Azimuthal correlations

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Azimuthal correlations

Why do we want to measure (two-particle) azimuthal correlations in non-central collisions?

- Resonance flow
- Azimuthally sensitive interferometry
- Correlations between high-p_T particles

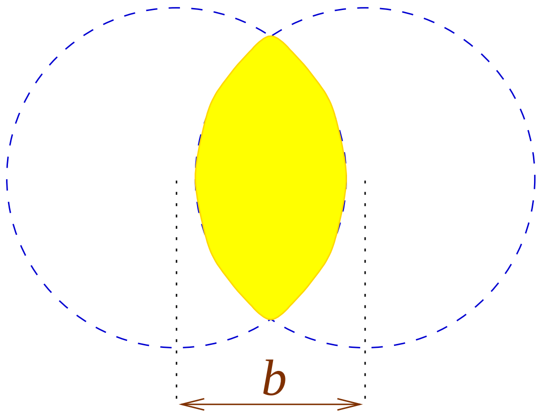
Different physical phenomena investigated...

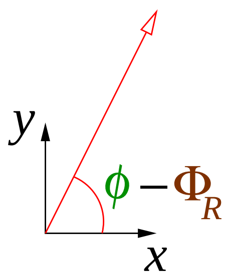
...different methods of analysis

A single observable?

Anisotropic flow

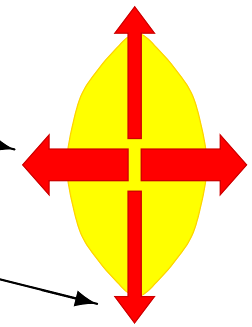
Non-central collision:





The particle source is anisotropic
(and around it there is only vacuum)

$\Rightarrow$ the pressure gradient along the impact parameter direction is stronger than the gradient perpendicular to the reaction plane



$\Rightarrow$ $\underbrace{\text{anisotropic}}_{\text{in } \textit{momentum} \text{ space}}$ particle emission: FLOW

Particles mainly emitted *in-plane* ($\phi = \Phi_R$) rather than *out-of-plane* ($\phi - \Phi_R = 90^{\circ}$).

Anisotropic flow

Anisotropy quantified by a Fourier expansion:

$$p_1(\phi - \Phi_R) \propto 1 + 2\, v_1 \cos(\phi - \Phi_R) + 2\, v_2 \cos 2(\phi - \Phi_R) + \ldots$$

Measuring anisotropic flow is a complicated issue:

$$v_n = \langle \cos n(\phi - \Phi_R) \rangle$$

lab. frame   not measured!

Many methods of analysis are available (even unbiased ones!)

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Many methods of analysis are available (even unbiased ones!)

... at least, for directly detected particles ($\pi^\pm$, $K^\pm$, p)

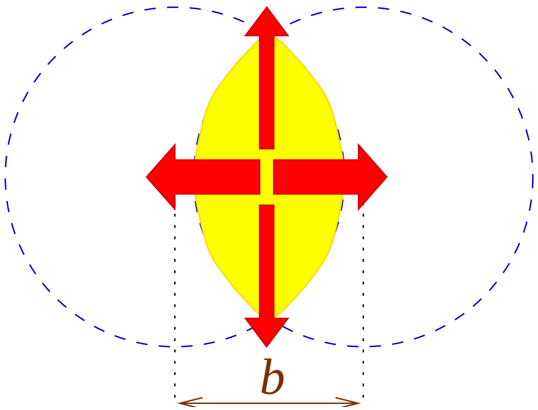
Improvements still possible for the flow of "resonances"

particles that decay before reaching the detector: π^0, K^0_S, Λ...

$\Rightarrow$ studied through their decay products

Azimuthally sensitive interferometry

Initial state:

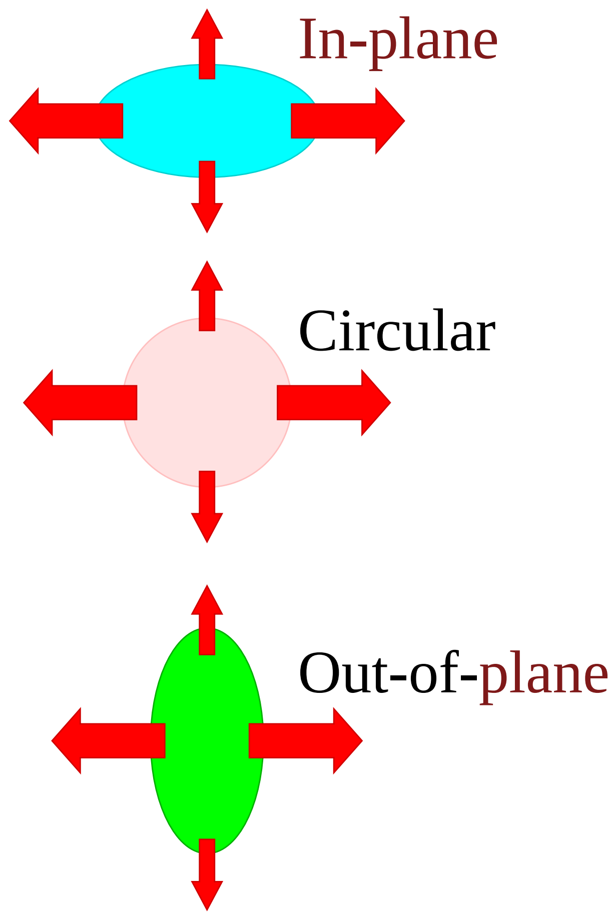


Pressure gradients

$\Rightarrow$ in-plane flow

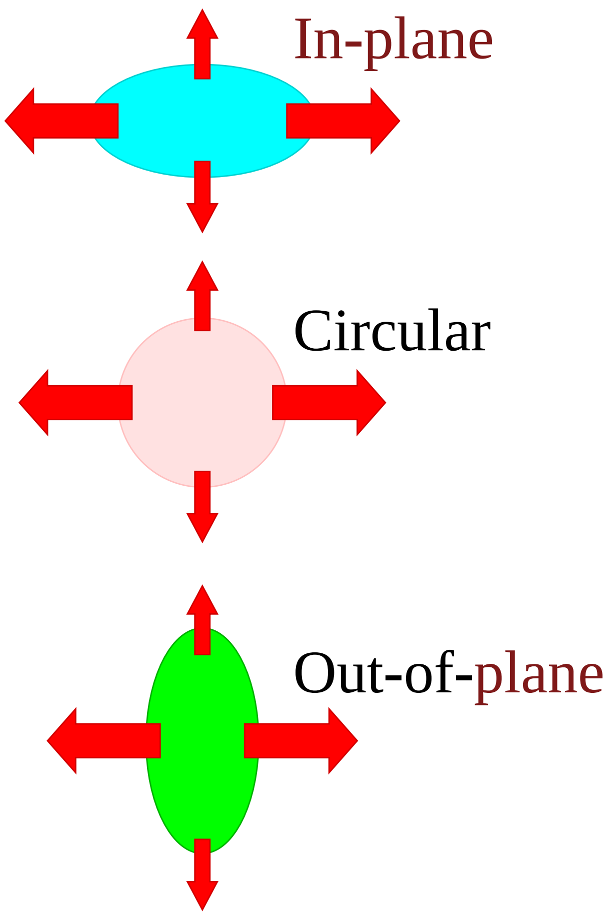
Azimuthally sensitive interferometry

Final state?



Azimuthally sensitive interferometry

Final state?

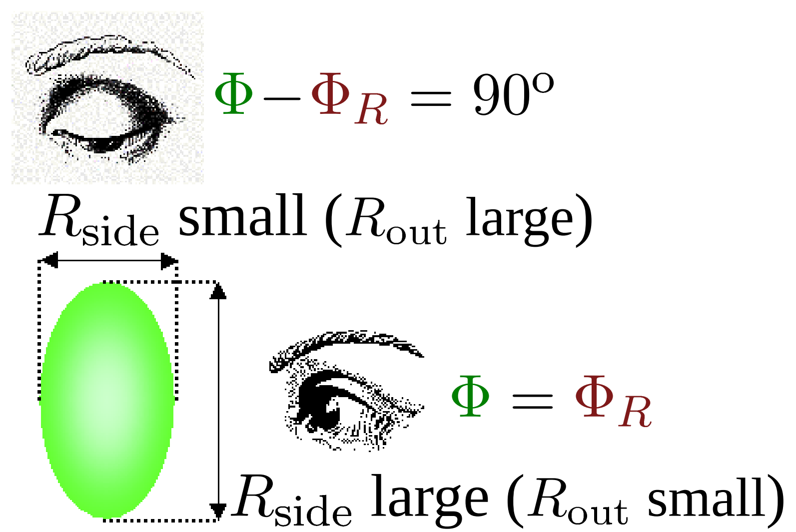


The final space-time configuration can be determined by two-particle interferometry

