



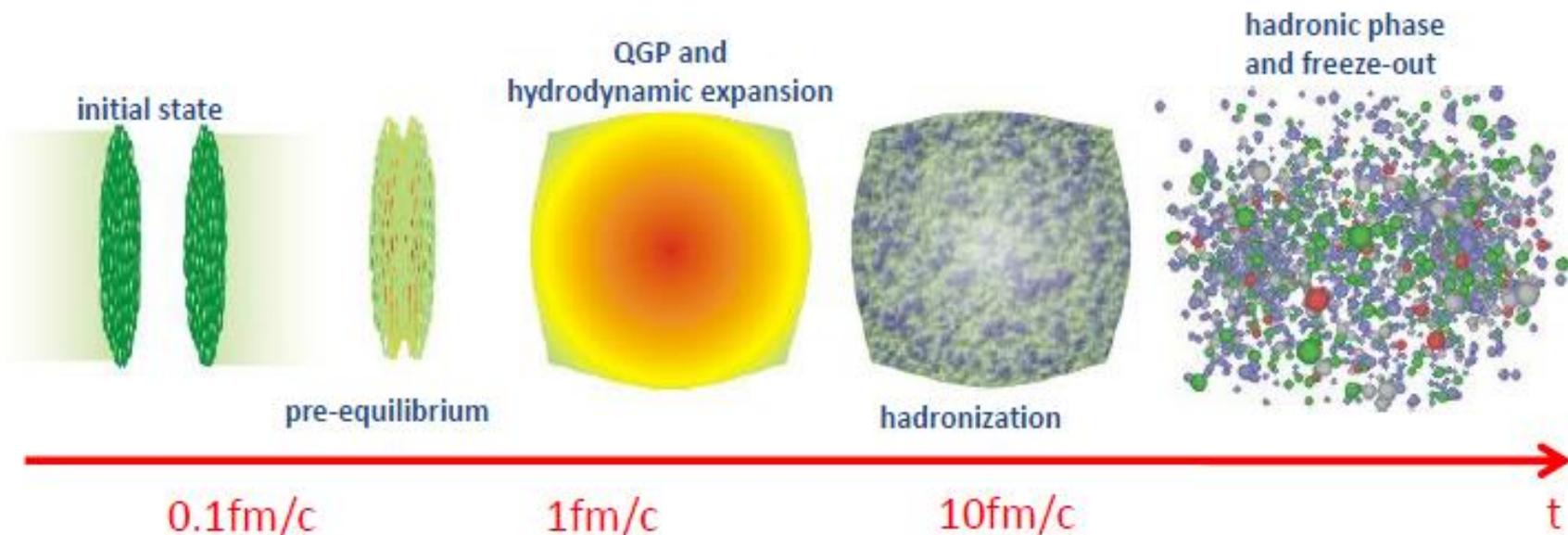
# 相对重离子碰撞中的纵向涨落



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- 初态纵向粒子关联
- 初态横向各向异性去关联
- 总结

