Modification of W+jet in Heavy ion collisions

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Outline

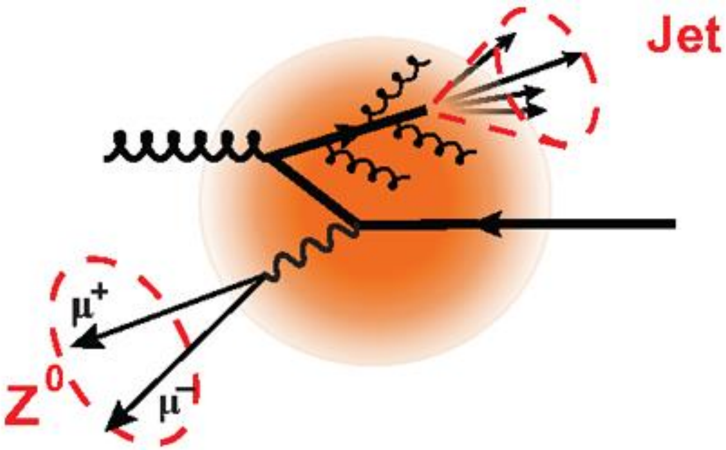
- Introduction
- Jet production within Sherpa
- Jet propagation within a Linear Boltzmann Transport (LBT) model
- Numerical results
- Summary

Introduction

- Z/W+jet: Golden channel to study jet quenching.

  V. Kartvelishvili, R. Kvatadze and R. Shanidze, Phys. Lett. B 356, 589 (1995)

  – High energy parton from hard scattering lose energy due to strong interactions.



  – Mean-free-path of Z/W boson is longer than the size of QGP.

  – Z/W boson will not participate in strong interactions directly.

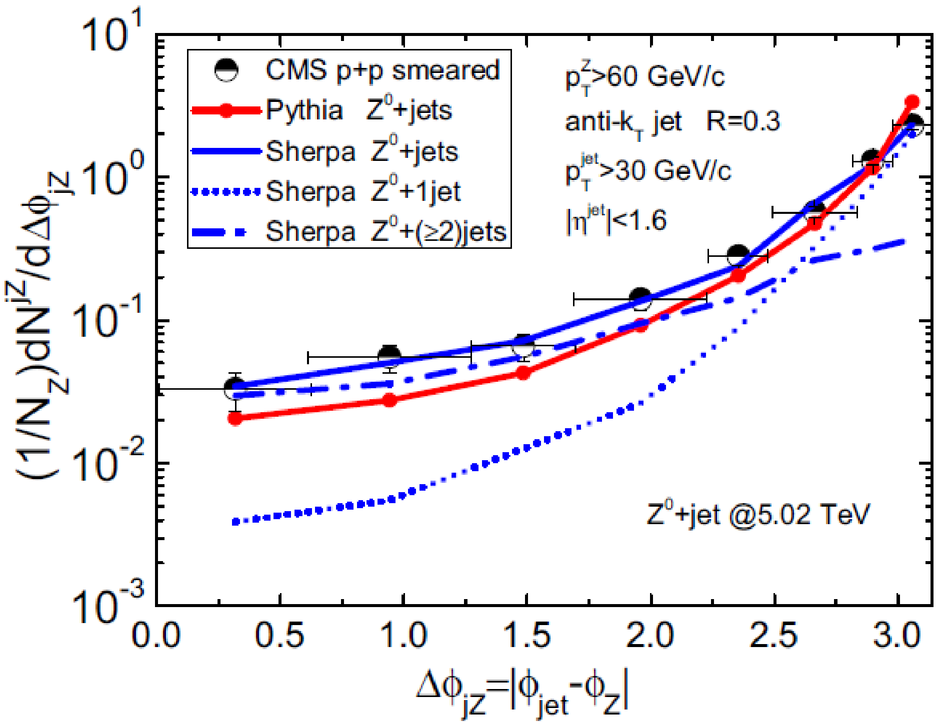
  – Large fraction of quark jets (> 70%).

  – No fragmentation contributions due to large mass.

- Important background to new physics, e.g. tops and Higgs.

Z+jet correlations in pp

- Z+jet azimuthal angle correlations
  Shan-Liang Zhang, T. Luo, X. N. Wang and B. W. Zhang, Phys.Rev. C98 (2018) 021901



  - NLO calculations suffer divergency at $\Delta\phi_{jZ} \approx \pi$.
  - LO+PS calculations underestimate in $\Delta\phi_{jZ} < 2$.
- We adopt NLO+PS and Eloss to study Z+jet correlations.

Sherpa

Sherpa: Simulate of High-Energy Reactions of PArticles in the SM.

Merging schemes are provided to calculate multijets.

T. Gleisberg, S. Hoeche, F. Krauss, M. Schonherr, S. Schumann, F. Siegert and J. Winter, JHEP **0902**, 007 (2009); S. Hoeche,F. Krauss,S. Schumann and F. S,JHEP 0905,053(2009);JHEP 1108,123(2011);JHEP 1304,027(2013).

– Low multiplicities: NLO matched to the parton shower.

– High multiplicities: LO merged on the parton shower.

Matching scheme can be simply formulated as:

$$\langle O\rangle^{(NloPs)} = \int d\Phi_B \left[B + \tilde{V} + I^S\right](\Phi_B)\widetilde{PS}_B(\mu_Q^2, O) + \int d\Phi_R \left[R - D^S\right](\Phi_R)\widetilde{PS}_R(t_R, O)$$

- B, $\tilde{V}$ and R is born, virtual and real terms respectively.
- D ($I^S = \int d\Phi_1 D^{(S)}$) is the (Integrated) subtraction term.
- $\widetilde{PS}$: the parton shower branch.

