Recent ATLAS results relevant for PDFs at low and high x, saturation in both pp and HI collisions

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on behalf of the ATLAS Collaboration

Diffraction and Low-x

IEAP CTU in Prague

SLEZSKÁ UNIVERZITA V OPAVĚ

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Introduction:

PDF (Parton Distribution Function):

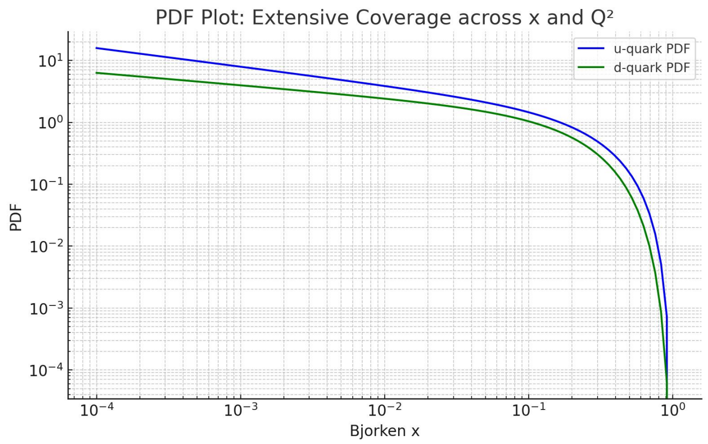
- Distribution of quarks and gluons (partons) inside a proton.
- Typically used for calculations in proton-proton collisions.

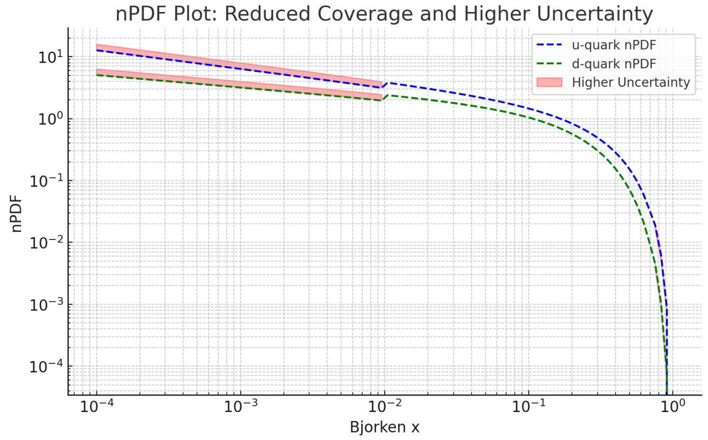
nPDF (nuclear Parton Distribution Function):

- Distribution of partons inside a nucleus (which contains multiple protons and neutrons).
- Accounts for modifications due to the presence of multiple nucleons, such as shadowing, EMC effect, and anti-shadowing.

x/Q^2 Coverage:

- **PDFs:** Have extensive coverage over a wide range of x (Bjorken-x) and Q^2 (momentum transfer squared) values.
- **nPDFs:** The x/Q^2 coverage is less extensive, particularly in regions of very low and very high x, leading to uncertainties in certain calculations involving nuclei.





Observation of $t\bar{t}$ production in lepton+jets and dilepton channels in *p*+Pb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV with the ATLAS detector

Measurement of the centrality dependence of the dijet yield in *p*+Pb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV with the ATLAS detector

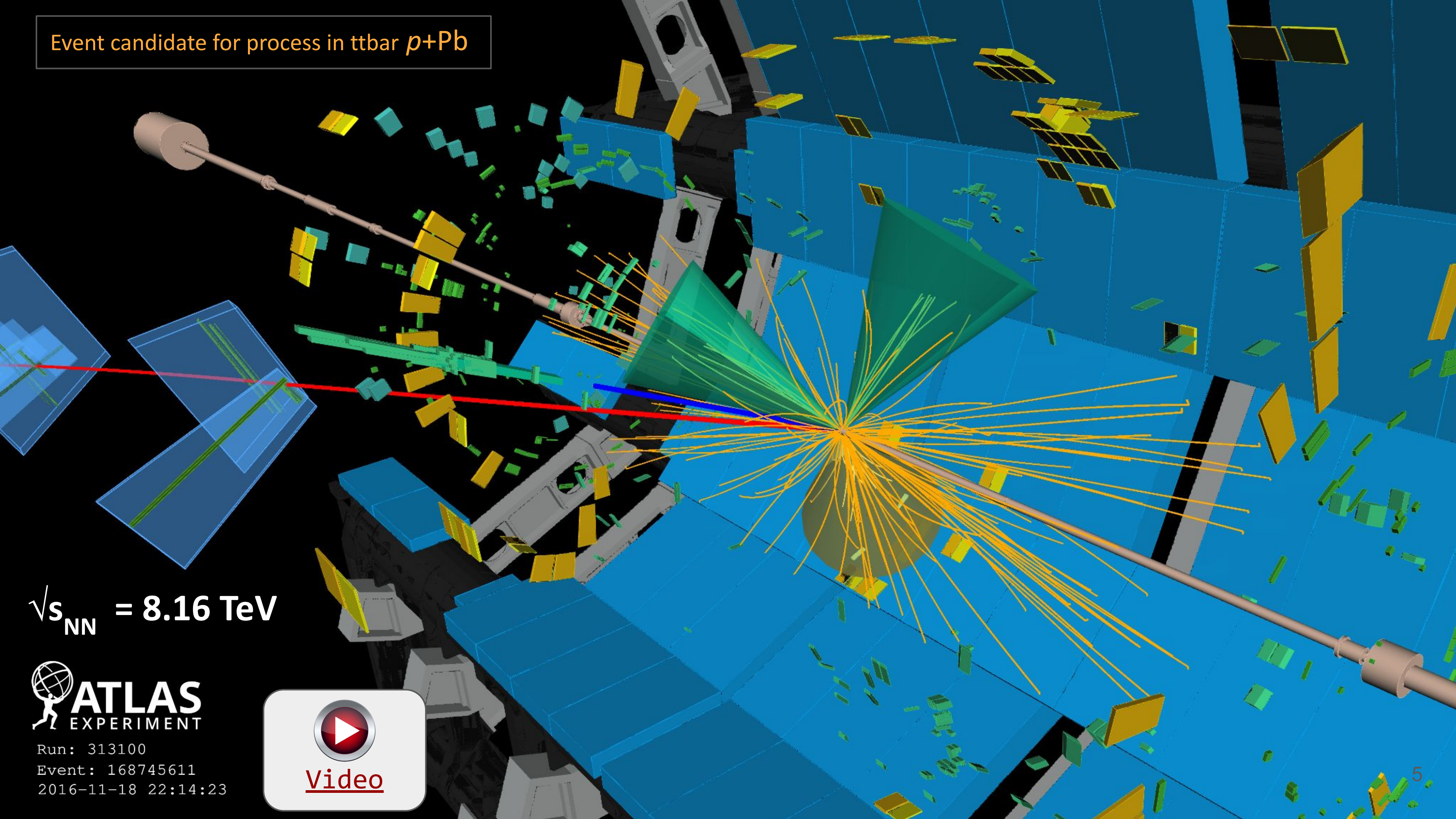
Photo-nuclear jet production in ultra-peripheral Pb+Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV with the ATLAS detector

Observation of $t\bar{t}$ production in lepton+jets and dilepton channels in *p*+Pb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV with the ATLAS detector

arXiv:2405.05078v1

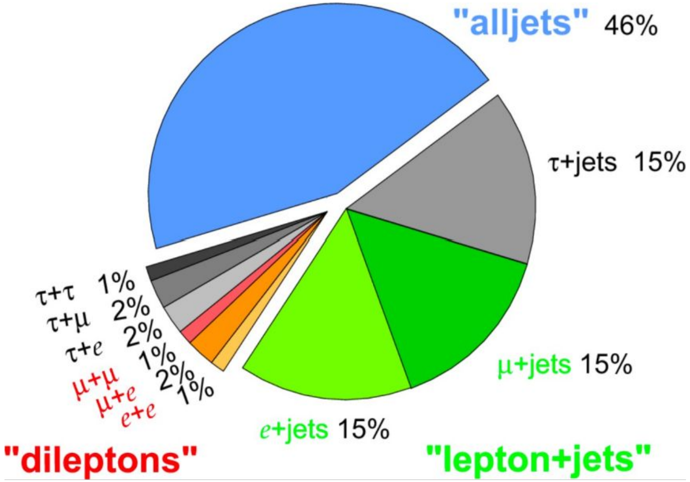
Submitted to JHEP

Event candidate for process in ttbar *p*+Pb

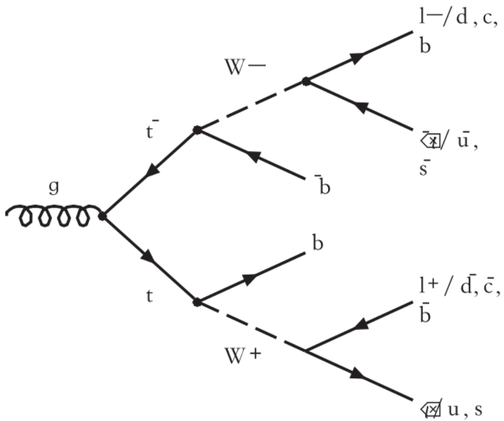


Motivation:

- In ATLAS observation of $t\bar{t}$ in *p*+Pb data individually in lepton+jets and dilepton channels - **this talk**
  - The first measurement using the **dilepton** channel in *p*+Pb collisions.
  - *p*+Pb data from 2016 with Integrated luminosity L = 165 nb^{-1}
  - All the plots can be found [TOPQ-2023-32]



- Top quarks provide novel probes of nuclear modifications to parton distribution functions (nPDF) in a poorly constrained kinematic region.
- Bjorken-x ~ 5 · 10^{-3} – 0.05 and Q^2 ~ m_t^2 ~ 3 · 10^4 GeV^2 (m_t stands for the top-quark mass)



$$\textbf{lepton + jets}: \quad t\bar{t} \rightarrow WbW\bar{b} \rightarrow \ell\nu_\ell bq\bar{q}'\bar{b}$$

$$\textbf{dilepton}: \quad t\bar{t} \rightarrow WbW\bar{b} \rightarrow \ell\nu_\ell b\ell\bar{\nu}_\ell\bar{b}$$

Event Selection:

	Channel	Selection
lepton+jets	e+jets	1 isolated electron with **p_T > 18 GeV** 0 isolated muons At least 4 jets with **p_T > 20 GeV**
	μ+jets	1 isolated muon with **p_T > 18 GeV** 0 isolated electrons At least 4 jets with **p_T > 20 GeV**
dilepton	ee	2 isolated electrons with **p_T > 18 GeV** 0 isolated muons Opposite Sign, **m_{ll} > 45 GeV** Veto m_{ll} in 80 – 100 GeV, At least 2 jets with **p_T > 20 GeV**
	$\mu\mu$	2 isolated muons with **p_T > 18 GeV** 0 isolated electrons Opposite Sign, **m_{ll} > 45 GeV** Veto m_{ll} in 80 – 100 GeV, At least 2 jets with **p_T > 20 GeV**
	eμ	1 isolated electron with **p_T > 18 GeV** 1 isolated muon with **p_T > 18 GeV** Opposite Sign, **m_{ll} > 15 GeV** At least 2 jets with **p_T > 20 GeV**

Background composition:

- Single top
- *W +jets*
  - W+b
  - W+c
  - W+light
- *Z +jets*
  - Z+b
  - Z+c
  - Z+light
- Diboson
- Fake lepton

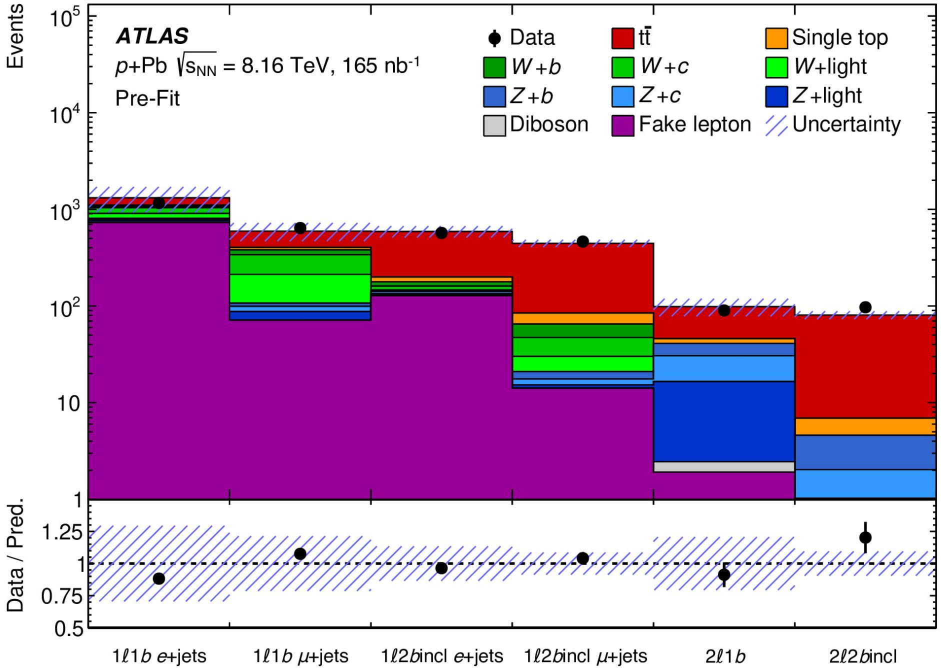
Regions:
=0b control
=1b and ≥2b signal

Background & Fit Strategy:

- The main background contributions:
  - *W+jets (l+jets)*
  - *Z+jets (dilepton)*
  - *non-prompt and fake lepton background*

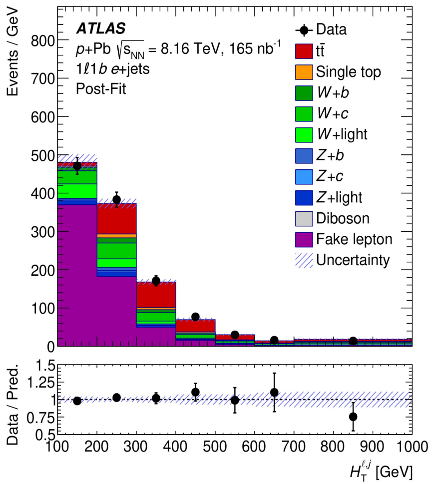
Simultaneous fit in 6 regions

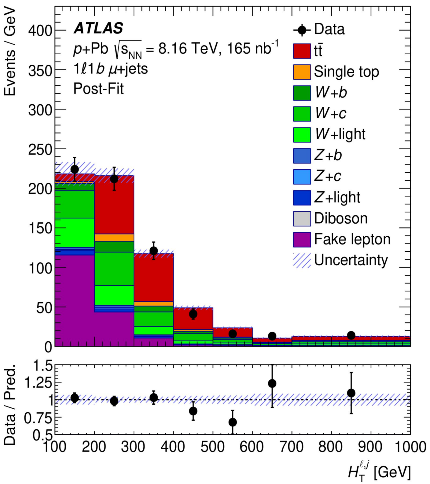
- ***4j1b1ℓ*** **(l+jets, 1b, ejets),**
- ***4j1b1ℓ*** **(l+jets, 1b, mujets),**
- ***4j2bincl1ℓ*** **(l+jets, >=2b, ejets),**
- ***j2bincl1ℓ*** **(l+jets, >=2b, mujets),**
- ***2j1b2ℓ*** **(dilepton, 1b),**
- ***2j2bincl2ℓ*** **(dilepton, >=2b).**

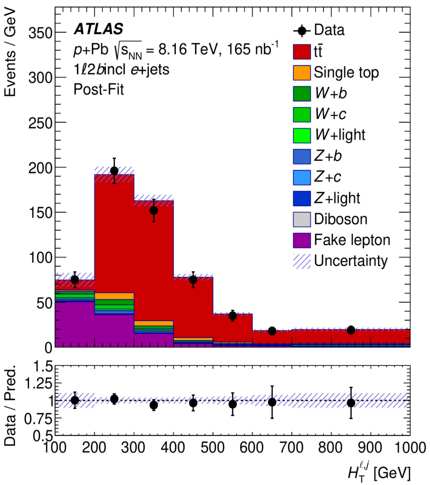


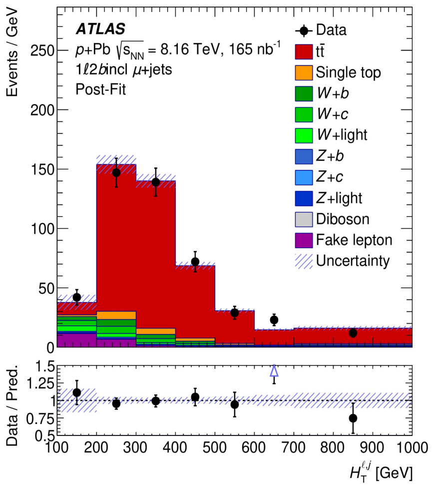
- The most signal events observed in the **ℓ+jets 2 b-jet** regions.
- The best signal-to-background ratio found in the **dilepton 2 b-jet** region.

