Directed and elliptic flow in ^{197}Au+^{197}Au at intermediate energies

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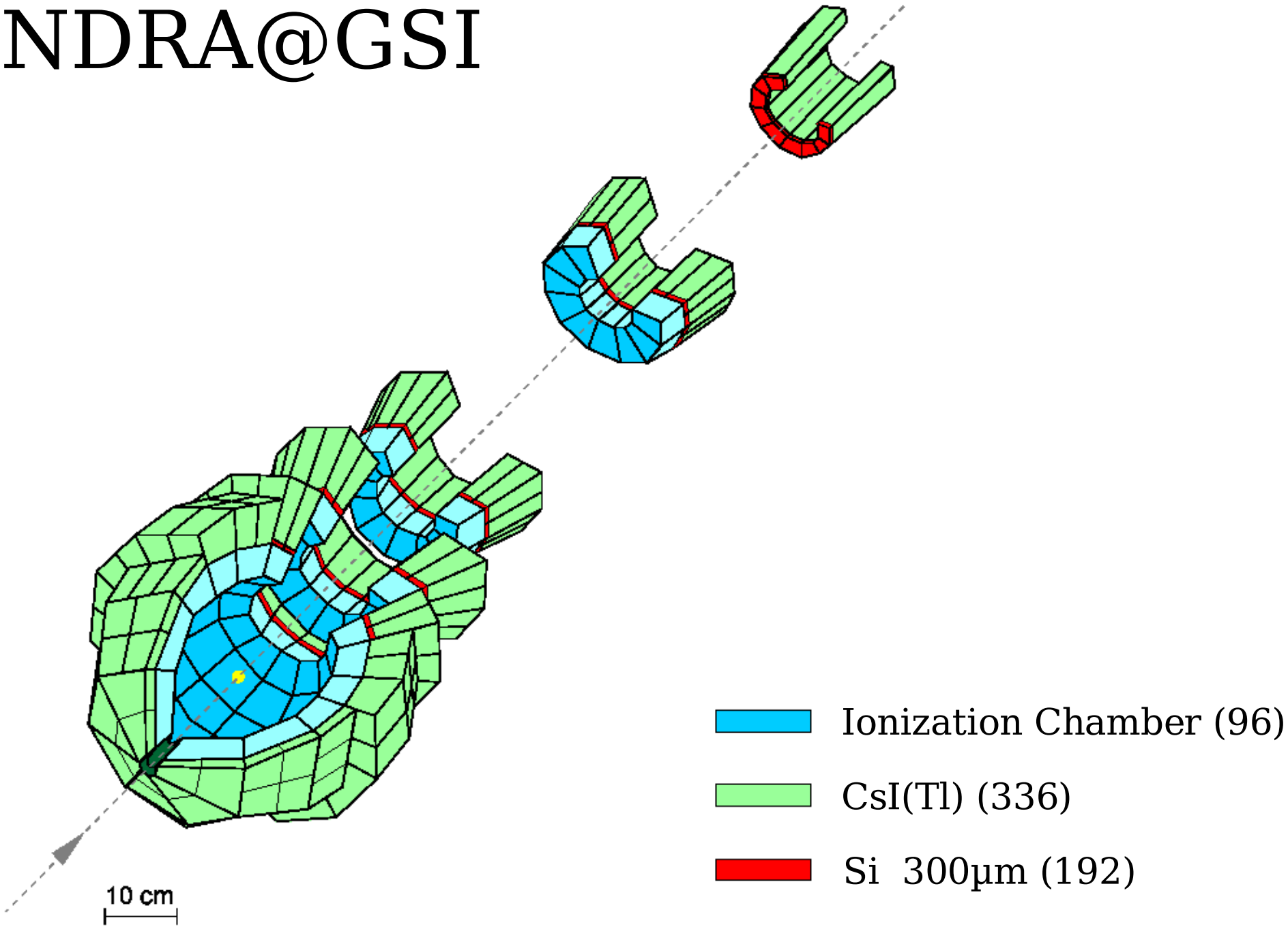
The INDRA and ALADIN Collaborations

[1)] GSI Darmstadt, Germany • [2)] GANIL Caen, France • [3)] IPN Orsay, France • [4)] LPC Caen, France
[5)] DAPNIA Saclay, France • [6)] IPN Lyon, France • [7)] INFN Napoli, Italy • [8)] INFN Catania, Italy
[9)] SINS Warsaw, Poland • [10)] IFJ Kraków, Poland • [11)] CNAM Paris, France

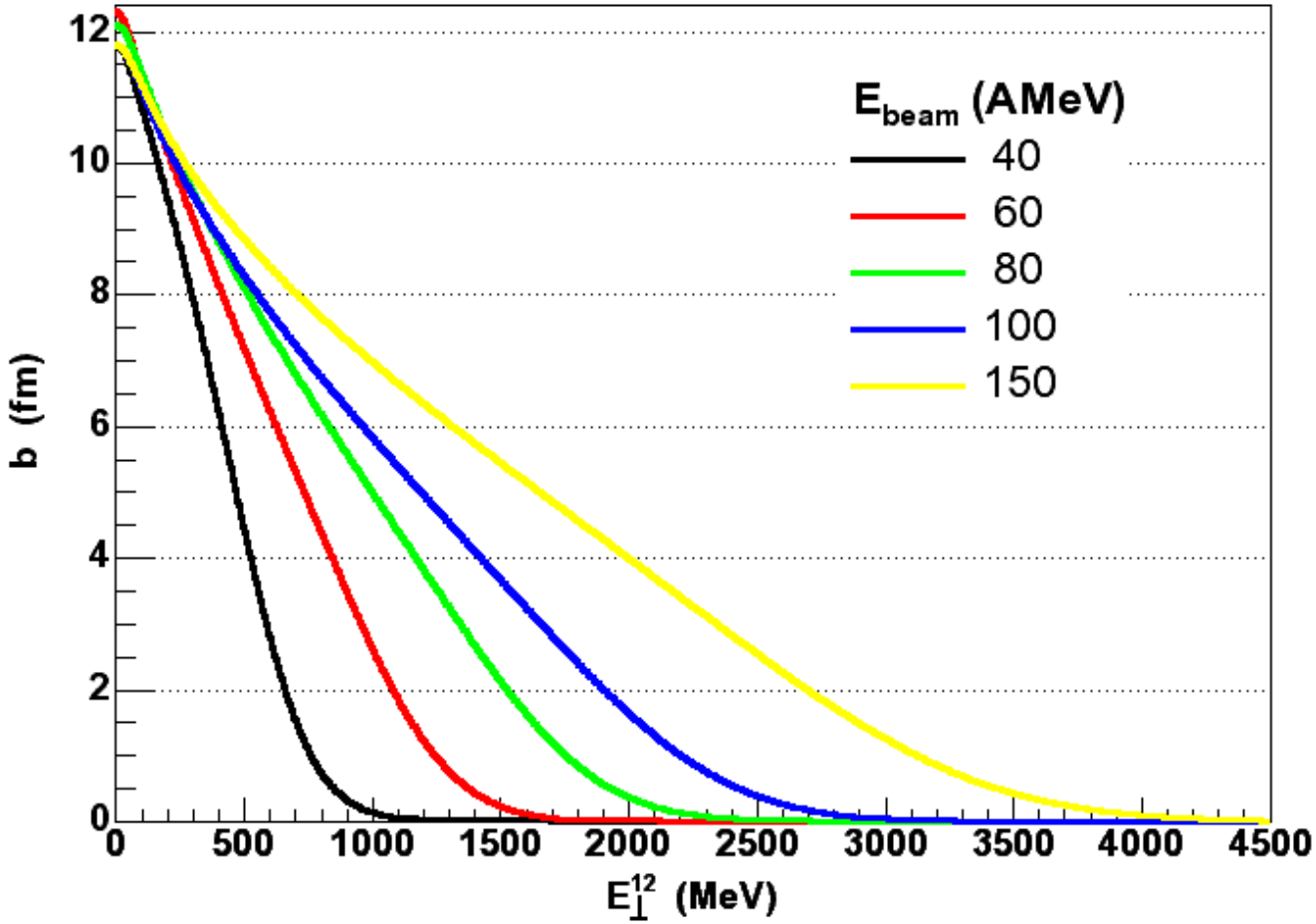
INDRA@GSI: Au+Au @ 40-150 AMeV

INDRA@GSI



Centrality selection

Au+Au, MULT≤5



Collective flow

“global”

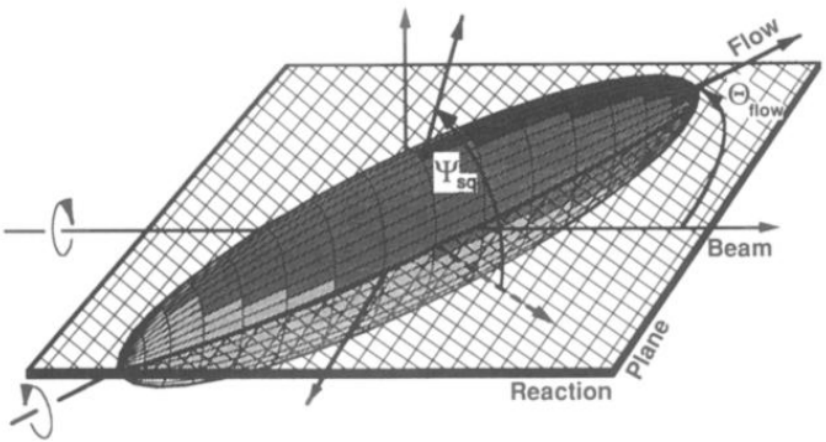


FIG. 3. A perspective view of a tri-axial ellipsoid. The major flow axis and the beam axis define the polar flow angle, θ_{flow}, and the reaction plane. The squeeze angle, ψ_{sq}, is defined as the azimuthal angle around the flow axis of the medium axis of the ellipsoid relative to the reaction plane.

H.H Gutbrod et al, PRC 42(1990)640

“detailed”

Fourier expansion of the azimuthal distributions measured with respect to the reaction plane

$$dN/d\varphi \propto 1+2\upsilon_1 \cos\varphi + 2\upsilon_2 \cos 2\varphi + \ldots$$

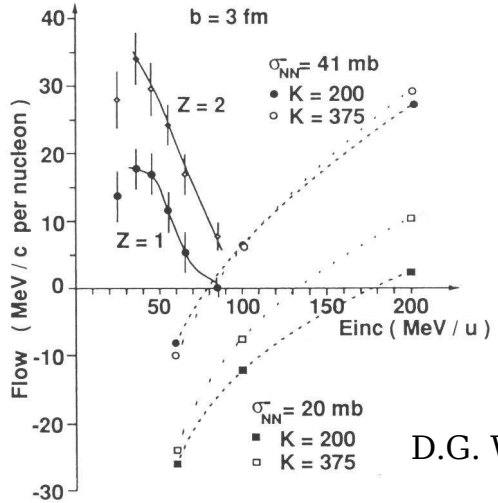
$$\upsilon_1 = \langle \cos\varphi \rangle$$

$$\upsilon_2 = \langle \cos 2\varphi \rangle$$

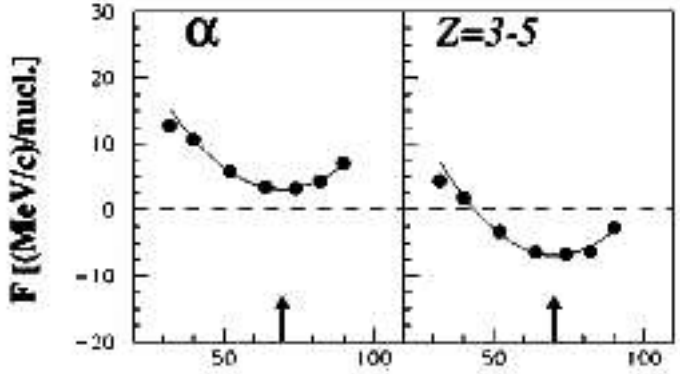
$$\upsilon_i = \upsilon_i(Z, y, p_\perp)$$

