Two-particle correlation via Bremsstrahlung

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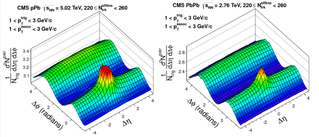
Outline

1. Introduction
2. Frameworks
3. Results
4. Summary & Outlooks

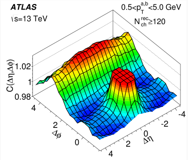
Introduction

Ridge structure

- η - independent shape in two-particle angular correlations
- Explained via elliptic and higher-order flows for AA collisions



However, flows in small systems?



Purpose

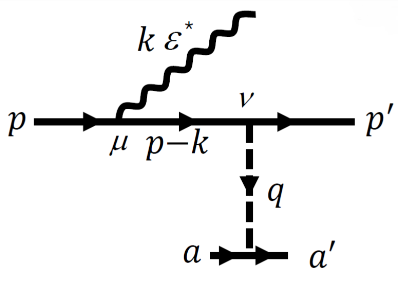
- Describe the Ridge through kinematics between jets and medium

CMS collaboration, *Physical Letters B* **724**, 213240 (2013)

ATLAS collaboration, *Physical Review Letters* **116**, 172301 (2016)

Kinematic interaction between jet & medium

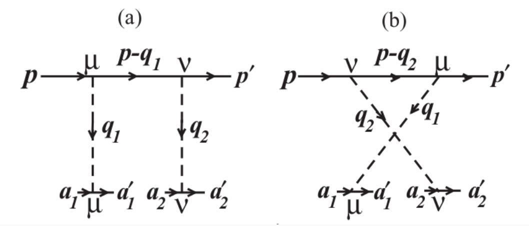
Jet particles lose their energy while passing through medium via...



1st order diagram for Bremsstrahlung

- Collision
- Radiation
  - Gluon radiation
  - **Photon radiation (Bremsstrahlung)**

Previous study in scattering



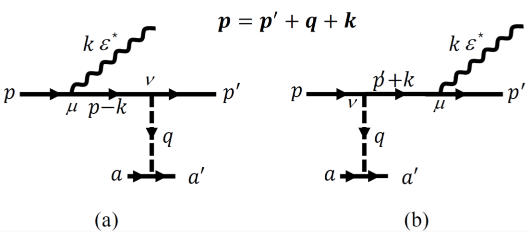
Two symmetric diagrams for parton scattering inside medium → **constructive interference**

$$d\sigma \sim |M_{(a)} + M_{(b)}|^2 = |M_{(a)}|^2 + |M_{(b)}|^2 + (\textbf{interference}) \qquad (1)$$

- Medium parton aligned along the jet particle
- Collective motion

C. Y. Wong, *Physical Review C* **85**, 064909 (2012)

Bremsstrahlung processes



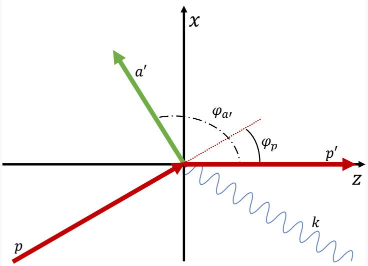
Two diagrams of γ emission and medium parton scattering might **interfere constructively**.

- **Expect to explain the Ridge behavior**

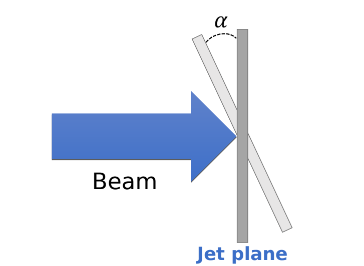
Frameworks

Coordinates

Use (E, y, φ) coordinates system



Jet plane



Jet plane + Beam direction

- Jet plane is independent of the beam direction
- Calculate cross section based on Jet plane

Initial condition

- $E_p = 10\,\mathrm{GeV} \rightarrow E_{p'} = (1 - 0.x) \cdot E_p\,\mathrm{GeV}$, x% energy loss
- $\varphi_p = 10^\circ \rightarrow \varphi_{p'} = 0^\circ$

Description for initial medium partons

Consider all possible initial medium partons' momentum

$$\int d^3\vec{a} \to \int f(y_a, a_T) \times dy_a da_T d\varphi_a \tag{2}$$

Distribution function $f(y_a, a_T)$ for describing momentums of initial medium partons

- Maxwell-Boltzmann distribution (**MB**)

$$f_{MB}(y_a, a_T) = \frac{E_a a_T}{2\pi m k_B T}\sqrt{\frac{1}{2\pi m k_B T}} \exp\left[-\frac{E_a^2 - m^2}{2 m k_B T}\right] \tag{3}$$

- Jüttner-Synge distribution (**JS**)

$$f_{JS}(y_a, a_T) = \frac{E_a a_T}{4\pi m^2 k_B T K_2(m/k_B T)} \exp\left[-\frac{E_a}{k_B T}\right] \tag{4}$$