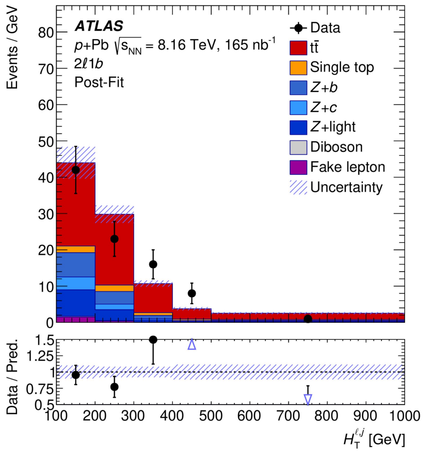
Fit results in signal regions:

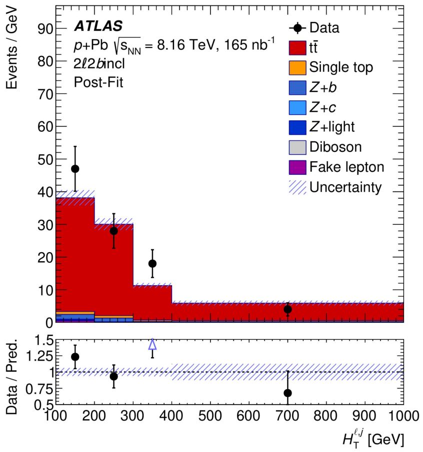








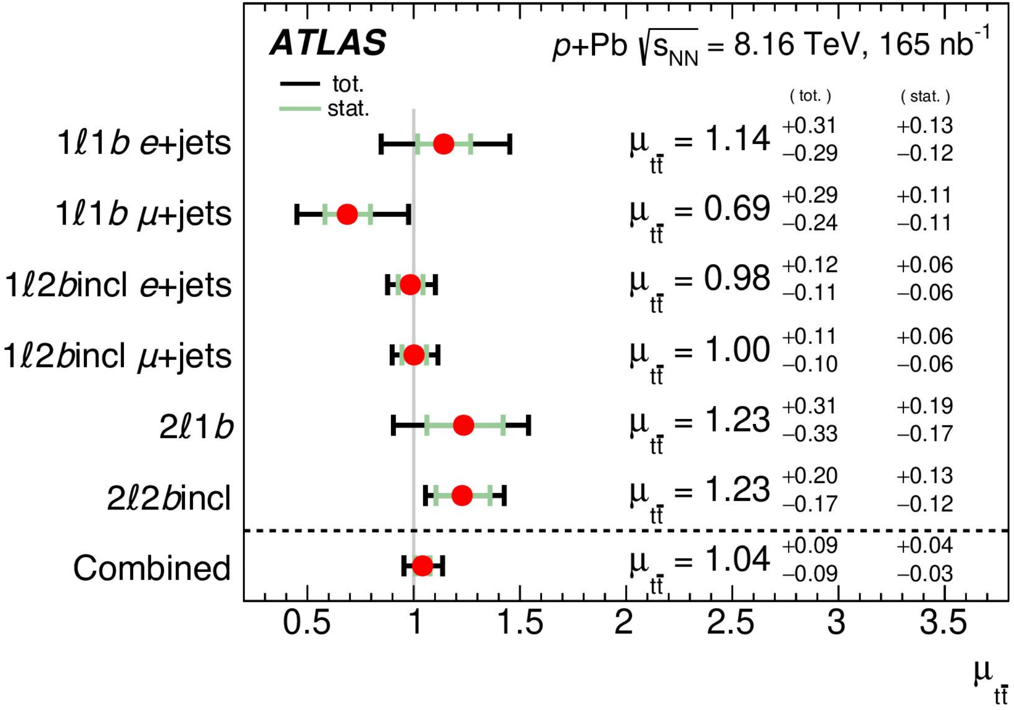




Fit signal strength μ on the single $H_T^{\ell,j}$ variable

$H_T^{\ell,j}$ - The scalar sum of the transverse momenta of the leptons and HI jets.

Signal strength:



- Best-fit value for the parameter we ultimately want to extract,

μ_{Total} = **1.04 +0.094 -0.088**

- ATLAS total uncertainty: ±9%
  (CMS total uncertainty: 18%)

- Relative statistical uncertainty: **~3.5%**

Systematics and significance:

Source	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ unc. up [%]	unc. down [%]
Jet energy scale	+4.6	-4.1
$t\bar{t}$ generator	+4.5	-4.0
Fake-lepton background	+3.1	-2.8
Background	+3.1	-2.6
Luminosity	+2.8	-2.5
Muon uncertainties	+2.3	-2.0
W+jets	+2.2	-2.0
b-tagging	+2.1	-1.9
Electron uncertainties	+1.8	-1.5
MC statistical uncertainties	+1.1	-1.0
Jet energy resolution	+0.4	-0.4
$t\bar{t}$ PDF	+0.1	-0.1
Systematic uncertainty	+8.3	-7.6

Observed significances:

- **l+jets** observed significance : ~ 14σ
- **Dilepton** observed significance : ~ 8σ
- **Combined** observed significance: ~ 16σ

- Observation of ttbar production in *p*+Pb in **combined** and also in **individual** l+jets and dilepton channels

First observation in dilepton channel with *p*+Pb collisions

Cross-Section & R_{pA} Measurement:

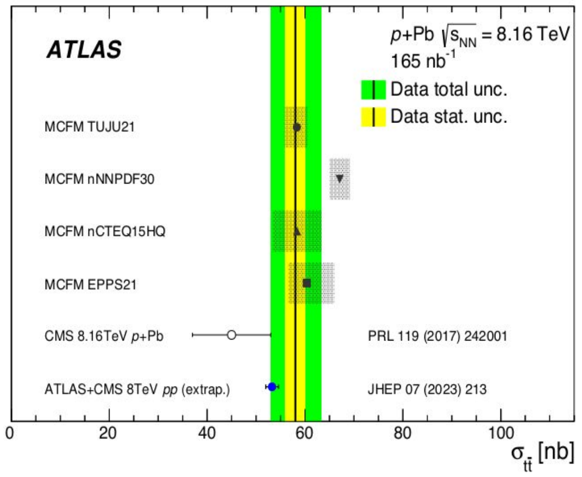
- The measured inclusive $t\bar{t}$ **cross section** for the p+Pb collisions is:

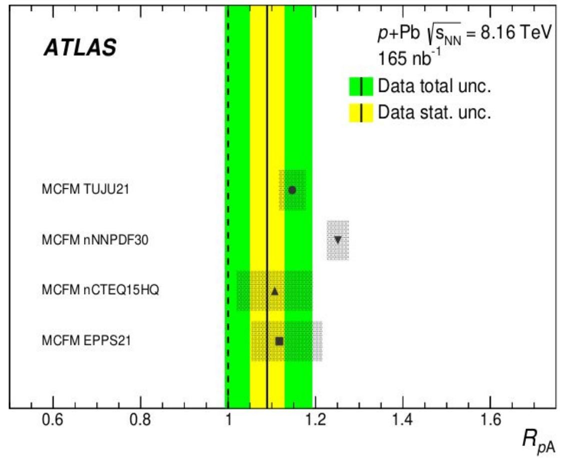
$$\sigma_{t\bar{t}} = \mu_{t\bar{t}} \cdot A_{\text{Pb}} \cdot \sigma^{\text{th}}_{t\bar{t}} = 58.1 \pm 2.0\,(\text{stat.})\,^{+4.8}_{-4.4}\,(\text{syst.})\text{ nb}$$

- **Nuclear modification factor**, measured for the first time at the LHC, is defined as:

$$R_{pPb} = \sigma_{pPb} / (A_{Pb} \cdot \sigma_{pp}) = 1.090 \pm 0.039\,(\text{stat.})\,^{+0.094}_{-0.091}\,(\text{syst.}).$$

