Observation of top quark production in proton-nucleus collisions

arXiv:1709.07411 [nucl-ex]

G. K. Krintiras on behalf of CMS collaboration
UCLouvain
Throwing a bullet through an apple... Why?

1. Initially only thought to give answers on hot questions about cold QCD matter
2. The first collisions of unequal species (pPb) @ LHC revealed surprises
   - signs similar to those of the Quark-Gluon Plasma (QGP)
   - interest exploded (the 5th most cited CMS paper in PLB!)


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Ideally LHC is meant for equal colliding species

- its “two-in-one” magnet design gave birth to “cogging” (O.o?)
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A lower (!) limit on the achieved energy ($\sqrt{s_{NN}}$)

Interest + ingenuity ⇒ $\mathcal{L}_{int} = 174\pm 9$ nb$^{-1}$ (!)
What HION questions could top production elucidate?

What happens to the gluon density in nuclei?

- bound gluon density poorly known

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Nuclear modification of PDF (nPDF)

Larger kinematic reach & new constraints (e.g. EPPS16)

First ever nPDF with LHC data!

- p+Pb @ LHC (7 TeV+2.75 TeV)
- Present nuclear DIS and Drell-Yan in p+A
- d+Au @ RHIC

0 < y < 3.2

E.g. x ∈ (10^{-2}, 10^{-1}) for top production

Initial stage: a big unknown

DGLAP

Compute observables at \(x, Q^2\)

Compute \(\chi^2\) for \(\{a_i\}\)

\(\{R_i^A(x, \{a_i\})\}\) at \(Q_0^2\)

Minimum?

NO

YES

vary \(\{a_i\}\)

(fulfilling sum rules)

Final answer
Can we measure the top quark in nuclear collisions @ LHC?

- What happens to the **gluon density** in nuclei?
- How the **confined** hadronic states emerge from partons?
- How color-charged partons, and colorless jets, interact with a **nuclear medium**?

But wait... Maybe that's “A Midsummer Night's Dream”?
The first search analysis for $tt$ in nuclear collisions!

- $l+jets$: $tt \rightarrow bW bW \rightarrow b l b j j' +$ missing momentum (MET) i.e.,
crucial to search for the lepton ($l=\text{e,}\mu$) & non-$b$ jets (a.k.a. the light jets $j,j'$)

- $j,j'$ jets are paired based on their proximity in $(\eta,\phi)$ space (min$\Delta R$ separation)
  → to construct the variable of interest; here the $m_{jj'}$ inv. mass

- main backgrounds (bkg.) from $W+jets$ and QCD multijet production

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**Physics objects**

- **Jets** $p_T>25$ GeV, $|\eta|<2.5$
- **b-tag**
- **Light jets**
- **B-jets**
- **Isolation or identification**
- **Failing leptons**
- **Passing leptons**

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**Combined fit**

Over $2 \times 3 = 6$ categories

$N(m_{jj'}) = N(bkg.)*[P(W)+f(QCD)*P(QCD)] + N(signal)*P(signal)$, $f\in[0,1]$

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**Categories**

1 triggered $l$ ($l=\text{e,}\mu$) + 0 extra leptons (offline) + 4 jets clustered with anti-kt ($R=0.4$) + systematic uncertainties

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**arXiv**: 1709.07411

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Excludes null $>5\sigma$?
tt process modeled with PYTHIA (v.6.424, tune Z2*)

- pN → tt + X (N=p,n) i.e., a mixture of pp and pn interactions – not crucial
  - effects from nuclear modifications studied with POWHEG (v2) interfaced with CT14+EPPS16
- split the total contribution in a resonant (left Fig.) and a non resonant (right Fig.) part
- resonant: both j,j’ (reco) matched with a light flavor parton (truth)
- proximity of j,j’ in (η,φ) reproduces a crucial feature

Parameterized with a CB+gamma

Parameterized with a asym. Gaussian+Landau

j,j’ tested pairing criteria

pPb (\(\sqrt{s_{NN}} = 8.16\) TeV)
The signal and data-driven background modeling

- EW processes (W+jets, also DY) modeled with PYTHIA (v.6.424, tune Z2*)
  - $pN \rightarrow W + X$ (N=p,n) i.e., a mixture of pp and pn interactions – this is crucial
  - Landau parameterization found as a proper description (hint: combinatorics)
  - Also supported from POWHEG (v2) interfaced with CT14+EPPS16
  - Effects from nuclear modifications inferred in-situ