Directed flow

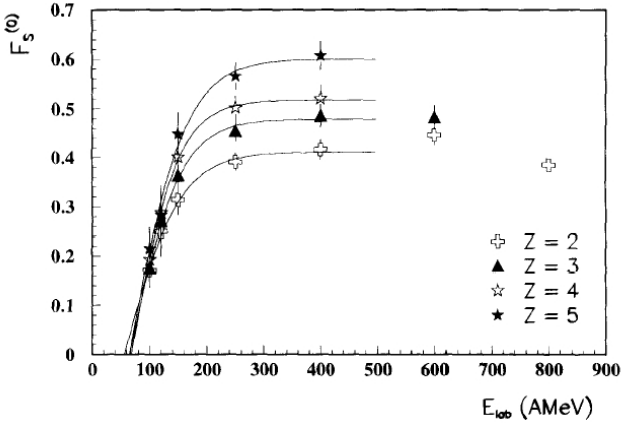
$^{40}Ar+^{27}Al$, Mur+Tonneau
J.P. Sullivan et al. PLB 249(90)8



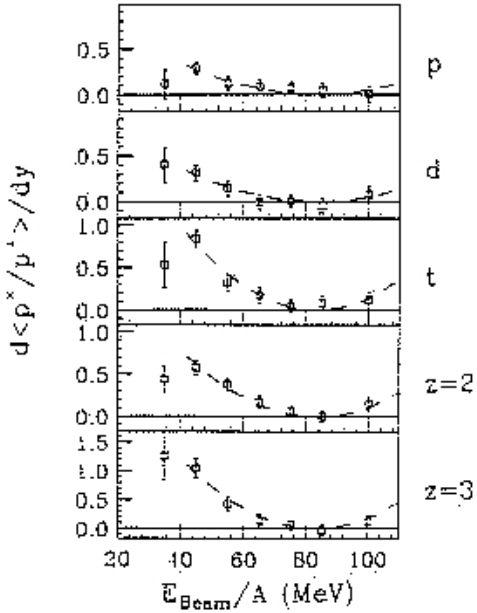
$^{58}Ni+^{58}Ni$, INDRA
D. Cussol et al. PRC 65(02)44604



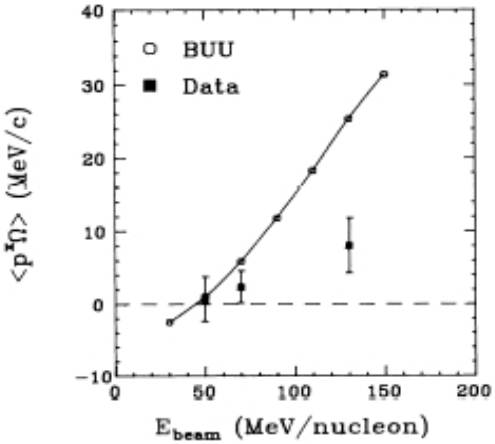
$^{197}Au+^{197}Au$, FOPI
P. Crochet et al. NPA 624(97)755



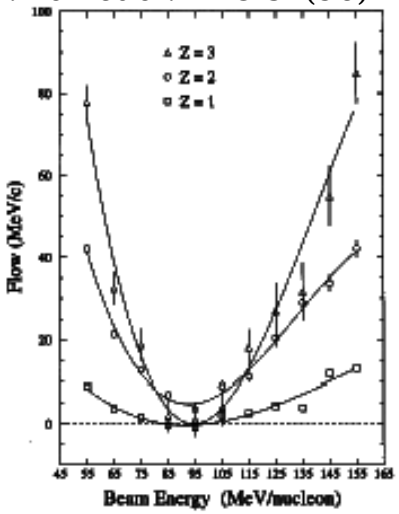
$^{40}Ar+^{51}V$, MSU 4π
D.G. Westfall et al. NPA 519(90)141c



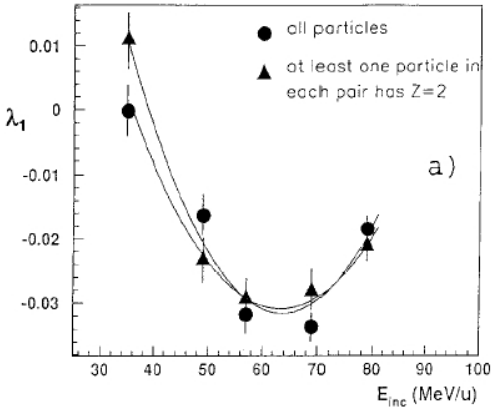
$^{139}La+^{139}La$, LBL Streamer Chamber
D. Krofcheck et al. PRL 63(89)2028



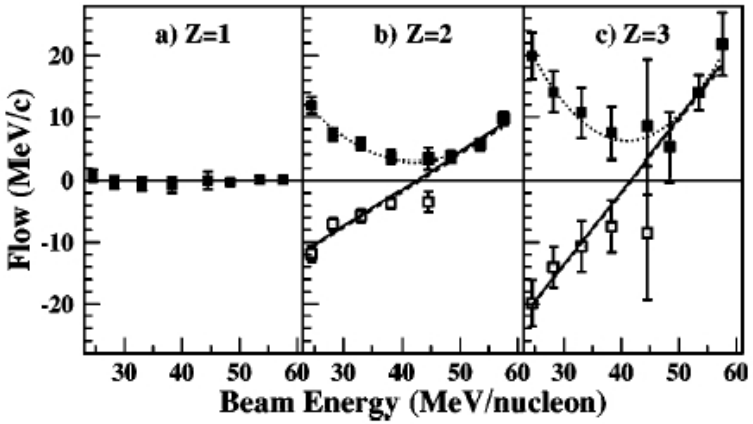
$^{40}Ar+^{45}Sc$, MSU 4π
R. Pak et al. PRC 54(96)2457



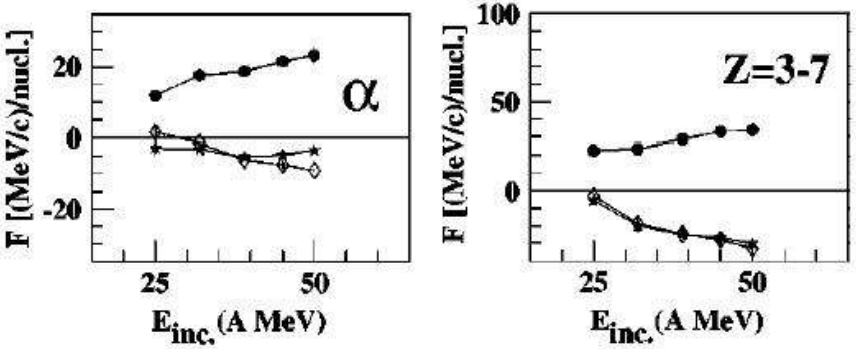
$^{64}Zn+^{58}Ni$, Mur+Tonneau
A. Buta et al. NPA 584(95)397



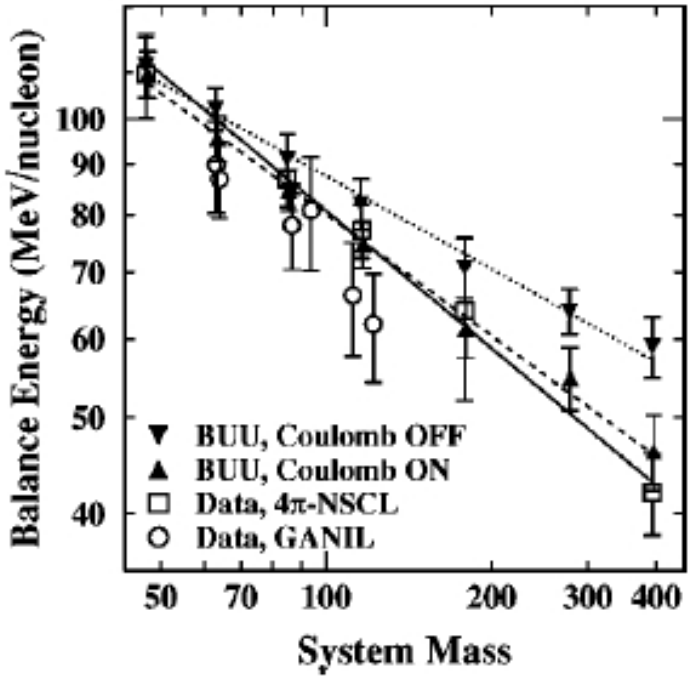
$^{197}Au+^{197}Au$, MSU 4π
D.J. Magestro et al. PRC 61(00)21602



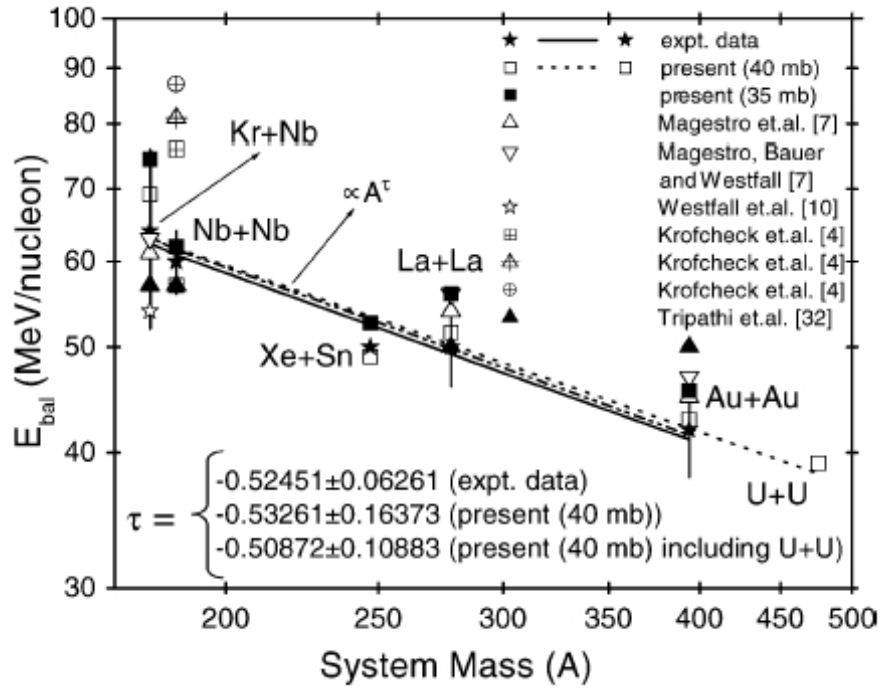
$^{129}Xe+^{nat}Sn$,
INDRA
D. Cussol et al.
PRC 65(02)44604



