

Flow

HW#3

List Hadrons including charm or bottom quark

- 1.) Quark content, mass, charge**
- 2.) Rank them with respect to their abundance**

How do you detect them ?

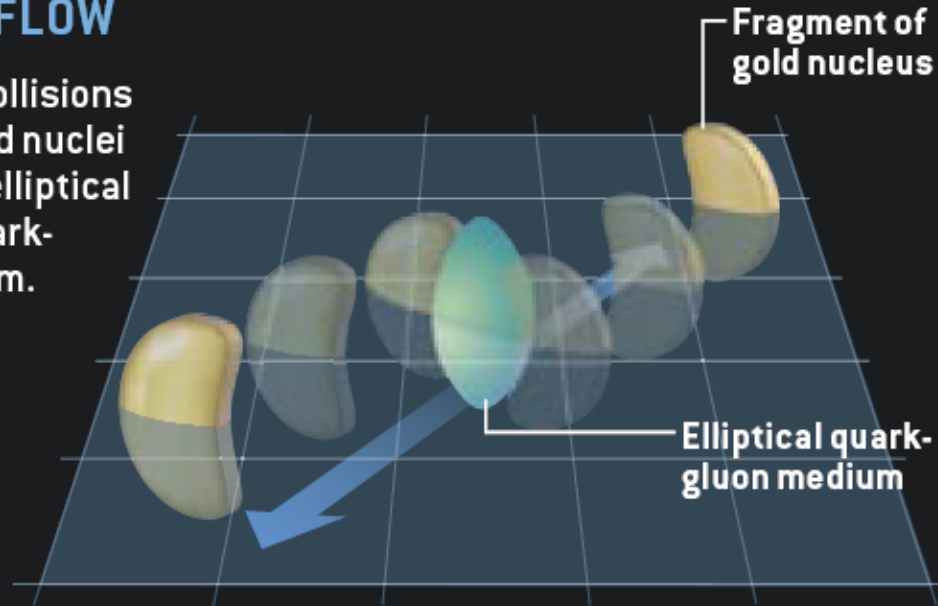
- 1.) Decay channel, Branching ratio**
- 2.) Which detector can detect or select decay particle?**

Elliptic flow

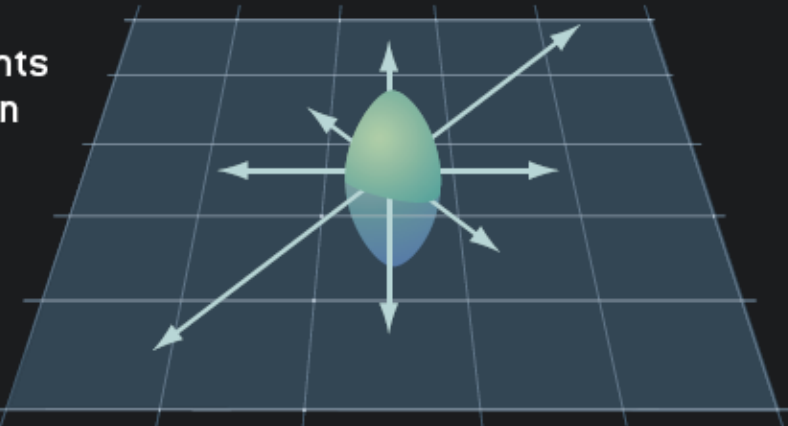
Elliptic flow → Transverse Flow (SPS, RHIC, LHC)

ELLIPTIC FLOW

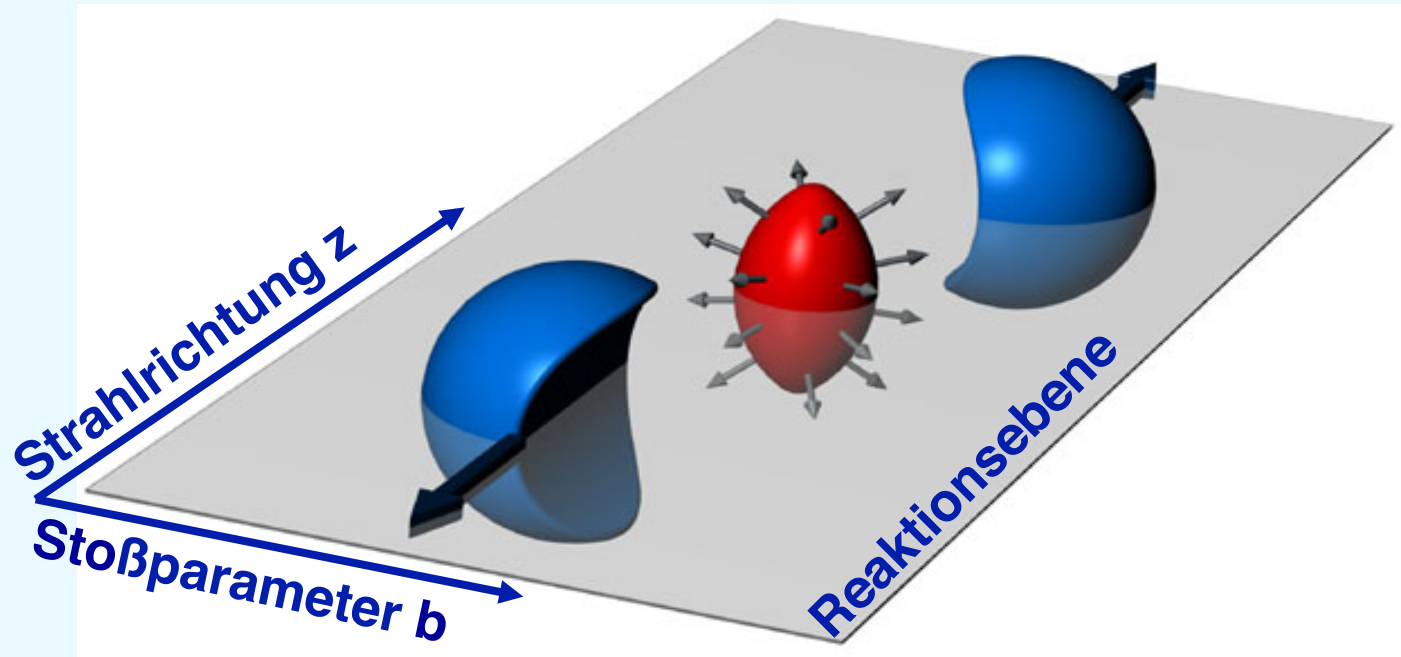
Off-center collisions between gold nuclei produce an elliptical region of quark-gluon medium.



