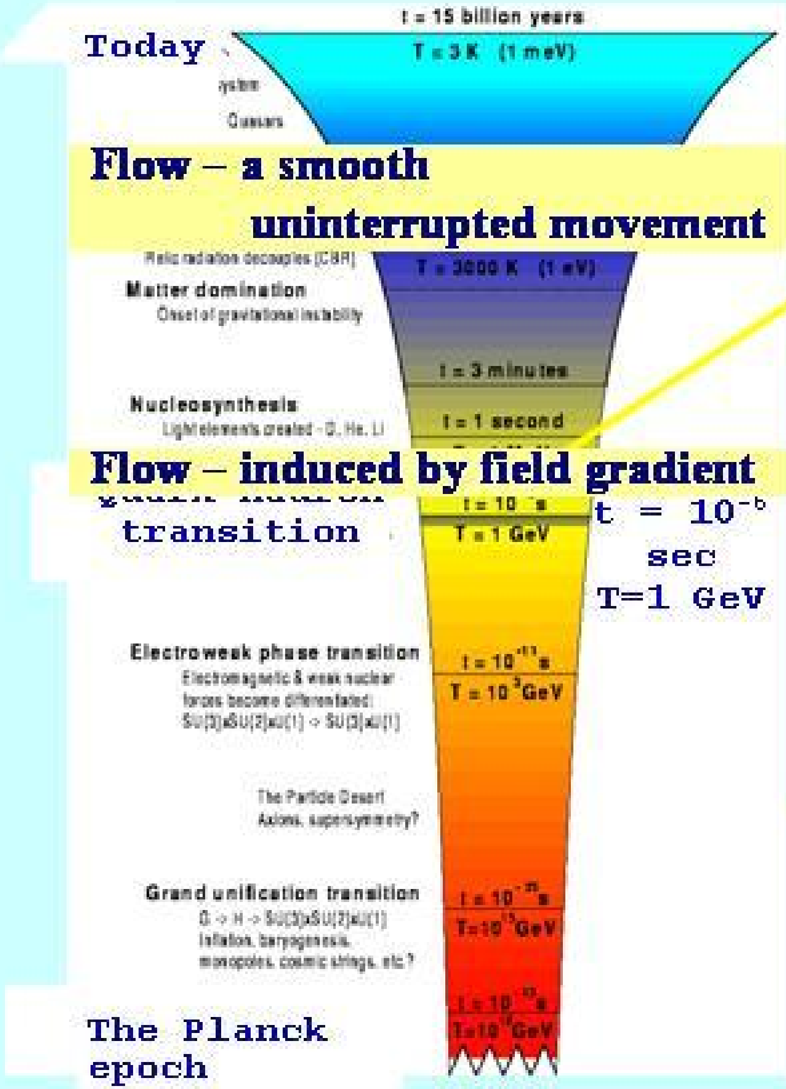
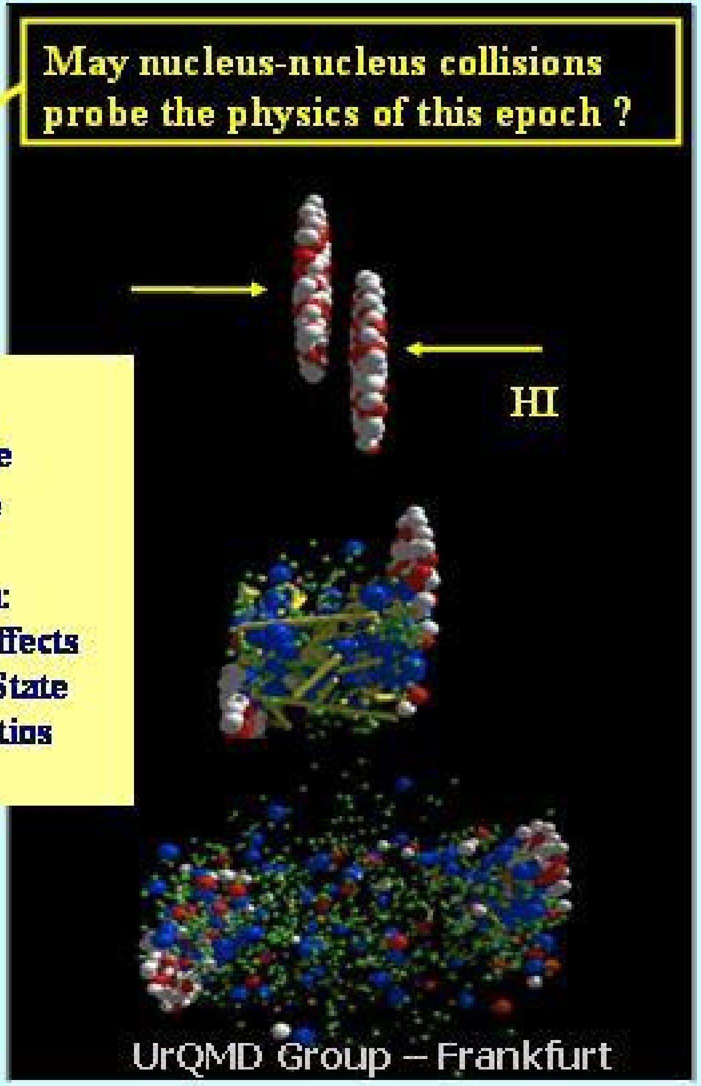
Collective phenomena in heavy ion collisions

M. Petrovici, C. Andrei, I. Berceanu , A. Herghelegiu, A. Pop, C. Schiaua



Why Flow?

- Properties of the initial phase
- Information on:
  In-medium effects
  Equation of State
  Phase transitios



Collective phenomena in heavy ion collisions

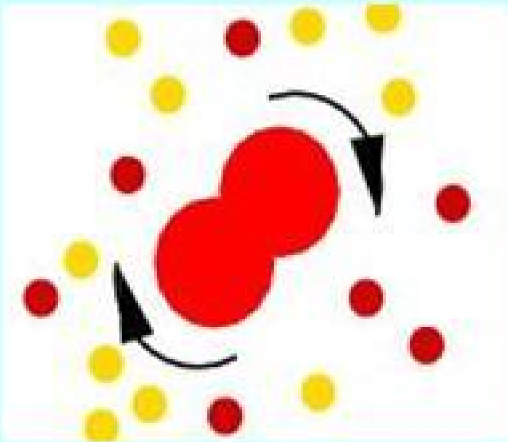
- Elliptic flow

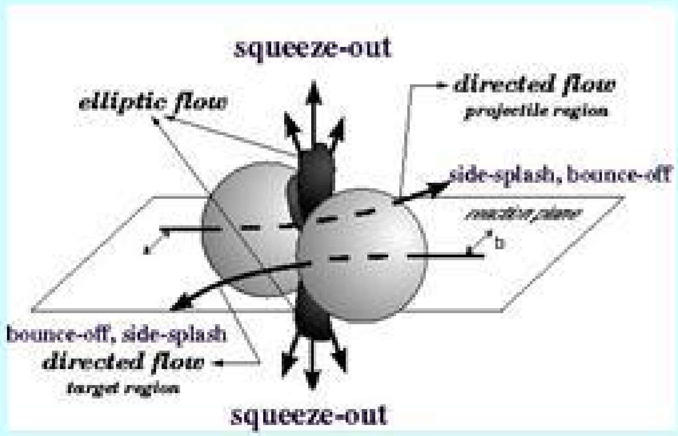
- Azimuthally symmetric flow

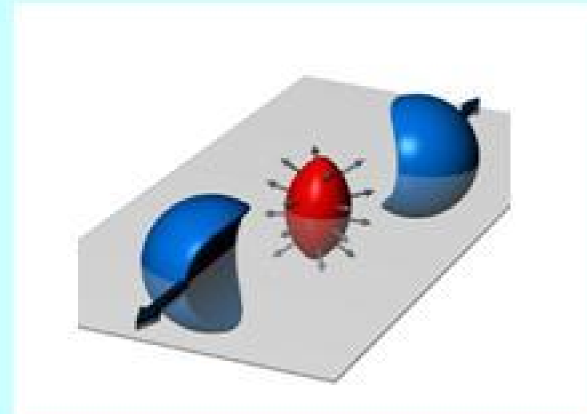
- $<p_t>$ as a function of mass at ultra-relativistic energies

- Outlook

What should be expected as a function of incident energy ?

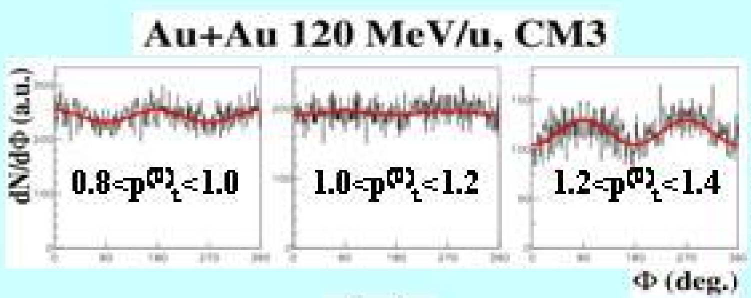




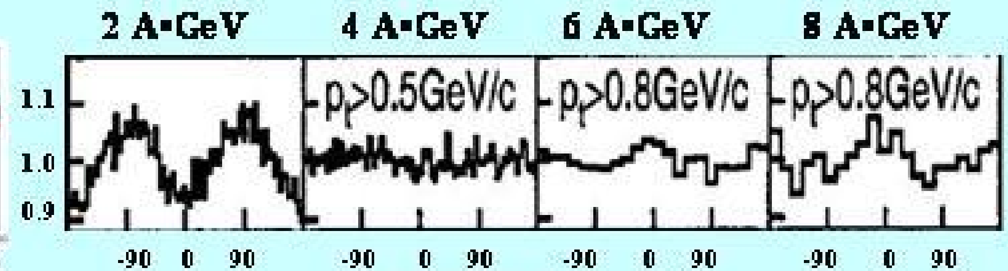


< 100 A·MeV | 100 A·MeV - ~600 A·MeV | ~4 A·GeV

The experimental evidences



A=2



protons

A.Andronic, G.Stoicea, M.Petrovici &FOPI Coll. N.P.A679(2001)765 C.Pinkenburg & EOS Coll. Phys.Rev.Lett. 83(1999)1295

a_2 excitation function

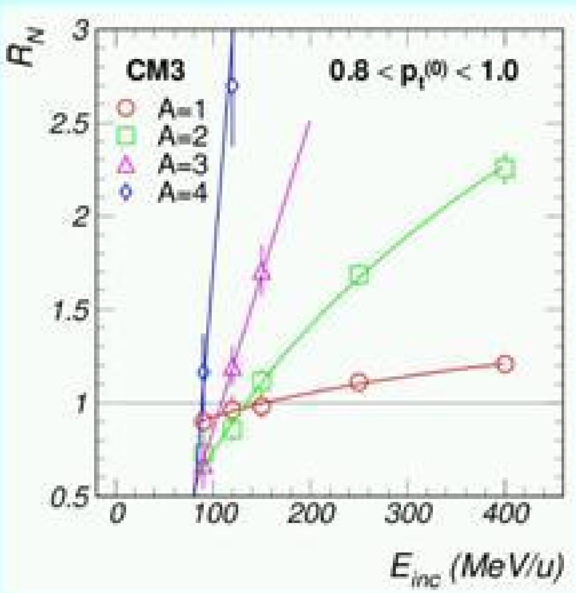
$$\left(\frac{dN}{d\phi}\right)^{exp} = a_0^{exp} \cdot (1 + a_1^{exp} \cos\phi + a_2^{exp} \cos 2\phi)$$

