

Hadron transverse momentum distribution in $pp \rightarrow Z + \text{jet}(h)$

Yiyu Zhou

in collaboration with Zhongbo Kang, Hongxi Xing and Fanyi Zhao

University of California, Los Angeles

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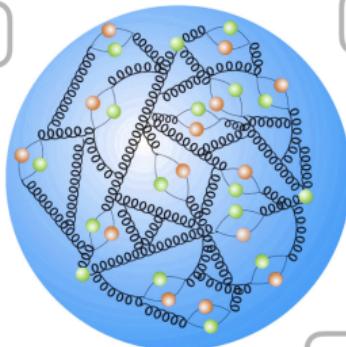
The many faces of the proton

QCD bound state of quarks and gluons

Origin of mass?

Gluon-dominated matter?

Heavy quark content?



Origin of spin?

3D imaging?

Nuclear modifications?

Picture from Zhongbo Kang's talk.

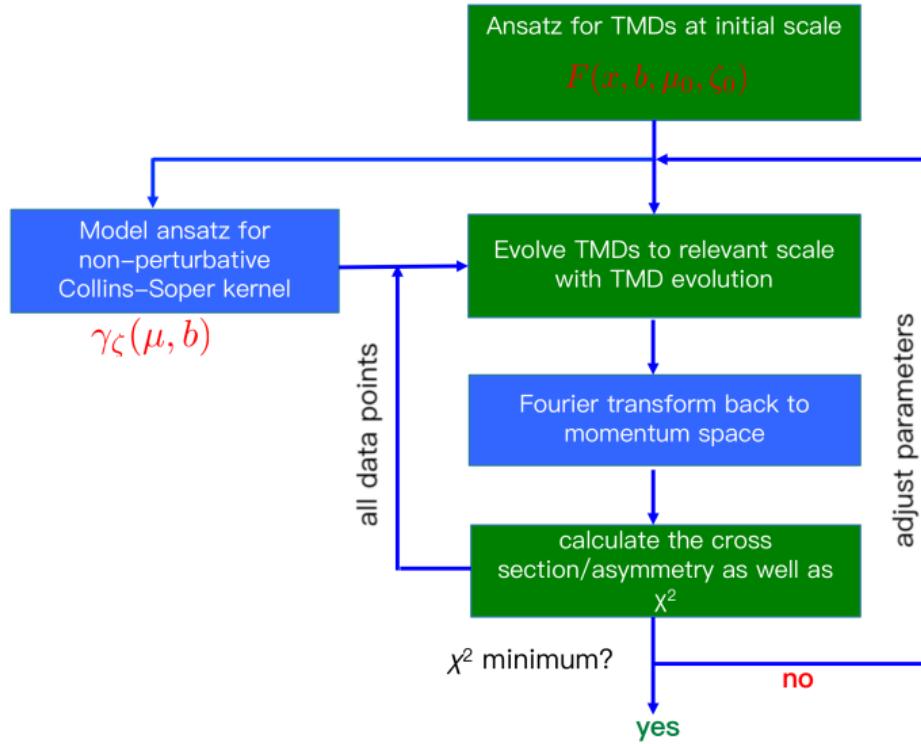
Leading Quark TMDFFs



		Quark Polarization		
		Un-Polarized (U)	Longitudinally Polarized (L)	Transversely Polarized (T)
Unpolarized (or Spin 0) Hadrons	L	$D_1 = \bullet$ Unpolarized		$H_1^\perp = \bullet - \bullet$ Collins
	T		$G_1 = \bullet - \bullet$ Helicity	$H_{1L}^\perp = \bullet - \bullet$
Polarized Hadrons	L			$H_{1T}^\perp = \bullet - \bullet$
	T	$D_{1T}^\perp = \bullet - \bullet$ Polarizing FF	$G_{1T}^\perp = \bullet - \bullet$	$H_1 = \bullet - \bullet$ Transversity