# 相对重离子碰撞的演化过程

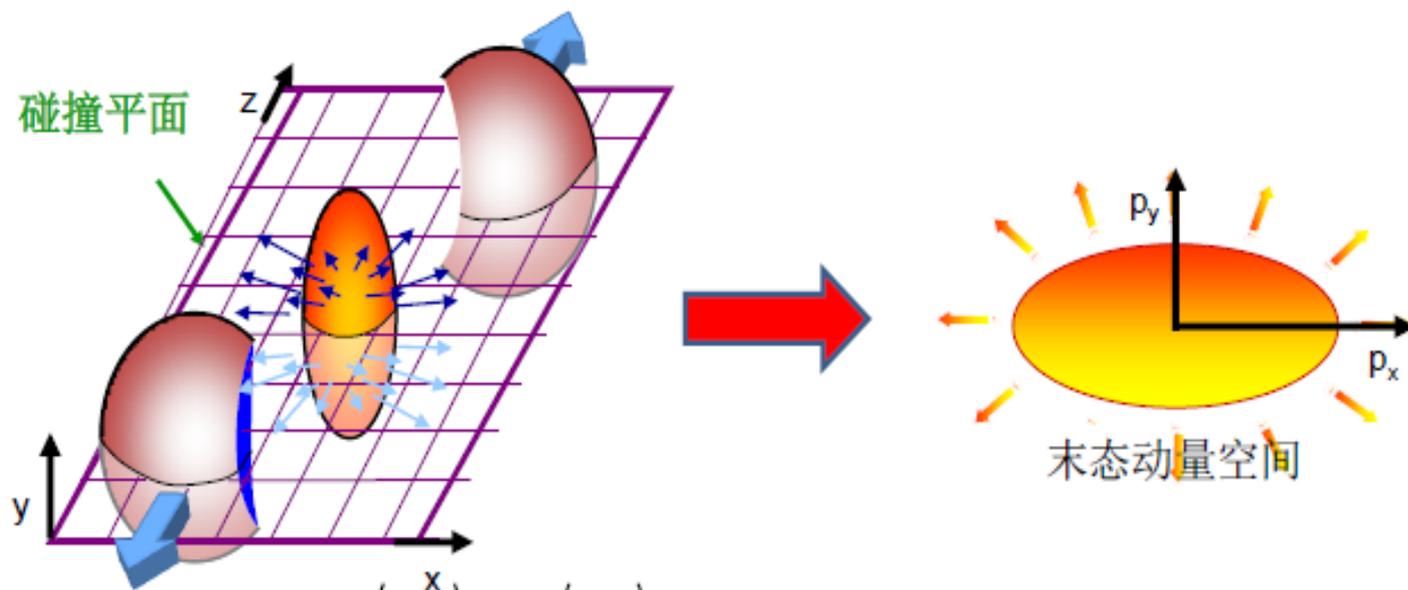


两重核被加速到近光速发生碰撞

经粒子内部的相互作用和热化作用后，核物质转化为QGP并以流体力学的形式开始扩散。

QGP在膨胀的过程中能量密度和温度不断下降并最终变为强子物质。

# 集体流效应

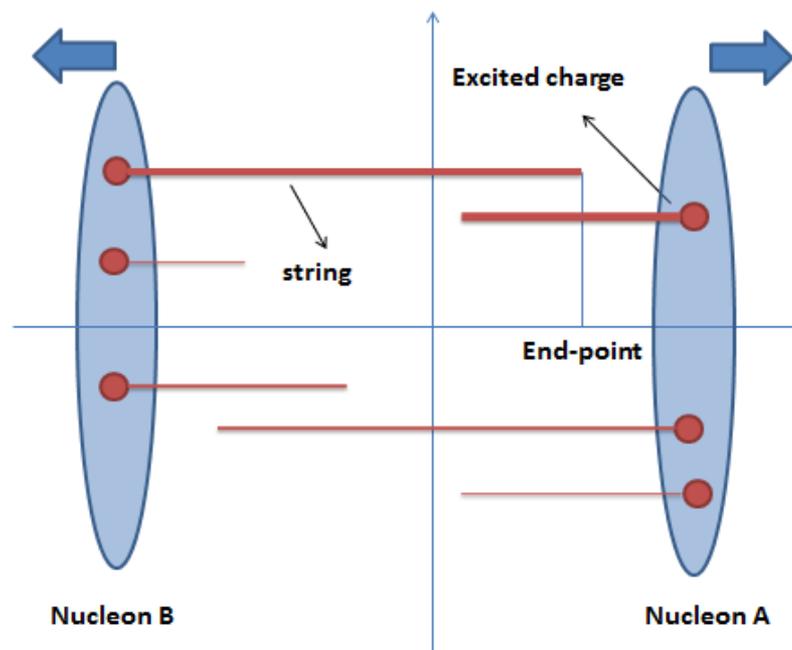
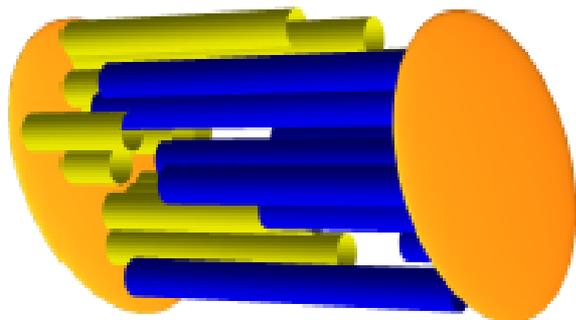


碰撞分为硬过程和软过程。 软过程—>集体流效应，硬过程—>喷注淬火

初态横向空间的涨落会通过热密物质的相互作用转化为末态集体流等效应。

通过流体力学模拟结果与实验数据的比较，可以确定夸克胶子等离子体的剪切粘滞系数。

# 初态纵向涨落



纵向源扩展模型 (Ref:arXiv1512.01945v1)

假设初态纵向方向的粒子多重数分布来源于与激发核（核子或夸克）相连的弦的融化。

影响因素：源数目，弦的长度和弦的强度



# 两粒子关联

关联定义: 
$$C(\eta_1, \eta_2) = \frac{\langle N(\eta_1, \eta_2) \rangle}{\langle N(\eta_1) \rangle \langle N(\eta_2) \rangle} \quad (1)$$

单粒子数密度平均值 
$$\langle N(\eta) \rangle = \langle N_A \rangle \langle \rho_A(\eta) \rangle + \langle N_B \rangle \langle \rho_B(\eta) \rangle \quad (2)$$

