The systematic study of path-length dependence of energy loss in PHENIX

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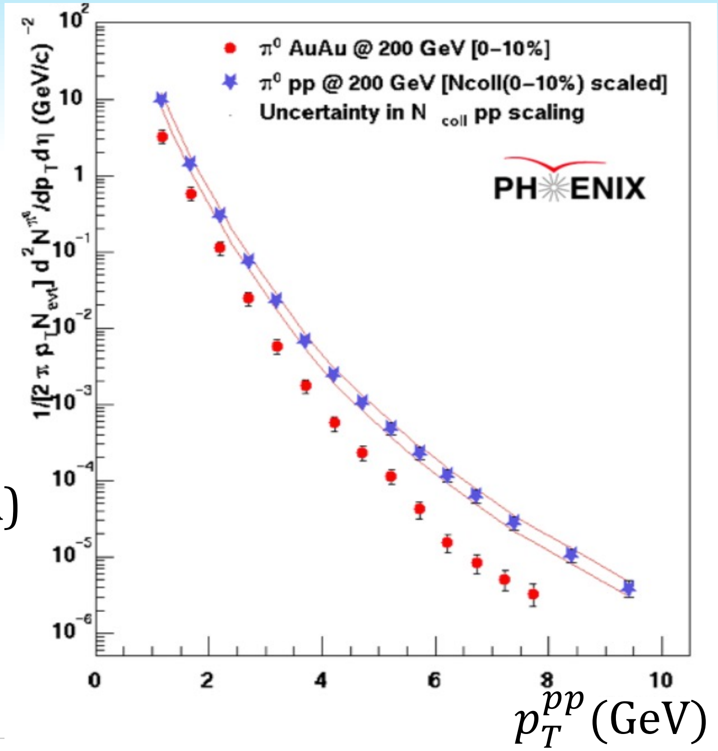
Outline

- Introduction
- Purpose
- Analysis method($S_{loss}, S'_{loss}, L, L^2, \Delta L^2$)
- Result
  - S_{loss} vs. p_T
  - S'_{loss} vs. p_T
  - S_{loss} vs. L^2
  - S'_{loss} vs. ΔL^2
- Summary
- Outlook

Introduction

- QGP
  - The phase transition from hadronic material to quark-gluon plasma
- PHENIX
  - To measure a wide variety of QGP signals from nuclear-nuclear (A+A) collisions
- **Main evidence of QGP generation at RHIC**
  1. **High-p_T hadron suppression**
  2. **Azimuthal anisotropy, v_2**

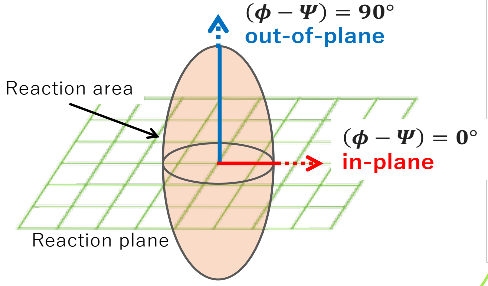


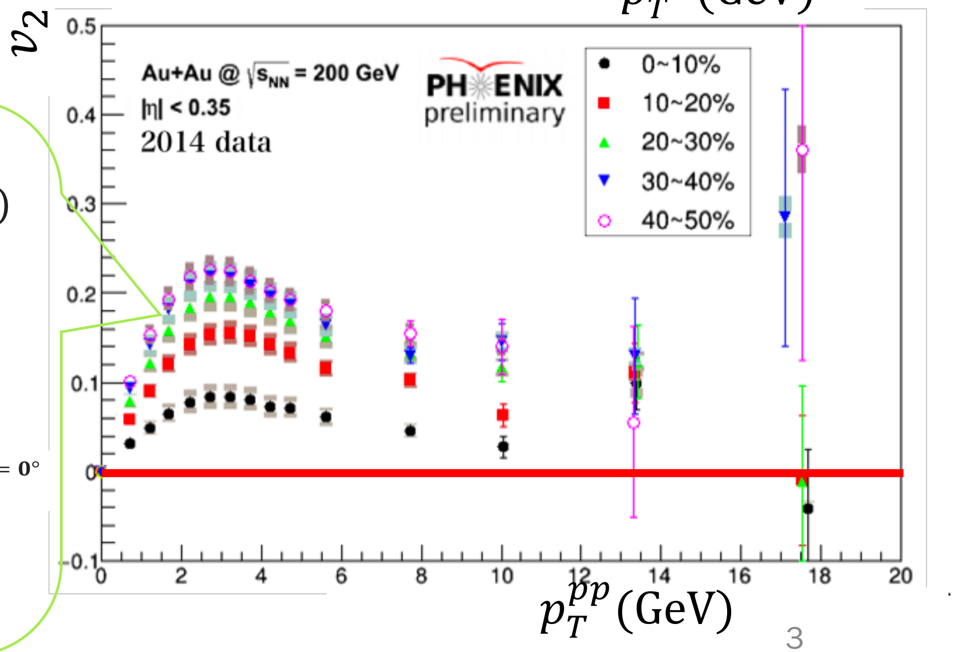
One of the characteristics of QGP :
Parton energy loss in QGP

v_2: azimuthal anisotropy

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

Ψ: azimuthal of reaction plane
ϕ: azimuthal of generated particle





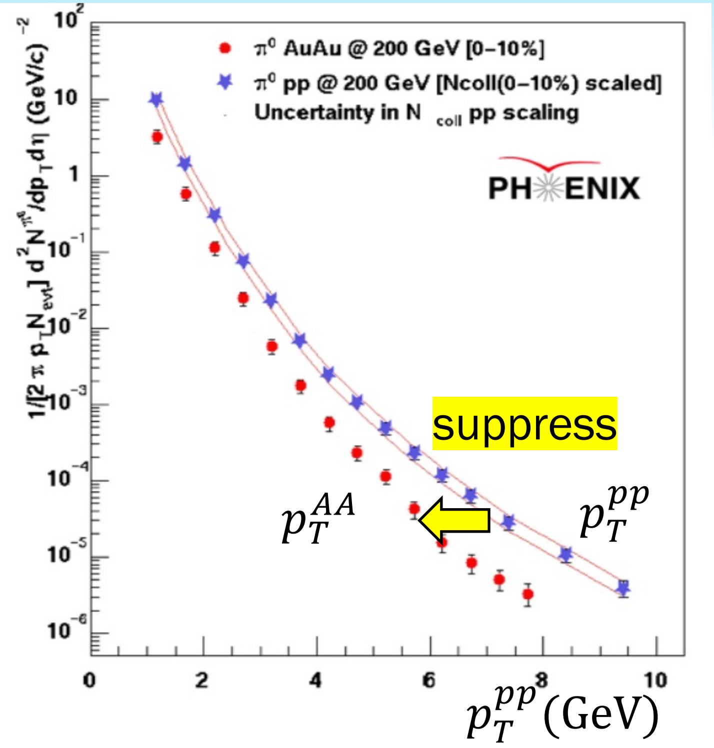
Introduction

A key observable : Parton energy loss in QGP

- S_{loss} **: the fractional momentum loss of high-**p_T **hadrons**

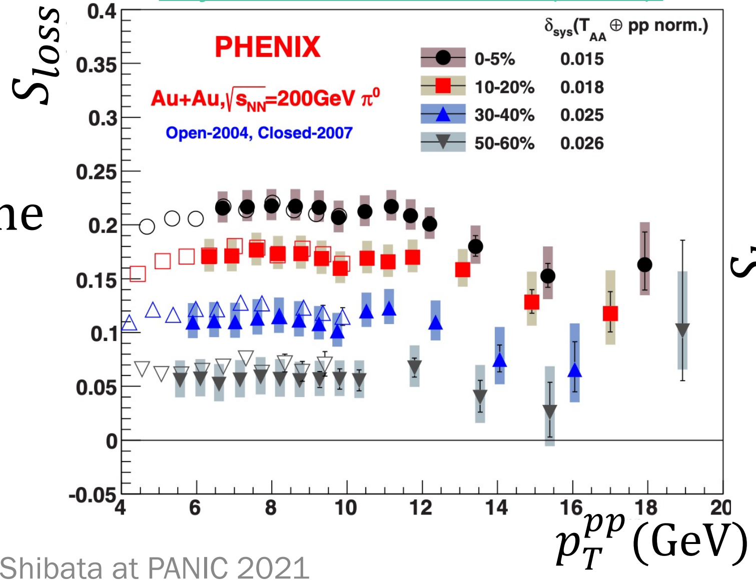
$$S_{loss} = \frac{p_T^{pp}(scaled) - p_T^{AA}}{p_T^{pp}(scaled)}$$