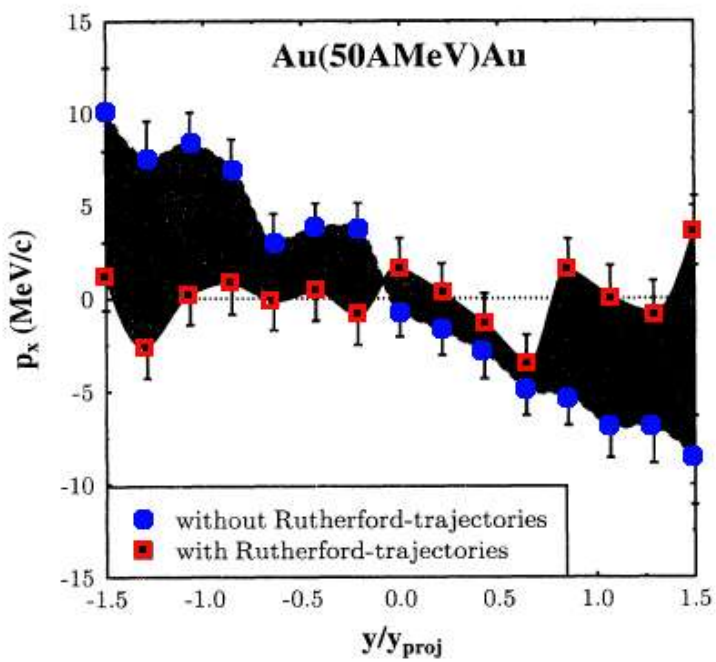
D.J. Magestro et al. PRC 61(00)21602

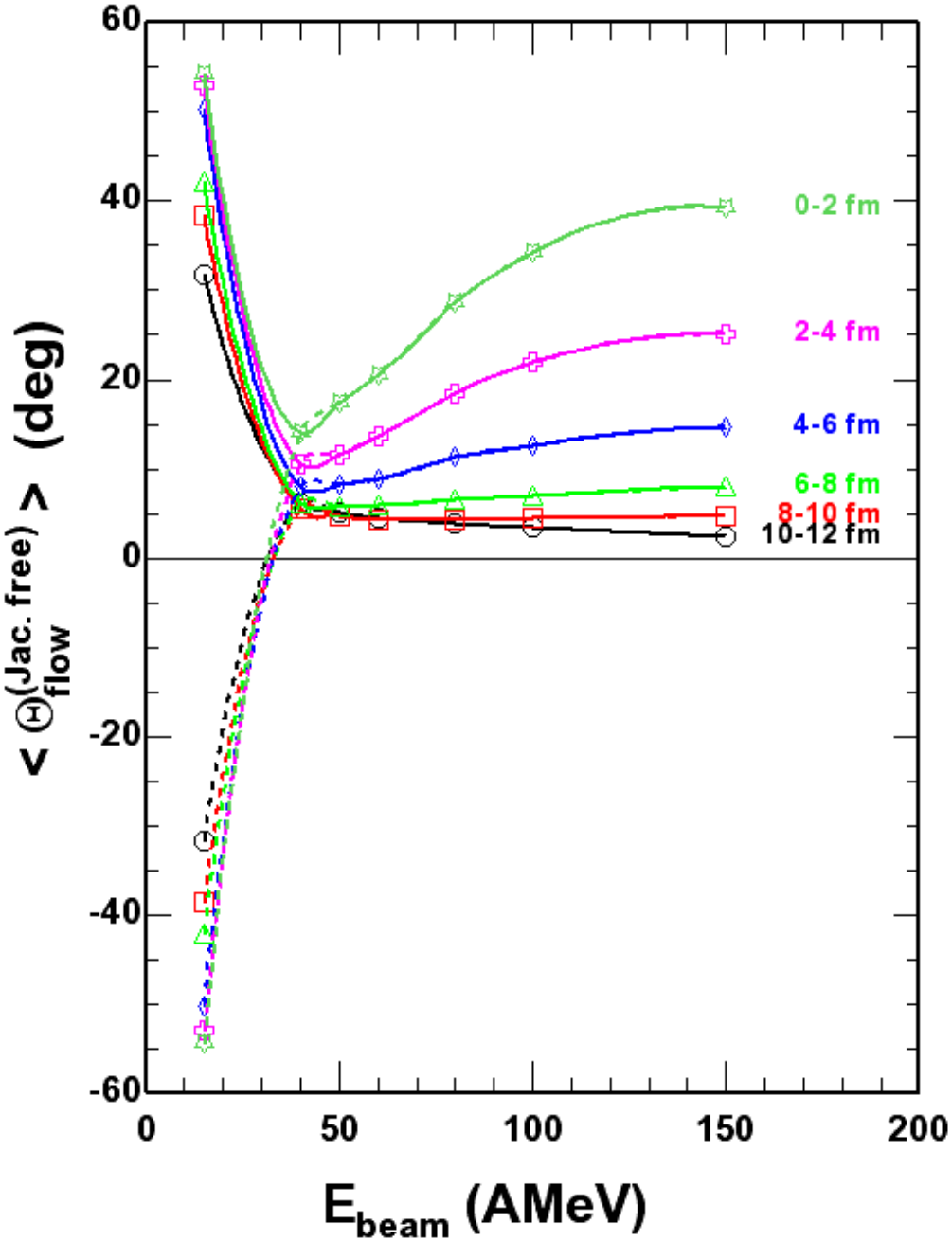


A.D. Sood et al. PLB 594(04)260
(QMD)



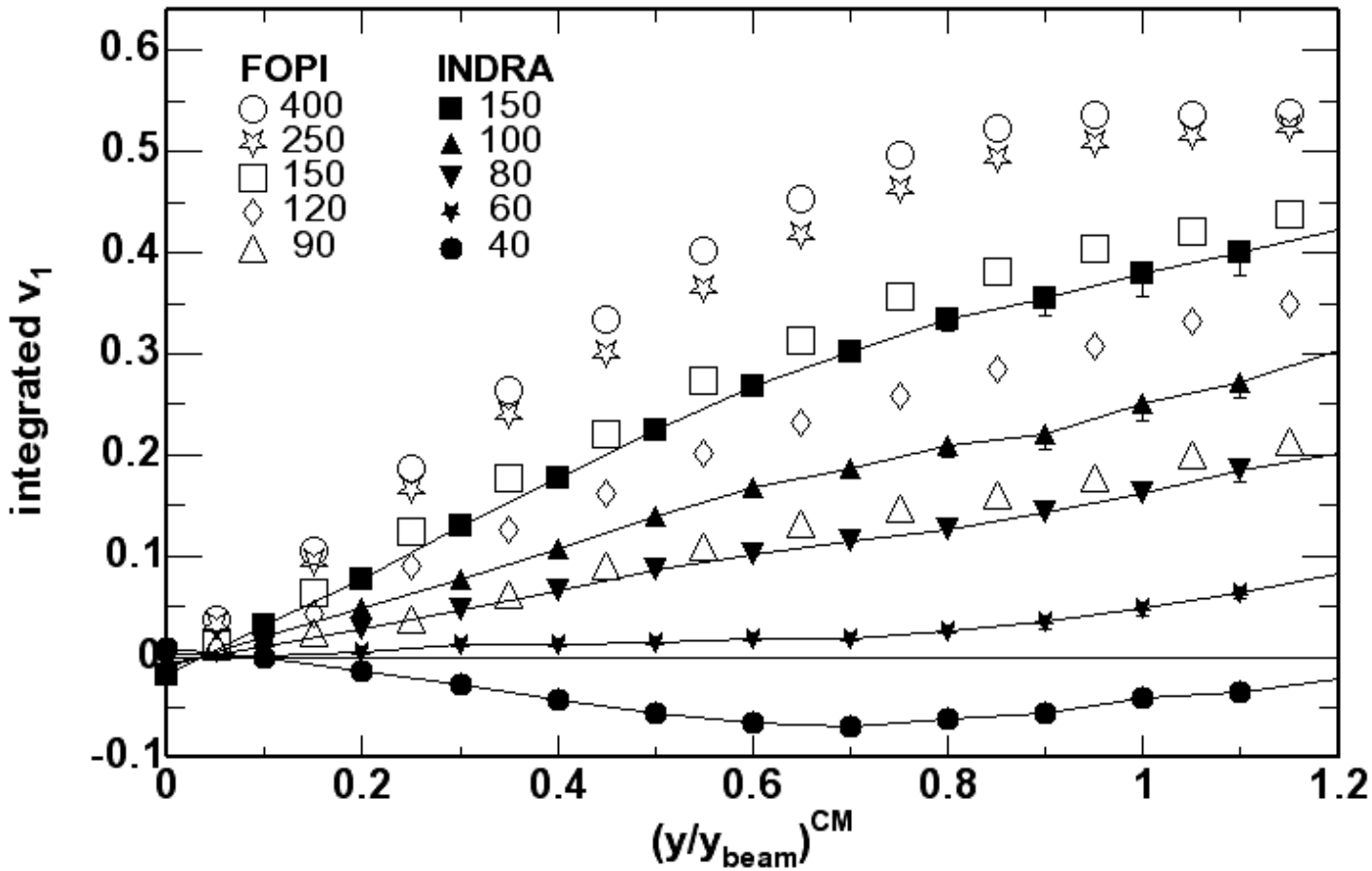
S. Soff et al. PRC 51(95)3320
(QMD)