- *The **most precise** $t\bar{t}$ cross-section measurement in HI collisions.*
- *The result is consistent with the cross section in pp collisions, extrapolated to $\sqrt{s}$ = 8.16 TeV and scaled by A_{Pb} = 208.*





Measurement of the centrality dependence of the dijet yield in *p*+Pb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV with the ATLAS detector

[Phys. Rev. Lett. 132, 102301]

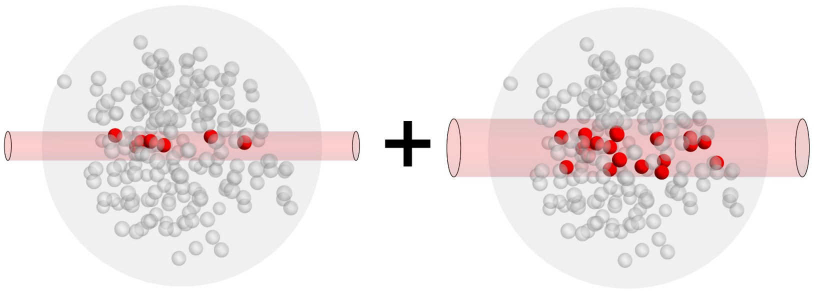
Motivation:

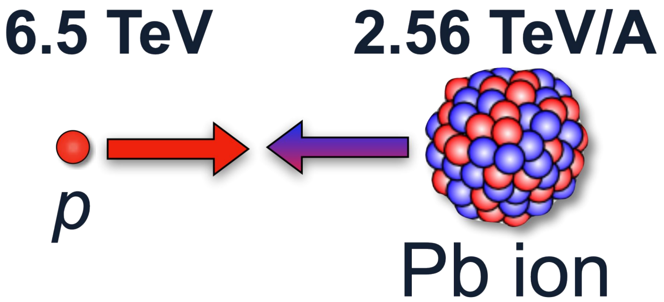
- Measure the centrality dependence of dijet yield in proton-lead (*p*+Pb) collisions at 8.16 TeV using the ATLAS detector.

- Insight into modifications of parton distribution functions (PDFs) within a nuclear environment.

- Investigate potential scaling trends with the Bjorken x variable for partons from the proton in *p*+Pb collisions.

- Contribute to the understanding of small proton configurations and the role of nuclear modification in high-energy collisions.





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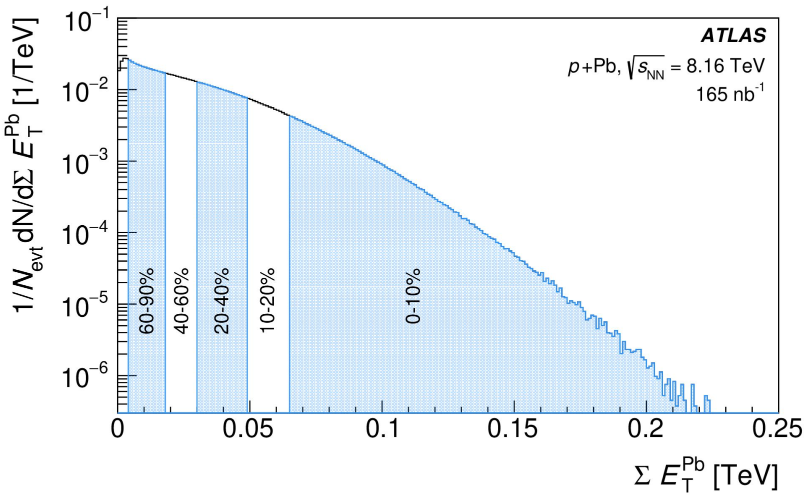
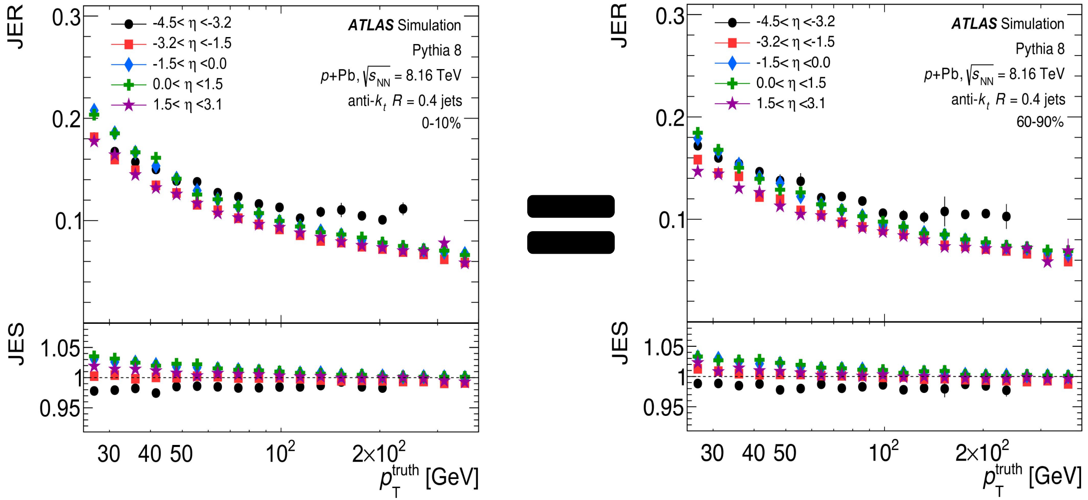
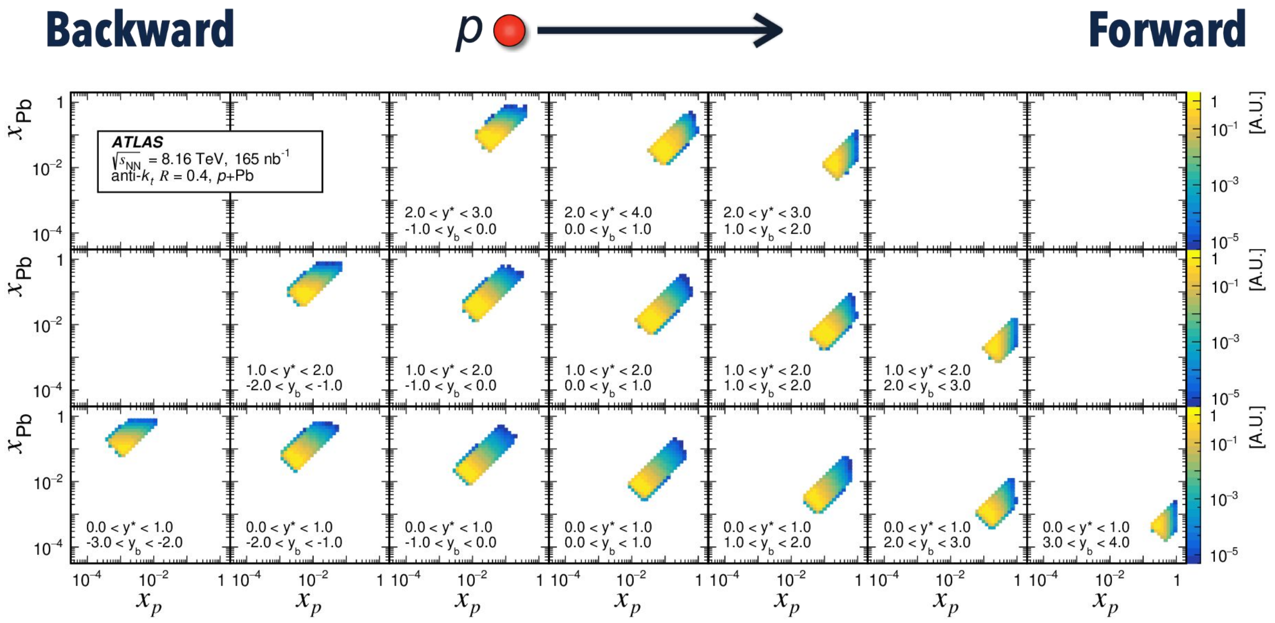
Jets in 2016 p+Pb collisions:

- Dijets in p+Pb at 8.16 TeV allow to provide input to color transparency effects in p+A collisions.
- Anti-k_t R = 0.4 calorimeter jets are considered in the analysis.
- Centrality is determined using ΣE_T in the Pb-going side of the Forward Calorimeter (FCal).
- Two centrality classes are studied: 0-10% - central events, 60-90% - peripheral events.
- Jet energy scale (JES) and jet energy resolution (JER) show no significant centrality dependence.





