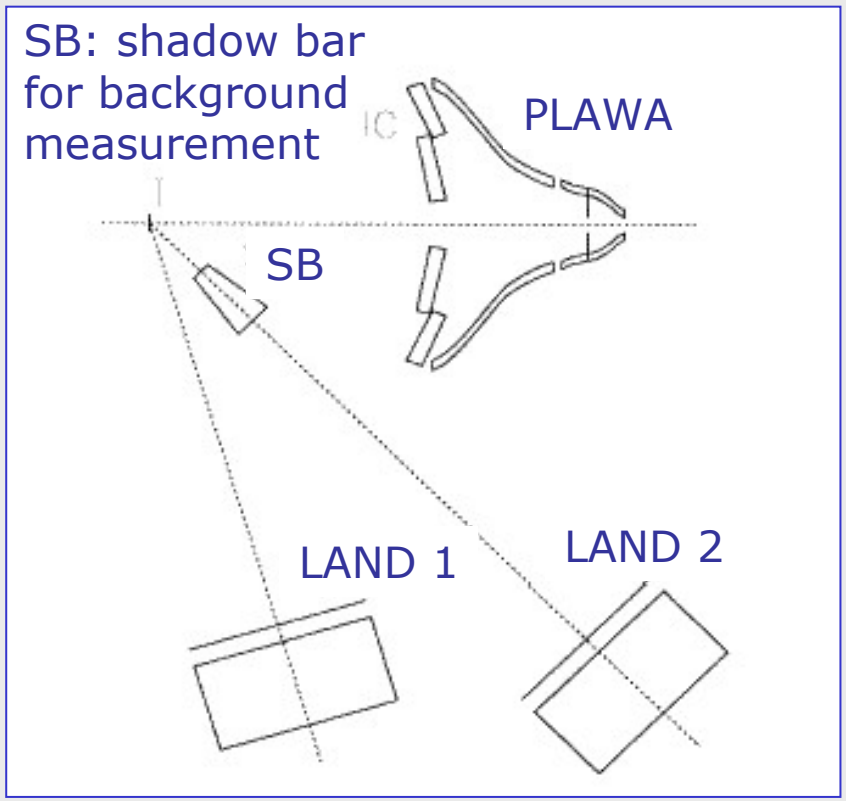


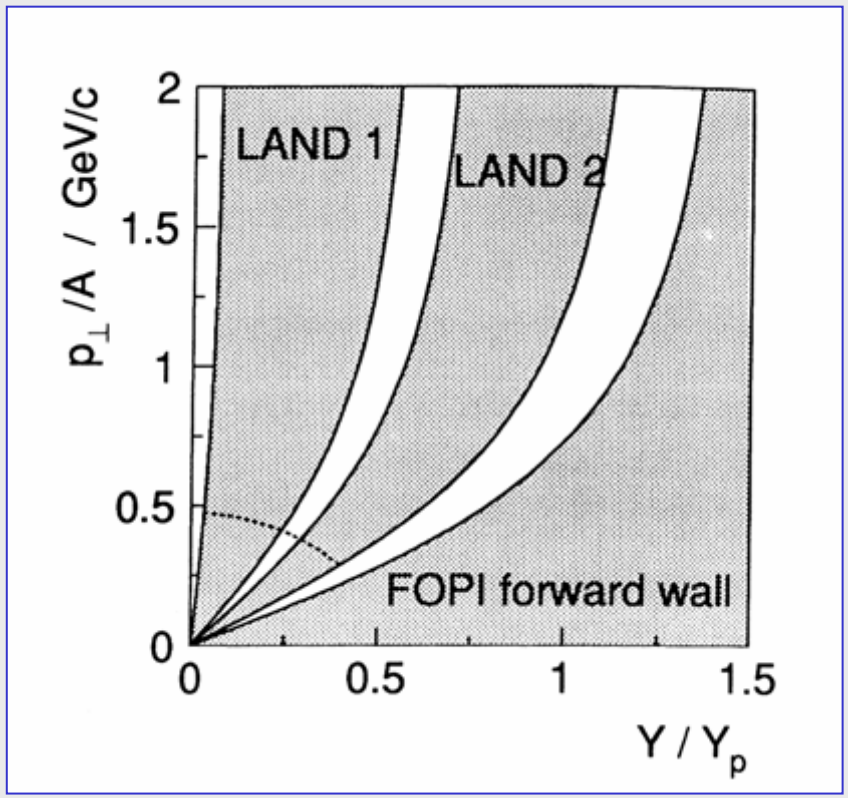
UrQMD: negligible sensitivity to directed flow



II. First results from FOPI/LAND experiment

Au+Au 400 A MeV





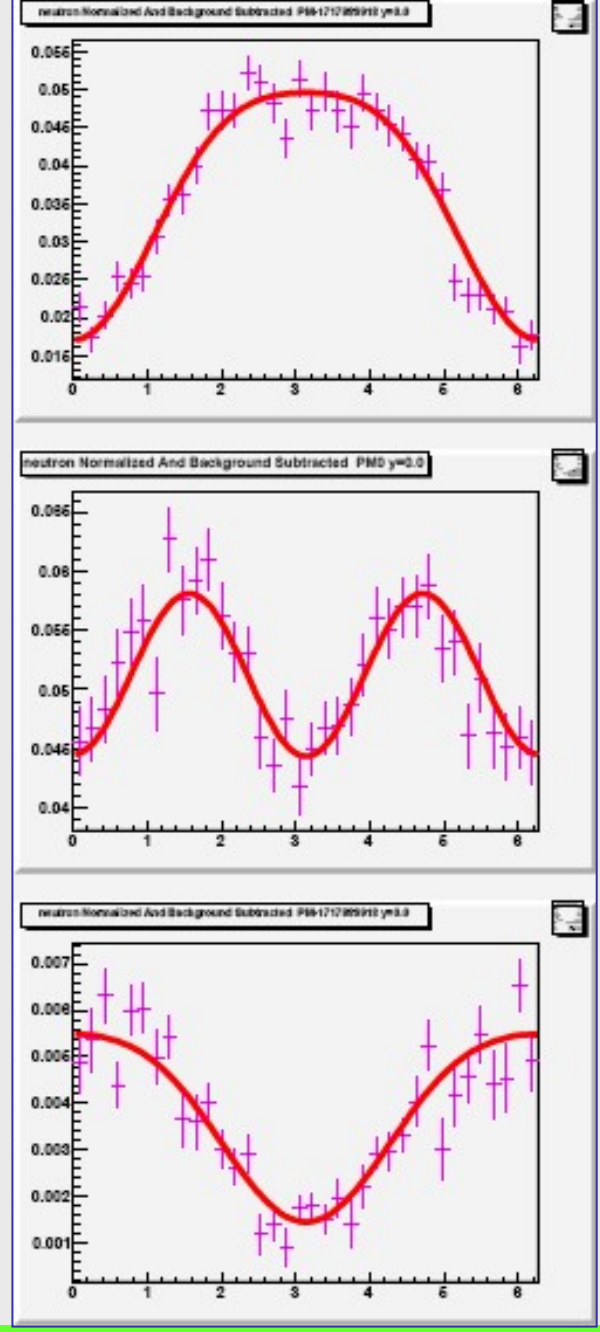
neutron squeeze-out: Y. Leifels et al., PRL 71, 963 (1993)