两粒子数密度平均值

$$\begin{aligned} \langle N(\eta_1, \eta_2) \rangle = & \langle N_A \rangle \langle \rho_A(\eta_1, \eta_2) \rangle + \langle N_A(N_A - 1) \rangle \langle \rho_A(\eta_1) \rangle \langle \rho_A(\eta_2) \rangle \\ & + \langle N_B \rangle \langle \rho_B(\eta_1, \eta_2) \rangle + \langle N_B(N_B - 1) \rangle \langle \rho_B(\eta_1) \rangle \langle \rho_B(\eta_2) \rangle \\ & + \langle N_A N_B \rangle [\langle \rho_A(\eta_1) \rangle \langle \rho_B(\eta_2) \rangle + \langle \rho_A(\eta_2) \rangle \langle \rho_B(\eta_1) \rangle] \quad (3) \end{aligned}$$

$\langle N(\eta) \rangle$ 是给定中心度下，产生粒子数密度。

$\langle \rho_{A,B}(\eta) \rangle$ 代表单源单位 $\eta$ 上产生粒子的平均数密度,单粒子平均放射率

$\langle \rho_{A,B}(\eta_1, \eta_2) \rangle$ 代表单个源上产生两粒子的平均数密度，两粒子平均放射率



# 两粒子关联

放射率  $\rho_A(\eta; y) = n = \frac{dN}{d\eta} \quad (y < \eta < y_b)$

$\rho_B(\eta; y) = n = \frac{dN}{d\eta} \quad (-y_b < \eta < y)$

(4)  $n$ 为单位长度上产生的粒子数  
 有弦强度涨落  $n$ 满足负二项式分布  
 无弦强度涨落  $n$ 为常数

平均放射率

单粒子  $\langle \rho_A(\eta) \rangle = \int_{-y_b}^{y_b} p(y) \rho_A(\eta; y) \theta(y_b - \eta) \theta(\eta - y) dy$

$\langle \rho_B(\eta) \rangle = \int_{-y_b}^{y_b} p(y) \rho_B(\eta; y) \theta(y_b + \eta) \theta(y - \eta) dy$

(5)

粒子对

$\langle \rho_A(\eta_1, \eta_2) \rangle = \int_{-y_b}^{y_b} p(y) \rho_A(\eta_1; y) \rho_A(\eta_2; y) \theta(y_b - \eta_1) \theta(\eta_1 - y) \theta(y_b - \eta_2) \theta(\eta_2 - y) dy$

$\langle \rho_B(\eta_1, \eta_2) \rangle = \int_{-y_b}^{y_b} p(y) \rho_B(\eta_1; y) \rho_B(\eta_2; y) \theta(y_b + \eta_1) \theta(y - \eta_1) \theta(y_b + \eta_2) \theta(y - \eta_2) dy$

(6)

$p(y)$ 代表弦端点的分布。假设端点固定时， $p(y)$ 为 $\delta$ 函数

假设端点满足均匀分布时， $p(y) = \frac{1}{2y_b}$



端点为固定点时,  $p(y) = \delta(y - y_0)$

$$\begin{aligned}\langle \rho_A(\eta) \rangle &= \int_{-y_b}^{y_b} p(y) \rho_A(\eta; y) \theta(y_b - \eta) \theta(\eta - y) dy \\ &= \int_{-y_b}^{y_b} \delta(y - y_0) n \theta(y_b - \eta) \theta(\eta - y) dy \\ &= \langle n \rangle_y\end{aligned}\tag{7}$$

$$\begin{aligned}\langle \rho_A(\eta_1, \eta_2) \rangle &= \int_{-y_b}^{y_b} p(y) \rho_A(\eta_1; y) \rho_A(\eta_2; y) \theta(y_b - \eta_1) \theta(\eta_1 - y) \theta(y_b - \eta_2) \theta(\eta_2 - y) dy \\ &= \int_{-y_b}^{y_b} \delta(y - y_0) n^2 \theta(y_b - \eta_1) \theta(\eta_1 - y) \theta(y_b - \eta_2) \theta(\eta_2 - y) dy \\ &= \langle n^2 \rangle_y\end{aligned}\tag{8}$$

同理可以运用于B核

表明在弦端点固定时, 产生粒子的数密度不依赖于 $\eta$ 的值



端点满足均匀分布时,  $p(y) = \frac{1}{2y_b}$

$$\begin{aligned}\langle \rho_A(\eta) \rangle &= \int_{-y_b}^{y_b} p(y) \rho_A(\eta; y) \theta(y_b - \eta) \theta(\eta - y) dy \\ &= \int_{-y_b}^{y_b} \frac{1}{2y_b} n \theta(y_b - \eta) \theta(\eta - y) dy \\ &= \langle n \rangle_y \frac{y_b + \eta}{2y_b}\end{aligned}\tag{9}$$

$$\begin{aligned}\langle \rho_A(\eta_1, \eta_2) \rangle &= \int_{-y_b}^{y_b} p(y) \rho_A(\eta_1; y) \rho_A(\eta_2; y) \theta(y_b - \eta_1) \theta(\eta_1 - y) \theta(y_b - \eta_2) \theta(\eta_2 - y) dy \\ &= \int_{-y_b}^{y_b} \frac{1}{2y_b} n^2 \theta(y_b - \eta_1) \theta(\eta_1 - y) \theta(y_b - \eta_2) \theta(\eta_2 - y) dy \\ &= \langle n^2 \rangle_y \frac{y_b^2 - \eta_1 \eta_2 - y_b |\eta_1 - \eta_2|}{4y_b^2}\end{aligned}\tag{10}$$