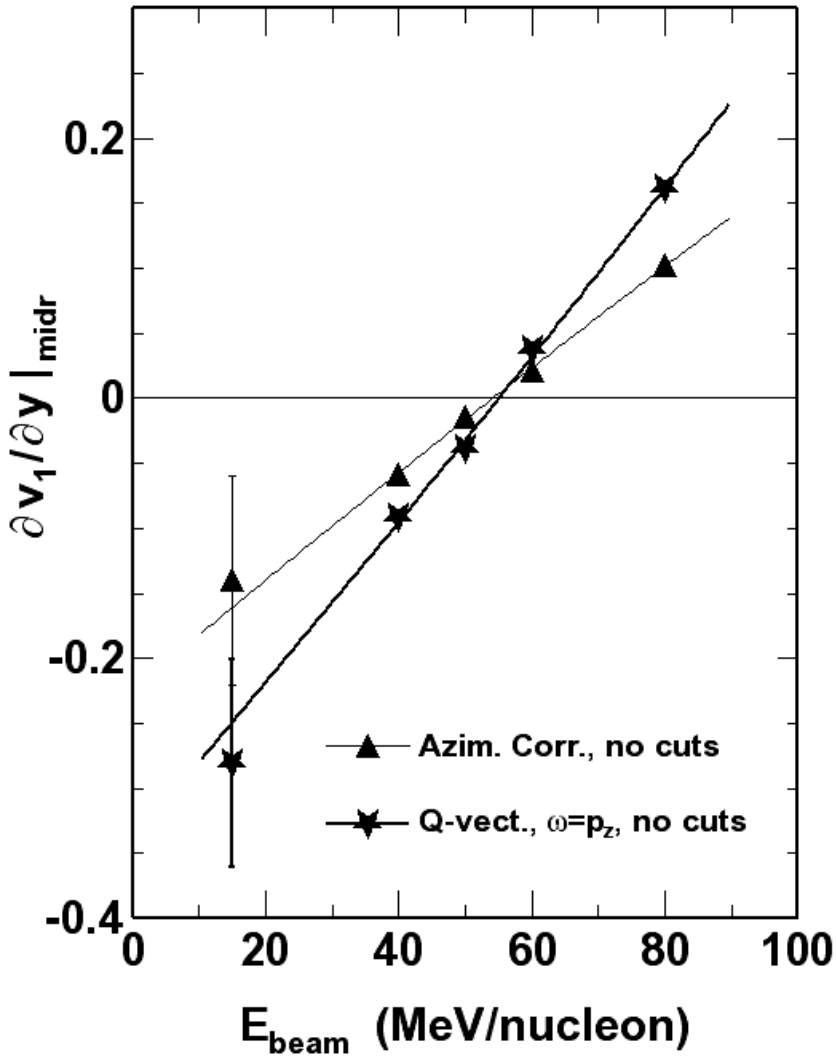


Mean flow angle

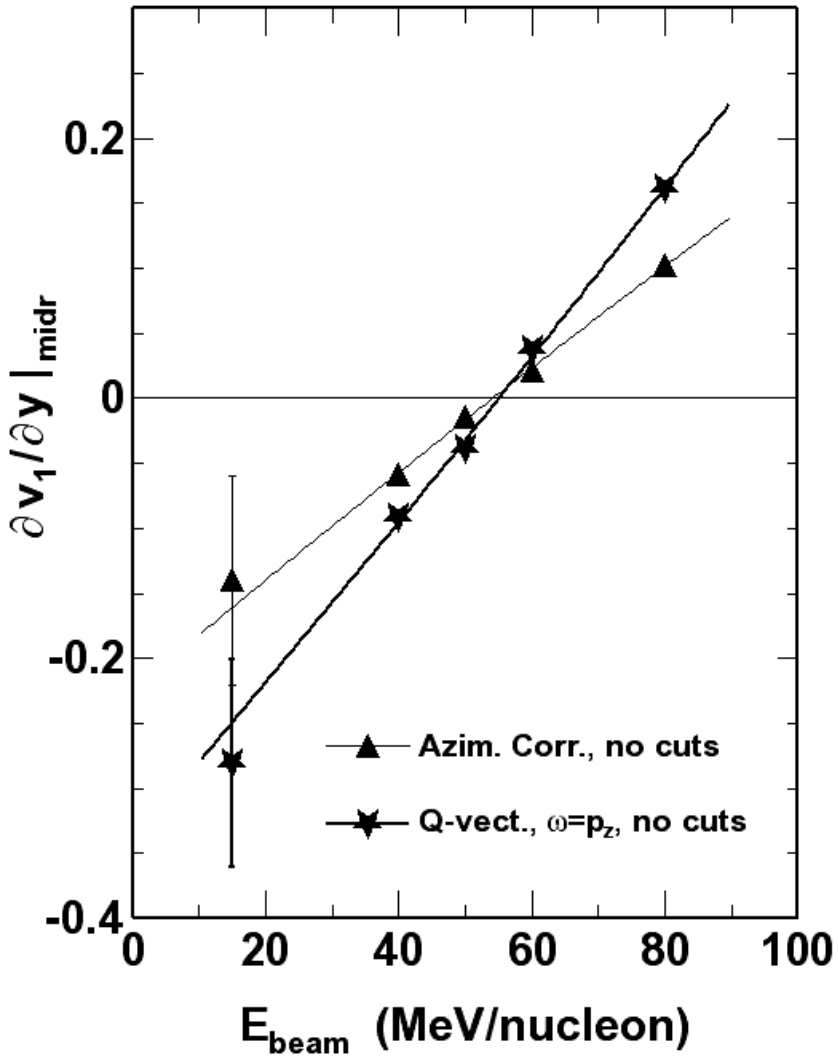
$^{197}Au+^{197}Au$, Z=2, b=2-5.3 fm



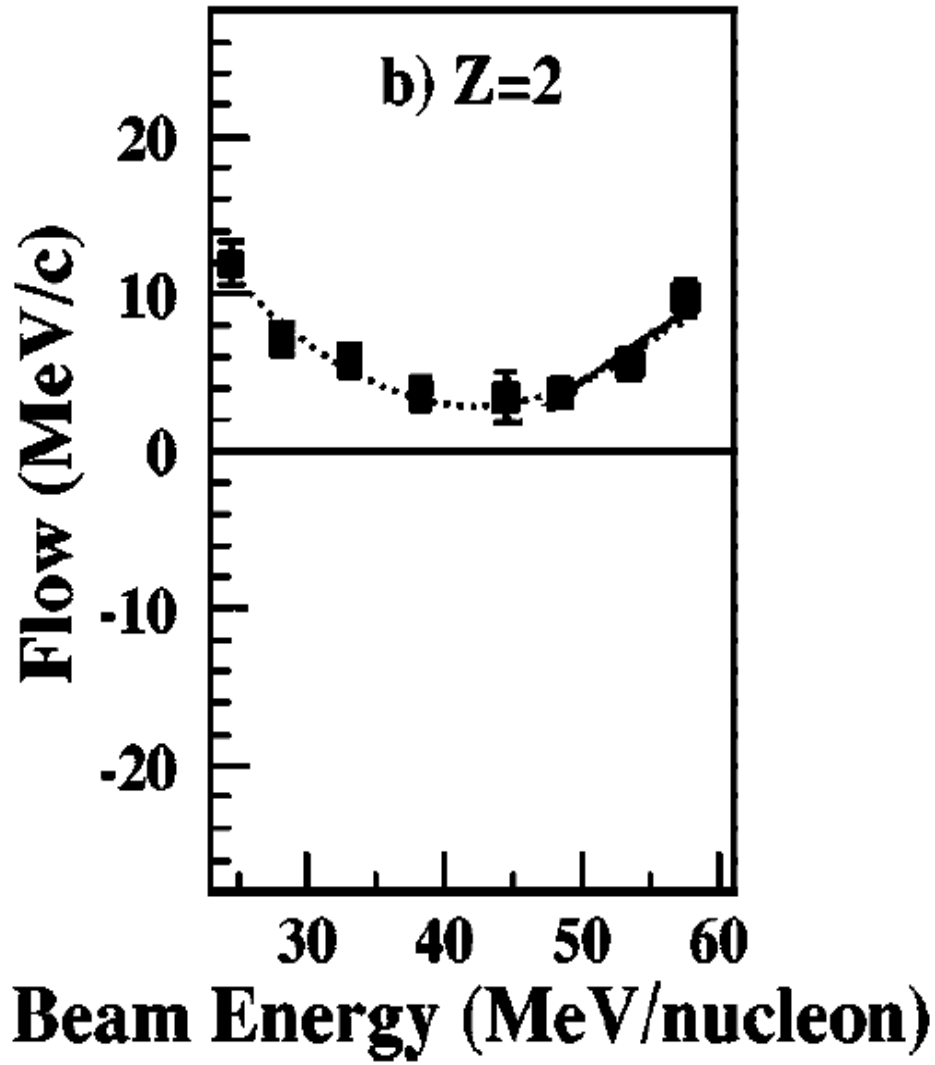
$^{192}Au+^{192}Au$, INDRA
Z=2, b<4 fm



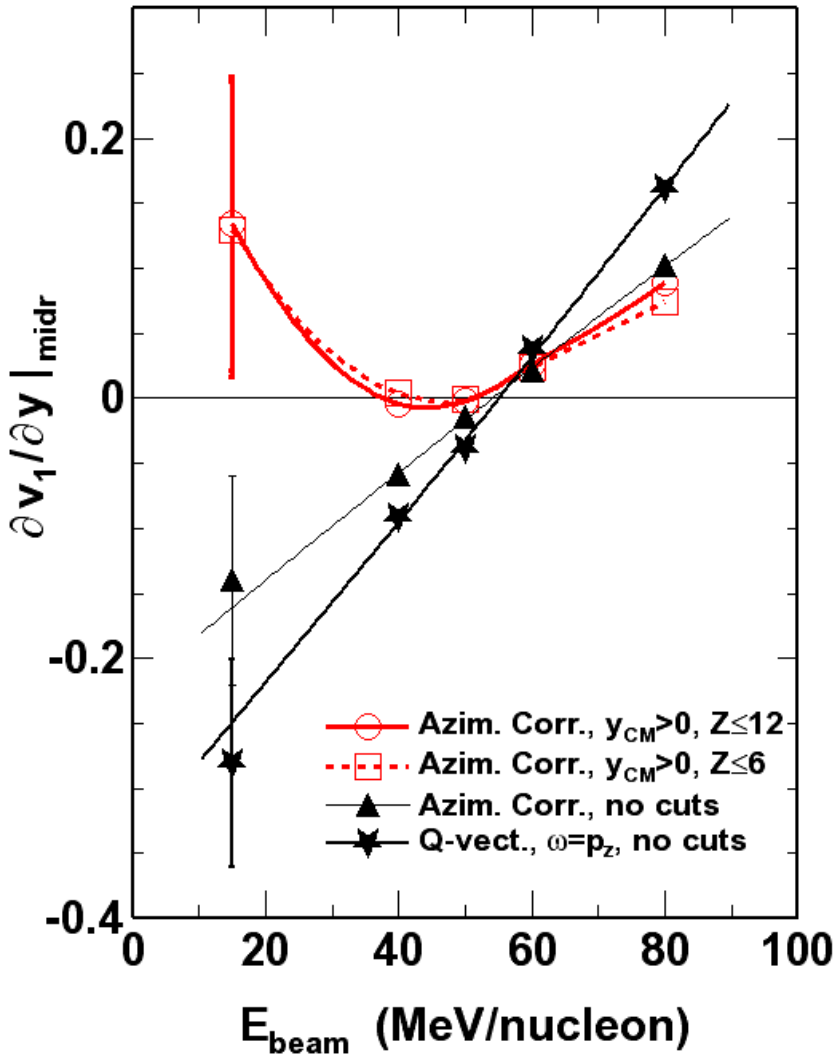
^{192}Au+^{192}Au, INDRA
Z=2, b<4 fm



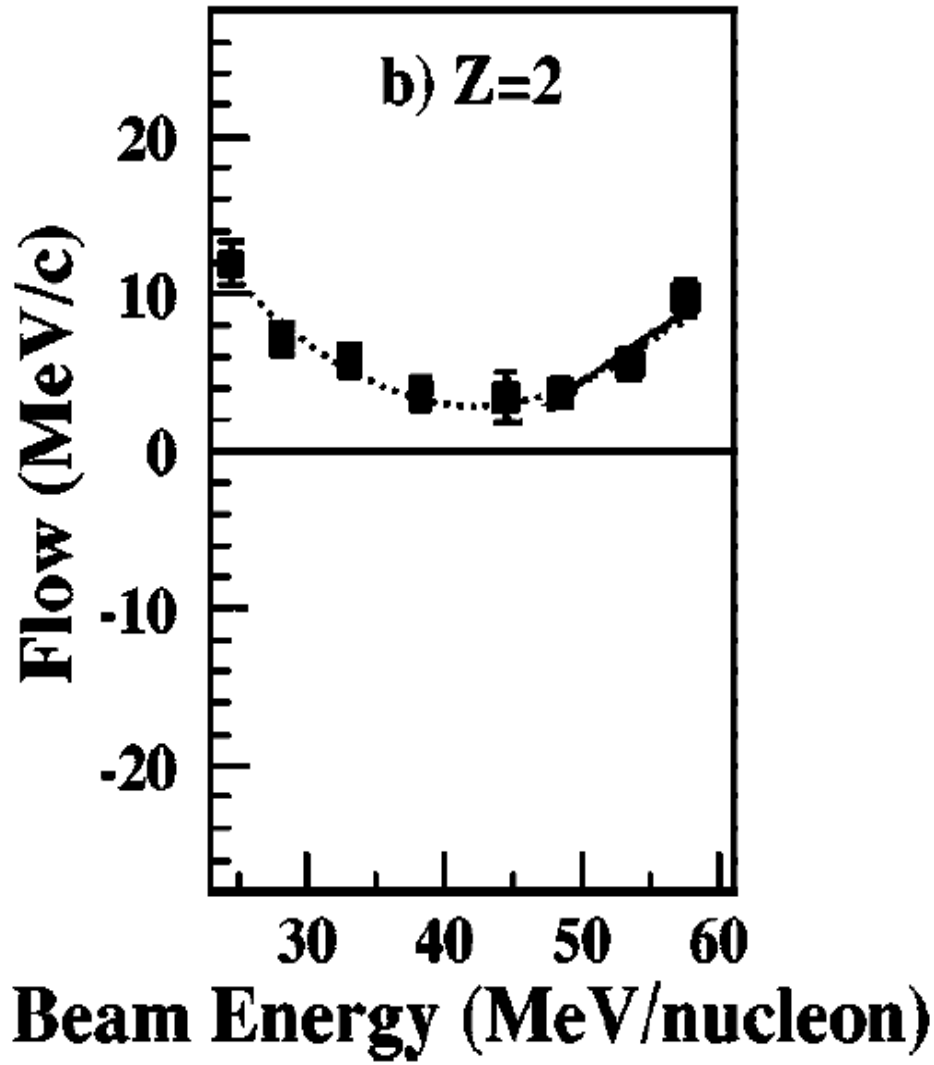
^{197}Au+^{197}Au, MSU 4π
D.J. Magestro et al.
PRC 61(00)21602