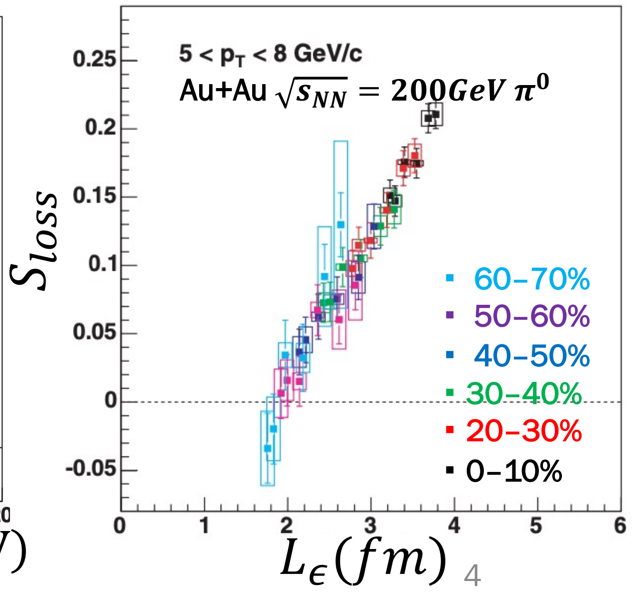
1. S_{loss} does not strongly depend on p_T, decreases as centrality increases. (Phys. Rev. C. 93. 024911 (2016))
2. S_{loss} scales with L_ϵ, an effective radius of the collision. (Phys. Rev. C. 76. 034904(2007))



Phys. Rev. C.76.034904 (2007)

Phys. Rev. C 93.024911 (2016)





Purpose

- Evaluation of the energy of parton in QGP from hadron spectra in various collision systems

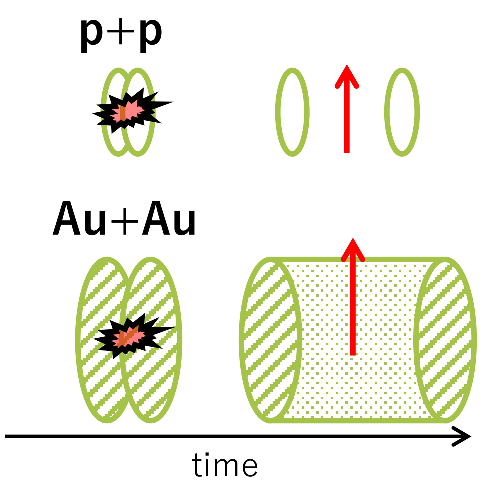
New!

Approach 1

Comparison particle yield in **A+A** and **p+p collisions**

$\boldsymbol{S_{loss}}$: the fractional momentum loss of high-p_T hadrons

$$S_{loss} = \frac{p_T^{pp} - p_T^{AA}}{p_T^{pp}}$$

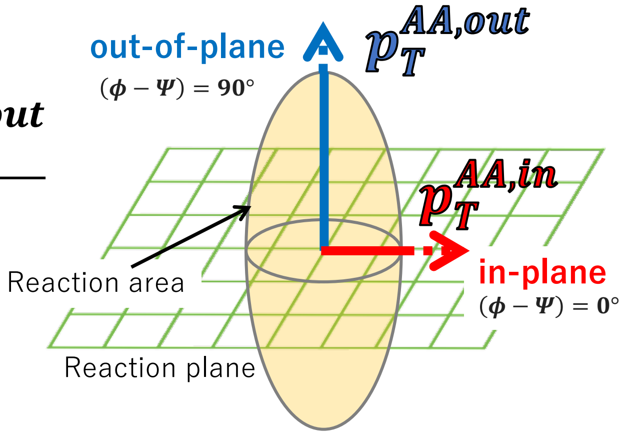


Approach 2

Comparison particle yield **in-plane** and **out-of-plane in A+A collisions**

$\boldsymbol{S'_{loss}}$: the fractional momentum loss of high-p_T hadrons considering **azimuthal anisotropy**

$$S'_{loss} = \frac{p_T^{AA,in} - p_T^{AA,out}}{p_T^{AA,in}}$$



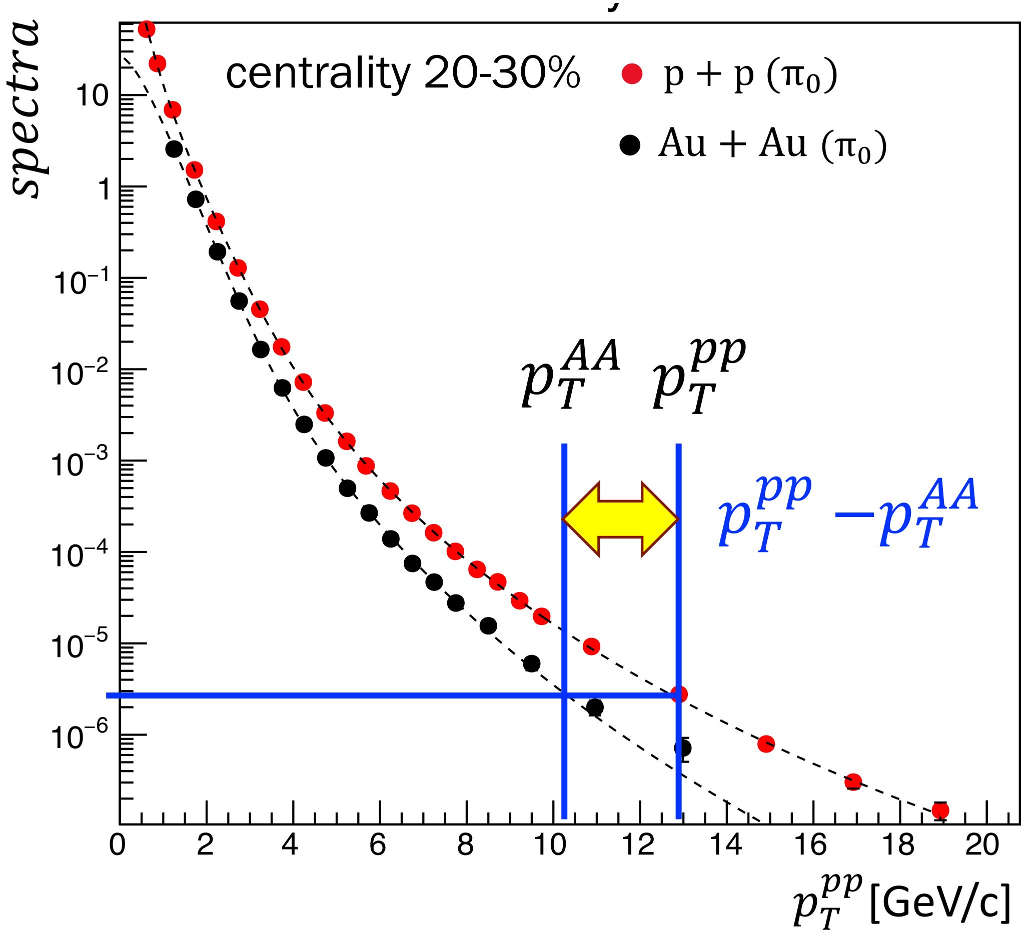
Analysis method for S_{loss}

S_{loss}: the fractional momentum loss of high-p_T hadrons

**Same as previous method, [Phys. Rev. C 93, 024911 (2016)]

1. Scale spectra in p+p collisions by the number of binary collisions.
2. Calculate S_{loss}.

$$S_{loss} = \frac{p_T^{pp}(scaled) - p_T^{AA}}{p_T^{pp}(scaled)}$$



Analysis method for S'_{loss}

S'_{loss}: the fractional momentum loss of high-p_T hadrons considering **azimuthal anisotropy v2**