同理可以运用于B核

表明在弦端点均匀分布时, 产生粒子的数密度依赖于 $\eta$ 的值



# 两粒子关联

关联综合表达式

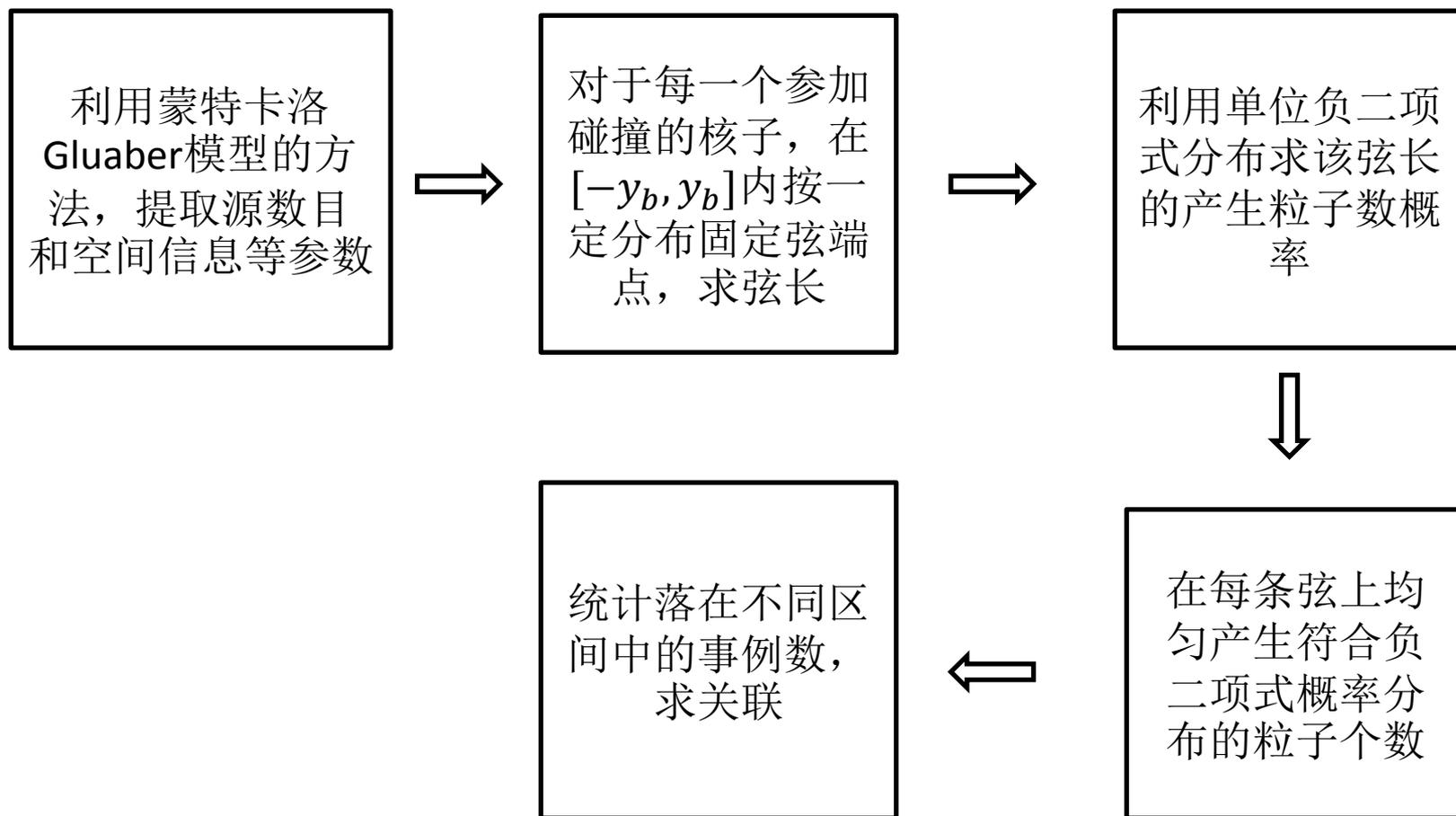
$$\begin{aligned} C(\eta_1, \eta_2) = & 1 + \frac{1}{y_b (\langle N_{A+B} \rangle y_b + \langle N_{A-B} \rangle \eta_1)} \frac{1}{(\langle N_{A+B} \rangle y_b + \langle N_{A-B} \rangle \eta_2)} \\ & \times \{ \langle N_{A+B} \rangle [(y_b^2 - \eta_1 \eta_2 - y_b (\eta_1 - \eta_2))] \\ & + \frac{\text{var}(n)}{\langle n \rangle^2} (2y_b^2 - y_b |\eta_1 - \eta_2|)] \\ & + \langle N_{A-B} \rangle I(n) y_b (\eta_1 + \eta_2) + y_b^2 \text{var}(N_{A+B}) \\ & + \text{var}(N_{A-B}) \eta_1 \eta_2 + \text{cov}(N_{A+B}, N_{A-B}) y_b (\eta_1 + \eta_2) \} \quad (17) \end{aligned}$$

