Results from FOPI on Nuclear Collective Flow in Heavy Ion Collisions at SIS energies

J.P. Alard, A. Andronic, V. Barret, Z. Basrak, N. Bastid, M.L. Benabderrahmane, R. Čaplar, P. Crochet, P. Dupieux, M. Dželalija, Z. Fodor, I. Gasparić, Y. Grishkin, O. N. Hartmann, N. Herrmann, K. D. Hildenbrand, B. Hong, D. Kang, J. Kecskemeti, Y. J. Kim, M. Kirejczyk, P. Koczon, M. Korolija, R. Kotte, M. Kowalczyk, T. Kress, A. Lebedev, Y. Leifels, X. Lopez, V. Manko, T. Matulewicz, M. Merschmeyer, D. Moisa, D. Pelte, M. Petrovici, F. Rami, W. Reisdorf, A. Schüttauf, Z. Seres, B. Sikora, K. S. Sim, V.Simion, K. Siwek-Wilczyńska, M. Smolarkiewicz, V. Smolyankin, J. Soliwoda-Poddany, M. R. Stockmeier, G. Stoicea, T. Tyminski, P. Wagner, K. Wiśniewski, D. Wohlfarth, Z. Xiao, I. Yushmanov, A. Zhilin

NIPNE Bucharest, Romania
KFKI Budapest, Hungary
LPC Clermont-Ferrand, France
GSI Darmstadt, Germany
FZ Rossendorf/Dresden, Germany
Korea University Seoul, Korea
Heidelberg University, Germany
ITEP Moscow, Russia
Kurchatov Institute, Moscow, Russia
IReS Strasbourg, France
KFKI Budapest, Hungary
Kurchatov Institute, Moscow, Russia
Warsaw University, Poland
RBI Zagreb, Croatia

FOPI

1- Motivations

2- FOPI detector overview

3- Directed and Elliptic flow

4- Data *versus* IQMD

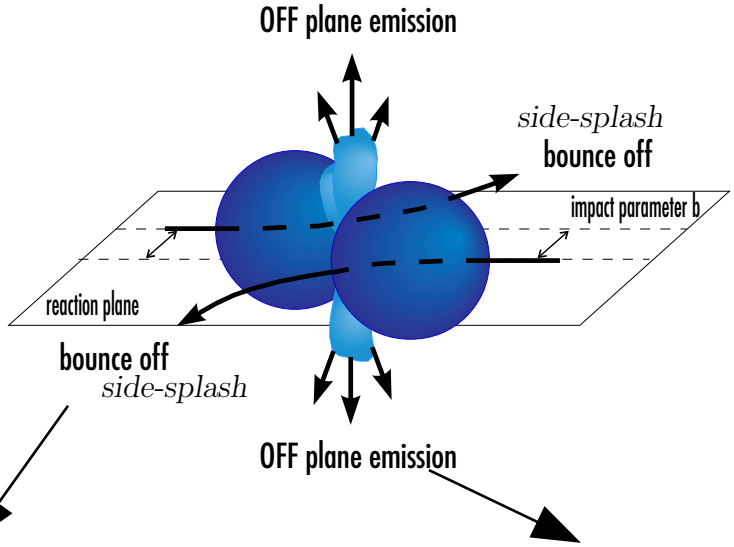
5- Conclusion & Outlooks

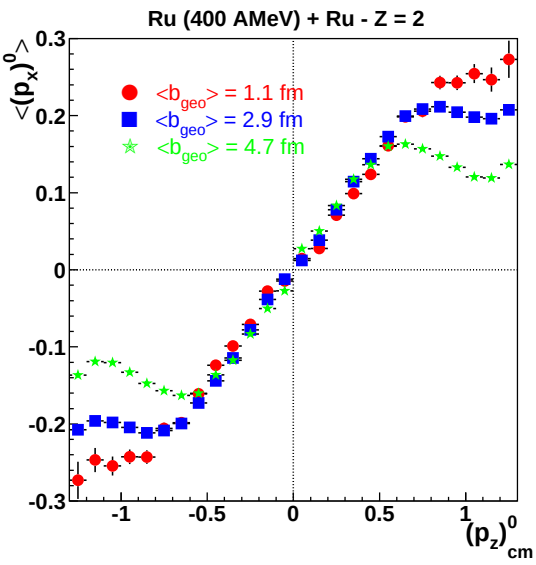
Au + Au, Xe + CsI, Ru + Ru, Ni + Ni, Ca + Ca
90 AMeV - 2AGeV