1. Divide spectra in A+A collisions into in-plane and out-of-plane.

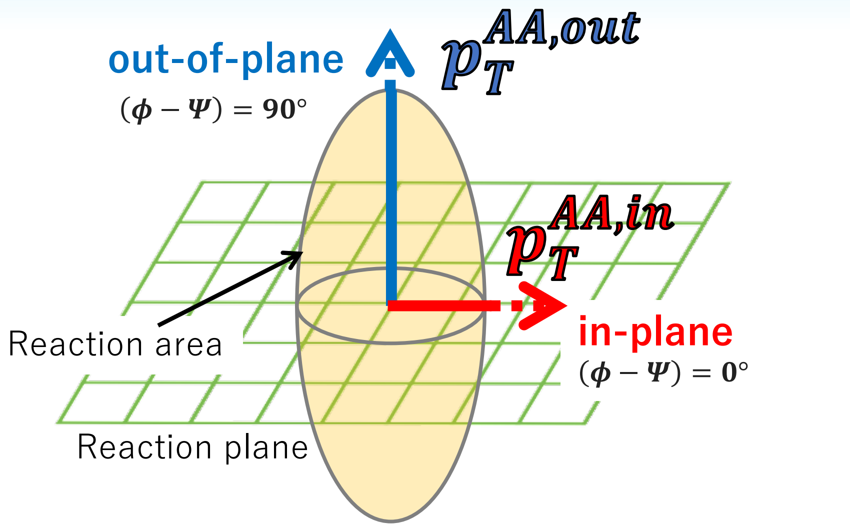
$\frac{dN}{dp_T}$: inclusive particle yield , $\left.\frac{dN}{dp_T}\right|_{in}$: yield in-plane , $\left.\frac{dN}{dp_T}\right|_{out}$: yield out-of-plane

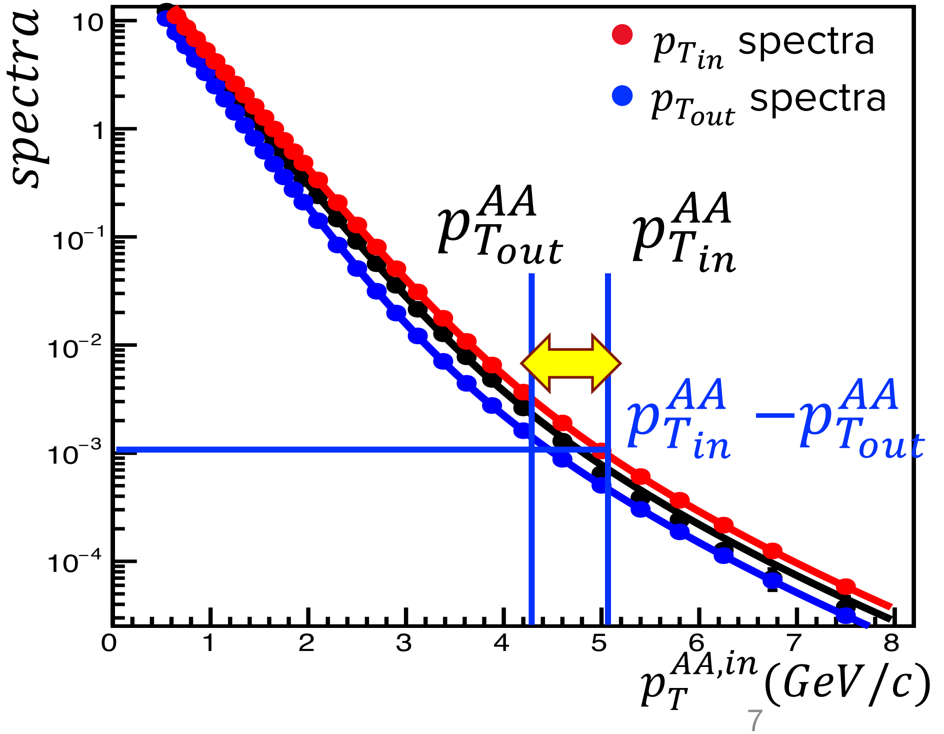
$$\left.\frac{dN}{dp_T}\right|_{in} = \frac{dN}{dp_T} \times (2v_2 + 1)\ (\phi - \Psi = 0°)$$

$$\left.\frac{dN}{dp_T}\right|_{out} = \frac{dN}{dp_T} \times (2v_2 - 1)\ (\phi - \Psi = 90°)$$

2. Calculate S'_{loss}.

$$S'_{loss} = \frac{p_{T_{in}}^{AA} - p_{T_{out}}^{AA}}{p_{T_{in}}^{AA}}$$





Estimation of Path-length ($L, L^2, \Delta L^2$)

1. Using Monte-Carlo method based on Glauber model.
2. For each parton-parton collision, calculate $\boldsymbol{L_{in}}$ and $\boldsymbol{L_{out}}$.
   - L_{in} : the length of the interaction area in the in-plane direction
   - L_{out}: the length of the interaction area in the out-of-plane direction
3. Calculate path-length for a given centrality class.
   - **L: mean path-length for S_{loss}**

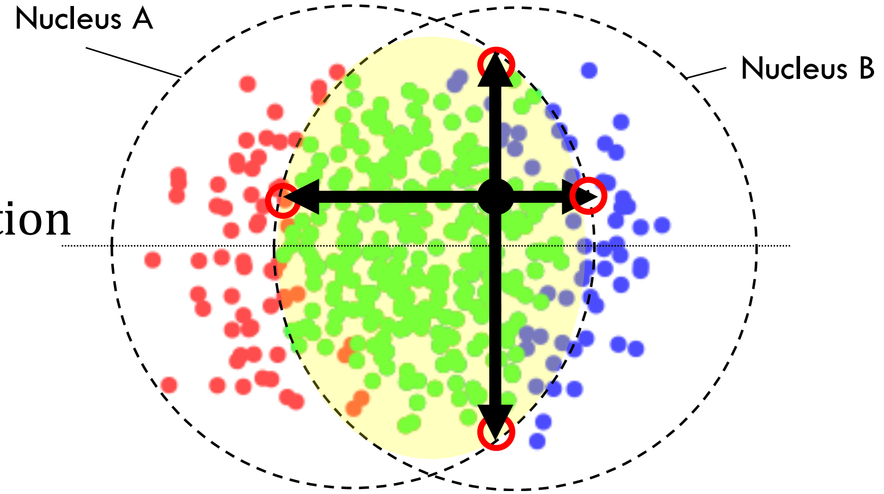
$$L = \frac{\overline{L_{in}} + \overline{L_{out}}}{2}$$