^{192}Au+^{192}Au, INDRA
Z=2, b<4 fm

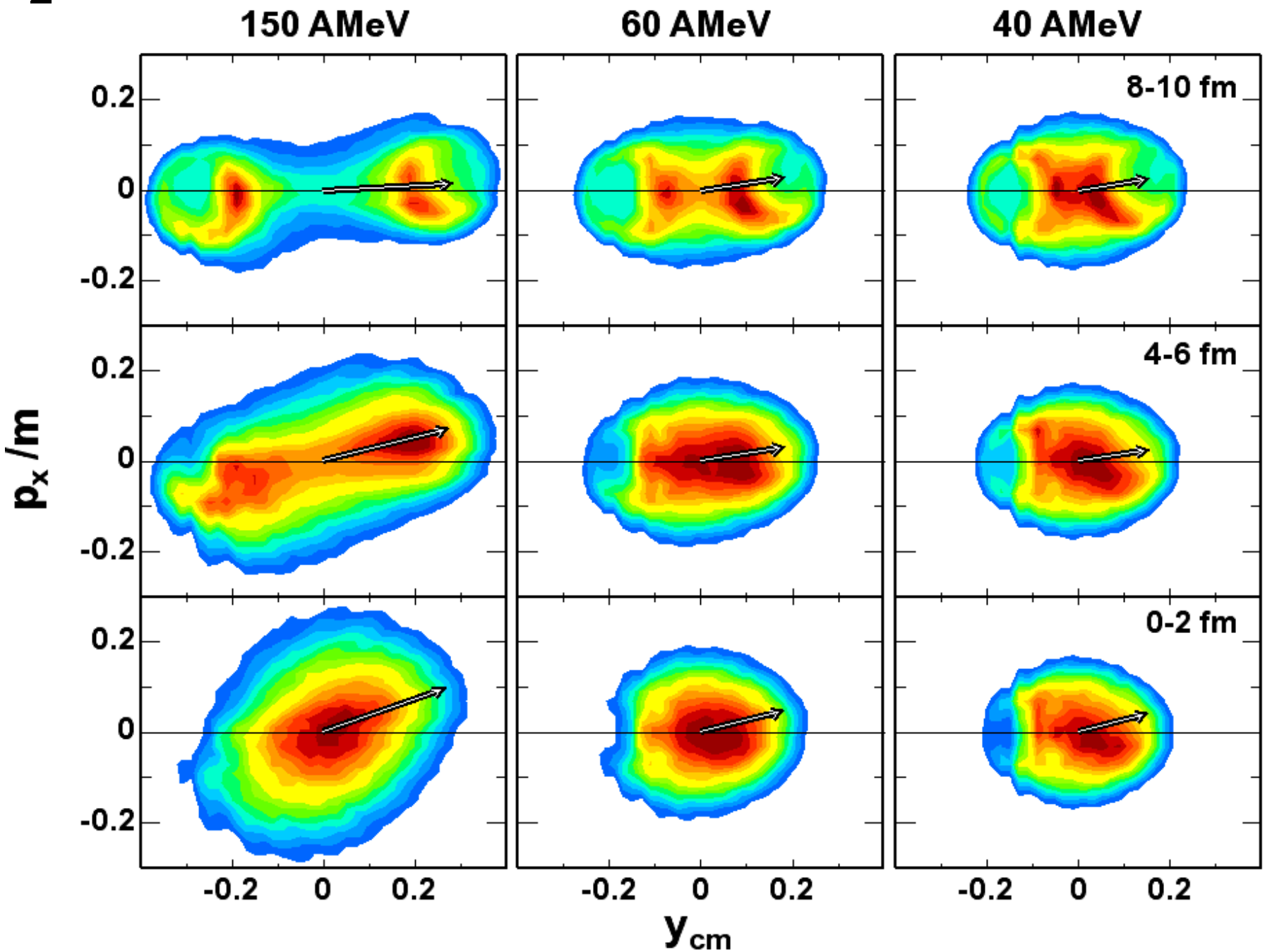


^{197}Au+^{197}Au, MSU 4π
D.J. Magestro et al.
PRC 61(00)21602

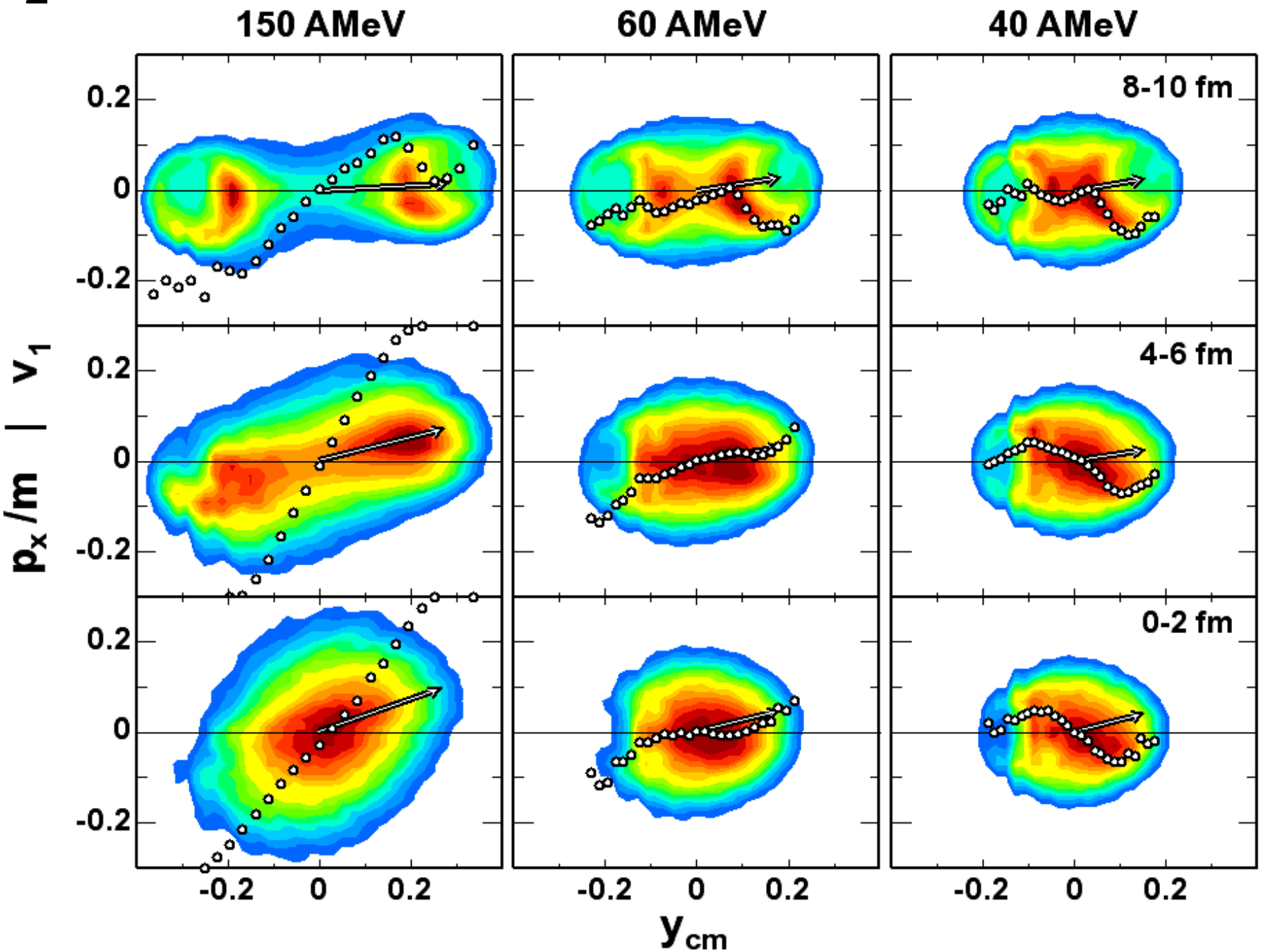


Origin of negative flow

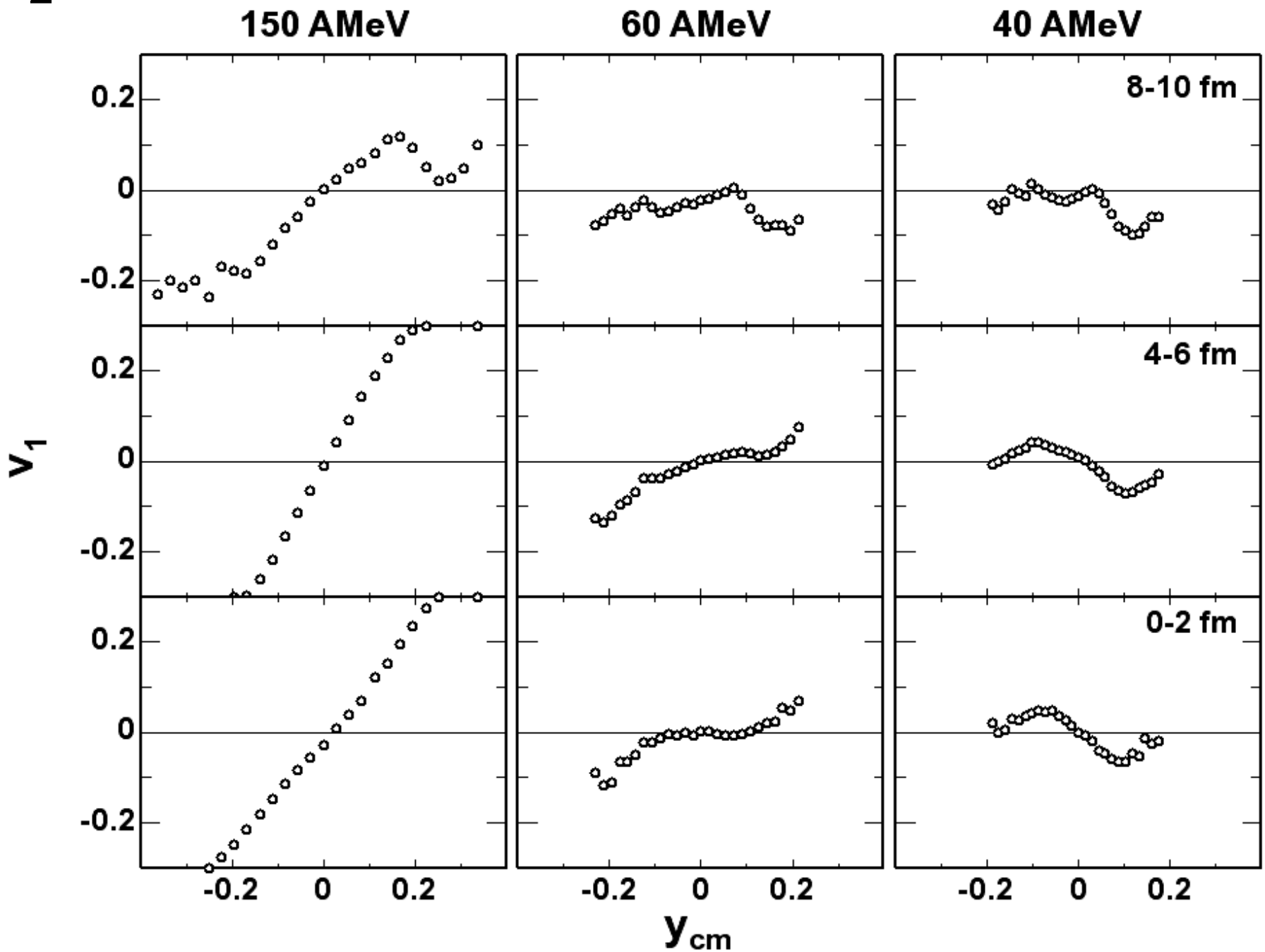
Z=2



Z=2



Z=2



Squeeze-out, elliptic flow

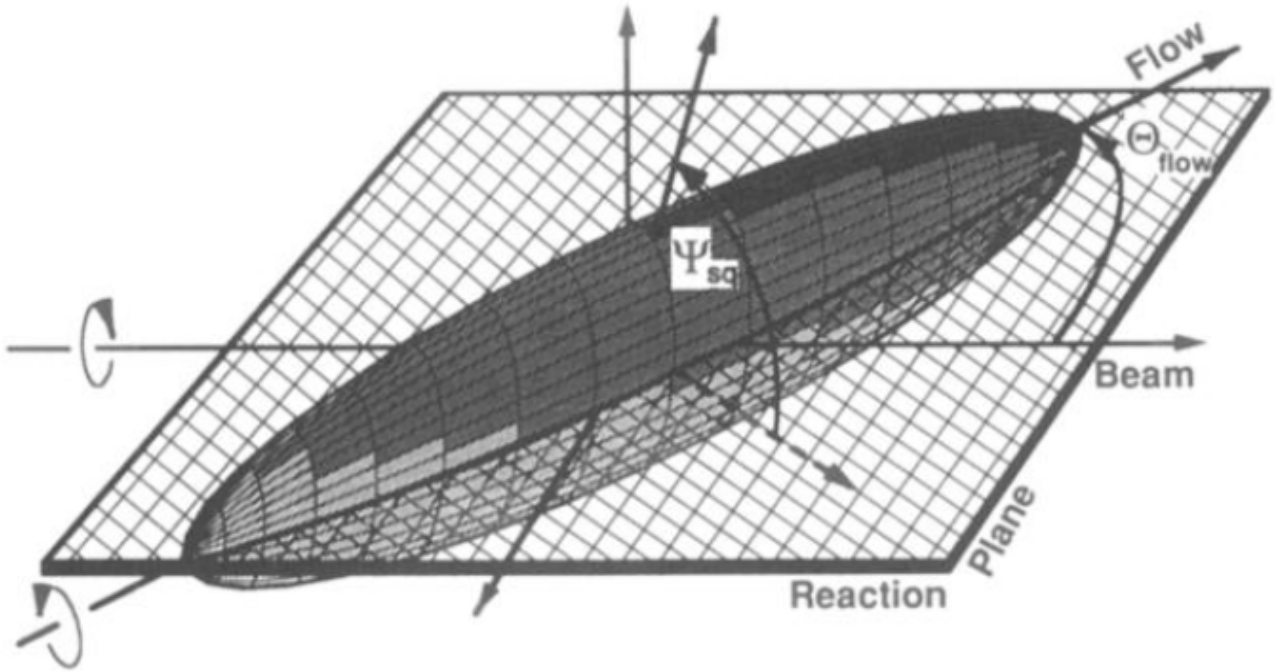
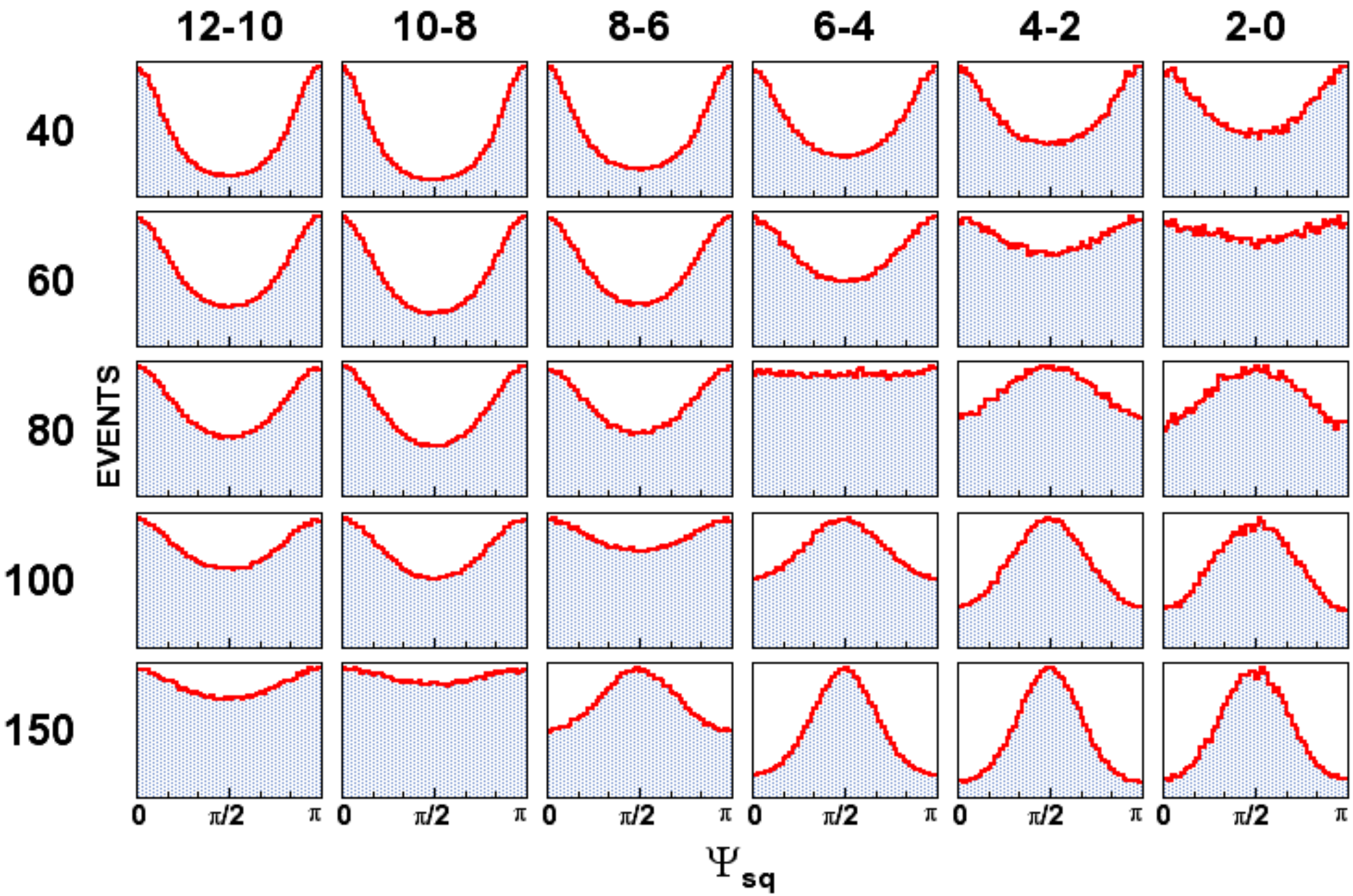