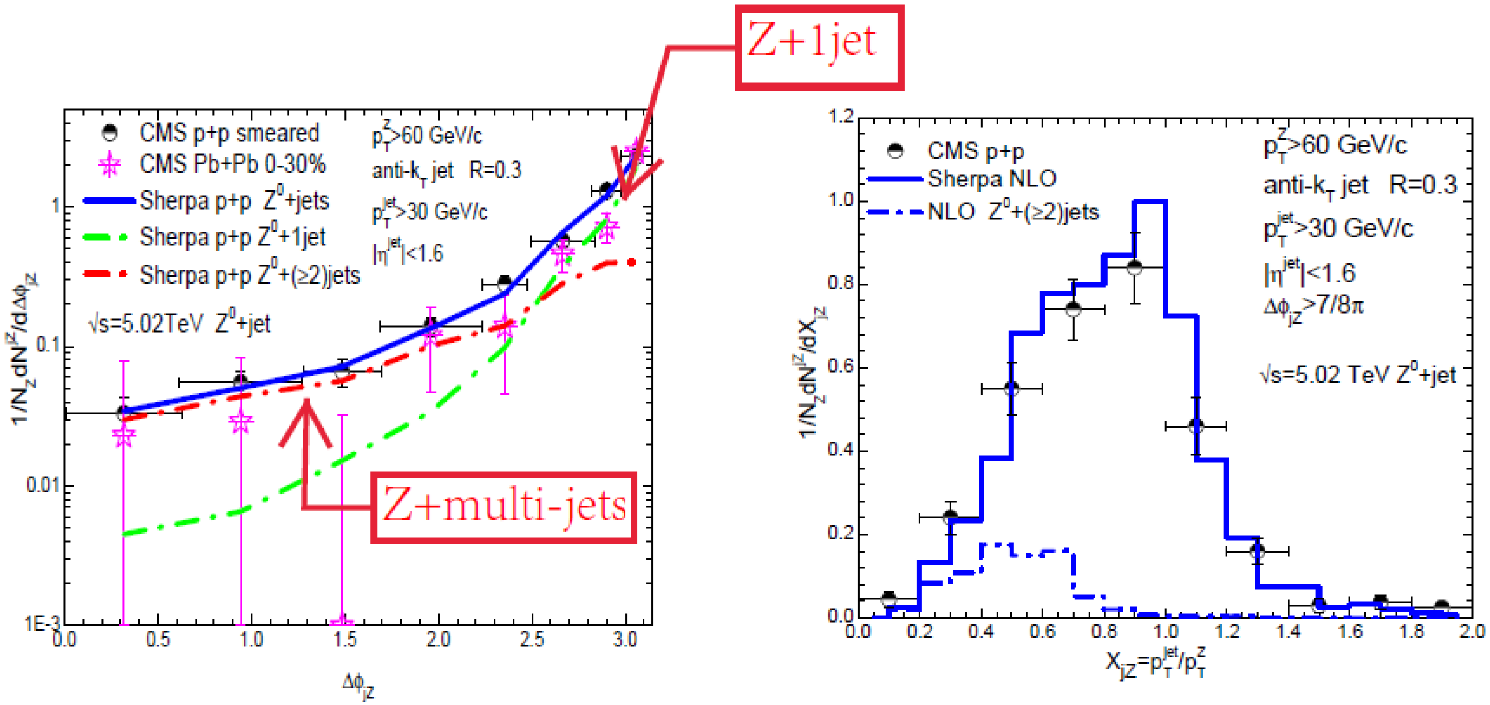
Sherpa: Gauge boson(γ, Z, W)+jets, b(c) jets, tops, Higgs...

Z+jets in pp collisions with Sherpa

- Z+jet correlations in p+p collisions.

  Loop ME: OpenLoops. F. Cascioli, P. Maierhofer and S. Pozzorini, Phys. Rev. Lett. 108, 111601

  PDF: CETQ14nlo.

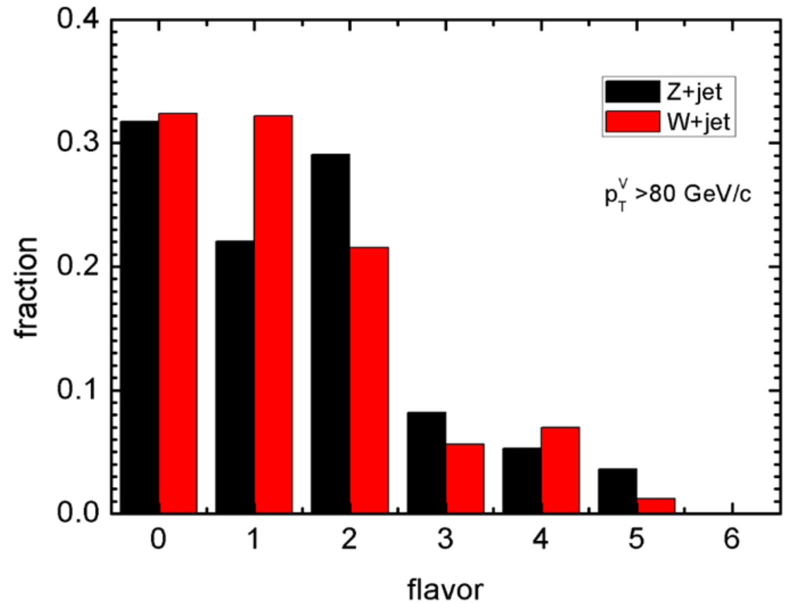


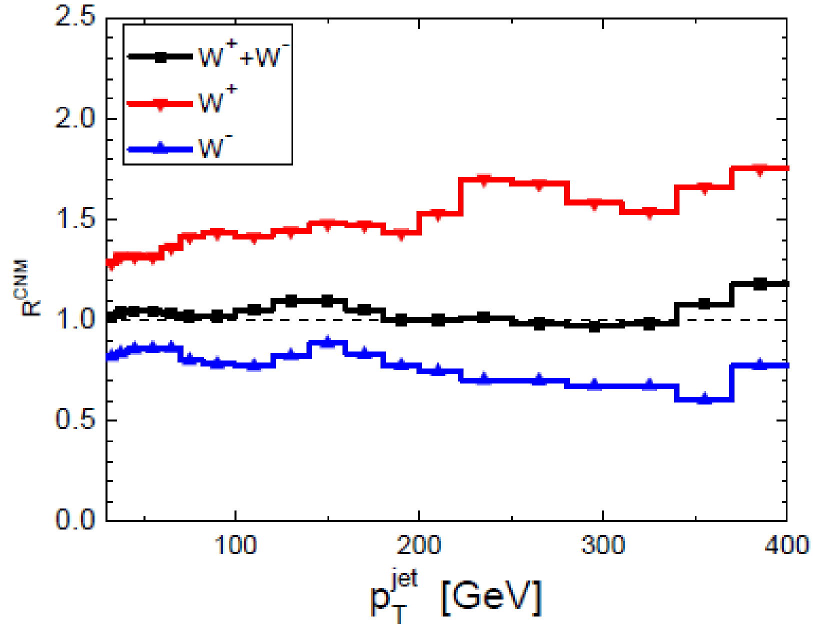
- NLO matched PS calculations show excellent agreement with experimental data in p+p collisions.

Shan-Liang Zhang, T Luo, X Wang, BWZ, PRC 98 (2018) 021901(R)

Production mechanism of W+jets

- Leading parton flavor fraction and CNM effect.