The pressure gradients in the elliptical region cause it to explode outward, mostly in the plane of the collision (*arrows*).

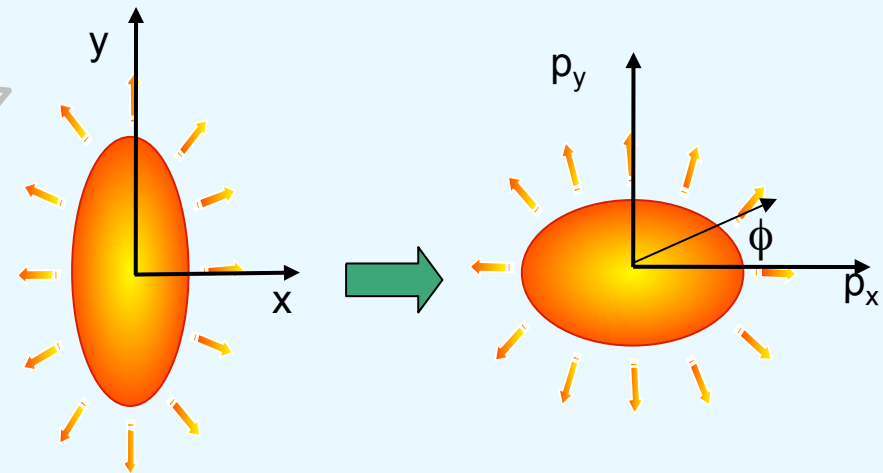
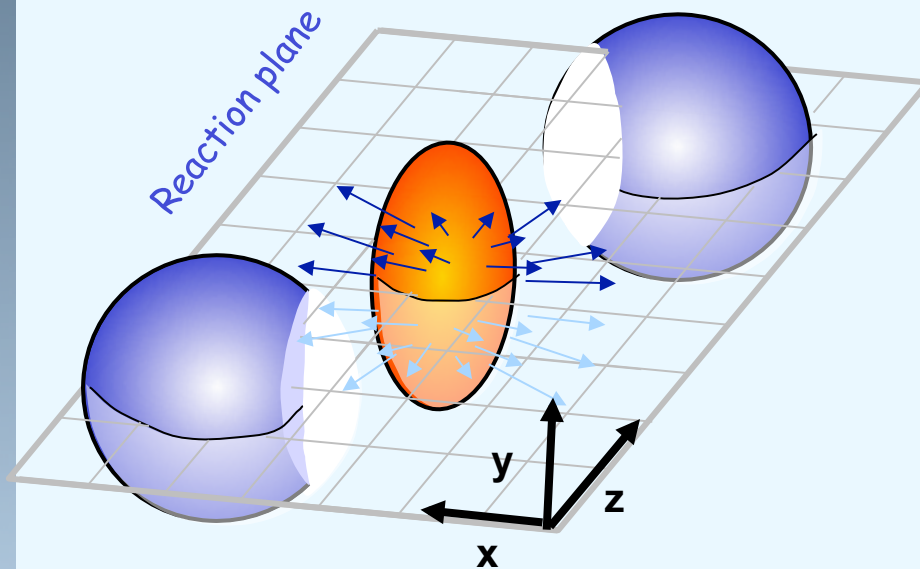
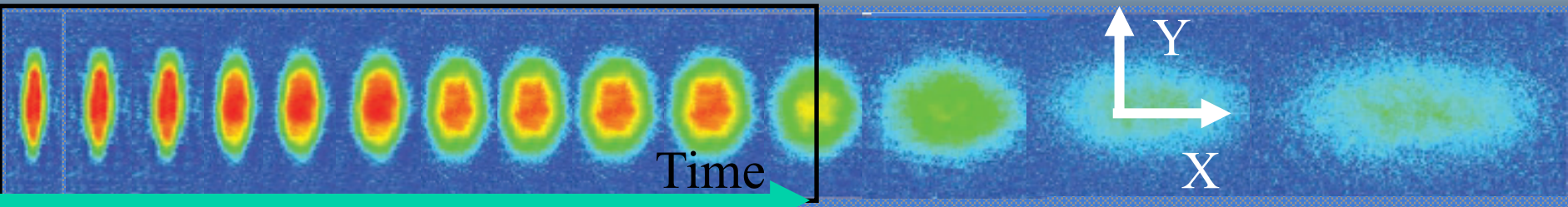