- Phenomenological Parton Distribution from Soft scattering model (**phPDs**)

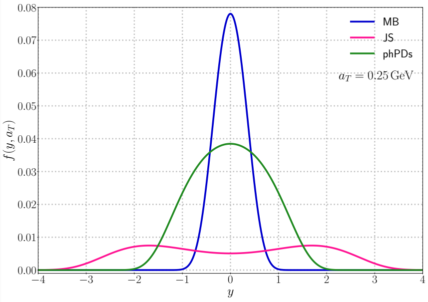
$$f_{phPDs}(y_a, a_T) = A_{Ridge}\left(1 - \frac{\sqrt{m_\pi^2 + p_T^2}\exp[|y_a| - y_B]}{m_\pi(m_d^2 + p_T^2)}\right)^a \exp\left[-\frac{\mathbf{E_a}}{k_B T}\right] \tag{5}$$

C. Y. Wong, *Physical Review C* **76**, 054908 (2007)

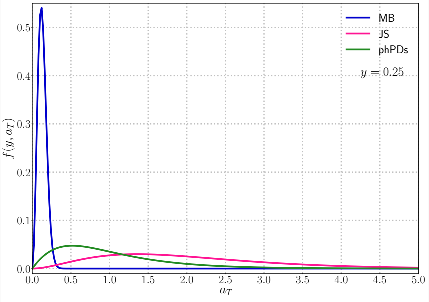
Description for initial medium partons

Set $T = 0.7\ \mathrm{GeV}$ From results of momentum kick model calculation

vs. Rapidity



vs. Transverse momentum



- JS/phPDs has larger range in rapidity than MB
- JS/phPDs is spread out in higher transverse momentum than MB

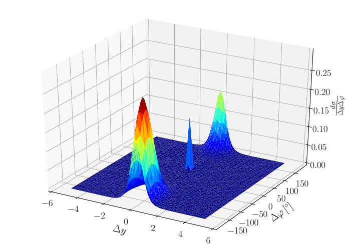
C. Y. Wong, *Physical Review C* **84**, 024901 (2011)

Results

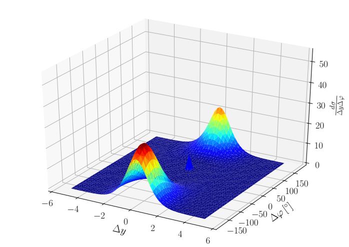
Correlation between p' and a'

$T = 0.7\,\mathrm{GeV}$ $\alpha = 0°$ 30% Energy loss

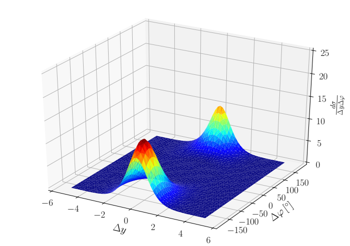
MB



JS



phPDs

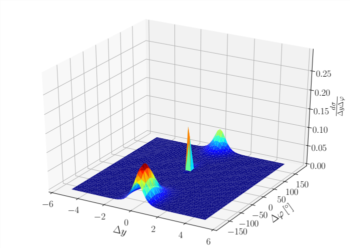


- Dependency of distribution function, $f(y_a, a_T)$
  - $FWHM_{MB} = 0.4, \quad FWHM_{JS} = 1.0, \quad FWHM_{phPDs} = 0.6$
    - MB gives the most narrow peak
    - JS gives the most wide peak
  - Scales are different each other

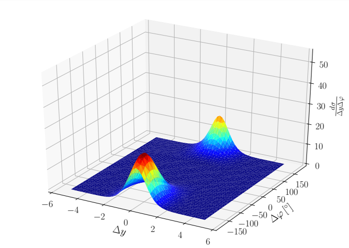
Correlation between p' and a'

$\mathbf{T} = \mathbf{0.5}\,\mathrm{GeV}$ $\alpha = 0^\circ$ 30% Energy loss

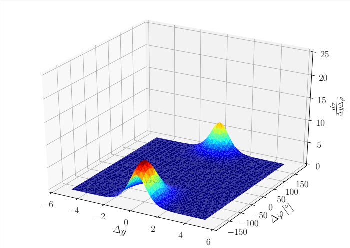
MB



JS



phPDs

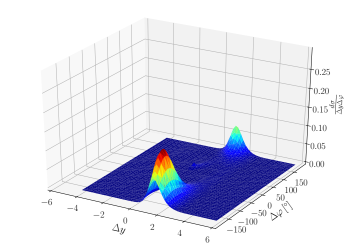


- Decreasing temperature, T
  - Overall scales are reduced by half
  - Shapes are not changed much

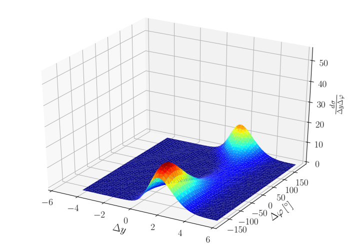
Correlation between p' and a'