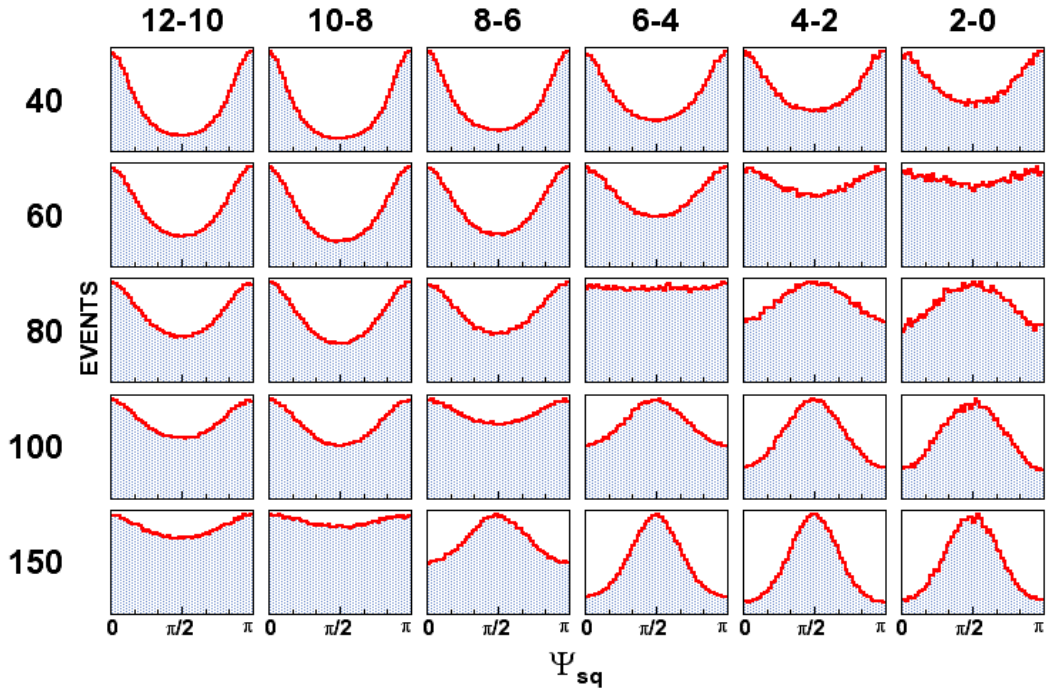


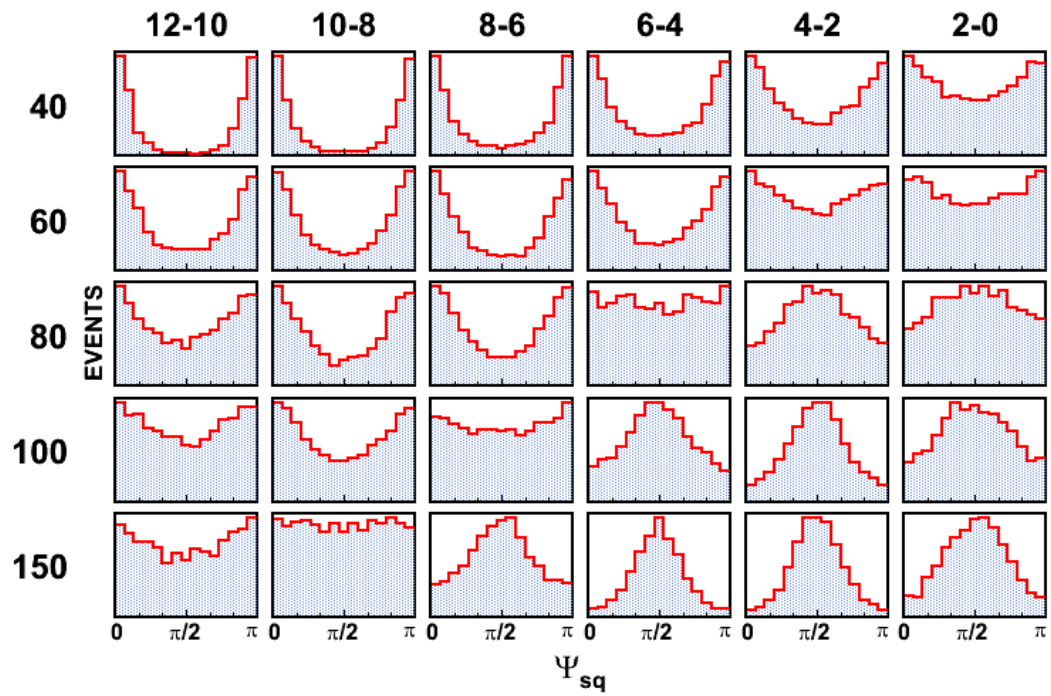
FIG. 3. A perspective view of a tri-axial ellipsoid. The major flow axis and the beam axis define the polar flow angle, θ_{flow}, and the reaction plane. The squeeze angle, ψ_{sq}, is defined as the azimuthal angle around the flow axis of the medium axis of the ellipsoid relative to the reaction plane.