关联的影响因素来源于三个方面源数目的涨落，弦长度涨落，弦强度涨落

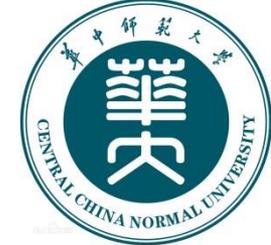
仅有源数目涨落

$$C(\eta_1, \eta_2) = 1 + \frac{\text{var}(N_A) + \text{var}(N_B) + 2\text{cov}(N_A, N_B)}{(\langle N_{A+B} \rangle)^2}$$

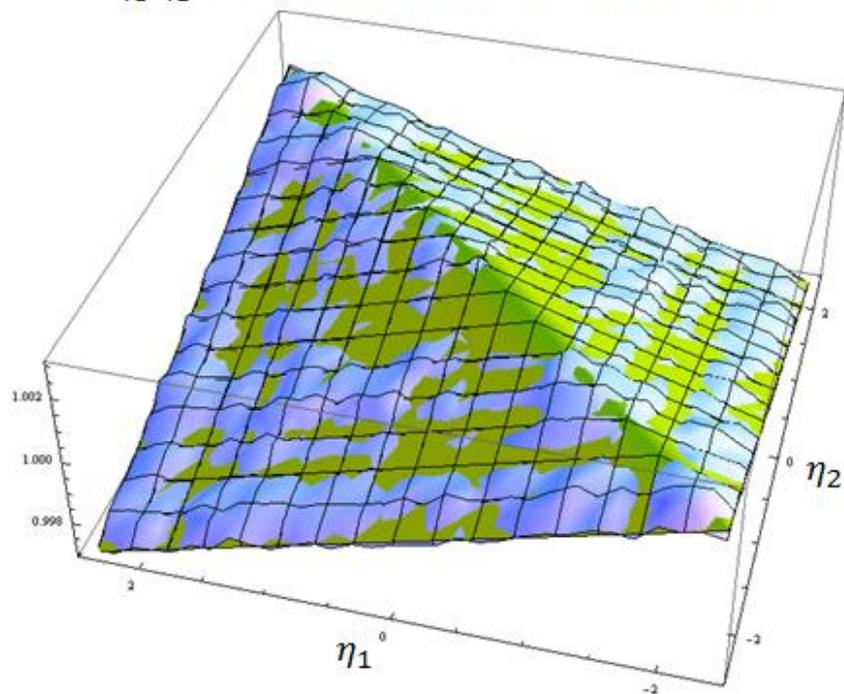
# 蒙特卡洛模拟方法



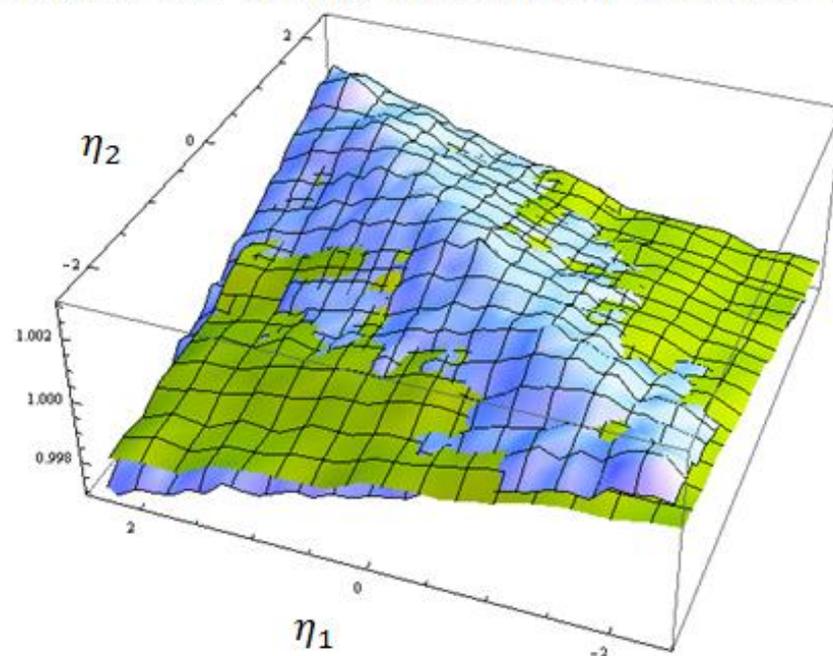
# 蒙特卡洛模拟方法



$C(\eta_1, \eta_2)$  Pb + Pb@35%-40% MC(蓝) VS解析(绿)