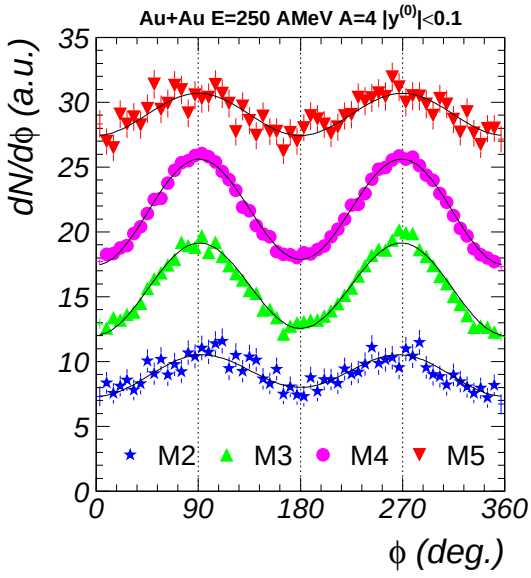
Motivations & Observables

Nuclear Equation of State

- ☐ Collision dynamics
- ☐ In-medium effects: σ_{nn}, MDI





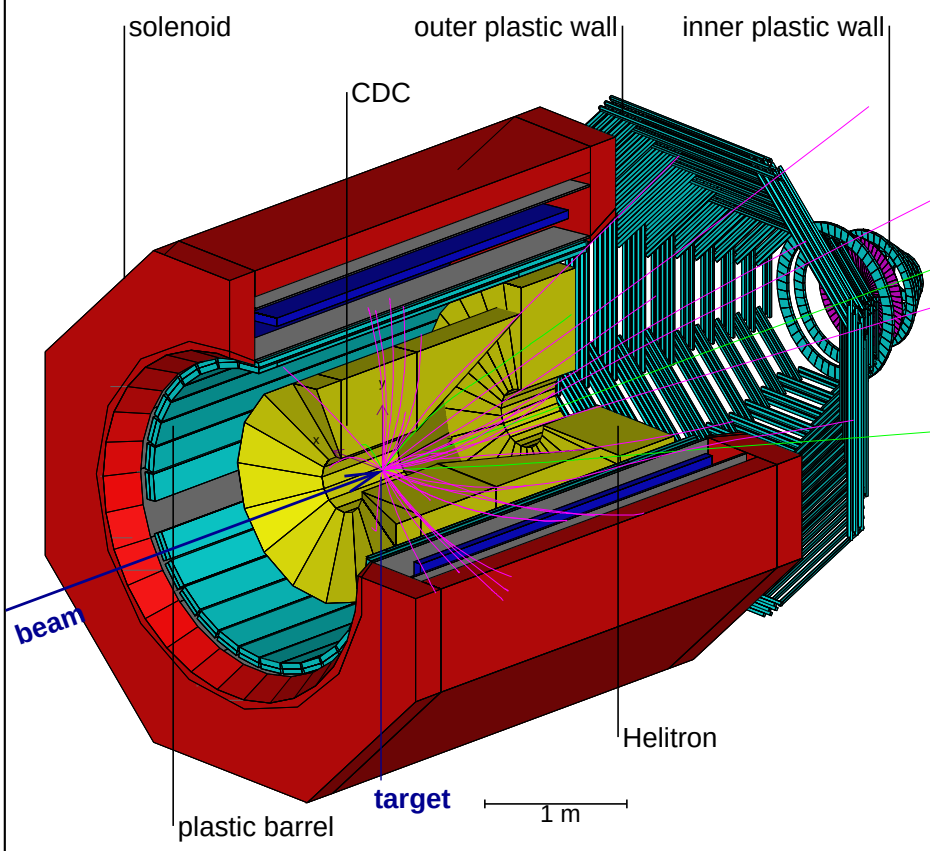


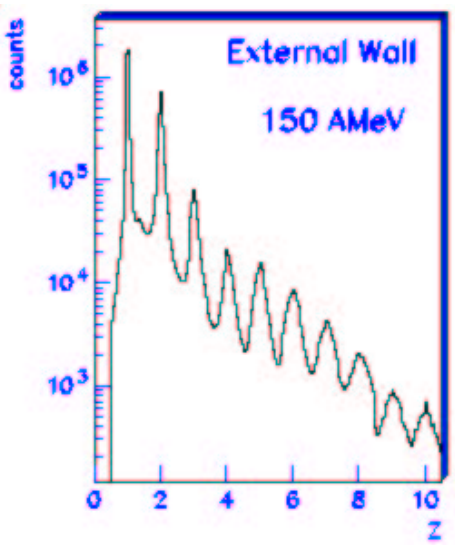
Global directed flow : $p_x^{dir} = \sum sign(y_{cm}) Z u_x \Big/ \sum Z, \quad u_x = \beta_x \gamma$