- QCD multijet process extracted from failed iso (ID) control region in $\mu(e)+\text{jets}$ channel
  - Kernel parameterization (hint: non trivial behavior for fake/non prompt l)
  - Pre-fit normalization from low-MET (< 20 GeV) events

All samples are tuned to reproduce the global pPb event properties.
Measuring the $t\bar{t}$ production cross section ($l+\text{jets}$)

- **Basic ingredients:** acceptance ($A$) and efficiency ($\varepsilon$)
  - $A = 0.060 \pm 0.002 \text{(tot)}$ ($0.056 \pm 0.002 \text{(tot)}$) in $\mu(\text{e})+\text{jets}$ channel
    - determined @ NLO with POWHEG (v2) in the fiducial region
  - $\varepsilon = 0.91 \pm 0.04 \text{(tot)}$ ($0.63 \pm 0.03 \text{(tot)}$) in $\mu(\text{e})+\text{jets}$ channel
    - measured in data with “tag-and-probe” method (Z boson candle)

- **Total number of signal (S) events in all 6 cats.:** $S = 710 \pm 130 \text{(tot)}$
  - combination dominated by $\mu+\text{jets}$ channel

Background completely determined from data!

- $\sigma_{\text{tt}} = 45 \pm 8 \text{(tot)}$ nb
- $d\sigma_{\text{tt}} / \sigma_{\text{tt}} = 17 \%$ (!)

$pPb \ (174 \text{ nb}^{-1}, |S_{NN}| = 8.16 \text{ TeV})$

- $e^{+}/\mu^{\pm} + \geq 4j \ (=0b)$
  - Data
  - $t\bar{t}$ correct
  - $t\bar{t}$ wrong
  - background
  - $\chi^2/\text{dof} = 22.8/50$

- $e^{+}/\mu^{\pm} + \geq 4j \ (=1b)$
  - Data
  - $t\bar{t}$ correct
  - $t\bar{t}$ wrong
  - background
  - $\chi^2/\text{dof} = 26.9/50$

- $e^{+}/\mu^{\pm} + \geq 4j \ (=2b)$
  - Data
  - $t\bar{t}$ correct
  - $t\bar{t}$ wrong
  - background
  - $\chi^2/\text{dof} = 32.0/50$

CMS

Events | $m_{jj}$ [GeV] | Events | $m_{jj}$ [GeV] | Events | $m_{jj}$ [GeV]
---|---|---|---|---|---
$1l4j0b$ | 50 100 150 200 250 300 | $1l4j1b$ | 50 100 150 200 250 300 | $1l4j2b$ | 50 100 150 200 250 300
50 | 60 80 100 120 140 160 | 50 | 60 80 100 120 140 160 | 50 | 60 80 100 120 140 160
100 | 120 140 160 180 200 220 | 100 | 120 140 160 180 200 220 | 100 | 120 140 160 180 200 220
150 | 160 180 200 220 240 260 | 150 | 160 180 200 220 240 260 | 150 | 160 180 200 220 240 260
200 | 220 240 260 280 300 320 | 200 | 220 240 260 280 300 320 | 200 | 220 240 260 280 300 320
250 | 260 280 300 320 340 360 | 250 | 260 280 300 320 340 360 | 250 | 260 280 300 320 340 360
300 | 320 340 360 380 400 420 | 300 | 320 340 360 380 400 420 | 300 | 320 340 360 380 400 420

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**Post-fit**

$pPb \ (174 \text{ nb}^{-1}, |S_{NN}| = 8.16 \text{ TeV})$

- $e^{+}/\mu^{\pm} + \geq 4j \ (=0b)$
  - Data
  - $t\bar{t}$ correct
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- $e^{+}/\mu^{\pm} + \geq 4j \ (=1b)$
  - Data
  - $t\bar{t}$ correct
  - $t\bar{t}$ wrong
  - background
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- $e^{+}/\mu^{\pm} + \geq 4j \ (=2b)$
  - Data
  - $t\bar{t}$ correct
  - $t\bar{t}$ wrong
  - background
  - $\chi^2/\text{dof} = 32.0/50$
The null hypothesis is excluded at a level of $>5\sigma$ taking into account syst. unc. by:
- the observed variation of the likelihood as a function of the POI
- PLR from pseudo-data generated from the background-only model