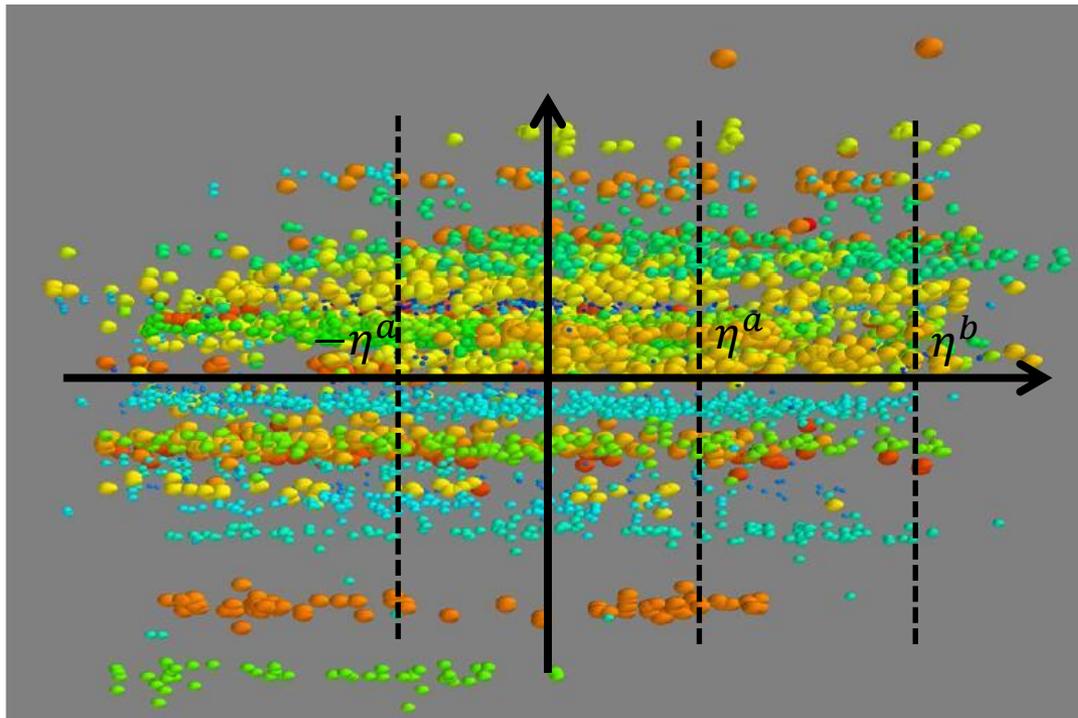
$C(\eta_1, \eta_2)$  Pb + Pb(MC) @20%-25%(绿) VS 35%-40% (蓝)



# 初态横向各向异性在纵向方向去关联

初态空间各向异性关联

$$r_n(\eta^a, \eta^b) = \frac{\langle Q_n(-\eta^a) Q_n^*(\eta^b) \rangle}{\langle Q_n(\eta^a) Q_n^*(\eta^b) \rangle} \quad (11)$$



