Measurement of D^0 Meson Tagged Jets in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV

Ondřej Lomický
(for the STAR Collaboration)
Czech Technical University in Prague

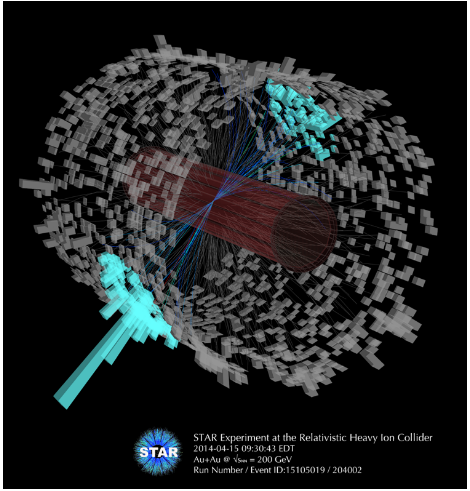
5th June 2024

Supported in part by U.S. DEPARTMENT OF ENERGY Office of Science

SQM2024
The 21st International Conference on Strangeness in Quark Matter
3-7 June 2024, Strasbourg, France

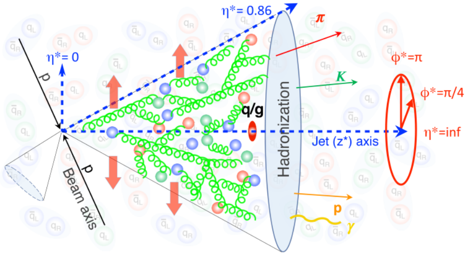
Outline

- Motivation
- STAR Detector
- D^0-jets reconstruction
- Results
- Outlook: Generalized Angularities results
- Summary

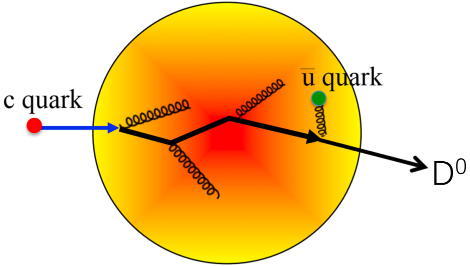


Credit: Y. Zhang (QPT 2017)

- Heavy quarks (**c**, **b**), created in the initial collision
- Strong interaction with medium → hard probe
- Study of QGP's transport studies



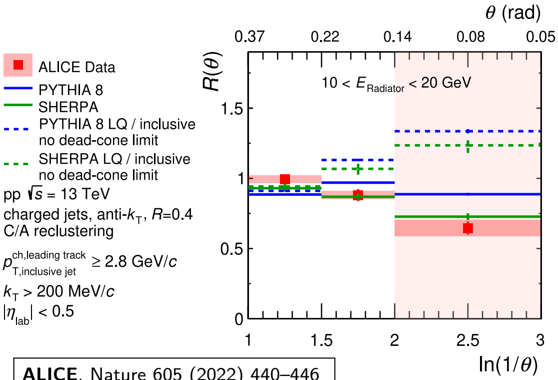
CMS, CMS-HIN-21-013 (2023)



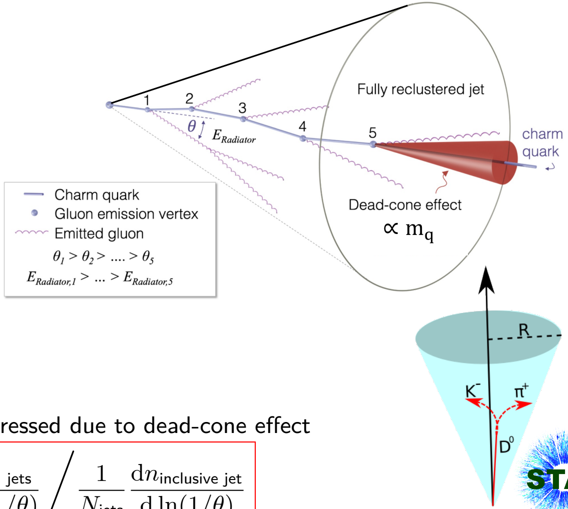
quark-gluon plasma

- Hard probes loses energy via radiation and scattering → parton shower (jet)
- Jets are reconstructed by a sequential clustering algorithm (anti-k_{T}, ...)
- Parton shower broadened due to medium