Kinematic domain:

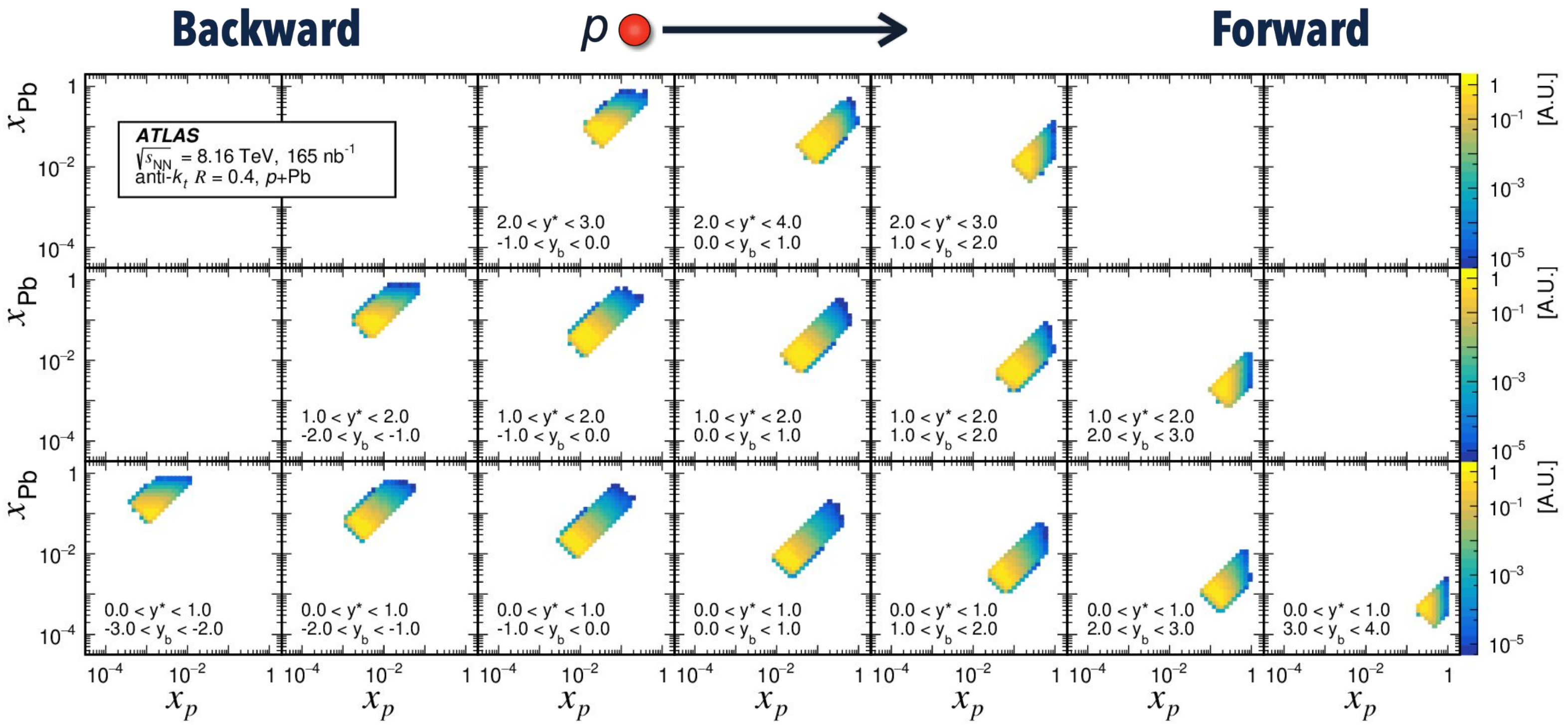


x_p
is the fraction of the proton's longitudinal momentum carried by the parton (quark or gluon) from the proton in the collision.

x_{Pb}
is the fraction of the lead nucleus' longitudinal momentum carried by the parton from the lead nucleus in the collision.

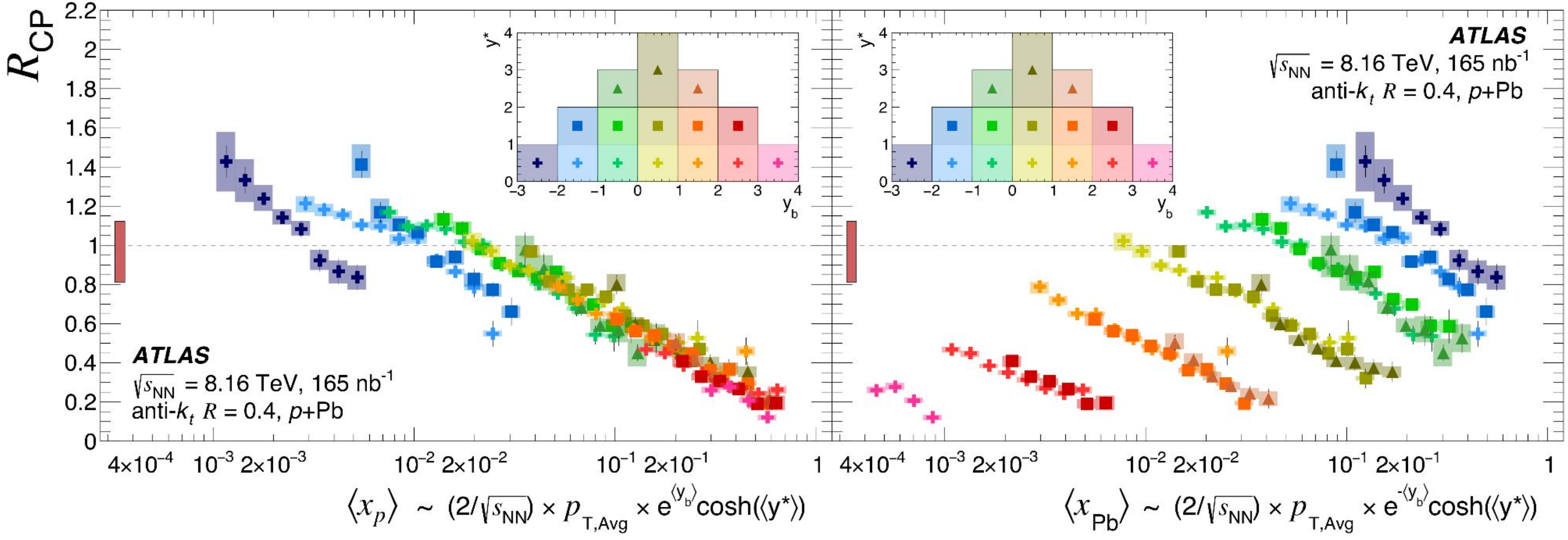
- It shows momentum fractions for p and Pb in different slices of y* and y_b. It can cover a large x_p-x_{Pb} space.
- The measurement probes the structure of both p and Pb over four orders of magnitude.
- The analysis is not directly carried out in parton system kinematic variables.

Kinematic domain:



- Work is underway to extract the cross section over the full phase space covered by this analysis.

Parton momentum fraction dependence:



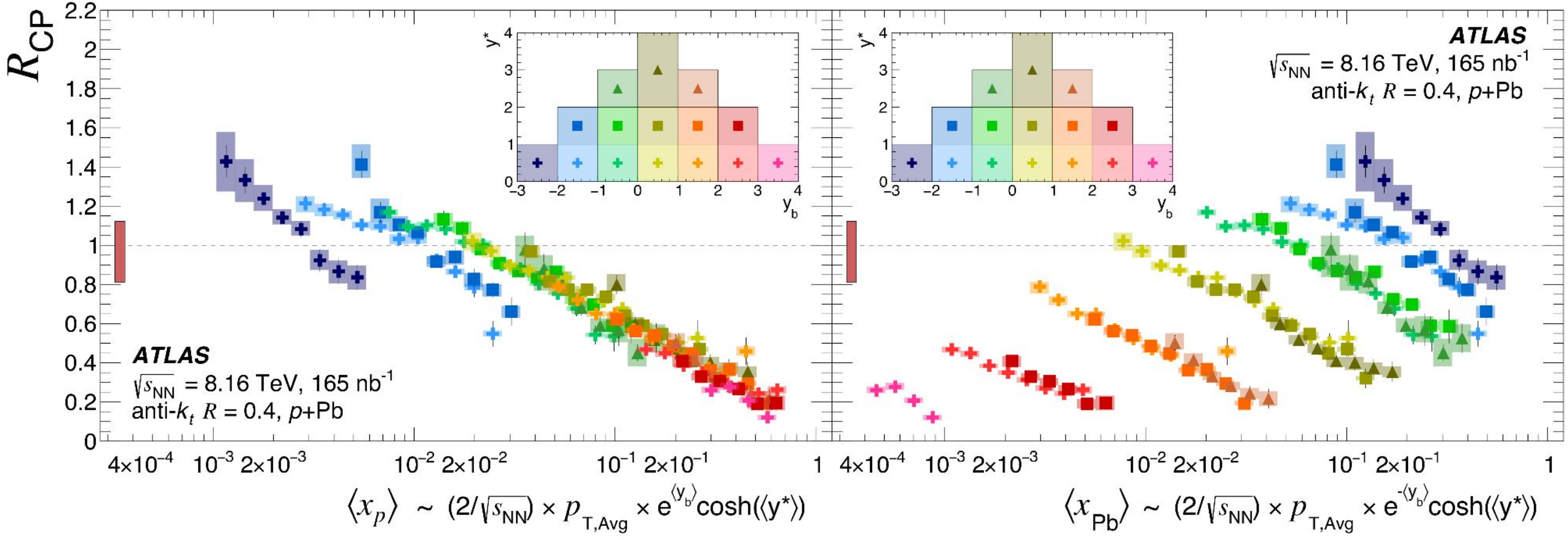
x_p dependence

- A log-linear scaling as a function of $\langle x_p \rangle$.
- The strongest suppression in the proton valence region.
- The log-linear scaling disappears in the low-x_p region.

x_{Pb} dependence

- Log-linear decreasing trend with increasing suppression for each slice in y_b.
- Strongest suppression observed at low-x_{Pb}.
- Values of $R_{CP} > 1$ in the $10^{-2} < x_{Pb} < 2 \cdot 10^{-1}$ range (~anti-shadowing).

Parton momentum fraction dependence:



- Left shows there is a strong suppression of jets produced in central vs peripheral collisions as a function of x_p, right shows a strong suppression for low x_{Pb}
- There is no common trend but rather separate trends for different slices in y_b.

Photo-nuclear jet production in ultra-peripheral Pb+Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV with the ATLAS detector

ATLAS-CONF-2022-021

Motivation:

- Ultra-Peripheral Collisions (UPCs) occur when the impact parameter is greater than the sum of the nuclear radii, leading to interactions via long-range electromagnetic forces.
- UPCs provide a unique way to probe the structure of nPDF through photon-hadron interactions.
- Goal to measure cross section of photo nuclear diet production
- The dijet pair allows us to measure differentially in the reconstructed kinematics of the hard scattering.
- The measurement is performed using a data set recorded in 2018 with an integrated luminosity of 1.72 nb^{-1} .

MORE DETAILS

Talk -Overview of the latest ATLAS and ATLAS-AFP photoproduction results

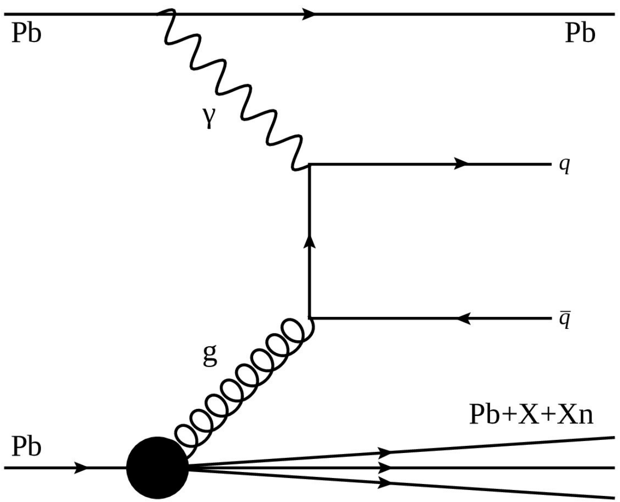
- *Andre Sopczak*

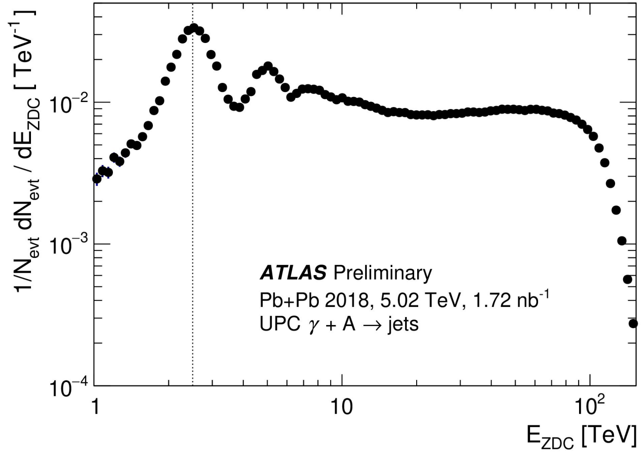
Talk -Overview of the latest ATLAS UPC+photonuclear results

- *Brian Andrew Cole*

Selecting Photo-nuclear Jet Events:

- Photo-nuclear jet events with cuts motivated by the particular event topology are selected
- **OnXn** requirement for nuclear breakup in exactly one ATLAS Zero-Degree Calorimeter (ZDC)



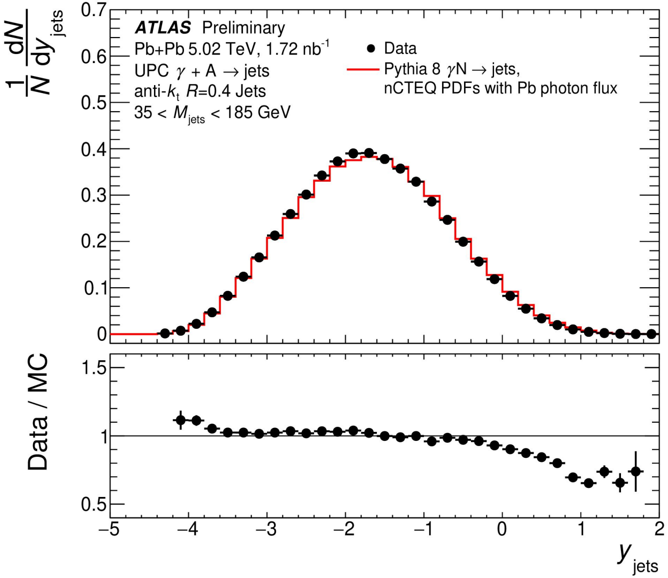


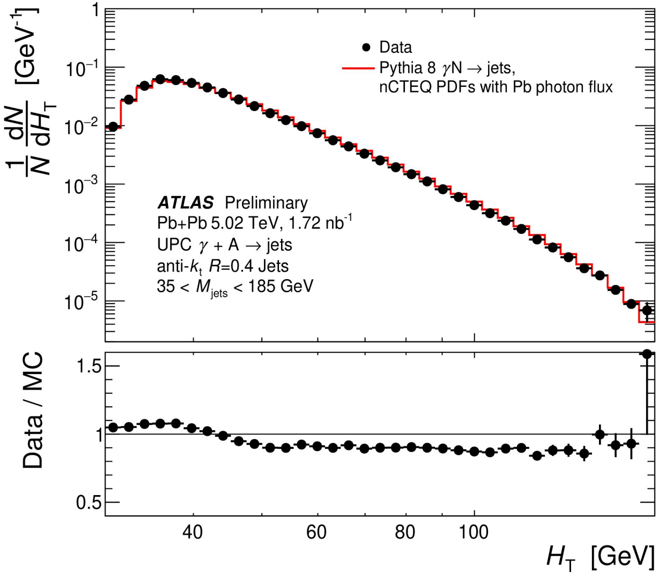
OnXn

- Indicates that there are no neutrons detected in one direction (denoted by "0n") and one or more neutrons detected in the opposite direction (denoted by "Xn").
- This condition helps identify photo-nuclear events, where a photon interacts with one nucleus, without causing the complete breakup of both nuclei.