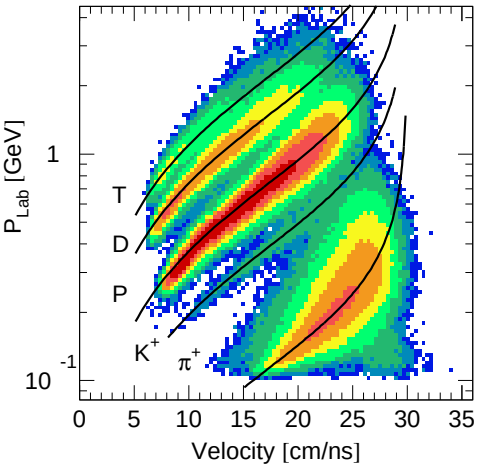
Flow angle: θ_F

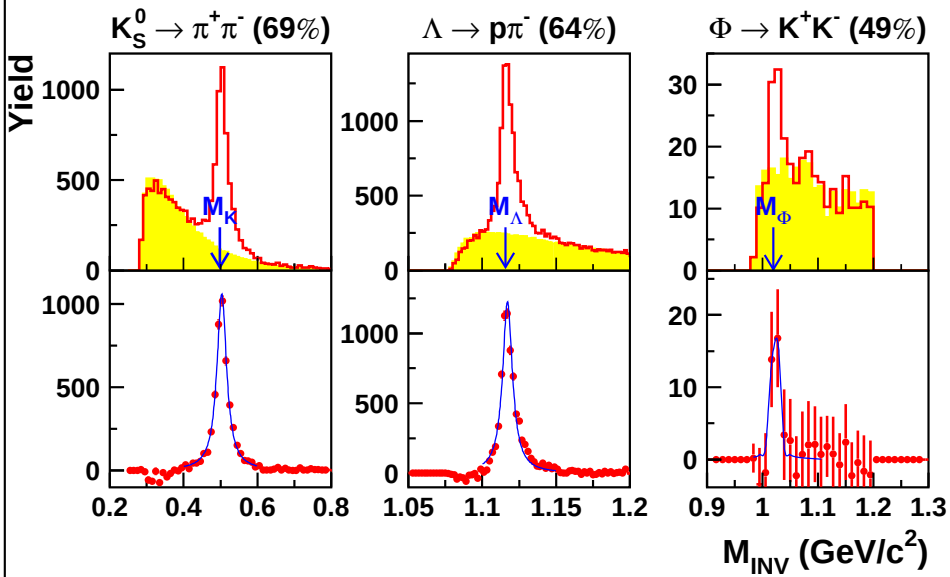
Differential flow : $\frac{dN}{d\varphi} \sim 1 + 2v_1 cos(\varphi) + 2v_2 cos(2\varphi)$