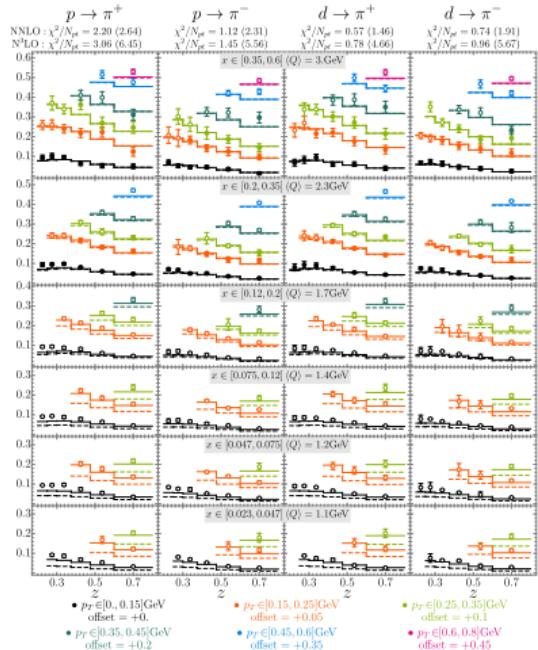
Leading quark TMD PDFs, [TMD Handbook, 2023]

TMD global analysis

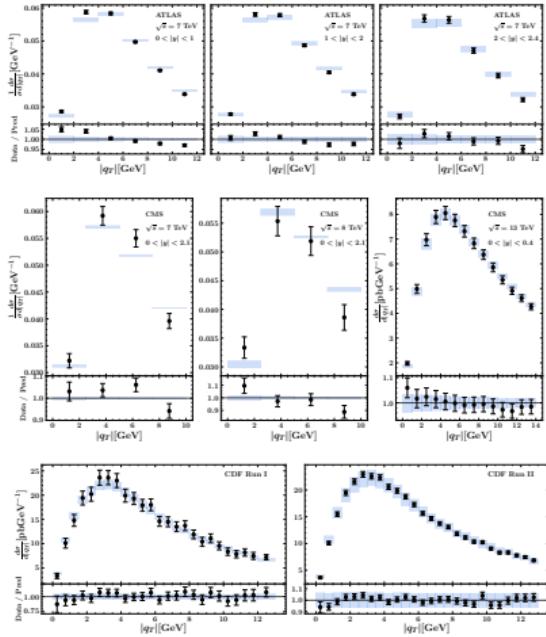


Picture from Zhongbo Kang's talk.

TMD global analysis



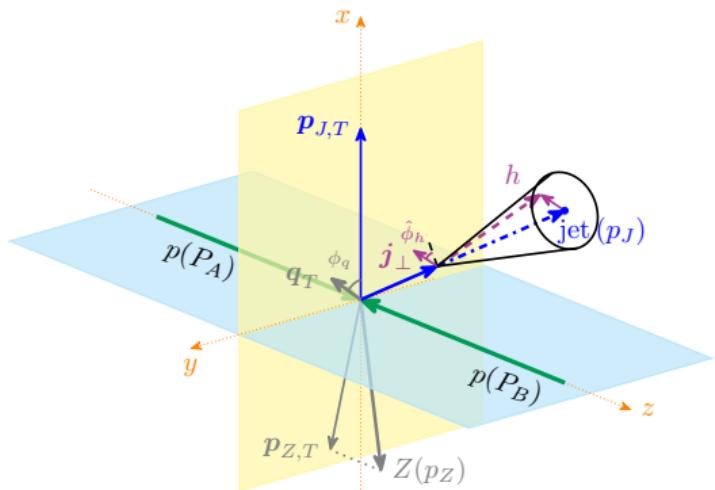
Fit to SIDIS data, [Scimemi and Vladimirov, 2019].



Fit to DY data, [MAP, 2022].

$Z + \text{jet}$ production in pp collision

- p_J and $\mathbf{p}_{J,T}$: jet momentum and transverse momentum,
- \mathbf{q}_T : transverse momentum imbalance,
 $\mathbf{q}_T = \mathbf{p}_{Z,T} + \mathbf{p}_{J,T}$,
- ϕ_{q_T} and ϕ_J : azimuthal angle of \mathbf{q}_T and jet.