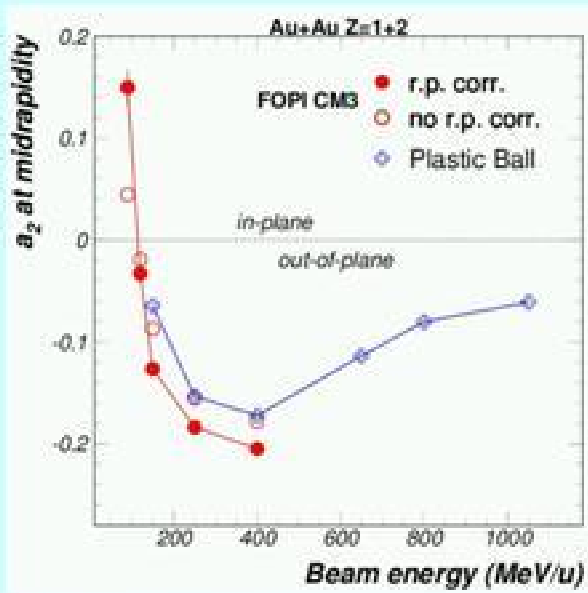
$$R_N^{exp} = \frac{\frac{dN}{d\phi}(\phi = 90^o) + \frac{dN}{d\phi}(\phi = 270^o)}{\frac{dN}{d\phi}(\phi = 0^o) + \frac{dN}{d\phi}(\phi = 180^o)}$$

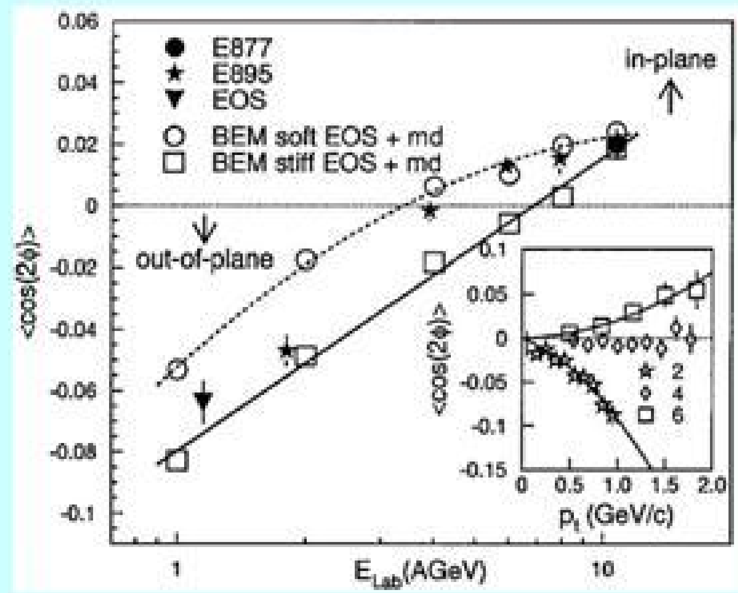
$$R_N^{exp} = \frac{1 - a_2^{exp}}{1 + a_2^{exp}}$$

$$a_2^{corr} = a_2^{exp} / \langle \cos 2\Delta\phi \rangle$$

$$R_N = \frac{1 - a_2^{corr}}{1 + a_2^{corr}}$$







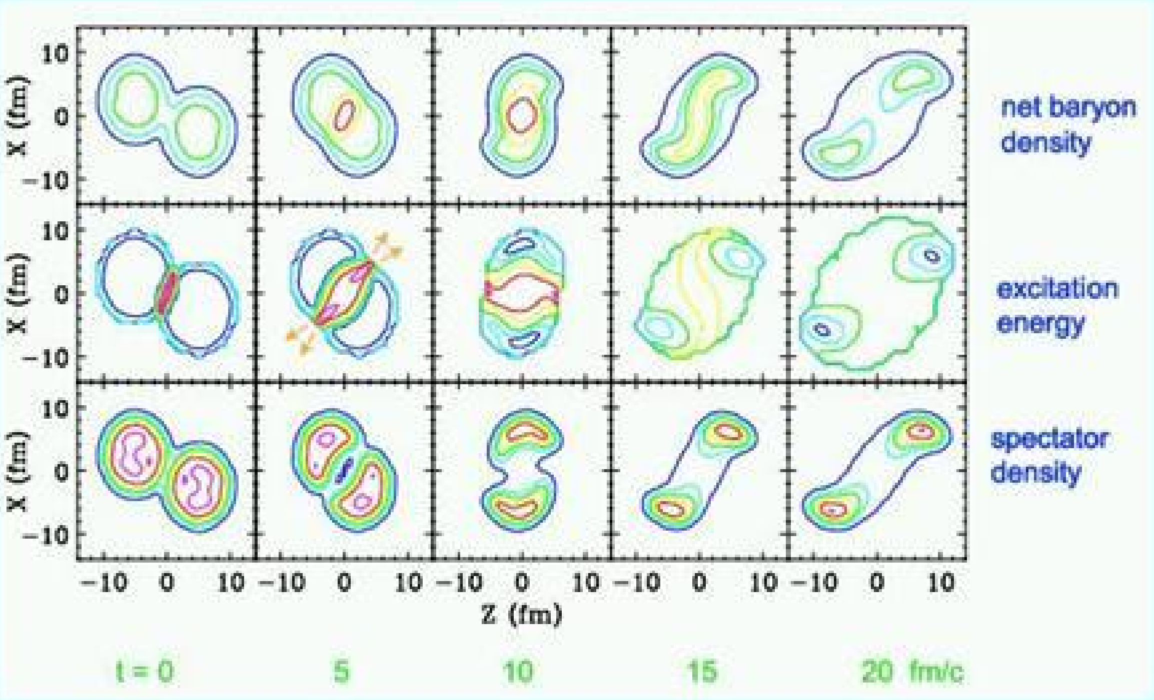
A.Andronic, G.Stoicea, M.Petrovici &
FOPI Coll. N.P.A679(2001)765

C.Pinkenburg & EOS Coll. Phys.Rev.Lett. 83(1999)1295

H.H. Gutbrod & Plastic Ball Coll
Phys.Rev.C 42(1990)640

BUU transport model predictions

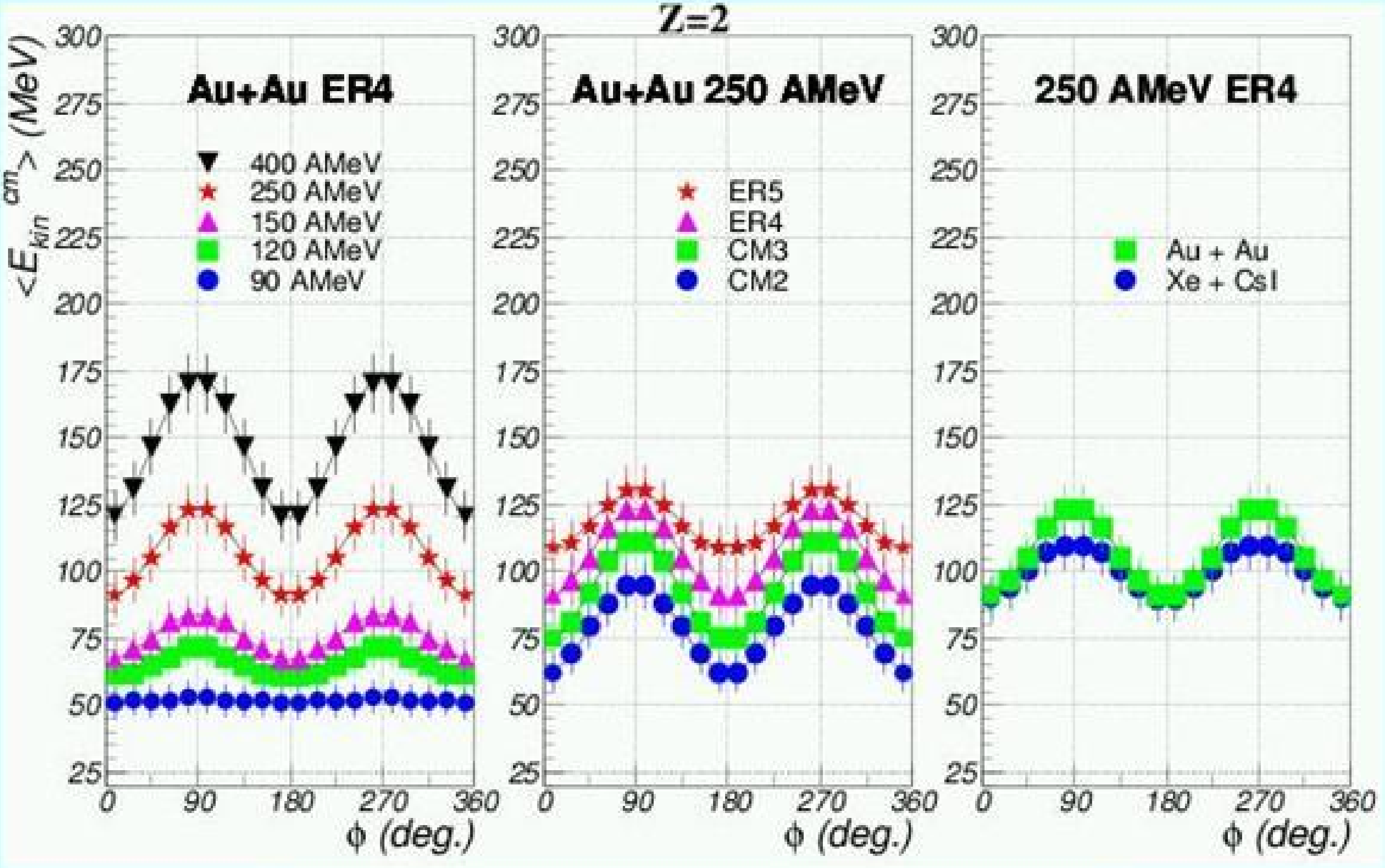
$^{124}Sn + ^{124}Sn$ 800 A•MeV



P.Danielewicz,, Nucl.Phys. A673(2000)375

Mean kinetic energy azimuthal distributions

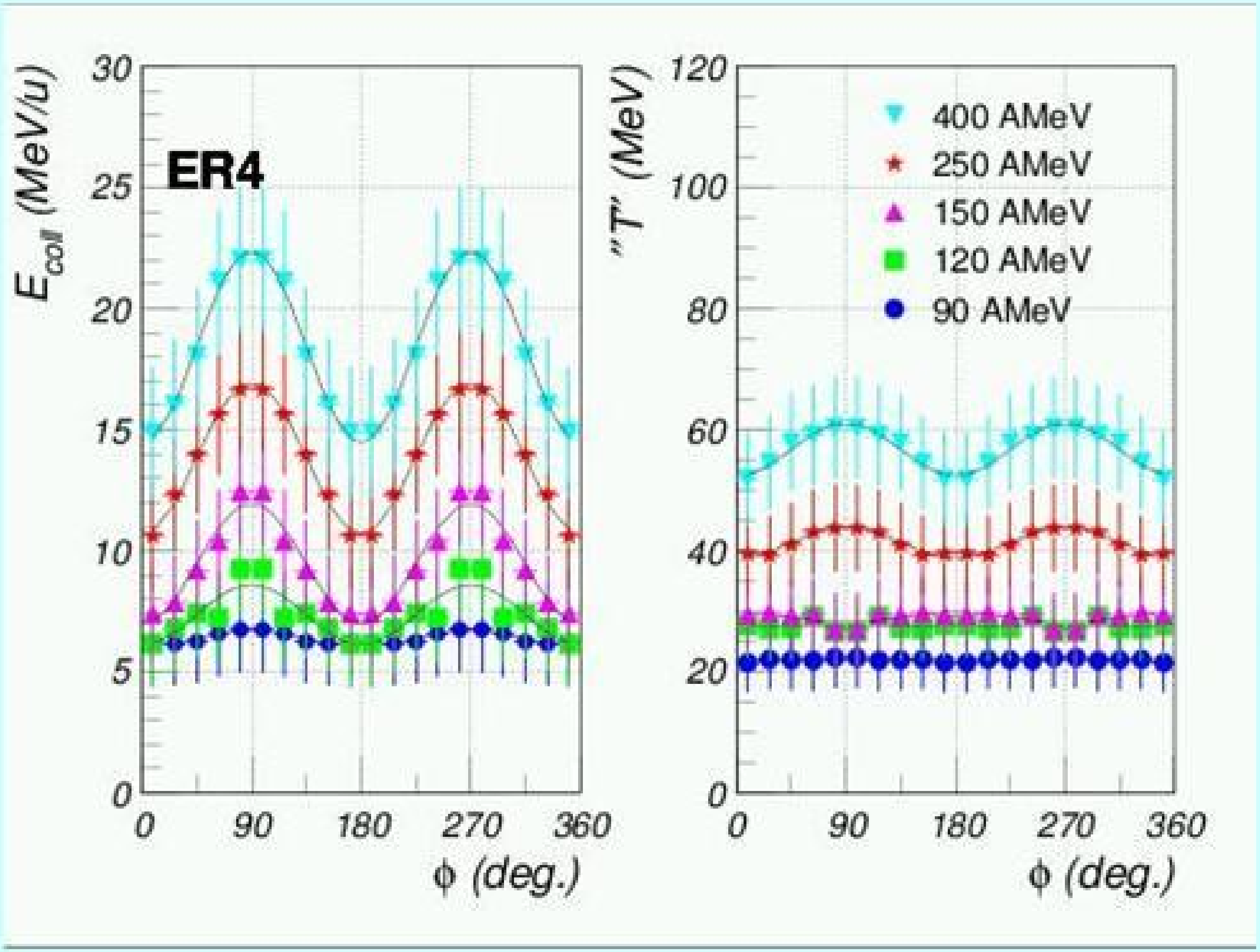
G.Stoicea, M.Petrovici & FOPI
Phys.Rev.Lett. 92(2004)072303