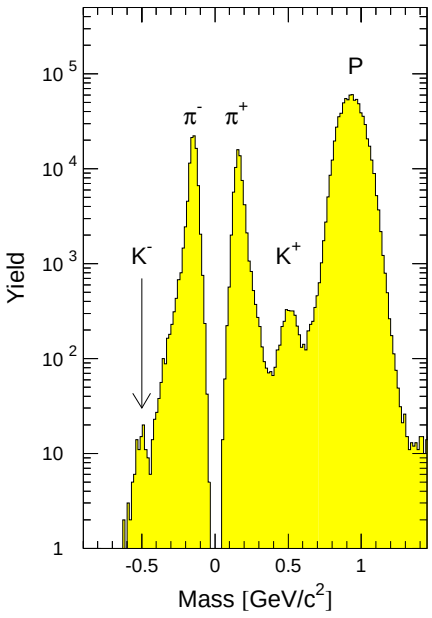
FOPI detector @ GSI



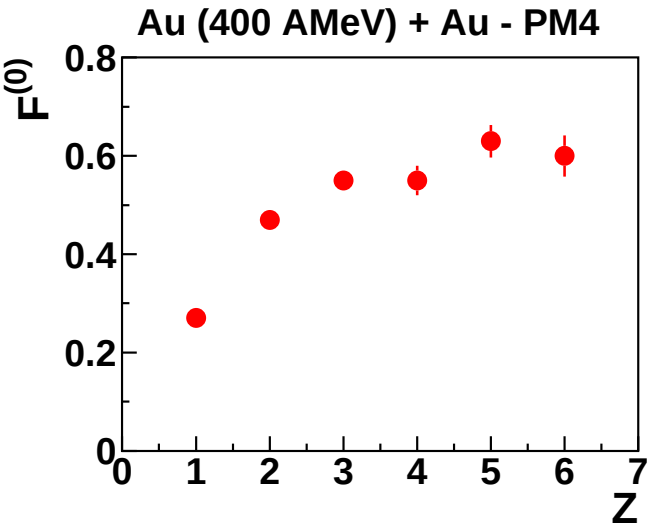




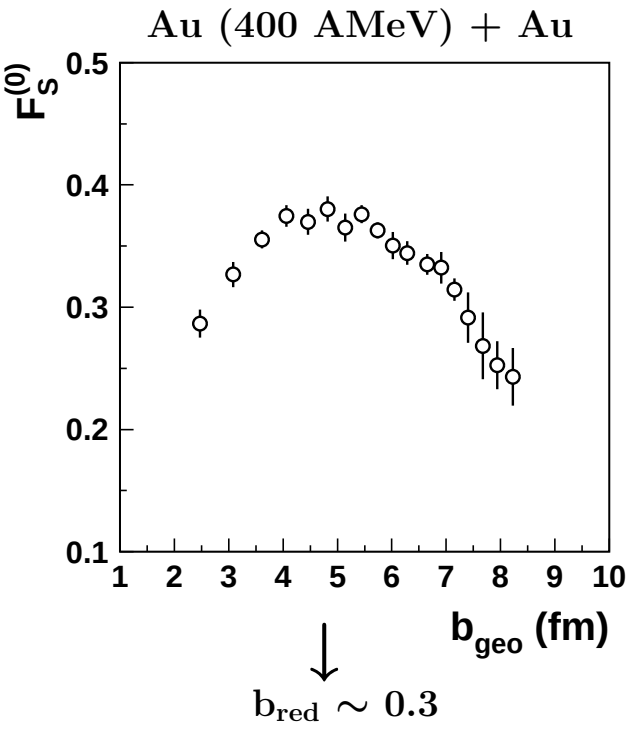




Directed flow *vs* Fragment Charge & Centrality



- High sensitivity of IMF (Z>2) to collective effects



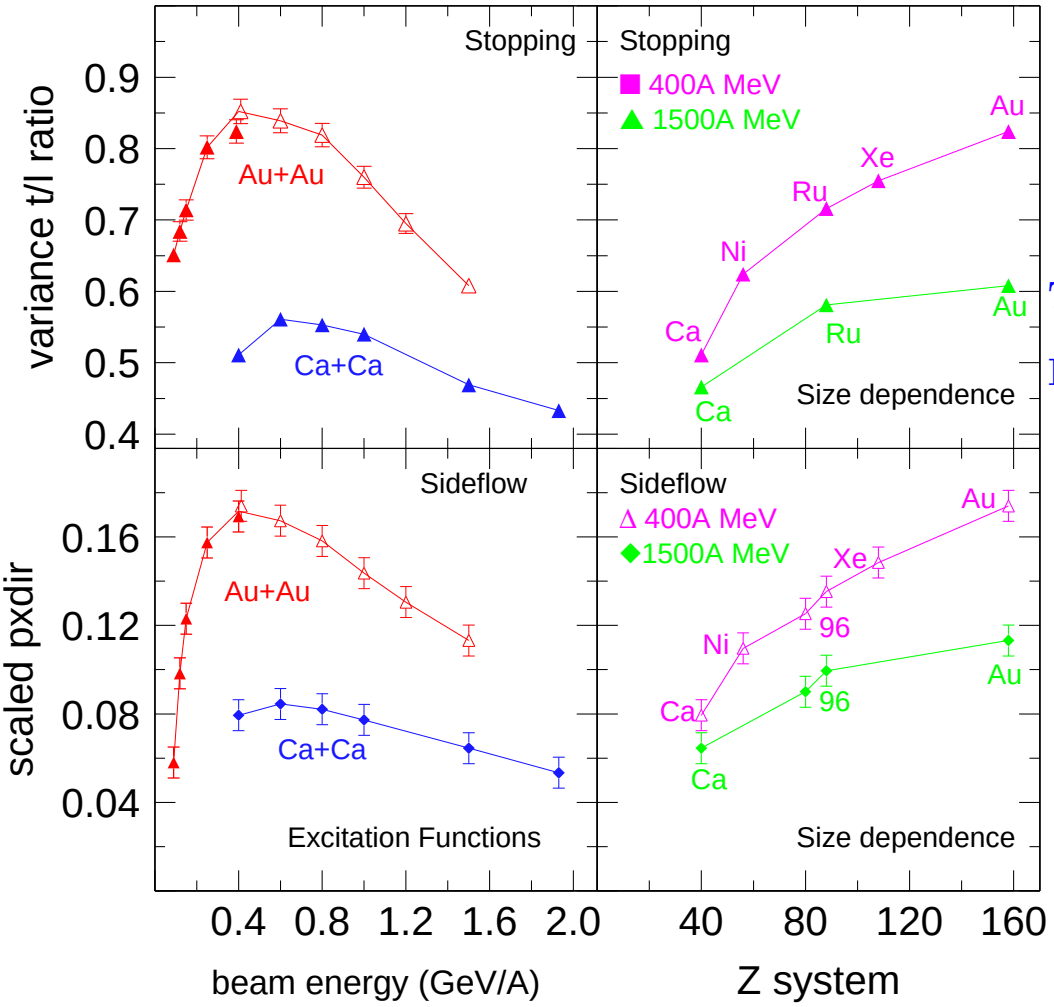
- Maximum at $b/b_{max} \sim 0.3$ (independently of the beam energy & system size)