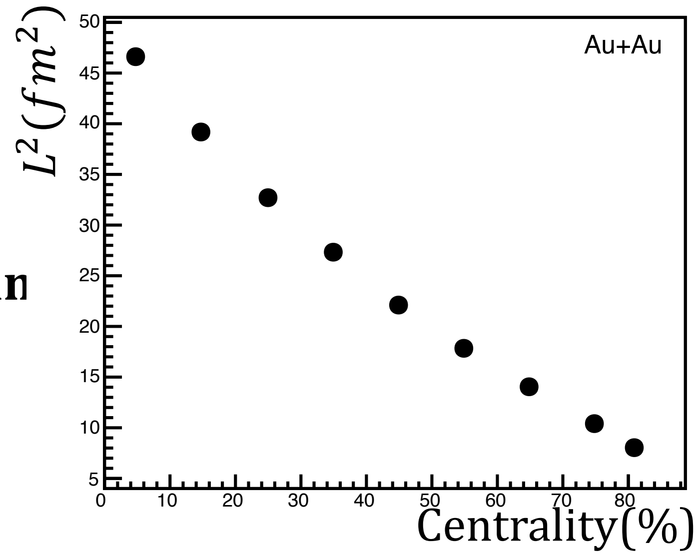
   - **L^2: squared path-length for S_{loss}**

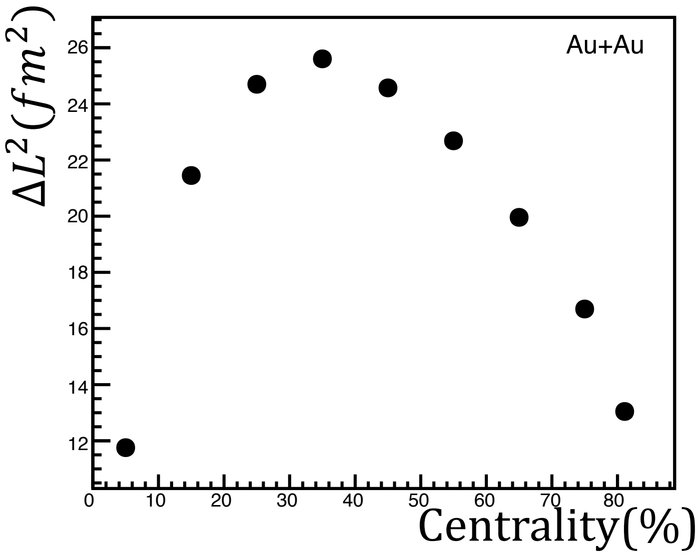
$$L^2 = \left(\frac{\overline{L_{in}} + \overline{L_{out}}}{2}\right)^2$$

   - **ΔL^2: a quantity for S'_{loss} correspondin to L^2 for S_{loss}**

$$\Delta L^2 = \overline{L_{out}}^2 - \overline{L_{in}}^2$$





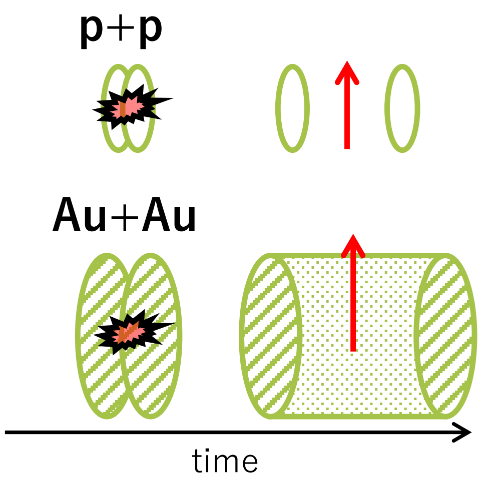


New measurements presented today

Approach 1 (S_{loss})

$$S_{loss} = \frac{p_T^{pp} - p_T^{AA}}{p_T^{pp}}$$

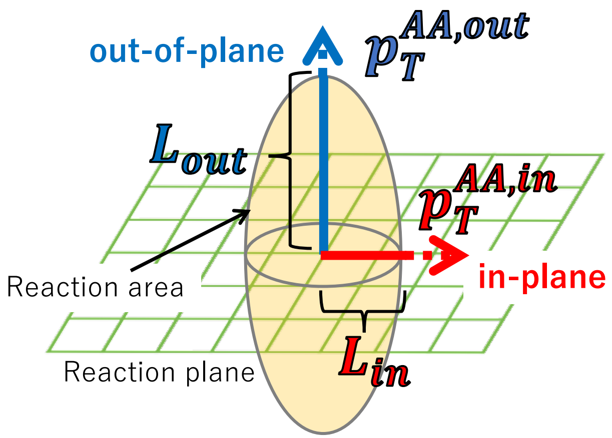
1. Particle and System
   - **$h^{\pm}$, Au+Au, 200GeV**
   - **π^0, Cu+Au, 200GeV**
2. plots
   - S_{loss} vs. p_T
   - S_{loss} vs. L^2



Approach 2 (S'_{loss})

$$S'_{loss} = \frac{p_T^{AA,in} - p_T^{AA,out}}{p_T^{AA,in}}$$

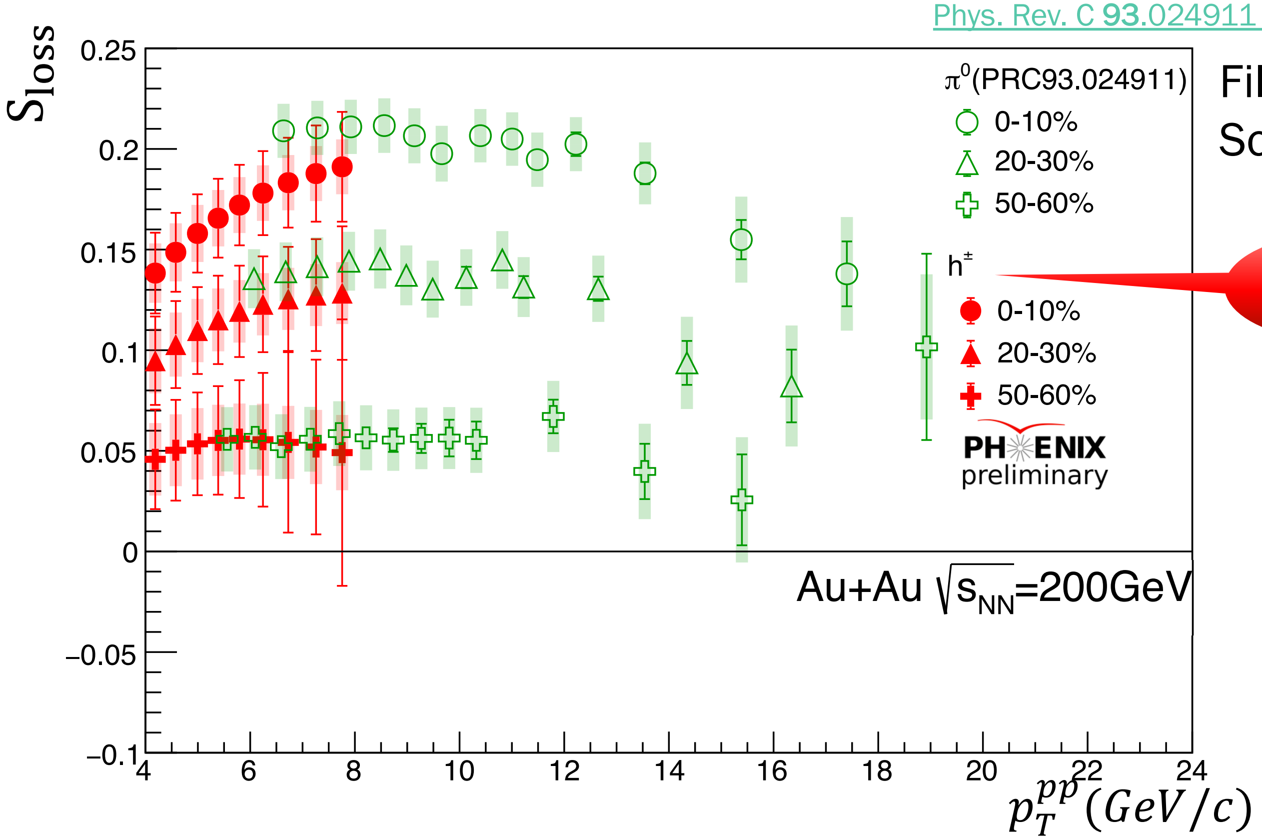
1. Particle and System
   - **$h^{\pm}$, Au+Au, 200GeV**
   - **π^0, Au+Au, 200GeV**
2. plots
   - S'_{loss} vs. p_T
   - S'_{loss} vs. $\Delta L^2 (= L_{out}^2 - L_{in}^2)$