Indeed, the first observation of top quarks in pPb!
To further support the consistency with the production of top quarks,

- the inv. mass of $jj'b$ triplet (hadronic top mass) is plotted
  - $b$ jet candidate with the highest $b$-tag discriminator value
  - the minimum difference to inv. mass of $l\nu b$ triplet (leptonic top mass) is considered

- signal and bkg. contribution scaled to post-fit $m_{jj'}$ values

Even a peak is reconstructed close to top mass!
First experimental **observation** of the top quark in nuclear collisions

- $\sigma_{tt}$ measured in two independent decay channels i.e., $\mu,e+$jets
  - $d\sigma_{tt}/\sigma_{tt} = 17\%$ in the $l+$jets combination
  - consistent with the scaled pp data as well as pQCD calculations

- Minimally rely on assumptions from MC simulation
  - paves the way for the study in AA collisions
I had a bad dream: I was facing a huge fireball in my own accelerator...
Slides
Measuring the $t\bar{t}$ production cross section ($\mu,e+\text{jets}$)

- $e+\text{jets}$ hampered more by bkg. contamination
  - less precise than $\mu+\text{jets}$ i.e., $d\sigma_{t\bar{t}} / \sigma_{t\bar{t}} = 23\%$ vs $18\%$

  - crucial consistency check

<table>
<thead>
<tr>
<th>$\mu^\pm + \geq 4j$ ($=0b$)</th>
<th>$\mu^\pm + \geq 4j$ ($=1b$)</th>
<th>$\mu^\pm + \geq 4j$ ($=2b$)</th>
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<tbody>
<tr>
<td>$\chi^2/\text{dof} = 25.3/50$</td>
<td>$\chi^2/\text{dof} = 27.2/50$</td>
<td>$\chi^2/\text{dof} = 36.0/50$</td>
</tr>
</tbody>
</table>

- $\mu+\text{jets}$:
  - $\sigma_{t\bar{t}} = 44\pm3\text{(stat)}\pm8\text{(syst)}$ nb

- $e+\text{jets}$:
  - $\sigma_{t\bar{t}} = 56\pm4\text{(stat)}\pm13\text{(syst)}$ nb
The leptonic top mass

The longitudinal $\nu$ momentum from the 4-momentum conservation in the $W(l\nu)$ vertex assumes as $W$ boson inv. mass the world average of 80.4 GeV. Ambiguities raised as:
- two real solutions: the one which minimizes $|p_{z,\nu} - p_{z,l}|$
- imaginary solutions: real part of the quadratic equation in $p_{z,\nu}$

$$p_{z,\nu} = \frac{\Lambda p_z}{p_T^2} \pm \frac{1}{p_T^2} \sqrt{\Lambda^2 p_z^2 - p_T^2 (E^2 E_T^2 - \Lambda^2)},$$

$$\Lambda = \frac{m_W^2}{2} + \vec{p}_T \cdot \vec{p}_T.$$
Splitting uncertainty in a stat & syst component

Neither trivial nor unique task

- **stat**: fix nuisances to post-fit values and refit with floating $\sigma^t_t$
- **syst**: $\sqrt{\text{tot}^2 - \text{stat}^2}$

Effect of identified sources for systematic variations

- fix all other nuisances to post-fit values and refit within $\pm 1\sigma$
- syst != quadratic sum of the effects (hint: mind the correlations)

### UNCERTAINTY DESCRIPTION

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<td>Background</td>
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<td>Luminosity</td>
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<td>Jet Energy Scale</td>
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<td>Lepton Efficiency</td>
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<tr>
<td>Acceptance</td>
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</tr>
</tbody>
</table>

**CMS Simulation Supplementary**

pPb ($\sqrt{s_{NN}} = 8.16$ TeV)

- $\mu^+ + \geq 4j(\geq 2b)$
- $pN \rightarrow tf+X$ (PYTHIA6 $Z2^*$)
- Anti-$k_T$, $R=0.4$
- $p_{T,jet}>40$ GeV, $|\eta_{jet}|<2.5$, $\Delta R(jet,\mu)>0.4$