$$\langle E_{kin}^{cm} \rangle \approx \frac{1}{2} m_0 < \beta_{flow}^2 > A_{IMF} + \frac{3}{2} "T"$$

$$E_{coll} = \frac{1}{2} m_0 \langle \beta_{flow}^2 \rangle$$

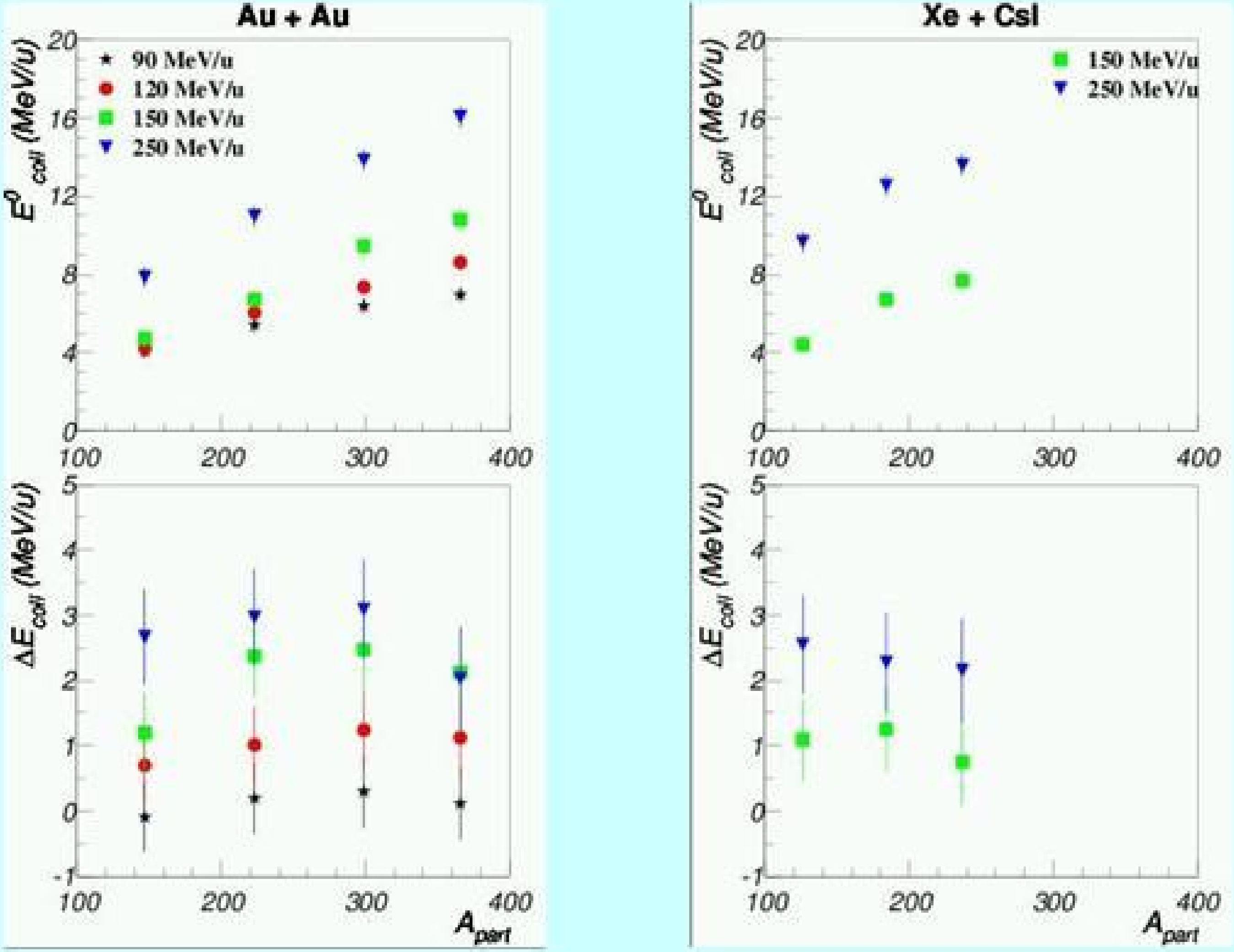
E_{coll} & “T“ azimuthal distributions



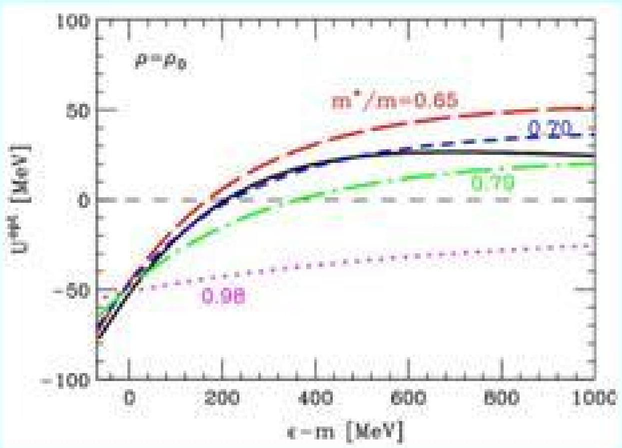
$$E_{coll} = E^0_{coll} - \Delta E_{coll} \cdot \cos 2\Phi$$

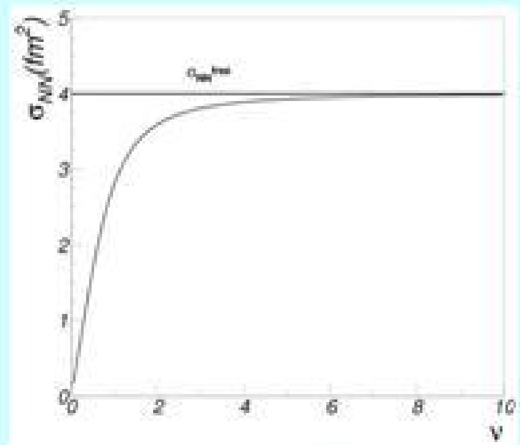
$$"T" = "T"_0 - \Delta "T" \cdot \cos 2\Phi$$

E_{coll}^0 & ΔE_{coll} - A_{part} dependence



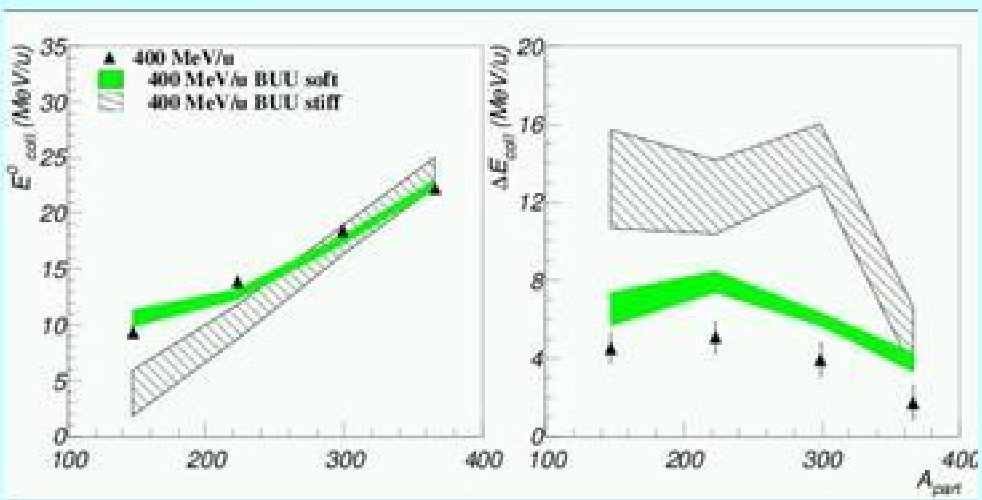
BUU transport model predictions

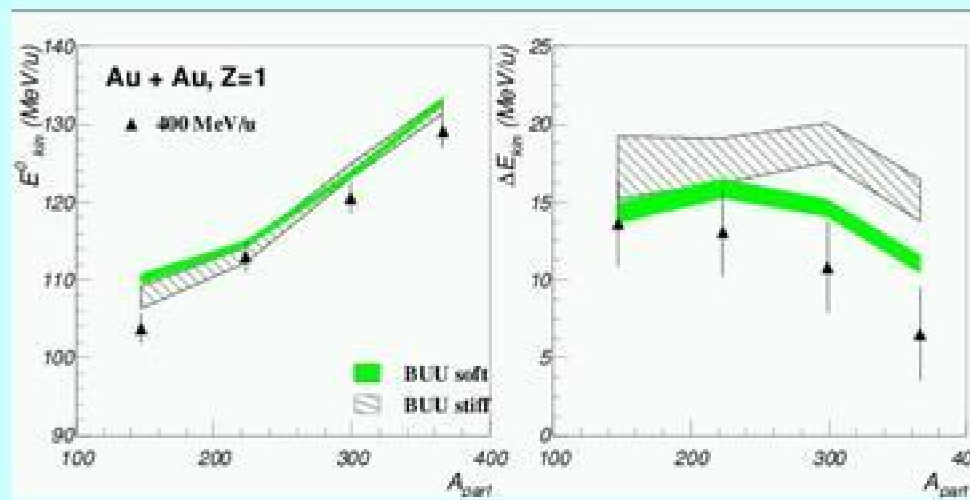




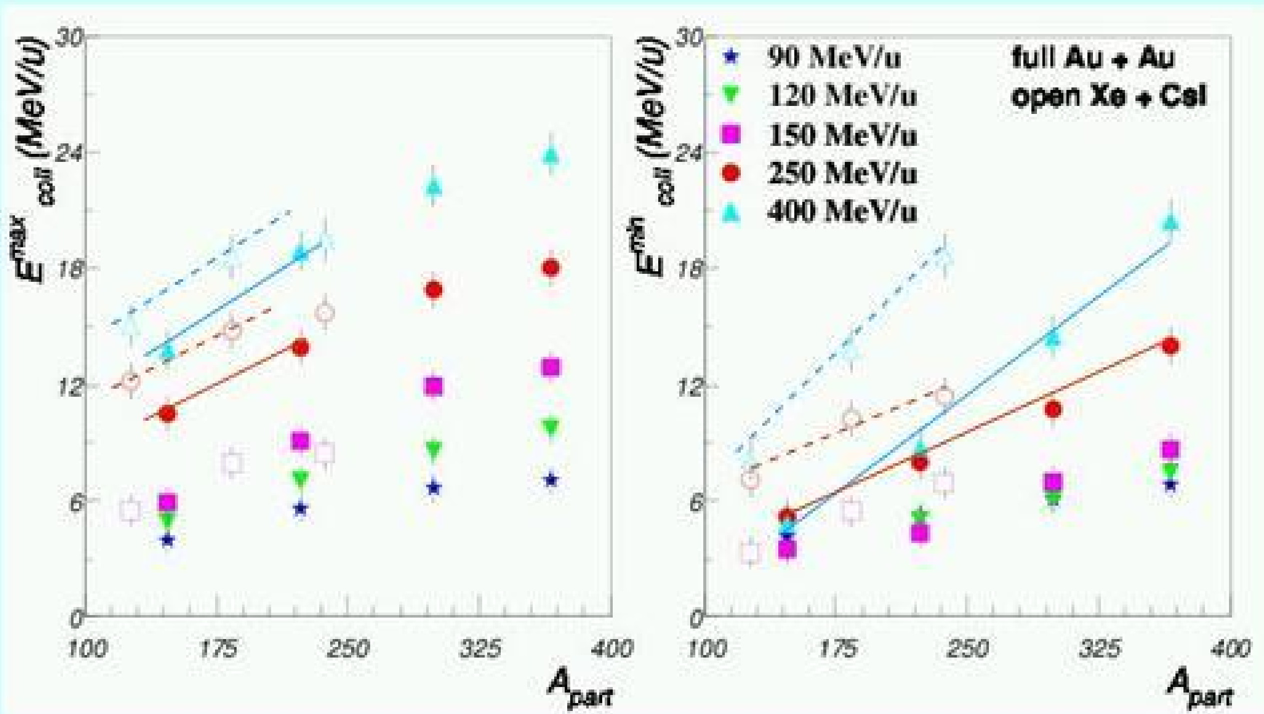
K	ν	m^*/m
Soft K=210 MeV	1	0.79
	1	0.7
	0.85	0.7
	0.85	1
	$\nu \longrightarrow \infty$ $\sigma = \sigma_{NN}^{free}$	0.7
	0.75	0.7
Stiff(Hard) K=380 MeV	1	1
	0.85	1
	1	0.79