Motivation: Heavy-quark jets



ALICE, Nature 605 (2022) 440–446



- Ratios of splitting angle θ probability distributions
- Heavy-flavor emission spectra at small angles suppressed due to dead-cone effect

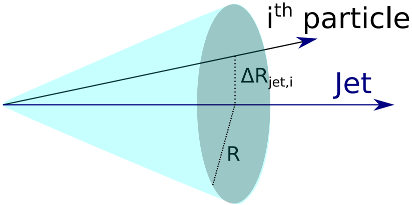
$$R(\theta) = \frac{1}{N_{\mathrm{D^0\ jets}}} \frac{\mathrm{d}n_{\mathrm{D^0\ jets}}}{\mathrm{d}\ln(1/\theta)} \Bigg/ \frac{1}{N_{\mathrm{jets}}} \frac{\mathrm{d}n_{\text{inclusive jet}}}{\mathrm{d}\ln(1/\theta)}$$

Motivation: Generalized angularities

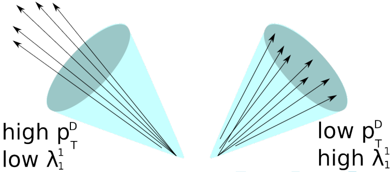
$$\lambda_\alpha^\kappa = \sum_{i\in\text{Jet}} \overbrace{\left(\frac{p_{\text{T},i}}{p_{\text{T,Jet}}}\right)^\kappa}^{\text{soft/hard}} \overbrace{\left(\frac{\Delta R_{\text{Jet},i}}{R}\right)^\alpha}^{\text{collinearity sensitive}}$$

Generalized angularities

- Jet p_T fraction carried by charged constituent i
- $p_\text{T,Jet}$ - calculated for inclusive jet
- $\Delta R_{\text{Jet},i}$ distance of constituent i to the jet axis
- IRC safe observable for parameters $\kappa = 1$, $\alpha > 0$. It is calculable from pQCD
- Study of **modification generalized angularities in HI collisions**

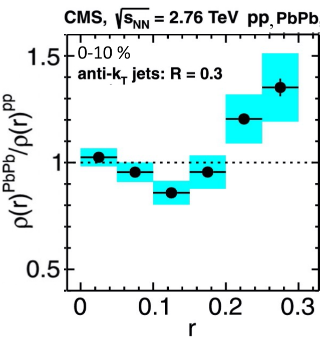


- $\lambda_1^1 = g$ - girth
- λ_2^1 - thrust
- $\lambda_0^2 = (p_\text{T}^\text{D})^2$ - momentum dispersion

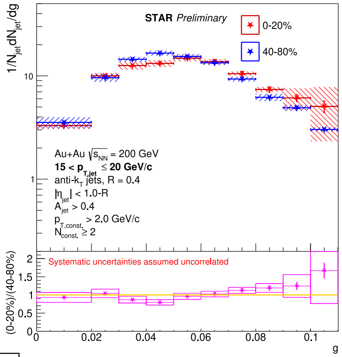


Strasbourg 2024

Motivation: Inclusive jet substructure in HI collisions



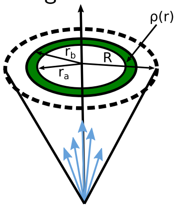
CMS, Phys. Lett. B 730 (2014) 243



- Energy redistribution to large distances from jet axis in the presence of QGP

Possible mechanism:

- Multiple scattering
- Medium-induced Bremsstrahlung
- Medium response



$$r = \sqrt{(\eta_{\text{track}} - \eta_{\text{Jet}})^2 + (\phi_{\text{track}} - \phi_{\text{Jet}})^2}$$