Reaktionsebene



Elliptic flow = (anisotropic) Flow

– a strong indicator of collectivity



$$v_2 = \frac{\langle p_x^2 \rangle - \langle p_y^2 \rangle}{\langle p_x^2 \rangle + \langle p_y^2 \rangle}$$

- non-central collisions: azimuthal anisotropy in coordinate-space.
- interactions → asymmetry in momentum-space.
- sensitive to early time in the system's evolution.
- Measurement: Fourier expansion of the azimuthal p_T distribution.

$$\frac{dN}{d\phi} \propto 1 + 2v_2 \cos[2(\phi - \Psi_R)]$$

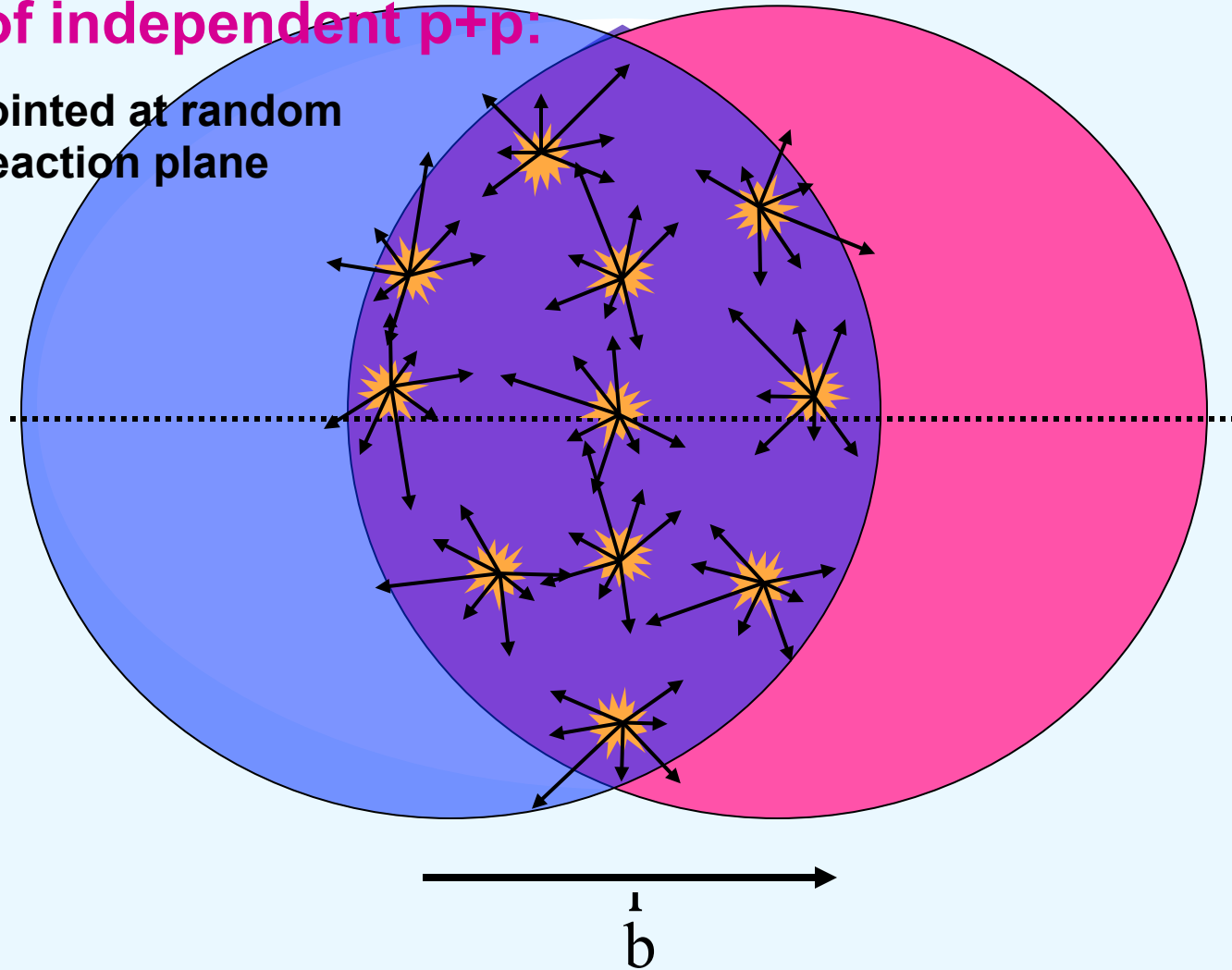
Elliptic flow

Reaction plane

How do semi-central collisions evolve?