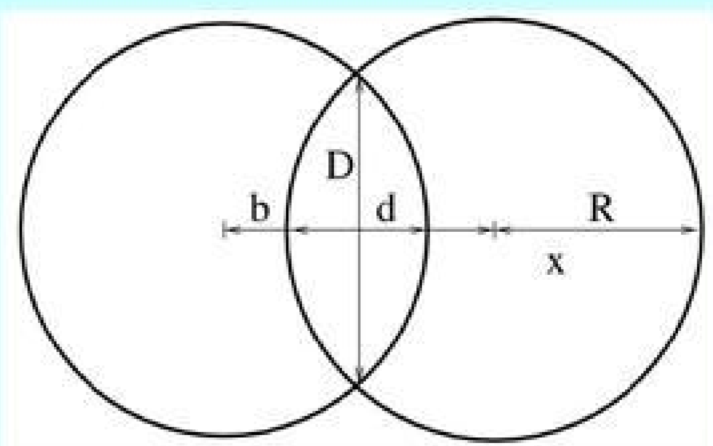
$$\sigma = \sigma_0 \tanh\left(\sigma_{free}/\sigma_0\right) \qquad \sigma_0 = \nu\, \rho^{-2/3}$$

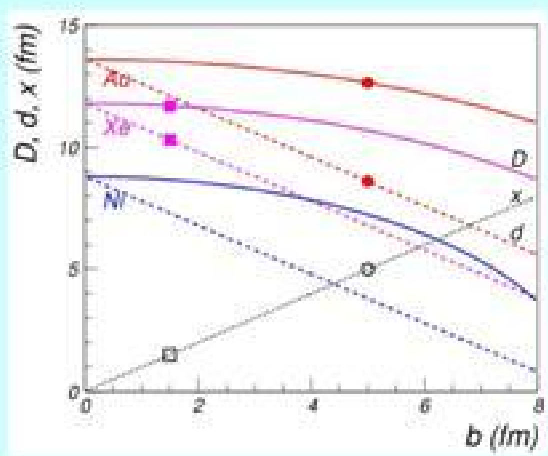


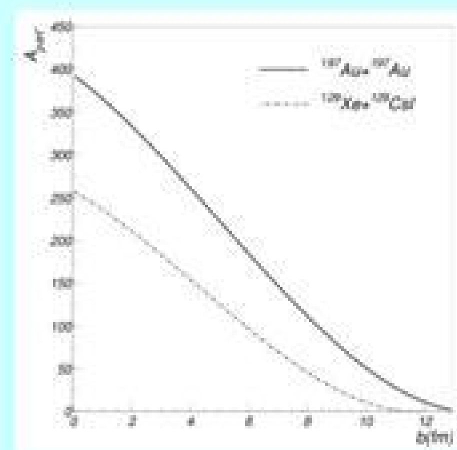


Fireball shape & shadowing effects

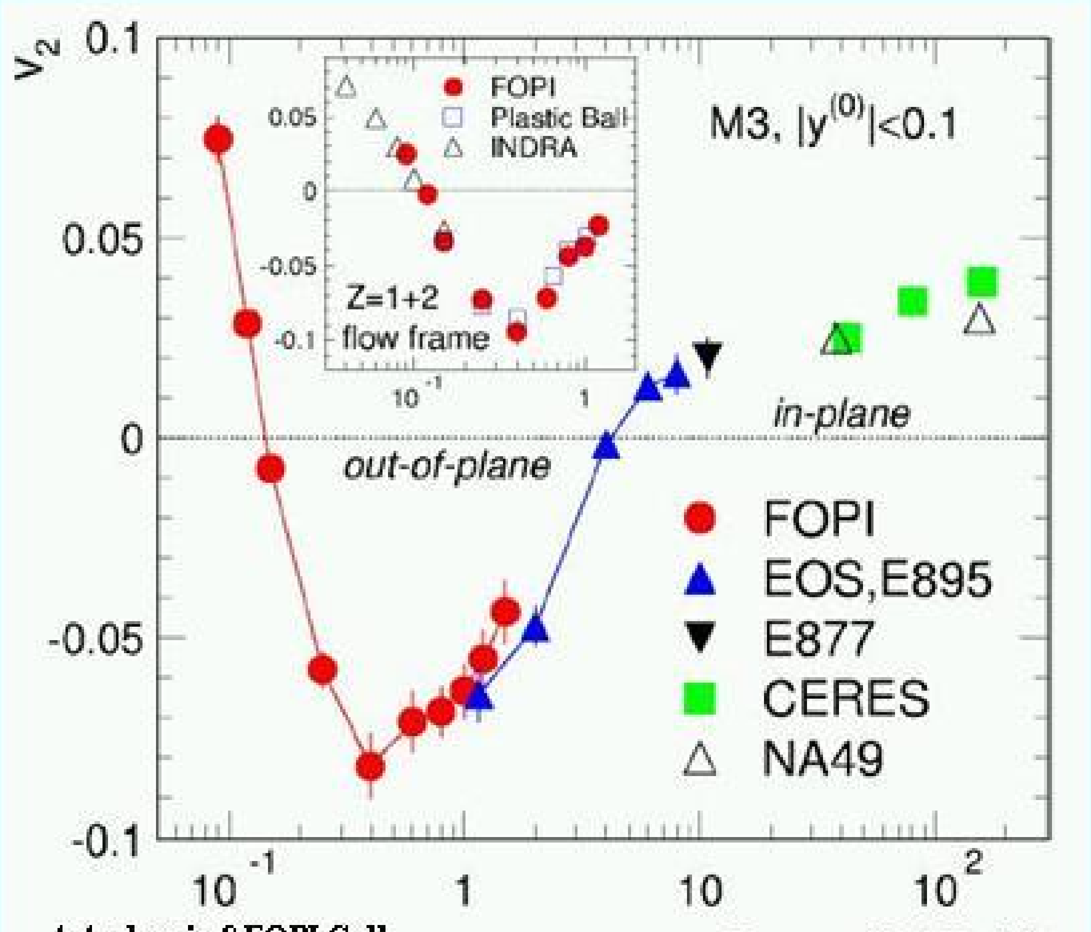








v_2 excitation function



A.Andronic &FOPI Coll.
Phys.Lett. B612(2005)173

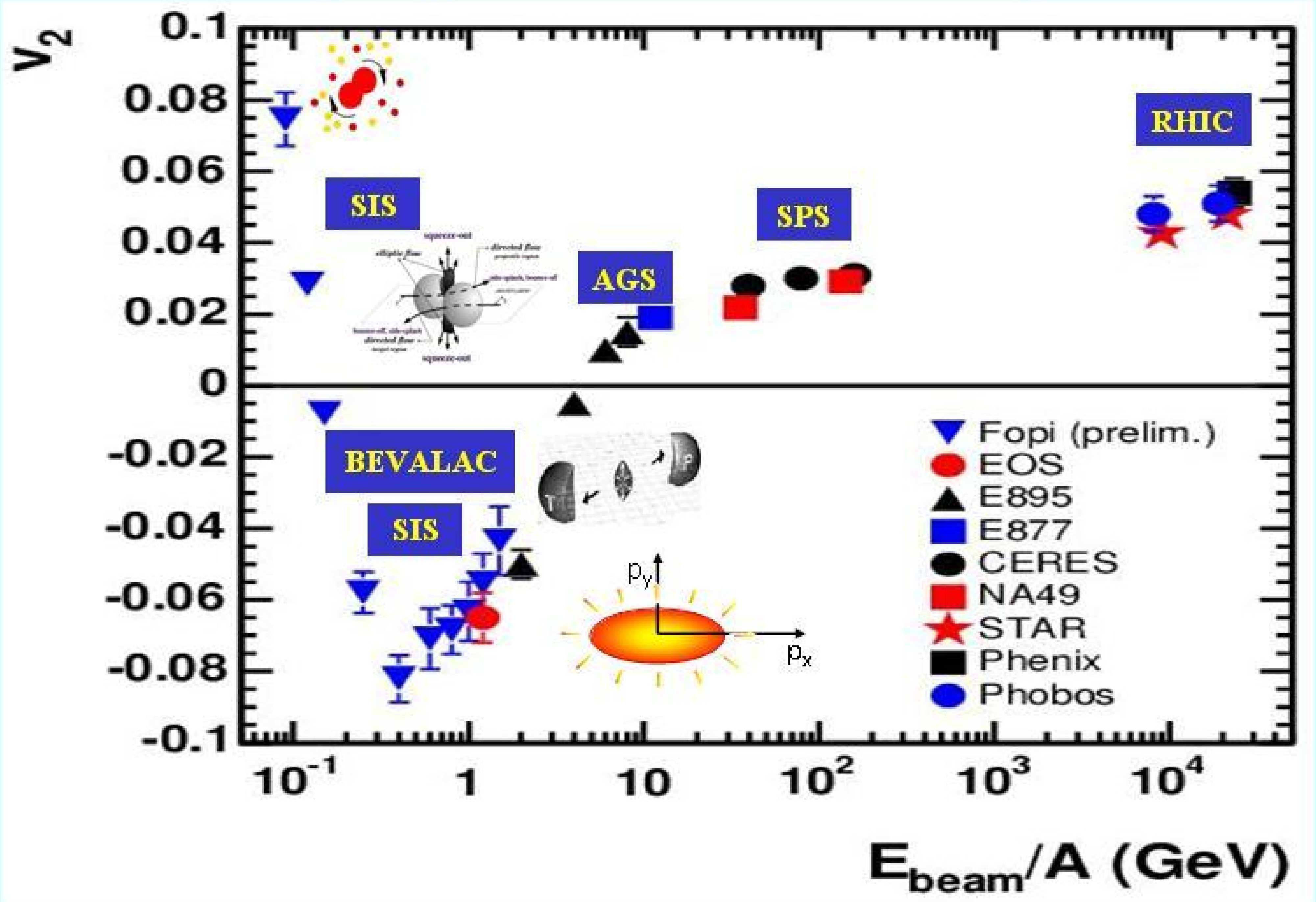
$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1 + \sum_{n=1}^{\infty} 2v_n \cos(n(\Phi - \Psi_r))\right)$$

$$v_2 = \langle \cos 2(\Phi - \Psi r) \rangle, \ \Phi = \tan^{-1}(p_y / p_x)$$

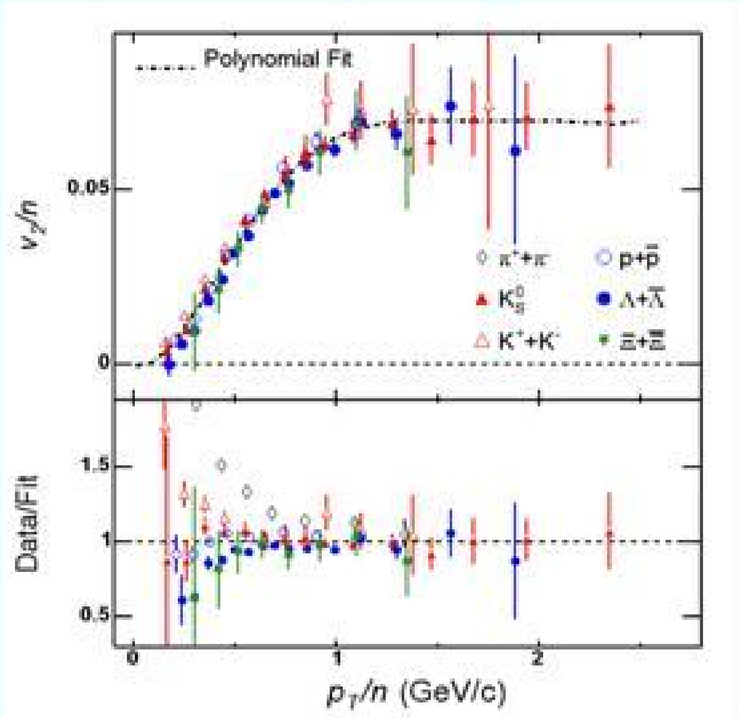
FOPI – Z=1 particles **E877 – all charged particles** **NA49 – pions**