Superposition of thermal & collective motion

→ *F. Rami and the FOPI Collab., Nucl.Phys A 646 (1999) 367*

Systematics of Directed Flow & Stopping

Excitation functions & System size dependences



$$\mathbf{vartl} = \frac{\sigma^2(y_y)}{\sigma^2(y_z)} \qquad (|y_y,\ y_z| < 1)$$

Thermal: $= 1$

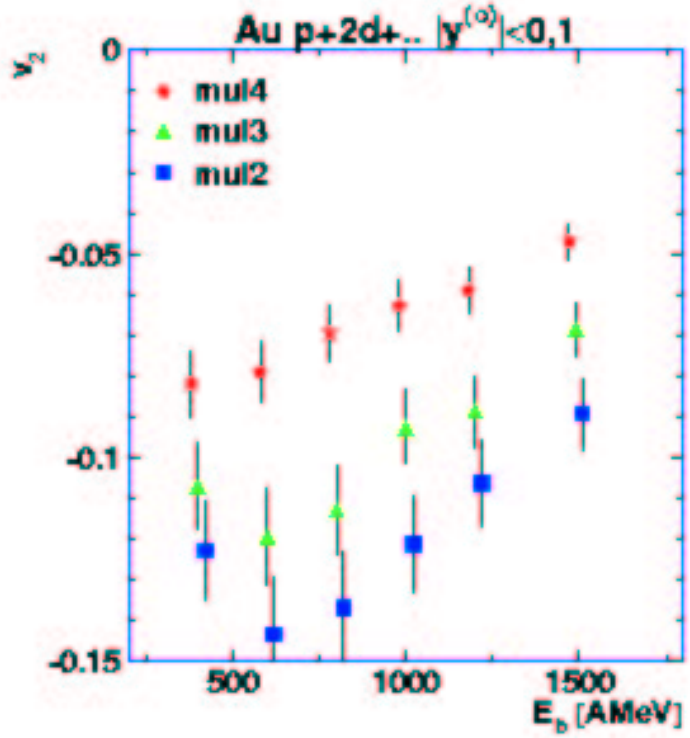
Hydrodynamics: >1

→ *W. Reisdorf and the FOPI Collab., GSI Report 2003-1 (2003) 44*

Directed flow & Stopping strongly correlated

Evidence for incomplete stopping

Elliptic Flow: Beam energy & Centrality dependence



→ *Analysis T. Kress, PhD thesis (2002)*

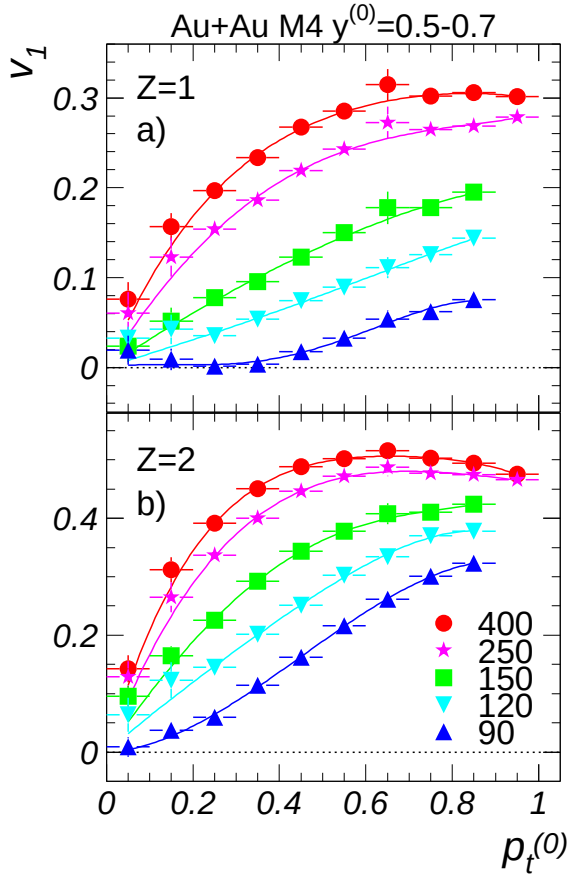
- **Out-of-plane preferred emission at SIS energies**
- **Vanishes around 100 AMeV and changes of sign**