S_{loss} vs. p_T ($h^{\pm}$, Au+Au)

$$S_{loss} = \frac{p_T^{pp}(scaled) - p_T^{AA}}{p_T^{pp}(scaled)}$$

Phys. Rev. C 93.024911 (2016)



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New!

- There is no significant difference between $h^{\pm}$s and π^0s within uncertainty.

S_{loss} vs. p_T (π^0, Cu+Au)

$$S_{loss} = \frac{p_T^{pp}(scaled) - p_T^{AA}}{p_T^{pp}(scaled)}$$

New!

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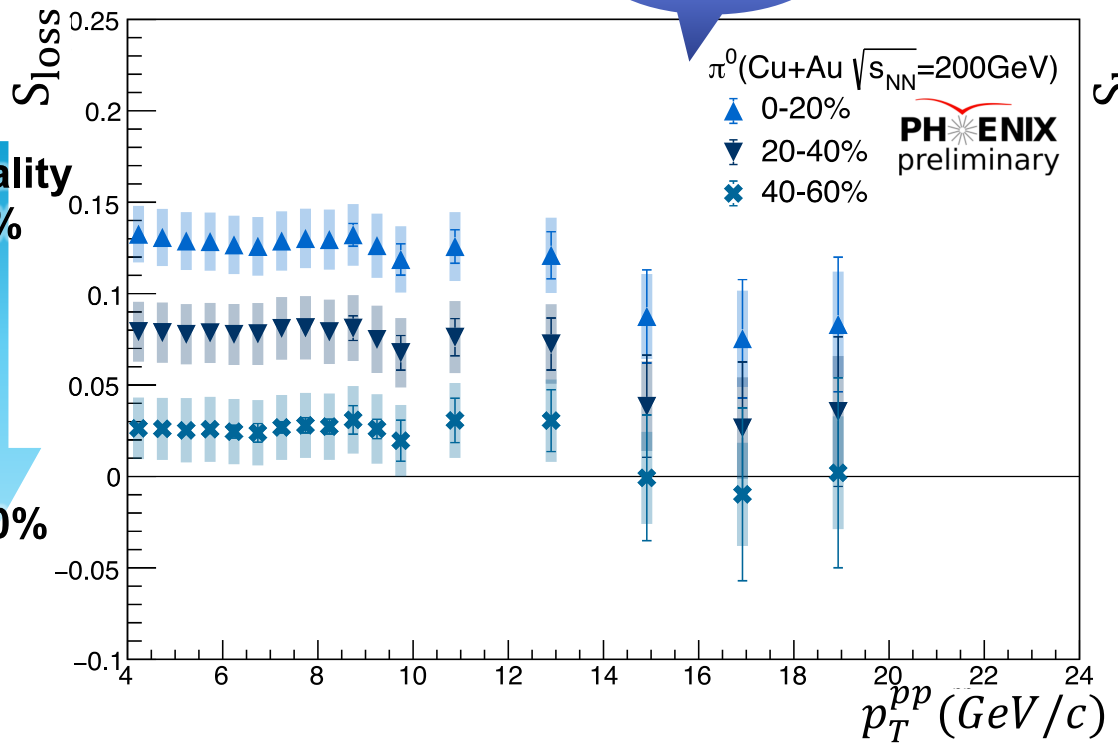
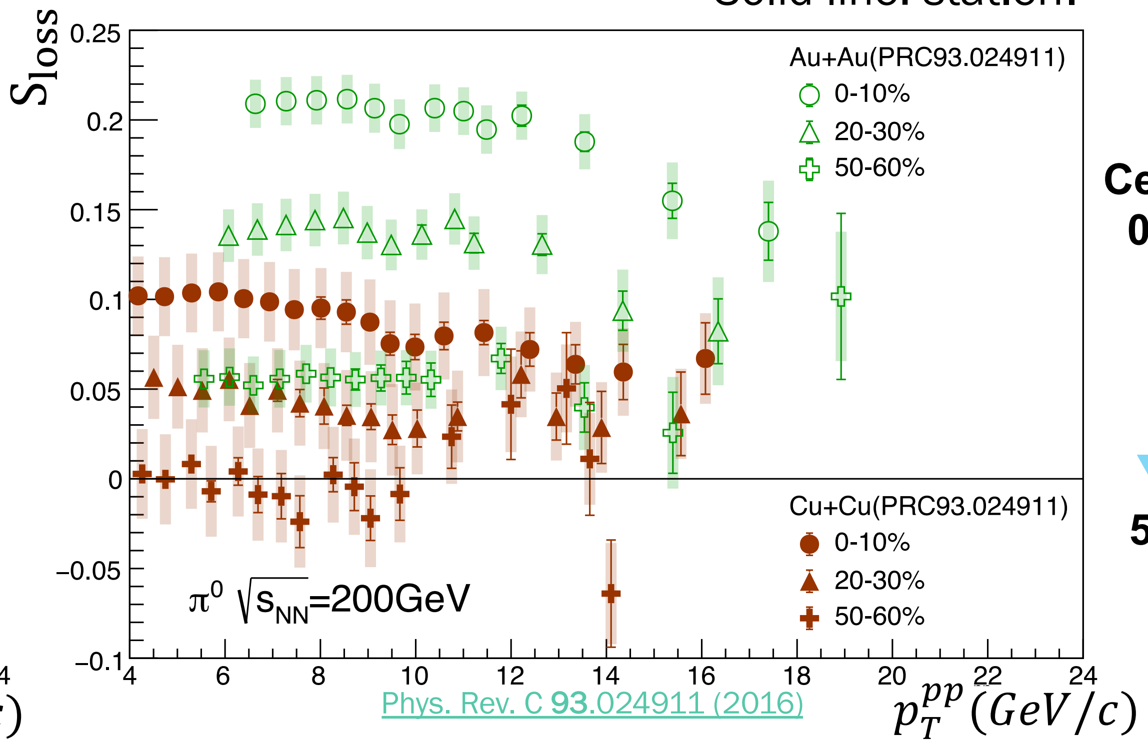
Centrality 0-10% → 50-60%





Phys. Rev. C **93**.024911 (2016)

- S_{loss} for π^0s in Cu+Au is almost constant up to p_T ~12 GeV and decreases at higher p_T.
- S_{loss} decreases as centrality increases.
- S_{loss} vs. p_T shows the same tendency in Au+Au, Cu+Cu, and Cu+Au.

asymmetric collisions

S'_{loss} vs. p_T ($h^{\pm}, \pi^0$(Au+Au))