EOS,E895 – protons **CERES – all charged particles**

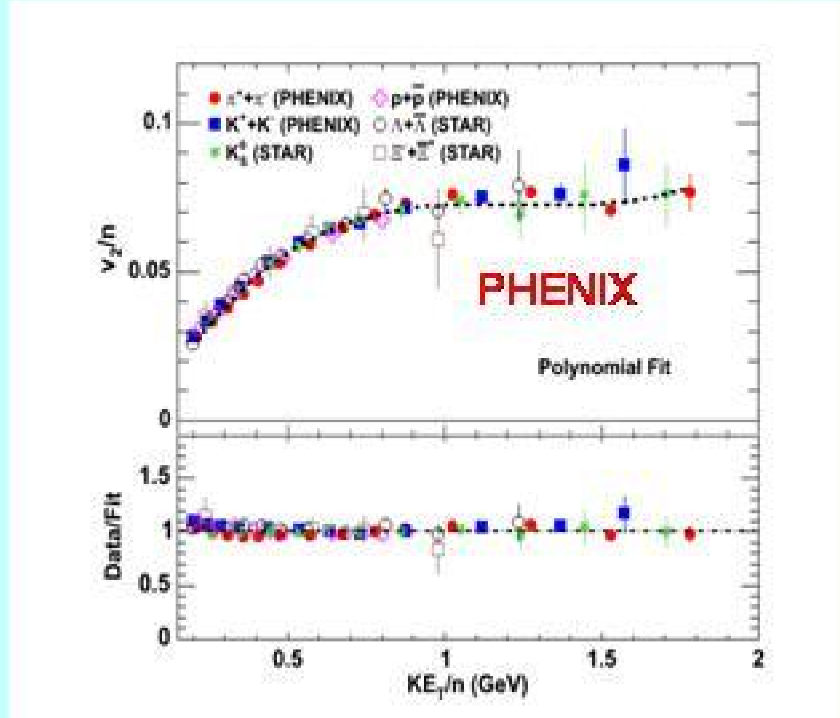
v_2 excitation function



Elliptic Flow - Quark Number Scaling

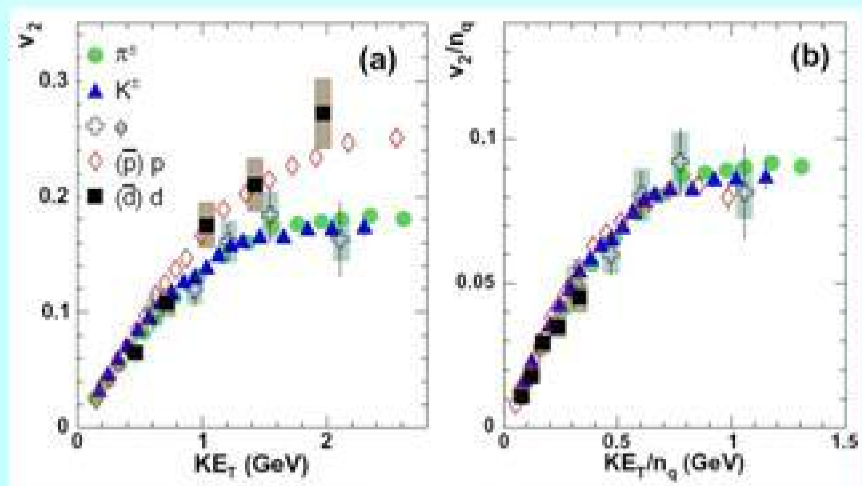


PRL 92 (2004) 052302; PRL 91 (2003) 182301



nucl-ex/0608033

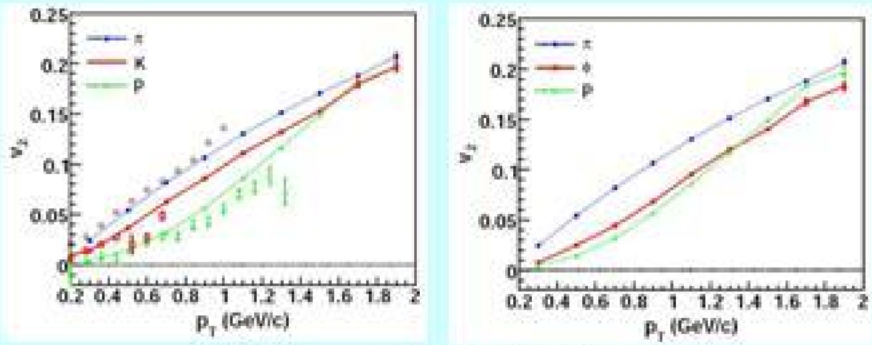
- At the moment of hadronization in nucleus-nucleus collisions at RHIC the dominant degree of freedom is related to number of constituent (valence) quarks
- These 'constituent quarks' exhibit an angular anisotropy resulting from collective interactions
- Hadrons seem to be formed from coalescence or recombination of the 'constituent quarks'