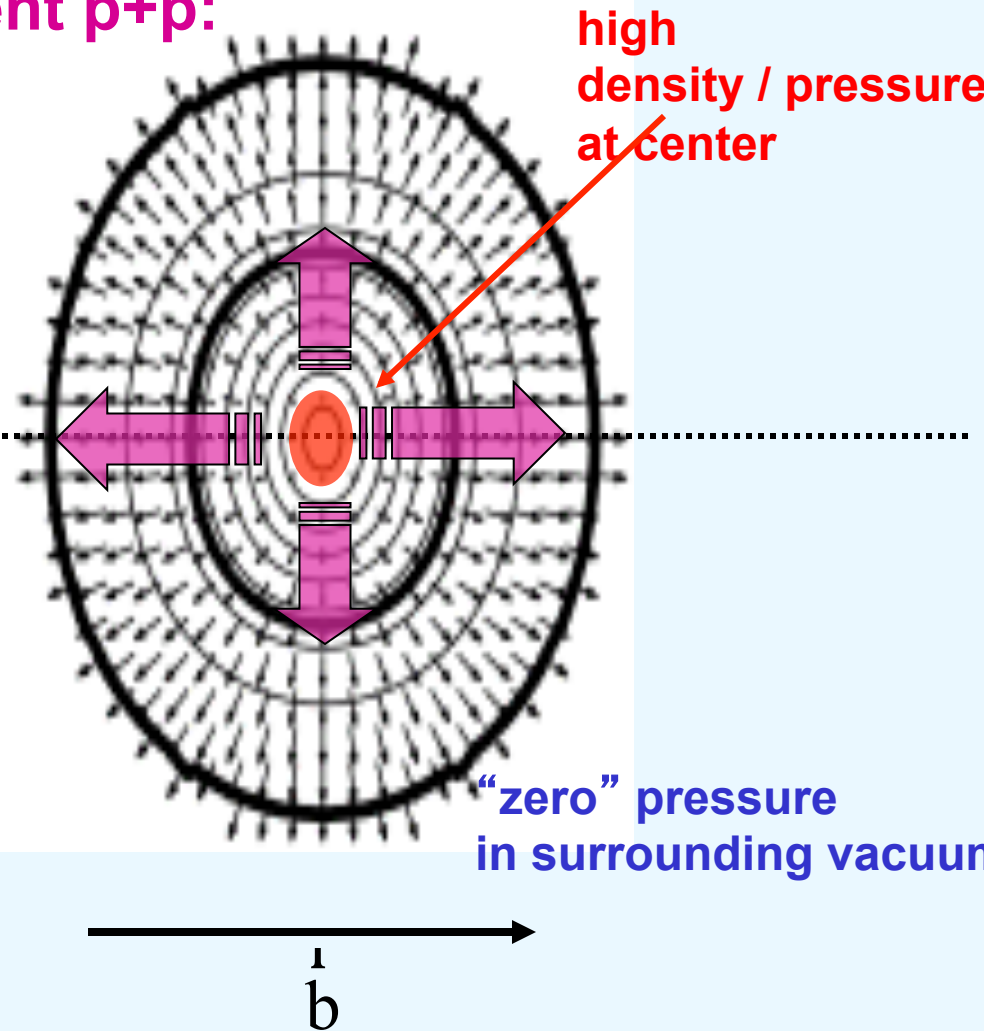
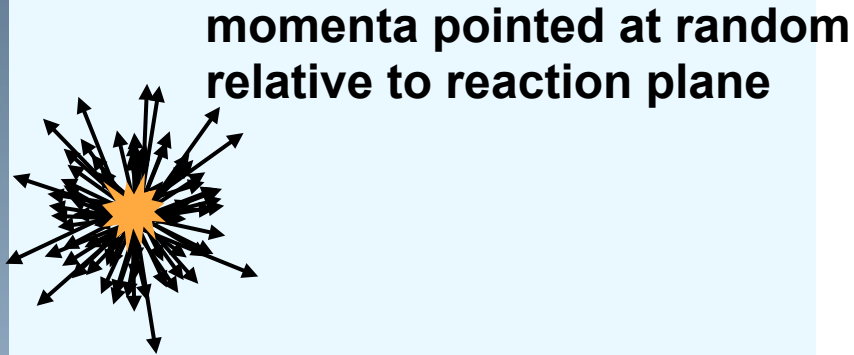
1) Superposition of independent p+p:

momenta pointed at random
relative to reaction plane



How do semi-central collisions evolve?