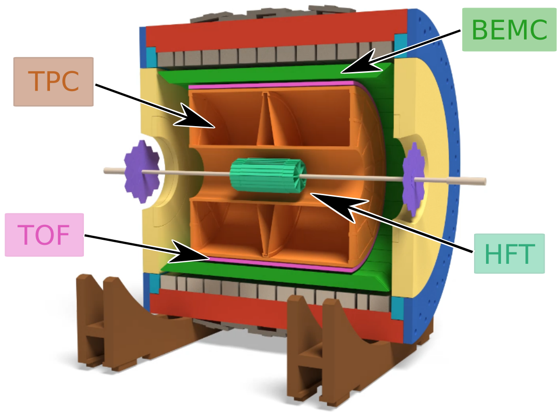
$$\rho(r) = \frac{1}{\Delta r} \frac{1}{N_{\text{Jet}}} \sum_{\text{Jet}} \frac{\sum_{\text{track}} p_{\text{T}}}{p_{\text{T, Jet}}}$$

$$g = \lambda_1^1 = \sum_{i \in \text{Jet}} \frac{p_{\text{T},i}}{p_{\text{T,Jet}}} \frac{\Delta R_{\text{Jet},i}}{R}$$

- Medium response depends on the mass of the underlying parton
- **Motivation to study heavy-flavor jets**

STAR Detector & Selection Criteria

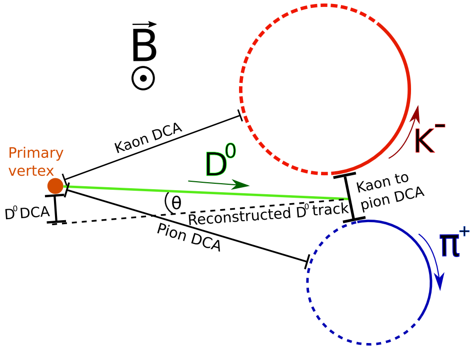
Credit: https://nsww.org/

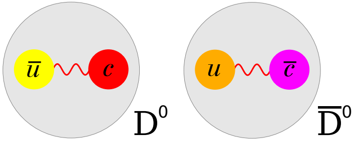


- **Event selection**
  - Au+Au $\sqrt{s_{\mathrm{NN}}} = 200$ GeV, run 2014
  - Minimum bias (MB) trigger
  - Centrality ranges: 0-10%, 10-40%, 40-80%
- **$D^0 \rightarrow K + \pi$ meson reconstruction**
  - Topological reconstruction using HFT+TPC
  - $1 < p_{\mathrm{T,D^0}}$ [GeV/c] < 10
  - PID: TPC+TOF
- **Constituent selection**
  - Charged (TPC): $0.2 < p_{\mathrm{T}}$ [GeV/c] < 30
  - Neutral (BEMC): $0.2 < E_{\mathrm{T,tower}}$ [GeV] < 30
  - $|\eta_{\mathrm{track/tower}}| < 1$
- **D^0-jet selection**
  - Anti-k_{T} full jets
  - $R = 0.4$ & $|\eta_{\mathrm{Jet}}| < 1 - R$

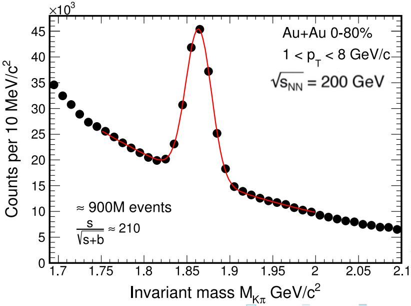
- Time Projection Chamber (**TPC**)
- Time-of-Flight Detector (**TOF**)
- Barrel Electromagnetic Calorimeter (**BEMC**)
- Heavy Flavor Tracker (**HFT**)

D^0 reconstruction





- **D^0 meson**
  - The lighest charmed hadron
  - $m_{D^0} = (1864.84 \pm 0.17)$ MeV/c^2
  - Decay length $\sim$ 123 μm
  - $D^0/\overline{D}^0 \to \pi^{+/-} + K^{-/+}$ (B.R. 3.89 ± 0.05 %)
  - $1 < p_{T,D^0}$ [GeV/c] < 10
- **Topological cuts**
  - Signal significance improvement