nucl-ex/0703024

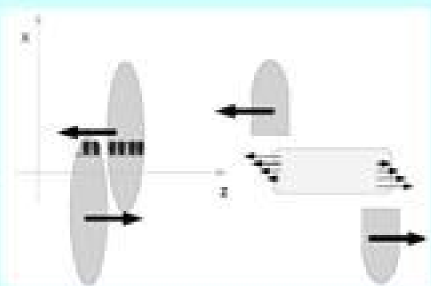
Other effects to be considered

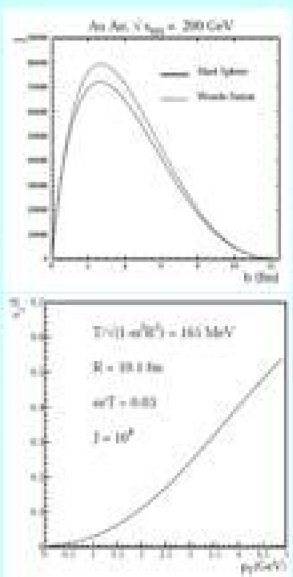
Hadronic dissipative effects



T.Hirano et al nucl-th/0608033

Angular momentum conservation

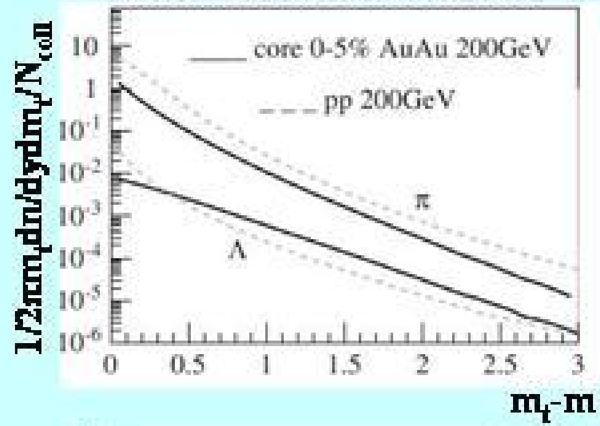


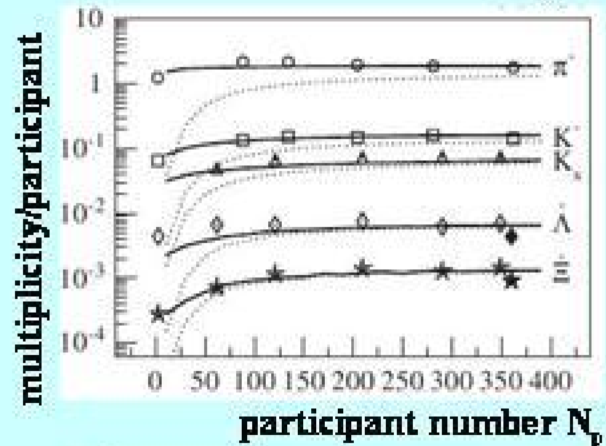


F.Becattini et al nucl-th/0711.1253

Core – Corona effects

K.Werner PRL 98(2007)152301



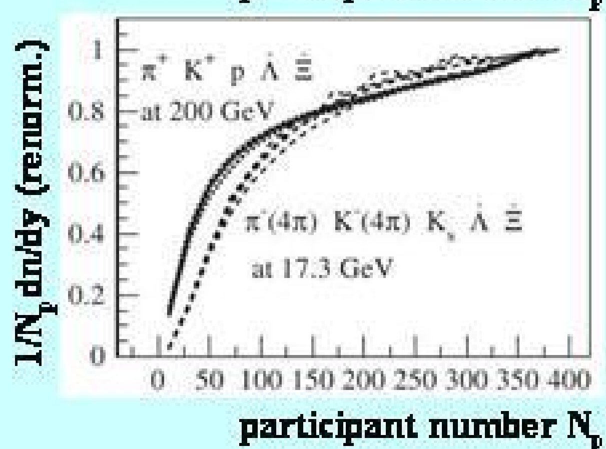


Pb+Pb

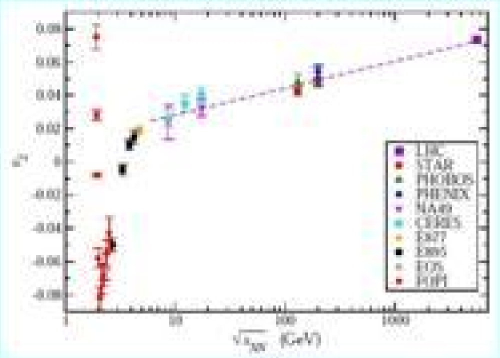
!7.3 GeV

total

core

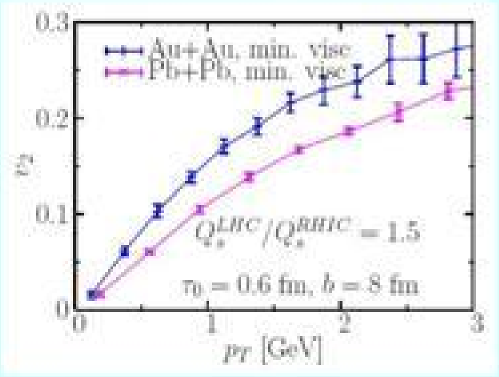


Expectations for LHC



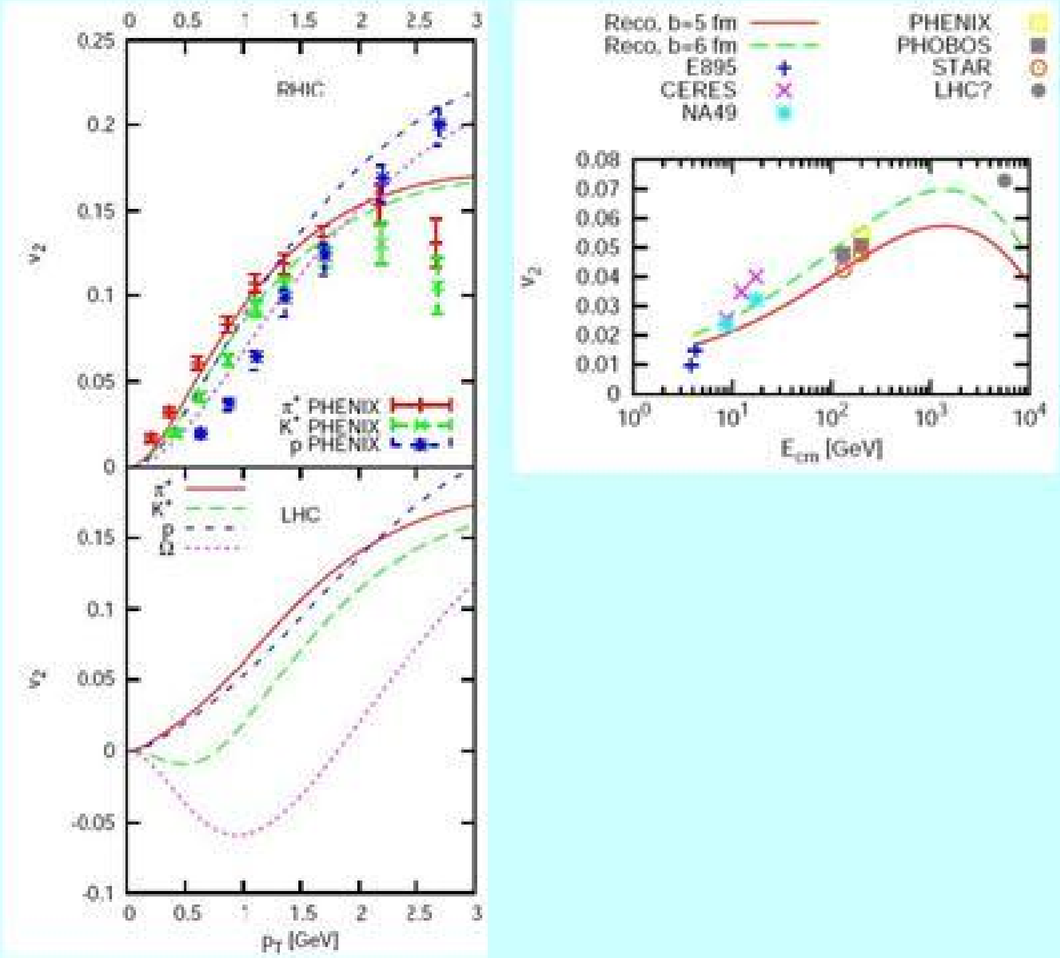
N.Borghini et al hep-ph /0707.0564

Parton transport



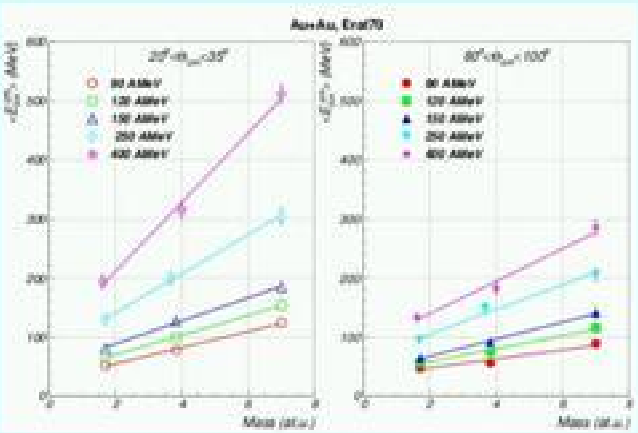
D.Molnar nucl-th/0707.125

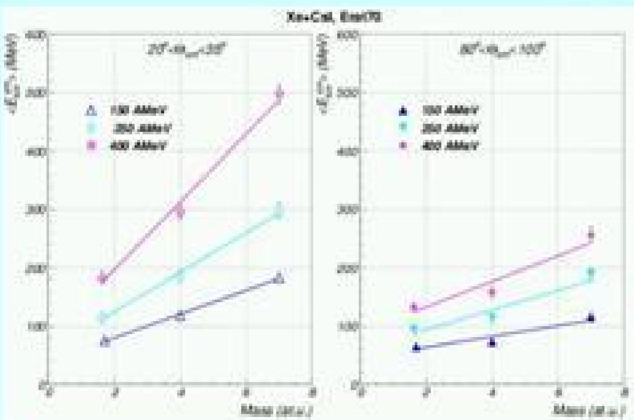
Parton recombination approach

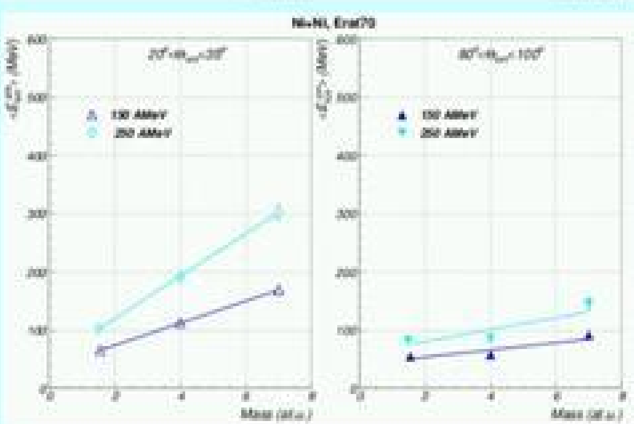


D.Krieg et al nucl-th/0708.3015

Highly central Au+Au,Xe+CsI,Ni+Ni collisions

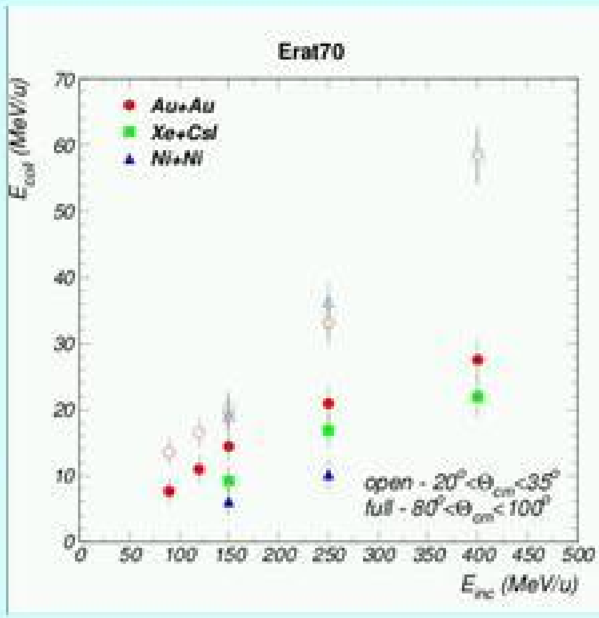


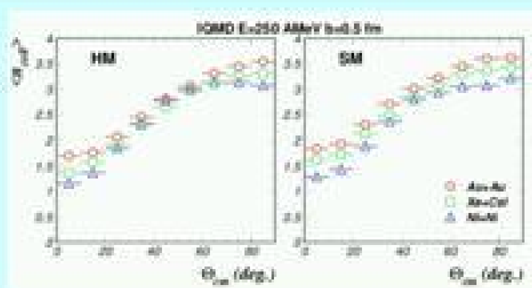


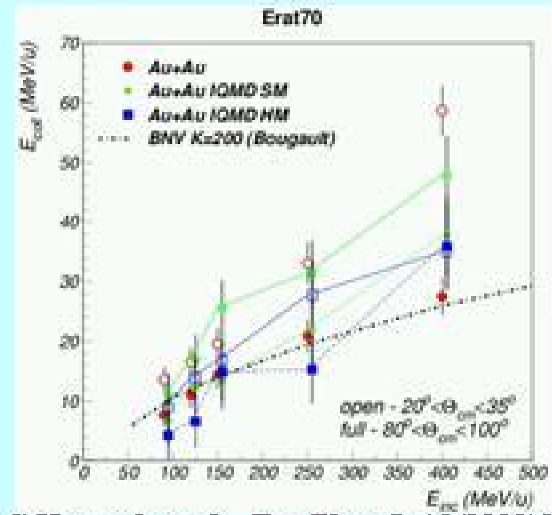


$$\langle E_{kin}^{cm}\rangle \approx \frac{1}{2} m_0 < \beta^2_{flow} > A_{IMF} + \frac{3}{2} "T"$$