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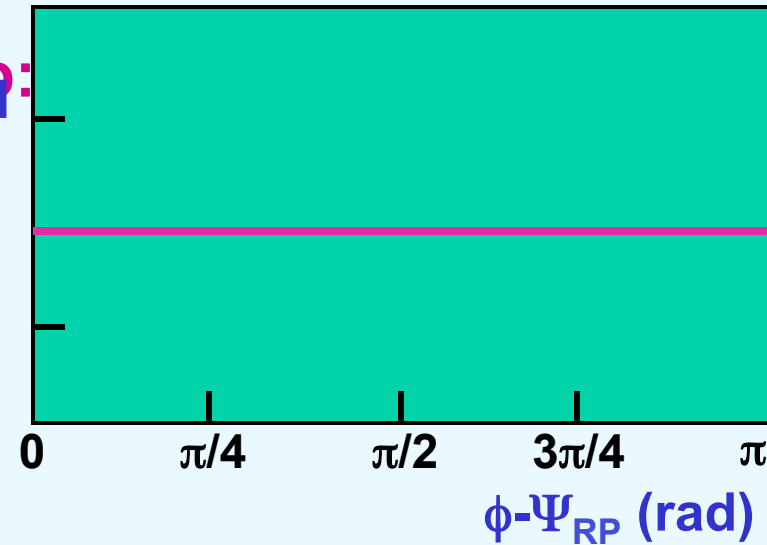
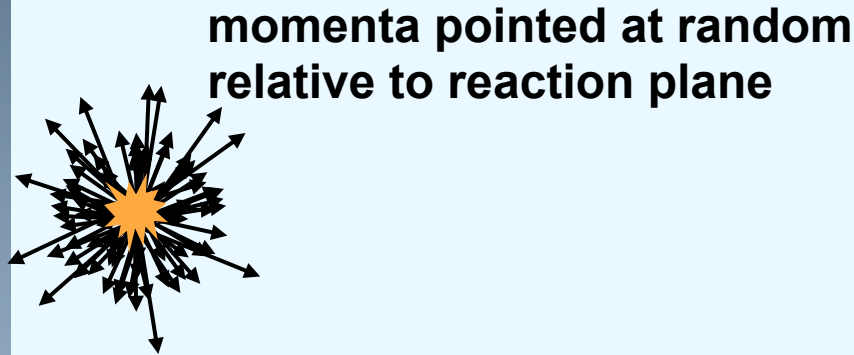
2) Evolution as a bulk system

Pressure gradients (larger in-plane) push bulk “out” → “flow”



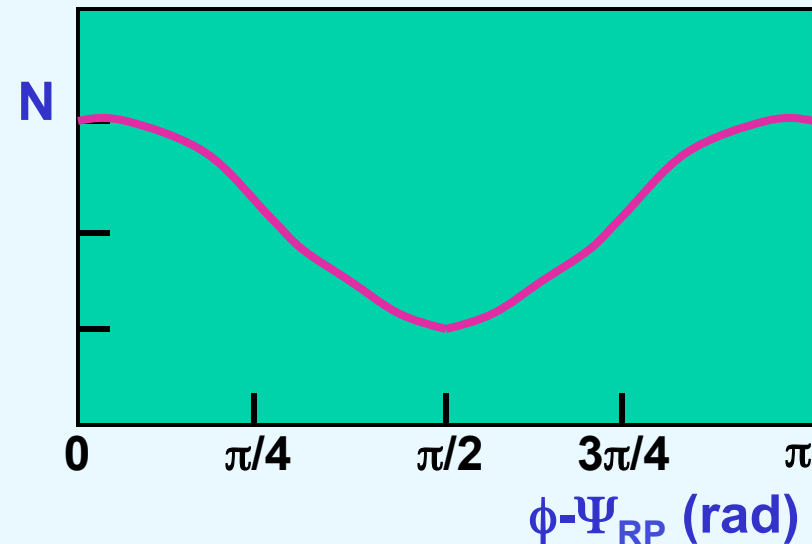
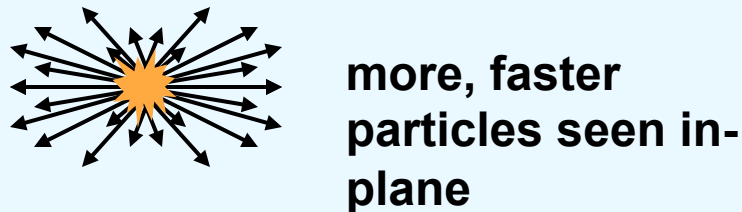
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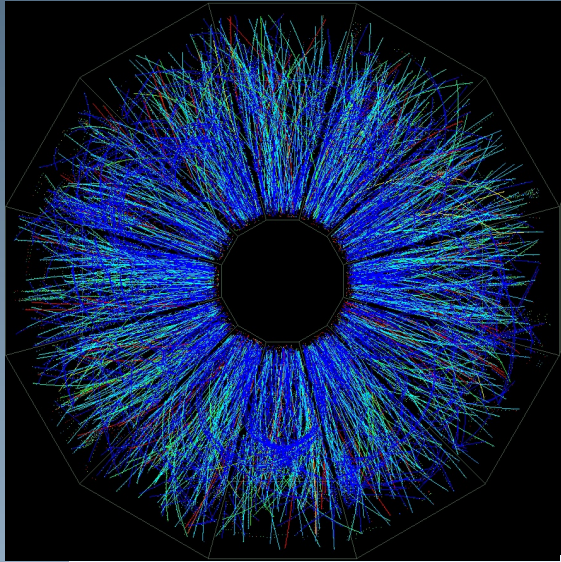