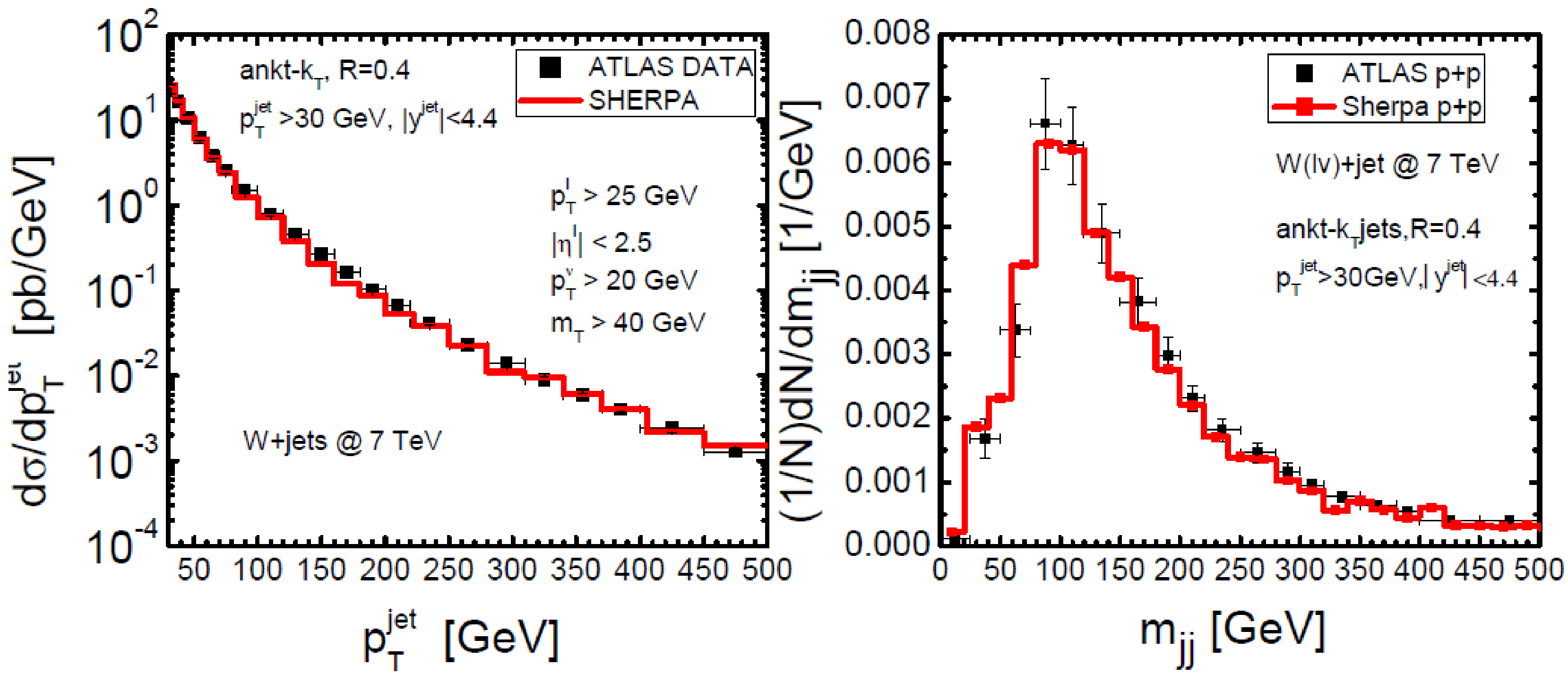




W carry charge, and change the flavor of the parton .
CNM has negligible effect on W+jets spectrums.
- W^+ is enhanced;
- W^- is suppressed due to CNM.

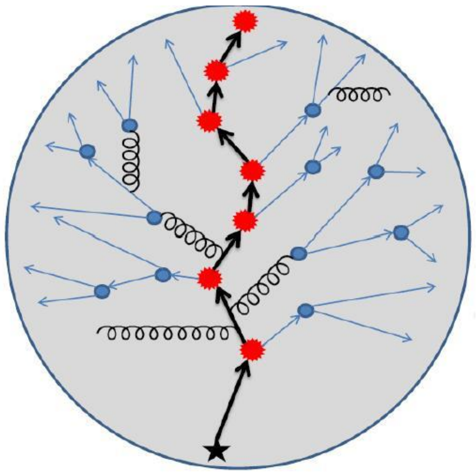
Production mechanism of W+jets

- Comparison with experimental data.



Well agreements with experimental data.

Linear Boltzmann Transport (LBT) model



Linear Boltzmann jet Transport

- Elastic collision + Induced gluon radiation.
- Follow the propagation of recoiled parton.
- Back reaction of the Boltzmann transport.

H. Li, F. L, G. l. Ma, X. N. W and Y. Z, PhysRevLett.106.012301;
X. N. Wang and Y. Zhu, PhysRevLett.111.062301;
Y. He, T. Luo, X. N. Wang and Y. Zhu, PhysRevC.91.054908.

$$p_1 \cdot \partial f_a(p_1) = -\int \frac{d^3p_2}{(2\pi)^3 2E_2} \int \frac{d^3p_3}{(2\pi)^3 2E_3} \int \frac{d^3p_4}{(2\pi)^3 2E_4} \times \frac{1}{2} \sum_{b(c,d)} [f_a(p_1)f_b(p_2) - f_c(p_3)f_d(p_4)] \boxed{|M_{ab\to cd}|^2} \times S_2(s,t,u)(2\pi)^4 \delta^4(p_1+p_2-p_3-p_4)$$

Elastic Scattering--Complete set of 2-2 scattering processes.

Radiation--Higher Twist: Guo and Wang (2000), Zhang, Wang and Wang (2004),Majumder (2012).

$$\frac{dN_g}{dx dk_\perp^2 dt} = \frac{2\alpha_s C_A P(x) k_\perp^4}{\pi (k_\perp^2 + x^2 M^2)^4} \hat{q} \sin^2\left(\frac{t-t_i}{2\tau_f}\right)$$

LBT: light/heavy flavor hadron, single inclusive jets, γ-hadron/jet,Z-jet.

T. Luo, S. Cao, Y. He and X. N. Wang, arXiv:1803.06785;
W. Chen, S. Cao, T. Luo, L. G. Pang and X. N. Wang, Phys. Lett. B 777, 86 (2018);
S. Cao, T. Luo, G. Y. Qin and X. N. Wang, Phys. Rev. C 94, no. 1, 014909 (2016).
S Zhang, T Luo, X Wang, BWZ, PRC 98 (2018) 021901(R)

Framework

Jet production(Sherpa)

Jets location are decided by probability of binary collisions

Jet propagation (LBT+(3+1)D hydro)

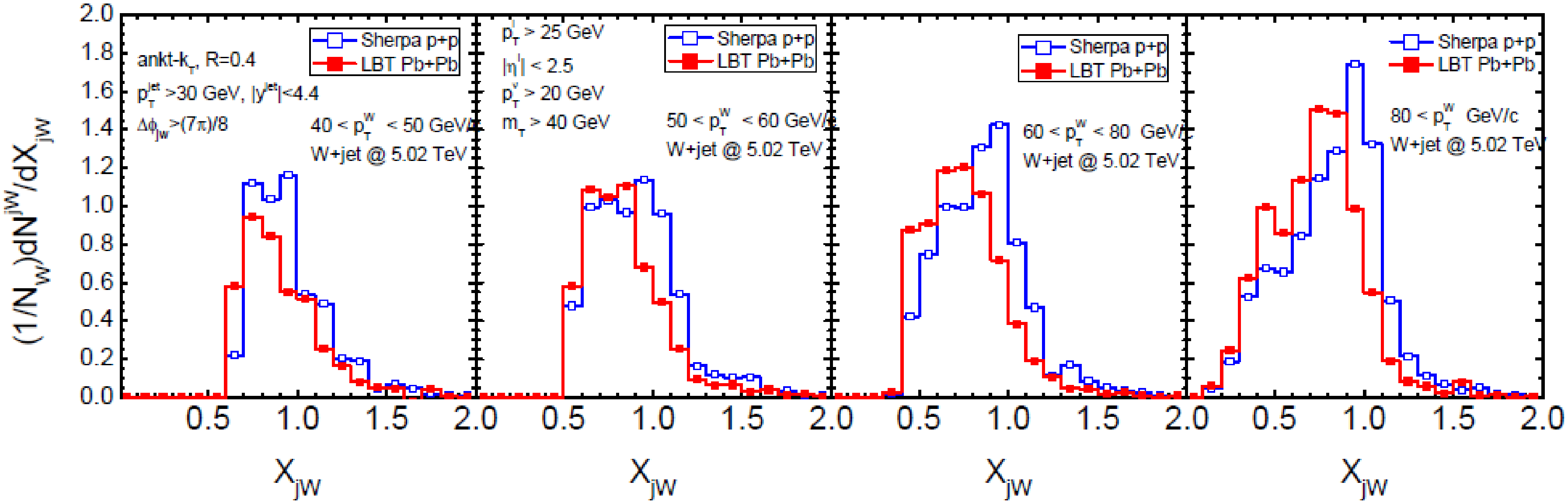
O. Kodolova, I. Vardanyan, A. Nikitenko and A.Oulianov, Eur. Phys. J. C 50, 117123 (2007).