TMD factorization

In small q_T , *i.e.*, back-to-back limit, TMD factorization [Kang, Lee, Terry and Xing, 2019] gives:

$$\begin{aligned} \frac{d\sigma^{p+p \rightarrow Z + \text{jet}(h) + X}}{d\mathcal{PS} dz_h d^2\mathbf{j}_T} &= \sum_{a,b,c} \int d\phi_J \int \prod_{i=1}^4 d^2\mathbf{k}_{iT} \delta^2 \left(\mathbf{q}_T - \sum_{i=1}^4 \mathbf{k}_{iT} \right) \\ &\quad \times f_a(x_a, k_{1T}^2, \mu, \nu) f_b(x_b, k_{2T}^2, \mu, \nu) \\ &\quad \times S_{\text{global}}(\mathbf{k}_{3T}, \mu, \nu) S_{cs}(\mathbf{k}_{4T}, R, \mu) \\ &\quad \times H_{ab \rightarrow cZ}(p_T, m_Z, \mu) \mathcal{D}_{1,c}^h(z_h, \mathbf{j}_T, p_T R, \mu), \end{aligned}$$

where $d\mathcal{PS} \equiv d\eta_J d\eta_Z dp_T d^2\mathbf{q}_T$, ϕ_J is the azimuthal angle of the jet, $\mathcal{D}_{1,c}^h$ are the TMD fragmenting jet functions (FJFs).

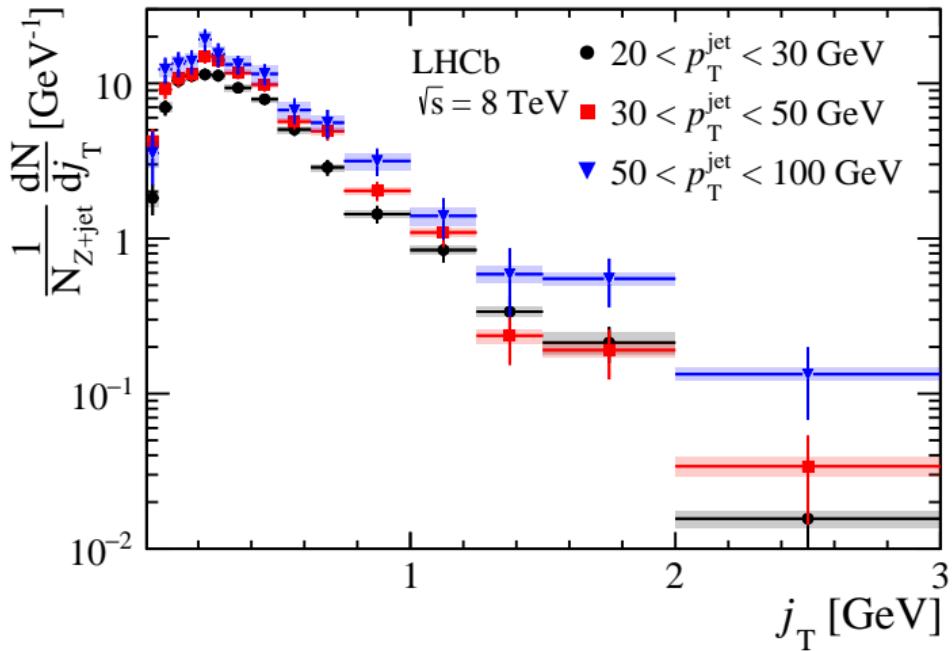
Difficulty in comparing to measurements

The TMD FJFs is factorized as TMD FFs convoluted with soft functions:

$$\mathcal{D}_{1,c}^h(z_h, \mathbf{j}_T, p_T R, \mu) = \int \frac{d^2 \mathbf{b}}{(2\pi)^2} e^{i \mathbf{j}_T \cdot \mathbf{b} / z_h} D_{h/i}(z_h, \mathbf{b}, \mu, \nu) S_i(\mathbf{b}, \mu, \nu R),$$