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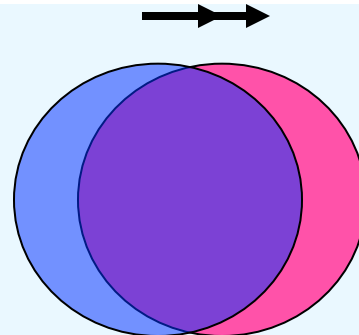
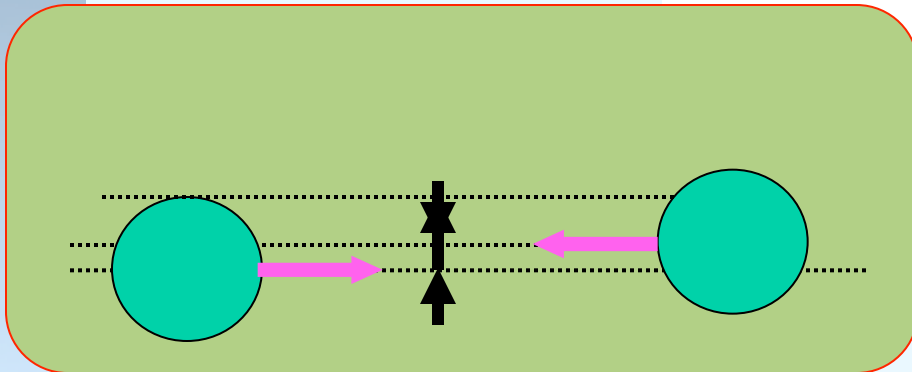
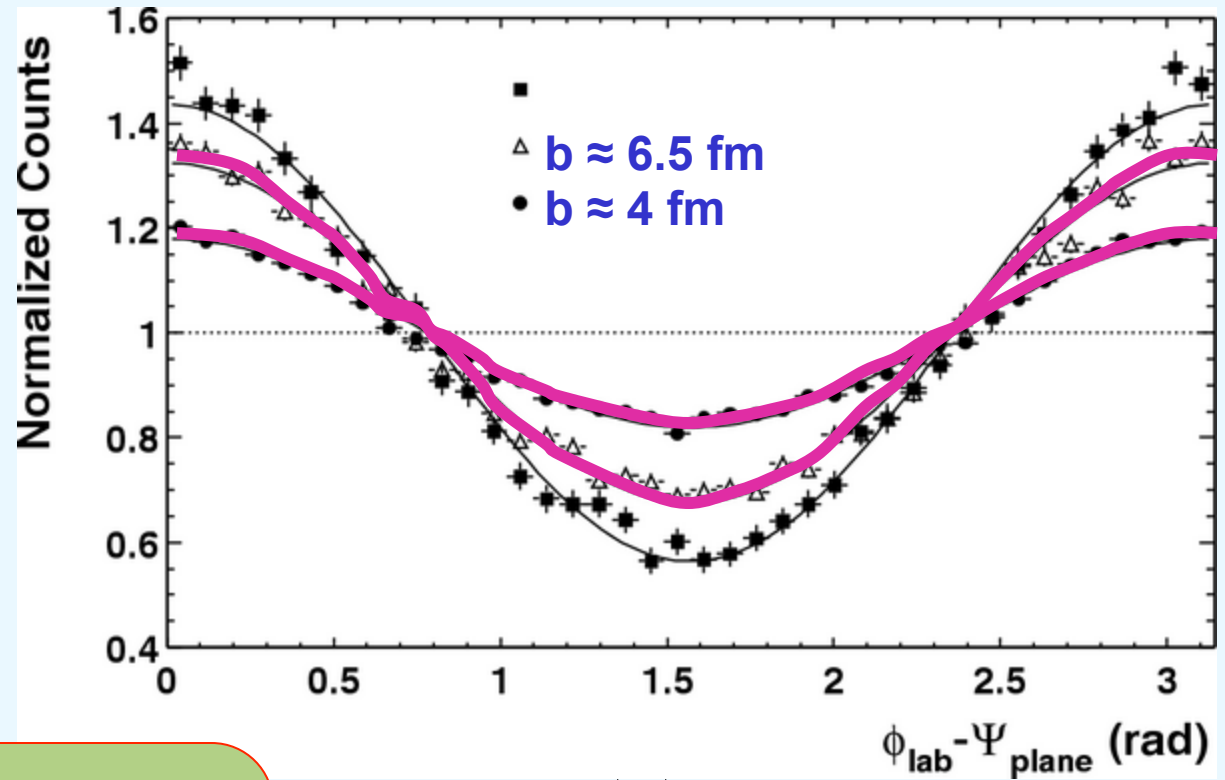