$$E_{coll} = \frac{1}{2} m_0 \langle \beta^2_{flow} \rangle$$

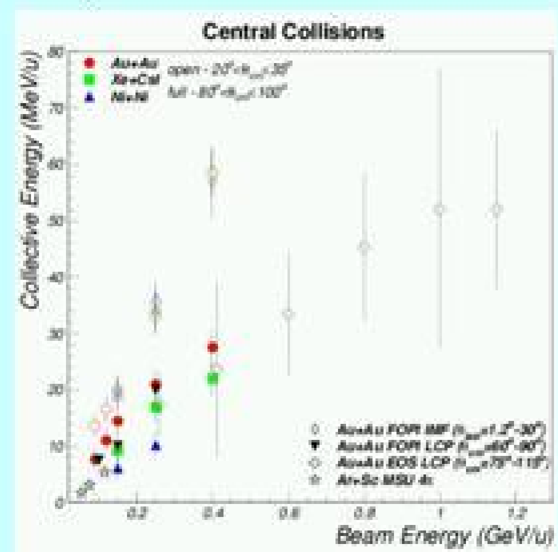




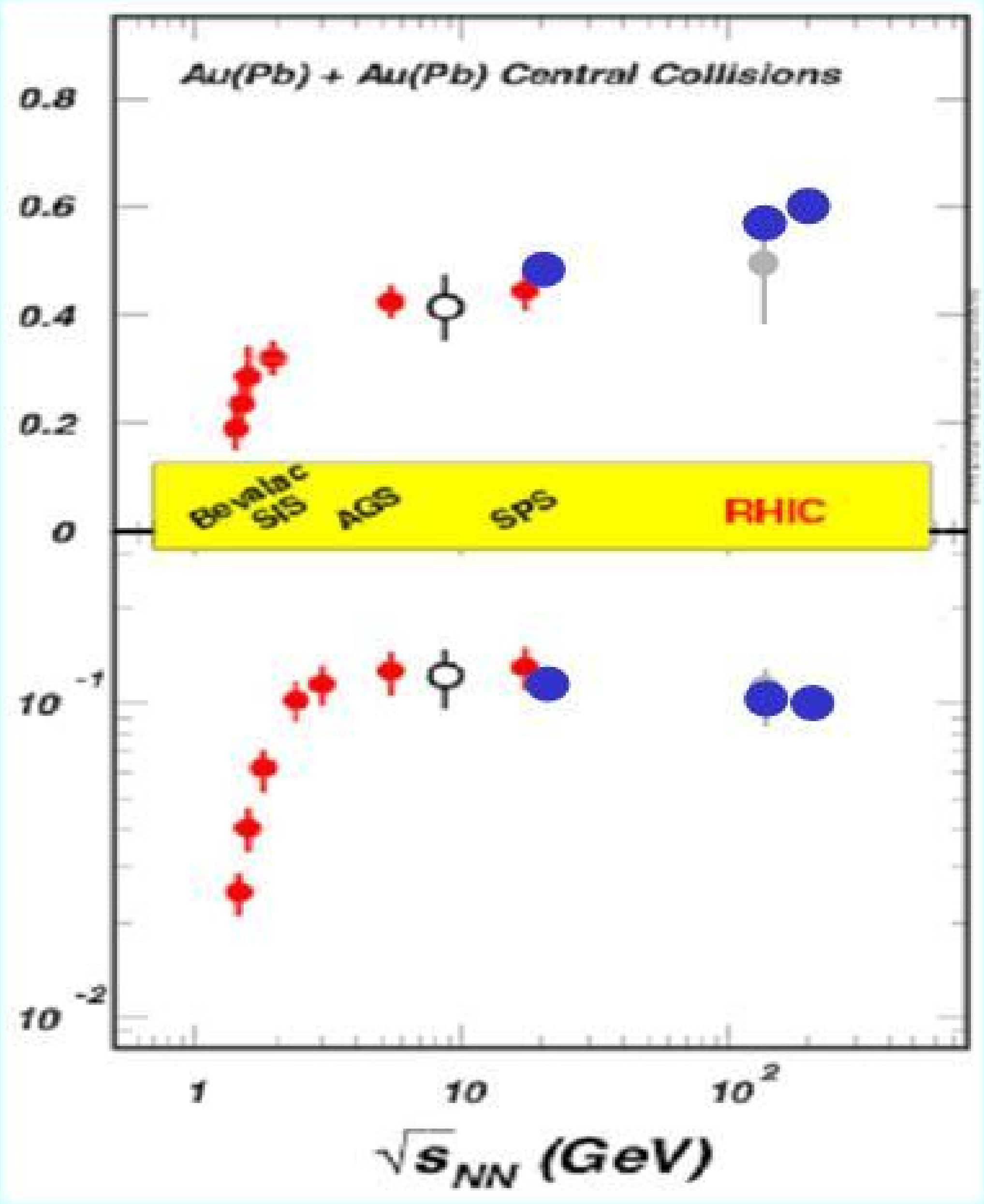


C.Hartnak et al.,, Eur.Phys.J. A1(1998)151

R.Bougault et al., Nouvelles de GANIL, no.58, June 1996

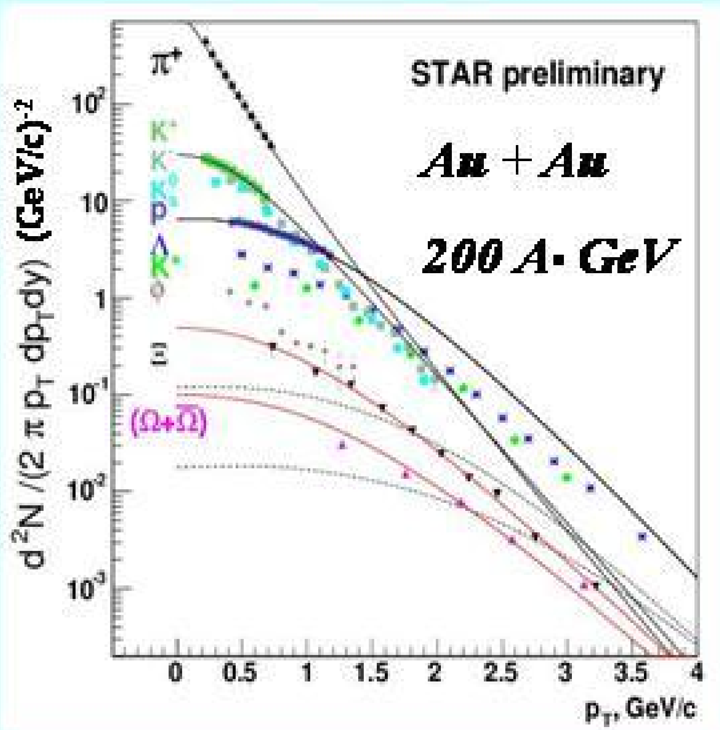


Transverse Flow

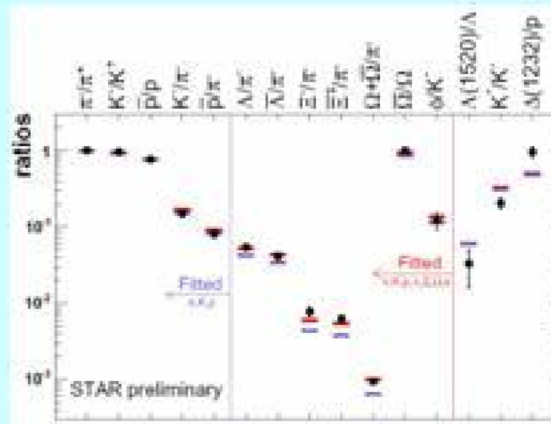


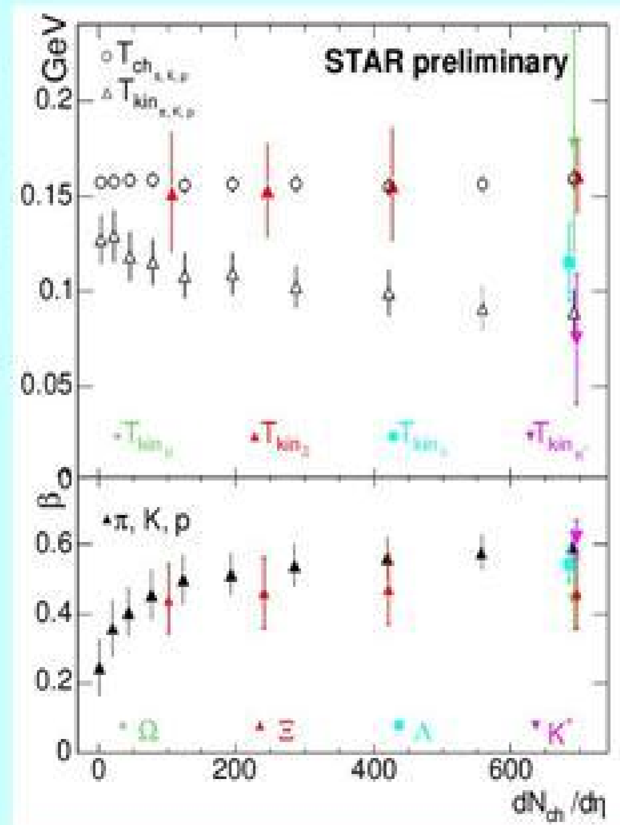
Transverse Flow @ RHIC

nucl-ex/0403014



Particle	T_{kin} (MeV)	$\langle\beta\rangle$ (c)
π, K, p	89 ± 10	0.59 ± 0.05
K^*	75 ± 35	0.62 ± 0.05
Λ, $\bar{\Lambda}$	115 ± 20	0.54 ± 0.05
Ξ^-, $\bar{\Xi}^+$	161 ± 20	0.46 ± 0.10
Ω, $\bar{\Omega}$	179 ± 60	0.45 ± 0.10



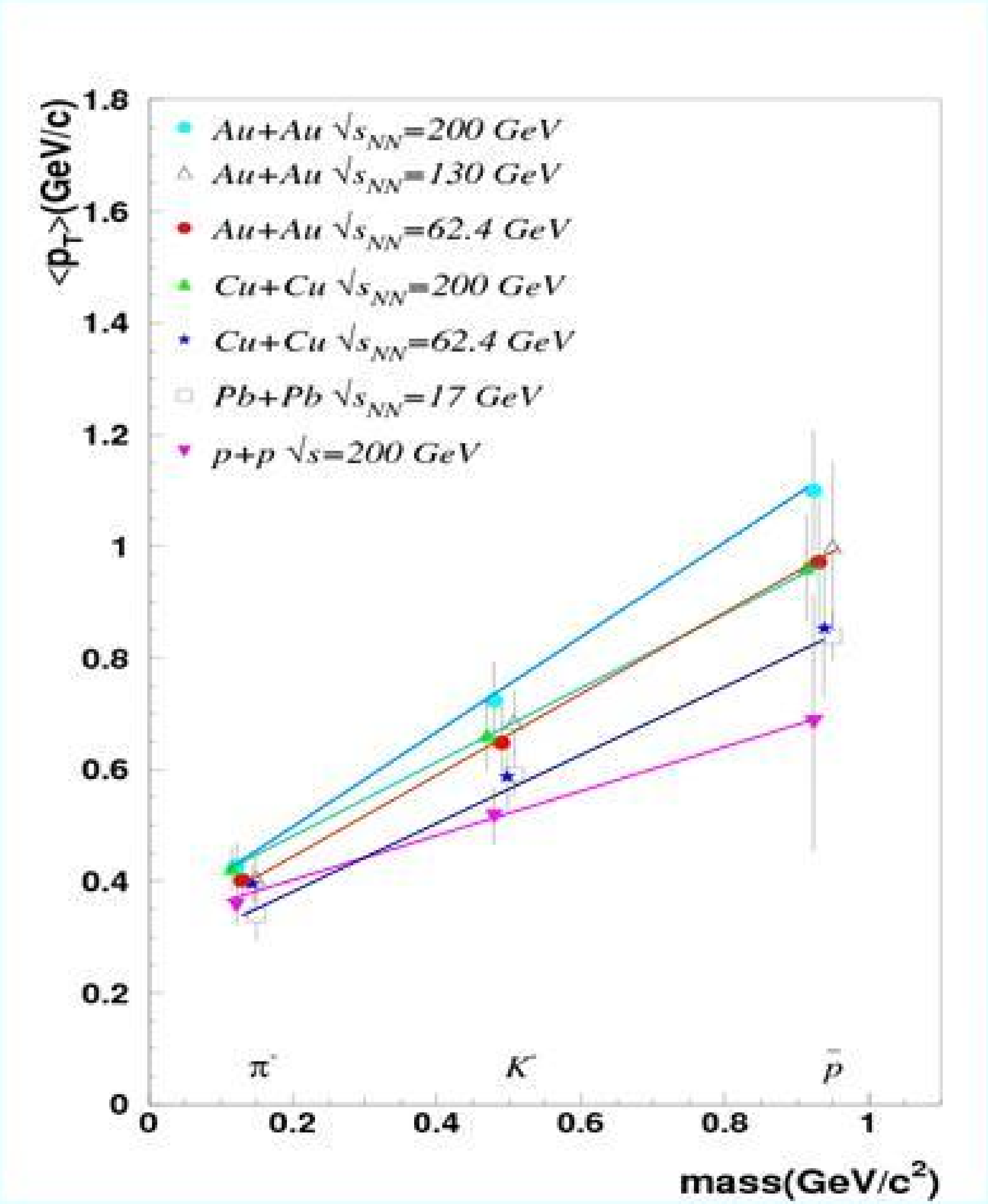


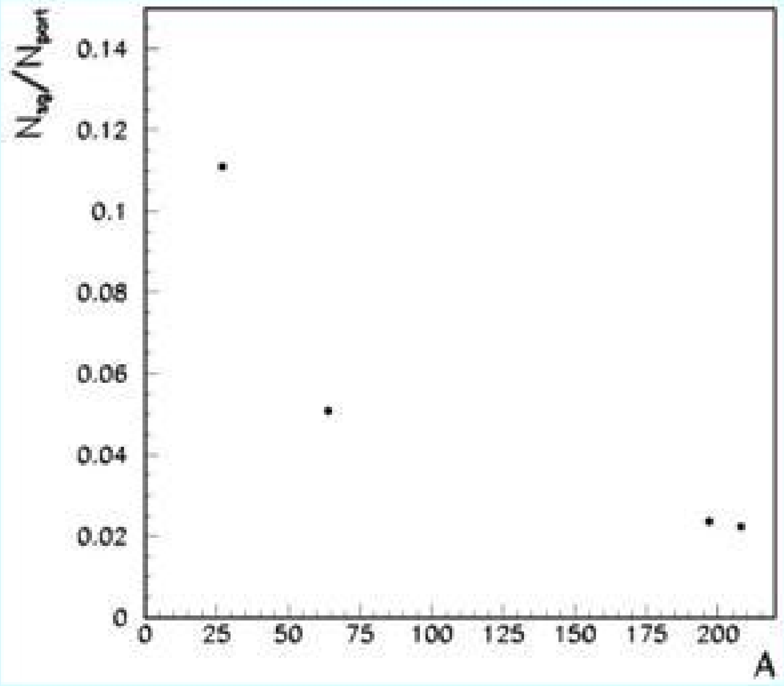
$$\frac{dN}{m_t dm_t} \sim \int_0^R r dr\, m_T K_1\left(\frac{m_t \cosh\rho}{T_{f0}}\right) I_0\left(\frac{p_t \sinh\rho}{T_{f0}}\right)$$

$$\rho = \tanh^{-1}\beta_r \qquad \beta_r = \beta_s \left(\frac{r}{R}\right)^{\alpha} \quad \alpha = 0.5, 0.7, 1, 2$$