azimuthal angular distributions for neutrons, background subtracted

$y/y_p = 0.2$:
- near target rapidity
- mostly directed flow

y/yp = 0.5:
- mid-rapidity
- strong squeeze-out

y/yp = 0.8:
- near projectile rapidity
- mostly directed flow

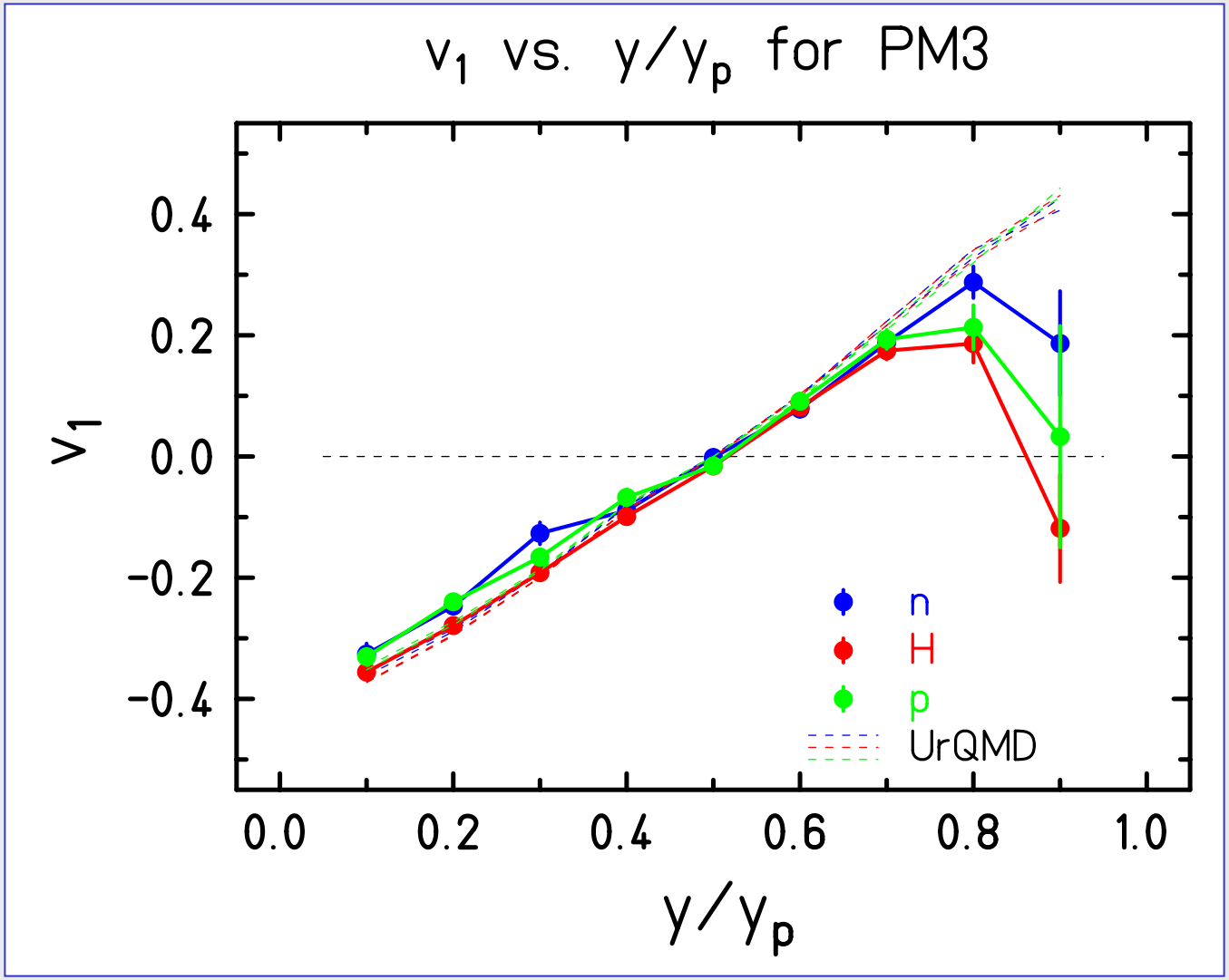


fitted with:

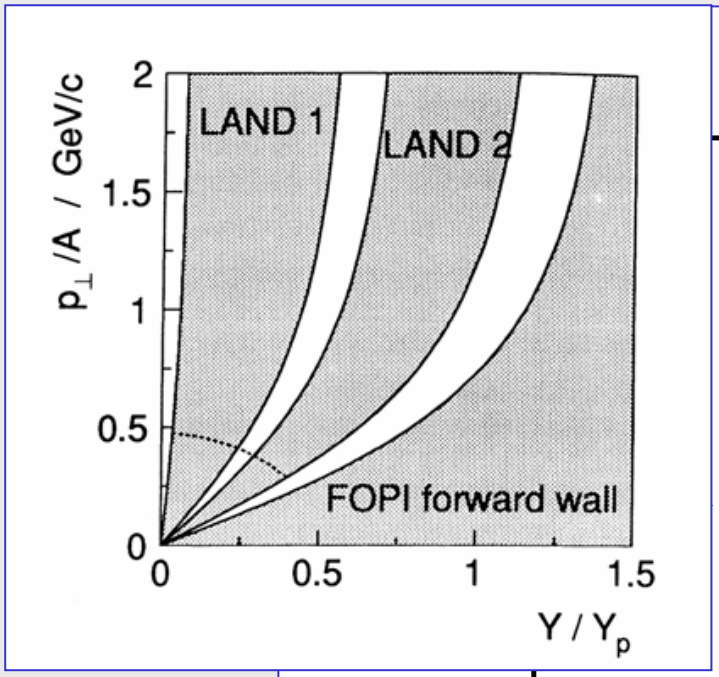
$f(\Delta\varphi)=a_0*(1.0+2v_1*\cos(\Delta\varphi)+2v_2*\cos(2\Delta\varphi))$