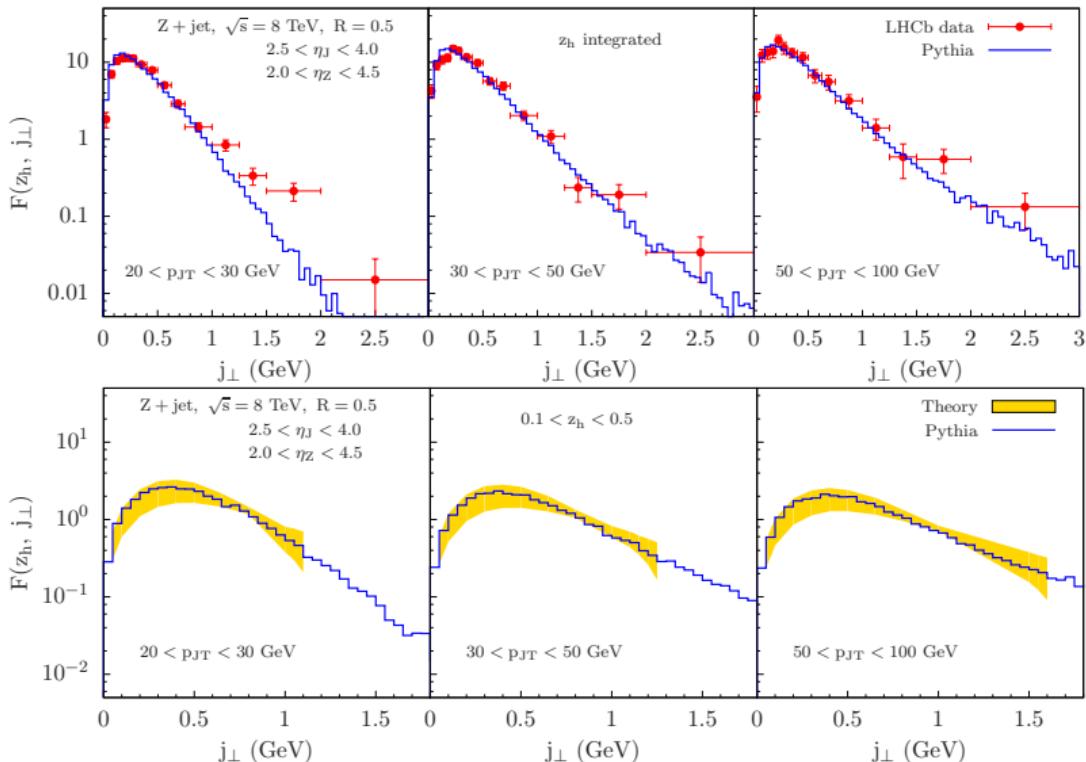
where $D_{h/i}$ are the TMD FFs, which can be further matched onto collinear FFs, and they are only well constrained at $z_h \gtrsim 0.05$.

Previous j_T -dependent measurements



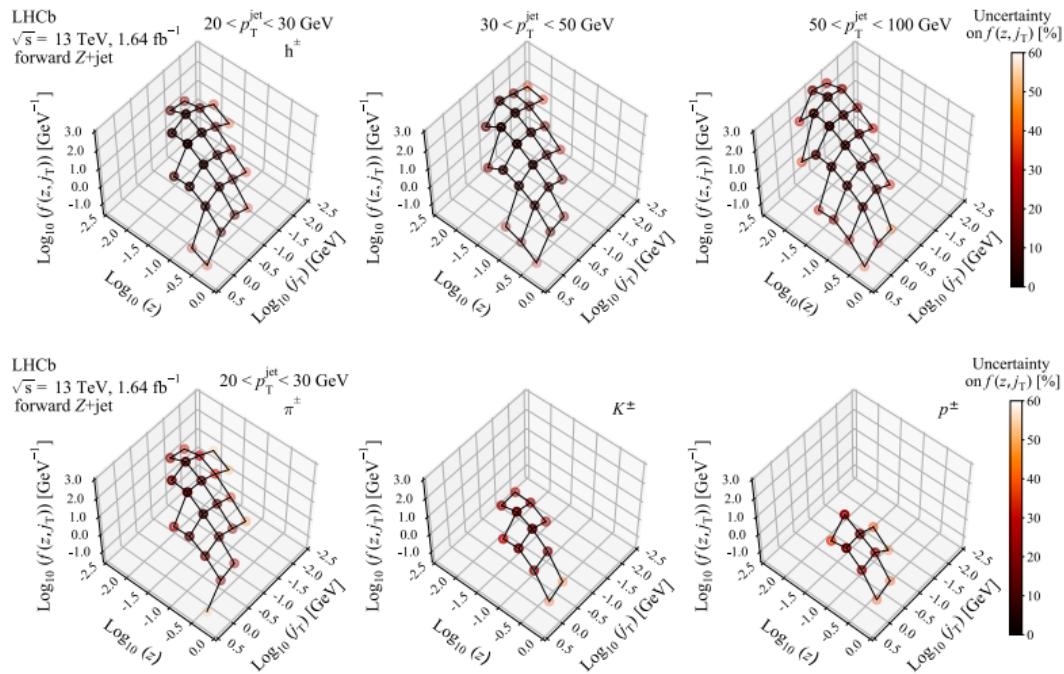
Distributions of the transverse momentum j_T of charged hadrons with respect to the jet axis in three bins of jet p_T , [LHCb, 2019]