Jet reconstruction(Fastjet)

$R_{jZ}, \phi_{jZ}, x_{jZ}, <x_{jZ}>, I_{AA}...$

W+jet asymmetry

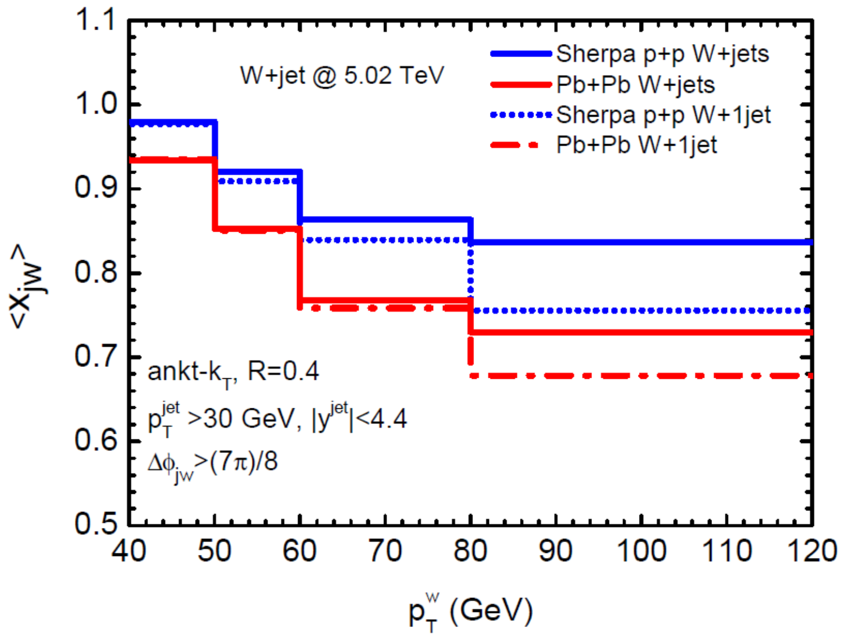
- Shift of momentum imbalance $x_{jW} = p_T^{jet}/p_T^W$

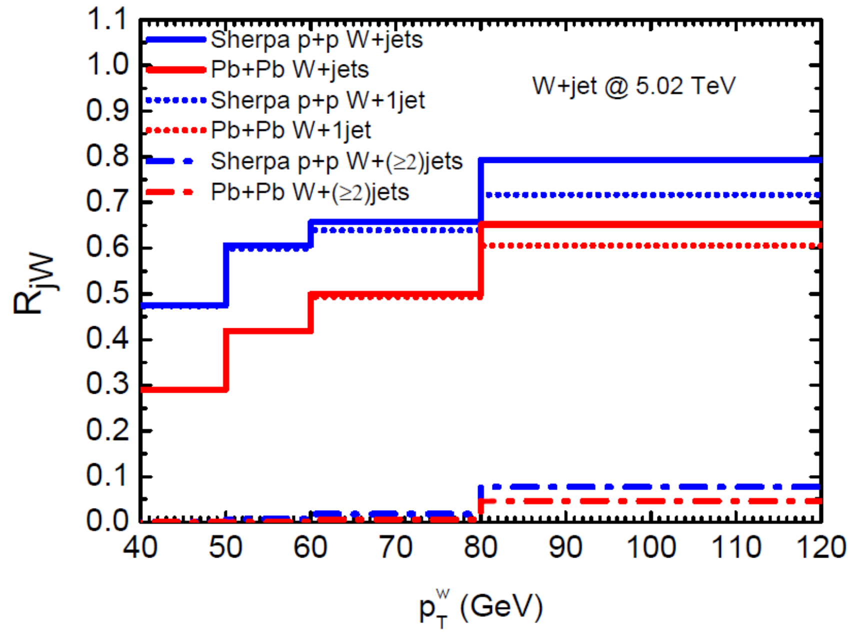


x_{jw} is shifted to smaller value.
- Transverse momentum of W boson is unattenuated.
- Jet transverse momentum is modified by medium.

Mean value of momentum imbalance

- Reduction of mean value of momentum imbalance and jet partners.



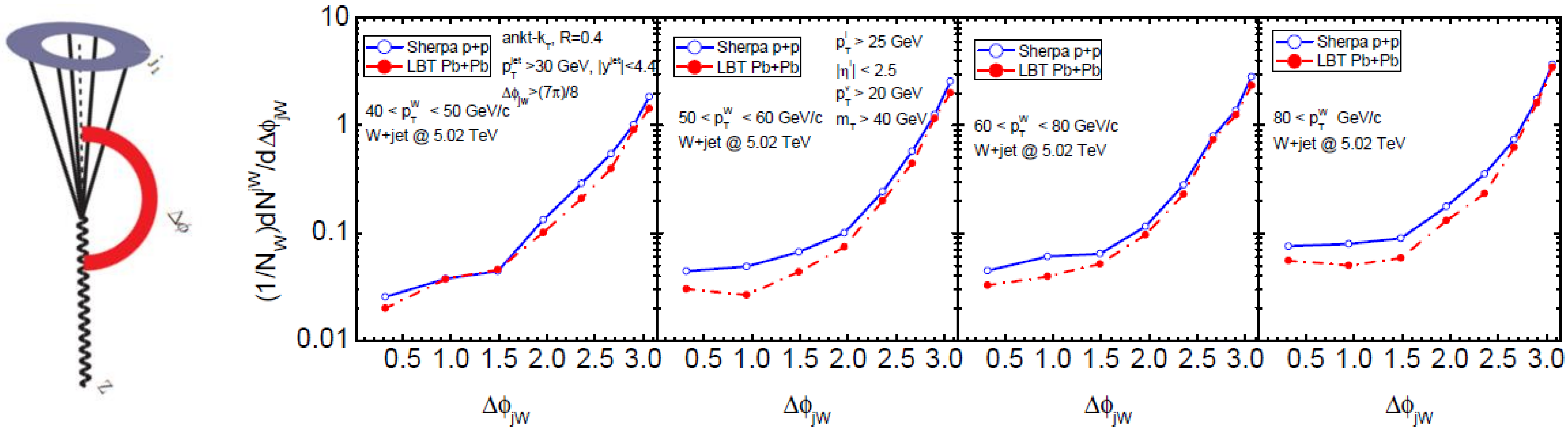


p_T^W (GeV)	40-50	50-60	60-80	>80
$\Delta\langle x_{jW}\rangle$	0.04514	0.06784	0.09568	0.10666
$\Delta\langle x_{jW}\rangle/\langle x_j w\rangle$pp	4.6%	7.4%	11.1%	12.8%