Squeeze-angle distributions



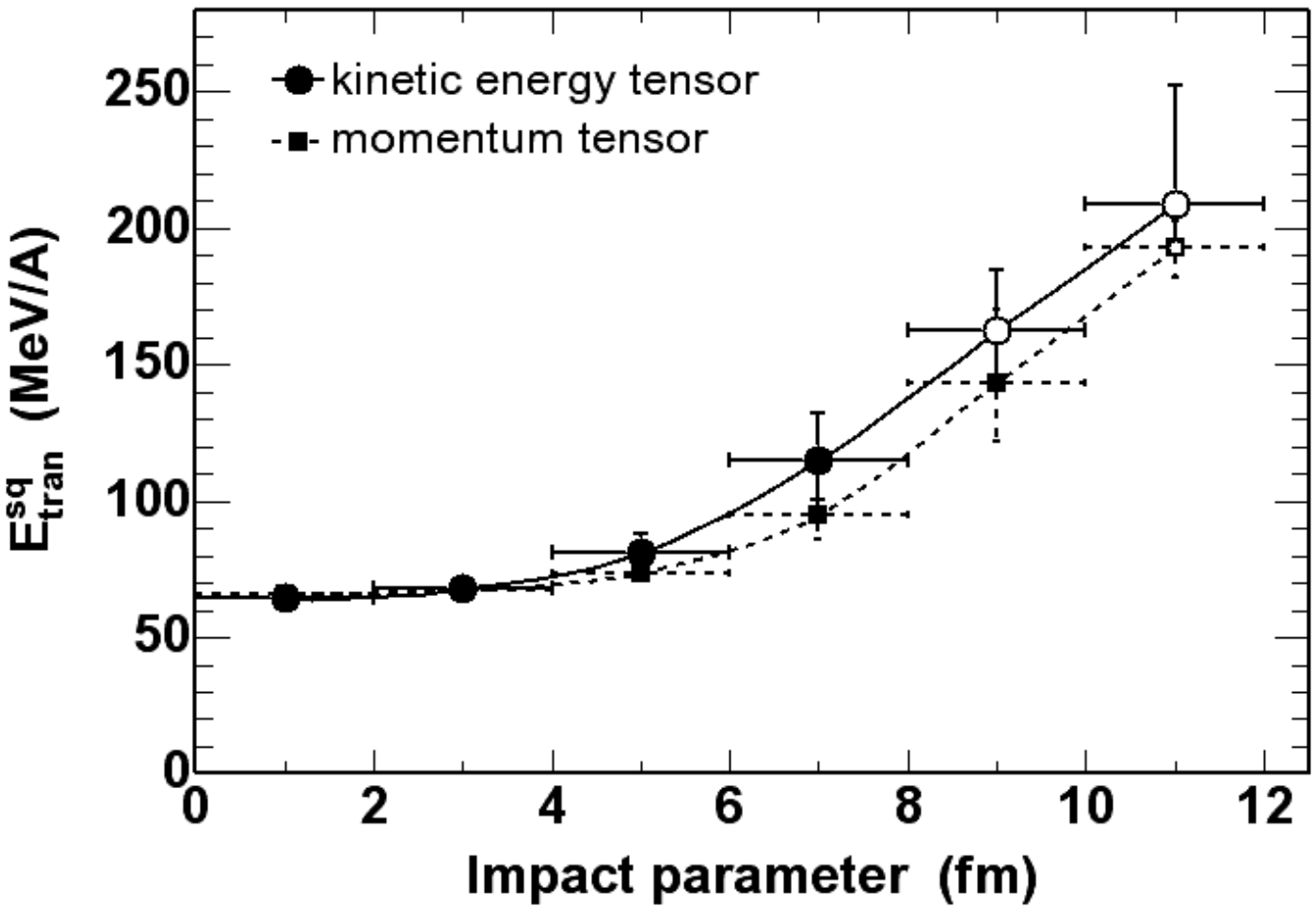


INDRA

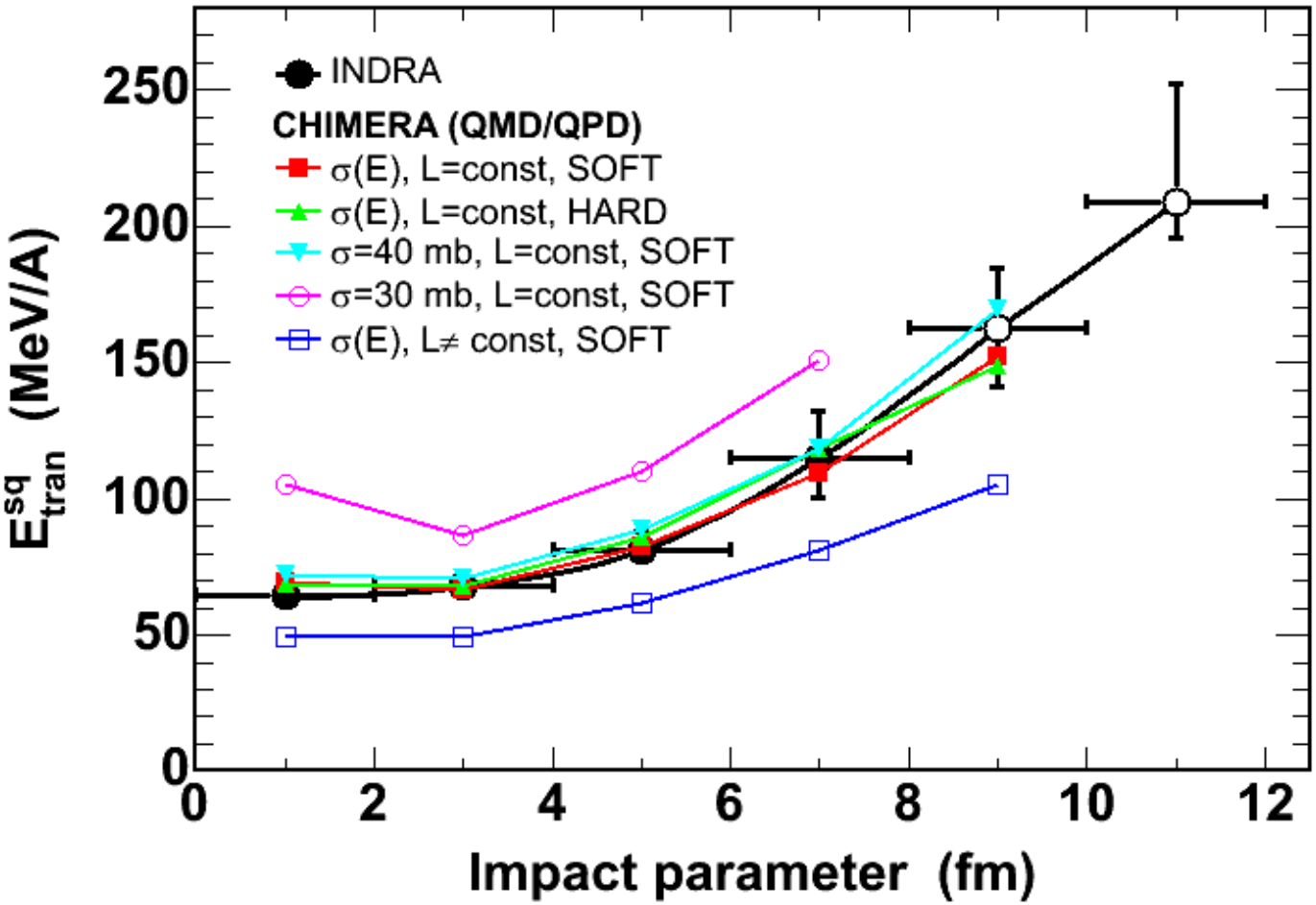


CHIMERA
(QMD/QPD)

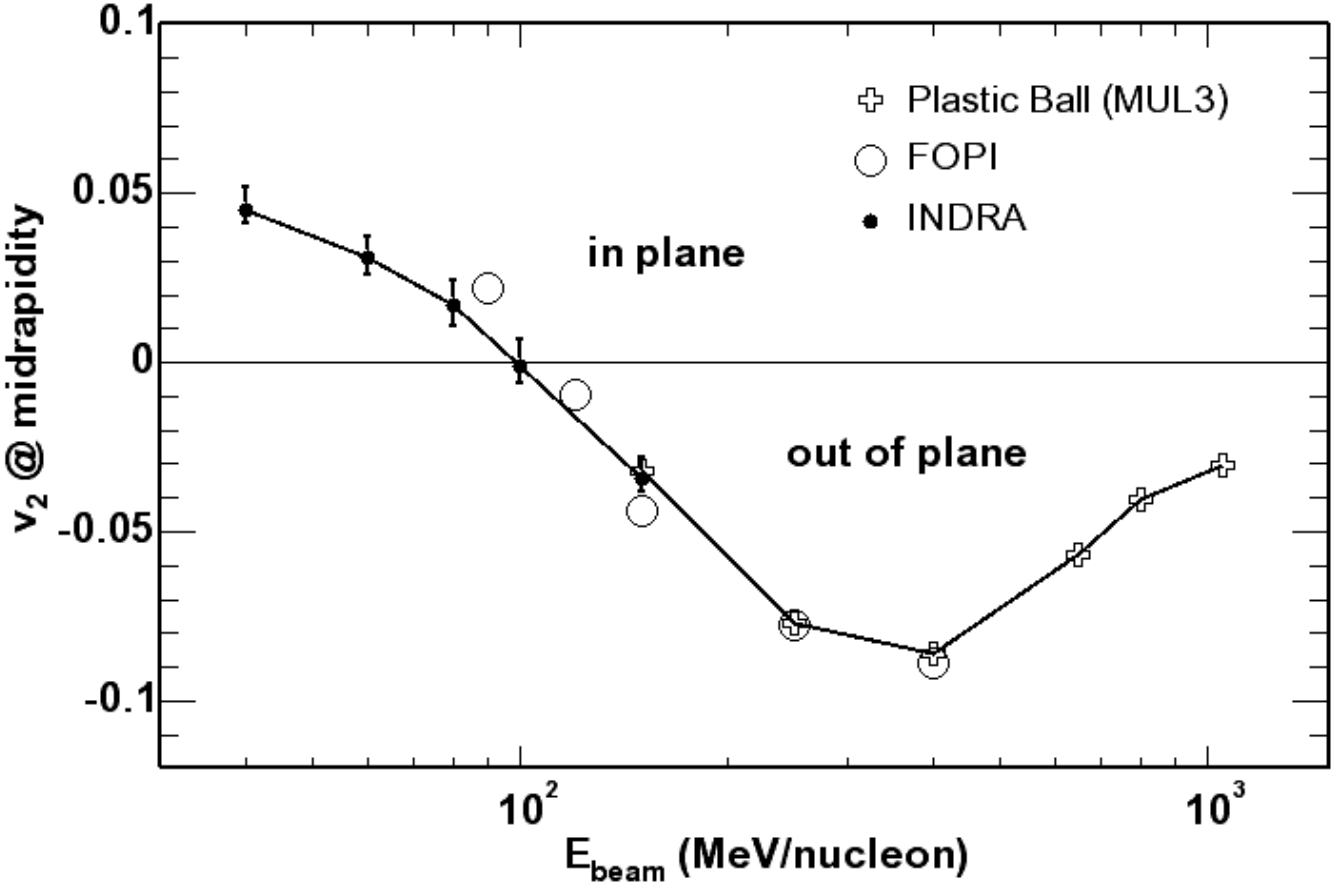
Global squeeze-out transition energy for different centralities