1/4j2b

**Careful treatment of UE dependence**
In order to ensure stability of the complex fit procedure

- \( N(\text{bkg.}) \) floats with \( N(\text{QCD}) \) constrained with \( \mu, \sigma \) from low-MET normalization
- \( N(\text{signal}) \) floats with event category coupling based on \( \epsilon_b \), the latter constrained with \( \mu \) from simulation and conservative \( \sigma \) :
  - \( N_{4j2b} = \epsilon_b \epsilon_b N(\text{signal}) \), \( N_{4j1b} = 2 \epsilon_b (1-\epsilon_b) N(\text{signal}) \), \( N_{4j0b} = (1-\epsilon_b)(1-\epsilon_b) N(\text{signal}) \)

In order to evaluate the uncertainty on the signal yields

- profiling of the likelihood is performed over the full set \( \Theta \) of nuisances
  - \( N(\text{bkg.}), f(\text{QCD}), \text{MPV} \) and width of Landau
  - \( \epsilon_b \)
  - \( A, \epsilon, L_{\text{int}} \)
  - JES effect on \( m_{jj} \)

\[
\mathcal{L}(\sigma_{t\bar{t}}, \Theta) = \prod_l \mathcal{P}_{\text{poisson}} \left( N_l^{\text{obs}}, N_l \right) \cdot \prod_i \mathcal{G}_{\text{auss}} \left( \theta_i^0, \theta_i, \sigma_{\theta_i} \right)
\]
Theoretical setup for cross section calculation

- Rely on the two fundamental concepts of QCD
  - **factorization** (calculable) and **universality** (input from PDFs)
    - \( \sigma_{pA} = A \times \sigma_{pp} \) (A=208 for Pb isotope @ LHC)

- MCFM (v8.0, nproc = 141) NLO event calculator with state-of-the-art (n)PDFs
  - bound nucleons' PDF: **EPPS16 NLO**; baseline free proton PDF: **CT14 NLO**
  - nPDF net effects result in a small +4% modification \( (R_{pPb}) \) of \( \sigma_{tt} \)
  - nPDF× PDF uncertainty from the provided 56+40 eigenvalues \( \rightarrow 9\% \)
  - full calculation repeated with **CT10+EPS09** combination
    - considering the 52+32 error sets \( \rightarrow 7\% \)
  - QCD scales choice: \( \mu_R = \mu_F = 172.5 \text{ GeV} \)
    - scale variations by halving/doubling the \( \mu_R, \mu_F \) \( \rightarrow 3\% \)
  - **k-factor** \( (\text{NLO} \rightarrow \text{NNLO}) \) obtained with **TOP++**

\[
\sigma_{tt} = 59.0 \pm 5.3 (\text{PDF}) + 1.6 (\text{scale}) \text{ nb} \\
\sigma_{tt} = 57.5 \pm 4.3 (\text{PDF}) + 1.5 (\text{scale}) \text{ nb}
\]

@ \( s_{NN}=8.16 \text{ TeV} \)
CMS performance figures for pPb 2016 data taking

Inv. mass spectrum of opposite-sign muon pairs within the [2, 200] GeV window
- di-muon triggers (online)
- $p_T > 4$ GeV and "soft" identification (offline)

CMS DP -2016/072

Inv. mass spectrum of opposite-sign electron pairs within the [60, 120] GeV window
- di-photon triggers (online)
- $p_T > 20$ GeV, $|\eta|<2.5$ and "loose" identification (offline)
EPPS16: First analysis with pPb LHC data!

Also Z boson data both from ATLAS

Dijet data constrains gluon distributions

Good description of heavy boson production but limited constraining power on the fit
### The availability of LHC pPb data; the game changer !?