D^0-jets reconstruction

- **Inclusive jets**
  - Charged (TPC) + neutral (BEMC)
- **Hadronic correction**
  - BEMC cannot recognize charged/neutral particles

$$E_{\text{neutr.}} = E^{\text{BEMC}}_{\text{tower}} - \sum_{\text{marched}} \sqrt{p^2_{\text{charged}} + m^2_{\pi^+}}$$

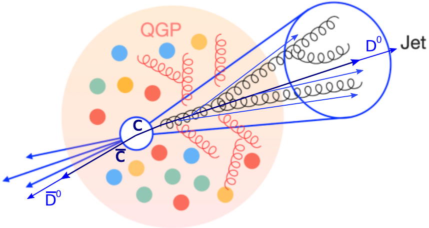
- **Background subtraction**
  - Background of relatively soft particles
  - Background density ρ calculated using k_{T}-algorithm

$$p^{\text{sub}}_{\text{T,Jet}} = p^{\text{raw}}_{\text{T,Jet}} - \rho A_{\text{Jet}}$$

  - Area A_{Jet} estimated as active area using ghost (infinitely soft particles)

FastJet (https://fastjet.fr/)

- C++ software package for jet reconstruction
- All common sequential recombination jet algorithms
- D^0 tagged jets reconstructed via **anti-k_{T}** algorithm



Modified, credit: https://www.int.washington.edu/node/776

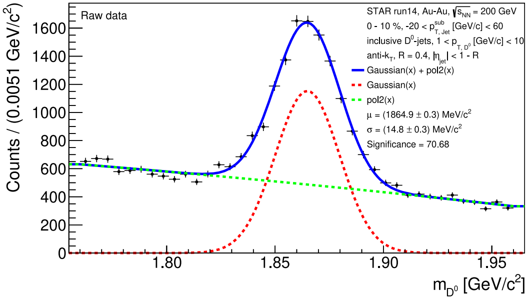
Strasbourg 2024

Detector resolution and background fluctuations → **unfolding required**

${}_s\mathcal{P}$lot

- Native class in RooStats and widely used in HEP
- All observables of D^0-jets candidates calculated using sWeights
- The observables must not be correlated with the discriminating variable (m_{D^0})

$$ {}_s\mathcal{P}_n(m_{\mathrm{D}^0,i}) = \frac{\sum_{j=1}^{2} \mathbb{V}_{nj} f_j(m_{\mathrm{D}^0,i})}{\sum_{j=1}^{2} N_j f_j(m_{\mathrm{D}^0,i})} $$



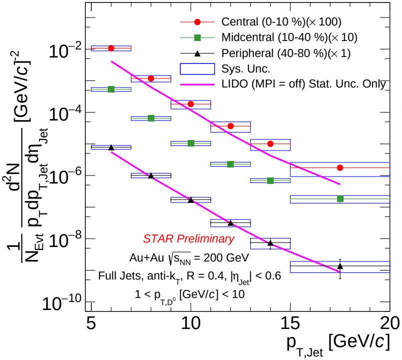
- $f_1(m_{\mathrm{D}^0})$ - pdf value of the signal contribution
- $f_2(m_{\mathrm{D}^0})$ - pdf value of the background contribution
- N_j - j-th yield
- $\mathbb{V}_{nj}$ - covariance matrix
- Easy implementation of the D^0 reconstruction efficiency correction $\varepsilon(m_{\mathrm{D}^0,i})$

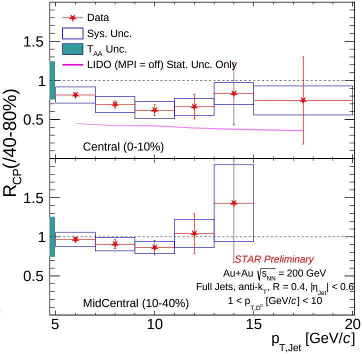
$$ {}_s\mathcal{P}_n(m_{\mathrm{D}^0,i}) \rightarrow \frac{{}_s\mathcal{P}_n(m_{\mathrm{D}^0,i})}{\varepsilon(m_{\mathrm{D}^0,i})} $$