$\Rightarrow$ oscillation of the HBT radii $R_{\rm side}$, $R_{\rm out}$

perpendicular to $\mathbf{K_T}_{\rm pair}$ (for $R_{\rm side}$); along $\mathbf{K_T}_{\rm pair}$ (for $R_{\rm out}$)

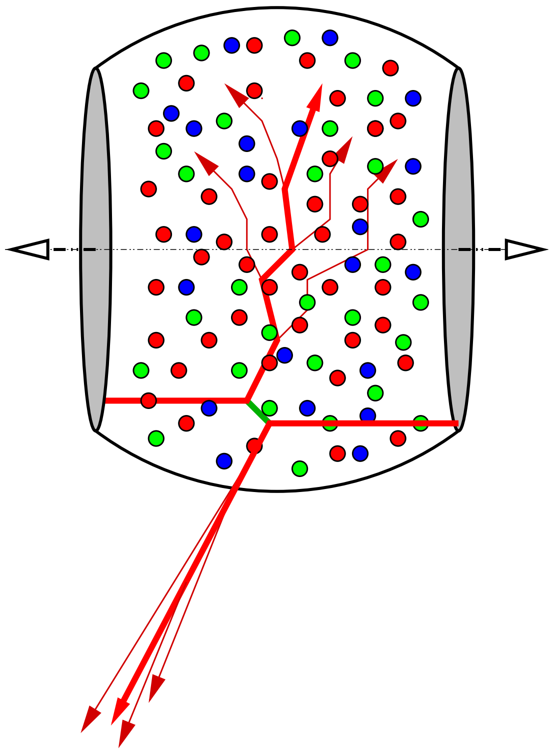
Example: out-of-plane configuration

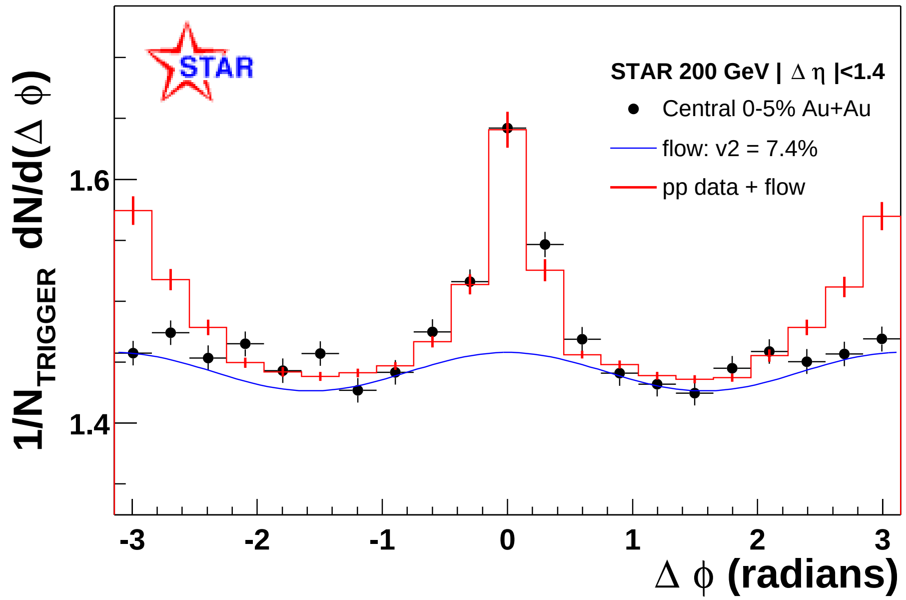


Azimuthal correlations of high p_T particles

Particles with high momentum (jets) lose energy while traversing the dense medium created

$\Rightarrow$ For a pair of jets created close to the edge, only one jet emerges (= detected with high p_T), while the back jet is quenched (= "not detected")





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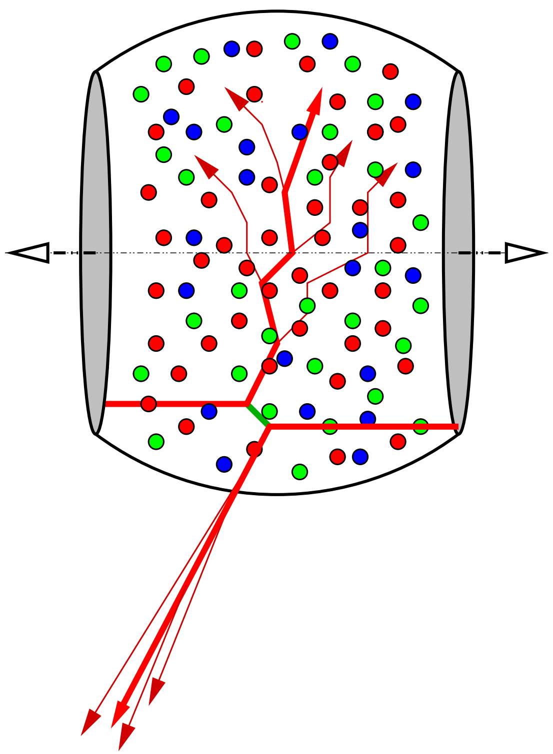