Data-MC Comparisons:

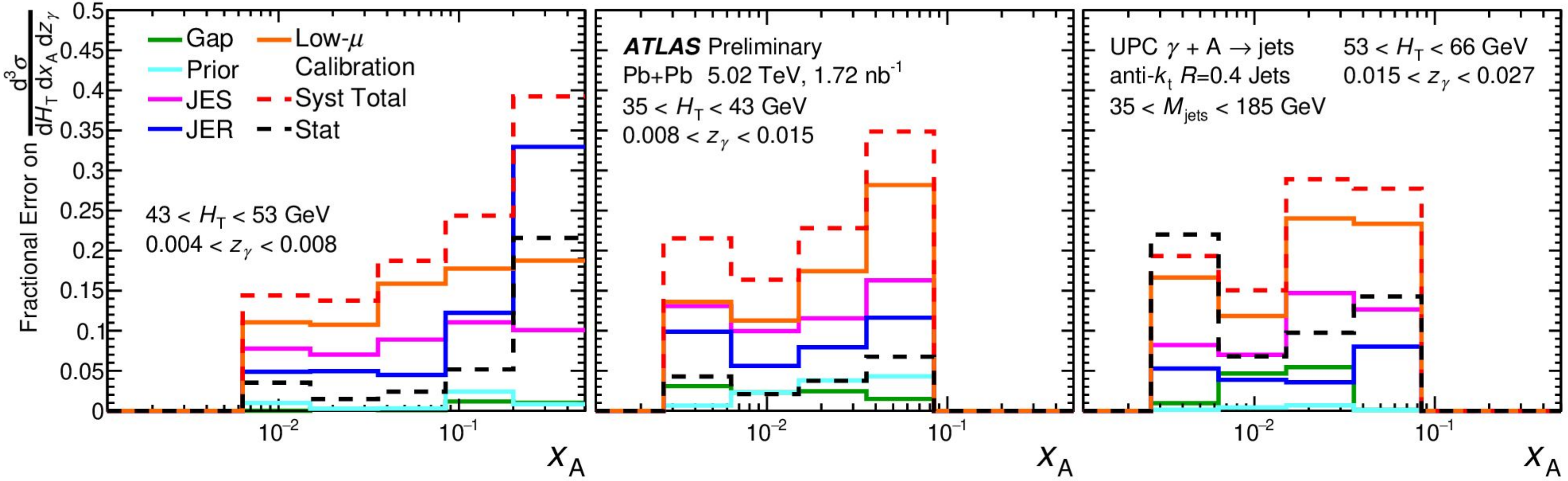
- The shape of the H_T (the scalar sum of the transverse momenta of jets in an event) distribution agrees fairly well between data and MC.
- This distribution is also sensitive to differences in jet response between data and MC.
- The y_{jets} distribution reflects the balance between energy on the photon and nucleus-going sides.





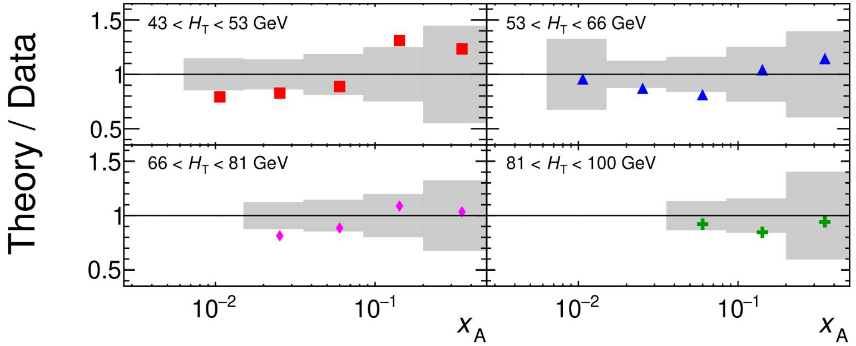
Systematic Uncertainties:

- The pseudorapidity gap selection (green) and sensitivity to the prior (cyan) uncertainties are subdominant
- The JES (magenta) and JER (blue) uncertainties are substantial but not dominant.
- Jet calibration sequence derived for high-μ data in a low-μ environment (orange) are dominant in most bins.



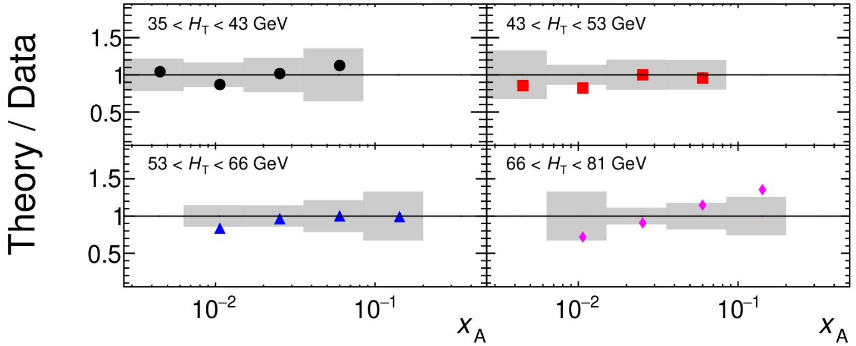
UPC Dijet Cross-Sections:

- At intermediate photon energies, we can access higher-x partons.
- Systematic uncertainties grow near the acceptance edge at high-x.



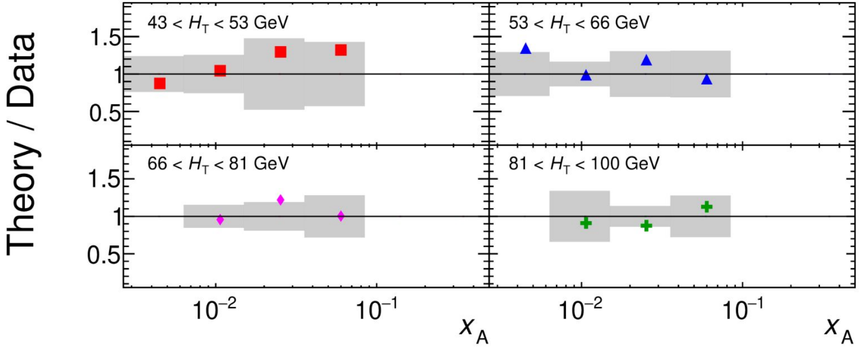
Photon Energy
0.004 < z_γ < 0.008

- Higher photon energy opens up the low-x shadowing region.
- Results are quite consistent with the theoretical model.



Photon Energy
0.008 < z_γ < 0.015

- The highest photon energy allows the most access to low x.
- Systematic control is more challenging near acceptance edges.



Photon Energy
0.015 < z_γ < 0.027

Conclusion:

Observation of $t\bar{t}$ production in lepton+jets and dilepton channels in *p*+Pb

- The first $t\bar{t}$ observation using the dilepton channel in *p*+Pb collisions at the LHC.
- The $t\bar{t}$ cross section is measured to be $\sigma_{t\bar{t}} = 57.9 \pm 2.0\ (\text{stat.})\ ^{+4.9}_{-4.5}\ (\text{syst.})$ nb.
- The most precise $t\bar{t}$ cross-section measurement in *p*+Pb collisions at the LHC.

Measurement of the centrality dependence of the dijet yield in *p*+Pb

- New input to understand the suppression of the jet production in p+A collisions.
- The results are compatible with an interpretation in terms of color fluctuation effects.
- Next: extraction of the dijet cross-section to constrain nPDFs

Photo-nuclear jet production in ultra-peripheral Pb+Pb

- Photo-nuclear jet production was measured by ATLAS in 5.02 TeV Pb+Pb collisions with 2018 data.
- Particle-Flow jets allow for the measurement to be extended even lower in jet p_T while maintaining good control over uncertainties.
- This data can add a wide range of kinematic coverage to existing nPDF constraints.