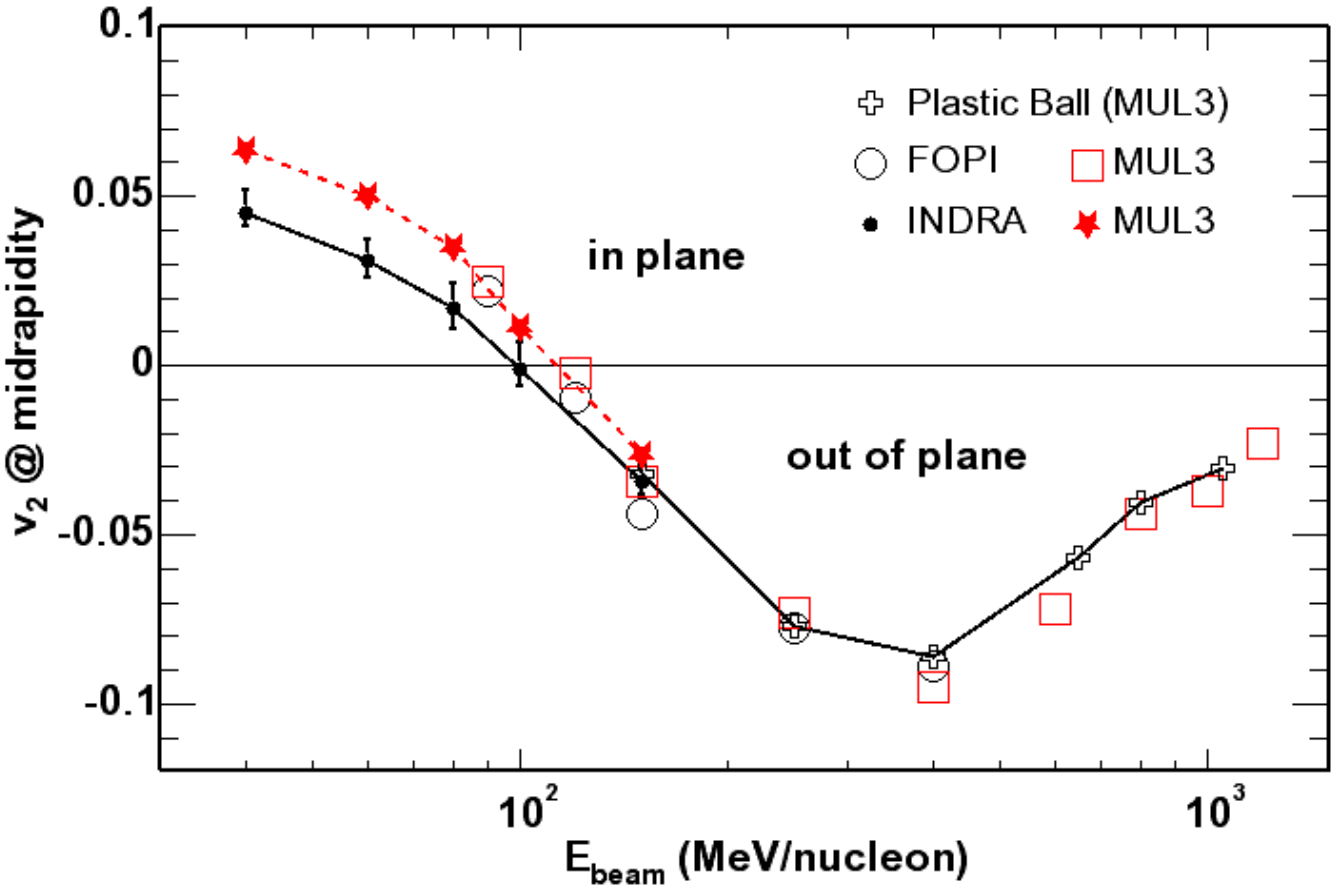
Global squeeze-out transition energy for different centralities



Elliptic flow for Z≤2, b=4-6 fm, rotated frame



Elliptic flow for Z≤2, b=4-6 fm, rotated frame



Summary

$^{58}Ni+^{58}Ni$
INDRA
D. Cussol et al.
PRC 65(02)44604

$^{129}Xe+^{nat/124}Sn$
INDRA
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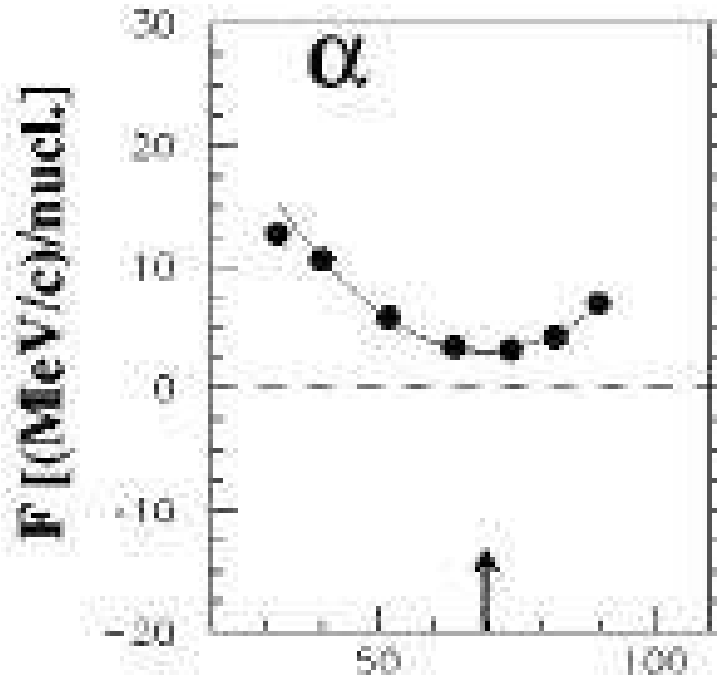
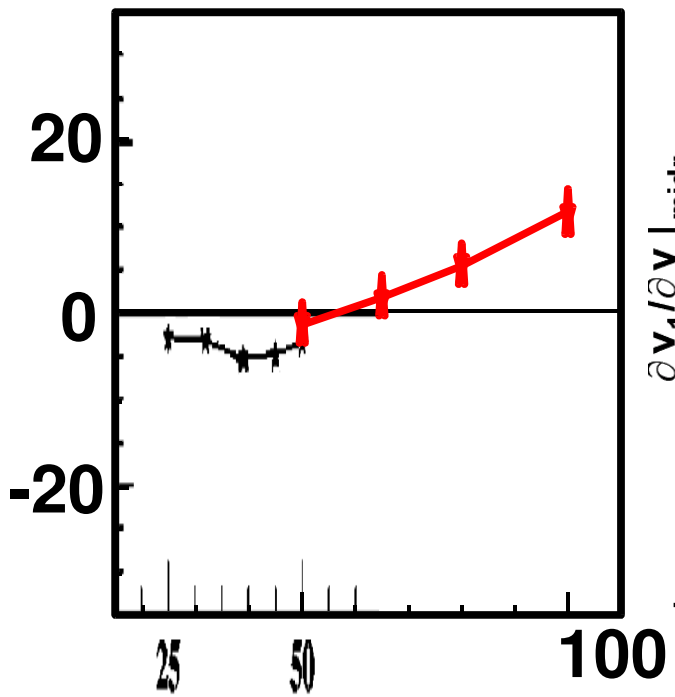
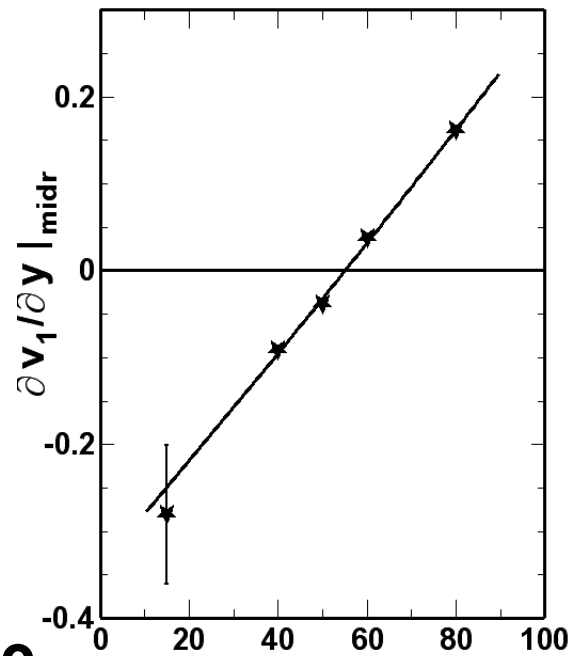
PRC 65(02)44604
+
INDRA@GSI

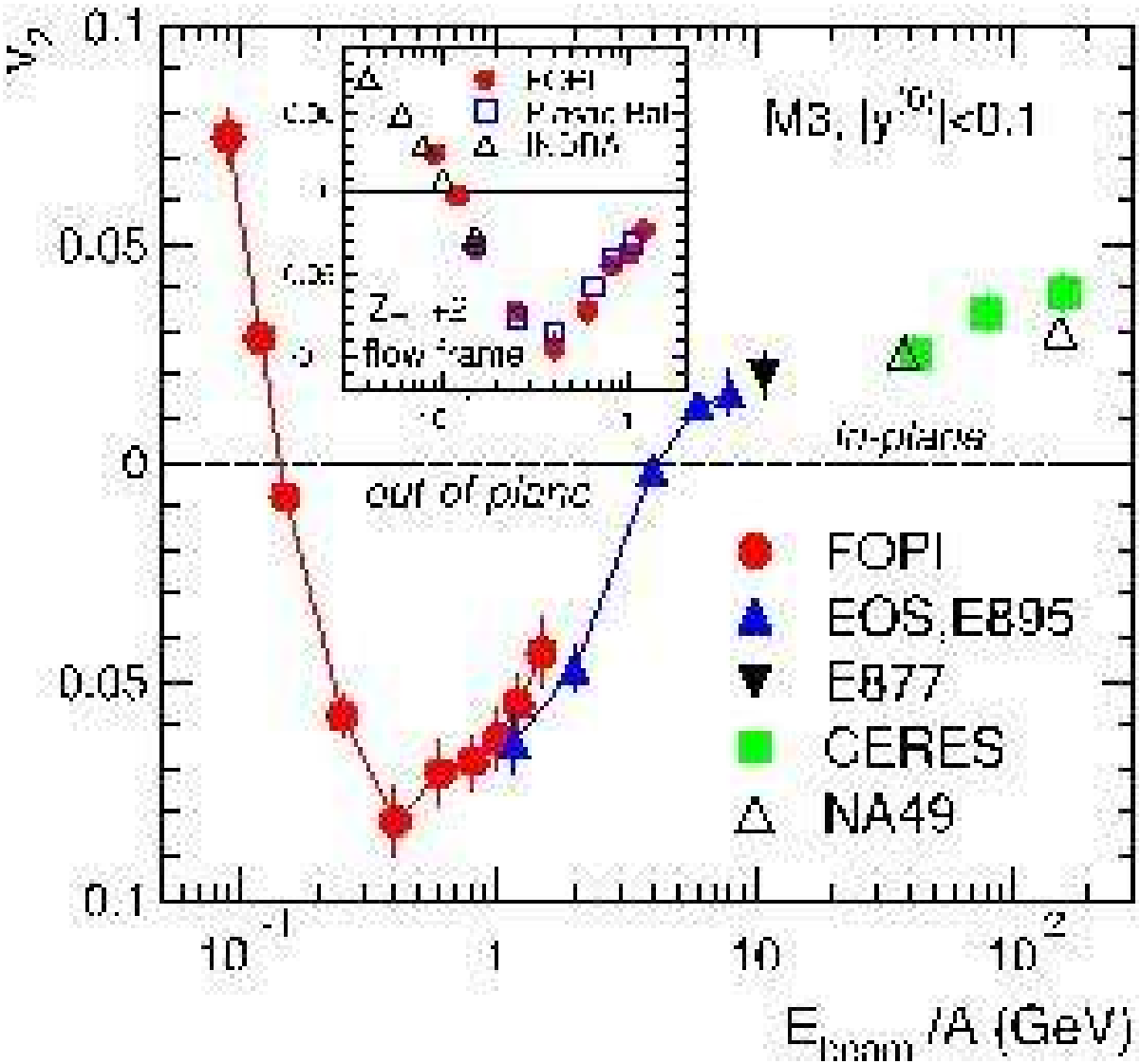
$^{197}Au+^{197}Au$
INDRA@GSI







Beam Energy (MeV/nucleon)



A. Andronic et al.
nucl-ex/0411024

For the Au+Au system:

- Directed flow changes its sign below 60 AMeV and becomes increasingly negative (anti-flow) at lower energies. There is no evidence for a parabolic behavior of the excitation function.
- The lack of minimum in the excitation function may indicate that only globally positive (repulsive) scattering can take place for very heavy systems (no transition to negative (attractive) scattering at lower energies).
- The observed anti-flow of fragments with respect to the flow of the bulk results most likely from the large Coulomb effects in heavy systems (entrance and exit channel trajectories, large “Coulomb rings”, proximity in velocity space at lower energies).
- The INDRA data confirms the FOPI value of the squeeze-out transition for $Z \leq 2$ to occur around 100 AMeV and allows to extend the v_2 excitation function down to the Fermi energies.