Comparison to previous measurements



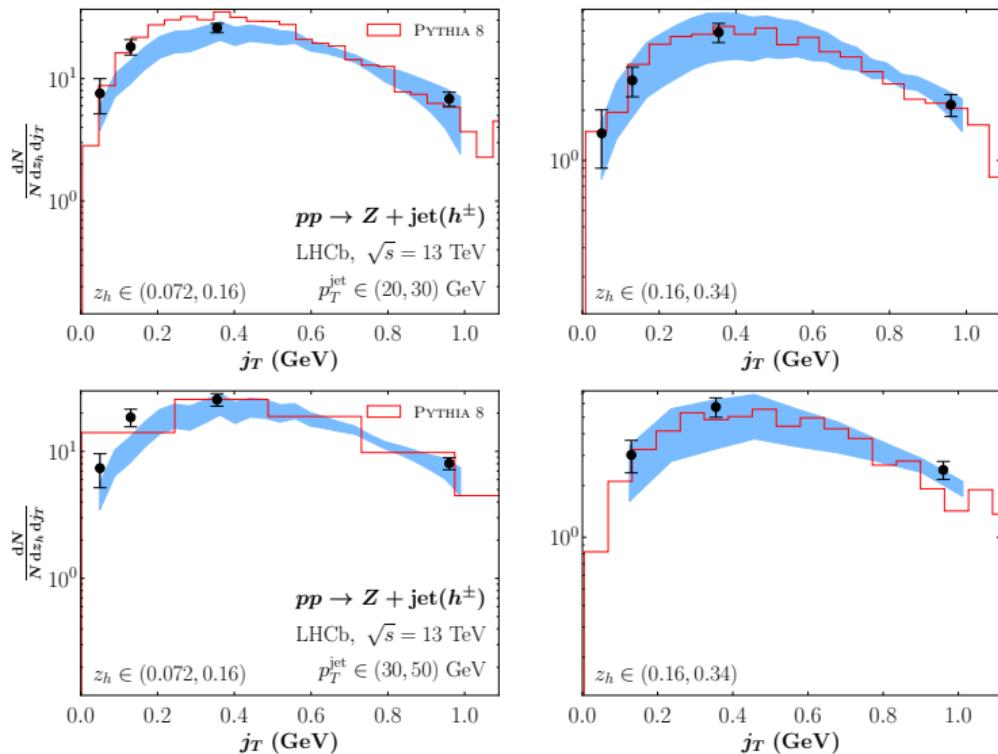
Comparison is only feasible with Pythia simulation, [Kang, Lee, Terry and Xing, 2019]

New measurements



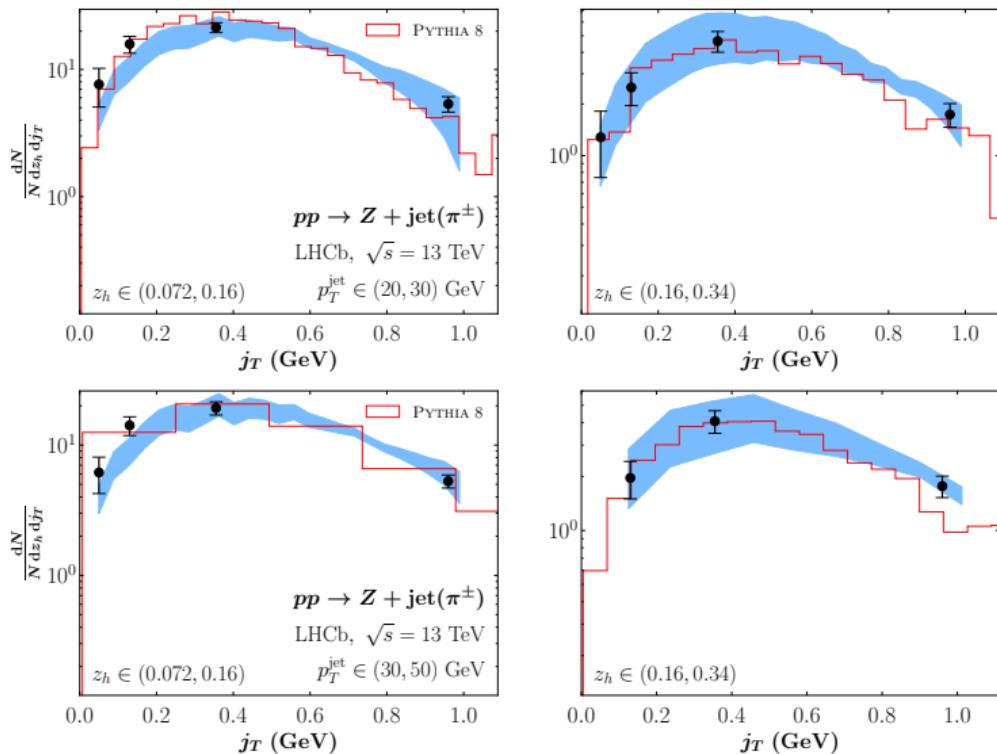
Distributions of the longitudinal momentum fraction z_h as well as transverse momentum j_T of charged hadrons, π^\pm, K^\pm and p/\bar{p} with respect to the jet axis in three bins of jet p_T , [LHCb, 2022]