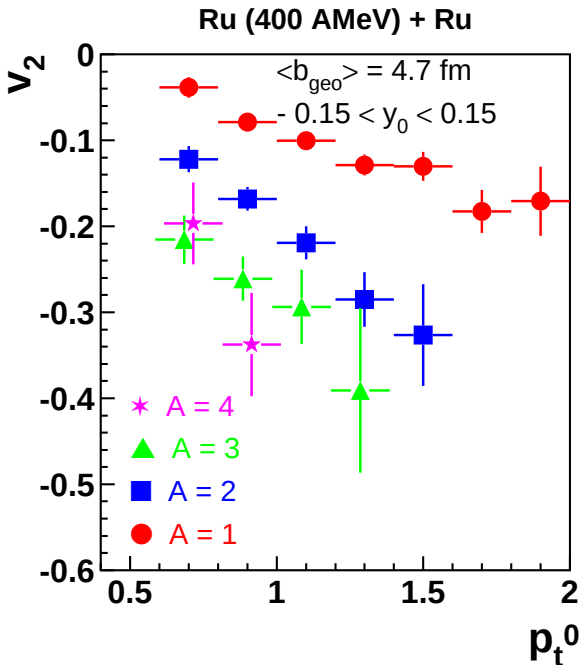
P. Crochet and the FOPI Collab., Nucl. Phys. A 624 (1997) 755
A. Andronic and the FOPI Collab., Nucl. Phys. A 679 (2001) 765

- **Explained by an expansion-shadowing scenario**

Shorter passage time of spectators at high energies lead to a decrease of elliptic flow

Differential Directed & Elliptic Flow





→ *A. Andronic and the FOPI Collab., Phys. Rev C 64 (2001) 041604(R)*

- **Influence of the collision dynamics**
- **Information on different stages of the collision**

  ⇒ High p_t particles: messengers of the high density phase

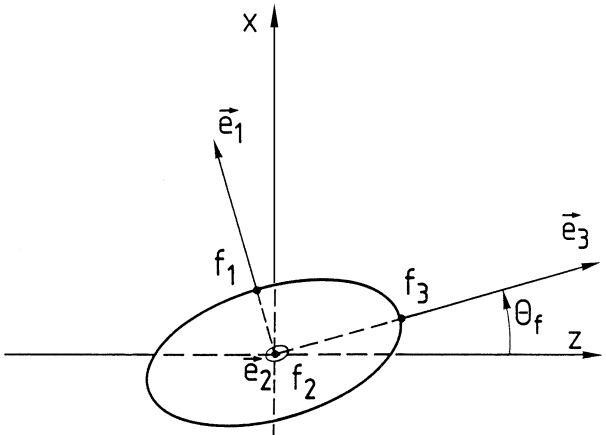
T. Gaitanos et al., Eur. Phys. Journal A12 (2001) 421

- **Influence of attractive mean field (low $p_t^{(0)}$) & repulsive nucleon-nucleon scatterings (high $p_t^{(0)}$) at 90 AMeV and for Z = 1**

Shape parameters: a constraint on in-medium σ_{nn}

In-plane and out-of-plane momentum distributions fitted with anisotropic gaussian distributions

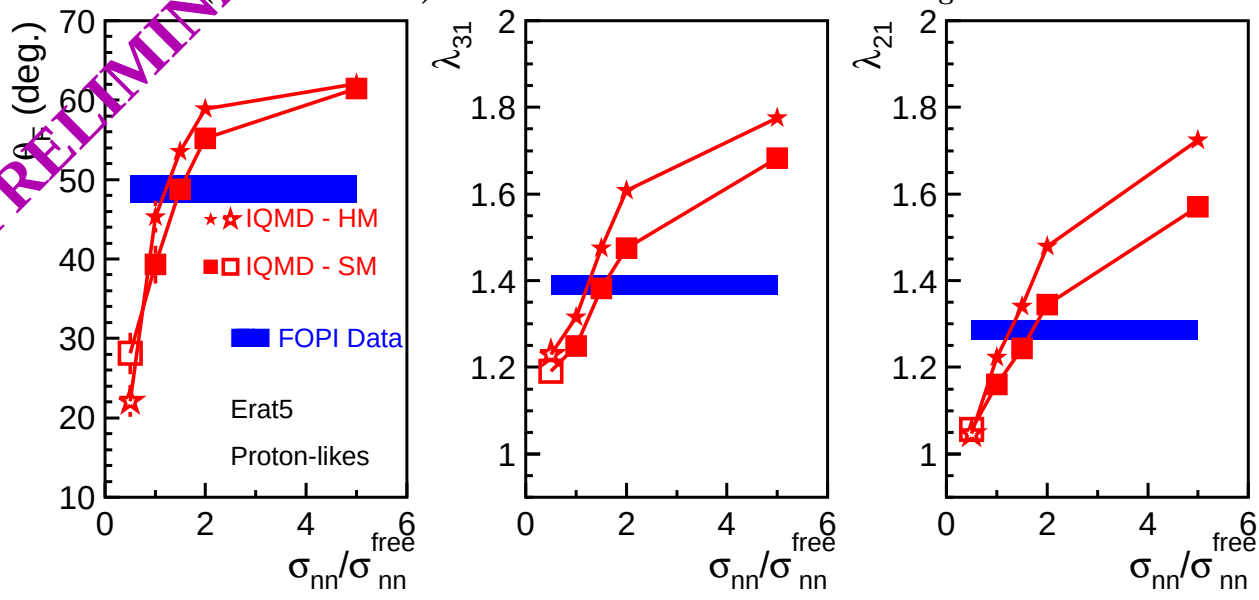
J. Gosset and DIOGENE collab., Phys. Lett. B 247 (1990) 233