W+jet azimuthal angle correlations

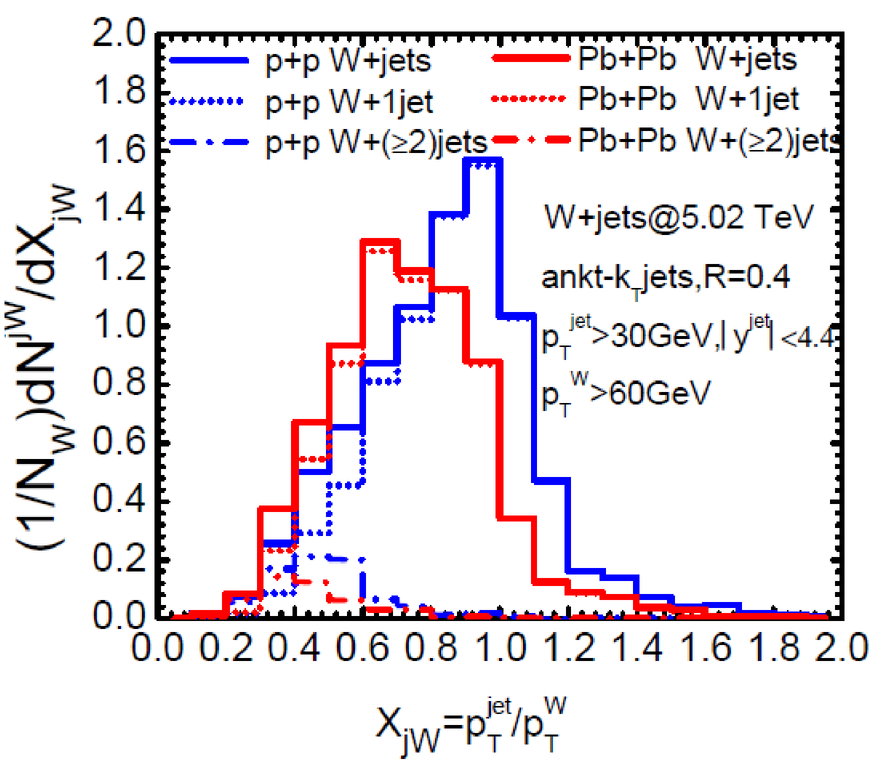
- The suppression of :

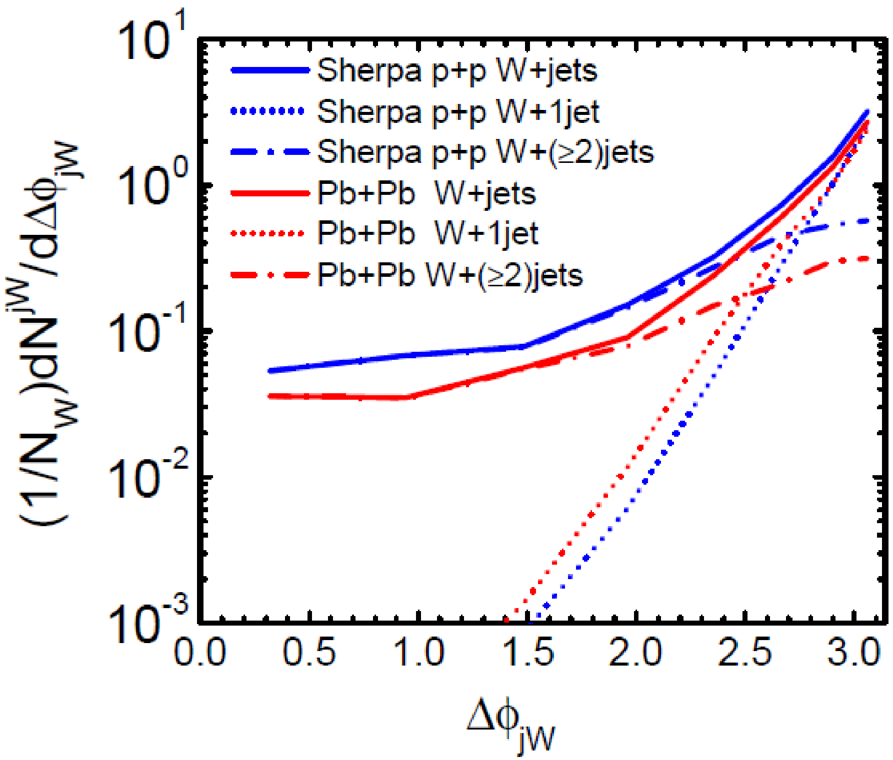
$$\Delta\phi_{jW} = |\phi_j - \phi_W|$$



$\Delta\phi_{jW}$ is moderately suppressed in Pb+Pb collisions, almost a constant.

The modification of W+jet correlations due to multi-jets





Multi-jets have almost 50% contributions in x_{jW} < 0.5 region.