$\Delta\varphi = \varphi_{particle} - \varphi_{reaction\ plane}$

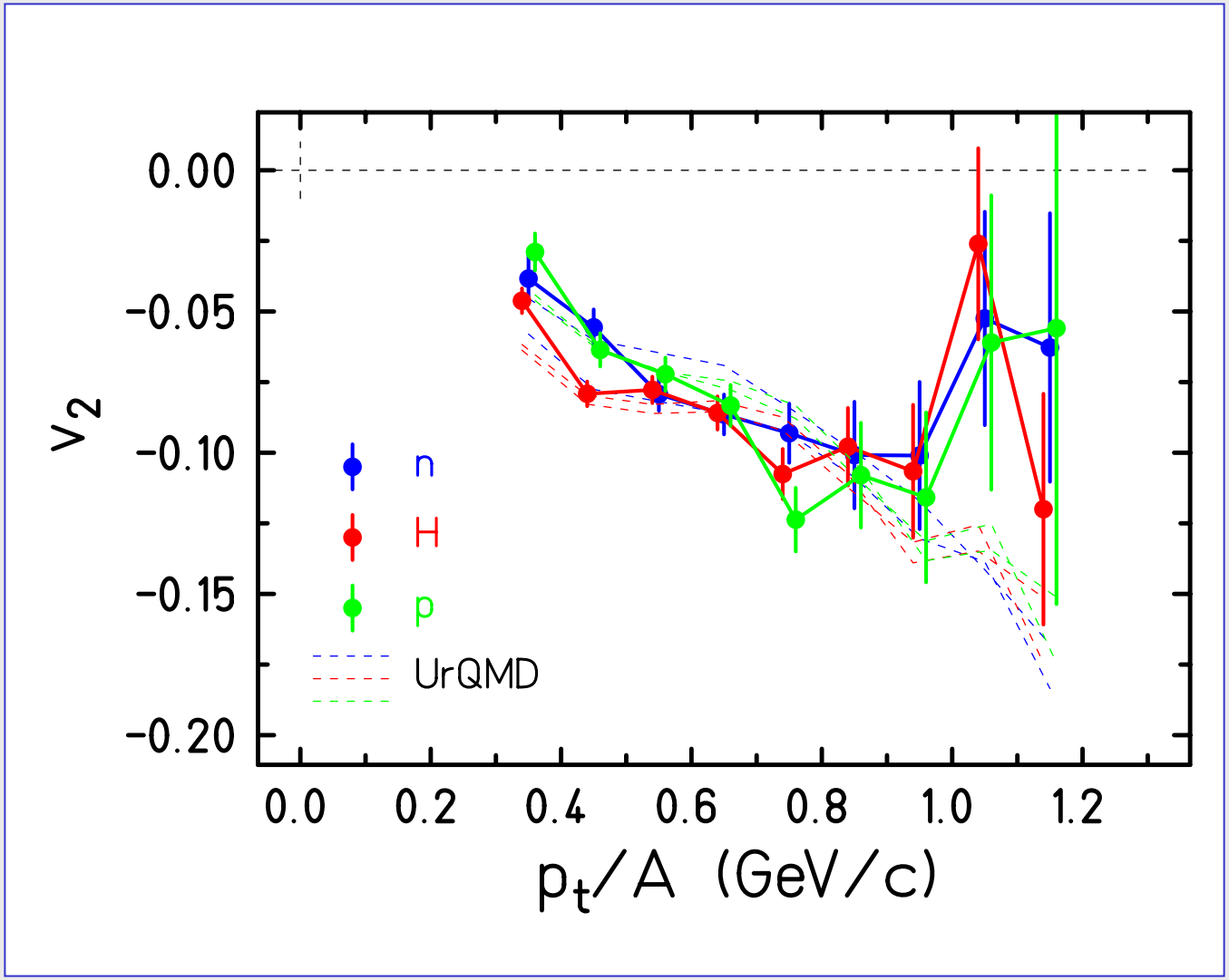
negligible sensitivity to directed flow



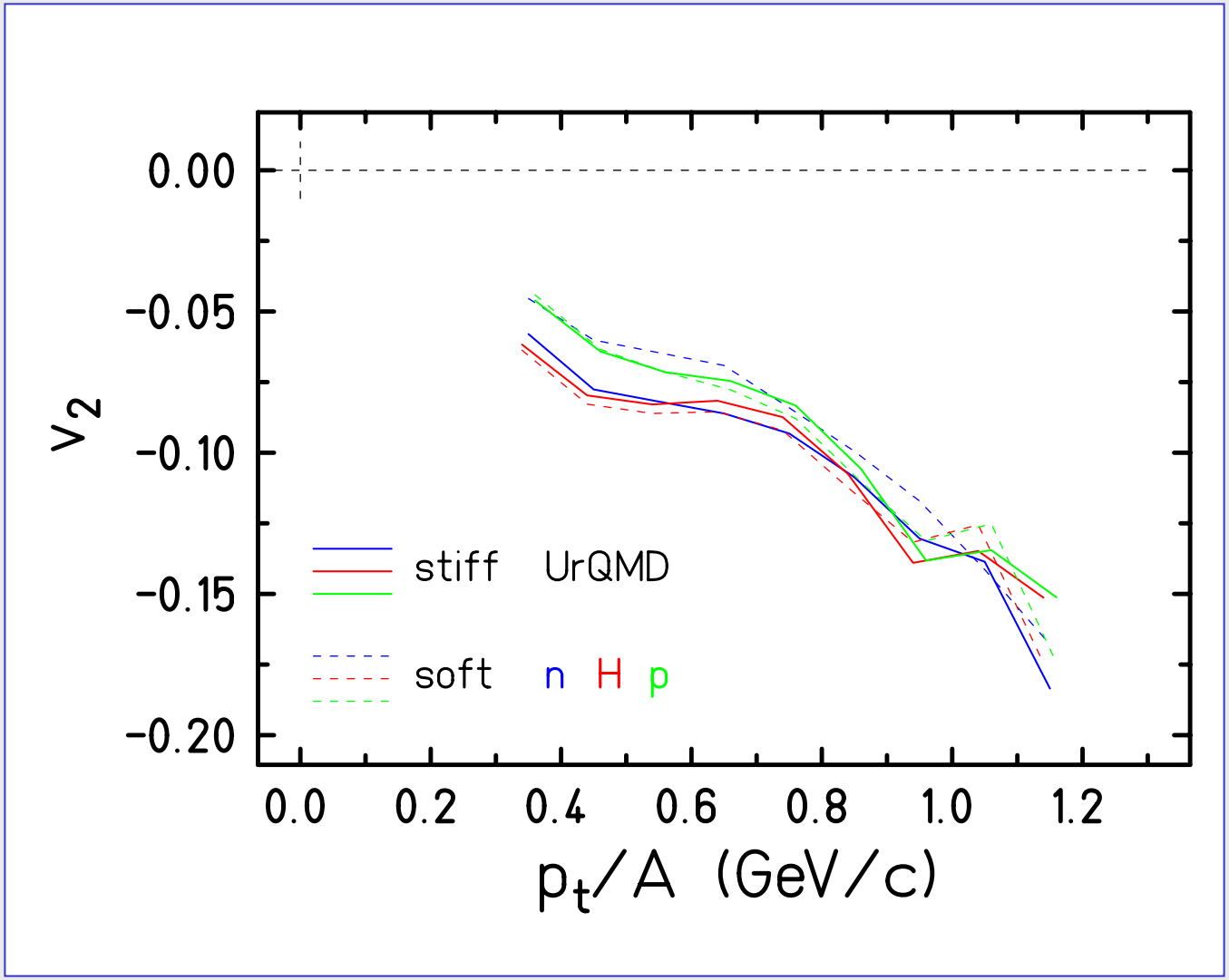
negligible sensitivity to directed flow



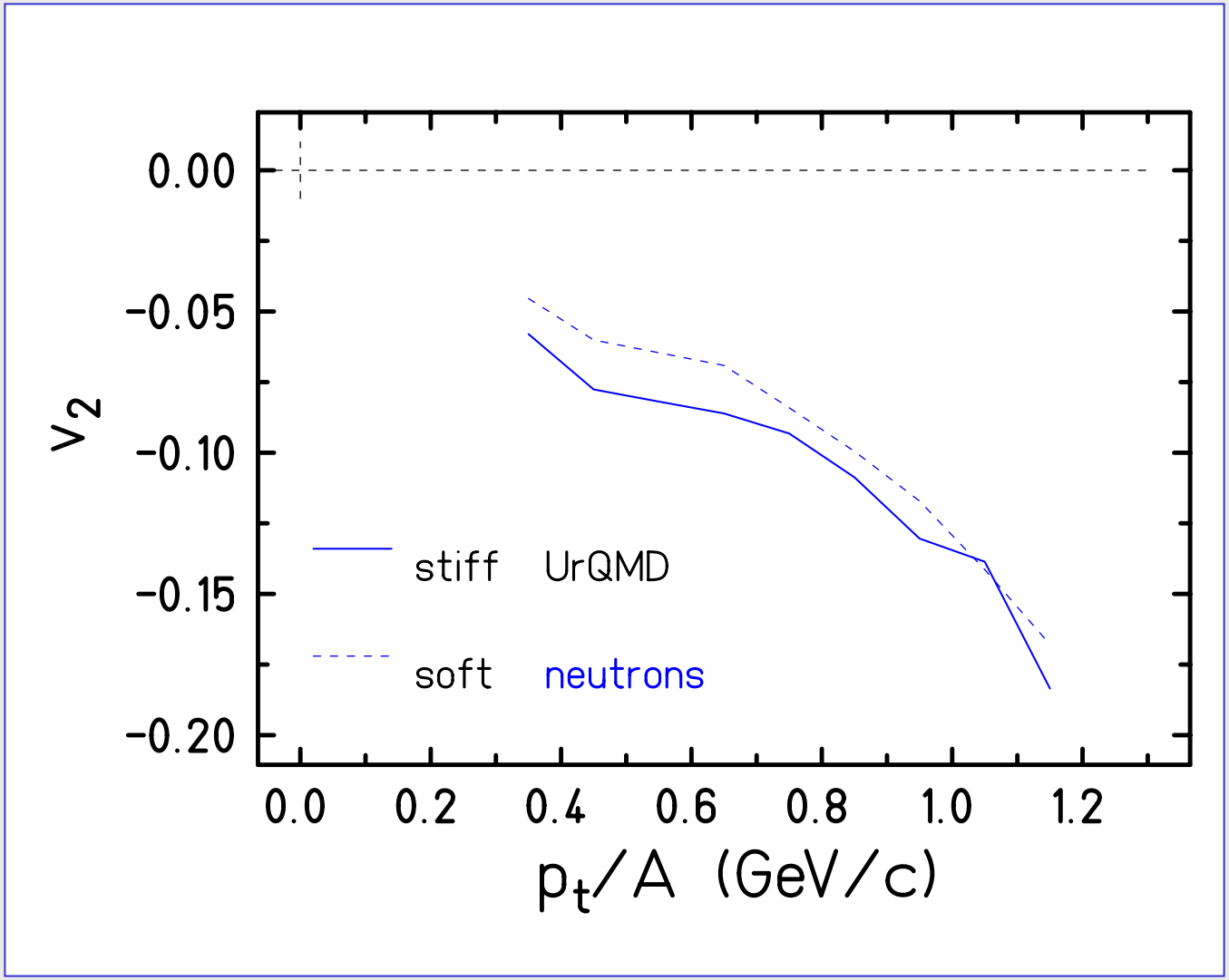
p_t dependence of v_2



UrQMD: sensitivity of v_2



UrQMD: sensitivity of v_2

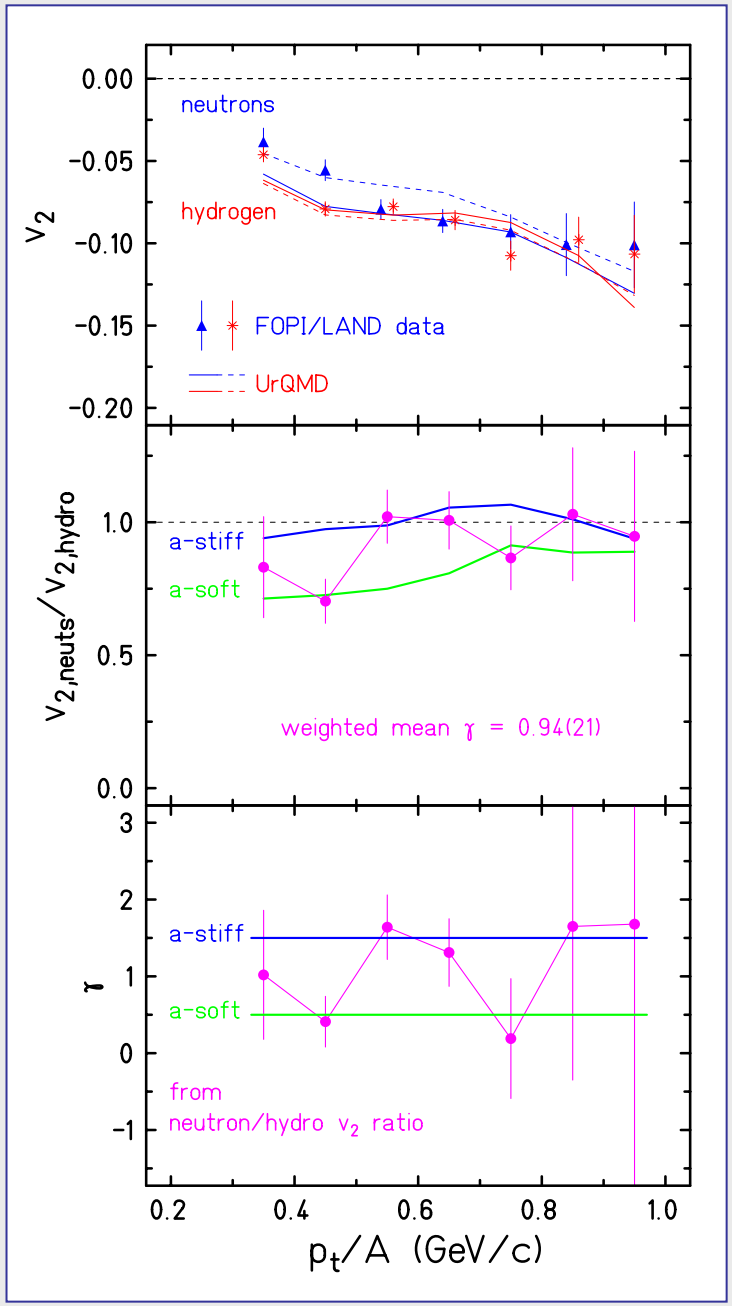


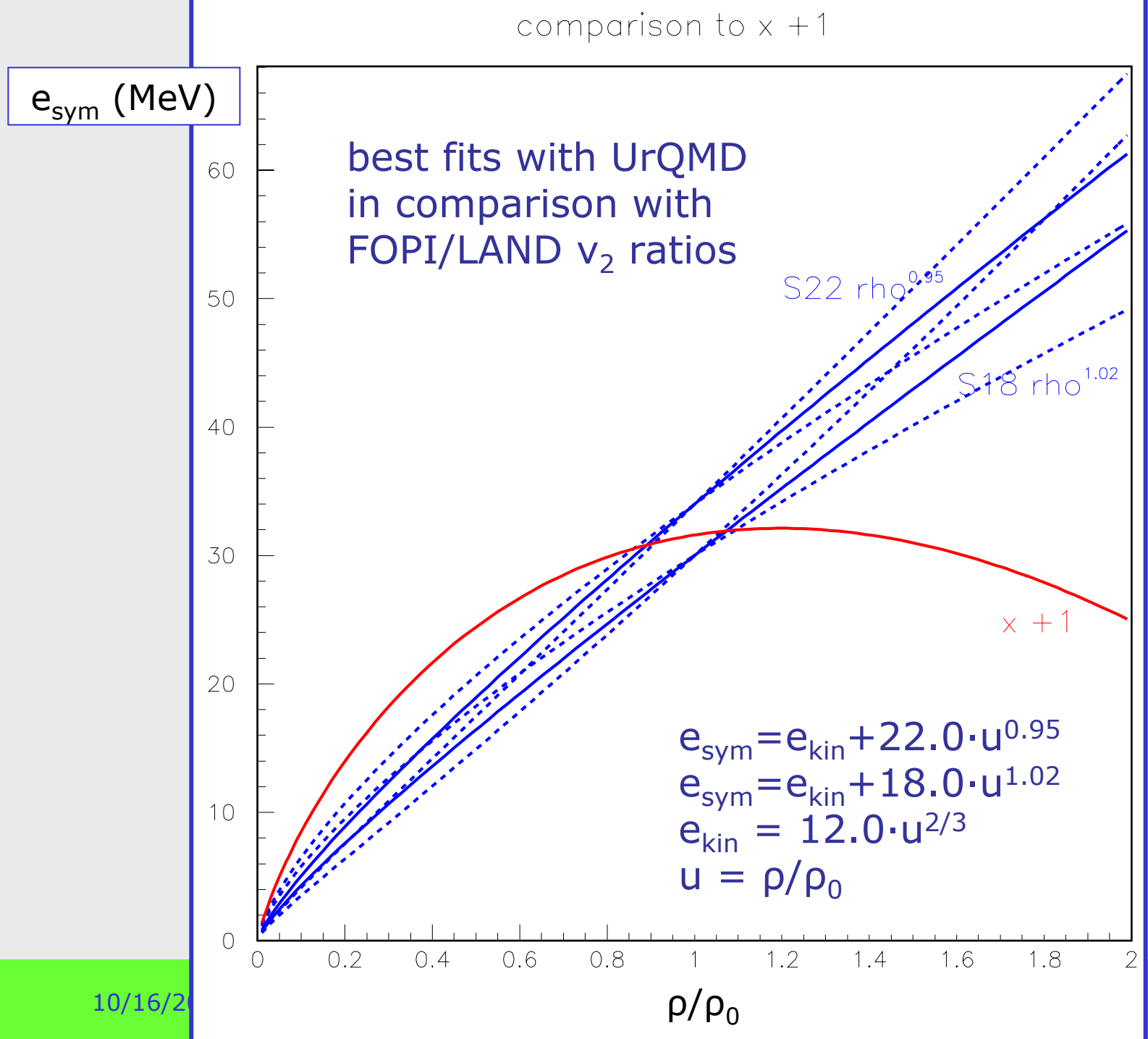
p_t dependence of v_2

Data:
(PM3-PM5, $0.25<y/y_p<0.75$)