Azimuthal distributions at RHIC



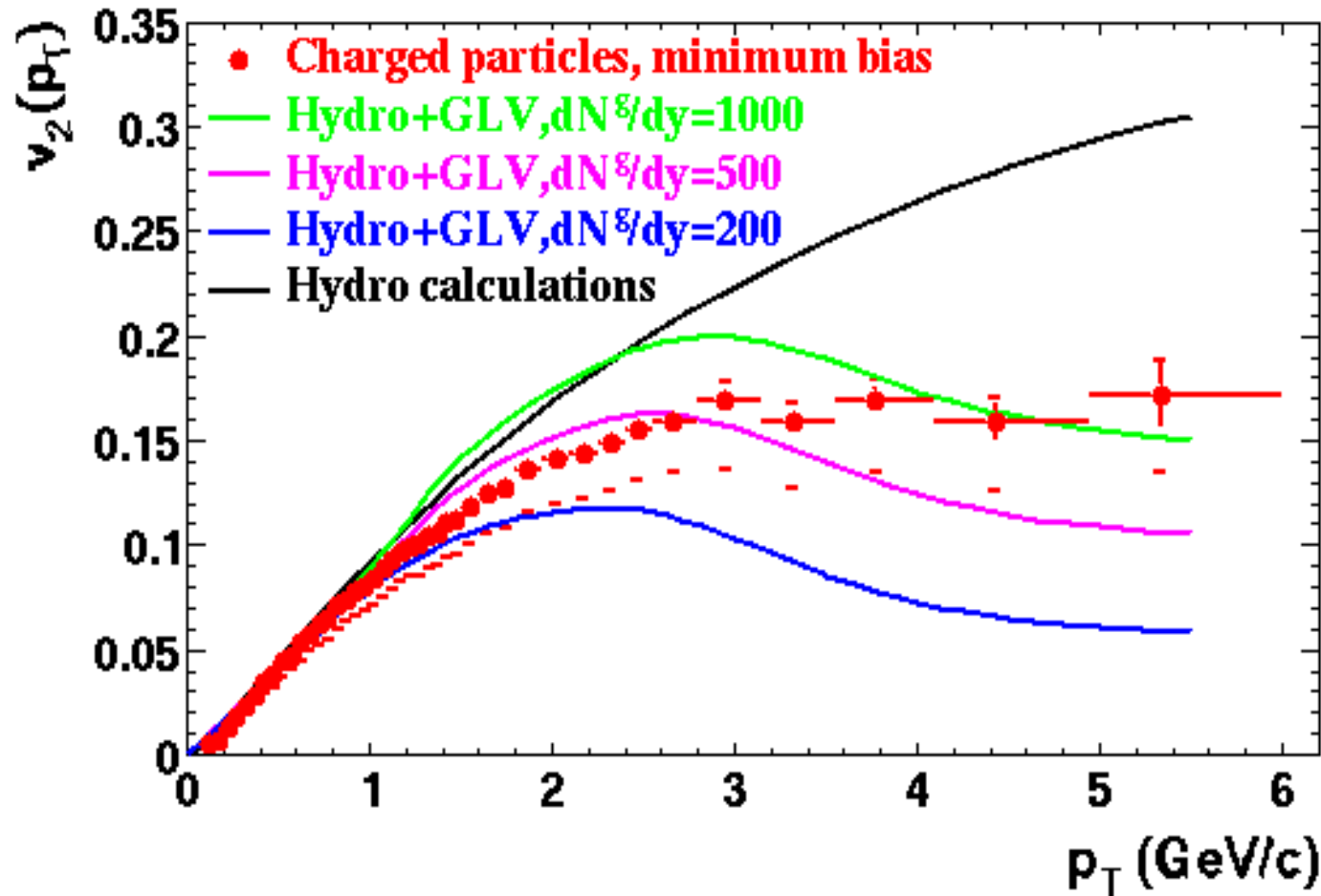
midcentral collisions

STAR, PRL90 032301 (2003)



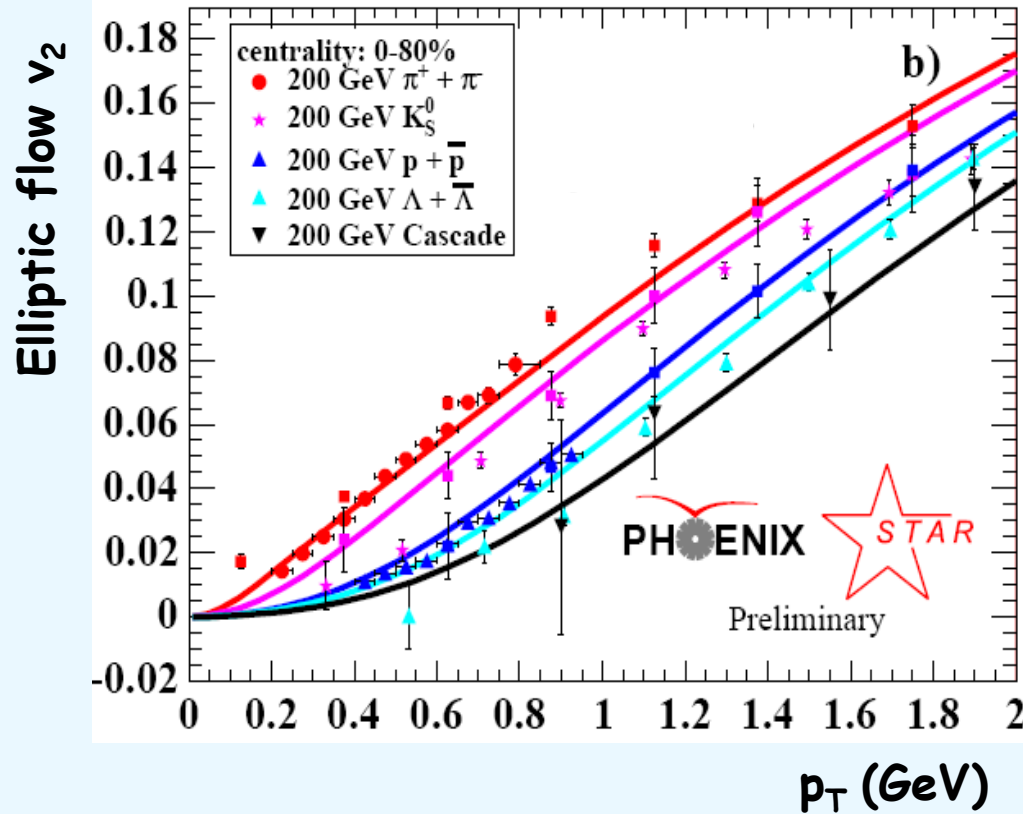
Elliptic flow at high p_T : data (STAR experiment)