Backup

The dijet yield was measured as a function of:

$$p_{T,\mathrm{Avg}} = \frac{p_{T,1} + p_{T,2}}{2}, \qquad y_b = \frac{y_1^{\mathrm{c.m.}} + y_2^{\mathrm{c.m.}}}{2}, \qquad \text{and}$$

$$y^* = \frac{|y_1^{\mathrm{c.m.}} - y_2^{\mathrm{c.m.}}|}{2},$$

$$R_{\mathrm{CP}}(p_{T,\mathrm{Avg}}, y_b, y^*) = \frac{\frac{1}{\langle T_{AB}^{0\%\text{–}10\%}\rangle} \frac{1}{N_{\mathrm{evt}}^{0\%\text{–}10\%}} \frac{d^3 N_{\mathrm{dijet}}^{0\%\text{–}10\%}}{dp_{T,\mathrm{Avg}}\, dy_b\, dy^*}}{\frac{1}{\langle T_{AB}^{60\%\text{–}90\%}\rangle} \frac{1}{N_{\mathrm{evt}}^{60\%\text{–}90\%}} \frac{d^3 N_{\mathrm{dijet}}^{60\%\text{–}90\%}}{dp_{T,\mathrm{Avg}}\, dy_b\, dy^*}},$$

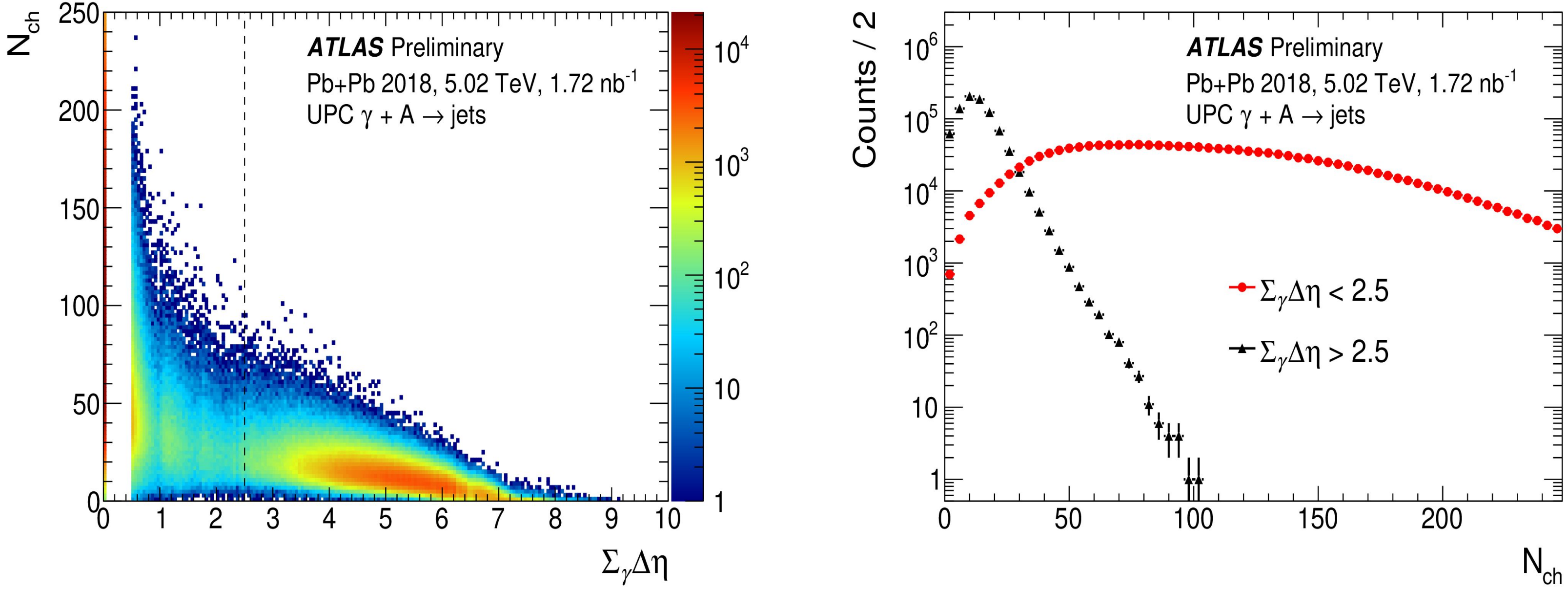
$$x_p = \frac{p_{T,1} e^{y_1^{\mathrm{c.m.}}} + p_{T,2} e^{y_2^{\mathrm{c.m.}}}}{\sqrt{s_{\mathrm{NN}}}} \simeq \frac{2 p_{T,\mathrm{Avg}}}{\sqrt{s_{\mathrm{NN}}}} e^{y_b} \cosh(y^*)$$

and

$$x_{\mathrm{Pb}} = \frac{p_{T,1} e^{-y_1^{\mathrm{c.m.}}} + p_{T,2} e^{-y_2^{\mathrm{c.m.}}}}{\sqrt{s_{\mathrm{NN}}}} \simeq \frac{2 p_{T,\mathrm{Avg}}}{\sqrt{s_{\mathrm{NN}}}} e^{-y_b} \cosh(y^*),$$

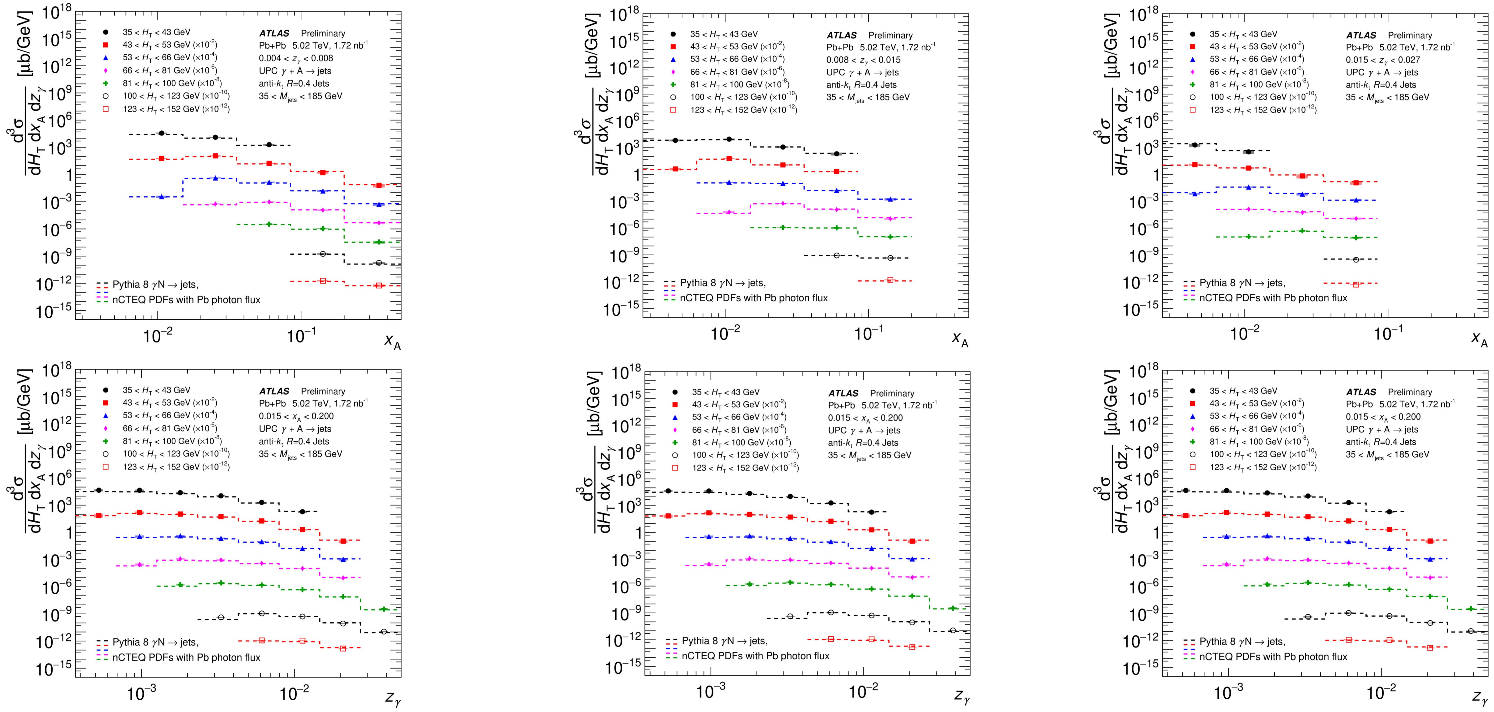
Selecting Photo-nuclear Jet Events:

- Large rapidity gaps on one side of the detector
- To veto $\gamma\gamma \rightarrow \mathbf{q\bar{q}}$, also require $\Delta\eta_A^{edge} < 3$.
- At least two Particle-Flow jets with pT > 15 GeV



UPC Dijet Cross-Sections:

Photon Energy 0.004 < z_γ < 0.008 | **Photon Energy 0.008 < z_γ < 0.015** | **Photon Energy 0.015 < z_γ < 0.027**



z_γ - Fraction of the photon's energy that is carried by the parton that interacts in the hard scattering.

x_A - Fraction of the nuclear momentum carried by the parton from the nucleus participating in the scattering process.