- $|v_2|$ increases as expected
- reproduced by UrQMD (b<7.5 fm)
- but 15% correction missing

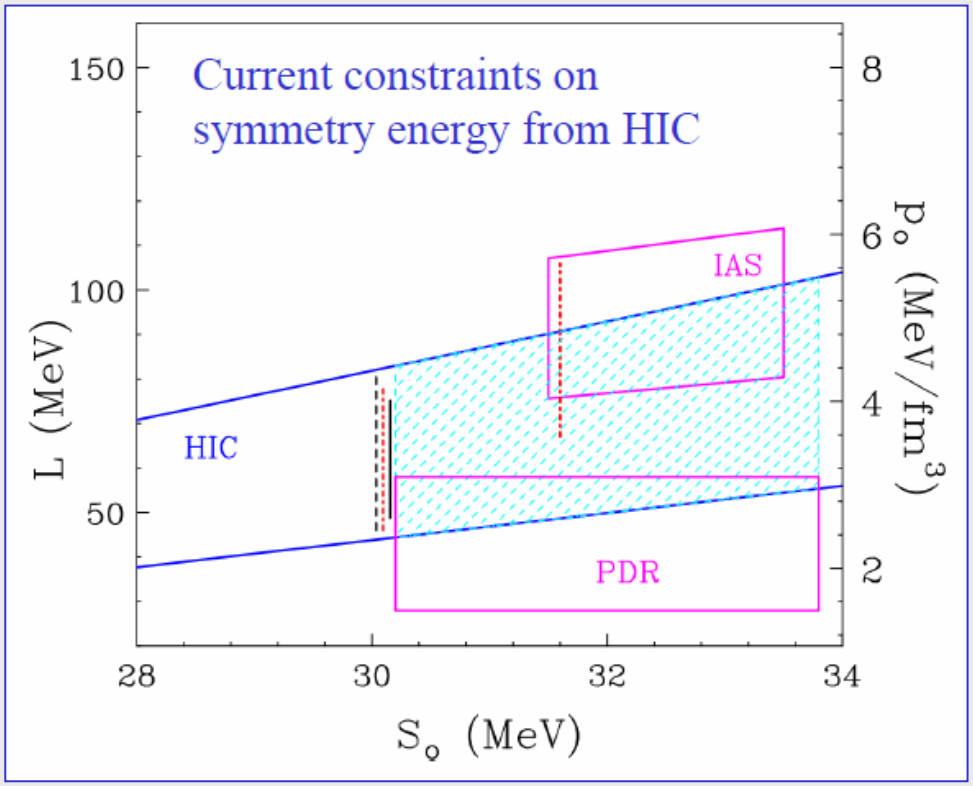
let's look at ratios only:
- large errors at large p_t
- UrQMD: decreasing sensitivity at $p_t>0.8$

result from neut/hydro ratios:
- $\langle\gamma\rangle = 0.94 \pm 0.21$
- potential part just below linear




comparison to x +1
e_{sym} (MeV)
best fits with UrQMD
in comparison with
FOPI/LAND v_2 ratios
S22 rho$^{0.95}$
S18 rho$^{1.02}$
x +1
$e_{sym}=e_{kin}+22.0\cdot u^{0.95}$
$e_{sym}=e_{kin}+18.0\cdot u^{1.02}$
$e_{kin} = 12.0\cdot u^{2/3}$
$u = \rho/\rho_0$
0
10
20
30
40
50
60
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
ρ/ρ_0

analysis of isospin diffusion and n/p ratios
in ^{112,124}Sn cross bombardments at 50 A MeV
M.B. Tsang et al.,
PRL 102, 122701 (2009)



HIC isospin diffusion and n/p ratios PRL 102 (2009)
IAS isobaric analog states, Danielewicz and Lee, NPA 818 (2009)
PDR pygmy dipole resonance, Klimkiewicz et al., PRC 76 (2007)