Strasbourg 2024

Results

D^0-jet transverse momentum spectra





- LIDO → Hybrid transport model for heavy quark evolution in medium with collisional and radiative energy losses
- LIDO agrees well with yield in peripheral events, slightly underpredicts yield in central events
- MPI might be important for low p_{T,D^0} yield

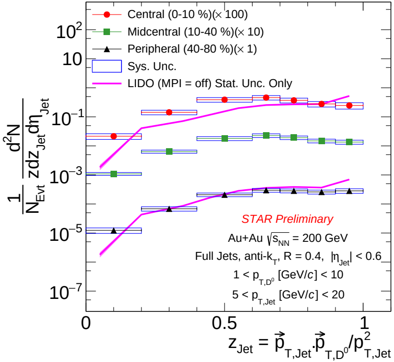
LIDO, Phys. Rev. C 98, 064901

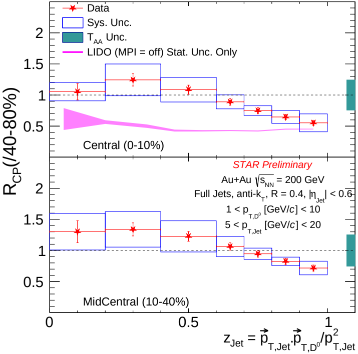
- Hint of suppression of D^0-jet yield in central events
- Ratio in midcentral events consistent with 1

Strasbourg 2024

D^0-jet fragmentation function

$$z_{\text{Jet}} = \frac{\vec{p}_{\text{T,Jet}} \cdot \vec{p}_{\text{T,D}^0}}{|\vec{p}_{\text{T,Jet}}|^2}$$



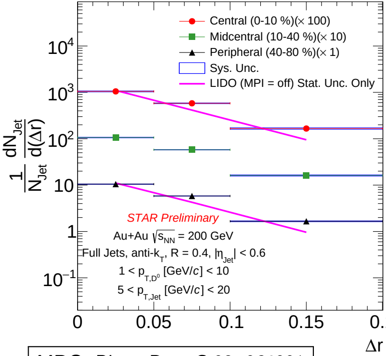


LIDO, Phys. Rev. C 98, 064901

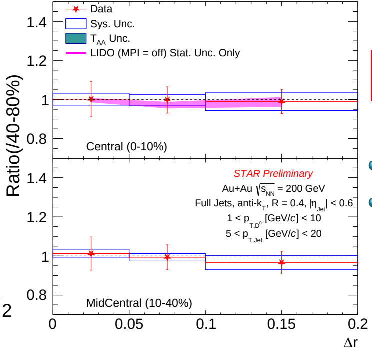
- z_{Jet} related to fragmentation function in DGLAP equation
- 2D unfolded with $p_{\text{T, Jet}}$ spectra
- LIDO slightly overpredicts hard-fragmented D^0 mesons
- LIDO agrees well with yield in peripheral events, slightly underpredicts yield in central events

- Hard fragmented D^0-jet yield suppressed in central/midcentral events
- Soft fragmented D^0-jet yield ratio consistent with 1 in central/midcentral events

Radial profile of D^0-jets



LIDO, Phys. Rev. C 98, 064901



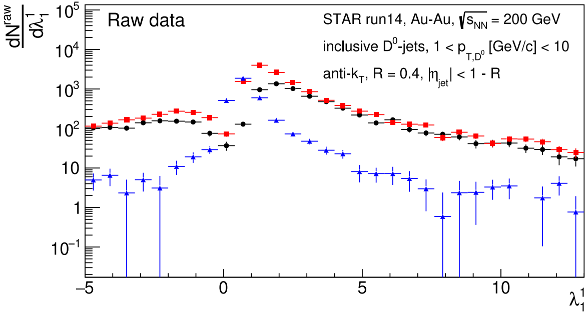
$$\Delta r = \sqrt{(\eta_{\text{Jet}} - \eta_{\text{D}^0})^2 + (\phi_{\text{Jet}} - \phi_{\text{D}^0})^2}$$