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Process</th>
<th>Observables</th>
<th>Motivation</th>
</tr>
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<tbody>
<tr>
<td>ALICE</td>
<td>Heavy quark production</td>
<td>$p_T^{D}, p_T^{D\rightarrow e}$</td>
<td>large-$x$ gluon</td>
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<tr>
<td>ALICE</td>
<td>Charged jets</td>
<td>$p_T^{\text{ch-jet}}$</td>
<td>medium and large-$x$ gluon</td>
</tr>
<tr>
<td>ALICE</td>
<td>Charged hadron production</td>
<td>$p_T^H$</td>
<td>medium and large-$x$ gluon</td>
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<tr>
<td>ALICE</td>
<td>Dijet correlations</td>
<td>$k_T = p_T^{\text{jet}} \sin(\Delta \phi_{\text{dijet}})$</td>
<td>medium and large-$x$ gluon</td>
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<tr>
<td>ALICE</td>
<td>Inclusive W production</td>
<td>$y_{W\rightarrow l}$</td>
<td>quark flavor separation medium-$x$ quarks</td>
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<tr>
<td>ATLAS</td>
<td>Inclusive charged particles</td>
<td>$p_T$</td>
<td>large-$x$ gluon</td>
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<td>ATLAS</td>
<td>Inclusive W production</td>
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<td>quark flavor separation medium-$x$ quarks</td>
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<tr>
<td>ATLAS</td>
<td>Inclusive Z production</td>
<td>$y_Z$ and $p_T^Z$</td>
<td>quark flavor separation medium-$x$ quarks</td>
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<td>CMS</td>
<td>Heavy quark jets</td>
<td>$p_T^{b\rightarrow \text{jet}}$</td>
<td>medium-$x$ gluon in-medium fragmentation</td>
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<tr>
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<td>Dijet production</td>
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<tr>
<td>CMS</td>
<td>Inclusive W,Z production</td>
<td>$y_{W\rightarrow l}$, $y_Z$ and $p_T^Z$</td>
<td>quark flavor separation medium-$x$ quarks</td>
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<td>small-$x$ gluon</td>
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<td>Inclusive Z production</td>
<td>$\sigma(Z\rightarrow l^+l^-)$</td>
<td>quark flavor separation small-$x$ quarks</td>
</tr>
</tbody>
</table>

Despite being based on the widest dataset, EPPS16 exhibits largest uncertainties, showcasing that methodological uncertainties are still a dominant component of nPDFs fits.
## Key characteristics of the latest fits of nPDFs

(in chronological order from left to right)

<table>
<thead>
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<td><strong>NNLO</strong></td>
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<td>LHC $p + Pb$ W, Z data</td>
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As compared to the PDF fitting landscape

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<th>Hessian $\Delta \chi^2=1.645$</th>
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<td>Parametrization</td>
<td>Neural Networks (259 pars)</td>
<td>Chebyshev (37 pars)</td>
<td>Bernstein (30-35 pars)</td>
<td>Polynomial (14 pars)</td>
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<td>HQ scheme</td>
<td>FONLL</td>
<td>TR'</td>
<td>ACOT-\chi</td>
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The "ridge" in pPb collisions

high multiplicity p+Pb

pPb $\sqrt{s_{NN}} = 5.02$ TeV at the LHC

(a) ALICE

(b) ATLAS

(c) CMS

ALICE COLLABORATION, PHYS. LETT. B 719 (2013) 29
ATLAS COLLABORATION, PHYS. REV. LETT. 110 (2013) 182302
CMS COLLABORATION, PHYS. LETT. B 718 (2013) 795
Two-particle correlations

Pair of two primary reconstructed tracks within |\( \eta \)|<2.4
- Trigger particle from a \( p_T^{\text{trig}} \) interval
- Associated particle from a \( p_T^{\text{assoc}} \) interval

Signal-pair distribution

\[
S(\Delta \eta, \Delta \phi) = \frac{1}{N_{\text{trig}}} \frac{d^2N^{\text{same}}}{d\Delta \eta d\Delta \phi}
\]

Background-pair distribution

\[
B(\Delta \eta, \Delta \phi) = \frac{1}{N_{\text{trig}}} \frac{d^2N^{\text{mix}}}{d\Delta \eta d\Delta \phi}
\]

Triangular shape in \( \Delta \eta \) due to limited acceptance

\( \eta = -2.4 \) \hspace{1cm} \( \eta = 0.0 \) \hspace{1cm} \( \eta = 2.4 \)

\( \Delta \eta = \eta^{\text{assoc}} - \eta^{\text{trig}} \)

\( \Delta \phi = \phi^{\text{assoc}} - \phi^{\text{trig}} \)
What HION questions could top production elucidate?

- What happens to the **gluon density** in nuclei?
- How the **confined** hadronic states emerge from partons?
  - Impact of ~0.5 GeV on the top mass ($M_{\text{top}}$) reconstruction
  - CR is **modified** in higher color charge density regimes wrt. to the vacuum
    - e.g. in pPb collisions with increased underlying event (UE) activity
  - How color-charged partons, and colorless jets, interact with a **nuclear medium**?
    - "switch-off" the cascade for some time → directly measure the space-time evolution of the medium

**JHEP**11, 043 (2014)
L. Apolinário et al. 4th HIN Jet WKSH (2016)

tt production as a tomography of in-medium losses (quenching)

L. Apolinário et al. 4th HIN Jet WKSH (2016)
W Mass ($\tau = 5.0$ fm)

pPb data adequate for CR tuning
A nice heuristic idea for a yocto-chronometer!