analysis of isospin diffusion and n/p ratios
in ^{112,124}Sn cross bombardments at 50 A MeV
M.B. Tsang et al.,
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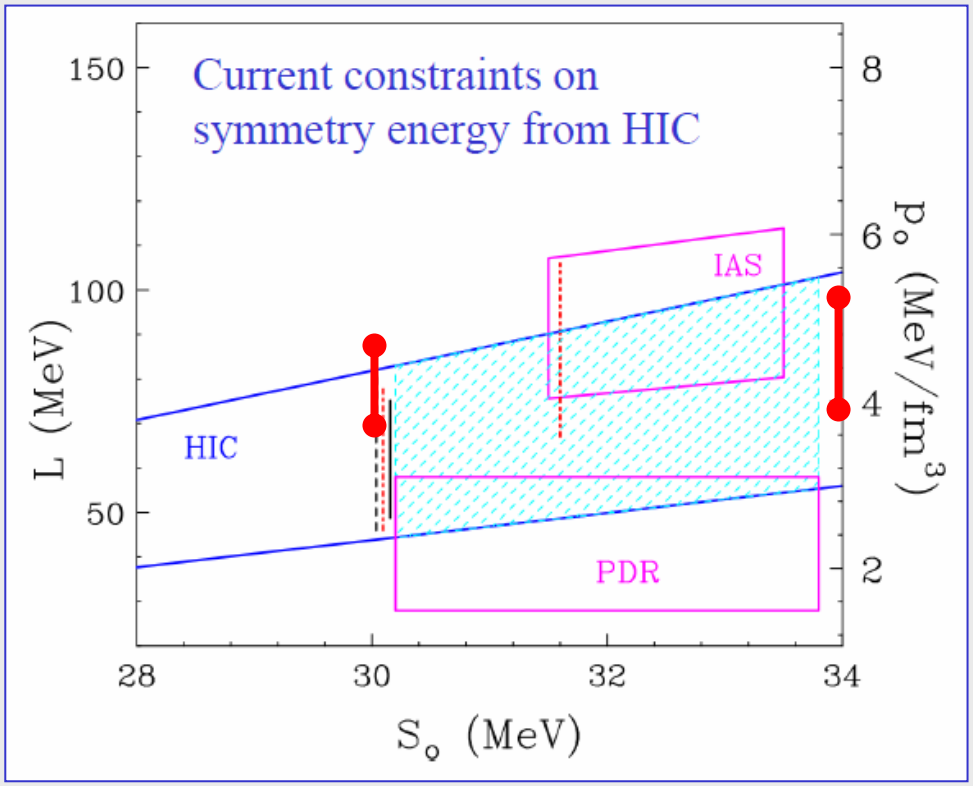
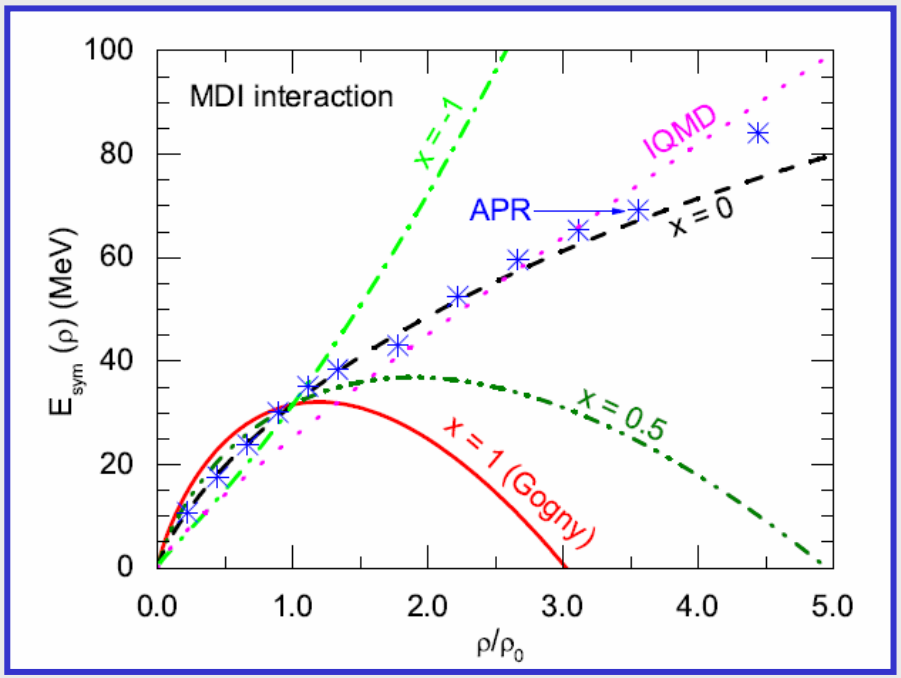
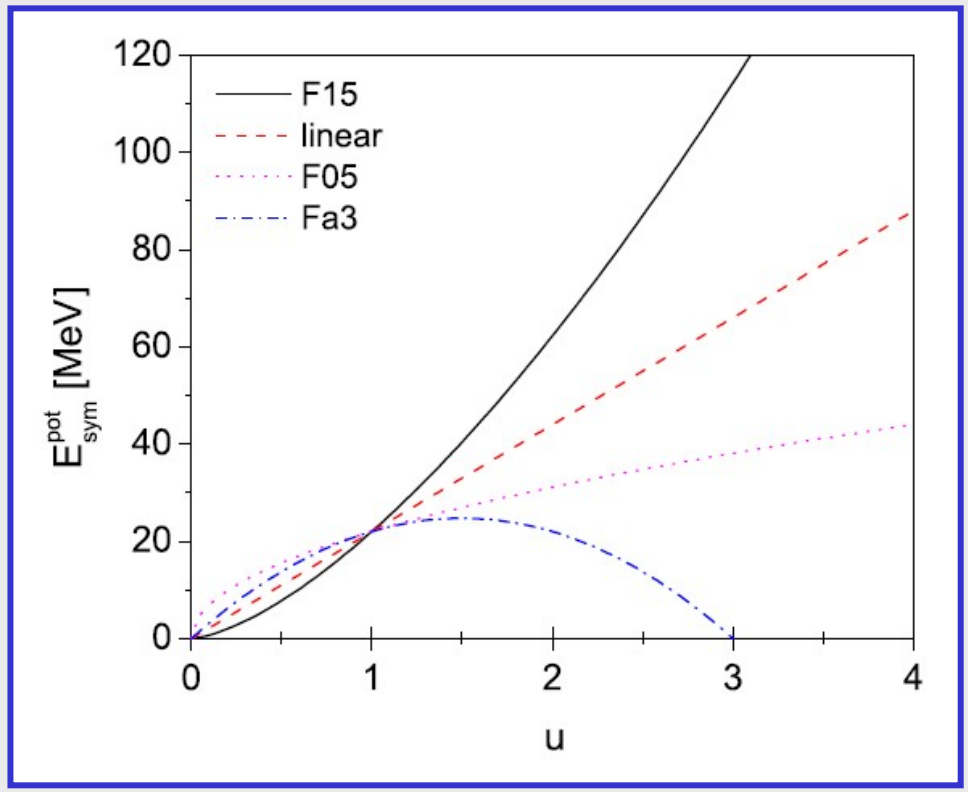


flow ratios + UrQMD:
$\langle\gamma\rangle$ = 0.94 ± 0.21
S_0/L = 34/87 ± 13 MeV or 30/79 ± 10 MeV

analysis of π^-/π^+ ratios in Au+Au
Zhigang Xiao et al.,
PRL 102, 062502 (2009)
FOPI data, W. Reisdorf et al.
NPA 781 (2007)

π ratios + IBUU04:
x=1 super soft





flow ratios + UrQMD:
$\langle\gamma\rangle$ = 0.94 ± 0.21
nearly linear

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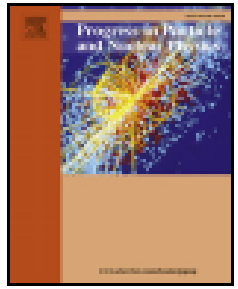


Review

Differential neutron–proton squeeze-out

W. Trautmann [a,*], M. Chartier [b], Y. Leifels [a], R.C. Lemmon [c], Q. Li [d], J. Łukasik [e], A. Pagano [f], P. Pawłowski [e], P. Russotto [g], P. Wu [b]

[a] GSI Darmstadt, D-64291 Darmstadt, Germany
[b] University of Liverpool, Liverpool L69 7ZE, United Kingdom
[c] STFC Daresbury Laboratory, Warrington, WA4 4AD, United Kingdom
[d] FIAS, Universität Frankfurt, D-60438 Frankfurt am Main, Germany
[e] IFJ-PAN, PL-31 342 Kraków, Poland
[f] INFN-Sezione di Catania, I-95123 Catania, Italy
[g] INFN-LNS and Università di Catania, I-95123 Catania, Italy