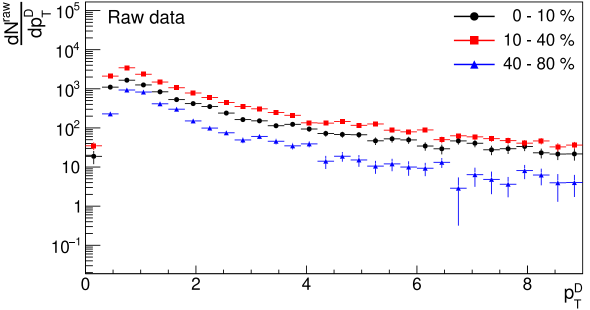
- 2D unfolded with jet p_{T} spectra
- LIDO qualitatively explains radial profile trends, along with ratio of radial profile for central and peripheral events

- Ratio of radial profiles consistent with 1 $\rightarrow$ No hint of D^0 radial profile modification at RHIC energies

Strasbourg 2024

Outlook: Angularities



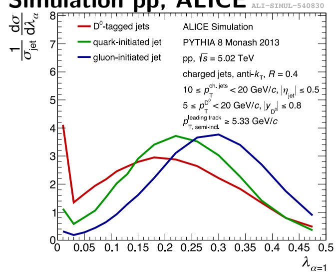


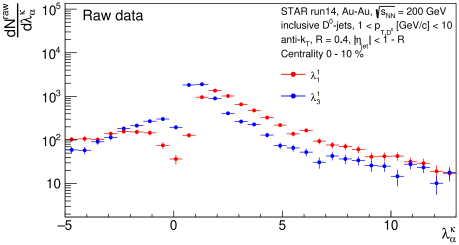
$$\lambda_\alpha^\kappa = \sum_{i\in\text{Jet}} \left(\frac{p_{\text{T},i}}{p_{\text{T,Jet}}}\right)^\kappa \left(\frac{\Delta R_{\text{Jet},i}}{R}\right)^\alpha$$

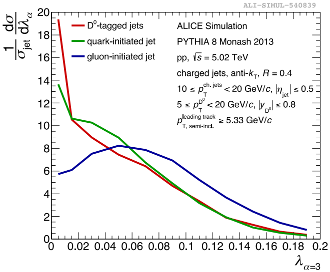
- Angularities:
  - $\lambda_{0.5}^1$, λ_1^1, $\lambda_{1.5}^1$, λ_2^1, λ_3^1, p_T^D $(\sqrt{\lambda_0^2})$ in different centralities
  - $0 \leq \lambda_\alpha^\kappa \leq 1$
  - Unphysical results caused by background subtraction
    $\rightarrow$ **2D unfolding based on Pythia simulation needed**
  - Study of their modification in HI collisions

- Lower α - higher sensitivity to **mass effects**
- Higher α - higher sensitivity to **Casimir color effects**

Simulation pp, ALICE







ALICE, PoS (HardProbes2023) 140

Summary

D^0-jets in heavy-ion collisions at RHIC

- Hint of D^0-jet suppression in central collisions, mainly from hard fragmented jets
- No modification of D^0-jet radial profile observed
- LIDO model underpredicts yield suppression in central collisions, but can describe radial profile ratio in central to peripheral collisions

Outlook

- Unfolding of different angularities $\lambda_{\alpha}^{\kappa}$
- Studying possible D^0-jet angularity modification in central HI collisions

Strasbourg 2024

This work was supported by a grant from The Czech Science Foundation, grant number: 23-07499S

Backup

- sPlot - contribution of signal and background
- $\lambda^1_{0.5}$ - Les Houches Angularity (LHA)
  - Sensitive for flavor discrimination (JHEP 10 (2022) 158)