Comparison to new data: charged hadrons



Jet $p_T \in (20, 30) \text{ GeV}$ and $(30, 50) \text{ GeV}$, collinear FFs are from [DSS, 2022].

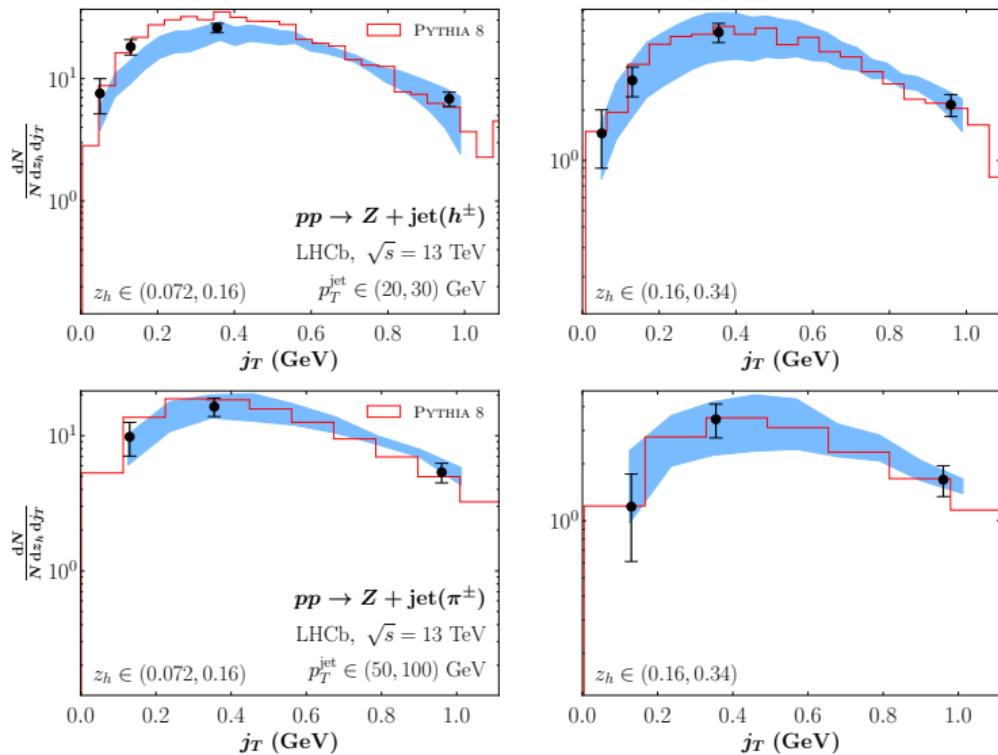
Comparison to new data: π^\pm



Jet $p_T \in (20, 30)$ GeV and $(30, 50)$ GeV, collinear FFs are from [DSS, 2022].

- Work on improving the prediction to $Z + \text{jet}(K^\pm)$ production.
- Make predictions to $pA \rightarrow Z + \text{jet}$ and $pA \rightarrow Z + \text{jet}(h)$ processes.

Comparison to new data



Charged hadron (upper) or π^\pm (lower) production, with jet $p_T \in (50, 100)$ GeV.