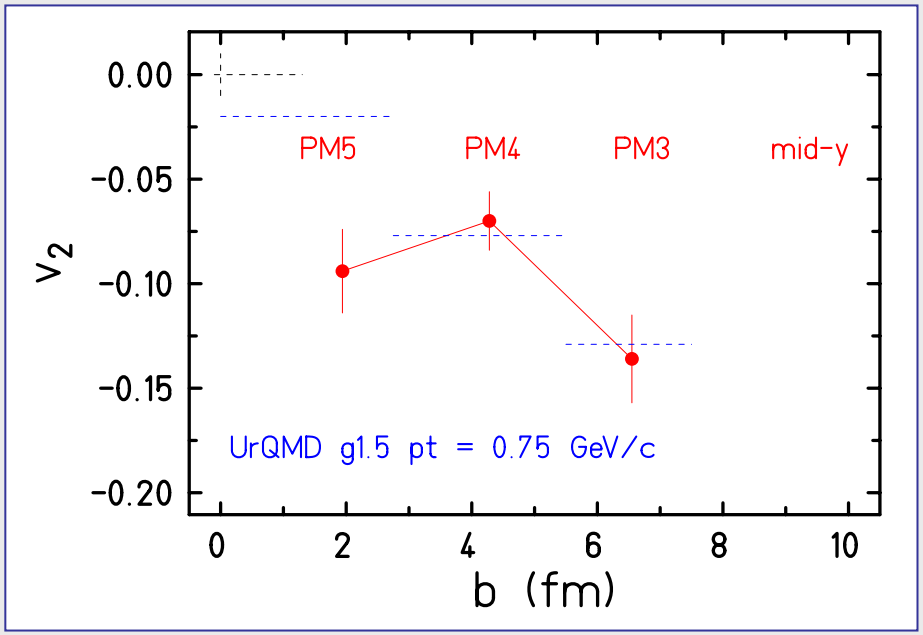
$\gamma = 0.6 \pm 0.3$
(from PM3 only)

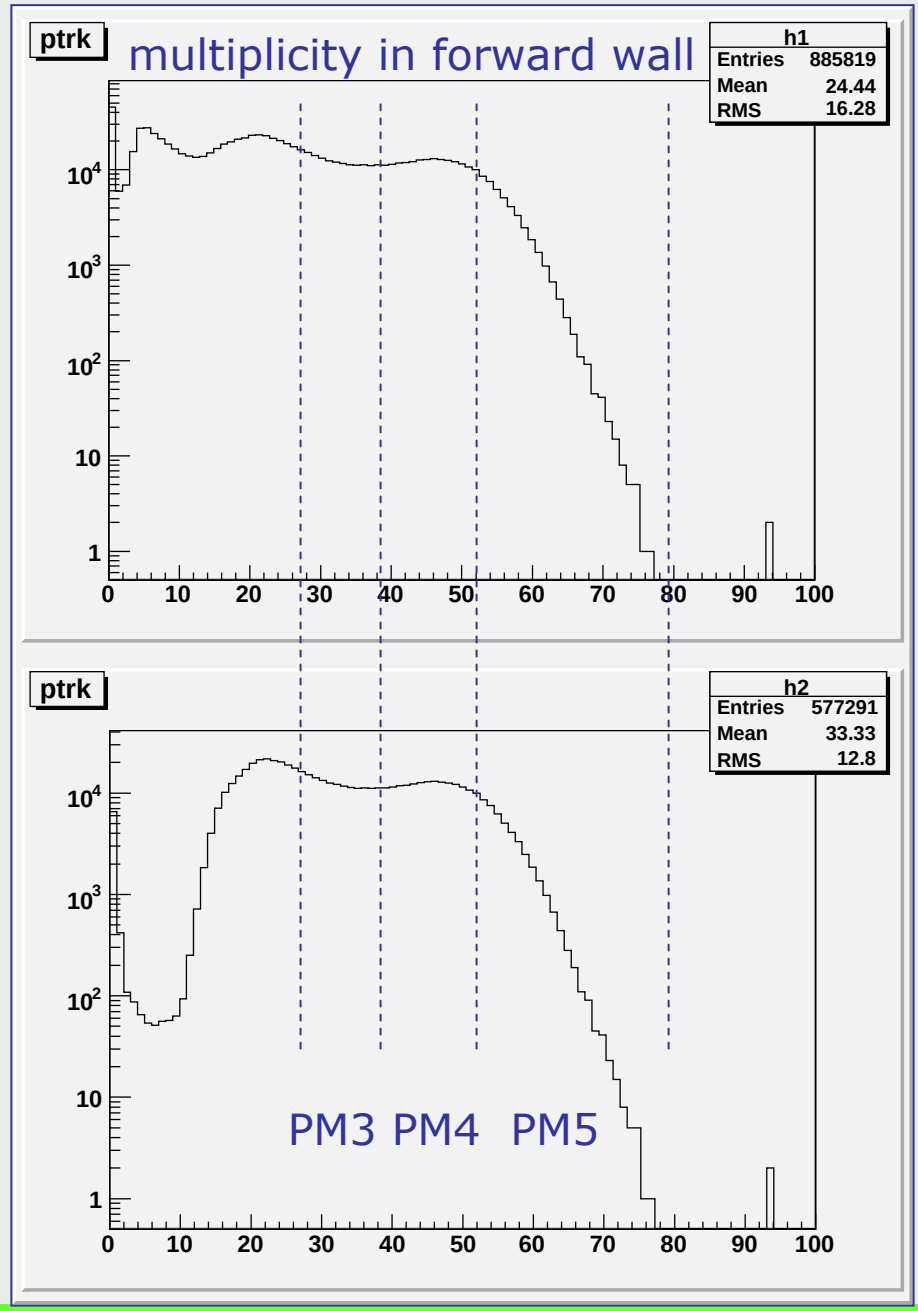
test of systematic uncertainties

physical parameters:	
impact parameter	$\Delta\gamma = 0.43 \pm 0.32$ (PM3 vs. PM3-5)
transverse momentum	$\Delta\gamma < 0.1$ (p_t<0.8 vs. p_t<1.2 GeV/c)
rapidity	$\Delta\gamma < 0.15$ (for PM3-5)
	statistics not really sufficient
	to evaluate errors more precisely
data analysis:	
various sorting gates	$\Delta\gamma < 0.1$
include protons separately	$\Delta\gamma$ negligible (protons not sensitive)
background subtraction	$\Delta\gamma = 0.21$ (100% vs. 60% of measured background)
UrQMD:	
Pauli blocking (y/n)	$\Delta\gamma = 0.08$ (for PM3-5)
constant S_0 ($=a_4$)	$\Delta\gamma = 0.07$ (S_0=22 vs. S_0=18 MeV)

test of centrality

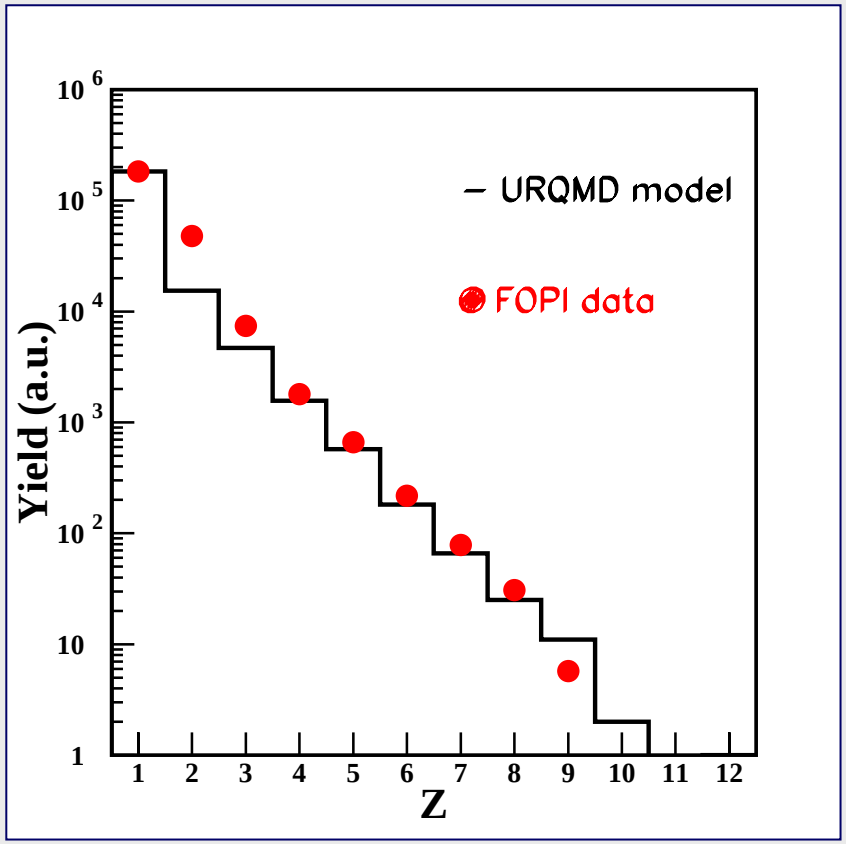
neutrons





v_2 in PM5 is not as small as expected, possibly due to lacking experimental impact-parameter resolution