- $\theta_F \rightarrow$ Directed flow
- $\lambda_{31} = (f_3/f_1)^2 \rightarrow$ Directed flow & Stopping
- $\lambda_{21} = (f_2/f_1)^2 \rightarrow$ Elliptic flow

PRELIMINARY

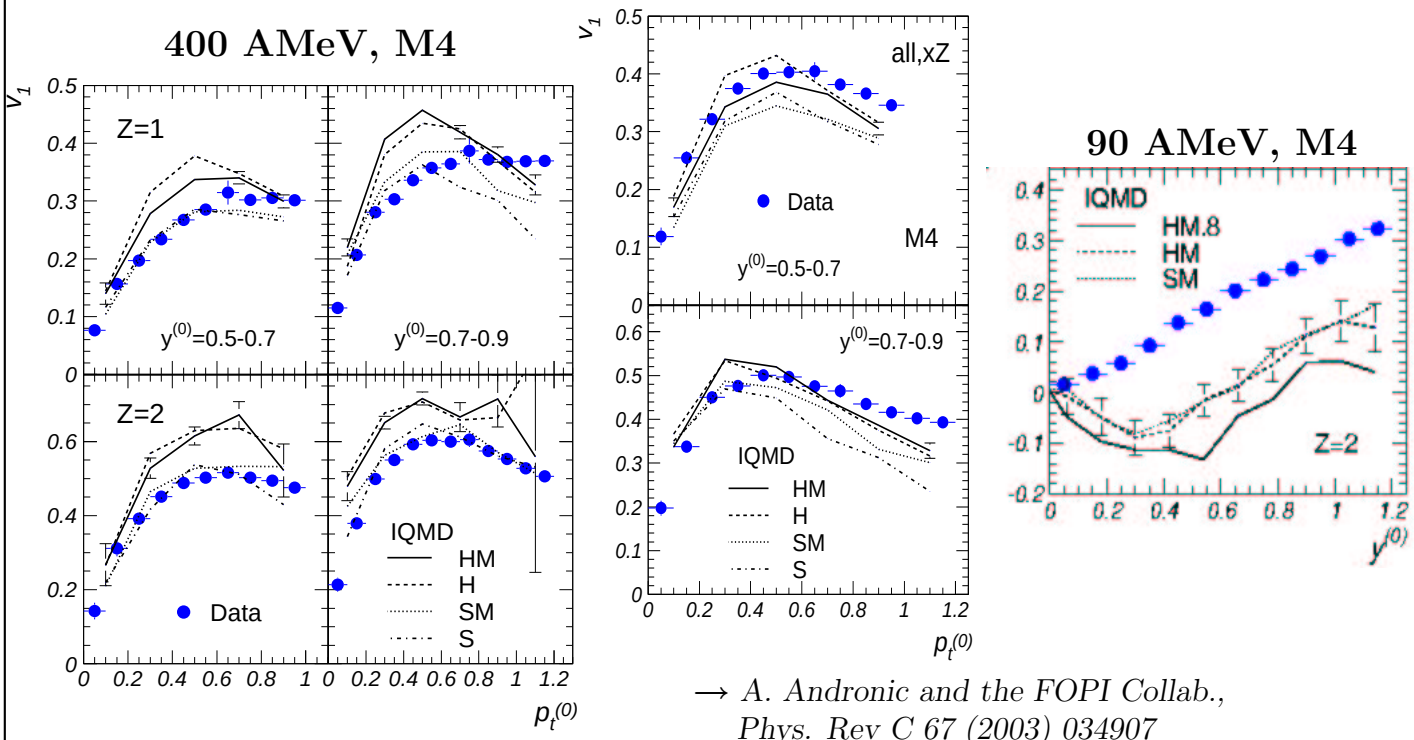
Ru (400 AMeV) + Ru - Proton-likes - $< b_{geo} > = 1.1$ fm