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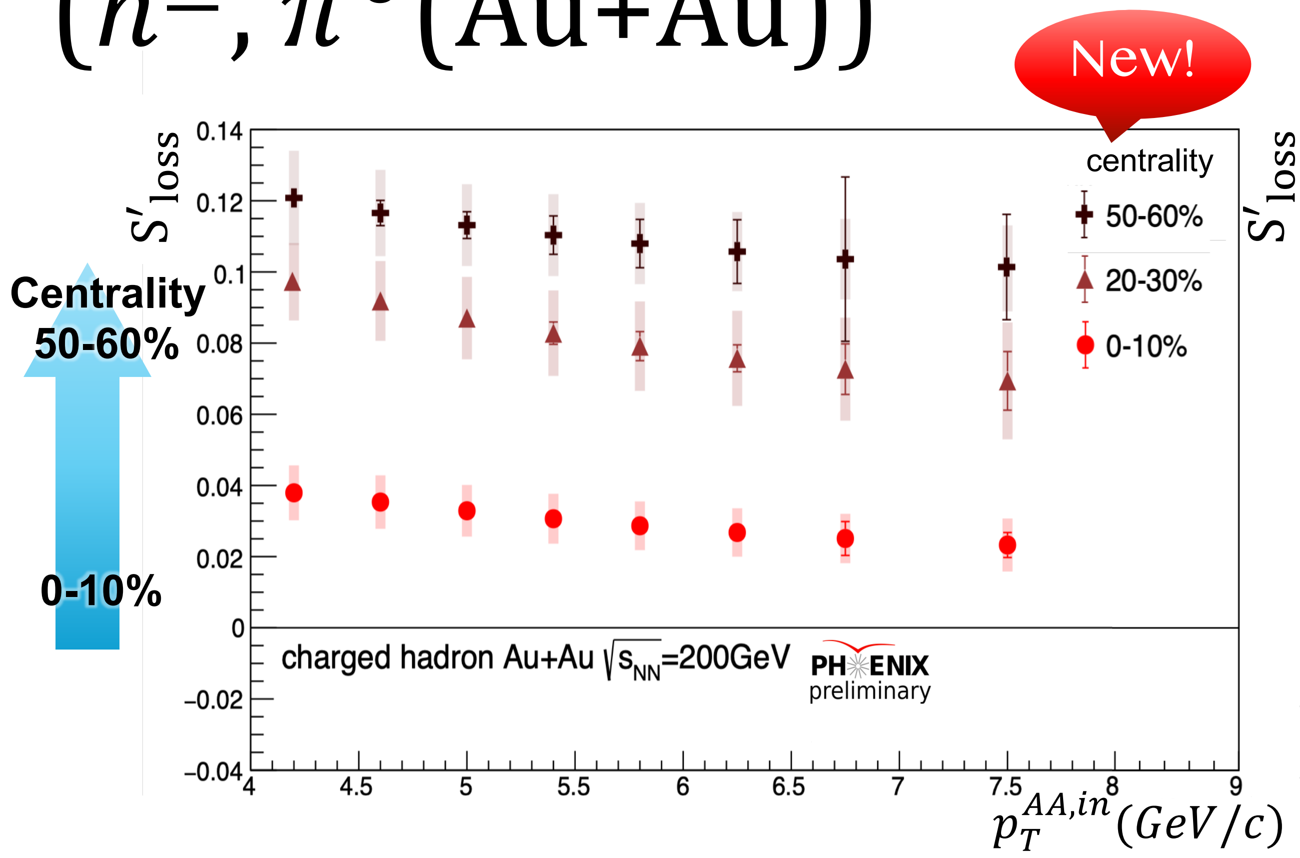
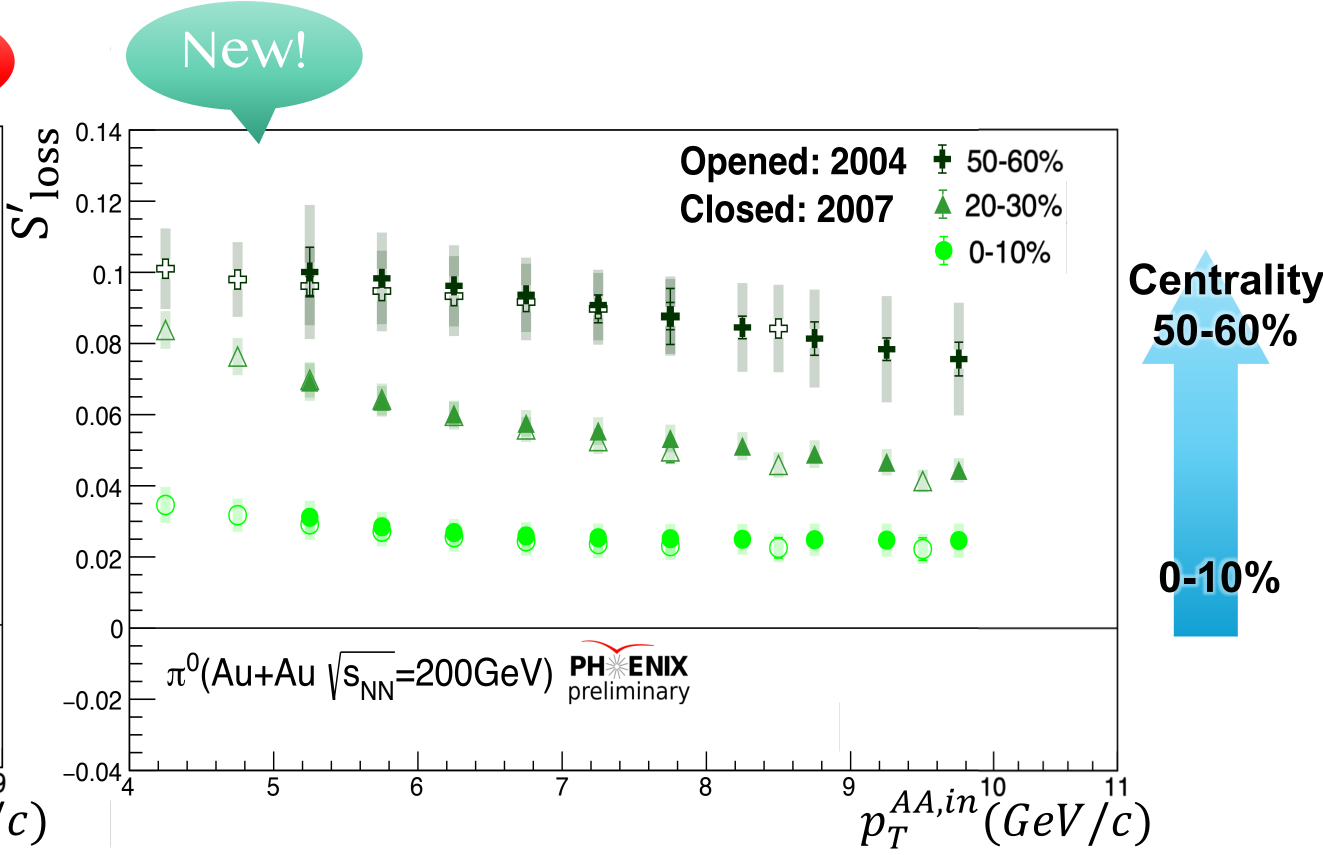
$$S'_{loss} = \frac{p_T^{AA,in} - p_T^{AA,out}}{p_T^{AA,in}}$$





- S'_{loss} for h$^{\pm}$s and π^0s slightly decrease up to p_T ~6 GeV and seems to be almost constant at higher p_T.
- S'_{loss} increases as centrality increases.
- There is no significant difference between $h^{\pm}s$ and π^0s.