test of cluster algorithm



Q.F. Li and
P. Russotto

Z distribution (in arbitrary units) of charged particles in Au+Au at 400 AMeV central collisions (arbitrarily normalized at Z=1)

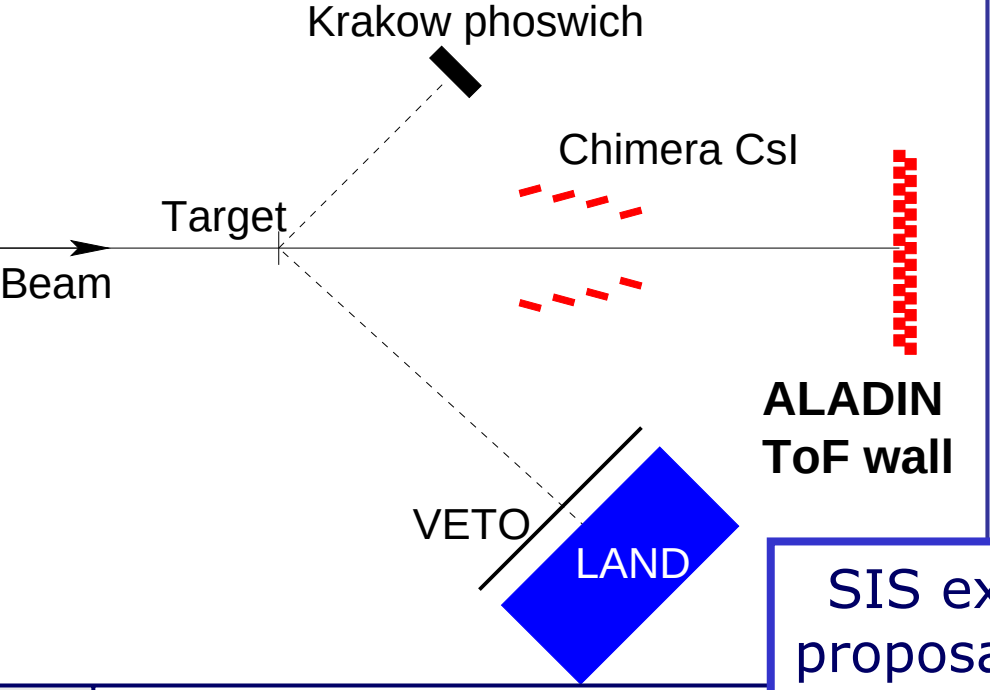
summary

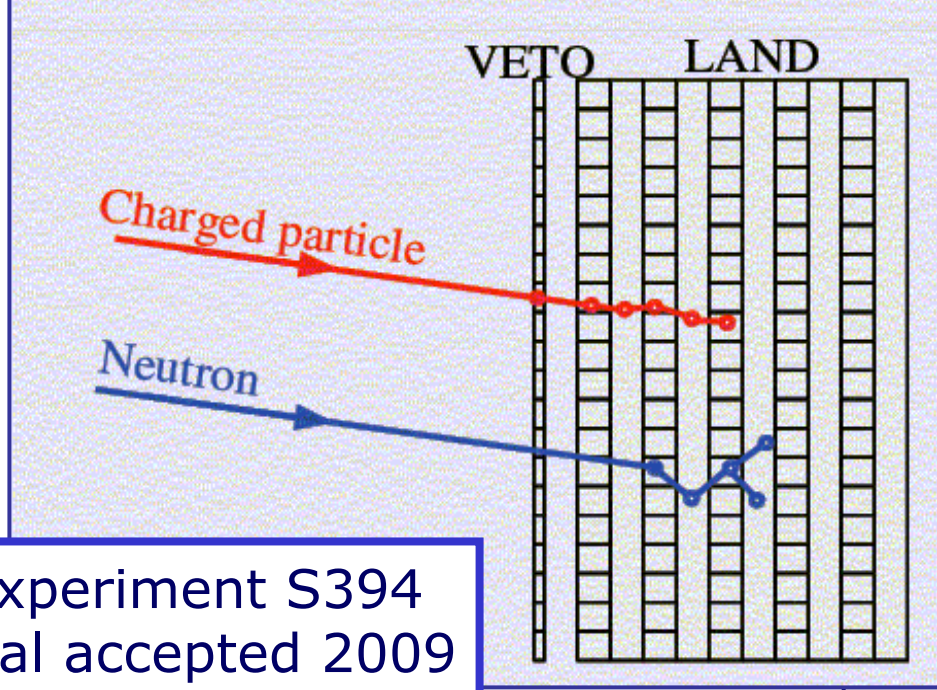
conclusions:
present elliptic flow result compatible with sub-saturation MSU result
not compatible with result from analysis of pion ratios
impact-parameter dependence barely consistent within errors

crucial for future experiment:
higher statistics
measure fragment data for consistency and check of cluster algorithm
support background measurement with simulations
more precise efficiency of LAND?

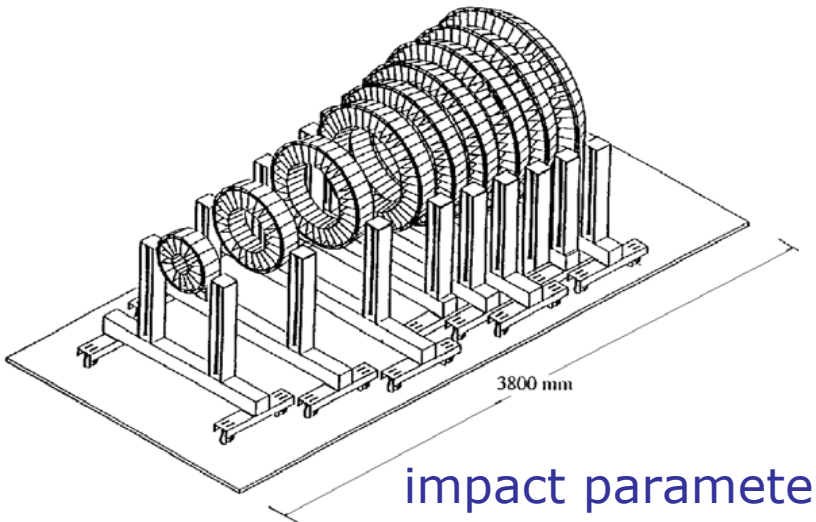
UrQMD:
impact parameter dependence
pion ratios

ultimate goal:
theory invariant conclusions





SIS experiment S394
proposal accepted 2009



impact parameter
orientation and modulus

calorimeter