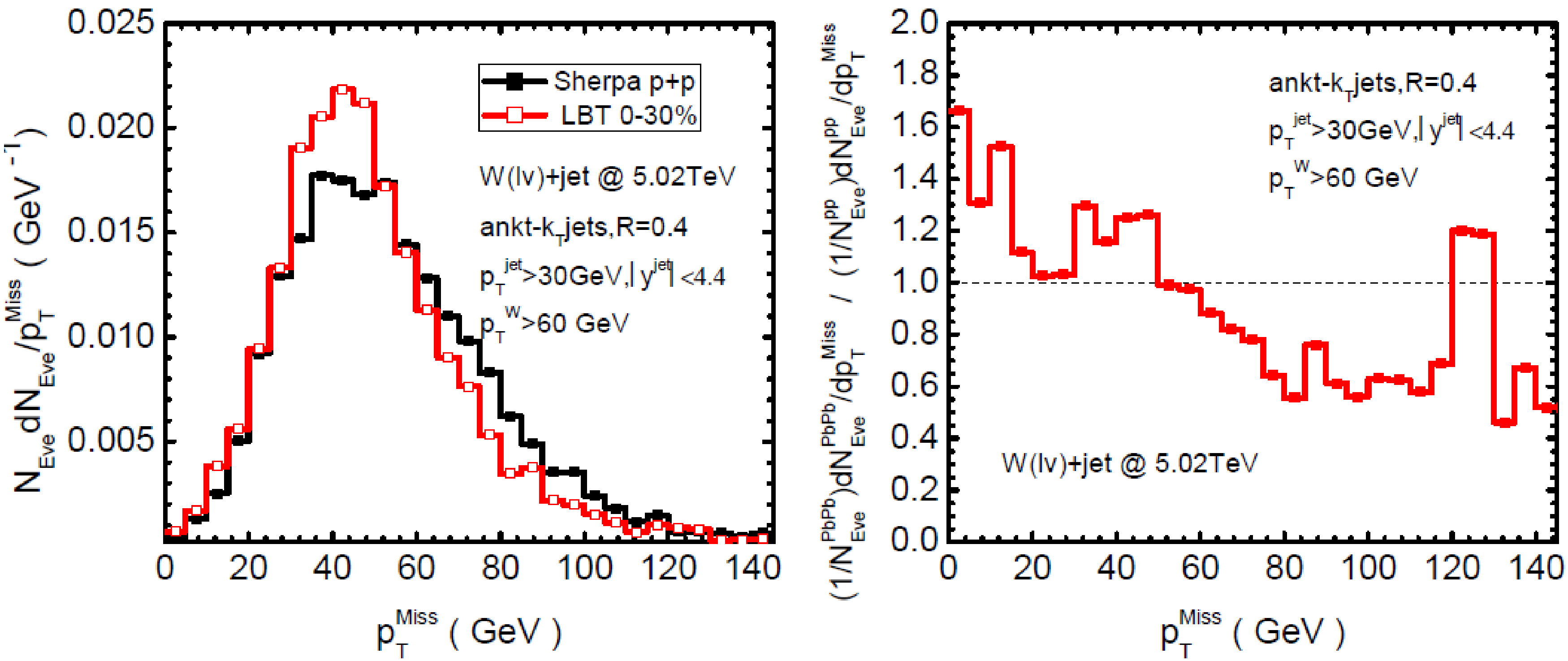
$\Delta\phi_{jW}$ is moderately suppressed in Pb+Pb collisions, almost a constant.

- The suppression of W+1 jet angle correlations is mild.
- W+multi-jets angle correlations is considerably suppressed.

Energy missing of W+jets

- The suppression of energy missing: $\vec{p}_T^{Miss} = -(\vec{p}_T^{\,l} + \sum \vec{p}_T^{\,jets})$

$$R_{AA}(p_T^{Miss}) = \frac{1}{\langle N_{coll} \rangle} \frac{dN^{AA}/dp_T^{Miss}}{dN^{pp}/dp_T^{Miss}}$$

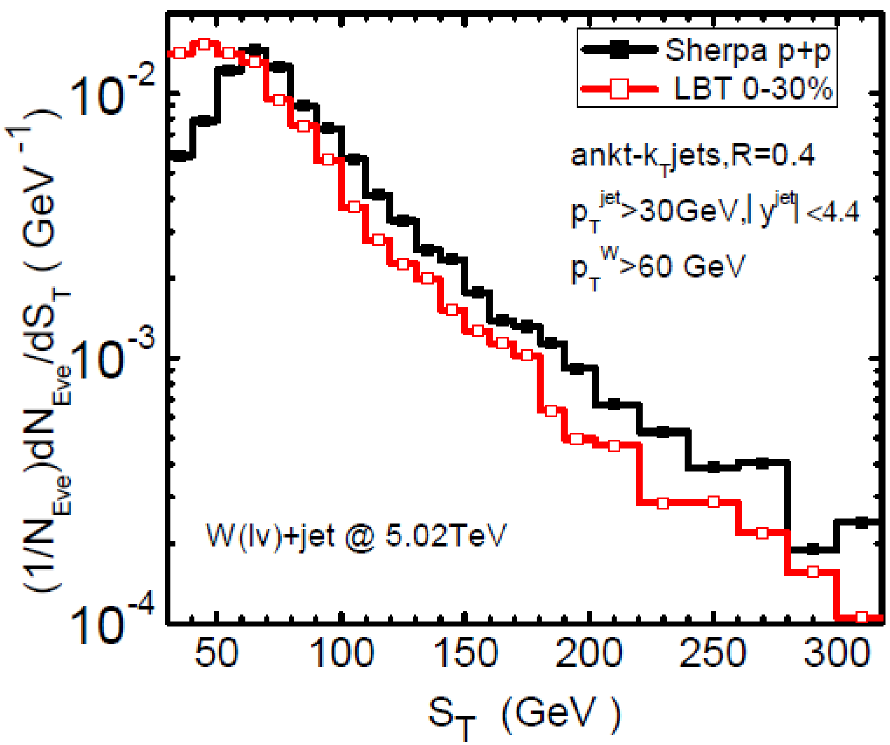


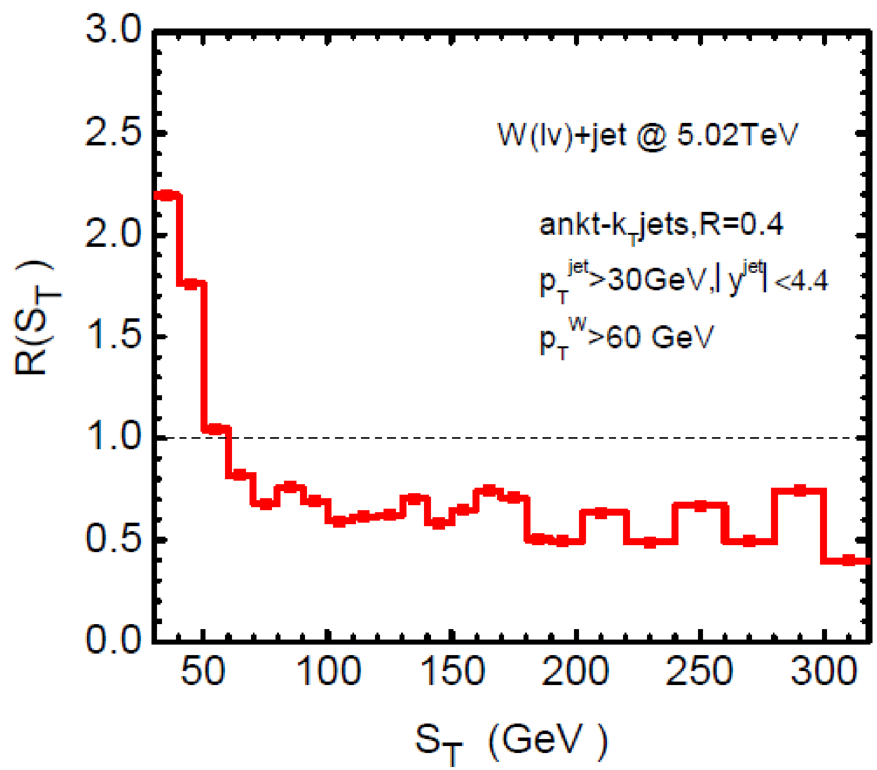
Jets lose energy and in the opposite direction of the neutrino or W boson.