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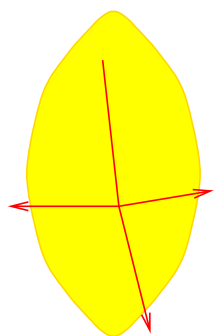
Amount of quenching depends on the length of the jet path in-medium



In non-central collisions, suppression pattern depends on the azimuths of the high p_T particles with respect to the reaction plane:

$\Rightarrow$ less quenching in-plane ($\phi = \Phi_R$), more out-of-plane

Two-particle correlations

Two particles characterized by $\left(\mathbf{p}_{T1}, \mathbf{p}_{T2}, y_1, y_2\right), \phi_1, \phi_2$

Rather than $\begin{cases} \phi_1 - \Phi_R \\ \phi_2 - \Phi_R \end{cases}$, use $\begin{cases} \Phi \equiv x\phi_1 + (1-x)\phi_2 : \text{ pair azimuth} \\ \Delta\phi \equiv \phi_2 - \phi_1 : \text{ relative angle} \end{cases}$

Two-particle distribution: $p_2(\Phi - \Phi_R, \Delta\phi)$ instead of $p_2(\phi_1 - \Phi_R, \phi_2 - \Phi_R)$

Fix $\Delta\phi$: $p_2(\Phi - \Phi_R)$ is the pair-angle Φ azimuthal distribution, which quantifies the anisotropy in $\Phi - \Phi_R$

... reminiscent of $p_1(\phi - \Phi_R)$

Two-particle correlations

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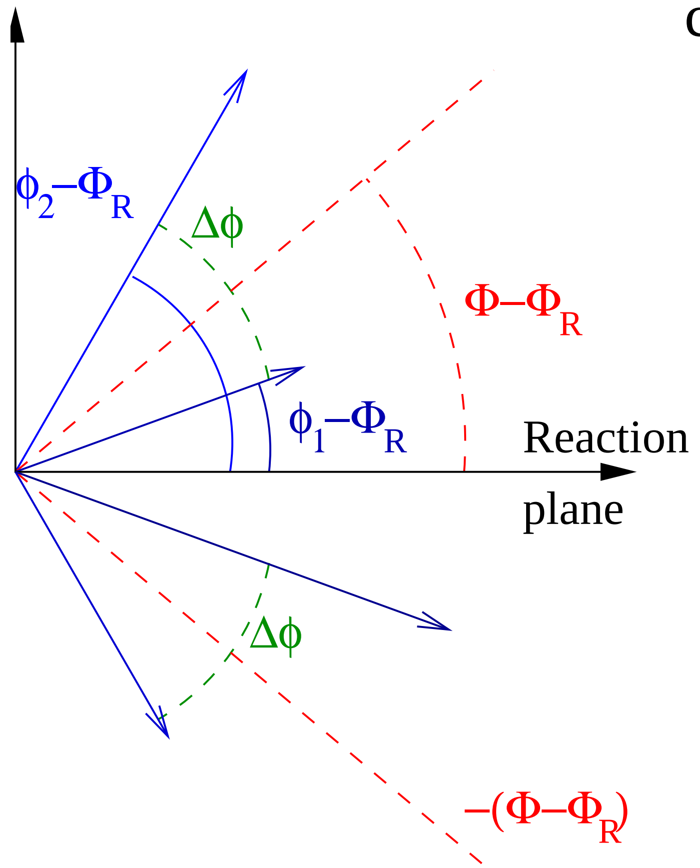
Introduce a Fourier expansion!

$$p_2(\Phi - \Phi_R) \propto 1 + \sum_{n\neq 0} v_n^{\text{pair}} \mathrm{e}^{in(\Phi - \Phi_R)}$$

“Pair anisotropic flow”

$$p_2(\Phi-\Phi_R) \propto 1 + \sum_{n\neq 0} v_n^{\rm pair} e^{in(\Phi-\Phi_R)}, \qquad v_n^{\rm pair} = \left\langle e^{-in(\Phi-\Phi_R)} \right\rangle$$

cannot be replaced by cos!