S'_{loss} vs. p_T ($h^{\pm}, \pi^0$(Au+Au))

$$S'_{loss} = \frac{p_T^{AA,in} - p_T^{AA,out}}{p_T^{AA,in}}$$

Filled box: syst.err.
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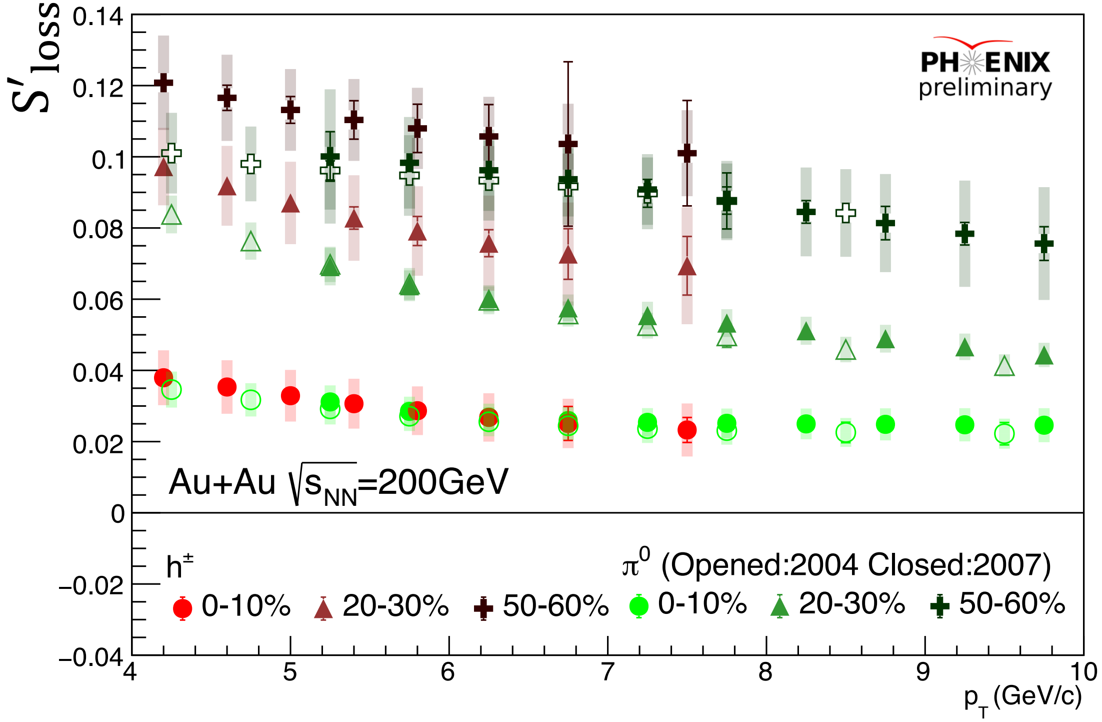


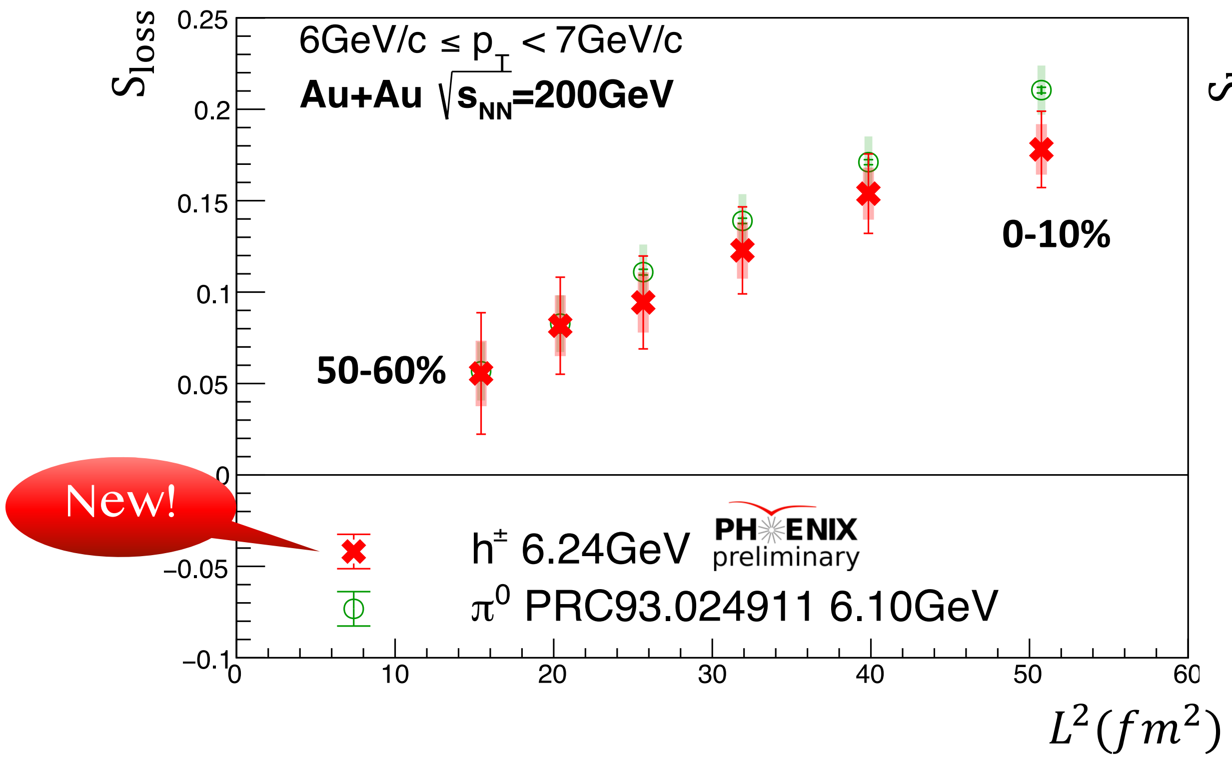
- S'_{loss} for h$^{\pm}$s and π^0s slightly decrease up to p_T ~6 GeV and seems to be almost constant at higher p_T.
- S'_{loss} increases as centrality increases.
- There is no significant difference between $h^{\pm}s$ and π^0s.