W+jets transverse momentum modification

- The suppression of energy total transverse energy:

$$S_T = \sum p_T^{jets} \qquad R_{AA}(S_T) = \frac{1}{\langle N_{coll} \rangle} \frac{dN^{AA}/dS_T}{dN^{pp}/dS_T}$$





Summary

Z/W+jet correlation in Pb+Pb at the LHC is studied by combining NLO+PS in Sherpa for initial Z/W+jet production and LBT for jet propagation in the expanding QGP from 3+1D hydrodynamics.

- x_{jW} is shifted to smaller value and R_{jW} is smaller in Pb+Pb.
  Large fraction of jets lose energy and fall below 30 GeV threshold.
- $\Delta\phi_{jW}$ is moderately suppressed in Pb+Pb collisions.
  Suppression of multijets lead to the modification of W+jet angle correlations.
- S_T and p_T^{Miss} are shifted to smaller value .
  Jets lose energy at the opposite direction of W boson.

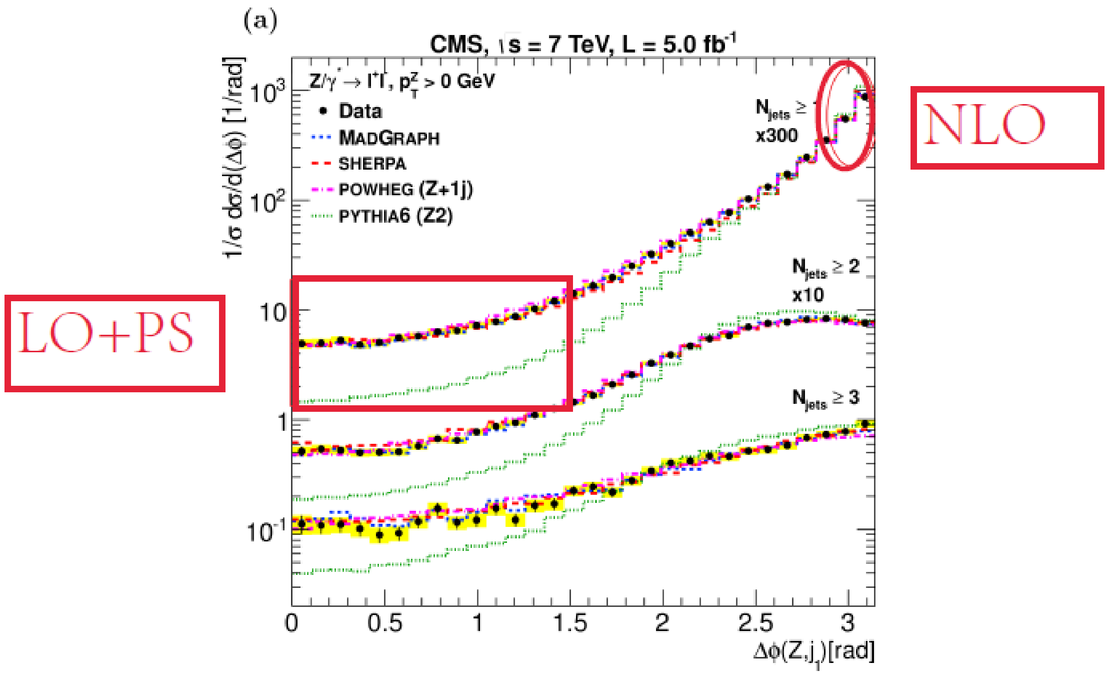
Thanks for your attention!

Backup

Z+jet correlations in pp

- Z+jet azimuthal angle correlations

  S. Chatrchyan et al. [CMS Collaboration], Phys. Lett. B **722**, 238 (2013)

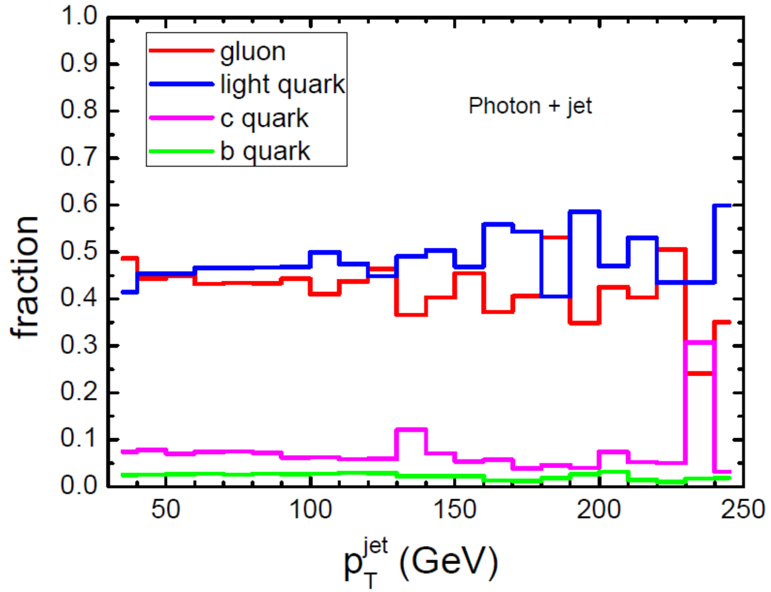


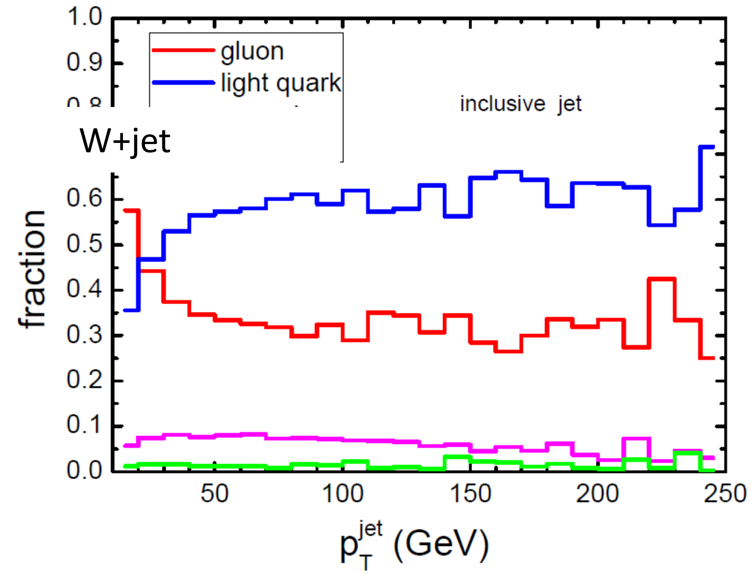
  – NLO calculations suffer divergency at $\Delta\phi_{\mathrm{jZ}} \approx \pi$.