$T = 0.7\,\mathrm{GeV}$ $\alpha = \mathbf{45}^\circ$ 30% Energy loss

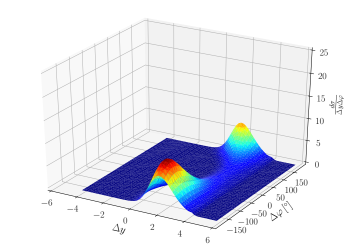
MB



JS



phPDs

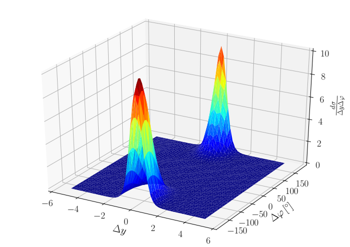


- Increasing rotation angle, α
  - Peak position is shifted to higher $\Delta y \approx 1.5$
    - $\Delta y_{peak} \sim 5.0$ when $\alpha \to 90^\circ$
  - Overall scales is reduced by half
  - Shapes are not changed much

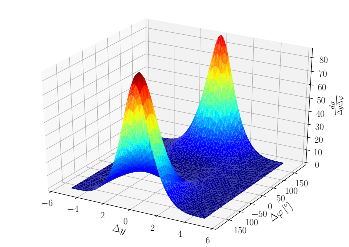
Correlation between p' and a'

$T = 0.7\,\mathrm{GeV}$ $\alpha = 0^\circ$ **50% Energy loss**

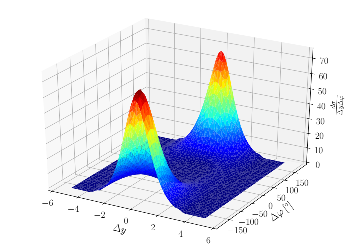
MB



JS



phPDs



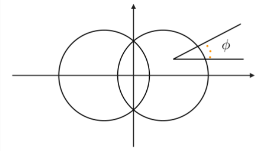
- Increasing Energy loss
  - Overall scales are raised more than 60%

Flow effect

Introduce the flow effect for the azimuthal angle

- Fourier decomposition for momentum anisotropy

$$\frac{dN}{d\varphi} = \frac{N}{2\pi}\left[1 + 2\sum_{n}^{\infty} v_n \cos(n\varphi)\right] \tag{6}$$

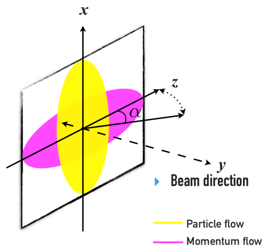


- Fourier expansion for invariant distribution

$$E\frac{d^3N}{dp^3} = \frac{1}{2\pi}\frac{dN}{p_T dy dp_T}\left[1 + 2\sum_{n}^{\infty} v_n \cos(n\varphi)\right] \tag{7}$$

- Consider only elliptic flow ($n = 2$)

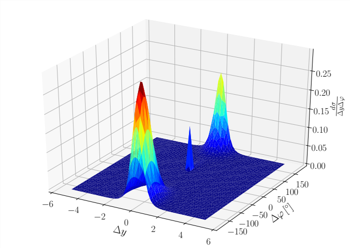
$$v_2 = \frac{\alpha}{T}\left(p_T - \langle v \rangle m_T\right) \tag{8}$$



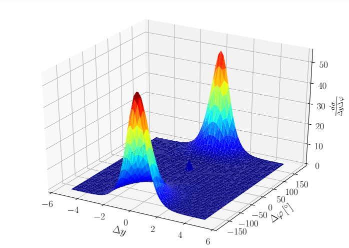
Correlation between p' and a'

$T = 0.7\,\mathrm{GeV}$ $\alpha = 0°$ 30% Energy loss **40% flow effect**

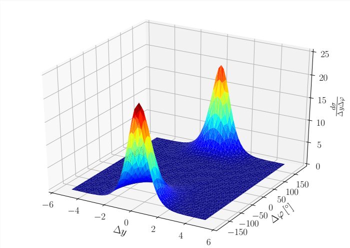
MB



JS



phPDs



- Adding flow effect
  - Peak is raised by ~ 2 times

Summary & Outlooks

Summary & Outlooks

Summary

Try to describe the Ridge structure through kinematic interpretation

- Correlation between p' and a'
  - $f(y, a_T)$: MB, JS and phPDs
    - MB gives the most narrow peak
    - JS gives the most wide peak
  - $T \downarrow$: Scale is getting reduced
  - $\alpha \uparrow$: Peak position shifts to higher Δy but not much change in shape
  - Energy loss $\uparrow$: Scale is getting larger
  - Flow effect $+$: Peak is getting larger

Outlooks

- Integrate over whole rotaion angle α
- Expand to **multiple scttering**
- Eventually include **Gluon Radiation**

Thanks for your attention!