各向异性

$$\vec{Q}_n = Q_n e^{in\Phi_n} = \frac{1}{N} \sum_{j=1}^N e^{in\phi_j}$$

方位角

$$\phi_j = \arctan\left(\frac{y_j}{x_j}\right)$$

消除短程相关性

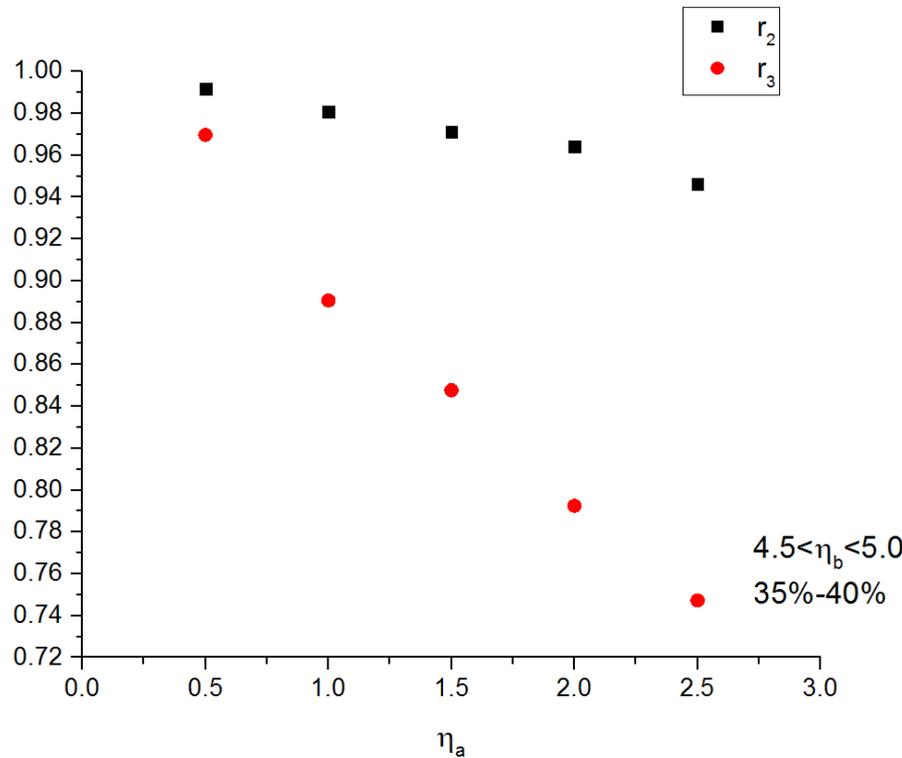


# 初态横向各向异性在纵向方向去关联

初态空间各向异性关联

$$r_n(\eta^a, \eta^b) = \frac{\langle Q_n(-\eta^a) Q_n^*(\eta^b) \rangle}{\langle Q_n(\eta^a) Q_n^*(\eta^b) \rangle} \quad (11)$$