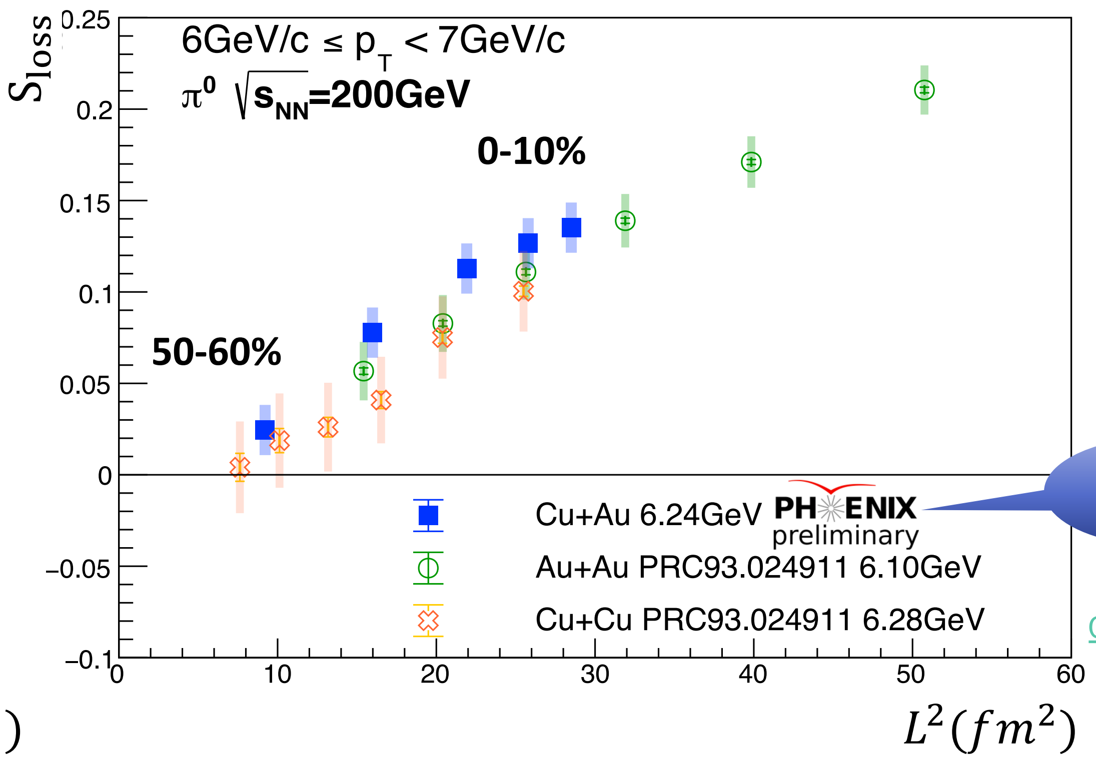
S_{loss} vs. L^2 ($h^{\pm}$(Au+Au), π^0(Cu+Au))

Filled box: syst.err.
Solid line: stat.err.

$$S_{loss} = \frac{p_T^{pp}(scaled) - p_T^{AA}}{p_T^{pp}(scaled)}$$

$$L^2 = \left(\frac{L_{out} + L_{in}}{2}\right)^2$$





New!

Phys. Rev. C 93.024911 (2016)

- S_{loss} is proportional to L^2 for both $h^{\pm}$s and π^0s, and it is common in Au+Au, Cu+Cu, and Cu+Au.
- It implies the gluon radiation loss is dominant.

S'_{loss} vs. $\Delta L^2 (= L^2_{out} - L^2_{in})$ $(h^{\pm}, \pi^0 (\mathrm{Au+Au}))$

$$S'_{loss} = \frac{p_T^{AA,in} - p_T^{AA,out}}{p_T^{AA,in}}$$

$$\Delta L^2 = L^2_{out} - L^2_{in}$$

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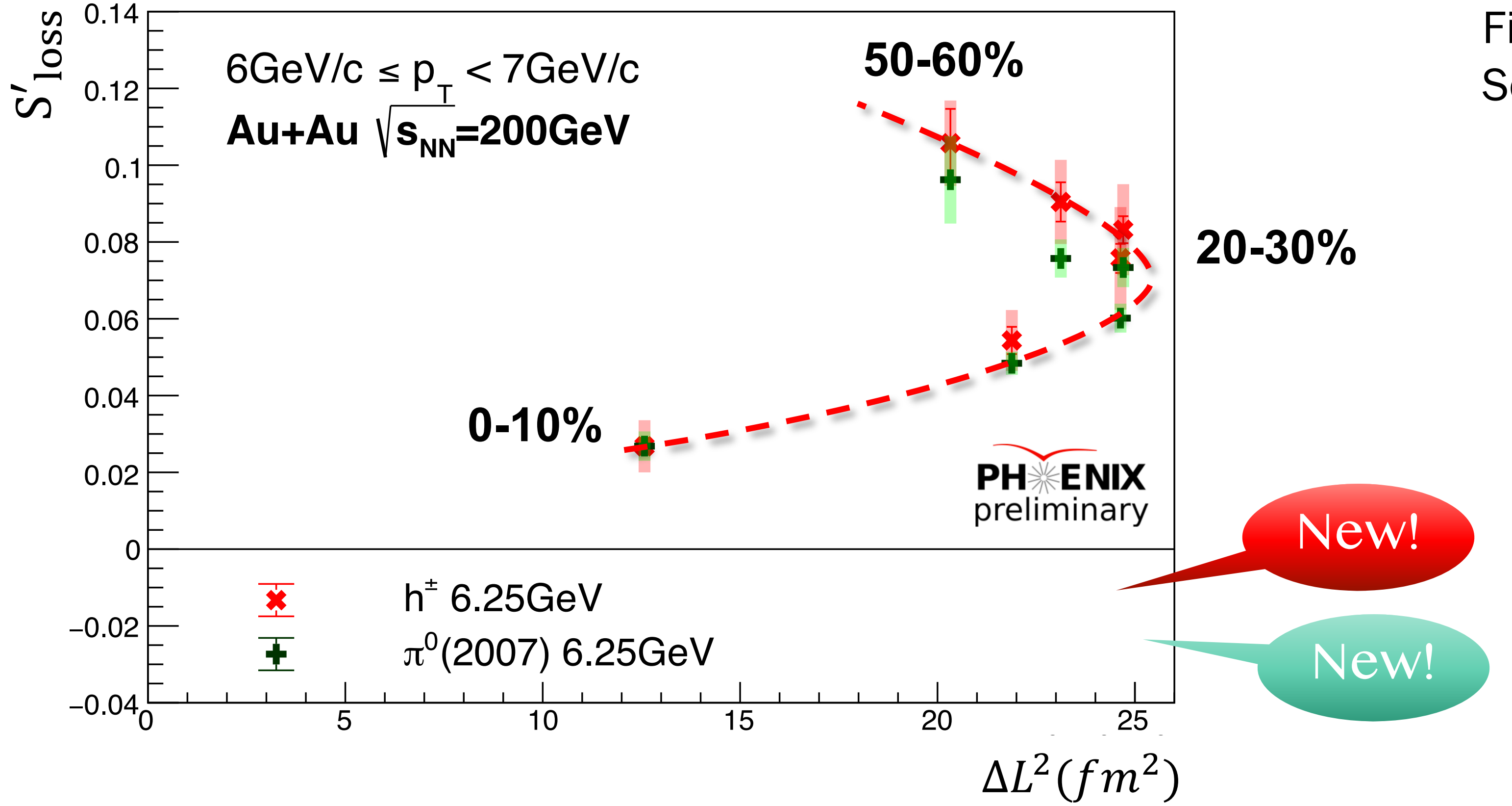

- S'_{loss} is not proportional to $L^2_{out} - L^2_{in}$.
- There is no significant difference between $h^{\pm}$s and π^0s within uncertainty.

S'_{loss} exhibits a different tendency from S_{loss}!

Summary

- We evaluated the energy loss of partons in QGP.
- We newly measured S_{loss} for π^0s in Cu+Au and $h^{\pm}s$ in Au+Au.
  - S_{loss} is proportional to L^2.
  - Throughout π^0s (Au+Au, Cu+Cu, and Au+Cu) and $h^{\pm}$s (Au+Au) cases, the S_{loss} vs. L^2 relation looks common within uncertainty.
- We introduced a new analysis approach that allows us to compare yield in-plane and out-of-plane, and we define S'_{loss}.
- We measured S'_{loss} for $h^{\pm}$s and π^0s in Au+Au.
  - S'_{loss} vs. p_T relation is common for $h^{\pm}$s and π^0s in Au+Au within uncertainty.
  - S'_{loss} is not proportional to $\Delta L^2 (= L_{out}^2 - L_{in}^2)$, different behavior from S_{loss}.
  - S'_{loss} vs. ΔL^2 is common for $h^{\pm}$s and π^0s in Au+Au within uncertainty.

Outlook

- Study of L^n dependences of S'_{loss} with multiple fitting functions
- Obtaining path-length with advanced simulation tools (ex. Jetscape)