Transforming $\Phi-\Phi_R \to -(\Phi-\Phi_R)$ with $\Delta\phi$ constant is *not* a symmetry!

$v_n^{\rm pair}$ is complex

($\neq$ “single-particle” anisotropic flow v_n)

“Pair anisotropic flow”

$$p_2(\Phi - \Phi_R) \propto 1 + \sum_{n\neq 0} v_n^{\rm pair}\, e^{in(\Phi-\Phi_R)}, \qquad v_n^{\rm pair} = \left\langle e^{-in(\Phi-\Phi_R)} \right\rangle$$

$$= 1 + 2\sum_{n\geq 1}\left(v_{c,n}^{\rm pair} \cos n(\Phi - \Phi_R) + v_{s,n}^{\rm pair} \sin n(\Phi - \Phi_R)\right)$$

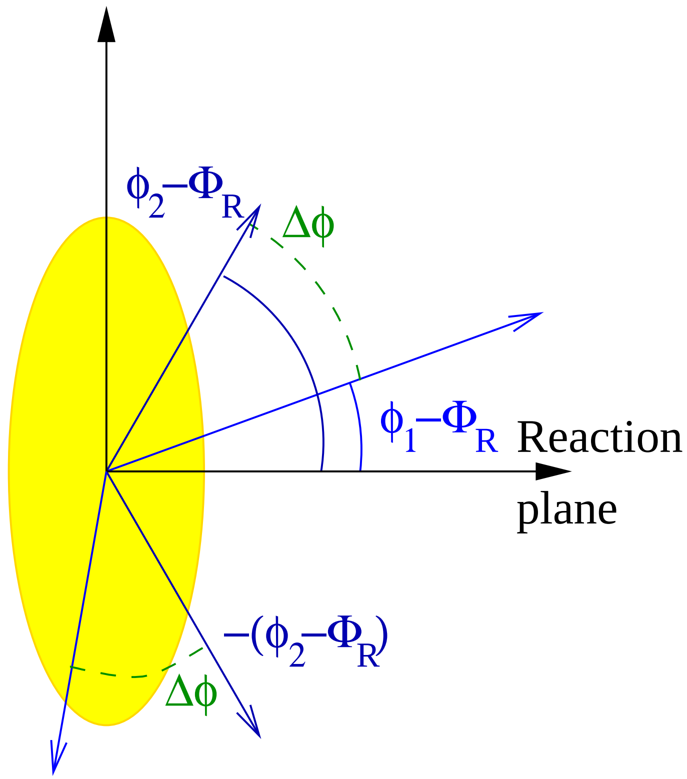
with $\underbrace{v_{c,n}^{\rm pair} = \langle \cos(n(\Phi - \Phi_R))\rangle}_{\text{cf. } v_n = \langle\cos(n(\phi - \Phi_R))\rangle}$, $\underbrace{v_{s,n}^{\rm pair} = \langle \sin(n(\Phi - \Phi_R))\rangle}_{\text{“new”}}$, real

Many methods already available for measuring $v_{c,n}^{\rm pair}$!

$\Rightarrow$ all methods of flow analysis

... can easily be modified to measure $v_{s,n}^{\rm pair}$ (or directly $v_n^{\rm pair}$)

“Pair anisotropic flow”: jet quenching



$\Phi = \phi_1$ (trigger particle)

In p-p, number of associated particles ϕ_2 per trigger particle depends on $\Delta\phi$ only.

If the deficit in high-p_T particles is due to in-medium energy loss, then for a given $\Delta\phi$ the number of pairs per trigger particle depends on the length of the path followed by the associated particle only

$\Rightarrow$ symmetry $\phi_2 - \Phi_R \to -(\phi_2 - \Phi_R)$

$$\vdots$$

$$v_{s,2}^{\rm pair}(\Delta\phi) = \left(v_{c,2}^{\rm pair}(\Delta\phi) - v_2^{\rm trig}\right)\tan(2\Delta\phi)$$

Azimuthally sensitive two-particle correlations

Azimuthal dependence of 2-particle correlations = pair anisotropic flow

- characterized by pair-flow coefficients $v_{c,n}^{\text{pair}}$, $v_{s,n}^{\text{pair}}$
  model-independent!
- same methods of analysis as for single-particle anisotropic flow
  → cumulants, Lee–Yang zeroes:
  no need to estimate Φ_R!
- omitted issue: relate $v_{c,n}^{\text{pair}}$, $v_{s,n}^{\text{pair}}$ to models of the correlations:
  - model-dependent predictions
  - different recipes for each specific application (resonance flow, HBT, high-p_T particle correlations)