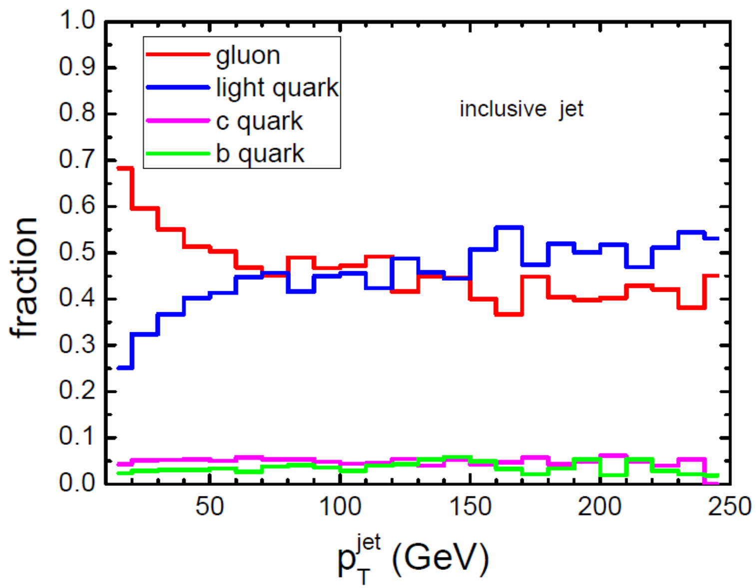
  – LO+PS calculations underestimate at $\Delta\phi_{\mathrm{jZ}} < 2$.

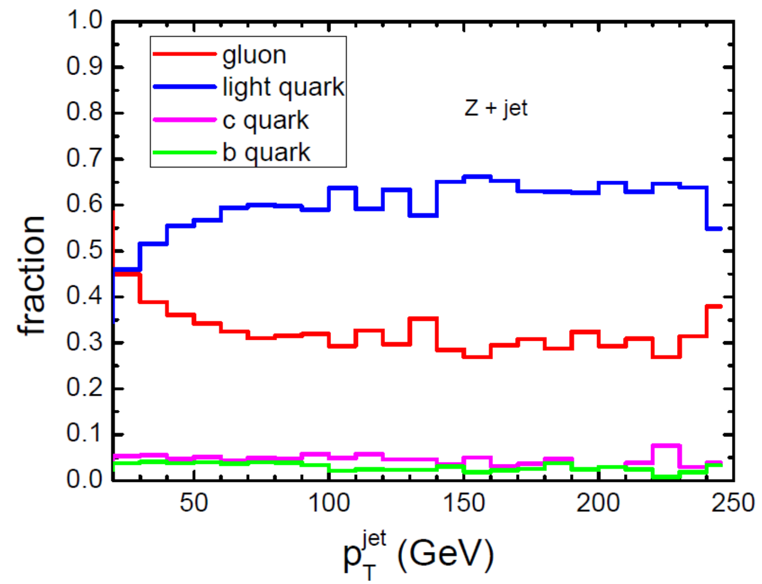
- We adopt NLO+PS and Eloss to study Z+jet correlations.

Dependence of jet flavor on P_T^jet



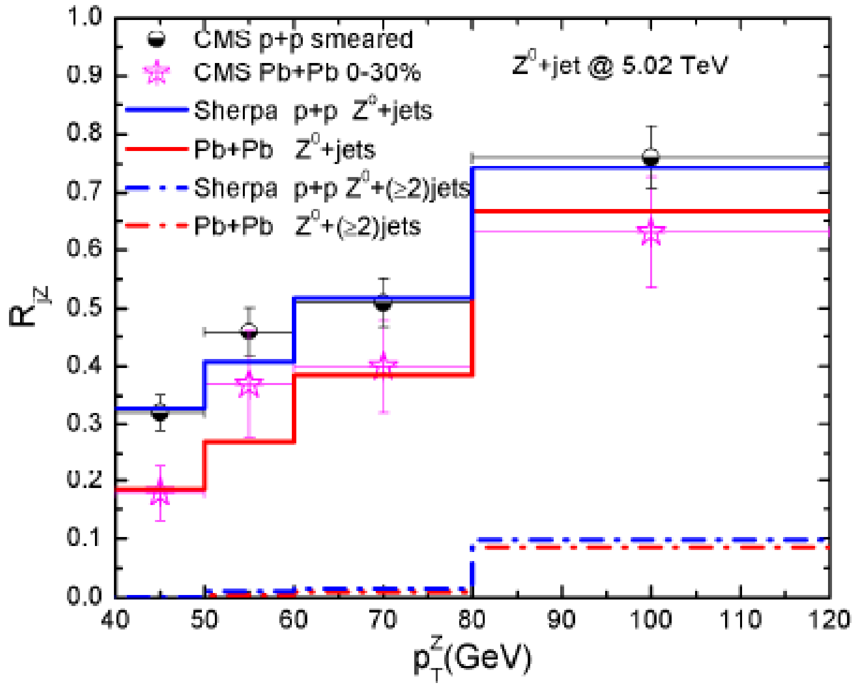


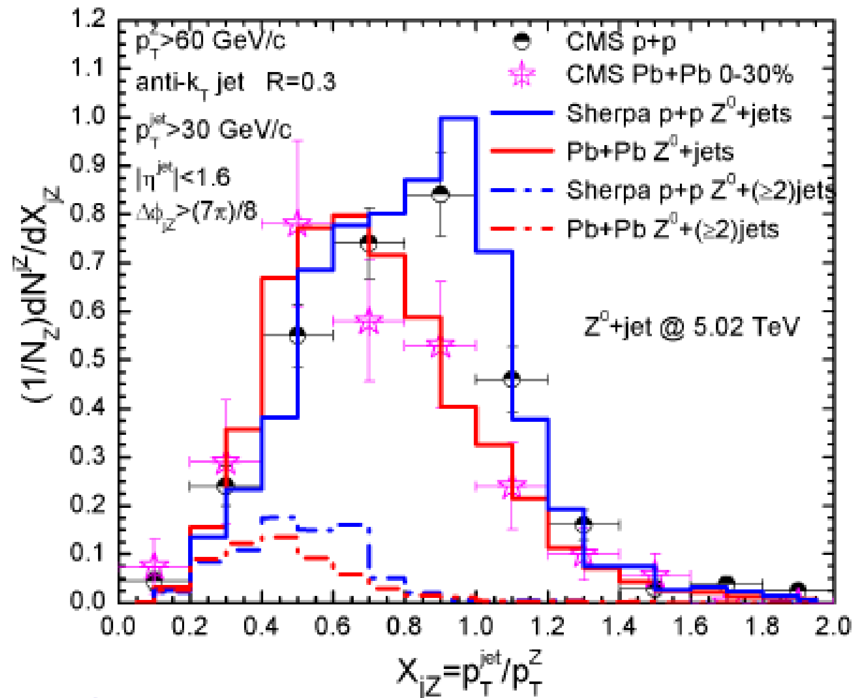




Z+jet correlations in heavy-ion collisions

- Fix the parameter α_s via the comparison with the Z+jet correlations.





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R_{jz} is overall suppressed .
Shift of momentum imbalance x_{jZ}
-- α_s= 0.20 that best describe experimental data in Pb+Pb collisions.

Z+jet asymmetry

- Shift of momentum asymmetry $x_{jZ} = p_T^{jet}/p_T^Z$ in different p_T^Z bins.