1



各向异性

$$\vec{Q}_n = Q_n e^{in\Phi_n} = \frac{1}{N} \sum_{j=1}^N e^{in\phi_j}$$

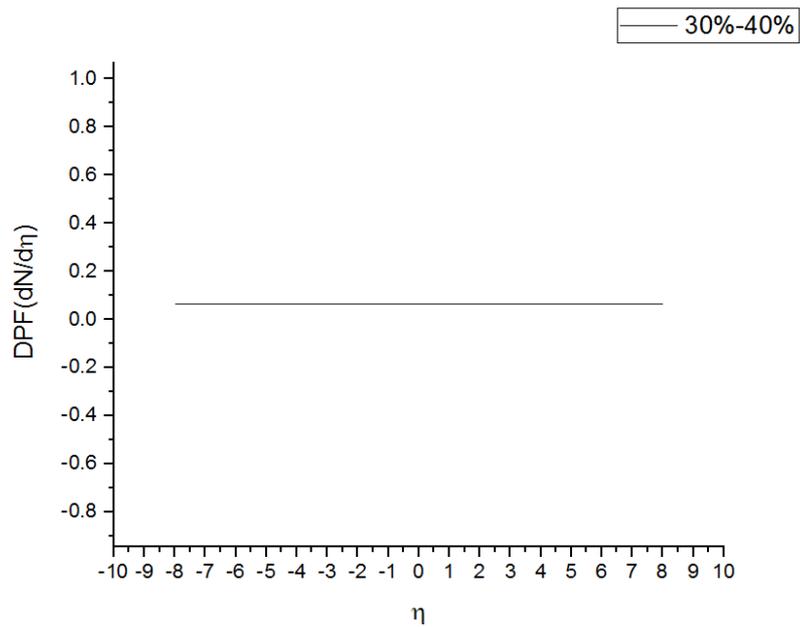
方位角

$$\phi_j = \arctan\left(\frac{y_j}{x_j}\right)$$

消除短程相关性

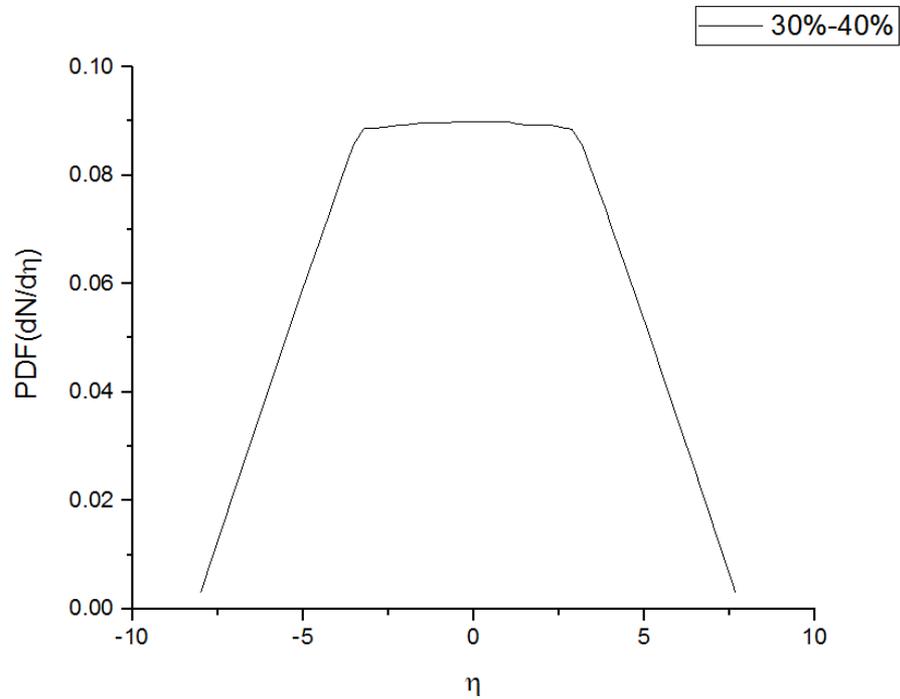
$$\frac{dN}{d\eta}$$

1



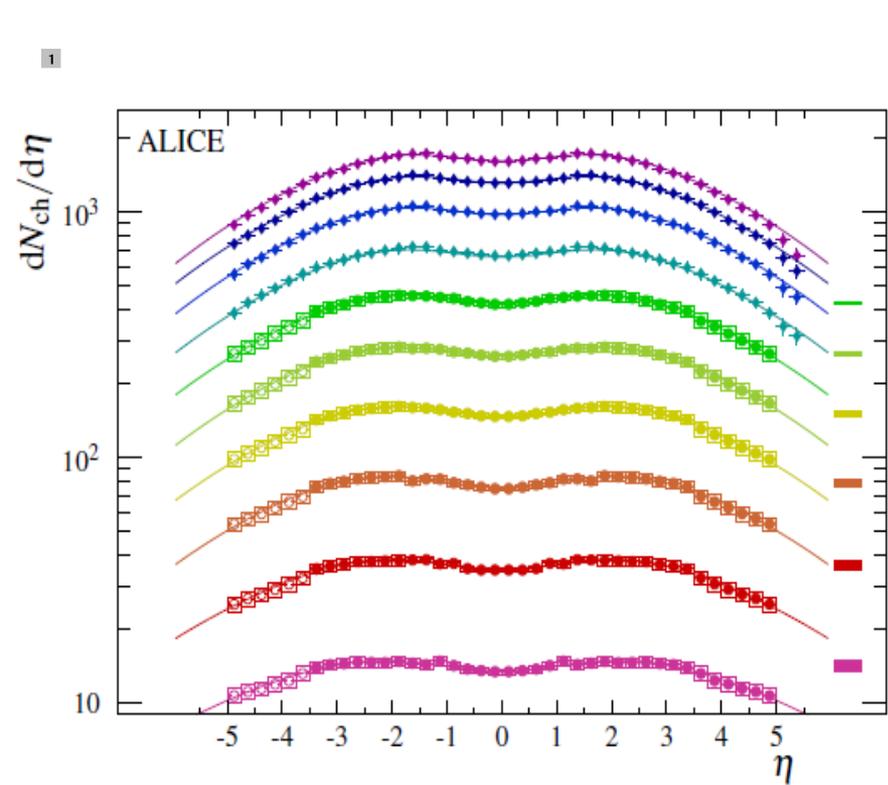
单端点

1

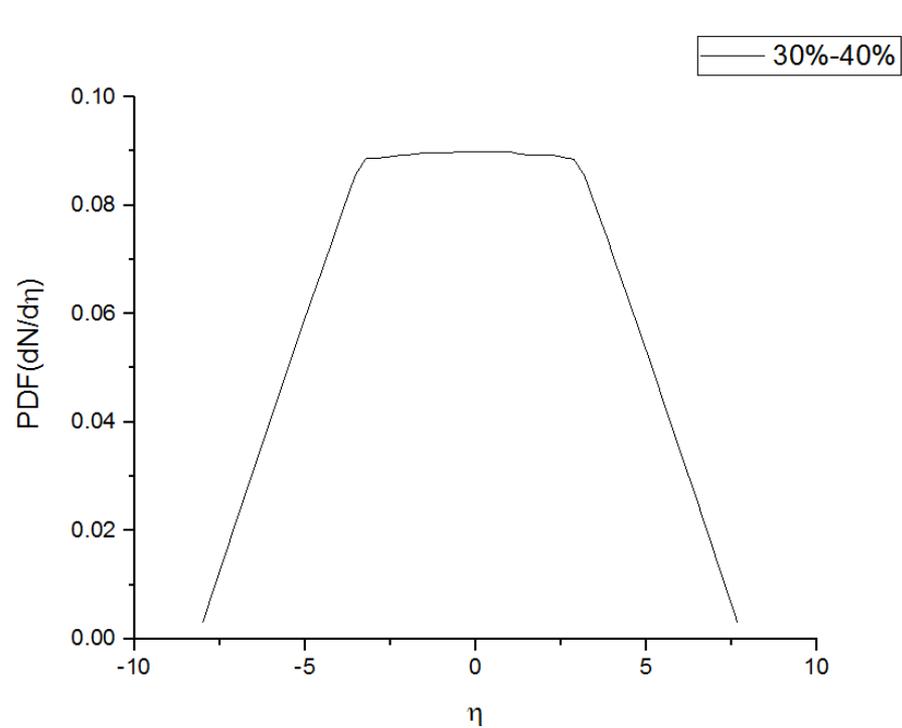


双端点

$$\frac{dN}{d\eta}$$



实验数据



双端点

# 总结

- 初态纵向模型中粒子多重数分布来源于弦的融化。
- 模型中两粒子关联有三种影响因素。（源数目，弦长度，弦强度）
- 初态横向各向异性会在纵向方向去关联。