 Depending on the chosen $p_T$, the antenna may still lose some energy. Knowing the energy loss, it is possible to build the density evolution profile of the medium.

\[ \Delta E/E = \left( \frac{t-t_0}{\tau} \right) \times 0.1 \]
Nuclear modification factor $R_{pPb}$ for $tt$ production in the $\ell$+jets channel and their decay isolated leptons with the central PDF sets of CT14+EPPS16 (dashed curves) and CT10+EPS09 (solid curves) as a function of

- transverse momentum (top)
- and rapidity (bottom)
Turning the modifications into universal quantities: nuclear PDFs (nPDFs)

\[ f_i^{p/A}(x_N, \mu_0) = R_i(x_N, \mu_0, A, Z) f_i(x_N, \mu_0) \]

- **R=1** indicates the absence of nuclear effects.

- **R≠1** discovered in the early 70's.

  - Scale controlling nuclear processes \( L_I = (Mx)^{-1} \)
  
  Distance between nucleons \( d = (3/4\pi\rho)^{1/3} \sim 1.2Fm \)

  - \( L_I < d \) for \( x > 0.2 \) nuclear DIS \( \sim \) incoherent sum of contributions from bound nucleons

  - \( L_I \gg d \) for \( x \ll 0.2 \) coherent effects of interactions with few nucleons are important
The EPOS Model(s)

- pp@LHC treated as AuAu@RHIC:
  - Multiple scattering approach EPOS (marriage of pQCD and Gribov-Regge):
    - initial condition for a hydrodynamic evolution if the energy density is high enough
  - event-by-event procedure
    - taking into account the irregular space structure of single events:
      - ridge structures in two-particle correlations
  - core-corona separation:
    - only a part of the matter thermalizes;
  - 3+1 D hydro evolution
    - conservation of baryon number, strangeness, and electric charge
The EPOS(LHC) Model @ pp

Core hadronization change particle ratio
- easier to produce strange baryons

Stat. Decay

Detailed description can be achieved
- $p_t$ behavior driven by collective effects (flow)
- particles with $p_t \sim 0.5$ GeV/c boosted up to $p_t=2-3$ GeV/c
- high $p_t$ particles ($p_t \sim 10$ GeV/c) suppressed by energy loss in fluid
- spectrum dominated by string (jet) particles only for $p_t > 5$ GeV/c
Cross ratios
- $K/\pi$ and $p/\pi$ ratios are or slowly rising; EPOS(LHC) looks best

Opposite charge ratios
- The ratios are close to 1, no dependence on $N_{\text{tracks}}$
Particularities of pPb collisions @ LHC

\[(B\rho)_p = (B\rho)_{Pb} = \frac{p_p}{e} = \frac{p_{Pb}}{Ze}\]

\[p_{Pb} = Zp_p\]

Equal beam rigidity fixes the momentum

Revolution period, \(T\), i.e. time needed for a particle to make a turn of length \(c\)?

\[T = \frac{C}{\nu}\]

\[T_p = \frac{C}{c} \sqrt{1 + \left(\frac{m_p c}{p_p}\right)^2} < T_{Pb} = \frac{C}{c} \sqrt{1 + \left(\frac{A m_p c}{Z p_p}\right)^2}\]

\[f_{RF} = h f_{rev} = h \frac{1}{T}\]

\(T\): revolution period
\(C\): accelerator circumference
\(c\): speed of light
\(h\): harmonic number

No more formulas!
What's special about pPb @ LHC: "cogging"

- Inv. mass spectrum of opposite-sign muon pairs within the [2, 200] GeV window
  - di-muon triggers (online)
  - $p_T > 4$ GeV and "soft" muon identification (offline)

- Inv. mass spectrum of opposite-sign electron pairs within the [60, 120] GeV window
  - di-photon triggers (online)
  - $p_T > 20$ GeV, $|\eta|<2.5$ and "loose" electron identification (offline)

CMS DP -2016/072