PRL 90, 032301



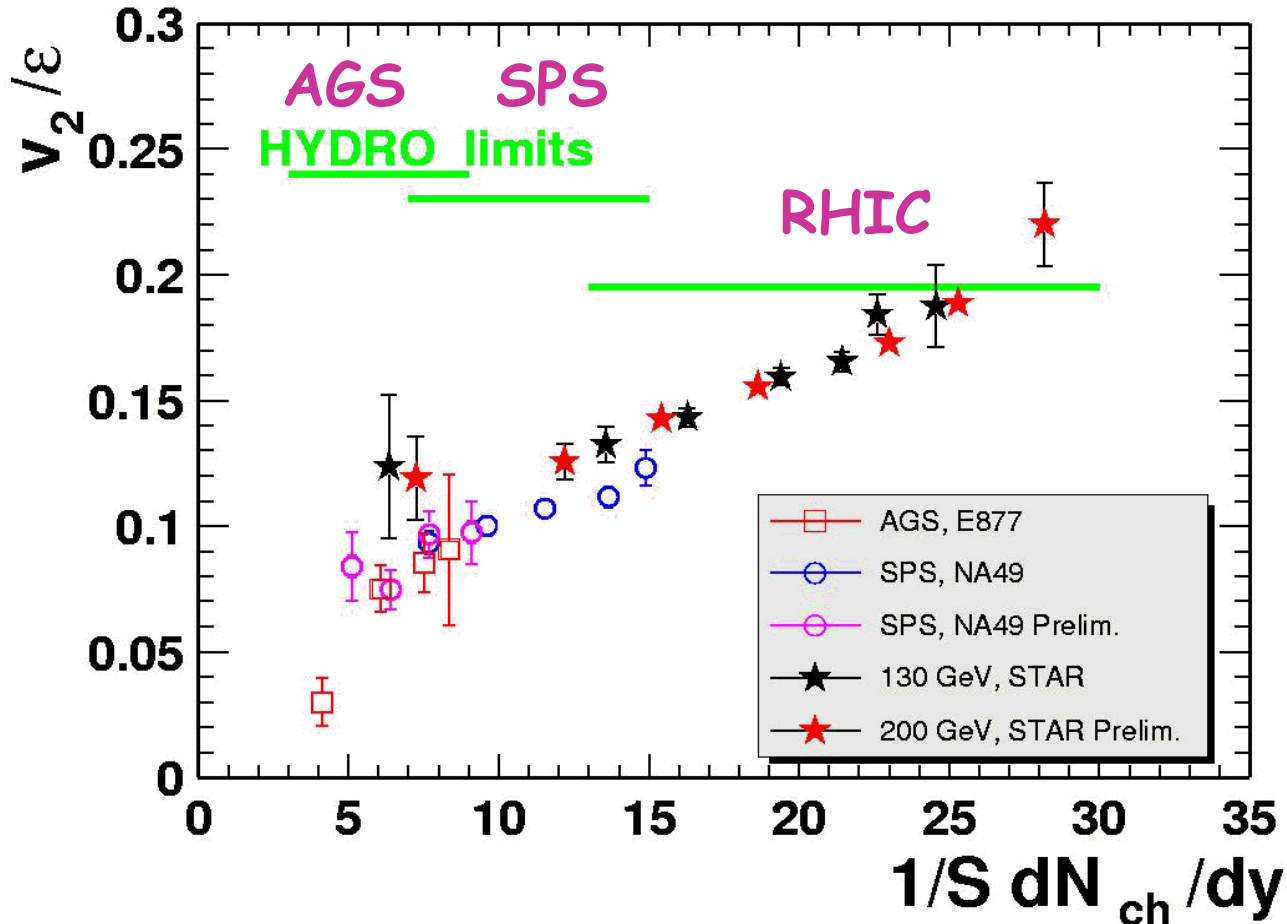
- $p_T < 2$ GeV: detailed agreement with hydrodynamics

Hydrodynamic Behavior



- v_2 at $p_T < 2$ GeV is described by fluid dynamics calculations (zero viscosity)
→ collective interactions at early stage (assumes QGP Equation of State based on lattice QCD: Equilibration time $t=0.6$ fm/c and $e=20$ GeV/fm³).

The System is Thermalized at RHIC



ϵ = spatial anisotropy
 $1/\epsilon$ = geometry normalization
 Energies:
 AGS: $\sqrt{s} = \sim 2 \text{ GeV}$
 SPS: $\sqrt{s} = 4-17 \text{ GeV}$
 RHIC: $\sqrt{s} = 130/200 \text{ GeV}$

First time in Heavy-Ion Collisions a system created which, at low p_{\perp} , is in **quantitative** agreement with ideal hydrodynamic model predictions for v_2 up to mid-central collisions