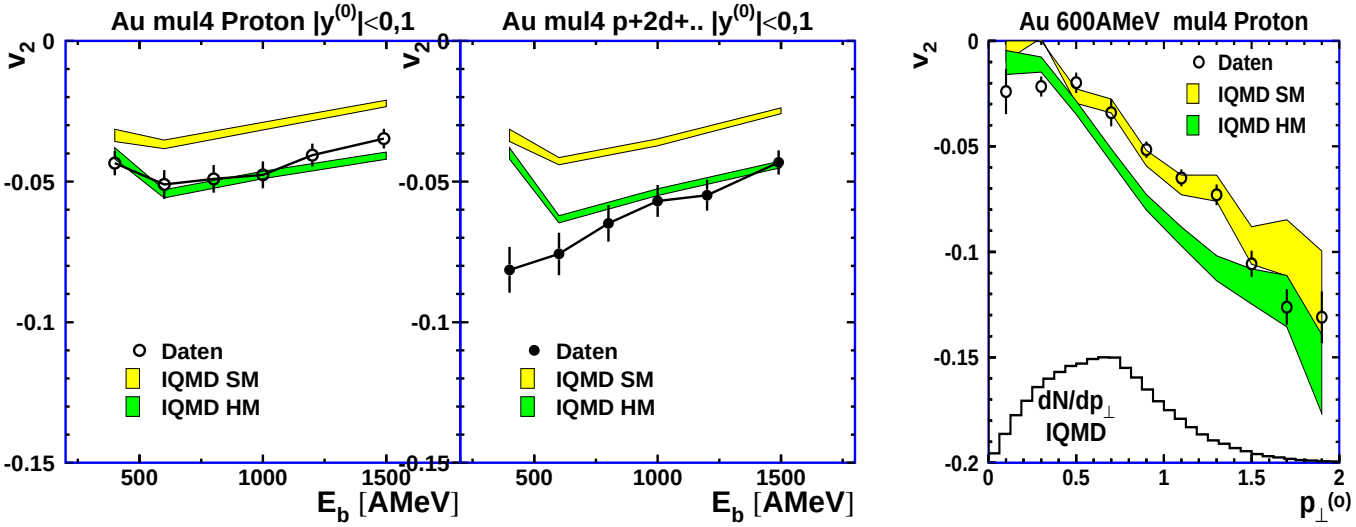
Data favour in-medium σ_{nn} close or slightly higher than σ_{nn}^{free}

In agreement with F. Rami and the FOPI Collab., Phys. Rev. Lett. 84 (2000) 1120

Flow & EoS in Au + Au reactions



→ *A. Andronic and the FOPI Collab., Phys. Rev C 67 (2003) 034907*



→ *T. Kress, PhD thesis (2002)*

- **A soft EoS with MDI best suited to explain directed flow data at 400 AMeV**
- **But none of the IQMD parametrizations can consistently explain all flow data**

Conclusion & Outlooks

Complete set of data at SIS energies measured with FOPI:

- Variation of beam energy from 90 AMeV to 2 AGeV
- Variation of system size from Ca to Au
- Variation of asymmetry in isospin (Ru/Zr)
- Variation of asymmetry in system size (Au/Ca & Pb/Ni)

- Main dependences of directed & elliptic flow are available
- Most features of flow data reproduced qualitatively well by IQMD model but not in detail
- Flow, stopping, fragment/particle production should be reproduced simultaneously

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FOPI Upgrade

January - February 2003:

- Experiment dedicated to sub-threshold Ξ^- measurement in Ni + Ni reactions at 1.93 AGeV
  $\Rightarrow$ High statistics for detailed flow studies with $\pi^{\pm}$, $K^{\pm}$, K^0_S, Λ, ...

- Experiment dedicated to the study of asymmetric systems Ni/Pb + Pb/Ni between 400 AMeV & 1160 AMeV

FOPI Collaboration

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IPNE Bucharest, Romania
ITEP Moscow, Russia
CRIP/KFKI Budapest, Hungary
Kurchatov Institute, Moscow, Russia
LPC Clermont-Ferrand, France
Korea University Seoul, Korea
GSI Darmstadt, Germany
IReS Strasbourg, France
FZ Rossendorf/Dresden, Germany
Univ. of Warsaw, Poland
Univ. of Heidelberg, Germany
RBI Zagreb, Croatia