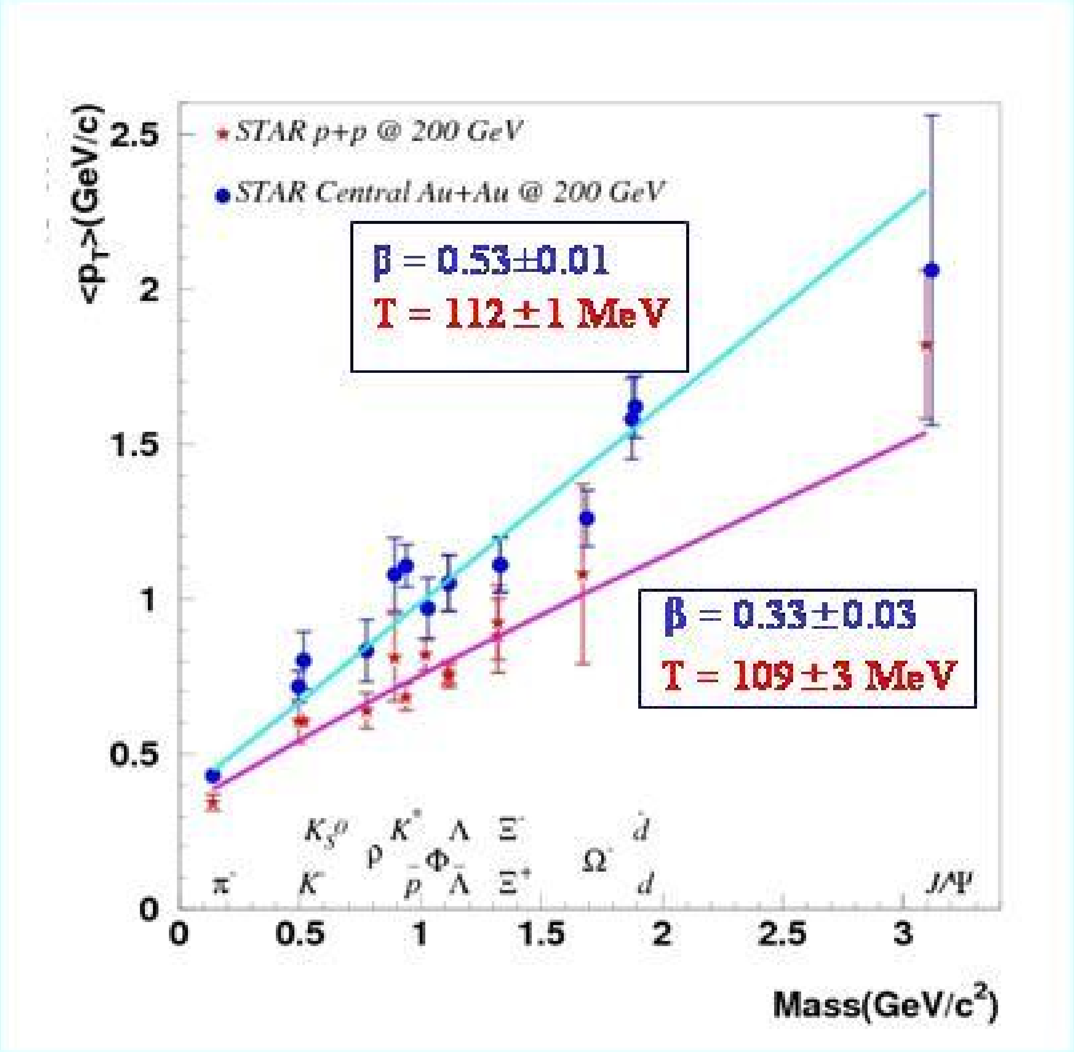
Schnedermann et al nucl-th/9307020

Transverse Flow





Transverse Flow



Λ, $\bar{\Lambda}$, $\Xi^{\pm}$, Ω^-, J/ψ

β = 0.36, T = 172 MeV

π, K, $\bar{p}$, d, $\bar{d}$

β = 0.59, T = 104 MeV

Past-Present-Future

	SPS	RHIC	LHC	
$\sqrt{s_{NN}}$ (GeV)	17	200	5500	
dN_{ch}/dy	500	850	1500-4000	
$t^{\square}_{QGP}$ (fm/c)	1	0.2	0.1	
T/T_c	1.1	1.9	3-4	Hotter
e (GeV/fm^3)	3	5	15-60	Denser
t_{QGP} (fm/c)	≤2	2-4	≥10	Longer
t_f (fm/c)	~10	20-30	30-40	
V_f(fm^3)	few 10^3	few 10^4	Few 10^5	Bigger

LHC: will open the **next chapter** in HI physics

significant step over & above existing facilities

THE place to do **frontline research** soon

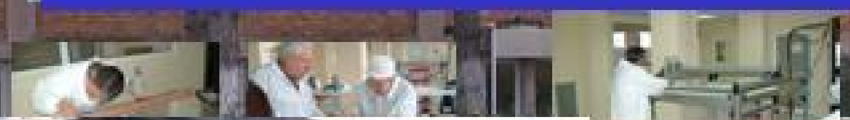
Outlook

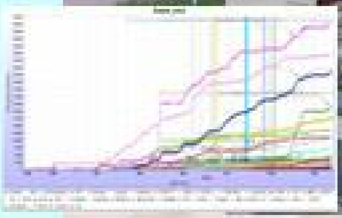
November 2002 – member of ALICE GRID

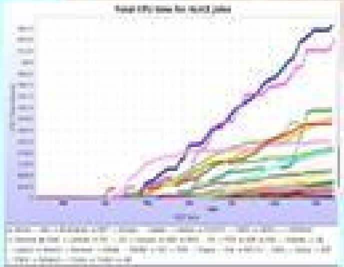
THE FIRST INTERNATIONAL
GRID APPLICATION IN ROMANIA

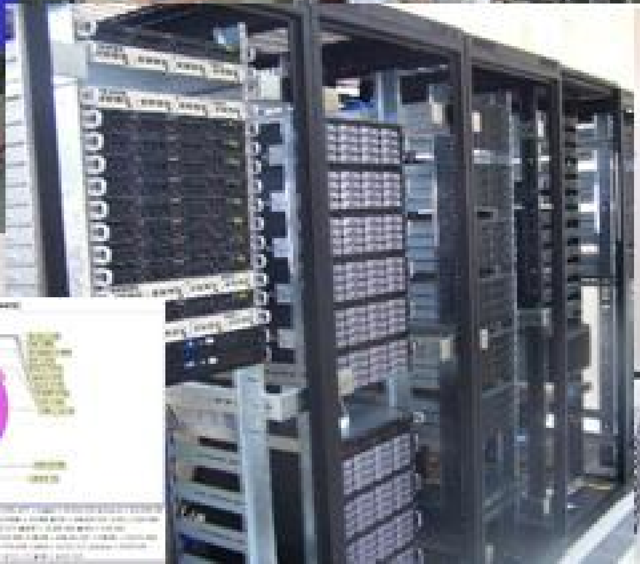
- *~ 700 CPU cores, 2GB RAM/core*
- *144 TB (raw) dedicated storage*
- *1 Gbit/s internal network.*
- *10 Gbit/s uplink.*
- *3 cooling units, industrial grade.*
- *3 x 80 kVA UPS, industrial grade.*
- *Diesel generator, 600 kVA*

NIHAM within ALICE GRID – present status





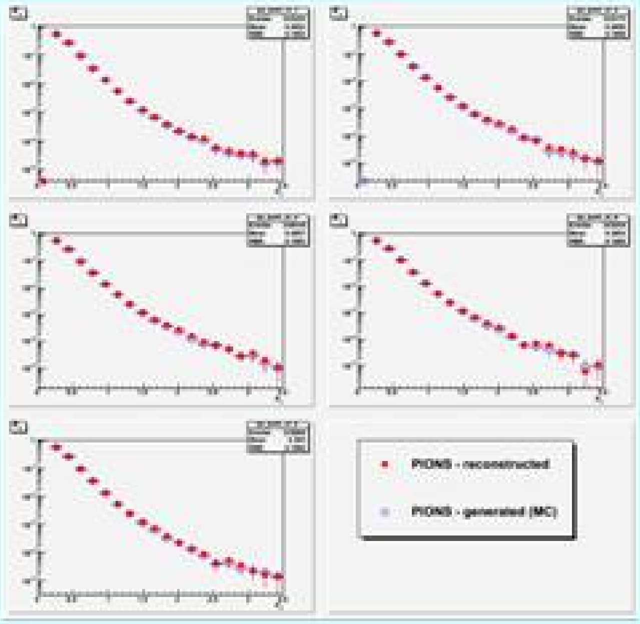


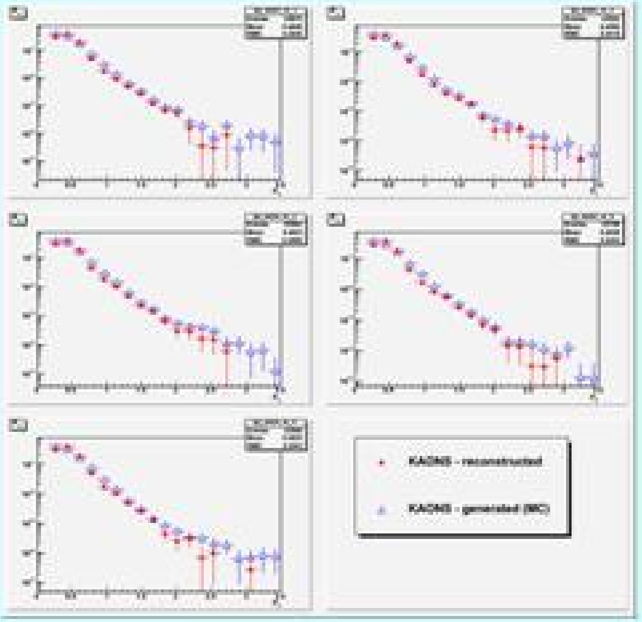


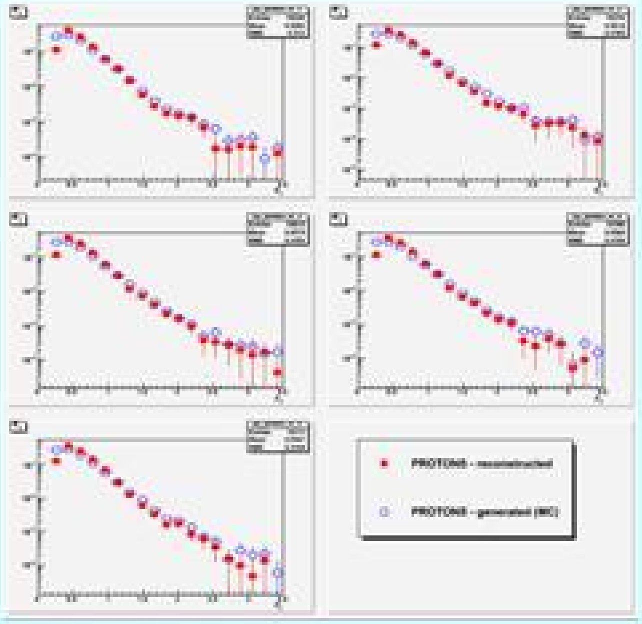
Outlook

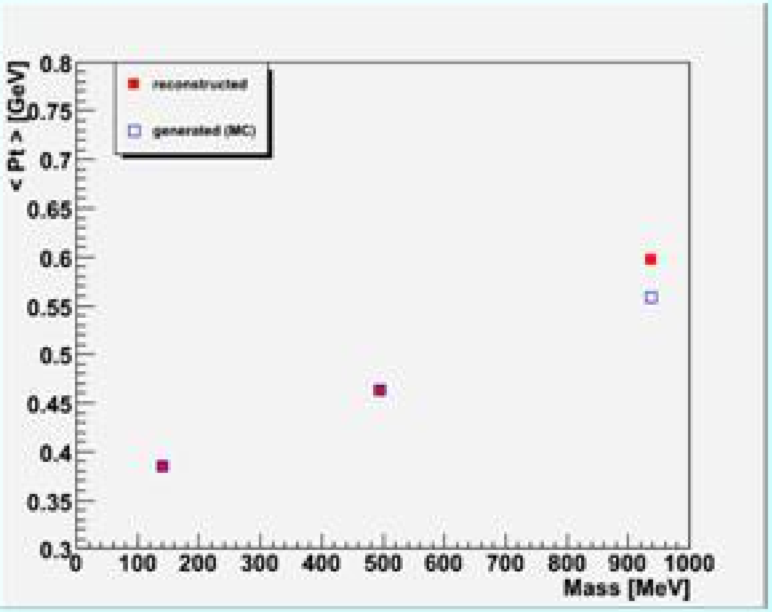
Pb + Pb 5.5 TeV

Hijing









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